

Shear wall Design in Residential Construction: A Comparison of Methods

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Current building codes and standards for residential construction are complex and easily misunderstood when it comes to the requirements pertaining to wood shear walls that act as the lateral load resisting system. These walls fall under two categories: engineered or prescriptive in regards to design. This paper will discuss a comparison of provisions and guidelines between the IBC, IRC, NDS, and WFCM. Details will focus on the differences, limitations, and general processes necessary to conduct wood shear wall designs. The results will give designers and builders a better understanding of the complexity of shear wall code provisions and how to go about designing and constructing shear walls through clarifying code intent. Other propriety systems or uncommon engineering-critical solutions will also be discussed and how to approach those projects.

Introduction

The architectural style common in today's residences may be characterized by highly perforated and offset wall surfaces with the inclusion of a large opening to accommodate garage doors at the front of the residence (McMullin and Merrick 2002; Barnes 2006). Complicating this design style is the interior spaces that are frequently open, both horizontally and vertically over one- and two-story spaces resulting in reduced building stiffness of the lateral system (Minor 2002). Protecting this investment from natural disasters such as high wind and earthquakes is an important task for builders/engineers. The performance of the home under such events depends largely on the performance the main lateral force resisting system (Ni et al. 2010; Shirazi and Pang 2012). Fortunately, wood generally performs very well during many external environmental conditions/events over the lifespan of the project, thus its applicability and usage for 80% to 90% of all residential structures in the United States. The lateral load resistance of light wood-frame buildings is generally provided by sheathed braced walls, often more commonly called shear walls (Ni et al. 2012).

The style of modern architectural homes is often in opposition to many code prescribed requirements that permit the average builder without an engineering licensure to design them. Furthermore, current building codes and standards for residential construction are complex and easily misunderstood when it comes to the requirements pertaining to wood lateral systems. Whether they are engineered or prescriptive, the design intent is often misunderstood which has the potential to result in improper construction of walls that can lead to poor performance and failure (both aesthetically and structurally).

This paper was part of a research project whose main research goal was a comprehensive review of the current available opportunities for shear walls in residential homes. Herein, this paper provides an examination of the current International Residential Code (IRC), National Design Specification for Wood Construction (NDS), International Building Code (IBC), and American Wood Council Wood Frame Construction Manual (WFCM) for One- and Two-Family Dwellings. The depth here will provide discussions and relative code provisions for wood shear wall design.

Residential Wall Types and Configurations

Most residential and light commercial construction is based on a “box” design. Three types of loads can be imposed on walls for such designs. First are out-of-plane loads (i.e., perpendicular to the wall). These loads result primarily from wind but can also result from seismic activity. All exterior walls are exposed to these out-of-plane forces. Secondly, vertical loads (i.e., axial loads) are transferred into some walls from the roof or upper-story walls. The vertical loads can be downward-acting gravity loads that result from the weight of the structure and occupancy or upward-acting (uplift) loads from wind or seismic events. Lastly are in-plane horizontal loads (i.e., parallel to the wall). These loads typically result from lateral forces imposed on building. For this last type of loading the walls that are needed to resist these loads are called “shear walls” or “shear panels” or “braced walls.” Figure 1 shows a hierarchy of factors relating to different aspects of a wall system that can affect performance. It will be observable later that many of these factors appear in the limitations and code provisions.

