DESIGN METHOD FOR ELASTOMERIC ADHESIVE BONDED WOOD JOIST-DECK SYSTEMS

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ABSTRACT

The paper describes the development of equations for designing joist-deck systems in which the two elements are connected with elastomeric adhesives. The equations permit calculation of tension and compression stress in the elements, shear stress at the bond line, and deflection. They apply for continuous sheathing or for panels with effective splice joints.

Graphs illustrating a specific application to residential floor systems are presented. These are interpreted to show that moderately rigid elastomeric adhesives, of the stiffer types available, should achieve 70 to 80% of the improvement in deflection that is possible with rigid adhesives.

The paper indicates that while creep may not be a deterrent to use of elastomeric adhesives structurally, additional study is needed.

Additional keywords: Stressed-skin panels, shear-slip, composite structures, stress analysis, glued building components, floors, roofs, housing, structural engineering, wooden structures.

NOTATION

A = a constant
A_d = area of deck
A_j = area of joist
B = a constant
b = width of joist
C_1 = a constant
C_2 = a constant
C_d = distance from centroidal axis to extreme fiber of deck
C_j = distance from centroidal axis to extreme fiber of joist
D = a constant
d = a subscript denoting deck
E = a constant
E_d = elastic modulus of deck
E_j = elastic modulus of joist
F = force
f_v = shear stress in glue line
G = shear modulus of adhesive
I = moment of inertia
j = a subscript denoting joist
K = stiffness of the glue line
L = span
ℓ = a subscript denoting left end of span
M = moment
P = concentrated load
q = shear flow at the glue line
r = a subscript denoting right end of span
t = thickness of glue line
u = a distance from left support to concentrated load
w = uniformly distributed loading
x = a distance from left support
y = vertical coordinate of point on elastic curve
z = distance between centroids of deck and joist
Δ = adhesive shear deformation
ϵ = axial member strain
γ = shear strain in glue line

INTRODUCTION

The design of stressed-skin panels using rigid adhesives permits developing composite action between sheathing and joists. The design procedure is well known and commonly used (American Plywood Association 1970).

Construction adhesives of the elastomeric type have come into commercial use in recent years. These relatively elastic adhesives (Gillespie and River 1972) are employed in bonding floor sheathing to joists

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and, although the increase in stiffness of these systems over ordinary nailed construction is recognized, a means of computing their stiffness and strength is not in general use.

Measurements that we have made, but have not published, make us believe that the strength and stiffness requirements elastomeric adhesives must have to perform well in joist-deck structures are within the range of available products. Creep properties cannot be established theoretically, but some studies indicate that elastomeric adhesives may be able to satisfy reasonable criteria for creep (Hoyle 1973).

We present here a general method for computing the stresses and deflections of joist-deck systems. It presents results showing how the adhesive modulus of rigidity affects the deflection and distribution of critical stress. Illustrations of application of the method to a specific floor system for 2- × 8-inch joists spaced 16 inches on centers, with ½-inch Structural I grade plywood sheathing (face grain perpendicular to joist span), showing the effect of modulus of rigidity of the adhesives, are presented. We have used a glue-line thickness of 0.03 inch, which we believe is a practical estimate of average thickness obtained with nailed elastomerically glued floor systems. The illustrations are based on the 13-ft span recommended for unglued floor systems constructed with 2- × 8-inch joists with an elastic modulus of 1,700,000 psi in Table J-1 of "Span Tables for Joists and Rafters" (NFPA 1971). A set of deflection versus span curves for glued and unglued floors using an elastomeric adhesive of average available modulus of rigidity ($G = 90$ psi) for joist sizes from 2×4 to 2×12 inches is also included. Information has also been compiled for adhesives with moduli of rigidity of 25 and 50 psi, and for ¾-inch plywood on 24-inch joist spacing; this may be obtained from the authors.

DESIGN METHOD

The theory required to describe the behavior of joist-deck systems having incomplete interaction is currently available in the literature. March and Smith (1955) have examined sandwich construction using a theory of elasticity approach. Norris et al. (1956) performed some supplemental mathematical analysis on March and Smith's work, and Kuenzi and Wilkinson (1971) utilized Norris' work to study the effect of adhesive or fastener rigidity on the behavior of composite beams. Newmark et al. (1951) considered the problem of incomplete interaction of a composite T-beam having a concrete deck connected to a steel I-beam by shear connectors. By considering the differential equation of the longitudinal force in each element of the T-beam, he obtained expressions for the stresses and deformations. The development presented below follows the approach used by Newmark et al. (1951). [Note: Subsequent to the completion of the work described in this paper Vanderbilt et al. (1974) reported the same approach as the authors in deriving the governing equations.]

The analysis is based on the following assumptions:

1. The glue line between the joist and the deck is continuous along the entire length of the beam.
2. The magnitude of the slip occurring at the glue line is directly proportional to the load transmitted by the glue line.
3. A linear strain distribution exists for the entire depth of the beam.
4. The joist and the deck deflect equal amounts at all points along the length of the beam.

