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Kodur, V.R.; Sultan, M.A.

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PERFORMANCE OF WOOD STUD SHEAR WALLS EXPOSED TO FIRE

by

V. K. R. Kodur and M. A. Sultan

Fire Risk Management Program, Institute for Research in Construction, National Research Council, Ottawa, Canada.

ABSTRACT

This paper presents the results of seven full-scale fire resistance tests conducted on load-bearing gypsum board protected, wood stud shear wall assemblies. The experimental studies were conducted to determine the effects of placement of shear membrane and type of insulation on the fire resistance of such assemblies. Details of the results, including the temperatures and deflections measured during the fire tests, are presented. Results from the studies indicate that the placement of shear membrane and insulation type significantly influence the fire resistance of such wood stud shear wall assemblies.

INTRODUCTION

As a result of a number of recent earthquakes and wind storms in North America, Japan and other parts of the world, there has been an increased focus on the design of buildings to resist lateral movement when exposed to high winds or earthquakes. In the case of buildings using wood frame construction, shear walls are often incorporated into the building design to resist these loads.

In residential buildings, these shear walls typically also form the critical boundaries between suites or between suites and corridors. Consequently, they are required to meet fire resistance requirements. There is limited information in the literature [1,2,3] on the fire performance of such assemblies. As a result, there are few references to shear wall designs in the 1995 edition of the National Building Code of Canada (NBC) [4] tabulated data on fire resistance ratings for wood stud shear walls.

To generate necessary fire resistance information, a collaborative research project was initiated to develop fire resistance and sound transmission performance for various types of shear wall assemblies of wood stud construction.

The intent of the present study is to determine the impact of using wood-based structural panels, in combination with gypsum board, on the fire resistance performance of walls. Systems tested were replicates of wall assemblies commonly used in North America [1] and listed in the NBC, but include plywood and oriented strand board (OSB) sheathing in addition to the gypsum board.

EXPERIMENTAL STUDIES

Test Assemblies

The experimental program consisted of fire tests on seven full-scale wood stud shear wall assemblies. The various details for each of the walls, such as depths, number of layers of gypsum board, shear wall membrane and insulation are given in Table 1. All of the assemblies, except Assembly No. 6, had a shear membrane. Assembly No. 7 had resilient channels on the exposed side to satisfy the NBC sound classification requirements.

The wall assemblies were 3048 mm high by 3658 mm wide with various total depths depending on the number of layers of gypsum board and the thickness of the shear membrane. The specific dimensions of a typical shear wall assembly tested are given in Figure 1. The cross-sectional sketch of each wall assembly is shown in Figure 2.

The wood studs used were nominal 2x4's (SPF No. 2, S-Dry, 38 mm thick by 89 mm deep) and conformed to CSA 0141-1970 [5]. Two types of shear wall panels were used: Plywood (12.5 mm thick, CSP Weldwood, COFI (Council of Forest Industry) Exterior Sheathing with an average mass per unit area 5.96 kg/m^2) and OSB (12.5 thick mm Weyerhaeuser Sturdy-Wood Structural Panels with a mass per unit area 8.08 kg/m^2).

Type X gypsum board ("Fireboard" C/Type X), conforming to CAN/CSA-A82.27-M91 [6], was used for the construction of the wall assemblies. The thickness of the gypsum board was 12.7 mm.

Two types of insulation were used: Glass Fibre-R12 (with a mass per unit area of 1.08 kg/m^2), Rock Fibre (with a mass per unit area of 1.11 kg/m^2). Both insulations satisfy CSA-A101 [7].

The resilient channels used in Assembly No. 7 were sections of 0.18 mm thick galvanized steel. These channels consisted of a 34 mm web and one flattened 18-mm flange lip. The flange between the web and flattened lip was perforated with 36 mm wide oblong holes.

Construction Details

The full-scale assemblies were constructed in accordance with CAN/CSA-A82.31-M91 [8]. The wood studs were spaced at 400 mm O.C. Prior to the construction of the assemblies, the wood studs were conditioned at room temperature (22°C) at a relative humidity of 50%. The studs were removed from the conditioning room only when ready to be used in construction. The average moisture content of the wood studs, measured prior to fire tests, was 12%.

In single layer (1x1) wall assemblies (Assembly No. 6), one layer of 12.7 mm thick Type X gypsum board was attached vertically to the wood studs, on both the exposed and unexposed sides, with Type S drywall screws, 41 mm long, and spaced at 400 mm O.C. along the edges and in the field of the board. The screw heads on both the exposed and unexposed faces were covered with joint compound. The gypsum board joints were finished with fibre tape and covered with joint compound. Screw locations and gypsum board joint locations are given in Reference [9].

