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Large structure response to high frequency excitation from rock blasting

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ABSTRACT

This paper describes measurement and interpretation of response of two, multiple story, older, urban structures to small charge weight, ultra-high frequency rock blast excitation from contiguous excavation. Time correlated responses were measured at the ends, top and bottom of the structures as well as in the foundation rock below the bottom. Observations based on the ten, instrumented positions during eight blast events provided over seventy time histories for analysis. The case study and measurements allowed the following conclusions: close-in blasting with direct rock to building wave transmission imposes short wave length excitation which fails to excite the large, massive structures synchronously. The structures respond predominantly in wave transmission mode where there is a noticeable difference in time, frequency, phase and amplitude of motions measured at the bottom and top corners of the structure. Excitation motions along the base also differ in time, frequency, phase and amplitude. The short wave length of the excitation motions leads to attenuation of the peak particle velocity along the base. Ultra-high excitation frequencies, which are much higher than the expected structural natural frequencies, lead to deamplification for all events

1. Introduction

The case study summarized by this paper provides the multiple position, time-correlated, velocity time histories needed to advance understanding of the non-uniform, deamplified response of large, urban structures to ultra-high frequency excitation. Much of the current regulation and understanding of structure response to construction blasting are based upon the observation of cosmetic cracking in and measurements of the blast response of residential, 1–2 story structures.[1,2] Interpretation of the frequency dependence of this observed response is in turn based upon principles of structural dynamics and the assumption of uniform excitation along the base of the structure. This study demonstrates that the assumption of uniform excitation along that base is inappropriate for close-in blasting near large urban structures.

Most often calculation of structural response, as described in texts on structural dynamics,[3] monographs[4] and articles[5] implicitly assumes that excitation wave lengths are long enough to excite buildings uniformly along the base and there is enough energy to excite the entire structure synchronously (or in phase). In other words excitation motions along the base of the structure are the same and response at the top occurs in modal phase with the bottom. Normally these assumptions are valid. For instance earthquakes (~ 1 Hz excitation frequencies, f) induce uniform excitation of large structures just as typical distant blasting vibrations (~ 20 Hz excitation frequencies) do of residential structures. With a surface wave propagation velocity (c) of 1000 m/s, the wave lengths ($\lambda = c/f$) of the earthquake and blasting vibration would be 1000 m and 50 m respectively. Both a 300 m wide office building and a 12 m wide residential structure are sufficiently smaller than the respective earthquake- and blast- induced and wave lengths to be uniformly or synchronously excited.

Now consider excitation of a large urban structure, say 60 m wide, by contiguous, small charge, blast fragmentation, which produces high excitation frequencies (>100 Hz for rock to rock transmission). Under these circumstances excitation along the bottom will not be uniform. Both excitation amplitudes and phase are likely to change significantly along the bottom. For instance, with a compressive wave propagation velocity of 3000 m/s, 150 Hz excitation frequency and a distance along the bottom of the structure of 60 m, the excitation pulse would have traveled 3 wave lengths (60/(3000/150)) and would have attenuated significantly.[6] In addition the time of arrival would not be equal at the ends of the building if the blast were detonated at one end. The peak would arrive some 60/3000 = 20 ms later at the other end. Any combination of propagation velocity and dominant frequency would produce varying degrees of phase differences. In other words one portion of the base may be displaced to the left while another is being displaced to the right.

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This paper presents unique measurements of time correlated attenuation and delays in first arrival times along a structure. Amplification and attenuation up through urban structures during response to contiguous blasting has been observed before.[7] However, there have been few to no in-depth studies of time correlated, high frequency, blast induced response and excitation along the base of larger urban structures. Measurements provided by this case study go beyond typical measurements made with single instruments to verify compliance with building regulations.

Multiple, time correlated responses were measured to obtain the response at various locations along these urban buildings that are larger and more massive than are residential structures upon which much blasting literature is based.[1] Current regulations often only require that the excitation motions be measured at one (or several) location(s) with no requirement for time correlation of the measurements. Building response is then most likely to be considered in phase and similar to that measured by the Siskind et al.[1] work with smaller residential structures and longer wave length excitation. Typically there is no requirement to measure excitation at multiple points and/or building response, and as a result compliance measurements provide no new information about the nature of larger building response to ultra-high frequency excitation.

2. Site and geology

This study was conducted in a dense urban location in New York City where blasting was required not just adjacent to buildings but contiguous to them as illustrated in Fig. 1. The two buildings were separated only by a narrow street which allowed response from a blast at one site to be measured at both buildings. Contiguous blasting produced excitation ground motions of unusually high amplitude and dominant frequencies.

