APPENDIX D
METHODS FOR ANALYSIS OF SHEAR WALL RESISTANCE

D1. General – Resistance of shear walls to in-plane lateral loading may be determined according to one of the methods presented in this Appendix. Each method is briefly summarized and the assumptions involved in formulation of the methods are presented. The appropriate method should be determined by the building designer or wall designer in accordance with the provisions of the governing building code.

D2. Methods – Analysis methods are presented with sufficient detail to allow the user to implement each method without consulting other sources. However, to obtain a better understanding of the methods and related research, the reader is referred to more detailed reports specified in Section D3 of this Appendix. The first three methods (Sections D2.1, D2.2, and D2.3) need input of unit shear resistance values that can be determined from Appendix B or measured experimentally in accordance with the provisions of Section 4.4.2. Alternatively, the shear wall resistance can be estimated using analytical methods (Sections D2.4 and D2.5).

D2.1 Perforated Shear Wall Method. This method relates shear capacity of a wall with perforations (i.e., doors or windows or both) to a wall of identical configuration without perforations through an empirical reduction factor, F, determined as follows:

$$F = \frac{r}{3 - 2r} \qquad \text{(DE.1)}$$

$$r = \frac{1}{1 + \frac{A_o}{H \Sigma l_i}} \qquad \text{(DE.2)}$$

where:

F = reduction parameter;
r = sheathing area ratio;
A_o = total area of openings;
H = height of the wall; and,
Σl_i = summation of length of all full height wall segments.

To implement this method, the designer shall multiply the shear wall resistance calculated based on the total wall length (including the length of perforations) by the reduction factor, $F \leq 1.0$, determined with Equation DE.1. The total shear resistance of a shear wall line is determined as follows:

$$V = F\,L\,v \qquad \text{(DE.3)}$$

where:

V = total lateral resistance of a perforated shear wall line;
F = reduction parameter determined using Equation DE.1;
L = total length of a shear wall line including length of perforations;
v = unit shear resistance determined from Appendix B or Sections 4.4.2, D2.4, or D2.5.

The method requires that overturning restraints are installed at the wall ends that typically coincide with building corners. The method has been validated for light-frame wood and cold-formed steel shear walls sheathed with wood structural panels with the maximum wall unit shear capacity (unfactored) not exceeding 1,200 lb/ft (See Appendix B).

D2.2 Segmented Shear Wall Method - This method uses resistance of fully sheathed segments located between wall openings. Each segment should be fully restrained against overturning. The contribution of the components above and below openings is ignored. The unit shear resistance is multiplied by the segment length to determined shear resistance of the segment. The total resistance of a shear wall line is determined as a sum of the resistances of all individual segments as follows:

$$V = \sum_{i=1}^{n} l_i \; v_i \qquad \text{(DE.3)}$$

where:

- V = total lateral resistance of a shear wall line;
- l_i = length of an individual shear wall segment;
- v_i = unit shear resistance of an individual shear wall segment determined from Appendix B or Section 4.4.2, D2.4 or D2.5;
- n = number of shear wall segments in a shear wall line.

D2.3 Ni-Karacabeyli's Method – This mechanics-based method is formulated such that the resistance of a nonperforated shear wall segment with a partial overturning restraint is expressed as a fraction of the resistance of an identical shear wall segment with a full restraint. The shear capacity ratio for a wall with a partial overturning restraint and the full overturning restraint can be determined as follows:

$$\alpha = \sqrt{1 + 2\varphi\gamma + \gamma^2} - \gamma \qquad \text{(DE.3)}$$

$$\varphi = \frac{R}{M C_N}, \qquad 0 \le \varphi \le 1 \qquad \text{(DE.4)}$$

where:

- α = ratio of the lateral load capacity of a wall segment with partial uplift restraint to the capacity of a wall segment with full uplift restraint;
- γ = wall segment aspect ratio;
- φ = uplift restraint effect which is equal to unity for the walls fully restrained against overturning;
- M = total number of nails along the end stud of a shear wall segment;
- C_N = capacity of a single nail connection that can be measured experimentally or estimated using the connection yield theory;
- R = uplift restraint force on the end stud of shear wall that can include contribution of partial overturning restraint, gravity load, corner effect, and other system effects.

The total resistance of a shear wall line is determined as a sum of the resistances of all individual segments as follows:

$$V = \sum_{i=1}^{n} \alpha_i \; l_i \; v_i \qquad \text{(DE.5)}$$

where:

- V = total lateral resistance of a shear wall line;
- α = see Equation DE.3;
- l_i = length of an individual shear wall segment;

v_i = unit shear resistance of an individual shear wall segment determined from Appendix B or Section 4.4.2, D2.4 or D2.5;
n = number of shear wall segments in a shear wall line.