The first assumption requires that the glue line be continuous, a condition easily met in the fabrication of the beam. The second assumption requires that the load-deformation curve for the glue be linear. Load and slip are not always linear. Study of a commercially available elastomeric adhesive that we believe may be similar to others revealed a linear behavior in the stress range of importance to the configurations discussed in this paper. The properties of typical elastomeric construction adhesives could be the topic of a future

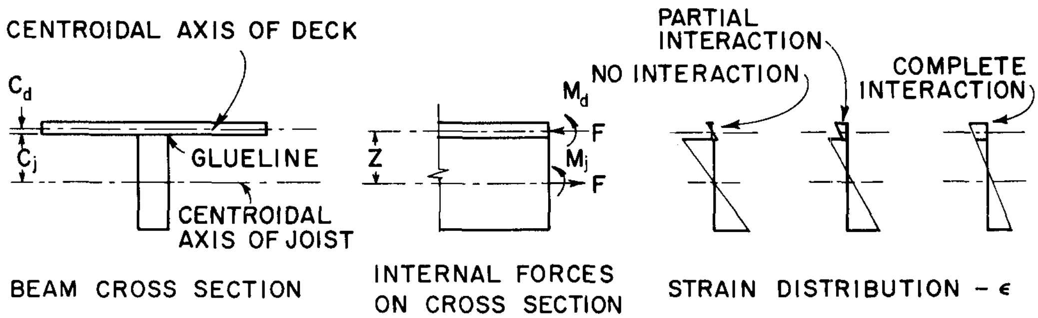

FIG. 1. Composite beam with zero, partial, and complete interaction between sheathing and joist.

paper. Assumption No. 3 appears to be met on the basis of a limited number of experimental observations and the fourth assumption is widely acknowledged.

Figure 1 shows the forces and the resulting strains that occur at a typical section of the composite beam.

M = external moment on beam at the section being considered
M_d = moment in the deck
M_j = moment in the joist
F = longitudinal force in the deck and the joist.

As the beam deflects, shear forces are developed on the surfaces of the deck and joist that are in contact with the glue line. Rather than working directly with the shear forces, however, it is more convenient to transform the cumulative effect of the shearing forces at a given section into a force that passes through the centroid of each element and a couple. These couples can be added to the moments that would exist in the deck and joist if the two elements were not connected. The resulting moments are shown as M_d and M_j in Fig. 1. The external moment at the section can be expressed as

$$M = M_d + M_j + Fz \quad , \tag{1}$$

where z is the distance between the centroid of the deck and the centroid of the joist.

The relative slip, Δ, which occurs between the deck and the joist, is given by the relationship

$$\Delta = t\gamma \quad , \tag{2}$$

where t is the thickness of the glue line and γ is the shear strain in the glue line. Since the load-deformation relationship has been assumed to be linear (assumption No. 2), γ can be expressed as

$$\gamma = \frac{f_v}{G} \quad , \tag{3}$$

where f_v is the shear stress in the glue line and G is the modulus of rigidity of the glue.

Substituting this expression for γ into equation (2) yields

$$\Delta = \frac{t\,f_v}{G} \quad . \tag{4}$$

The shearing stress, f_v, may be expressed as the shear flow, q, divided by the width of the joist, b. Hence,

$$f_v = \frac{q}{b} \quad , \tag{5}$$

and Eq. (4) becomes

$$\Delta = \frac{t\,q}{Gb} = \frac{q}{Gb/t} \quad . \tag{6}$$

The term Gb/t represents the stiffness of the glue line. Designating the stiffness by K leads to

$$\Delta = \frac{q}{K} \quad . \tag{7}$$

The shear flow q is equal to the rate of change in F along the beam. Hence Eq. 7 can be rewritten as

$$\Delta = \frac{1}{K}\frac{dF}{dx} \quad . \tag{8}$$

The rate of change in the slip along the beam is given by

$$\frac{d\Delta}{dx} = \frac{d}{dx}\left(\frac{1}{K}\frac{dF}{dx}\right) = \frac{1}{K}\frac{d^2F}{dx^2} . \tag{9}$$

The rate of change of slip is also equal to the difference in the strain in the deck and the strain in the joist at the level of the glue line. This relation is expressed as

$$\frac{d\Delta}{dx} = \varepsilon_j - \varepsilon_d , \tag{10}$$

where a tensile strain is positive and a compressive strain is negative.

From the interaction of stresses due to moment and axial load and using the notation of Fig. 1, ϵ_d and ϵ_j can be expressed as

$$\varepsilon_d = - \frac{F}{E_d A_d} + \frac{M_d c_d}{E_d I_d} , \tag{11-a}$$

$$\varepsilon_j = + \frac{F}{E_j A_j} - \frac{M_j c_j}{E_j I_j} , \tag{11-b}$$

where E_d and E_j are the moduli of elasticity, I_d and I_j are the moments of inertia, and A_d and A_j are the areas of the deck and joist, respectively. Substituting these expressions into Eq. (10) yields

$$\frac{d\Delta}{dx} = F\left[\frac{1}{E_d A_d} + \frac{1}{E_j A_j}\right] - \left[\frac{M_d c_d}{E_d I_d} + \frac{M_j c_j}{E_j I_j}\right] \tag{12}$$

Equating Eqs. (9) and (12) yields

$$\frac{1}{K}\frac{d^2F}{dx^2} = F\left[\frac{1}{E_d A_d} + \frac{1}{E_j A_j}\right] - \left[\frac{M_d c_d}{E_d I_d} + \frac{M_j c_j}{E_j I_j}\right] \tag{13}$$

