Impact Resistance of Advanced Framed Wall Systems with Insulating Sheathing as the Primary Sheathing

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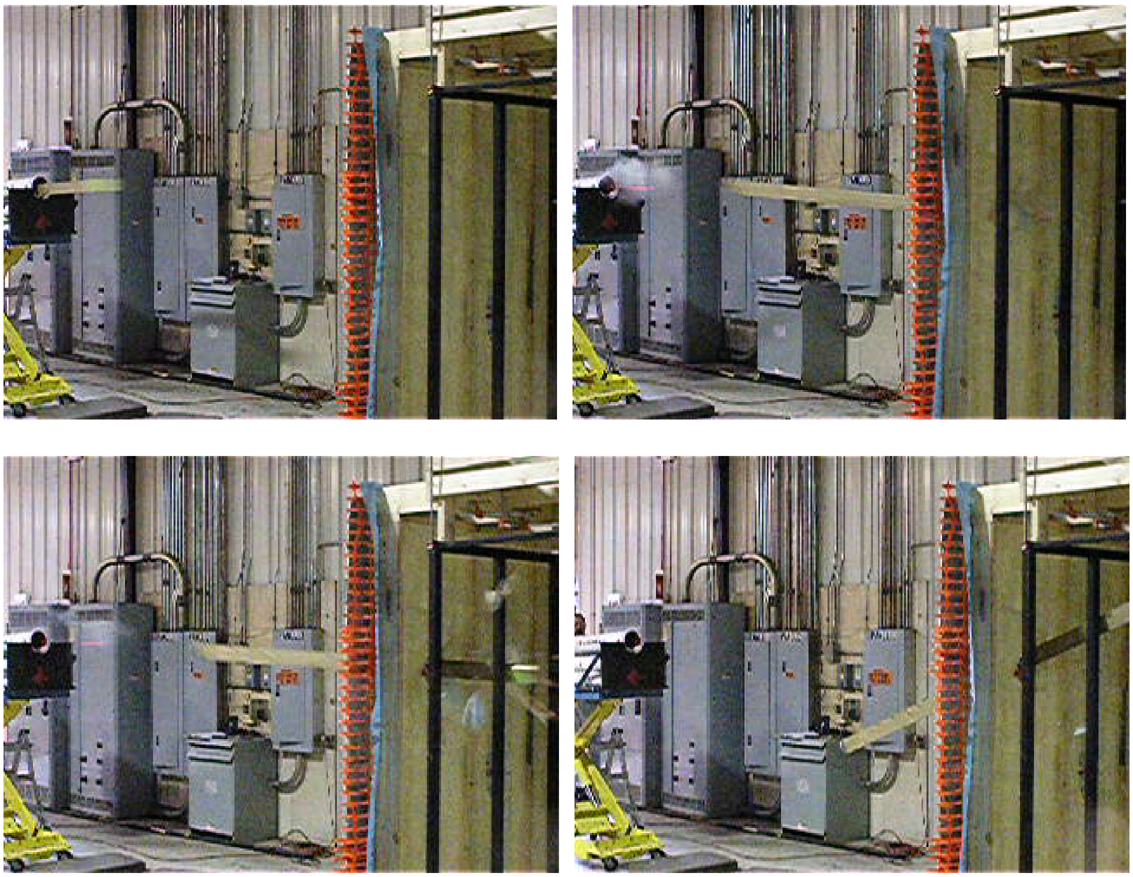
Abstract:

Advanced framed wall systems that use that use a stud spacing of 24 inches on center and eliminate the plywood or OSB sheathing from the wall and replace it with insulating sheathing is a type of enclosure assembly that has been designed to be energy efficient combined with efficient material use. The purpose of this research program was to determine the impact resistance performance of advanced framed wall systems with insulating sheathing as the primary sheathing from wind blown debris. With no standards available for testing wall assemblies, a window industry standard ASTM E1886-05 and E1996-05 Missile Level D, Wind Zone 1 and Wind Zone 2 Enhanced Protection and Wind Zone 3 Basic Protection Standard was adopted was used as a starting point for the research. The testing demonstrated two surprising outcomes: 1. None of the walls passed at an impact velocity of 50 fps including the ½" OSB wall, and 2. The high performance wall assembly (1" of insulating sheathing, housewrap, and 2 inches of closed cell spray foam installed in the cavity space) out-performed the baseline house (framed wall with 1/2" OSB sheathing) at a slightly reduced impact velocity of 43fps. These results indicate that high performance wall assemblies provide equivalent or even better impact performance then standard wall assemblies.

