DSA

# IR 18-3

# FOUNDATION ANALYSIS AND DESIGN FORCES: 2022 CBC

**Disciplines:** Structural

**History:** Revised 02/13/24 Under 2022 CBC
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Division of the State Architect (DSA) documents referenced within this publication are available on the DSA Forms or DSA Publications webpages.

## PURPOSE

This Interpretation of Regulations (IR) clarifies requirements for the design of foundation elements that resist forces from the seismic force resisting system (SFRS) of the building superstructure on projects under DSA jurisdiction.

## SCOPE

This IR applies to the analysis and design of new foundation systems resisting seismic forces from the superstructure of a new building. This IR does not apply to the design of a rehabilitation project utilizing the performance based seismic design approach per California Existing Building Code (CEBC) Section 317.5 in accordance with the American Society of Civil Engineers Standard 41: Seismic Evaluation and Retrofit of Existing Buildings (ASCE 41).

## BACKGROUND

California Building Code (CBC) Section 1617A.1.15 amends the American Society of Civil Engineers Standard 7: Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7), Section 12.13.1. This amendment defines additional requirements for the design strength of the foundation elements and the connection of the SFRS to the foundation. By requiring amplified seismic design forces, this code provision intends to prevent inelastic behavior in these elements and connections and thus preserve the assumed ductility of the SFRS upon which the system design and expected building response are based.

In addition to the strength of foundation members and connections, the complete design of a building to resist a code prescribed seismic event also includes justification of stability and the capacity of the supporting subgrade (i.e., soil). While CBC Section 1617A.1.15 does not require these aspects to be designed for the amplified design forces, they are integral with the foundation design by virtue of the global seismic analysis of a building. The complexity resulting from this interrelatedness, warrants clarification and guidance to facilitate the proper application of these requirements.

## 1. AMPLIFIED SEISMIC FORCES

CBC Section 1617A.1.15 requires foundations and SFRS connections to the foundation to be designed for amplified seismic forces through the creation of ASCE 7 Section 12.13.1.1. Three amplified seismic load conditions are defined by the provision, which requires compliance with the lesser of the three. As such, it is not necessary to quantify (i.e., calculate) each loading condition, provided the design is substantiated for any one of the three.

### 1.1 Strength of Superstructure

Per ASCE 7 Section 12.13.1.1, Item #1, the foundation and superstructure connection can be designed for the strength of the superstructure elements. This loading condition shall be determined by a nonlinear analysis considering the global post-elastic behavior of the structure and all relevant yielding mechanisms based on expected material strengths per Section 1.2 below. The nonlinear analysis shall be in accordance with one of the following:

**1.1.1** Nonlinear response history analysis per ASCE 7 Chapter 16.

**1.1.2** Nonlinear pushover analysis in accordance with an approved form *DSA 1-AMM: Request for Alternate Design, Materials and Methods of Construction*. Refer to *Procedure (PR) 18-01: Request for Alternate Design, Materials and Methods of Construction* for additional information.

### 1.2 Fully Yielded Structural System

Per ASCE 7 Section 12.13.1.1, Item #2, the foundation and superstructure connection can be designed for the maximum forces that can be delivered by a fully yielded SFRS. This loading condition is determined by a calculation of the plastic strength of the components of the SFRS that are designed to yield and dissipate energy (e.g., beam flexure in special moment frames, link beams in eccentrically braced frames, buckling restrained brace core yielding, brace buckling and yielding in concentrically braced frames, etc.) considering all material expected strengths and strain hardening. These plastic strength capacities are then applied to the SFRS and used to calculate boundary reactions at the foundation. The fully yielded system analysis is commonly performed by hand calculations and can typically consider each line of seismic resistance separately. The determination of plastic strength shall be based on the following:

**1.2.1** Nominal strength with strength reduction factors (i.e., “phi” factors) of 1.0.

**1.2.2** Expected material strength in accordance with the applicable material design standard adopted by the CBC.

**1.2.3** In the absence of expected material strength provisions in the adopted material design standard, the expected strength shall be established in accordance with ASCE 41.

