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Non-linearity is not only softening: examples from L'Aquila (2009) and Christchurch (2011) earthquakes

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The widely used 1-d modelling of soil behaviour used in common engineering practice is based on the assumption of largely homogeneous strata with softening constitutive behaviour and do not take into account the role of fluids. In real soils, however, the presence of alternating strata with velocity inversions and the role of fluid pressure in non-cohesive materials provide different observational results.
After L'Aquila (2009) and Christchurch (2011) earthquakes it was possible to compare soil behaviour in purely elastic domain (using noise measurements) with strong motion recordings using a newly developed technique based on S-transform.
The main result for l'Aquila is that some stations show a time-varying behavior, while others did not change their frequency with respect to the one evaluated from noise measurements. Even when a time-varying fundamental frequency was observed, it was difficult to attribute it to a classical, softening non-linear behaviour. Even for the strongest recorded shocks, with peak ground acceleration reaching 0.7 g, variations in frequency and amplitude seems not relevant from building design standpoint.
For Christchurch, in the coda of several accelerograms there are clear signs of energy at frequency lower than the fundamental one in the elastic domain (softening non-linearity), but at the same time it is possible to recognize hints of hardening non linearity due to hysteretic dilatant behaviour of soils. From engineering design point of view, the maxima of integral ground motion correlated with damage are reached well in advance of the onset of the softening non-linearity.