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TESTS OF BEAMS HAVING WEBS WITH LARGE
CIRCULAR LIGHTENING HOLES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

TESTS OF BEAMS HAVING WEBS WITH LARGE
CIRCULAR LIGHTENING HOLES

By L. Ross Levin

SUMMARY

Strength tests were made on two sets of beams having webs with large circular lightening holes. The main conclusion drawn from the tests is that allowable web stresses derived from pure shear tests and allowable flange stresses derived from compression tests cannot be applied in the design of beams without making corrections for interaction. The test data are insufficient to establish a method for making such a correction.

INTRODUCTION

Published design information on shear webs with flanged, circular lightening holes is confined to empirical formulas. Most of the tests on which these formulas are based were made with fixtures producing pure shear, or approximately pure shear, in the web, and the structural members bounding the webs were very heavy in order to distribute the shear as uniformly as possible along the edges of the test specimen. In the two most extensive investigations published (references 1 and 2), failure was always observed to be precipitated by buckling of the sheet in the neighborhood of the line joining the centers of the lightening holes even when the holes were so large that their reinforcing flanges almost touched the edge members of the webs; obviously, the heavy edge members bridged over the dangerous region where the transverse net section is very small.

In actual structures, the shear webs would be bounded by angles or flanges of relatively much smaller cross-sectional area than the edge members used in the tests of references 1 and 2. These angles might not be capable of bridging over the dangerous sections in webs

with large holes, particularly when subjected to large normal stresses caused by bending of the structure. An empirical solution of the problem would require an investigation several times larger than that of reference 2 and does not appear feasible at the present time. In order to obtain some preliminary information, however, a few exploratory tests were made on two series of webs furnished by the Curtiss-Wright Corporation Airplane Division (Buffalo, N. Y.). The results of these tests and of some related tests are presented herein.

SYMBOLS

A	effective cross-sectional area of flange (two angles plus one-sixth of web), square inch
D	clear diameter of lightening holes, inches
I	geometric moment of inertia of cross section, inches ⁴
L	total length of specimen, inches
P	load at failure, kips For shear specimens, load applied at edge of specimen. For beams, concentrated load applied at center of beam.
Q	static moment of one half of cross section about neutral axis, inches ³
h	depth of web or beam, inches On shear specimens, depth of web measured between rivet lines. On beam specimens, effective depth of beam measured between centroids of flanges.
t	thickness of web, inch
σ	maximum normal stress in flange at ultimate load, ksi
τ	shear stress at ultimate load, ksi

TEST SPECIMENS AND PROCEDURE

The shear webs used for the tests were of 24S-T aluminum alloy 0.064-inch thick; the nominal dimensions are shown in figure 1. Specimens were prepared from these webs for two types of test: shear tests and beam tests. On shear test specimens, the ends of the webs were flanged over, and transverse stiffeners were riveted to the webs at the middle as shown in figure 2(a). On beam test specimens, flange angles and transverse stiffeners were riveted to the webs as shown schematically in figure 2(b). The sizes of the flange angles, as well as other identifying dimensions, are listed in table 1. The transverse stiffeners were in all cases $3/4$ by $3/4$ by $1/8$ inch steel angles.

The shear tests were made in a test jig shown schematically in figure 3; a description of the method of attaching the specimens to this jig may be found in reference 2. The beam specimens were tested as simply supported beams between two grids of round steel rods that prevented lateral failure of the compression flanges. The rods were spaced 1 inch between centers in each grid; the grids were so spaced as to allow the beam only a few thousandths of an inch clearance on each side. The maximum friction force was estimated to be less than two pounds and was neglected.

Some of the beams suffered only small permanent deformations, because the stresses at failure were low. It was decided to utilize these specimens for additional tests as follows: The webs and flanges were straightened, stiffeners were riveted to the webs midway between lightening holes, and the beams were retested after inverting them to have undamaged flanges on the compression sides. With stiffeners in each bay between lightening holes, the webs may be expected to develop the maximum shear strengths of which they are capable. The results of these tests were, therefore, held to be of sufficient general interest to warrant their inclusion in table 1, although they are only indirectly related to the main tests.

TEST RESULTS

The test results are given in table I. In order to make the comparison independent of deviations from the nominal dimensions, stresses rather than loads are given. The stress developed by the pure shear specimens at maximum load was calculated for the gross area by the formula

$$\tau = \frac{P}{Lt} \quad (1)$$

so that a direct comparison might be made with the results of reference 2. The shear stress developed by the beam specimens was calculated by the standard formula

$$\tau = \frac{PQ}{2It} \quad (2)$$

where I and Q were computed for the full section because the critical section at the middle of the beam was full. The maximum normal stress in the flange was calculated by the formula

$$\sigma = \frac{PL}{4hA} \quad (3)$$

The webs tested in pure shear buckled in the region about the line connecting the centers of the lightening holes. These buckles became deeper as the load increased until complete collapse occurred. On the beam specimens, the web began to buckle in a similar manner. At the same time, however, the flanges began to twist, and the failure of the specimen was caused by a simultaneous collapse of the web and of the compression flange near the middle of the beam.