In asymmetrical (1x2) wall assemblies (Assemblies No. 3 to No. 5 and No. 7), the exposed side had one gypsum board layer (installed as above) and the unexposed side had two gypsum board layers: a face layer and a shear wall panel (CSP or OSB) as the base layer. The base layer shear panel on the unexposed side was attached to the wood studs with 76.2 mm long non-galvanized common nails spaced at 150 mm O.C. on the panel edges and 300 mm O.C. in the field of the panels. The face layer gypsum board on the unexposed side was attached to the shear wall panels and studs with 41 mm long Type S drywall screws spaced at 400 mm O.C. along the edges and in the field of the gypsum board. Details of screw locations and gypsum board joint locations are given in Reference [9]. Screw heads on both the exposed and unexposed faces were covered with joint compound. Gypsum board joints were also taped and covered with joint compound. Similar construction practices were used for the other asymmetrical installation (2x1) Assemblies No. 1 and No. 2 with wood studs spaced at 400 mm O.C. [9] and the shear panel located on the exposed side.

The insulation (rock and glass fibre batts, 89 mm thick by 381 mm wide and 1194 mm long) was placed between the studs.

For Assembly No. 7, the resilient channels were attached to the wood studs, with 25 mm long, self-drilling, self-tapping steel screws spaced at 300 mm O.C. The resilient channel details are shown in Figure 3. The gypsum board was attached to the channels with 25 mm long, Type S drywall, steel screws spaced at 300 mm O.C. Eight rows of channels were installed horizontally, perpendicular to the studs, at 400 mm O.C. using similar construction practices to those specified in ULC Assembly U-311 [10]. The gypsum board was oriented horizontally and attached to the resilient channels. There were two horizontal joints, 3658 mm long, and a vertical unbacked joint, 1219 mm long.

Further details on the construction of the wall assemblies are given in References [1, 9].

Instrumentation

Type K (20 gauge) chromel-alumel thermocouples, with a thickness of 0.91 mm, were used to measure the temperatures at a number of locations throughout an assembly. Inside the cavities, the thermocouples were attached to 6 wire hangers installed midway between the studs and at mid-depth of the studs at distances of 1/4 and 3/4 of the height of the wall. Thermocouples located on the stud/base layer interface and those located between the base and face layers were taped into position. A number of small holes, 12.7 mm in diameter, were drilled through the wood stud assemblies at the bottom to allow the thermocouple wiring to exit the assembly. The exact locations of thermocouples across the cross-section of the walls and on the unexposed surface of the wall assemblies are found in Reference [9].

The deflection of the unexposed surface was measured at different locations using displacement trnsducers based on the electro-mechanical method [11].

Test Conditions And Procedures

The wood stud shear wall assemblies were tested in a propane-fired vertical furnace as shown in Figure 4. The tests were carried out by exposing the assemblies to heat in a vertical furnace. The assemblies were sealed at the edges against the furnace using ceramic fibre blankets. The furnace temperature was measured by nine (20 gauge) shielded thermocouples in accordance with CAN/ULC-S101-M89 [12] which is similar to ASTM E119 [13]. The average of the nine thermocouple temperatures was used to control the furnace temperature.

The loading device used in this study is illustrated in Figure 4. Details on this loading device are presented in Reference [14]. The components of this device are a strong steel frame, in which the wall assembly is placed, and 8 hydraulic jacks fitted at the top to simulate vertical structural loads. The load calculations for assemblies were carried out based on the material characteristics of the wall. The applied loading on the wall assemblies used in this study is presented in Table 1.

The ambient temperature at the start of each test was approximately 22°C. During the test, the wall assembly was exposed to heating on the exposed side, in such a way that the average temperature in the furnace followed, as closely as possible, the CAN/ULC-S101 [12] standard temperature-time curve.

The failure criteria were derived from CAN/ULC-S101-M89 [12]. The assembly was considered to have failed if a single point thermocouple temperature reading on the unexposed face rose 180°C above ambient or the average temperature of the 9 thermocouple readings under the insulated pads on the unexposed face rose 140°C above the ambient temperature or there was passage of flame or gases hot enough to ignite a cotton wad waste.

The furnace and wall assembly temperatures, as well as the deflections, were recorded at 1 minute intervals using Labtech Notebook data acquisition software and a

Fluke Helios-I data acquisition system. The gauge pressure of the loading system was also recorded at 1 minute intervals.

RESULTS AND DISCUSSION

The results of the 7 full-scale fire resistance tests are summarized in Table 1 in which the failure times and mode of failure are given for each assembly. For all wall assemblies, the unexposed surface temperature (average of single reading temperatures) at the time of structural failure was below the temperature failure criteria. All wall assemblies failed structurally through excessive deflection.

A typical temperature distribution at the various locations in Assembly No. 1, as well as on the unexposed surfaces, is shown in Figure 5, while the measured deflections are shown in Figure 6. A detailed temperature distribution at the various locations in the assemblies, as well as on the unexposed surfaces, and measured deflection data for Assemblies No. 1 to No. 7 can be found in Reference [9].

