Virtual and Field Reconnaissance of Structural and Geotechnical Damage of the Petrinja, Croatia December 29, 2020, M_w6.4 Earthquake

Nenad Bijelić (EPFL), Marko Bartolac (GF Zagreb)
Ingrid Tomac (UCSD)

11/18/2021

… in collaboration with EERI LFE x StEER and GEER report authors

EERI LFE x StEER – Joint Reconnaissance Report

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

StEER STRUCTURAL EXTREME EVENTS RECONNAISSANCE

PETRINJA, CROATIA DECEMBER 29, 2020, M_w 6.4 EARTHQUAKE

JOINT RECONNAISSANCE REPORT (JRR)

Collapsed unreinforced masonry building on Strossmayer St. in Petrinja. Photo by Damir Lazarević

January 2021

PETRINJA, CROATIA DECEMBER 29, 2020, M_w 6.4 EARTHQUAKE

JOINT RECONNAISSANCE REPORT (JRR)

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Virtual Assessment Structural Team (VAST) Authors:
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Virtual Assessment Structural Team (VAST) Editors:
Ian Robertson, University of Hawaii

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GEER Reconnaissance Report

Geotechnical Reconnaissance and Engineering Effects of the December 29, 2020, M6.4 Petrinja, Croatia Earthquake, and Associated Seismic Sequence

Lead Report Editors and GEER Team Leaders: Ingrid Tomac, U.C. San Diego
Sonja Zlatović, Zagreb Univ. of Applied Sciences

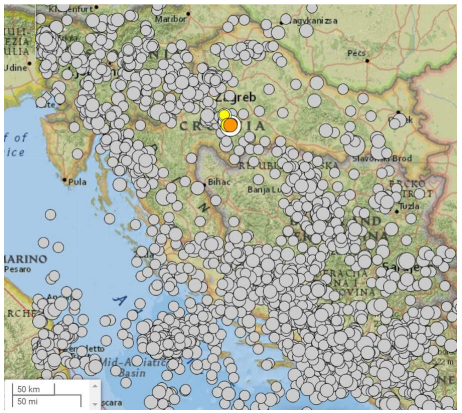
Authors (Leaders then Alphabetical): Ingrid Tomac, Sonja Zlatović, Adda Athanasopoulos-Zekkos, Jelena Bleiziffer, Dubravko Domitrović, Tihomir Frangen, Verica Gjetvaj, Marin Govorčin, Igor Gukov, Marijan Herak, Petar Hrženjak, Dellena Kinikles, Ivan Kosović, Biljana Kovačević-Zelić, Bojan Matoš, Darko Matešić, Ivan Mihaljević, Zorana Mijic, Marta Miletić, Jack Montgomery, Jelena Parlov, Davor Pavelić, Ivica Pavičić, Dunja Perić, Nguyen Pham, Ivan Salković, Josip Terzić, Ingrid Tomac, Igor Vlahović, Zvonimir Vlahović, Helena Vučenović, Katerina Ziotopoulou, Petar Krešimir Žderić

HCPI – Croatian Center for Earthquake Engineering

Volunteers associated with HCPI

Presentation roadmap

The setting & seismicity



Walk through the epicenter – structural aspects

Walk through the epicenter – geotech aspects

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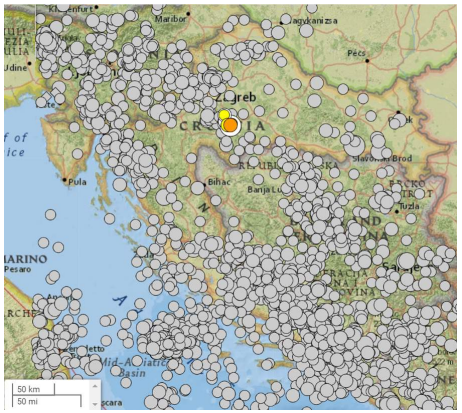


