

SHEAR AND BUCKLING RESISTANCE OF CLADDING MATERIALS USED AS STRUCTURAL DIAPHRAGMS IN FARM BUILDINGS

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INTRODUCTION

Structural diaphragms are used widely to stiffen and brace farm buildings, particularly insulated buildings having both exterior and interior claddings. Here, diaphragms are often the most suitable means of resisting the horizontal components of wind force. The critical farm building design problem is usually wind that blows perpendicular to the long walls as in Figure 1.

Alternative forms of wind bracing, such as knee bracing from the walls to the roof trusses, are often employed. Knee bracing is particularly unsuitable for buildings where walking passages are located next to the outside walls; here the open rectangular box made possible by ceiling and endwall diaphragms is a much better alternative. There are practical limitations to the length/breadth ratio of a ceiling used as a structural diaphragm, but the great majority of insulated farm buildings are proportioned within these limitations.

Wind forces for design of most building shapes, including typical gable-roofed farm buildings, can be estimated from the Canadian Structural Design Manual (2). Basic principles for design of fir plywood diaphragms are outlined in a technical bulletin^a, and Turnbull^b further developed these principles as applied to typical Canadian farm buildings.

Hammil (4) tested plywood-sheathed diaphragms to evaluate nailed fastenings,

shear strength and buckling failure of plywood at various wall stud spacings. Nominal four-edge panel support spacings evaluated in these tests were 48 x 96 inches (122 x 244 cm), 24 x 96 inches (61 x 244 cm), 16 x 96 inches (41 x 244 cm), and 48 x 48 inches (122 x 122 cm). Plywoods 7/16 inch (11 mm) and 3/8 inch (9.5 mm) thick were used in Hammil's buckling-shear tests, but the 5/16-inch (8-mm) thickness now used extensively in Canadian farm buildings was not included.

CSA Standard 086-1970 (3) gives allowable unit stresses for Douglas Fir plywood, and a technical bulletin^c gives dimensional characteristics of various grades and thicknesses to determine allowable shear forces etc. for diaphragm design.

Obviously, plywood is not the only cladding material used for farm buildings, but the literature contained little information on diaphragm properties of other farm-type claddings such as aspen flakeboard or sheet metals. Unpublished preliminary tests by Turnbull indicated that aluminum claddings in the thicknesses usually used for farm buildings showed inadequate buckling resistance for most diaphragm requirements, so aluminum was not included in this series.

PROCEDURE

Based on Hammil (4), a test rig was designed to apply compression loads diagonally across a lumber frame sized to take one 48 x 96-inch (122 x 244-cm) panel of wood-based cladding or one 32 x 96-inch (81 x 244-cm) metal roofing sheet.

See Figure 3 for details of the test rig. All test specimens were designed to give four-edge support to the cladding, and the spacings of intermediate members across the sheets were based on the popular truss spacings of 4 ft (122 cm) (see Figure 2), and 2 ft (61 cm). Panel

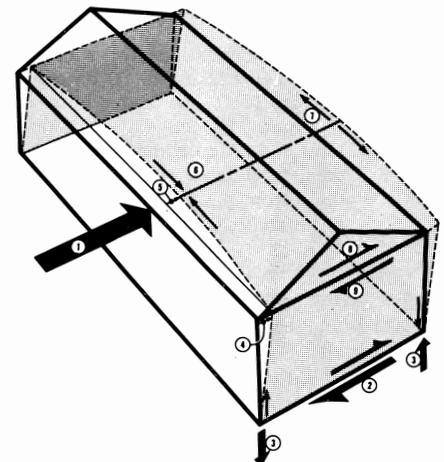


Figure 1. Diaphragm principle for resisting wind perpendicular to the long wall of a typical farm building. 1. Critical wind force, direction perpendicular to long wall. 2. Foundation horizontal reaction to wind force. 3. Foundation reaction to overturning at endwall. 4. Shear deformation in end wall diaphragm. 5. Shear bending deformation in ceiling diaphragm. 6. Plate beam compression due to ceiling bending. 7. Plate beam tension due to ceiling bending. 8. Ceiling shear stress. 9. Endwall shear stress.

