IRC Bracing Methods, Relevant Test Data, and Recommended Design Values for Wind Bracing Analysis of Conventional Wood-Frame Homes

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Introduction

This report addresses the following three objectives:

1. Reviews available literature regarding in-plane (racking) shear capacity of wall constructions relevant to bracing methods found in the 2006 International Residential Code (IRC).
2. Evaluates the data in regard to similarities and differences in test methods, results, and other factors to determine characteristic ultimate shear strength values as well as recommended allowable design shear values for each bracing method.
3. Identifies and recommends corrections or enhancements to the bracing methods as currently prescribed in the IRC.

There are three parts and an appendix to this report:

PART 1: Construction Requirements for IRC 2006 Bracing Methods (R602.10.3)
PART 2: Review and Evaluation of Relevant Wall Bracing Test Data
PART 3: Summary & Recommendations
Bibliography
APPENDIX A: Tabulated Test Data and Table References

While some of the findings in this report and the data included in Appendix A are relevant to design of seismic bracing, the focus of this report was on design shear values appropriate for design of wind bracing for conventional wood-frame homes within the scope of the IRC. Additional work, including consideration of seismic response modifiers for the various bracing methods in the IRC, is required for the purpose of re-evaluating the seismic bracing provisions in the IRC.

It should be recognized that the current bracing amounts in the IRC were based on an evaluation of seismic load only and are not necessarily adequate for wind loading in all conditions of use. Thus, this study is considered as a first step toward a thorough and practical re-evaluation of bracing amounts and bracing method requirements in the IRC for the purpose of ensuring adequate resistance to racking loads caused by wind.

PART 1: Construction Requirements for IRC 2006 Bracing Methods (R602.10.3)

The following is a summary of the relevant requirements related to the various bracing methods listed in Section R602.10.3 of the IRC.

Method 1 Bracing

- 1x4 continuous diagonal brace (undefined species/grade) or approved metal strap
- Angle of not more than 60^{o} or less than 45^{o} from horizontal
- 2-8d nails (2-1/2" x 0.113") nails or 2 staples (min. 16g x 1-3/4"x7/16" crown) to each stud and plate
- Stud spacing of 24"oc maximum (implied)

Method 2 Bracing

- Diagonal wood board sheathing, minimum 5/8-inch thick (undefined species/grade)
- Angle of diagonal boards not defined (45^{o} is implied)
- 2-8d nails (2-1/2" x 0.113") or 2 staples (min. 16g x 1-3/4"x7/16" crown) to each bearing
- Stud spacing 24"oc maximum

Method 3 Bracing

- 5/16" WSP for 16"oc framing or 3/8" WSP for 24"oc framing (minimums)[1]
- Horizontal or vertical panel placement permitted[2]
- 6d common nail (2" x 0.113") at 6" edges and 12" field[3]

Method 4 Bracing

- ½" or 25/32" thick structural fiberboard sheathing
- Horizontal or vertical panel placement permitted (blocking required at horizontal joint)
- 1-1/2" galv. roofing nail, 8d common nail (2-1/2" x 0.131") or staple (min. 16g x 1-1/2"x7/16" crown) at 3"oc edges and 6"oc field (add ¼" to length of roofing nail and staple for 25/32" thick sheathing)
- Studs spacing of 16"oc maximum

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[1] Pending 2006/2007 ICC change will require minimum 3/8" WSP for 16"oc and 24"oc framing.
[2] Pending 2006/2007 ICC change will require blocking at horizontal joints which is not currently required.
[3] Pending 2006/2007 ICC change will require minimum 8d common nail (2-1/2" x 0.131")

Method 5 Bracing

- Minimum ½" thick GWB or gypsum sheathing
- Horizontal or vertical panel placement permitted
- 7"oc nail fastener spacing[4]; fastener for gypsum sheathing 1-1/2" galv roofing nail, 8d common nail (2-1/2"x0.131"), or staple (min. 16g x 1-1/2" x 7/16" crown); fastener for GWB 13g x 1-3/8" x 19/64" head nail, 0.098" x 1-1/4" annular-ringed nail, 5d cooler nail, 0.086" x 1-5/8" x 15/64" head nail, or gypsum nail (0.086" x 1-7/8" x 19/64" head); fasteners for 5/8" thick material increase by 1/8" to ¼" depending on fastener; adhesives are permitted but not required (except in SDC C and D where prohibited)
- Stud spacing of 24"oc maximum

Method 6 Bracing

- 3/8" or ½" Particleboard wall sheathing
- Horizontal or vertical panel placement permitted (end joints must be staggered for horizontal application and blocking is required)
- 6d common nail (2" x 0.113") at 6"oc edges and 12"oc field
- Stud spacing 16"oc maximum

Method 7 Bracing

- Portland cement plaster (minimum 3-coats) ¾" minimum thickness (expanded metal lath) or minimum 7/8" thickness (wire lath)
- Corrosion-resistant expanded metal lath or woven wire lath fastened with 11g x 1-1/2" x 7/16" head nails or 16g x 7/8" staples spaced no more than 6", or as approved.
- Stud spacing of 16"oc maximum

Method 8 Bracing

- 7/16" thick hardboard panel siding
- Vertical siding panel installation only is implied (horizontal hardboard siding was not intended to serve as bracing)
- 0.092" x 2" x 0.225" head nails at 6"oc edges and 12"oc field
- Stud spacing of 24"oc maximum (implied)

Minimum Interior Finish (inside face of braced wall)

