4.3 Procedures for Building Systems

This section provides Tier 2 evaluation procedures that apply to all building systems: general, configuration and condition of the materials.

4.3.1 General

4.3.1.1 LOAD PATH: The structure shall contain one complete load path for Life Safety and Immediate Occupancy for seismic force effects from any horizontal direction that serves to transfer the inertial forces from the mass to the foundation.

Commentary:

There must be a complete lateral-force-resisting system that forms a continuous load path between the foundation, all diaphragm levels, and all portions of the building for proper seismic performance. The general load path is as follows: seismic forces originating throughout the building are delivered through structural connections to horizontal diaphragms; the diaphragms distribute these forces to vertical lateral-force-resisting elements such as shear walls and frames; the vertical elements transfer the forces into the foundation; and the foundation transfers the forces into the supporting soil.

If there is a discontinuity in the load path, the building is unable to resist seismic forces regardless of the strength of the existing elements. Mitigation with elements or connections needed to complete the load path is necessary to achieve the selected performance level. The design professional should be watchful for gaps in the load path. Examples would include a shear wall that does not extend to the foundation, a missing shear transfer connection between a diaphragm and vertical element, a discontinuous chord at a diaphragm notch, or a missing collector.

In cases where there is a structural discontinuity, a load path may exist but it may be a very undesirable one. At a discontinuous shear walls, for example, the diaphragm may transfer the forces to frames not intended to be part of the lateral-force-resisting system. While not ideal, it may be possible to show that the load path is acceptable.

A complete load path is a basic requirement for all buildings. The remaining evaluation statements in this handbook target specific components of the load path and are intended to assist the design professional in locating potential gaps in the load path. While non-compliant statements further along in the procedure might indicate a potential discontinuity or inadequacy in the load path, the identification of a complete load path is a necessary first step before continuing with the

Tier 2 Evaluation Procedure: No Tier 2 evaluation procedure is available for load paths in non-compliance.

4.3.1.2 ADJACENT BUILDINGS: An adjacent building shall not be located next to the structure being evaluated closer than 4% of the height for Life Safety and Immediate Occupancy.

Tier 2 Evaluation Procedure: The drifts in the structure being evaluated shall be calculated using the Linear Static Procedure in Section 4.2. The drifts in the adjacent building shall be estimated using available information and the procedures of this Handbook. The SRSS combination of both building drifts shall be less than the total separation at each level. Alternatively, if no information is available on the adjacent building, the drifts in the adjacent building shall be assumed to equal three-quarters of the available separation. The SRSS combination of this assumed drift and the calculated drift of the structure being evaluated shall be less than the total separation at each level. In addition, the design professional shall render a judgment on the potential seismic performance of the adjacent building and any potential hazard to the structure being evaluated.

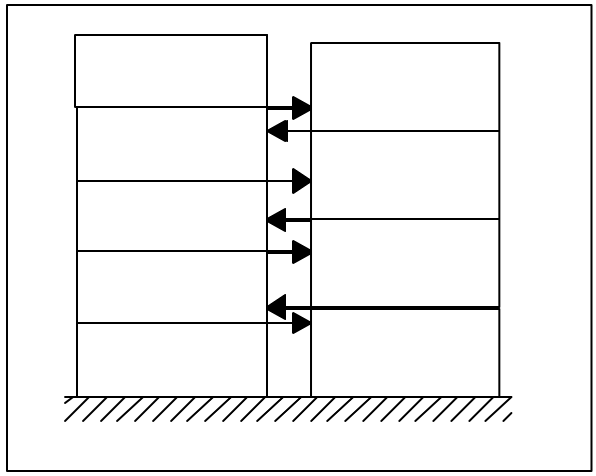
Commentary:

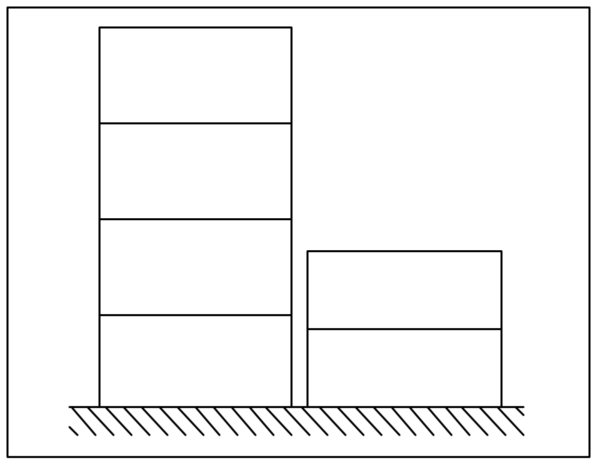
Buildings often are built right up to property lines in order to make maximum use of space, and historically buildings have been designed as if the adjacent buildings do not exist. As a result, the buildings may impact each other, or pound, during an earthquake. Building pounding can alter the dynamic response of both buildings, and impart additional inertial loads on both structures.