Contribution No. 370, from Engineering Research Service, Research Branch, Agriculture Canada, Ottawa, Ontario K1A 0C6.

^a Council of the Forest Industries of B.C. 1968. Fir plywood diaphragms. Bull. 64-112.

^b Turnbull, J.E. 1971. Procedure for design of plywood diaphragm ceilings for farm buildings. Contrib. No. 459, Eng. Res. Service, Can. Dep. Agric., Ottawa, Ont. K1A 0C6.

^c Council of the Forest Industries of B.C. 1967. Fir plywood design fundamentals and physical properties. Bull. 66-137.

RECEIVED FOR PUBLICATION NOVEMBER 15, 1973

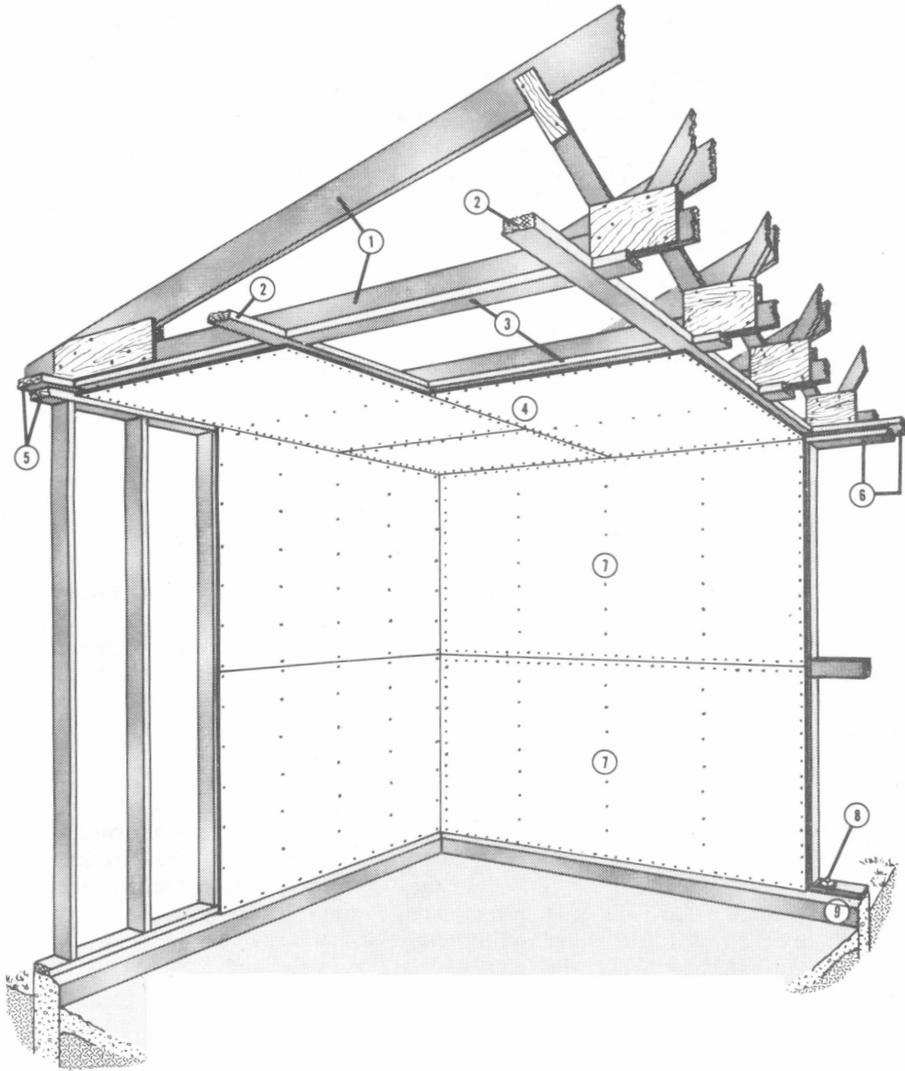


Figure 2. Typical connections for a ceiling-endwall diaphragm system, stud wall construction. 1. Trusses 122 cm (4 ft) on center. 2. 3.8-cm (1-1/2-inch) strapping. 3. Cross-blocking at 122 cm (4 ft) on center both ways. 4. Ceiling sheathing nailed all 4 edges, end joints staggered 122 cm (4 ft). 5. Sidewall plate beam nailed continuous to resist plate beam tension due to ceiling bending moment. 6. Endwall plate beam nailed to transmit ceiling shear to endwall sheathing 7. 7. Endwall sheathing nailed all 4 edges to transmit ceiling shear from plate beam 6 to sill 8. 8. Treated wood sill bolted to transmit shear and uplift to foundation 9.

edges were nailed to the 4 x 6-inch (9 x 14-cm) Douglas Fir test frame with 1-1/2-inch (38.1-mm) x 10-gauge (3.43-mm) large head galvanized roofing nails. Perimeter nail spacings were calculated to guarantee failure of the claddings, requiring a very close spacing to adequately load the stronger cladding materials.

Since Douglas Fir plywood has been fully investigated for diaphragm properties, 5/16-inch (8-mm) 'select sheathing' grade was used as a control.

As a basic comparison, a working shear load of 65.6 lb/inch of panel width was calculated from the allowable unit shear stress of 210 lb/inch² as tabulated in CSA 086 (3).

This 5/16 inch control plywood was nailed to the test frame at the nominal support spacing of 24 x 48 inches (61 x 122 cm) (five replicates) and compared with 48 x 48-inch (122 x 122-cm) support spacing, and 3/8-inch (9.5-mm) Fir plywood, 5/16-inch (8-mm) Spruce plywood and 3/8-inch (9.5-mm) unsanded Aspenite^d, all on 48 x 48-inch (122 x 122-cm) grid spacings.