Walk through the epicenter – structural aspects

Walk through the epicenter – geotech aspects

The setting

EU member since 2013

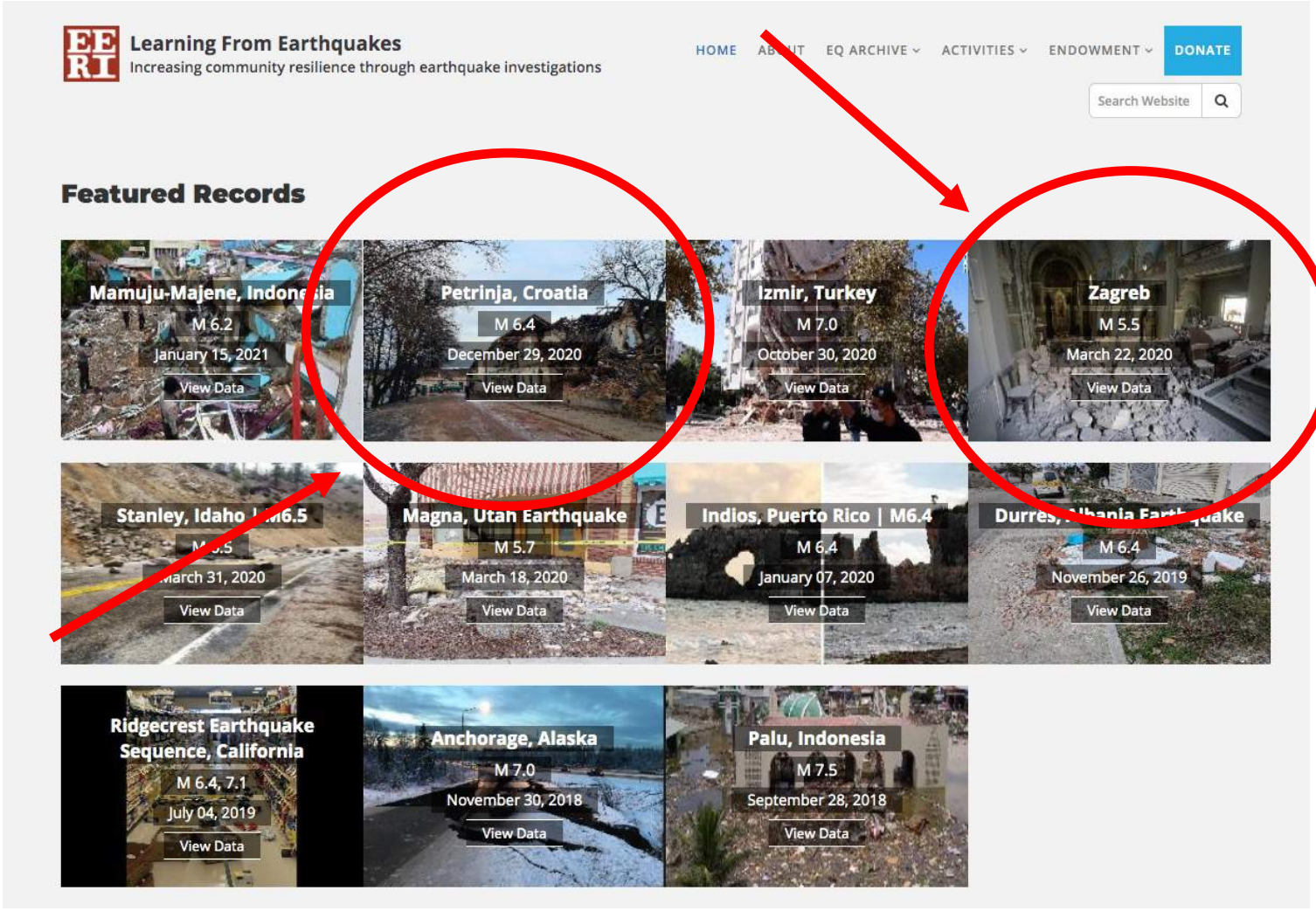
Plitvice Lakes national park

The setting

Location of the December 29, 2020 earthquake in Croatia (source: New York Times 2020)

- Population: ~ 4 million
- Area: 56,594 km^2 (21,851 sq mi)
  - about 0.7 of Austria
- Capital: Zagreb
- Two big earthquakes in 2020
  - March, M5.5 Zagreb
  - December, M6.4 Petrinja

EERI Learning From Earthquakes (LFE)



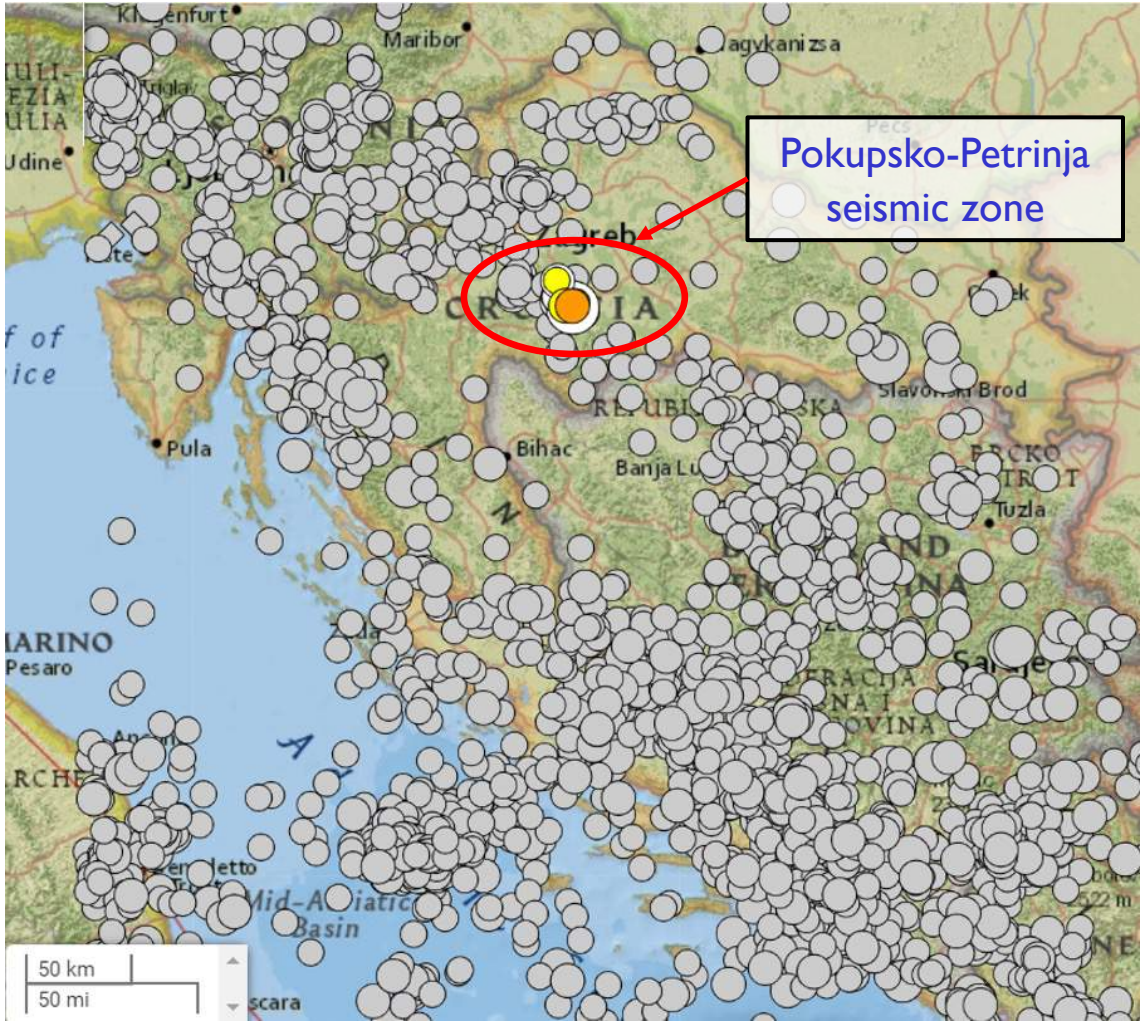
http://www.learningfromearthquakes.org/

December 29, 2020 M6.4 Petrinja, Croatia Earthquake

Location of the December 29, 2020 earthquake in Croatia (source: New York Times 2020)

