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Modeling seismic capacity of stalagmites

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Program:

1. Motivation
2. Eigenproblem modeling and tuning the FEM model of a stalagmite
3. Time history response to scaled „El Centro 1940" strong motion record

Problem statement:

The need for modeling seismic capacity of precarious rocks, stalagmites and other seismically vulnerable geophysical features derives from general needs to verify long term seismic hazard at a particular area or territory of a country.

Improving seismic hazard assesments is required in seismic desing of large dams or nuclear power plants.

The stalagmites are studied in detail within the framwork of speleoseismology This research serves further improving modeling seismic hazard in key, difficult areas of seismic design of important structures.

The presented results cover the early, first stage of this research i.e. linearized Finite Element modeling of a very tall and slender stalagmite

Object of analysis:

The stalagmite data under investigation is taken from Gribovszki, K., Kovács, K., Mónus, P. et al. Estimating the upper limit of prehistoric peak ground acceleration using an in situ, intact and vulnerable stalagmite from Plavecká priepast cave (Detrekői-zsomboly), Little Carpathians, Slovakia—first results. J Seismol 21(5), 1111–1130 (2017). https://doi.org/10.1007/s10950-017-9655-3

This stalagmite with height 4.3 m was an object of extensive research. It was subjected to measurements of its free vibrations. The first three modes of vibrations were identified by Gribovszki et al. 2017 with natural frequencies as follows:
f_1= 3.0 Hz, f_2= 14.5Hz, f_3=16.0 Hz, f_4 = 36.0 Hz, f_5 = 41.0 Hz

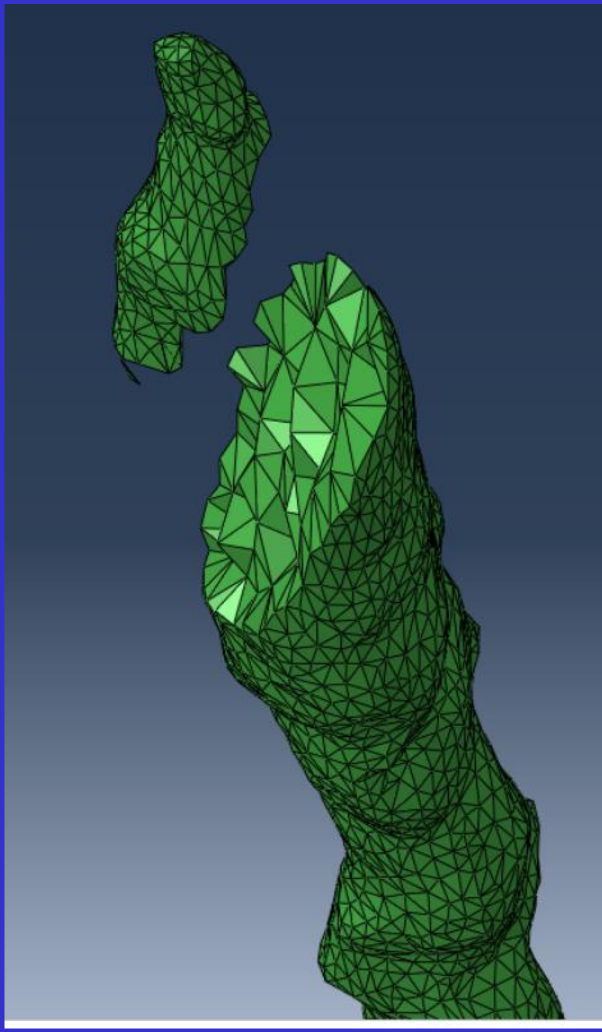
For the purpose of this analysis a preliminary assements of **damping ratio ξ** from free vibrations of this stalagmite was carried out. The results based on the method of logarthimic decrement gave value of ξ equal to 3%

Finite Element Method (FEM) Model:

For the purpose of this analysis the stalagmite is modeled as a uniform 3D object using solid C3D4 tetrahedral elements in the ABAQUS program
Two models were analysed:
with the number of elements equal to (a) 110689 and (b) 625321
Number of the dynamic degrees of freedom equals respectively (a) 87465 (b) 438876

The geometry of the stalagmite has been obtained using laser scan by courtesy of A. Arpáš, B. Balžan and M. Ruttkay, Archeological Institute of the Slovak Academy of Sciences.

