Newsletter # 37

Structural Strains Induced in Large Urban Structures by High Frequency Excitation Pulses Are Small when Calculated from Time Correlated Velocity Time Histories of Structural Response

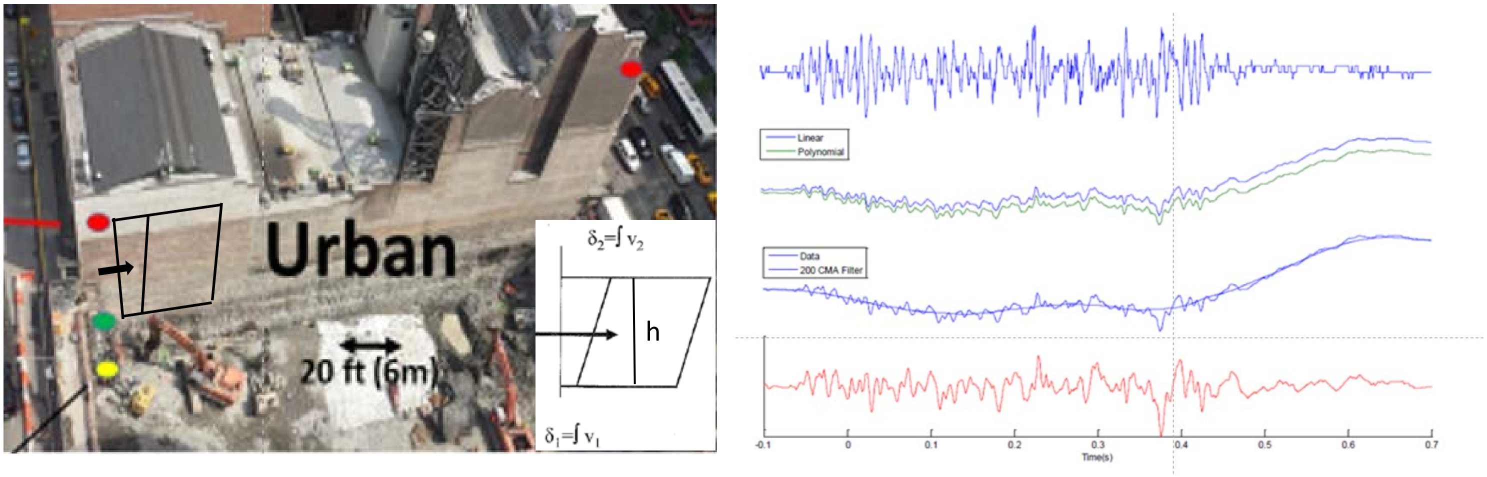

Figure 1: (Right) Displacement calculation using baseline correction and 200 point central-moving-average filtering of the integrated velocity time histories (δ =∫vdt): (a) (top right) Velocity recording, (b) Displacement after linear and second order polynomial baseline correction, (c) 200 point central-moving-average filtering produces the smooth line about which "b" oscillates, (d) (bottom) the difference between the two curves in "c" (smooth subtracted from jaggedly oscillating) that produces the final displacement time history that oscillates about zero. (Left) Photo of urban structure with plane shear strain superimposed along west wall between the green and red dots, which are the locations of the seismographs from which the displacements were calculated.

This newsletter presents the relative displacements and strains that were calculated from time correlated structural response time histories. Comparison of these types of relative displacement and strain responses on urban and residential structures illustrate their differences in response that result from differences in excitation frequencies and natural frequencies of the responding structures. This newsletter is part of a series of 8 (#s 34-42) that focus on the measurement of structural strains with velocity transducers.

Strains in walls can be calculated from time correlated structural velocity response time histories through a multi-step process. First the velocity response time histories are integrated to determine displacement time histories **(δ=∫vdt)** at two locations shown on the inset on the structure on the left side of Figure 1. Determination of the displacement time histories requires correction of baseline irregularities. An example of the four steps in this correction process is shown in Figure 1 on the right. (Dowding et al 2016). First, the velocity time history (a) in the figure) is baseline corrected. Linear and second order polynomial baseline corrections were tested as shown in (b). As can be seen the polynomial correction did not return the displacement curve to zero at the end of motion. The displacement time history was returned to zero at the end of motion by subtracting the 200 point central-moving–average (smooth continuous line) from the jaggedly oscillating line in (c) to produce the displacement time history that oscillates about zero in (d).

