Study of soil effects from March 11 Japan earthquake could improve building design

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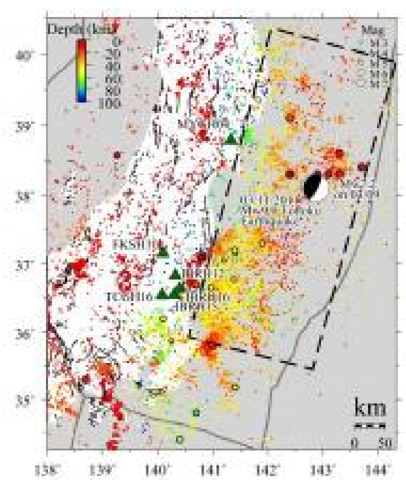

This map shows the region in which the soils study took place following the March 11 earthquake. The epicenter is indicated by the large black and white circle, while the six measuring stations that provided data are represented with the green triangles. Epicenters of the other events analyzed by the study are shown in large circles. Credit: (Courtesy of Chunquan Wu)

Japan's March 11 Tohoku Earthquake is among the strongest ever recorded, and because it struck one of the world's most heavily instrumented seismic zones, this natural disaster is providing scientists with a treasure trove of data on rare magnitude 9 earthquakes. Among the new information is what is believed to be the first study of how a shock this powerful affects the rock and soil beneath the surface.

Analyzing data from multiple measurement stations, scientists at the Georgia Institute of Technology found that the quake weakened subsurface materials by as much as 70 percent. That nonlinear response from the top layer of the Earth's crust affected how the movement of faults deep beneath the surface was delivered to buildings, bridges and other structures.

Understanding how the soil responds to powerful earthquakes could be important to engineers and architects designing future buildings to withstand the level of acceleration measured in this quake. The information will also help seismologists develop new models to predict the effects of these rare and extremely powerful events.

"The degree of nonlinearity in the soil strength was among the largest ever observed," said Zhigang Peng, an associate professor in Georgia Tech's School of Earth and Atmospheric Sciences. "This is perhaps not too surprising because the ground shaking generated by this earthquake – acceleration as much as three times the Earth's gravity – is also among the highest ever observed."

The findings were reported in a special issue of the journal *Earth, Planets and Space* (EPS). The research was sponsored the National Science Foundation (NSF) and by the Southern California Earthquake Center (SCEC).

Peng and graduate student Chunquan Wu were among the first scientists to examine data recorded by the high-quality seismometers that are part of the Japanese Strong Motion Network KIK-Net. The stations have accelerometers both on the surface and in boreholes located on bedrock far beneath it. The researchers chose to study data from six stations that have strong velocity contrasts between the surface soil layers and the underlying bedrock.

"In this study, we were trying to understand the relationship between soil nonlinearity and peak ground acceleration (PGA), which is a measure the ground shaking," said Wu. "We want to understand what parameters control this kind of response."

By comparing data on the acceleration of motion from sensors on the bedrock to comparable information from surface sensors, they were able to study how the properties of the soil changed in response to the shaking. The researchers computed the spectral ratios of each pair of station measurements, and then used the ratios to track the temporal changes in the soil response at various sites at different levels of peak ground acceleration.

"The shear modulus of the soil was reduced as much as 70 percent during the strongest shaking," Wu explained. "Typically, near the surface you have soil and several layers of sedimentary rock. Below that, you have bedrock, which is much harder than the surface material. When seismic waves propagate, the top layers of soil can amplify them."

Nonlinear response from soils is not unusual, though it varies depending on their composition. Similar but smaller effects have been seen in other earthquake-prone areas such as California and Turkey, Wu said. The shallow layers of the Earth's upper crust can be complex, composed of varying types of soil, clay particles, gravel and larger rock layered in sediments.

Because the March 11 quake lasted an unusually long time and generated a wide range of ground motions of greatly varying strengths, it provided an unprecedented data set to scientists interested in studying nonlinear soil behavior.

Beyond the immediate effect of the strongest shock, the researchers were interested in how the soils recover their strength after the shaking stops. That recovery time can vary from fractions of a second to several years, Wu said.

"It is still not clear whether there could be longer recovery times at certain sites," Wu noted. "This is a function of soil type and other factors."

If the soils are very porous, water can lengthen the recovery. "For porous media, the ground shaking could cause water to go into the pores, which will also reduce the shear modulus of the soil. If water is involved, the recovery time will be much longer."

Soil response to aftershocks, which ranged up to magnitude 7.9 after the main Tohoku earthquake, was also studied.

Information developed by the Georgia Tech researchers will be provided to seismologists developing new hazard models of very powerful earthquakes. Knowing how soils respond to strong shaking is also important to predicting how motion deep within the Earth will be translated to structures built on the surface.

"Understanding how soil loses and regains its strength during and after large earthquakes is crucial for better understanding and predicting strong ground motions," Peng noted. "This, in turn, would help earthquake engineers to improve the design of buildings and foundations, and could ultimately help to protect people in future earthquakes."

Provided by Georgia Institute of Technology

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