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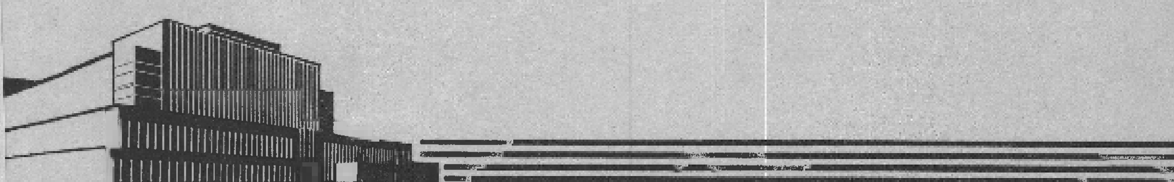

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE DESIGNING FOR STRENGTH OF FLAT PANELS WITH STRESSED COVERINGS[1]

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U. S. Department of Agriculture

At the present time many houses are constructed using panels with plywood covering in which the coverings are expected to act as a unit with the frame members to which they are glued in order to give bending strength and stiffness to the panel.

It is very easy for even the technically trained engineer to go wrong in trying to evaluate the strength properties of a panel with stressed covering. The purpose of this article is to present, in a manner which can be understood by all, the fundamental principles involved in the use of stressed-covered panels in house construction. Approximate rules for construction and for calculation are set up which will avoid most of the pitfalls of bad construction and complicated calculations and yet give safe dependable construction without being over conservative.

No satisfactory method has ever been presented for simply and accurately calculating the ultimate strength of stressed-covered panels nor of thin plates with the sides held in various ways under compression loads, but much has been done in studying the elastic behavior of thin plates to the point where buckling begins. (See Timoshenko. Theory of Elastic Stability. 1936)

Attention must be directed to the elastic stability of thin plates for the fundamental conceptions of how the panels will fail and how best to design them to meet the conditions of service. The panel with stressed covering may be classed as one of three types of beams. The solid rectangular beam is the first type and the stress in compression at maximum load is approximately the modulus of rupture of the beam. The second type comprises the I and box beams in which the top and bottom flanges are too thick to buckle. When the compression flange is very thick, the stress at maximum load approaches

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[1] Original report by J. A. Newlin, 1940.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

the modulus of rupture of the rectangular beam. As the top flange of such a beam is made thinner and thinner as compared with the other dimensions, then the stress at maximum load becomes the maximum crushing strength of the material in the flange (as a short column) when the parts become as thin as possible without local buckling. These beams are said to have a form factor. The third type is the beam with a thin covering which will buckle at maximum load at a stress not greater and often much less than the compressive strength of the covering as a short column.

Panels with stressed coverings are of the third type. It is essential in panels with stressed coverings to take into account the buckling tendency in any attempt to calculate either the load at proportional limit or maximum load.

The behavior of long thin plates under compressive loads in the direction of their length and with various side conditions furnishes certain conceptions as to the action of the thin covering in panels and suggests how to design to take advantage of the strength of the covering.

The following relations of loads and stress to the properties of the materials and geometric dimension and fastenings are essential to a clear conception of the rules for design and methods of calculation.

The relations for a thin plate (free from waves when not loaded of a length to break up into full length waves, all edges being held in line and with a uniform compressive load along one end edge and supported on the opposite edge is given by the formula

$$(1) \quad W = Kh\sqrt{\frac{A}{f}}$$

where $\underline{W}$ is the width between the side supports, $\underline{K}$ is a factor depending upon the fixity at the side supports, $\underline{h}$ is the thickness of the thin plates, $\underline{A}$ is the stiffness of the material in the thin plate (in homogeneous material it is the modulus of elasticity), and $\underline{f}$ is the stress at which buckling begins.

This means that if the width between the studs is doubled the stress in the covering to cause buckling will be divided by four, everything else being constant, also that if everything else is to remain constant the width between studs will vary as the thickness of the covering.

If the material is not homogeneous then $\underline{A}$ is equal to the square root of the product of the modulus of elasticity of the covering along and across the length of the material as determined by bending tests. The $\underline{K}$ in the formula varies from 1.9 where the edges are held in line but free to rotate to 2.48 in the event the edges are rigidly clamped. In wall panels the edges are more or less elastically clamped which will give a K intermediate between the above extremes.

The most realistic way of estimating the maximum load which the panel can be depended upon to sustain appears to be the use of the ordinary engineering formulas with which it is assumed the designer is familiar and the more or less arbitrary rules based on the foregoing discussion as to the width of strips of covering between adjacent longitudinal members, which will be assumed to contribute to the strength and rigidity of the panels.

The following formula gives a width between longitudinal members which is here designated as a basic width:

$$(2)\quad b = 3.2h\sqrt{\frac{A}{S}}$$

where b may be designated as a basic stud or longitudinal member spacing (clear distance not center to center) and S is the maximum crushing strength of the thin sheet as a short column parallel to the length of the stud.

Formula (2) could be written

$$b = 2.13h\sqrt{\frac{A}{\frac{4}{9}S}}$$

in which the 2.13 is an edge fixity factor about half way between 1.90 for simply supported edges and the 2.48 for rigidly clamped edges, and $\frac{4}{9}S$ is the critical buckling stress of the panel of width b.