The assumption that the slab and the joist have equal deflections at all points along the beam requires that the curvature also be equal. Hence,

$$\frac{M_d}{E_d I_d} = \frac{M_j}{E_j I_j} . \tag{14}$$

Rewriting Eq. (1) and substituting for M_d in terms of M_j yields

$$M - Fz = M_d + M_j = \left[\frac{M_j}{E_j I_j}\right] E_d I_d + M_j . \tag{15}$$

Or,

$$M - Fz = \frac{M_j E_d I_d + M_j E_j I_j}{E_j I_j} , \tag{16-a}$$

$$M - Fz = \frac{M_j}{E_j I_j} (E_d I_d + E_j I_j) . \tag{16-b}$$

Rewriting Eq. (16) and utilizing Eq. (14) yields

$$\frac{M - Fz}{E_d I_d + E_j I_j} = \frac{M_j}{E_j I_j} = \frac{M_d}{E_d I_d} . \tag{17}$$

Using the results of Eq. (17) and substituting into Eq. (13) yields

$$\frac{1}{K}\frac{d^2F}{dx^2} = F\left[\frac{1}{E_d A_d} + \frac{1}{E_j A_j}\right] - \left[\frac{M - Fz}{E_d I_d + E_j I_j}\right] (c_d + c_j) . \tag{18}$$

Replacing $(c_d + c_j)$ with z and rewriting the above equation results in

$$\frac{1}{K}\frac{d^2F}{dx^2} = F\left[\frac{1}{E_d A_d} + \frac{1}{E_j A_j} + \frac{z^2}{E_d I_d + E_j I_j}\right] - \frac{Mz}{E_d I_d + E_j I_j} . \tag{19}$$

Equation (19) can be condensed by redefining terms as follows:

$$\Sigma EI = E_d I_d + E_j I_j , \tag{20-a}$$

$$\frac{1}{\overline{EA}} = \frac{1}{E_d A_d} + \frac{1}{E_j A_j} , \tag{20-b}$$

$$\overline{EI} = \Sigma EI + \overline{EA}\, z^2 \tag{20-c}$$

Substituting these expressions into Eq. (19) yields

$$\frac{1}{K}\frac{d^2F}{dx^2} = F\,\frac{\overline{EI}}{(\Sigma EI)\,(\overline{EA})} - \frac{Mz}{\Sigma EI} , \tag{21}$$

or

$$\frac{d^2F}{dx^2} - FK\,\frac{\overline{EI}}{(\Sigma EI)\,(\overline{EA})} = - \frac{MKz}{\Sigma EI} . \tag{22}$$

Letting

$$C_1 = \frac{K\,\overline{EI}}{(\Sigma EI)\,(\overline{EA})} , \tag{23-a}$$

$$C_2 = \frac{Kz}{\Sigma EI} , \tag{23-b}$$

Eq. (22) becomes

$$\frac{d^2F}{dx^2} - C_1 F = - C_2 M , \tag{24}$$

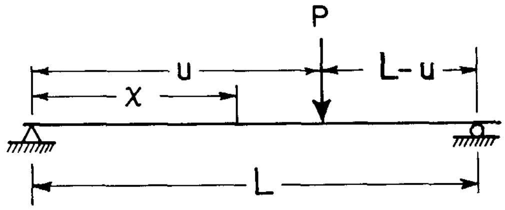

FIG. 2. Loading and geometry.

which is the expression governing the force F along the beam. Since the external moment M is a function of x and is dependent upon the type of loading, Eq. (24) must be solved anew for each type of loading being considered.

Simple beam, point load

The case of a single concentrated load on a simply supported beam is developed below. Using the principle of superposition, the results for this case can be extended to more complicated loadings. Figure 2 shows the beam and the nomenclature.

The moment in the beam at a distance x from the left support is given as

$$M_\ell = P\left[\frac{L-u}{L}\right] x = P\left[1-\frac{u}{L}\right] x\,, \tag{25}$$

where $x \leqslant u$. Substituting this value of M_l for M in Eq. (24) yields

$$\frac{d^2F_\ell}{dx^2} - C_1 F_\ell = - C_2 P \left[1-\frac{u}{L}\right] x\,, \tag{26}$$

which has as its general solution the expression

$$F_\ell = A\cosh(\sqrt{C_1}\,x) + B\sinh(\sqrt{C_1}\,x) + \frac{C_2}{C_1} P\left[1-\frac{u}{L}\right] x\,. \tag{27}$$

Likewise, the moment for the right-hand portion of the beam in Fig. 2 can be expressed as

$$M_r = Pu\left[1-\frac{x}{L}\right], \tag{28}$$

where $x \geqslant u$. Substituting this value of M_r into Eq. (24) yields

$$\frac{d^2F_r}{dx^2} - C_1 F_r = - C_2 Pu\left[1-\frac{x}{L}\right], \tag{29}$$

which has as its general solution the expression

$$F_r = D\cosh(\sqrt{C_1}\,x) + E\sinh(\sqrt{C_1}\,x) + \frac{C_2}{C_1} Pu\left[1-\frac{x}{L}\right]. \tag{30}$$

Equations (27) and (30) contain the four constants, A, B, D and E, which can be evaluated by considering the four boundary conditions for the beam.

At $x = 0$, $F_\ell = 0$

At $x = L$, $F_r = 0$

At $x = u$, $F_\ell = F_r$ and $\dfrac{dF_\ell}{dx} = \dfrac{dF_r}{dx}$.