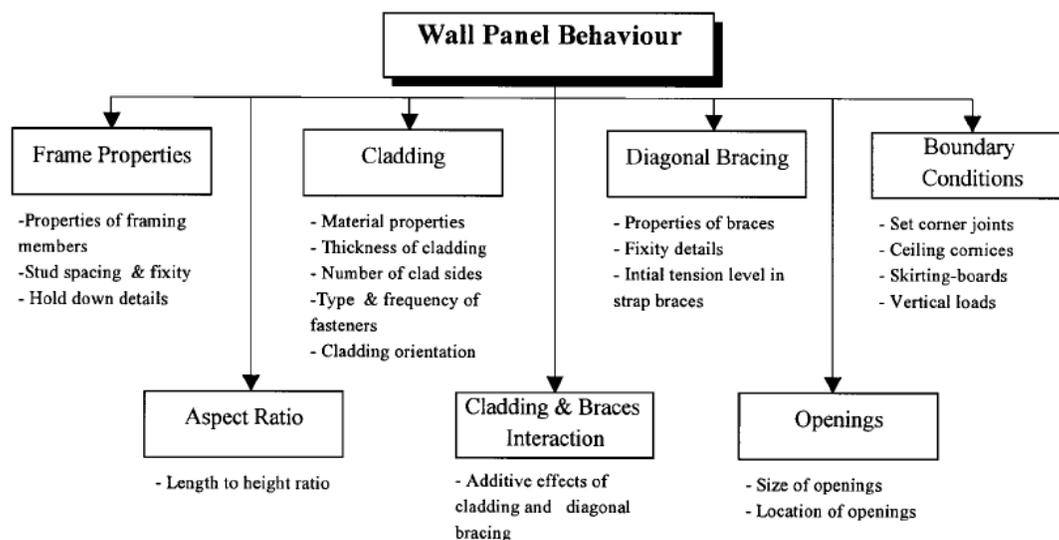


Figure 1: Factors Affecting Lateral Behavior of Shear Walls

Lateral force resistance to wind and seismic loads in wood frame structures is provided by shear walls in the majority of homes (Shirazi and Pang 2012). In this configuration, shear walls resist forces by allowing the sheathing panel to rotate, essentially racking the wall horizontally in shear (Yeh et al. 2009). In box design, horizontal diaphragms

(e.g., roof and floor systems) work in conjunction with vertical shear walls to support gravity loads, resist lateral loads, and provide structural stability. The required minimum length of a shear wall panel generally ranges from 4' to 8' of wall with no openings.

For the design of shear walls with openings, the designer has the option of using the segmented, perforated, or force transfer around openings classifications. Of the classifications analyzing shear walls discussed two are the most often adopted. Segmented shear walls are full-height, fully sheathed wall segments that function independently to resist lateral loads. Perforated shear walls contain framed openings for windows and doors. Perforated shear walls rely upon continuous structural elements over windows and door openings to make the shear wall function as a single unit. These elements are called “drag struts.” Generally, greater lengths of perforated shear walls are needed to resist lateral loads than segmented shear walls. Also, in perforated shear walls, more attention in the detailing and design is needed above doors and windows, where framing functions as drag struts. The benefit of perforated shear walls is that they only need to be anchored at their ends while the ends of each segment of a segmented shear wall need to be anchored. There are 16 methods in the IRC (IRC Table R602.10.4) to select from for lateral resistance options as listed here:

- Portal Frame with Hold-downs
- Portal Frame at Garage
- Continuously Sheathed Wood Structural Panel
- Continuously Sheathed Wood Structural Panel adjacent to Garage Openings
- Continuously Sheathed Portal Frame
- Continuously Sheathed Structural Fiberboard
- Let-in Bracing
- Diagonal Wood Boards
- Wood Structural Panel
- Wood Structural Panel with Stone or Masonry Veneer
- Structural Fiberboard Sheathing
- Gypsum Board
- Particleboard Sheathing
- Portland Cement Plaster
- Hardboard Panel Siding
- Alternate Braced Wall

Because of the relative complexity of choosing and analyzing braced-wall sections per the IRC, the Engineered Wood Association (APA) published *A Guide to the IRC Wood Wall Bracing Provisions* (APA 2009). This publication walks the designer through the basic wall provisions in a step-by-step manner and greatly simplifies applying these provisions in a residential structure design. Shear walls may also be constructed with masonry, concrete, ICF (Insulated Concrete Forms) and with structural insulated panels (typically referred to as SIP). SIPs consist of wood structural panels which sandwich a rigid insulation core, which is typically polystyrene (although urethane is also used). Engineered homes with large openings may use moment frames to resist lateral loads in addition to shear walls. Alternatives to moment frames can include:

- Move or re-size window or door opening to meet the wider braced-wall requirements.
- Hire a design professional to provide an engineered solution.

- Use a code listed shear wall product that meets the intent of the code while providing a narrow wall solution such as a Simpson Strong-Tie® Wood Strong-Wall® or Steel Strong-Wall®.

Building Codes and Standards

To design shear walls (both prescriptive and engineered), various codes and specifications designers must take into account when designing Wood Framed (WF) systems. To design a WF residential structure, the design professional must be familiar with the following codes and design standards (Memari et al. 2014):

- International Residential Code (IRC) (ICC 2015b)
- International Building Code (IBC) (ICC 2015a)
- American Wood Council (AWC) National Design Specification for Wood Construction (AWC 2015)
- AWC Wood Frame Construction Manual (WFCM) for One- and Two-Family Dwellings (AWC 2012)
- American Forest and Paper Association (AFPA) Special Design Provisions for Wind and Seismic (SDPWS) (AWC 2015)

The building codes give Building Officials the authority to approve alternate materials, designs and methods of construction that comply with the intent of the provisions of the code and are at least the equivalent to those prescribed in the code. It is imperative that designers of residential structures using wood framing systems become familiar with the IRC, IBC, NDS, WFCM, and SDPWS codes and standards to assure that efficient and structurally sound design solutions are achieved. Each has a unique set of design-related information but they are all compatible. It is also important that designers use the latest editions of these documents because they are continually updated with new design information based on ongoing research. When residential structures are beyond the limitations set forth by the IRC and WFCM, the design must be engineered. This could include designing connection systems for high-wind areas, tornado-prone regions, or high-seismic risk categories. The NDS provides all the requisite information for the design of these systems.

