TESTING AND ADOPTION OF SPRAY POLYURETHANE INSULATION FOR WOOD FRAME BUILDING CONSTRUCTION

Phase 2 -- Wall Panel Performance Testing

Prepared for

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EXECUTIVE SUMMARY

A total of 45 wall panels (fifteen groups of three) were tested in accordance with ASTM standard test methods. Thirty panels were tested for racking (shear) resistance and fifteen panels were tested for compressive (axial) resistance. Eighteen of the thirty racking panels were filled with spray polyurethane foam (SPF) and twelve of the fifteen compressive panels were filled with SPF. The remaining panels served as controls. The Society of the Plastics Industry, Inc., provided sprayed polyurethane foam in containers listed as 1.5 pcf density.

Test Methods

These panels were tested in accordance with ASTM Standard E72, "Standard Methods of Conducting Strength Tests of Panels for Building Construction". Section 9 of the standard covers resistance of walls to compressive loads and Section 14 covers resistance of walls to racking loads.

The significance of the racking tests centers around SPF's ability to provide racking resistance for the wall against wind loading in lieu of diagonal bracing. The compressive test measures the resistance of panels to an axial load imposed by live or dead loads on top of walls, such as overhead floors or roofs.

There are two commonly used ASTM standard test methods which are applicable for determining the racking resistance of building panels, ASTM E72, Section 14 and ASTM E564. ASTM E72 is designed to evaluate the racking load resistance of sheathing materials on a standard 8 ft. x 8 ft. wood frame and E564 is designed to measure the racking performance of an entire wall assembly. The intent of these tests was to determine how SPF-filled wall panels compare with conventionally braced wall panels. ASTM E72, Section 14, was selected as the most appropriate method for purposes of this program.

ASTM E72, Section 9, was selected as the most appropriate compressive load test method. It is the recognized standard method for determining the compressive resistance of standard building panels.

Racking Test Results

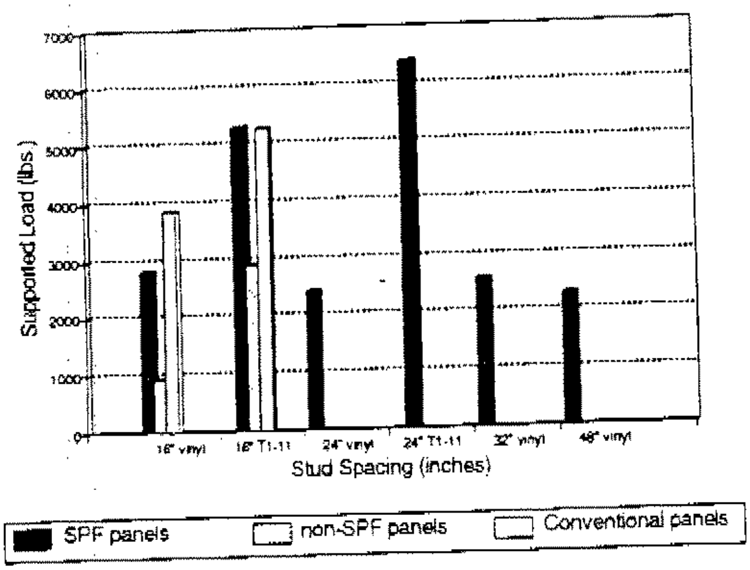
The racking test results showed that the SPF panels with textured plywood siding (T 1-11) had greater racking resistance than the conventional T 1-11 siding, with 16" on center stud spacing. The SPF panels with vinyl siding applied direct to the studs provided an average of 70 percent of the racking resistance of the conventional sheathed vinyl siding panels for all stud spacing.

The racking panels described as "conventional" construction in these tests are representative of standard building practice. However, the conventional 4 foot wide plywood sheathing corner brace covers half of the 8 ft. wide test panels whereas, in reality, the percentage of wall covered by plywood bracing would be much less. As a result, the total racking resistance of the

conventional panels tested would meet or exceed the racking resistance of similar field elements and the SPF panels could meet or exceed the racking resistance of conventional field construction.

Based on the results of the SPF panels with vinyl siding and stud spacings of 16", 24", 32" and 48" on center, stud spacing does not appear to be a major factor in total racking resistance. The figure below shows the maximum racking loads resisted for all ten sets (30 panels) of racking tests.

Racking Test Results
Maximum Supported Load vs. Stud Spacing



There were three distinct failure mechanisms in all of the racking panels. These were failure of gypsumboard sheathing at the taped joint and fasteners, failure of the panel base plate in flexure, and failure of the SPF material itself.