Applying these conditions leads to the following expressions for the constants:

$$A = 0,\; B = -\frac{C_2}{C_1}\frac{P}{\sqrt{C_1}}\frac{\sinh[\sqrt{C_1}\,(L-u)]}{\sinh(\sqrt{C_1}\,L)} \tag{31-a}$$

$$D = -\frac{C_2}{C_1}\frac{P}{\sqrt{C_1}}\sinh(\sqrt{C_1}\,u) \tag{31-b}$$

$$E = \frac{C_2}{C_1}\frac{P}{\sqrt{C_1}}\operatorname{cotanh}(\sqrt{C_1}\,L)\sinh(\sqrt{C_1}\,u). \tag{31-c}$$

The resulting expression for F_l is

$$F_\ell = \frac{C_2}{C_1} P\left[\left[1-\frac{u}{L}\right] x - \frac{1}{\sqrt{C_1}}\frac{\sinh[\sqrt{C_1}\,(L-u)]}{\sinh(\sqrt{C_1}\,L)}\sinh(\sqrt{C_1}\,x)\right]. \tag{32}$$

With F_l known, the moments in the deck and the joist can be determined from Eq. (17), and the resulting stress distribution throughout the depth of the beam can then be determined from the following equations:

$$f_j = \frac{F}{A_j} \pm \frac{M_j c_j}{I_j} \tag{33-a}$$

$$f_d = \frac{-F}{A_d} \pm \frac{M_d c_d}{I_d}. \tag{33-b}$$

The shear flow, q, in the glue line was previously expressed as

$$q = \frac{dF}{dx} , \tag{34}$$

which, upon differentiating Eq. (32) yields,

$$q_{\ell} = \frac{C_2}{C_1} P \left[\left[1 - \frac{u}{L}\right] - \frac{\sinh [\sqrt{C_1} (L - u)] \cosh (\sqrt{C_1} x)}{\sinh (\sqrt{C_1} L)} \right] . \tag{35}$$

The shear stress, f_v, in the glue line is obtained by dividing q by the width of the glue line, b. Hence,

$$f_v = \frac{q}{b} . \tag{36}$$

The deflection, y, of the beam can be determined by integrating the equation for the curvature of the beam as given by Eq. (17). That is

$$\frac{d^2y}{dx^2} = - \frac{M}{EI} = \frac{Fz - M}{E_d I_d + E_j I_j} = \frac{Fz - M}{\Sigma EI} . \tag{37}$$

When F and M are expressed in terms of x, the double integration of Eq. (37) yields

$$y_{\ell} = \frac{P}{\Sigma EI} \left[\frac{x}{6} \left[1 - \frac{u}{L}\right] (x^2 + u^2 - 2 uL) \left[\frac{z C_2}{C_1} - 1\right]\right] + \frac{z F_{\ell}}{C_1 \Sigma EI} , \tag{38}$$

where F_l is given by Eq. (32).

Simple beam, continuous loading

The basic procedure was extended to the case of a simply supported beam loaded with a uniform load, w, having units of force per unit length. The resulting expression for the deflection at any distance x from the support is

$$y = \frac{1}{\Sigma EI} \left[\frac{zF}{C_1} + \frac{wx}{24} (x^3 - 2Lx^2 + L^3) \frac{\Sigma EI}{EI}\right], \tag{39}$$

where F is given as

$$F = \frac{wC_2}{C_1^2} \left[\left[\tanh (\sqrt{C_1} x/2) - \tanh (\sqrt{C_1} L/2)\right] \sinh (\sqrt{C_1} x) - \frac{C_1}{2} x^2 + \frac{C_1 L}{2} x \right] , \tag{40}$$

and all other terms are as previously defined.

A computer program was then writtten to study the effects of changing the glue-line stiffness, beam cross section, and beam span. The results of this study are presented in the next section.

RESULTS

Employing this design method, we have calculated the stresses and deflection for a composite T-section glued floor system. For this illustration we have used a ½-inch Structural I grade, 5-ply plywood (32/16 Identification Index, Group 1, allowable properties) for the deck. The joists are 2- × 8-inch lumber with an assumed elastic modulus of 1,700,000 psi, spaced 16 inches center-to-center. The plywood face grain is perpendicular to the joists. Loading used was 40 psf live and 10 psf dead.

Glue-line thickness is 0.03 inch and adhesive moduli of rigidity are 25, 50 and 90 psi. These rigidity values have been measured by us for three commercially available elastomeric construction adhesives. We have also computed results for a highly rigid adhesive such as a phenol-resorcinol-formaldehyde type.

The choice of thickness is not arbitrary. The best information we have been able to obtain by direct observation and by consultation with others indicates that 0.03 inch is a reasonable value for the average thickness of field assembled joints positioned by nails. The nails have an added effect, at least during early cycles of load, on deflection. We chose to ignore this because we do not believe it is reliably permanent and because we think these types of structures will eventually be made without nails.

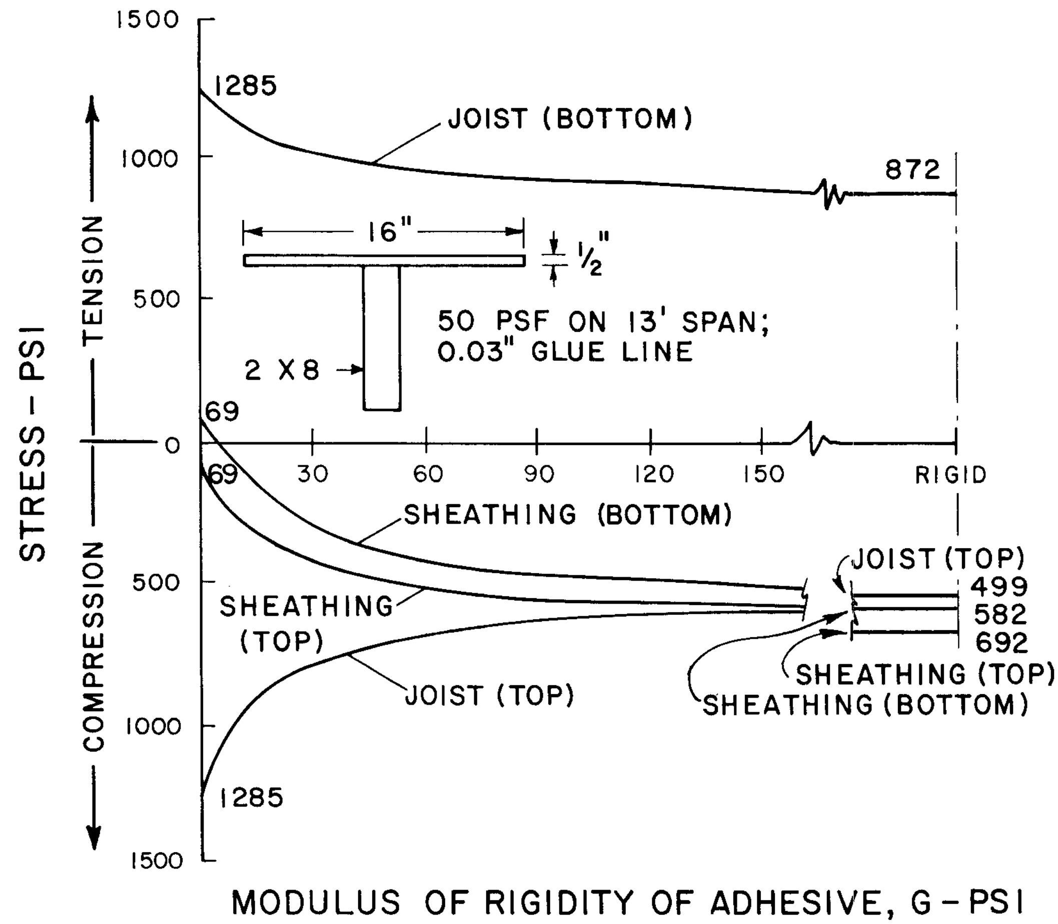

FIG. 3. Stress at extreme fiber of joist and sheathing.

The maximum recommended span for 2-× 8-inch joists of the elastic modulus given above and at 16-inch spacing is 13′-1″ (NFPA 1971). We have used a 13-foot span for this illustration.

Figure 3 shows the computed stress at the extreme fiber of the plywood and the lumber for the 50 psf total load. At G = 0 psi, stresses are for an unglued system, assuming freely sliding contact between joist and deck. The extreme fiber stresses in the joist are of equal and opposite sign, as are those in the decking plywood. The joist is the major load-resisting element.

Stresses for a rigidly bonded system appear at the extreme right in Fig. 3. Stress is greatest in tension at the bottom of the joist. The maximum compression stress is in the plywood, and it exceeds that obtained if lower rigidity adhesives are used. The stresses in the sheathing and joist are nearly equal at the sheathing-joist glue line when rigidly bonded. The slight difference is due to the difference in elastic modulus of the two materials.

For intermediate values of G, the stresses are between these two extreme conditions. It is evident that even relatively low values of G impart a substantial composite action effect.

The glue-line shear stress is related to the shear modulus of the adhesive as shown in Fig. 4. The composite action obtained with typical elastomeric construction ad-

