Retrofit Grants Guidelines for Voluntary Seismic Retrofit of Concrete Buildings

Contents

Legend

Requirements for compliance with these guidelines are shown thus.

Discussion is provided in boxed text.

The intended audience for Sections 1 through 3 of these guidelines is building owners, permit applicants, engineers, architects, and other stakeholders. Sections 4 through 11 contain technical engineering material and their intended audience is the Design Engineer (e.g. Structural Engineer).

These guidelines are intended to support the City of Berkeley's program of retrofit grants for seismically vulnerable buildings. Additional information about the program, including rules and procedures, is available at https://www.cityofberkeley.info/retrofitgrants/.

1. Objective and participation

These guidelines are intended for buildings with seismic safety deficiencies related to structural elements of reinforced concrete or similar materials.

Depending on their structural characteristics, buildings of concrete construction can be vulnerable to collapse in earthquakes. The most vulnerable such buildings have elements like columns, wall piers, and joints of beams and slabs that can fail in a sudden manner, and are often called "non-ductile" (i.e., brittle) concrete buildings.

These guidelines reflect the Retrofit Grants Program's emphasis on life safety in vulnerable buildings. Retrofit to these guidelines and requirements is intended to reduce loss of life from building collapse. The retrofit requirements might not prevent serious or irreparable damage, and do not guarantee continued use of a building after strong earthquake shaking.

The **Preferred Retrofit Scope**, described in Section 6, is intended to retrofit a building so that the structure may have damaged components but would be unlikely to collapse during shaking corresponding to a "Basic Safety Earthquake 2E". This earthquake level is an industry standard, which is assumed to have a 3% probability of occurring in the next 30 years of building life and, for Berkeley, corresponds to about a 6.5 magnitude earthquake on the Hayward Fault.

It is also permitted in these guidelines to undertake less retrofit work than the Preferred Scope, as long as the applicant carries out at least a **Minimum Retrofit Scope**, described in Section 6, to address the critical seismic deficiencies found in older concrete buildings.

Participation in the Retrofit Grants Program is voluntary. However, cost reimbursement under the Retrofit Grants Program for retrofit of concrete buildings is contingent on meeting or exceeding the requirements in these guidelines.

2. Design Engineer

Seismic evaluation and retrofit design per these guidelines shall be carried out by a California registered Structural Engineer or by a California registered Civil Engineer, referred to in these guidelines as the "Design Engineer." The Design Engineer shall have the appropriate structural engineering experience and competence with the ASCE 41 standard and with the seismic evaluation and retrofitting of concrete or masonry buildings as applicable.

The State of California governs the registration of professional engineers, and requires that engineers practice only in areas where they have demonstrated competence. The license status of any professional engineer can be checked at http://www.bpelsg.ca.gov/consumers/lic_lookup.shtml. The successful execution of a seismic retrofit project and the resulting building performance in an earthquake rely heavily on the work done by the Design Engineer. Building owners are encouraged to seek references for the engineer that they plan to engage, and to understand the engineer's experience and qualifications applicable to the building type, size, and other characteristics.

Questions that an owner may want to ask a structural or civil engineer before selecting him or her include:

- Do you have experience with seismic retrofitting of concrete buildings?
- Do you have experience using the seismic evaluation and retrofit standard ASCE 41-17?
- Can you describe structures that you have evaluated or retrofitted that are most similar to my building?
- Are you familiar with the City of Berkeley's Retrofit Grants Program technical guidelines for this type of building (i.e., this document), and have you worked on projects that use this or similar guidelines?

3. Eligible buildings and procedures

Except as identified in Section 5, any building whose seismic force-resisting system relies on concrete wall or concrete frame elements, reinforced masonry wall elements, or any building that uses concrete columns to support floors or roofs, is eligible to be considered for the Retrofit Grants Program addressed by these guidelines.

Eligibility is not limited to structures that are entirely concrete. Buildings in which concrete frames have reinforced or unreinforced masonry infill are eligible, as are buildings of precast concrete. Reinforced masonry buildings and lift slab buildings are eligible.

As defined in Section 5, the following buildings are not eligible:

- Buildings that were constructed to "benchmark" or subsequent building codes
- Buildings that already meet or exceed the performance objective of Structural Collapse Prevention for a BSE-2E hazard per Section 6
- Buildings that are eligible to instead use the separate Guidelines for Rigid Wall – Flexible Diaphragm (RWFD) Buildings. (Typically low-rise buildings with concrete or reinforced masonry walls and wood-framed floor or roof construction)

4. Applicable standards

<u>Governing building codes and standards</u>

All work performed to comply with these guidelines shall comply also with the current edition of the *California Building Code* (CBC) and the *California Existing Building Code* (CEBC), as adopted by the City of Berkeley. All references to the "building code" in reference standards shall be understood as references to the CBC and CEBC. Standards listed in Section 4 shall be considered part of these Guidelines to the extent prescribed in each such reference.

The seismic retrofit work performed under the retrofit grants program addressed by these guidelines is voluntary. Thus, the work must conform to the requirements for voluntary alteration in CEBC Section 403.9.

The principal reference standard used in the seismic evaluation and retrofit design of eligible buildings shall be ASCE/SEI 41-17 *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE 41). This 2017 version shall be used with these guidelines, superseding the references to the 2013 version of ASCE-41 referenced in the 2016 CEBC and Berkeley Municipal Code (BMC) 19.28.070.

The CBC references the ASCE-41 standard. It also references ASCE 7-10, which is permitted to be used, as applicable, to design new structural elements that are part of a seismic retrofit. For the purposes of these Guidelines, the more recent ASCE 7-16 is considered an approved alternative to ASCE 7-10.

The CBC, ASCE-41, and ASCE 7 reference material standards such as ACI-318 *Building Code Requirements for Structural Concrete* which is to be used, as applicable, in evaluation and retrofit design.

ASCE 41 provisions that address topics covered by the governing building code (including ASCE 41 Sections 1.5.9 Construction Documents and 1.5.10 Construction Quality Assurance) are not applicable because they are superseded by requirements of the building code, as adopted by the City of Berkeley. (See also Sections 9, 10 and 11).

Engineering resources

ASCE 41 and ASCE 7 both include commentary sections that might be useful to design professionals. Figure C1-1 of ASCE 41 is a flowchart for the seismic evaluation process that can be a helpful starting point for navigating ASCE 41. Similarly, Figure C1-2 provides a flowchart for the seismic retrofit process.

Other resources that may be helpful include:

Seismic Design of Reinforced Concrete and Masonry Buildings (1992) by Tom Paulay and Nigel Priestley. This book describes seismic design principals for reinforced concrete and reinforced masonry buildings, including the capacity-design approach, acceptable ductile behavior modes (e.g. flexure), non-ductile behavior modes to prevent (e.g. shear or sliding shear) and desirable seismic detailing.

FEMA 306/307/308: Evaluation and Repair of Earthquake Damaged Concrete and Masonry Wall Buildings (1998). The Reinforced Concrete chapter of FEMA 306 describes behavior modes of concrete elements and how to differentiate elements with high ductility capacity vs. low ductility capacity. FEMA 307 shows examples of damage patterns and force-displacement response of test specimens exhibiting these behaviors.

SEAOC Structural/Seismic Design Manual, Volume 3: Examples for Concrete Buildings (latest edition published 2016 for the 2015 IBC). While focused on new buildings, the design examples illustrate concepts that are also applicable to retrofit of existing buildings, such as detailing and understanding the desired response of concrete structures to earthquake forces.

FEMA 547: Techniques for the Seismic Rehabilitation of Existing Buildings (2006). This document provides example details and practical considerations for choosing a retrofit approach.

SEAOSC Design Guide – City of Los Angeles NDC Building Ordinance (2016). This document discusses methods of satisfying the Los Angeles “Mandatory Earthquake Hazard Reduction in Existing Non-Ductile Concrete Buildings” ordinance. It includes summaries of common deficiencies and provides design examples for the evaluation and retrofit of non-ductile concrete buildings.

5. Establishing building eligibility

The objective of the Retrofit Grants Program is to address buildings that represent a significant risk to life under seismic actions.

Buildings that were constructed to the Benchmark or subsequent Building Codes per Table 3-2 of ASCE 41 are not eligible, unless the structural engineer can demonstrate that despite the recent construction of the building, a clear seismic deficiency exists that would be unexpected in a building meeting the Benchmark Code.

For most building types applicable to these Guidelines, the benchmark code means buildings designed to the 1995 California Building Code (CBC), which is based on 1994 Uniform Building Code (UBC), or a subsequent building code, typically constructed around 1997 or later. The 1995 CBC became effective statewide on January 1, 1996.

The Design Engineer shall conduct a seismic evaluation to the extent necessary to identify the building's most serious seismic deficiencies and to show that the building does not meet Structural Collapse Prevention for a BSE-2E hazard per Section 6 of these guidelines. Buildings that already meet this performance objective are not eligible. Buildings having any of the critical seismic deficiencies of Section 7 can be assumed to not meet the performance objective.

For buildings that are clearly deficient with regard to seismic safety, the seismic evaluation need not be overly detailed, and need not establish exactly how vulnerable a building is. In such a case, the intention of these guidelines is that the Design Engineers focus attention on retrofit solutions more than on seismic evaluation.

Buildings that are eligible to use the Retrofit Grants Guidelines for Voluntary Seismic Retrofit of 'Tilt-up' and Other Rigid Wall – Flexible Diaphragm (RWFD) Buildings, shall use those RWFD Guidelines. Such buildings are not eligible to use the Guidelines for Concrete Buildings to obtain a Retrofit Grant, except for non-RWFD portions of the structure.