While a 200 center point moving average was employed in the example, fewer points over which the average is determined (50 to 100) will also allow displacement to come to zero after the excitation. The important criteria is that the time interval over which that average is made should include one to three periods of a mixed frequency pulse's dominant frequency.

Shear strains shown in Table 1 were calculated by subtracting time correlated displacements at the yellow and red dots on the left side of Figure 1 to obtain the relative displacement between them. The relative displacement is the same as differential structure displacements or inter story drift in earthquake engineering. These relative displacement time histories are then searched for the largest difference during the time of the event. This maximum relative displacement is transformed into in-plane shear strain or out of plane bending strain as shown in the explanation at the end of this newsletter or in Chapter 5 of my Construction Vibrations. book

Table 1 Comparison Measured Responses of Urban and Residential Structures to Ultra-High and Low Frequency Blast Excitation

Strucrue and Blast	Basement and One Story Response				Above Ground Response				Crack Response	
	PPV Rock mm/s	Freq Excite HZ	Relative Displacem't µm	Shear Strain µ strain	PPV Grd Floor mm/s	Freq Excite HZ	Relative Displacem't µm	Shear Strain µ strain	Peak Vibration µm	Max Weather µm
Urban Buildings										
3 to 5 Story Urban Building (1)				h = 5.8m				h = 11.6 m		
Shot a	27.4	333	20	3.3	5.1	59	28	2.4		
Shot c	70.4	250	72	12.5	10.8	143	58	5		
Shot b	132.6	500	89	15.1	13.6	125	54	4.7		
Shot d	198.1	500	334	57.5	9.8	167	70	6		
3 to 5 Story Urban Building (2)										
Shot h (basement midwall response)	5.1	143	18	2[1]						
Single Story Residential Structures				h = 2.5m						
Trailer: Pennsylvania	3.6	7 to 20	210	86.1					4.2	24
Bungalow 1: Indiana	5.8	6 to 25	180	73.8					0.3	12
Wood Frame: Indiana	7.6	15 to 20	133	54.5					13.6	52
Adobe: New Mexico	8.1	4 to 14	250	102					0.9	25

[1] Bending strain

As shown in Table 1, strains induced in urban structures by ultra-high frequency (300+ Hz) blast induced rock motions are small; 12 µm in the basement and 5 µ strains in the super structure for 70 mm/s peak particle velocity (PPV) excitation. Their minimal magnitude is further illustrated in Table 1 by comparing urban structure responses with those of a variety of residential structures to surface coal mining blasts (Dowding & McKenna, 2005). Responses of the 3 to 5 story urban structures, buildings 1 and 2, are tabulated in the upper half of the table and those of four, single story residential structures are tabulated on the lower half. Relative displacements are those from time correlated differences of integrated structural response velocities.

Comparisons in Table 1 allow several observations to be made. As illustrated with the response spectra in Newsletter #36, ultra-high frequency excitation should produce significantly lower responses than lower frequency excitation with similar PPV's. Table 1 verifies this observation. Measured relative displacement in column 3 of the urban structure with an excitation PPV of 27 mm/s is 20 µm while for a residential structure with an excitation PPV of only 8 mm/s it is 250 µm. The ratio of residential relative displacement to urban relative displacement (per residential PPV to urban PPV) is some (250/20)/(8/27) = > ~ 40. Since relative displacements are proportional to strains, this ratio would be the same for strains as it is for relative displacements.

Estimating expected relative displacements for high frequency response of urban structures on the basis of PPVs yields estimates that are opposite to that measured. If relative displacement is a function of PPV only, and experience with residential structures indicates relative displacements of 200 µm are produced by PPVs of 6 mm/s then shots b and d should have produced relative displacements of 200*(130 to 200)/6 = 5300 µm. Measured relative displacements produced by excitation with PPVs of ~ 25 mm/s at ultra-high frequencies are only 20µm, which is less than 1/100th of that expected from experience with low frequency excitation of residential structures i*f PPV is employed as the index of correlation.*

The insignificant magnitude of the relative displacements and strains of urban structures in Table 1 is further verified in the bottom half of Table 1 by crack response data of residential structures in the two rightmost columns described in Newsletters #16 and #17. These residential structures sustained higher blast-induced strains than urban structures. Despite these higher induced strains the corresponding cosmetic crack response to blast induced ground motions was 5 to 20 times lower than induced by the maximum weather response (Dowding and McKenna, 2005). Thus blast induced strains of this magnitude (50 to 100 μ strain) are 5 to 20 times less than the strains induced in the course of naturally occurring events such as normal weather induced changes in temperature and humidity.