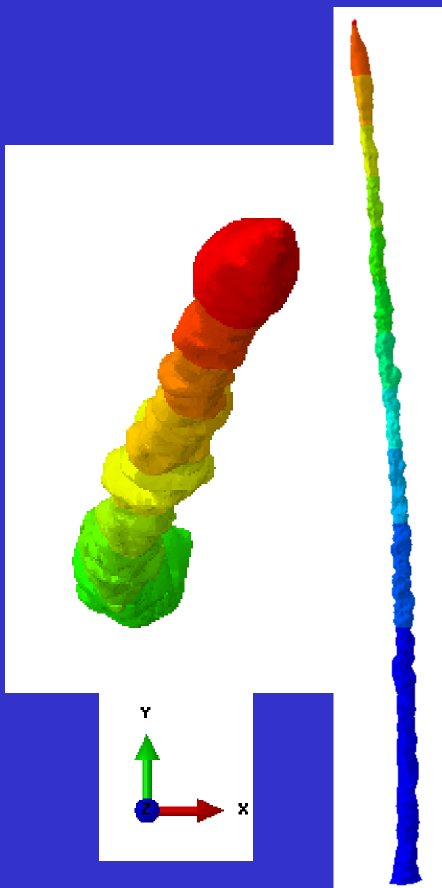
A crossection of FEM model mesh is shown to the right.



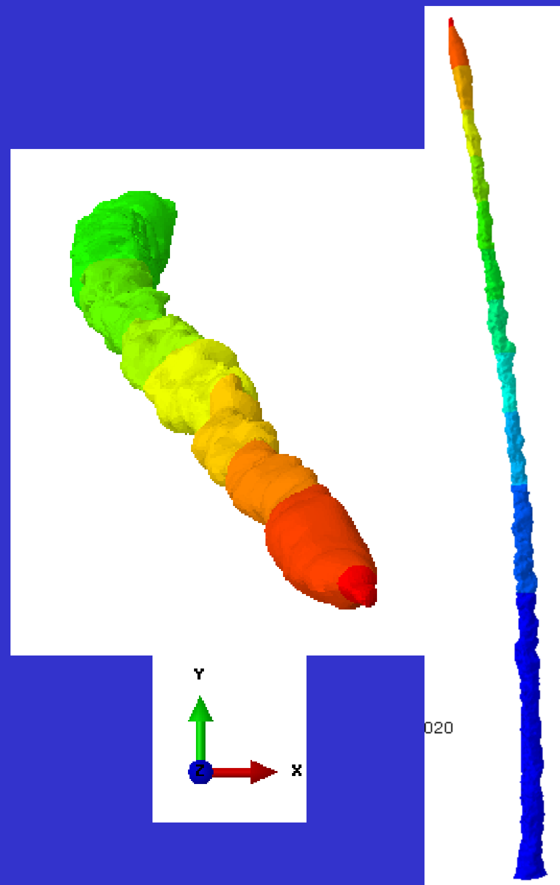
Eigenproblem solution:

The natural periods (frequencies) of the stalagmite were computed iteratively. First, a value of Young Modulus E and shear modulus G was assumed based on the literature survey. Next these values were iteratively corrected in order to calibrate the FEM model with results of the measurements of free vibrations of this stalagmites (Gribovszki et al., 2017 https://doi.org/10.1007/s10950-017-9655-3)
The results of such, calibrated eigenproblem solution are shown in the next slide (the colors shown on the surface of the stalagmite are maps depending on relative displacements of the respective natural modes).

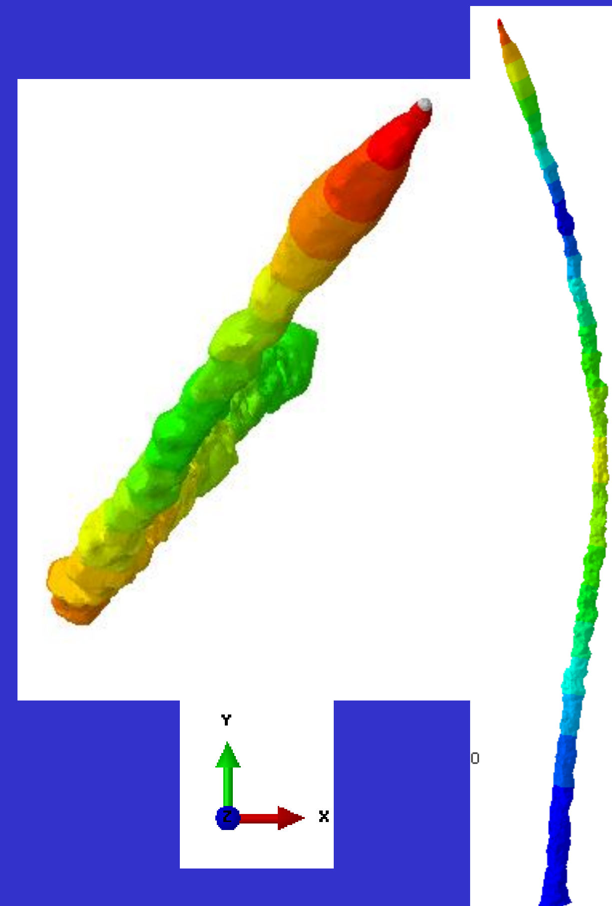
The first three natural modes of the stalagmite as computed using ABAQUS program