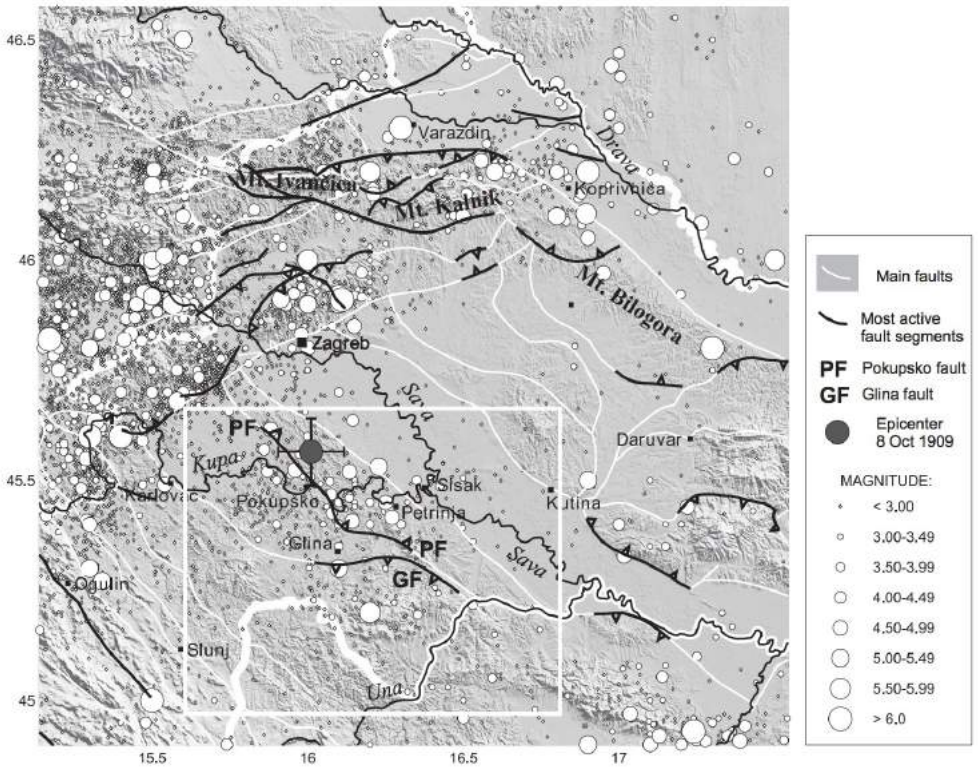
- Mainshock:
  - December 29, 2020 at 12:20pm local time
  - 3km southwest of Petrinja and 47km south of Zagreb
  - Hypocenter depth 10 km
- Foreshocks:
  - December 28, 2020
  - M5.2 and M4.7
- Hundreds of aftershocks:
  - M4.7 and M4.8 on Dec 30, 2020
  - M 4.9 on Jan 6, 2021

Seismicity of Croatia



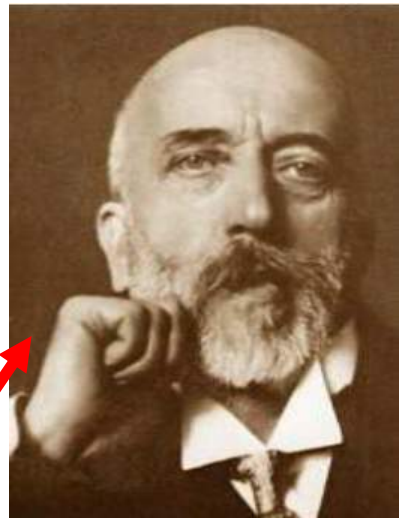
Epicenters of earthquakes with moment magnitudes M>3 in Croatia since 1950. source: USGS ComCat. (USGS 2021).

Seismicity of Croatia – October 8, 1909 Kupa Valley Earthquake



Pokupsko epicenter area with epicenters from the Croatian Earthquake Catalogue. The 1909 mainshock is shown as a dark gray circle with one standard deviation error bars. (From Herak and Herak 2010, Figure 1)

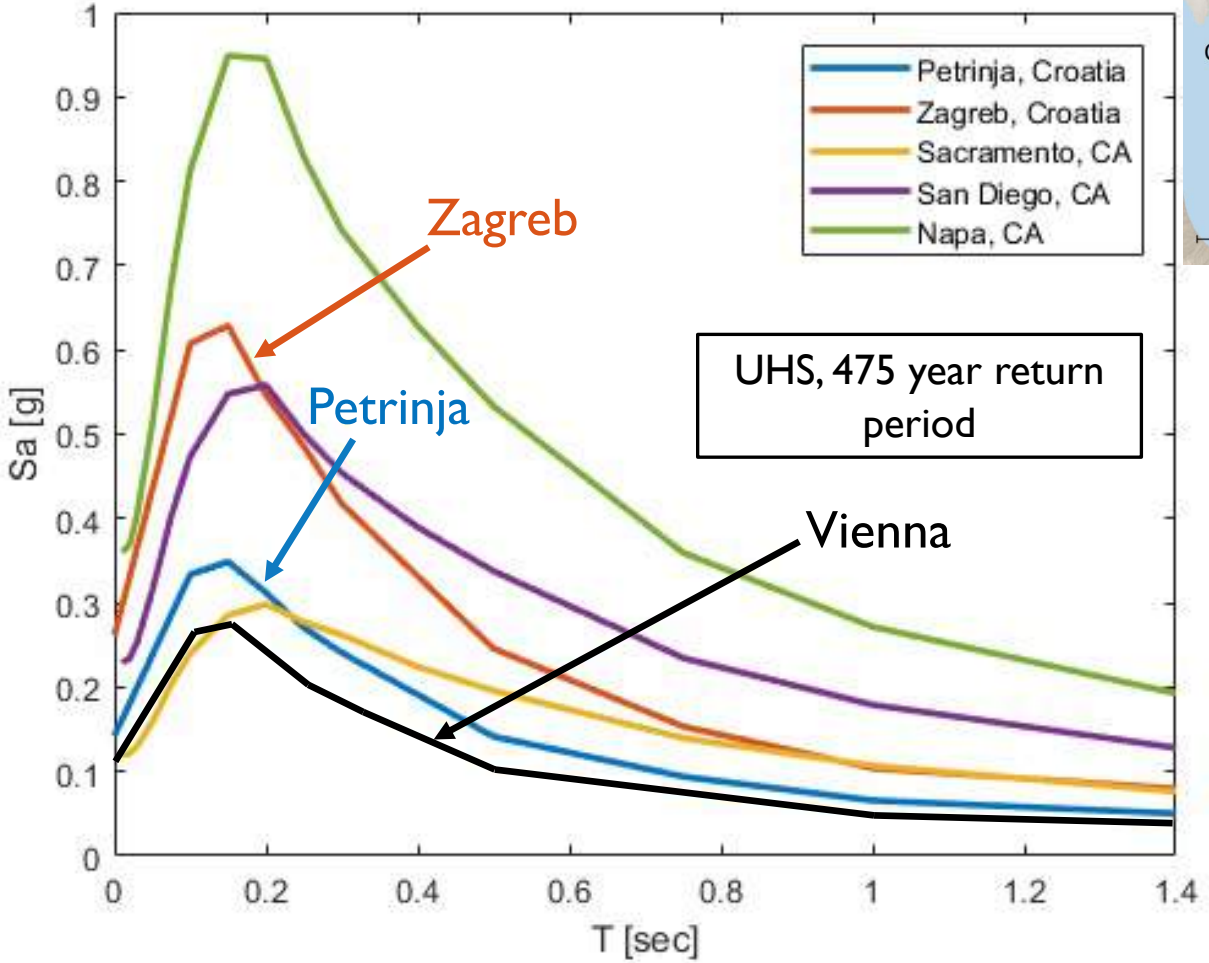
- Magnitude: M_S 6.0
- *"… the **strongest event** known to have ever been noted in the Kupa Valley epicentral region, and it **plays a key role in defining the hazard there**." (Herak and Herak, 2010)*



