Planning and Development
Building & Safety Division

City of Berkeley Framework Guidelines for Soft, Weak or Open Front Building Retrofit Design

This document presents Guidelines for complying with Chapter 19.39 of the Berkeley Municipal Code, specifically Section 19.39.100.

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Part A. Requirements for All Soft, Weak or Open Front (SWOF) Retrofit Projects

A.1 Intent, Scope, and Criteria

A.1.1 Retrofit Intent

Berkeley Municipal Code (BMC) Chapter 19.39 is intended to reduce earthquake risks by limiting structural damage in the vulnerable first stories of typical wood-frame SWOF buildings. The engineering criteria given in BMC Section 19.39.100 and addressed in these Guidelines were selected to support this overall intent. Compliance with BMC Chapter 19.39 is not intended to achieve the seismic performance expected of a new building. Instead, the provisions aim to reduce risk by addressing the principal seismic weaknesses of a SWOF building with significantly less design effort, construction cost, and tenant disruption than would be needed to achieve new building equivalence. Risk reduction does not take a comprehensive approach to life safety, does not aim to protect property or function, and is not necessarily equivalent to new construction under the current building code.

A.1.2 Retrofit Scope (BMC Section 19.39.100.B)

Regardless of which engineering criteria are used, BMC Chapter 19.39 does not require retrofit actions above the critical story (typically the ground story) and the floor diaphragm immediately above it. BMC Chapter 19.39 does require retrofit or confirmation of adequacy for each critical story, for each diaphragm immediately above a critical story, and for load path elements from those stories and diaphragms through the foundation.

A.1.3 Engineering Criteria (BMC Section 19.39.100.A)

Each building subject to BMC Chapter 19.39 shall be retrofitted in conformance with one of the following engineering criteria.

1. 2012 International Existing Building Code (IEBC) Appendix Chapter A4 (see Guidelines Part B);

2. ASCE 41-06, *Seismic Rehabilitation of Existing Buildings*, using a performance objective of S-5 (Collapse Prevention) in the BSE-C earthquake (see Guidelines Part C);

3. ASCE 41-13, *Seismic Evaluation and Retrofit of Existing Buildings*, using a performance objective of S-5 (Collapse Prevention) in the BSE-2E earthquake (see Guidelines Part D);

4. FEMA P-807, *Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings With Weak First Stories*, as a pre-approved substantially equivalent standard under procedures of California Building Code (CBC) Section 104.11 for Alternative materials, design and methods of construction, and with a retrofit objective as established by the Building Official (see Guidelines Part E); or

5. Subject to project specific approval by the Building Official, 2003 IEBC Appendix Chapter A4, for buildings with Seismic Engineering Evaluation Reports submitted prior to January 1, 2014, that include structural design calculations and construction documents demonstrating conformance to Chapter A4 of the 2003 IEBC and that are suitable for building permit submittal. Since retrofit designs that qualify for 2003 IEBC Appendix Chapter A4 must already have been performed, no additional guidelines for the 2003 IEBC are included in these Guidelines.

A.2 Permit Submittal Requirements

Confirm with the Permit Service Center the number of copies of construction drawings required to be submitted. In addition, submit two (2) copies of structural calculations, special inspection forms, and any other supporting documentation to the City of Berkeley Permit Service Center (PSC) when applying for a building permit.

A.2.1 Construction Drawings

Construction drawings shall be prepared by a registered design professional and shall be stamped and signed prior to permit issuance. Drawings shall include, at minimum:

1. The registered design professional's seal and signature on each drawing sheet.

2. All information necessary for plan review and for construction. Drawings shall accurately reflect the results of the engineering investigation and structural calculations.

3. The first sheet shall include a statement that the work was designed in compliance with Berkeley Municipal Code (BMC) Chapter 19.39 as required to allow the building to be removed from the Inventory of Potentially Hazardous SWOF Buildings (see Guidelines Section A.6).

4. The work proposed under the seismic retrofit permit may trigger additional requirements. Please see Building and Safety Division website for a list of triggered requirements based on the type and valuation of work.

A.2.2 Structural Calculations and Supporting Documents

Structural calculations shall be prepared by a registered design professional. Calculations and supporting documents shall demonstrate compliance with the selected engineering criteria. Calculations and supporting documents shall be specific to the engineering criteria used and shall include, at minimum:

1. The registered design professional's seal and signature on the cover page of structural calculations and reports.

2. A statement that the calculations were prepared to demonstrate compliance with BMC Chapter 19.39 as required to allow the building to be removed from the Inventory of Potentially Hazardous SWOF Buildings (see Guidelines Section A.6).

3. Identification of the engineering criteria used for the retrofit design. Where FEMA P-807, ASCE 41-06, or ASCE 41-13 is used, identification of the performance objective.

4. Building investigation and other reports referenced by the calculations, with a report summary indicating how the findings or conclusions are reflected in the calculations (see Guidelines Section A.3.1).

5. Identification of structural properties and capacities assumed for all existing materials and elements, including any capacity reductions for damage, deterioration, or defect.

6. Identification of structural properties and capacities assumed for all new materials and elements, including product literature for proprietary devices.

7. If requested by the Building Official, verification calculations for engineering software.

8. Other information required by the Building Official.

A.2.3 Prior Engineering Evaluation Reports

Building owners are encouraged to share previously approved engineering evaluation reports with the registered design professional. To facilitate plan review, submittals may incorporate engineering evaluation reports previously approved in Phase I of the Soft Story program. However, previous evaluation reports and schematic retrofit designs by themselves will generally not be allowed as an adequate basis for a retrofit permit. See Guidelines Section A.1.3 item 5.

A.3 Assessment of Existing Building Conditions

A.3.1 Building Investigation

In support of a retrofit design, the registered design professional shall conduct an investigation of the existing building. The registered design professional shall document procedures, findings, and conclusions of the investigation and incorporate them into the permit submittal documents. The documentation may reference previously approved engineering evaluation reports (see Guidelines Section A.2.3) or other materials submitted to support findings and conclusions.

A.3.1.1 Scope of investigation. At minimum, the investigation shall comply with any investigation and assessment provisions in the specific engineering criteria selected from BMC Section 19.39.100, as modified by subsequent Parts of these Guidelines. Otherwise, the investigation scope and methods may generally be set at the discretion of the registered design professional. All findings shall be included in the permit submittal documents. The Building Official is authorized to require additional investigation as needed to fulfill the intent of BMC Chapter 19.39. With the approval of the Building Official, field verification of assumed conditions may be performed during the construction phase.

The investigation shall include identification, verification, and assessment of existing conditions relevant to the engineering assumptions applied in the retrofit design. The investigation shall be based on a combination of non-destructive testing or inspection, destructive testing or inspection, and reference to record documents. Where record documents are used to reduce the scope of testing or other on-site work, appropriate field verification is required.

A.3.1.2 Timing of investigation. Unless otherwise required by the specific engineering criteria selected from BMC Section 19.39.100, as modified by subsequent Parts of these Guidelines, and with the approval of the Building Official, investigation may be deferred to the construction phase. In such cases, the deferred investigation shall be specified as a deferred submittal item in accordance with CBC Section 107.3.4.1.

A.3.2 Existing Materials and Components

Where the applicable engineering criteria specify material or structural properties of existing elements, those criteria shall be used. Otherwise, the general rules of this section apply.

A.3.2.1 Damage and defects. The capacity of any element damaged by deterioration, wear, or other causes or altered so as to differ from its intended condition shall be reduced based on the judgment of the registered design professional, subject to review of condition assessment findings and the approval of the Building Official. This provision shall apply where the applicable engineering criteria do not make an explicit provision for capacity reduction.

A.3.2.2 Relation of nominal and expected strength to allowable stress. Where element capacities are based on allowable stresses from codes and standards, nominal strengths shall be taken no greater than the allowable stresses multiplied by the following factors: 1.7 for steel; 2.5 for masonry; 2.0 for wood. Where the element is ductile or deformation-controlled, the expected strength shall be taken as 1.25 times the nominal strength. (ASCE 31-03 Section 4.2.4.4.)

A.3.2.3 Concrete footings and stem walls. Evaluation and design of existing concrete footings shall be permitted to assume default concrete strength based on ASCE 41-13.

A.3.2.4 Unreinforced brick footings. The capacity of an existing brick footing to resist shear or pullout of an existing or new anchor shall be established by testing or by reference to approved tests of similar conditions. Where the capacity of an anchor is limited by failure of the footing or grout, the anchored wall or frame element shall be considered non-ductile or force-controlled. Retrofit elements designed with FEMA P-807 may only be used with brick footings when testing has demonstrated that the anchor will develop the strength of the wall or frame element or will yield in a ductile fashion.

A.3.2.5 Steel anchor bolts at wood sill plates. *Reserved*

A.3.2.6 Concrete or masonry retaining walls. *Reserved.*

A.3.2.7 Raised ground floor framing. Where ground floor framing is raised above adjacent grade, the cripple walls need not be analyzed or retrofitted as a separate story as long as they are no more than 14 inches in height and the framing is fully blocked or has a continuous perimeter rim joist. At the discretion of the Building Official, cripple walls taller than 14 inches may be analyzed as a rigid base if they are fully sheathed and properly detailed throughout the perimeter and directly below any first story wall sheathed with wood structural panels or carrying significant first story loads.

A.3.2.8 Sheathed wood-frame walls and partitions. Wood-frame walls and partitions shall be permitted to use peak strength values from Guidelines Part E. Where these values are used, they shall be taken as expected strengths and reduced to nominal strength per Guidelines Section A.3.2.2 where used on non-ductile or force-controlled elements. This provision is subject to the following limitations:

1. A wall assembly may be considered deformation-controlled if all sheathing materials that are individually force-controlled are ignored in the strength calculation.

2. Retrofit designs based on *R* values from the building code shall use only code-approved sheathing materials and combinations appropriate to the assumed *R* value.

A.3.2.9 Adjacent buildings and building separation. For purposes of complying with BMC Chapter 19.39:

1. Hazards from adjacent buildings do not need to be addressed, except where the buildings have shared structural elements.

2. Building separation provisions do not need to be addressed.

3. Analysis and retrofit design does not need to account for potential pounding.

A.4 Site Seismicity, Soil, and Geotechnical Considerations

A.4.1 Site Class E

Buildings located in areas labeled “NEHRP E” on the latest USGS map of “Soil Type and Shaking Hazard in the San Francisco Bay Area” will be assigned to Site Class E unless site-specific investigation in accordance with ASCE 7-10 Chapter 20 indicates otherwise. The USGS map is available at http://earthquake.usgs.gov/regional/nca/soiltype/map/.

A.4.2 Site Class F

Site response analysis for structures on Site Class F sites pursuant to ASCE 7-10 Section 11.4.7 is not required. BMC Chapter 19.39 does not require mitigation of existing geologic site hazards such as liquefiable soil.

A.4.3 Seismic Ground Motion Values

Where seismic ground motion values are calculated per ASCE 7-10 Section 11.4 or by similar provisions, the value of F_a shall be taken as 1.3 for Site Class E. This requirement applies to any code-based procedure for calculating seismicity parameters, such as that used by IEBC Appendix Chapter A4. It also applies where criteria such as ASCE 41 or FEMA P-807 apply equations similar to those in ASCE 7-10 Section 11.4.

A.4.4 Geologic Site Hazards

For purposes of complying with BMC Chapter 19.39, geologic site hazards, including potential liquefaction, landslide, and fault rupture, need not be analyzed or mitigated.

A.5 Testing and Inspection

All work shall comply with inspection and testing requirements of CBC Chapters 1 and 17 as they apply to existing buildings and structures. Additional field verification, testing, and inspection may be required in accordance with the selected engineering criteria or as directed by the Building Official. Structural observation by the registered design professional responsible for the retrofit design is required for all seismic retrofit projects performed in accordance with the BMC Chapter 19.39.

A.6 Requirements for Removal from the Inventory

To remove a building from the Inventory of Potentially Hazardous SWOF Buildings (BMC Section 19.39.040), the owner shall do all of the following:

1. Complete the seismic retrofit work along with the required city inspections.

2. Provide the City of Berkeley building inspector with completed special inspection reports, structural observation reports, and any other documents required.

3. Obtain an approved final inspection.

4. Provide a final letter of structural observation wet-signed from the responsible registered design professional indicating that site visits have been made and the work has been completed in conformance with approved plans. This letter should be addressed to the Building and Safety Division, 2120 Milvia St, Berkeley, CA 94704 or to the area inspector.

5. Provide the final affidavit from the special inspection agency for projects requiring special inspections.

Part B. 2012 IEBC Appendix Chapter A4

B.1 General Clarifications

Where the stated purpose, scope, reference codes or other requirements of 2012 IEBC Appendix Chapter A4 conflict with those of BMC Chapter 19.39, the provisions of BMC Chapter 19.39 shall apply, subject to the discretion of the Building Official.

IEBC references to “soft, weak, or open-front wall lines” shall be understood to mean any critical story as contemplated by BMC Chapter 19.39. It is possible that a building will have more than one critical story.

B.2 Specific Clarifications

B.2.1 Application of CBC Provisions for New Construction (IEBC A403.1 and A405)

IEBC Appendix Chapter A4 generally relies on code provisions for new construction. In the context of Chapter A4, the following clarifications apply:

1. With reference to ASCE 7-10 Table 12.2-1, building height limitations on certain seismic force resisting systems are not applicable where those systems are used only for retrofit of critical stories. Limitations based on seismic design category are applicable.

2. Where new sheathing is applied to existing studs to create new light-frame walls, those wall elements shall be designed as bearing wall systems.

3. Since IEBC Chapter A4 is based on code provisions for new construction, code provisions for existing buildings (such as CBC Section 3401.4.2) that allow like materials for alterations, shall not apply to retrofit elements.

B.2.2 Required Strength (IEBC A403.3 and A403.4)

Notwithstanding any other requirement of Section A403.3 or A403.4, if the retrofit elements are located so as to minimize torsion in each critical story, the total expected strength of retrofit elements added to any critical story need not exceed 1.7 times the expected strength of the story immediately above in a two-story building, or 1.3 times the expected strength of the story immediately above in a three-story or taller building.

B.2.3 Story Strength Calculation

Calculation of story strength and identification of irregularities in Section A403.3 shall be based on the expected strength of all wall lines, even if sheathed with nonconforming materials. The strength of a wall line may be reduced to account for documented inadequacy in load path or overturning resistance. In the absence of such documentation, wherever the strength of two stories is being compared, an adequate load path shall be assumed for all walls and partitions in the upper story.

The expected strength of the story above may be calculated using the FEMA P-807 criteria given in Part E. Although the FEMA P-807 provisions for combining the strengths of sheathing materials conflict with provisions in SDPWS Section 4.3.3.3.2 (AF&PA, 2009) that would otherwise apply to IEBC Appendix Chapter A4, they are considered appropriate when applied consistently for purposes of comparing the strengths of different stories or wall lines.

B.2.4 Scope of Analysis (IEBC A403.2)

The exception to IEBC Section A403.2, which in certain conditions allows retrofit in only one direction, shall apply only with Building Official approval and only where the wall lines in the non-retrofitted direction are shown to be adequate to resist any imposed torsion.

B.2.5 Design Base Shear and Design Parameters (IEBC A403.3)

1. The symbol Δ_0 should be read as Ω_0 in multiple places.

2. To account for the allowance made in ASCE 7-10 Section 12.8.1.3, the value of S_{DS} need not be taken greater than 1.33, so that the value of $0.75S_{DS}$, including the 75 percent factor allowed by Section A403.3, need not be taken greater than 1.00.

B.2.6 Changes Approved for 2015 IEBC Appendix Chapter A4
Subject to approval by the Building Official, 2012 IEBC provisions may be interpreted or applied consistent with changes approved for the 2015 edition of IEBC. These include:

1. Section A403.5: Increased demand due to P-Δ effects and story sidesway stability shall be considered in retrofit stories that rely on the strength and stiffness of cantilever columns for lateral resistance.

