CHAPTER 2
INTRODUCTION

2-1. General.

This chapter provides an introduction to the basic concepts of designing buildings to resist inertia forces and related effects caused by earthquakes. An earthquake causes vibratory ground motions at the base of a structure, and the structure actively responds to these motions. For the structure responding to a moving base there is an equivalent system: the base is fixed and the structure is acted upon by forces (called inertia forces) that cause the same distortions that occur in the moving-base system. In design, it is customary to visualize the structure as a fixed-base system acted upon by inertia forces. Seismic design involves two distinct steps: determining (or estimating) the earthquake forces that will act on the structure, and designing the structure to provide adequate strength, stiffness, and energy dissipation capabilities to withstand these forces.

2-2. Ground Motion.

a. General. The response of a given structure depends on the characteristics of the ground motion; therefore, it would be highly desirable to have a quantitative description of the ground motion that might occur at the site of the building during a major earthquake. Unfortunately, there is no description that fits all the ground motions that might occur at any particular site. The characteristics of the ground motion are dependent on the magnitude of the earthquake (i.e., the energy released), the distance from the source of the earthquake (depth, as well as horizontal distance), the distance from the surface faulting (this may or may not be the same as the horizontal distance from the source), the nature of the geological formations between the source of the earthquake and the building, and the nature of the soil in the vicinity of the building site (e.g., hard rock or alluvium). Although fully accurate prediction of ground motion is not possible, the art of ground motion prediction has progressed in recent years to the point that nationally approved design criteria have been developed by consensus groups of geotechnical and building design professionals.

b. Representation of Ground Motion. The motion at the site can be described by a single number, such as peak ground acceleration (A_g). This single number, however, does not give the information on the characteristics (or signature) of the earthquake.

(1) Response spectra. For design purposes, it would be ideal to forecast the acceleration time history of a future earthquake having a given hazard of occurrence; however, the complex random nature of an accelerogram makes it necessary to employ a more general characterization of ground motion. Specifically, the most practical representation is the earthquake response spectrum. Although this spectrum is used to describe the intensity and vibration frequency content of accelerograms, its most important advantage is that spectra from several records can be normalized, averaged, and then scaled according to seismicity to predict future ground motion at a given site. The physical definition of an acceleration response spectrum is shown in Figure 2-1. A set of linear elastic single-degree-of-freedom (SDOF) systems having a common damping ratio, **$**,

