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TESTS OF BEAMS HAVING WEBS WITH LARGE

CIRCULAR LIGHTENING HOLES

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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 allow-
able flange stresses derived from compression tests
cannot be applied in the design of beams without making
corrections for interaction. The test data are in-
sufficient 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

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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 inves-
tigation 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, effec-
         tive 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

$$\tau = \frac{P}{Lt} \tag{1}$$

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

$$\tau = \frac{PQ}{2It} \tag{2}$$

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

$$\sigma = \frac{PL}{4hA} \tag{3}$$

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 for-
mulas (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 1 shows that the 4-inch
webs developed stresses differing by less than 2 per-
cent 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 pre-
dicted 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 1 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 speci-
men 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 com-
pression 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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