Buildings that are the same height and have matching floors will exhibit similar dynamic behavior. If the buildings pound, floors will impact other floors, so damage due to pounding usually will be limited to nonstructural components. When the floors of adjacent buildings are at different elevations, floors will impact the columns of the adjacent building and can cause structural damage (see Figure 4-2). When the buildings are of different heights, the shorter building can act as a buttress for the taller building. The shorter building receives an unexpected load while the taller building suffers from a major stiffness discontinuity that alters its dynamic response (see Figure 4-3). Since neither building is designed for these conditions, there is a potential for extensive damage and possible collapse.

Buildings that are the same height and have matching floor levels need not comply with this statement. Non-compliant separations between buildings that do not have matching floors must be checked using calculated drifts for both buildings. The SRSS combination is used because of the low probability that maximum drifts in both buildings will occur simultaneously and out of phase. When information on the adjacent building is not available, conservative assumptions for drift are made in the procedure.

The potential hazard of the adjacent building must also be evaluated. If a neighbor is a potential collapse hazard, this must be noted.





Commentary:

It is very common for mezzanines to lack a lateral-force-resisting system. Often mezzanines are added on by the building owner. Unbraced mezzanines can be a potential collapse hazard, and should be checked for stability.

Lateral-force-resisting elements must be present in both directions to provide bracing. When the mezzanine is attached to the main structure, the supporting elements of the main structure should be evaluated considering both the magnitude and location of the additional forces imparted by the mezzanine.

If the load path is incomplete or non-existent, mitigation with elements or connections needed to complete the load path is necessary to achieve the selected performance level.

Figure 4-2. Unmatching Floors

Commentary:

Good details and construction quality are of secondary value if a building has an odd shape that was not properly considered in the design. Although a building with an irregular configuration may be designed to meet all code requirements, irregular buildings generally do not perform as well as regular buildings in an earthquake. Typical building configuration deficiencies include an irregular geometry, a weakness in a given story, a concentration of mass, or a discontinuity in the lateral force resisting system.

Vertical irregularities are defined in terms of strength, stiffness, geometry, and mass. These quantities are evaluated separately, but are related and may occur simulaneously. For example, the frame in Figure 4-4 has a tall first story. It can be a weak story, a soft story, or both depending on the relative strength and stiffness of this story and the stories above.

One of the basic goals in seismic design is to distribute yielding throughout the structure. Distributed yielding dissipates more energy and helps prevent the premature failure of any one element or groups of elements. For example, in moment frames (as discussed in Section 4.4) it is desirable to have strong columns relative to the beams to help distribute the formation of plastic hinges thoughout the building and prevent the formation of a story mechanism. Code provisions regarding vertical irregularities are intended to achieve this result. Significant irregularities that cause damage to be concentrated in certain areas require special treatment.

Horizontal irregularities involve the horizontal distribution of lateral forces to the resisting frames or shear walls. Irregularities in the diaphragm itself (i.e., diaphragms that have projecting wings or re-entrant corners) are discussed in Section 4.5.

Figure 4-3. Buildings of Different Height

4.3.1.3 MEZZANINES: Interior mezzanine levels shall be braced independently from the main structure, or shall be anchored to the lateral-force-resisting elements of the main structure.

Tier 2 Evaluation Procedure: The load path from the mezzanine to the main structure shall be identified. The adequacy of the load path shall be evaluated for the forces in Section 4.2 considering the effect of the magnitude and location of any forces imparted by the mezzanine on the main structure.

Commentary:

The story strength is the total strength of all the lateral force resisting elements in a given story for the direction under consideration. It is the shear capacity of columns or shear walls, or the horizontal component of the capacity of diagonal braces. If the columns are flexural controlled, the shear strength is the shear corresponding to the flexural strength. Weak stories are usually found where vertical discontinuities exist, or where member size or reinforcement has been reduced. It is necessary to calculate the story strengths and compare them. The result of a weak story is a concentration of inelastic activity that may result in the partial or total collapse of the story.

An examination of recent earthquake damage revealed a number of buildings that suffered mid-height collapses. It appears that this situation occured most often in the near field area of major earthquakes and only affected mid-rise buildings between five and fifteen stories tall. These types of buildings are typically designed for primary mode effects, with strength and stiffness reductions up the height of the structure. This reduction in strength and stiffness coupled with unexpected higher mode effects may have been the potential cause of the mid-height collapses.

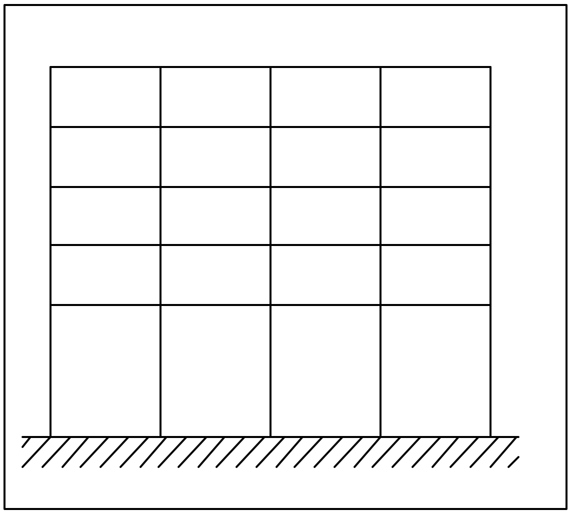
A dynamic analysis could be performed to determine if there are unexpectedly high seismic demands at locations of strength discontinuities. Compliance can be achieved if the elements of the weak story can be shown to have adequate capacity near elastic levels.

Commentary:

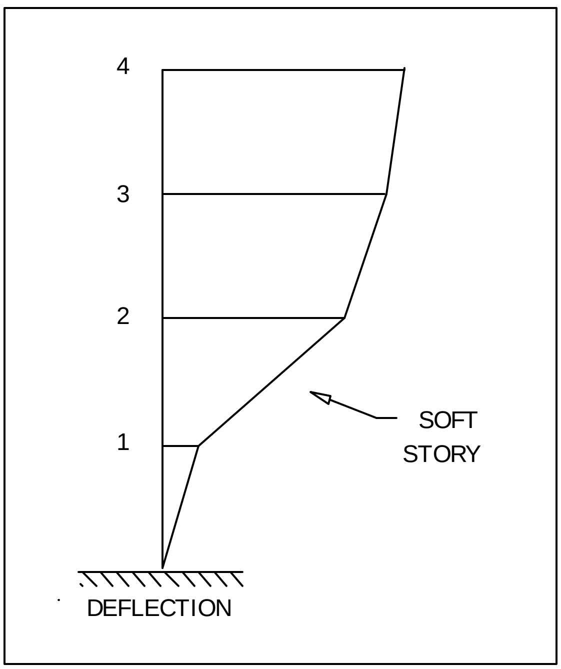
This condition commonly occurs in commercial buildings with open fronts at ground-floor storefronts, and hotels or office buildings with particularly tall first stories. Figure 4-4 (see following page) shows an example of a tall story. Such cases are not *necessarily* soft stories because the tall columns may have been designed with appropriate stiffness, but they are *likely* to be soft stories if they have been designed without consideration for interstory drift. Soft stories usually are revealed by an abrupt change in interstory drift. Although a comparison of the stiffnesses in adjacent stories is the direct approach, a simple first step might be to plot and compare the interstory drifts as indicated in Figure 4-5 (see following page) if analysis results happen to be available.

The difference between "soft" and "weak" stories is the difference between stiffness and strength. A column may be limber but strong, or stiff but weak. A change in column size can affect strength and stiffness, and both need to be considered.

An examination of recent earthquake damage revealed a number of buildings that suffered mid-height collapses. It appears that this situation occurs most often in the near field area of major earthquakes and only affects mid-rise buildings between five and fifteen stories tall. These types of buildings are typically designed for primary mode effects and reduce in strength and/or stiffness up the height of the structure. This reduction in strength and/or stiffness coupled with unexpected higher mode effects may have the potential to cause mid-height collapses. A dynamic analysis should be performed to determine if there are unexpectedly high seismic demands at locations of stiffness discontinuities.



4.3.2 Configuration



4.3.2.1 WEAK STORY: The strength of the lateral-force-resisting-system in any story shall not be less than 80% of the strength in an adjacent story, above or below, for Life Safety and Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with the procedures in Section 4.2 shall be performed. The story strength shall be calculated, and the adequacy of the lateral-force-resisting elements in the non-compliant story shall be checked for the capacity to resist one half the total psuedo lateral force.

4.3.2.2 SOFT STORY: The stiffness of the lateral-force-resisting-system in any story shall not be less than 70% of the stiffness in an adjacent story above or below, or less than 80% of the average stiffness of the three stories above or below for Life Safety and Immediate Occupancy.

Commentary:

Geometric irregularities are usually detected in an examination of the story-to-story variation in the dimensions of the lateral-force-resisting system (see Figure 4-6, following page). A building with upper stories set back from a broader base structure is a common example. Another example is a story in a high-rise that is set back for architectural reasons. It should be noted that the irregularity of concern is in the dimensions of the lateral-force-resisting system, not the dimensions of the envelope of the building, and, as such, it may not be obvious.

Geometric irregularities affect the dynamic response of the structure, and may lead to unexpected higher mode effects and concentrations of demand. A dynamic analysis is required to more accurately calculate the distribution of seismic forces. One story penthouses need not be considered.

Tier 2 Evaluation Procedure: An analysis in accordance with the Linear Dynamic Procedure of Section 4.2 shall be performed. The adequacy of the elements in the lateral-force-resisting system shall be evaluated.