References

Dowding, C.H., Hamdi, E., & Aimone-Martin, C. T. (2016) Strains Induced in Urban Structures by Ultra-High Frequency Blasting Rock Motions: A Case Study. Rock Mechanics and Rock Engineering, 49:4073-4090 DOI: 10.1007/s00603-016-0921-4

Dowding, C.H. and McKenna (2005) Crack Response to Long-Term Environmental and Blast Vibrations Ef10 fects, ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 131, No. 9, Sept pp 1151-
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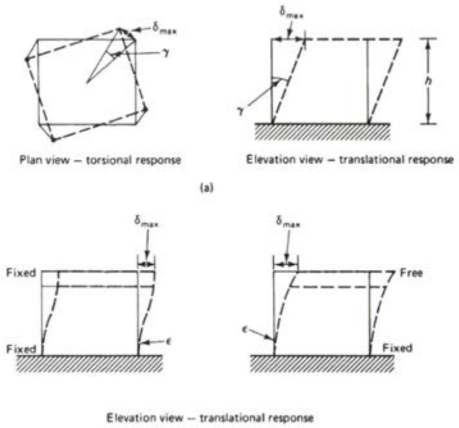

Details of transforming relative displacement or inter story drift into shear and bending strain

Figure 2: Showing the difference between in the plane of the wall shearing strains (upper right) and out of the plane of the wall bending strains (with fixed-fixed and fixed-free end conditions)

Differential displacement, δ_{max}, can be translated into shearing or tensile strains depending on its form. The simplest form of differential displacement is that of translation, shown in the elevation views in Figure 2 (Dowding, 1996). The “in the plane of the wall” shearing strain, γ_{max} in the plane of the wall is the angle change and for small angles is

$$\gamma_{max} = \delta_{max}/h,$$

where h is the vertical distance between the two locations at which the response velocities were measured.

Out of the plane of the wall bending strains, (perpendicular to the wall) are also illustrated in Figure 2 and can be estimated from beam theory as

$$\varepsilon_{max} = \sigma_{max}/E = (M_{max}\ d)/EI$$

where M is the maximum moment, d is the distance from the neutral axis to the outer beam fiber (1/2 the wall's thickness), E is Young's modulus of elasticity, and I is the moment of inertia of the beam (a slice of the wall). In this case the beam comprises the entire wall, bricks, wall framing, and interior wall board. Furthermore, the maximum moment can be shown to be

$$M_{max} = (\delta_{max}6EI)/h2 \text{ or } (\delta_{max}3EI)/h2$$

for the fixed-fixed or fixed-free restraint conditions, where h is the distance between measurement points. Therefore, the wall bending strains can be estimated by substituting the moment into the strain equation for fixed-fixed and fixed-free respectively

$$\varepsilon_{max} = (\delta_{max}6d)/h2 \text{ or } (\delta_{max}3d)/h2$$

In-plane shearing strains are larger than the out of plane bending strains as shown by a typical example. A 10 Hz or single story residential structure would sustain a differential displacement of 0.254 mm if excited by a 7 delay quarry blast with a peak particle velocity of 25 mm/s. Thus the shear strain would be

$$\gamma_{max}= \delta_{max}/h = 0.0254 \text{ cm}/300\text{cm} = 100 \text{ x } 10\text{-}6 \text{ cm/cm or } 100\ \mu$$

and the bending strain would be

$$\varepsilon_{max} = (\delta_{max}\ 3 \text{ to } 6\ d)/h2 = (0.025 \text{ cm}*3 \text{ to } 6*\ 10\text{cm})/300\text{cm}2 = 13 \text{ to } 26\ \mu$$