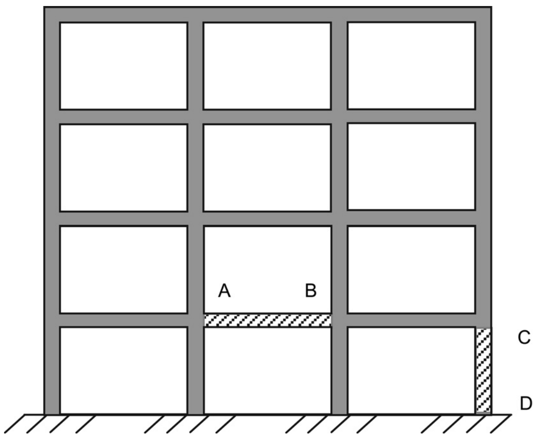
Example 1 Earthquake Load Combinations: Strength Design §12.4.2.3

This example demonstrates the application of the strength design load combinations that involve the seismic load E given in §12.4.2.3. This will be done for the moment-resisting frame structure shown below.

S_{DS} = 1.10
I = 1.0
ρ = 1.3
f_1 = 0.5
Snow load $S = 0$



Beam A-B and Column C-D are elements of the special moment-resisting frame. Structural analysis has provided the following beam moments at A, and the column axial loads and moments at C due to dead load, office building live load, and left-to-right (→) and right-to-left (←) directions of lateral seismic loading.

	Dead Load, D	Live Load, L	Left-to-Right Seismic Load ($\rightarrow Q_E$)	Right-to-Left Seismic Load ($\leftarrow Q_E$)
Beam Moment at A	−100 kip-ft	−50 kip-ft	+120 kip-ft	−120 kip-ft
Column C-D Axial Load	+90 kips	+40 kips	+110 kips	−110 kips
Column Moment at C	+40 kip-ft	+20 kip-ft	+160 kip-ft	−160 kip-ft

Sign Convention: Positive moment induces flexural tension on the bottom side of a beam and at the right side of a column. Positive axial load induces compression. Note that for the particular location of Column C-D, the seismic Axial Load and Moment at C are both positive for the left-to-right (→) loading and are both negative for the right-to-left (←) loading. This is not necessarily true for the other elements of the structure.

Find the following.

1. Strength design seismic load combinations (Comb.)

2. Strength design moments at beam end A for seismic load combinations

3. Strength design interaction pairs of axial load and moment for the design of column section at C for seismic load combinations

Calculations and Discussion	***Code Reference***

1. Governing strength design seismic load combinations

$1.2D + 1.0E + 0.5L$ . . . (Note $0.2S = 0$) (Comb. 5)

$0.9D + 1.0E$ (Comb. 7)

where for a given type of load action such as moment M or axial load P

$E = E_h + E_v$ (Eq 12.4-1)
$E_h = \rho Q_E$ (Eq 12.4-3)
$E_v = 0.2S_{DS}D$ (Eq 12.4-4)

Combined, these yield

$$E = \rho Q_E + 0.2S_{DS}D$$

when the algebraic sign, ±, of Q_E is taken as the same as that for D, and

$$E = \rho Q_E - 0.2S_{DS}D$$

when the algebraic sign, ±, of Q_E is taken as opposite to that for D.

For the given values of : $\rho = 1.3$, $S_{DS} = 1.10$, the load combinations are

$1.2D + 1.3Q_E + (0.2)(1.1)D + 0.5L = 1.42D + 1.3Q_E + 0.5L$ (Comb. 5)

when the signs of Q_E and D are the same, and

$1.2D + 1.3Q_E - (0.2)(1.1)D + 0.5L = 0.98D + 1.3Q_E + 0.5L$ (Comb. 5)

when the signs of Q_E and D are opposite.