IRC

The IRC (ICC 2015) is deemed a prescriptive code for one- and two-family dwellings with no more than three stories. It also applies to townhouses with no more than three units. The IRC applies to the large majority of residential construction in the United States. The IRC provides extensive prescriptive design information in the form of tables and figures for WF construction using sawn lumber for roofs, floors, walls, and wood foundations. It also recognizes the use of engineered wood products, including prefabricated wood I-joists, glued laminated timber (glulam), and structural composite lumber (SCL) for joists, rafters, beams, and headers. But each of these “engineered” components must be designed using engineered-design procedures, as set forth in other referenced documents. The IRC also recognizes the WFCM as an alternate design standard. In addition, the IRC provides separate bracing requirements for homes which

are continuously sheathed with OSB, plywood or structural fiberboard (except seismic controlled) with masonry veneer conditions.

Exterior walls of WF construction shall be designed and constructed in accordance with the provisions of Chapter 6 in the IRC or in accordance with AF&PA's NDS. Within the IRC many tables exist that relate to design provisions for shear walls. Table 1 in this paper lists the relevant tables for designing shear walls based on main categories and topics with the appropriate code table in the IRC. Where the conditions are not within the parameters of the tables, the design is required to meet the NDS. The most relevant design tables within the IRC for shear wall sizing are R602.10.3(1), R602.10.3(3), and R602.10.5.

Table 1: Relevant Tables in the IRC for Designing Shear walls.

Category	Topic	Table Designation
Bracing methods	Applicable Methods for Shear walls	R602.10.4
Wood studs	Size, height and spacing	R602.3(5) R602.3.1
	Fastener schedule for structural members	R602.3(1-3)
Dimensions & Proportioning of Shear walls	Minimum length of braced wall panels	R602.10.5
	Braced wall line spacing	R602.10.1.3
	Minimum number of bracing units on each side of the circumscribed rectangle	R602.12.4
	Method BV-WSP wall bracing requirements	R602.10.6.5
Design Forces and Values	Bracing requirements based on wind speed	R602.10.3(1) R602.10.3(2)
	Bracing requirements based on seismic design category	R602.10.3(3) R602.10.3(4)
	Minimum hold-down forces for method ABW braced wall panels	R602.10.6.1
	Tension strap capacity required for resisting wind pressures perpendicular to method PFH, PFG and CS-PF braced wall panels	R602.10.6.4

For IRC Wind and Seismic Design Categories (SDC) A-C, braced wall panels should be installed near the ends of the braced wall line up to 12'-6" from the end. The IRC limits the total combined end distance for the outer most panels in a braced wall line to no more than 12'-6". For SDC D0-D2 the IRC states that braced wall panels may begin no more than 8'-0" from each end of the braced wall line. Panels shall be spaced no more than 25' on center along the braced wall line. It is also allowable to take up to a 4' offset and still maintain the same braced wall line. An offset is when there is a break in the wall line, for example, for a porch and front door, or a bay window. If there is more than a 4' offset, the code states that you must start a new braced wall line, which means additional braced wall panels.

Continuous sheathing methods require structural panel sheathing to be used on all sheathable surfaces on one side including areas above and below openings and gable end walls. The IRC specifies minimum wall-sheathing thickness and fastening requirements for structural panels, cellulosic fiberboard, and gypsum sheathing. Wall sheathing are be fastened directly to framing members and, when placed on the exterior side of an exterior wall, shall be capable of resisting the wind pressures. Braced walls

need to have gypsum wallboard installed on the side of the wall opposite the bracing material. An approved interior finish material with an in-plane shear resistance equivalent to gypsum board is permitted. Furthermore, gypsum wall board must be at least a 1/2 inch (12.7 mm) thick and be fastened with nails or screws. Interior finish material are not be glued in Seismic Design Categories D0, D1 and D2. All panels must be identified for grade, bond classification, and performance category by a grade mark or certificate of inspection issued by an approved agency and will conform to the requirements in the IRC.

IBC

The IBC (ICC 2015) is essentially an engineered design code, although several prescriptive tables are in the document, such as for wood shear walls and diaphragms, which are included in Chapter 23. The IBC is used when the residence exceeds the scope of the IRC. Chapter 23 provides the basic design information for wood but refers extensively to the National Design Specification (NDS) (AWC 2015) and SPDWS (AFPA 2015) standards for more extensive design information. Panels complying with ANSI/APA PRP-210 shall be permitted to use design values for Plywood Siding in the AFPA SDPWS. For species not Douglas Fir-Larch or Southern Pine, the specific gravity for species of lumber in NDS must be used instead.