D2.4 Shear Through Panel Rotation - This method is used to determine shear resistance of a fully restrained light-frame nonperforated shear wall segment through modeling the rotation response of individual sheathing panels that are fastened to the wall framing with nails or screws. The method is formulated with an assumption that a sheathing panel rotates around its center as a rigid body (infinite in-plane shear modulus). The contribution of an individual nail to the total shear resistance is determined based on the distance from the nail to the center of panel rotation and relative nail displacement. The unit shear wall value (characteristic strength) of an individual shear wall panel is determined as follows:

$$v = \frac{C_N \sum_{i=1}^{total} K_i}{B} \qquad \text{(DE.5)}$$

$$K_i = (\sin\beta)\sqrt{\left(\frac{x_i}{B}\cos\beta\right)^2 + \left(\frac{y_i}{H}\sin\beta\right)^2} \qquad \text{(DE.6)}$$

where:

C_N = peak resistance of individual sheathing fastener that can be measured experimentally or determined using the connection yield theory;
B = sheathing panel width;
H = sheathing panel height;
β = angle between the diagonal and the vertical edge of individual sheathing panel;
i = sheathing fastener enumerator, i changes from 1 to the total number of sheathing fasteners in a panel;
x_i = horizontal coordinate of i-th fastener relative to the panel center;
y_i = vertical coordinate of i-th fastener relative to the panel center;
K_i = geometric characteristic of fastening schedule of a sheathing panel.

The total resistance of a shear wall line can be determined using methods described in Sections D2.2, D2.3, or D2.4 of this Appendix. The resistance of an individual sheathing fastener, C_N, can be measured experimentally or estimated analytically using the connection yield theory. Narrow shear wall segments with aspect ratio greater than 2:1 can have significant bending component in their response and should not be analyzed with Equations DE.5 and DE.6 unless the bending contribution is included. Because this method does not model wall ductility, energy dissipation mechanism, and other failure modes, the designer should detail the wall configuration so that none of these factors can negatively affect the wall response under a design event.

D2.5 Alternate Rational Analyses – This section is not intended to limit the use of alternate design methods that use recognized principles of mechanics and engineering. Examples of such methods include finite element analysis, matrix analysis, energy-based formulations, closed-from solutions, and others.

D3. Publications – Relevant information regarding methods for estimating resistance of light-frame shear walls can be found in the following publications:

Dolan, J., and Heine, C., Monotonic Tests of Wood Frame Shear Walls with Various Openings and Base Restraint Configurations, Prepared for the NAHB Research Center, Inc. by Virginia Polytechnic Institute and State University, Blacksburg, VA, 1997.

Dolan, J., and Heine, C., Sequential Phased Displacement Cyclic Tests of Wood Frame Shear Walls with Various Openings and Base Restraint Configurations, Prepared for the NAHB Research Center Inc. by Virginia Polytechnic Institute and State University, Blacksburg, VA, 1997.

Dolan, J., and Heine, C., Sequential Phased Displacement Tests of Wood Framed Shear Walls with Corners, Prepared for the NAHB Research Center, Inc. by Virginia Polytechnic Institute and State University, Blacksburg, VA, 1997

Dolan, J., and Johnson, A., Cyclic and Monotonic Tests of Long Shear Walls with Openings, Prepared for the American Forest & Paper Association by Virginia Polytechnic Institute and State University, Blacksburg, VA, 1996.

NAHB Research Center, Inc., Monotonic Tests of Cold-Formed Steel Shear Walls with Openings, Prepared for the U.S. Department of Housing and Urban Development, American Iron and Steel Institute, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, MD, 1997.

NAHB Research Center, Inc., The Performance of Perforated Shear Walls with Narrow Wall Segments, Reduced Base Restraint, and Alternative Framing Methods, Prepared for the U.S. Department of Housing and Urban Development and The National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, MD, 1998.

NAHB Research Center, Inc., Perforated Shear Walls with Conventional and Innovative Base Restraint Connections, Prepared for the U.S. Department of Housing and Urban Development and The National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, MD, 1999.

HUD, Residential Structural Design Guide: A state-of-the-art review and application of engineering information for light-frame homes, apartments, and townhouses, Prepared for the U.S. Department of Housing and Urban Development (HUD) and The National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, MD, 2000

Ni, C., and Karacabeyli, E., Effect of overturning restraint of performance of shear walls, Proceedings of the World Conference on Timber Engineering, Whistler Resort, British Columbia, Canada, 2000.

Ni, C., Karacabeyli, E., and Ceccotti, A., Design of shear walls with openings under lateral and vertical loads, Paper prepared for PTEC'99, Draft v. 4, December 2, 1998.

Salenikovich, A. J., The racking performance of light-frame shear walls, Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2000.

Sugiyama, H., and Matsumoto, T., Empirical Equations for the Estimation of Racking Strength of a Plywood Sheathed Shear Wall with Openings, Summary of Technical Papers, Annual Meetings, Trans. of A.I.J. Japan, 1994.

Sugiyama, H., and Yasumura, M, Shear Properties of Plywood Sheathed Wall Panels with Openings. Trans. of A.I.J., No. 338. Japan, 1984.