



The flexibility of a diaphragm depends on its construction as well as on its aspect ratio (length:width). Long, narrow diaphragms, for example, are more flexible in bending along their long dimension than short, wide diaphragms. In other words, rectangular diaphragms are relatively stiff in one loading direction and relatively flexible in the other. Similarly, long shear walls with few openings are stiffer than walls comprised of only narrow shear wall segments. While analytic methods are available to calculate the stiffness of shear wall segments and diaphragms (refer to Section 6.5), the actual stiffness of these systems is extremely difficult to predict accurately (refer to Section 6.2). It should be noted that if the diaphragm is considered infinitely rigid relative to the shear walls and the shear walls have roughly equivalent stiffness, the three shear wall reactions will be roughly equivalent (i.e.,  $R_1 = R_2 = R_3 = 1/3[w][I]$ ). If this assumption were more accurate, the interior shear wall would be overdesigned and the exterior shear walls underdesigned with use of the tributary area method. In many cases, the correct answer is probably somewhere between the apparent over- and under-design conditions.

The tributary area approach is reasonable when the layout of the shear walls is generally symmetrical with respect to even spacing and similar strength and stiffness characteristics. It is particularly appropriate in concept for simple buildings with diaphragms supported by two exterior shear wall lines (with similar strength and stiffness characteristics) along both major building axes. More generally, the major advantages of the tributary area LFRS design method are its simplicity and applicability to simple building configurations. In more complex applications, the designer should consider possible imbalances in shear wall stiffness and strength that may cause or rely on torsional response to maintain stability under lateral load (see *relative stiffness design approach*).

### ***Total Shear Approach (“Eyeball” Method)***

Considered the second most popular and simplest of the three LFRS design methods, the *total shear approach* uses the total story shear to determine a total amount of shear wall length required on a given story level for each orthogonal direction of loading. The amount of shear wall is then “evenly” distributed in the story according to designer judgment. While the total shear approach requires the least amount of computational effort among the three methods, it demands good “eyeball” judgment as to the distribution of the shear wall elements in order to address or avoid potential loading or stiffness imbalances. In seismic design, loading imbalances may be created when a building’s mass distribution is not uniform. In wind design, loading imbalances result when the surface area of the building is not uniform (i.e., taller walls or steeper roof sections experience greater lateral wind load). In both cases, imbalances are created when the center of resistance is offset from either the center of mass (seismic design) or the resultant force center of the exterior surface pressures (wind design). Thus, the reliability of the total shear approach is highly dependent on the designer’s judgment and intuition regarding load distribution and structural response. If used indiscriminately without consideration of the above factors, the total shear approach to LFRS design can result in poor performance in severe seismic or wind events. However, for small structures such



as homes, the method has produced reasonable designs, especially in view of the overall uncertainty in seismic and wind load analysis.

### ***Relative Stiffness Design Approach (Rigid Diaphragm)***

The *relative stiffness approach* was first contemplated for house design in the 1940s and was accompanied by an extensive testing program to create a database of racking stiffnesses for a multitude of interior and exterior wall constructions used in residential construction at that time (NBS, 1948). If the horizontal diaphragm is considered stiff relative to the shear walls, then the lateral forces on the building are distributed to the shear wall lines according to their relative stiffness. A stiff diaphragm may then rotate some degree to distribute loads to all walls in the building, not just to walls parallel to an assumed loading direction. Thus, the relative stiffness approach considers torsional load distribution as well as distribution of the direct shear loads. When torsional force distribution needs to be considered, whether to demonstrate lateral stability of an “unevenly” braced building or to satisfy a building code requirement, the relative stiffness design approach is the only available option.

Although the approach is conceptually correct and comparatively more rigorous than the other two methods, its limitations with respect to reasonably determining the real stiffness of shear wall lines (composed of several restrained and unrestrained segments and nonstructural components) and diaphragms (also affected by nonstructural components and the building plan configuration) render its analogy to actual structural behavior uncertain. Ultimately, it is only as good as the assumptions regarding the stiffness of shear walls and diaphragms relative to the actual stiffness of a complete building system. As evidenced in the previously mentioned whole-building tests and in other authoritative design texts on the subject (Ambrose and Vergun, 1987), difficulties in accurately predicting the stiffness of shear walls and diaphragms in actual buildings are significant. Moreover, unlike the other methods, the relative stiffness design approach is iterative in that the distribution of loads to the shear walls requires a preliminary design so that relative stiffness may be estimated. One or more adjustments and recalculations may be needed before reaching a satisfactory final design.

However, it is instructional to consider analytically the effects of stiffness in the distribution of lateral forces in an LFRS, even if based on somewhat idealized assumptions regarding relative stiffness (i.e., diaphragm is rigid over the entire expanse of shear walls). The approach is a reasonable tool when the torsional load distribution should be considered in evaluating or demonstrating the stability of a building, particularly a building that is likely to undergo significant torsional response in a seismic event. Indeed, torsional imbalances exist in just about any building and may be responsible for the relatively good performance of some light-frame homes when one side (i.e., the street-facing side of the building) is weaker (i.e., less stiff and less strong) than the other three sides of the building. This condition is common owing to the aesthetic desire and functional need for more openings on the front side of a building. However, a torsional response in the case of underdesign (i.e., “weak” or “soft” story) can wreak havoc on a building and constitute a serious threat to life.