### 1.3 Load Combinations with Overstrength Factor

Per ASCE 7 Section 12.13.1.1, Item #3, the foundation and superstructure connection can be designed for forces resulting from the structural analysis of load combinations including the overstrength factor. The overstrength factor is established in ASCE 7 Section 12.4.3.1 for use in the load combinations defined in ASCE 7 Section 2.4.5.

## 2. EXCEPTIONS AND PRESCRIPTIVE COMPLIANCE

In conjunction with requiring the design of foundations and SFRS connections for amplified seismic forces, CBC Section 1617A.1.15 also defines three exceptions to the requirement. Additionally, DSA recognizes certain configurations of SFRS types and foundation geometries that are deemed compliant with the intent of CBC Section 1617A.1.15 on a prescriptive basis without more detailed structural analysis.

### 2.1 Exception 1: Design Loads Required by Adopted Standards

Design for the prescribed amplified load conditions does not negate compliance with design strength requirements established by other design standards adopted by the CBC. For example, the column to foundation connection requirements of the American Institute of Steel Construction (AISC) Specification 341, Section D2.6 may require design for forces that exceed the amplified forces required by the CBC.

### 2.2 Exception 2: Demonstrated Adequate Performance

When it is demonstrated that inelastic deformation of the foundation and superstructure connection will not result in a weak story or cause collapse of the structure, then design for amplified seismic forces is not required. A nonlinear seismic analysis per Section 1.1 above is required to demonstrate this performance level as described in Section 2.2.1 and 2.2.2 below.

**2.2.1** The analysis model shall include the strength and stiffness of the foundation elements and capture the post-elastic response of the foundation and the structure, including the redistribution of forces in the structure and foundation.

**2.2.2** The inelastic rotational demands shall be shown not to exceed the rotational capacity of joints.

**2.2.3** The foundation system shall comply with the ductile detailing requirements of American Concrete Institute Building Code Requirements for Structural Concrete (ACI 318), Section 18.6.

**2.2.4** When approved at a pre-application meeting in advance of the project submission for plan review, DSA may accept a linear analysis of a single-story building with no structural irregularities. The foundation system shall be represented in the structural analysis model of the building.

**2.2.5** Grade beams that are subject to flexure from columns that are part of the seismic force-resisting system may be designed and detailed utilizing the ductile detailing requirements per Section 2.2.3 above and permitted to be modeled as linear. The grade beams shall frame directly into the column and be decoupled from other foundation elements to allow inelastic rotation to occur. The rotation and flexural deformation of the foundation and connection shall be considered in drift and deformation compatibility. Isolated spread footings which have been decoupled from grade beams shall be designed for forces including the overstrength factor per Section 1.3 above. For additional information, refer to Section 2.2 of *IR 18-5: Foundation Design and Detailing*.

### 2.3 Exception 3: Light-Framed Walls with Shear Panels

Foundations resisting seismic loads from light-framed walls (i.e., repetitive framing consisting of wood or cold-formed steel studs) with shear panels are generally not required to comply with the amplified seismic force design requirement. This exception does not apply when an adopted material design standard requires design for a higher force level. For example, where the American Iron and Steel Institute North American Standard for Seismic Design of Cold-Formed Steel Structural Systems (AISI S400) designates the connection of shear wall hold-downs to the foundation as a capacity protected component, it shall be designed for the forces required by the standard. Refer to AISI S400 Sections B3 and E1.4.1.2 for additional information.

### 2.4 Prescriptive Compliance

Compliance with CBC Section 1617A.1.15 is deemed to be met under certain specific prescriptive conditions. In these cases, DSA will not require calculations to substantiate the design strength subject to the amplified seismic loads. Compliance with all other applicable code provisions is required, including demonstration of design strength required by the load combinations of ASCE Section 2.3.

