Numerical Analysis of Stress Distribution in the Prototype Test of the Wood Framed Bearing Wall*

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Abstract——The stress distribution in the plywood bearing wall panel specimens being tested by different methods of the prototype test was analysed numerically by finite element method. The contour plot of shear stress and the principal stresses of the panel in three test methods were caluculated and discussed. In the diagonal compression test (method A) the stress concentration was observed near the loading and reacting points. This stress concentration became more conspiquous as the framing thickness decreased. In the simple racking test (method B) the stress concentration was most conspiquous and the shear stress distribution showed clearly the sudden discontinuity of stresses at the bolted point just under the loading point. Uniform stress distribution was found in the racking test with hold-down ties wellknown as ASTM type (method C). The load transmission abilities of these three test methods along the edges of the panels were in the order of C>B>A. While the test method C is the most pertinent method to provide the uniform shear in the specimen, the test method A is thought to be useful when used in tests including a great number of specimens such as the outdoor durability as it is very simple and handy to test.

Introduction

In the building process of the present prefabricated wooden houses, various methods of the construction have been thought out. Among them the stressed-skin panel construction has been widely adapted in Japan, wall, roof and floor of which are composed of the stressed-skin panels. The stressed-skin panel consists of facing and framing. The facing glues to one or both sides of the framing members so that all parts act integrally. The facing resists flexural and direct stresses, thus lifting up the load-carrying capacity of the framing and permitting a reduction in the size of the framing. The framing resists shear forces as well as flexural forces. Bonding the facing to the framing with adhesive is the most effective system, although mechanical fastening may be used.

At present the stressed-skin panel, being the important component which has an influence upon the performance of houses, has many difficult problems on the rational design and the estimation of the performance. The diagonal compression and the horizontal shear are the typical method to test the load bearing ability of

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plywood-skin panel. When we design the construction in practice based on the results of these tests, it is neccessary that we are well aware of the stress distribution in these tests. The stress distribution in the panel, however, has not been sufficiently investigated yet.

This study was intended to do the stress analysis of the plywood bearing wall panels in three test methods which have been used as prototype test methods in the countries and to make clear its performance. The stress analysis was done by the finite element method which has been lately making remarkable progress and diffusion by means of computer.

Method of Analysis

Computer Program

The computer program used in this study, is the plane linear analysis program by the finite element method. It was made in the light of the programs of Y. K. Cheung and I. P. King1), S. Sanbongi and N. Yoshimura2), and F. Kikuchi *et al.*3). The element used in this program is the triangular element and the matrix calcuculation to obtain the displacement is done by using the unit partitioning. The caluculated shear stresses and the principal stresses are drawn by the automatic plotter using the plot routine. All the computations were performed on a FACOM 230-75 computer at the Data Processing Center, Kyoto University.

Idealization of the Test Method

In order to investigate the stress distribution by the numerical analysis, the test methods must be idealized. Figure 1 shows the idealization types of three test methods used in this study.

Test type A is a very simplified test method of the bearing wall and it has been reported that the simplicity of attachments at the supporting and loading point provided good enough reappearrance of the test results in many replications on a specimen and this method was handy and useful when used in tests including a great number of specimens such as outdoor performance by H. Sasaki *et al.*4).

Test type B has been used generally as the rigidity and shear strength test of the wood based panel for wall of the prefabricated house in our country, which is specified as JIS A 1414-735). In this method the panel fixed to the base by the way agreeable to the actual form.

Test type C is wellknown as ASTM E72-686) and has been used in America and England. In consideration of the vertical compressive load by the roof or the upper floors, two tie rods are applied at one end, one on each side of the specimen to prevent an upward movement of this edge of the specimen5).