- ½" Gypsum wall board
- Vertical or horizontal unblocked installation
- 8"oc nail spacing (see Method 5 GWB for fastener sizes) or alternatively pairs of nails at 12"oc; or 12"oc screw spacing for 24"oc stud spacing or 16"oc screw

[4] For gypsum sheathing, IRC Table R602.3(1) requires a 4"oc edge and 8"oc field fastener spacing, but the requirements in IRC Section R602.10.3 for Method 5 state a minimum 7"oc edge nail spacing for both GWB and gypsum sheathing when used as bracing. In the 1995 CABO when gypsum sheathing and GWB were first added as a bracing method, it was clear that the gypsum sheathing nailing schedule of 4"oc edges and 8"oc field were to be used for both GWB (interior panels) and gypsum sheathing (exterior panels). This requires correction in the IRC code. See later evaluation of Method 5 bracing strength.

spacing for 24”oc stud spacing (minimum #6 drywall screw implied); fastener spacing is permitted to be increased 4” to 8” if adhesive used.

PART 2: Review and Evaluation of Relevant Wall Bracing Test Data

The literature was surveyed and reviewed for test data relevant to wall bracing methods currently used in the IRC. This data is summarized and reported in tabular form in Appendix A. Approximately 25 reports were reviewed addressing as many as 100 different tests of wall assemblies (see Appendix A). Test conditions varied by test method, degree of restraint applied, boundary conditions, aspect ratio of wall segments, and spacing of framing members, and many other factors. However, an effort has been made to reconcile these differences toward the goal of establishing characteristic strength values and nominal allowable design values for the IRC bracing methods. In addition, several inconsistencies were found in the IRC bracing installation requirements and are noted. Recommendations are made as appropriate.

The primary intended use of this evaluation is for wind bracing where ultimate strength of the bracing methods is of primary concern and a customary safety factor of 2 applied to the ultimate strength values will sufficiently control stiffness concerns at nominal design loading such that serviceability concerns are implicitly satisfied (e.g., drift of the wall or structure will be less than a code-accepted limit of H/200 at design load). Therefore, in the derivation of recommended allowable design values a safety factor of 2 was applied for all bracing methods. This is also consistent with the factor used to develop the seismic bracing amounts currently in the IRC.

For seismic design applications, additional considerations may be required in relation to control of drift and, more importantly, differences in seismic response modification factors that should be applied to the various bracing methods. Currently, relative differences in seismic response modifiers for the various IRC bracing methods are not adequately defined in building codes and standards. In addition, cyclic test data on various bracing methods represented in the IRC is becoming increasingly available and may impact the basis of resistance properties for seismic bracing.

In general, the life-safety performance of residential construction has been adequate when structures have been built in accordance with bracing methods and amounts currently prescribed in the IRC. For example, there were no known collapses (due to inadequate bracing) of single family homes that had bracing consistent with current requirements in the IRC (which have been reanalyzed and increased relative to prior model residential codes, i.e., CABO and the HUD MPS). However, for homes compliant with current IRC bracing provisions for Portland cement stucco bracing, about 50% experienced cracking of stucco and interior finishes in this 300-year return period event. One statistical study of the performance of a representative sample of homes has shown that further increase to bracing comes with severely diminished returns in reducing damage (e.g., doubling the bracing amount would only reduce the average crack damage state frequency from 50% to 45% of the homes in an event like the Northridge earthquake). Similar trends probably exist for other bracing methods and wall assemblies, whether engineered or conventionally constructed. Such considerations should guide and constrain future decisions related to IRC bracing requirements for seismic performance. It is recognized that the issues and needs involved will not be easily resolved and require judgment and careful consideration of laboratory, analytical, and experiential evidences.

With that said, the findings from the various sources of test data are presented in detail for each of the IRC bracing methods in the sections that follow. Again, the focus in this effort is toward wind bracing, not seismic.

Method 1 Bracing

The following analysis of the shear strength of a Method 1 brace per the IRC provisions in R602.10.3 is based on the data in Appendix A and references #1, #2, #7, #8, #10, and #12 as listed in the appendix. Because the test data includes results from fully-restrained and unrestrained test conditions, they are treated separately below and then evaluated in regard to establishing an adequate allowable design value that accounts for a reasonable degree of partial restraint to overturning that would be experienced in actual building construction.

- Fully-restrained Test Data (ASTM E72 or similar)

The lowest ultimate shear value in Appendix A was 3,560 lbs for 8'x8' wall (from Ref #1) and it applies to 24"oc Hem-fir framing, No2 spruce 1x4 at 45^{o}, with ½" GWB fastened 8"oc on opposite face. The highest value for similar construction conditions was 4,920 lbs for 8'x8' wall with 16"oc studs (also from Ref #1). For other wall construction and brace installation conditions, the value can be much higher (e.g., up to 5,667 lbs – see Ref #2 of Appendix A for example)

The above tests included GWB interior finish. A 1x4 brace alone in various tests shows about 3,200 lbs average (+/- 1,000 lbs) depending on species and other conditions of assembly. One test (Ref #10 in Appendix A) gave a similar value for each of two 63^{o} angled let-in braces in a horizontal board sheathed wall when separate test value for board sheathing alone was subtracted. In tension, one test showed 1,900 lbs ultimate shear capacity (see Ref #7 in Appendix A).

Based on tests of similar walls with GWB only (addressed later), with 1x4 brace only, and with both combined, it appears that for additive purposes the GWB provides about 250 plf (ultimate) and the brace provides about 1,500 lbs (ultimate) when combined. Thus, as a representative fully-restrained 1x4 Method 1 ultimate shear strength value (including ½" GWB interior finish) can be determined as follows: 250 plf x 8 ft + 1,500 lbs/brace = 3,500 lbs per Method 1 brace (ultimate).