DISCUSSION

Pure Shear Tests

It will be noted that table I gives two sets of predicted shear stresses for the pure shear specimens. The "predicted average" stress is calculated from formulas (4) and (5) of reference 2; these two formulas,

taken together, represent the average of the test results of reference 2. The "predicted allowable" stress is calculated from formulas (4) and (6) of reference 2; these two formulas, taken together, represent the lower edge of the band over which the results of reference 2 scatter.

Comparison of the experimental with the predicted shear stresses given in table I shows that the 4-inch webs developed stresses differing by less than 2 percent from the predicted average stresses. The use of the predicted allowable stresses would, therefore, be conservative for these webs. The stresses developed by the 6-inch webs, however, were only about two-thirds of the predicted average, or eight-tenths of the predicted allowable stresses.

Two possible explanations were suggested for the failure of the 6-inch webs to develop the predicted strength. One observation was that these webs had a D/h ratio of 0.83, which is larger than the value of 0.75 specified in reference 2 as the limit of established validity of the formulas. The other observation was that the hole flanges of the specimens used in this investigation were only about half as deep as those of the specimens discussed in reference 2 and that the lower flange depth might result in lower strength. This suggestion prompted tests of two specimens on which the flanges were machined down to about one-half their original depth (table 1). Inspection of the results in table I indicates, however, that the shear carried by the specimens with reduced flange depths was equal to that carried by the specimens with full-depth flanges within the experimental scatter. This fact, together with the fact that the 4-inch webs developed the strengths predicted by the formulas of reference 2 in spite of the low depths of the flanges, suggests strongly that the depth of the hole flanges has no material influence on the strength of the web so long as this depth remains within the practical limits. A similar conclusion was reached in reference 1. Taken at face value, then, the available evidence tends to indicate that the formulas of reference 2 may become unconservative for $D/h > 0.75$, but more tests are needed to establish with certainty the fact that the ratio D/h is the only factor responsible for the discrepancy.

Beam Tests

As mentioned in the discussion of test results, the beam specimens failed by simultaneous collapse of the web and of the flange. It was concluded from these tests and from other tests of beams with solid webs that the shear buckles in the webs induced twisting of the flanges. This twisting reduced the ability of the flanges to withstand the compressive stresses caused by beam action and the ability of the flanges to bridge over the dangerous sections in webs with large holes.

Because the webs and the flanges failed simultaneously, table 1 gives the web stresses as well as the flange stresses at failure. The web stresses may be compared logically with the stresses developed by the same type of web in the pure shear tests. It should be noted, however, that experimental shear stresses obtained in pure shear tests scatter considerably (reference 2); furthermore, if a beam has a web with very low shear stiffness, the flange angles will carry some shear, and formula (2) will require some correction. It is not at all surprising, therefore, that beam webs may sometimes be found to carry apparently higher shear stresses than corresponding webs tested in pure shear. No simple standard of comparison exists for the flange stresses, although the estimated column yield stress of 46 ksi may be used as a guide in evaluating the relative efficiency achieved by the flange angles. Again, the stresses developed in a beam test may exceed the arbitrary standard value of 46 ksi because it does not constitute an absolute maximum.

Inspection of table 1 shows that on specimen 6, the 4-inch beam with the heaviest flange angles, the web stresses were slightly higher than those developed by similar webs in pure shear (specimens 1 and 2), and the flange stress was slightly higher than the column yield stress of 46 ksi. Obviously, then, this combination of web and flange angles is very efficient. The use of lighter flange angles (specimens 7 and 8) results in loss of efficiency; the web stresses as well as the flange stresses decrease. A beam with a solid web (specimen 9) using the intermediate size of flange angle carried slightly higher flange stresses than the corresponding specimen 7 with lightened web; a comparison between the web stresses of specimens 9 and 7 is meaningless because the stresses for specimen 7 are based simply on the gross area.

The 6-inch beam with the heaviest flange angles (specimen 10) carried about 84 percent of the shear stress developed by the corresponding pure-shear specimen 4, in spite of the fact that the flange carried only a stress of about one-third of the column yield stress and consequently was able to take over some of the shear load. This combination of web and flange angles is, therefore, not very efficient; a decrease in the size of the flange angles (specimens 11, 12, and 13) results in higher flange stresses but at the expense of a further lowering of the web stresses. The solid-web beam 14 developed appreciably higher flange stresses than the corresponding beam 11 with lightened web.

CONCLUSIONS

The following conclusions may be drawn from the tests presented herein:

1. The formulas for webs in pure shear given in an earlier investigation may become unconservative if the limit of validity $D/h = 0.75$ specified in the earlier investigation is exceeded.

2. Allowable web stresses derived from pure shear tests and allowable flange stresses derived from compression tests cannot be applied directly to the design of beams. Allowance must be made for interaction effects. The test data available are insufficient to establish a method for making such an allowance.

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ABSTRACT:

Strength tests were made on two sets of beams having webs with large circular lightening holes. Webs tested in pure shear buckled about the lines connecting the centers of the holes. On beam specimens, web buckled in similar manner and flange began to twist. Web stresses derived from pure shear tests and flange stresses from compression test cannot be applied directly to the design of beams. Allowance must be made for interaction.

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