Natural period
T_1= 0.333 s
natural frequency
f_1= 3.00 Hz



Natural period
T_2= 0.312 s
natural frequency
f_2= 3.21 Hz

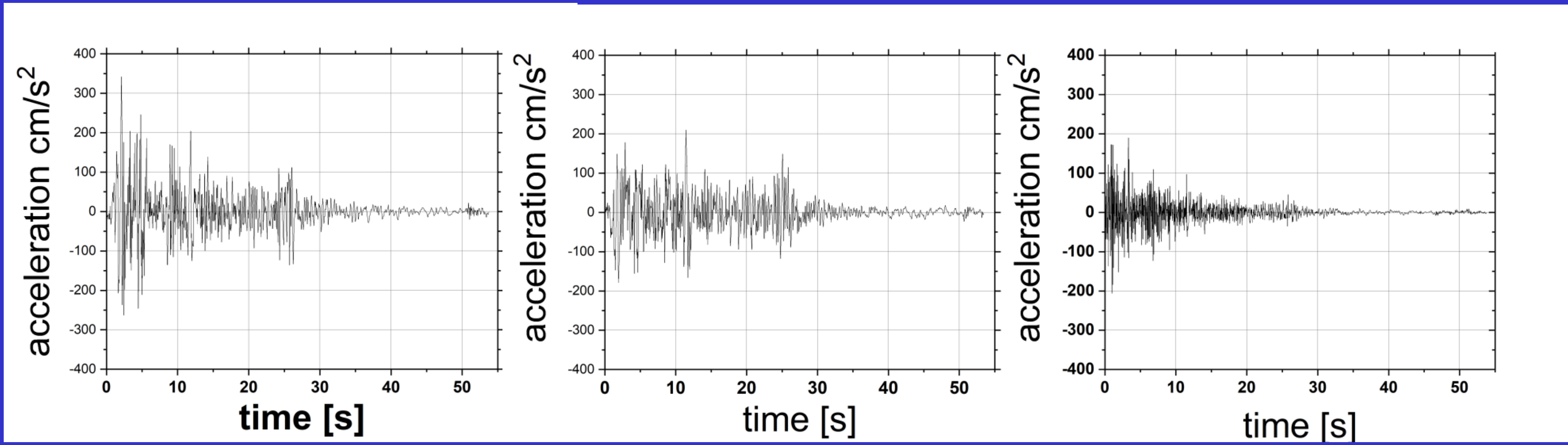


Natural period
T_3= 0.0691 s
natural frequency
f_3= 14.47 Hz

Time history response:

In order to compute seismic response a benchmark record of the familiar (among engineers) strong motion "El Centro" seismic record was chosen. All the components of this record were scaled down with a 0.5xxx multiplier. This way Modified Mercalli seismic intensity of about VI was achieved.

In three figures below the two horizontal NS, EW and vertical acceleration components of the El Centro 1940 record (M7.1, Hypocentral dist: 12.2 km) are shown from left to right.