- Unrestrained Shear Test Data (ASTM E564)

Very few tests of unrestrained let-in braces were found in the literature in Appendix A. For the brace alone and minimal framing (e.g., 24"oc SPF studs in 8'x8' wall with single top and bottom plates and 2-8d common nails for brace attachment), the unrestrained braced frame provided about 600 lbs in total shear resistance (see Ref #8 in Appendix A). However, for the same brace and framing when combined with ½" GWB with fasteners at 8"oc (also identical conditions to that above in the fully-restrained tests), the brace value in compression load direction was 1,825 lbs (COV = 5%) and 1,633 lbs (COV = 9%) in tension. Thus, a reasonable unrestrained Method 1 brace value (with GWB interior finish) is 1,600 lbs per brace panel (ultimate).

- Allowable Shear Value Recommendation

There was no test data found to help ascertain the effect of partial restraint (between unrestrained and fully-restrained test conditions) on the ultimate shear capacity of a Method 1 brace panel. Furthermore, it is unclear to what degree restraint is provided in actual end use and how much this varies. But, let-in bracing has been used as a successful bracing practice within the confines of lower hazard conditions and limited building size (e.g., one and two story house construction). Therefore, it is necessary to provide a nominal design value that considers the potential impact of partial restraint as well as a customary safety margin. Based on traditional housing design practice a safety margin of 2 is generally considered adequate and, in comparison to other accepted design safety margins (such as for steel strap bracing used in commercial structures with a safety factor of 1.67 relative to yield or about 1.9 relative to rupture; or 1.67 for overall building overturning stability), it could be considered moderately conservative. Furthermore, the variance (within test repetitions) was reasonably low for all bracing methods (e.g., COV << 10%).

To account for the effects of partial restraint that might occur in an actual building construction some reduction of the fully-restrained test value (or increase of the unrestrained test value) is necessary. For Method 3 wood structural panel bracing in the IRC, a reduction factor of about 0.9 was applied to fully restrained test values to correspond with a minimum degree of corner restraint provided by a 2-foot corner segment (without consideration of any restraint provided by net dead load that may be present in an actual building under load) – see Ref #17 in Appendix A. Testing in Canada (Forintek Labs) indicates that dead load on walls can have at least an equivalent restraining effect on walls as the corner restraint used as a basis in Ref #17 in Appendix A. For the purpose of Method 1 bracing, a more conservative partial-restraint reduction factor of 0.8 will be used (which provides a value associated with a degree of partial restraint approximately in the middle between the fully-restrained and unrestrained shear test data). <u>Thus, an allowable design value for Method 1 let-in bracing (including interior finish) is as follows: 0.8 x 3,500 lbs / 2 = 1,400 lbs per Method 1 brace panel (allowable design value).</u>

The above nominal allowable design value may be used with the lowest bound wall framing practice as permitted in the IRC (e.g., 24"oc framing, SPF studs, and minimum interior finish of ½" GWB). However, this value is predicated on the use of 2-8d common nails for the brace attachment to framing. Therefore, the current IRC fastening requirement for Method 1 braces should be revised to require 2-8d common nails and/or

3-8d pneumatic nails (0.113" x 2-1/2") as currently only 2-8d pneumatic nails are specified. All of the available test data is based on 8d common or 10d common nails for the brace connection (although only test data with 2-8d common nails in the braces were considered above). In addition, the IRC requirements for Method 1 braces should specify a minimum species and grade for the 1x4 brace (a minimum No1 Spruce is recommended even though the above value is based on older test data using No2 spruce).

It must be realized that these bracing values are considered as nominal values and that they do not consider the remainder of a wall line or whole building that may not contain a Method 1 brace (or other brace type), but which provides a significant additional contribution to lateral resistance of the overall building. This additional resistance can not easily be accounted for in a prescriptive code format and with current design tools available to determine whole-building lateral strength of light-frame structures with conventional framing practices and details. In fact, design data for let-in bracing does not exist in any U.S. building code or design standard and, furthermore, these standards do not provide a design method that accounts for partial restraint conditions representative of shear walls or wall bracing in conventional residential construction. Therefore, current codified engineering principles and data are somewhat defective or lacking in providing suitable guidance for efficient evaluation of conventional light-frame wood construction.

Method 2 Bracing

Only one source was found in the literature regarding shear wall test data for diagonal board sheathed walls (see Appendix A, Ref #10). For 1x diagonal board sheathing with 2-8d per stud/plate bearing on a 2x4@16"oc framing of No1 Common SYP and fully restrained ultimate unit shear value of 1,435 plf was attained. However, prior to using this data for the purpose of defining a characteristic ultimate shear value for Method 2 bracing as defined in the IRC, some adjustments are necessary. These adjustments include:

> Nail size adjustment factor (based on NDS 2005):
> 8d pneumatic (0.113") / 8d common (0.131") = 75 lbs/ 101 lbs = 0.74
>
> Sheathing thickness adjustment factor (based on NDS 2005):
> 5/8" vs. 1" = 66 lbs / 75 lbs = 0.88
>
> Framing lumber density adjustment (based on NDS 2005):
> SPF / SP = 60 lbs / 66 lbs = 0.91
>
> Stud spacing adjustment factor:
> 16"oc / 24"oc = 0.67
> Note that this adjustment is conservative because strength is based predominantly on connections of boards to top and bottom plates, not the studs although this is somewhat depending on load direction relative to angle of boards.

