

Seismic anisotropy of a building

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The Robert A. Millikan Library is a reinforced concrete building located on the campus of the California Institute of Technology in Pasadena, USA. The building has been studied by earthquake engineers since it was first instrumented in the late 1960s. Continuous measurements at 200 Hz are made by 19-bit real-time seismometers on each of the 10 floors and in the basement. These seismometers measure the response of the library in the north-south direction and in the east-west direction.

Shear-wave splitting occurs when a linearly polarized shear wave passes through a seismically anisotropic medium. When this occurs, the wave is split into orthogonal slow and fast shear waves. Splitting is observed in global seismology, occurring in the upper mantle due to the crystal lattice structure of olivine, and in exploration seismology where shale and/or fractured rock are anisotropic. The cross-section of the library in Figure 1 shows structural differences in the two horizontal orientations, causing speculation that the mechanical properties of this building are anisotropic.

Previous studies have used actual earthquakes, and also a synchronized shaker permanently located on the roof, to study the response of the building to excitation. Our study used seismic interferometry to analyze the wave motion in the two horizontal directions due to the Yorba Linda earthquake of 3 September 2002. We do this by deconvolving recorded traces at different floors. Figure 2 shows the raw data from each floor.

It is possible to deconvolve all floors with any single floor, each giving a different type of waveform. We concentrate on the deconvolutions with respect to the trace at the top floor (floor 10). This simplifies the problem by making the building response independent of its ground coupling at the base. By deconvolving all floors with respect to the trace at the 10th floor, surprisingly simple waveforms are produced. These deconvolved waveforms are acausal (nonzero for $t < 0$) and comprise a single upgoing and downgoing wave. By picking the peaks of the waveforms, an estimate of the shear-wave velocity inside the building can be obtained. Figure 3 shows the waveforms produced by the deconvolution of all floors with the trace at the 10th floor. Also, the accelerometers on floors 2 and 8 in the north-south direction seemed to be faulty and didn't give a reliable output.

The hypothesis that the mechanical properties of the building were anisotropic was proved correct by the contrast between shear-wave velocities in the east-west direction and

David Thompson on studying abroad: "Deciding to study abroad for a year has opened up several new doors for my geophysical career. The study which we have carried out gave me an excellent insight into how postgraduate research is done. The experience which I have gained during my time abroad will serve me well when making decisions regarding my future after graduation. For students of geophysics, the opportunity to study abroad is highly recommended. The field is truly an international community, and an experience like this provides an excellent head-start to becoming part of it."

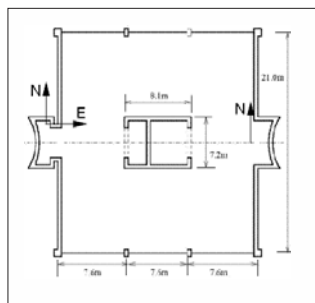


Figure 1. Cross-section of the Millikan Library with location of seismometers.

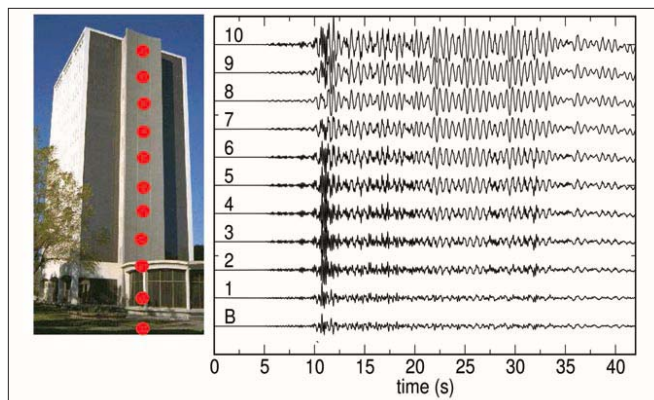


Figure 2. Response of the building due to excitation.

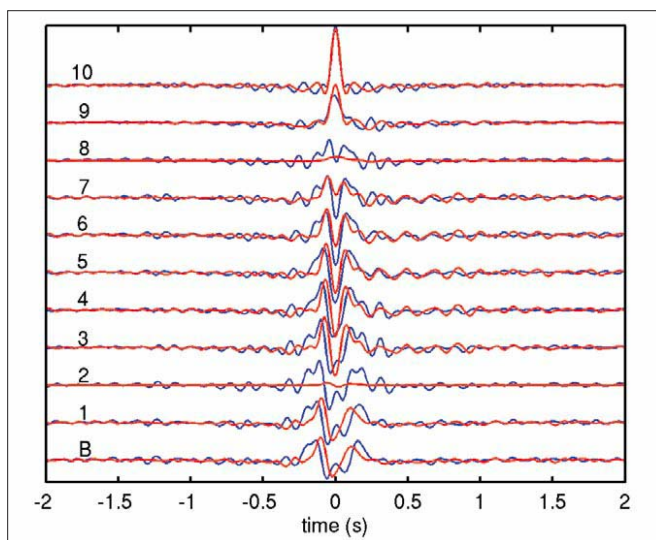


Figure 3. Deconvolved waveforms for the north-south direction on the east side of the building (red) and east-west direction (blue).

in the north-south direction. Figure 3 shows the differing arrival times of the waveforms in the two horizontal directions, with the north-south direction having the shorter travel time. The results for each of the polarizations are: north-south direction (east side of building) = 385 m/s; east-west direction = 286 m/s. Seismic anisotropy is clearly a characteristic of the Millikan Library; the waves polarized in the north-south direction travel faster than those polarized in the east-west direction. The symmetry axes of the building align with the orientations of the accelerometers (east-west and north-south, respectively); hence there is no need to perform an Alford rotation to decompose the split shear waves into their fast and slow directions.

This application of seismic interferometry shows that techniques currently used in exploration seismology can be used in structural engineering as well.

Suggested reading. "Extracting the building response using seismic interferometry: Theory and application to the Millikan Library in Pasadena, California" by Snieder and Safak (*Bulletin of the Seismological Society of America*, 2006). [TJE](#)

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