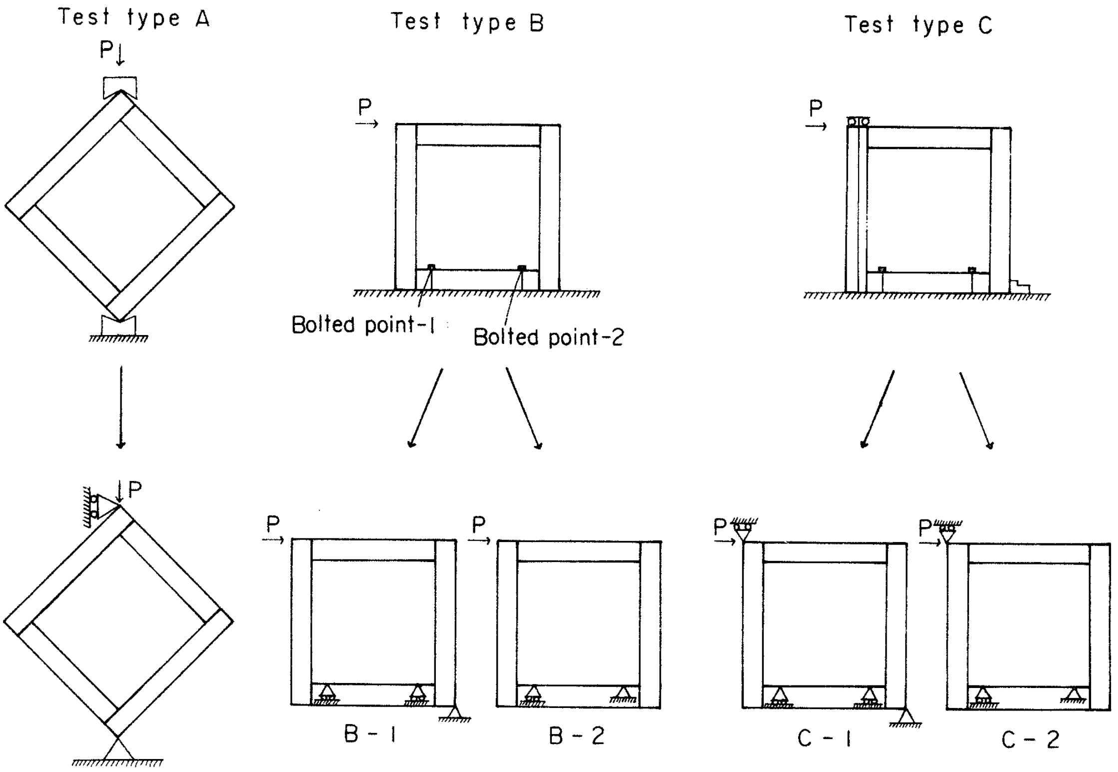


Fig. 1. Idealization of the test methods used in this study.

Then the idealized panel was separated into a number of imaginary finite elements as shown in Figure 2. The number of the elements and nodal points are 1152 and 625 respectively.

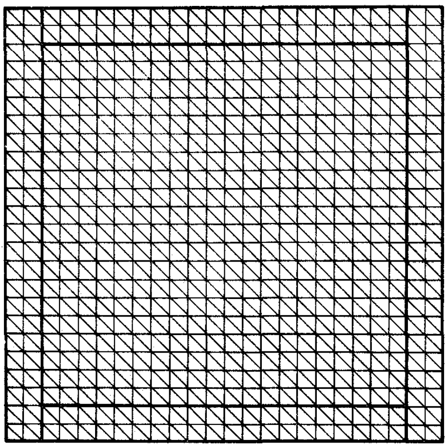


Fig. 2. Idealization of the panel separated into a number of imaginary finite elements.

Caluculation

As an example of the numerical analysis the following most simple case was used. The square panel with side length a, width and thickness of the framings a/12 and a/48 - a/8 respectively and facing thickness a/62 were supposed. It was also assumed that the facing was attached completely to the framing by the adhesive. Although the overlaping part of the framing and facing should be analyzed three-dimensionally, for the purpose of the simplification the analysis was made two-dimensionally by used of the compound elastic constants of the facing and framing.

The elastic constants used in the caluculation were quoted from the observed values in the durability test by H. SASAKI *et al.*[4], and are showed in Table 1.

Table 1. Elastic constants of the framing and the facing used in the calculation.

Member	Supposed material	Elastic constant
Framing	Western Hemlock	$E_L=$ 109000 kg/cm^2 $E_T=$ 4400 kg/cm^2 $\mu_{LT}=$ 0.51 G_{LT}*= 6300 kg/cm^2
Facing	3-ply lauan plywood	$E_1=$ 90000 kg/cm^2 $E_2=$ 37000 kg/cm^2 $\mu_{12}=$ 0.135 G_{12}*= 3200 kg/cm^2

* G from E_{45} using Jenkin's formula.

Result

Test method A

Figure 3 shows the principal stresses and the contour plot of shear stress τ_{xy} of the test panel of framing thickness 10, 40 and 60 mm subjected to a diagonal deformation -1.355 mm. When the framing thickness is 40 mm, the deformation is identical to the compressive load 2 tons. Due to the asymmetry of the corner joint of framing, the stress distribution of facing near the loading and reacting points was asymmetric. As the shape of the specimen used here and the forces applied on it were quite symmetrical about the center point of the specimen, the stress pattern was also symmetrical with respect to a point. The stress concentration was observed near the loading and reacting corners. This stress concentration became more conspiquous when the framing thickness decreased. On the contrary the stress state at corners except the loading and reacting points was very low and this inclination became more remarkable as the framing thickness decreased.

