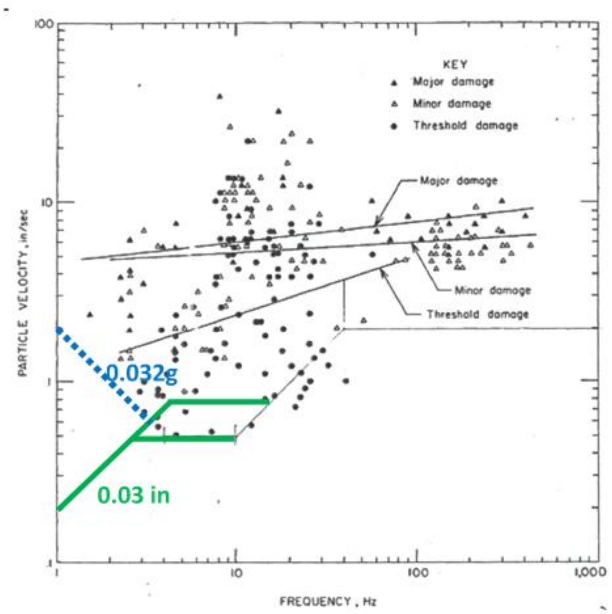
CONST-VIBRATIONS Listserv Newsletter # 4
Reasons for the boundaries and corners of the Z curve in RI 8507

In addition to observation of cosmetic cracking, boundaries of the Z curve were influenced by past USBM control limits, non-cracking observations for excitation frequencies greater than 40 Hz, and lack of observations of cosmetic cracking below 4 Hz and below a PPV of 12.7 mm/s (0.5 ips)



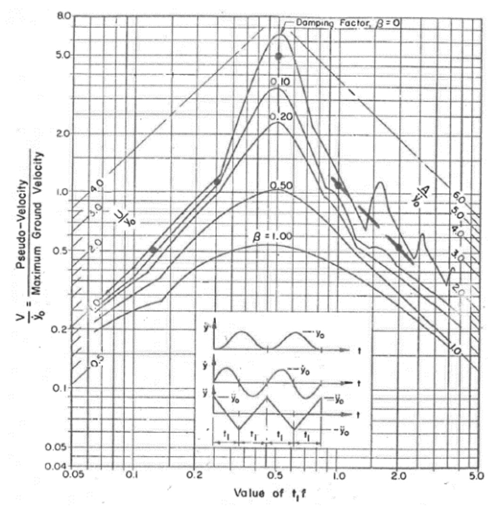


FIG. 2.44d DEFORMATION SPECTRA FOR DAMPED ELASTIC SYSTEMS SUBJECTED TO A SEQUENCE OF FOUR PARABOLIC VELOCITY HALF-CYCLES

Left: Superposition of the lower bounds of the Z curve on observations of cracking in dry-wall and plaster & lath walled structures in Figure 54 from RI 8507 shows the lack of observations of cosmetic cracking above 40 Hz and below 4 Hz. Dashed blue line of constant acceleration ~ 0.03g bounds the observed cosmetic cracking data below 4 Hz.

Right: Normalized deformation response spectrum shows a single degree of freedom structure will respond along a line of constant acceleration ($A/\ddot{y}_0$) when excited with frequencies below the fundamental, which validates the blue constant acceleration bound in Figure 54

There are four regions of dominant frequency of ground motions defined by Z curve that bound data analyzed by the US Bureau of Mines (USBM) in RI 8507: > 40 Hz, 40 - 10 Hz, 10 - 4 Hz and <4 Hz. Data on Figure 54 from RI 8507 were collected from all sources in the world at the time 8507 was published. These points of cosmetic cracking were identified in Newsletters #1 and 2. Newsletter #3 described the consistency of the constant displacement bound between 10 and 40 Hz. This letter will offer explanations of the other bounds.

The frequency, f > 40 Hz, peak particle velocity (PPV) = 50.8 mm/s (2 ips) bound is a legacy of Bulletin 656, as 50.8 mm/s was the control limit that resulted from that study. Study of the data above f = 40 Hz shows that there are no cracking points below 101.6 mm/s (4 in/s) and the continuation of the 0.2 mm (0.008 in.) constant displacement bound. The Z curve corner at 40 Hz occurs because 0.2 mm (0.008 in.) of ground displacement is equal to 50.8 mm/s of peak particle velocity at 40 Hz. Intersection of the 12.7 mm/s (0.5 in/s) control limit for plaster and lath walls with the 0.2 mm displacement line occurs at 10 Hz and forms the lower corner of the 10 to 40 Hz Z curve boundary.

The most mysterious corner is the intersection of the 0.76 mm (0.03 in.) line of constant displacement and the 12.7 mm/s (0.5 in/s) plaster and lath control limit. Lower bound data points defining instances of cosmetic cracking for frequencies below 4 Hz in Figure 54 all appear above the ascending blue dashed line of constant acceleration of 0.03g, not along the descending green line of constant displacement. In hind sight, this line of constant displacement of 0.76 mm (0.03 in.) does not seem justified by observations of cosmetic cracking induced by blasting vibrations.

A constant ground acceleration bound for excitation frequencies less than the natural or fundamental structural frequency is consistent with the principles of structural dynamics. This consistency is shown by the above right tripartite normalized plot of structural deformation induced by two full or 4 half cycles of excitation (Veletsos and Newmark, 1964). Normalized excitation frequency, t_1f, is plotted on the x axis, where f is the structure natural frequency and t_1 is one half the excitation period, T. Normalized structural deformation, U/y_0, is plotted on the axis ascending diagonally to the left. As described in Newsletter #3, the cosmetic cracking bound between 10 and 40 Hz lies along a line of constant ground excitation displacement of 0.2mm (0.008 in.). That line of constant normalized deformation (U/y_0) is seen between $t_1f = 0.25$ and 0.125 (20 Hz to 40 Hz excitation frequency) for a 10 Hz or one story structure on this tripartite graph. Now consider a 5 Hz or 2 story structure excited by ground motion with dominant excitation frequencies of 2.5 Hz and 1.25 Hz or t_1f of 1 and 2 on the tripartite plot. Those responses lie along a line of constant normalized acceleration, $A/\ddot{y}_0$. Figure 54 above left shows that the lower bound of PPV's associated with observation of cosmetic cracking at excitation frequencies below 4 Hz is the ascending blue dashed line of constant acceleration of 0.032 g. This line intersects the 12.7 mm/s (0.5 in/s) bound for plaster and lath walls at 4 Hz.

All things being equal, one would expect higher excitation velocities (PPV's) to be necessary to amplify structural response (relative displacement, deformation, or strain) when excitation frequencies are either lower (less than 4 Hz) or higher (greater than 10 Hz) than the natural frequency of responding two or one story structures respectively. This principle can be stated another way: structural deformation, relative displacement or strain declines with constant PPV when excitation frequencies are either below or above the fundamental (or natural) frequency of a structure. Note how in Figure 54 above the PPV's associated with cosmetic cracking were found to be greater for excitation frequencies either lower or higher than the natural frequencies of two or one story structures (5 to 10 Hz natural frequencies respectively).

This principle and observation of frequency dependency of structural response can be demonstrated visually without mathematics or graphs with the rubber band – coffee mug example described in my book Construction Vibrations.

REFERENCES

Veltsos, 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 Elastic and Inelastic Systems, Technical Documentary Report No. RTD TDR 63-3096, Vol III, AD 444 989. This document can be found on line at https://apps.dtic.mil/docs/citations/AD0444989 as of the date of this newsletter.