6. Retrofit scope (Preferred Scope and Minimum Scope)

The **Preferred Retrofit Scope** is that required to meet the performance objective of Structural Collapse Prevention for a BSE-2E (Basic Safety Earthquake 2E) hazard, per ASCE 41.

However, to be considered eligible for the Retrofit Grants Program addressed by these guidelines, the project shall incorporate at least the **Minimum Retrofit Scope.** Requirements for the Minimum Retrofit Scope are as follows:

- Submitted structural calculations shall list the building's seismic deficiencies and identify which deficiencies the design proposes to retrofit.
- Submitted structural calculations shall identify the reasons that the work included is being prioritized over other retrofit work that would be needed to meet the Preferred Retrofit Scope for the building. Reasons given shall consider relative vulnerability, and are permitted to consider expected cost or disruption of retrofit measures.
- The critical seismic deficiencies of Section 7 shall be addressed.
- The design shall meet the requirements for partial retrofit in Section 2.2.5 of ASCE 41.
- The performance objective for the work included in the Minimum Scope shall be Structural Collapse Prevention for a BSE-2E hazard, such that if the building were subsequently retrofitted to the Preferred Scope, elements already retrofitted would not have to be further retrofitted.

The Preferred Retrofit Scope is consistent with the Basic Performance Objective for Existing Buildings (formerly called the Basic Safety Objective) defined in ASCE 41. In Berkeley, the BSE-2E hazard level corresponds to about a 6.5 magnitude earthquake on the Hayward Fault (with the correlation to earthquake magnitude assuming 84th percentile motions, 1.6 km distance to closest fault rupture).

A Minimum Scope should not differ from the Preferred Scope by retrofitting elements to a lower standard. The Minimum Scope differs in that it does not retrofit all deficiencies required for the

Preferred Scope, but those deficiencies that are retrofitted are done so to the same Collapse Prevention standard. The objective of this requirement is to facilitate a subsequent, more complete retrofit meeting the Preferred Scope.

The purpose of requiring an evaluation listing the building's seismic deficiencies is to help the Design Engineer and applicant make an informed decision about the proposed scope of retrofitting, and to help evaluate whether the proposed work is consistent with the intent of the Program to make a measurable reduction of seismic risk. A Minimum Scope can make sense when the existing building has a number of clearly severe deficiencies and a number of other less severe deficiencies, when the applicant's construction budget is insufficient to address all identified deficiencies.

Section 2.2.5 of ASCE 41 requires that a partial retrofit does not reduce seismic performance nor create a new structural irregularity. The retrofit is required to incorporate structural elements that are appropriately connected to the existing structure.

Risk Category. Note that in these guidelines the Preferred Retrofit Scope and Minimum Retrofit Scope do not depend on the Risk Category for the building.

For buildings assigned to Risk Category III or IV, a mandatory retrofit, e.g., triggered in the CEBC by major repair or alteration, would require a higher objective. Because the Retrofit Grants Program is focused on providing basic safety through mitigating structural collapse, the use of this minimum objective for Risk Category III or IV is considered acceptable for these voluntary retrofits. For buildings assigned to Risk Category III or IV, the applicant should understand that retrofit to this minimum objective will not address the damage-control or continued occupancy performance that is likely desired for the facility. For buildings assigned to Risk Category III or IV, the City may choose to approve grant funding for retrofit to a higher objective than the Preferred Scope.

7. Critical seismic deficiencies

The Minimum Scope shall address all deficiencies that pose a significant risk of collapse or loss of gravity support in an earthquake. This shall include at least the following deficiencies, in buildings where they occur. Parentheses indicate ASCE 41 Tier 1 Checklist items that identify these deficiencies:

The deficiencies listed below have in past earthquakes led to collapse in older concrete buildings. In buildings where these deficiencies occur they should be addressed because of their high potential to cause collapse.

- Slab punching shear ("Flat slab frames" in Table 17-22. "Flat slabs" in Tables 17-22, 17-24, and 17-26)

Applies to buildings with existing concrete suspended floor or roof slabs without beams, where connections of slab to columns have limited shear strength to accommodate slab rotation demands associated with seismic lateral displacement of the building, and where the existing slab lacks continuous reinforcement or tendons in the bottom of the slab passing through the column core to prevent floor collapse in the event of punching shear failure. Retrofit measures to consider include, for example, providing supplemental gravity load resisting capacity to support the weight of the slab plus superimposed loads in the event of punching shear failure in the slab.

- Column (or load-bearing wall pier) shear behavior ("No shear failures" in Table 17-22. "Deflection compatibility" in Tables 17-22, 17-24, 17-26, 17-30, and 17-32)

Applies to buildings with existing concrete columns (or load-bearing wall piers) whose expected response to seismic lateral deformation consists of shear failure, as opposed to flexural yielding of the column or adjacent beams or spandrels. Retrofit measures to consider include, for example, (a) improving shear strength of the column to be greater than the shear demand corresponding to flexural yielding of the column, or (b) providing a supplemental load path with lateral deformation capacity, such as supplemental steel columns, to support the tributary gravity load in the event of shear failure in the existing concrete column.