Test method B

As there was little difference between the calculated results on test method B-1 and B-2, only the test method B-1 is showed in Figure 4. In the test method B-1

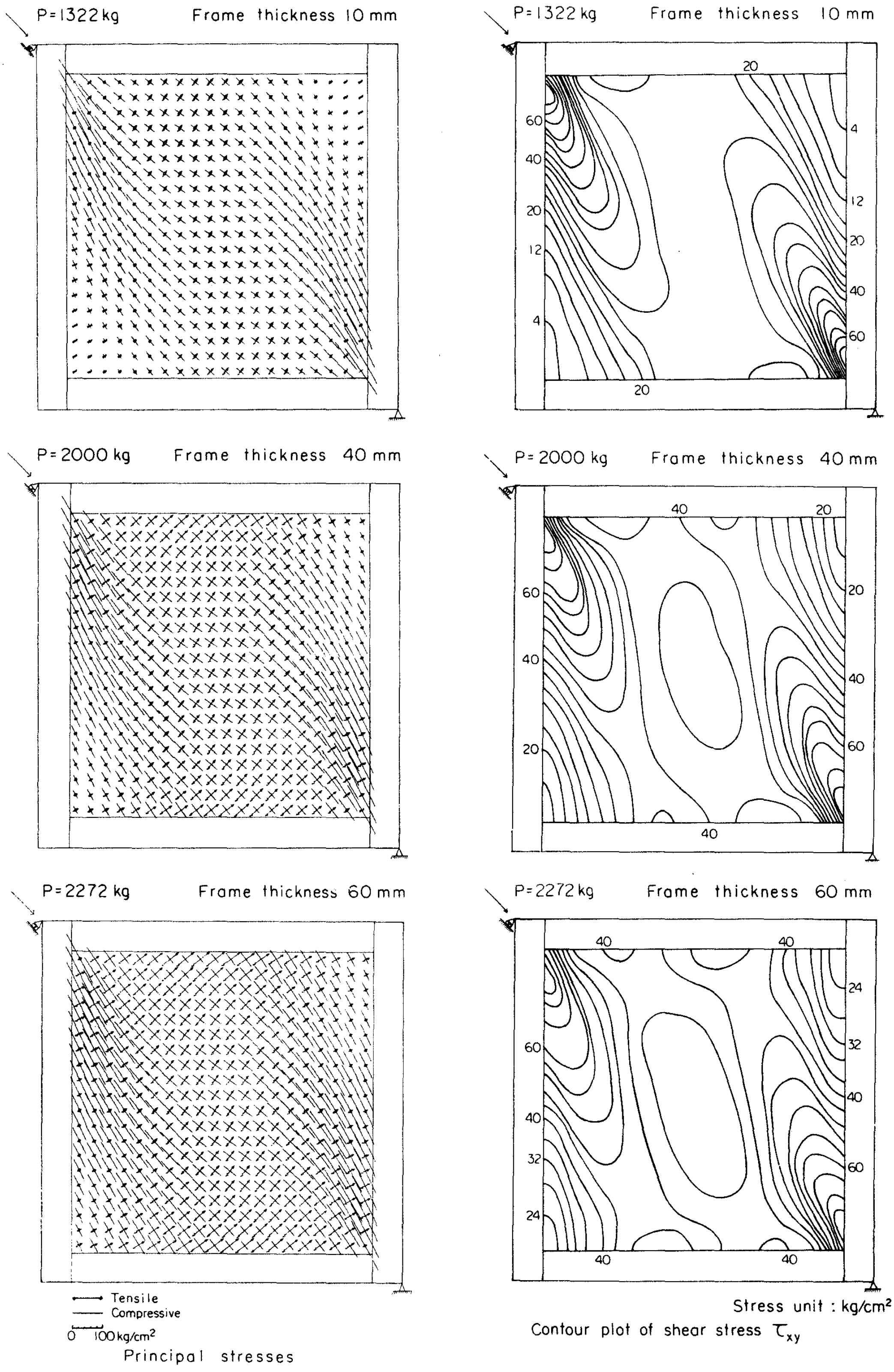
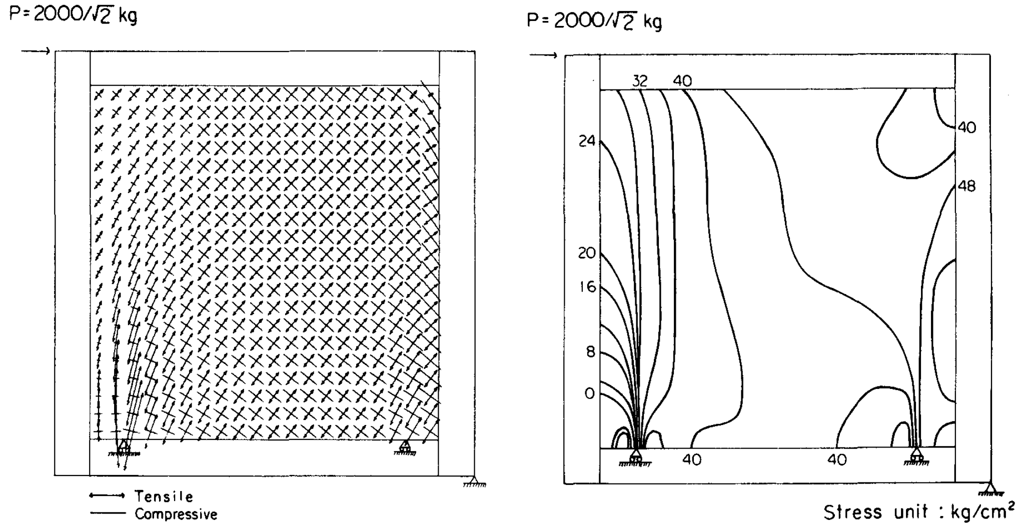


