THE EVALUATION OF A POSSIBLE SOURCE OF BOTH P AND S WAVE ENERGY : PRELIMINARY REPORT.

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1. Introduction. The study of shear wave propagation in crystalline rock bodies that are being tested as possible nuclear waste disposal sites may provide valuable supplementary information to P wave data for the study of the distribution of cracks, fractures, faults and pore fluids (Wright and Langley, 1980). A limited quantity of useful shear wave data was obtained at Chalk River, Ontario, in October 1977, using a shear wave gun designed by R. Turpening (Lam and Wright, 1980). However, the high cost of operating the gun precluded further testing, so that a cheaper source of S wave energy had to be found. Consequently, at the end of October, 1979, an experiment was undertaken at Chalk River to test a shear wave hammer, designed and built by Mr. Earl Fulkerson of Canton, Michigan. The objectives were threefold: (i) to determine if it was possible to generate horizontally polarised shear waves at various locations on the Chalk River site, (ii) to find the distance range over which the source gives useful P and S wave energy, and (iii) to compare the seismograms produced when the source was operated over different thicknesses of overburden. The purpose of this preliminary report is to give a short summary of the results of this experiment, and to justify the use of the source in future, more detailed experiments.

2. Experimental Procedure. The rock body itself consists mainly of a monzonitic orthogneiss and a more mafic paragneiss covered with a thin veneer of glacial sediments. Surface outcrops occur in parts of the locality tested, and thin sheets of gabbro are known to exist in some regions of the rock body. The source consists of a weight of 1500 kg that can be dropped vertically from a height of over 2m on to a steel base plate firmly

embedded in the glacial overburden above the rock body. To produce horizontally polarised shear waves the weight can also be made to slide down a steel ramp inclined at 45° to the vertical from a maximum height of 0.93m. The source was operated in these three different modes at each location.

The surface recorders consisted of twelve alternate arrays of vertical and horizontal component geophones, each placed 15m apart; they were deployed in three different locations. The source was operated at distances between 30m and 600m from the geophones over glacial overburden ranging in thickness from less than a metre to several tens of metres. Each 'shot' was produced six times, occasionally ten times, and the seismograms were stacked as they were recorded. Seismic energy was also recorded by a string of hydrophones placed in a borehole, but only P wave arrivals could be identified.

3. Results. The source generated more elastic wave energy when the overburden thicknesses were at least several metres. The signals identified visually as S are usually true S, though some may be the converted wave (P)S* , particularly when the overburden thickness below the source was less than several metres. The SV amplitudes are on average 1.8 times those of P, regardless of the type of shot, while the signal frequencies of P and S are typically 90 and 60 Hz respectively. The horizontal-component seismograms for the inclined shots showed no evidence of SH polarisation, and, moreover, the SH amplitudes were only rarely enhanced relative to the P and SV amplitudes on changing from vertical to inclined shots. These unexpected results are attributed largely to the combined effect of the high velocity

and density contrasts and the irregularity of the boundary between the glacial overburden and the rock body.

For two of the three profiles studied, the SV amplitudes decay more rapidly as a function of distance than SH, which usually decays more rapidly than P. The amplitude-distance (A-Δ) curves are best described by a power law of the form $A = C\Delta^{-n}$, with the exponent n lying between 0.4 and 2.1. These comparatively slow decreases in amplitude occur where the sediments are thinnest, and suggest extensive scattering and P to S conversions along the transmission paths. For the third profile, recorded over the greatest thickness of overburden, the P amplitudes also diminish a little more slowly as a function of distance ($n \sim 1.7$) than SH or SV amplitudes, both of which decay inversely as the square of the distance. There is therefore qualitative evidence that anelastic attenuation is slightly greater for S than for P along the third profile, where scattering effects are minimal. The effective distance range over which the inclined source can be used is at least 600 m. From the earlier work of Lam and Wright (1980), this range can be increased to about 1.3 km for the vertical shots when the maximum height is used.

In spite of the absence of SH polarisation, S wave velocities of 2.90 ± 0.05 km/s and 3.73 ± 0.10 km/s with matching P velocities of 5.26 ± 0.12 km/s and 6.35 ± 0.17 km/s were obtained for two segments of the first profile. For the second profile, the S wave velocity was 3.66 ± 0.11 km/s in the region adjacent to the higher velocity portion of profile 1; the corresponding P wave data were of insufficiently high quality to enable a reliable velocity to be derived. The best data were obtained for profile 3, recorded over gabbro, which yielded S and P velocities of 3.92 ± 0.06 km/s and 6.56 ± 0.17 km/s respectively. The errors in all of these velocities and the velocities themselves have been calculated by averaging the reciprocal slopes of several time-distance curves. The individual apparent velocities and their formal standard errors were estimated by the maximum likelihood method of Bartlett (1949).

The comparatively large formal errors on the P wave velocities are due to real deviations from linearity in the time-distance data, and are not due to uncertainties in picking the first breaks. The lower errors for the S wave data are partly due to the use of both SV and SH data, thus giving approximately twice as many observations of S as P. However, the travel time-distance data for S also show less scatter about the maximum likelihood lines than the P data. This effect may be an artifact introduced by the observer in the subjective process of picking the S arrival times; alternatively, it may be a real phenomenon caused by varying saturation conditions in the glacial overburden, which will cause subtle variations in P travel times but no corresponding variations in S travel times. No systematic differences between SH and SV travel times were detected.

Discussion and Conclusions. The weight drop source yielded useful S wave data, irrespective of whether it was used in the vertical or slanted positions. The absence of SH polarisation on the horizontal-component instruments is not the result of a technical deficiency in the source, but is most probably due to the complexity of the boundary and the large changes of elastic parameters between the overburden and the rock body. A similar absence of S wave polarisation was reported for a shear wave gun operated in the same area (Lam and Wright, 1980). The same weight drop source has recently been compared with more expensive, commercially available, shear sources in an area of sedimentary rocks with less extreme velocity and density contrasts, and generally yields superior results (R. Stewart, personal communication). Some excellent examples of SH polarisation from this slanted weight drop source were obtained in the Michigan Basin, using a three-component lock-in geophone placed in a borehole; the experiment has been described briefly by Stewart, Toksöz and Turpening (1980).

Plans for future experiments involve recording in a borehole with a three-component lock-in type of transducer. SH polarisation should be more readily observable under these conditions because the seismic energy has to traverse the irregular sediment-rock body interface only once.

The results of the tests at Chalk River show that useful S wave velocities and amplitudes can be obtained, even in exceptionally inhomogeneous environments. I therefore conclude that the inclined weight drop device is a useful source of both P and S waves at distances up to at least 600 m, and should be adopted as the seismic source for future borehole experiments.

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* The notation (P)S denotes a signal that has travelled from the source through the overburden as a P wave, and is converted to S at the boundary between the overburden and the rock body. The signal then continues as a shear wave through the rock body and up through the sediments to the receiver.

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