Impact Resistance of Advanced Framed Wall Systems with Insulating Sheathing as the Primary Sheathing

Testing Results



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Acknowledgements

The following summarizes the results of the Impact Resistance of Advanced Framed Wall System with Insulating Sheathing as the Primary Sheathing research project. This research was completed through funding from the Department of Energy's Building America Program and from assistance from Cardinal Glass Industries and The Dow Chemical Company.

Introduction

In recent years significant changes to the residential building industry have been made. The drive for high performance building enclosures fueled by the need to create more energy efficient buildings has opened the door for new building systems, materials, and technology in the market. Understanding the properties of the various materials led to integrated enclosure design that increased the energy efficiency of the enclosure assemblies while optimizing the material use to ensure that the new approaches were still cost effective. These new systems, while they may in many aspects still resembled traditional building assemblies, are in fact significantly different.

Advanced framed wall systems that use that use a stud spacing of 24 inches on center and eliminate the plywood or OSB sheathing from the wall and replace it with insulating sheathing is type of enclosure assembly that has been designed to be energy efficient combined with efficient material use. With the significant changes that have been made to the assembly from traditional designs, old performance standards cannot be assumed. Water and moisture management performance, being integral to the long term durability of enclosure systems have been evaluated and integrated into the design of the system, however other performance standards also need to be addressed. In high wind zone locations such as hurricane and tornado prone zones, additional performance standards are needed such as lateral load resistance (addressed in other research) and impact resistance from wind blown debris.

The purpose of this research program was to determine the impact resistance performance of advanced framed wall systems with insulating sheathing as the primary sheathing from wind blown debris. A research plan was implemented to physically test various advanced framed wall systems for impact resistance.

Impact Protocol

In order to compete the research a standard (baseline) needed to be established to which the panels could be tested. Relevant standards for testing the impact resistance of wall assemblies were researched, however it was found that no standards were available. Since no specific testing protocol existed for wall systems, direction was taken instead from the window industry to create a test protocol.

The test protocol used was based on ASTM E1886-05 and E1996-05 Missile Level D, Wind Zone 1 and Wind Zone 2 Enhanced Protection and Wind Zone 3 Basic Protection Standard. The ASTM Missile Level D Standard requires that an 8ft (+/- 4”), 9lb (+/- 0.25lb), Yellow Pine or Douglas Fir 2x4 be launched with a muzzle velocity of 50.0 fps (+/- 2%) at a minimum of 1 ½ times the length of the 2x4 from the face of the test specimen within 2 ½” radius of the designated impact location.

This test protocol was used as the baseline to test various wall panels to determine their impact resistance. The criterion used was a simple pass/fail metric, where if the 2x4 penetrated all the way through the wall assembly (past the interior face of the framing members) the system did not pass. If the 2x4 did not penetrate all the way through to the inside face of the framing members then the wall system passed.

Test panels

The test panels were designed to emulate the conditions of actual wall assemblies in the field. The panel heights were 8'- 1" with an anchored sill plate and out of plane restrained single top plate to simulate the connection to the roof trusses. The panel widths were 6'- 1 1/2" wide and consisted of three 24 inch 2x6 stud bays.

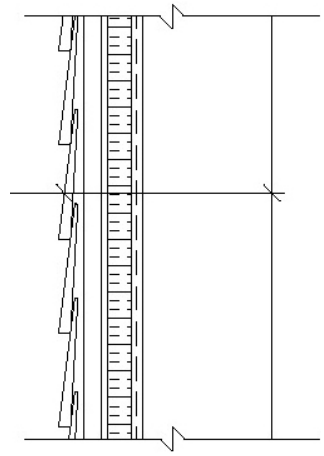
Figure 1: Test Panel Configuration

Four wall systems were constructed as part of the testing with two wall panels of each design being constructed. The wall systems consisted of one baseline wall panel (representing current standard residential construction practices) and three advanced wall systems (each subsequent wall panel building of the initial panel and designed to be more resistant to impact than the previous panel). To be more conservative, batt or loose cavity fill insulation and interior drywall were not included in the panel design.