**2.4.1** A shallow foundation supporting a concrete or masonry shear wall is deemed to comply when all the following prescriptive conditions are met:

**2.4.1.1** Footing length does not project beyond the ends of the wall more than 2 times the footing depth. See Figure 2.1 below.

**2.4.1.2** Footing width does not project beyond the face of the wall more than 2 times the footing depth on either side. See Figure 2.1 below.

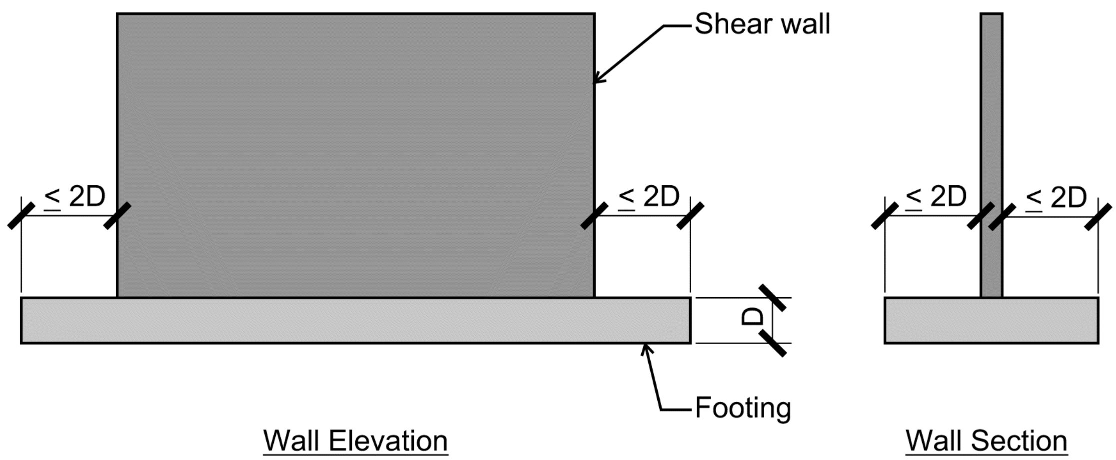


**Figure 2.1: Footing Extension Limits, Prescriptive Compliance**

**2.4.1.3** Footing is not required to couple shear wall segments together for overturning stability. Where multiple walls occur on a continuous footing, overturning stability shall be demonstrated for each wall independently by conceptually dividing the continuous footing into discrete footings associated with each wall. This division is solely for the purpose of evaluating overturning stability and need not affect the detailing and construction of the continuous footing. See Figure 2.2 below.

