BUILDING RESPONSE TO SEISMIC EXCITATION

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Natural Frequency

The 1994 Uniform Building Code (UBC) gives the following empirical formulas for the fundamental frequency f_n and period T of a tall building.

$$f_n = \frac{1}{Ct\ h^{3/4}} \tag{1}$$

$$T = Ct\ h^{3/4} \tag{2}$$

where

h is the height.

Ct is an empirical factor given in Table 1.

Table 1. Empirical Factor Ct		
Type	English $Ct\left(\frac{sec}{ft^{3/4}}\right)$	Metric $Ct\left(\frac{sec}{meters^{3/4}}\right)$
Masonry and wood buildings	0.020	0.049
Reinforced concrete moment resisting frames and eccentrically braced frame	0.030	0.073
Steel moment resisting frames	0.035	0.0853

Note that alternate formulas for the fundamental frequency and period are given in Appendix A.

Seismic Loads, Historical Equation

Earthquake ground motion occurs in vertical and horizontal axes.

Buildings are designed to support their own weight in the vertical axis. Thus, they are able to withstand vertical ground motion. On the other hand, buildings may sway like inverted pendulums in response to horizontal ground motion.

A historical equation for the lateral force F on building due to a seismic event is

$$F = C\,W \tag{3}$$

where

C is a coefficient, taken as 0.1
W is the weight of the building

Equation (2) fails to account for the following:

1. The building's geometry, stiffness, and ductility
2. The building's fundamental period of vibration
3. Effects of soil condition
4. Distribution and magnitude of the equivalent static shear force.

Equation (2) is thus considered as obsolete.

Base Shear Load per 1994 UBC

The design formula for the base shear V is

$$V = \left[\frac{Z\,I\,C}{Rw}\right] W \tag{4}$$

where

W is the seismic dead load (including permanent equipment, a percentage of storage and warehouse live loads, partition loads, and certain snow loads).

The coefficients Z, I, C, and Rw are defined in Tables 2 through 5, respectively.

Equation (4) is taken from 1994 UBC equation 28-1.

Table 2. Z Seismic Zone Factor	
Z corresponds to the expected peak ground acceleration in the lateral axis for a particular region with a 10% probability of being exceeded in 50 years. The unit is percent of gravity G. Refer to 1994 UBC Figure 16.2	
Z (G)	Zone Description
0	Zone 0
0.075	Zone 1
0.15	Zone 2A
0.20	Zone 2B
0.30	Zone 3
0.40	Zone 4

Table 3. I Seismic Importance Factor
I = 1.0 for normal occupancies, 1.25 for essential or hazardous facilities. Increasing the importance factor can be looked at as increasing the *recurrence interval* for which peak accelerations are computed, effectively increasing the seismic forces expected to act on the structure. Refer to 1994 UBC Table 16-K.

Table 4. C Dynamic Response Spectrum Value
C is a coefficient that accounts for the effect of periodic modes of vibration, damping, and soil quality on a building's response to typical seismic ground motion. $C = \frac{1.25\,S}{T^{2/3}} \leq 2.75$ where S (for soil characteristics) ranges from 1.0 for the stiffest subsurface conditions to 2.0 for the poorest subsurface conditions (i.e., soft clay). T is the fundamental period of vibration in seconds. Refer to 1994 UBC Equations 28-2 and 28-3.

Table 5. Rw Lateral-force-resisting system coefficient	
Rw relates the building's structural system (specifically, the part of the structural system that resists horizontal forces) to its performance under seismic loads. In particular, the structure's ability to absorb energy (ductility) is rewarded in assigning values to Rw.	
Rw	Description
4	Light steel frame walls with tension bracing
6	Masonry shear walls
8	Plywood shear panel buildings with 3 or less stories
12	Steel or concrete special moment resisting frames (SMRF)

Spectral Acceleration and Spectral Velocity

PGA is the peak acceleration experienced by a particle on the ground.

PGV is the peak ground velocity.

SA is the building spectral acceleration. It is approximately the acceleration that the building experiences as modeled by a particle on a massless vertical rod having the same natural period of vibration as the building. This calculation assumes that the building behaves as a single-degree-of-freedom system. In reality, the building behaves as a multi-degree-of-freedom of system.

SV is the building spectral velocity.

References

1. H. Bachmann, et al., Vibration Problems in Structures, Birkhauser Verlag, Berlin, 1995.

APPENDIX A

<u>Alternate Natural Frequency and Period Formulas</u>

The following empirical formula is given in Reference 1 for the fundamental frequency f_n of a tall building

$$f_n = \frac{46 \;(\text{meter Hz})}{h} \tag{A-1}$$

where h is the building height.

The corresponding period T is

$$T = \frac{h \;(\text{sec/ meters})}{46} \tag{A-2}$$

Reference 1 notes that equation (1a) usually gives as a good an estimate of the frequency as sophisticated analytical models.