Therefore, a characteristic fully-restrained ultimate shear strength value for Method 2 bracing is determined as follows: 0.74 x 0.88 x 0.91 x 0.67 x 1,435 plf = 570 plf. To this value, an ultimate shear value for GWB interior finish must be included and 250 plf is recommend as used also for Method 1 bracing above. Because a condition of partial restraint will occur in actual building construction and because board sheathing is similar to Method 1 in the brace mechanics involved, a partial restraint factor of 0.8 is also recommended for board sheathing. As before, a safety factor of 2 will be used. Thus, an allowable design value for Method 2 bracing per the IRC is determined as follows: 0.8 x (570 plf + 250 plf) / 2 = 330 plf.

Method 3 Bracing

Many tests have been conducted on wood structural panels (see Appendix A). Various design values are also published in building codes. However, these design values are predicated on engineering a fully-restrained load path for the shear walls. In conventional construction, a load path exists to the extent of creating a "partially-restrained" load path for shear wall or braced panel restraint. Based on work done in the IRC as previously described, a partial restraint condition for Method 3 bracing was based on testing of a 8' x 12' wall restrained by a minimum 2' corner return in a cyclic test methodology (see Appendix A, Ref#17 as well as other studies that subsequently investigated the performance of corner restrained wall systems in many variations of wall construction). Therefore, a partially-restrained ultimate unit shear value for Method 3 bracing has been established at 634 plf for seismic bracing (based on 7/16"OSB sheathing with 8d common nails at 6"oc edges and 12"oc field with ½" GWB on the interior with a 7"oc edge and 10"oc field nail pattern and SPF framing lumber). For the same wall construction (but fully restrained and also cyclically loaded), the ultimate unit shear was 693 plf. Thus, a 2-foot corner provided restraint 90% as effective as a fully-restrained wall. Using a customary safety factor of 2, a nominal allowable design value for Method 3 bracing (partially restrained) is 634 plf / 2 = 315 plf. This is the value that was used to determine seismic bracing amounts in the IRC (Table R602.10.1) for Method 3 and R602.10.5.1 (continuous structural sheathing) bracing amounts.

However, for wind design purposes a non-cyclic value is preferable and test data from Ref #17 (and others) in Appendix A show at least a factor of 1.2 difference between the cyclic and non-cyclic test data (which may be particularly related to the use of the SPD protocol). For the same wall construction discussed above (but fully restrained and monotonically loaded), the value was 865 plf. Therefore, for wind design and a fully-restrained condition, a characteristic ultimate shear strength of 865 plf will be used (includes standard GWB interior finish). Consequently, the allowable design value for Method 3 bracing as adjusted for partial restraint and safety factored is determined as follows: 0.9 x 865 plf / 2 = 390 plf. Based strictly on the reviewed test data, this value applies only for 8d common sheathing nails.

The general acceptability of this nominal allowable design value for Method 3 bracing in the IRC is confirmed by a number of independent studies and data, including whole building tests, as summarized in Appendix A (see data on Method 3 from References #2, #5, #6, #9, #12, and #13 through #22). In fact, this number may be considered conservative. And, subsequent testing has shown that the same wall constructions tested with 8d pneumatic (0.113" diameter) sheathing nails gave similar performance and sometimes better in terms of peak capacity (see Appendix A, Ref #18 and #19 for example where fully-restrained monotonic tests of the same wall construction above produced ultimate unit shear values of 845 plf to 934 plf in four different wall tests). Tests recently conducted by APA and reviewed in the literature also come to a similar conclusion. The reasons for this are not yet fully understood.

While the IRC currently permits the use of 6d common (or 8d pneumatic 0.113" diameter) nails with Method 3 bracing, pending code changes may change this requirement to a minimum 8d common nail for sheathing connections. Based on the test data reviewed in Appendix A, such a change could be considered to be within the "noise" of variance in wall test data even within a common wall type and may not have a significant impact and, therefore, may be an unnecessary change to what has become a standard practice (e.g., use of 8d pneumatic 0.113" diameter nails for sheathing connections). For the purpose of continuing the use of this standard sheathing nail, the test data of Appendix A was reviewed and a value of 470 plf applied to 7/16" OSB sheathing and SPF studs with 6d common or 8d pneumatic (0.113" x 2-1/2) nails at 6"oc on edges and 12"oc in the field without GWB interior finish (see Appendix A, Ref #20). To adjust to 3/8" thick sheathing, nail value ratios from the NDS yield the following: 50 lbs / 52 lbs x 470 plf = 0.96 x 470 plf = 451 plf. To include a standard ½" GWB interior finish, the value is increased as follows based on the reviewed test data for walls with and without GWB interior finish: 451 plf + 250 plf = 701 plf. This value is reasonably consistent and conservative in comparison to a nearly identical wall construction in a whole building test resulting in an average net unit shear value of 771 lbs (or roughly 710 plf if the 3/8" wood structural panel shear contribution is adjusted to SPF framing lumber from radiata pine) even though the GWB fastening was at 12"oc on studs and 16"oc on plates – see data from reference #22 in Appendix A. Therefore, the following allowable design value for Method 3 bracing with minimum 3/8" wood structural panels and 0.113"x2-1/2" sheathing nails at 6"oc edges and 12"oc field is determined as follows: 0.9 x 710 plf / 2 = 320 plf.