$0.9D + 1.3Q_E + (0.2)(1.1)D = 1.12D + 1.3Q_E$ (Comb. 7)

when the signs of Q_E and D are the same, and

$0.9D + 1.3Q_E - (0.2)(1.1)D = 0.68D + 1.3Q_E$ (Comb. 7)

when the signs of Q_E and D are opposite.

By inspection, the governing seismic load combinations are

$$1.42D + 1.3Q_E + 0.5L$$

when the signs of Q_E and D are the same,

$$0.68D + 1.3Q_E$$

when the signs of Q_E and D are opposite.

2. Strength design moments at beam end A for seismic load combinations

a. For the governing load combination when the signs of Q_E and D are the same

$$1.42D + 1.3Q_E + 0.5L$$

with $D = M_D = -100$, $Q_E = M_{QE} = -120$, and $L = M_L = -50$

$$M_A = 1.42\,(-100) + 1.3\,(-120) + 0.5(-50) = -323 \text{ kip-ft}$$

b. For the governing load combination when the signs of Q_E and D are opposite

$$0.68D + 1.3Q_E$$

with $D = M_D = -100$ and $Q_E = 120$

$$M_A = 0.68(-100) + 1.3(120) = 88 \text{ kip-ft}$$

∴ Beam section at A must be designed for

$$M_A = -323 \text{ kip-ft and } + 88 \text{ kip-ft}$$

3. Strength design interaction pairs of axial load and moment for the design of column section at C for seismic load combinations

The seismic load combinations using the definitions of E given by Equations 12.4-1 through 12.4-4 can be used for the design requirement of a single action such as the moment at beam end A, but they cannot be used for interactive pairs of actions such as the axial load and moment at the column section C. These pairs must occur simultaneously because of a common load combination. For example, both the axial load and the moment must be due to a common direction of the lateral seismic loading and a common sense of the vertical seismic acceleration effect represented by $0.2\,S_{DS}D$. There can be cases where the axial load algebraic signs are the same for Q_E and D, while the moment algebraic signs are different. This condition would prohibit the use of the same load combination for both axial load and moment.

To include the algebraic signs of the individual actions, the directional property of the lateral seismic load effect Q_E, and the independent reversible property of the vertical seismic load effect $0.2\,S_{DS}D$, it is proposed to use

$$E = \rho(\rightarrow Q_E) \pm 0.2\,S_{DS}D, \text{ and } \rho(\leftarrow Q_E) \pm 0.2\,S_{DS}D.$$

The resulting set of combinations is

$$1.2D + \rho(\rightarrow Q_E) + 0.2\,S_{DS}D + L$$
$$1.2D + \rho(\rightarrow Q_E) - 0.2\,S_{DS}D + L$$
$$1.2D + \rho(\leftarrow Q_E) + 0.2\,S_{DS}D + L$$
$$1.2D + \rho(\leftarrow Q_E) - 0.2\,S_{DS}D + L$$
$$0.9D + \rho(\rightarrow Q_E) + 0.2\,S_{DS}D$$
$$0.9D + \rho(\rightarrow Q_E) - 0.2\,S_{DS}D$$
$$0.9D + \rho(\leftarrow Q_E) + 0.2\,S_{DS}D$$
$$0.9D + \rho(\leftarrow Q_E) - 0.2\,S_{DS}D$$

(Note: a factor of 0.5 applies to L if $L \leq 100$ psf [except at garages and public assembly areas])

For the specific values of $\rho = 1.3$ and $S_{DS} = 1.10$, the load combinations provide the following values for M_A, and the interaction pair P_C and M_C. Note that the interaction pair P_C and M_C must occur simultaneously at a specific load combination of gravity load, and lateral and vertical seismic load effects. The interaction design of the column section must satisfy all of the eight pairs of P_C and M_C from the seismic load combinations along with the pairs from the gravity load combinations and wind load combinations.