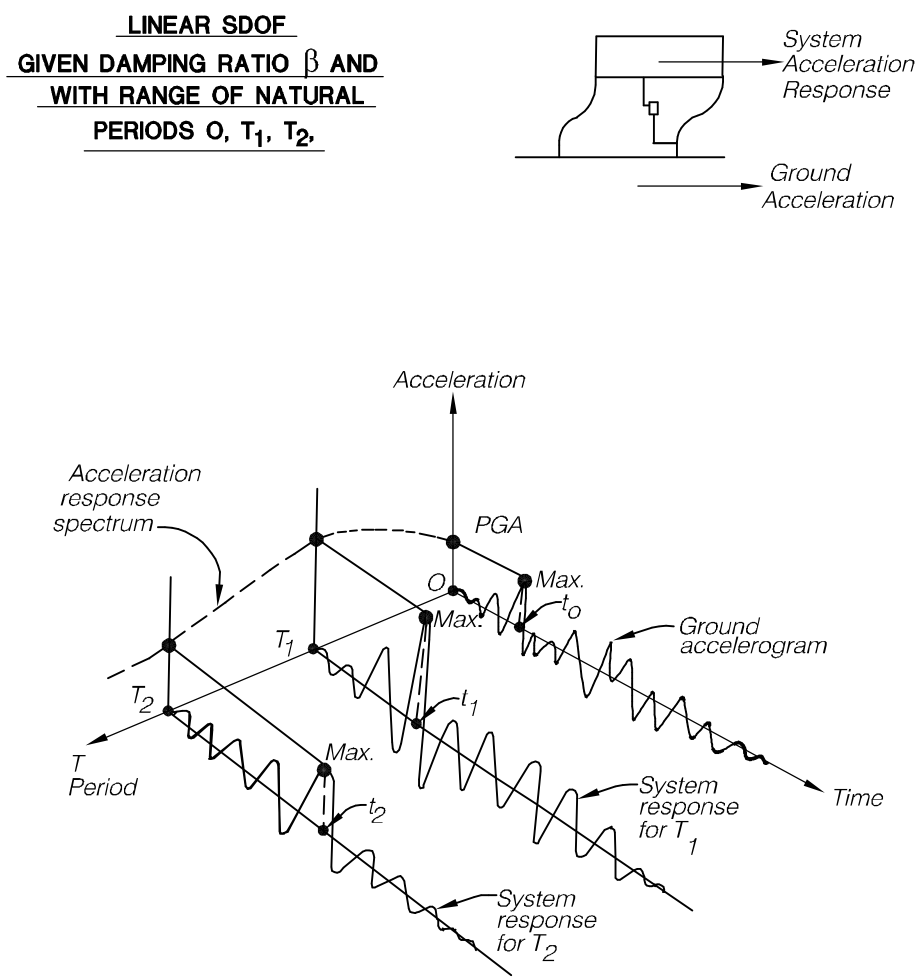


Figure 2-1 Description of acceleration response spectrum

but each having different harmonic periods over the range O, T_1, T_2, etc., is subjected to a given ground motion accelerogram. The entire time history of acceleration response is found for each system, and the corresponding maximum value, S_a, is plotted on the period axis for each system period. The curve connecting these S_a values is the acceleration response spectrum for the given accelerogram and damping ratio. The peak response of the oscillator (S_a) is a point on the response spectra for the period of the oscillator. The ground motion in this document is defined by two spectral ordinates, as described in Chapter 3. The two ordinates represent spectral response accelerations as a percentage of the acceleration due to gravity, g. Equations are also provided for the development of response spectra from the two ordinates, and for the modification of the spectral response for various soil conditions at the site. For firm sites, the design spectral ordinate at 0.2 second, S_{DS}, is roughly equivalent to two and one-half times the Z coefficient in the Uniform Building Code (UBC), or the A_a coefficient in the prior NEHRP provisions. The spectral ordinate at 1.0 second for firm sites is approximately equivalent to 1.2 times the A_v coefficient in the prior NEHRP provisions. The response spectra are prescribed for dynamic analyses, and the equations also define equivalent lateral forces for static analysis. These changes in the representation of ground motions were instigated by USGS as a result of an extensive national program to develop spectral parameters that better represent actual site response, and to incorporate the most current knowledge regarding regional seismicity. The new design values will result in higher seismic design forces, as compared to the 1997 UBC or FEMA 222A in sites near major faults and in areas of very low or negligible seismicity (e.g., UBC Zone 0). In some areas of previously low or moderate seismicity, the new seismic design forces may be lower than previously prescribed.

(2) Time histories of ground motion are required for nonlinear inelastic dynamic analyses, and can also be used for general dynamic analyses. Time histories may be actual or modified ground motion records, or may be synthetic time histories developed to match a target spectrum. Since a single time history cannot be completely representative of all possible ground motions at the site, a suite (e.g., usually at least three) of time histories is generally required. Time histories are not prescribed by this document, and their use requires authorization from the cognizant design authority.

2-3. Site Hazards Other than Ground Motion.

a. General. The analysis and design procedures of this document are primarily aimed at improving the performance of structures under the loads and resulting deformations imposed by seismic shaking. Other seismic hazards could, however, exist at the building site that could damage the structure, regardless of its ability to resist ground shaking. These hazards include fault rupture, liquefaction or other shaking-induced soil failures, landslides, and inundation from offsite effects such as dam failure or tsunami.

b. Evaluation and Mitigation. The risk and possible extent of damage from such site hazards should be considered in the site selection process. In some situations, it may be feasible to mitigate the site hazards. In many cases, the likelihood of the site hazard occurring will be sufficiently small that the design of the structure to resist ground shaking is appropriate. Where a site geological hazard exists, it may be feasible to mitigate it, either by itself or in connection with the design of the structure. It is also possible that the risk from a site hazard is so extreme and difficult to control that construction on the site will not be cost-effective. Chapter 3 and Appendices F and G provide guidance for the evaluation and mitigation of site geological hazards.

2-4. Behavior of Structures.