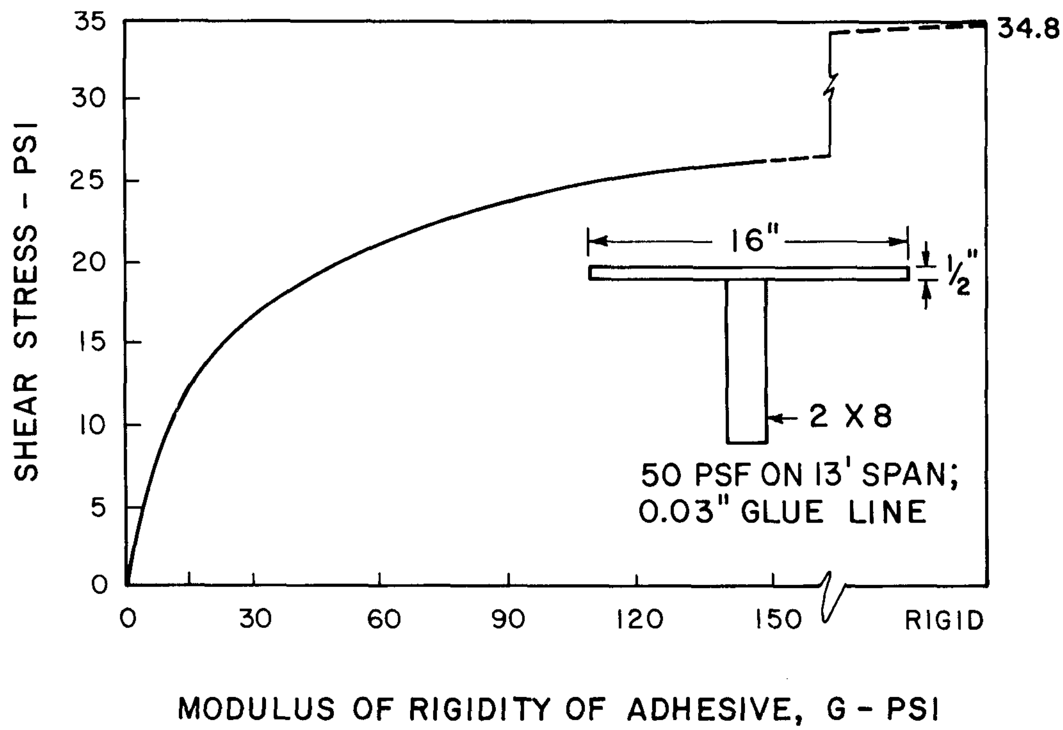

FIG. 4. Shear stress at glue line between joist and sheathing.

hesives in the range G = 25 to 90 psi results in glue-line shear stresses that are not high and should be within the strength limitations of such adhesives.

In Fig. 5, the midspan deflection is related to adhesive shear modulus. The rigidly bonded system depicted in Fig. 5 deflects about one-half as much as an unglued system (54% less). Elastomeric adhesives with G equal to 25 psi result in a deflection of 72% of the unglued beam. The stiffer elastomeric construction adhesives (G = 90 psi) allow the system to deflect 63% of the unglued beam deflection. The lower rigidity adhesives provide about half the effectiveness of rigid glues, while the stiffer commercial elastomeric construction adhesives provide 80% of the composite action to be expected with a rigid adhesive such as a phenol-resorcinol.

Such elastomeric construction adhesives are versatile gap-fillers, not highly sensitive to surface conditions, temperature, or moisture content for forming effective bonds. Their creep and recovery properties need further definition, and it would be premature to assume them to be inadequate in those respects.

Figure 5 can be used to estimate the effect of glue-line thickness variation. The deflection at any ordinate is the consequence of the product Gb/t. Thus, to estimate the effect of a larger glue-line thickness, for example 0.045-inch, Gb/t would be 3000. This would correspond to the ordinate at G = 60 psi in Fig. 5. The deflection is changed about 5% as a result of this 50% change in glue-line thickness. It is seen that large changes in glue-line thickness, or adhesive shear modulus, will not have a large effect on deflection if Gb/t remains in the relatively flat region of the Fig. 5 curve.

This design method applied to systems with different joist sizes gives results like those in Fig. 6, which is for a G = 90 psi adhesive. The span for the systems is improved from 15% for 12-inch joist to 22%

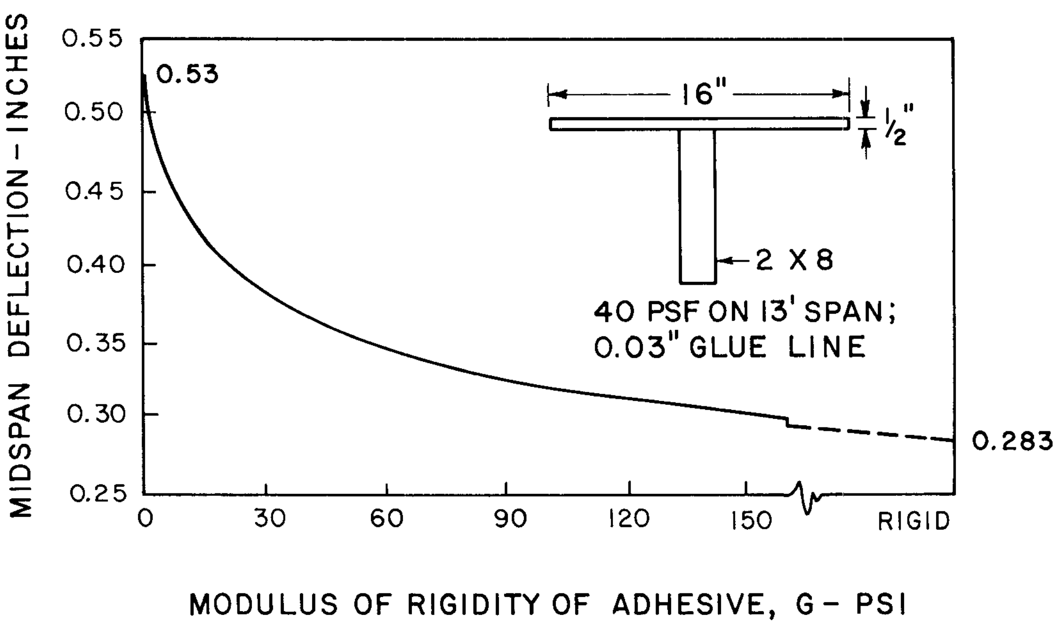

FIG. 5. Deflection at midspan for various moduli of rigidity of adhesives.