A. Mohorovičić

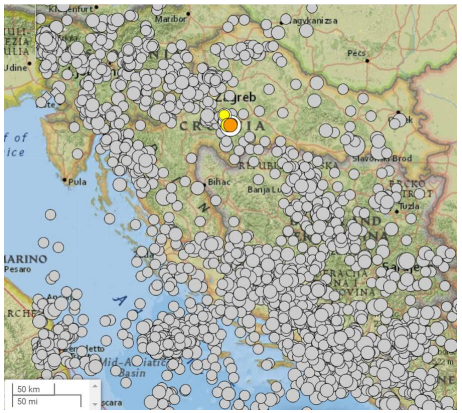
The "Moho" guy!

Seismic hazard – Uniform Hazard Spectra (UHS)



Presentation roadmap

The setting & seismicity



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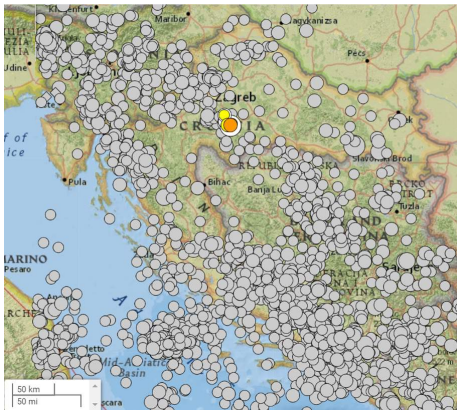


Walk through the epicenter – structural aspects

Walk through the epicenter – geotech aspects

Walk through the epicenter – Petrinja downtown

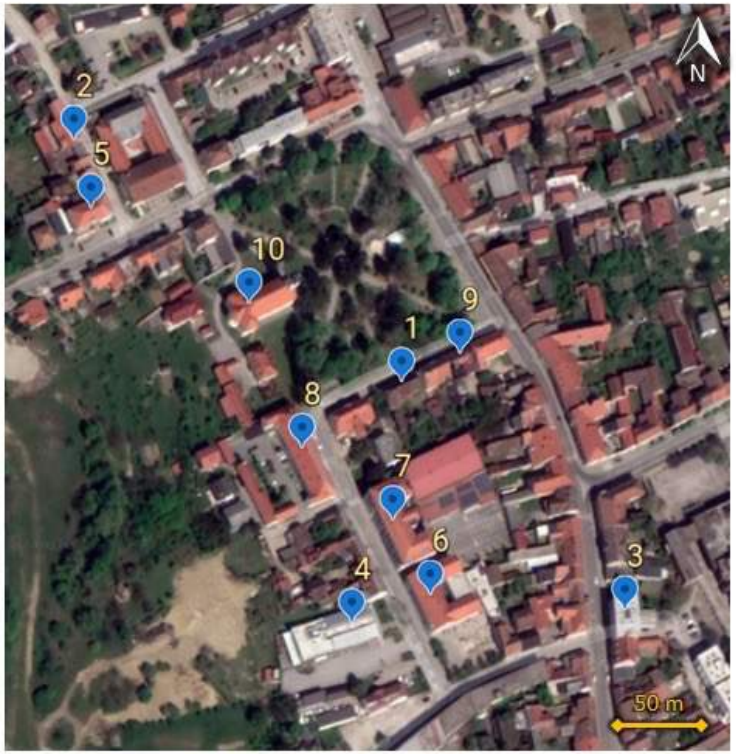

1. Collapsed URM buildings


5. Petrinja Health Center


6. First Primary School


7. Petrinja High School


2. URM and confined masonry




3. Apartment building


4. KTC supermarket


8. Petrinja Town Hall


9. Chamber of Crafts


10. Church of St. Lawrence

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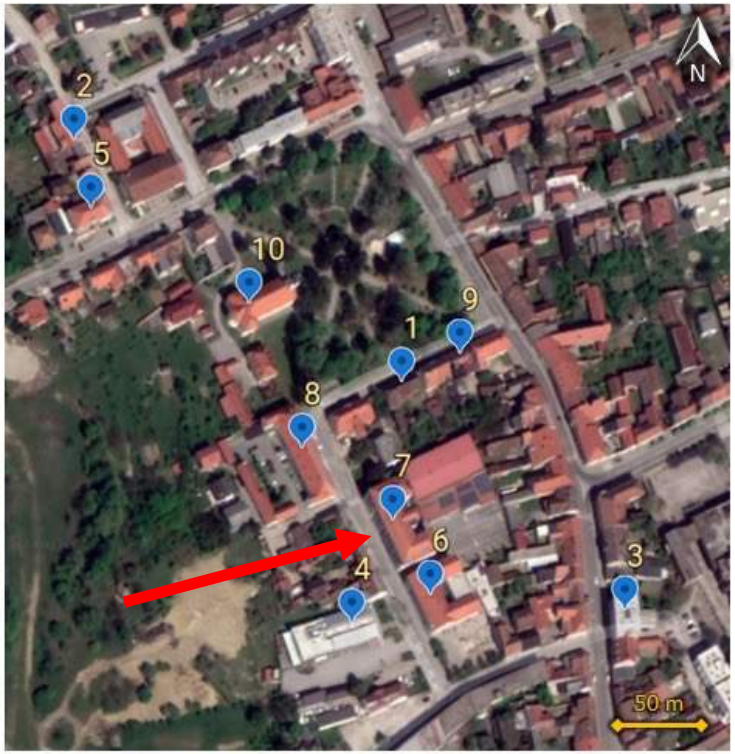


