15.6.4 Special Hydraulic Structures
Special hydraulic structures are structures that are contained inside liquid-containing structures. These structures are exposed to liquids on both wall surfaces at the same head elevation under normal operating conditions. Special hydraulic structures are subjected to out-of-plane forces only during an earthquake where the structure is subjected to differential hydrodynamic fluid forces. Examples of special hydraulic structures include separation walls, baffle walls, weirs, and other similar structures.

15.6.4.1 Design Basis
Special hydraulic structures shall be designed for out-of-phase movement of the fluid. Unbalanced forces from the motion of the liquid must be applied simultaneously “in front of” and “behind” these elements.

Structures subject to hydrodynamic pressures induced by earthquakes shall be designed for rigid body and sloshing liquid forces and their own inertia force. The height of sloshing shall be determined and compared to the freeboard height of the structure. Interior elements, such as baffles or roof supports, also shall be designed for the effects of unbalanced forces and sloshing.

15.6.5 Secondary Containment Systems
Secondary containment systems, such as impoundment dikes and walls, shall meet the requirements of the applicable standards for tanks and vessels and the authority having jurisdiction.

Secondary containment systems shall be designed to withstand the effects of the maximum considered earthquake ground motion where empty and two-thirds of the maximum considered earthquake ground motion where full including all hydrodynamic forces as determined in accordance with the procedures of Section 11.4. Where determined by the risk assessment required by Section 1.5.2 or by the authority having jurisdiction that the site may be subject to aftershocks of the same magnitude as the maximum considered motion, secondary containment systems shall be designed to withstand the effects of the maximum considered earthquake ground motion where full including all hydrodynamic forces as determined in accordance with the procedures of Section 11.4.

15.6.5.1 Freeboard
Sloshing of the liquid within the secondary containment area shall be considered in determining the height of the impound. The primary containment has not been designed with a reduction in the structure category (i.e., no reduction in importance factor $I_e$) as permitted by Section 1.5.3, no freeboard provision is required. Where the primary containment has been designed for a reduced structure category (i.e., importance factor $I_e$ reduced) as permitted by Section 1.5.3, a minimum freeboard, $\delta_s$, shall be provided where

$$\delta_s = 0.42DS_{ac}$$

where $S_{ac}$ is the spectral acceleration of the convective component and is determined according to the procedures of Section 15.7.6.1 using 0.5 percent damping. For circular impoundment dikes, $D$ shall be taken as the diameter of the impoundment dike. For rectangular impoundment dikes, $D$ shall be taken as the plan dimension of the impoundment dike, $L$, for the direction under consideration.

15.6.6 Telecommunication Towers
Self-supporting and guyed telecommunication towers shall be designed to resist seismic lateral forces determined from a substantiated analysis using reference documents.

15.7 TANKS AND VESSELS

15.7.1 General
This section applies to all tanks, vessels, bins, and silos, and similar containers storing liquids, gases, and granular solids supported at the base (hereafter referred to generically as “tanks and vessels”). Tanks and vessels covered herein include reinforced concrete, prestressed concrete, steel, aluminum, and fiber-reinforced plastic materials. Tanks supported on elevated levels in buildings shall be designed in accordance with Section 15.3.

15.7.2 Design Basis
Tanks and vessels storing liquids, gases, and granular solids shall be designed in accordance with this standard and shall be designed to meet the requirements of the applicable reference documents listed in Chapter 23. Resistance to seismic forces shall be determined from a substantiated analysis based on the applicable reference documents listed in Chapter 23.

a. Damping for the convective (sloshing) force component shall be taken as 0.5 percent.
b. Impulsive and convective components shall be combined by the direct sum or the square root of
technical one. Model building codes such as the International Building Code (ICC 2009) and NFPA-5000 (NFPA 2006) contain prescriptive lists of building types by occupancy category. Individual communities can alter these lists when they adopt local codes based on the model code, and individual owners or operators can elect to design individual buildings to higher occupancy categories based on personal risk management decisions. Classification continues to reflect a progression of the anticipated seriousness of the consequence of failure from lowest risk to human life (Risk Category I) to the highest (Risk Category IV). Elimination of the specific examples of buildings that fall into each category has the benefit that it eliminates the potential for conflict between the standard and locally adopted codes and also provides individual communities and development teams the flexibility to interpret acceptable risk for individual projects.

