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Photo-elastic Examination of a Cylindrical Strut Intended for Recording Compressive Loads

By

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Summary.—Photo-elastic methods are used to establish how much of a cylindrical steel strut, mounted for measurement of compressive force by strain-gauges, has uniform stress distribution, even when the end load is concentrated near the axis of the strut.

It is found that a strut 16 in long, and 6 in diameter has virtually uniform stress distribution over the middle $2\frac{1}{2}$ in.

1. *Introduction.*—A weighbar, in the form of a cylindrical strut with rounded ends, had been tentatively designed for measuring, by means of strain gauges at its middle section, the compressive load exerted by a projected 1,000-ton testing machine.

The designed dimensions for the strut are shown in Fig. 1, giving a length/diameter ratio of $2\frac{2}{3}$ which (according to a conventional design rule†) when the resultant load is axially applied, should give a region of about 4 in. length over which the stress distribution is independent of the manner in which the end loads are applied.

When mounted on the testing machine, the strut is to be aligned by means of a centering device and bedded down on the seatings by the application of a 1,000-ton load. The areas in contact at its two ends would subsequently be a fraction of the total end area varying somewhat with the load.

It was required to show experimentally whether or not sufficient length had been allowed to produce a mean value of the strain on the perimeter of the middle section which would not vary under all likely conditions of end loading.

2. *Experimental Method.*—A model of the strut was made from ' Catalin 800 ' to $\frac{1}{20}$th scale, with end caps shaped as for the intended prototype. The model was loaded through a pair of these end caps by means of a special clamp. It was then placed in an immersion cell containing a mixture of liquids having the same refractive index as Catalin (*see* Appendix) and the fringe pattern photographed, using monochromatic light in a direction at right angles to the axis of the model. In this way it was unnecessary to resort to slicing. All loadings were made at room temperature.

The distribution of end load was then changed by altering the shape of the bearing surface and the experiment repeated. In most of the arrangements, photographs were taken at different degrees of loading. The greater number of fringes with higher loads gave a sensitive indication of the stress distribution.

Four different cases were chosen, so as to embrace the extreme conditions of load distribution (maximum and minimum areas of contact) as well as the most probable. The arrangement in these four cases and the degrees of loading used are shown in Fig. 2.

† According to this rule, the stress is independent of the end load distribution at a distance from the end greater than 1 diameter.

* R.A.E. Report No. S.M.E. 3400, received 3rd April, 1947.

In case 1, the end pieces were made in the form of truncated cones with spherical surfaces of equal radius to the end of the strut. The projected area of contact was $\frac{1}{2}$ the total cross-section of the strut.

In Case 2, the bearing surfaces were plane, so as to concentrate the load near the axis.

In Case 3, the ends were of the same diameter as the strut, but the radius was greater than that of the end surface of the strut, in the ratio 15/16. Here (as in Case 2) the pressure would become more and more spread out with increasing load.

Case 4 was intended to represent approximately the actual conditions expected. The seatings were again of full width, and of the same radius as the strut end surfaces for a diameter one half that of the strut, being then increased to a spherical radius $1\frac{1}{2}$ times that of the end surfaces.

3. *Experimental Results.*—The results are shown in Fig. 3 where the portion over which the stress appears sensibly uniform has been marked in each photograph.

Interpretation of the Figures is obtained by considering the cylinder to be made up of a large number of thin laminæ of thickness δt normal to the light path. Where the stress is entirely axial and denoted by $\widehat{xx}$, the relative retardations of successive laminæ are additive, giving a fringe order proportional to $\int \widehat{xx}\, dt$ through the model. Where the stress has a radial component, the direction of principal stress changes along the light path, and the relative retardations are no longer additive. For a ray passing through the axis of the cylinder, however, we have a fringe order proportional to $\int_{-r}^{r} (\widehat{\theta\theta} - \widehat{xx})\, dt$, r being the radius of the strut, and this is constant in the x—direction only in the portion where the stress is uniform. The state of uniform stress is thus indicated by

(*a*) uniform brightness (or darkness) along the axis

(*b*) straightness of the fringes near the axis.

