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A PORTAL FRAME DESIGN FOR RAISED WOOD FLOOR APPLICATIONS

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A Portal Frame Design for Raised Wood Floor Applications

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Abstract

The performance of narrow shear walls or bracing segments without hold-downs has been recognized by the International Residential Code (IRC) in the U.S. by setting a maximum aspect ratio of 6:1 in the 2004 code change cycle. The background information supporting the code change has been presented (Williamson and Yeh, 2004). However, due to the lack of test data on raised wood floors at that time, the U.S. building codes restrict this application to construction on rigid foundations, such as a concrete foundation, stem wall, or slab.

In order to address the raised floor issue such as occurs in basement or crawl space construction and in second or third level floors, a research project was conducted by APA - The Engineered Wood Association in late 2004 on narrow shear walls constructed on the top of a raised wood floor assembly without hold-downs. A total of 12 full-scale cyclic shear wall tests were conducted in this study. Several different raised floor configurations were first tested to determine the difference between engineered-wood raised floors using I-joists and solid-sawn raised floors, and to evaluate the effect of joist orientation relative to the braced wall segment. The wall heights tested were 2438 mm (8 feet) and each total wall segment was 3658 mm (12 ft) long. The SEAOSC (1997) cyclic load protocol was used in this test program.

1. Introduction

Unlike many other countries, in the U.S., wood framing is the dominant type of construction for new homes. With housing starts of approximately 2 million units per year, this represents a huge market for wood products. In recent years new home construction has seen an increasing trend toward 2 and 3 story construction with a high percentage of narrow wall segments due to the demand by architects and owners for maximum window areas. This report presents test data for a wood portal frame design with no hold-down devices built on top of a raised wood floor as would be typical for 2 and 3 story construction, intended for use in a fully sheathed structures.

The 2003 International Residential Code (IRC, Section R602.10.5) permits a 4:1 aspect ratio wood structural panel braced wall segment if a) the structure is fully sheathed with wood structural panels and b) openings next to such segments are limited to 0.65 times the story height. These 4:1 aspect ratio segments can be used in any of 3 stories. There are no specific hold-down requirements in the IRC for this 4:1 aspect ratio wall segment, except a corner framing detail is specified at corners. Thus, in actual field applications, the fully sheathed perpendicular walls and dead loads would provide the end restraint for this 4:1 aspect ratio wall segment rather than hold-down devices.

Using this IRC 4:1 aspect ratio wall segment as a currently acceptable baseline, tests were conducted on a 406 mm (16-in.)-wide portal frame design (6:1 aspect ratio) with similar end restraint as the IRC 4:1 aspect ratio wall segment to investigate if such an alternate narrow wall segment would provide equal or better performance when built on a raised wood floor. Similar comparative testing has been done with wall segment elements built on a steel test frame (rigid foundation) and results showed the 6:1 aspect ratio portal frame designs perform approximately equal to or better than the IRC 4:1 aspect ratio wall segment (APA, 2003).

2. Materials and Test Assemblies

Table 1 summarizes details of each test.

Table 1. Raised floor wall testing description

Wall Test(1)	Degree of End Restraint	Wall Segment Type	Joist Depth (mm)	Rim Joist Type	Joist Type	Joist Orientation(2)	Connection of Braced Wall to Raised Floor(3)
RF1	High	R602.10.5	302	28.6 mm OSB	PRI-20	Perp.	see footnote 3
RF2	High	R602.10.5	302	PRI-20	PRI-20	Perp.	see footnote 3
RF3	High	R602.10.5	286	2x12	2x12	Perp.	see footnote 3
RF4	High	R602.10.5	302	PRI-20	PRI-20	Parallel	see footnote 3
RF5	High	R602.10.5	286	2x12	2x12	Parallel	see footnote 3
RF6	Low	R602.10.5	302	PRI-20	PRI-20	Parallel	see footnote 3
RF7	Low	Portal Frame	302	PRI-20	PRI-20	Parallel	see footnote 3
RF8	Low	Portal Frame	302	PRI-20	PRI-20	Parallel	2 LTP4 at each wall segment(3)
RF9	Low	Portal Frame	302	PRI-20	PRI-20	Parallel	302 mm OSB overlap with rim joist(3)
RF10	Low	Portal Frame	286	2x12	2x12	Parallel	235 mm OSB overlap with rim joist (3)
RF11	Low	R602.10.5	302	PRI-20	PRI-20	Parallel	see footnote 3
RF12	High	Portal Frame	302	PRI-20	PRI-20	Parallel	2 LTP4 at each wall segment(3)