Historically, the building codes and the standard have used a variety of factors to determine the occupancy category of a building. These factors include the total number of persons who would be at risk were failure to occur, the total number of persons present in a single room or occupied area, the mobility of the occupants and their ability to cope with dangerous situations, the potential for release of toxic materials, and the loss of services vital to the welfare of the community.

Risk Category I structures generally encompass buildings and structures that normally are unoccupied and that would result in negligible risk to the public should they fail. Structures typically classified in this category have included barns, storage shelters, gatehouses, and similar small structures. Risk Category II includes the vast majority of structures, including most residential, commercial, and industrial buildings, and has historically been designated as containing all those buildings and structures not specifically classified as conforming to another category.

Risk Category III includes buildings and structures that house a large number of persons in one place, such as theaters, lecture halls, and similar assembly uses; buildings with persons having limited mobility or ability to escape to a safe haven in the event of failure, including elementary schools, prisons, and small healthcare facilities. This category has also included structures associated with utilities required to protect the health and safety of a community, including power generating stations and water treatment and sewage treatment plants. It has also included structures housing hazardous substances, such as explosives or toxins, which if released in quantity could endanger the surrounding community, such as structures in petrochemical process facilities containing large quantities of H2S or ammonia.

Failures of power plants that supply electricity on the national grid can cause substantial economic losses and disruption to civilian life when their failures can trigger other plants to go offline in succession. The result can be massive and potentially extended power outage, shortage, or both that lead to huge economic losses because of idled industries and a serious disruption of civilian life because of inoperable subways, road traffic signals, and so forth. One such event occurred in parts of Canada and the northeastern United States in August 2003.

Failures of water and sewage treatment facilities can cause disruption to civilian life because these failures can cause large-scale (but mostly non-life-threatening) public health risks caused by the inability to treat sewage and to provide drinking water.

Failures of major telecommunication centers can cause disruption to civilian life by depriving users of access to important emergency information (using radio, television, and phone communication) and by causing substantial economic losses associated with widespread interruption of business.

Risk Category IV has traditionally included structures, the failure of which would inhibit the availability of essential community services necessary to cope with an emergency situation. Buildings and structures typically grouped in Risk Category IV include hospitals, police stations, fire stations, emergency communication centers, and similar uses.

Ancillary structures required for the operation of Risk Category IV facilities during an emergency also are included in this risk category. When deciding whether an ancillary structure or a structure that supports such functions as fire suppression is Risk Category IV, the design professional must decide whether failure of the subject structure will adversely affect the essential function of the facility. In addition to essential facilities, buildings and other structures containing extremely hazardous materials have been added to Risk Category IV to recognize the potential devastating effect a release of extremely hazardous materials may have on a population.

The criteria that have historically been used to assign individual buildings and structures to occupancy categories have not been consistent and sometimes have been based on considerations that are more appropriate to fire and life safety than to structural failure. For example, university buildings housing more than a few hundred students have been
Criteria for Mechanical Anchors in Concrete Elements and AC308, Acceptance Criteria for Post-installed Adhesive Anchors in Concrete Elements. For post-installed anchors in masonry, seismic prequalification procedures are contained in ICC-ES acceptance criteria AC01, Acceptance Criteria for Expansion Anchors in Masonry Elements AC58, Acceptance Criteria for Adhesive Anchors in Masonry Elements and AC106, Acceptance Criteria for Predrilled Fasteners (Screw Anchors) in Masonry Element.

C15.6.5 Secondary Containment Systems

This section differs from the requirements in NEHRP (2003). In preparing the 2002 edition, the ASCE 7 committee felt that the NEHRP (2000) requirements for designing all impoundment dikes for the maximum considered earthquake ground motion when full and to size all impoundment dikes for the sloshing wave was too conservative. Designing the impoundment dike full for the maximum considered earthquake assumes the failure of the primary containment and the occurrence of a significant aftershock. Significant (same magnitude as the maximum considered earthquake ground motion) aftershocks are rare and do not occur in all locations.