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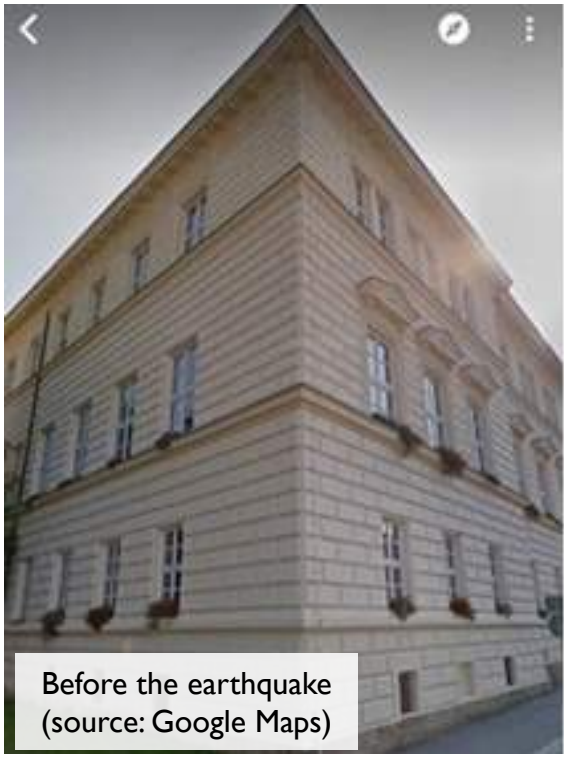
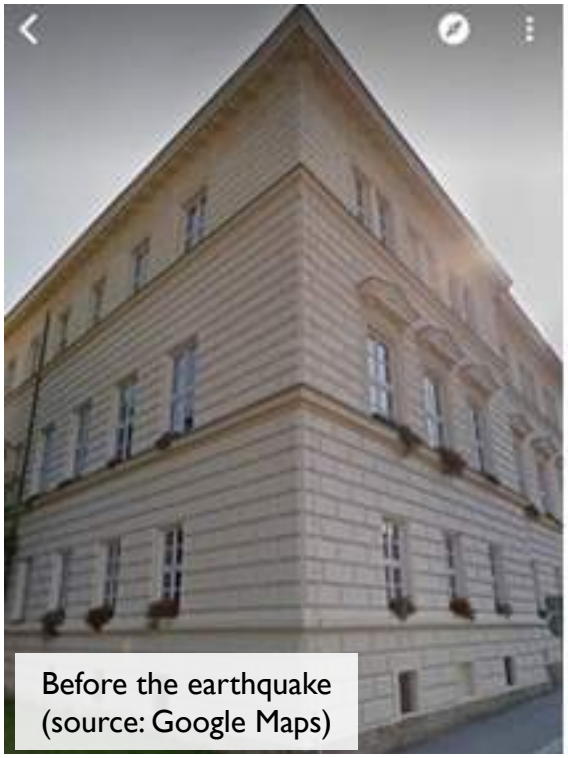
Petrinja High School



Transverse wall of the Petrinja High School

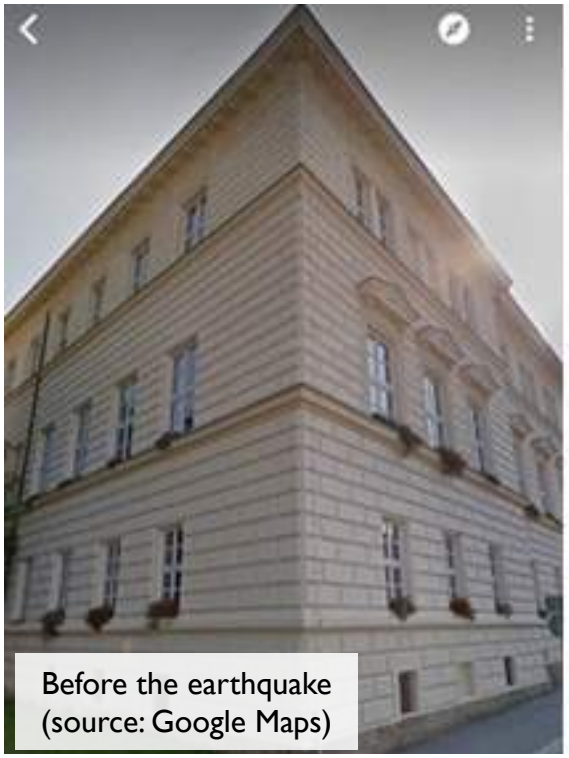
- Built around 1860
- URM walls with jack-arch floors
- Hollow clay tiles on the roof
- Façade looks amazing!

Petrinja High School – transverse wall



Transverse wall of the Petrinja High School

Petrinja High School – transverse wall



Transverse wall of the Petrinja High School

- Shear crack on the outside on the transverse wall
- Localized damage above the windows

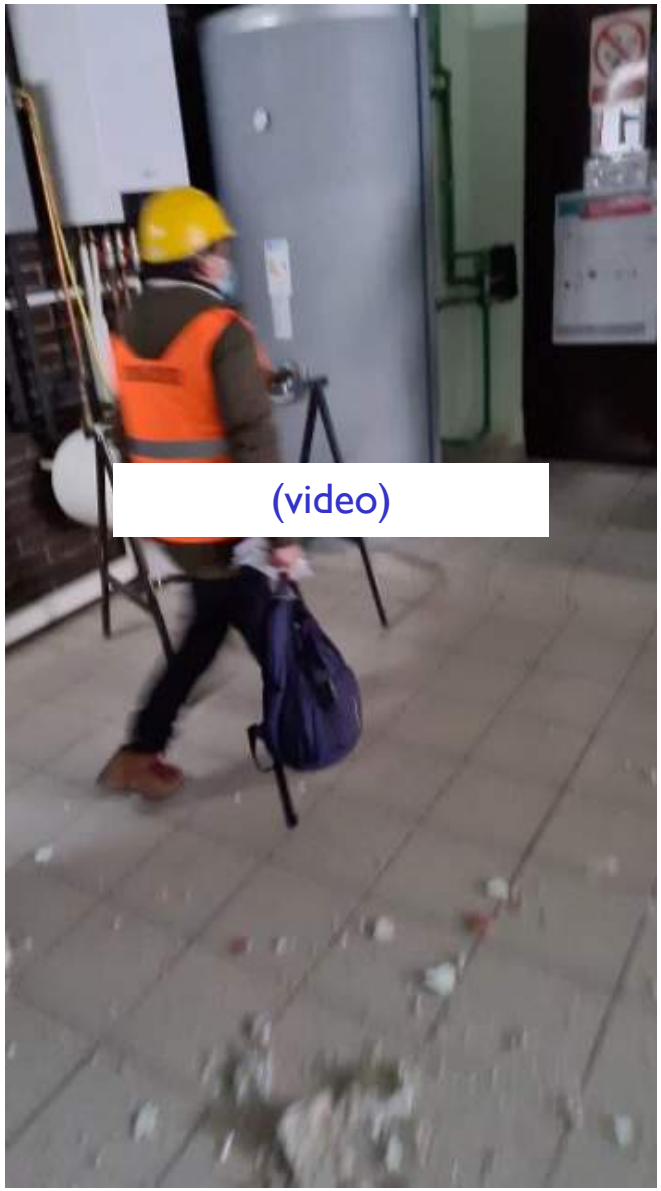
Petrinja High School – Main building interior

Before the earthquake (source: Domagoj Damjanović)

After the earthquake

Petrinja High School – Main building interior

Petrinja High School – Sports Hall



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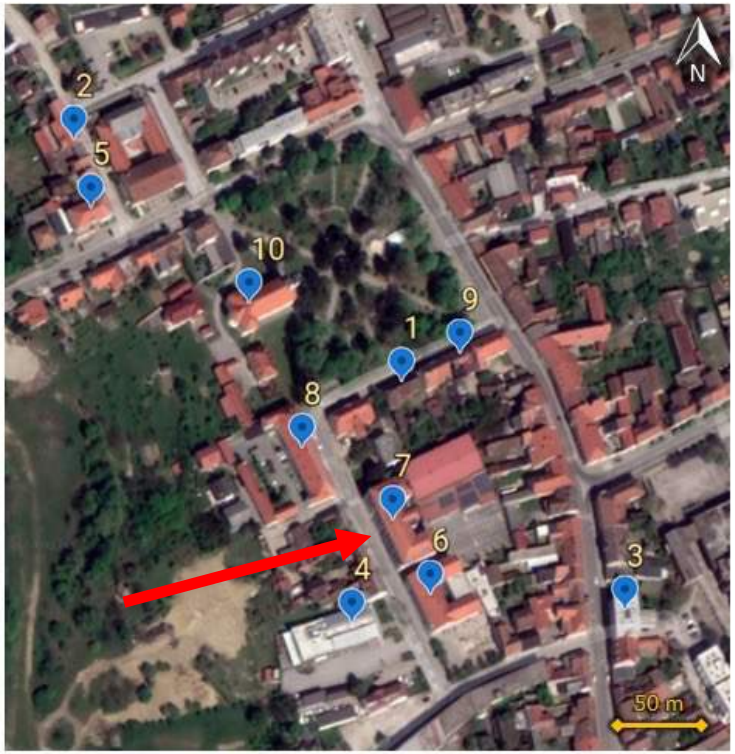


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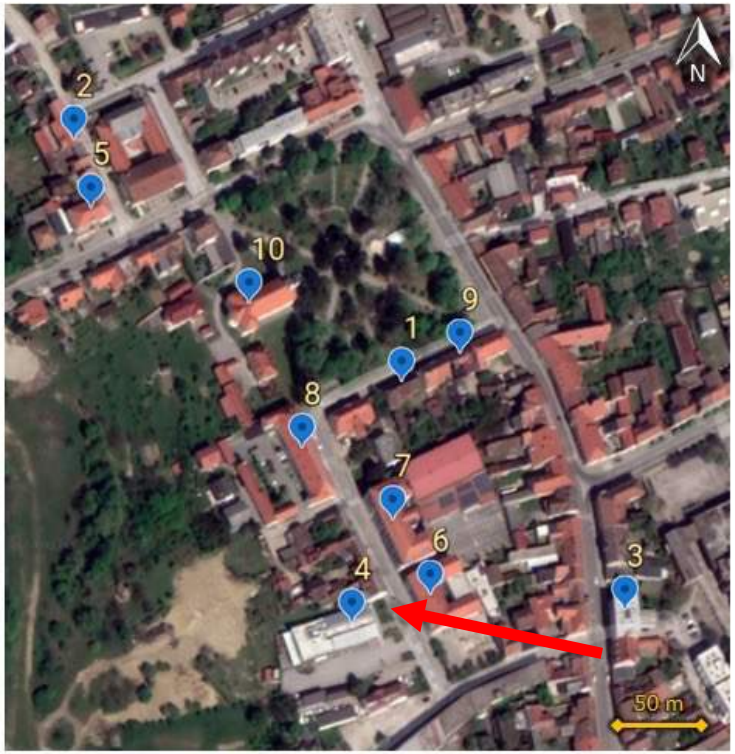