Galvanized steel roofing tests were also included but the support frames were altered to accommodate a 36 x 96-inch

^d Registered trademark of MacMillan Bloedel Ltd., for 'mat-formed particle board, type 1', described in CSA Standard 0188-1968.

(91.4 x 244-cm) roofing sheet which, when rolled into corrugated roofing, covered a nominal width of 32 inches (81.3 cm). Steel thicknesses tested were 30 gauge (0.305 mm, minimum thickness before galvanizing), and 28 gauge (0.378 mm) with 1.25 oz/ft² (381 g/m²) zinc coating. These correspond to two popular farm roofing thicknesses used in Canada. The corrugation pattern was a typical farm roofing profile^e with major ribs spaced at 8-inch (20.3-cm) and 0.4-inch (1-cm) depths, similar to Figure 1-M, Canadian Code for Farm Buildings 1970 (1). Each test was replicated five times. Specimens were loaded diagonally with a hand-operated hydraulic jack and loading jig (Figure 3). Loads were measured with a 25,000-lb (111-kN) Universal load cell at the corner opposite the hydraulic cylinder. The load cell was wired to a Daytronic amplifier and a digital readout system.

Panel deformations were recorded in inches as read from the dial indicator and these were converted to diagonal strain as follows (see Figure 4):

$$S = \frac{D}{G} = \frac{D}{101.75} \text{ (for wood panels) } \dots \dots \dots (1)$$

$$= \frac{D}{94.5} \text{ (for steel panels) } \dots \dots \dots (2)$$

where

- S = diagonal strain (inches/inch)
- D = panel diagonal deformation (inches)
- G = diagonal gauge distance across test panel (inches)

RESULTS

Data Interpretation

A linear regression on the control plywood tests between load limits of 2,000 to 10,000 lb ($V = 20.4$ to 102.0 lb/inch of panel width) gave the following:

$$V = 48,106 S + 22.80 \dots \dots \dots (3)$$

Taking $V = 65.5$ lb/inch (the shear load per unit panel width corresponding to the allowable unit shear stress for 5/16-inch fir plywood control), equation (3) gives $S = 0.000890$ inch/inch. For comparison, test shear loads V for all other materials were interpolated about $S = 0.000890$ inch/inch (see Figure 5). From this the mean shear load V for each material was calculated to indicate 'comparative shear load' (Table I).