4. *Sensitivity of Observation.*—In Case 4, Fig. 3, the fringe order at the centre is bordering on 9, and a change of $\frac{1}{8}$ order would be easily noticeable in the central region. Thus it can be estimated that, in the portion marked, $\int_{-r}^{r} (\widehat{\theta\theta} - \widehat{xx})\, dt$ is constant within 1 in 72 *i.e.* within about $1\frac{1}{3}$ per cent.

The length of the uniform region corresponds to a length of $2\frac{1}{2}$ in. in the full-size strut (overall length 16 in). This length is considerably less than indicated by the rule quoted above (*see* footnote, p.1).

5. *Conclusions.*—The results show that the strut, as designed, will be in sensibly uniform stress (under axial loading) for a distance of $1\frac{1}{4}$ in each side of the middle section.

After bedding in, the surface of the seatings will be expected to give contact over the indented area at full load only. This indented area, projected, is expected to be no greater than half the cross-section of the strut. The variation in end-load distribution, between no load and full load, is likely to be from $\frac{1}{4}$ to $\frac{1}{2}$ the strut sectional area. As this variation is considerably less than that between the extreme Cases 2 and 3 in the above photo-elastic tests, the constancy of the strain-load factor will be greater than 1 in 72. During an actual test, the range of loading would usually be much smaller than the capacity of the machine, and the variation in the strain/load factor correspondingly less.

It is concluded, therefore, that constancy of the strain/load factor will be achieved well within 1 per cent over the middle $2\frac{1}{2}$ inches of the bar.

APPENDIX

The composition of the immersion liquid to give the same refractive index as Catalin 800 is:—

α—Bromonaphthalene	3 parts
Aniline	11 parts

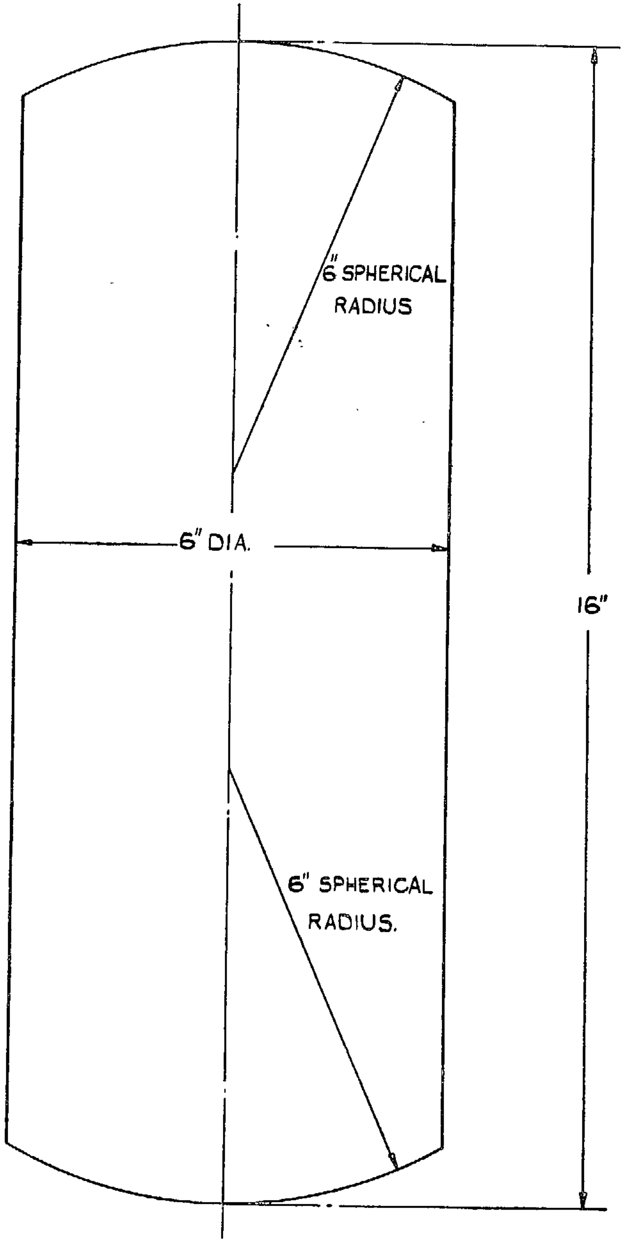

FIG. 1. Dimensions of steel strut.