	M_a	P_c	M_c
$1.42D + 1.3E + 0.5L$	−11	<u>290.8</u>	<u>274.8</u>
$0.98D + 1.3E + 0.5L$	33	251.2	257.2
$1.42D - 1.3E + 0.5L$	<u>−323</u>	4.8	−141.2
$0.98D - 1.3E + 0.5L$	−279	−34.8	−158.8
$1.12D + 1.3E$	44	243.8	252.8
$0.68D + 1.3E$	<u>88</u>	204.2	235.2
$1.12D - 1.3E$	−268	−42.2	−163.2
$0.68D - 1.3E$	−224	<u>−81.8</u>	<u>−180.8</u>

The governing values are underlined for M_A [same as determined in Part (2)] and for the interaction pairs of P_C and M_C required for the design of the column section at C.

Commentary

The eight seismic load combinations resulting from the proposed definition of E provide an automatic method of considering the individual algebraic signs of the load actions, the direction of the lateral seismic load, and the independent ± action of $0.2\,S_{DC}D$. There is no need to use the "same sign" and "opposite sign" limitations of Equations 12.4-2 and 12.4.2.1 since all possible combinations are represented. This is important for interactive pairs of actions that must be evaluated for a common load combination.

When the Modal Response Spectrum Analysis procedure of §12.9 is used, the algebraic signs of seismic load actions are lost because of the process of combining the individual modal responses. The signs to be used for an interaction pair of actions due to a given direction of lateral loading can be obtained from the primary mode response where the primary mode is the mode having the largest participation factor for the given direction of lateral seismic loading. Or, alternatively, the signs can be obtained from the equivalent lateral force procedure of §12.8.

Example 2
Combinations of Loads §2.4

The code permits the use of allowable stress design for the design of wood members and their fasteners (ASCE/SEI 7-05 §2.4 and §12.4.2.3). Section 2.4 defines the basic load combinations for allowable stress design.

This example illustrates the application of this method for the plywood shear wall shown below. The wall is a bearing and shear wall in a light wood framed building.

The following information is given:

Seismic Design Category B

$I = 1.0$

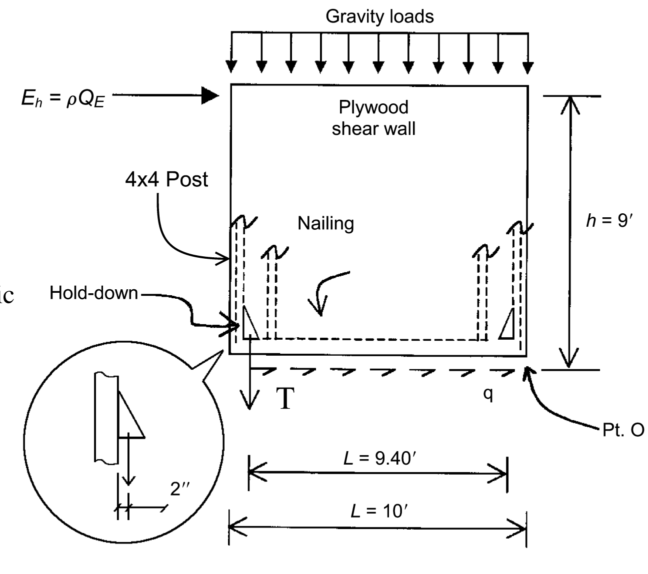
$\rho = 1.0$

$S_{DS} = 0.3$

$E = E_h = \rho Q_E = 4$ kips (seismic force due to the base shear determined from §12.4.2)

Gravity loads

Dead $w_D = 0.3$ klf (tributary dead load, including weight of wall)



Shear Wall Elevation

Moment arm from center of post to center of hold-down bolt

$$L = 10 \text{ ft} - (3.5 + 2.0 + 3.5/2) = 10 \text{ ft} - 7.25 \text{ in} = 9.4 \text{ ft}$$

Determine the required design loads for shear capacity q and hold-down capacity T for the following load combinations.

1. Basic allowable stress design

Calculations and Discussion — Code Reference

1. Basic allowable stress design §12.4.2.3