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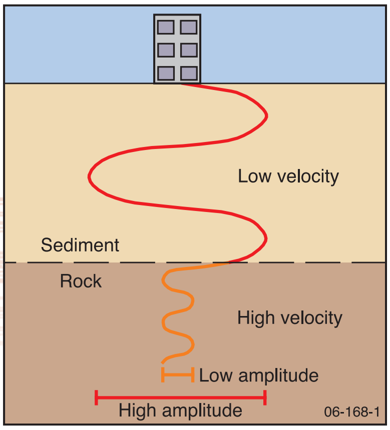
ESTIMATING the influence of *sediments on ground shaking*

Predictive shear-wave velocity models for the Los Angeles Basin show limited relevance to Australian conditions.

Andrew McPherson

Many of Australia's major population centres are built on alluvial plains or coastal margins characterised by significant thicknesses of unconsolidated sediment. Such soils and sediments near the surface can modify ground shaking during earthquakes by reducing the velocity of earthquake waves and increasing their amplitude. This amplification can increase the risk of earthquake damage in Australian cities and other areas underlain by significant quantities of unconsolidated sediment.



▲ **Figure 1.** Sediments near the Earth's surface can amplify earthquake energy waves by reducing their velocity and increasing their amplitude.

Understanding the geophysical behaviour of sediments

Predicting the potential impact of earthquakes on built structures requires an understanding of the behaviour of sediments when they are subjected to ground shaking. One of the best methods is direct measurement of variables such as shear-wave velocity (V_s), a measure of the speed of the large-amplitude waves that damage structures (figure 1). Unfortunately, such data do not exist or are not readily available for much of Australia—so how else can we estimate shear-wave velocity?

A collaborative project to develop models for predicting shear-wave velocity in near-surface sediments using geological data has recently been completed by Geoscience Australia staff in conjunction with colleagues in the United States Geological Survey's (USGS) Earthquake Hazards Team.

A key outcome of the successful development of these models would be better earthquake site response prediction, for input into Australian earthquake hazard and risk models.

The USGS has acquired a number of detailed datasets in the Long Beach area of California (figure 2) as part of a combined groundwater and seismic hazard assessment project in the Los Angeles Basin.

These datasets are unique in that they provide both measured geophysical data (such as V_s) and corresponding geological variables (such as sediment grain size, lithology, age, roundness and sorting). Data from six reference core sites were analysed to develop models for predicting Vs based on geological variables.

The models are intended to be applied in areas where geophysical data are sparse or absent, but where 3D geological data are available (for example, from drilling logs). They thus provide a potential mechanism for predicting shear-wave velocity at Australian sites for which sufficient geological data are available.

▲ **Figure 2.** Long Beach study area, Los Angeles Basin, California. Reference profiles are marked. (Image: D Ponti, USGS).

Developing the predictive model

One of the key variables influencing V_s is sediment grain size, so to enable prediction of V_s from geological data it is necessary to establish a relationship between grain size and lithology. This relationship then permits reclassification of geological data from drilling logs and the application of the predictive model. This is particularly important in the Australian context, because most of our available geological data are only in the form of lithologic information, with little or no grain size information.

Two classification systems were developed to characterise and group grain size data, one with four classes and one with twelve. The four-class system—gravel, sand, silt, clay—provides the strongest relationship between average grain size and lithology.

Multiple regression analyses were run to develop a series of equations for predicting V_s. These models were tested against subsets of the Los Angeles data to determine their applicability, and were found to give a reasonable predictive capability against the original data (figure 3). However, problems remain, particularly with the ability to correctly account for V_s amplitude shifts relating to grain size.

Several variables were expected to be useful in modelling V_s. Depth, grain size and geological age, of which the latter is essentially depth dependent, were found to be the most useful predictors. In contrast, variables such as grain sorting and roundness, which would be expected to be significant due to their influence on the physical structure of sediments, were shown to be very poor predictors using the available data.

Testing against Australian data

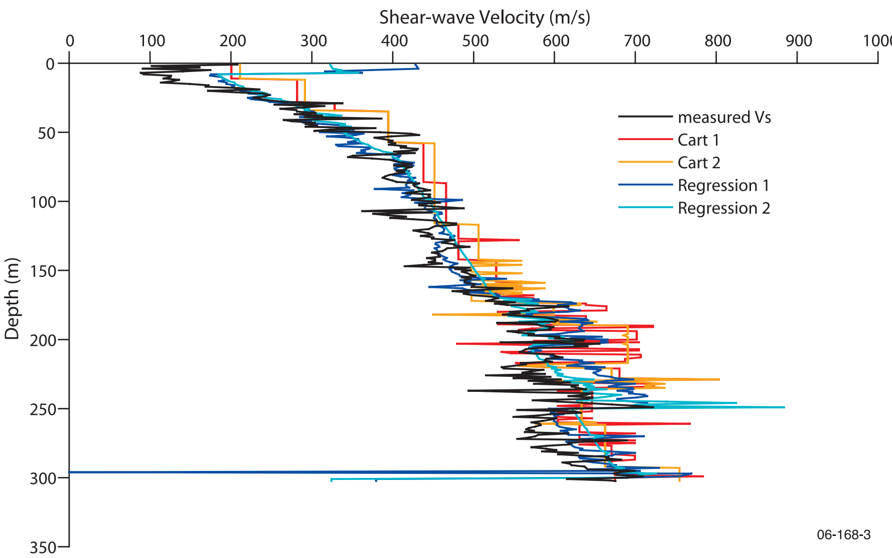
When the developed models were tested against data from sites in Newcastle, Australia, the results were disappointing. In figure 4, the highly linear predicted V_s results demonstrate the significant influence exerted by the depth variable. They also demonstrate the inability of the various models to capture any medium-to-fine scale variation in V_s.

Lessons learned

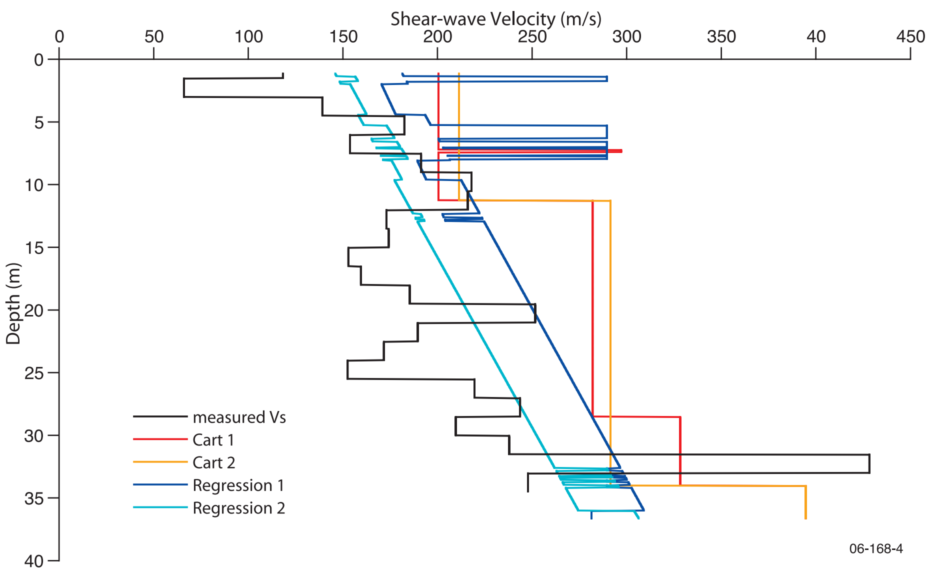
The properties of unconsolidated sediments clearly influence the behaviour of earthquake energy, as represented by measured shear-wave velocity. The predictive models developed for materials in the Los Angeles Basin may be suitable for approximate shear-wave velocity prediction in that region.

Unfortunately, these models appear to be unsuitable for application to sedimentary environments such as those in Newcastle. The variability in observed and predicted shear-wave velocities, and the large discrepancies between them, can potentially be attributed to a number of factors, including:

- **Sampling resolution of the geological data underpinning the lithology classification.** This may be insufficient to accurately differentiate the geological materials. In the case of the Long Beach data, grain size is recorded as a median value for each logged lithological interval, reducing the ability to detect any relationship between small-scale grain-size and V_s variations. This can be significant if you have, for example, a gravel bed within a thick sand sequence.



▲ **Figure 3.** Comparison of predicted shear-wave velocity for various models against measured V_s from a reference site from Long Beach, California.



▲ **Figure 4.** Comparison of predicted shear-wave velocity for various models against measured V_s from a reference site from Newcastle, Australia.

- **Sampling resolution of the geophysical data used to generate the predictive equations.** The V_s data in Newcastle were collected at 0.05 metre intervals. The V_s data in Long Beach were collected at a minimum interval of 0.5 metres, a 10-fold difference in spatial resolution that may have effectively 'smoothed' the LA data compared to that from Newcastle. Resampling of the Newcastle data at a coarser resolution does little to change the result.
- **The analytical techniques applied to the data.** The methods employed in the data analysis assume a linear relationship between the variables. The observed non-linear change in V_s with depth—in association with other geological variables—suggests that non-linear analysis may be necessary.
- **Differences in geological evolution.** The LA Basin is actively subsiding and has several kilometres of essentially unconsolidated sediment, whereas the Newcastle area is characterised by tens of metres of sediment overlying bedrock. The pronounced linear trend in the Long Beach data may suggest a diagenetic trend (explaining the significance of the depth and age variables), while the profile in Newcastle would be too shallow and potentially too young to have developed such features.

Conclusion

To gain a more accurate picture of earthquake site response in any given area it is desirable to measure the geophysical properties of the sediments directly. If this is not practical, the minimum requirement for predictive capability would be the acquisition of detailed geological data calibrated by limited direct geophysical measurements.

Where such detailed calibration of site response models using direct measurement is not feasible, indirect measurement using techniques such as spatial autocorrelation or microtremor methods may need to be considered. The geological environment in which any of these methods is applied also requires careful consideration.

For more information phone Andrew McPherson +61 2 6249 9315 (email andrew.mcpherson@ga.gov.au)