Estimation of an upper limit on prehistoric peak ground acceleration using the parameters of intact stalagmites and the mechanical properties of broken stalagmites in Domica cave, Slovakia

European Geosciences Union General Assembly
08-12 April 2013, Vienna, Austria
Session TS8.2, area Blue Posters, B202

K. GRIBOVSZKI (1), **K. KOVÁCS** (1), **P. MÓNUS** (1), **CHUAN-CHOU SHEN** (2), **Á. TÖRÖK** (3), **L. BRIMICH** (4), **P. VARGA** (1), **A. NOVÁK** (1), **S. KELE** (5)

(1) Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Science, Hungarian Academy of Sciences, kgribovs@ggki.hu (2) Department of Geosciences, National Taiwan University (3) Engineering Geology Division, Department of Construction Materials and Engineering Geology, Budapest University of Technology and Economics (4) Geophysical Institute, Slovak Academy of Sciences (5) Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Science, Hungarian Academy of Sciences

ABSTRACT: The examination of special shaped, vulnerable, intact stalagmites (STM) in Domica cave (southeastern Slovakia) is the continuation of our previous examination of STMs in Baradla cave (northeastern Hungary). The aim of our investigation is to estimate the upper limit for horizontal peak ground acceleration generated by paleoearthquake.

There are many vulnerable, special shaped (high, slim, H/D > 20) and more or less cylindriform STMs in Domica cave. The most vulnerable of STMs is 5m high and the diameter, at the profile of cylinder at different heights, is 5 or less than 5cm. This STM(5m) is situated in *Ördög-lik* (*Čertova diera*) Hall of Domica cave.

The method of our investigation is the same as before: the density, the Young's modulus and the tensile failure stress of broken STM samples have been measured in mechanical laboratory, whereas the natural frequency of intact STMs was determined by in situ observation. The value of horizontal ground acceleration resulting in failure and the theoretical natural frequency of STM were assessed by theoretical calculations.

The age of the samples taken from a STM(2,26m) standing in Domica cave have been determined by Multi Collector – Inductively Coupled Plasma Mass Spectrometry analysis (MC-ICPMS). Our measurements show, that STM(2,26m) is still growing and the oldest and bottommost part of it is not older than 116kyears. The age of the oldest part of STM(2,26m) is nearly the same as 5.1m high STM(5.1m) situated in *Olimposz* Hall of Baradla cave (130k years).

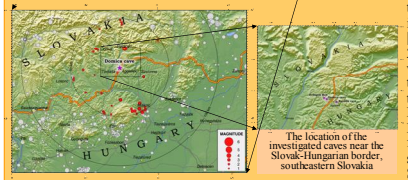
The a_g value (upper limit for horizontal peak ground acceleration needs to break STM(5m) in *Ördög-lik* Hall) coming from theoretical calculation is almost the same (≈ 0.059g) as it is in case of STM(5.1m) in *Olimposz* Hall (≈ 0.055g) . On the grounds of our measurements and theoretical calculations, we can state that the geological structures close to Baradla and Domica caves did not excite such paleoearthquakes in the last (2-5) thousand years, which would have produced a horizontal ground acceleration larger than 0.061g. (About 2-5kyears ago the STM(5m) could be 4,9m high by the results of age determination. 4,9m high STM(5m) could have broken by the effect of 0.061g horizontal ground acceleration as we assume its movement as a rigid body.) This value can arise even in case of moderate size earthquakes. The natural frequency of STM(5m) --situated in *Ördög-lik* Hall-- is low, about 1 Hz, since this low value is in the frequency range of nearby earthquakes, therefore resonance effect can occur. Because of the resonance the horizontal ground acceleration resulting in failure can be even smaller than our determined 0.059g value.

