Potential Deficiencies in Concrete Buildings and Mitigation Requirements

The following are requirements for identifying, evaluating, and retrofitting certain potential seismic deficiencies in concrete buildings.

	Potential Deficiency	Requirements	Commentary
1	**Weak story:** The structure includes one or more stories having lateral strength less than the story above.	The structure shall not have vertical structural irregularity of Type 5a nor Type 5b in Table 12.3-2 of ASCE 7.	If the structure has a weak story or extreme weak story, to meet the alternate engineering criteria for concrete buildings, the weak story must be eliminated by retrofitting. Otherwise, the structure must meet ASCE 41 with a performance objective of Structural Collapse Prevention (S-5) with the BSE-2E earthquake hazard level.
2	**Lateral-force-resisting-element irregularity:** The lateral-force-resisting system includes one or more concrete walls or frames that are not continuous to the foundation.	The building shall not have a horizontal structural irregularity Type 4 of Table 12.3-1 or vertical structural irregularity Type 4 of Table 12.3-2 of ASCE 7.	If the structure has either of the specified irregularities—in-plane or out-of-plane offset or discontinuity— to meet the alternate engineering criteria for concrete buildings, the irregularity must be eliminated by retrofitting. Otherwise, the structure must meet ASCE 41 with a performance objective of Structural Collapse Prevention (S-5) with the BSE-2E earthquake hazard level.
3	**Non-ductile moment frame:** The main lateral-force-resisting-system includes concrete moment frames that do not satisfy strong-column-weak-beam requirements or that have shear-governed columns or beams.	Comply with all of the following: 1. Moment frame columns shall satisfy Section 18.7.3 of ACI 318 and Section 18.7.6.1 of ACI 318. 2. Moment frame beams shall satisfy Section 18.6.5.1 of ACI 318.	Section 18.7.3 requires strong-column weak-beam strength proportions. Section 18.6.6.1 requires columns to be flexure governed. Section 18.6.5.1 requires beams to be flexure governed. Such requirements are essential for ductile behavior of concrete moment frames.

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4	**Shear-governed concrete column or wall pier:** The structure includes one or more concrete columns or wall piers that is shear-governed and is susceptible to failure resulting in loss of gravity load support.	For each column or wall pier, comply with at least one of the following: 1. Columns and wall piers shall have design shear strength satisfying Section 18.7.6.1 of ACI 318 or greater than the maximum shear that can be delivered to the column or wall pier. For wall piers, joint faces shall be taken as the top and bottom of the clear height of the wall pier. 2. Provide or demonstrate an alternate load path to support design gravity load assuming a failure of the column or wall pier such that it cannot support gravity load. 3. For wall piers in buildings that do not have a torsion irregularity ratio *TIR* per Section 12.3.2.1.1 of ASCE 7 exceeding 1.4, demonstrate compliance with the Tier 1 Quick Check for shear stress in concrete walls in that story in each plan direction per Section 4.4.3.3 of ASCE 41. Pseudo seismic force V shall be 2 times the pseudo seismic force at the BSE-1E earthquake level, but need not exceed that at BSE=2E. System modification factor M_s shall be for Collapse Prevention performance.	1. Shear governed columns or wall piers can be a serious deficiency that leads to building collapse. Retrofitting columns or wall piers by jacketing, such as with fiber reinforced polymer (FRP), can be used to make the elements flexure governed. 2. If failure of columns or wall piers can be shown not to cause collapse because of an alternate load path for gravity load, the shear-governed behavior is permitted. An example of an acceptable alternate load path is a beam that can span over a failed column or wall pier to supports not susceptible to failure, or an added column adjacent to the susceptible column or wall pier. The alternate load path is to be a complete load path, i.e. to the foundation and supporting soil, that does not rely on non-compliant elements. 3. If the building meets the quick-check for shear at the specified level and does not have a *TIR* greater than 1.4, it is judged that there is enough wall that the consequences of shear failure of wall piers will be limited. Option 3 is not permitted for structures with high plan-torsion irregularity because of a concern that columns or wall pier on one side of the building plan could suffer undo damage in such a case.

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5	**Punching shear in concrete slab:** One or more concrete floor or roof slabs is supported by columns without beams and is susceptible to loss of gravity load support following punching shear failure.	Comply with one or more of the following: 1. Demonstrate compliance with Section 18.14.5 of ACI 318 with earthquake force *E* and design story drift Δ_x taken as 2 times the earth-quake force and story drift at the BSE-1E earthquake level, but need not exceed that at BSE-2E, determined in accordance with Section 7.4. of ASCE 41. 2. Demonstrate compliance with at least one of the following in each plan direction at each column: (a) Section 8.7.4.2.2 of ACI 318. The slab bottom bars must be continuous through the column or spliced using mechanical or welded splices. (b) Section 8.7.5.6 of ACI 318. 3. Provide an alternate load path to support design gravity load, as-suming a failure at the slab-column interface such that the slab-column interface cannot support gravity load.	1. Section 18.14.5 addresses acceptable punching shear stress from gravity load as a function of story drift, a key indicator of susceptibility to punching shear of slab-column connections. 2. Section 8.7.4.2.2 requires two slab bottom bars to pass between the column cage longitudinal bars in each plan direction. Section 8.7.5.6 requires two prestressing tendons to pass through the column cage in each plan direction. The slab bottom bars or tendons help prevent collapse of the slab if punching shear initiates. 3. If the existing condition is susceptible to punching shear, a possible retrofit solution is to provide a path of support such as a collar at the top of a column that supports the bottom of the slab beyond the expected punching shear failure plane.

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6	**Weak connection of concrete wall to flexible diaphragm:** The structure includes one or more concrete walls supporting one or more flexible diaphragms, where the wall is not adequately anchored to the diaphragm.	For each flexible floor or roof diaphragm, comply with CEBC Chapter A2, or ASCE 41 with a performance objective of Structural Collapse Prevention with the BSE-2E earthquake level.	The objective of this item is to make it unlikely that a concrete wall will separate from a flexible floor or roof diaphragm in a way that could lead to floor or roof collapse. For floor or roof diaphragms that have timber framing in combination with a complete grid of concrete floor beams, CEBC Chapter A2 may be used to demonstrate that existing concrete floor beams are connected to the walls in such a way that they resist out-of-plane forces on the walls at least equal to the forces prescribed in CEBC Chapter A2.
7	**Inadequate length of bearing connection:** One or more beams or slabs is supported by a bearing connection with short bearing length.	Provide bearing length to support gravity load, such that the bearing length satisfies all of the following: 1. Section 18.14.4.1(d) of ACI 318. 2. Two times the displacement demand at the BSE-1E earthquake level, determined in accordance with Section 7.4 of ASCE 41, but need not exceed that at BSE-2E.	In some cases, including at building expansion joints, concrete floor structures, either cast-in-place or precast, have bearing supports. In older structures such bearing supports may not have adequate bearing length compared to earthquake displacement demands. 1. Section 18.14.4.1(d) requires a bearing length of 5 inches for beams, or 2 inches + L/180 for slabs.