(1) Wall tests RF4 and RF5 were built with 8d box nails, all others 8d common. RF9, RF10, and RF12 had an unblocked sheathing joint near wall mid height.
(2) Joist orientation relative to wall segment; either parallel, or perpendicular.
(3) All tests had sole plate to rim joist connection with 3-16d @ 406 mm o.c. at braced wall segment per IRC Table R602.3(1), plus additional connection as noted.

2.1 Wall Segments

For the wall framing, dry 38.1 mm x 88.9 mm (2x4) No. 2 Douglas-fir (DF) lumber was used. The header was built up using two lumber 38.1 mm x 286 mm (2x12) No. 2 DF members, with an 11.9 mm (15/32-in.) OSB spacer used on the backside of the 2x12's to create a header surface that was flush with the 2x4 framing. APA Rated Sheathing oriented strand board (OSB) with a thickness of 9.5-mm (3/8-in.) and a span rating of 24/0, Exposure 1, was used for all wall sheathing. Nails used for attaching wall sheathing to framing were 8d common (3.3 mm diameter x 63.5 mm long), except two tests (as noted, RF4 and RF5) were built with 8d box nails (2.9 mm x 63.5 mm). Nails used for stitch nailing of the double end studs were 10d common (3.8 mm x 76.2 mm), spaced 610 mm (24 in.) o.c., per code. Nails used for attaching the sole plate to the raised floor were 16d sinkers (3.8 mm x 82.5 mm).

Hold-down devices were used in some tests. . The tests using hold-down devices were intended to simulate the case with a high degree of end restraint, such as that provided by the fully sheathed return wall, header, and dead weight from above. The hold-down devices used were Simpson Strong Tie PHD5's attached to a single 2x4 that was nailed to the wall framing with 16-16d sinker nails.

A Simpson Strong Tie LSTA 24 strap (31.7 mm wide x 610 mm long, 20-gage steel) was used in the portal frame tests to provide vertical continuity and resistance to loads normal to the sheathing surface, and to provide some reinforcement for lateral loadings.

2.2 Raised Floor Assemblies

The raised floor assemblies were built with a continuous No. 2 DF 2x4 bottom plate. The rim joist was either 28.6 mm (1-1/8-in.) APA OSB Rim Board, a No. 2 DF 2x12 joist, or a PRI-20 I-joist. The PRI-20 I-joist had a 44.4-mm (1-3/4-in.) wide x 33.3-mm (1-5/16-in.) thick flange, with a 9.5-mm (3/8-in.) OSB web. When the solid-sawn 2x12 rim joists were used, the same material was used for the floor joists. When engineered wood products were used as the rim joist, PRI-20 I-joists were used for the floor joists. APA Rated Sheathing OSB with a thickness of 9.5 mm (3/8-in.), with a span rating of 24/0, Exposure 1, was used for the wall portion of the raised floor. APA Rated Sheathing OSB with a thickness of 18.2 mm (23/32-in.), with a span rating of 48/24, Exposure 1, was used for all floor sheathing.

Nails used for attaching wall sheathing to rim joist, rim joist to sill plate, and rim joist to joist (where applicable) were 8d common (3.3 mm diameter x 63.5 mm long). Four 1/2-in.-diameter sill bolts with 50.8 mm x 50.8 mm x 4.8 mm (2-in. x 2-in. x 3/16-in.) plate washers were used to fasten the sill plate to the test frame. Placement of the sill anchorage is shown in Figure 1.