Buildings and other structures are composed of horizontal and vertical structural elements that resist lateral forces. The horizontal elements, diaphragms and horizontal bracing, are used to distribute the lateral forces to vertical elements. The vertical elements that are used to transfer lateral forces to the ground are shear walls, braced frames, and moment resisting frames. The structure must include complete lateral and vertical-force-resisting systems capable of providing adequate energy dissipation capacity to withstand the design ground motions within the prescribed limits of deformation and strength demand.

a. Demands of Earthquake Motion. The loads or forces that a structure sustains during an earthquake result directly from the distortions induced in the structure by the motion of the ground on which it rests. Ground motion is characterized by displacements, velocities, and accelerations that are erratic in direction, magnitude, duration, and sequence. Earthquake loads are inertia forces related to the mass, stiffness, and energy-absorbing (e.g., damping and ductility) characteristics of the structure. During the life of a structure located in a seismically active zone, it is generally expected that the structure will be subjected to many small earthquakes, some moderate earthquakes, one or more large earthquakes, and possibly a very severe earthquake. In general, it is uneconomical or impractical to design buildings to resist the forces resulting from the very severe or maximum credible earthquake within the elastic range of stress; instead, the building is designed to resist lower levels of force, using ductile systems. When the earthquake motion is large to severe, the structure is expected to yield in some of its elements. The energy-absorbing capacity (ductility) of the yielding structure will limit the degree of life-threatening damage; buildings that are properly designed and detailed can survive earthquake forces substantially greater than the forces associated with allowable stresses in the elastic range. Seismic design concepts must consider building proportions and details for their ductility and for their reserve energy-absorbing capacity for surviving the inelastic deformations that would result from the maximum expected earthquake. Special attention must be given to the connections that hold together the elements of the lateral-force-resisting system.

b. Analysis of Structural Response. As indicated above, the response of structures to severe ground motion is a complex combination of elastic and inelastic actions. Additionally, as yielding is initiated in individual structural elements, subsequent loads are redistributed among the remaining elastic elements. Linear analyses assume that the response can be adequately represented by an elastic mode of the structure with various response modification factors to represent ductility or the energy absorption capabilities of the structure. Linear elastic and dynamic analyses with a global response modification factor, *R*, are prescribed in FEMA 302, and are incorporated by reference in this document for compliance with Performance Objective 1A (Life Safety). These linear elastic analyses are also prescribed in this document for Performance Objectives 2A, 2B, and 3B with modification factors, *m*, for deformation-controlled structural components or elements. Nonlinear analyses can be either elastic or inelastic. Nonlinear elastic analyses, also known as "pushover" analyses, subject an elastic model of the structure to a predetermined pattern of static forces. A force/displacement curve is then constructed by iterative analyses with yield "hinges" placed at the yielding ends of the structural elements. Compliance is determined by matching a target displacement with acceptable inelastic deformation of the yielding elements. Nonlinear inelastic analyses are usually time-history dynamic analyses with predetermined elastic/inelastic characteristics for the structural elements. Guidance on the use and limitations of the above analytical procedures is provided in Chapters 4 and 5.

c. *Response of Elements Attached to the Structure.* Elements attached to the floors of the building or structure (e.g., mechanical equipment, ornamentation, piping, nonstructural partitions) respond to floor motion in much the same manner that the building responds to ground motion; however, the floor motion may vary substantially from the ground motion. The high-frequency components of the ground motion tend to be filtered out at the higher levels in the building, while the components of ground motion that correspond to the natural periods of vibration of the building tend to be magnified. If the elements are rigid and are rigidly attached to the structure, the forces on the elements will be in the same proportion to the mass as the forces on the structure, or $F = ma$ (i.e., the accelerations of the elements will be about the same as the acceleration of the floor on which they are supported). However, elements that are flexible and have periods of vibration close to any of the predominant modes of the building vibration will experience accelerations substantially greater than the accelerations on the structure (i.e., accelerations of elements will be greater than floor accelerations). The above actions are approximated by the design force equations in Chapter 6 of FEMA 302, and as prescribed in Chapter 10 of this document for the various performance objectives.

2-5. Fundamentals of Seismic Design.

