Part II—Building

CHAPTER 5

STABILITY

SECTION 501

STRUCTURAL FORCES

General discussion

Section 501 provides the requirements for the structural design of buildings and other structures. This section specifies the forces for which structures need to be designed and the required performance.

This section requires a structure to be designed for all the expected forces that the structure will be subjected to throughout its life. This is the same requirement found in Chapter 16 of the *International Building Code*.

The principles for the design of structures are the same regardless of whether the prescriptive or the performance code is used. The methods for analysis will be the same for both approaches. The performance code gives the designer more flexibility in determining the expected forces and prescribes the performance of the structure when subjected to particular forces. The designer can look to the design performance level desired of the structure rather than simply applying a minimum solution.

Structural forces are related to the material chapters of the prescriptive code—including the design of masonry, wood, steel, concrete, and aluminum—as well as to other portions of the code.

This document encourages building owners to become involved in the decision-making process that determines the design performance level of a building in relation to a specific event such as an earthquake. This code prescribes a minimum design performance level, based on the intended use of the building, but an owner may need to enhance the performance for different reasons. The current prescriptive approaches do not clearly state the performance level the code provides. Therefore, an owner is often not aware that he or she may not be getting the performance level desired from the building. The approach provided in this code, specifically in Chapter 3, is intended to address this issue.

501.1 Objective

The objective statement for structural forces clarifies what is required with respect to the structural design of buildings and other structures. This statement has three parts, and each part has been written with specific intentions for structural design.

The first part of the statement, "to provide a desired level of structural performance," requires that buildings be designed to perform to acceptable levels. These levels may be similar for all structures subjected to a specific loading. For example, buildings must be designed so that all structural members are within allowable stress levels and acceptable deformations when subjected to expected dead and live loads. This would be a reasonable level of structural performance and would apply to all buildings.

However, there are times when different levels of structural performance are acceptable for a given event. For example, during a major earthquake (also known as a rare earthquake based on the frequency of occurrence), it would be reasonable to expect severe damage to a single-family dwelling, moderate damage to a school, and minor damage to a hospital. In this example, these would all be reasonable levels of structural performance. In no event would collapse be a reasonable performance level.

The second part of the statement, "when structures are subjected to the loads that are expected," requires buildings and other structures to be designed for generally accepted loads and load combinations. For example, the *International Building Code* specifies the live load for various types of occupancies. These would be examples of generally accepted loads. The design of a concrete floor requires that the calculated floor dead load be added to the specified live load along with other applicable loads for partitions, mechanical equipment, etc., and that the floor be designed for the combination of all these loads. This is an example of a generally accepted load combination.

The last statement, "during construction or alteration and throughout the intended life," requires that buildings or other structures perform not only during their construction and subsequent alteration but also that the durability of the structure be sustained throughout its life.

The building or structure shall perform as intended under normal conditions. Performance levels deemed appropriate must be defined by the following limiting states of tolerable damage: structural and nonstructural performance levels shall be applicable to natural, technological, and fire hazard events reasonably expected to impact the structural and nonstructural systems during the projected life of the building or structure.

Mild impact. During and after a hazard event, basic vertical- and lateral-force-resisting systems of the building are expected to retain their entire pre-hazard event strength and stiffness. Minor structural damage that occurs as a result of a hazard event shall not delay re-occupancy.

During and after a hazard event, nonstructural systems required for normal building use, including lighting, glazing, plumbing, HVAC, and computer systems, must remain fully operational, although minor cleanup and repair of some items may be required. Basic access and life-safety systems, including doors, stairways, elevators, emergency lighting, fire alarms, and suppression systems, shall be fully operational. Large or heavy items that pose a falling hazard, including parapets, cladding panels, heavy plaster ceilings, suspended ceilings, glazing systems, lighting fixtures, and storage racks, shall be designed to prevent damage or failure of the items from excessive movement.

Moderate impact. During and after a hazard event, basic vertical- and lateral-force-resisting systems of the building are expected to retain nearly all their pre-hazard event strength and stiffness. Moderate structural damage may occur as a result of the hazard event and will delay re-occupancy; however, the structural damage should not be so extensive as to prevent repair or rehabilitation.

During and after a hazard event, nonstructural systems required for normal building use, including lighting, glazing, plumbing, HVAC and computer systems, shall remain significantly functional, although cleanup and repair of some items may be required. Basic access and life-safety systems including doors, stairways, elevators, emergency lighting, fire alarms, and suppression systems shall remain fully operational.

High impact. During and after a hazard event, structural elements and components are expected to have significant damage. However, the building or structure shall be designed such that hazards from large falling debris, either inside or outside the building, are prevented. The amount of structural damage shall not be such that repair of the structure is not possible; however, significant delays in re-occupancy or a decision not to repair the damage may result.

During and after a hazard event, nonstructural systems required for normal building use, including lighting, glazing, plumbing, HVAC, and computer systems, may be significantly damaged, and their functions may be limited. Egress routes within the building may be impaired by lightweight debris, and the HVAC, plumbing, and fire safety systems may be damaged, resulting in loss of function.