Compressive Test Results

The compressive load tests did not show any increase in the strength of the panels due to SPF. No mechanism developed in the test panels to transfer the applied axial loads from the wall plates, studs and sheathing to the SPF material. The principle mode of failure was crushing of the top plate at the studs. Adding SPF did not appear to contribute to compressive resistance of the panels nor did it adversely affect their performance.

1.0 INTRODUCTION

In 1989, the Society of the Plastics Industry, Inc. (SPI), Polyurethane Foam Contractors Division contracted the NAHB Research Center (Research Center) to conduct a research program entitled "Testing and Adoption of Spray Polyurethane Insulation for the Home Building Industry". The first phase of the program consisted of a feasibility study consisting of a detailed literature review and an engineering analysis of the strength and thermal properties of building panels with sprayed polyurethane foam (SPF). Phase II of the program consisted of laboratory testing to verify conclusions of the engineering analysis in the first phase. This report presents the results of Phase II.

Laboratory tests were performed to investigate the comparative racking and axial strengths of wall constructions containing SPF, panels without SPF, and conventionally constructed control panels. Fifteen groups of three test panels representing a total of 45 wall panels were built. These panels were tested in accordance with the methods specified in ASTM Standard E72, "Standard Methods of Conducting Strength Tests of Panels for Building Construction". Section 9 of the standard covers resistance of walls to compressive (axial) loads and Section 14 covers resistance of walls to racking (shear) loads.

The significance of the racking load tests centers around the ability of the SPF to provide racking resistance against wind loading in lieu of panel or diagonal bracing used in conventional construction. The axial test measures the resistance of panels to a compressive load as would be imposed by the dead or live loads of overhead floors or roofs carried by the walls.

The method of construction of the wall panels is discussed in Section 2.0 and the methods of testing are discussed in Section 3.0. The results of the tests are presented is Section 4.0, and the performance of the various panels is compared and discussed in Section 5.0. The appendices, referenced at appropriate points, contain detailed calculation procedures, data sheets, and test results for all the test panels.

2.0 CONSTRUCTION OF TEST PANELS

2.1 Panel Construction

All panels were constructed of standard 2 x 4 "stud" framing. The racking test panels were 8-feet high and 8-feet long; the axial panels were 8-feet high and 4-feet wide. Conventional half-inch thick, 4' x 8' gypsum wall board (drywall) was applied to the "interior" face of the wood framing with drywall screws. For the 8 x 8 racking panels, the horizontal joint between the sheets of drywall was taped and finished with standard drywall compound.

The panels were constructed on a flat, elevated table and squared in a wooden form prior to sheathing and subsequent SPF application. The exterior faces of the axial and racking panels were covered with either vinyl siding over 15# building paper, 5/8" thick T 1-11 plywood siding panels (textured plywood with vertical grooves at regular intervals to simulate narrower boards) or "conventional" sheathing and siding materials (racking panels only). The conventional panels consisted of a 4 x 8 sheet of 1/2" thick plywood and a 4 x 8 sheet of 1/2" fiberboard sheathing placed side by side and nailed to the framing members, covered with vinyl or T 1-11 siding. The 1/2" plywood sheathing panel represents a method of corner bracing commonly used in conventional construction, and the fiberboard sheathing is typical of non-structural sheathing used on the remainder of the structure.

The materials used to assemble the test panels, except for the sprayed polyurethane foam, were obtained at a local retail lumber outlet. The dimensional lumber was selected by testing its stiffness to assure that all 2 x 4 material fell within plus or minus 10 percent of the allowable for stud grade Spruce-Pine-Fir 2 x 4 lumber (see Appendix A for detailed calculation). All non-conforming 2 x 4s were returned to the lumber outlet.

SPI provided sprayed polyurethane foam in containers listed as 1.5 pcf density, see appendices for additional information. Application was performed by an SPI-member contractor familiar with the SPF application process. A braced wooden form was used to hold the panels upright and square during spraying operations.

4.0 TEST RESULTS

4.1 Racking Test

The 30 racking panels were tested in accordance with the procedure described in Section 3.1. The results, including maximum load, for each configuration were obtained by averaging the values obtained from the three panels of the same configuration. Table 4 summarizes the average maximum racking load achieved for each of the 10 panel configurations.

Table 4
Average Maximum Racking Load (Pounds)
Supported by Each Panel Configuration

	SPF Panels		Non-SPF Panels	
Stud Spacing	Vinyl	T 1-11	Vinyl	T 1-11
16"	2,800	5,300	913	2,890
24"	2,420	6,387	---	---
32"	2,588	---	---	---
48"	2,298	---	---	---
16" Conventional	---	---	3,853	5,262

The average deflections and sets for each racking panel configuration are presented in Tables 5 through 14. These tables list deflections and sets observed for each 400 lb. loading increment. The results were obtained by averaging the values obtained for the three panels of the same configuration. If all three panels failed to achieve a 400# incremental level, then no deformation or set values are listed for that loading level. Calculation procedures are described in Appendix A.

Table 5
Average Racking Results for Walls with Vinyl Siding and 16" On-Center Studs -- SPF Filled Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.055	0.020	31.981
800	0.130	0.043	29.564
1,200	0.234	0.095	37.557
1,600	0.407	0.156	36.993
2,000	0.634	0.225	34.644

Table 6
Average Racking Results for Walls with Vinyl Siding and 24" On-Center Studs -- SPF Filled Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.065	0.030	40.097
800	0.143	0.062	42.319
1,200	0.289	0.114	41.841
1,600	0.522	0.186	38.029

Table 7
Average Racking Results for Walls with Vinyl Siding and 32" On-Center Studs -- SPF Filled Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.071	0.037	51.527
800	0.162	0.086	52.769
1,200	0.298	0.157	52.776
1,600	0.467	0.228	48.508
2,000	0.746	0.327	43.564
2,400	1.416	0.599	42.302

Table 8
Average Racking Results for Walls with Vinyl Siding and 48" On-Center Studs -- SPF Filled Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.065	0.038	59.485
800	0.147	0.080	54.280
1,200	0.281	0.139	49.156
1,600	0.494	0.200	40.194

Table 9
Average Racking Results for Walls with Vinyl Siding and 16" On-Center Studs -- No SPF in Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.090	0.061	66.546
800	0.340	0.251	73.224

Table 10
Average Racking Results for Walls with Conventional Vinyl Siding and 16" On-Center Studs -- No SPF in Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.112	0.083	70.187
800	0.174	0.119	65.809
1,200	0.239	0.150	61.087
1,600	0.300	0.203	71.782
2,000	0.460	0.269	58.858
2,400	0.619	0.364	58.944
2,800	0.756	0.443	58.538
3,200	1.168	0.731	62.404

Table 11
Average Racking Results for Walls with T 1-11 Siding and 16" On-Center Studs -- SPF Filled Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.058	0.022	36.376
800	0.113	0.040	32.949
1,200	0.165	0.063	37.373
1,600	0.207	0.081	38.487
2,000	0.248	0.100	40.143
2,400	0.288	0.117	40.174
2,800	0.332	0.139	41.332
3,200	0.384	0.162	41.694
3,600	0.412	0.188	45.251
4,000	0.517	0.217	41.371
4,400	0.608	0.248	40.020

Table 12
Average Racking Results for Walls with T 1-11 Siding and 24" On-Center Studs -- SPF Filled Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.031	0.008	25.058
800	0.071	0.020	27.141
1,200	0.119	0.040	32.826
1,600	0.170	0.064	37.359
2,000	0.225	0.090	39.614
2,400	0.276	0.111	39.824
2,800	0.322	0.128	39.802
3,200	0.371	0.144	39.001
3,600	0.420	0.159	38.076
4,000	0.492	0.183	37.018
4,400	0.575	0.213	36.559

Table 13
Average Racking Results for Walls with T 1-11 Siding and 16" On-Center Studs -- No SPF in Wall Cavities