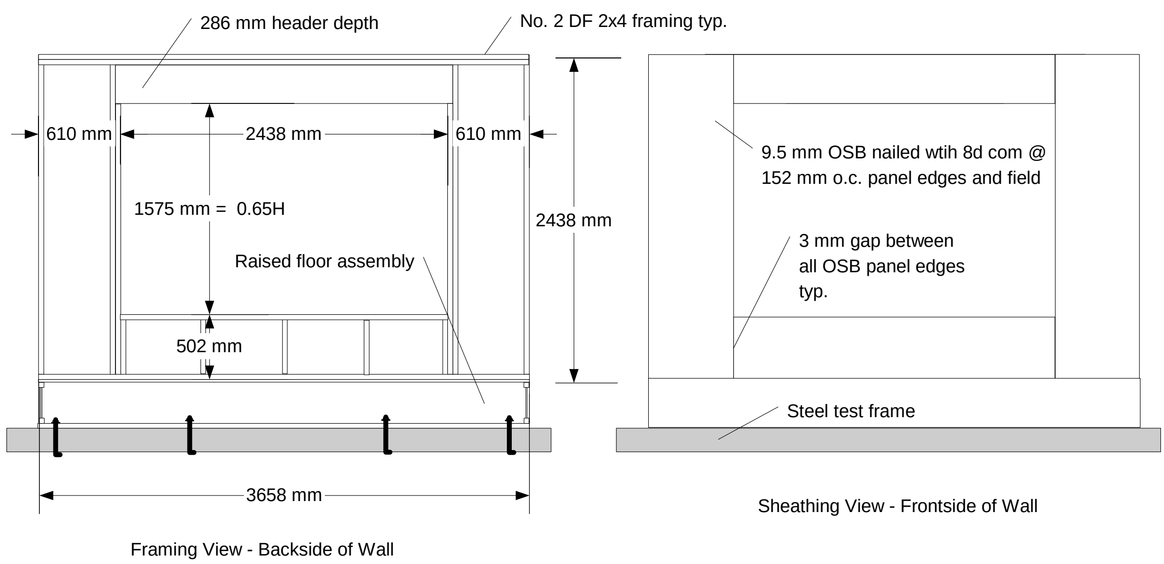

Figure 1. Wall construction details for the 4:1 aspect ratio walls segments used as the baseline

Figure 1 shows the typical R602.10.5 wall segment test specimen with a low degree of end restraint. This R602.10.5 wall segment is currently permitted in the IRC and is considered the baseline in this test program. The raised floor assembly with perpendicular joists had joists spaced 610 mm (24 in.) o.c. perpendicular to the rim joist. The raised floor assembly with parallel joists had the outer joist spaced 406 mm (16 in.) o.c. parallel to the rim joist.

Figure 2 shows the typical portal frame built on top of the raised floor assembly, where two LTP4 plates are used in addition to the 3-16d sinker nails to connect the wall segment to the raised floor.