In line with the foregoing discussion, the following paragraphs present a general method of calculating the strength and stiffness of panels with stressed covering, a discussion of the essential construction features, and a modification of the method of calculation applicable to plywood only which greatly simplifies the procedure with this material.

Method of Calculation

Strength and Stiffness of Panels with Stressed Covering

First. From the properties of the face material calculate b, the basic spacing of longitudinal members for both the compression and tension faces.

Second. Calculate the moment of inertia of the section disregarding all covering in excess of b when the clear distance between longitudinal members is greater than b.

Third. In calculating the stiffness use the moment of inertia as calculated above and the modulus of elasticity of the covering as determined from compression tests. Complete the calculation using the ordinary engineering formula.

Fourth. In calculating the maximum load use the moment of inertia as calculated above.

(a) If the distance between longitudinal members is one-half b or less use the maximum crushing strength parallel to the longitudinal members as the stress on the compression side or the maximum strength in tension on the tension face, whichever gives the smaller load.

(b) As the distance between the longitudinal members is increased beyond one-half b the stress on both faces should be decreased uniformly until at b the stress is two-thirds the stress at one-half b.

Fifth. When the spacing between the longitudinal members is greater than 2b, the panel should not be considered in building construction as a panel with a stressed covering since the design loads might cause the initial buckling of the covering.

Construction Features

There are certain construction features that must be observed if satisfactory and safe panels are to be made. A satisfactory and safe panel may be defined as one which throughout the expected life of the panel will not buckle due to the design load stresses and which will show a reasonable factor of safety at all times between its design load and the load to cause failure.

A brief review of the types of failure at maximum load of various panels tested in bending and as a column at the Forest Products Laboratory will plainly demonstrate the necessity of certain details not being overlooked or neglected. In the bending tests of the floor panels with plywood top coverings in which the spacing between the joists was a little greater than one-half b, the following typical failures were found:

(a) When the construction was good in every way and there were no pronounced weaknesses in the joists or covering, then the failure was characterized by the plywood being torn from the joists (the failure being either between the plywood and joists or within the plywood) starting at or near the point of maximum bending moment. The buckling of the plywood is the cause of the failure. (b) When the joists were checked the failure was usually by shear in the joists. (c) When the joists were good but the gluing between the joists and covering or within the plywood was poor then the failure was by horizontal shear at the ends of the joists either between the joist and plywood or within the plywood. (d) When the construction and material were good throughout, except that no headers or other means of holding the joists apart were provided, then the tension covering pulled the lower edges of the joists together as it buckled up between the joists and the top covering was torn loose from the joists by this bending action and shear. The wall panels, which had plywood coverings and others of dense wallboard, tested both as a column and in bending failed almost entirely by the material being torn from the studs at the middle of the height. Sometimes the failure was between the stud and covering and sometimes in the covering. One of the panels, which had framing members in both directions halved together at the joints failed by shear in the framing when tested in bending.

The foregoing observations lead to the following conclusions:

(a) It is essential to have good gluing between the frame and the covering (small spots not glued cause a weakness, due to concentration of stresses, out of all proportion to their size) and it is almost equally important to have good bond and strength within the covering.

(b) The longitudinal members should be at least twice as thick (cross sectional dimension next to the covering) as the covering.

(c) Headers are essential with relatively thin high longitudinal members such as joists.

The influence on strength of putting in members at right angles to the longitudinal members is dependent upon whether or not they are so placed as to break up the natural wave length. In general their influence is a small increase of strength of uncertain amount and should be neglected.

The fastening of the coverings to the longitudinal members by any means less rigid than gluing (such as nailing) should not be considered as giving a stressed covering.

Plywood

Plywood on account of the influence of moisture and other factors and its nonhomogeneous characteristics makes the application of the preceding formulas a little complicated. This is especially true due to the fact that the stiffness of plywood of a span or spans correct for inclusion in the formulas is dependent upon the distortion in shear which may account for one-half of the total distortion in three-ply plywood.

However, from assumed relations of the various properties that do not vary between species enough to influence the results materially, the following formulas applicable to plywood have been derived which are simple and not greatly in error:

$$\text{For three-ply plywood } b = 31h\sqrt{\frac{\text{Total thickness}}{\text{Parallel plies thickness}}}$$

$$\text{For five or more plies } b = 36h\sqrt{\frac{\text{Total thickness}}{\text{Parallel plies thickness}}}$$

With b determined for plywood as above, the strength and stiffness of the panel may be determined from the strength values for clear wood. First calculate the moment of inertia of the section neglecting the crossplies and all covering in excess of b. Then calculate the stiffness using the modulus of elasticity for the species and condition taken from the strength tables. In calculating the ultimate strength for spacing of longitudinal members one-half b or less, use for high grade plywood 85 percent, for a medium grade of plywood 75 percent of the maximum strength in compression parallel to the grain of clear wood in small sizes and at the proper moisture content; and for spacing greater than one-half b reduce the stress uniformly from that allowed at one-half b to two-thirds this amount at a spacing of b.[3]

For safe loads[3] use the basic strength in compression parallel decreased for grade of plywood and increased for dryness instead of the maximum crushing strength used above.

In calculating the strength on the tension face, substitute modulus of rupture for the maximum crushing strength, and for calculating the safe load substitute the basic stress in extreme fiber for the allowable stress in compression parallel to the grain.

Figure 1 gives a graphic picture of the relations which exist between the distance between longitudinal members and the loads and stresses. It shows how buckling becomes a major factor as the width between these members increases and the gross error on the side of increased danger which would be introduced by using the maximum crushing strength as the stress at maximum load and disregarding the buckling factor.

[3]For values pertinent to the foregoing consult "Wood Handbook," U. S. Dept. Agr. unnumbered publication, Washington 25, D. C.

From the foregoing it might appear that the use of panels with stressed covering was questionable. The facts are, however, that while poor weak panels can be made and might readily be made without realizing it, good panels can in general be made from the same material. In fact, it is usually easy to design panels with strength beyond the requirements of service and at practically no additional cost over the weak panel, if the factors pointed out here are given due consideration.

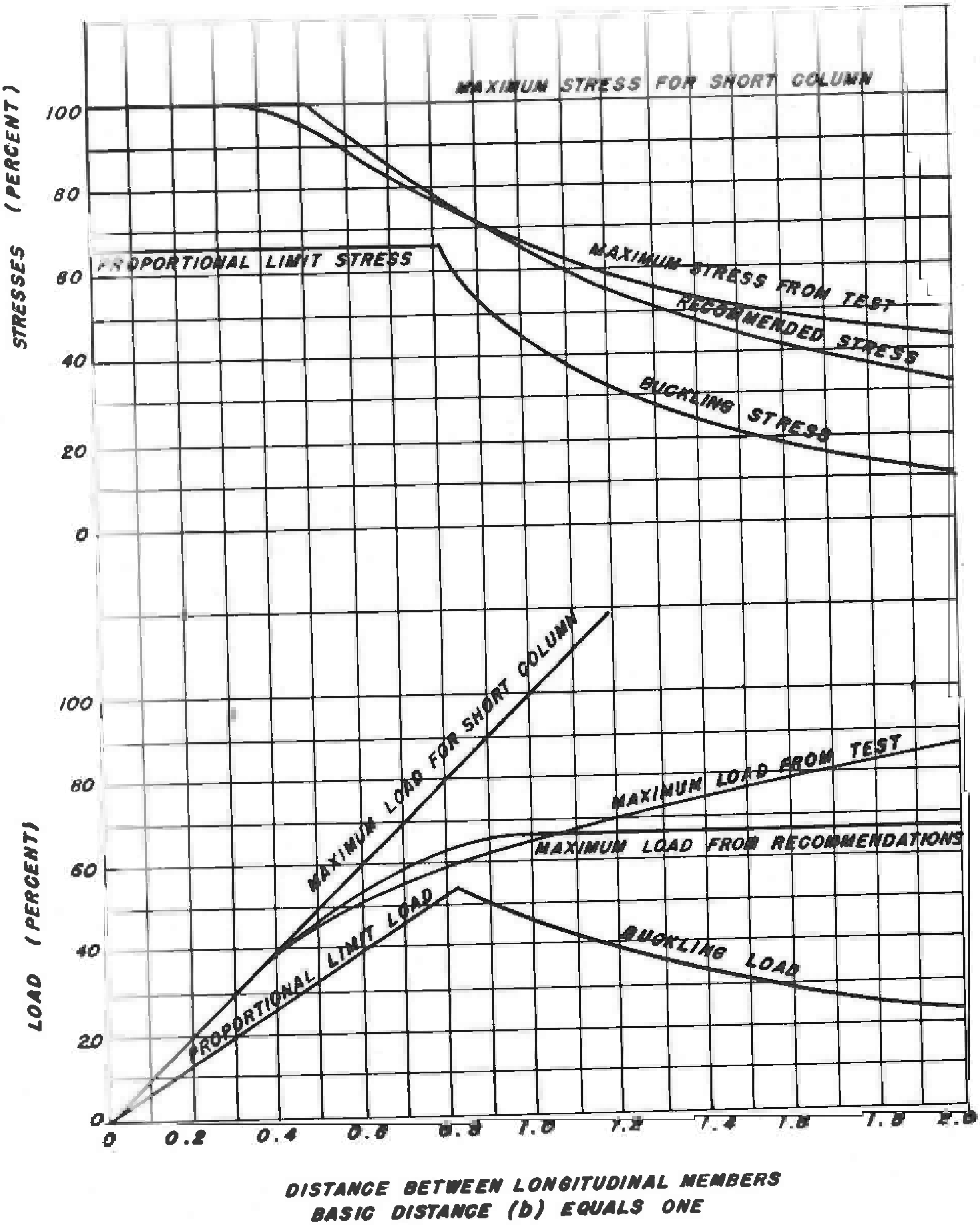

Figure 1.--Influence of buckling of stressed covering. Loads and stresses in the plywood compression cover as related to the distance between longitudinal members expressed in percent of that for plywood when acting as a short column.

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