The IBC permits the combination of engineered elements/systems with conventionally specified systems as long as the limits of Sections 2308.1 and 2 are met. For elements not described within the IBC, these elements or systems shall be designed in accordance with accepted engineering practice and provisions in the IBC. Within the IBC the main provisions are for walls fastened with staples and not nails. Here the IBC enforces that such designs satisfy the requirements and limitations of SDPWS. Within the IBC many tables exist that relate to design provisions to shear walls. Table 2 in this paper lists the relevant tables for designing shear walls based on main categories and topics with the appropriate code table in the IBC 2015.

Table 2: Relevant Tables in the IRC for Designing Shear walls.

Category	Topic	Table Designation
Bracing methods	Applicable Methods for Shear walls	2308.6.3(1-5)
Wood studs	Size, height and spacing	2308.5.1
	Fastener schedule for structural members	2304.10.1
Dimensions & Proportioning of Shear walls	Wall bracing requirements	2308.6.1
	Min thickness of Wall Sheathing	2308.5.11
Design Forces and Values	Allowable shear values	2306.3(1)
		2306.3(2)
		2306.3(3)

The most relevant design tables within the IBC for shear wall sizing are 2306.3(1), 2306.3(2), and 2306.3(3). The IBC has provisions for WF shear walls sheathed with gypsum board, and lath and plaster. These systems need to be designed and constructed in accordance with Section 2306.3 and are permitted to resist wind and seismic loads.

Gypsum and plaster wood framed wall assemblies are not be used to resist loads imposed by masonry or concrete walls according to IBC. Values in the IBC are for short-term loading due to wind or seismic loading.

IBC 2015 has special provisions / additional requirements for conventional wood framed construction for seismic Design Category D or E. While in the IBC 2012 these provisions were in Section 2308.12 and its subsections, the requirements for Seismic Design Category B or C are in Section 2308.11. In the 2015 version of the IBC, these provisions have been reorganized into their respected areas of lower SDC categories. Structures of conventional light-frame construction and assigned to Seismic Design Category D or E shall not exceed one story above grade plane. Spacing between interior and exterior shear wall lines cannot exceed 25 feet. The sum of lengths of braced wall panels at each braced wall line are required to conform to the required percentage of wall length necessary to be braced per braced wall line. Panel sheathing joints are to occur over studs or blocking. Sheathing needs to be fastened to studs, top and bottom plates and at panel edges occurring over blocking. Wall framing to which sheathing used for bracing is applied is permitted to be nominal 2-inch-wide or larger members. An additional requirement is that no wall sheathing cannot be attached to framing members by adhesives. Conventional light-frame construction is not to be used in irregular portions of structures assigned to Seismic Design Category D or E. Such irregular portions of structures are permitted to be designed to resist the forces to the extent such that the irregular features do not affect the performance of the conventional framing system.

NDS/SPDWS

The NDS (AWC 2015) is the primary reference for the engineered design of wood structures. In addition to setting forth the design procedures for components, such as bending members and compression members, it provides the extensive information needed for the design of connections in WF structures. The 2015 IBC references the 2015 NDS as the required design standard in those jurisdictions adopting the 2015 IBC. The supplement to the NDS provides allowable stress values for virtually all grades and sizes of sawn lumber and timbers as well as for most combinations of glulam. Design values for proprietary products, such as wood I-joists, must be obtained from the manufacturer's code evaluation reports. As shear walls function as the mechanism to resist wind and seismic forces, the Special Design Provisions for Wind and Seismic (SDPWS) Section of the NDS applies. The SPDWS (AFPA 2015) standard provides detailed information for the engineered design of structures exposed to wind and seismic loads. The SDPWS covers materials, design, and construction of members, fasteners, and assemblies. The main shear wall sections of the SDPWS are in Chapter 4. In addition to providing detailed lateral load design guidelines, the SPDWS also provides some prescriptive tables for shear walls and diaphragms similar to those in the IBC. The lateral load resisting system must be proportioned, designed, and detailed to all chapter provisions.

Tables are provided for shear walls unit (nominal) shear capacity in a combination format for wind and seismic. Column A of Tables 4.3 A, C, B and D are for seismic, while column B of Tables 4.3 A, C, B and D are for wind. In shear wall capacities, the sheathing material can be similar or dissimilar. When they are the same material the capacity of a single side of sheathing may be doubled. When the materials are different on each side of the wall, Section 4.3.3.2 states that the values are not cumulative. Instead it is 2 times the smaller value or 1 time the larger value. The larger of these two values is used. There is one exception to this and that is for wind design. If the framing is shear walls with a combination of wood structural panel, siding, or fiberboard on one side and gypsum on the other a sum may be taken for exterior walls. Unblocked walls are permitted when framed in accordance with Table 4.3.3.2 and the strength is adjusted with an unblocked factor that ranges from 0.4 to 1.0 depending on nail spacing and stud spacing. Unblocked walls however cannot exceed 16' in height.

