Roof Diaphragms and Low-Rise Seismic Design

BY COLIN A. ROGERS AND ROBERT TREMBLAY

When roof deck diaphragms are used to transmit lateral loads from seismic events to vertical bracing elements, more robust diaphragm designs may be be required.

SINGLE-STORY BUILDINGS typically incorporate a steel roof deck diaphragm that is relied upon to transfer lateral wind and seismic loads to the vertical bracing bents. Roof deck diaphragms in North America are commonly constructed of corrugated cold-formed steel panels that are connected to one another at sidelaps and to the underlying structure. Design of these diaphragms for in-plane shear forces can be carried out using the SDI *Diaphragm Design Manual* (Luttrell, 2004). The flexural capacity of the diaphragm can be developed through the use of continuous chord members (Fig. 1a). Transfer of the horizontal forces to the vertical bracing bents relies on the action of the diaphragm collector elements (Fig. 1a). Diaphragms may also contribute to the overall dynamic properties and response of a building due to their in-plane flexural and shear flexibility.

North American model building codes (ASCE, 2005; NRCC, 2005) and steel design specifications (AISC, 2005a,b; CSA, 2005) allow engineers to use reduced seismic loads in design, provided that the seismic load resisting system (SLRS) of the structure is adequately designed and detailed to withstand strong ground shaking through ductile response. Building codes and standards include special provisions to achieve satisfactory inelastic seismic performance for the various SLRSs used in steel building construction (Tremblay, 2005). In particular, the design of the vertical structural system must be carried out with strict compliance to capacity design principles; i.e., fuse elements of the SLRS are sized and detailed to dissipate seismic input energy through cyclic inelastic response, whereas the remaining elements should be provided with sufficient capacity to carry the maximum forces that are anticipated along the lateral load path.

The vertical braces of steel buildings are typically selected as the energy-dissipating fuse element in the seismic load resisting system, while the diaphragm and other elements in the SLRS are designed to have a capacity that is equal to or exceeds the expected resistance of the braces (Fig. 1b). When tension-compression bracing is used, the steel bracing members designed for compression inherently possess significant reserve strength when loaded in tension, which means that large brace tension loads must be considered in the design of the surrounding protected structural components, including roof diaphragm systems. The 2005 National Building Code of Canada (NBCC) (NRCC, 2005) seismic provisions have led to the need for much thicker roof deck panels and more closely spaced diaphragm connection patterns compared with past practice, which is especially true in areas of high seismicity. Complying with these newly introduced design requirements

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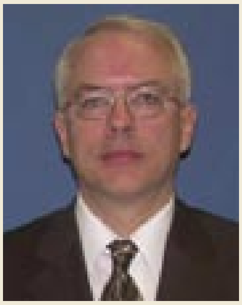