ACKNOWLEDGEMENT The in-situ measuremets in caves was supported by bilateral project between the Hungarian and Slovak Academy of Sciences, 2011-12. The authors wish to thank Zoltán Jerg for providing professional expert caver guide in *Ördög-lik* Hall of Domica Cave, and we also thank the help of Lajos Gaál and Igor Balciar (Slovak Caves Administration, Liptószentmiklós) for enabling us the accomplishment of the in-situ part of this research in Domica cave. "This study was supported by the TAMOP-4.2.2.C–11/1/KONV-2012-0015 (Earth-system) project sponsored by the EU and European Social Foundation."

1. SEISMICITY IN HUNGARY

The seismic activity inside the Pannonian basin can be considered moderate compared to the peripheral areas. Construction of a reliable seismotectonic model for the territory proved to be a challenging task, due to the diffuse distribution of epicentres. The earthquake activity and present day deformation is mainly driven by the counter-clockwise rotation and northward movement of the Adriatic microplate.

2. THE CAVES AND THE MEASURED STALAGMITES



The location of the investigated caves near the Slovak-Hungarian border, southeastern Slovakia

STM(1,8m)

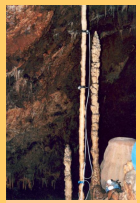
STM(2,26m) in open part for visitors of Domica cave, from which the core-samples was taken for age determination. Behind and over to STM(2,26m) STM(1,8m) can be seen.

STM(1,84m)broken and stuck together

In 2004 we investigated stalagmites (STM) in Baradla cave [Szeidovitz et al. 2008], and in 2010-11 we had the possibility to examine STMs at the Slovak part of Baradla cave, named Domica. We have found and investigated several different slim STMs at the open part for tourist visitors and in *Ördög-lik* Hall (*Čertova diera*) of Domica cave. Almost all of the slim STMs are broken at the open part for visitors of Domica (**Fig.** STM(1,84m) broken), but not in *Ördög-lik* Hall, where **such a suitable** STM(5m) is still standing intact, how suitable **we have never been found before**.

We could find and measure only one intact and slim STM(1,8m) situated at the end of *Szűzfolyosó* (*Panenská chodba*) next to Lake of Domica at the open part for visitors. We recorded the oscillation of this STM(1,8m) and took core-samples for age determination from STM(2,26m), below and next to STM(1,8m).

3. NON-INTRUSIVE IN-SITU EXAMINATIONS OF STALAMITES IN CAVES

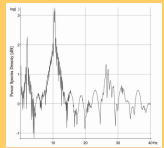


geophones were fastened on the stalagmites

Considering that in situ measurements of these slim and high stalagmites (STM) had to be done non-intrusively, we confined ourselves only to determine the **dimensions** and **natural frequencies** of them. In case of STMs slim enough (Height/Diameter>20) resonance effect can occur [Lacave et al. 2000].

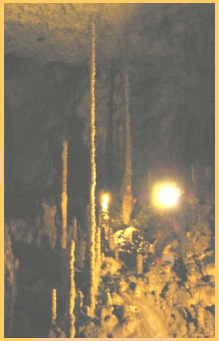
In order to measure the natural frequency, geophones were fastened on the stalagmites, and they were excited by small amplitude forced vibration obtained by a gentle hit. It can be seen on **Table 1**, that all the measured lowest natural frequencies of STMs are below 20Hz, this means that they fall into the frequency range of nearby earthquakes.

If the natural frequency of stalagmite is below 20Hz then **resonance can occur**. Our theoretical calculations (equations by using cantilever beam theory) did not take into consideration the phenomenon of resonance, which means that in reality the STMs would break at a lower value of horizontal acceleration than the computed ones.