When w/h ratios are greater than 2:1, the nominal capacities need to be adjusted by $2bs/h$. The aspect ratio factor (WSP) shall also be used $= 1.25 - 0.125h/bs$, which is applicable to shear walls with an aspect ratio greater than 2:1. A common misunderstanding of the $2bs/h$ factor is that it represents an actual reduction in unit shear capacity for high aspect ratio shear walls. The actual strength reduction associated with high aspect ratio shear walls is less severe in the new 2015 Version. The $2bs/h$ factor accounts primarily for stiffness compatibility of the high aspect ratio segment. Where $2bs/h$ is used to comply with load distribution requirements of Section 4.3.3.4.1, the strength reduction adjustments of Section 4.3.4.2 for high aspect ratio shear wall segments need not be applied.

Perforated shear wall capacities are taken as the tabulated nominal unit shear capacity multiplied by the sum of the shear wall segment lengths. An additional adjustment factor (C_o) is applied. The C_o factor can range from 0.36 to 1.0 and is dependent on percentage of full height sheathing and Max opening height. Perforated walls exceeding a 3.5:1 ratio are not permitted to use the sum of shear wall segments. Provisions for accounting for the strength contribution of high aspect ratio shear wall segments within a perforated shear wall were revised in the 2015 Version. Where a high aspect ratio for perforated shear wall segments ($h/bs > 2:1$) was considered in the calculated strength of the perforated shear wall, the shear capacity of the overall perforated shear wall requires adjustments by the $2bs/h$ factor. Because the more severe $2bs/h$ factor is used, unit shear values of high aspect ratio shear wall segments within a perforated shear wall are not required to be adjusted by the aspect ratio factors defined in Section 4.3.4.2. While this revised method will generally permit increases in design strength of perforated shear walls incorporating high aspect ratio segments, there are cases where there is little change such as perforated shear walls comprised entirely of identical high aspect ratio perforated shear wall segments

Sheathing is to be attached to members using nails or other approved fasteners. Often other approved fasteners include wood screws and adhesives. Adhesive can only be used with SDC A-C and must have a secondary system for wood structural panel shear walls. Tables 4.3 A, C, B and D make recommendations for nailing patterns (and

screws for drywall) that affect the shear strength. The SDPWS makes additional upper bounds for the limitations in the spacing of fasteners. To use Tables 4.3 A, C, B and D you need to know several values beyond if you are in wind or seismic. These include: min. nominal panel thickness, min fastener penetration, fastener type, and panel edge fastener spacing. Before you can use these tables, you need to know which table to use. Here these are based on the sheathing materials. Table 4.3A is for wood based panels, Table 4.3B is for wood panels applied over gypsum, Table 4.3C is for gypsum and Portland cement plaster only, and lastly Table 4.3D is for lumber sheathing. Tables are provided for lateral loads and withdrawal loads.

Staples are beyond the scope of the NDS, and Evaluation Service Report (ESR) 1539 (ICC Evaluation Service 2005). The International Staple, Nail, and Tool Association (ISANTA) provides the necessary design information for staples. This report also provides tables for converting the nailing schedules published in the IRC and WFCM to other equivalent types and sizes of nails.

WFCM

The WFCM (AWC 2012) is a companion document to the IRC. It is limited to one- and two-family residences having no more than three stories. WFCM has applicable limitations, which outline building dimensions and load assumptions as the WFCM provisions are intended primarily for detached one- and two-family dwellings similar to the IRC requirements. Wind provisions for sizing of wall sheathing, fastening schedules, uplift straps, shear anchorage, and shear wall lengths are included in the WFCM and are applicable for other use groups within the load limitations of the WFCM tables (Showalter et al. 2015). The WFCM provides extensive tables for floors, walls, and roofs for both the prescriptive and engineered design methods for framing using sawn lumber. Applications outside the scope of the WFCM tabulated requirements are beyond the applicability of the WFCM and must be designed in accordance with accepted engineering practice. This parallels the approach taken in Section R301.1.3 of the IRC, which permits unconventional elements of one and two-family dwellings to be designed per the IBC and NDS.

Engineering design detailed in the 2015 WFCM provides the minimum load for the purpose of establishing specific resistance requirements for buildings that meet the scope of the WFCM document. In engineering design, the wood shear walls approach is much more generic and open ended as compared prescriptive. The prescriptive approach can be broken down two ways. The first is by wall type, either segmented or perforated. The second is by wind and seismic loadings. In both cases there are limitations for when the prescriptive approach is permitted by the WFCM.