The wall systems tested were as follows:

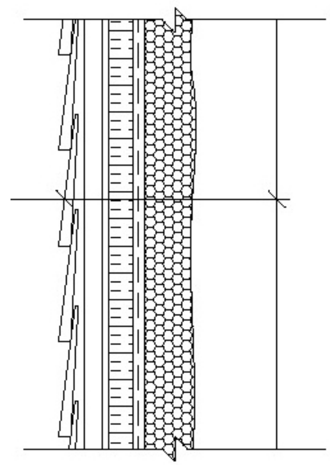
Wall 1

- 2x6 @ 24" OC wall construction
- DOW Weathermate Plus housewrap installed horizontally to the exterior of the suds, with a minimum 6" vertical overlaps, and fastened to the framing with 1-1/2" cap nails spaced 6" OC.
- 1" Styrofoam Residential Sheathing insulating sheathing fastened to framing with 2" cap nails
- Hardie Board fibercement siding installed with 1x4 furring strips.



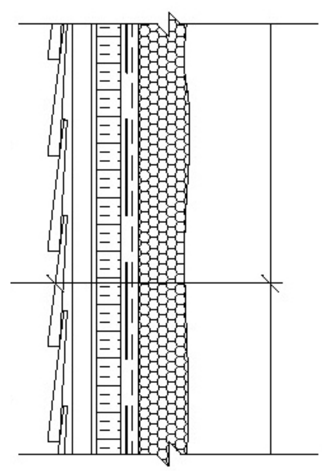
Wall 2 (Wall 1 + high density closed cell spray foam)

- 2x6 @ 24" OC wall construction
- 2" of high density closed cell spray foam
- DOW Weathermate Plus housewrap installed horizontally to the exterior of the suds, with a minimum 6" vertical overlaps, and fastened to the framing with 1-1/2" cap nails spaced 6" OC.
- 1" Styrofoam Residential Sheathing insulating sheathing fastened to framing with 2" cap nails
- Hardie Board fibercement siding installed with 1x4 furring strips.

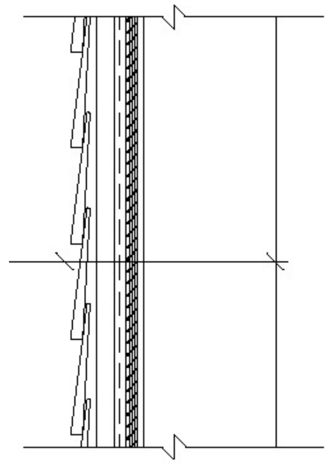


Wall 3 (Wall 2 + snow fence material)

- 2x6 @ 24" OC wall construction
- 2" of high density closed cell spray foam
- DOW Weathermate Plus housewrap installed horizontally to the exterior of the suds, with a minimum 6" vertical overlaps, and fastened to the framing with 1-1/2" cap nails spaced 6" OC.
- GSI Heavy Duty Snow Fence installed with 3" nails at 6" OC.
- 1" Styrofoam Residential Sheathing insulating sheathing fastened to framing with 2" cap nails
- Hardie Board fibercement siding installed with 1x4 furring strips.



Wall 4 (Baseline Wall)



- 2x6 @ 24" OC wall construction
- ½ " OSB sheathing
- DOW Weathermate Plus housewrap installed horizontally to the exterior of the suds, with a minimum 6" vertical overlaps, and fastened to the framing with 1-1/2" cap nails spaced 6" OC.
- Hardie Board fibercement siding installed with 1x4 furring strips.

The impact location (middle of center stud bay) was also chosen so that material reaction would be consistent with the boundary conditions found in the field (stretch/tear of house wrap at nail heads, stud deflection, etc).

All of the walls tested were clad with fiber cement siding over 1x4 furring strips. This was chosen as a middle ground for performance. As the cladding varies, the impact resistance will vary as well. It can be assumed that cladding systems such as brick veneer and stucco will likely be more resistant to impact than siding materials such as fiber cement and wood. Conversely, vinyl siding will likely provide the least amount of resistance for a wall assembly.

Impact Testing

The initial phase of testing of advanced framed wall system with insulating sheathing as the primary sheathing was completed on June 15, 2006. The testing was done with the help of Cardinal Glass Industries at their Laminated Glass Factory in Amery Wisconsin.

Each panel was clamped at the top and the bottom to a metal frame to provide the out of plane resistance for the panels.

Figure 2: Front and back of wall test set up

An air cannon was used to launch the 2x4 projectile at the test velocity[1].