^e Westeel-Rosco Ltd., 1 Atlantic Ave., Toronto, Ontario.

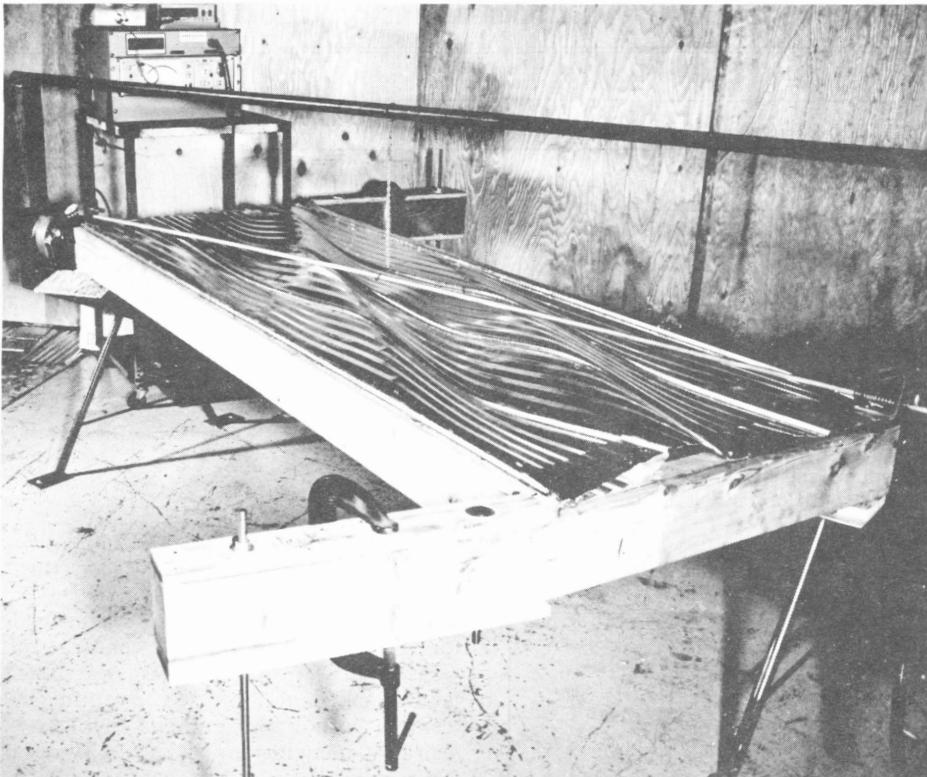


Figure 3. Galvanized sheet steel roofing shear test apparatus.

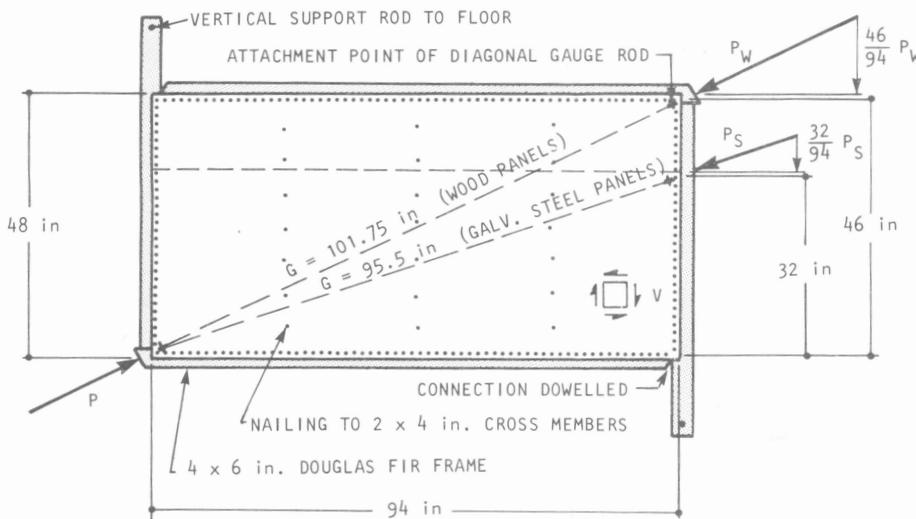


Figure 4. Test panel loading diagram for calculating the relationships between diagonal test load P (lb) and panel shear V (lb/inch).