Engineering Design Approach

Engineering design is separated by wind and seismic loadings based on Section 2.4.4.2. Engineering design does not specify which walls must provide shear resistance but does state that walls parallel to the applicable load shear provide the required shear resistance at each level and that the sum of all individual walls must meet or exceed the sum of

the total collected horizontal diaphragm loads from above. Among the provisions for engineering design, there exists many tables in Chapter Two to aid the design of shear walls. Table 3 in this paper lists the most relevant tables needed for designing engineered shear walls in the WFCM.

In both wind and seismic design, the WFCM Section 2.4.4.2, describes that the total shear loads shall be calculated using tables. For wind design, tabulated values for wind are found in Tables 2.5A and 2.5B. The tables are structured in such a fashion that the value generated by the tables is the unit lateral load on the diaphragm above the level you are designing. To use the tables you need to know the following: 3-second gust mph (available range 110-195), roof pitch (0:12 to 12:12) and the roof span dimension (available dimension 24'-60' in 12' internals). Table 2.5A gives you the load for parallel to the ridge and Table 2.5B gives perpendicular to ridge. Both tables have the same necessary criteria. Other wall heights and exposure categories are permitted and are adjustable. The trend of short walls and small roof pitches gives a greater reduction of length. For different exposure categories the values in the tables need to be multiplied by adjustment factors in Section 2.1.3.1. For different wall heights, the values in the tables have to be multiplied by the following factor $(H+1)/11$.

Table 3: Relevant Tables in the WFCM for Designing Engineered Shear walls.

Category	Topic	Table
Loads	Lateral Framing Connection Loads from wind	2.1
	Uplift Connection Loads from wind	2.2A
	Wind load loads	2.5A 2.5B
	Lateral Loads from Seismic	2.6

For seismic design, Table 2.6 gives the lateral loads. Tabulated values do not specify a numerical load like the wind tables do. Here, the story shear is based on an equation for each level and the seismic weight of the floor. To be able to calculate the values you need to know: floor weight, wall weight (parallel and perpendicular), roof weight, and partition weights. You need to further know what the seismic factors S_{ds} and R are for your particular system. The equations from Table 2.6 are based on the assumption that the building is rectangular, seismic weight is based on mid-story heights, and you need to include 20% of the ground snow in the roof weight where it exceeds 30 psf. If it is 50 and 70 psf, roof weight is increased by 10 and 14 psf, respectively.

Prescriptive Design Approach

Prescriptive design procedures have limitations for usage based upon how the provisions in the WFCM were formulated. External walls must be considered shear walls. However the entire external walls permitted need not meet shear wall requirements unless needed for strength. If external walls are not sufficient then internal walls are permitted to be used. As part of this, shear walls must be placed within the structure in two orthogonal directions. This is often not an issue to locate sufficient

areas unless the house has non-traditional design attributes. Among the provisions for prescriptive design, there exists many tables in Chapter Three to aid the design of shear walls. Table 4 here lists the most relevant tables needed to design shear walls from the prescriptive approach for solid segmented and perforated walls by in the WFCM.

In the WFCM, tabulated values for wind and seismic are given but often are adjusted based on an adjustment factor for different materials, roof pitches, lengths, aspect ratios, and nailing patterns. Looking at the adjustment factors they range from 0.35 to 1.58 for wind and 1.0 to 1.6 for seismic which makes sense based on seismic weight.

Table 4: Relevant Tables in the WFCM for Designing Prescriptive Shear walls.

Category	Topic	Table
Connections	Nailing Schedule	3.1
	Foundation connection resisting lateral loads	3.2A-C 3.3
Sheathing requirements	Wall Sheathing requirements	3.13A
	Wall cladding requirements	3.13b
	Segmented sheathing requirements for wind	3.17A
	Segmented sheathing requirements for EQ	3.17C
Capacities and Design	Shear walls resisting uplift and shear	3.4B
	Unit shear capacities	3.17D
	Perforated Shear wall height adjustments	3.17E
	Segmented and Perforated Shear wall hold down capacity	3.17F

Segmented Design

The prescriptive design approach has provisions that account for the behavior of segmented formulations. In both wind and seismic design, the WFCM Section 3.4.4.2 has the shear wall lengths tabulated based upon a standard shear wall for each load type. The tables are structured in such a fashion that the value generated by the table is the minimum length of a full height shear wall perpendicular to the building dimension. To use the table you need to know the 3-second gust mph (available range 110-195) and the building dimension (available dimension 12-80 with up to 40' in 4' internals and beyond in 10' intervals). Exposure B and C are provided in Tables 3.17A.

