CONST-VIBRATIONS Listserve Newsletter #3

Linkage of the Z curve with response spectra demonstrates its consistency with the principles of structural dynamics

Comparison of the the lower boundaries of the Z curve with response spectra for shots that caused cosmetic cracking shows that lines of constant peak ground displacement are of similar magnitude for either method of analysis.

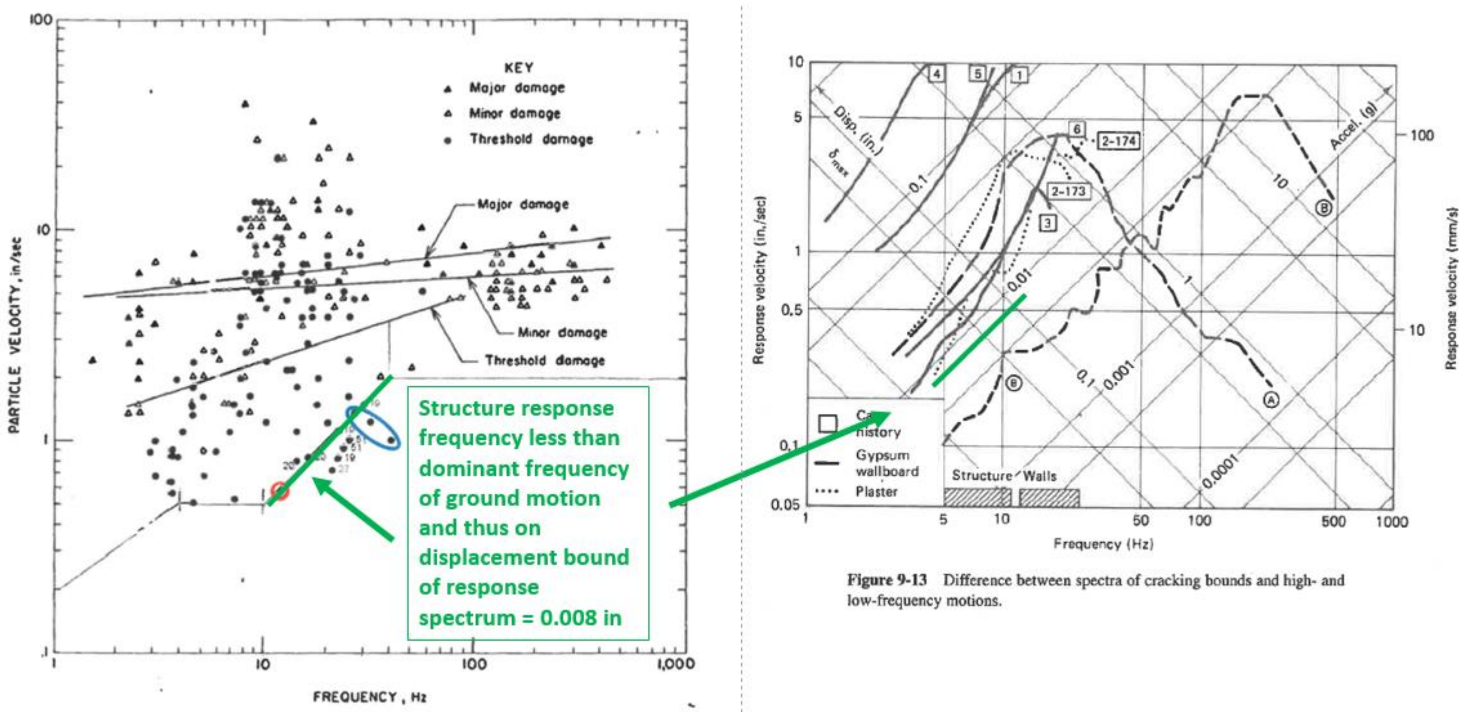

Figure 9-13 Difference between spectra of cracking bounds and high- and low-frequency motions.

Comparison of constant displacement bounds on: 1) Z curve superimposed on Figure 54 from RI 8507 with 2) response spectra of ground motions causing cosmetic cracking along lower bound of Z curve.

