Constraints on Long-Term Seismic Hazard From Vulnerable Stalagmites

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Earthquakes hit urban centers in Europe infrequently, but occasionally with disastrous effects. This raises the important issue for society, how to react to the natural hazard: potential damages are huge, and infrastructure costs for addressing these hazards are huge as well. Obtaining an unbiased view of seismic hazard (and risk) is very important therefore.

In principle, the best way to test Probabilistic Seismic Hazard Assessments (PSHA) is to compare with observations that are entirely independent of the procedure used to produce the PSHA models. Arguably, the most valuable information in this context should be information on long-term hazard, namely maximum intensities (or magnitudes) occurring over time intervals that are at least as long as a seismic cycle. Such information would be very valuable, even if it concerned only a single site.

Long-term information can in principle be gained from intact stalagmites in natural caves. These have survived all earthquakes that have occurred, over thousands of years - depending on the age of the stalagmite. Their "survival" requires that the horizontal ground acceleration (HGA) has never exceeded a certain critical value within that period.

We are focusing here on a case study in the Little Carpathians in Slovakia. A specially shaped (candle stick style: high, slim and more or less cylindrical form), intact and vulnerable, 4 m high stalagmite (IVSTM) in Plavecká priepast cave has been examined in 2013 and 2014. This IVSTM is suitable for estimating the upper limit for HGA generated by pre-historic earthquake.

We determined by in-situ, non-destructive measurements the natural frequency and the harmonic oscillations of IVSTM, and in geo-mechanical laboratory the material properties (the density, the Young's modulus and the tensile failure stress) of broken speleothem specimens have been measured. Based on the laboratory measurements and a simple mechanical model, the theoretical natural frequency (f_0), the harmonic oscillations (f_1, f_2) and the HGA values resulting in failure (a_g) have been calculated for IVSTM. The critical HGA level determined by this technique can be caused even by a low or moderate size earthquake.

The age and the growth rate of one column in the Plavecka priepast cave was determined by taking core samples from two different heights.

The interpretation of IVSTM from Plavecká priepast cave gives critical HGA values for different times in the past, therefore curves of critical HGA backward into the past have been constructed, for the surface and for the cave.

This technique can yield important new constraints on seismic hazard, as geological structures close to Plavecká priepast cave did not generate strong paleoearthquakes in the last few thousand years, which would have produced HGA larger than the upper acceleration threshold that we determine from the IVSTM. Therefore we compared the effect of the Carnuntum event (350 AD), the Markgrafneusiedler event (2500 BP) and the Jókő (Dobra Voda) earthquake (10.01.1906) and the PGA value determined by PSHA calculation (SHARE Map) to the upper limit of the horizontal ground motion calculated from the IVSTM.