Serviceability

Updated *Design Guide 3* offers Guidance

By Charles J. Carter, P.E., S.E.

Updated in 2003, this AISC design guide now provides more extensive coverage for serviceability considerations in steel building structures.

Serviceability is defined in the AISC *Specification* as "a state in which the function of a building, its appearance, maintainability, durability, and comfort of its occupants are preserved under normal usage." Although serviceability issues have always been a design consideration, changes in codes and materials have added importance to these matters.

The shift to a limit-states basis for design is one example. Since 1986, both the AISC LRFD and AISC ASD specifications have been based upon the limit states design approach in which two categories of limit states are recognized: strength limit states and serviceability limit states. Strength limit states control the safety of the structure and must be met. Serviceability limit states define the functional performance of the structure and should be met.

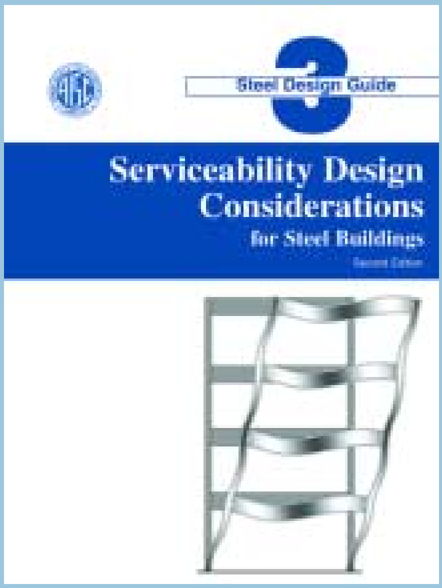
The distinction between the two categories centers on the consequences of exceeding the limit state. The consequences of exceeding a strength limit may be buckling, instability, yielding, fracture, etc. These consequences are the direct response of the structure or element to load. In general, serviceability issues are different in that they involve the response of people and objects to the behavior of the structure under load. For example, the occupants may feel uncomfortable if there are unacceptable deformations, drifts, or vibrations.

Whether or not a structure or element has passed a limit state is a matter of judgment. In the case of strength limits, the judgment is technical and the rules are established by building codes and design specifications. In the case of serviceability limits, the judgments are frequently non-technical. They involve the perceptions and expectations of building owners and occupants. Serviceability limits have, in general, not been codified, in part because the appropriate or desirable limits often vary from application to application. As such, they are more a part of the contractual agreements with the owner than life-safety related. Thus, it is proper that they remain a matter of contractual agreement and not specified in the building codes.

Ideally, the distinction between strength and serviceability would disappear, and problems or failures of any kind would not occur. In reality, all design methods are based upon a finite, but very small probability of exceedance. Because of the non-catastrophic consequences of exceeding a serviceability limit state, a higher probability of exceedance is allowed by current practice than for strength limit states.

The foregoing is not intended to say that serviceability concerns are unimportant. In fact, the opposite is true. By having few codified standards, the designer is left to resolve these issues in consultation with the owner to determine the appropriate or desired requirements.

Serviceability problems cost more money to correct than would be spent preventing the problem in the design phase. Perhaps serviceability discussions with the owner should address the trade-off between the initial cost of the potential level of design vs. the potential mitigation costs associated with a more relaxed design. Such a comparison is only possible because serviceability events are, by definition, not safety-related. The customer or his or her agent must identify the needed criteria for the engineer. Nevertheless, the engineer must foster the active involvement of the customer in the design stage of a structure and address the need for informed discussion of standards and levels of building performance.



Numerous serviceability design criteria exist, but they are spread diversely

Serviceability involves the response of people and objects to the behavior of the structure under load.

through codes, journal articles, technical committee reports, manufacturers' literature, office standards and the preferences of individual engineers. This design guide gathers these criteria for use in establishing serviceability design criteria for a project.

Serviceability Requirements in the AISC Specification

The 1999 AISC *LRFD Specification* lists five topics that relate to serviceability concerns. They are:

1. camber
2. expansion and contraction
3. deflections, vibrations, and drift
4. connection slip
5. corrosion

Camber

Camber may or may not be a solution to a serviceability issue, and the authors have attempted to identify appropriate and inappropriate use of camber in this design guide. In most instances, the amount of total movement is of concern rather than the relative movement from the specified floor elevation, in which case camber is not an appropriate solution. There are, however, situations where camber is appropriate, such as in places where it is possible to sight down the underside of exposed framing.

Expansion and Contraction

Expansion and contraction is discussed to a limited extent. The goal of this design guide is to discuss those aspects of primary and secondary steel framing behavior as they impact non-structural building components. For many types of low-rise commercial and light industrial projects, expansion and contraction (in the limited context given above) are rarely an issue. This does not mean that the topic of expansion and contraction is unimportant. In fact, the opposite is true. For large and/or tall structures, careful consideration is required to accommodate absolute and relative expansion and contraction of the framing and the non-structural components.

Connection Slip

Connection slip has not been addressed explicitly in this design guide. However, it is the authors' intent that the various drift and deflection limits include the movements due to connection slip. Where connection slip, or especially the effect of accumulated connection slip in addition to flexural and/or axial deformations, will produce movements in excess of the recommended guidelines, slip-critical joints should be considered. Slip-critical joints are also required in specific instances enumerated in Section 5 of the 2000 RCSC *Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts*. It should be noted that joints made with snug-tightened or pretensioned bolts in standard holes will not generally result in serviceability problems for individual members or low-rise frames. Careful consideration should be given to other situations.

Corrosion

Corrosion, if left unattended, can lead to impairment of structural capacity. Corrosion is also a serviceability concern as it relates to the performance of non-structural elements and must be addressed by proper detailing and maintenance. The primary concerns are the control or elimination of staining of architectural surfaces and prevention of rust formation, especially inside assemblies where it can induce stresses due to the expansive nature of the oxidation process. Again, the solutions are proper detailing and maintenance.

Serviceability Requirements in ASCE 7

ASCE 7-02, *Minimum Design Loads for Buildings and Other Structures* addresses serviceability in paragraph 1.3.2 Serviceability as follows: "Structural systems, and members thereof, shall be designed to have adequate stiffness to limit deflections, lateral drift, vibration, or any other deformations that adversely affect the intended use and performance of buildings and other structures."

ASCE 7-02 provides an appendix with commentary entitled "Serviceability Considerations." While this appendix is non-mandatory, it does draw attention to the need to consider five topic areas related to serviceability in the design of structures:

- deflection, vibration, and drift
- design for long-term deflection
- camber
- expansion and contraction
- durability

The ASCE 7 appendix introduction notes that "serviceability shall be checked using appropriate loads for the limit state being considered." The commentary to the Appendix provides some suggestions with regard to loads and load combinations. For example, two load combinations are suggested for vertical deflections of framing members:

$$D + L$$
$$D + 0.5S$$

These are recommended for limit states "involving visually objectionable deformations, repairable cracking or other damage to interior finishes, and other short term effects." For serviceability limit states "involving creep, settlement, or other similar long-term or permanent effects," the suggested load combination is:

$$D + 0.5L$$

With regard to lateral drift, the commentary cites the common interstory drift limits of $L/600$ to $L/400$. The commentary also notes that an absolute interstory drift limit of $^3/_8$ in. (10 mm) may often be appropriate to prevent damage to non-structural elements. This absolute limit may be relaxed if there is appropriate detailing in the non-structural elements to accommodate greater drift. The commentary provides the following load combination for checking short-term effects:

$$D + 0.5L + 0.7W$$

The reader is encouraged to refer to the appendix commentary, which provides additional insights into the issue of serviceability and an extensive list of references. This guide addresses the following serviceability design criteria:

- roofing
- skylights
- cladding
- interior partitions and ceilings
- vibrations
- equipment

Most of these criteria limit relative and absolute deflection and, in the case of vibrations, place limits on the range of response and controls for the physical characteristics of structures and elements. Additionally, the presentation and discussion of a consistent loading and analysis approach is essential to these criteria. Without these three elements (load, analysis approach, and serviceability limit) a serviceability design criterion is useless.

This design guide provides serviceability design criteria for selected applications. Source material has been documented wherever possible. Many of the design criteria are based upon the authors' own judgment and rules of thumb from their own experience. It should be noted that when applicable building codes mandate specific deflection limits, the code requirements supersede the recommendations of this design guide.

Structures framed in structural steel accommodate numerous occupancies and building types. The design guide addresses ten occupancy types and the specific serviceability design considerations associated with these occupancies as follows:

- Storage/Warehouses
- Manufacturing
- Heavy Industrial/Mill Buildings
- Mercantile/Shopping Malls
- Health Care and Laboratory Facilities
- Educational
- Office Buildings
- Parking Structures
- Residential/Apartments/Hotels
- Assembly/Arenas
- Seismic Applications

Additionally, the design guide provides in-depth coverage of the following specific areas of serviceability:

- Design considerations relative to roofing, including ponding stability, roofing, membrane roofs, and metal roofs.
- Design considerations relative to skylights.
- Design considerations relative to cladding, frame deformation, and drift, including cladding-structure interaction, foundation-supported cladding for gravity loads, frame-supported cladding at columns, frame-supported cladding for gravity loads along spandrels, and special considerations for tall buildings.
- Design considerations relative to interior partitions and ceilings, including support deflection, flat and level floors, specifying camber and camber tolerances, and maintaining floor elevation.
- Design considerations relative to vibration/acceleration, including basic discussions of human response to vibration, machines and vibration, tall building acceleration—motion perception, and reference to the AISC floor vibration design guide for more detailed information.
- Design considerations relative to equipment, including elevators, conveyors, cranes, and mechanical equipment.

Design Guide 3: Serviceability Design Considerations for Steel Buildings, 2nd ed., *is available online through AISC's ePubs membership area at* ***www.aisc.org/ePubs****. AISC gratefully acknowledges the efforts of the three authors of the design guide: James Fisher and Michael West, both of Computerized Structural Design, Inc., and Lawrence G. Griffis, of Walter P. Moore Engineers and Consultants.* ★