The type of structural system used will determine the magnitude of the design lateral forces. The decision as to the type of structural system to be used will be based on the merits and relative costs for the individual building being designed. There are innovative systems available for particular structural configurations and conditions, such as eccentric braced frames, seismic isolation, friction devices, and other response control systems. These systems are described below.

a. *Gravity-Load System.* The basic elements of a gravity load system are: (a) horizontal elements (e.g., slabs, sheathing, beams, girders, or trusses) that collect the dead and live loads in various levels in the structure; (b) the vertical-resisting elements (e.g., columns and bearing walls) that receive the gravity loads from the horizontal elements: and (c) the foundations (e.g., footings, piers, piles) that receive the loads from the vertical elements and transfer them to the ground. The suitability of various foundation systems and allowable values for their design must be determined from available data or by a program of soil borings and laboratory tests.

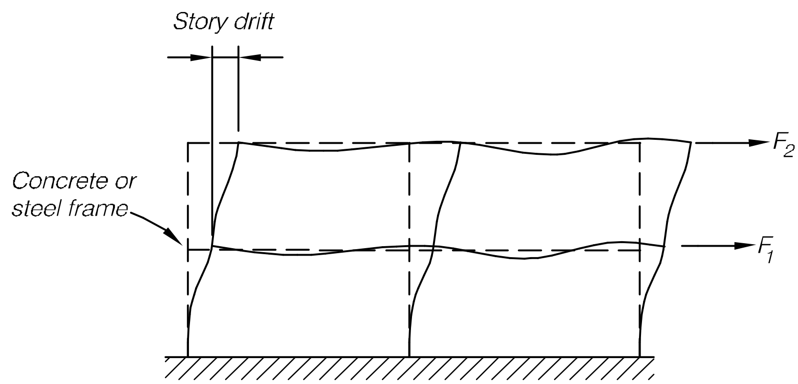
b. Lateral-Force-Resisting Systems.

(1) General. A building is not merely a summation of parts (walls, columns, trusses, and similar components), but is a completely integrated system or unit that has its own properties with respect to lateral-force response. The designer must trace the forces through the structure into the ground, and make sure that every connection along the path of stress is adequate to maintain the integrity of the system. It is necessary to visualize the response of the complete structure, and to keep in mind that the real forces involved are not static, but dynamic; are usually erratically cyclic and repetitive; may be significantly larger than the design forces; and can cause deformations well beyond those determined from the design forces.

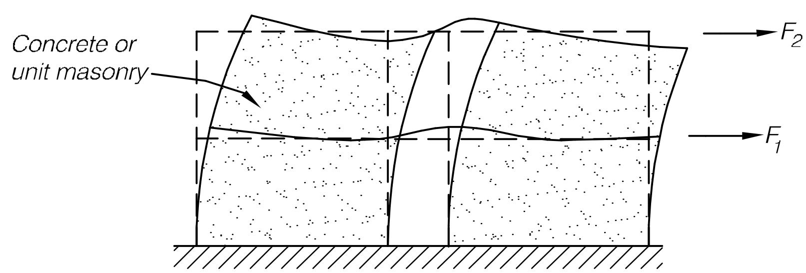
(2) Lateral force system types. Over a dozen approved lateral-force-resisting systems are described in Chapter 7. All of the vertical elements of these lateral-force systems consist of: (a) moment-resisting frames within a three-dimensional space frame system; (b) a coordinated system of shear walls; (c) a three-dimensional system of braced frames; or (d) a combination or "dual system" of moment-resisting frames with either shear walls or braced frames. These vertical elements may be used in various combinations within a building, as described herein. All of the horizontal elements of these lateral-force systems consist of either diaphragms or horizontal bracing systems. The vertical elements of the lateral-force-resisting systems are illustrated in Figure 2-2.

(a) In buildings where a moment-resisting frame resists the earthquake forces, the columns and beams act in bending (*a* of Figure 2-2). During a large earthquake, story-to-story deformation (story drift) may be a matter of inches, without causing failure of columns or beams. The drift, however, may be sufficient to damage elements that are rigidly tied to the structural system, such as brittle partitions, stairways, plumbing, exterior walls, and other elements that extend between floors. For this reason, buildings can have substantial interior and exterior nonstructural damage, possibly approaching 50 percent of the total building value, and still be considered structurally safe. Moment frames are desirable architecturally because they are relatively unobtrusive compared with shear walls or braced frames, but they may be a poor economic risk unless special damage control measures are taken.

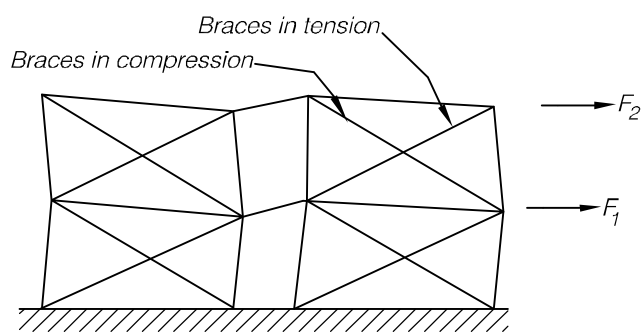
(b) Buildings with shear walls (*b* of Figure 2-2) are usually rigid compared with buildings with moment-resisting frames. With low design stress limits in shear walls, deformation due to shear forces (for low buildings) is negligible. Shear wall construction is an excellent method of bracing buildings to limit damage to nonstructural components, but architectural considerations may limit its applicability. Shear walls are usually of reinforced unit masonry or reinforced concrete, but may be of wood in wood-frame buildings up to and including three stories. Shear wall design is relatively simple, except when the height-to-width ratio of a



(a) FRAME ACTION BY MOMENT-RESISTING BENTS



(b) SHEAR WALLS AS VERTICAL CANTILEVERS



(c) BRACED FRAMES OF STEEL

Figure 2-2 Vertical elements of the lateral force resisting systems.

wall becomes large. Overturning may then be a problem, and if the foundation soil is relatively soft, the entire shear wall may rotate, causing localized damage around the wall. Another difficult case is the shear wall with openings such that it may respond more like a frame than a wall.

(c) Braced frames (Figure 2-2) generally have the stiffness associated with shear walls, but are somewhat less restrictive architecturally. It may be difficult to find room for doorways within a braced frame; however, braces are less obtrusive than solid walls. The concern for overturning mentioned above for shear walls also applies to braced frames. Braced frames may be concentric (*c* in Figure 2-2) or eccentric (Figure 7-23).

(d) Horizontal elements in the lateral-force-resisting system include floor and roof diaphragms and horizontal bracing systems. Diaphragms may consist of wood sheathing or plywood, steel decking with or without concrete fill, or cast-in-place or precast concrete slabs. Diaphragms and horizontal bracing systems are classified as flexible, stiff, or rigid, based on their deformation relative to the vertical-resisting elements. Design and acceptance criteria for these elements are provided in Paragraph 7-7 of Chapter 7.

(e) Structural systems may be used in various combinations. There may be different systems in the two directions, or systems may be combined in any one direction, or may be combined vertically. FEMA 302 permits the use of R factors applicable to the structural system in each orthogonal direction. Specific R values are provided for acceptable dual systems, and the lower R value is prescribed for a vertical combination of two structural systems.

c. Configuration and Simplicity. A great deal of a building’s resistance to lateral forces is determined by its plan layout. The objective in this regard is symmetry about both axes, not only of the building itself, but of its lateral-force-resisting elements and of the arrangement of wall openings, columns, shear walls, and so on. It is most desirable to consider the effects of lateral forces on the structural system from the start of the layout, since this may save considerable time and money without detracting significantly from the usefulness or appearance of the building. Experience has shown that buildings that are asymmetrical in plan have greater susceptibility to earthquake damage than symmetrical structures with simple and direct load paths for lateral forces. The effect of asymmetry is to induce torsional oscillations of the structure and stress concentrations at re-entrant corners. Asymmetry in plan can be eliminated or improved by separating L-, T-, and U-shaped buildings into distinct units by use of seismic joints at the junctions of the individual wings. It should be noted, however, that this causes two new problems: providing floor joints that are capable of bridging gaps large enough to preclude adjacent structures from pounding each other, and providing wall and roof joints that are capable of keeping out the weather. Asymmetry caused by the eccentric location of lateral-force-resisting structural elements—such as in the case of a building that has a flexible front because of large openings and an essentially stiff (solid) rear wall—can usually be avoided by better conceptual planning. For example, modify the stiffness of the rear wall or add rigid structural partitions to make the center of rigidity of the lateral-force-resisting elements closer to the center of mass. When a building has irregular features, such as asymmetry in features, such as asymmetry in plan or vertical discontinuity, the assumptions used in developing seismic criteria for buildings with regular features may not apply. For example, planners often omit partitions and exterior walls in the first story of a building to permit an open ground floor; in this case, the columns at the ground level are the only elements available to resist lateral forces, and there is an abrupt change in the rigidity of the vertical elements of the lateral force resisting system at that level. This condition, generally referred to as soft story, is undesirable. It is advisable to carry all shear walls down to the foundation. It is best to avoid creating buildings with irregular features; however, when irregular features are unavoidable, special design considerations are required to account for the unusual dynamic characteristics and the load transfer and stress concentrations that occur at abrupt changes in structural resistance.

