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Propagation of plastic zones in a strip weakened by an array of holes

J. KAPKOWSKI and J. STUPNICKI (WARSZAWA)

In this note is presented an experimental study on a strip weakened by an array of five holes and subjected to uniaxial tension until limit load is reached, at which large plastic flow begins to develop. The process of initiation and propagation of plastic zones is studied and the conventional bearing capacity of the strip is estimated.

1. The method of plastic design

The application of plastic design methods to the estimation of the optimum shape of structural elements has been proposed in ref. [1]. The procedure proposed there based, on the extremum principles of plasticity, enables us to obtain in a relatively simple manner the shape of the element for a prescribed load. In the complete solution, which is for the majority of practical problems very difficult to find, the limit state of stress should be reached at the same moment in the entire volume of the element. Using plastic design methods we may in many cases obtain a solution constituting good approximation of the ideal solution.

According to the extremum principles of plasticity, the actual bearing capacity is bounded by two estimates — a lower one resulting from an appropriate statically admissible stress field, and an upper one resulting from an appropriate kinematically admissible collapse mechanism. The first of these principles is mainly used in plastic design practice. Assumed, namely, is a statically admissible stress field satisfying all equilibrium conditions and static boundary conditions, and moreover the condition that the yield criterion is nowhere violated. The safe estimate of the shape of the element design coincides with the boundaries of such a stress field. The element designed according to such a procedure has an actual bearing capacity not smaller than that assumed in calculations. Selecting the most appropriate statically admissible stress field from the class of stress fields considered, we may choose the optimum shape, assuming any arbitrary criterion of optimalization (for example, minimum weight of the element).

For experimental studies, a strip weakened by five holes and loaded by uniaxial tension is chosen. The holes with diameters $d = 0.25b$, where b is the width of the strip, form the regular array shown in Fig. 2. One of the statically admissible stress fields given in ref. [1] is assumed. From this field, which is shown in Fig. 1a, results the estimate of the distances between the rows of holes. For the Huber-Mises yield condition and the plane state of stress, this type of stress field yields the optimum distance given in [1]:

$$s = \left(\frac{1}{2} + \frac{1}{2}\sqrt{\frac{3}{2} - \frac{1}{\sqrt{2}}}\right)d + \frac{1}{\sqrt{2}}t.$$

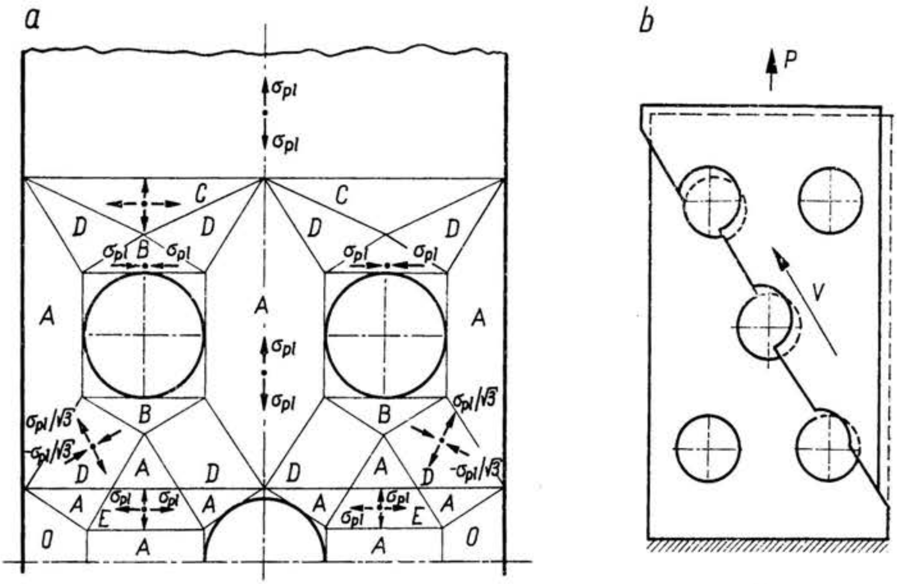
a
b
σpl
σpl/√3
-σpl/√3
A
B
C
D
E
0
P
V

FIG. 1.