Figure 3: Air Cannon

[1] The velocity of the studs cannot be directly controlled. The air cannon is pressurized to a certain air pressure before firing and the velocity of the stud is measured during each test. Due to this, slight variations to the stud velocity are common during the testing. In addition, the alternate velocities were determined by choosing alternate air pressure levels and measuring the corresponding velocities. This is why the velocity for the third tests ended up on an odd number.

Impact at 50.0 fps

Penetration failures were observed with all of the wall systems (including the OSB sheathed wall) at this stud velocity. These results were surprising as it was expected (based on information from other sources) that the OSB wall would be adequate to resist the impact.

Stud launched from end of cannon

Stud impacting Wall 1

Stud penetrating through Wall 1

Figure 4: Wall 1 (Insulating Sheathing + Housewrap) fail at 50 fps

Stud launched from end of cannon

Stud impacting Wall 2

Stud penetrating through Wall 2

Figure 5: Wall 2 (Insulating Sheathing + Housewrap + 2" Closed Cell Spray Foam) fail at 50 fps

Stud launched from end of cannon

Stud impacting Wall 3

Stud penetrating through Wall 3

Figure 6: Wall 3 (Insulating Sheathing + Snow Fence + Housewrap + 2" Closed Cell Spray Foam) fail at 50 fps

Stud launched from end of cannon | Stud impacting Wall 4 | Stud penetrating through Wall 4

Figure 7: Wall 4 (Housewrap + ½ inch OSB Sheathing) fail at 50 fps

Figure 8: Stud penetration through all wall assemblies at 50 fps

Since all the wall designs (including the baseline wall) failed at this test velocity the test protocol was modified in order to determine the resistance threshold of the various assemblies. The velocity of the stud was reduced to approximately 40 fps from 50 fps.

Impact at 40 fps

Based on the observed failures from the initial round of testing, two of the Wall designs (Walls 1 and 3) were removed from the testing at this velocity. It was seen (and expected) during the first round, that Wall 1 (insulating sheathing and housewrap) would have minimal resistance to impact and therefore it was decided to begin this new round of testing with Wall 2 (insulating sheathing, housewrap, and closed cell spray foam). Wall

3 (addition of the snow fence material) was not tested as was assumed to have a slightly higher capacity than Wall 2; however, there did not appear to be an appreciable increase in performance. Without significant performance increase, the addition work and variation from standard construction practices required to install the snow fence material did not seem to be justified.

At this new velocity, both Wall 2 (insulating sheathing and closed cell spray foam) and Wall 4 (OSB), were able to resist the force of impact of the stud, though damage to both systems was noted.

Stud launched from end of cannon

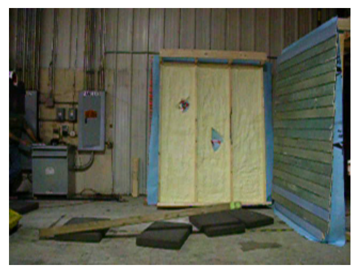
Stud impacting Wall 2

Stud on the ground after rebounding off of Wall 2

Figure 9: Wall 2 (Insulating Sheathing + Housewrap + 2" Closed Cell Spray Foam) pass at 40 fps

Stud launched from end of cannon

Stud impacting Wall 4



Stud on the ground after rebounding off of Wall 4

Figure 10: Wall 4 (Housewrap + 1/2 inch OSB Sheathing) pass at 40 fps

Figure 11: Cracking of both Closed Cell Foam and OSB Sheathing at 40 fps

Since both walls passed at this launch velocity, the velocity was increased to try to narrow the performance band.

Impact at 43 fps

At this velocity, the maximum threshold of Wall 2 was reached with two of the tests resisting the studs from penetrating through the wall assembly and one test allowing the stud to penetrate. At this same velocity, the OSB panel failed on all tests. This indicated that Wall 2 with insulating sheathing and 2 inches of closed cell spray foam was a slightly better performing wall than Wall 4 constructed with ½ inch OSB sheathing.

Stud launched from end of cannon

Stud impacting Wall 2

Stud penetrated cladding but not through Wall 2

Figure 12: Wall 2 (Insulating Sheathing + Housewrap + 2" Closed Cell Spray Foam) pass at 43 fps

Stud launched from end of cannon

Stud impacting Wall 2

Stud penetrating through Wall 4

Figure 13: Wall 4 (Housewrap + 1/2 inch OSB Sheathing) fail at 43 fps

Figure 14: No penetration of Wall 2 and penetration of Wall 4 at 43 fps

To determine the amount of additional capacity that the 2 inches of closed cell spray foam added to the impact resistance of the panel, Wall 1 (insulating sheathing only) was retested at a velocity of 30 fps.