- Columns with significant axial load AND large spacing of confining tie reinforcement ("Column axial stress check" AND "Column-tie spacing" in Table 17-22)

Applies to buildings with existing concrete columns where both of the following apply:

(a) Axial stress exceeds $0.20f'_c$ from unfactored gravity loads alone, and $0.30f'_c$ from seismic overturning forces alone (using the ASCE 41 Quick Check procedure of Section 4.4.3.2).

AND

(b) Reinforcement tie spacing exceeds d/4 throughout the column length, or $8d_b$ at potential plastic hinge locations.

The ASCE 41 Tier 1 Checklist items cited here appear only in the Concrete Moment Frames (Type C1) table (17-22). However, if a column has BOTH of these deficiencies in any building type (including "gravity columns" in buildings with shear walls), these Guidelines consider this a critical deficiency. Retrofit measures to consider include, for example, improving column confinement, such as by jacketing with concrete, steel, or fiber reinforced polymer (FRP).

- Walls with major vertical discontinuities ("Vertical irregularities" in Table 17-2)

Applies to buildings with existing concrete or masonry walls that do not extend to foundations. Retrofit measures to consider include, for example, (a) providing a continuous load path for earthquake forces from the discontinuous wall to the foundation, and/or (b) improving the strength and deformation capacity of elements (typically beams and/or columns) that support the discontinuous wall.

- Buildings with lateral strength below 60% of "Shear stress check" in Tables 17-22, 17-24, 17-26, 17-30, 17-32, 17-34), unless the building has flexure governed walls demonstrated by a Tier 3 analysis to meet Structural Collapse Prevention performance for the BSE-2E level.

Applies to buildings with lateral strength that is less than 60% of that required to pass the ASCE 41 Tier 1 Quick Check "Shear stress check" for the applicable building type. The percentage specified here recognizes that the Tier 1 Quick Check is intended to be conservative, such that the building's lateral strength can often be shown to be adequate through more detailed procedures (Tier 2 or Tier 3). Having lateral strength greater than this percentage does not imply that Tier 2 or Tier 3 analysis would show the building's lateral strength to be adequate.

- Inadequate seating length for gravity support ("Topping slab," "Girder-column connection," and "Corbel bearing," in Tables 17-30, 17-32, and 17-34)

Applies to buildings with existing floors or framing elements whose gravity support relies on bearing connections at the ends of the span, such as precast concrete beams or slabs supported on corbels, with limited seating length and without an adequate structural connection to prevent the beam or slab from sliding off the seat in an earthquake. Adequacy of seating length should consider potential story drift and relative displacement between the seat and the supported member. Retrofit measures to consider include, for example, (a) providing a ledger, capable of supporting the gravity loads from the supported member, to increase available bearing length of the seat to accommodate seismic relative displacement, and/or (b) providing a connection or other restraint, adequate for the imposed seismic forces, to prevent unseating.

8. Application of ASCE 41 for projects using these guidelines

8.1. Seismicity parameters and Site Class (ASCE 41 Section 2.4)

Any building located in an area labeled "NEHRP E" on the latest USGS map of "Soil Type and Shaking Hazard in the San Francisco Bay Area" shall be assigned to Site Class E unless site-specific investigation in accordance with ASCE 7 Chapter 20 indicates otherwise.

Site-specific procedures are not required for compliance with these guidelines.

The USGS map of soil type is at https://earthquake.usgs.gov/hazards/urban/sfbay/soiltype/map/

Per ASCE 7 Chapter 20, which is referenced by ASCE 41 Section 2.4,1.6, "Where the soil properties are not known in sufficient detail to determine the site class, Site Class D… shall be used unless the Authority Having Jurisdiction or geotechnical data determine that Site Class E or F soils are present at the site." For the purpose of these guidelines, the City (Authority Having Jurisdiction) references the USGS map for the requirement of Site Class E, unless site-specific investigation indicates otherwise. For sites labeled "NEHRP B or C" per the USGS map, the corresponding Site Class B or C may be used in lieu of the default Site Class D, unless site-specific investigation indicates otherwise. Site Class A is not expected to occur in Berkeley.

The site-specific ground motion procedures that are in some cases required by ASCE 41 Section 2.4 are not required for the voluntary retrofit projects subject to these guidelines.

Seismic hazard parameters as needed may be obtained from the USGS application, using "2013 ASCE 41" as the Design Code Reference Document, at

https://earthquake.usgs.gov/designmaps/us/application.php

8.2. Building type and required tier for seismic evaluation (ASCE 41 Section 3.2.1)

If the Design Engineer judges that the Tier 1 Checklist for a Common Building Type is sufficiently applicable to the eligible building, then a Tier 1 evaluation procedure may be used, although a Tier 3 evaluation shall be used if triggered by Table 3-4 of ASCE 41.

Concrete frames with infill.