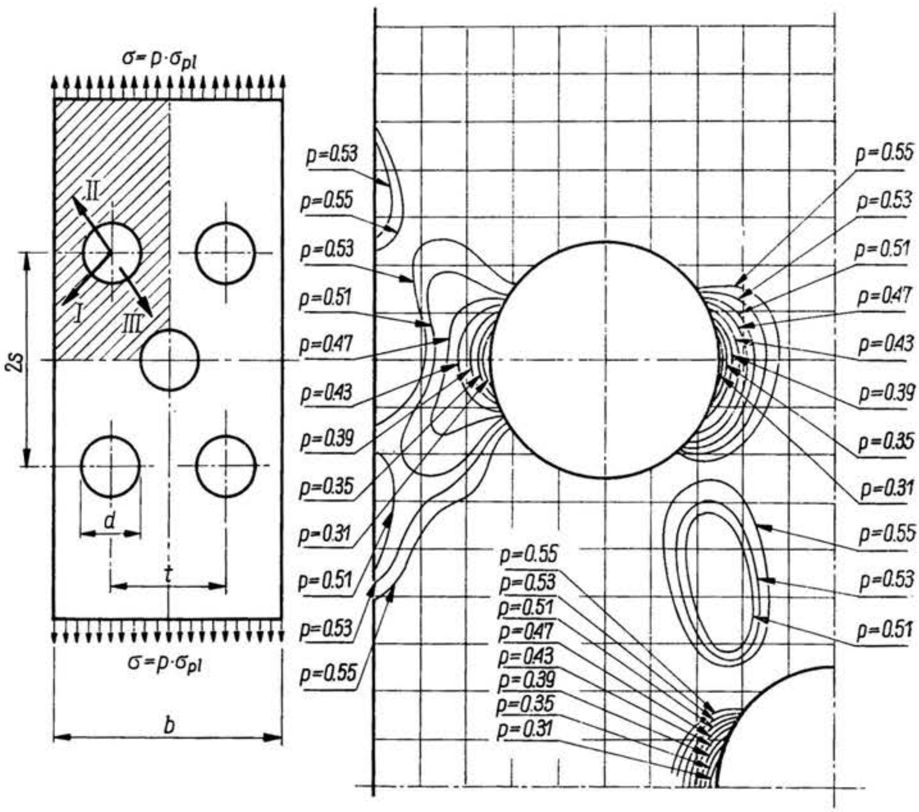
σ = p·σpl
I
II
III
2s
d
t
b
p=0.55
p=0.53
p=0.51
p=0.47
p=0.43
p=0.39
p=0.35
p=0.31

FIG. 2.

