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Soil Amplification in Great Hanshin Earthquake

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During this earthquake, strong acceleration records were obtained in free fields in many sites in and around the Kobe city. Some of the recording sites consist of multi-level vertical arrays, which demonstrated very peculiar features of seismic amplification in reclaimed lands and Holocene and Pleistocene soil layers. Particularly it has been found that, when the max acceleration at the depth of 80-100m exceeds 200-300 cm/s^2, the upper layer will not amplify the acceleration anymore except for the shallowest layer in most case.

Among the soil amplifications under strong seismic motions, the most interesting was those recorded by the Kobe Municipal Office in the man-made Port Island. In this site fill layer consisting of coarse gravelly sand (decomposed granite) of 17.5m thick liquefied, causing obvious decrease of horizontal seismic response in the fill layer. Due to the liquefaction, horizontal accelerations at the ground surface were very much damped, in a good contrast to the vertical acceleration which was rather amplified in the liquefied sand layer, resulting in an extraordinarily large acceleration ratio (more than one) between vertical and horizontal surface accelerations. Similar trend was also found in the acceleration records in the neighboring Rokkou Island where liquefaction seemed to occur in sand fill layer.

However in deeper Pleistocene layers in the Port Island, the acceleration ratio between vertical and horizontal tends to decrease to a normal value near one half, which is also coincidental with those measured at ground surface in inland sites of Kobe city where Pleistocene soils are at the súrface level or in a shallow part.

The down-hole acceleration records in the Port Island have been analyzed with the inversion technique to estimate S-wave velocity and damping corresponding to the main shock as well as an small aftershock (max horizontal surface acc ≒ 10cm/s^2) which occurred about two minutes later to find the following major facts.

1. The equivalent S-wave velocity for the main shock is 20 to 40% lower than initial small strain value even for Pleistocene soil down to 80m deep. For the liquefied shallow sand fill layer, S-wave velocity decreases down to 20% of the initial value as an average for the total seismic duration of the main shock (See Fig.1).
2. In the small aftershock, tne S-wave velocity in deeper ground including the soft Holocene clay is recovered to initial values, while the liquefied sand retains the same low velocity presumably due to sustained liquefaction two minutes after the main shock (See Fig.1).
3. According to the inversion analysis of vertical acceleration records based on the vertical multi-reflection theory of P-wave, the estimated P-wave velocity for the main shock (analyses for the earlier part of the record) is almost equivalent to or a little smaller than that for initial small strain value. It is interesting enough, however, to note that for the aftershock the P-wave velocity seems to apparantly decrease dramatically for the layers upper than Holocene soft clay (See Fig.2).

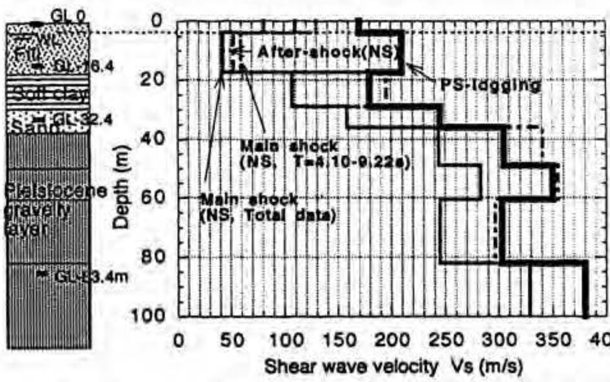

Fig.1 Results of Inversion for S-wave velocity

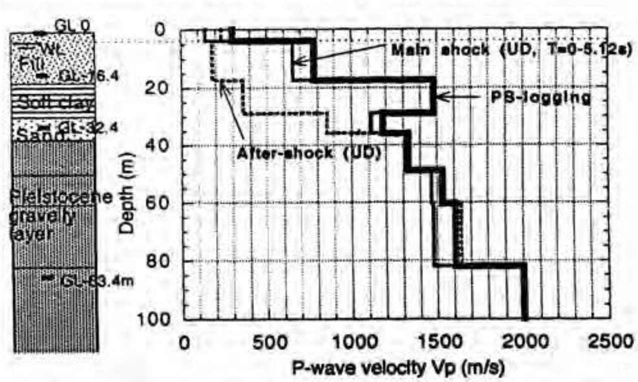

Fig.2 Results of Inversion for P-wave velocity