Method 4 Bracing

Several studies have investigated the racking performance of fiberboard sheathing (see Appendix A and references #1, #3, #4, #5, and #7). For fully-restrained walls with typical GWB finish on the interior face, the ultimate shear value ranges from about 570 plf (24"oc SPF framing with 4"oc edge nailing) to 730 plf (16"oc DF framing with 4"oc edge nailing). Higher values are achievable depending on framing and fastening conditions. The data seems to vary predictably or as expected with differences in assembly conditions. For the assembly conditions for Method 4 bracing and GWB interior finishes in the IRC, the characteristic ultimate shear value for Method 4 bracing is about 730 plf (see data from Ref #1 and #5). However, this value is for a 4" inch edge nail spacing. Tests of Method 4 bracing without GWB interior finish show ultimate shear values in the range of 380 plf (Ref #5) to 500 plf (Ref #7). The 500 plf value for ½" fiberboard alone is based on a 3" edge nail spacing. As before, it appears that the strength of the GWB interior finish is additive and, thus, a characteristic ultimate shear value could be determined as follows: 500 plf (fiberboard) + 250 plf (GWB) = 750 plf. Again, several data sources in Appendix A substantiate a value in this range for Method 4 bracing with interior GWB finish installed in accordance with the IRC requirements.

Note that for the same wall system (including GWB interior finish), the cyclic test value was about 515 plf (see Ref #5 in Appendix A). Furthermore, when tested in an unrestrained condition, the value dropped to 170 plf (4'x8' wall panel test without interior finish) based again on Ref #5 in Appendix A. This effect of restraint is not dissimilar from that observed in the test data for Method 3 bracing discussed above. The drop in ultimate shear value relative to single direction monotonic testing of fully-restrained walls was also similar to that observed with similar Method 3 walls due to degradation of the GWB caused by cyclic loading.

To determine a design value for Method 4 bracing (with interior GWB) per the IRC, a safety factor of 2 is again recommended to be consistent with traditional practice and the derivation of current bracing amounts in the IRC for seismic resistance. Also, a partial restraint reduction factor of 0.9 is recommended given similarities between Method 4 and Method 3 bracing (see discussion above on Method 3 bracing with respect to partial restraint of wall bracing or shear wall assemblies). Thus, an allowable design value for Method 4 bracing (with GWB interior finish) is determined as follows based on this review of the available data: 0.9 x 750 plf /2 = 340 plf.

Method 5 Bracing

A number of sources of data were found for various applications of GWB (interior finish panels) and gypsum sheathing (exterior sheathing panels). The data are summarized in Appendix A (see references #1, #2, #5, #8, #10, and #13). The data are evaluated separately below for two purposes: (1) to determine characteristic shear values for Method 5 bracing per the IRC and (2) to characterize shear values for standard GWB interior finish per the IRC.

Exterior Gypsum Sheathing (exterior braced walls)

For Method 5 bracing using exterior gypsum sheathing (4"oc edge and 8"oc field fastening) with ½" GWB on the interior face (8"oc fastener spacing), the data indicate an ultimate shear value of 665 plf to 775 plf for fully-restrained test conditions with 24"oc and 16"oc, respectively, studs of Western Hemlock (see Appendix A, reference #1). This also agrees closely with separate testing of these facings whereby ultimate shear values of 308 plf (GWB finish) and 487 plf (gypsum sheathing) were reported for 16"oc framing (see Ref #2 data in Appendix A). Thus, it appears that (as one would expect) the values are additive (e.g., 308 plf + 487 plf = 795 plf which is similar to the 775 plf value found in Ref #1 for the two facings combined; the higher result may be due to the use of higher density framing members in Ref #2). Thus, for Method 5 exterior gypsum sheathing a representative ultimate shear value (fully-restrained test condition) is 665 plf which gives allowance for the use of 24"oc framing as permitted in the IRC for Method 5. This representative value could be increased to 775 plf if Method 5 exterior gypsum sheathing bracing is restricted to 16"oc framing. As with the bracing methods evaluated above, these values include the application of a standard ½" GWB interior finish.

In keeping with the treatment of previous bracing methods, a nominal allowable design value must consider a safety factor as well as effects of partial restraint. A safety factor of 2 is used again here for consistency. Unrestrained shear test data for gypsum sheathing was not found, however, some unrestrained shear tests of GWB sheathing were found in the literature (see Appendix A, references #5). The reduction in ultimate shear strength relative to the fully-restrained condition was not dissimilar to that seen and discussed earlier for Method 1 and Method 3 and Method 4 bracing. Therefore, partial-restraint reduction factor of 0.9 is recommended. Thus, an allowable design value for Method 5 bracing with exterior gypsum sheathing (with standard ½" GWB interior finish) is determined as follows: 0.9 x 665 plf / 2 = 300 plf. For reasons stated above, this value could be increased to 350 plf if stud spacing is restricted to a maximum of 16"oc instead of 24"oc as currently permitted for Method 5 bracing in the IRC.

Interior GWB panel bracing (interior walls)

The use of GWB as a bracing method has only recently been added to residential codes (sometime after the 1995 CABO code) while gypsum sheathing has existed as a "structural sheathing" for some longer time. Unfortunately, when GWB was added as a bracing option, the maximum fastener spacing was given as 7"oc which is not comparable to the 4"oc edge and 8"oc field fastening that had been (and still is) required for exterior gypsum sheathing in Table R602.3.1 of the IRC. This creates an internal inconsistency within the requirements and gypsum panel options for Method 5 bracing in the IRC. Therefore, a characteristic shear value for GWB will be developed considering both a 4"oc edge fastening as well as an GWB attachment consistent with interior finish requirements (e.g., 8" maximum edge nail spacing).