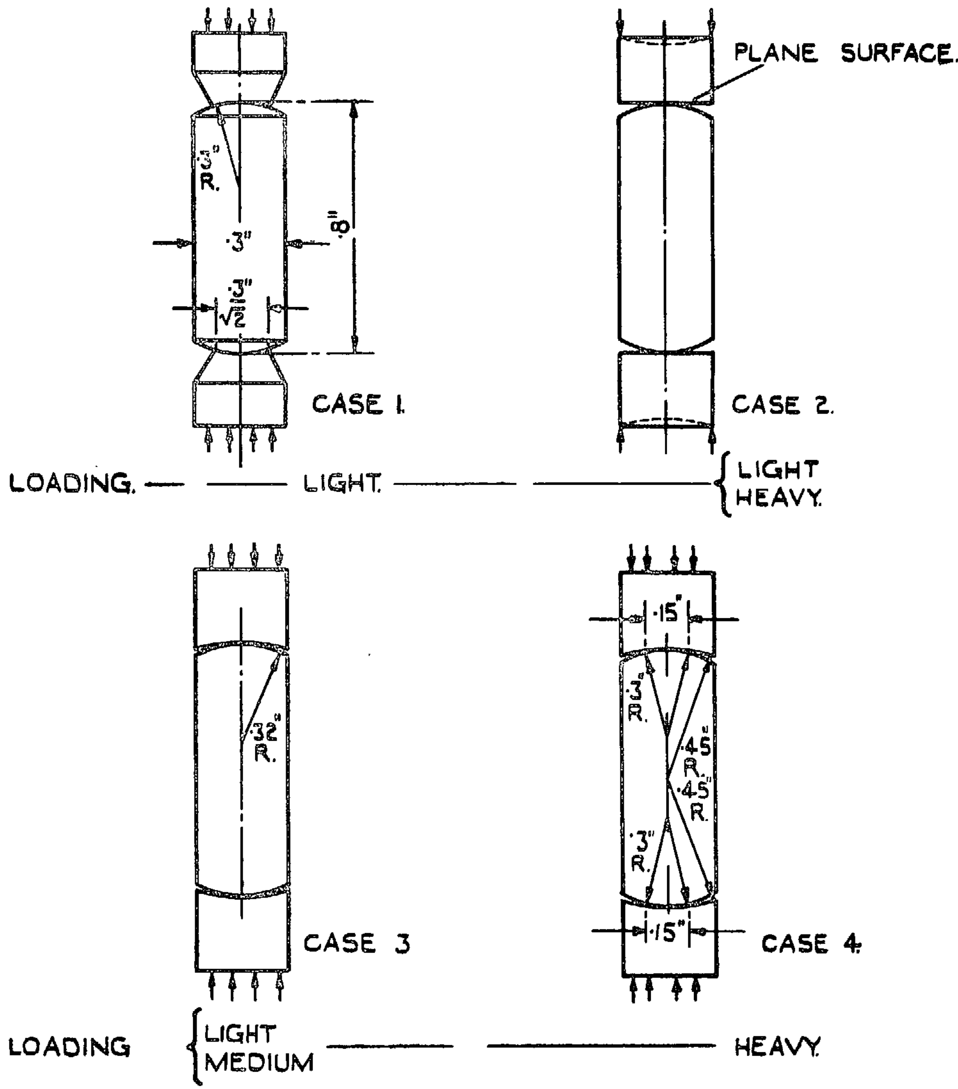

FIG. 2. Shapes of seating tested.