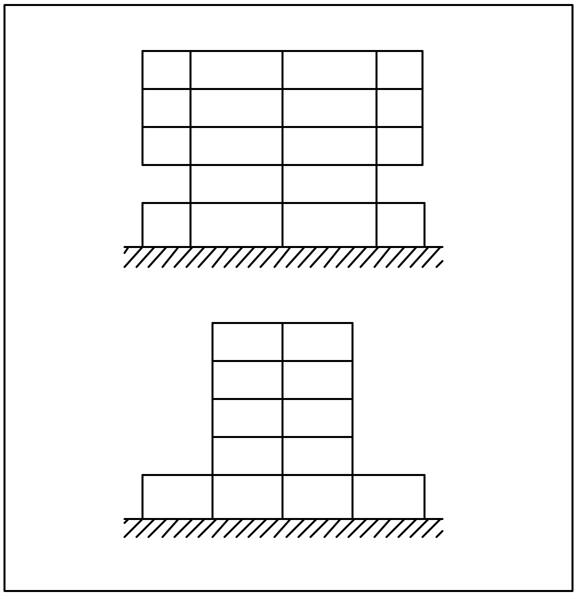


Figure 4-4. Tall Story

Figure 4-5. Soft Story

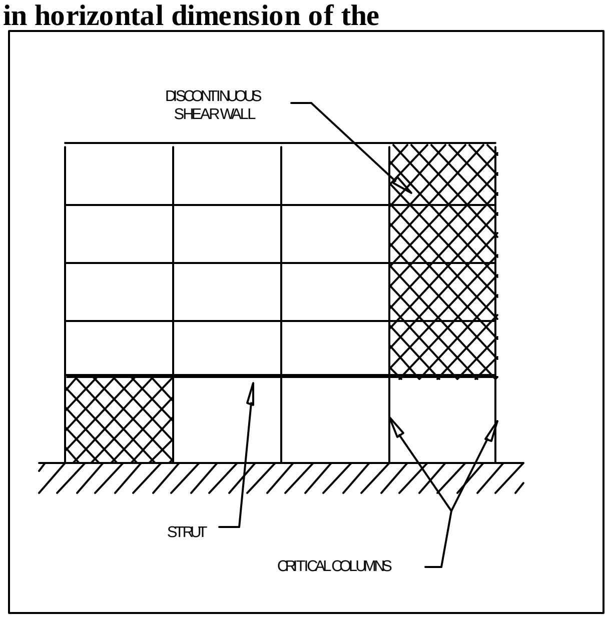
Commentary:

Vertical discontinuities are usually detected by visual observation. The most common example is a discontinuous shear wall or braced frame. The element is not continuous to the foundation but stops at an upper level. The shear at this level is transferred through the diaphragm to other resisting elements below. This force transfer can be accomplished either through a strut if the elements are in the same plane (see Figure 4-7) or through a connecting diaphragm if the elements are not in the same plane (see Figure 4-8, on following page). In either case, the overturning forces that develop in the element continue down through the supporting columns.

This issue is a local strength and ductility problem below the discontinuous element, not a global story strength or stiffness irregularity. The concern is that the wall or braced frame may have more shear capacity than considered in the design. These capacities impose overturning forces that could overwhelm the columns. While the strut or connecting diaphragm may be adequate to transfer the shear forces to adjacent elements, the columns which support vertical loads are the most critical. It should be noted that moment frames can have the same kind of discontinuity.

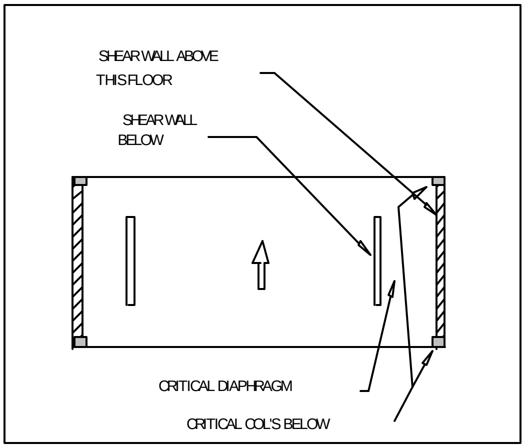
Compliance can be achieved if an adequate load path to transfer seismic forces exists, and the supporting columns can be demonstrated to have adequate capacity to resist the overturning forces generated by the shear capacity of the discontinuous elements.

4.3.2.3 GEOMETRY: There shall be no change in horizontal dimension of the



lateral-force-resisting system of more than 30% in a story relative to adjacent stories for Life Safety and Immediate Occupancy, excluding one-story penthouses.

Tier 2 Evaluation Procedure: An analysis in accordance with the Linear Dynamic Procedure of Section 4.2 shall be performed. The adequacy of the lateral-force-resisting elements shall be evaluated.



Commentary:

Mass irregularities can be detected by comparison of the story weights (see Figure 4-9). The effective mass consists of the dead load of the structure tributary to each level, plus the actual weights of partitions and permanent equipment at each floor. Buildings are typically designed for primary mode effects. The validity of this approximation is dependent upon the vertical distribution of mass and stiffness in the building. Mass irregularities affect the dynamic response of the structure, and may lead to unexpected higher mode effects and concentrations of demand.

A dynamic analysis is required to more accurately calculate the distribution of seismic forces. Light roofs and penthouses need not be considered.

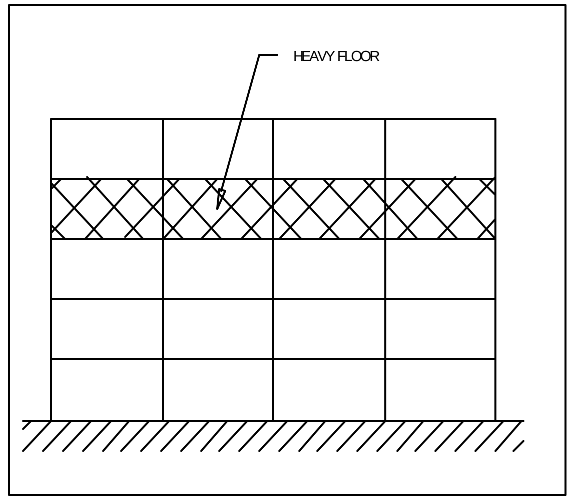


Figure 4-6. Geometric Irregularities

4.3.2.4 VERTICAL DISCONTINUITIES: All vertical elements in the lateral-force-resisting system shall be continuous to the foundation.

Tier 2 Evaluation Procedure: The adequacy of elements below vertical discontinuities shall be evaluated to support gravity forces and overturning forces generated by the capacity of the discontinuous elements above. The adequacy of struts and diaphragms to transfer load from discontinuous elements to adjacent elements shall be evaluated.

Figure 4-7. Vertical Discontinuity In-Plane

Commentary:

Whenever there is significant torsion in a building, the concern is for additional seismic demands and lateral drifts imposed on the vertical elements by rotation of the diaphragm. Buildings can be designed to meet code forces including torsion, but buildings with severe torsion are less likely to perform well in earthquakes. It is best to provide a balanced system at the start, rather than design torsion into the system.

One concern is for columns that support the diaphragm, especially if the columns are not intended to be part of the lateral-force-resisting system. The columns are forced to drift laterally with the diaphragm which induces lateral forces and p-delta effects. Such columns often have not been designed to resist these movements.

Another concern is the strength of the vertical elements of the lateral force resisting system that will experience additional seismic demands due to torsion.

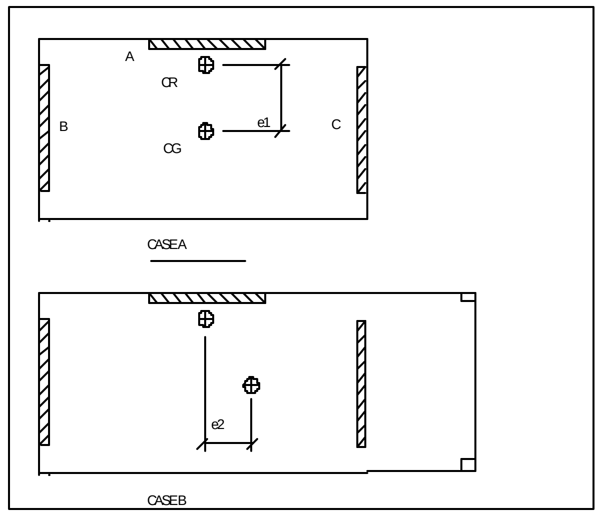
In the Case A building shown in Figure 4-10, the center of gravity is near the center of the diaphragm while the center of rigidity is also near the centerline but close to wall A. Under longitudinal loading, the eccentricity, e1, between the center of gravity (center of earthquake load) and the center of rigidity (center of resistance) causes a torsional moment. The entire earthquake force is resisted directly by wall A and the torsional moment is resisted by a couple consisting of equal and opposite forces in walls B and C. These two walls have displacements in opposite directions and the diaphragm rotates.

These are very simple cases for analysis and design and if the systems are designed and detailed properly, they should perform well. With the ample proportions suggested by the length of the walls in Figure 4-10, stresses will be low and there will be little rotation of the diaphragm. The hazard appears when the diaphragm, and consequently the diaphragm stresses, become large; when the stiffness of the walls is reduced; or when the walls have substantial differences in stiffnesses.

The Case C building shown in Figure 4-11 (see following page) has a more serious torsional condition than the ones in Figure 4-10. Wall A has much greater rigidity than wall D as indicated by their relative lengths.

For transverse loading, the center of rigidity is close to wall A and there is a significant torsional moment. All four walls are involved in the resistance to the torsional moment. Walls B, C, and D, although strong enough for design forces, have little rigidity and that allows substantial rotation of the diaphragm. There are two concerns here. First, displacement at E and F, that induces sidesway moments in the columns that may not have been recognized in the design. Their failure could lead to a collapse. Second, the stability of the building under transverse loading depends on wall D. The Case D building shown in Figure 4-11 is shown with wall D failed. The remaining walls, A, B, and C, are in the configuration of Figure 4-10 and now there is a very large eccentricity that may cause walls B and C to fail. Note that this is an example of a building that lacks redundancy.

Figure 4-8. Vertical Discontinuity Out-of-Plane



4.3.2.5 MASS: There shall be no change in effective mass more than 50% from one story to the next for Life Safety and for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with the Linear Dynamic Procedure of Section 4.2 shall be performed. The adequacy of the lateral-force-resisting elements shall be evaluated.

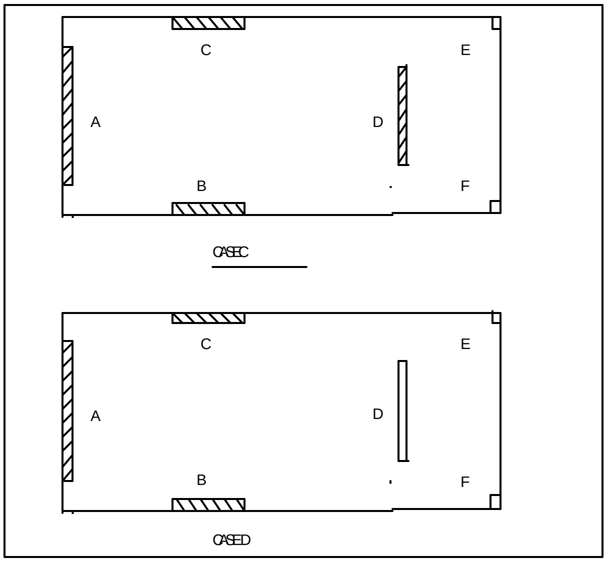


Figure 4-9. Heavy Floor

4.3.2.6 TORSION: The distance between the story center of mass and the story center of rigidity is less than 20% of the building width in either plan dimension for Life Safety and Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with the procedures in Section 4.2 shall be performed. The adequacy of the lateral-force-resisting system including torsional demands shall be evaluated. The maximum story drift including the additional displacement due to torsion shall be calculated. The adequacy of the vertical-load-carrying elements under the calculated drift, including P-delta effects, shall be evaluated.

Commentary:

Deteriorated structural materials may jeopardize the capacity of the vertical- and lateral-force-resisting systems. The most common type of deterioration is caused by the intrusion of water. Stains may be a clue to water-caused deterioration where the structure is visible on the exterior, but the deterioration may be hidden where the structure is concealed by finishes. In the latter case, the design professional may have to find a way into attics, plenums, and crawl spaces in order to assess the structural systems and their condition.

The design professional should be careful when dealing with a building that appears to be in good condition and is known to have been subjected to earthquakes in the past. One is tempted to say that the building has "withstood the test of time"; however, the earthquakes the building was subjected to may not have been significant or the good appearance may only be a good cosmetic repair that hides damage that was not repaired. Examples of problems include cracked concrete walls and frames, torn steel connections, bent fasteners or torn plywood in diaphragms and walls,

Commentary:

The condition of the wood in a structure has a direct relationship as to its performance in a seismic event. Wood that is split, rotten, or has insect damage may have a very low capacity to resist loads imposed by earthquakes. Structures with wood elements depend to a large extent on the connections between members. If the wood at a bolted connection is split, the connection will possess only a fraction of the capacity of a similar connection in undamaged wood.

Figure 4-10. Torsion: Cases A and B

Commentary:

Fasteners connecting structural panels to the framing are supposed to be driven flush with, but should not penetrate the surface of the sheathing. This effectively reduces the shear capacity of the fastener and increases the potential for the fastener to fail by pulling through the sheathing.

For structures built prior to the wide use of nailing guns (pre-1970), the problem is generally not present. More recent projects are often constructed with alternate fasteners, such as staples, T-nails, clipped head nails, or cooler nails, installed with pneumatic nail guns and often overdriven, completely penetrating one or more

Figure 4-11. Torsion: Cases C and D

4.3.3 Condition of Materials

4.3.3.1 DETERIORATION OF WOOD There shall be no signs of decay, shrinkage, splitting, fire damage, or sagging in any of the wood members, and none of the metal accessories shall be deteriorated, broken, or loose.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of this damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

Commentary:

Environmental effects over prolonged periods of time may lead to deterioration of steel elements. Significant rusting or corrosion, can substantially reduce the member cross sections, with a corresponding reduction in capacity.

Often steel elements have surface corrosion which looks worse than it is, and is likely not a concern. When corrosion is present, care should be taken to determine the actual loss in cross section. Such deterioration must be considered in the evaluation when it occurs at critical locations in the lateral force resisting system.

4.3.3.2 OVERDRIVEN FASTENERS There shall be no evidence of overdriven fasteners in the shear walls

Tier 2 Evaluation Procedure: The extent of overdriven fasteners shall be identified. The consequences of overdriven fasteners to the lateral-force-resisting system shall be determined. The adequacy these shear walls shall be evaluated considering the extent of overdriven fasteners and impact on the capacity.

4.3.3.3 DETERIORATION OF STEEL: There shall be no visible rusting, corrosion, cracking or other deterioration in any of the steel elements or connections in the vertical- or lateral-force-resisting systems.

Commentary:

Deteriorated concrete and reinforcing steel can significantly reduce the strength of concrete elements. This statement is concerned with deterioration such as spalled concrete associated with rebar corrosion and water intrusion. Cracks in concrete are covered elsewhere in this Handbook. Spalled concrete over reinforcing bars reduces the available surface for bond between the concrete and steel. Bar corrosion may significantly reduce the cross section of the bar.

Deterioration is a concern when the concrete cover has begun to spall, and there is evidence of rusting at critical locations.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of this damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

Commentary:

Corrosion in post-tensioning anchors can lead to failure of the gravity load system if ground motion causes a release or slip of prestressing strands.

anchors (see Figure 4-12), with or without corrosion, have performed poorly under cyclic loads.

4.3.3.4 DETERIORATION OF CONCRETE:

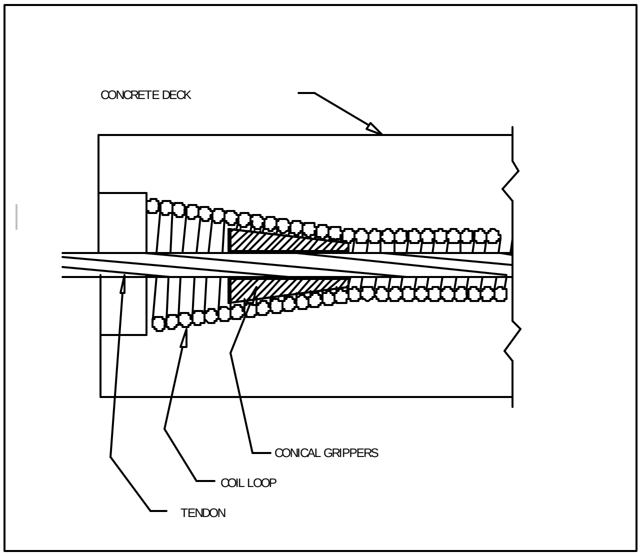


Figure 4-12. Coil Anchor

There shall be no visible deterioration of concrete or reinforcing steel in any of the vertical- or lateral- force-resisting elements.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of this damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

Commentary:

Precast concrete elements are sometimes only nominally interconnected and may be subject to shrinkage, creep, or temperature stresses that were not adequately considered in design. Distress caused by these factors could directly affect the lateral strength of the building. The most common damage is cracking and spalling at embedded connections between panels. This includes both the nominal connections along the vertical edges and the chord connections at the level of the

The performance of precast concrete wall systems is completely dependent on the condition of the connections.

4.3.3.5 POST-TENSIONING ANCHORS:

There shall be no evidence of corrosion or spalling in the vicinity of post-tensioning or end fittings. Coil anchors shall not have been used.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of this damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

Commentary:

Deteriorated or poor quality masonry elements can result in significant reductions in the strength of structural elements. Damaged or deteriorated masonry may not be readily observable.

4.3.3.6 PRECAST CONCRETE WALLS:

There shall be no visible deterioration of concrete or reinforcing steel or evidence of distress, especially at the connections.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of this damage to the

Commentary:

Older buildings constructed with lime mortar may have surface repointing but still have deteriorated mortar in the main part of the joint. One test is to tap a small hole with a nail in the repointing and, if it breaks through, powdery lime mortar shows on the nail. If it does not break through after aggressive blows, the wall probably is repointed full depth. This also can be seen by looking behind exterior trim or trim or wall fixtures where the new repointing never reached. Mortar that is severely eroded or can easily be scraped away has been found to have low shear strength, which results in low wall strength. Destructive or in-plane shear tests are required to measure the strength of the bond between the brick and mortar in order to determine the shear capacity of the walls.

lateral-force-resisting system shall be determined. The adequacy of damaged walls shall be evaluated considering the extent of the damage and impact on the capacity of each damaged wall.

4.3.3.7 MASONRY UNITS: There shall be no visible deterioration of masonry units.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of this damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

Commentary:

Small cracks in concrete elements have little effect on strength. A significant reduction in strength is usually the result of large displacements or crushing of concrete. Only when the cracks are large enough to prevent aggregate interlock or have the potential for buckling of the reinforcing steel does the adequacy of the concrete capacity become a concern.

Crack width is commonly used as a convenient indicator of damage to a wall, but it should be noted that recent studies (ATC 43 - *Evaluation and Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*) list other factors, such as location, orientation, number, distribution and pattern of the cracks to be equally important in measuring the extent of damage present in the shear walls. All these factors should be considered when evaluating the reduced capacity of a cracked element.

