APPENDIX C
LATERAL LOAD DISTRIBUTION MODELS

C.1 General – This appendix presents methods for distribution of lateral building forces to shear walls in light-frame construction. 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.

C.2 Methods – Load distribution 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 C4 of this Appendix.

C2.1 Tributary Area Method (Flexible Diaphragm Method) – The tributary area method is used to distribute the story lateral load between the shear walls based on tributary areas assigned to each shear wall. In wind design, the tributary areas are associated with exterior wall surfaces, whereas in seismic design, the tributary areas are associated with plan configurations. The tributary area method assumes that the diaphragm acts as a flexible beam and does not provide a mechanism to distribute forces between the walls. Due to extensive experience, this method is considered as accepted engineering practice and is widely used with lateral load analysis of residential buildings.

Although the tributary area method is simple to use and in most cases it provides conservative solutions, according to recent research findings (Section C4) it misrepresents the response of light-frame construction and can result in misguided design decisions. For example, the method lacks the ability to effectively use the resistance of intermediate and short wall segments that are abundant in the irregular-shaped residential buildings. In addition, the method can result in nonconservative designs of shear wall components on the element level due to underestimation of loads acting on individual walls.

C2.2 Rigid Diaphragm Method without Torsion – This method is used to distribute the story lateral load between the shear walls based on the relative shear wall stiffnesses. The principal assumption is that the diaphragm stiffness is relatively high compared to the stiffness of supporting shear walls. Thus, the rigid diaphragm distributes loads to the supporting walls in proportion to their relative stiffnesses. The wall capacity is typically used as a measure of its stiffness. The total story shear load is distributed to individual shear wall lines according to the ratio of the wall capacity (stiffness) to the total capacity of all parallel walls on the story under consideration. Recent research findings (Section C4) have shown that the rigid diaphragm method is a more accurate model for light-frame wood construction compared to the tributary area method. However, insufficient information is available on performance of buildings with significant plan irregularities to assess appropriate limitations on use of this method, if any. The reader is further referred to NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA 368, BSSC 2001) for detailed descriptions of irregularities that affect the building response.

C2.3 Rigid Diaphragm Method with Torsion – This method is an extension of the method described in Section C2.2. In addition to distributing the total story lateral force to the shear walls based on their relative stiffnesses, an additional force is assigned to each wall due to rotation of the rigid diaphragm. The rotation occurs when the load vector and the resistance vector are not collinear, resulting in a force couple in addition to direct shear. This method is typically used to model response of irregular buildings with complicated branched plans. The torsion force component can either increase or offset the direct shear force component. However, model building codes do not allow for a reduction of the direct shear force due to the torsion effects. Current model building codes also limit the degree of lateral resistance that can be provided by torsional response through limits on building plan aspect ratio (length to width) where torsional analysis is permitted. When designing buildings with branched plans, the engineer should exercise judgement on whether sections of an irregular diaphragm are sufficiently interconnected to provide a unit action or the diaphragm should be modeled as a group of individual diaphragms. The magnitude of the torsional component is determined as follows:

$$V_T = \frac{M_T \; r_i \; V_i}{J} \qquad \text{(C.E1)}$$

$$J = \sum_{i}^{n} V_i \; r_i^{\,2} \qquad \text{(C.E2)}$$

where:

- V_T = torsional shear load on a wall line;
- M_T = torsional moment – a product of total story shear load and perpendicular distance between the load vector and resultant resistance vector for load direction under consideration;
- r_i = distance from the wall to the center of stiffness (center of resistance);
- V_i = design shear wall capacity (or consistent measure of stiffness);
- J = torsional moment of inertia of the story.

C2.4 Plate Element Method – This method models a diaphragm with two-dimensional elements formulated using plate theory. The diaphragm movement is restricted by imposing spring reactions that represent shear walls. The in-plane stiffness of the plate elements and stiffness of connections between the plates can be adjusted to improve accuracy of the model. This model can be solved by commercial or proprietary computed-aided structural analysis procedures. Recent research demonstrated that the plate element method accurately models light-frame wood construction (HUD 2001).

C3. Alternative 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.

C4. Publications – Relevant information regarding methods for distribution of lateral forces in light-frame construction can be found in the following publications:

Building Seismic Safety Council, NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings (FEMA Publication 369), Washington, DC, 2001.

Building Seismic Safety Council, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA Publication 368), Washington, DC, 2001.

Fisher, D., Filiatrault, A., Folz, B., Uang, C., and Seible, F., Shake Table Tests of a Two-Story Woodframe House. Report No. SSRP – 2000/15. Division of Structural Engineering, University of California, San Diego, 2000.

HUD, Residential Structural Design Guide, U.S. Department of Housing and Urban Development (HUD), Washington, DC, 2000.

HUD, Whole Structure Testing and Analysis of a Light-Frame Wood Building (Three Reports), U.S. Department of Housing and Urban Development (HUD), Washington, DC, 2001.

Kasal, B., and Leichti, R. J., Incorporating Load Sharing in Shear Wall Design of Light-Frame Structures. Journal of Structural Engineering, Vol. 118, No. 12, pp. 3350-3361, 1992.

Phillips, T. L., Itani, R. Y., and McLean, D. I., Lateral Load Sharing by Diaphragms in Wood-Framed Buildings, Journal of Structural Engineering, Vol. 119(5), pp. 1556-1571, 1992.