Concrete frames with infill panels of masonry or similarly stiff materials shall be classified as type C3 (Concrete frames with infill masonry shear walls) unless a more appropriate classification is demonstrated by testing or analysis. For concrete frames with weak infill panels, such as those with perforations or window openings, the structural engineer shall evaluate whether the Tier 1 checklists of type C1 (Concrete moment frames) provide more appropriate evaluation requirements.

8.3. Tier 1 evaluation checklists (ASCE 41 Chapter 17)

The Design Engineer shall complete the ASCE 41 Tier 1 Collapse Prevention Basic Configuration Checklist (Table 17-2) and the most appropriate building-specific checklist.

In the Table 17-2 checklist, the Design Engineer should provide known information on adjacent buildings and the potential for soil liquefaction, slope failure, or surface fault rupture, even in the case of a Minimum Scope in which such hazards will not be addressed.

In addition to Table 17-2, the checklists most likely to be applicable to eligible concrete buildings are:

- Table 17-22, for ASCE 41 building type C1, Concrete moment frames
- Table 17-24, for ASCE 41 building types C2 and C2a, Concrete shear walls
- Table 17-26, for ASCE 41 building types C3 and C3a, Concrete frames with infill masonry
- Table 17-28, for ASCE 41 building type PC1a, Precast walls with stiff floor or roof diaphragms
- Table 17-30, for ASCE 41 building type PC2, Precast concrete frames with shear walls
- Table 17-32, for ASCE 41 building type PC2a, Precast concrete frames without shear walls
- Table 17-34, for ASCE 41 building types RM1 and RM2, Reinforced masonry bearing walls. Concrete elements of RM1 and RM2 buildings, such as columns and slabs, should also be checked for applicable deficiencies of Table 17-24: "Deflection compatibility" and "Flat slabs."

Following the ASCE 41 procedures, any of the required issues for which the Tier 1 checklist item is marked Unknown (U) or Noncompliant (NC) must be addressed by further Tier 2 or Tier 3 evaluation or by retrofit.

8.4. Retrofit approach

The seismic evaluation and retrofit design shall pay careful attention to building elements that have little ductility or deformation capacity. Proposed retrofit solutions shall consider ways to provide deformation capacity in non-ductile elements. Retrofit solutions that only add strength and stiffness to a building without protecting non-ductile elements shall be carefully evaluated to understand whether assumed lateral displacement demand might be exceeded, causing unanticipated damage to non-ductile elements. (See also Section 8.9.)

Formerly, seismic retrofit approaches focused on providing strength (and as a by-product, stiffness) to the lateral-force-resisting system, often to a level equal to 75% to 100% of the design base shear used for new construction. These past approaches may have paid less attention to the non-ductile elements such as gravity columns or punching shear. In recent decades, after the failure of concrete buildings in earthquakes that originated in gravity framing, and because insight has been gained by the nonlinear analysis of concrete structures, more focus is being paid to directly addressing non-ductile elements—improving their deformation capacity rather than only trying to reduce deformation demand. Fiber reinforced polymer (FRP) wrapping of shear-critical concrete gravity columns is an example of a retrofit that improves the columns' lateral deformation capacity. A component ductility solution of this type should be considered, in addition to measures such as added walls that would reduce the deformation demand on the columns.

8.5. Yielding and non-yielding actions (ASCE 41 Section 1.2)

The Design Engineer's application of ASCE 41 shall use a capacity-design approach to identify expected and possible governing mechanisms of nonlinear (yielding) behavior of the structure.

Per ASCE 41 Section 1.2 (Definitions and Notations) Deformation-Controlled Actions are those that are allowed to yield; Force-Controlled Actions are not allowed to yield. Proper application of ASCE 41 requires classification of the structural elements and actions accordingly, which is done by determining strength hierarchies and the potential mechanisms of nonlinear behavior under lateral earthquake displacement. This approach is referred to as capacity design. Further explanation is provided in FEMA 306 (1999) and Paulay and Priestley (1992).

8.6. Collapse Prevention level considering actual mechanisms (ASCE 41 Section 2.2)

In developing conclusions on whether a structure meets the Structural Collapse Prevention performance level, the Design Engineer shall consider qualitatively and quantitatively whether one can realistically envision a mechanism of structural collapse under severe earthquake force and deformation demand. The Design Engineer shall do this in addition to considering specific component deformation acceptance limits for collapse prevention, drawing conclusions from both types of indications. With adequate justification, it is acceptable to modify default ASCE 41 component acceptance limits to better match applicable research findings and considerations of collapse mechanisms.

8.7. Material properties and condition assessment (ASCE 41 Sections 3.2.3, 4.2.1, 5.2.6, 6.2.4)

A written report of component properties and condition investigations and findings shall be submitted for approval with the structural calculations. The report and calculations shall make clear the material and member capacities used in the design, and their basis, including the knowledge factor, κ. If κ less than 1.0 is used, the structural engineer shall consider the potential for negative consequences on the assumed building behavior if the material strength is greater than assumed.

