Regression function of a sedimentary depth versus a Ts-Tp travel time based on VSP

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Overviewing conventional methods of investigation for underground velocity-structures, vertical seismic profile (VSP) method can directly give a high-resolution seismic image of the immediate vicinity of the borehole in both of P and S wave information. Therefore, the VSP result always functions as a calibration standard for other geophysical prospect methods. However, VSP is only limited to a few areas since it is too costly to be widely used. A dozen of deep-wells with VSP down to 2000 meters in the Kanto area have been drilled over past 15 years by NIED. In order to extend the high-quality VSP results to widely areas, we try to use these VSP data to obtain regression functions for sedimentary depth versus Ts-Tp travel times.

The VSP method can record both the down-going and the upgoing waves passing by the borehole receivers, initiated from a surface seismic source. The ability to record the downgowing wavefield at each receiver location in the borehole is a critical advantage over conventional surface seismic recording methods. Not only P waves, but also S waves can be recorded clearly by the specially designed vibrators. From the VSP data, we extracted the travel times of P wave asTp, and S wave as Ts. Then, we made regression functions of a sedimentary depth D versus a Ts-Tp travel time at NRT, CHB, YRO, EDS and FUT in the Chiba area, Japan.

YRO : D(kilometer) = $1.012(Ts\text{-}Tp)^2 + 0.6051(Ts\text{-}Tp)$; (1)
FUT : D(kilometer) = $0.8739(Ts\text{-}Tp)^2 + 0.2298(Ts\text{-}Tp)$; (2)
CHB : D(kilometer) = $0.562(Ts\text{-}Tp)^2 + 0.2564(Ts\text{-}Tp)$; (3)
NRT : D(kilometer) = $0.4091(Ts\text{-}Tp)^2 + 0.3092(Ts\text{-}Tp)$; (4)
EDS : D(kilometer) = $0.5276(Ts\text{-}Tp)^2 + 0.0662(Ts\text{-}Tp)$; (5)

The gradients in the regression functions become gradually smaller from middle Chiba toward north Chiba. The velocities in general at YRO and FUT in middle Chiba are great than that in north Chiba. The similar regression functions at both NRT and CHB can be reasonably attributable to the near distance and the similarity in geological sedimentary environments.

The NRT well with 1300 meters in depth went down through Shimousa, Kazusa groups in Quaternary sedimentary and penetrated Pre-Neogene bedrock at 850 meter. The VSP Ts-Tp travel time at NRT is 1.1 seconds at the 850 meter of bedrock level. On the other hand, incident seismic P-wave at the bedrock converted to S-wave and appeared as PS-phase at surface. The travel time between PS and P, which is equivalent of the VSP Ts-Tp travel time, is 1.13 seconds by the Receiver Function method. Bedrock depth is 870 meters by the regression function (4), which is very much coincident with the true depth.

The advantages of using the regression functions are, 1) the deeper structures even if without data can be extrapolated by the regression functions; and 2) the sedimentary depth can be predicted if there is a similar geological sedimentary environment. For instance, both CHB and FUT wells, which were untouched the bedrock, even if with 2000-meters in depth, we can predict the bedrock depth by combination of the result of receiver function Ts-Tp and the regression functions.

There are dense strong-motion networks nearby the costly VSP wells in Kanto area, Japan. The equivalent Ts-Tp travel-times can be obtained by the receiver functions from the accumulated records nearby. Combined with the regression functions, sedimentary depth down to the Pre-Neogene bedrock can be estimated precisely.