Severe impact. During and after a hazard event, significant degradation in the stiffness and strength of the lateral-force-resisting system, large permanent deformation of the structure and, to a more limited extent, degradation in vertical load-carrying capacity must be expected. However, all significant components of the gravity-load-resisting system must continue to carry their gravity load demands. It shall be expected that the structure may not be technically practical to repair and is not safe for re-occupancy, as additional hazard event activity, even at a reduced level, could induce collapse.

During and after a hazard event, nonstructural systems required for normal building use, including lighting, plumbing, glazing, HVAC, and computer systems may be completely nonfunctional. Egress routes within the building may be impaired by debris, and the HVAC, plumbing, and fire safety systems may be significantly damaged, resulting in loss of function. The building or structure shall be designed to avoid failures that could injure large numbers of persons, either inside or outside the building or structure. Significant failure of large or heavy items such as parapets, cladding panels, heavy plaster ceilings, suspended ceilings, glazing systems, lighting fixtures, or storage racks may pose a falling hazard.

501.2 Functional statements

The first statement specifies that the structure should be designed to provide a reasonable level of structural performance to protect the occupants from injury. Because the needs of the occupants vary, differing design performance levels would be required for critical occupancies such as hospitals and emergency rescue facilities as well as for high occupancy buildings such as large theaters and auditoriums. A specific reference is made to Chapter 3, which provides guidance in determining the design performance level.

The second statement indicates that the structure must be designed and constructed to achieve acceptable performance to protect property, both on-site as well as adjacent to the site. The property (or "amenity," as used in this section) would not only be the structure itself but would also include its contents. Again, depending on the needs of the owner, occupants, and community, this performance level may vary.

501.3 Performance requirements

The performance requirements are specified in seven sections. The first section requires that structures and portions of structures remain stable and not collapse during construction or alteration through the intended life of the structure. This section requires that structures be designed so that there are no hazards during construction and so that the materials used are durable and maintained throughout the life of the structure.

The second section recognizes that structures will, from time to time, experience minor damage from a variety of hazards such as fires, small earthquakes, or over-stresses due to concentrated loads. This section requires the structure as a whole to be capable of absorbing these local damage areas without causing major damage to the entire structure. For example, this may require that buildings be provided with more than one line of resistance in each direction for lateral loads.

The third section requires that the deformation of the structure from design loads be within tolerable limits. For example, under dead and live loads, the floor of a building should not vibrate or deflect so as to cause discomfort to the tenants. Also, under seismic loads, the structure should be designed so that it does not deflect an amount sufficient to impact adjacent structures.

The fourth section specifies the forces that the structure must be designed to resist. This list covers some of the loads addressed in Section 501.3.4.

1., 2., 3. The design professional must evaluate all loads and combinations of loads as is accepted standard practice. For dead, live, impact, and other loads not specifically commented on below, the designer must evaluate best current practice as recognized in authoritative documents. In all cases, the design engineer must demonstrate that the magnitude of events is appropriate for the performance level and magnitude of damage to be tolerated.

4. Explosion hazards can be described in terms of exceeding a defined energy release within a building, structure, or portion of a building or structure. Pressure loads can also be used to define explosion hazards. In all cases, the design engineer must demonstrate that the magnitude of events is appropriate for the performance level and magnitude of damage to be tolerated.
5. Soil and hydrostatic loads can play a critical role in the performance of structures. These loads will be site-specific and are heavily dependant on the type of soil and location relative to water sources.
6. Flood hazards are described in terms of the mean return period for the 1-percent annual chance flood event (100 years) and the 0.2-percent annual chance flood event (500 years). For many locations, the land adjacent to bodies of water that may be affected by floods of one or both of these mean return periods is shown on maps prepared by the Federal Emergency Management Agency. The area that is expected to be inundated by the 1-percent annual chance flood is commonly known as the "A Zone" (the "V Zone" along some open coastlines). Where such maps do not show the presence of a flood hazard adjacent to a body of water and for flood hazards with mean return periods greater than the 100- or 500-year flood events, such events are to be determined on a site-specific basis. Standard methodologies are to be used to make the determinations and may include application of rainfall-runoff models, hydraulic models, storm surge models, and/ or evaluation of historic records of storm events and flooding. ASCE 24, Flood Resistant Design and Construction, covers standard methodologies to account for flood hazards.
7. Wind hazards are described in terms of the mean return period of a defined magnitude of wind speed (3-second gust) in defined geographic areas (zones). The authoritative document, ASCE 7 and Commentary, was used as the primary reference for the mean return periods.
8. If there are other forces that are expected to affect the structural performance of the structure, the designer must also design for those other forces and consequences. Such forces can include, but are not limited to, windborne debris impact loads or hail impact loads and shall be accounted for in the design of structures to achieve the desired performance level.
9. Snow hazards are described in terms of the mean return period of a defined magnitude of surface snow precipitation in defined geographic areas (zones). The authoritative document, ASCE 7 and Commentary, was used as the primary reference for the mean return periods.
10. Rain loads are provided in terms of mean return intervals for both primary and secondary drainage capacity requirements.
11. Seismic hazards are described in terms of the mean return period of a defined magnitude of seismic-induced ground motion in defined geographic areas (zones). See the following section for more detailed information.

