more important for unheated fixed-base large-span structures with small eave heights located in climates with large temperature swings, or for cold-storage facilities. The effects of thermal expansion and contraction should be considered in very large pre-engineered buildings, measuring hundreds of feet in length. Thermal contraction of steel frames seems to be more dangerous than thermal expansion, because during contraction the steel is under tensile stress which, if large enough, can damage the connection bolts or welds.

Temperature changes are felt most acutely by exposed metal roofing, as discussed in some depth in Chap. 6, and by metal siding, but the trapezoidal design of their metal panels can relieve the expansion and contraction to some degree. It is more difficult to accommodate thermal stresses in continuous secondary structural members, girts and purlins, located in unheated buildings. Consider the worst-case scenario, when the structure is fully loaded with snow and the purlins have contracted toward the middle of the building. Then, the primary frames will probably end up being laterally displaced from the original vertical position by the contracting purlins (and girts, if those are continuous) and metal sheathing. The result: an unplanned-for level of torsion in the frames.

Some building codes and the *MBMA Manual* are silent on temperature loads. How much of a temperature change should be assumed in the design? The answer depends on the climate, building use, and insulation levels. If this loading is included at all, thermal stresses due to *at least* a 50°F rise or fall (100°F total variation) from the probable temperature at the time of the erection should be considered.

3.2 METHODS OF DESIGN AND LOAD COMBINATIONS

The loads discussed above need not be lumped together indiscriminately. It is highly improbable, for instance, that a once-in-a-lifetime hurricane will occur at the same time as a record snowfall. The odds of the roof live load, an allowance for infrequent roof maintenance and repair effects, being present during a major earthquake are similarly slim. To produce a realistic picture of combined loading on the structure, two approaches have been traditionally taken, reflected in the ultimate and the allowable stress designs methods.

3.2.1 Ultimate Design Method

In this method, also known as the strength design method, the loads are added together in various combinations, using *load factor* multipliers for each load and modifying the total by a "probability factor." The resulting combined load is then compared to the "ultimate" capacity of the structure. The load factors reflect a degree of uncertainty and variability of the loads, as was already mentioned. For steel design, this method is followed in the Load and Resistance Factor Design (LRFD) Specification for Structural Steel Buildings published by the American Institute of Steel Construction[5], that contains a list of load combinations similar to those of ASCE 7.

The LRFD method of structural analysis provides a more uniform reliability than the allowable stress design discussed below and may become prevalent in the future for structural steel buildings. As of this writing, however, it does not yet have a widespread acceptance in the design community, and therefore it is not covered here in greater detail.

Further, the users of LRFD in metal building systems may actually be at a disadvantage relative to the users of the allowable stress design method (ASD). How so? The load factors of LRFD (1.2 for dead and 1.6 for live load) have been established to ensure an equal level of reliability with ASD at a certain ratio of live to dead loads. Below this ratio, LRFD generally provides a more economical design; above it, ASD does.

It is easy to find what ratio of live to dead load provides the same level of reliability for both LRFD and ASD methods. At that ratio, the average ("global") LRFD load factor should be 1.5, which is also the implied safety factor of ASD method (recall that the allowable bending stress in compact wide-flange members is $0.66F_y$, inverting which yields 1.5). So, for the dead load of, say, 1.0 psf and the live load of R times 1.0 psf, the following equation can be constructed to find the ratio R:

$$1.0 \times 1.2 + R \times 1.0 \times 1.6 = (R + 1.0) \times 1.5$$

From this equation, the "break-even" ratio of live to dead load R is 3.0. As the reader certainly knows, in metal building systems the dead load is extremely small (typically 2 to 3 psf), and any realistic design level of live or snow loading will exceed the dead load by a factor of more than 3.0, making ASD design more economical for this type of construction.

3.2.2 Allowable Stress Design Method

In this method, some fractions of loads that represent perceived probabilities of the simultaneous load occurrence are added together in various combinations. The total stress level from the loads in each combination is then computed and compared with the allowable stress value (expressed as a function of the yield stress for steel members). The allowable stress can usually be increased by one-third for wind or earthquake loading.

There is no universal agreement or a single best way to combine the loads acting on the building. Specifiers should follow the provisions of the governing building code, or, if not available, of a nationally recognized standard such as ASCE 7 modified for project conditions if needed.

For single-story metal building systems, the following "basic" load combinations used to be commonly specified:

Dead + snow (or roof live load)
Dead + wind (or earthquake)
Dead + snow + earthquake
Dead + $^1/_2$ wind + snow
Dead + wind + $^1/_2$ snow

These sensible load combinations can still be found in some state codes and are included in both the *Uniform Building Code,* 1997 ed.,[6] and the *International Building Code,* 2000 ed., as "alternate basic load combinations." Both include one more combination in their list:

$$0.9 \text{ Dead} + \text{Earthquake}/1.4$$

The earthquake load in another "alternate" combination is also divided by a factor of 1.4.

ASCE 7, since its 1995 edition, is using another approach to combining loads, where the effects of all the loads are essentially simply added together. For metal building systems subjected only to dead, live, roof live, snow, wind, and earthquake loads, the critical ASD load combinations are as follows:

Dead + snow (or roof live load) [+ some other loads such as temperature and soil pressure]
Dead + wind (or earthquake)
Dead + live + snow (or roof live load) + wind (or earthquake)

If there are two or more loads acting in addition to the dead load, the total of those loads (excluding the dead load) may be reduced by a factor of 0.75. The total shall not be less than the effect of the dead load plus the largest unreduced load. No further stress increase is permitted for these load combinations. The earthquake load is excluded from being reduced in this manner, and there are separately defined load combinations when this load is present.

The load combinations in the latest editions of ASCE 7 are more severe than those listed previously, because the one-third stress increase for wind acting in combination with dead load is not allowed, and because the extreme levels of both snow and wind loading are simply combined.

The *International Building Code,* 2000 ed. (IBC), contains its own provisions for load combinations. There are two sets of combinations for the allowable stress design method. The first one ("basic") is similar to the combinations of ASCE 7 (1995 and later editions), but its combinations involving only dead and lateral loads are: