Research of intact and vulnerable stalagmites in caves of Belgian Ardennes, a contribution to seismic hazard assessment in Belgium – First tests

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Introduction and research questions

Assessment of the long-term seismic hazard is particularly necessary for the management of critical infrastructure, e.g. chemical or nuclear installations.

Data extending beyond instrumental and historic limits include ground motions necessary to break candlestick stalagmites. The presence of undamaged candlestick stalagmites in a cave provides invaluable information about the level of ground motions that have not been reached locally.

In parallel, the knowledge of the transfer function of ground motion from inside cave to the freefield is necessary to transpose these underground observations to the surface and thus to become usable in seismic hazard studies.

The research will be carried out in the Belgian Ardennes, particularly in the Han-sur-Lesse karst system (Fig.1) situated less than 100 km E/SE from the lower Rhine Graben.

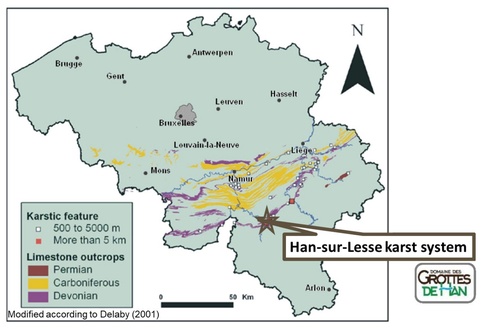


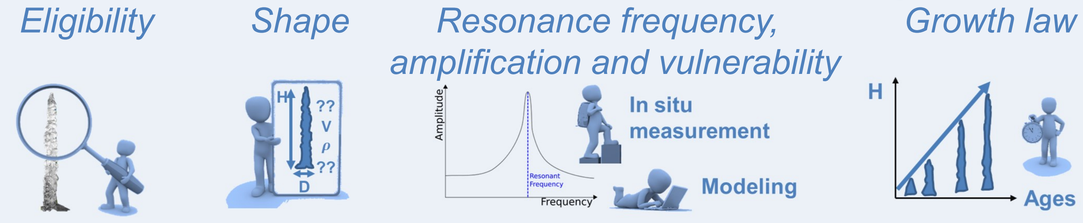
Fig.1 Limestone outcrops in Belgium and localisation of the Han-sur-Lesse karst system

Research axes and methodologies

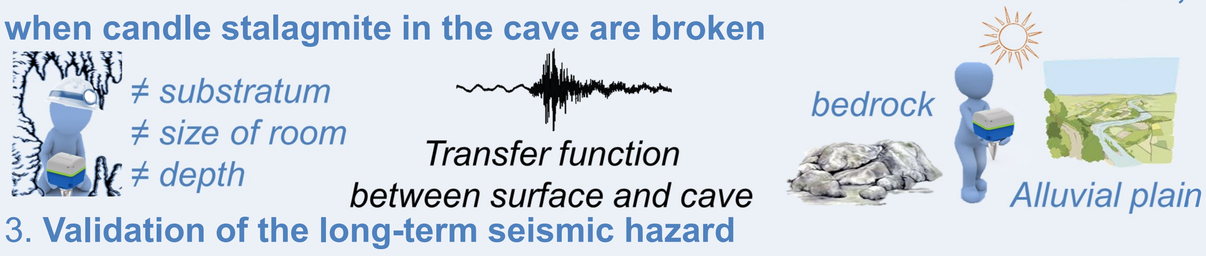
Three research axes will be implemented :

1. **Evaluation of the present and past resistance of stalagmites**

Eligibility — *Shape* — *Resonance frequency, amplification and vulnerability* — *Growth law*



2. **Determination of the levels of freefield soil movement that result, when candle stalagmite in the cave are broken**



3. **Validation of the long-term seismic hazard**

A. *Estimated movement of the ground for the moderate and important earthquakes*

B. *Ground motion levels calculated by seismic hazard analysis for different return periods*

First steps to evaluate the methodology

Feasibility study of a in situ measurement of natural resonance frequency of stalagmite without forced excitation

Studying the natural resonance frequency with seismic noise

Seismic sensors have been placed on an metal post (Fig.2) without forced excitation. The recordings have been analysed as explained in Fig.3.

