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# FOREST PRODUCTS LABORATORY

In cooperation with the University of Wisconsin

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# WOOD-BEAM DESIGN METHOD PROMISES ECONOMIES

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A new design method for calculating the horizontal shear in wooden beams, developed by the Forest Products Laboratory through mathematical analysis and tests, assumes that, because of the shear distortion in the vicinity of the base of checks or fissures that are present in all beams, the upper and lower halves of the beam act to some extent as independent beams. The result is to relieve the mean shearing stress in the neutral plane, and since this reduced shearing stress is not considered in present design methods, they are often over-conservative and therefore uneconomical to use. In certain cases, such as floor beams of highway bridges and railway ties, usual design methods predict stresses that are two or three times the ultimate shearing stress of the material. Still these members are carrying their loads without failure. In the discussion presented here an attempt is made to explain the elastic behavior of a checked beam under load and thus to explain the discrepancy existing between the facts of experience and the predictions of the usual methods of calculating shear. The background for this explanation is furnished by an approximate mathematical analysis of the problem combined with the results of a series of about 200 tests, in which the loads causing shearing failure were observed on built-up artificially checked beams varying from 3/4 x 1-1/2 in. to 8 x 16 in. in cross section and with varying amounts of checking. On the basis of the theory and the results of tests, practical directions are given for the more realistic calculation of loads that will cause shearing failure.

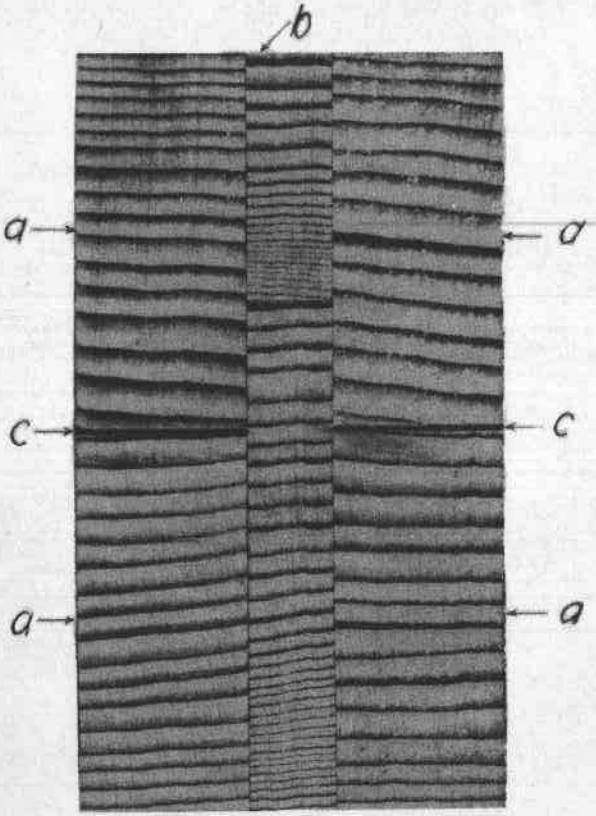
In the tests, built-up artificially checked beams of carefully matched material were used. A typical section is shown in Figure 1. The checks are placed in the middle of the lateral faces, as this is the position in which they are most likely to occur and to cause failure by shear. A characteristic failure, by horizontal shear, of a naturally checked structural timber loaded at two points is shown in Figure 2. In all other tests referred to in this paper the beams were loaded at one point only.

## Two-Beam Action

An explanation of the behavior of a checked beam is found in the fact that, owing to the shear distortion in the material in the

Figure 1.--(left)--Cross-section of a built-up artificially checked beam such as was used in the test. The four parts a were glued to the central portion or web b. The joints c were paraffined to prevent sticking of any glue that might protrude from adjacent joints and to minimize friction.

Figure 2.--(right)--Characteristic failure of a timber beam, failure occurring in horizontal shear in the neighborhood of the neutral axis.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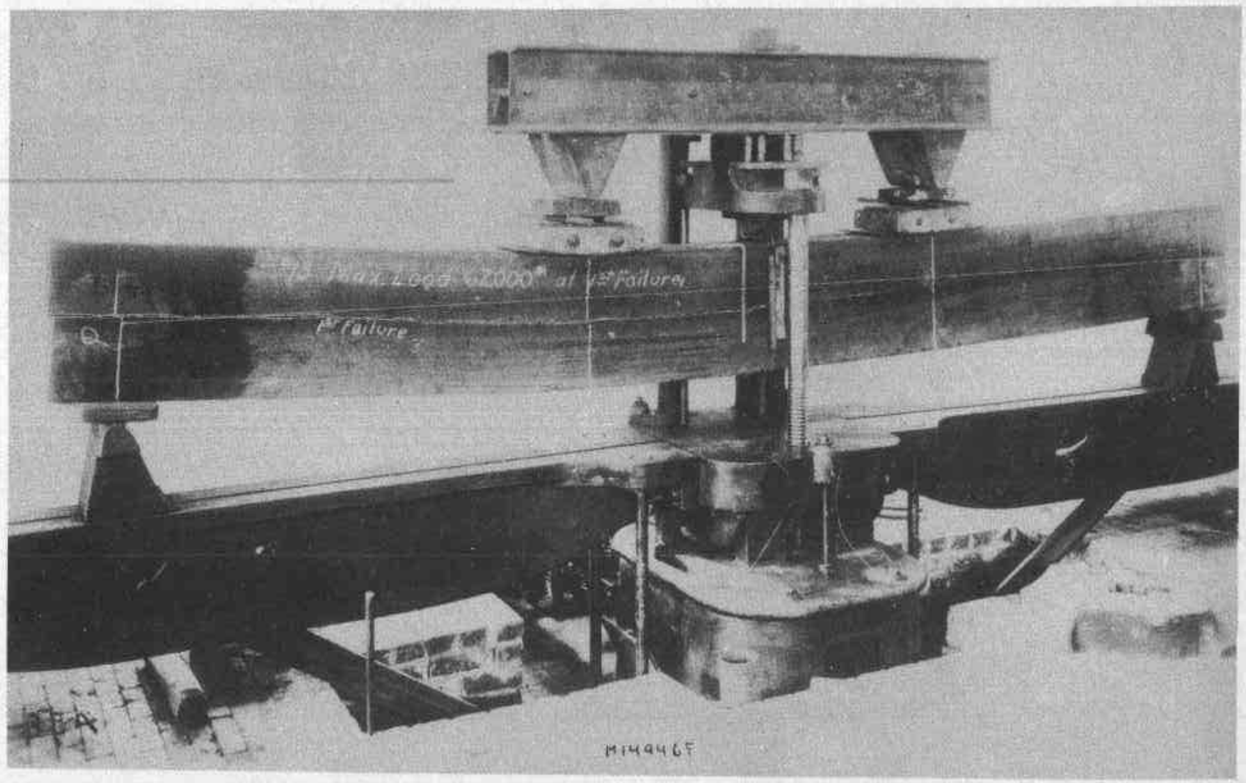
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vicinity of the base of the checks, the upper and lower halves of the beam act to some extent as independent beams. An approximate mathematical analysis indicates a vertical distribution of shearing stress as shown in Figure 3. The shearing stress plotted is the mean shearing stress at failure averaged over the full width of the beam. The existence of the "two-beam action" is evident from the curves. The mean shearing stress in the neutral plane is relieved by the action of the upper and lower halves of the beam as partly independent beams. The significance of this action is emphasized by the further result of the mathematical analysis that the reaction R at the support nearer the load may be expressed as the sum of two terms, of which only the first is associated with shearing stress in the neutral plane. Thus it is found that

$$(1)\quad R = B + A/a^2$$

where

$$(2)\quad B = 2/3\ Jbh,$$

J being the mean of the shearing stress in the neutral plane over the full width of the beam, and b and h being the width and depth, respectively, of the beam. The portion B of the reaction is precisely the reaction that would be associated with the mean shearing stress J in the neutral plane in the usual theory of beams and may be referred to as the "single-beam portion" of the reaction.

In the second term of equation 1, a is the distance from the load to the nearer support, and A is a quantity determined chiefly by the dimensions of the beam, the longitudinal Young's modulus, and the mean longitudinal displacement on the lower face of the upper half of the beam at points immediately over the support. The portion of the reaction expressed by this term is attributed to the independent action of the upper and lower halves of the beam and is not associated with shear in the neutral plane. It is the "two-beam portion" of the reaction. The values of the two-beam and single-beam portions of the reaction at the instant of failure were determined by testing a large number of beams and by combining the results of tests of pairs of carefully matched beams loaded to failure, the concentrated loads being applied at different points. On entering the results of each pair of tests in equation 1 two equations were obtained that could be solved for B and A.