Tabulated values for seismic are found in Table 3.17C. The tabulated sheathing lengths are based on 10' walls and 10' top plate to ridge heights. The table is further broken down based on the story location you are considering for design. Other materials are permitted and are modified based on an adjustment factor. Adjustment factors for variations on standard shear wall construction are provided in Table 3.17C footnotes and Table 3.17D. The tables are structured in such a fashion that the value generated by the table is the minimum length of a full height shear wall. To use the table, you need to know the following: SDC (A-C only), minimum building dimension (available dimension 12-36' in 4' internals), building length to width ratios (1 to 3 in 0.5 internals), the level you are designing in the building, and lastly the ground snow load (30, 50 and 70 psf are available).

Perforated Design

Section 3.4.4.2.2 in the WFCM contains criteria needed for constructing perforated shear walls. This section states that an adjustment factor is applied to Table 3.17A and 3.17C values are conducted. The adjustment factors found in Table 3.17E are based upon the size (height) of the framed openings (windows or doors), the wall height (8, 9 or 10 ft), and the percentage full height sheathing on segment shear wall (10-100% in 10% intervals). These give way to adjustment factors between 1.00 to 2.50.

Summary and Comparison of Codes

To achieve a simplification for a non-engineering professional to design residential structures that are common, many of these codes have limitations based upon their formulation and intent to aid designers. Each code has different limitations which makes for a more difficult time switching from one format to another. Table 5 was created to show the comparison of the different assumptions and limitations these individual codes.

Table 5: Comparison of Limits and Assumptions for the Codes

Limitation Type	IBC	WFCM		IRC	SDPWS
		Engr.	Persc.		
Mean Roof Height	Not Limited	33'	33'	Function of wall	N/A
No. of Stories	3	3	3	3	N/A
Building Dimensions	Not Limited	80	80	Function of capacity	N/A
Shear wall line offset	4'	4'	4'	4'	N/A
Shear wall floor offset	Not allowed	Not allowed	Not allowed	Not allowed	N/A
Segment Aspect Ratio	N/A	See SDPWS	Table 3.17D	N/A	Table 4.3.3 Up to 3.5:1
Studs Spacing	16"-24"	16"-24"	16"-24"	8" - 24"	16"-24"
Wind	Speeds of 85-150 mi/h Exposures B-D	Speeds of 110-195 mi/h Exposures B-D		Speeds of 110-130 mi/h Exposures B-D	Not Limited
Seismic	All	Seismic design Categories A, B, C, D0, D1, and D2		Seismic design Categories A, B, C, D0, D1, and D2	Not Limited

SDPWS and NDS are the most robust and comprehensive codes as they are tailored towards an engineering professional utilizing these documents. The WFCM does not include a comprehensive engineering analysis that would be performed by a licensed engineer, instead it was meant to be a time saving device. In addition, WFCM limits the building width and length to 80 ft and 3 stories which covers most residential homes. Further the complexity is broken into prescriptive design of residential structures and engineered design each of which are different as was discussed.

Limitations in prescriptive designs are stricter as compared to engineering design based conservative notions to simplify options for non-trained engineers conducting the design.

Regardless of the code (except the SDPWS), three conditions must be met. The first is the shear wall line offset, here a line of shear walls cannot shift in plan more than 4'. The second is the shear wall story offset, here shear walls must be stacked on top of one another unless you meet the specific exception in Section 2.1.3.3d of the WFCM which focuses on proper detailing and ensuring a continuous load path. No walls, including shear walls, can have a stud spacing greater than 24" o.c. in any of the codes discussed. Lastly, note that the shear wall segment aspect ratios can be a limiting factor and vary across several of these codes. The ratio cannot exceed a 2:1 ratio unless you apply the NDS's SDPWS Section 4.3.3.4.1 exception 1 and 2 which will permit a ratio of 3.5:1.

The IRC follows closely to the WFCM but has less wind speed ranges as compared to the WFCM and its supplemental documents covering higher areas. IBC provisions permit shear walls to be designed and constructed in accordance with the SDPWS and the applicable provisions of Sections 2305, 2306 and 2307. The main difference here is that the values and provisions given directly in the IBC are for stapled walls.

Structural design for shear walls within these code documents varies as was discussed. When it comes to capacities for walls to resist in plane wind loads and seismic loads, the procedures change but so does the values the different codes give for designing. Table 6 was developed for two reasons. The first was to identify the unit for selecting the proper wall. The second was for comparing the permitted capacities for different materials across codes. Of all the codes, only the IRC provides capacities based on a minimum length and not a unit shear value. This makes sense as the IRC provides simplifications but it also limits designs as these lengths can be large.

We can see that across the different types of materials in Table 6 that the shear capacities change. This is expected as materials can have vastly different capacities. What is surprising is the variability of unit shear capacity from code to code. Often the more simplified codes have lower values but in some cases significantly. Additionally, the WFCM for engineered design reverts back to the SDPWS code. Lastly it needs to be noted that if you intend to use a specific material a careful choice of code will be needed as not all the codes cover the same materials.