> ASCE 41 Sections 5.2.6 and 6.2.4. prescribe a knowledge factor, κ to be applied to the material strength. The assumption of weaker materials will not always lead to more conservative (i.e., safer) seismic evaluation and retrofit conclusions, because of a potential to affect the assumed hierarchy of strength and the assumed resulting behavior. For example, if an engineer uses κ = 0.75 and under-predicts the flexural strength of an element, this would under-predict the shear demand on the column and may miss identifying the column as shear critical.

Factors for expected strength of concrete and reinforcement (ASCE 41 Table 10-1)

It is permitted to assume alternative factors in Table 10-1, if justified by applicable research or testing on past projects.

> Research referenced in FEMA 306, and results from previous testing of concrete buildings in the Bay Area have shown:
>
> - For concrete compressive strength, a factor of 1.33 might be more appropriate than the default value of 1.50 in Table 10-1.
> - For reinforcement yield strength, in the strain range of most relevance to seismic response under large earthquake motions, a factor of 1.13 to 1.25, depending on bar diameter, might be more appropriate than the default value of 1.25 in Table 10-1. For nominal 60 ksi reinforcement, an expected strength of 68 to 70 ksi has been commonly observed. For nominal 40 ksi reinforcement (which is typically smaller bars, which have more hardening than larger bars), an expected strength of 48 to 50 ksi has been observed.

Testing for concrete structures (ASCE 41 Section 10.2.2.4)

If the Design Engineer demonstrates through analysis that variability of the strength of a material does not significantly affect seismic performance or the resulting retrofit design, the following are permitted, related to that material:

- An amount of destructive testing less than ASCE 41 requirements.
- Postponement of testing until the construction phase, if that facilitates the collection of samples without disruption to building use.
- Testing omitted.

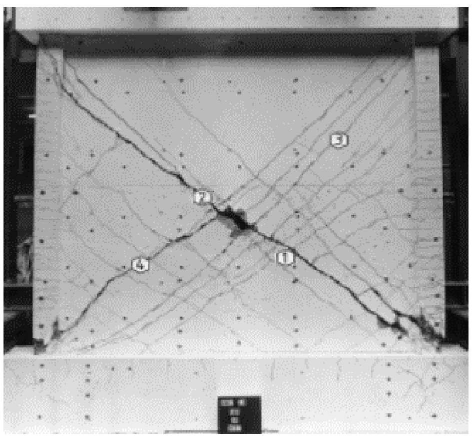
8.8. Concrete and masonry structural elements (ASCE 41 Chapters 10 and 11)

In using the nonlinear procedure for concrete or masonry, it is acceptable to use deformation limits based on applicable testing or analysis, provided that the Design Engineer provides justification and also reviews the research (if any) cited by ASCE 41 applicable to the comparable prescriptive deformation limits.

Concrete wall nonlinear behavior (ASCE 41 Chapters 10)

For the nonlinear procedure, concrete walls governed by shear having a horizontal reinforcement ratio less than 0.007 shall be assumed to rapidly lose strength at a total shear strain of not more than 0.004, unless applicable test results are provided to indicate otherwise.

Shear-governed concrete walls: Testing has shown that lightly reinforced concrete walls governed by pre-emptive shear failure can suffer rapid strength degradation after the formation of diagonal shear cracks. The light reinforcement is not able to restrain the diagonal cracks from opening widely, as shown in the tested wall below from Paulay and Priestley (1992).



Similar test results have been found by Barda (1976) and Hidalgo (2002). Currently ASCE 41 acceptance limits and modeling guidelines for such walls allow deformation limits higher than shown in testing. These guidelines recommend more conservative limits. In older concrete wall buildings, horizontal reinforcement ratio is typically close to minimum reinforcement requirements of 0.0025, and thus such walls can suffer rapid strength loss soon after the onset of diagonal cracking.

8.9. Foundation flexibility and wall stiffness assumptions (ASCE 41 Section 7.2.3.5, Table 10-5, and Section 11.3.4.1)

For structural elements (such as columns, or slab-columns connections) whose acceptability depends on their ability to withstand lateral drift demands, if such elements are proposed to be acceptable without retrofit, the analysis shall include consideration of:

(a) Foundation flexibility of the seismic force-resisting system.

(b) Realistic stiffness assumptions for walls, based on research recommendations.

For structural elements (such as walls or foundations) whose acceptability depends on force demands, if such elements are to be retrofitted using Retrofit Grant funds, the analysis shall include consideration of (a) and (b) listed above.

For some structural elements, such as columns of the gravity framing system or punching shear at slab-column connections, acceptable performance depends on the seismic lateral drift demand imposed on these elements. In a building with concrete structural walls, lateral drift demands may be underestimated if the walls are assumed to be rigidly fixed against rotation at the base, or if the stiffness of the walls is over-predicted.

