Acceptable Diaphragm-Rigidity Assumptions for Distribution of Horizontal Forces in Light-Frame Construction

SEAOC Seismology Committee

During the Dec. 4, 1999 meeting of the SEAOC Seismology Committee, discussions regarding UBC requirements for seismic analysis of light-frame structures were conducted. As a result, the following recommended interpretation of UBC Section 1630.6 "Horizontal Distribution of Shear" was, by unanimous vote of the sections, agreed upon:

(Following the final paragraph of Section 1630.6):

> For detached 1 and 2 family dwellings constructed of light framing, seismic forces may be distributed horizontally by assuming flexible diaphragm behavior.

Reason:

Small light frame detached 1 and 2 family residential structures have traditionally been designed using flexible diaphragm assumptions, or by a "hybrid" approach of treating closely-spaced walls as a unit (i.e., as rigidly connected) and treating the remaining diaphragm as flexible. These structures have historically performed satisfactorily when subjected to strong seismic shaking. Two exceptions, both of which were addressed in the 1997 UBC, have been related to the height-to-length ratio of shear wall panels (primarily at garage doors) and the use of plaster and drywall materials to resist seismic forces.

In the seismology committee's opinion, the use of rigid diaphragm assumptions for small light framed wood diaphragms may not significantly improve the seismic behavior of these structures. Although a "rigid" assumption may better reflect the rigidity of the system while the response remains elastic; the inability to accurately calculate the rigidity of the various elements, including the rigidity contributed by finishes and nonstructural elements, can cause a wide range of results in the analysis of the relatively small spans involved in residential construction, leading to results which may not be significantly better than produced by the conventional "flexible" assumption. In comparison, a "flexible" assumption offers the benefit of often encouraging designers to locate vertical resisting elements in better proportion with the structure mass. When inelastic horizontal seismic deflections occur, a redistribution of forces between the vertical resisting elements will tend to produce relatively similar results, irregardless of the assumptions of rigidity that were used.

Larger, multi-story light framed structures, such as apartments, condominiums, or even very large custom residences, have in the past been demonstrated to have experienced damage during moderate earthquake events that was directly attributed to the rigid behavior of the diaphragms. In particular, the presence of adhesives, concrete topping and rigid ceiling materials between floors may tend to produce relatively rigid diaphragms. Consideration of potentially rigid behavior is therefore recommended for these types of structures.

For reference, attached is a summary of existing UBC provisions related to the horizontal deflection of light-frame structures. Comments have been added in italics.

Relevant Code Sections of 1997 UBC
Related to
Calculation of Wood Deflections

Section 1605 – Design
1605.2 Rationality. Any system or method of construction to be used shall be based on a rational analysis in accordance with well-established principles of mechanics. *These words appeared in the 1976 UBC.*

> *This dictates that whatever analysis is used, whether rigid, flexible, or whatever, must be done in accordance with established engineering principles.*

1605.2.1 Distribution of Horizontal Shear. The total lateral force shall be distributed to the various vertical elements of the lateral-force-resisting system in proportion to their rigidities considering the rigidity of the horizontal bracing system or diaphragm. *These words appeared in the 1973 UBC.*

> *While an assumption of flexible behavior might be permitted under this statement, it would still be necessary to distribute forces to elements along any line of force in proportion to rigidity. The word "considering" implies thinking, judgement and perhaps calculations by the engineer.*

1630.2.3 Simplified design base shear.
1630.2.3.4 Applicability.
Sections 1630.1.2, 1630.1.3, 1630.2.1, 1630.2.2, 1630.5, 1630.9 and 1631 shall not apply when using the simplified procedure. *(This section first appears in the 1997 UBC)*

> *Note that calculation of deflections and hence drifts are excluded, except for moment frame systems.*

1630.6 Horizontal Distribution of Shear

Where diaphragms are not flexible, the mass at each level shall be assumed to be displaced from the center of mass in each direction …. (etc.)

Diaphragms shall be considered flexible for the purposes of distribution of story shear and torsional moment when the maximum lateral deformation of the diaphragm is more than two times the average story drift of the associated story. *The "two times" rule first appears in the 1988 UBC.*

1630.7 Horizontal Torsional Moments. Provisions shall be made for the increased shears resulting from horizontal torsion where diaphragms are not flexible. *This language appears in the 1973 UBC.*

1630.9 Drift. Drift or horizontal displacements of the structure shall be computed where required by this code. *(emphasis added by underline)*

> In the 1973 UBC, this section reads:
> "Lateral deflections or drift of a story relative to its adjacent stories shall be considered in accordance with accepted engineering practice."
> *See 1994 UBC comment below.*

> *As currently worded, Sections 1630.9 and 10 command that lateral deflections, and hence the rigidities of at least some resisting elements, must be computed. "Where required" results from Section 1630.10.*

1630.10 Story Drift Limitation
1630.10.1 General. Story drifts shall be computed using the Maximum Inelastic Response Displacement, Δ_M. *(emphasis added by underline – it gives no exception for light-frame construction)*

The "shall be computed" language first appears in the 1997 UBC. The 1994 UBC uses more circumspect language, "Computed story drifts shall not exceed…"

1633.2.9 Diaphragms.
1. The deflection in the plane of the diaphragm shall not exceed the permissible deflection of the attached elements. *These words first appear in the 1988 UBC.*

This does not relate to rigid vs. flexible diaphragm analysis assumptions.

Section 2315 – Wood Shear Walls and Diaphragms

2315.1 General. Particleboard vertical diaphragms and lumber and wood structural panel horizontal and vertical diaphragms may be used to resist horizontal forces in horizontal and vertical distributing or resisting elements, provided the deflection in the plane of the diaphragm, as determined by calculations, tests or analogies drawn therefrom, does not exceed the permissable deflection of attached distributing or resisting elements. See UBC Standard 23-2 for a method of calculating the deflection of a blocked wood structural panel diaphragm. *(emphasis added by underline)*

Permissable deflection shall be that deflection up to which the diaphragm and any attached distributing or resisting element will maintain its structural integrity under assumed load conditions, i.e., continue to support loads without danger to occupants of the structure.

These same words (except for renumbering of the UBC standard) are found in the 1973 UBC.