Several tests of GWB braced wall assemblies were found in the literature (see Appendix A and references #2, #5, #8, and #13. Test data for interior lath and plaster finishes were also found in the literature (see reference #10 in Appendix A), but it is not considered here. It is noted in the historic literature on housing construction that such an interior finish (wood lath and plaster) is generally considered to provide adequate bracing without separate addition of bracing elements to a home (e.g., ultimate shear value was 814 plf for a fully-restrained shear wall test).

Several references in Appendix A give an ultimate shear value of about 250 plf for ½" GWB with 7"oc edge and 16"oc field nailing and this is only modestly reduced to 210 plf when tested cyclically. Increasing the field nailing to 7"oc appears to have only a minor increase to the shear capacity (e.g., within the variance of normal test results). These values are for fully restrained test conditions. When unrestrained, the shear value is reduced to about one-half the fully-restrained test value. This behavior is similar to that discussed previous for other bracing methods. Test of walls with GWB on both sides (at 8"oc edge and 8"oc field) give ultimate shear values of 500 plf to 538 plf for 24"oc and 16"oc framing, respectively. Similar values were achieved also with the use of adhesive and a wider fastener spacing (e.g., 16”oc edges). Thus, it appears that for a 7”oc edge fastening with up to 16”oc field fastening or with 8”oc edge fastening with 8”oc field fastening, a reasonable ultimate shear value for ½” GWB is about 250 plf. However, this is substantially less than other bracing methods, even when considered as a two-sided bracing method (e.g., applied to both sides of wall gives about 500 plf ultimate shear resistance). If instead the nailing pattern on at least one face of such a wall is increased to 4”oc edge and 8”oc field then the ultimate shear is essentially identical to an Method 5 wall construction with exterior gypsum sheathing on one side and GWB on the other (see above).

The following characteristic ultimate shear values and allowable design values (accounting for partial restraint and safety factoring as before) are recommended for variations in the application of Method 5 bracing in the IRC (although the fastener types and sizes are the same) for braced wall constructions with maximum stud spacing of 24”oc:

<u>Two-sided Applications</u>

- GWB (4”/8” fastening per gypsum sheathing) + GWB (8”/8” fastening per finish)[5]

Ultimate shear value = 415 plf + 250 plf = 665 plf

> The value of 415 plf is less than that reported in the literature (see Ref #2 Appendix A for example), but it facilitates an additive approach that results in a total shear value for the construction that does generally agree with the test data in Appendix A and allows consistency with the treatment of exterior gypsum sheathing as described above.

Allowable design value = 0.9 x 665 plf / 2 = 300 plf

> The above value applies to framing at 24”oc. If restricted to 16”oc framing, the value can be increased to 330 plf – see discussion above regarding exterior gypsum sheathing.

- GWB (8”/8”) + GWB (8”/8”) – a standard interior partition wall

Ultimate shear value = 250 plf + 250 plf = 500 plf (based on data as discussed above)
Allowable design value = 0.9 x 500 plf / 2 = 220 plf

- GWB (4”/8”) + GWB (4”/8”)[5]

Ultimate shear value = 415plf + 415 plf = 830 plf
Allowable design value = 0.9 x 830 plf / 2 = 370 plf

<u>One-sided Applications (opposite wall face is open or has non-structural sheathing or siding</u>

- GWB (4”/8” fastening per gypsum sheathing)[5]

Ultimate shear value = 415 plf
Allowable design value = 0.9 x 415 plf / 2 = 190 plf

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[5] See previous footnote 4. Prior to the IRC, the CABO 1995 code required both gypsum sheathing and GWB to be fastened with a 4”/8” schedule, not the 7” fastener spacing currently in the IRC for Method 5.

- GWB (8”/8” per interior finish)
Ultimate shear value = 250 plf
Allowable design value = 0.9 x 250 plf / 2 = 110 plf

Method 6 Bracing

No literature was identified with regard to particle board ultimate shear strength and other wall bracing properties. In addition, fastening requirements for this sheathing product were recently stricken from Table R602.3(1) of the IRC, but existed in the prior CABO code. It is unclear why this was done. However, it leaves a gap in the IRC as to appropriate fastening of particle board sheathing panels. In the CABO code, the fastening requirement was identical to wood structural panels (e.g., 6d common nail at 6”oc edges and 12”oc field). It is presumable that the bracing value for Method 6 is intended to be similar to that of Method 3 bracing. In the future, connection requirements should be re-instated in the IRC for particle board sheathing installation, or the bracing method should be removed from the code as it may be used rarely (if at all) for modern site-built housing construction. For the purposes of this study, however, it will be treated as Method 3 bracing as was apparently the intention in codes pre-dating the IRC.