Similarly, seismic force demands on walls and foundations may be overestimated if their stiffness is overestimated, possibly leading to unnecessary retrofit of these elements,

Table 10-5 prescribes default values for the stiffness of concrete elements. Section 11.3.4.1 prescribes default values for the stiffness of reinforced masonry walls. The sections prescribe using gross-section properties for the G_cA_v shear stiffness. (G_c approximately equals 0.4 E_c.) This can overestimate stiffness for walls in which diagonal shear cracking occurs. In some cases, flexural stiffness may also be overestimated by the prescriptive default values. Schotanus and Maffei (2007) provide a discussion and recommendations for concrete wall stiffness assumptions.

8.10. Adjacent buildings (ASCE 41 Section 3.2.5 and Table 17-2)

The seismic evaluation shall evaluate buildings for:

- Pounding against adjacent buildings
- Hazards to the subject building from an adjacent building (such as falling parapets).

For a Minimum Retrofit Scope, retrofitting for these deficiencies is not required.

8.11. Geologic site hazards (ASCE 41 Section 3.3.4)

The seismic evaluation shall evaluate and retrofit buildings for:

- Soil liquefaction and lateral spreading of soil
- Earthquake induced slope failure or landslide
- Surface fault rupture.

For a Minimum Retrofit Scope, retrofitting for these deficiencies is not required.

Adjacent buildings and geologic site hazards: Adjacent building hazards or geologic site hazards are required to be evaluated. Adjacent building hazards can be evaluated visually and qualitatively. Soil liquefaction can be evaluated using applicable maps (http://myplan.calema.ca.gov/ and https://geomaps.wr.usgs.gov/sfgeo/liquefaction/susceptibility.html). Landslide hazard can be evaluated visually and through applicable maps of this hazard (http://myplan.calema.ca.gov/). For a Minimum Retrofit Scope, adjacent building hazards or geologic site hazards need not be addressed by retrofitting if they represent a risk to life that is less than that of other deficiencies of the building, or if addressing such hazards has proportionally higher cost versus benefit compared to addressing other deficiencies of the building.

9. Construction quality assurance

All work performed to comply with these guidelines shall comply with CBC Chapter 17 as adopted by the City of Berkeley, and with regulations and procedures applicable to other voluntary work regulated by the Berkeley Building and Safety Division.

Structural observation in accordance with CBC Section 1704.6 is required.

In addition to the requirements of CBC Sections 1705.3 and 1705.12, special inspection shall be required for:

- Fiber reinforced polymer (FRP) reinforcing in accordance with the FRP product ICC-ES report and ICC-ES Acceptance Criteria 178 (AC178).

10. Requirements for plans

Submitted plans shall include structural and architectural drawings, and might also include mechanical, electrical, and plumbing (MEP) drawings as needed. Such drawings shall include all information and details needed to properly construct the specified seismic improvements. In addition, such submitted drawings shall include:

- ☐ Identification of non-seismic work made necessary by the seismic retrofit scope.
- ☐ Identification of voluntary additional work not required by the seismic retrofit scope.
- ☐ If phased construction is intended, identification of the work to be completed in each phase.

The drawings should make clear what work is made necessary by seismic retrofitting, and what work is not required by the retrofitting—for example remodeling work that is convenient to do at the same time as retrofitting. FEMA funding restrictions require that certain types of concurrent "upgrades" not related to the seismic retrofit, such as additions of rooms, be considered a different project with separate plans. Phased projects are permitted, but Retrofit Grants are intended for projects that will construct significant seismic retrofitting in the short term.

Structural Drawings shall include:

- ☐ The statement of Special Inspections referenced in Section 1704.3 of the CBC.
- ☐ Reference to any existing drawings and reports for the buildings that are relevant to understanding its seismic performance, including existing structural drawings, architectural drawings, and geotechnical reports.
- ☐ The site class for the building, and the seismic design parameters for the BSE-2E earthquake level ($S_{XS\_BSE\text{-}2E}$, $S_{X1\_BSE\text{-}2E}$).
- ☐ In the Project Summary section of the General Notes the following or similar statement: "This project is intended to comply with the Retrofit Grants Guidelines for voluntary seismic retrofit of concrete buildings."
- ☐ For a retrofit to the Preferred Scope, in the Project Summary section of the General Notes the statement "The Seismic retrofit performance objective is Structural Collapse Prevention for the BSE-2E earthquake level (defined in ASCE 41-17), applicable to the entire building."
- ☐ For a retrofit to less than the Preferred Scope, in the Project Summary section of the General Notes the statement "The Seismic retrofit performance objective is Structural Collapse Prevention for the BSE-2E earthquake level, applicable to those elements being retrofitted, but not applicable to the entire building."
- ☐ For a retrofit to less than the Preferred Scope, in the Project Summary section of the General Notes a statement "The Seismic retrofit work shown herein is designed to address the following deficiencies:" followed by a list of deficiencies being addressed.

11. Requirements for structural calculations

Structural calculations consistent with the structural drawings shall be submitted and shall include all information needed to demonstrate compliance with the requirements of these guidelines. In addition, calculations shall meet the following requirements:

11.1. Building characteristics and eligibility

The structural calculations shall indicate:

- ☐ Date of original construction and building code.
- ☐ Date(s) of previous seismic evaluation or retrofit, if applicable, and criteria/standard.
- ☐ Description of the seismic-force-resisting system of the existing structure, and whether it relies on concrete wall or concrete frame elements, or reinforced masonry wall elements.
- ☐ Description of the gravity structural system of the existing structure, and whether it uses concrete columns to support floors or roofs,
- ☐ Whether the existing building is constructed to the "benchmark" building provisions of ASCE 41 Table 3-2.
- ☐ That the Design Engineer has reviewed the Grants Guidelines for RWFD Buildings and confirms that the existing building does not qualify to use those guidelines instead, indicating the reasons that the building is not eligible for the RWFD Guidelines.
- ☐ The need to retrofit to achieve the performance objective identified in Section 5. One way that this can be shown is to demonstrate that the building has one or more of the critical seismic deficiencies of Section 7.
- ☐ The building type per ASCE 41 Table 3-1 (e.g. C1, C2, C2a, C3, C3a, PC1a, PC2, PC2a, RM1, RM2), including discussion if the building does not exactly match one building type.
- ☐ All material properties assumed for existing materials, and the basis for assumptions. (See Section 8.7.)

11.2. Building vulnerability and seismic deficiencies

The structural calculations shall include:

- ☐ ASCE 41 Tier 1 Collapse Prevention checklists, including the "Basic Configuration" checklist (Table 17-2) and the most appropriate building-specific checklist based on the building type (Tables 17-22 to 17-34).
- ☐ Identification in the gravity load path of any discontinuities (such as transfer girders) and key connections (such as bearing connections of beams or slabs on seats with limited seating length).
- ☐ Identification in the seismic force path of any discontinuities (such as discontinuous walls) and key connections (such as whether floor slabs are well connected to lateral-force resisting elements).
- ☐ A list of the building's seismic deficiencies, and identification of those that the structural engineer considers to pose a significant risk of collapse or loss of gravity support in an earthquake.
- ☐ For a seismic evaluation using the Linear Static Procedure or Linear Response Spectrum Procedure, computation of pseudo lateral force per ASCE 41 Section 7.4.1.3 or Section 7.4.2.3."
- ☐ Computation of the ASCE 41 Tier 1 Quick Check "Shear stress check" for the applicable building type. (See applicable Tables 17-22, 17-24, 17-26, 17-30, 17-32, 17-34)

11.3. Retrofit scope

The structural calculations shall:

- ☐ Quantify the seismic performance benefit of the structural retrofit design shown in the submitted structural drawings.
- ☐ Identify whether any of the critical seismic deficiencies of Section 7 exist in the building, and if so confirm that these deficiencies are addressed by the retrofitting.

<u>If retrofitting to the Preferred Scope:</u>

- ☐ Demonstrate that the retrofitted structure meets Structural Collapse Prevention for the BSE-2E earthquake level.

<u>If retrofitting to at least the Minimum Scope but less than the Preferred Scope:</u>

- ☐ List the deficiencies to be retrofitted, and identify the reasons that the work included is being prioritized over other retrofit work, per Section 6.
- ☐ Demonstrate that, for those elements being retrofitted, the elements after retrofitting meet Structural Collapse Prevention for the BSE-2E level.
- ☐ Confirm that the retrofitted structure meets the requirements for partial retrofit in ASCE 41 Section 2.2.5.

11.4. Mechanism of seismic response and behavior mode of structural elements

For both the existing and retrofitted structure, the structural calculations shall include, as applicable:

- ☐ Identification of the potential and governing mechanisms of nonlinear (yielding) behavior under lateral displacement. This might be done by calculation of the plastic mechanism load (lateral base shear strength, as a percentage of seismic weight) for each possible mechanism.

> The SEAOC Seismic Design Manual (SEAOC 2016), Volume 3 Example 2, provides an example of evaluating a governing plastic mechanism.

<u>For concrete columns (or load-bearing wall piers):</u>

- ☐ Calculation of the governing mode of nonlinear behavior under lateral displacement: flexure, shear, or flexure-shear.
- ☐ Estimate of the story drift corresponding to (a) yielding and (b) loss of gravity load-carrying capacity.

<u>For buildings with concrete slab-column connections (without beams):</u>

- ☐ Calculation of the demand-capacity ratio for punching shear under gravity loads (as a measure of the remaining capacity available to resist additional stresses from earthquake-imposed rotation at the slab-column joint).
- ☐ Identification of whether continuous reinforcement or tendons are present in the bottom of the slab, passing through the column core (to prevent floor collapse in the event of punching shear failure).

<u>For concrete walls and wall piers/spandrels:</u>

- ☐ Calculation of the governing mode of nonlinear behavior under lateral displacement: flexure, shear, or flexure-shear.
- ☐ Lateral strength corresponding to the governing behavior mode.

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