## Test Results Suggest Design Procedure

In this procedure it was assumed that the values of A and of the mean shearing stress J in the neutral plane at failure were independent of the position of the load. The justification of both assumptions is found in the fact that the results of the tests were represented approximately by equation 1 with A and B as constants for the whole series. The

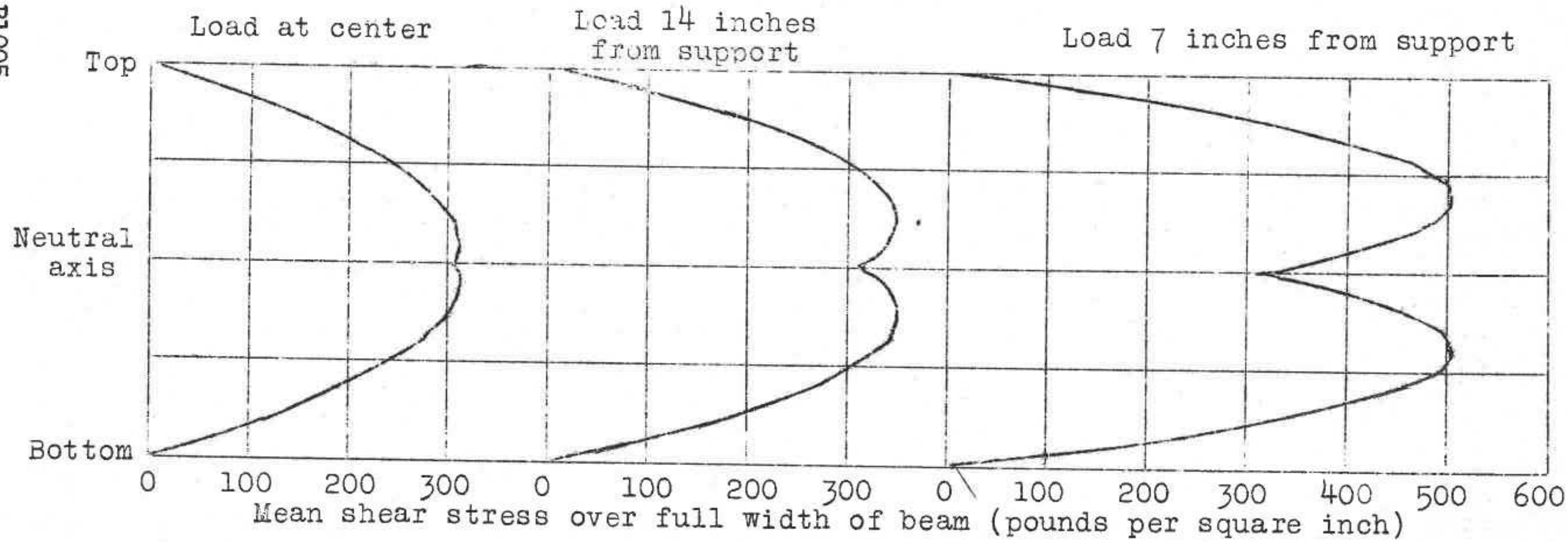


Figure 3.--Theoretical variation of horizontal shear stress in checked beams for various positions of a single concentrated load. Beams were 2-1/2 x 4-1/2 x 45 in. on a span of 42 in. The depth of the checks was 1 in.

tests showed that as a concentrated load approaches a support, the two-beam portion of the reaction increases rapidly, while the single-beam portion associated with shear in the neutral plane, remains practically constant and becomes a correspondingly smaller fraction of the reaction. As a consequence, the point of application of the minimum concentrated load to produce failure by shear is not just inside the support, as is commonly assumed because of the usual simple beam theory, but is at some distance from the support. The results of the tests of three series of beams are given in the accompanying table and are represented graphically in Figure 4. The single-beam and two-beam portions of the reaction shown in the table were computed by combining in pairs the mean reaction corresponding to a = 7 with that corresponding to each of the other points of loading. If these reactions are combined in pairs in other ways, results varying somewhat from those shown may be obtained.

The results of the numerous tests may be summarized in the following statements: For checked beams with a span-depth ratio of 9 to 1 the point of application of the minimum concentrated load causing failure by shear is at a distance from the support approximately three times the height of the beam. The distance of the critical point from the support is somewhat greater for longer spans and somewhat less for shorter spans; but in any case, for loads applied at three times the height of the beam from the support, the two-beam portion of the reaction at the nearer support is approximately one-sixth.

## Design Recommendations

1. If there are moving loads, place them so that the heaviest concentrated moving load is at a distance from the support of three times the height of the beam. After this has been done the following recommendations apply both to static loads and to the moving loads.

2. Neglect all concentrated loads within a distance from the support equal to the height of the beam.

3. Consider all concentrated loads that are from one to three times the height of the beam from the support as being at three times the height of the beam from the support and compute the resulting reaction. Neglect one-sixth of the reaction. This one-sixth is the two-beam portion of the reaction and is not associated with shear in the neutral plane.

(Note: For very small span-depth ratios -- less than 6 to 1 -- place the loads designated in recommendations 1 and 3 above at the middle of the span.)

4. Consider all other concentrated loads in the usual manner.

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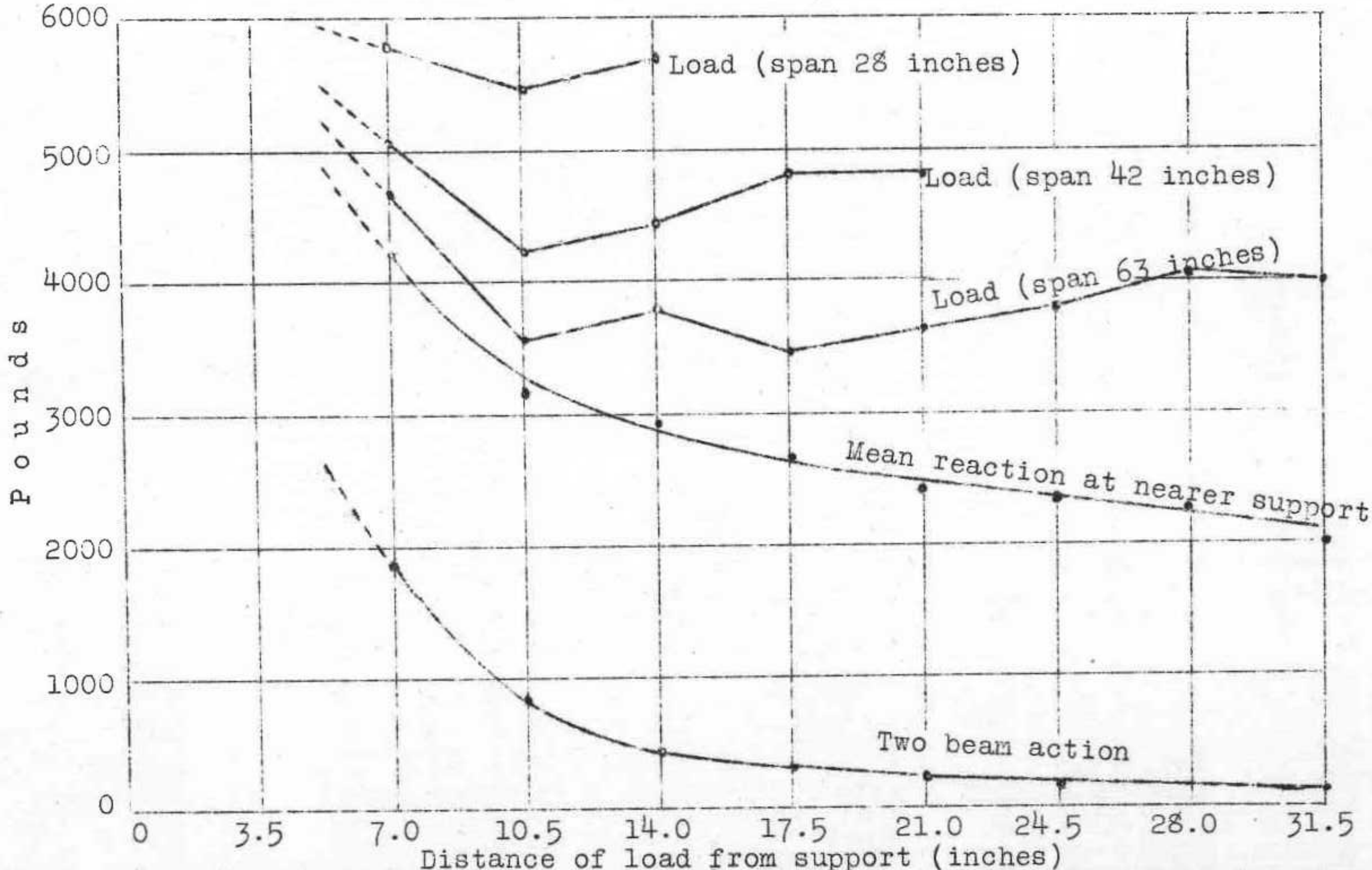


Figure 4.--Test results of built-up artificially checked beams of various lengths. Note the relative values of the single-beam and two-beam portions of the reaction and the increasing importance of the latter as the load is placed nearer the support.