Method 7 Bracing

A relatively few reports address shear strength of Portland cement stucco wall bracing (see Appendix A, references #23 and #24). In generally, the data is scattered over a range from about 500 plf to over 1,500 plf for utltimate shear strength. Early test data seemed to suggest that stapled connection of the metal lath or wire mesh provided the higher values. But, some of the latest values (based on cyclic testing of partially restrained walls with openings) using standard furring nails resulted in a net ultimate unit shear value of about 1,700 plf on average (including standard GWB interior finish). This value is based on dividing the maximum load by the length of the wall less the widths of all openings. And, half of this net length included 2’-wide (4:1) aspect ratio segments. Thus, Portland cement stucco appears to be one of the strongest bracing methods recognized in the IRC, even though it is brittle (cracks) like GWB when displaced beyond about 0.2% drift, it is reinforced with metal lath or wire. Oddly, published design values in model codes are generally less than 200 plf. For the purpose of IRC bracing Method 7, a nominal ultimate value of 750 plf + 250 plf = 1000 plf is suggested (the 250 plf is for GWB interior finish). A lower value of 500 plf (stucco only) was not used for reasons given with data in Appendix A for reference #24. Even though the test data included conditions of partial restraint (with 450 plf of dead load as per Ref #23), it is likely that for wind design dead load may be absent and partial restraint will be provided by a lesser means such as corner returns only. Therefore, a partial restraint factor of 0.9 will be applied as done before for the other IRC bracing methods (as much as a matter of consistency rather than precision in this case). Finally, a customary safety factor of 2 will be used as applied previously for other bracing methods. Thus, an allowable design value for Method 7 bracing is computed as follows: 0.9 x 1000 plf / 2 = 450 plf.

Method 8 Bracing

A few tests of hardboard panel siding bracing were found in one reference (see Appendix A, reference #8). For minimum 3/8" thick hardboard with SPF studs spaced at 16"oc and fastening with 0.099" x 2" nails at 4"oc edges and 8"oc field, the ultimate shear strength is about 730 plf (including ½" Gypsum interior finish with standard fastening). The ultimate shear value for hardboard panel siding alone is about 540 plf (based on reference #5 in Appendix A, averaging cyclic and non-cyclic tests with fully restrained 4'x8' wall panels). However, the IRC permits up to 24"oc framing, specifies a slightly smaller nail diameter (e.g., 0.092"), and also uses a greater nail spacing (6"oc edges and 12"oc field). But, it also requires a greater panel thickness of 7/16". Thus, the available test data requires some correction or, alternatively, the IRC connection requirements should be revised to agree with the tests data and to allow a greater shear strength value. The latter is suggested because the strength adjustments necessary to agree with the current IRC installation requirements would practically halve the ultimate shear value for hardboard siding panel bracing (e.g., 540 plf x ½ = 270 plf). Such a reduction would create a low allowable design value of about 0.9 x (270 plf + 250 plf) / 2 = 221 plf using a safety factor and partial restraint adjustment and including 250 plf for GWB interior finish consistent with the evaluation of previous bracing methods. Thus, with connections consistent with the reviewed test data, a suggested allowable design value for Method 8 is 0.9 x 730 plf / 2 = 330 plf which is similar to the values determined previously for Methods 2, 3, and 4.

PART 3: Summary & Recommendations

- Shear Values for IRC Wall Bracing Methods

Based on a review and evaluation of the available test data as described in this report, Table 1 summarizes the findings and recommendations in terms of shear strength values for the various IRC bracing methods.

TABLE 1
IRC Bracing Methods and Shear Strength Values for Wind Bracing[1]

Bracing Method	Description[2]	Characteristic Ultimate Shear Strength[3]	Allowable Shear Strength[4]	Code Nominal Comparative Values
1	1x4 let-in brace, No1 Spruce, 2-8d common (2-1/2" x 0.131") or 3-8d (2-1/2"x0.113) nails per stud and plate bearing, 45° to 60° brace angle relative to plates, studs at 24"oc max (or approved equivalent metal brace)	3,500 lbs per brace	1,400 lbs per brace	None
2	Minimum 5/8" thick diagonal boards at 45° angle relative to plates with 2-8d (2-1/2" x 0.113") nails at each stud and plate bearing, studs at 24"oc max	820 plf	330 plf	840 plf per NDS/SDPWS 2005 (unfactored and for 8d common nailing with 3-8d at boundaries)

Bracing Method	Description[2]	Characteristic Ultimate Shear Strength[3]	Allowable Shear Strength[4]	Code Nominal Comparative Values
3	Minimum 7/16" thick wood structural panel with 8d common (2-1/2" x 0.131") nails at 6"oc on all edges and 12"oc at intermediate supports, studs at 24"oc max	865 plf	390 plf	670 plf per NDS/SDPWS (unfactored)
	Minimum 3/8" thick wood structural panel with 8d (2-1/2" x 0.113") nails at 6"oc on all edges and 12"oc at intermediate supports, studs at 24"oc max	710 plf	320 plf	560 plf per NDS/SDPWS (unfactored)
4	½" or 25/32" thick structural fiberboard sheathing with nails or staples in accordance with IRC Table R602.3(1) at 3"oc along all panel edges and 6"oc at intermediate supports, studs at 16"oc max	750 plf	340 plf	645 plf per NDS/SDPWS (unfactored)
5 (both sides)	½" or 5/8" gypsum wall board or sheathing panels on both sides of wall with both sides attached in accordance with Table R602.3(1) for gypsum sheathing with fasteners at 4"oc on edges and 8"oc at intermediate supports (horizontal unblocked or vertical panel installation); studs at 24"oc max.	830 plf	350 plf	See below for "one side"
	½" or 5/8" gypsum wall board or sheathing panels on both sides of wall with one side attached in accordance with Table R602.3(1) for gypsum sheathing with fasteners at 4"oc on edges and 8"oc at intermediate supports and the other attached in accordance with Table R702.3.5 with fasteners at 8"oc on edges and maximum 16"oc at intermediate supports (horizontal unblocked or vertical panel installations); studs at 24"oc max.	665 plf	300 plf	See below for "one-side"
	½" or 5/8" gypsum wall board on both sides attached in accordance with Table R702.3.5 with fasteners at 8"oc on edges and maximum 16"oc at intermediate supports (horizontal unblocked or vertical panel installations); studs at 24"oc max.	500 plf	220 plf	See below for "one side"
5 (one side)	½" or 5/8" gypsum wall board or sheathing panels on one side of wall attached in accordance with Table R602.3(1) for gypsum sheathing with fasteners at 4"oc on edges and 8"oc at intermediate supports (horizontal unblocked or vertical panel installations); studs at 24"oc max.	415 plf	190 plf	300 to 350 plf per NDS/SDPWS (unfactored)
	½" or 5/8" gypsum wall board on one side of wall attached in accordance with Table R702.3.5 with fasteners at 8"oc on edges and maximum 16"oc at intermediate supports (horizontal unblocked or vertical panel installations); studs at 24"oc max.	250 plf	110 plf	120 to 180 plf per NDS/SDPWS (unfactored)
6	3/8" or ½" thick particle board sheathing fastened in accordance with Method 3 panels, SPF studs at 16"oc maximum	Test data not found in the reviewed literature, but original introduction in CABO code indicates intent of equivalence to Method 3		335 to 390 plf per NDS/SDPWS (unfactored)
7	Minimum ¾" thick Portland Cement stucco applied to wire mesh or expanded metal lath with fasteners in accordance with IRC R703.6 spaced at 6"oc on all framing members, SPF studs at 16"oc max.	1,000 plf	450 plf	360 plf per NDS/SPDWS (unfactored)