Results from the tests (Table 1) have indicated the two factors which significantly influenced the performance of the wall assemblies were the presence of the shear membrane and the type of insulation in the wall cavity. From Table 1, it can be seen that the fire resistance of the wall assembly with a shear membrane (Assembly 1) is higher than the assembly without shear membrane (Assembly 6). This could be attributed to the additional stiffness provided by the shear membrane. Further, the presence of a shear membrane on the exposed side protected the studs, which in turn delayed the strength loss of the wall assembly. This is illustrated in Figure 7 where the cross-sectional temperature distributions at the exposed and unexposed edges of the studs and at the centre of the studs are compared for three wall Assemblies No. 1, No. 3 and No. 6. It can be seen from the Figure that the temperatures in Assembly No. 1 are lower throughout the duration of fire exposure than Assemblies No. 3 (wall assembly with shear membrane on the unexposed side) and No. 6.

The presence of a shear membrane also enhanced the structural performance of the wall. This can be seen in Figure 8 which shows the comparative deflection of three walls with time for stud No. 6. The additional stiffness provided by the shear membrane delayed the deflection propagation in the wall, as compared to the wall with no shear membrane. Further, it can be seen also, that the wall assemblies with shear membrane (Assemblies No. 1 and 3) attained higher deflection at failure than the wall without any shear membrane (Assembly No. 6).

The type of insulation also played a major role on the performance of the shear wall assemblies exposed to fire. This can be seen from Figure 9 which shows the cross-sectional temperature distribution at the exposed and unexposed edges of the studs and at the centre of the stud is compared for wall assemblies with glass fibre insulation (Assembly No. 3) and rock fibre insulation (Assembly No. 5). It can be seen from the Figure that the temperatures in Assembly No. 5 are lower than those in Assembly No. 3. When gypsum board at the exposed face fell, the insulation was exposed to furnace heat. In the assembly with glass fiber insulation, the insulation melted and both the sides of the stud and shear membrane were exposed to heat, while in the assembly with rock fiber insulation the insulation remained in place and protected the stud on both sides as well as the shear membrane. The rock fibre insulation played a significant role in limiting the temperature rise in the center of the stud and shear membrane. This slow rise in temperature reduced the strength loss in the studs thus increasing its fire resistance.

The insulation also protected the plywood membrane on the unexposed side, as can be seen from the time-temperature plot. This helped to enhance the stiffness of the wall as can be seen from Figure 10 which shows the comparison of deflections with time for Assemblies No. 3 and No. 5. In this case also the larger deflections attained at failure is due to the delayed rise in temperatures in plywood and wood studs.

FACTORS INFLUENCING FIRE RESISTANCE

Based on the results of the experimental studies, the effect of various factors on the fire resistance of wood stud shear wall assemblies can be summarised as follows: discussed here.

Effect of Shear Membrane

The influence of a shear membrane (plywood) on the fire resistance rating of load-bearing wood stud shear wall assemblies is shown in Figure 11 where the results from fire tests on Assemblies No. 6, No. 3 and No. 1 are compared. The structural failure criterion was reached at 36, 43 and 48 minutes for Assemblies No. 6, No. 3 and No. 1, respectively (see also Table 1). The results show that the addition of a shear membrane in a 1x1 wall assembly increases the fire resistance, with the greater increase occurring when the shear membrane is placed on the exposed side of the assembly.

Effect of Shear Membrane Location

The comparative results in Figure 11 can also be used to determine the effect of the shear membrane location on the fire resistance rating. The fire resistance rating for the wall assembly with the shear panel on the exposed side was 48 minutes while the assembly with the shear panel on the unexposed side was 43 minutes as shown in Figure 11. From these results, it can be inferred that the fire resistance rating of a shear wall is higher only when the fire occurs on the same side as the shear membrane.

Effect of Shear Membrane Type

The effect of the type of shear membrane on fire resistance is shown in Figure 12 where the results from fire test on wall assemblies with OSB and plywood shear membranes are compared. The fire resistance rating obtained for the shear wall assembly with plywood was 48 minutes while the assembly with OSB was 47 minutes. These results indicate that the type of shear membrane material does not significantly influence the fire resistance performance of the assembly.

Effect of Insulation Type

Figure 13 shows the effect of insulation type on the fire resistance of load-bearing wood stud shear walls. In this figure, the results from the fire test on a glass fibre insulated wall assembly are compared to that from the rock fibre insulated assembly. The failure of the glass fibre insulated wall assembly occurred at 43 minutes while the failure of the rock fibre insulated assembly occurred at 54 minutes. These results suggest that the use of rock fibre insulation provides a higher fire resistance compared to glass fibre insulation.