2. Section A403.8: Wood diaphragms are allowed to transmit lateral forces by rotation or cantilever.

3. Section A404.2.4: For prescriptive designs, cable elongation may be checked using a 4,000 pound axial load.

B.2.7 Default Strength Values for Existing Materials and Components
Default values for seismic evaluation and retrofit design involving existing components in sound condition may be taken from ASCE 41-13 (Table 12-2, etc.), SDPWS (AF&PA, 2009, Tables 4.2A through 4.2D), or Guidelines Table B.2.7, with adjustments for nominal vs. expected strength, ASD, or LRFD as appropriate for code-based design using IEBC Chapter A4. For the strength of existing walls and partitions, see Section B.2.3.

Table B.2.7 Default Nominal Strength Values for Existing Materials and Components

Existing Material or Component	Default Nominal Strength Value [1]
Roof diaphragms with straight sheathing and roofing applied directly to the sheathing, in shear	300 plf [2]
Roof diaphragms with diagonal sheathing and roofing applied directly to the sheathing, in shear	750 plf [2]
Floor diaphragms with straight tongue-and-groove sheathing, in shear	300 plf [2]
Floor diaphragms with straight sheathing and finished wood flooring with board edges offset or perpendicular, in shear	750 plf [2]
Floor diaphragms with diagonal sheathing and finished wood flooring, in shear	750 plf [2]
Plain concrete footings	f'_c = 1500 psi
Douglas Fir wood	Same as DF No.1
Reinforcing steel	f_y = 40,000 psi
Structural steel	F_y = 33,000 psi

[1] For ASD see Guidelines Section A.3.2.2 for conversion factors from nominal strength to allowable stress.
[2] For LRFD, the capacity reduction factor or resistance factor may be taken as 1.0.

Part C. ASCE 41-06

C.1 General Clarifications

Where the stated purpose, scope, reference codes or other requirements of 2012 IEBC Appendix Chapter A4 conflict with those of BMC Chapter 19.39, the provisions of BMC Chapter 19.39 shall apply, subject to the discretion of the Building Official.

See Part D of these Guidelines for additional clarifications that might apply to ASCE 41-06. It is the intent of the Building & Safety Division to discontinue, or discourage, the use of ASCE 41-06 once ASCE 41-13 is published.

C.2 Specific Clarifications

C.2.1 Earthquake Hazard Level

The BSE-2E hazard defined in ASCE 41-13 may be applied in place of the BSE-C hazard.

C.2.2 Required Strength

Notwithstanding any other requirement of ASCE 41-06, if the retrofit elements are located so as to minimize torsion in each critical story, the total expected strength of any retrofitted critical story need not exceed 1.7 times the expected strength of the story immediately above in a two-story building, or 1.3 times the expected strength of the story immediately above in a three-story or taller building.

C.2.3 Story Strength Comparison

The strength of a wall line may be reduced to account for documented inadequacy in load path or overturning resistance. In the absence of such documentation, wherever the strength of two stories is being compared, an adequate load path shall be assumed for all walls and partitions in the upper story.

Part D. ASCE 41-13

D.1 General Clarifications

Where the stated purpose, scope, reference codes or other requirements of 2012 IEBC Appendix Chapter A4 conflict with those of BMC Chapter 19.39, the provisions of BMC Chapter 19.39 shall apply, subject to the discretion of the Building Official.

ASCE 41-13 section numbers shown in Part D refer to the 2013 pre-publication version of ASCE 41-13. Section numbers in the final version, expected to be published in July 2014, might be different.

D.2 Specific Clarifications

D.2.1 Required strength

Notwithstanding any other requirement of ASCE 41-13, if the retrofit elements are located so as to minimize torsion in each critical story, the total expected strength of any retrofitted critical story need not exceed 1.7 times the expected strength of the story immediately above in a two-story building, or 1.3 times the expected strength of the story immediately above in a three-story or taller building.

D.2.2 Story Strength Comparison

The strength of a wall line may be reduced to account for documented inadequacy in load path or overturning resistance. In the absence of such documentation, wherever the strength of two stories is being compared, an adequate load path shall be assumed for all walls and partitions in the upper story.

D.2.3 Retrofit Procedures (ASCE 41-13 Sections 1.5.5 and 3.3.1)

For purposes of compliance with BMC Chapter 19.39, Tier 3 Systematic Retrofit is required, subject to scope modifications in Guidelines Sections A.1.2 and D.2.1.

D.2.4 Seismic Hazard (ASCE 41-13 Section 2.4)

For purposes of compliance with BMC Chapter 19.39, the Site-Specific Procedure of Section 2.4.2 need not be used.

D.2.5 Seismic Hazard Parameters (ASCE 41-13 Section 2.4.1)

Seismic hazard parameters for the BSE-2E hazard may be obtained using the USGS tool available at http://earthquake.usgs.gov/designmaps/us/application.php. From the Design Code Reference Document menu, select “2013 ASCE 41.” From the Earthquake Hazard Level menu, select “BSE-2E”.

For purposes of calculating seismic hazard parameters with the USGS tool, Site Class F need not be assumed.

D.2.6 Site Classes (ASCE 41-13 Section 2.4.1.6.1)

Where the Site Class is known from available documents, the known Site Class should be used. Where the Site Class is not known, the Site Class may be estimated from the USGS map available at http://earthquake.usgs.gov/regional/nca/soiltype/map/.
Site Class F need not be assumed.

D.2.7 Benchmark Buildings (ASCE 41-13 Section 4.3)

In ASCE 41-13 Table 4-6, the benchmark date of 1976 for Building Types W1 and W2 does not apply. Per BMC Section 19.39.020 *Scope and Applicability*, the provisions of Chapter 19.39 apply to buildings designed prior to 1978.

D.2.8 Modeling Primary and Secondary Components (ASCE 41-13 Section 7.2.3.3)

As noted in ASCE 41-13 Section 7.2.3.3, only primary components are to be modeled in linear analyses. In particular, for purposes of establishing the distribution of story forces, discontinuous upper story walls and partitions should not be modeled unless their stiffness is reduced to account for lack of overturning resistance or load path to elements below. However, for purposes of comparing the strength or stiffness of adjacent stories, all elements contributing significant strength or stiffness should be included to avoid underestimating the capacity of the upper stories. See Guidelines Section D.2.2.

D.2.9 Modeling Overturning (ASCE 41-13 Section 7.2.8)
As noted in Section C7.2.8, existing walls without hold-downs, where “dead loads alone are used to resist overturning,” should be considered force-controlled for purposes of checking overturning. However, they may still be considered deformation-controlled for purposes of checking shear strength, as long as the demands and capacities assigned to them account for the lack of hold-downs. Alternatively, where conservative, existing walls without hold-downs may be designated as secondary and removed from the linear model for purposes of distributing design forces to retrofit elements.

D.2.10 Limitations on Use of Linear Procedures (ASCE 41-13 Section 7.3.1.1)
As noted in ASCE 41-13 Section 7.3.1.1, linear procedures are not allowed where the maximum DCR exceeds 3.0, if a weak story or torsional irregularity exists. To clarify, this limitation applies only if a weak story or torsional irregularity would remain in the critical story of the building as retrofitted. Ideally, the retrofit should eliminate or greatly mitigate these irregularities, so linear procedures should still be usable to demonstrate compliance with BMC Chapter 19.39.

D.2.11 Period Determination for LSP (ASCE 41-13 Section 7.4.1.2)
Where steel moment resisting frames are used along relatively few wall lines and only for the critical story retrofit, parameters for period determination need not be taken as those for steel moment frame structures.

Part E. FEMA P-807

FEMA P-807, unlike the other documents cited in BMC Section 19.39.100, is written in a guideline or narrative style, rather than as a code standard. Enforceable provisions in "code language" are therefore provided here, adapted from FEMA P-807 Appendix B. In general, use of FEMA P-807 for compliance with BMC Chapter 19.39 shall mean compliance with the provisions in these Guidelines; FEMA P-807 itself constitutes a commentary to these provisions.

E.1 Compliance

E.1.1. Performance Objective

E.1.1.1. Hazard level. The spectral demand shall be $0.5S_{MS}$, calculated in accordance with ASCE 7-10 Section 11.4 except that for sites in Site Class E, the value of F_a shall be taken as 1.3.

Commentary: *The value of F_a is modified for Site Class E to adjust the demand for site effects not considered explicitly in the development of FEMA P-807 (see FEMA P-807 section 2.6.1). When calculating S_{MS}, the allowance in ASCE 7-10 Section 12.8.1.3 does not apply, as it only applies to the calculation of C_S for code-based design.*

E.1.1.2. Performance level. Acceptable performance shall be based on drifts corresponding to the Onset of Strength Loss in the seismic force-resisting elements.

Commentary: *Onset of Strength Loss criteria are already embedded in the criteria given in this Part.*

E.1.1.3. Maximum drift limit probability of exceedance. The maximum drift limit *POE* for validation of the retrofit design shall be 20 percent.

Exception: The maximum drift limit *POE* for assessment or for retrofit design shall be 40 percent, as long as the additional requirements of Guidelines Section E.7.3 are met.

E.1.2. Required scope of work

Compliance with the provisions of BMC Chapter 19.39 using FEMA P-807 requires:

1. Correction of all aspects of eligibility non-compliance per Guidelines Section E.3, and
2. Correction of all building survey non-compliance per Guidelines Section E.4, and either

3a. Demonstration of an acceptable existing condition per Guidelines Section E.6, or

3b. Design and execution of a retrofit in accordance with Guidelines Section E.7 and other applicable codes and regulations.

Where retrofit is required but the provisions of Guidelines Section E.7 cannot be satisfied, the building shall be considered ineligible for compliance with BMC Chapter 19.39 using FEMA P-807.

E.2 Definitions

Commentary: *In some instances, the notation and terminology differ slightly from those in FEMA P-807 Chapters 1-7.*

E.2.1. Terminology

Terms used in Guidelines Part B shall have the meanings provided here. Terms not defined here shall have the meanings provided in the building code.

CENTER OF STRENGTH. At each story, the location in plan that represents the weighted average location of the load in all wall lines, at the drift associated with the story strength.

DRIFT. For a given story, the calculated or postulated lateral deflection within that story divided by the story height, normally expressed as a percentage.

FIRST STORY. The story of interest with respect to assessment or retrofit, spanning vertically between the first floor and the second floor. Depending on the building and its relationship to grade, the story designated as the First Story can be an underfloor area or cripple story, a basement, the first story above grade, or another story above grade. The First Story can be partial in plan. For a building with multiple stories of interest, the First Story can vary as each story of interest is analyzed.

LOAD-DRIFT CURVE. For a wall assembly, wall line, or story, the relationship characterizing the variation of shear resistance versus drift, for the full range of relevant drifts. For a wall assembly, the load value is given in units of force per unit length. For wall lines and stories, the load value is given in units of force.

LOAD-ROTATION CURVE. For a story, the relationship characterizing the variation of torsional resistance versus story rotation, for the full range of relevant rotations, given in units of torque as a function of rotation angle.

PROBABILITY OF EXCEEDANCE (*POE*). The desired or calculated probability that the structure will respond beyond the drift limits representing the desired performance level, in at least one direction, when subjected to a specified hazard level. Within BMC Chapter 19.39 and these Guidelines, *POE* means the probability of exceeding the drift limits associated with Onset of Strength Loss.

Commentary: *As used in these Guidelines, POE is identical to what FEMA P-807 Chapters 1 through 7 typically call "drift limit POE."*

QUALIFYING WALL LINE. For purposes of checking eligibility of floor or roof diaphragms, a wall line that contributes substantially to the peak story strength and has an adequate load path connecting it to the diaphragms it affects.

Commentary: *See FEMA P-807 Section 2.6.4 for discussion of rules for "qualifying" wall lines. The definition is subject to the judgment of the registered design professional and the Building Official.*

SPECTRAL CAPACITY. For a given POE, the highest level of spectral acceleration a structure can sustain without responding beyond the drift limits representing the desired performance level, given as a multiple of the acceleration of gravity, and calculated separately in each principal direction.

SPECTRAL DEMAND. See Guidelines Section E.1.1.1. The spectral demand is given as a multiple of the acceleration of gravity.

STORY. For purposes of applying engineering criteria in BMC Section 19.39.100 and these Guidelines, see the building code definition and these Guidelines' definition of First Story.

STORY STRENGTH. The maximum load value from the story load-drift curve, calculated separately in each principal direction.

STORY STRENGTH, BASE-NORMALIZED. The story strength divided by the total seismic weight of the building.

STORY STRENGTH, STORY-NORMALIZED. The story strength divided by the sum of the tributary floor weights of all the floors above the story in question.

STORY TORSIONAL STRENGTH. The maximum torsional resistance value from the story load-rotation curve.

STRENGTH DEGRADATION RATIO. In each direction, a value between 0.0 and 1.0 calculated as the first story strength divided by the load corresponding to a drift of 3 percent from the first story load-drift curve.

TORSION COEFFICIENT. A value that need not be taken greater than 1.4, calculated as the first story torsional demand divided by the first story torsional strength.

TORSIONAL ECCENTRICITY. The absolute value of the plan distance, in *x* and *y* components, between the second story center of strength and the first story center of strength.

TRIBUTARY FLOOR WEIGHT. The total seismically active weight tributary to a single floor level comprising dead load and applicable live load, snow weight, and other loads as required by the building code.

UPPER STORY. Any story above the first story.

WALL ASSEMBLY. A unique combination of sheathing materials over wood-stud framing.

WALL LINE. A collection of full-height and partial-height wall segments or frames within a single story that satisfies the rules in Guidelines Section E.5.1.2.

Commentary: *A wood-frame wall line is generally assumed to contribute strength only in the direction parallel to its length. A wall line expected to contribute strength in a direction other than parallel to its length, such as a cantilever column or fixed-based moment frame, must be modeled appropriately.*

WALL SEGMENT. A portion of wood-frame wall made from a single wall assembly. For purposes of this definition, any sheathed run of wood-stud framing that could contribute to a story's lateral strength or stiffness shall be considered a potential wall segment, whether or not the framing and sheathing were intentionally designed, detailed, sized, or located to contribute that strength or stiffness.

E.2.2. Notation

A_U The base-normalized upper-story strength, calculated separately for each direction.

A_W The weak-story ratio, calculated separately for each direction.

C_D The strength degradation ratio, calculated separately for each direction.

C_T The torsion coefficient.

C_U The minimum of the story-normalized story strengths of any of the upper stories, calculated separately for each direction.

Commentary: *Where the story strength is roughly constant for all upper stories, C_U will generally be the story-normalized strength of the second story.*

COS_i The plan location, in x and y coordinates, of the center of strength of story i.

e_x, e_y The x and y components, respectively, of the torsional eccentricity.

f_w The load-drift curve for wall line w.

F_i The load-drift curve for story i, calculated separately for each direction.

h_w The floor-to-ceiling height of wall line w.

H_1 The floor-to-ceiling height of the tallest first story wall line, determined separately in each direction.

I A subscript index indicating floor or story. Story i is between floor i and floor $i+1$.

L_w The length of wall line w, taken as the longest possible length of wall that satisfies the rules in Guidelines Section E.5.1.2, including the length of any openings within it.

L_x The overall building dimension in the x direction.

L_y The overall building dimension in the y direction.

POE Probability of Exceedance

Q_{open} The adjustment factor for openings in a wall line.

Q_{ot} The adjustment factor for overturning of a wall line.

Q_s The story height factor for the first story, calculated separately for each principal direction.

S_c The spectral capacity, calculated separately for each direction.

S_d The spectral demand.

t_i The load-rotation curve for story i.

T_i The story torsional strength of story i.

V_{1r} The story strength of the retrofitted first story, calculated separately for each direction.

V_i The story strength of story i, calculated separately for each direction.

V_U The story strength of the upper story that determines the value of C_U.

Commentary: *Where the story strength is roughly constant for all upper stories, V_U will generally be the second story strength.*

w A subscript index indicating a single wall line.

W The total seismic weight of the building, equal to the sum of all the tributary floor weights.

W_i The tributary floor weight of floor i.

WSP Wood structural panel
x A subscript index indicating one of two principal directions.
$\alpha_{POE,0}$ The *POE* adjustment factor for a C_D value of 0.0.
$\alpha_{POE,1}$ The *POE* adjustment factor for a C_D value of 1.0.
δ_{φ} Drifts at which load-drift curves are characterized. See Table E.5.1.1.
Δ_i In each direction, the drift at which the story strength of story *i* occurs.
τ_1 The first story torsional demand.

E.3 Eligibility

E.3.1. General

Buildings that do not comply with the requirements of Guidelines Section E.3 shall be considered ineligible for compliance using FEMA P-807.

Exception: Buildings in which all aspects of non-compliance will be eliminated through alteration or retrofit are eligible for compliance using FEMA P-807.

E.3.2. Massing

1. The building has no more than four stories above grade plane at any point around its perimeter.

2. The building's wood-framed stories are not supported by an above-grade podium structure.
   Commentary: *Item 1 relies on the building code's definition of story above grade plane. Item 2 is referring to a concrete podium structure generally extending at least one story above grade and topped by a concrete diaphragm that provides a base for wood framing above. Item 2 is not intended to rule out concrete foundation elements or stem walls that extend above grade.*

E.3.3. Upper stories

1. The upper-story seismic force-resisting systems are bearing wall or building frame systems of wood-frame walls with shear panels.

2. The upper-story floor-to-floor heights are between 8 feet and 12 feet and are constant within each story.

3. In each upper story, in each principal direction, the distance from the center of strength to the center of mass of the floor below it is no more than 25 percent of the corresponding building dimension.
   Commentary: *The intent of this approximate rule is to ensure that no upper story is prone to significant torsion, and that inertial forces from upper stories should transfer to the first story near the geometric center of the second floor. See FEMA P-807 Section 2.6.2.*

4. No upper story or floor above an upper story has a weight irregularity as defined by ASCE 7-10 Table 12.3-2, Type 2.

5. No upper story has a vertical geometric irregularity as defined by ASCE 7-10 Table 12.3-2, Type 3.

E.3.4. First story, basement and foundation

1. The first story height may vary, but the maximum first story height, from top of foundation to

top of second floor framing is between 8 feet and 15 feet.

2. The first story seismic force-resisting systems are bearing wall or building frame systems of wood-frame walls with shear panels or combine such systems with steel moment-resisting frame systems, steel cantilever column systems, or steel buckling-restrained braced frame systems.

   Commentary: *FEMA P-807 is not suitable for assessing or designing concentrically braced frames, concrete shear walls, or reinforced masonry shear walls. See FEMA P-807 Section 6.5. If these systems exist or are proposed as retrofit elements, compliance must be demonstrated using one of the other methods allowed by BMC Section 19.39.100.*

3. The first story includes no full-height concrete or masonry walls.

4. The first story walls and frames have continuous concrete footings or concrete slab-on-grade foundations. If some or all of the first floor is raised over a crawl space, the crawl space has concrete stem walls to the underside of the first floor framing.

   Commentary: *Concrete stem walls are considered to provide a base similar to a concrete foundation. Wood-framed cripple walls may be considered to meet this eligibility condition at the discretion of the Building Official. See Guidelines Section A.3.2.7.*

5. First story walls and frames may be partial height over a concrete or reinforced masonry retaining wall or foundation stem wall, but any partial-height wall or frame is at least four feet tall from top of stem wall to underside of second floor framing.

6. If the building has a basement, the basement walls and the floor diaphragm just above them are capable of transferring seismic forces between the foundation and the first story, and the basement story is laterally stronger than the first story above it.

E.3.5. Floor and roof diaphragms

Floor and roof diaphragms shall satisfy the eligibility requirements of this subsection.

Exception: Diaphragms shown to have no deficiencies or irregularities that would prevent development of the strength of any seismic force-resisting wall or frame or would otherwise control the overall seismic response of the structure need not satisfy the eligibility requirements in this subsection.

> ***Commentary:*** *The intent of these approximate rules for diaphragms is to ensure that the structure does not develop a premature mechanism or failure mode. See FEMA P-807 Section 2.6.4 for additional explanation and guidance.*

1. No portion of the second floor diaphragm between qualifying wall lines has an aspect ratio greater than 2:1.

2. The second floor diaphragm does not cantilever more than 25 feet from a qualifying wall line.

3. If the second floor diaphragm cantilevers more than 10 feet from a qualifying wall line, diaphragm chords are adequate to develop the lesser of the strength of the diaphragm or the diaphragm forces associated with the peak strength of the qualifying wall line.

4. No floor or roof diaphragm has a reentrant corner irregularity in which either projecting leg of the diaphragm beyond the reentrant corner is longer than 15 percent of the corresponding plan dimension of the building, unless each leg of the diaphragm satisfies the aspect ratio and cantilever rules of this subsection.

> ***Commentary:*** *This provision differs from the irregularity defined in ASCE 31-03 or as Type 2 in ASCE 7-10 Table 12.3-1 in order to limit diaphragm demands. See FEMA P-807 Section 2.6.4.*

5. No floor or roof diaphragm has a vertical offset unless load path components are present and adequate to develop the diaphragm strength across the offset.

6. No floor or roof diaphragm has cutouts or openings within it such that, along any line across the diaphragm, the sum of the opening widths along that line is more than 25 percent of the overall diaphragm dimension along that line.

E.4 Building Survey

E.4.1. General

Structural components shall be investigated in accordance with Guidelines Section E.4 as needed to confirm eligibility per Guidelines Section E.3 and to support structure characterization per Guidelines Section E.5, assessment per Guidelines Section E.6, and retrofit design per Guidelines Section E.7.

E.4.2. Wall framing and sheathing

The investigation shall determine the length and location in plan of all wall segments and wall lines in all stories as needed to calculate load-drift curves.

The investigation shall determine the size and location of openings in each wall line as needed to calculate adjustment factors for openings and adjustment factors for overturning.

The investigation shall determine all unique frames or wall assemblies in the first story and representative wall assemblies in the upper stories. Where sheathing includes wood structural panels or where sheathing load-drift data is a function of nailing, the investigation shall also determine the nail size and edge nail spacing. Panel edge nailing shall be investigated over at least five nail spaces and as needed to confirm a reliable spacing assumption.

> ***Commentary:*** *Unless building-specific conditions indicate a need for more extensive investigation, the minimum recommended investigation should include one location of each distinct wall assembly in the first story and in any upper story, but not less than one perimeter and one interior wall line in the first story and in any upper story. If prior investigation reports based on destructive investigation are available, they may be relied on. If original drawings are available, they may be relied on to reduce the scope of investigation, but some investigation is still necessary to confirm the reliability of the drawings.*

E.4.3. Floor and roof framing and diaphragm

The investigation shall determine the construction of floor and roof framing and diaphragm sheathing, including the direction of framing and the mechanism of gravity load transfer, as needed for calculation of adjustment factors for overturning. The second floor shall be investigated. Subject to approval of the Building Official, the roof and upper floors need not be investigated in detail where there is evidence that their relevant attributes are similar to those of the second floor.

E.4.4. Load path components

The investigation shall determine the nature of the load path components and connections for transfer of forces between diaphragms and walls or frames as needed to confirm that the wall line will participate in resisting drift.

> ***Commentary:*** *For non-WSP sheathing, the intent is to confirm that fastening reasonably conforms to conventional construction requirements. For existing WSP shear walls with nail spacing closer than six inches, it should be confirmed at representative locations*

that shear wall top and bottom connection capacity is appropriate to the sheathing capacity.

The investigation shall determine the presence or absence of hold-down hardware at the base of all first story walls, as well as the adequacy of installation of representative types at representative locations.

The investigation shall confirm that anchors are provided at the base of the first story walls.

Table E.4.4 shows where the load path may be assumed adequate or is subject to investigation or confirmation. Table E.4.4 applies only to walls whose strength is counted in the analysis. For any condition subject to investigation, the load path may be assumed lacking, and the corresponding wall strength may be ignored, but only if assumed so consistently throughout the building.

Commentary: *The load path may be assumed lacking, but not selectively so as to "correct" torsion or other irregularities. This provision is similar to ASCE 41 limits on the designation of secondary components.*

Exception: Wherever the strength of two stories is being compared, an adequate load path must be assumed for all walls and partitions in the upper story.

Commentary: *The exception prevents underestimating the upper story strength. The exception also applies to calculations of weak story or soft story ratios in ASCE 41 or IEBC A4 and to application of the 1.3 or 1.7 caps on retrofit strength for ASCE 41 and IEBC A4 retrofits.*

The adequacy of an investigated load path may be confirmed by the judgment of the design professional, without calculations, but is subject to approval by the Building Official. Judgment should be based on the presence of a positive connection with multiple or redundant attachments distributed over the length of the wall line. For partitions perpendicular to floor framing above, blocking between floor joists nailed to the partition top plate (through a lath nailer, if present) should be deemed adequate for partitions with non-WSP sheathing.

Table E.4.4. Investigation Requirements for Load Path between Partitions and Floor Framing Above

Condition	**First / Target Story**	**Second / Upper Stories**
Perimeter walls with non-WSP sheathing	May be assumed adequate	May be assumed adequate
Demising walls/partitions between units or between units and common areas	May be assumed adequate	May be assumed adequate
Any wall or partition with WSP sheathing where the top of the panel is nailed directly to a header beam, floor girder, or rim joist	May be assumed adequate	May be assumed adequate
Any wall or partition with WSP sheathing where the top of the panel is nailed only to a single or double top plate.	Confirm or provide load path	Confirm or provide load path
Room partitions within units, perpendicular to floor framing above	Investigate	May be assumed adequate
Room partitions within units, parallel to floor framing above	Investigate	Investigate

E.4.5. Foundation elements

The investigation shall determine the nature of the existing foundation elements and supporting soils as needed for calculation of adjustment factors for overturning.

E.5 Structure Characterization

E.5.1. Story strength

E.5.1.1. Wall assemblies. For each wall assembly present, a load-drift curve shall be computed by summing contributions from Table E.5.1.1 at each drift level for each layer of sheathing. With approval of the Building Official, test results specific to the wall assembly or its components may be used in place of Table E.5.1.1.

Commentary: *See FEMA P-807 Section 4.4 and Appendix F regarding the development of Table E.5.1.1 and the use of alternate test data.*

The values in Table E.5.1.1 are subject to the following additional requirements:

1. Horizontal wood sheathing or wood siding shall be at least 1/2" thick and fastened to existing studs with at least two nails per board per stud. Otherwise, the expected strength shall be taken as 0.
2. Where siding panel edges are lapped, each panel shall be nailed separately. Otherwise, the expected strength shall be taken as 0.

Table E.5.1.1. Expected Strength for Load-Drift Curves [plf]

Sheathing Material	Drift, δ_i [%]								
	0.5	0.7	1.0	1.5	2.0	2.5	3.0	4.0	5.0
Stucco	333	320	262	0	--	--	--	--	--
Horizontal wood sheathing or wood siding	85	96	110	132	145	157	171	0	--
Diagonal wood sheathing	429	540	686	913	0	--	--	--	--
Plaster on wood lath	440	538	414	391	0	--	--	--	--
Plywood panel siding (T1-11), 6d@6	354	420	496	549	565	505	449	0	--
Gypsum wallboard	202	213	204	185	172	151	145	107	0
Plaster on gypsum lath	402	347	304	0	--	--	--	--	--
WSP, 8d@6	521	621	732	812	836	745	686	0	--
WSP, 8d@4	513	684	826	943	1,018	1,080	1,112	798	0
WSP, 8d@3	1,072	1,195	1,318	1,482	1,612	1,664	1,686	1,638	0
WSP, 8d@2	1,393	1,553	1,713	1,926	2,096	2,163	2,192	2,130	0
WSP, 10d@6	548	767	946	1,023	1,038	1,055	1,065	843	0
WSP, 10d@4	707	990	1,275	1,420	1,466	1,496	1,496	1,185	0
WSP, 10d@3	940	1,316	1,696	1,889	1,949	1,990	1,990	1,576	0
WSP, 10d@2	1,120	1,568	1,999	2,248	2,405	2,512	2,512	2,231	0

E.5.1.1.1. Wall assemblies without WSP sheathing. The assembly load drift curve is the sum of the load drift curves for each of the sheathing layers.

E.5.1.1.2. Wall assemblies with WSP sheathing. The assembly load drift curve is whichever of the following two load-drift curves has the larger peak strength:

1. The assembly load-drift curve using 50 percent of the strength of the wood structural panel layers and 100 percent of the strength of the other sheathing materials.

2. The assembly load-drift curve using 100 percent of the strength of the wood structural panel layers and 50 percent of the strength of the other sheathing materials.

E.5.1.2. Wall line assignment. Each segment of sheathed wall framing within a story shall be assigned to a wall line. Wall lines shall satisfy the following rules:

1. Full-height wall segments separated by window or door openings but connected by sheathed segments and continuous framing above or below the opening shall be assigned to the same wall line, unless other rules require them to be treated separately.

2. Wall segments assigned to the same wall line shall not be offset out-of-plane from adjacent segments by more than four feet.

3. At bay windows, the wall segments within the common plane shall be assigned to the same wall line if they satisfy the other rules, but the wall segments within the cantilevered portions of the bay shall not be counted toward the wall-line strength.

4. Wall segments of different heights, including wall segments along a stepped foundation, shall be assigned to separate wall lines.

5. A wall segment of varying height due to a sloped foundation shall be assigned to a separate wall line, and its height shall be taken as the average height of the segment.

6. Wall segments of different wall assemblies shall be assigned to separate wall lines.

7. Where hold-downs exist at each end of a wall segment, that segment may be considered a separate wall line.

8. Wall segments less than one foot long shall be treated as openings.

9. Wall segments between openings with height-to-length ratios greater than 8:1 shall be treated as openings.

10. Steel elements (moment frames, cantilever columns, etc.) shall be assigned to separate wall lines.

11. Wall segments or frames considered to have significant damage, deterioration, or construction defects may be counted toward a wall line's strength but shall have their load-drift strength values reduced.

E.5.1.3. Wall line load-drift curve. For each wall line, a load-drift curve shall be computed by multiplying the applicable wall assembly load-drift curve by the wall line's length and by applicable adjustment factors per Guidelines Equation E.5.1.3-1.

$$f_w = (v_w)(L_w)(Q_{open})(Q_{ot}) \qquad \text{(Equation E.5.1.3-1)}$$

where:

f_w is the load-drift curve of wall line *w*, expressed as a function of drift.

v_w is the load-drift curve of the wall assembly associated with wall line *w*, as derived per Guidelines Section E.5.1.1 and adjusted for height variation per Guidelines Section E.5.1.3.1.

E.5.1.3.1. Adjustment for height variation. Where first story wall lines in a given direction are of different heights, the load-drift curve of the wall assembly of each wood-frame wall line shall be adjusted to account for increased drift demands in all but the tallest first story wall line. This may be done by shifting the assembly load-drift curve from the standard set of drifts given in Table E.5.1.1 to an adjusted set of drifts for each wall line, given by Equation E.5.1.3.1-1.

$$\delta_{jh} = (\delta_j)(h_w/H_1)^{0.7} \qquad \text{(Equation E.5.1.3.1-1)}$$

E.5.1.3.2 Adjustment for openings. Each wall line load-drift curve shall account for the effects of openings within it. This may be done by applying the adjustment factor for openings, given by Equation B5.1.3.2-1 and Equation B5.1.3.2-2.

$$Q_{open} = 0.92a - 0.72a^2 + 0.80a^3 \qquad \text{(Equation E5.1.3.2-1)}$$

$$a = \frac{1}{\left(1 + \frac{\sum A_o}{h_w \sum L_f}\right)} \qquad \text{(Equation E.5.1.3.2-2)}$$

where:

$\sum A_o$ = sum of the areas of the openings within the wall line

$\sum L_f$ = sum of the lengths of the full-height wall segments within the wall line.

E.5.1.3.3. Adjustment for overturning. Each wall line load-drift curve shall account for the effects of overturning demand and resistance. This may be done by applying the adjustment factor for overturning, given by Equation E.5.1.3.3-1 or, for existing upper-story wall lines only, by Table E.5.1.3.3.

$$Q_{ot} = 0.4\left(1 + 1.5\frac{M_r}{M_{ot}}\right) \leq 1.0 \qquad \text{(Equation E.5.1.3.3-1)}$$

where M_{ot} is the overturning demand on the wall line and M_r is the resisting moment due to all available dead loads tributary to the wall line plus the effects of any tie-down hardware.

Commentary: *See FEMA P-807 Section 4.5.3.2 for guidance on calculating* Q_{ot}.

Table E.5.1.3.3. Default Adjustment Factor for Overturning, Q_{ot}, for Existing Upper Story Wall Lines

Number of stories above	Perpendicular to Framing	Parallel to Framing	Unknown or mixed
Two or more	0.95	0.85	0.85
One	0.85	0.80	0.80
None (Top story)	0.75	0.75	0.75

E.5.1.4. Story load-drift curves. For each story, in each direction, a load-drift curve shall be computed by adding the load-drift curves of all the walls in that story and aligned in that direction.

Commentary: *Where all the wall line load-drift curves are mapped to the same set of drifts, the summation is straightforward. Where some first story wall lines have load-drift curves mapped to a height-adjusted set of drifts, load values at the standard drift values should be determined by linear interpolation. Once interpolated values are calculated, the various load-drift curves can again be added in a straightforward way based on the standard drift values. See FEMA P-807 Section 4.6 for additional discussion.*

E.5.2. First story torsion

E.5.2.1. Center of strength. The center of strength for the first and second stories shall be determined based on the wall line loads at the drift at which the story strength in the corresponding story and direction occurs.

Commentary: *FEMA P-807 Section 4.6.4 illustrates the calculation of the center of strength.*

E.5.2.2. First story torsional demand. The first story torsional demand represents the effect of the first story strength acting at the torsional eccentricity, given by Equation E.5.2.2-1.

$$\tau_1 = e_x V_{1y} + e_y V_{1x} \qquad \text{(Equation E.5.2.2-1)}$$

E.5.2.3. First story load-rotation curve. For the first story, a load-rotation curve shall be derived, relating torsion about the story center of strength to the resulting rotation of the story, assuming a rigid second floor diaphragm and accounting for the load-drift behavior of each first story wall line. The load-rotation curve shall consider rotation angles up to at least the rotation associated with 5 percent in-plane drift in at least one first story wall line.

Commentary: *FEMA P-807 Section 4.6.6 illustrates one method for calculating of the load-rotation curve, dividing the rotation range of interest into ten even increments.*

E.5.3. Characteristic coefficients

E.5.3.1. Base-normalized upper-story strength. The base-normalized upper-story strength shall be calculated for each principal direction per Equation E.5.3.1-1.

$$A_U = \frac{V_U}{W} \qquad \text{(Equation E.5.3.1-1)}$$

E.5.3.2. Weak-story ratio. The weak-story ratio shall be calculated for each principal direction per Equation E.5.3.2-1.

$$A_W = \frac{V_1}{V_U}$$ (Equation E.5.3.2-1)

E.5.3.3. Strength degradation ratio. The strength degradation ratio, C_D, shall be calculated for each principal direction based on the first story load-drift curves.
Commentary: *FEMA P-807 Section 4.7.4 illustrates the calculation of the strength degradation ratio.*

E.5.3.4. Torsion coefficient. The torsion coefficient, given by Equation E.5.3.4- 1, need not be taken greater than 1.4.

$$C_T = \frac{\tau_1}{T_1}$$ (Equation E.5.3.4-1)

E.5.3.5. Story height factor. The story height factor shall be calculated for each principal direction per Equation E.5.3.5-1, where H_1 is given in inches.

$Q_s = 0.55 + 0.0047\ H_1$ (Equation E.5.3.5-1)

E.6 Assessment

E.6.1. Assessment relative to the performance objective

Subject to the additional requirements of Guidelines Section E.1.2, any eligible structure shall be deemed to comply with the requirements of these Guidelines if its spectral capacity in each principal direction exceeds the spectral demand.

E.6.1.1. Spectral capacity. Spectral capacity in each direction shall be calculated from Equations E.6.1.1-1 through E.6.1.1-5, using drift limit *POE* adjustment factors given in Table E.6.1.1 for the drift limit *POE* specified in Guidelines Section E.1.1.3. Drift limit *POE* adjustment factors for intermediate values of drift limit *POE* shall be calculated by linear interpolation.

Commentary: *BMC Chapter 19.39 does not require the calculation of a POE. However, given a spectral demand, the POE of a structure can be calculated. See FEMA P-807 Section 5.4.2 or Appendix B model provision 6.2.*

$$S_c = C_D^3 S_{c1} + \left(1 - C_D^3\right) S_{c0}$$ (Equation E.6.1.1-1)

$$S_{c1} = \alpha_{POE,1} S_{\mu 1}$$ (Equation E.6.1.1-2)

$$S_{c0} = \alpha_{POE,0} S_{\mu 0}$$ (Equation E.6.1.1-3)

$$S_{\mu 1} = (0.525 + 2.24A_W)(1 - 0.5C_T)Q_s A_U^{0.48}$$ (Equation E.6.1.1-4)

$$S_{\mu 0} = (0.122 + 1.59A_W)(1 - 0.5C_T)Q_s A_U^{0.60}$$ (Equation E.6.1.1-5)

Table E.6.1.1. Drift limit probability of exceedance adjustment factors.

POE	$\alpha_{POE,1}$	$\alpha_{POE,0}$
2%	0.36	0.29
5%	0.44	0.37
10%	0.53	0.46
20%	0.66	0.60
30%	0.77	0.73
50%	1.00	1.00
60%	1.14	1.16
70%	1.30	1.37
80%	1.52	1.66

E.7 Retrofit

E.7.1. Retrofitted first story strength

The first story strength of the retrofitted structure shall account for all existing unaltered elements, existing altered elements, new elements provided to increase story strength, and new elements provided to correct aspects of eligibility or building survey non-compliance.

Exception: Out-of-plane or weak axis strength of existing or retrofit elements need not be considered where the sum of those strengths is deemed insignificant to the total story strength.

> ***Commentary:*** *The Exception is intended to allow wood frame walls and pin-based frames to be ignored in their weak directions, and to allow the Building Official to accept the registered design professional's judgment or to require modeling of fixed-based frames and cantilever columns in their weak directions.*

E.7.2. Retrofit compliance

The retrofit design shall demonstrate that both of the following conditions are true:

1. The retrofitted structure's spectral capacity in each principal direction exceeds the spectral demand.

2. The first story strength of the retrofitted structure in each principal direction satisfies Equation E.7.2-1 or Equation E.7.2-2.

$V_{1r} \leq 1.7V_U$, for 2-story buildings (Equation E.7.2-1)

$V_{1r} \leq 1.1V_U(0.11A_U + 1.22)$, for 3-story and taller buildings (Equation E.7.2-2)

Commentary: *The intent of Equations E.7.2-1 and E.7.2-2 is to ensure that over-strengthening the first story is not miscounted as beneficial. Given the maximum POE, if the required first story strength cannot be achieved without exceeding this limit, it indicates that the proposed retrofit would push failure to the second story and would not achieve its intended effect. Where the exception to Guidelines Section E.1.1.3 is applied, the higher POE value will give the same spectral capacity for less first story strength, effectively allowing a lighter retrofit that might satisfy the equation.*

FEMA P-807 Section 6.2.1 provides formulas for estimating the strength of the retrofitted first story needed to reach the required spectral capacity, but use of the estimating formulas is not required.

E.7.3 Additional requirements where the Exception to Guidelines Section E.1.1.3 is applied

The retrofit design shall demonstrate that all of the following additional conditions are true:

1. The first story strength of the retrofitted structure in each principal direction satisfies Equation E.7.3-1.

2. The retrofit design satisfies the requirements of Guidelines Section E.7.3.1.

$V_{1r} \geq 0.9V_U(0.11A_U + 1.22)$ (Equation E.7.3-1)

E.7.3.1 Minimized torsional eccentricity. Retrofit elements shall be located along perimeter wall lines so as to minimize the torsional eccentricity of the retrofitted structure, or so as to satisfy Equations E.7.3.1-1 and E.7.3.1-2. This requirement may be modified with the approval of the Building Official to accommodate other building or planning code requirements or to avoid disproportionate construction costs.

