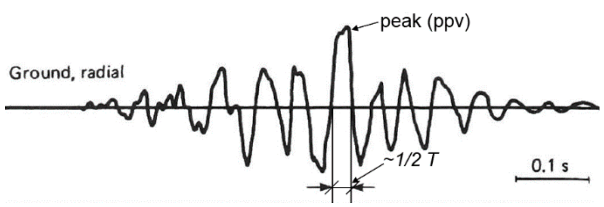
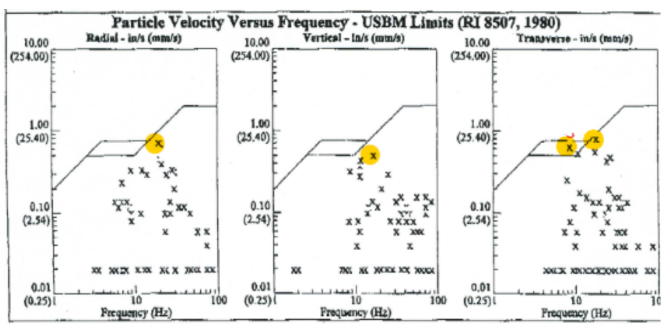
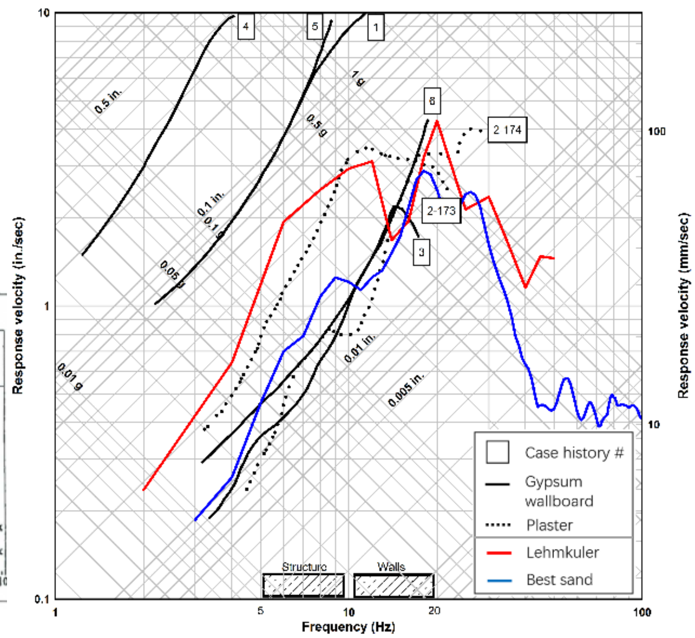
CONST-VIBRATIONS Listserv Newsletter # 15
Use of Pseudo Velocity Response Spectra (PVRS) to
Assess Possible Cases of Increased Probability of Cosmetic Cracking

Comparison of the PVRS of excitation ground motions of concern with those associated with cracking in RI 8507 can clarify issues arising from the choice of dominant excitation frequency (the “f” in the “Z” curve)







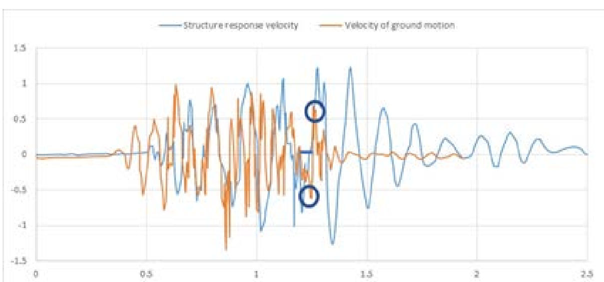


Figure 1 (top left), PPV zero crossing pulse; Figure 2 (mid left) Best Sand transverse time history with “non-PPV” zero crossing pulse at ~ 10 Hz exceeding Z curve limits; Figure 3 (bottom left), Lhemkuhler response (blue) and excitation (orange) time histories associated with crack observation in plaster and lathe; and Figure 4 (right), response spectra of Best Sand and Lhemkuhler ground motions.

Recent Newsletters have generated comments that can be addressed by calculation of pseudo velocity response spectra (PVRS) of excitation ground motions. There is continued concern about the meaning of the Siskind “driving pulse” (in orange in Figure 3) discussed in Newsletter # 14 in conjunction with the Lhemkuhler case. Plausibility of a non-PPV, zero crossing pulse lying above the Z curve being the driver arose after Newsletter #5. Finally, there are the perennial questions about the meaning and usefulness of response spectra.

First let’s revisit the definition of a non-PPV, zero crossing pulse that exceeds the Z curve. As shown in Figure 1 a pulse is a zero crossing event in the time history with a defined pulse amplitude (PPV in this example) and frequency determined by adjacent zero crossing [f= 1/(2(1/2T)] in this example. As can be seen in Figure 1 there are many zero crossing pulses, which are depicted with an “X” in Figure 2. There is one that is associated with the PPV for each component, the yellow highlighted X. In the transverse component, there is a second yellow highlighted X at 10 Hz that exceeds the Z curve, but has a lower amplitude than the yellow highlighted X at ~ 20 Hz, which is the PPV. The yellow highlighted X at ~ 10 Hz is a “non-PPV pulse that exceeds the Z curve”.

Comparison of the PVRS of ground motions of concern with those associated with cracking in RI 8507 can clarify the driving and non-PPV pulse issues and thereby demonstrate usefulness of response spectra. PVRS of excitation motions associated with the driving pulse and the example (Best Sand) of non-PPV pulse Z curve exceedance are compared in Figure 4. The spectra in black are those associated with cosmetic cracking observations reported in RI 8507. Response spectra of Lhemkuhler and Best Sand are colored in red and blue respectively. Case numbers of the black RI 8507 PVRS refer to the following structures in RI 8507; 2 = struct 51, 3 = struct 19; and 6 = struct 61. Ground motions for cases 2 & 3 were produced by surface mine blasting, while that for case 6 was produced by construction blasting (Dowding, 1996 and Corser,1979). Details about these cases can be found in Chapter 9 in my book Construction Vibrations.

The PVRS of the transverse motions in the Best Sand case (in blue) exceed slightly the lowest RI 8507 PVRS in the 5 to 10 Hz frequency band and fall below in the 10 to 20 Hz range. These two frequency bands are natural frequencies of one to two story structures and walls respectively. While, multiple factors (such as old age, high existing strains, etc) would have to coalesce for these motions to cause cosmetic cracking with this PVRS, the similar PVRS amplitudes would lend weight to an assessment of a violation of any regulation based upon the Z curve. Thus PVRS comparison can provide an additional approach for checking cases where non-PPV pulses exceed the Z curve.

The PVRS of the excitation motions in the Lhemkuhler case (in red) exceed significantly the lowest RI 8507 PVRS in the 5 to 12 Hz frequency zone. This large exceedance lends weight to the observation of a cosmetic crack in the plaster and lathe walls in the Lhemkuhler house. It also lends credence to the importance of a driving pulse in the excitation of a structure. As shown in Figure 2, the largest structural response (in blue) occurs during or slightly after the driving pulses (in orange) whose peaks are marked with black circles.

PVRS comparison is useful because it describes the maximum relative displacements between the bottom and top of the responding structures when subjected to the full wave form of the excitation. Induced relative displacement is directly proportional to induced strain in the walls of the structure, which is what produces cosmetic cracks. The PVRS relative displacements in the 5 to 20 Hz range are important because they define the maximum relative displacements sustained by residential and similar commercial structures, which have natural frequencies in that range. By considering the full waveform, the PVRFS automatically includes all issues regarding driving pulses. In other words it eliminates the need to determine which pulses (encircled “X”s in Figure 2) to compare with the Z curve from RI 8507.

When PVRS spectra are plotted on tripartite paper as in Figure 4 above, relative displacement can be read directly off the graph along lines labeled as (0.01, 0.1 in. etc.) The lines of constant relative displacement are simply lines along which the “response” velocity (on the y axis) divided by 2πf is constant. Natural frequency of the responding structure is the “f” in Figure 4.

Comparison of the instrumentation in the Lhemkuhler and Best Sand cases helps to illuminate the usefulness of the response spectrum. Lhemkuhler involved recording of both ground excitation and structural response velocity time histories shown in Figure 3. Thus it is possible to pick a pulse by comparing excitation and response time histories. The timing of these two pulses was confirmed with arrival of the air overpressure wave. Best Sand involved only the ground excitation particle velocity time history required by regulation. Since regulatory monitoring normally will not involve measurement of structural response, any of the pulses (encircled “X”s in Figure 2) could have been the “forcing” pulse and thus they all need to be considered.

There are many sources of support for employing PVRS as it has been employed in earthquake engineering and structural dynamics for more than a half of a century. While there is not space in this newsletter to develop the PVRS concept, it is fully developed in chapters 5 and 9 in my book, Construction Vibrations, and is addressed in any text on structural dynamics. Most seismograph companies offer software to calculate PVRS. Alternatively, NUVIB2 can be employed to calculate response spectra. It and the user’s manual is available for free at http://www.civil.northwestern.edu/people/dowding/acm/.

References

Corser, P. G. (1979) Wall Cracking in Residential Structures from Surface Mining and Hard Rock Construction Blasts, MS Thesis, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL