Building Periods: Moving Forward (and Backward)

By William P. Jacobs, V, P.E.

The determination of the fundamental period of a building is an integral part of the lateral load calculation procedure in today's building codes; however, navigating your way through the twists and turns of the various assumptions and limits involved can become confusing rather quickly. Should the fundamental period be calculated differently for the determination of wind and seismic loading? Are the results of a computer based eigenvalue analysis always adequate? What damping values should be assumed? The purpose of this article is to try to answer these and several other questions regarding code-based period determination techniques to help remove the confusion and allow designers to "move forward."

The Fundamentals

The fundamental building period is simply the inverse of the building frequency at the lowest harmonic – easy right? Basically, every system has a set of frequencies in which it "wants" to vibrate when set in motion by some sort of disturbance (in building design, typically a seismic or wind event) based on the system's mass and stiffness characteristics. The shortest frequency is known as the natural frequency. The inverse of frequency is the period of the system, and more specifically, the inverse of the natural frequency is the fundamental period.

In seismic design, the closer the frequency of an earthquake is to the natural frequency of a building, the more energy is introduced into the building structure. Buildings with shorter fundamental periods attract higher seismic forces as the code-based design spectrum exhibits higher accelerations at shorter periods. For wind design, the opposite behavior is observed. Longer fundamental periods are indicative of buildings that are more susceptible to dynamic amplification effects from sustained wind gusts and result in higher design forces. In order to investigate the magnitudes of these wind and seismic effects, the fundamental period of the building must first be determined.

This article focuses on the provisions of the American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-05). The following sections cover the specifics of ASCE 7-05 period calculations as they pertain to seismic and wind load determination.

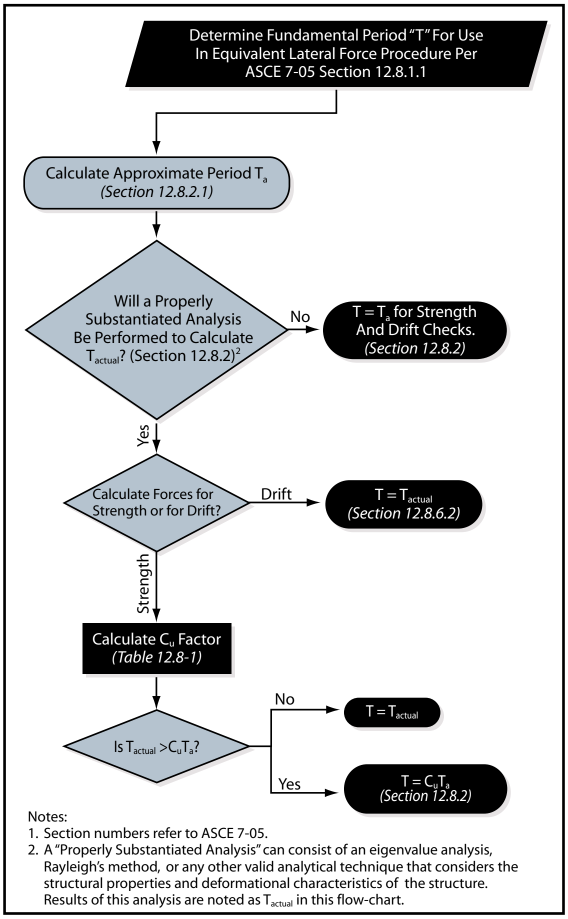
Seismic Periods

Most designers are familiar with the use of the fundamental period of the structure, T, in conjunction with calculating the seismic response coefficient, C_s, for base shear determination using the equivalent lateral force procedure. A flow-chart for navigating these provisions is provided in *Figure 1,* and further discussion follows.

The most straightforward method for determining the building period involves the use of the empirical formulas for the calculation of the approximate building period, T_a, presented in Chapter 12 of ASCE 7-05. A subset of these formulas is displayed in the seismic section of *Table 1* and plotted in *Figure 2 (page 26)*. These equations are based on data from several instrumented buildings subjected to ground motion during seismic events such as the San Fernando and Northridge earthquakes. The data was used to determine both lower bound and upper bound approximate period equations using regression analysis. The formulas provided in ASCE 7-05 represent the lower bound equations and are intentionally formulated to provide a conservative (short) estimation of the fundamental building period. Shorter building periods result in higher and more conservative base shears.

Properly Substantiated Analysis

If the engineer desires, the building period used to calculate equivalent lateral forces for both strength and drift limits can be set equal to the approximate period, T_a, without further calculation. Note that this practice may result in significantly overly conservative results, as ASCE 7-05 allows the use of a "properly substantiated analysis" to determine the fundamental building period in lieu of the approximate empirical equations – within certain limits. A "properly substantiated analysis" can take many forms, such as the use of Rayleigh's method. Most commercial building software programs will quickly and easily perform an eigenvalue analysis to determine the mode shapes and periods of a building, and practicing engineers will most likely use this method. It is important to note that the periods determined using an eigenvalue analysis can be significantly longer than those determined using the approximate equations. This discrepancy is primarily due to three factors. First, the analytical model on which the eigenvalue analysis is performed does not generally include the stiffening effect of the non-structural infill and cladding that is present in the actual building. Second, the analytical model does not generally include the



Notes:
1. Section numbers refer to ASCE 7-05.
2. A "Properly Substantiated Analysis" can consist of an eigenvalue analysis, Rayleigh's method, or any other valid analytical technique that considers the structural properties and deformational characteristics of the structure. Results of this analysis are noted as T_{actual} in this flow-chart.

Figure 1: Seismic Equivalent Lateral Force Fundamental Period Flow-Chart.

Approximate Fundamental Period Equation:			
$T_a = C_t h_n^x$ *(ASCE 7-05 Eqn. 12.8-7)*			
SEISMIC Approximate Fundamental Period Parameters			
Structure Type	C_t	x	Reference[1]
Steel Moment-Resisting Frames	0.028	0.8	Table 12.8-2
Concrete Moment-Resisting Frames	0.016	0.9	Table 12.8-2
Eccentrically Braced Steel Frames	0.03	0.75	Table 12.8-2
All Other Structural Systems	0.02	0.75	Table 12.8-2
WIND Approximate Fundamental Period Parameters			
Structure Type	C_t	x	Reference[1]
Steel Moment-Resisting Frames	0.045	0.8	Commentary Eqn. C6-14
Concrete Moment-Resisting Frames	0.023	0.9	Commentary Eqn. C6-15
All Other Structural Systems (h<400 ft)	0.013	1	Commentary Eqn. C6-18
All Other Structural Systems (h>400 ft)	0.0067	1	Commentary Eqn. C6-19
Note 1: References are to ASCE 7-05			

Table 1: Approximate Fundamental Period Parameters.

stiffening effect of “gravity-only” columns, beams, and slabs. Third, as previously noted, the approximate equations are skewed to provide shorter periods.

For strength design, ASCE 7-05 limits the maximum building period to the approximate building period, T_a, multiplied by the factor C_u from Table 12.8-1. The cap generally coincides with the upper bound of building periods as determined in the same study used to determine the lower bound approximate equations. The cap is intended to prevent possible errors resulting from erroneous assumptions used in the “properly substantiated analysis” that could result in unconservative building periods when compared to those determined under actual seismic events. For the determination of seismic drift, ASCE 7-05 removes the cap and allows the engineer to use the building period resulting from analysis without restriction.

Code Quirks

Building period determination can have a substantial impact on the seismic design of a structure. For instance, did you know that a small dimensional change can result in 50 percent less base shear? Look closely at the values for the approximate period parameters provided in *Table 1*. If the lateral resisting system consists of concentrically braced frames, the approximate period equation would be that of an “other” system and is equal to $0.02h_n^{0.75}$. If the brace work points are moved away from the joints, and the system is now considered an “eccentrically” braced system, the approximate period equation increases to $0.03h_n^{0.75}$. The change in approximate fundamental period of 50 percent (0.03 vs. 0.02) could translate directly to a corresponding reduction in base shear. If these systems were detailed as R=3 “Steel Systems Not Specifically Detailed for Seismic Resistance,” as is common on the east coast, this revision could be accomplished with minimal additional detailing – and with a base shear reduction of 50 percent! This is an extreme example; however, it is worth pointing out that seemingly minor assumptions and changes in the fundamental building period can have far reaching effects for seismic design.

Wind Periods

While the use of the fundamental building period for seismic design calculations is well established, the parameters used for wind design have traditionally not been as clear. For wind design, the building period is only relevant for those buildings designated as “flexible” (having a fundamental building period exceeding one second). When a building is designated as flexible, the fundamental building period is introduced into the gust-effect factor, G_f, in the form of the building natural frequency, which is simply the inverse of the fundamental building period.

So, what building period should be used? Prior to ASCE 7-05, little guidance was provided and designers typically used either the approximate equations within the seismic section or the values provided by an automated eigenvalue analysis. Unfortunately, neither of these solutions is the best option, and the first can actually be unconservative. As previously discussed, the approximate seismic equations are intentionally skewed towards shorter building periods. Thus for wind design, where longer periods equate to higher base shears, their use can provide potentially unconservative results. Also, the results of an eigenvalue analysis can yield building periods much longer than those observed in actual tests, thus providing potentially overly conservative results. So what is a designer to do? The good news is that the ASCE 7-05 Commentary presents recommendations for building natural frequencies to be used for wind design. These recommendations are re-written in the same form as the approximate empirical equations provided in the seismic section in *Table 1 (page 25)* and plotted in *Figure 2* for comparison. Many of these recommendations originated from the same study performed to determine approximate equations for seismic design and represent an upper bound of the measured building periods. This upper bound equation results in conservative wind load estimates. The ratio of the “wind” periods to the “seismic” periods is approximately 1.4 to 1.6, thus mirroring the coefficient for the upper limit on calculated period for seismic design.

Damping

Another consideration that goes hand-in-hand with the determination of building periods is the value of damping for the structure. Damping is any effect that reduces the amplitude of vibrations. For buildings, damping results from many conditions ranging from the presence of interior partition walls, to concrete cracking, to deliberately engineered damping devices. For seismic design, five percent of critical damping is typically assumed for systems without engineered damping devices. The damping values used for wind design are much lower as buildings subject to wind loads are generally responding within the elastic range as opposed the inelastic range for seismic loading, where additional damping is provided from severe

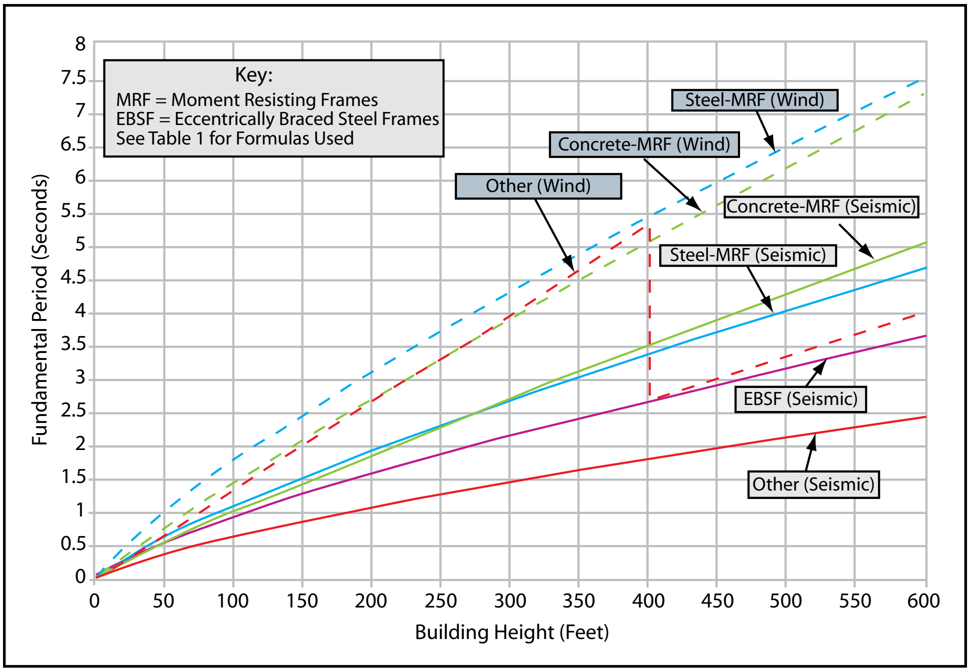


Figure 2: Approximate Fundamental Period vs. Building Height.

concrete cracking and/or plastic hinging.

Again, the ASCE 7-05 Commentary provides guidance, suggesting a damping value of one percent be used for steel buildings and two percent be used for concrete buildings. The Commentary is explicit that these wind damping values are typically associated with determining wind loads for serviceability and simply states that "because the level of structural response in the serviceability and survivability states is different, the damping values associated with these states may differ."

So, what values are design engineers supposed to use for ultimate level (1.6W) wind loads? Several resources are available that provide values of damping for service and ultimate loads. The values provided vary greatly depending upon the resource and the type of lateral force resisting system used – from a low of 0.5 percent to a high of 16 percent or more. For simplicity, the author suggests using the recommended one percent and two percent values for steel and concrete buildings, respectively, for both service and ultimate loads for two reasons. First, as buildings are subjected to ultimate level forces, severe cracking of concrete sections and plastic hinging of steel sections have the dual effect of both increasing damping but also softening the building and increasing the fundamental building period.