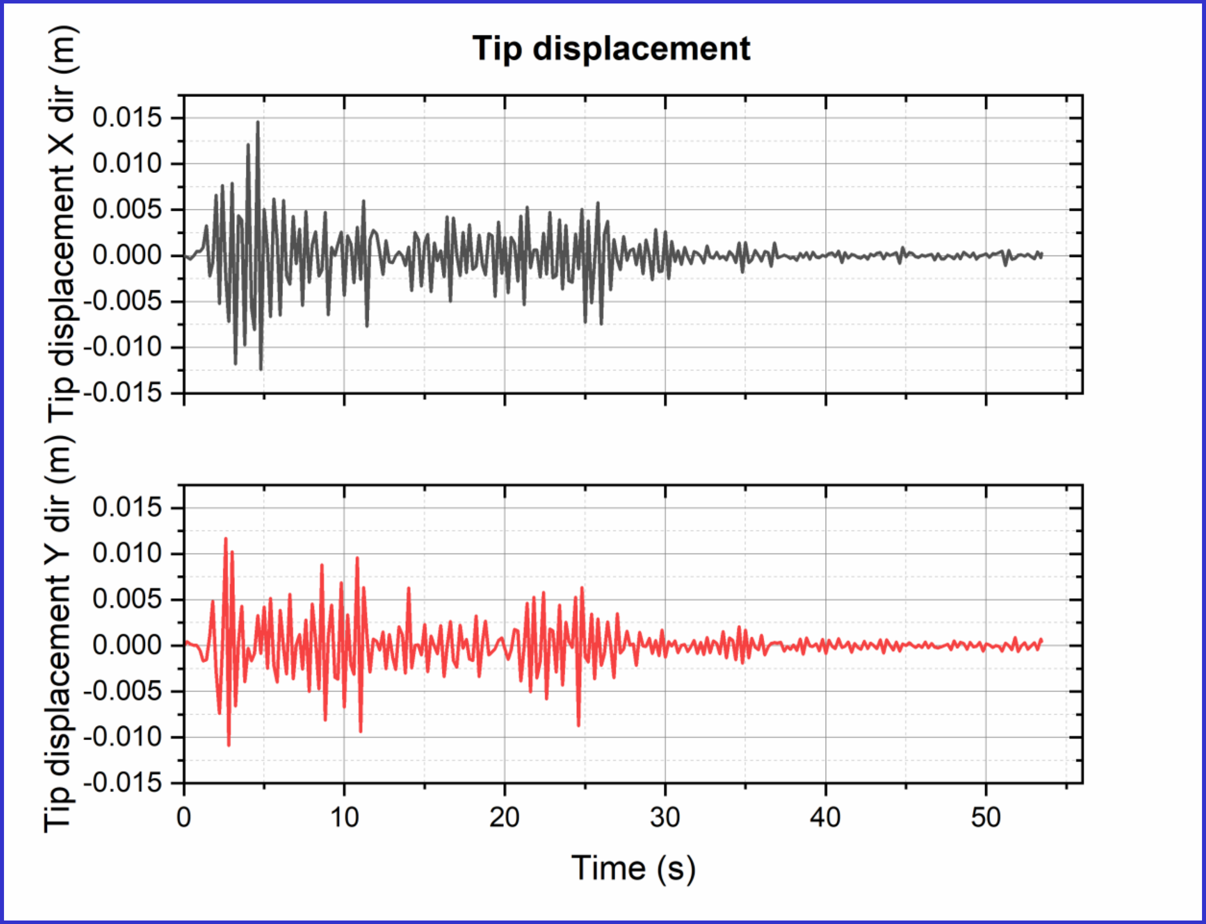


http://www.vibrationdata.com/elcentro.htm

Seismic response:

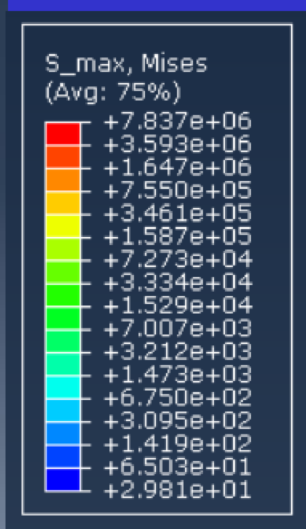
The numerical integrations of the FEM model under the seismic excitations of scaled ElCentro 1940 record were carried out with the assumption of 3% viscous damping.

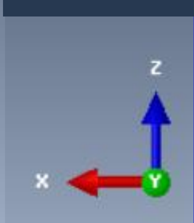
In the two figures below, horizontal displacements are shown as functions of time (the max response displacements equal 1.46 cm in the X direction and 1.17 cm in the Y direction



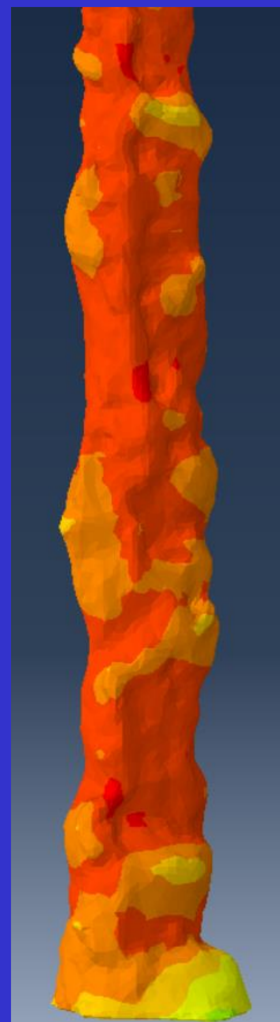
Seismic response:

Following figures present maps of VonMises stresses[1] [Pa]

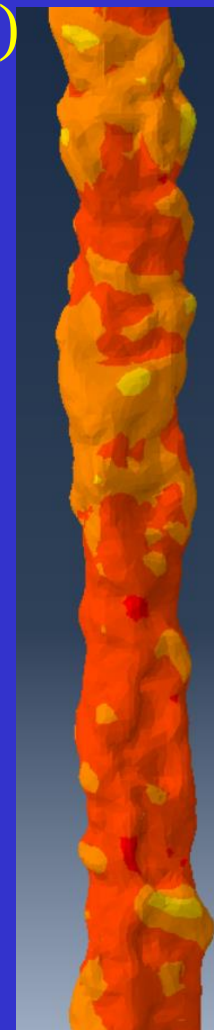




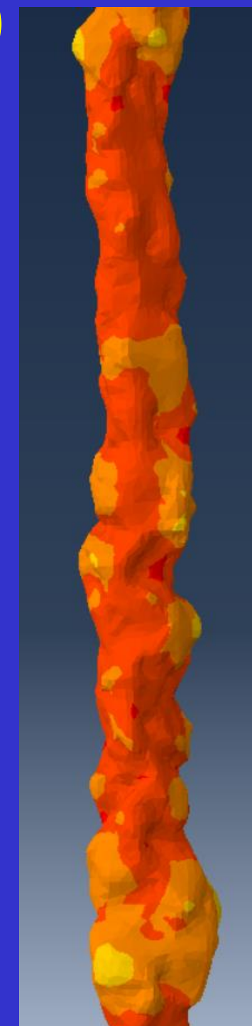
a)

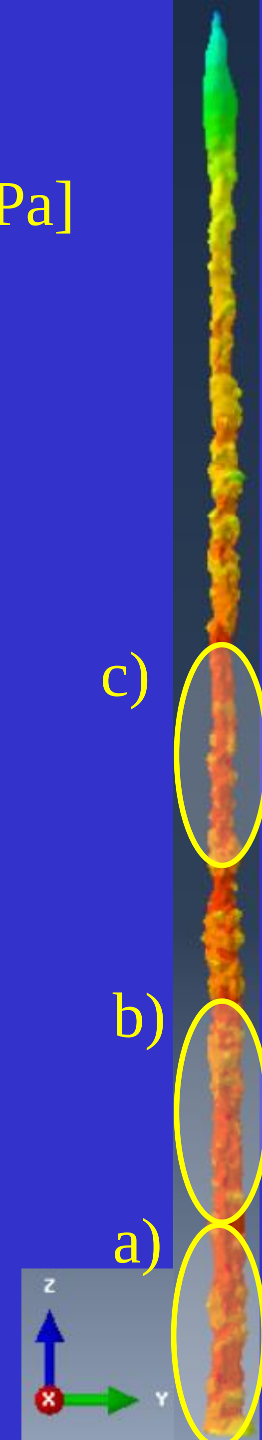


b)



c)





[1] Criterion of Vom Mises-Huber-Heincke:
Von Mises, R. (1913). "Mechanik der festen Körper im plastisch-deformablen Zustand". Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-Physikalische Klasse. 1913 (1): 582–592

Final remarks, conclusions and future research plans

1. Preliminary results of Finite Element Method modeling of seismic vibrations of a stalagmite under strong motion seismic excitations of MM intensity equal to about VI is presented
2. The linearized model was calibrated with measured free-vibrations of the stalagmite
3. Respective equivalent viscous damping ratio was calculated based on measurements of free vibrations of the stalagmite
4. This, linear FEM model will be used as an initial step in further analyses of seismic capacity of the stalagmite with application of non-linear time history analyses
5. The non-linear analyses are planned to be carried out using Monte Carlo simulations in both (i) seismic excitations modelling and (ii) in cross-section modelling of the stalagmite to account for its random structure including presence of voids.
6. The seismic random capacity of the stalagmite will be later used in order to asses seismic risk on the ground surface (design acceleration of the “control motion” used in seismic design of nuclear power plants and important dams)