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INVESTIGATION OF WEB BUCKLING IN STEEL BEAMS

Authors' Closure

The data on aluminum alloy beams presented by Messrs.
Moore and Hartmann are valuable additions to the results ob-
tained on steel beams by the authors. Unfortunately, the data
on the aluminum beams give only the ultimate load with no indi-
cation of the load at which the beam would become useless due
to excessive deflections. As already stated in the paper, the
load at failure has no significance except that of being a
measure of the toughness of a beam after it has passed its
usefulness. In structural design the load at which the deflec-
tion exceeds the maximum permitted by the usefulness of the
building must be taken as the basis of estimating the factor
of safety. Since all the aluminum alloy beams had depth-thick-
ness ratio of only 25 and less, buckling of the web would not
take place at stresses less than the yield-point stress of the
material. No information is given as to the stress in the web
at the yielding of the beam, consequently, Messrs. Moore and
Hartmann give little support to their criticism of the authors
recommendation that the average web shear be computed on net
area (ht) rather than on the gross area (Dt). The observed
stresses presented in Fig. 24(b) do not necessarily represent
the stresses which cause yielding of the beam. Professor West-
ergaard has shown (in a paper unpublished as yet) that the con-
centration of shearing stress at the fillet between the web and
the flange of the beam may become significant for beams having

relatively small fillets. Fig. 21 also shows that the computed stresses at the yielding of the beam, instead of being greater, as they should according to Messrs. Moore and Hartmann's discussion, are less than the yield-point stresses of the web material.

One half of the beams reported by Messrs. Moore and Hartmann failed by what has been termed web crippling. An investigation of web crippling was also carried out at Lehigh University with the cooperation of the Bethlehem Steel Company and its subsidiary the McClintic-Marshall Corporation, at the time of the tests of web buckling. The results were not included in the paper in order to make a definite distinction between the two types of stress condition. They are therefore presented herewith.

Web crippling is principally a local failure produced by excessive compressive stresses, and the problem of preventing its occurrence is most common in the design of structural beams supported on seat angles. The aim of the investigation was to establish the stress at which yielding due to web crippling took place.

The program included the testing of six Bethlehem B 22-58 rolled beams, four of which were cut from the same section and two from another section. The information for these beams which had an h/t ratio of about 52, is given in Table III. Three of the beams were designed to fail at the

point of application of the load and the other three to fail at the supports. The nominal bearing lengths were 7 and 11 inches for the center failures, and 3-1/2 and 5-1/2 inches for the end failures.

In order to prevent failure due to end twisting, steel plates were welded to the bottom flange at each end of the beam. In each end plate, at a height even with the top flange, there was a slot which served as a guide for bars welded to the center of the top flange. This arrangement, as shown in Fig.26 allowed the top flange to deflect vertically but restrained it from moving laterally.

All the beams were supported by rollers and loaded at the center of the span. A roller was also used for the application of the load for beams No. 1 and 2, but a spherical bearing block was employed for this purpose in the testing of the remaining four beams. Steel bearing plates of the proper length were used to transfer the load from the rollers and bearing block to the beam. Vertical deflections and strain gage observations were taken on all beams. Except for Beam No. 1, all beams were whitewashed before testing.

Strain lines in the web appeared at both supports at a load of 115,000 lb., and at the center at a load of 200,000 lb. At a load of 190,000 lb., the strains in Beam No.1 increased greatly, indicating that the actual yielding of the beam occurred. The strains observed at a point immediately

above the flange indicate that the yield point of the material in the web was reached at considerably lower loads. However, this local yielding did not have any effect on the beam as a whole. The beam continued to take load until a maximum of 202,000 lb. was reached at which time the web crippled at the end, as shown in Fig. 27.

In computing the actual bearing length at the root of the web it was assumed that the stress was distributed through the flange on an angle of 45°. The total bearing length thus equals the length of the bearing plate plus twice the thickness of the flange at the root of the web. The thickness of the flange was measured by micrometers at a point next to the fillet as indicated in Table I. The length of the bearing plate was 3-1/2 inches at the supports where the beam was designed to fail. The compressive stress at the root of the web at the yield point of the beam was 50,500 lb. per sq.in., which compares very well with the average tensile yield-point stress of 49,000 lb. per sq.in. for the web material. The full yield-point stress of the web was thus utilized in this beam.

Beam No. 2 was designed to fail at the loading point where the length of the bearing plate was seven inches. Strain lines appeared at the supports at a load of 100,000 lb. and at the loading point at 140,000 lb. Since the failure of this beam occurred at the loading point no definite

indication of yielding could be obtained from the deflection curves. The strain gage results showed that the strains near the root of the web increased at a high rate above a load of 120,000 lb. The strains measured at the center of the web indicated a yielding at a load of 160,000 lb., which was taken as the yield-point load of the beam. The beam continued to take load until a maximum of 223,000 lb. was reached, at which time the web crippled at the loading point as shown in Fig. 28.

At the yield point of the beam the maximum compressive stress at the root of the web was 49,000 lb. per sq.in., or the same as the tensile yield-point stress of the web material.

Beam No. 3 was designed to fail at the supports where length of the bearing plates was 5-1/2 inches. To prevent failure at the center, stiffeners were welded to both sides of the web at this point.

The first strain lines appeared in the web near the center at a load of 60,000 lb. The strain lines continued to form and at a load of 110,000 lb. they appeared in the web at the supports. The observed strains indicated yielding at a load of 220,000 lb., which was taken as the yield point of the beam, while the deflection curves indicated yielding at a load of 230,000 lb. At the maximum load of 231,500 lb. the web crippled at one of the supports, as

shown in Fig. 29. The bearing plate used for this beam was too thin for effective distribution of the load from the roller to the flange of the beam and consequently contributed to a concentration of stress at the center of the plate, causing local failure at low average stress.

The maximum compressive stress at the root of the web was 41,000 lb. per sq.in. at the yield point of the beam. This is considerably less than the tensile yield-point stress of 50,000 lb. per sq.in. for the material in the web.

As Beam No. 4 was designed to fail at the center, stiffeners were welded to the web at the supports. The length of the bearing plate at the center of this beam was 11 inches.

The first strain lines appeared in the web at the supports at a load of 90,000 lb. and at 120,000 lb. they appeared under the loading point. The observed strains indicated a yielding at a load of 210,000 lb. which was taken as the yield-point load. The beam continued to take load until a maximum of 264,400 lb. was reached, at which time the web crippled at the center of the beam as shown in Fig. 30. The bearing plate was too thin also for this beam for uniform distribution of the load.

At the yield-point load the maximum compressive
stress at the root of the web was 43,200 lb. per sq.in.,
which is considerably less than the tensile yield-point
stress of the web material.

Beam No. 5 was similar to Beam No. 1, having a
bearing length of 3-1/2 inches at the supports where it
was designed to fail. The first strain lines appeared in
the web at the supports at a load of 60,000 lb. and at the
loading point at a load of 130,000 lb. The vertical de-
flections as well as the strains, showed that the beam
yielded at a load of 160,000 lb. A slight crippling of the
web at the support was noted at 190,000 lb., and at a load
of 205,000 lb. the web crippled.

At the yield-point load of 160,000 lb. the computed
stress at the root of the web was 41,900 lb. per sq.in.,
which compares favorably with the yield-point stress of
44,660 lb. per sq.in. for the web material.

Beam No. 6 was similar to Beam No. 2, having a bear-
ing length of seven inches at the loading point. As this
beam failed at the center, the vertical deflections indi-
cated that there was no yielding of the beam as a whole.
The strain curves, however, indicated a bending tendency
in the web at ahload of 80,000 lb. The rate of strains in-
creasedssharply at a load of 150,000 lb. which was taken as
the yield-point of the beam. The beam continued to take load

until a maximum of 209,500 lb. was reached and at this load the web crippled under the center.

At the yield-point load of the beam the maximum compressive stress at the root of the web was 45,000 lb. per sq.in. which is very close to the yield-point stress of 44,660 lb. per sq.in. for the web material.

Both the flexural and shearing stresses were low in all of these beams, so there was no indication of yielding due to these stresses.

Since only six beams were tested in this investigation, no general conclusions can be drawn. However, the results indicate that:

1. The appearance of the first strain lines has no relation to the yielding of the beam as whole but is an indication of high local stress.

2. The compressive stress at the root of the web at the yield point of the beam corresponds very well with the tensile yield-point stress of the material for properly designed bearing plates.

3. The yielding was caused by the compressive stresses at the root of the web.

4. The following formula may be used in computing the compressive stress at the root of the web:

$$f = \frac{R}{t(A+2N)}$$

where:

      f = compressive stress

      R = load on bearing plate

      t = thickness of web

      A = length of bearing plate

      N = thickness of flange at edge of fillet

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