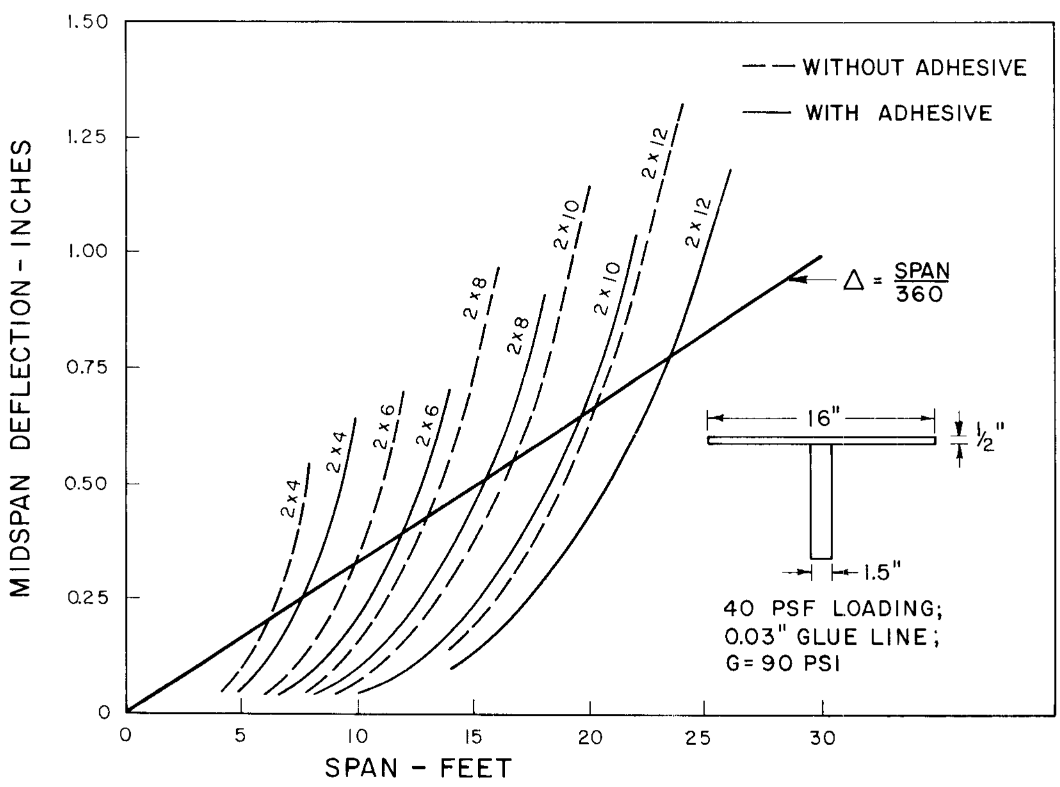

FIG. 6. Midspan deflection vs. span for various joist sizes.