Bracing Method	Description[2]	Characteristic Ultimate Shear Strength[3]	Allowable Shear Strength[4]	Code Nominal Comparative Values
8	Minimum 7/16" thick hardboard panel siding (vertical installation only) fastened with minimum 2" x 0.099" nails at 4"oc edges and 8"oc at intermediate supports, SPF studs at 24"oc max.	730 plf	330 plf	None

Table Notes:

1. Values for all bracing methods, except Method 5 as described, include minimum ½" GWB interior finish on inside face installed in accordance with Table R702.3.5 of the IRC.
2. Descriptions may vary from or add to current requirements in IRC R602.10.3, but are consistent with findings in this report. Bracing method requirements in the IRC should be updated to agree with these descriptions where different.
3. The test conditions for the characteristic ultimate shear values listed vary by bracing method due to availability of data and other reasons discussed in the report:

- Method 1 (ASTM E72, non-cyclic, fully restrained)
- Method 2 (ASTM E72, non-cyclic, fully-restrained)
- Method 3 (ASTM E72 or E564, non-cyclic, fully-restrained)
- Method 4 (ASTM E72 or E564, non-cyclic, fully-restrained)
- Method 5 (ASTM E72, non-cyclic, fully-restrained)
- Method 6 (same as method 3)
- Method 7 (ASTM E72 or E564, non-cyclic, fully-restrained; also considered cyclic partially restrained test data with boundary conditions of stucco at perimeter of wall detailed to simulate continuity of the stucco cladding on a building)
- Method 8 (ASTM E564, non-cyclic, fully-restrained)
- While cyclic tests data was also considered (e.g., ASTM E2126 or similar test methods) and is included in the data of Appendix A, it was not emphasized in establishing design values in Table 1.

4. Nominal allowable design shear value = (partial restraint factor) x (characteristic ultimate shear strength) / (safety factor) – refer to text for derivations for each bracing method. Partial restraint factors varied from 0.8 to 0.9 where 0.8 was used for non-plate-type bracing methods (i.e., Method 1 and Method 2) and a value of 0.9 was used for all others. A safety factor of 2 was used in all cases.

- Application of Design Values

Taken in the context of their derivation, the recommended design shear values in Table 1 are appropriate to use in a traditional manner of analyzing the shear strength of a conventional home or wall line by summing the length of full-height braced wall panel sections and multiplying that length by the allowable design values in Table 1. Panels which do not comply with the minimum length requirements (aspect ratios) in the IRC are not considered, nor are segments of wall that exist between prescribed braced wall panels. Furthermore, it is assumed that additional forces through wall bracing assemblies related to wind uplift from the roof are adequately resolved through load path requirements currently existing in the IRC. Experience with conventional construction in low-hazard wind regions tends to confirm this assumption on a broad scale, even though damage from extreme and rare events does occur on an annual basis in low-hazard wind regions due to the millions of homes exposed to what is considered to be an acceptably low risk for any given home.

The above-described design methodology to enable use of the bracing values in Table 1 is a necessary simplification of the true design problem and it causes some conservative bias to occur in any engineering analysis as well as prescriptive bracing requirements based on such an analysis. Thus, it may be appropriate to consider systemic biases relative to the manner in which an analysis is performed. For example, a cursory review of whole building test data in general suggests a minimum conservative bias of 10% and typically as high as 40% or more for completed buildings with all structural and non-structural components installed. This bias depends on the configuration of a given building as well as what is or is not considered in a given engineering analysis. The careful evaluation of whole building lateral resisting system test data to characterize systemic biases in analysis of lateral resistance of light-frame wood homes is beyond the scope of this study. It is only mentioned here because it is a significant consideration and a well-documented concern when attempting to reconcile the results of an engineering analysis with past successful conventional construction practices (or in the use of engineering analyses to efficiently correct deficiencies in past practices).

In the end, any practical and rational engineering analysis approach must be in reasonable agreement with (i.e., calibrate to) what as "worked" successfully in the past and also effectively discriminate against practices that have clearly not performed adequately in actual experience. Ultimately, this type of practical judgment underlies the development and maintenance of all codified engineering methodologies and prescriptive construction practices, no matter how sophisticated or simplistic in substance and format.

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