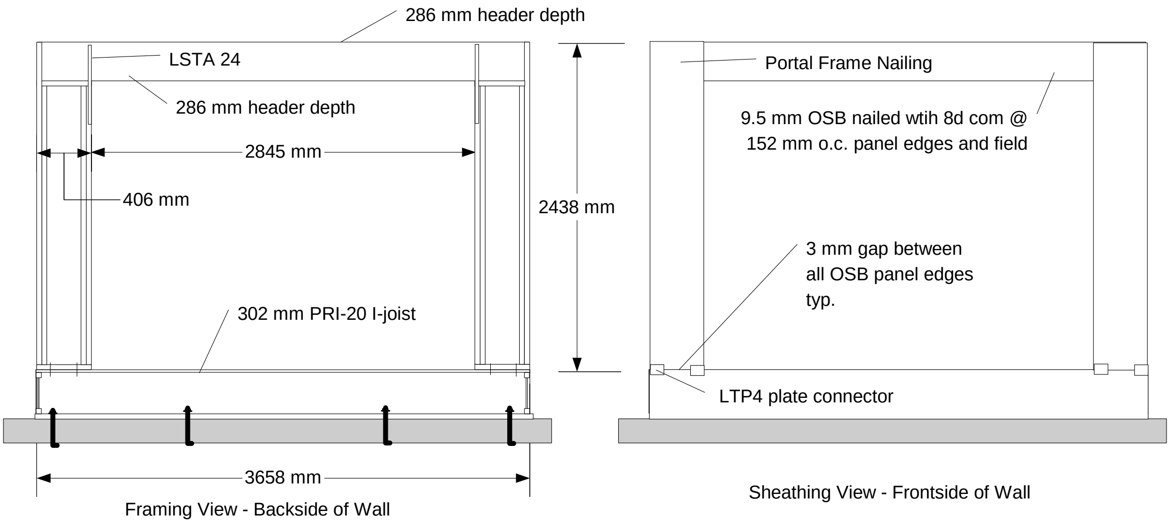

Figure 2. Wall construction details for the 6:1 aspect ratio portal frame wall segments

For the low degree of end restraint condition, only the minimum anchor bolts, placed as shown in Figures 1 and 2 were used to restrain the assembly from uplift. For the high degree of end restraint condition, a single 2x4 attached to the wall with 16-16d sinkers was used and this 2x4 was connected to a Simpson PHD5 hold-down. Complete details with figures have been published (APA, 2004).

Tests RF1-RF5 were conducted to determine effect of different raised floor configurations and establish which to use as the worst case for subsequent testing. A high degree of end restraint was used in Test RF1-RF5 to force the highest loads possible on the raised floor and wall assembly. The test results for the parallel and perpendicular joist orientation were very close to each other, but the parallel joist case was slightly more critical. By inspection, the parallel joist case provides less material to resist compressive forces due to the wall racking. Therefore, the remaining tests (RF6 – RF12) were conducted with the parallel joist orientation. Tests RF6 and RF11 established the baseline for a low degree of end restraint. Tests RF7-RF10, with a low degree of end restraint, were of different portal frame-wall-segment to raised-floor connections. Previous testing (APA, 2003) has shown that the critical relative performance comparisons between the portal frame and baseline occur for the low degree of end restraint condition.

3. Test Set-Up and Procedure

For the portal frame tests, load was applied to the walls via a load head beam-to-header connection using five 19 mm x 152 mm (3/4-in. x 6-in.) lag screws evenly spaced along the length of header. For the 4:1 aspect ratio wall segment tests, a combination of similarly sized bolts and lag screws were used. The OSB sheathing was free to rotate in that the OSB sheathing was neither bearing on the foundation frame nor on the load beam above. A 3.2-mm (1/8-in.) gap was left as spacing between adjacent OSB panels. Walls were tested both with a high degree of end restraint and a low degree of end restraint to investigate the range of response expected for a segment which does not require hold-down devices, but which does have some degree of end restraint provided by the surrounding structure.

4. Test Results

A summary of the test results is shown in Tables 2 and 3 and Figures 3 and 4. The test results in Table 2 are the absolute average values of the positive and negative displacement excursions.

Table 2. Summary of test results (data is average of +/- excursions)

Degree of End Restraint	Wall Type	Wall Test	Load (kN) at		Maximum	
			6.1 mm	12.2 mm	Load (kN)	Defl. (mm)
Low	R602.10.5	RF6	2.24	3.57	10.07	83.2
	R602.10.5	RF11	1.94	3.19	9.96	92.6
	Portal Frame	RF7	2.18	3.73	8.06	69.8
	Portal Frame	RF8	2.58	4.40	10.07	75.6
	Portal Frame	RF9	2.54	4.42	11.00	76.8
	Portal Frame	RF10	2.77	4.74	10.18	62.5
High	R602.10.5	RF1	3.93	6.00	14.14	57.2
	R602.10.5	RF2	3.85	6.34	13.69	62.5
	R602.10.5	RF3	4.12	6.59	13.77	68.7
	R602.10.5	RF4	3.63	5.54	12.39	56.1
	R602.10.5	RF5	3.91	6.16	12.43	61.4
	Portal Frame	RF12	3.78	6.51	16.78	85.1

