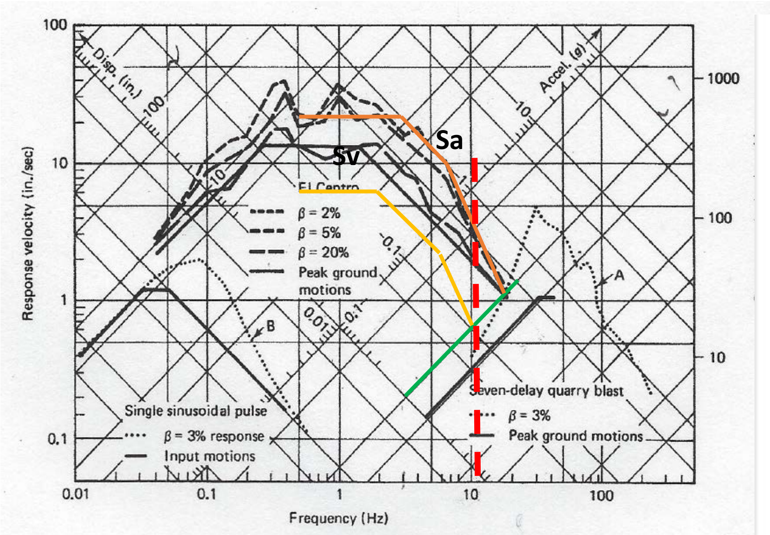
CONST-VIBRATIONS Newsletter #33

Both Earthquake and Construction Vibration Design Spectra Are Based on Strain from Relative Displacement Response



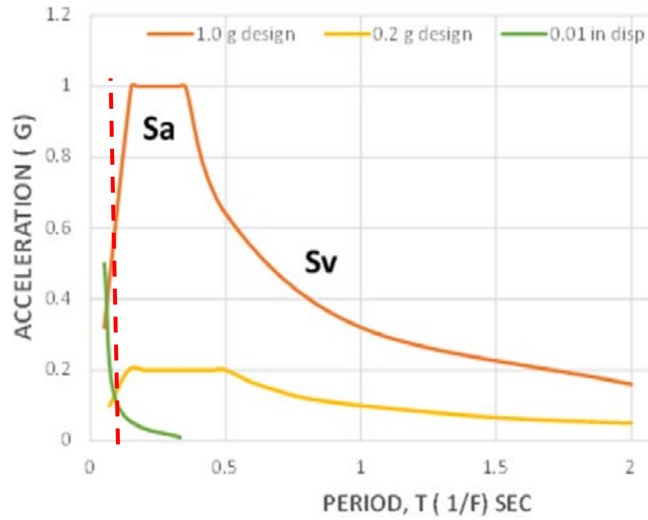


Figure 1 (left) Frequency (f) Based Pseudo Velocity Design Spectra.
Figure 2 (right) Period (T=1/f) Based Acceleration Design Spectra with Same Bounds as Figure 1.
Both Sv-f (Figure 1 on left) and Sa-T (Figure 2 on right) Specrtra Present Bounds for Calculating Relative Displacements, δ, for Structures of Various Natural Frequencies (f = 1/T) when perturbed by either a 1.0 g or a 0.2 g Design Earthquake Based upon Ground Motions from the El Centro Earthquake. The Sv-f form Most Clearly Distinguishes the 0.01 in Relative Displacement Below which No Cosmetic Cracking Can Occur.

Calculation of strain is the foundation of structural dynamics for both earthquake and construction induced ground motions. Building strains produce cosmetic cracks and if large enough eventually produce structural cracking. As described in Chapter 5 of Construction Vibrations, strains are best estimated by employing ground motion time histories to calculate the relative displacement, δ, of single degree of freedom (SDOF) models of structures of concern.

Codification of dynamic design of structures has led to the description of expected relative displacement (δ) dynamic response to ground motions through both pseudo velocity response ($Sv = 2\pi*f*\delta$) and pseudo acceleration response ($Sa= 4\pi*f^2*\delta$) spectra. These spectra are traditionally presented as graphs of log frequency, f, vs log Sv and period (T = 1/f) vs Sa as shown in Figures 1 (left) and 2 (right) above. Since Sa, Sv, & δ are related through f, they can all be graphed simultaneously on Sv tripartite log paper as shown in Figure 1 with log Sv as a function of log f. Despite the ability of the log Sv vs log f presentation to present simultaneously all three important design parameters, δ, f, and Sa the arithmetic Sa vs T presentation in Figure 2 seems to be preferred in the earthquake engineering community. This preference may result from two issues. First the ground motions for earthquakes are recorded in units of acceleration. Second, period, T, refers to buildings rather than ground motion, which is the appropriate frame of reference for structural design. With either the Sv-f or Sa-T spectra, it is important to remember that relative displacement, δ, is the important parameter being sought because it produces strains and cracking.

Both structural strain and shear force can be calculated from the relative displacement, δ. In the plane of the wall, shear strain, γ, is the simplest to calculate:

$$\gamma = \delta/H$$

where H is the distance over which the relative displacement, δ, is calculated. It can be the height of the structure or the distance between floors. Out of plane bending strain can be calculated also as shown in Chapter 5 of Construction Vibrations, but is too lengthy for this newsletter.

Base shear force in the structure, f_s, for those interested in calculating stresses can also be calculated from δ and Sa through their relationship to the SDOF linear spring stiffness, k and mass, m;

$$f_s = k*\delta = m*Sa$$

Induced shear stresses in columns or walls supporting a structure would then be the base shear force, f_s divided by the total base area, A, of the columns.

$$\sigma = f_s/A = (m*Sa)/A = (m*4\pi*f^2*\delta)/A$$

While Sa is really the pseudo acceleration, it is equivalent to the absolute acceleration for typically damped (less than 10% of critical) systems (Veletsos and Newmark, 1964, Gupta. 1990).

The same earthquake design spectra are displayed in Figures 1 and 2 to demonstrate the advantages of the log Sv-f form over the arithmetic Sa-T form. A **1 g design** and a **0.2 g design** spectrum distinguished by their color are shown in each form. The Sv and Sa constant bounds are identified in each with **Sv** and **Sa.** The constant value bounds are can be seen as constant in the Sv – f form but not in the Sa-T form. The **green line** identifies the relative displacement, δ, where the probability of cosmetic cracking becomes greater than zero. The **dashed red line** identifies a single story structure in both forms through its natural frequency (f = 10 Hz) in the Sv-f form and its period (T = 0.1 sec) in the Sa-T form.

The confluence of the red and green lines in the 0,1 to 0.2 second region of the Sa-T form demonstrate the challenges of understanding what is being presented. Whereas in the Sv-f form implications of the data are more obvious. For instance the Sv-f form more easily demonstrates that any earthquake designed structure with a natural frequency less than 10 Hz (basically all engineered structures) is designed to prevent cosmetic cracking by blasting vibrations. This observation is illustrated in the Sv-f form best. Left of the dashed 10 Hz **red** line **rust** and **orange** color design spectra lie above the constant safe, relative displacement ,δ, **green** line. In other words their designs include the consideration of greater relative displacements, δ's, or strains. The relative displacement axis (labeled Disp.) slopes upward to the left. This consequence is less obvious in the crowded short period, T, region on the extreme left of the Sa-T form.

When conversing with an earthquake engineer or seismologist, refer to the Sv-f form in Figure 1 in this Newsletter. Show them Sv-f spectra in Newsletter #3 (Figure 9-13 in Construction Vibrations). Compare the relative displacements of the Figure 9-13 spectra (or green line in Figure 1 above) with those included in their earthquake designs. Point out the conservativeness of blasting with PPV's less than 12 mm/s or 0.5 ips at dominant frequencies of 20 Hz and greater that produce relative displacements less than those for which their earthquake resistant building(s) was (were) designed.

References

Gupta, A. J. (1990) Response Spectrum Method In Seismic Analysis and Design of Structures, CRC Press, Boca Raton, FL, 170 pgs

Veletsos, A.S., and Newmark, N.M. (1964) Design Procedures for Shock Isolation Systems of Underground Protective Structures, Vol III, Response Spectra of Single Degree of Freedom System Elastic and Inelastic Systems, RTD TDR 63-3096 AD44989 Vol II, Air Force Weapons Laboratory, Kirkland, AFB.