$e_x \leq 0.10L_x$ (Equation E.7.3.1-1)

$e_y \leq 0.10L_y$ (Equation E.7.3.1-2)

Commentary: *Where the Exception to Guidelines Section E.1.1.3 is needed, but the additional requirements of Section E.7.3 cannot be satisfied, it indicates that there is no retrofit solution that both strengthens the target story sufficiently and protects the upper story from damage. In these cases, the Building Official may allow an owner to over-strengthen using ASCE 41-13 or IEBC A4, but better performance is likely to be achieved by voluntarily strengthening one or more upper stories as well as the critical target story.*

E.7.4 Design criteria for retrofit elements
Retrofit elements shall conform to the general requirements in this section and to the applicable requirements in the following subsections.

> ***Commentary:*** *See Guidelines Section E.3.4 for discussion of retrofit systems for which FEMA P-807 is suitable.*

1. Where retrofit elements are sized based on unit strengths from codes or standards, the expected strength, without strength reductions or resistance factors, may be used.
   > ***Commentary:*** *The allowance of expected strength, which is typically greater than nominal strength (see Guidelines Section A.3.2.2) is appropriate because FEMA P-807 requires retrofit elements to be ductile (or, in ASCE 41 terms, deformation-controlled).*

2. The load-drift curve of each retrofit element type shall be based on expected material properties, including overstrength. The full expected capacity, without strength reduction or resistance factors, shall be used to calculate load-drift curves and peak strengths.

3. Each retrofit element shall be such that a load-drift curve based on similar elements alone would have a strength degradation ratio, C_D, greater than or equal to 0.8.

4. The load-drift curve of each retrofit element type shall be defined up to five percent interstory drift or as needed to fully characterize the retrofit design per Guidelines Section E.5.

5. Materials and systems for all retrofit elements shall be generally consistent with provisions of the building code for new construction of the same occupancy and risk category. Building code Section 3401.4.2 and other provisions that allow like materials for alterations do not apply to retrofits mandated by BMC Chapter 19.39. However, the Building Official may waive restrictions on certain systems based on building height, irregularity, seismic design category, or other conditions not related to the critical deficiencies of the story being assessed or retrofitted.
   > ***Commentary:*** *FEMA P-807 presumes that retrofit elements will be reliably ductile (as indicated by the requirement for a minimum C_D value in item 3 above). Systems detailed as special should generally be deemed to comply with this requirement, but systems detailed as intermediate or ordinary may also be shown to be adequate. The final sentence of this provision allows intermediate and ordinary steel frames to be used in seismic design category D and E; see also ASCE 7-10 Sections 12.2.5.6 and 12.2.5.7.*

6. Design criteria for load path components and connections shall be appropriate to the performance objective and shall be based on the building code for new construction, appropriate provisions of other criteria allowed by BMC Section 19.39.100, or principles of capacity design.

E.7.4.1. Wood structural panel shear walls. Load-drift curves for wood structural panel retrofit elements shall be calculated in accordance with Guidelines Section E.5. Existing shear walls modified by replacing sheathing materials or by adding supplemental wood structural panels shall be considered retrofit elements.

E.7.4.2. Steel special moment-resisting frames. Steel retrofit elements that conform to the requirements of AISC 341-10 for Special Moment Frames shall be deemed to comply with the provision requiring a C_D value greater than or equal to 0.8. The load-drift curve may be characterized per FEMA P-807 Figure 6-7 as follows: $V_y = ZF_{ye}$ with post-yield strengthening up to $1.2V_y$ at d_{max}, with $d_{max} = d_y + 4\%$.

E.7.4.3. Steel intermediate moment-resisting frames. For steel retrofit elements that conform to the requirements of AISC 341-10 for Intermediate Moment Frames, the load-drift curve may be characterized per FEMA P-807 Figure 6-7 as follows: $V_y = ZF_{ye}$ with no post-yield strengthening, and $d_{max} = d_y + 2\%$.

E.7.4.4. Steel ordinary moment-resisting frames. For steel retrofit elements that conform to the requirements of AISC 341-10 for Ordinary Moment Frames, the load-drift curve may be characterized per FEMA P-807 Figure 6-7 as follows: V_y per AISC 360 Chapter F, using F_{ye} instead of F_y, $d_{max} = 2\%$.

E.7.4.5. Steel special cantilever columns. For steel retrofit elements that conform to the requirements of AISC 341-10 for Special Cantilevered Column systems, the load-drift curve may be characterized per FEMA P-807 Figure 6-7 as follows: $V_y = ZF_{ye}$ with no post-yield strengthening, and $d_{max} = d_y + 2\%$.

E.7.4.6. Steel ordinary cantilever columns. FEMA P-807 shall not be used to demonstrate compliance of steel ordinary cantilever columns as retrofit elements.

E.7.4.7. Steel buckling-restrained braced frames. Steel retrofit elements that conform to the requirements of AISC 341-10 for buckling-restrained braced frames shall be deemed to comply with the provision requiring a C_D value greater than or equal to 0.8.

Commentary: *FEMA P-807 Section 6.5.5 offers further guidance on characterizing and designing these elements.*

E.7.4.8. Damping systems. FEMA P-807 may be used to demonstrate compliance of hysteretic damping systems that rely on the yielding of steel components by modeling the retrofit elements as bi-linear systems similar to other structural steel systems. The Building Official is authorized to require third party peer review at the expense of the permit applicant.

FEMA P-807 shall not be used to demonstrate compliance of other damping systems, including viscous- or friction-damped systems.

Commentary: *Viscous- and friction-damped systems cannot be designed with FEMA P-807 because the FEMA P-807 surrogate models did not include these mechanisms.*

E.7.5 Design criteria for load path elements and components

The retrofit design shall confirm or provide a load path from the second floor diaphragm through the first story seismic force-resisting elements and their foundations, to the supporting soils. The ultimate strength of load path components shall be reduced with strength reduction factors as needed to ensure that the load-path elements are able to develop the strength and the intended mechanism of first story wall and frame elements. Specific design criteria may be derived from principles of capacity design, from other criteria allowed by BMC Section 19.39.100, or from building code provisions for new construction involving the overstrength factor, Ω_0.

E.7.5.1. Foundations and overturning. New foundation elements shall be provided as needed to resist bearing, sliding, and overturning forces associated with the retrofit elements acting at their strength. Connections and load path components related to wall or frame overturning shall not assume any acting dead load except for the self-weight of the retrofit element unless the retrofit element incorporates existing gravity load-carrying framing or unless the design and construction explicitly transfer existing dead load to the retrofit element. The weight of foundation elements may be considered if adequately connected.

E.7.5.2. Second floor diaphragm. The second floor diaphragm shall be strengthened as needed to ensure that expected forces can be transferred between the diaphragm and the first-story elements.

E.7.5.3. Fixed-base frame columns. Moment-resisting frame systems and cantilever column systems whose capacity assumes other than a pin-based condition shall be provided with connection details demonstrated to develop the assumed fixity and the assumed column strength. In general, an anchor-bolted base plate without substantial embedment within a foundation element is not considered to provide a fixed-base condition.

E.8 Design quality assurance

E.8.1. Structural calculations

Structural calculations and documentation of assessments and retrofit designs using FEMA P-807 shall include, at minimum:

1. Plans and/or elevations for each floor level identifying each wall line and showing the wall assembly, length, location, and openings.

2. A schedule of wall assemblies and load drift curves for existing, altered, and new elements.

3. A list or schedule of wall lines with overturning and opening adjustments.

4. Derivation of characteristic coefficients.

5. Spectral capacity calculations.

6. Site-specific spectral demand calculations.

E.8.2. Use of the FEMA P-807 Weak Story Tool

Reserved

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For further information, contact:

Soft Story Program
Building and Safety Division
2120 Milvia Street
Berkeley, CA 94704
Tel: 510 981 7451
Main line: 510 981 7440
Email: jmcnulty@cityofberkeley.info
http://www.cityofberkeley.info/softstory