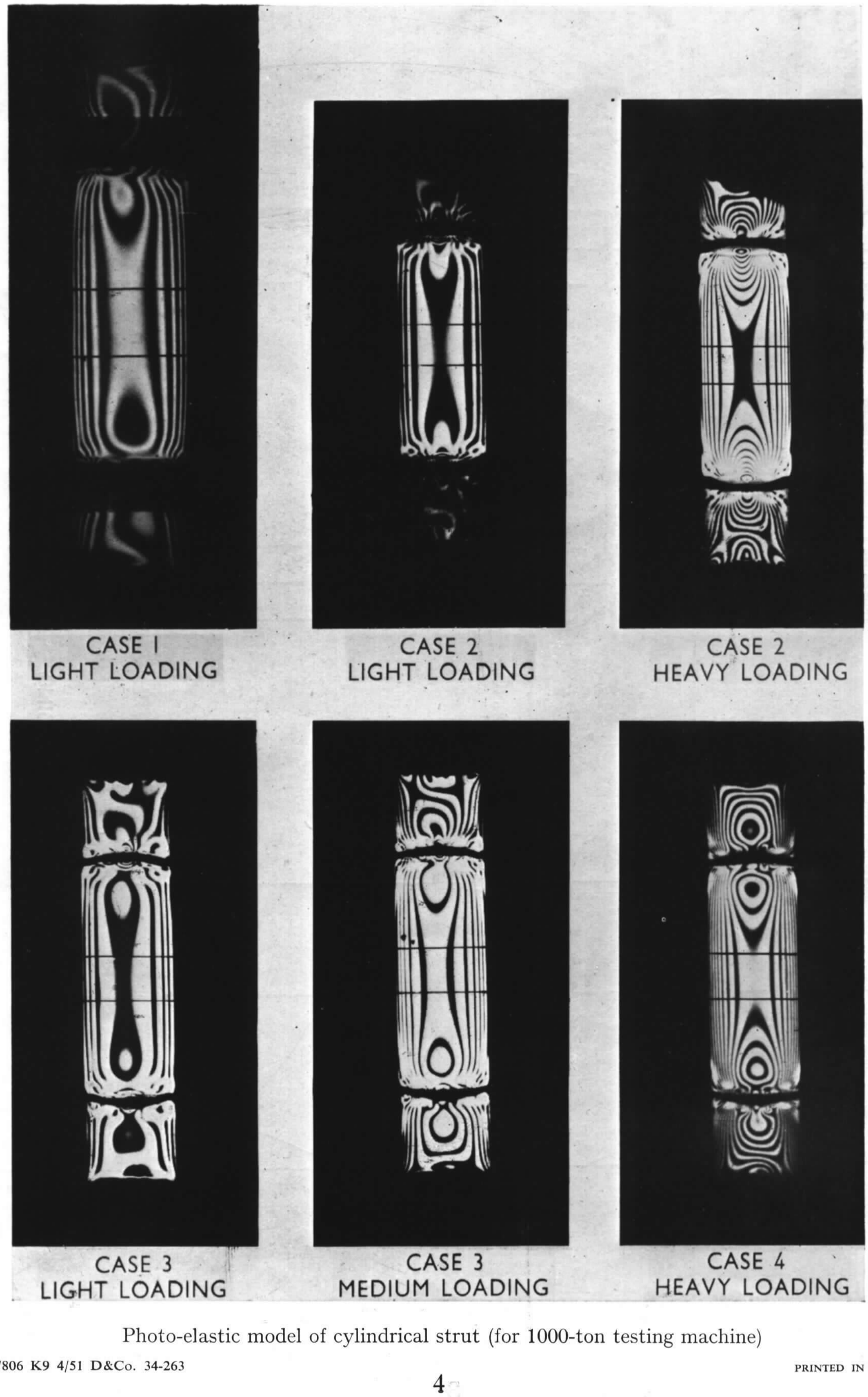

Photo-elastic model of cylindrical strut (for 1000-ton testing machine)

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