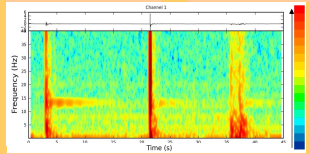


Power Spectral Density of oscillation of STM(5m)

STM(2,39m) irregular shape stalagmite, Domica cave, next to entrance



STM(5m) in Devil's Hall, Domica cave



The oscillation and Power Spectral Density of STM(1,8m) along the recorded signal of the excited stalagmite

NAME	PLACE	HEIGHT (m)	DIAMETER (cm)	H/D	measured f_0 (Hz)	measured f_1 (Hz)	measured f_2 (Hz)
STM(5m)	Ördög-lik Hall, Domica cave	5,00	average: 5 (7-4)	100	2	10,2; 10,6 geophone	26; 27
STM(1,8m)	Domica cave, Szűzfolyosó	1,80	average: 5 (6-4)	36	6-8	12,7; 13,3 geophone	
STM(2,26m)	Domica cave, Szűzfolyosó	2,26	average: 8 (11-4)	28	14,2		
STM(2,39m)	Domica cave, next to entrance	2,39	irregular shape		7,3; 8,1	30,6	

Table 1. Results of non-intrusive in-situ examinations of stalagmites: dimensions and measured natural frequencies

4. MECHANICAL PROPERTIES OF STALAGMITES DETERMINED BY LABORATORY MEASUREMENTS

Mechanical laboratory measurements were performed on several samples originating from STMs, which was found lying broken on the ground in *Ördög-lik* Hall and at the open part for visitors of Domica cave. Tensile failure stress (σ_u) was measured by Brazilian test, while dynamic Young-modulus (E) was determined by using ultrasound velocity propagation values. Our results show, that the σ_u of samples originating from *Ördög-lik* Hall of Domica cave is higher (2,75>> 1,62MPa) than σ_u of samples from *Olimposz* Hall of Baradla cave, however E value is almost the same (23,6≈20,8 GPa)

Brazilian test

	density, ρ [kg/m³]	dynamic Young-modulus, E [GPa]	tensile failure stress, σ_u [MPa]
open part for visitors of Domica cave	2368,1 ± 104,1	23,1±4,4	2,52±0,36
Ördög-lik Hall of Domica cave	2347,6 ±115,8	23,6±4,0	2,75 ±0,56

Table 2. Results of mechanical laboratory measurements, mean values

5. OSCILLATION OF STALAGMITES BY THEORETICAL CALCULATIONS

The natural frequency of a stalagmite

$$f_0 = \frac{1}{\pi}\sqrt{\frac{3ED^2}{16\rho H^4}}$$

The horizontal ground acceleration resulting in failure of a stalagmite

$$a_g = \frac{r\sigma_u}{2\rho H^2}$$

D: diameter measured at the horizontal section of the cylindrical shaped stalagmite,
r: radius
H: height of the stalagmite, ρ: density of the stalagmite, E: dynamic Young-modulus,
σ_u: tensile failure stress of the stalagmite **Cadorin et al. 2001**

NAME	PLACE	HEIGHT (m)	DIAMETER (cm)	H/D	measured f_0 (Hz)	theoretical f_0 (Hz)	a_g (m/s²)
STM(5m)	Ördög-lik Hall, Domica cave	5,00	average: 5 (7-3,5)	100	2	0,9	0,59
STM(1,8m)	Domica cave, Szűzfolyosó	1,80	average: 5 (6-4)	36	6-8	6,6	4,11
STM(2,26m)	Domica cave, Szűzfolyosó	2,26	average: 8 (11-4)	28	14,2	6,7	4,17
STM(2,39m)	Domica cave, next to entrance	2,39	irregular shape		7,3; 8,1	---	---

Table 3. Table 1. completed with natural frequency and horizontal ground acceleration resulting in failure obtained by theoretical calculations

6. SAMPLING AND AGE DETERMINATION

We took core-samples from STM(2,26) standing at *Szűzfolyosó* of Domica cave (near the lake) at two different heights (at the top and at the bottom of it) in order to determine its age and rate of growing. The core-samples were examined and measured in „High-precision Mass Spectrometry and Environment Change Laboratory (HISPEC)" Taiwan by MC-ICPMS method. The bottom of STM(2,26) is about 115kyears old, while the top of it is recent. The mean growing velocity is about 1mm/50years, which shows slower growing rate than it was previously determined by us in Baradla cave. By this data we can assume, that STM(5m) was 4,9m high ≈ 5kyears ago.