While designing for aftershocks has never been part of the design loading philosophy found in ASCE 7, secondary containment must be designed full for an aftershock to protect the general public. The use of two-thirds of the maximum considered ground motion as the magnitude of the design aftershock is supported by Bath’s Law, according to which, the maximum expected aftershock magnitude may be estimated as 1.2 scale units below that of the main shock magnitude.

The risk assessment and risk management plans as described in Section 1.5.2 should be used to determine when the secondary containment is to be designed for the full maximum considered earthquake seismic when full. The decision to design secondary containment for this more severe condition should be based on the likelihood of a significant aftershock occurring at the particular site and the risk posed to the general public by the release of the hazardous material from the secondary containment.

Secondary containment systems must be designed to contain the sloshing wave where the release of liquid would place the general public at risk by exposing them to hazardous materials, scouring of foundations of adjacent structures, or causing other damage to the adjacent structures.

C15.6.6 Telecommunication Towers

This section as presented in ASCE 7 differs from the requirements in NEHRP (2000). Telecommunication towers are contained in the Appendix to NEHRP (2000). Although limited in what is presented, the ASCE 7 committee felt that it benefited the design professional and building officials to leave these requirements in the standard.

C15.7 TANKS AND VESSELS

This section contains specific requirements for tanks and vessels. Most (if not all) industry standards covering the design of tanks and vessels contain seismic design requirements based on earlier (lower force level) seismic codes. Many of the provisions of the standard show how to modify existing industry standards to get to the same force levels as required by ASCE 7-05 and NEHRP (2003). As the organizations responsible for maintaining these industry standards adopt seismic provisions based on NEHRP, the specific requirements in ASCE 7 can be deleted and direct reference made to the industry standards.

C15.7.2 Design Basis

The effective increase in liquid density specified in Section 15.7.2.c(1) is not to be applied to the liquid density used in Eq. 15-9 for the calculation of the hydrodynamic hoop forces defined in Section 15.7.1.c(2). The effective liquid density increase specified in Section 15.7.2.c(1) is automatically accomplished by adding $N_h$ (Eq. 15-9) to the static liquid hoop force per unit height.

C15.7.6 Ground-Supported Storage Tanks for Liquids

In this section, the same force reduction factor $R$ is applied to the impulsive and the convective base shears. The convective response is generally so flexible (period between 2s and 10s) that any increased flexibility on account of nonlinearity has negligible influence on the period and damping of the convective response. It is, therefore, not justified to apply the ductility reduction to the convective response—however, the overstrength reduction can still be applied. The overstrength factor, $\Omega_o$, unfortunately represents an upper-bound value of overstrength. Therefore, the Seismic Task Committee decided to use an approximation of the lower bound of overstrength equal to 1.5.

Additionally, the formulation provided for the convective load underestimates the load when
stiffness and all mechanical, electrical, plumbing, and other systems necessary for the normal operation of the structure are expected to be functional. If repairs are required, these can be conducted at the convenience of the occupants.

The risk to life safety during an earthquake in a structure meeting this performance level is negligible. Note, that in order for a structure to meet this level, all utilities required for normal operation must be available, either through standard public service or emergency sources maintained for that purpose. Except for very low levels of ground motion, it is generally not practical to design structures to meet this performance level.

The immediate occupancy level is similar to the operational level although somewhat more damage to nonstructural systems is anticipated. Damage to the structural systems is very slight and the structure retains all of its pre-earthquake strength and nearly all of its stiffness. Nonstructural elements, including ceilings, cladding, and mechanical and electrical components, remain secured and do not represent hazards. Exterior nonstructural wall elements and roof elements continue to provide a weather barrier, and to be otherwise serviceable. The structure remains safe to occupy; however, some repair and clean-up is probably required before the structure can be restored to normal service. In particular, it is expected that utilities necessary for normal function of all systems will not be available, although those necessary for life safety systems would be provided. Some equipment and systems used in normal function of the structure may experience internal damage due to shaking of the structure, but most would be expected to operate if the necessary utility service was available. Similar to the operational level, the risk to life safety during an earthquake in a structure meeting this performance level is negligible. Structural repair may be completed at the occupants’ convenience, however, significant nonstructural repair and cleanup is probably required before normal function of the structure can be restored.

At the life safety level, significant structural and nonstructural damage has occurred. The structure may have lost a substantial amount of its original lateral stiffness and strength but still retains a significant margin against collapse. The structure may have permanent lateral offset and some elements of the seismic-force-resisting system may exhibit substantial cracking, spalling, yielding, and buckling. Nonstructural elements of the structure, while secured and not presenting falling hazards, are severely damaged and cannot function. The structure is not safe for continued occupancy until repairs are instituted as strong ground motion from aftershocks could result in life threatening damage. Repair of the structure is expected to be feasible, however, it may not be economically attractive to do so. The risk to life during an earthquake, in a structure meeting this performance level is very low.

At the collapse prevention level a structure has sustained nearly complete damage. The seismic-force-resisting system has lost most of its original stiffness and strength and little margin remains against collapse. Substantial degradation of the structural elements has occurred including extensive cracking and spalling of masonry and concrete elements and buckling and fracture of steel elements. The structure may have significant permanent lateral offset. Nonstructural elements of the structure have experienced substantial damage and may have become dislodged creating falling hazards. The structure is unsafe for occupancy as even relatively moderate ground motion from aftershocks could induce collapse. Repair of the structure and restoration to service is probably not practically achievable.

The design ground motion contained in the Provisions is taken as two-thirds of the maximum considered earthquake ground motion. Such ground motion may have a return period varying from a few hundred years to a few thousand years, depending on the regional seismicity. It is expected that structures designed in accordance with the requirements for Group I would achieve the life safety or better performance level for these ground motions. Structures designed in accordance with the requirements for Group III should be able to achieve the Immediate Occupancy or better performance level for this ground motion. Structures designed to the requirements for Group II would be expected to achieve performance better than the life safety level but perhaps less than the immediate occupancy level for this ground motion.
shear modulus for the materials as a function of the level of shaking. In general, softer soils with lower shear-wave velocities exhibit greater amplifications than stiffer soils with higher shear-wave velocities. Increased levels of ground shaking result in increased soil stress-strain nonlinearity and increased soil damping which, in general, reduces the amplification, especially for shorter periods. Furthermore, for soil deposits of sufficient thickness, soil amplification is generally greater at longer periods than at shorter periods.

An extensive discussion of the development of the $F_s$ and $F_v$ site coefficients is presented by Dobry, et al. (2000). Since the development of these coefficients and the development of a community consensus regarding their values in 1992, earthquake events have provided additional strong-motion data from which to infer site amplifications. Analyses conducted on the basis of these more recent data are reported by a number of researchers including Crouse and McGuire (1996), Dobry et al. (1999), Silva et al. (2000), Joyner and Boore (2000), Field (2000), Steidl (2000), Rodriguez-Marek et al. (2001), Borchert (2002), and Stewart et al. (2003). Although the results of these studies vary, the site amplification factors are generally consistent with those in Tables 11.4-1 and 11.4-2.

**C11.4.5 Design Response Spectrum.** The design response spectrum (Figure 11.4-1) consists of several segments. The constant-acceleration segment covers the period band from $T_s$ to $T_L$; response accelerations in this band are constant and equal to $S_{DS}$. The constant-velocity segment covers the period band from $T_s$ to $T_L$, and the response accelerations in this band are proportional to $1/T$ with the response acceleration at 1-sec period equal to $S_{DI}$. The long-period portion of the design response spectrum is defined on the basis of the parameter, $T_L$, the period that marks the transition from the constant-velocity segment to the constant-displacement segment of the design response spectrum. Response accelerations in the constant-displacement segment, where $T \geq T_L$, are proportional to $1/T^2$. Values of $T_L$ are provided on maps in Figures 22-15 through 22-20.

The $T_L$ maps were prepared following a two-step procedure. First, a correlation between earthquake magnitude and $T_L$ was established. Then, the modal magnitude from deaggregation of the ground-motion seismic hazard at a 2-second period (1-second period for Hawaii) was mapped. Details of the procedure and the rational for it are found in Crouse et al. (2006).

**C11.4.7 Site-Specific Ground Motion Procedures.** The objective of a site-specific ground-motion analysis is to determine ground motions for local seismic and site conditions with higher confidence than is possible using the general procedure of Sections 11.4.