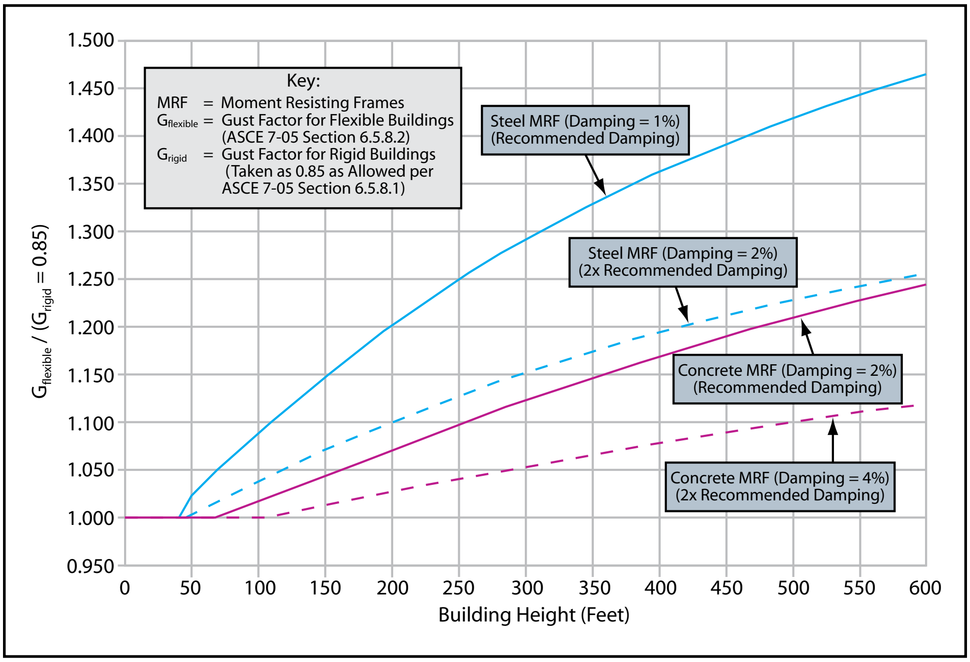


Figure 3: Effect of Building Flexibility on Gust Factor for 100-foot x 100-foot Building.

It has been postulated that the increase in damping and period generally compensate each other, and adequate results can be obtained by utilizing factored forces based on service level periods and damping values. Second, as is shown in the following section, the level of damping has only a minor effect on the overall base shear for wind design for a large majority of low and mid-rise building structures. Where serviceability criteria govern, such as accelerations for tall buildings, a more in-depth study of damping criteria is typically warranted.

Low/Mid-Rise

Figure 3 illustrates the effect of the fundamental building period and damping values on the gust factor for a representative 100-foot x 100-foot building structure. The building footprint has a considerable effect on these values, and buildings with larger footprints are less prone to dynamic effects. In general, buildings less than 50 feet tall can be considered rigid no matter the lateral force resisting system used. For this representative case, even at 150 feet tall, the overall effect of the building dynamic response on the wind base shear (as predicted by the ratio of the flexible gust factor G_f to the rigid gust factor $G = 0.85$) is less than 15 percent for a steel moment resisting frame and less than 5 percent for a concrete moment resisting frame with the recommended damping values. Stiffer structural systems, such as braced frames and shearwall buildings, exhibit even less dynamic response. It can safely be stated that for a large majority of building construction in the United States, which consists of low-rise and mid-rise construction, the effect of the building period on wind base shears is minimal.

High-Rise

Figure 3 also illustrates that the effect of dynamic building response and damping values on wind forces can be significant for taller buildings. The topic of dynamic wind response is an involved one, and there is a wealth of information in the literature regarding it. The ASCE 7-05 Commentary and References serve as an excellent starting point for those looking to broaden their knowledge in this area.

It should first be recognized that the use of the code-based gust effect factor is an approximation based on several simplifying assumptions. One of these assumptions is that the building has a linear mode shape and a uniform mass distribution over the height of the building. The ASCE 7-05 Commentary provides an alternate procedure which can be used to capture more accurately the distribution of mass and stiffness throughout the building height based on redistributing the peak-base moment throughout the building, similar to the equivalent lateral force procedure for seismic design. Also, the code-based provisions assume that only along-wind response (wind blowing against the face of the building) and not across-wind or torsional response will control the building design. Again, the Commentary provides useful insight into this issue including a web-site (**http://aerodata.ce.nd.edu/interface/interface.html**) that can be used to aid in the determination of the effects of across-wind and torsional response in the preliminary stages of design. Finally, the prescribed forces in ASCE 7-05 are for "regular-shaped" buildings only. A wind-tunnel analysis should be performed for all unusually shaped structures. It has also been the experience of the author's firm that a wind tunnel analysis is beneficial for buildings exceeding thirty stories in height in terms of accelerations, cladding pressures, and base overturning moments.

Conclusion

In summary, the computation of the fundamental building period is an essential element for calculating lateral load effects due to both seismic and wind forces. Code prescribed empirical equations for calculating approximate building periods are easy to implement and are now provided for both seismic and, in a slightly different form, wind design. By understanding the background behind these equations and the assumptions inherent in the Code, the designer can confidently "move forward" with their implementation.▪

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