4.3.3.8 MASONRY JOINTS: The mortar shall not be easily scraped away from the joints by hand with a metal tool, and there shall be no areas of eroded mortar.

Tier 2 Evaluation Procedure: The extent of loose or eroded mortar shall be identified. Walls with loose mortar shall be omitted from the analysis, and the adequacy of the lateral-force-resisting system shall be evaluated. Alternatively, the adequacy of the walls may be evaluated with shear strength determined by testing.

Commentary:

Diagonal wall cracks, especially along the masonry joints, may affect the interaction of the masonry units, leading to a reduction of strength and stiffness. The cracks may indicate distress in the wall from past seismic events, foundation settlement, or other causes.

Crack width is commonly used as a convenient indicator of damage to a wall, but it should be noted that recent studies (ATC 43 - *Evaluation and Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*) list other factors, such as location, orientation, number, distribution and pattern of the cracks to be equally important in measuring the extent of damage present in the shear walls. All these factors should be considered when evaluating the reduced capacity of a cracked element.

4.3.3.9 CONCRETE WALL CRACKS: All existing diagonal cracks in the wall elements shall be less than 1/8" for Life Safety and 1/16" for Immediate Occupancy, shall not be concentrated in one location, and shall not form an X pattern.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of the damage to the lateral-force-resisting system shall be determined. The adequacy of damaged walls shall be evaluated considering the extent of the damage and impact on the capacity of each damaged wall.

4.3.3.10 REINFORCED MASONRY WALL CRACKS: All existing diagonal cracks in the wall elements shall be less than 1/8" for Life Safety and 1/16" for Immediate Occupancy, shall not be concentrated one location, and shall not form an X pattern.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of the damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

Commentary:

Diagonal wall cracks, especially along the masonry joints, may affect the interaction of the masonry units, leading to a reduction of strength and stiffness. The cracks may indicate distress in the wall from past seismic events, foundation settlement, or other causes.

Crack width is commonly used as a convenient indicator of damage to a wall, but it should be noted that recent studies (ATC 43 - *Evaluation and Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*) list other factors, such as location, orientation, number, distribution and pattern of the cracks to be equally important in measuring the extent of damage present in the shear walls. All these factors should be considered when evaluating the reduced capacity of a cracked element.

Commentary:

Diagonal wall cracks, especially along the masonry joints, may affect the interaction of the masonry units, leading to a reduction of strength and stiffness. The cracks may indicate distress in the wall from past seismic events, foundation settlement, or other causes.

Offsets in the bed joint along the masonry joints may affect the interaction of the masonry units in resisting out-of-plane forces. The offsets may indicate distress in the wall from past seismic events, or just poor construction.

Crack width is commonly used as a convenient indicator of damage to a wall, but it should be noted that recent studies (ATC 43 - *Evaluation and Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*) list other factors, such as location, orientation, number, distribution and pattern of the cracks to be equally important in measuring the extent of damage present in the shear walls. All these factors should be considered when evaluating the reduced capacity of a cracked element.

4.3.3.11 UNREINFORCED MASONRY WALL CRACKS: There shall be no existing diagonal cracks in the wall elements greater than 1/8" for Life Safety and 1/16" for Immediate Occupancy, or out-of-plane offsets in the bed joint greater than 1/8" for Life Safety and 1/16" for Immediate Occupancy.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. Damaged walls or portions of walls shall be omitted from the analysis, and the adequacy of the lateral-force-resisting system shall be evaluated.

Commentary:

Small cracks in concrete elements have little effect on strength. A significant reduction in strength is usually the result of large displacements or crushing of concrete. Only when the cracks are large enough to prevent aggregate interlock or have the potential for buckling of the reinforcing steel does the adequacy of the concrete element capacity become a concern.

Columns are required to resist diagonal compression strut forces that develop in infill wall panels. Vertical components induce axial forces in the columns. The eccentricity between horizontal components and the beams is resisted by the columns. Extensive cracking in the columns may indicate locations of possible weakness. Such columns may not be able to function in conjunction with the infill panel as expected.

4.3.3.12 CRACKS IN INFILL WALLS: There shall be no existing diagonal cracks in the infilled walls that extend throughout a panel, are greater than 1/8" for Life Safety and 1/16" for Immediate Occupancy, or out-of-plane offsets in the bed joint greater than 1/8" for Life Safety and 1/16" for Immediate Occupancy.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of the damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.

4.3.3.13 CRACKS IN BOUNDARY COLUMNS: There shall be no existing diagonal cracks wider than 1/8" for Life Safety and 1/16" for Immediate Occupancy in concrete columns that encase masonry infills.

Tier 2 Evaluation Procedure: The cause and extent of damage shall be identified. The consequences of the damage to the lateral-force-resisting system shall be determined. The adequacy of damaged lateral-force-resisting elements shall be evaluated considering the extent of the damage and impact on the capacity of each damaged element.