Fig. 3. Principal stresses and contour plot of shear stress τ_{xy} of a plywood panel subjected to a diagonal deformation -1.355 mm (test type A).

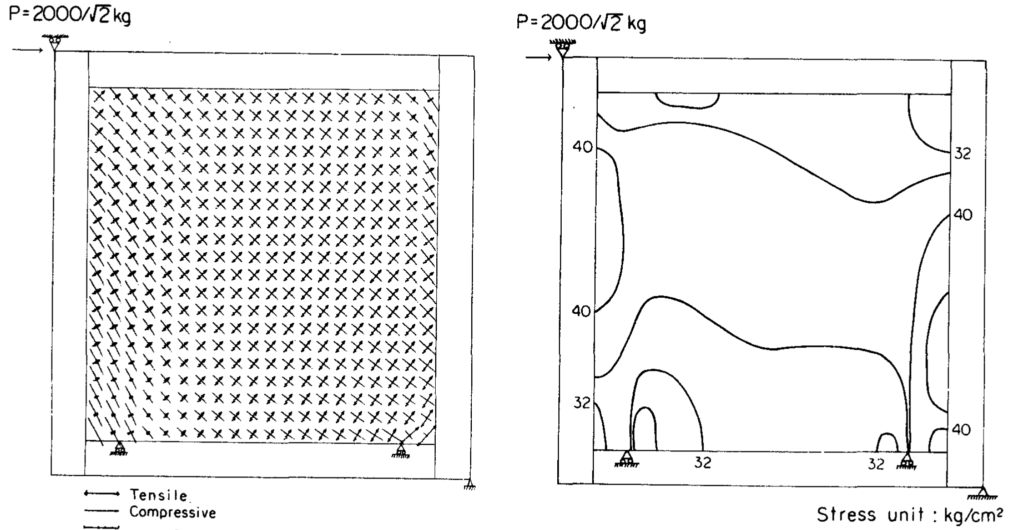
the test panel was subjected to a horizontal shear load $2\times\sqrt{2}$ tons. At the bolted point-1 just under the loading point, the stress concentration was most conspiquous and the shear stress τ_{xy} had a clear and sudden discontinuity. It was supposed clearly that the destruction of the panel started at this part. At the bolted point-2 the stress concentration was, however, not high and except in the part directly adjacent to the bolt the stress pattern was fairy uniform.



Principal stresses

Contour plot of shear stress τ_{xy}

Fig. 4. Principal stresses and contour plot of a ply wood panel subjected to a raking load (test type B-1).



Principal stresses

Contour plot of shear stress τ_{xy}

Fig. 5. Principal stresses and contour plot of a plywood panel subjected to a raking load (test type C-1).