Effect of Resilient Channels

The effect of resilient channels on the fire resistance rating of load-bearing wood stud shear walls is shown in Figure 14 for wall assemblies with and without resilient channels. Since a wall assembly with 1 layer of gypsum board on the exposed side and 1 layer of gypsum board and 1 layer of plywood on the unexposed side gives a lower fire rating, as compared to a 2x1 assembly, the resilient channels was installed on the exposed face of a 1x2 assembly. The failure of the wall assembly with resilient channels occurred at 37 minutes while in the wall assembly without resilient channels the failure occurred at 43 minutes. These results, shown in Figure 14, indicate that, for the assembly with the resilient channels located on the exposed side of the wood stud shear wall, the fire resistance rating decreased by about 12% compared to an assembly without resilient channels.

Effect of Load Intensity

To determine the effect of load on the fire resistance of walls, the fire test on Assembly No. 5 was repeated by varying the applied load on the assembly. The loading on Assembly No. 4, as compared to that on Assembly No. 5, was approximately 15-20% higher. Assembly No. 4, which had an increased load, failed at 43 minutes while

Assembly No. 5 failed at 54 minutes. These results indicate that an approximate increase of 15-20% in the design load will lead to a decrease in the fire resistance of approximately 15-20%.

CONCLUSIONS

Full scale fire tests were conducted to determine the effects of placement of the shear membrane on the exposed/unexposed face, type of shear wall membrane, insulation type, load intensity and resilient channel installation on the fire resistance rating of gypsum board protected wood stud shear wall assemblies. Based on the results from the tests, the following conclusions can be drawn:

1. For load-bearing gypsum board protected wood stud wall assemblies, the addition of a plywood or an OSB shear membrane increases the fire resistance of the assembly.
2. The maximum increase in the fire resistance of an assembly occurred when the fire exposure was on the same side as the shear membrane.
3. The type of shear membrane (plywood or OSB) does not influence the fire resistance of a load-bearing wood-stud shear wall assembly.
4. For load-bearing wood stud shear walls, rock fibre insulation provided better fire resistance compared to glass fibre insulation.
5. For load-bearing wood stud shear walls, the installation of the resilient channels on the fire-exposed side decreases the fire resistance by about 12%.
6. The fire resistance of load-bearing wood stud and wood stud shear walls, decreases with increases of applied load.

REFERENCES

1. Sultan, M.A., Lougheed, G.D., Monette, R.C., MacLaurin, J.W. and Denham, E.M.A., Temperature Measurements in Full-Scale Insulated Gypsum Board-Protected Wall Assemblies with Resilient Channels, Internal Report No. 676, Institute for Research in Construction, National Research Council of Canada, Ottawa, 1994.
2. Richardson, L.R. and Onysko, D.M., Fire-endurance Testing of Building Constructions Containing Wood Members, Fire and Materials, Vol. 19, 1995, pp. 29-33.
3. Richardson, L.R. and McPhee, R.A., Fire-resistance and Sound-transmission-class Ratings for Wood-frame Walls, Fire and Materials, Vol. 20, 1996, pp. 123-131.
4. National Building Code of Canada (Part 9), National Research Council Canada, Ottawa, 1995.
5. CSA 0141-1970, Softwood Lumber, Canadian Standards Association, Rexdale, Ontario, 1970.
6. CAN/CSA-A82.27-M91, Gypsum Board-Building Materials and Products. Canadian Standards Association, Rexdale, Ontario, 1991.
7. CSA-A101-M83, Thermal Insulation, Canadian Standards Association, Rexdale, Ontario, 1983.
8. CAN/CSA-A82.31-M91, Gypsum Board Application, Canadian Standards Association, Rexdale, Ontario, 1991.
9. Kodur, V.K.R., Sultan, M.A. and Denham, E.M.A., Temperature Measurements in Full-Scale Wood Stud Shear Walls, Internal Report No. 729, Institute for Research in Construction, National Research Council, Ottawa, Canada, 1996.
10. ULC List of Equipment and Materials, Vol. 3, Fire Resistance Ratings, Underwriters' Laboratories on Canada, 1991.
11. Lie, T.T. and Berndt, J.E., Remote Measurement of Large Deflections in Fire Tests, Division of Building Research, National Research Council Canada, Building Research Note No. 84, 1972.

12. CAN/ULC-S101-M89, Standard Methods of Fire Endurance Tests of Building Construction and Materials, Underwriters' Laboratories of Canada, Scarborough, Ontario, 1989.
13. ASTM E119-88, Standard Methods of Fire Tests of Building Construction and Materials, ASTM, Philadelphia, Pa., 1990.
14. Shorter, G. W. and Harmathy, T. Z., Fire Research Furnaces at the National Research Council, Fire Study No. 1, Division of Building Research, National Research Council Canada, NRC 5732, 1960.

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