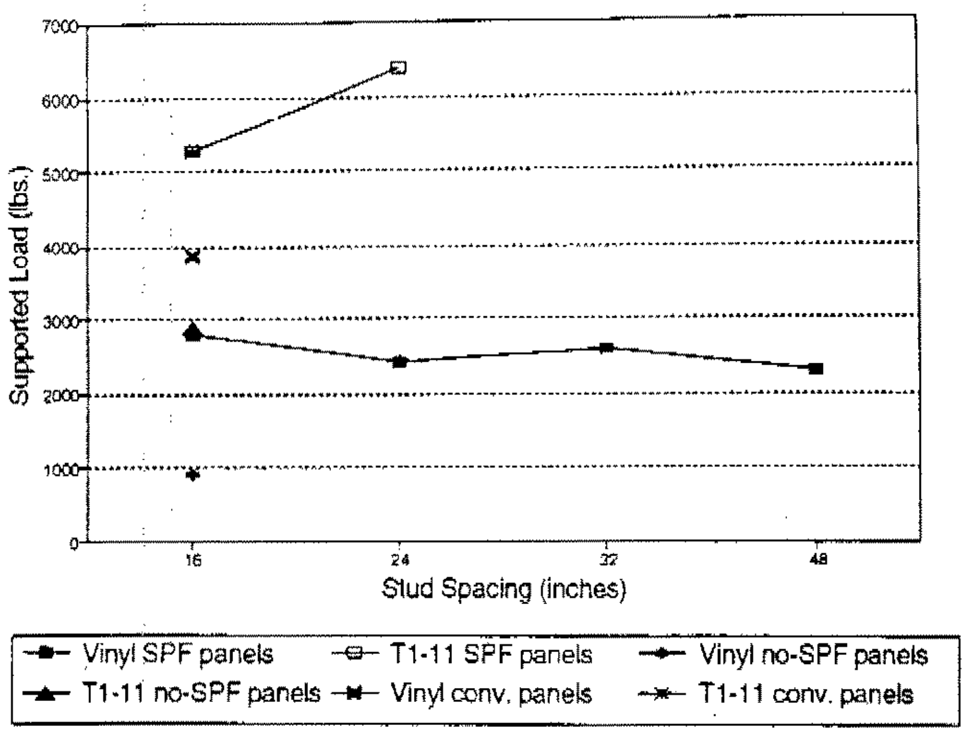
LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.049	0.034	67.830
800	0.116	0.072	61.535
1,200	0.191	0.116	60.355
1,600	0.287	0.178	61.445
2,000	0.439	0.312	72.021

Table 14
Average Racking Results for Walls with Conventional T 1-11 Siding and 16" On-Center Studs -- No SPF in Wall Cavities

LOAD (POUNDS)	DEFORMATION (INCHES)	SET (INCHES)	SET AS PERCENT DEFORMATION
0	0.000	0.000	0.000
400	0.030	0.010	25.328
800	0.065	0.022	25.846
1,200	0.104	0.038	31.518
1,600	0.152	0.064	40.534
2,000	0.207	0.097	46.284
2,400	0.294	0.153	51.549
2,800	0.409	0.193	47.409
3,200	0.474	0.246	51.933
3,600	0.616	0.367	59.760

A graph depicting maximum racking load vs. stud spacing for each configuration is presented in Figure 12. The maximum average load for each configuration can be found in Figure 12 by identifying the configuration from the legend.

Figure 12
Maximum Supported Racking Load vs. Stud Spacing



4.2 Axial Test

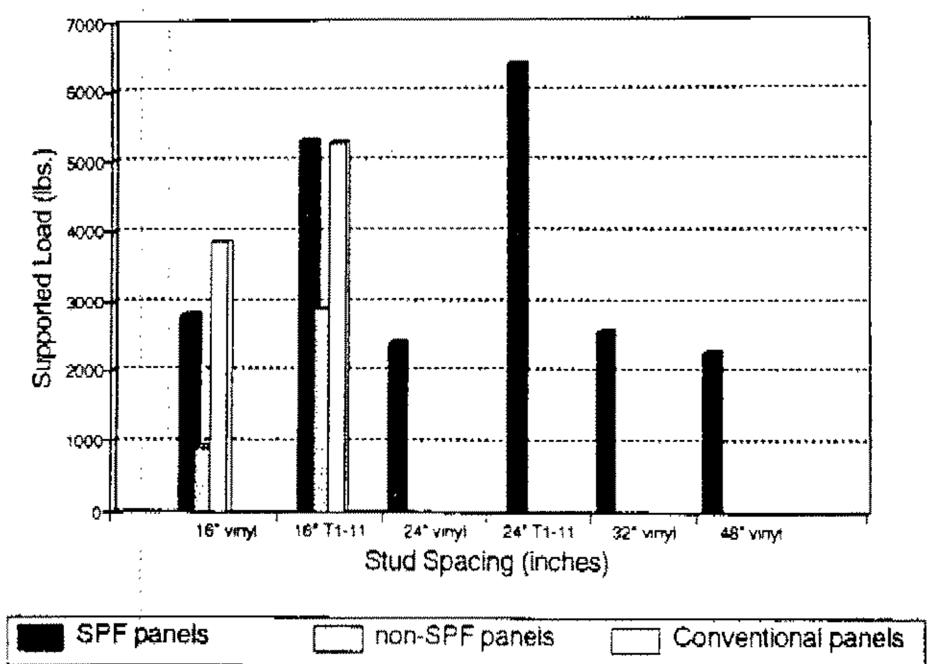
The 15 axial panels were tested in accordance with the procedures described in Section 3.2. The average maximum compressive load supported by each panel configuration is summarized in Table 15. Tables 16 and 17 summarize results of average compressive deformation and lateral deflection obtained for each panel configuration.

5.0 DISCUSSION

5.1 Observations from Racking Tests

On average, SPF panels with vinyl siding and studs spaced at 16" on center provided over 70 percent of the racking strength of the conventional vinyl siding panel with 16" on center studs and sheathing. SPF panels with T 1-11 siding and studs at 16" on center had greater racking strength than the conventional T 1-11 siding panels with studs at 16" on center. Figure 13 shows the ultimate racking loads for each of the sets of panels.

Figure 13
Racking Test Results
Maximum Supported Load vs. Stud Spacing



Housing built entirely with SPF-filled wall cavities (3" minimum thickness) would likely not require conventionally braced construction. Since lateral bracing is required at corners of walls and other limited locations only, the total resistance of a building with SPF-filled cavities could equal or exceed that of a conventionally-braced building.

he racking panels described as "conventional" construction in this report are representative of tandard practice in residential building. However, the 4 x 8 plywood sheathing corner brace :overs half of the 8 ft. wide test panels whereas, in reality, the percentage of wall covered by ›lywood bracing would be much less. As a result, the maximum racking strength values of the 'conventional" test panels exaggerate the racking strength values for conventional construction in the field compared to SPF installed in the entire wall.

Based on the results of the SPF panels with vinyl siding and stud spacing of 16", 24", 32" and 48" on center, stud spacing does not appear to be a major factor in total racking strength. The ultimate racking load values for vinyl siding panels with SPF are within 25 percent of each other for all stud spacings. The 24" on center T 1-11 siding with SPF actually had greater maximum racking load values than the panels with 16" on center stud spacing. This suggests that it is the panel or bracing materials themselves such as T 1-11, gypsumboard, SPF and sheathing, and their fastenings that are resisting the racking loads, and not the composite action of all the panel elements working together. Composite action developed between the SPF and the studs does not appear to be a major factor in developing racking resistance.

Both the T 1-11 and vinyl sided SPF-filled panels had lower overall deflections than the non-SPF control panels, and the sets for the SPF-filled panels were significantly lower than the non-SPF control panels. This indicates that during a "design" racking event such as a hurricane, there would be less permanent deformation of these wall elements and possibly less damage to a structure that was braced with SPF-filled walls.

There were three distinct failure mechanisms in the racking panels. These were failure of gypsumboard sheathing at the taped joint and fasteners, failure of the base plate at the heel in flexure, and failure of the SPF material in a variety of ways. The gypsumboard sheathing always failed in the same manner. Initially a hairline crack appeared the taped joint which would widen as the loading increased. Next, shearing deformation of the panel caused tearing of the gypsumboard sheathing at the fastening screws, beginning at the bottom heel of the panel. This tearing got progressively worse as the panel base plate deflected upward at the heel. Lastly, gypsumboard fasteners would begin pulling out of the framing elements, and tearing of the gypsumboard around the fasteners would become more pronounced.

The heel of the panel base plate often deflected upward in excess of 3/4" before the maximum resistance was reached, and this was related to the manner in which the base of the panel was fastened to the test stand. The anchor bolts used to attach the panel to the 4" x 6" bottom foundation beam are located approximately 48" apart so as to avoid coinciding with the various stud locations. These bolts are placed 20" to 24" in from the front and rear edges of the panel which creates a cantilever effect on the end of the base plate. As the panels are loaded they begin to rotate, and the cantilevered portion at the heel of the base plate rises off the foundation as the panel begins to rotate.

The third failure mechanism is failure of the SPF material itself. The SPF always failed after the gypsumboard and the panel base plate heel failure mechanism were well formed. A SPF failure immediately preceded the loss of racking resistance and the end of the test. This failure was usually accompanied by an audible popping noise. The type of failure is consistent but the location of the failure is not. A diagonal crack would form extending from the top or bottom plate at 30 to 45 degrees from the vertical. The most common failure location was the bottom of the first stud space adjacent to the applied load. This failure sometimes continued across the first stud space and into the second space. In several cases with a smaller stud spacing (16" and 24") a series of saw tooth cracks would appear across the top or bottom edge of the panel. One exception to this pattern was the 48" on center vinyl sided SPF-filled panels which bowed or buckled out of plane forming a concave surface in the wall cavities.

5.2 Observations from Axial Tests

The axial test results indicated the lack of a mechanism to transfer the applied axial loads to the SPF material. The principle mode of failure in the axial panels was crushing of the top plate at the studs. The inclusion of sprayed polyurethane foam in the wall panels did not appear to contribute to compressive resistance of the panels.