Ultimate test shears V_u are also shown in Table I, expressed as a mean and standard deviation. The 'safety factor' (V_u/V) was calculated to indicate shear strength of each material at failure in relation to its strength at $S = 0.00089$ inch/inch.

There was no significant difference between the shear resistances of 5/16-inch (8-mm) Fir plywood at support spacings of 24 x 48 inches (61 x 122 cm) and 48 x 48 inches (122 x 122 cm). This

indicated that for diaphragm ceilings, support by trusses and blocking at 4-ft (122-cm) spacings both ways is apparently satisfactory.

Visual Observations

Plywood during the tests showed the same characteristic diagonal buckling as observed by Hammil (4) but the mode of final failure was quite variable. Some panels sheared longitudinally, some sheared across the panels, and some failed

by withdrawing the nails along the edges at 'wave crests' of the buckling pattern. The 5/16-inch (8-mm) Fir plywood control was unfortunately the most variable material tested (see standard deviations (SD), Table I).

Aspenite was much stiffer than the plywoods although its ultimate shear strength was about equal to that of the control plywood. Buckling of the Aspenite panels was uniformly square-pyramid-shaped, either upwards or downwards. Final failure was a uniform tension tear across the diagonal of each panel area bounded by the 48 x 48-inch (122 x 122-cm) support frame and a sharp compression bend across the other diagonal, with the failure lines corresponding to the four edges of the pyramid. Perimeter nail withdrawal was a lesser problem with Aspenite than with plywood.

Galvanized steel tests at failure all showed diagonal buckling as in Figure 3 with tearing and nail withdrawal at the panel ends in particular.

Determination of Recommended Working Shear Loads

Table I is useful for comparison only, because not all factors of safety indicated here were adequate for good design. Aspenite in particular required considerable reduction of the shear load, to improve the 1.3 factor of safety shown in Table I. A working shear load was found by moving back down the Aspenite mean curve (Figure 5) to the point where the V on S relationship becomes essentially linear ($V = 130$ lb/inch, instead of 168.5 as in Table I).

Table II summarizes the recommended working shear loads for the materials tested. Shear loads for materials other than Aspenite were also adjusted by a multiplying factor of 65.6/71.2 corresponding to that required to bring the 5/16-inch (8-mm) control plywood to 210 psi (145 N/cm²) recommended in CSA 086-1970 (3).

SUMMARY

Relative shear resistance values were determined for 5/16-inch (8-millimeter) and 3/8-inch (9.5-millimeter) Douglas Fir plywood, 5/16-inch (8-millimeter) Spruce plywood, 3/8-inch (9.5-millimeter) Aspenite flakeboard, and galvanized steel roofing in 30 gauge (0.305-millimeter) and 28 gauge (0.378-millimeter). For 5/16-inch (8-millimeter) Fir plywood, no significant difference was found in shear-buckling resistance at support spac-