d. *Redundancy*. Redundancy is a highly desirable characteristic for earthquake-resistant design. Redundancy can be achieved with multiple load paths. For example, a multistory steel moment frame building, with all the joints designed to be moment-resisting, has greater redundancy than a similar building with only selective moment-resisting joints in that a flaw or unexpected failure of one joint can be offset by redistribution of loads to the other joints. Redundancy can also be achieved with parallel or "back-up" systems, such as the moment-resisting frames in a dual framing system in which the frames are designed for a nominal lateral force, but are expected to preclude collapse after the shear walls or braced frames have failed. Redundancy is defined by the reliability factor *D* described in paragraph 4-1, and lack of redundancy results in increased seismic load effects, as indicated in Equation 4-4 and 4-5.

e. *Ductile vs. Brittle Response*. Although ductile response is highly desirable from an earthquake energy dissipation standpoint, ductile structures will be more flexible, and the designer must give proper consideration to the resulting drift to preclude structural instability and undue damage to nonstructural elements. Similar consideration must be given to structural elements with anticipated brittle response (e.g., shear in concrete columns). These elements must be designed so as to preclude brittle response (e.g., adequate shear strength in concrete columns to permit flexural yielding of column or connecting beams) or designed with adequate capacity to resist the unreduced demand forces. When a building is subjected to earthquake ground motion, a pattern of lateral deformations that varies with time is induced into the structure. At any given point in time, a particular state of lateral deformation will exist in the structure, and at some time within the period in which the structure is responding to the ground motion, a maximum pattern of deformation will occur. At relatively low levels of ground motion, the deformations induced within the building will be limited, and the resulting stresses that develop within the structural components will be within the elastic range of behavior. Within this elastic range, the structure will experience no damage. All structural components will retain their original strength, stiffness, and appearance, and when the ground motion stops, the structure will return to its pre-earthquake condition. At more severe levels of ground motion, the lateral deformations induced into the structure will be larger. As these deformations increase, so will demands on the individual structural components. At different levels of deformation, corresponding to different levels of ground motion severity, individual components of the structure will be strained beyond their elastic range. As this occurs, the structure starts to experience damage in the form of cracking, spalling, buckling, and yielding of the various components. As components become damaged, they degrade in stiffness. In general, when a structure has responded to ground motion within this range of behavior, it will not return to its pre-earthquake condition when the ground motion stops. Some permanent deformation may remain within the structure, and damage will be evident throughout. Depending on how far the structure has been deformed, and in what pattern, the structure may have lost a significant amount of its original stiffness, and possibly, strength. Brittle elements are not able to sustain inelastic deformations and will fail suddenly; the consequences may range from local and repairable damage to collapse of the structural system. At higher levels of ground motion, the lateral deformations induced into the structure will strain a number of elements to a point at which elements behave in a brittle manner, or as a result of the decreased overall stiffness, the structure loses stability. Eventually, partial or total collapse of the structure can occur. The structural performance levels used in this document relate the extent of a building's response to earthquake hazards to these various possible damage states. Figure 1-1 illustrates the behavior of a ductile structure as it responds with increasing lateral deformation. The figure is a schematic plot of the lateral force induced in the structure as a function of lateral deformation. Four discrete points are indicated, representing the discrete performance levels: Immediate Occupancy, Safe Egress, Life Safety, and Collapse Prevention. At the Immediate Occupancy Level, damage is relatively limited. The structure retains a significant portion of its original stiffness, and most, if not all, of its strength. At the Collapse Prevention level, the building has experienced extreme damage. If laterally deformed beyond this point, the structure can experience instability and collapse. At the Life Safety Level, substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness; however, a substantial margin remains for additional lateral deformation before collapse would occur. At the Safe Egress level, the damage is intermediate between the Immediate Occupancy and the Life Safety levels. It should be noted that for given buildings, the relative horizontal and vertical scales shown on this plot may vary significantly, and the margin of deformation between individual performance levels may not be as large as indicated in this figure. Figure 1-2 is a similar curve, representative of the behavior of a nonductile, or brittle, structure. Note that for such a structure, there may be relatively little margin in the responses that respectively define the three performance levels. For a given structure and design earthquake, it is possible to estimate the overall deformation and force demand on the structure, and therefore, the point on the corresponding curves shown in Figures 1-1 or 1-2 to which the earthquake will push the building. This either will or will not correspond to the desired level of performance for the structure. The building should also be checked for compliance with the allowable story drift levels prescribed in Table 6-1 to preclude unacceptable damage to nonstructural systems and components. When structural/seismic design is performed, modifications to the structural model are made to alter its strength, stiffness, or ability to dampen or resist induced deformations. These actions will alter the characteristics of both the shape of the curves in these figures, and the deformation demand produced by the design earthquake on the building, such that the expected performance at the estimated deformation level for the structure is acceptable.