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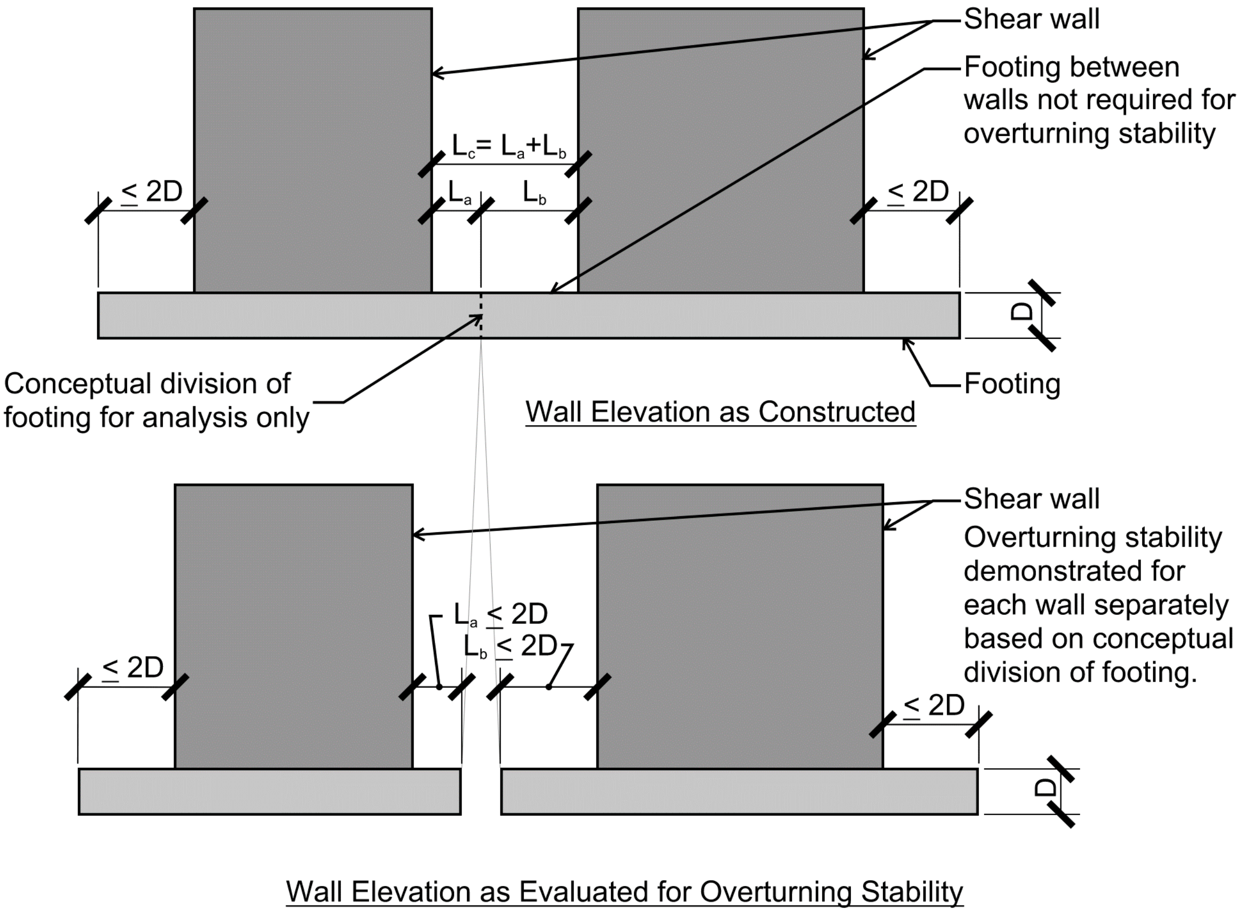


**Figure 2.2: Multiple Shear Walls on Common Footing, Prescriptive Compliance**

**2.4.1.4** Footing is neglected in the design of shear resistance to seismic forces at wall openings. All the vertical seismic forces at the edge of wall openings shall be resisted in the spandrel wall elements and not the footing. See Figure 2.3 below.

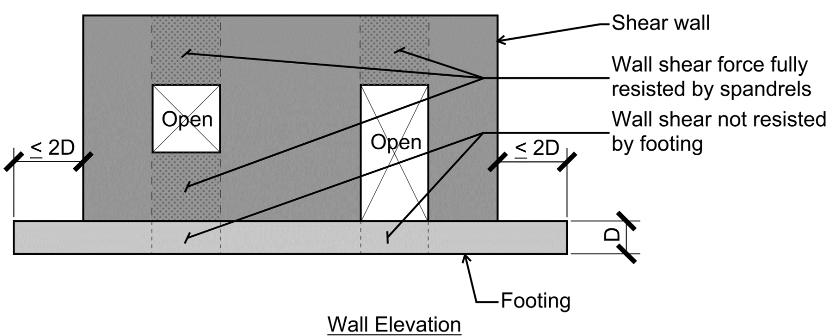


**Figure 2.3: Shear Wall with Openings, Prescriptive Compliance**

**2.4.1.5** Footing does not support columns or piers that support discontinuous shear walls. Refer to ASCE 7 Figures C12.3-3 and C12.3-4 for examples.

