- Using very low roof slopes (such as $^1/_4$:12) in cold regions, which can result in a depression at the first interior purlin line near the eaves and invite leakage and ice buildup there, as further examined in Chap. 11. This buildup, in combination with the load from suspended sprinkler mains (see discussion in Sec. 10.7), could lead to overload of the purlins located next to the eaves.
- Insufficient purlin bracing—or no bracing at all—coupled with lack of purlin stability at supports.

The last point is by far the most serious and merits separate space.

10.9.6 Failures Caused by Lack of Purlin and Girt Bracing

As discussed in Chap. 5, purlins and girts without lateral bracing possess but a fraction of the load-carrying capacity of the sections that are fully braced. To recall that discussion, the bracing should be able to accomplish three tasks:

1. To laterally brace compression flange
2. To restrain purlins or girts against rotation
3. To restrain the whole assembly of purlins and roofing from lateral translation

To be effective in meeting these goals, the bracing system must provide stability to the whole C or Z section, not just to one flange of it. For this reason, metal roofing, even the through-fastened variety, cannot accomplish all three tasks. Of course, the member must be stable both between and *at* the supports, meaning that the discrete bracing needs to be supplemented by some sort of antiroll devices.

However, in the author's experience with investigating failures of metal buildings, properly designed purlin and girt bracing is still encountered relatively rarely. In many older buildings there is no bracing at all. Laterally unbraced girts and purlins tend to fail by the lateral-torsional buckling mode (Fig. 10.18), well before their full flexural capacity is realized. This may help explain why some pre-engineered buildings fail under heavy, but not extreme, snow and wind loading. Note that the buildings in Figs. 10.16, 10.17, and 10.18 have no discrete bracing of secondary members.

Many other engineers involved with metal building systems have corroborated these observations, both verbally and in print. Zamecnik,[11] for example, has investigated several pre-engineered buildings with evident failures of roof purlins suffered under the snow loads well *below* the design values. Some of those roofs have partially collapsed. He places much of the blame on inadequate purlin bracing. (The MBMA disputes these conclusions and insists that the failed buildings were of older vintage, perhaps improperly engineered, and therefore not representative of modern practice.)

Peraza[12] describes his investigations of several metal building collapses in the 1990s. In one case where the manufacturer's designers relied on the standing-seam roofing to provide full bracing to the purlins, the investigators concluded that the actual degree of lateral bracing was only about 60 percent. Peraza points out that for standing-seam roofing, "it undoubtedly was known at the time that 100% bracing was an unrealistic expectation." For another failed roof structure, the investigators concluded that the purlins could carry only about 59 percent of the load that the fully braced purlins could carry. That building also included an interesting system of strap bracing, judged questionable at best.

The percentages noted above are consistent with the results of the independent base tests in which the author was involved. In those tests, even with the most lenient interpretation of the results, the degree of lateral bracing provided by structural standing-seam roofing with trapezoidal profile in the positive purlin region was found to be only 52 percent. The tests were stopped when the purlins had rotated so much under load that the roofing assembly was bearing against the test frame a generous distance away.

This brings up a very important point. The strength and stiffness of distorted (rotated) C and Z sections diminishes with the increasing degree of rotation. When these sections finally lay flat, they are only as strong as their weak-axis section properties allow. The more the roof purlins rotate under constant loading, the weaker they become and the more they deflect vertically. In the absence of

FIGURE 10.18 Buckling of laterally unbraced girts and endwall column under wind loading. (*Photo: J.R. Miller & Associates.*)

effective purlin bracing or other external factors that can eventually arrest the rotation, purlins may continue to rotate, and their load-carrying capacity continue to decrease, until the purlin strength becomes insufficient to carry the loading. Figure 10.16 is quite representative of the large purlin deformations that tend to accompany roof collapses.

The independent base tests mentioned above have identified another problem with unbraced or lightly braced purlins: Much of their rotation under load, as well as vertical and lateral deflection, may be irreversible. When the next heavy loading occurs, the purlins may be already weakened.

The benefits of purlin bracing are evident from the experience of FM Global customers. During the harsh winter of 1995–1996, there were practically no collapse losses at facilities where FM Global engineering recommendations were implemented.

10.9.7 The Collapse Scenarios

A question can be asked: Why does excessive purlin rotation and failure under heavy snow loading tend to bring the whole building down? Couldn't the assembly of purlins and roofing hang from the interior primary frames as a membrane? Unfortunately, the membrane analogy does not work at the end walls: those usually cannot support the enormous horizontal catenary forces generated by the membrane action (see the discussion on overhead door behavior in Sec. 10.4). There is also a problem with the presence of flange braces ("kickers") at the bottom flanges of primary frames.