Impact at 30 fps

It was determined that the threshold level for Wall 1 was at 30 ft/s with 2 out of 5 tests at this velocity being able to resist the impact force of the 2x4.


Stud launched from end of cannon


Stud impacting Wall 1


Stud penetrated cladding but not through Wall 1

Figure 15: Wall 1 (Insulating Sheathing + Housewrap) pass at 30 fps


Stud launched from end of cannon


Stud impacting Wall 1


Stud penetrating through Wall 1

Figure 16: Wall 1 (Insulating Sheathing + Housewrap) fail at 30 fps

Figure 17: No penetration of Wall 1 at 30 fps

This result seemed to indicate that the addition of the closed cell spray foam to Wall 2 added an appreciable amount of impact resistance to the wall assembly.

Wall 5 Impact at 50 fps

As a final measure, a panel was retrofitted to see what type of wall assembly would be able to meet the 50ft/s original test protocol. The retrofit wall design included a layer of

½ OSB sheathing between the foam insulating sheathing and the closed cell spray foam. This design was able to resist the impact force of the 2x4 when tested at 50 ft/s.

Stud launched from end of cannon

Stud impacting Wall 5

Stud rebounding off of Wall 5 after impact

Figure 18: Wall 5 (Insulating Sheathing + Housewrap + 1/2 " OSB Sheathing + 2" Closed Cell Spray Foam) pass at 50 fps

Discussion

In all cases the failure was localized to the area of impact. Puncture and shear failure of the materials was observed. The impact seemed to have very little effect on the surrounding construction and no effect on adjoining stud bays.

Wall 1

From these initial test results it was demonstrated that walls design with insulating sheathing only, have little resistance to impact from wind blown debris. The cladding system seemed to play the larger part in the performance of the wall assembly. This could be shown with the variations in pass or fail at the 30fps threshold. There appeared to be a significant chance that if the 2x4 penetrated the cladding system, then it would penetrate the insulating sheathing as well. This result was expected.

Wall 2

A more surprising result was that there was very little difference between the performance of Wall 2 (Insulating Sheathing + Housewrap + 2" Closed Cell Spray Foam) and Wall 4 (Housewrap + 1/2 inch OSB Sheathing). There appeared to be some composite action between the closed cell spray foam and the housewrap material. The bond between the two materials appeared to redistribute the impact force much better than the OSB sheathed wall alone. This could be seen by the size and distribution of the cracks in the closed cell foam. The failure location was more spread out and not limited to the immediate area of impact.

Wall 3

Adding the snow fence material seemed to have little impact in the performance and may be associated with the type of material chosen and placement of the material in the assembly. The material appeared to be more brittle than expected and tore instead of flexing as was hoped.

Wall 4

The baseline wall provided less resistance to impact than was expected. The failure at 50 fps was dramatic with the 2x4 projectile stud penetrating to half of its length through the assembly.

Wall 5

The site retrofit of a wall panel to create Wall 5 demonstrated how a wall could be constructed to resist puncture at 50 fps test velocity. The performance of this wall seemed to be less affected by the cladding performance than any of the other test walls. The stud penetrated through the fiber cement siding however did not penetrate through the remaining layers and bounced off the wall assembly. Damage to the remaining layers did occur though the stud was not able to penetrate in such a way as to remain lodged in the wall assembly as was seen in other wall panels.

Conclusion

It was surprising that none of the original wall assemblies were able to resist the impact at 50 ft/s (requirement for hurricane proof glass). Initially this seemed to be counter intuitive. How could walls have a lower performance than window systems and not have come under the same requirements that windows have? It may be related to the risk associated with a wall failure being not as severe as a window failure. The loss of a window has been catastrophic due to the pressure change in the house resulting from the large opening left by the broken glass. The puncture type failure of the wall assemblies would not likely create this same magnitude of a problem due to the relatively small hole left by this type of failure. If this is the case then, while the design of Wall 5 was the only panel able to meet the impact resistance guidelines adopted from the window industry, it may not be a standard by which wall systems need to be designed to.

The close performance between Wall 2 and Wall 4 demonstrate some possible additional structural and durability benefits beyond extra insulating value and air sealing characteristics of closed cell spray foam in building assemblies.

About this Report:

This research was completed through funding from the Department of Energy's Building America Program and from assistance from Cardinal Glass Industries and The Dow Chemical Company.

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