Newsletter #38

Response of Three Story (Three Degree of Freedom) Model Shows that the Highest Strains Are Produced by Excitation Motions at the Fundamental (Natural) Frequency

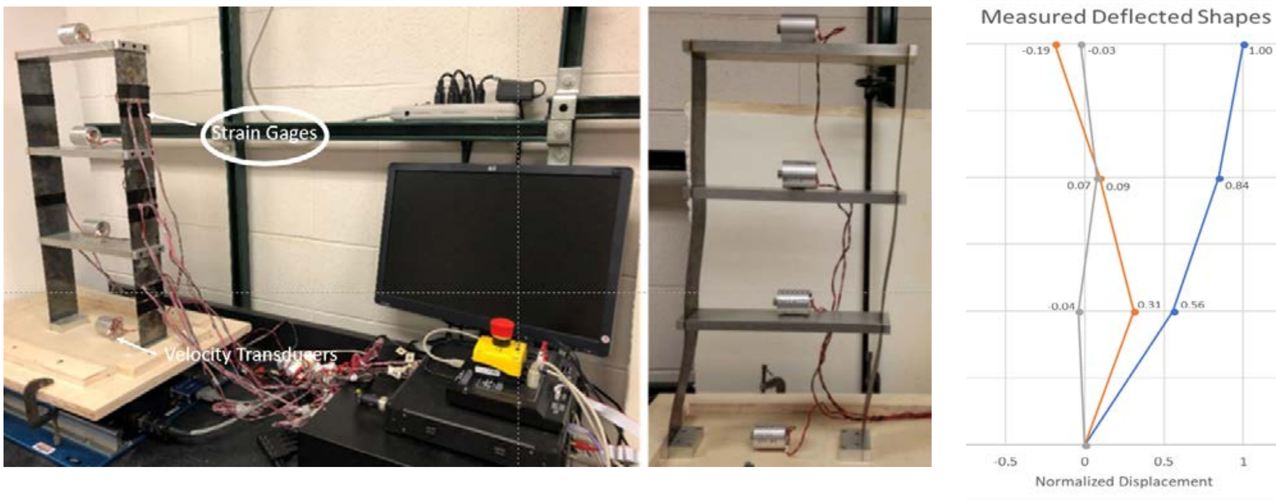

Figure 1 Three story (3 degree of freedom) model structure fitted with foil strain gauges and Geospace velocity transducers (left photo). Structure responding in fundamental mode (middle photo). Modal deflection shapes with maximum deflections at steady state excitation at the modal frequencies; blue = fundamental, orange=second , and black=third (right)

This newsletter presents magnitudes of modes of response higher than the fundamental when a multi (3) degree of freedom structure is perturbed by ground motions with excitation frequencies greater than the natural (fundamental) frequency of the responding structure. This investigation was carried out with the model shown in left photo of Figure 1 to measure the inter story drift displacement with velocity gauges (silver cylinders) shown in the center photo of Figure 1. Strains calculated from the velocity responses are compared to those measured directly with leaf strain gauges encircled in white on the left most photo of Figure 1.

The model was perturbed sinusoidally with a constant displacement or 0.3 mm at its three modal frequencies of 1.88 (the fundamental or natural), 5.43 (second) and 8.24 Hz (third). It was also perturbed with a mixed frequency content (15-30 Hz) blast vibration scaled to a maximum displacement of 0.3 mm. Maximum wall bending strains from interstory drift and strain leaf gauges are compared in Table 1 below. Response to continuous sinusoidal excitation at differing modal frequencies was compared at 5 pulses to equalize the amount of displacement energy for the three modal frequencies. Responses to the transient blast vibration are the maxima for each inter story no matter when it occurred during the 0.75 sec duration of the mixed frequency blast excitation. Other methods of comparison such as the same duration of excitation will yield other relations, but this is sufficient to draw some basic conclusions.

Table 1 Comparison of strains from velocity response and strain guage measuremnt

Frequency	Mode	Maximum Excitation			Bending strains at 5th pulse			
		displacm't	velocity		G-L1	L1-L2	L3-L2	
Hz		mm	mm/s		μstrain	μstrain	μstrain	
Excitation at frequencies matching first three modes of response with constant displacemnt (0.3 mm)								
1.91	1	0.3	3.7		58	23	19	vel transducer
					42	38	10	strain guage
5.55	2	0.3	10.4		15	10	18	
					12	8	10	
8.33	3	0.3	15.6		6	5	4	
					9	7	3	
Excitation with 15-30 Hz blast vibration with maximum displacement of 0.3 mm								
15-30	Blast Vib	0.3	30		7	3.5	7	vel transducer
					10	8	9	strain guage
					7.5	7	8	com seismograph

Table 1: Comparison of bending strain responses calculated from inter story drift with that measured by strain gages.
There were two types of excitation: 1) continuous displacement of 0.3mm at frequencies associated with the first three modes of response, and 2) a mixed frequency blast vibration scaled to produce a maximum excitation displacement near 0.3 mm.
Strains are calculated between stories; G-L1 is the strain between the ground and first floor.

Foil strain gauges were employed to validate the method of calculating strains from inter story drift displacements obtained by integrating velocity time histories as described in Newsletter #37. Strains measured by the foil strain gauges are the out of plane strains that are obtained from beam bending theory. See Dowding and Diels (2019) for details employed with this model.

As can be seen in Table 1, strains calculated from velocity responses, while not equal to those measured with the foil gauges, are similar and display the same trends. As shown in Figure 2 below, strain time histories calculated from velocity responses and those from measured strain gauge response are also similar, which further validates the calculated strains. Strains calculated from velocity time histories obtained by the commercial seismograph more closely match those measured with the foil gauges than those obtained with the Geospace velocity transducers. There are many reasons for this difference but the most important is the need to use voltage (Vt) output to velocity (Vt/in/s) conversion factors at the low excitation frequencies for the Geospace velocity transducers. This issue is discussed more fully in the article (Dowding and Diels, 2019). Commercial seismographs overcome this low frequency response with several techniques that include but are not limited to employing different transducers, frequency based amplitude compensation, etc.

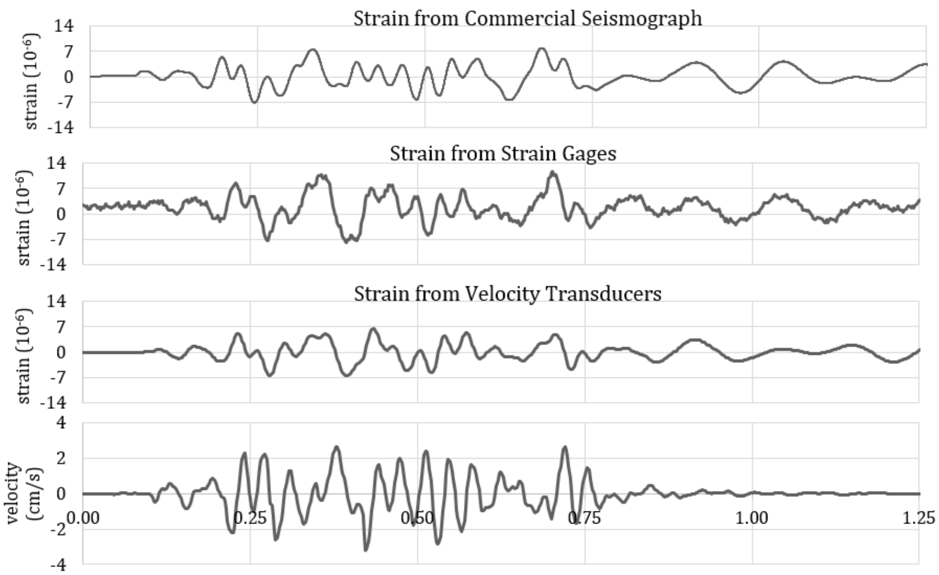

Figure 2 Time histories of strains calculated with G-L1 velocity responses measured with different velocity transducers (top and 3rd down) are the same or similar to those measured directly with foil strain gauges (2nd from the top). Bottom time history is the multi frequency velocity time history of the blast excitation. Similarity of directly measured strains and time histories with those from velocity based inter story drift validates calculation of strain from velocity time histories of inter story drift.

Conclusions

1) The model behaves in the expected theoretical fashion; excitation at frequencies higher than the fundamental frequency produce lower response both in terms of inter story drift and strain with the same number of pulses with the same peak displacement

2) Even when the structure is a multi-degree of freedom system (3 in this case) continuous excitation at frequencies higher than the fundamental does not produce larger directly measured strains at frequencies other than at the fundamental frequency. Sinusoidal excitation at the second and third modal frequencies of a three degree of freedom system produced smaller strains despite excitation at with peak particle velocities 2 to 3 times larger.

3) Excitation with blast vibration frequency characteristics (15 to 30 Hz dominant frequency) and same displacement as the constant frequency excitation produced maximum directly measured strains that were only some 60% of those produced by an equivalent one second of excitation at the fundamental frequency (1.88 Hz). This smaller response occurred despite excitation with peak particle velocities that were some 8 times those at the fundamental frequency.

4) Strains can be calculated with inter story drift or differential displacement from velocity measurements within limits.

5) The form of the strain time histories calculated from inter story drift is similar and almost the same as that from direct measurement.

6) Increasing the agreement of calculated and directly measured strains above that reported herein requires more work on transducer selection, transducer placement, and baseline correction processes.

References

Dowding, C. & Diels, E. (2019) Use of Response Velocity to Calculate Building Strains from Blasting Vibrations, Proceedings 11th World Conference on Explosives and Blasting, European Federation of Explosive Engineers http://www.civil.northwestern.edu/people/dowding/acm/publications/dowding/Full%20Report%201%20reduced.pdf