    In the 1996 *Recommended Lateral Force Requirements and Commentary* [Structural Engineering Association of California (SEAOC) Blue Book], Appendix B: Conceptual Framework for Performance-Based Seismic Design (Vision 2000), the design load is specified by a series of four earthquake design levels (events) and is expressed as a corresponding set of probabilistic earthquake ground motions (p. 396).

    "Recurrence Interval" is comparable to "mean return period," and "frequent" through "very rare" events are comparable respectively to "small" through "very large" events in the performance code. The 1999 SEAOC Blue Book, Appendix G, is identical to the above (p. 320). The rare event is also specified as the design level earthquake ground motion (Commentary to 1986 SEAOC Blue Book, p. 97).

Event	Probability of Exceedence	Recurrence Interval
Frequent	50% in 30 years	43 years
Occasional	50% in 50 years	72 years
Rare	10% in 50 years	475 years
Very rare	10% in 100 years	970 years

In the 1998 *Performance-Based Seismic Engineering Guidelines, Part I–Strength Design Adaptation, Draft No. 1* (SEAOC Seismology PBE Ad hoc Committee, dated 5/98), the design load is specified the same as in Appendix B of the 1996 SEAOC Blue Book, except the probabilistic ground motions for the frequent and very rare events are revised. The recurrence interval for the frequent event has decreased. The revision was done partly to express the interval in terms of the same 50-year probability of exceedance as the occasional and rare events.

The very rare event is no longer specified probabilistically but deterministically as approximately 150 percent of the rare event. In the Western United States, this typically corresponds to a mean recurrence interval of 2,000+ years. This change was made partly because of the use of the very rare event design load for buildings near active faults. SEAOC apparently has calibrated this with enough confidence to specify a very rare event as 150 percent of a rare event.

Event	Probability of Exceedence	Recurrence Interval
Frequent	87% in 50 years	25 years
Occasional	50% in 50 years	72 years
Rare	10% in 50 years	475 years
Very rare	Not applicable	Not applicable

In the 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA 302 and 303, dated 2/98), the design load is specified at the very rare event level. The other event levels are not mentioned. The very rare event is expressed as the lesser of the probabilistic and deterministic maximum earthquake ground motions. The probabilistic level is that which will be developed with a 2-percent probability of being exceeded in 50 years (2 percent in 50 years), equivalent to an approximate mean recurrence interval of 2,500 years. The deterministic level is specified as 150 percent of the median 5 percent damped spectral response accelerations at all periods resulting from characteristic earthquakes on any known active fault within a particular region. The spectral response accelerations are mapped and included in the FEMA document.

The 1998 FEMA-273 NEHRP *Guidelines for the Seismic Rehabilitation of Buildings* uses the following:

Event	Probability of Exceedence	Recurrence Interval
Medium	50% in 50 years	72 years
Large	10% in 50 years	474 years
Very large	2% in 50 years	2,475 years

A small event comparable to the frequent event specified in the above references is not included. Also, an event between the medium and large events is included that is not found in any of the above references.

The performance code proposes to use a combination of the 1998 SEAOC and FEMA 273 data as follows:

Event	Probability of Exceedence	Recurrence Interval
Small	87% in 50 years	25 years
Medium	50% in 50 years	72 years
Large	10% in 50 years	474 years
Very large	2% in 50 years	2,475 years

The language "Large" and "Very large" in the Event column originates from FEMA-302, NEHRP *Recommended Provisions for the Seismic Regulation of Buildings and Other Structures*. These particular provisions were also the basis for the *International Building Code* requirements. More specifically, in FEMA 302 and the IBC, Maximum Considered Earthquake (MCE) ground–shaking demands (similar to the very large demands in this code) in near-fault regions such as coastal California or the New Madrid region of Missouri are taken as the lesser of either probabilistically-determined shaking or deterministic shaking based on the largest earthquake likely to occur in the region. Proposed Footnote 2 establishes these same criteria. Also, FEMA 302 and the IBC Design (DBE) ground-shaking demands (similar to large loading) are taken as demands with two-thirds the intensity of motion as MCE (Very large) demands. Footnote 1 ensures that these values in the performance code and the IBC are similar.

12. Ice hazards are described in terms of the mean recurrence interval of a defined magnitude of surface icing in defined geographic areas (zones). The authoritative document, ASCE 7 and Commentary, was used as the primary reference for the mean return periods.
13. For hail loads see Item 8.

The fifth section recognizes the need to address uncertainties involved with design, construction, building use, and material properties.

The sixth section requires that alterations and demolitions be done in a safe manner to avoid injury to the workers on the site and the public adjacent to the site.

The seventh section requires that the grading of sites be done in a safe manner so as to prevent damage to the adjacent property.