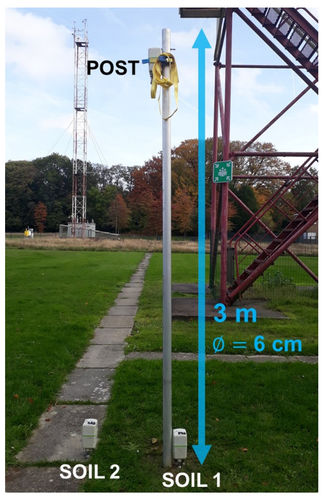


Fig.2 : Metal post used for frequency tests

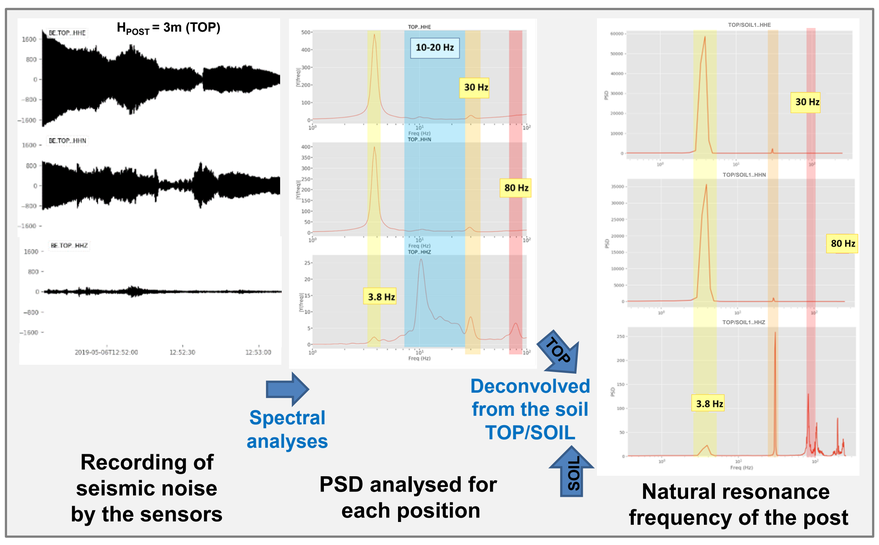


Fig.3 : Methodology used to obtain natural resonance frequency of the post

Influences of the level of the sensor

Measurement of the frequency at different levels on the post and numerical modelling (Fig.4) show that the influence on the resonance frequency increases with the elevation of the sensors relative to the base (variation around 2 Hz). Model calculation indicates that this variation is smaller for stalagmite material properties (around 0,3 Hz).

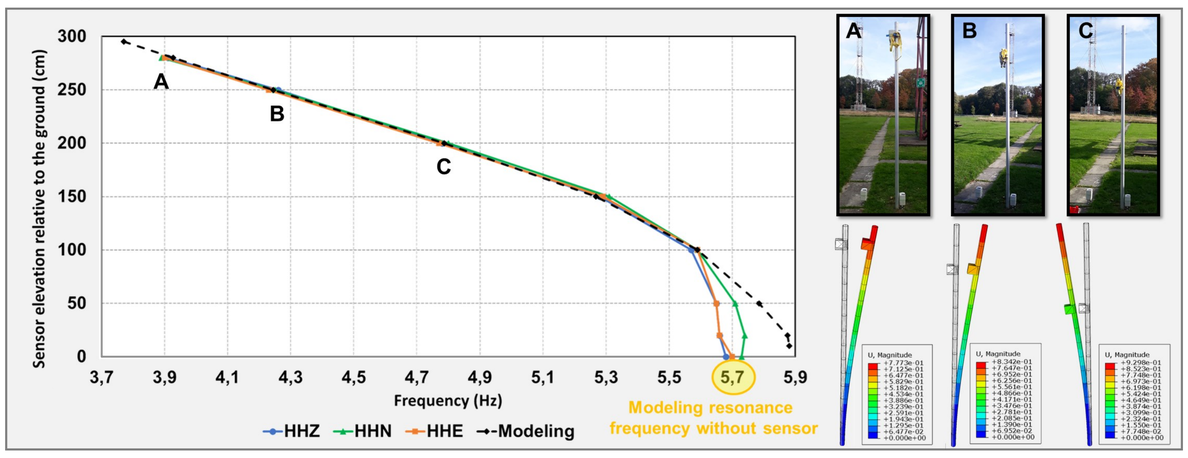


Fig.4 : Influences of the elevation of the sensor on resonance frequency

Influences of the weight of the sensor

Numerical modelling of ideal stalagmites shows that the influence on the resonance frequency increases with the sensor mass (Fig.5).

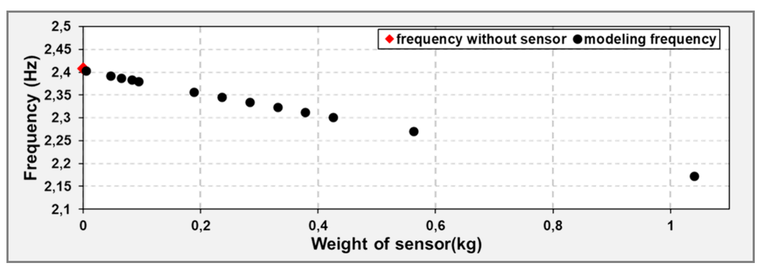


Fig.5 : Influences of the sensor mass on the frequency for stalagmites properties

Definition of an eligibility criterion of stalagmites

Eligible stalagmites must have a natural resonance frequency in the band of regional earthquake ground motions (< 20 Hz). To meet this demand the criterion shown in Fig.6 was defined.

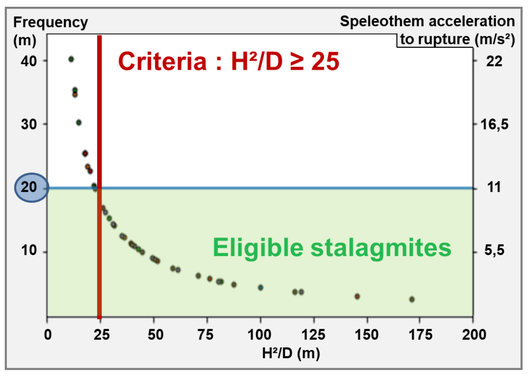


Fig.6 : Definition of the eligibility criterion of stalagmites (H - height ; D - diameter)

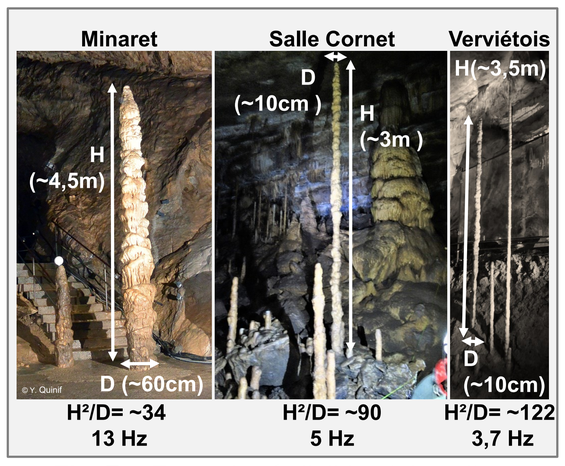


Fig. 7 : Example of eligible stalagmites in Han-sur-Lesse cave

A first search of eligible stalagmites has been carried out in the Han sur Lesse cave (Fig.7).

Better knowledge of the shape of stalagmites by 3D scan

A FARO Focus 3D infrared phase scanner was used to measure the **size** and investigate the **irregularity in shape** of the stalagmites (Fig.8 a,b) .

This 3D scan was used in **numerical modelling** to estimate the resonance frequency of the stalagmite (Fig.8 c).

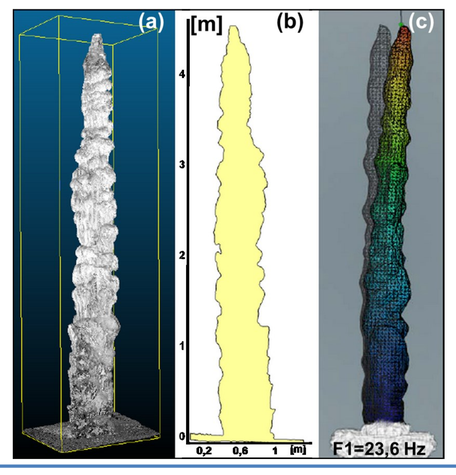


Fig. 8: Minaret Stalagmite Han-sur-Lesse
(a) 3D scan
(b) Section view
(c) Numerical modeling (travertine material properties)

Conclusion

The first tests of the planned methods indicate a good prospect of success, when they are applied systematically.

- The first research of eligible stalagmites confirmed the suitability of the Han sur Lesse cave due to **the broad diversity of stalagmites**.
- The 3D scan test confirms **the possibility to use this technique and chosen equipment** for stalagmites scanning and modelling.
- The frequency tests show that **ambient noise** can be used to find resonance frequency of a post. The tests also suggest placing **the sensors as low as possible** and **favoring light sensors** to limit the impacts on resonance frequency.

Acknowledgment

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References: Delaby 2001 , Paleoseismic investigations in Belgian caves. Geologie en Mijnb. 80, 323-332