Table 3. Ratio of average portal frame tests results divided by baseline tests results

Degree of End Restraint	Wall Comparison Between	Load (kN) at		Maximum	
		6.1 mm	12.2 mm	Load (kN)	Defl. (mm)
Low	RF7/(ave. of RF6&11)	1.04	1.10	0.80	0.79
	RF8/(ave. of RF6&11)	1.23	1.30	1.00	0.86
	RF9/(ave. of RF6&11)	1.21	1.31	1.10	0.87
	RF10/(ave. of RF6&11)	1.32	1.40	1.02	0.71
High	RF12/RF4	1.04	1.18	1.35	1.52
	RF12/(ave. of RF1,2,3,4& 5)	0.97	1.06	1.26	1.39

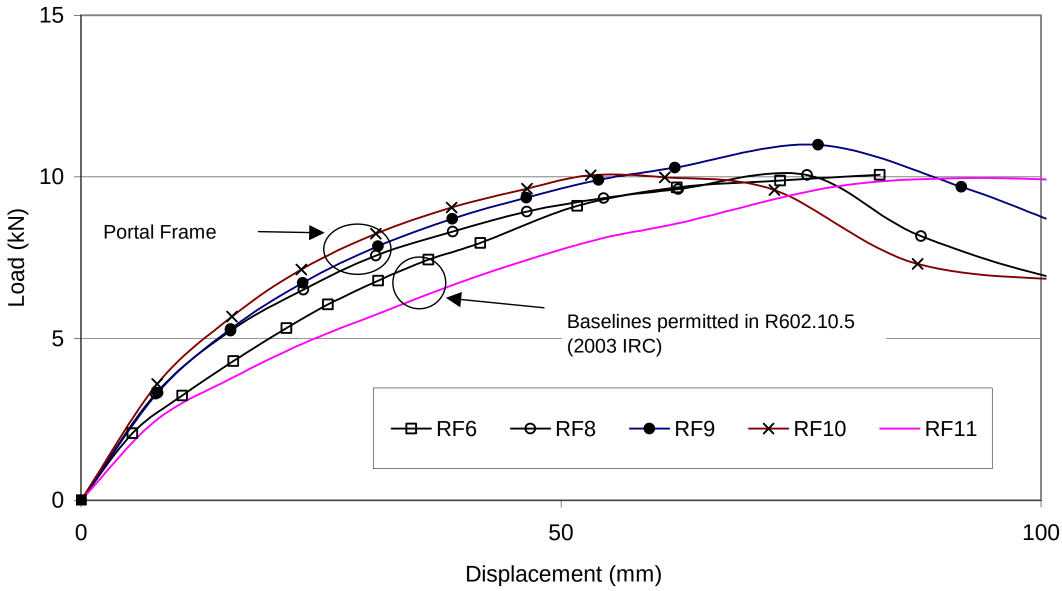

Figure 3. Backbone curve summary – positive and negative excursions averaged for tests with a low degree of end restraint (Test RF7 is omitted for clarity)