Results of tests of built-up, artificially checked spruce beams

(Various lengths; breadth, 2-1/2 in.; height 4-1/2 in.; depth of checks, 1 in.)

| Distance (a) from load to nearer support | Load at failure | | | Mean reaction at nearer support | Single-beam action | Two-beam action | Two-beam action x $a^2$ |
|---|---|---|---|---|---|---|---|
| | 28-in. span | 42-in. span | 63-in. span | | | | |
| Inches | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds |
| 7.0 | 5,770 | 5,050 | 4,660 | 4,226 | ........ | 1,872 | 91,700 |
| 10.5 | 5,460 | 4,240 | 3,560 | 3,186 | 2,354 | 832 | 91,700 |
| 14.0 | 5,680 | 4,430 | 3,780 | 2,911 | 2,473 | 438 | 85,800 |
| 17.5 | ....... | 4,800 | 3,460 | 2,649 | 2,349 | 300 | 91,900 |
| 21.0 | ....... | 4,800 | 3,630 | 2,410 | 2,183 | 227 | 100,100 |
| 24.5 | ....... | ....... | 3,780 | 2,310 | 2,140 | 170 | 102,000 |
| 28.0 | ....... | ....... | 4,050 | 2,250 | Failed in tension...... | | |
| 31.5 | ....... | ....... | 3,970 | 1,985 | 1,869 | 116 | 115,100 |

5. Neglect 10 percent of the uniform load. This 10 percent is taken care of by two-beam action.

6. Assume lateral distribution of the various loads to adjacent parallel beams or stringers on the basis of their assumed placement.

7. Calculate the shearing stress in the neutral plane by the usual formula, using the full width of the beam and all of the reaction, obtained as directed, that is not included in the two-beam portion.

8. Use 90 percent of the safe shearing stresses previously recommended by the Forest Products Laboratory, since these recommendations did not take into account the effect of two-beam action.

The use of these recommendations will result in a considerable saving of material. The highway bridge, on account of the effects of lateral distribution of the loads to adjacent stringers, is probably the structure that will show the greatest difference in the results of the application of the new and old methods. An application of the two methods of calculation to a highway bridge follows:

Consider a single concentrated load $\underline{P}$ moving along a floor beam or joist. Assume the span to be 16 ft., the height of the joist, $\underline{h}$, 16 in., and its width, $\underline{b}$, 5 in., and all dimensions full nominal size. Assume also that when the load is in the center of the span the floor carries one-fourth of it to each of the two adjacent beams, one on either side. In such a case it has been calculated that the side beams will carry a little more than 40 percent of the load when the load is at three times the height of the beam from the support. The shearing stress, $\underline{J}$, in the neutral plane is given by

$$J = \frac{3}{2} \times \frac{5}{6} \times \frac{R}{bh} \qquad (4)$$

where $\underline{R}$ = reaction due to the load $\underline{P}$ placed at three times the height of the beam from the support.

But, according to the assumptions as to lateral distribution,

$$R = \frac{6}{10} \times \frac{3}{4} \times P = \frac{9}{20} P \qquad (5)$$

Assuming 100 lb. per sq. in. as the tabular value for the safe shearing stress and reducing it by 10 percent as explained earlier, it follows from (4) and (5) that

$$90 = \frac{3}{2} \times \frac{5}{6} \times \frac{9}{20} \times \frac{P}{5 \times 16} \qquad (6)$$

Hence, $\underline{P}$ = 12,800 lb., the safe load in shear.

Under the old assumption that maximum shear in the neutral plane will occur as the heavy wheel leaves the span, using the full tabular value of 100 lb. per sq. in. as the safe shearing stress, and noting that at the end of the beam there is no lateral distribution, the safe load P is found from

$$100 = \frac{3}{2} x \frac{P}{5 x 16}$$

From which P = 5,333 lb.

This method of computation leads to a safe load less than one-half that permitted by the new method.

In the case of a single beam with no lateral distribution, we omit the factor 6/10 from equations 5 and 6, obtaining

$$R = \frac{3}{4} P$$

and

$$90 = \frac{3}{2} x \frac{5}{6} x \frac{3}{4} x \frac{P}{5 x 16}$$

Then P = 7,680 lb.

This load is more than 40 percent greater than that permitted by the old method of calculation.