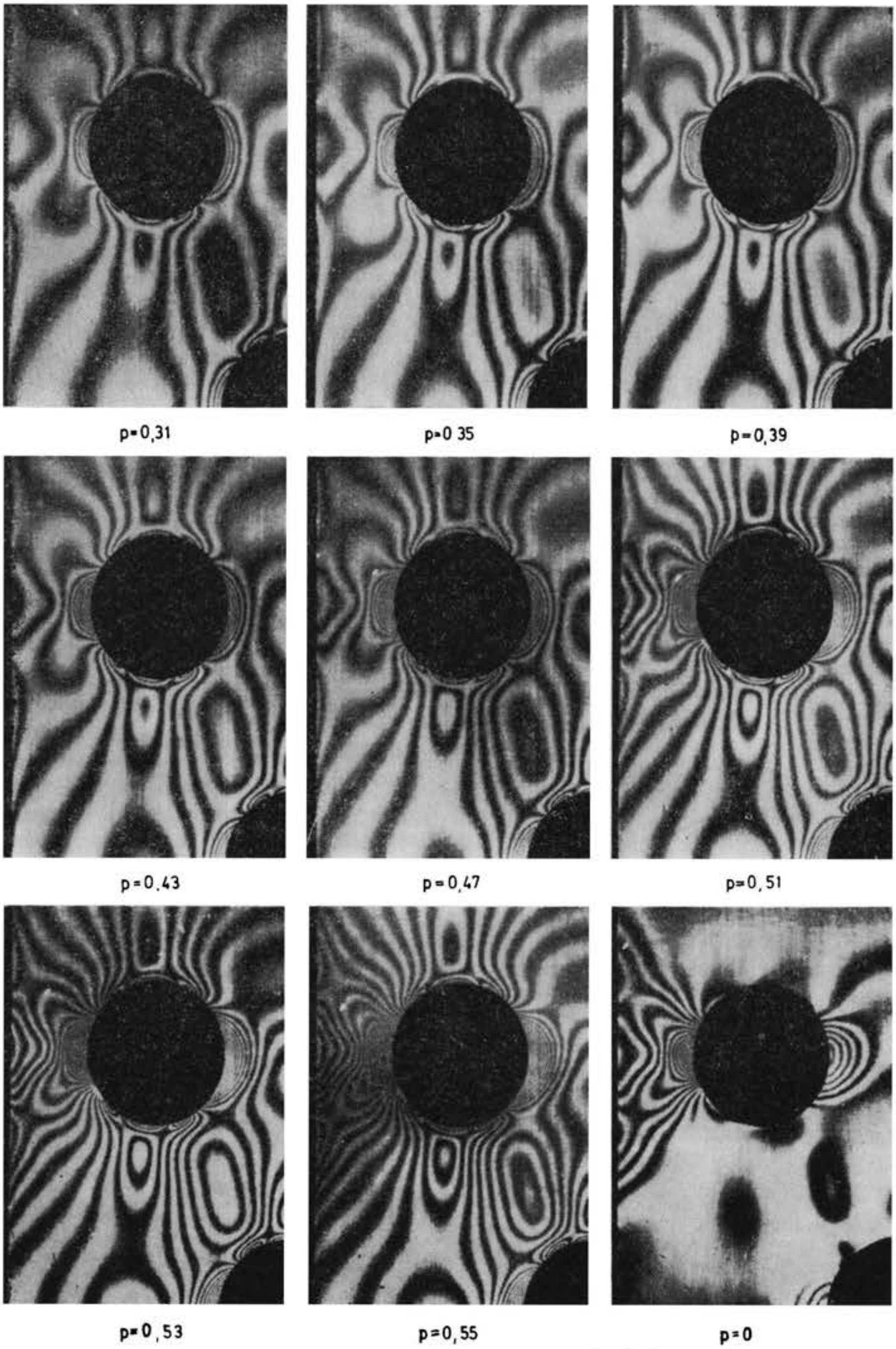

FIG. 3.

The strip is loaded at its ends by the uniformly distributed stresses

$$\sigma = p\sigma_{pl},$$

where p is the loading factor. The lower bound of the bearing capacity resulting from the assumed stress field is equal to

$$\sigma_0 = 0.5\sigma_{pl}.$$

2. Experimental results

The aim of the experimental study was primarily to establish the value of the actual bearing capacity of the strip, and to ascertain how far this value departs from the theoretical bearing capacity assumed in the plastic design procedure. Further the propagation of plastic zones was observed for the sake of qualitative analysis of the incipient stage of the collapse mechanism. Experiments were performed by means of the birefringent coatings method. Monochromatic circularly polarized light was used. The photoelastic coating was applied to the strip of an aluminium alloy (Al-Cu-Mg) by means of an original technique. The material of the coating was polimerized directly on the etched surface of the specimen. The uniform thickness of the coating and the required smoothness of its surface were assured by a glass plate located at the prescribed distance from the specimen. This technique ensures perfect adhesion between the coating and the specimen. In this way, a thin layer can be obtained responding to the great local gradients of deformation.

Using photographs of isochromatic fringes (Fig. 3), the boundaries of plastic regions were established. The method of characteristics described in the previous work [2] was used in calculations. Boundaries of plastic zones for various values of the loading factor are presented in Fig. 2. Only one quadrant of the strip is shown in the figure. The extrapolated bearing capacity of the perforated strip is estimated to have the value.

$$\sigma^* = 0.56\sigma_{pl}.$$

This value is 12 per cent larger than the theoretical lower bound.

Plastic zones propagate initially in the direction I (Fig. 2) and then simultaneously in directions II and III. Of interest is the qualitative agreement of the process observed with the kinematically admissible collapse mechanism (Fig. 1b).

References

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2. J. KAPKOWSKI, J. STUPNICKI, *Experimental study of elastic-plastic plane states of stress by means of the birefringent coatings method* [in Polish], Archiwum Budowy Maszyn, **18**, 1, 1971,

TECHNICAL UNIVERSITY OF WARSAW

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