Near-source effects on horizontal response spectra for periods of vibration greater than approximately 0.5 second include directivity, which increases ground motions for fault rupture propagating toward the site, and directionality, which increases ground motions normal (perpendicular) to the strike of the fault. These effects are discussed in Somerville et al. (1997) and Abrahamson (2000).

**C11.5 IMPORTANCE FACTOR AND OCCUPANCY CATEGORY**

Large earthquakes are rare events that will include severe ground motions. Such events are expected to result in damage to structures even if they were designed and built in accordance with the minimum requirements of the standard. The consequence of structural damage or failure is not the same for the various types of structures located within a given community. Serious damage to certain classes of structures, such as critical facilities (e.g., hospitals), will disproportionately affect a community. The fundamental purpose of this section and subsequent requirements that depend on this section is to improve the ability of a community to recover from a damaging earthquake by tailoring the seismic protection requirements to the relative importance of that structure. That purpose is achieved by requiring better performance of those structures that:

1. Are necessary to response and recovery efforts immediately following an earthquake,
2. Present the potential for catastrophic loss in the event of an earthquake, or
3. House a very large number of occupants or occupants less able to care for themselves than the average.

The first basis for seismic design in the standard is that structures will have a suitably low likelihood of collapse in the very rare event defined as the maximum considered earthquake (MCE) ground motion. A second basis is that life threatening damage, primarily from failure of nonstructural elements in and on structures, will be unlikely in an unusual but less rare earthquake ground motion, which is given as the design earthquake ground motion (defined as two-thirds of the MCE).

Given the occurrence of ground motion equivalent to the MCE, a population of structures built to meet these design objectives will probably still experience substantial damage in many structures, rendering these structures unfit for occupancy or use. Experience in past earthquakes around the world has demonstrated that there will be an immediate need to treat injured people, to extinguish fires and prevent conflagration, to rescue people from severely damaged or collapsed structures, and to provide sustenance to a population deprived of its normal means. Experience also has shown that these needs are best met when structures essential to response and recovery activities remain functional.
The standard addresses these objectives by requiring that each structure be assigned to one of the four occupancy categories presented in Chapter 1 and by assigning an importance factor to the structure based upon that occupancy category. (The two lowest categories, Ordinary and Low Hazard, are combined for all purposes within the seismic provisions). The occupancy category is then used as one of two components in determining the Seismic Design Category (see Section C11.6) and is a primary factor in setting drift limits for building structures under the design earthquake ground motion (see Section C12.12).

Figure C11.5-1 shows the combined intent of these requirements for design. The vertical scale is the likelihood of the ground motion with the MCE being the rarest considered. The horizontal scale is the level of performance of the structure and attached nonstructural components from collapse prevention at the low end to operational at the high end. (These performance levels are discussed further at other locations in the commentary.) The basic objective of collapse prevention at the MCE for ordinary structures (Occupancy Category II) is shown at the lower right by the solid triangle; protection from life-threatening damage at the design ground motion (defined by the standard as two-thirds of the MCE) is shown by the open triangle. The performance implied for higher occupancy categories is shown by square and circles. The performance anticipated for less severe ground motion is shown by dotted symbols. The three (net) classes and the numerical values assigned are far too coarse to assure the portrayed outcome for all structures, but it is judged to be adequate for the purpose given present limitations of knowledge and tools.

C11.5.1 Importance Factor. The importance factor is used throughout the standard in quantitative criteria for strength. In most of those quantitative criteria, the importance factor is shown as a divisor on the factor $R$ or $R_p$ in order to send a message to designers that the objective is to reduce damage for important structures in addition to preventing collapse in larger ground motions. The $R$ and $R_p$ factors adjust the computed linear elastic response to a value appropriate for design; in many structures, the largest component of that adjustment is ductility (the ability of the structure to undergo repeated cycles of inelastic strain in opposing directions). Inelastic strain damages a structure so, for a given strength demand, reducing the effective $R$ factor (by means of the importance factor) increases the required yield strength, thus reducing ductility demand and related damage.

C11.5.2 Protected Access for Category IV Structures. Those structures considered essential facilities for response and recovery efforts must be accessible to carry out their purpose. For example, if the collapse of a simple canopy at a hospital could block ambulances from the emergency room admittance area, the canopy must meet the same structural standard as the hospital. This requirement must be considered in the siting of essential facilities in densely built urban areas.