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# Directivity and Sensitivity of Fiber-Optic Cable Measuring Ground Motion using a Distributed Acoustic Sensing Array


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## 1. Introduction

- Silixa Ltd's 'intelligent' Distributed Acoustic Sensing (iDAS™) spatial resolution is 1 m over up to 50 km.
- Interrogator sends out 10 nanosecond light pulse and interprets backscattered light as cable strain due to ground motion.
- This work is part of the larger PoroTomo project

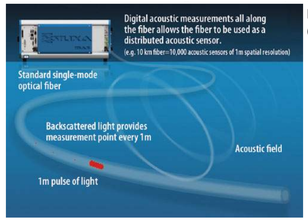
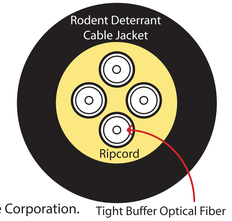
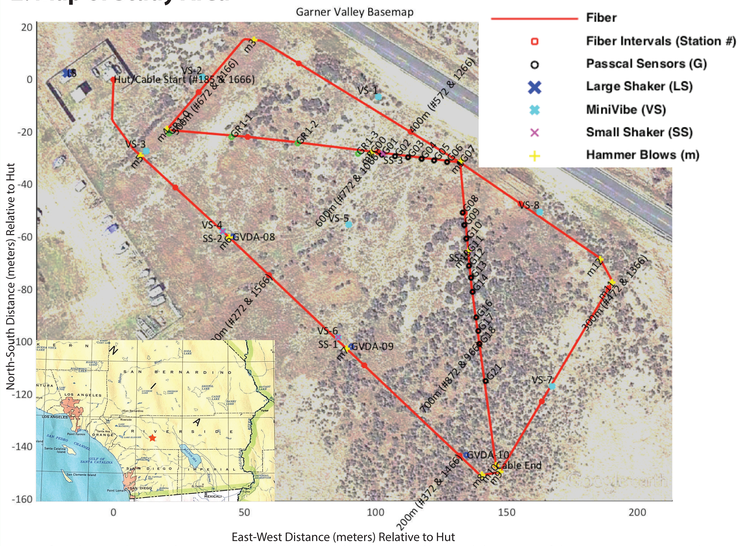



Diagram of DAS functionality (Parker et al., 2014)




Cable by Optical Cable Corporation. Tight Buffer Optical Fiber

## 2. Map of Study Area




Map of study area showing locations of the cable and other sensors, along with locations of the various sources used. Inset shows regional map of Southern California with red star indicating the location of the study area.

## 3. Sources Used

45 kN shear shaker on top of the Mini-Me structure available through NEES@UCLA.

45 kN shear shaker:
- On Mini-Me structure
- Swept from 0 to 10 Hz and back to 0 over 60 seconds
- Repeated 10 times

450 N portable mass shaker available through NEES@UCLA.

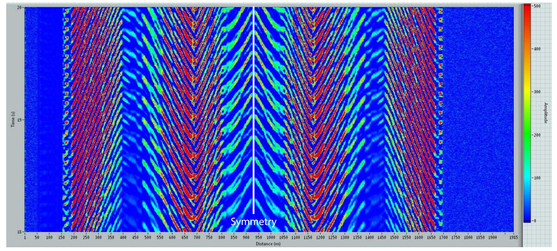
450 N vertical shaker:
- Swept from 5 to 35 Hz over 29 seconds
- 4 locations
- Repeated 10 times at each location

27 kN T15000 IVI 'minivib' vertical shaker operated by GEOVision.

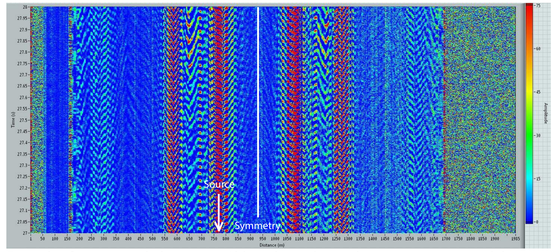
27 kN vertical shaker:
- Swept from 20 to 100 Hz over 10 seconds
- 8 locations
- Repeated 10 times at each location

Hammer blows at 13 different locations around the array are another source of data used in this study. The locations of the hammer blows are noted on the map of the study area.

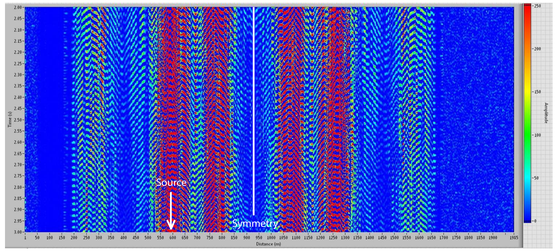
## 4. Responses to Swept Sources




Example of one 45 kN shaker sweep. This is the largest swept source, and is located outside of the array. The cable is spliced together at the end, causing the mirror image in this plot. Noise at the beginning and end are sections of cable not in the ground.

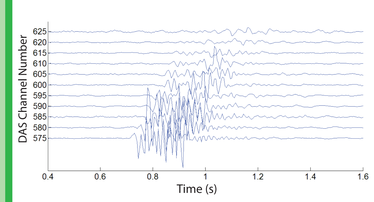


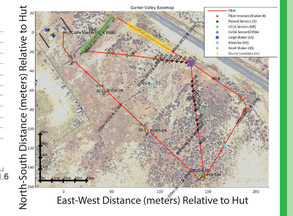

Example of one 450 N shaker sweep. Although it is the weakest swept source used the sweep can be seen across the entire array. Noise at the beginning and end are sections of cable not in the ground. The shaker was located at DAS channel 772 and is labeled SS-3 on the map.



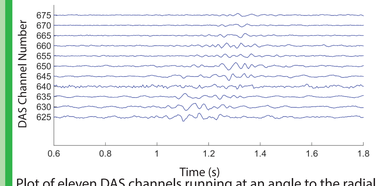

Example of one 27 kN minivib sweep. The minivib truck was located near DAS channel 595 and is labeled VS-1 on the map. Noise at the beginning and end are sections of cable not in the ground.

## 5. Directional Sensitivity to Hammer Impact



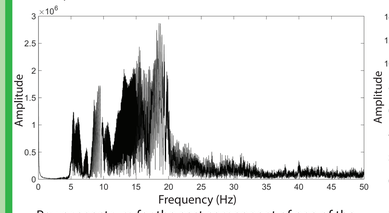

Plot of eleven DAS channels running radially away from the source (denoted by a star on the map) spaced five meters apart. The arrival at each channel is above the noise level. The section of cable is highlighted on the map in yellow. The response is to a hammer impact on a steel plate. Note that the amplitude of the response decreases as the distance to source increases. The nearest DAS channel, channel 575, is 21 meters from the source, while DAS channel 625 is 71 meters from the source.



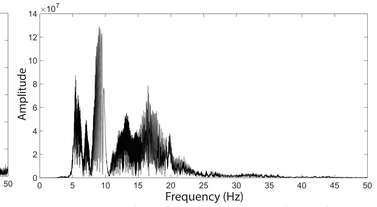

Plot of eleven DAS channels running at an angle to the radial direction from the source (denoted by a star on the map) spaced 5 meters apart. The arrival at each channel in this case is at or just above the noise level. The section of cable is highlighted on the map in green. The response corresonds to the same hammer impact as the above plot. The nearest DAS channel, channel 640 is at the corner and is approximately 90 degrees from the source, while the farthest DAS channel, channel 690, is about 60 degrees from the source.

## 6. Frequency Sensitivity

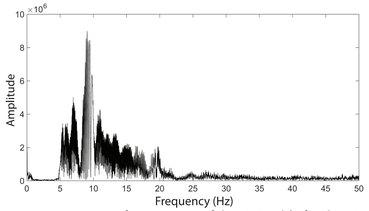
The below plots show power spectrum plots of three different types of sensors that were used in the study: accelerometers, seismometers, and the DAS array. Note that each of the sensors records a different property, so differences in the power spectra are expected.




Power spectrum for the east component of one of the accelerometers for the 45 kN shear shaker.



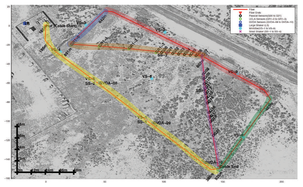

Power spectrum for the east component of one of the PASSCAL seismometers for the 45 kN shear shaker.



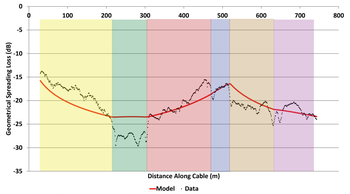

Power spectrum for one trace of the DAS cable for the 45 kN shear shaker.

## 7. Directional Sensitivity to the 45 kN Shaker

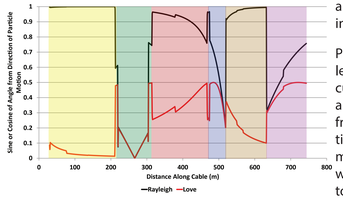
The below plots show highlighted segments of the DAS mapped cable along with highlighted segments of the 1/R geometrical spreading loss plot and fiber orientation effect plot for one 45 kN shear shaker test.



Map of study area with each section of cable highlighted a different color, corresponding to the colors on the graphs.




Plot of geometrical spreading loss. The red curve is modeled and the black dots are data. The geometical spreading loss was calculated from the total energy in the waveform. There is both directivity of the cable and directivity of the source to consider when analyzing these results.




Plot showing expected sensitivity along the cable length to Love and Rayleigh waves. The plot was calculated by computing the difference between the angle of the cable and the direction of particle motion from the 45 kN shaker. The cable will be most sensitive to Rayleigh waves when parallel to particle motion and it will be most sensitive to Love waves when 45 degrees from particle motion. Spikes are due to small, offset segments of cable in the corners.

## 8. Conclusions

- The DAS system is most effective if the fiber-optic cable is oriented in the direction of maximum strain, as the cable is most affected by axial strain.
- Utilizing different sections of the cable layout will allow for analysis of different types of waves as well as analysis of anisotropy in the study area.
- The DAS system is sensitive to a wide range of source strengths and frequencies.
- The fiber-optic cable using DAS is sensitive to strain. When making comparisons with other types of sensors (accelerometers, seismometers, etc.), adjustments with the data need to be made.

## 9. Acknowledgements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## 10. References


1. Parker, T., S. Shatalin, and M. Farhadiroushan (2014), Distributed Acoustic Sensing - a new tool for seismic applications, First Break, February 2014, 61—69.
2. Silixa, Ltd., intelligent Distributed Acoustic Sensor, 2011. <www.silixa.com/technology/iDAS> (accessed 16 April 2014).