Test method C

As the little difference of stress pattern was also found between the boundary conditions C-1 and C-2, only the caluculated result on the test method C-1 is showed in Figure 5. The test panel was subjected to a same horizontal shear load as applied on the test method B. At the bolted point-1 the stress concentration appeared slightly, but it was small beyond comparison with that in the test method B. The stress pattern as a whole was very uniform and it was regarded that the central part was subjected to the state of pure shear with respect to x and y axes.

Discussion

Transmission of load along edges

Figure 6 shows the load transmission abilities of these three test methods along the edges of panel expressed by the distributions of shear stresses along two edges for the test type A and the upper edge for each of test type B-1 and C-1. The load transmission ability became larger in the order as the test type C>B>A. In the test type A shear stress distributions of the two edges were different. The reason of the difference was explained by that the figure of the corner joint of the framing was asymmetrical.

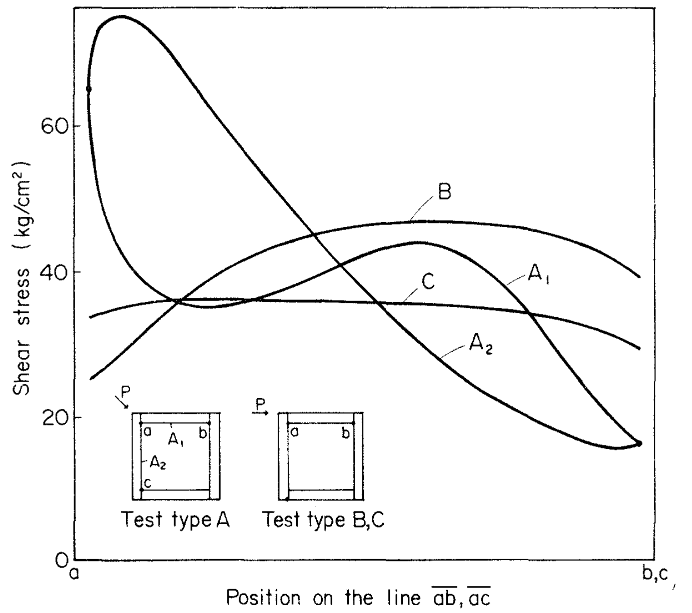


Fig. 6. Distribution of shear stress τ_{xy} along the edges of the panel in three test methods.

Figure 7 shows the distribution of the shear stress along the line $\overline{AB}$ for panels made of framings of several thicknesses. The ratio of shear stresses at the upper section a-a and the lower section b-b of middle part of the curves $\tau_{xy}(\mathrm{a})$ and $\tau_{xy}(\mathrm{b})$

$$\gamma=\frac{\tau_{xy}(\mathrm{a})}{\tau_{xy}(\mathrm{b})}$$

were plotted as a function of the frame thickness of the panel in the upper right of the figure. This ratio γ may well express the load transmission ability. If the frame was thick enough and the action point of the external force was put on the line $\overline{\mathrm{AB}}$, the values γ would be converged to unity. The value γ became lower as the framing thickness increased, it was, however, not expected to reduce the value to unity in the extent of the actual framing thickness.

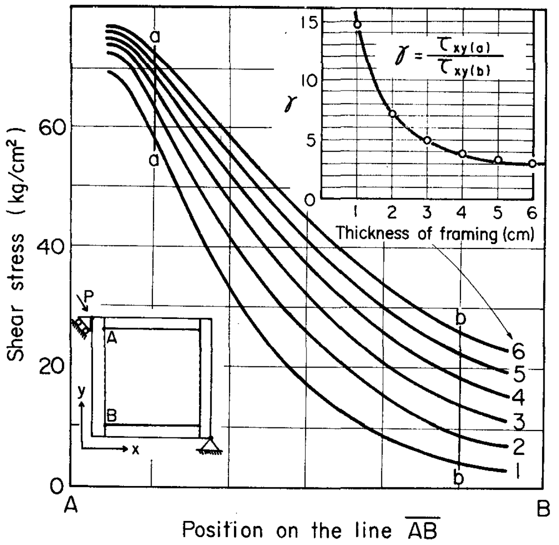


Fig. 7. Distribution of shear stress τ_{xy} along the line AB and ratio of stress reduction $\tau_{xy}(\mathrm{a})/\tau_{xy}(\mathrm{b})$ as function of thickness of the frame of the panel.

Stress distribution along diagonals

Figure 8 shows the shear stress distributions along the two diagonals of the panels loaded by each of three test methods. In the test type A the stress distribution along the diagonal in the loading direction differed very much from that along another diagonal. This can be interpreted as the dominant compression in the loading direction and the insufficient tension in the lateral direction due to the low load transmission and rotation of the framings. In the test type B the stress distributions of two diagonals were about the same at the middle part, but the sudden change was observed at the bolted point-1, while uniform stress distributions along both diagonals in the test type C were obtained. From these, it is concluded that the hold-down ties pushes down the head of the panel to prevent the bold from beeing pulled up and acts as a reasonable complementary shearing force to produce a pure shearing field over the panel specimen.

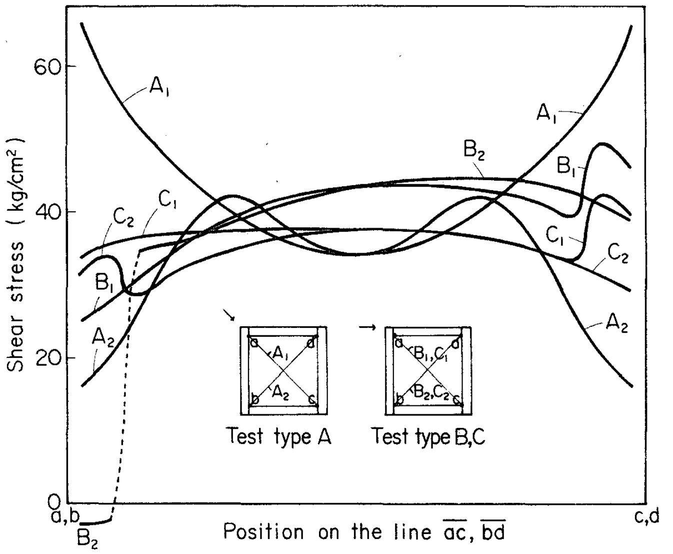


Fig. 8. Distribution of shear stress τ_{xy} along the two diagonals of the panel in three test methods.

Actual strength and stress distribution of the panel

It is interesting to discuss the actual destruction of the panel with reference to the stress distribution computed here. Wood framed plywood square panels sized to 450mm in one edge were loaded in each test method A and B⁴⁾ and the average breaking loads were 1880kg and 770kg respectively. Table 2 shows the stresses computed numerically in the specific finite elements of the panels subjected to the forces corresponding to the breaking load.

Table 2. Stresses computed numerically in the specific elements of the panels subjected to the forces corresponding to the breaking load.

Test type	Average breaking load* (kg)	Destruction type	Stresses computed in the specific finite elements						
			Element having the maximum stresses				Element at the center of the panel		
			Location adjacent to	Shear stress (kg/cm^2)	Principal stresses (kg/cm^2)		Shear stress (kg/cm^2)	Principal stresses (kg/cm^2)	
					Max.	Min.		Max.	Min.
A	1880	**	Loading corner	87.1	−4.7	−230.0	34.2	30.3	−42.6
B	770	***	Bolt point-1	13.5	78.0	−16.9	12.7	12.9	−12.6

* From data by H. Sasaki *et al.*⁴⁾

** Rolling shear of facing just after the occurrence of small shear failures spreading over the facing.

*** Rolling shear of facing at bolted point-1 just under the loading point.

Shearing stress at the center of the panel where a number of small shear failures of surface were observed just before the destruction of the panel were only 34.2 kg/cm^2 in the caluculation. This value was far smaller than the panel shear strength of lauan plywood 87 kg/cm^2 ⁷⁾. The difference of these values was interpreted as the three dimensional displacement (hypabolic paraboloidal) of the panel surface in the experiment.

In the finite element subjected to the minimum (or maximum) normal stress -230 kg/cm^2 for test method A (78 kg/cm^2 for B) the largest force must be transmitted from the framing to the facing. This force might be one of the determining factors of the rolling shear occurred in the facing.

Shearing stress 87.1 kg/cm^2 at the loading corner in test method A was just equal to the panel shear strength of lauan plywood mentioned above. Though this suggested the shear failure, no distinctive failure observed first in this part. This fact could be explained as that even if the shear failure occurred here, it would be restricted to propergate within narrow limits as the stress pattern was too steep to spread the crack.

Conclusion

In the test type A the stress concentration near the loading and reacting points was conspiquous. The load transmission along the edges was very poor. In the test type B the stress concentration at the bolted point-1 was very conspiquous, but the load transmission was not very poor. In the test type C the load transmission along the edges was good enough and most uniform stress distribution was obtained.

Acknowledgements

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