f. *Connectivity*. It is essential to tie the various structural elements together so that they act as a unit. The connections between the elements are at least as important as the elements themselves. Prevention of collapse during a severe earthquake depends upon the inelastic energy-absorbing capacity of the structure, and this capacity should be governed by the elements rather than by their connections; in other words, connections should not be the weak link in the structure. As a general guide, if no other requirements are specified, connections should be adequate to develop the useful strength of the structural elements connected, regardless of the calculated stress due to the prescribed seismic forces.

g. *Separation of Structures.* In past earthquakes, the mutual hammering received by buildings in close proximity to one another has caused significant damage. The simplest way to prevent damage is to provide sufficient clearance so that free motion of the two structures will result. The motion to be provided for is produced partly by the deflections of the structures themselves, and partly by the rocking or settling of foundations. The gap must equal the sum of the total deflections from the base of the two buildings to the top of the lower building.

(1) In the case of a normal building less than 80 feet in height using concrete or masonry shear walls, the gap shall be not less than the arbitrary rule of 1 inch (25mm) for the first 20 feet (6.10m) of height above the ground, plus ½ inch (13mm) for each 10 feet (3.05m) of additional height.

(2) For higher or more flexible buildings, the gap or seismic joint between the structures should be based on the sum of the deflections determined from the required (prescribed) lateral forces. If the design of the foundation is such that rotation is expected to occur at the base due to rocking or due to settlement of foundations, this additional deflection (as determined by rational methods) will be included.

(3) In situations where it is impractical to provide adequate clearance, the consequences of potential damage due to hammering must be considered. If the floor levels of the two buildings are approximately the same and the floor systems are relatively robust (e.g., concrete beams and slabs), the resulting damage may be limited to local spalling that is readily repaired. If the floor levels are significantly offset and the bearing walls or columns of either building are vulnerable to hammering action from the rigid floor systems of the other building, the potential damage is unacceptable. In such instances, either adequate clearance must be provided, or the vulnerable structural components must be strengthened or provided with back-up elements to avoid the possibility of structural failure.

h. *Seismic Joints*. Junctures between distinct parts of buildings, such as the intersection of a wing of a building with the main portion, are often designed with flexible joints that allow relative movement. When this is done, each part of the building must be considered as a separate structure that has its own independent bracing system. The criteria for separation of buildings in Paragraph *a* above will apply to seismic joints for parts of buildings. Seismic joint coverage will be flexible and architecturally acceptable.

i. Elements that Connect Buildings. Certain types of structures commonly found in industrial installations are tied together at or near their tops by connecting parts such as piping, conveyors, and ducts. The support of these elements will allow for the relative movement between buildings.