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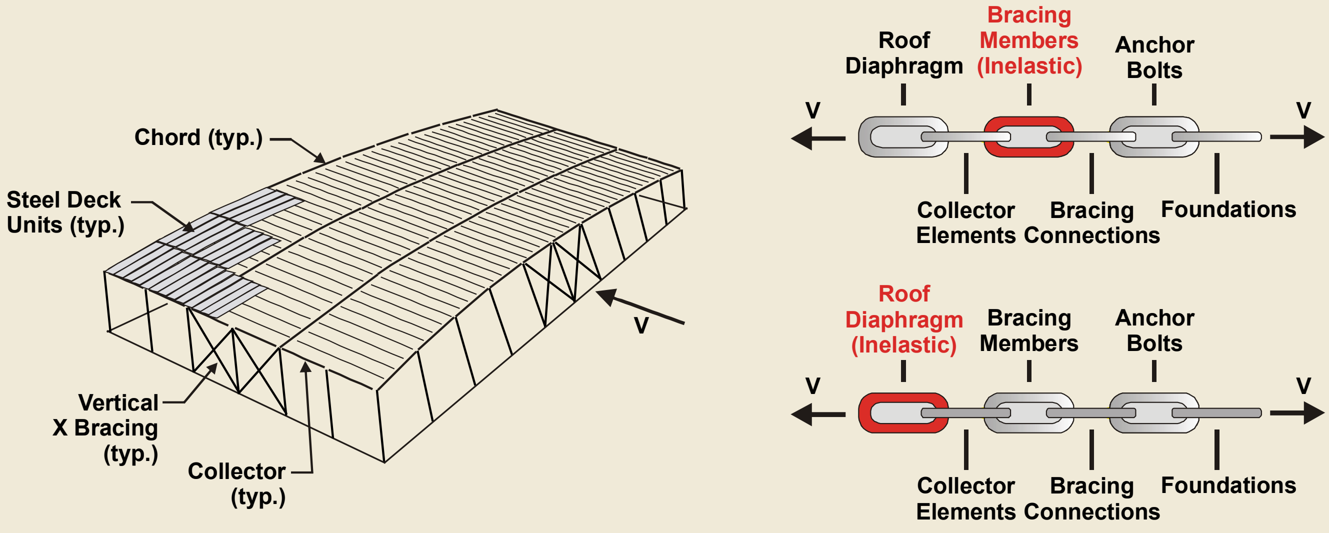

Figure 1a.

Figure 1b.

Single-story buildings with capacity-based design concepts for SLRS.

has significantly impacted the cost of steel building structures, making this system less attractive economically than in past years (Tremblay and Rogers, 2005).

This paper contains a description of the U.S. seismic design provisions for low-rise steel buildings, as well as a design example of a single-story building located in Boston. It also presents the interim findings of a study currently under way for which the objective is to develop seismic design strategies that account for the flexibility and ductility of the roof diaphragm in low-rise steel buildings. The scope of research includes quasi-static diaphragm shear tests (Tremblay et al., 2004; Essa et al., 2003), large-scale dynamic diaphragm tests (in progress), and ambient vibration building measurements (Paultre et al., 2004; Lamarche, 2005; Tremblay et al. 2008), as well as dynamic analyses of representative buildings (in progress). At project end, the aim is to make design recommendations, including: diaphragm stiffness under seismic loading, period of vibration for the building, seismic force modification factors, ductile detailing requirements, and inelastic performance levels.

> "Current seismic provisions in the U.S. do not result in entirely consistent design between the steel framing and the diaphragms."

Conclusions

Seismic provisions of modern building codes rely more and more on capacity design procedures to better control the inelastic response of structures, providing a desired hierarchy of yielding in the structures. For braced steel frames, yielding is typically concentrated in the vertical system. Other components along the lateral load path, such as the roof diaphragm—including its chords and collectors—must be designed to resist the forces that will develop upon yielding in the vertical components of the seismic load resisting system. Current seismic provisions in the U.S. do not result in entirely consistent design between the steel framing and the diaphragms. If full-capacity design principles were required, much higher design forces would need to be applied for diaphragms. For simple metal roof deck design, the example studied herein showed that the roof deck would need to be increased from 0.0295 in. to 0.0474 in. (22 ga to 18 ga) with a more closely spaced fastener arrangement. Alternative approaches can be studied to reduce the force demand. The designer can take advantage of the flexibility of the roof diaphragm, as this is currently permitted for the seismic retrofit of existing structures. Parametric studies performed in Canada have shown that there is a significant potential for savings if the period from dynamic analysis could be used in design. However, field test data seem not to match this data, and caution must be exercised before using the period prediction that accounts for roof diaphragm flexibility in seismic design. One other approach consists of allowing inelastic deformation in roof diaphragms. These deformations can develop in the form of bearing or tearing in the vicinity of the deck fasteners. Deformation capacity is limited, however, and means must be taken to ensure that they will be properly distributed over the diaphragm area so that no concentration will develop that can lead to complete failure of the diaphragm. Research projects have been undertaken to examine these two possibilities. MSC

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