TABLE I RELATIVE TEST SHEAR RESISTANCE OF FARM BUILDING SHEATHING MATERIALS

Sheathing material	Thickness		Support grid spacing		Comparative shear load, V^\dagger		Ultimate test shear, V_u		Safety factor, V_u/V
	(inches)	(mm)	(inches)	(cm)	(lb/inch) \pm SD	(N/cm)	(lb/inch) \pm SD	(N/cm)	
Fir plywood (sheathing grade)	5/16	8	24 X 48	61 X 122	71.2 \pm 15.4	125	225.3 \pm 40.2	395	3.2
	5/16	8	48 X 48*	122 X 122	72.7 \pm 7.6	127	181.5 \pm 18.2	318	2.5
	3/8	9.5	48 X 48	122 X 122	86.8 \pm 9.4	152	242.6 \pm 18.2	425	2.8
Spruce plywood	5/16	8	48 X 48	122 X 122	55.3 \pm 2.7	97	169.2 \pm 11.6	296	3.0
'Aspenite' (unsanded)	3/8	9.5	48 X 48	122 X 122	168.5 \pm 12.6	295	224.3 \pm 10.2	393	1.3
Galvanized steel roofing									
30 gauge	.0139	.353	32 X 48 [§]	81 X 122 [§]	24.6 \pm 3.1	43	50.5 \pm 5.0	88	2.0
28 gauge	.0168	.427	32 X 48 [§]	81 X 122 [§]	31.7 \pm 5.1	56	60.9 \pm 6.1	107	1.9

† Comparative test shear loads V are in units of shear force per unit of panel width and are those that produced shear strains equal to that in 5/16-inch (8-mm) Fir plywood when stressed at 71.2 lb/inch (125 N/cm).

* Support grid spacing comparable to the ceiling strapping and blocking shown in Figure 2.

§ This is the support spacing corresponding to the laid width of galvanized steel roofing.

