PS Logging in Large Diameter Boreholes

Borehole diameter, at least up to 300mm, is not in itself a limiting factor for extracting high quality shear wave (S) and compressional wave (P) data from the PS Logger®. This conclusion was reached by collating numerous data examples, where borehole diameter was explicitly known, and reviewing the science behind the PS Logger®. "Textbook" quality waveforms, and hence highly accurate shear wave velocities, were in evidence for diameters from 76mm to 300mm and can be fully supported by established PS Logger® theory.

Background

The initial application for the PS Logger® was to provide compression (P) and shear (S) wave velocities for earthquake susceptibility. With the widespread adoption for geotechnical investigations borehole diameters between 75mm and 150mm became common, well within the "normal" range for the PS Logger®. It was only when the PS Logger® was increasingly deployed for geotechnical investigations on offshore wind farms (OWF) that significantly larger borehole diameters were routinely encountered. The reason was not necessarily that larger diameters (over 200mm) were being drilled but rather was from "washout" of loose granular sediments especially nearer to the mud line. Despite the widespread use of drilling muds, the complex drilling environment used on heave compensated drill ships means some washout will usually be present by the time the PS Logger® is run, as this is invariably the final test before the borehole is completed.

Real World Data

The increasing use of the 3-Arm Caliper probe on OWFs to provide QC information to assess the confidence in the PS Logger® results also provided the opportunity to determine the effect of borehole diameter, amongst other factors, on the final data quality.

For the PS Logger®, when considering the ray paths of interest, the effective vertical distance of travel for the waves is 3.125m (when using the 1m filter tube), the distance from the source to the far receiver. If the borehole is washed out reasonably consistently and smoothly over this extent this effectively presents the PS Logger® with a large diameter borehole. Sections of boreholes with consistently large diameters, up to 300mm, were seen to still be able to produce top quality shear waveforms *as shown in Figure 1*.

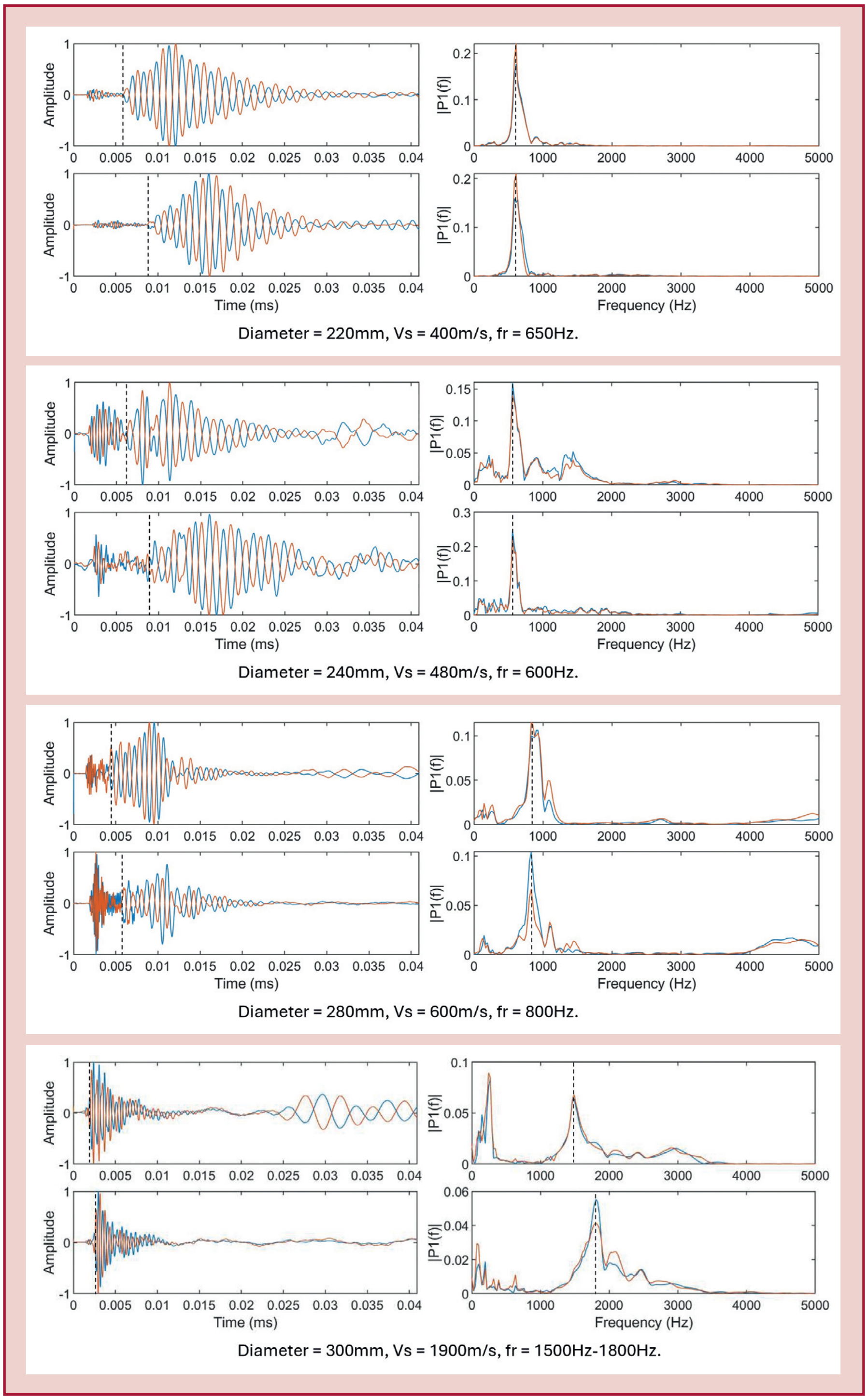


Figure 1: Shear Waveforms in Large Diameter Boreholes.

There are many other factors that affect the transmission of shear wave energy from the seismic source along the borehole wall including, rugosity, cavitation, compaction, fractures and the presence of noise from the drilling platform. Like many geophysical probes the theory of operation for the PS Logger® is predicated on the borehole presenting as a smooth cylinder. To record its waveforms, all energy from the PS Logger® "suspension" method is transmitted to the borehole fluid first. The pressure waves in the fluid then transmit energy into the borehole wall, some of which travels up the borehole toward the receivers where the energy is re-transmitted back into the borehole fluid to the receivers. As rugosity or roughness of the borehole wall increases the irregularity can cause the waveforms to become less coherent. Cavities in the borehole also adversely affect the coherence of the recorded shear waves especially if the source or receiver is adjacent to the cavity. Fractures, especially open fractures, at or near the borehole wall can introduce multiples or reduce the energy in the desired waveforms. For unconsolidated formations, the level of compaction is also significant with highly compacted sediments able to produce high quality waveforms. Data quality also tends to improve with depth as non-source generated noise from the drilling platform decreases.

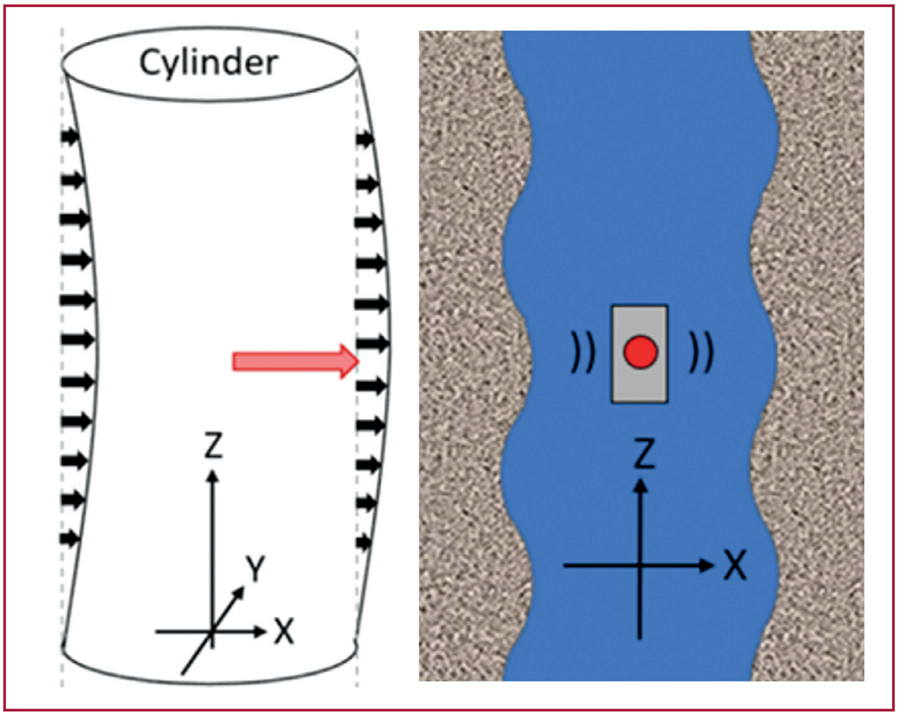


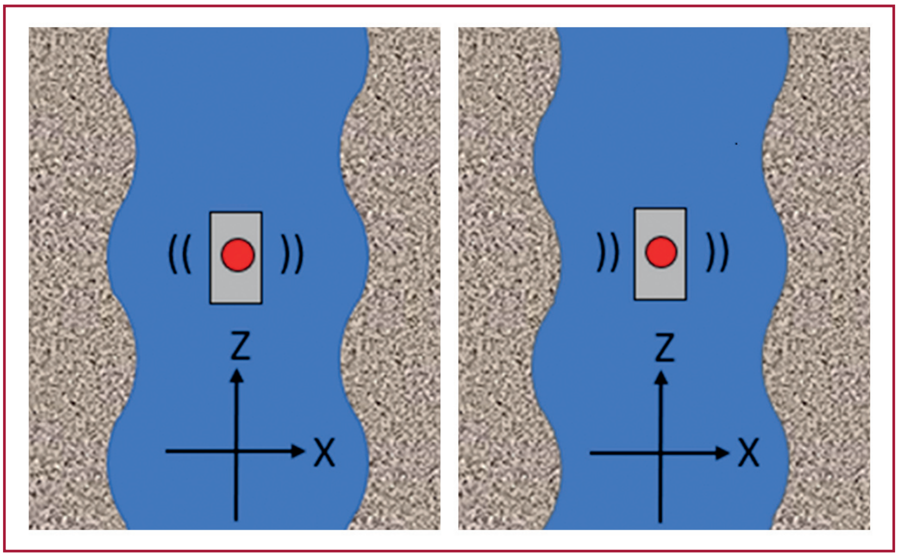
Figure 2: Fundamental Flexural Mode (reverses between shots).

Theory

The PS Logger® is a dipole tool which excites a flexural or bending mode in the borehole wall, using a solenoid operated shuttle striking the inside of a steel cylinder alternately in opposite directions, *as shown in Figure 2*. The flexural wave at the borehole wall travels to the receivers at the formation shear wave velocity if the source frequency is sufficiently low. Monopole tools, such as conventional sonic probes, are limited as they excite only the Stoneley mode which relies on refraction of shear waves along the borehole wall, which is not possible in slow formations where the shear velocity of the formation is less than the fluid velocity. *Figure 3* shows a comparison between the particle motions at the borehole wall for Stoneley and flexural modes.

The PS Logger® was initially developed for use in boreholes up to 150mm diameter where the affect of the borehole diameter itself caused minimal disruption to the signal. The underlying assumptions however can be seen to be still valid if the frequencies involved are low enough, with the PS Logger® source centre frequency of around 1.5kHz or less being considered low enough not to introduce borehole effects in even large diameter boreholes.

Figure 3: Stoneley Mode versus Flexural Mode.



The data examples across a range of borehole diameters *as shown in Figure 1*. clearly show the presence of the flexural mode, characterised by the 180° reversal of the signals between left and right shots. Frequency analysis of the signals also confirms that the frequency of the flexural mode waves is sufficiently low as to be largely unaffected by increasing diameter.

Conclusion

The ability of the PS Logger® to extract accurate shear wave velocities (Vs) is determined not by the borehole diameter but by a range of other factors as discussed above. In boreholes with relatively smooth consistent borehole walls, with minimal interference from external noise, the PS Logger® has been shown to produce consistent results regardless of borehole diameter.

A paper entitled "Validation of the applicability of the PS logger borehole probe for diverse geotechnical scenarios" has recently been submitted by Robertson Geo to the XVIII ECSMGE 2024 conference, in which borehole diameter considerations are discussed in more detail.