Similar critical locations of bounding lines of constant peak ground displacement in both the Z curve and response spectra of shots causing cosmetic cracking demonstrate the consistency of the Z curve with principles of structural dynamics. This consistency underscores the robustness and importance of RI 8507 and the Z curve. It demonstrates simply how both dominant frequency and ground motion intensity (measured by peak particle velocity- PPV) are equally important in the causation of cosmetic cracking.

This observation of the congruence of the Z curve and the principles of structural dynamics is unpacked by comparing graphically data points from the lower bound of the Z curve and response spectra of their particle velocity time histories. The comparison is shown in the figure above. Figure 54, on the left relates PPV, dominant ground motion frequency and the occurrence of cosmetic cracking. Figure 9-13 on the right from Construction Vibrations (Dowding, 1996) compares the pseudo velocity response spectra (PVRS) of the ground motions of the shots causing cosmetic cracking that lie along the lower intensity boundary of the Z curve in Figure 54. Response spectra 2-174 and 2-173 are those that cracked structure 51, so labeled in Figure 54. Spectrum 3 is that which cracked structure 20. Spectra 1,4,5 &6 caused cosmetic cracking in other case studies included in RI 8507 and described in Dowding(1996).

The Z curve and response spectra are related directly through the peak ground displacement associated with the shot as shown by the green lines in the figures. Peak displacement associated with points in Figure 54 are obtained from the assumption of a sinusoidal relation between velocity, v, and displacement, d

$$v = 2\pi f d,$$

where f is the frequency.

Thus for structure 20, where PPV is 20 mm/s (0.79 ips) and f was 14.3 hz (Siskind 1981),

$$d = v/(2\pi f) = 20/(2 \times 3.14 \times 14.3) = 0.224 \text{ mm } (0.0088 \text{ in})$$

The peak ground displacement is also contained in the pseudo velocity response spectrum (PVRS), but requires a little more explanation. The PVRS for structure 20, case 3 in Figure 9-13 becomes constant along an inclined line of relative displacement at 0.25 mm (= 0.01 in.) for frequencies below 5 Hz. This constancy of relative displacement occurs because structures with low natural frequency are so compliant, soft or take so long to respond that they do not respond to ground motions that are changing rapidly. Thus induced relative displacement approaches the peak ground displacement because the mass of the structure does not respond. This response is explained more thoroughly and easily with the rubber band – coffee mug response model in Chapter 5 of Construction Vibrations. If you have seen the rubber band model or have a copy of the book you can skip the next paragraph where I'll try to explain compactly the PVRS.

A pseudo velocity response spectrum (PVRS) in Figure 9-13 is a collection of calculated maximum relative displacements induced in structures (with $3 < f < 100$ Hz) by the same ground motion times $2\pi f$ to equal a "pseudo" velocity. Thus for the shot cosmetically cracking structure 20, a structure with a natural frequency of 15 Hz (the peak of the PVRS) would respond the most. Given that structure 20 was a single story structure with a natural frequency of 7 to 8 Hz, it probably responded with a pseudo velocity of only 1 in/sec; not the peak of 2.5 in/sec. Note how the PVRS shows that structures with declining natural frequencies (lower than 8 hz) respond with lower and lower pseudo velocities BUT rather constant relative displacements of approximately 0.01 in. in figure 9-13 on the right above. Relative displacement responses of these low natural frequency (very compliant) systems approach the peak ground displacement because the masses of these systems react so slowly. This explanation is much easier to understand with the aid of the rubber band -- coffee mug response model described in Chapter 5 of Construction Vibrations.

In both Z curve and response spectra (Figures 54 and 9-13 above), a line of constant ground displacement defines the lower boundary of the incidence of cosmetic cracking. This constancy and similarity of the magnitude of peak ground displacement links these two means of defining the relationship of dominant frequency of ground motions and intensity of these motions and their effect on the potential for causing cosmetic cracking. The Z curve demonstrates simply that the greater the dominant frequency – relative to the natural frequency of residential structures (5 to 10 hz) – the greater is the intensity of ground motions (PPV) needed to cosmetically crack structures. The PVRS shows that ground motions that have dominant frequencies in the range of natural frequencies of impacted structures cause the greatest relative displacement. The larger the relative displacement, the greater the strain, and thus the grater the potential for cosmetic cracking.