elf_base_shear_a: Equations & Use

by Tom Irvine ASCE 7-22 Equivalent Lateral Force (ELF) procedure, Section 12.8

English units: W and V in kips, h_n in ft. Metric units: W and V in kN, h_n in m. Spectral accelerations S_{DS}, S_{D1} and S_1 are in g, and periods in seconds. The seismic response coefficient C_s is dimensionless, so the force equations are the same in both systems; only the period coefficient C_t changes (page 2).

1. Seismic Base Shear (12.8.1)

$$V = C_s W \qquad (12.8\text{-}1)$$

W = effective seismic weight (Section 12.7.2). The app uses Method 2 for C_s:

$$C_s = \frac{S_{DS}}{R/I_e} \quad (12.8\text{-}3) \qquad \text{not to exceed} \qquad C_s = \frac{S_{D1}}{T\,(R/I_e)} \ \text{ for } T \le T_L \quad (12.8\text{-}4)$$

$$C_s = \frac{S_{D1}\,T_L}{T^2\,(R/I_e)} \ \text{ for } T > T_L \quad (12.8\text{-}5)$$

Lower limits:

$$C_s = 0.044\,S_{DS}\,I_e \ \ge \ 0.01 \quad (12.8\text{-}6) \qquad \text{and, where } S_1 \ge 0.6\,g: \quad C_s = \frac{0.5\,S_1}{R/I_e} \quad (12.8\text{-}7)$$

The results list each value and the equation that governs. S_1 is the mapped MCE_R parameter (Section 11.4.2 or 11.4.4).

2. Elastic Base Shear

$$V_e = S_a\,W, \qquad S_a = S_{DS}\ (T \le T_s), \quad \frac{S_{D1}}{T}\ (T_s < T \le T_L), \quad \frac{S_{D1}T_L}{T^2}\ (T > T_L), \qquad T_s = \frac{S_{D1}}{S_{DS}}$$

V_e is the base shear if the structure stayed elastic, using the same spectral shape as Method 2. When no limit governs, $V = V_e\,I_e / R$, so $V_e / V = R / I_e$. When a lower limit governs, V_e / V is less than R / I_e and the plot notes it.

3. Fundamental Period (12.8.2)

$$T_a = C_t\, h_n^x \quad (12.8\text{-}8) \qquad T = \min\left(T_{computed},\ C_u T_a\right) \quad \text{or} \quad T = T_a$$

Approximate period coefficients, Table 12.8-2:

Structure type	C_t (ft)	C_t (m)	x
Steel moment-resisting frames	0.028	0.0724	0.8
Concrete moment-resisting frames	0.016	0.0466	0.9
Steel eccentrically braced frames (B1, D1), BRBF	0.03	0.0731	0.75
All other structural systems	0.02	0.0488	0.75

Coefficient for the upper limit on calculated period, Table 12.8-1 (linear interpolation between rows):

S_{D1} (g)	C_u
$\geq$ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
$\leq$ 0.1	1.7

4. Seismic Design Factors and the Plot

$$\text{Design} : V = C_s W \qquad \text{Strength} : \Omega_0 V \qquad \text{Displacement} : \delta_{DE} = \frac{C_d\, \delta_e}{I_e} + \delta_{di} \quad (12.8\text{-}16)$$

R (response modification coefficient) reduces the elastic force to the design force, crediting ductility.
Ω_0 (overstrength factor) estimates the real strength; elements that must stay elastic use $E_{mh} = \Omega_0 Q_E$ (12.4.3).
C_d (deflection amplification factor) converts the elastic displacement under V to the expected inelastic displacement; δ_{di} is the added diaphragm displacement (zero for a rigid diaphragm). For displacement and drift, Eq. 12.8-6 need not be applied (12.8.6.1) and the computed T need not be capped at $C_u T_a$ (12.8.6.2).
The external plot shows base shear against roof displacement normalized by δ_E, the elastic displacement at V_e: blue: elastic line to V_e; red: idealized pushover to $\Omega_0 V$; black dot: (δ_e, V); red dot: $C_d \delta_e / I_e$.
The pushover shape between V and $\Omega_0 V$ is illustrative. Only V, $\Omega_0 V$, V_e and $C_d \delta_e / I_e$ are code values.
The overlay curve uses a second system with the same T and W, so both share V_e and the elastic line.

5. Limits of the App

Height limits, Seismic Design Category restrictions, redundancy ρ, irregularities and the vertical distribution of forces (12.8.3) are not checked. Values of R, Ω_0 and C_d are from ASCE 7-22 Table 12.2-1 for the systems listed on page 3.

6. Systems in the App (ASCE 7-22 Table 12.2-1)

Seismic force-resisting system (Table 12.2-1 line)	R	Ω_0	C_d
C1 Steel special moment frames	8	3	5.5
C3 Steel intermediate moment frames	4.5	3	4
C4 Steel ordinary moment frames	3.5	3	3
C5 Special reinforced concrete moment frames	8	3	5.5
C6 Intermediate reinforced concrete moment frames	5	3	4.5
C7 Ordinary reinforced concrete moment frames	3	3	2.5
B1 Steel eccentrically braced frames	8	2	4
B2 Steel special concentrically braced frames	6	2	5
B3 Steel ordinary concentrically braced frames	3.25	2	3.25
B26 Steel buckling-restrained braced frames	8	2.5	5
B27 Steel special plate shear walls	7	2	6
B4 Special reinforced concrete shear walls (building frame)	6	2.5	5
A1 Special reinforced concrete shear walls (bearing wall)	5	2.5	5
B6 Ordinary reinforced concrete shear walls (building frame)	5	2.5	4.5
A8 Special reinforced masonry shear walls (bearing wall)	5	2.5	3.5
B17 Special reinforced masonry shear walls (building frame)	5.5	2.5	4
A16 Light-frame (wood) walls, wood structural panels	6.5	3	4
A17 Light-frame (cold-formed steel) walls, wood panels or steel sheets	6.5	3	4
D1 Dual: SMF + steel eccentrically braced frames	8	2.5	4
D2 Dual: SMF + steel special concentrically braced frames	7	2.5	5.5
D3 Dual: SMF + special reinforced concrete shear walls	7	2.5	5.5

A = bearing wall systems, B = building frame systems, C = moment-resisting frame systems, D = dual systems with special moment frames capable of resisting at least 25% of the prescribed seismic forces. See the table footnotes in ASCE 7-22 for the conditions attached to individual entries.

Reference

ASCE/SEI 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, American Society of Civil Engineers, 2022. Sections 11.4, 12.2, 12.4.3, 12.8.1, 12.8.2 and 12.8.6; Tables 12.2-1, 12.8-1 and 12.8-2.