It is known from research in shear wall design that the nailing patterns and fastener type can have a large impact of the shear capacity of the shear wall. Nail spacing is varied from 2-12" o.c. and is different for perimeters and interiors of a sheathing panel. Depending on the materials these values vary. Each code identified earlier has different limitations, as such these limitations also affect the nailing requirements. Table 7 here highlights for several different materials used for sheathing the prescribed nailing requirements. The SDPWS provides the most detail while the WFCM also references manufacturer specifications for certain types of products. The IBC provides the least

amounts of provisions related to material type while focusing specifically on stapling requirements.

Table 6: Comparison of Shear Capacity Ranges Permitted in Walls.

Sheathing Type for Wall	WFCM			IBC	IRC*	SDPWS	
	Engineered	Prescriptive		Wind &	Wind	E.Q.	Wind
	Wind & E.Q.	Wind	E.Q.	E.Q.	& E.Q.	Range	Range
Wood structural panels: structural 1	Refer to SDPWS	308-1260	221-902	155-475	Lengths	400-1740	560-2435
Wood structural panels: sheathing	Refer to SDPWS			N/A	Lengths	360-1740	505-2435
Plywood siding	Refer to SDPWS	N/A	N/A	140-430	Lengths	280-820	390-1150
Particleboard	Refer to SDPWS	N/A	N/A	N/A	Lengths	240-1040	335-1455
Structural fiber board	Refer to SDPWS	297-397	212	150-325	Lengths	340-520	475-730
Gypsum wallboard, gypsum base for veneer, water resistant gypsum backing	Refer to SDPWS	75-100	75-100	75-250	Lengths	150-500	150-500
Gypsum sheathing board	Refer to SDPWS			75-175	Lengths	150-400	150-400
Gypsum lath	Refer to SDPWS	N/A	N/A	100	Lengths	200-360	200-360
Expanded metal woven wire lath with Portland cement	Refer to SDPWS	N/A	N/A	180	Lengths	360	360
Horizontal lumber sheathing	Refer to SDPWS	N/A	N/A	N/A	Lengths	100	140
Diagonal lumber sheathing	Refer to SDPWS	N/A	N/A	N/A	Lengths	600	840
Double diagonal lumber sheathing	Refer to SDPWS Refer to SDPWS	N/A	N/A	N/A	Lengths	1200	1680
Vertical lumber sheathing	N/A	N/A	N/A	N/A	Lengths	90	125

* For the IRC shear capacities are not given, instead wall lengths and the amount of walls needed are given.

Table 7: Comparison of Sample Nailing Pattern Requirements

Panel type	SDPWS	WFCM	IBC	IRC
Wood structural panel	6" o.c. at panel edges 6" o.c. interior if panel is $\geq 7/16"$ or studs $< 24"$ o.c. then 12" o.c. interior	6" o.c. at panel edges 12" o.c. else	6" o.c. at panel edges 12" o.c. else	6" o.c. at panel edges 12" o.c. else
Particleboard	6" o.c. at panel edges 6" o.c. interior if panel is $\geq 3/8"$ or studs $< 24"$ o.c. then 12" o.c. interior	See manufacturer	N/A	6" o.c. at panel edges 12" o.c. else
Structural fiberboard	4" o.c. at panel edges 6" o.c. interior	3" o.c. at panel edges 6" o.c. else	N/A	3" o.c. at panel edges 6" o.c. else
Gypsum wallboard	6" o.c. at panel edges	7" o.c. at panel edges 10" o.c. else	Staples provisions given	7" o.c. at panel edges 7" o.c. else

Conclusions

As discussed in this paper, the design of wood framed shear walls to resist in plane wind and seismic forces resulting in lateral loads is variable depending on the code selected. The WFCM and IRC provide a more simplified version, particularly tailored towards those who are not engineering professionals. Whereas the SDPWS along with the NDS are intended for those individuals who wish to use a more detailed approach and are the most robust but also the most complex. Here, we attempted to help peel back the complexity to provide a broader picture comparison for approaching the use of these documents.

An additional takeaway from this paper, and part of the funded research sponsored by the PHRC was to look at where the codes can be advanced. We can see in several of the Tables given that not all codes cover the same material or some lack certain types of systems. A potential list for where the authors feel the codes can be refined in successive editions to be more useful and easier to compare is provided.

- Ensure all codes cover the same material types for sheathings including updating the codes for new materials and finishes.
- Provide better/more clear requirements on fasteners types and a wider spread of applicable types for wind vs seismic, particularly adhesives.
- Better and more refined procedures / limitations on engineered and prescriptive proprietary systems.

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