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Shallow subsurface control on earthquake damage patterns: first results from a 3D geological voxel model study (Tokyo Lowland, Japan)

Jan Stafleu (1), Freek Busschers (1), and Susumu Tanabe (2)

(1) TNO - Geological Survey of the Netherlands, Geomodelling, Utrecht, Netherlands (jan.stafleu@tno.nl), (2) Geological Survey of Japan, AIST, Central 7, Higashi 1-1-1, Tsukuba 305-8567, Japan (s.tanabe@aist.go.jp)

The Tokyo Lowland is situated in a Neogene sedimentary basin near the triple junction of the North American, Pacific, and Philippine tectonic plates. The basin is filled with Neogene and Quaternary sediments up to a thickness of 3 km. In the upper 70 m of the basin, thick sequences of soft Holocene sediments occur which are assumed to have played a key role in the spatial variation of damage intensity during the 1923 Kanto earthquake (Magnitude 7.9 to 8.3). Historical records show this earthquake destroyed large parts of the Tokyo urban area which in that time was largely made up by wooden houses. Although the epicentre was 70 km to the southwest of Tokyo, severe damage occurred north of the city centre, presumably due to ground motion amplification in the soft Holocene sediments in the shallow subsurface.

In order to assess the presumed relation between the damage pattern of the 1923 earthquake and the occurrence of soft Holocene sediments in the shallow subsurface, we constructed a 3D geological voxel model of the central part of the Tokyo Lowland. The model was constructed using a methodology originally developed for the lowlands of the Netherlands.

The modelling workflow basically consists of three steps. First, some 10,000 borehole descriptions (gathered for geomechanical purposes), were subdivided into geological units that have uniform sediment characteristics, using both lithological and geomechanical (N-value) criteria. Second, 2D bounding surfaces were constructed, representing tops and bases of the geological units. These surfaces were used to place each voxel (100 by 100 by 1 m) within the correct geological unit. The N-values and lithological units in the borehole descriptions were subsequently used to perform a 3D stochastic interpolation of N-value and lithological class within each geological unit.

Using a vertical voxel stack analysis, we were able to create a map showing the accumulated thickness of soft muds in the Holocene succession. A comparison of this map with a published map of the damage-ratio of wooden houses that were destroyed during the Kanto earthquake in 1923, shows a remarkable relation between zones of maximum destruction and the occurrence of the so-called ‘zero’ muds, the latter representing the sediments most sensitive for ground motion amplification.

Our results show that the 3D geological voxel modelling approach presented here is able to make a spatial analysis of earth quake damage sensitivity in the Tokyo Lowland. This makes our workflow also is a promising tool for seismic hazard assessments in other areas in Japan were detailed insights in earth quake damage from historical records are absent.