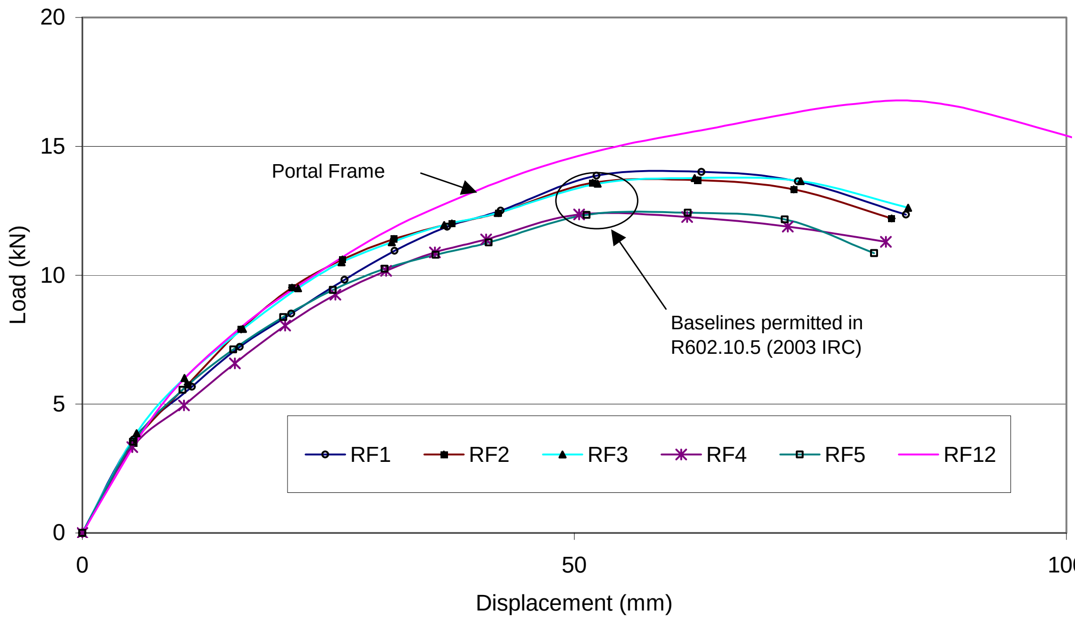

Figure 4. Backbone curve summary – positive and negative excursions averaged for tests with a high degree of end restraint

4.1 Failure Modes

All of the raised floor tests had the wall segment, rather than the raised floor segment, dominate the failure. R602.10.5 wall segments had classic shear wall failure mechanisms where the failure was dominated by the nailed connection of the sheathing to the framing.

Some nail fatigue was observed in these wall tests as is common for wood structural panel shear wall tests conducted with the SPD (SEAOSC, 1997) load protocol.

The portal frame wall failure region was more concentrated at either the wall connection to the raised floor or the sheathing overlapping the header, or both. In some tests the OSB failed in bending (tension) where it overlaps the header, as previously reported (APA, 2003). Almost all metal strap components failed in fatigue before the 72 cycles of the SPD protocol were finished, as is typical of these strap components subjected to the SPD (SEAOSC, 1997) load protocol.

4.2 Portal Frame vs. Existing Bracing Comparison

As shown in Table 3 by ratios greater than 1 (or within a few percent, e.g. 0.97) all portal frame test results except RF7 (a design that will not be recommended) had better stiffness and maximum load capacity compared to the existing bracing permitted in R602.10.5. The deflection at peak load for the portal frames was less than the existing permitted bracing for the low degree of end restraint walls, but higher for the high degree of end restraint walls. The high degree of end restrain condition is believed to be more representative of actual end use conditions because perpendicular walls, finishes, and dead weight will all add a degree of end restraint. For the high degree of end restraint, the portal frame has equal or better performance characteristics by every measure.

5. Comparison to Previous Testing

The testing described in this report was similar to previous testing (APA, 2003) in that the purpose was to make relative performance comparisons between portal frame bracing and existing permitted bracing. However, in this report, all relative comparisons were made for wall segments built on top of a raised wood floor assembly. Note that the raised floor portal frames had a different bottom of wall attachment to the “foundation” as described, and RF9, RF10 and RF12 had an unblocked panel edge at mid-height of the wall segment. Comparisons of tests results between wall segments built on a rigid foundation to those built on a raised floor show that

- The raised floor reduces wall stiffness but not ultimate strength, and
- The effect of the raised floor is not as significant as is the degree of end restraint applied to wall segments.

6. Conclusions

Portal frame wall segments having a 6:1 aspect ratio wall segment, whether built on a rigid foundation or a raised floor foundation, have comparable performance to the 24-in. braced wall segments currently permitted by code (see 2003 IRC, Section R602.10.5) built on the same.

7. References

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