**2.4.2** The prescriptive conditions required by Section 2.4.1 above may be evaluated locally for a continuous footing supporting multiple shear walls or wall piers. When the prescriptive conditions are evaluated locally, those portions of the continuous footing not in compliance with all the conditions shall be designed (i.e., substantiated with calculations) for the amplified seismic forces per CBC Section 1617A.1.15. Any additional reinforcement required by this design shall be developed in the footing in accordance with ACI 318.

**2.4.3** Connections of the following SFRS to the foundation are deemed to comply when all the of the vertical reinforcement required by the SFRS design is fully developed into to the foundation. Development by lap splice is acceptable when permitted by the SFRS design requirements.

**2.4.3.1** Cast-in-place concrete shear walls.

**2.4.3.2** Cast-in-place concrete moment frames.

**2.4.3.3** Masonry shear walls.

## 3. STABILITY AND SUBGRADE CAPACITY

Design for stability and adequate subgrade capacity does not require consideration of the amplified seismic forces described in Section 1 above.

### 3.1 Stability

In accordance with CBC Section 1605A.1.1, stability of the SFRS and its foundation against overturning and sliding shall be met under the load combinations of ASCE 7 Section 2.3 or 2.4. The reduction of the seismic overturning moment permitted by ASCE 7 Section 12.13.4 may be applied except when the alternative allowable stress design load combinations of CBC Section 1605A.2 are used.

### 3.2 Subgrade Capacity

The capacity of the subgrade (i.e., soil or rock) resisting loads from the building foundation shall be demonstrated under the load combinations of ASCE 7 Section 2.3 or 2.4 or CBC Section 1605A.2. Depending on the foundation type, the subgrade capacity includes the allowable bearing pressure of shallow footings, skin friction or end bearing of deep foundation elements, as well as lateral bearing and friction resisting horizontal loads. In accordance with CBC Section 1803A.7, the geotechnical engineer shall establish the subgrade capacity, unless the presumptive values of CBC Section 1806A are permitted.

**3.2.1** When the allowable stress design load combinations of ASCE 7 Section 2.4 or CBC Section 1605A.2 are used, the design shall comply with ASCE 7 Section 12.13.6. The factor of safety applied to establish soil bearing values shall not be less than the overstrength factor per CBC Section 1605A.1.1.

**3.2.2** When strength design load combinations of ASCE 7 Section 2.3 are used, the design shall comply with ASCE 7 Section 12.13.5. Strength reduction factors (i.e., resistance factors) shall be defined by the geotechnical engineer in the geotechnical report per CBC Section 1605A.1.1.

## 4. ANALYSIS METHODS

Recognizing the interrelatedness of those aspects of the foundation design that require consideration of amplified seismic loads (e.g., foundation design strength) and those that do not (e.g., stability), the analysis methodologies described in this section are accepted by DSA to demonstrate compliance with CBC Section 1617A.1.15. The methods apply only to the design of foundation strength (i.e., moment, shear, and axial forces), not the connection of the SFRS superstructure to foundation, which requires no special consideration.

### 4.1 Case 1: Deep Foundations

Deep foundation systems do not require special structural analysis allowances to achieve the overturning stability under amplified seismic loads that is required to design the foundation elements. In deep foundation systems, resistance to overturning is provided through piles or cast-in-place piers. While skin friction capacity is not required to exceed amplified load demands (see Section 3.2 above) the analysis shall establish design forces for the foundation under the amplified loads by assuming overturning resistance through the deep foundation elements (i.e., piles or piers). That is, the foundation design is based on whatever magnitude of skin friction demand is required to achieve overturning stability.

### 4.2 Case 2A: Shallow Foundation Stability Under Amplified Seismic Loads

If the SFRS and its foundation is stable for overturning under the amplified seismic load condition, these forces can be applied directly to the structural analysis.