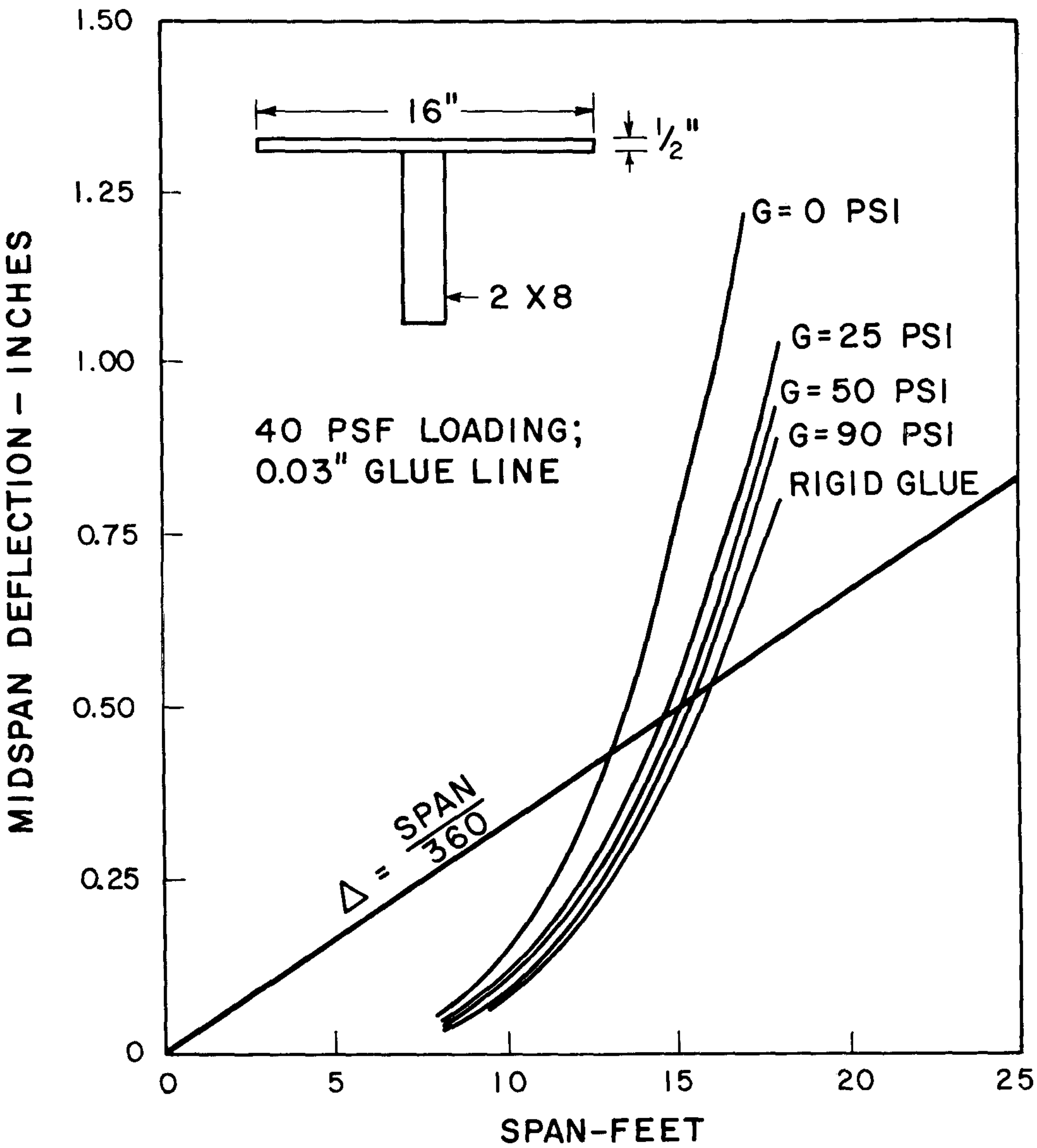

FIG. 7. Midspan deflection vs. span for various adhesive moduli of rigidity.

for 4-inch joist. The larger effect for the smaller joist is the consequence of a proportionally larger contribution by the ½-inch plywood sheathing. The Fig. 6 criteria is for floors, but the adhesive effect would be of the same percentage values for any deflection and load criteria.

Figure 7 has been included to show the marked improvement a low G adhesive can provide as well as the gains for other adhesives that are available. It also indicates the extent to which an elastomeric construction adhesive can approach, in effect, the performance of a rigid laminating adhesive.

Table 1 is a summary of stress information for unglued systems and elastomeric glued systems, which will be of interest to

TABLE 1. *Allowable floor spans and related joist and deck stresses as affected by adhesive shear modulus*

Joist Size, Nominal, inches	Shear Modulus psi	Span ft.-in.	Stresses: Deck Top psi	Deck Bottom psi	Joist Top psi	Joist Bottom psi	Glue line shear psi
2 x 4	0	6-4	*	*	-1310	+1310	0
	25	6-11	-310	-60	-1070	+1300	15
	50	7-4	-430	-190	-920	+1300	25
	90	7-9	-550	-330	-780	+1320	33
2 x 6	0	9-11	*	*	-1310	+1310	0
	25	11-1	-440	-280	-1030	+1300	19
	50	11-7	-600	-450	-900	+1310	27
	90	12-0	-730	-590	-820	+1330	33
2 x 8	0	13-1	*	*	-1310	+1310	0
	25	14-8	-560	-440	-1010	+1310	20
	50	15-3	-740	-630	-920	+1320	27
	90	15-7	-860	-740	-860	+1330	31
2 x 10	0	16-9	*	*	-1310	+1310	0
	25	18-8	-760	-600	-1010	+1310	20
	50	19-3	-860	-770	-940	+1320	25
	90	19-6	-960	-870	-900	+1330	29
2 x 12	0	20-4	*	*	-1310	+1310	0
	25	22-8	-810	-730	-1020	+1310	20
	50	23-2	-960	-880	-970	+1320	24
	90	23-5	-1040	-960	-940	+1320	26

†For standard residential floor design criteria of L/360 at 40 psf live load and 50 psf total load. Decking is 1/2-inch Structural I plywood. Joists are on 16-inch centers with an assumed elastic modulus of 1,700,000 psi. Sheathing must be continuous for these stresses to apply. Average glue-line thickness is 0.03-inch. Negative values are compression.

*These stresses are negligibly small.

readers wishing to interpret this paper with respect to required material properties for several joist sizes.

In ordinary building practice, gaps exist between the 4- × 8-foot sheathing panels. No rigorous method for calculating the deflection and stress when gaps occur in the deck is presented here. Research by Rose (1970) indicates that gaps reduce the effectiveness of the *deck* by about 50%, with respect to stiffness. The shear modulus of the adhesive used by Rose was not reported. Gaps do invalidate the stress pattern as developed in Fig. 3 and Table 1, however. When adhesives with shear moduli in the 25- to 90-psi range are used to bond the deck and joists, gaps have a substantial effect on component deflection. The increase greatly exceeds that due to the increased flexure of the joist at the gap. It is related to the reduced adhesive strain and adhesive reaction resulting from segmenting the deck, and will be the subject of a forthcoming paper. It is therefore important to consider ways of producing effective structural joints between panels, either by glued-blocking or end-jointing. This would be a feature worthy of some measurement and definition.

CONCLUSIONS

1. Equations for midspan deflection and critical design stresses with adhesive modulus of rigidity as a parameter for joist-deck, or one-skin stressed skin panels, are presented. Similar equations can be written for other arrangements of sheathing and joists.
2. For the configuration used in this study:
   (a) Useful composite action is possible with commercially available elastomeric construction adhesives.
   (b) Shear stresses are not large enough to be a limitation.
   (c) The mechanical properties that adhesives should possess for effective structural use have been suggested.
3. When decking continuity is possible, system spans can be increased about 20%.
4. Where effective sheathing continuity is provided, the stresses listed in Table 1 will apply.
5. A design manual could be developed to permit designers to execute rapidly the calculations needed.
6. Adhesive creep has not been specifically examined here and deserves further study. A creep property definition is needed.
7. The effect of service temperature on adhesive strength and rigidity must be established.

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