j. Bridges Between Buildings. Clusters of buildings are often connected by bridges. In most cases it would not be economically feasible to make bridges sufficiently rigid to force both buildings to vibrate together. A sliding joint at one or both ends of the bridge can usually be installed.

k. Stairways. Concrete stairways often suffer seismic damage because they act like struts between the connected floors. This damage can be avoided by anchoring the stair structure at the upper end and providing a slip joint at the lower end of each stairway, or by tying stairways to stairway shear walls.

l. "Short Column" Effects. Whenever the lateral deflection of any column is restrained, when full height deflections were assumed in the analysis, it will carry a larger portion of the lateral forces than assumed. In past earthquakes, column failures have frequently been inadvertently caused by the stiffening (shortening) effect of deep spandrels, stairways, partial-height filler walls, or intermediate bracing members. Unless considered in the analysis, such stiffening effects will be eliminated by proper detailing for adequate isolation at the junction of the column and the resisting elements.

m. Design and Analysis Procedures. Step-by-step design and analysis procedures are provided for buildings conforming to Performance Objective 1A in Table 4-5, and illustrated in a flow chart in Figure 4-1. Similar procedures for buildings with enhanced performance objectives, using linear elastic analysis with the *m* modification factors, are provided in Table 4-6, and in a flow chart in Figures 4-2 and 4-3. The nonlinear elastic static procedures for Performance Objective 3B are described in Table 4-7, and in a flow chart in Figure 4-4.

n. Nonstructural Participation. For both analysis and detailing, the participation effects of nonstructural filler walls and stairs must be considered. The nonstructural elements that are rigidly tied to the structural system can have a substantial influence on the magnitude and distribution of earthquake forces. Such elements act somewhat like shear walls, stiffening the building and causing a reduction in the natural period, and an increase in the lateral forces and overturning moments. Any element that is not strong enough to resist the forces it attracts will be damaged, and should be isolated from the lateral-force-resisting system. Following are some design considerations to minimize damage to nonstructural components, and to preclude life safety hazards to the occupancy of the building.

(1) Details that allow structural movement without damage to nonstructural elements can be provided. Damage to items such as piping, glass, plaster, veneer, and partitions may constitute a major financial loss. To minimize this type of damage, special care in detailing, either to isolate these elements or to accommodate the movement, is required.

(2) Glass windows should be isolated with adequate clearance and flexible mountings at edges to allow for frame distortions.

(3) Rigid nonstructural partitions should have room to move at the top and sides.

(4) In piping installations, the expansion loops and flexible joints used to accommodate temperature movement are often adaptable to accommodating seismic deflections.

(5) Freestanding shelving can be fastened to walls to prevent toppling. Shelves can be provided with lips or edge restraints to prevent contents from falling off in an earthquake.

o. Alternatives to the Prescribed Provisions. Alternatives to the seismic provisions of this document are permitted if they can be properly substantiated. The most common alternatives are the use of more rigorous analytical procedures or the use of innovative systems.

(1) Rigorous analyses. Simple or approximate analyses are generally based on assumptions that require a significant degree of conservatism. A more rigorous analysis may require more precise knowledge of the physical characteristics of the structural elements and materials, but may incorporate less conservatism, thus permitting the acceptance of an otherwise nonconforming structure.

(2) Innovative systems. Systems and devices are available for controlling and/or limiting the response of structures to earthquake ground motion. The best known of these systems are seismic isolation systems (sometimes called base isolation systems). Seismic isolation is based on the premise that the structure can be substantially decoupled from potentially damaging earthquake motions. By decoupling the structure from the ground motion, seismic isolation reduces the level of response in the structure from the level that would otherwise occur in a conventional fixed-base building, or conversely, offers the advantage of designing with a reduced level of earthquake load to achieve the same degree of seismic protection and reliability as a conventional fixed-base building. Other innovative systems include passive and active energy dissipation devices. Limited guidance for the design of seismic isolation and energy dissipation systems is provided in Chapter 8. These systems are relatively new and sophisticated concepts that require more extensive design and detailed analysis than most conventional schemes. Peer review must be an essential part of any project that includes seismic isolation or energy dissipation devices.