**4.2.1** The structural analysis results from the amplified seismic load conditions shall be used to design the foundation member strength (i.e., internal moment, shear, and axial forces) and the SFRS superstructure-to-foundation connections.

**4.2.2** Separate load combinations in accordance with Section 3 above shall be used to demonstrate compliance with subgrade capacity requirements.

**4.2.3** This method shall be used when the SFRS and its foundation system can be statically resolved without overturning instability under the amplified seismic load condition. Depending on the structural analysis used to design the building, this is reflected as follows:

**4.2.3.1** Computer model with rigid boundary restraints representing subgrade: Results show no vertical uplift at any of the boundary restraints.

**4.2.3.2** Computer model with spring restraints representing subgrade: Compression-only springs are used, or the results show no tension in any of the springs.

**4.2.3.3** Hand analysis of individual SFRS lines on continuous footing: Resulting subgrade reaction for each line falls within the length of the footing.

**4.2.3.4** Hand analysis of individual SFRS lines on discrete spread footings: Uplift transferred from the column to the spread footing is offset by the weight of the footing multiplied by a load factor of 0.9.

### 4.3 Case 2B: Shallow Foundation Instability Under Amplified Seismic Loads

**4.3.1** Rocking of shallow foundations (net uplift along the entire soil to foundation interface) occurs if the structure on any given line of resistance is unstable under amplified seismic loads. If an overturning instability occurs at the base, the design may scale down the overstrength factor described in Section 1.3 above until stability is achieved. The foundation size does not need to be increased to eliminate the overturning instability under amplified seismic loads. The overstrength factor shall not be scaled down below the factored load combinations of ASCE 7 Section 2.3.6 with seismic load $E_h$, which includes the redundancy factor ($\rho$) per ASCE 7 Section 12.4.2.1.

**4.3.2** When the overstrength factor is reduced as described in Section 4.3.1 above, the reduced value shall be determined for each load combination and each footing separately. The strength of the footing shall satisfy all load combinations prescribed by the CBC. The determination of the reduced overstrength factor values shall be explicitly explained and documented in the structural calculations. It is not acceptable to use the least value for the overstrength factor for all load combinations.

**4.3.3** When determining the counteracting effects of the gravity load on overturning stability, the analysis shall consider the following gravity load effects to capture a realistic seismic load at which rocking is initiated:

**4.3.3.1** Foundation concrete over-pour.

**4.3.3.2** Soil on top of the footing.

**4.3.3.3** Friction at the sides of the foundation (upper-bound limit) as recommended by the project geotechnical engineer.

**4.3.3.4** Slab-on-grade spanning or engaging more slab area than directly above the footing only.

**4.3.3.5** Live load per ASCE 7 Section 2.3.6, Exception #1 at floors, including that described in Section 4.3.3.4 above.

**4.3.3.6** Intersecting walls or footings.

**4.3.4** The following are examples of how to determine the point at which overturning stability is first achieved:

**4.3.4.1** For a continuous footing or combined footing, the point at which overturning stability is achieved shall be the point when the entire underside of the footing is in uplift except for the end tip in compression. The end tip in compression shall be idealized as a concentrated load equal to the gravity load effects as described in Section 4.3.3 above using the load combinations of ASCE 7 Section 2.3.6.

**4.3.4.2** For isolated spread footings, the point at which overturning stability is achieved shall be when the applied uplift force equals the gravity load effects described in Section 4.3.3 above.

**4.3.5** The connection of the superstructure to the foundation shall be designed for the full amplified seismic forces required by CBC Section 1617A.1.15. Reduction of the overstrength factor per Section 4.3.2 above shall not be applied to the connection design. ←

**REFERENCES:**

2022 California Code of Regulations (CCR) Title 24
Part 2: California Building Code (CBC), Sections 1605A.1.1, 1617A.1.15.