CHAPTER 9: Wind and Seismic Loads on Buildings

9.2 Seismic Loads Using ASCE Standard 7-93

Description

A major portion of the United States is believed to be subject to seismic activity sufficient to cause significant structural damage although many of these areas do not have any seismic design code requirements. Chapter 9 of American Society of Civil Engineers Standard 7-93 has comprehensive requirements for seismic design applicable throughout the United States. The seismic requirements of ASCE Standard 7-93 are based on the 1991 edition of NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings.

This application computes the seismic forces, shears, and overturning moments at each level of a building, following the Equivalent Lateral Force Procedure of Section 9.4 of ASCE Standard 7-93. The building must meet the limitations for use of this procedure given in section 9.3.5 of ASCE Standard 7-93

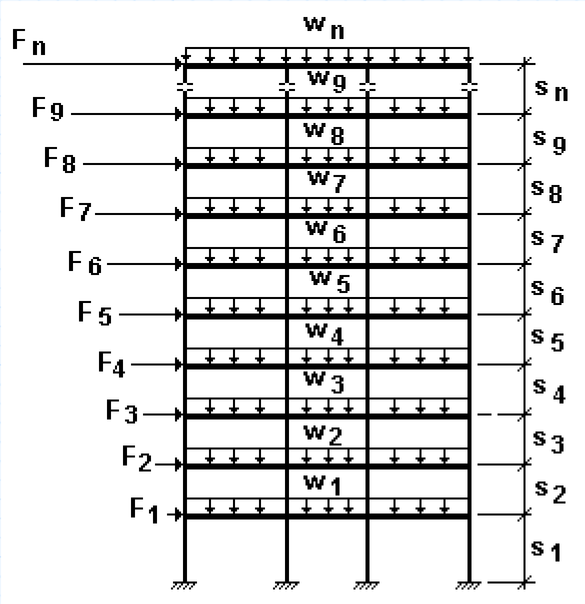
The required input includes the effective peak acceleration coefficient, the effective peak velocity-related acceleration coefficient, site coefficient, response modification coefficient, calculated period of vibration (optional), numerical coefficient used in determining the approximate period of vibration, story heights, and the seismic dead loads of each story.

A summary of input and computed variables is shown on pages 7 and 8.

Reference:
ASCE Standard 7-93 "Minimum Design Loads for Buildings and Other Structures."

Input

Notation



Input Variables

Effective peak acceleration coefficient determined from Map 9-1 of ASCE Standard 7-93:

$$A_a := 0.15$$

Effective peak velocity-related acceleration coefficient determined from Map 9-2 of ASCE Standard 7-93:

$$A_v := 0.11$$

Site coefficient determined from Table 9.3-1 of ASCE Standard 7-93:

$$S := 1.0$$

Response modification coefficient determined from Table 9.3.2 of ASCE Standard 7-93:

$$R := 4.5$$

The user must verify that the structural system limitations and height limits of Table 9.3.2 are not exceeded for the seismic performance category.

Fundamental period of vibration of the structure in the direction under consideration established using the structural properties and deformational characteristics of the resisting elements in a properly substantiated analysis, ASCE 7-93, 9.4.2.2. *Enter T = 0 sec if the fundamental period of vibration has not been calculated:*

$$T := 0 \cdot sec$$

Factor C_T determined from ASCE 7-93, section 9.4.2.2, with units added:

$$C_T := 0.035 \cdot \frac{s}{ft^{0.75}}$$

Story heights:

$$s := ([16\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 12\ \ 13.5])^T \cdot ft$$

Seismic dead load at each story:

$$w := [960\ \ 960\ \ 960\ \ 960\ \ 960\ \ 960\ \ 960\ \ 960\ \ 960\ \ 960\ \ 1200\ \ 845]^T \cdot kip$$

Computed Variables

n	numerical subscript designating the top level
i	range variable subscript designating levels 1 through n
h_i	height of each level above ground level
w_i	seismic dead load at each story
W	total seismic dead load
F_i	lateral seismic force applied at each level
V_i	lateral shear force at each story
τ_i	overturning moment reduction factor
M_i	overturning moment in each story
M_f	foundation overturning moment

ORIGIN set equal to 1 to agree with customary usage: **ORIGIN** $:= 1$

Calculations

Number of stories: $n := \text{length}(s)$ $n = 12$

Height of each story above ground:

$i := 1..n$ $x := 1..n$ $h_i := \sum_x \left((x \le i) \cdot s_x \right)$

$h^T = [16\ \ 28\ \ 40\ \ 52\ \ 64\ \ 76\ \ 88\ \ 100\ \ 112\ \ 124\ \ 136\ \ 149.5]\ ft$

Total seismic dead load: $W := \sum w$ $W = \left(1.165 \cdot 10^4\right)\ kip$

Total building height: $h_n = 149.5\ ft$

Approximate fundamental period from ASCE 7-93, Eq. (9.4-4):

$$T_a := C_T \cdot \left(h_n\right)^{\frac{3}{4}} = 1.496\ s$$

Functions of A_v for linear interpolation of values of C_a in ASCE 7-93, Table 9.4.1

$f1(A_v) := 2.1 - 4 \cdot A_v$ $f2(A_v) := 1.8 - 2 \cdot A_v$ $f3(A_v) := 1.6 - A_v$

Coefficient for upper limit on calculated fundamental period of vibration of the structure from ASCE 7-93, Table 9.4.1:

$$C_a := \textbf{if}\left(A_v \le 0.1, 1.7, \textbf{if}\left(A_v \le 0.15, f1(A_v), \textbf{if}\left(A_v \le 0.2, f2(A_v), \textbf{if}\left(A_v \ge 0.4, 1.2, f3(A_v)\right)\right)\right)\right)$$

$C_a = 1.66$

Maximum permissible calculated fundamental period for use in ASCE 7-93, Equation (9.4.2)):

$C_a \cdot T_a = 2.484\ s$

Seismic coefficient, calculated from ASCE 7-93 Eq. (9.4-2) if the period of vibration has been calculated, or from Eq. (9.4-3) if the the period of vibration has not been calculated:

$$C_s := \textbf{if}\left(T = 0 \cdot s, \frac{2.5 \cdot A_a}{R}, \frac{1.2 \cdot A_v \cdot S}{R \cdot \left(\left(\frac{\textbf{if}\left(T < C_a \cdot T_a, T, C_a \cdot T_a\right)}{s}\right)^{\frac{2}{3}}\right)}\right) = 0.083$$

Seismic base shear, ASCE 7-93, Eq. 9.4-1:

$$V_1 := C_s \cdot W = 970.417\ \mathbf{kip}$$

Period of vibration for use in determining the value of exponent k for use in ASCE 7-93, Eq. (9.4-6):

$$T' := \textbf{if}\left(T = 0\ \mathbf{s}, T_a, \textbf{if}\left(T < C_a \cdot T_a, T, C_a \cdot T_a\right)\right) = 1.496\ \mathbf{s}$$

The value of T' is equal to T_a if T is not calculated, T, if T is less than C_aT_a, or C_aT_a if T is greater than C_aT_a.

Exponent k, related to the building period as shown in ASCE 7-93, 9.4.3:

$$k := \textbf{if}\left(T' < 0.5\ \mathbf{s}, 1, \textbf{if}\left(T' \geq 2.5 \cdot sec, 2, 1 + \frac{T' - 0.5\ \mathbf{s}}{2.0\ \mathbf{s}}\right)\right) = 1.498$$

The value of k is linearly interpolated between 1 and 2 for values of T' between 0.5 and 2.5 seconds.

Vertical distribution factor C_v at levels 1 through n, ASCE 7-93, Eq. (9.4-6), with the formula modified to give the distribution factor at all levels:

$$C_{v_i} := \frac{w_i \cdot \left(\dfrac{h_i}{\text{SIUnitsOf}(h)}\right)^k}{\displaystyle\sum_{i=1}^{n} \left(w_i \cdot \left(\dfrac{h_i}{\text{SIUnitsOf}(h)}\right)^k\right)}$$

$$C_v^{\mathrm{T}} = \begin{bmatrix} 0.006 & 0.015 & 0.025 & 0.038 & 0.051 & 0.066 & 0.083 & 0.1 & 0.119 & 0.138 & 0.198 & 0.161 \end{bmatrix}$$

Lateral seismic force induced at any level, ASCE 7-93, Eq. (9.4-5), with formula modified to give the forces at all levels:

$$F := \overrightarrow{C_v \cdot V_1}$$

$$F^{\mathrm{T}} = \begin{bmatrix} 6.2 & 14.4 & 24.6 & 36.4 & 49.7 & 64.3 & 80.2 & 97.1 & 115 & 134 & 192.3 & 156.1 \end{bmatrix}\ kip$$

Seismic design story shear in each story, ASCE 7-93, Eq. (9.4-7), with the formula modified to give the shear at all levels:

$$V_x := \sum_i \left((i \ge x) \cdot F_i \right)$$

$$V^T = [970.4 \;\; 964.2 \;\; 949.8 \;\; 925.2 \;\; 888.7 \;\; 839 \;\; 774.6 \;\; 694.5 \;\; 597.4 \;\; 482.4 \;\; 348.4 \;\; 156.1] \; kip$$

Overturning moment reduction factor, (ASCE 7-93, 9.4.5):

$$\tau_i := \mathbf{if}(i \ge n - 9, 1.0, \mathbf{if}(i \ge (n - 19), 1.0 - (n - 9 - i) \cdot 0.02, 0.8))$$

$$\tau^T = [0.96 \;\; 0.98 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1 \;\; 1]$$

Overturning moment in each story, ASCE 7-93, Eq. (9.4-9), with formula modified to give overturning moment at all levels:

$$M_x := \tau_x \cdot \left(\sum_i \left((i \ge x) \cdot F_i \cdot \left(h_i - h_x \right) \right) \right)$$

$$M^T = [88010 \;\; 78505 \;\; 68710 \;\; 57608 \;\; 46943 \;\; 36875 \;\; 27579 \;\; 19246 \;\; 12076 \;\; 6288 \;\; 2107 \;\; 0] \; kip \cdot ft$$

Foundation overturning moment, ASCE 7-93, 9.4.5:

$$M_f := 0.75 \cdot \sum_i \left(F_i \cdot h_i \right)$$

$$M_f = 80403 \; kip \cdot ft$$

Summary

Enter structural system description

"Ordinary moment frame of steel" (ASCE 7-93, Table 9.3-2.)

Effective peak acceleration coefficient (ASCE 7-93, Map 9-1): $A_a = 0.15$

Effective peak velocity-related acceleration coefficient (ASCE 7-93, Map 9-2): $A_v = 0.11$

Site coefficient (ASCE 7-93, Table 9.3-1): $S = 1$

Calculated period of vibration, T = 0 sec if not calculated: $T = 0\ s$

Foundation overturning moment, ASCE 7-93, 9.4.5: $M_f = 80403\ kip \cdot ft$

Response modification coefficient (ASCE 7-93, Table 9.3.2): $R = 4.5$

Factor C_T (ASCE 7-93, 9.4.2.2): $C_T = 0.035\ \dfrac{s}{ft^{\frac{3}{4}}}$

Level numbers i above ground, story heights s, height h of each level above ground, seismic dead load w per story, force F at each level, story shear V at each level, overturning reduction factor τ at each level, and overturning moment M at each level:

$$s = \begin{bmatrix} 16 \\ 12 \\ 12 \\ 12 \\ 12 \\ 12 \\ 12 \\ 12 \\ 12 \\ 12 \\ 12 \\ 13.5 \end{bmatrix} ft \qquad h = \begin{bmatrix} 16 \\ 28 \\ 40 \\ 52 \\ 64 \\ 76 \\ 88 \\ 100 \\ 112 \\ 124 \\ 136 \\ 149.5 \end{bmatrix} ft \qquad w = \begin{bmatrix} 960 \\ 960 \\ 960 \\ 960 \\ 960 \\ 960 \\ 960 \\ 960 \\ 960 \\ 960 \\ 1200 \\ 845 \end{bmatrix} kip$$

$$F=\begin{bmatrix}6.23\\14.42\\24.6\\36.44\\49.74\\64.35\\80.15\\97.07\\115.03\\133.98\\192.34\\156.07\end{bmatrix}\ kip \qquad V=\begin{bmatrix}970\\964\\950\\925\\889\\839\\775\\694\\597\\482\\348\\156\end{bmatrix}\ kip \qquad \tau=\begin{bmatrix}0.96\\0.98\\1\\1\\1\\1\\1\\1\\1\\1\\1\\1\end{bmatrix} \qquad M=\begin{bmatrix}88010\\78505\\68710\\57608\\46943\\36875\\27579\\19246\\12076\\6288\\2107\\0\end{bmatrix}\ kip\cdot ft$$