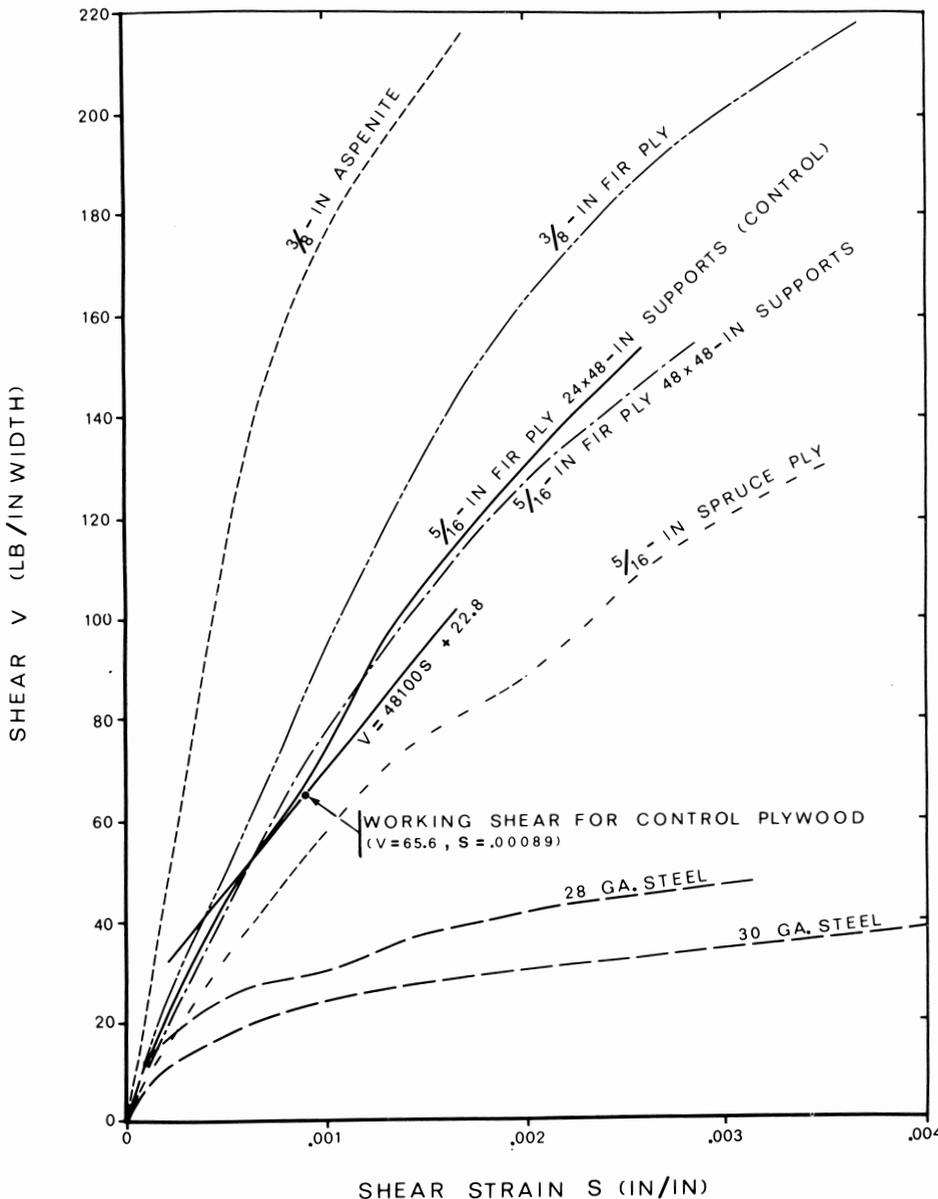


Figure 5. Shear load versus shear strain for cladding materials used as diaphragms.

ings of 2 X 4 feet (61 X 122 centimeters) or 4 X 4 feet (122 X 122 centimeters). This indicates that roof trusses spaced and blocked at 4-foot (122-centimeter) centers both ways as shown in Figure 2 can give adequate support for a plywood ceiling diaphragm.

As expected, Spruce plywood was slightly lower in shear strength than Fir plywood. Aspenite showed very high shear stiffness, with a recommended working shear load of 130 pounds per inch (227 Newtons per centimeter) compared with 80 pounds per inch (140 Newtons per centimeter) for Fir plywood of the same thickness. This material is not popular as an interior farm building cladding because it tends to develop a black mold on the surface and it deteriorates rapidly when exposed to the humid environment in typical livestock and vegetable storage buildings. However, it holds paint and resists weathering very well when used as exterior wall cladding. It could readily be fastened to make an exterior structural diaphragm.

Shear strength of the cladding material is seldom the limiting factor in diaphragm design, so that even galvanized roofing steel when properly fastened is adequate to wind-brace many typical farm buildings. For illustration, a 5/16-inch (8-millimeter) Fir plywood ceiling is adequate in shear strength to wind-brace a one-story stud wall building 36 X 450 feet (10 X 150 meters). On the same basis, 3/8-inch (9.5-millimeter) Aspenite could be adequate for a building 36 X 1,070 feet (10 X 326 meters), and 30-gauge steel roofing for a building 36 X 187 feet (10 X 73 meters).

Roofing steel as a diaphragm has the added advantage that lap-nailing can be easily done at all four edges. This greatly

TABLE II RECOMMENDED WORKING SHEAR LOADS FOR FARM BUILDING SHEATHING MATERIALS

Sheathing material	Thickness		Support grid spacing		Working shear load		Adjusted safety factor
	(inches)	(mm)	(inches X inches)	(cm X cm)	(lb/inch)	(N/cm)	
Fir plywood (sheathing grade)	5/16	8	24 X 48	61 X 122	65.6	115	3.4
	5/16	8	48 X 48	122 X 122	65.6	115	2.8
	3/8	9.5	48 X 48	122 X 122	80.0	140	3.0
Spruce plywood (sheathing grade)	5/16	8	48 X 48	122 X 122	50.9	89	3.3
	3/8	9.5	48 X 48	122 X 122	130	228	1.7
Galvanized steel roofing							
	30 gauge	.0139	32 X 48	81 X 122	22.7	40	2.2
28 gauge	.0168	.427	32 X 48	81 X 122	29.2	51	2.1

improves the efficiency of the nailed connections as compared with the two rows of nails used at the butted edge joint of the thicker diaphragm materials. A sheet steel diaphragm could be built at the ceiling, at the roof surface, or both if required. For a roof diaphragm, four-edge nailing support would require that trusses be spaced at 32 inches (81 centimeters) or whatever the laid width of the roofing profile might be, to coincide with the

edge lap joints.

REFERENCES

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