Both of the buildings are over 100 years old and are landmarked structures. They are four- to six-story unreinforced brick masonry buildings, built 1890 and 1920, and are typical of those structures built New York City at that time. They both have basements, details of which are shown by the photographs of the excavation in Fig. 2.

The rock supporting these structures is a mica schist whose foliation dips into the excavations from beneath the structures. It is a dark-gray to silvery, rusty-weathering, generally coarse grained, foliated but poorly layered to massive gneiss or schistose gneiss, composed of quartz, oligoclase, microcline, biotite, and muscovite, and generally sillimanite and garnet.[8] Vertical rock faces are supported by rock bolts that are 3–10 m long. As will be described later in the data section, propagation velocities confirm the relative stiffness of the rock mass.

3. Transducer description and installation

Buildings and rock were instrumented with seismographs that were connected in series to provide a common time base that was accurate within one sample interval of 0.0005 s. When the closest seismograph to a blast detects ground motion that exceeds the threshold value, it begins permanent recording and triggers the other seismographs. Since the “other” seismographs contained 0.25 s of “pre-trigger data” in memory, their time correlation is only dependent upon the response of the secondary seismograph to the triggering signal, which is accurate to within one sample interval or 0.0005 s. The LARCOR Mini Seis II four channel seismographs deployed in this investigation and associated velocity geophone transducers meet the International Society of Explosive Engineers (ISEE) standards. They have flat responses between 2 and 250 Hz. Transducer output is digitized at 2048 samples per second (sps). Seismographs begin recording (for 6 s duration with 0.25 s of pre-trigger) when the particle velocity exceeds a preset threshold. This method of time correlating responses has been employed for over a decade.[9]

3.1. Building 1 transducer locations

Transducer locations are named to identify their locations relative to the buildings on which they are located. The locations and nomenclature are summarized in Table 1. Two transducers, sensitive to horizontal motions were located at the street level, B, and roof top, A of the north, N, and south, S, corners of the west wall nearest the excavation as shown in Fig. 2 (left). One was oriented parallel (denoted radial or R) and the other perpendicular (denoted transverse of T) to the wall west building wall. The lower (B) geophones were bolted on brackets which in turn were bolted into the mortar between bricks on the building about 1 m (3–4 ft) above street level. The upper (A) transducers were also bolted to brackets and bolted into the mortar on the inside of the parapet wall just above roof mastic.

All four transducers (two upper, A, and two lower, B) at a corner were connected to one four-channel seismograph, which automatically provides a common a common time base for the four time histories. Data described herein are those where south and north seismographs were also connected by cable to provide a common time base. This cable connection provides a pathway for the trigger signal from the seismograph nearest the blast to the more distant seismograph, which responds within one sample interval or at times at most two sample intervals or 0.001 s. For blasts close to the north corner of building 1, the majority of blasts in this study, the north seismograph would trigger the south seismograph.

In addition one triaxial sensor with three velocity transducers was

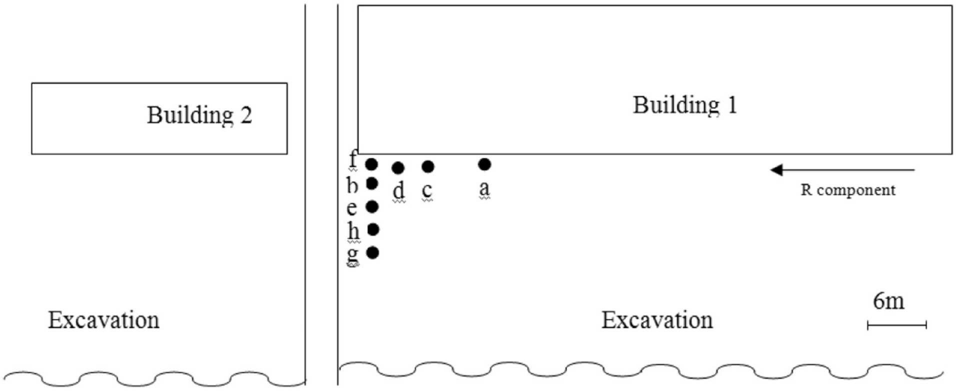

Fig. 1. Blast locations shown with respect to the buildings. As can be seen from the scale, fragmentation of rock was required immediately adjacent, or contiguously, to the buildings (shots f, d, c & a), which produced the ultra-high frequency excitation motions.