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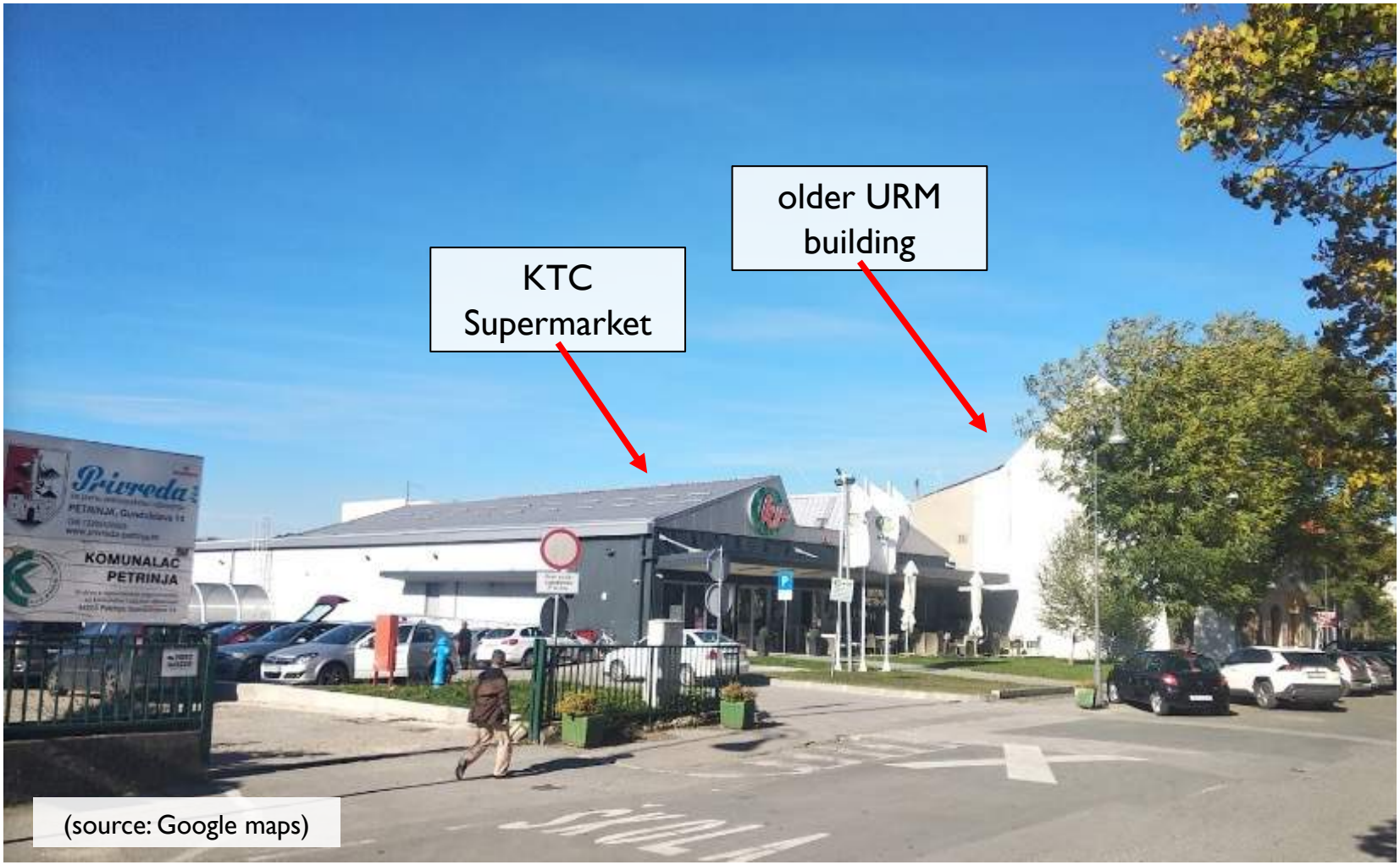
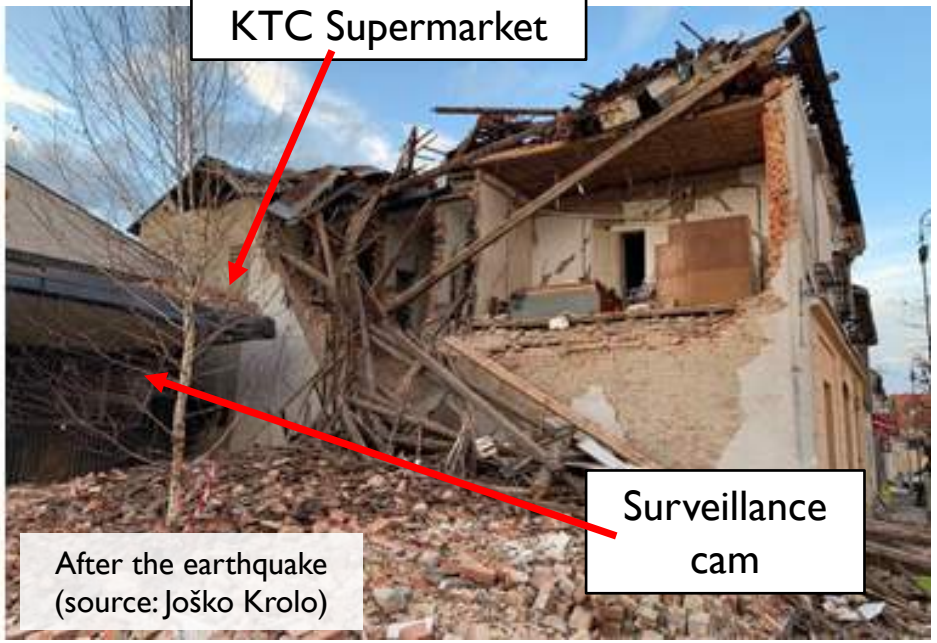
KTC Supermarket & an older URM building



KTC Supermarket & an older URM building

Gable wall and roof collapse. Typical wall and floor construction in older URM buildings – thick clay brick masonry walls, timber floors, and roofs.

KTC Supermarket & an older URM building



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KTC Supermarket

Surveillance cam

(source: Google maps)

(video)

(source: Sonja Belovarac Radenović)

KTC Supermarket

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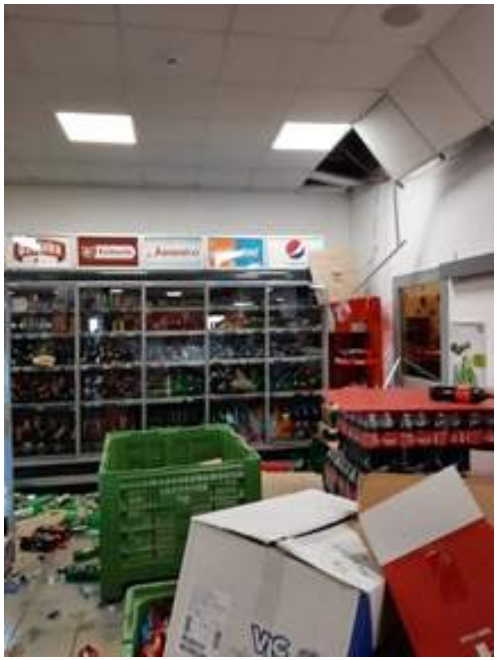
KTC Supermarket



Hung ceiling assembly damage

Products on the floor of the KTC supermarket due to the earthquake

(source all photos: Sonja Belovarac Radenović)

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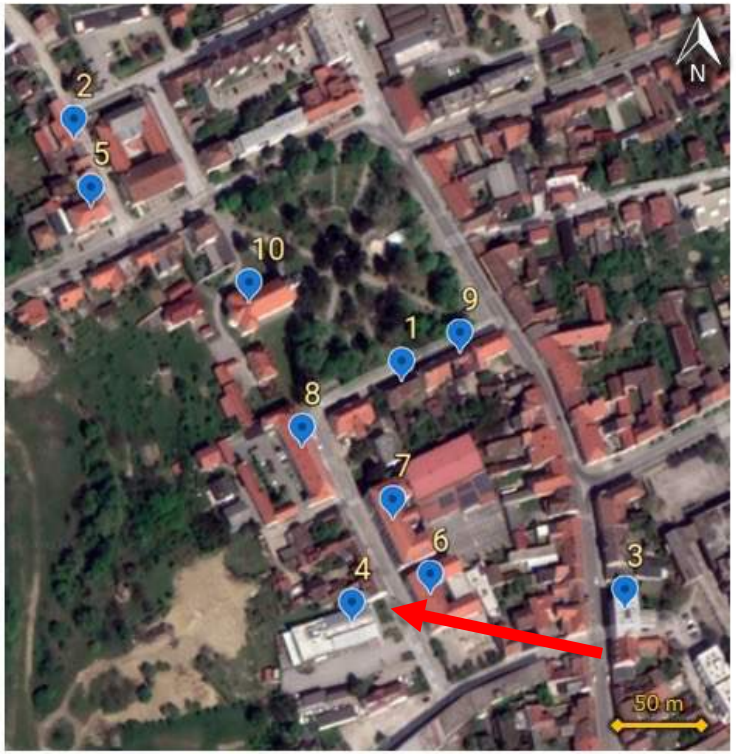


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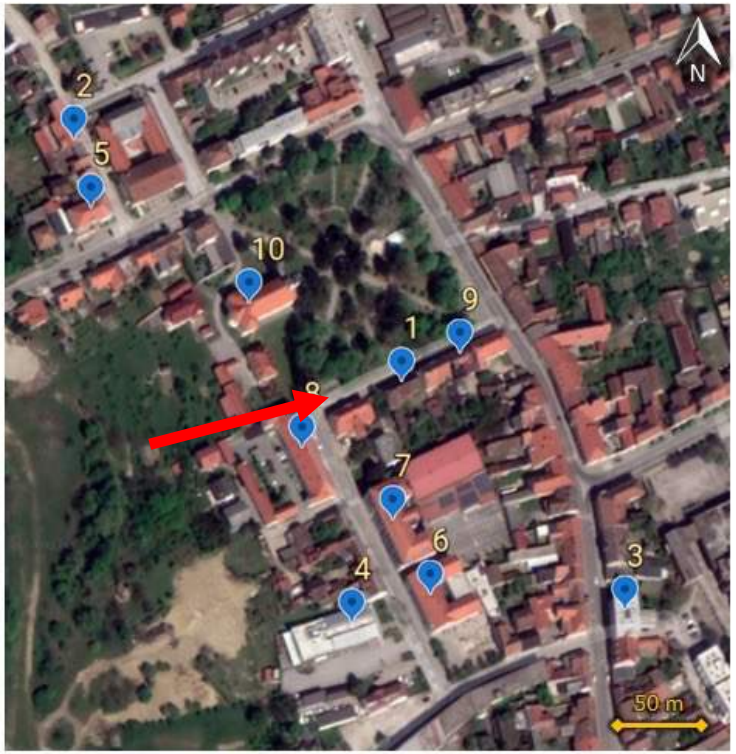


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Walk through the epicenter – view from the park


(source: Google maps)

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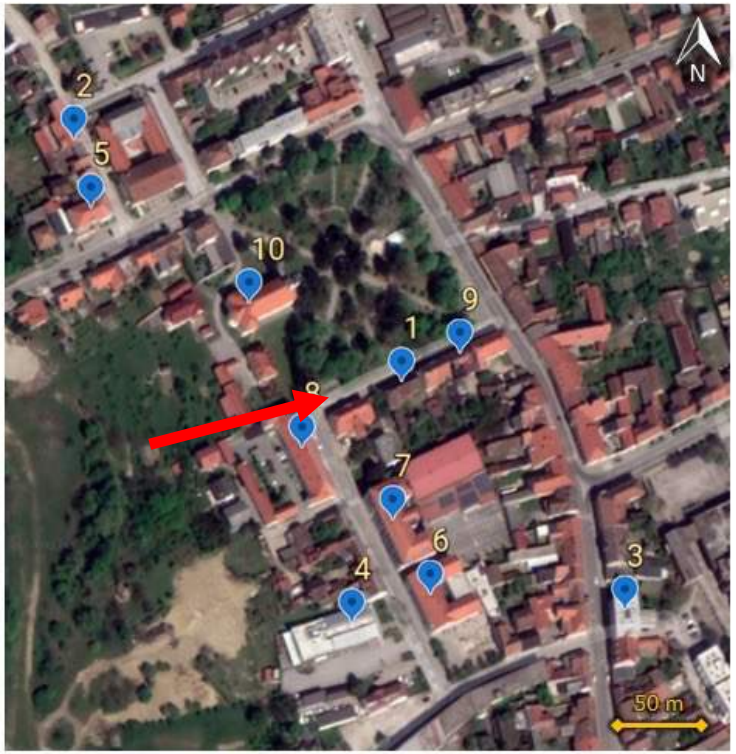


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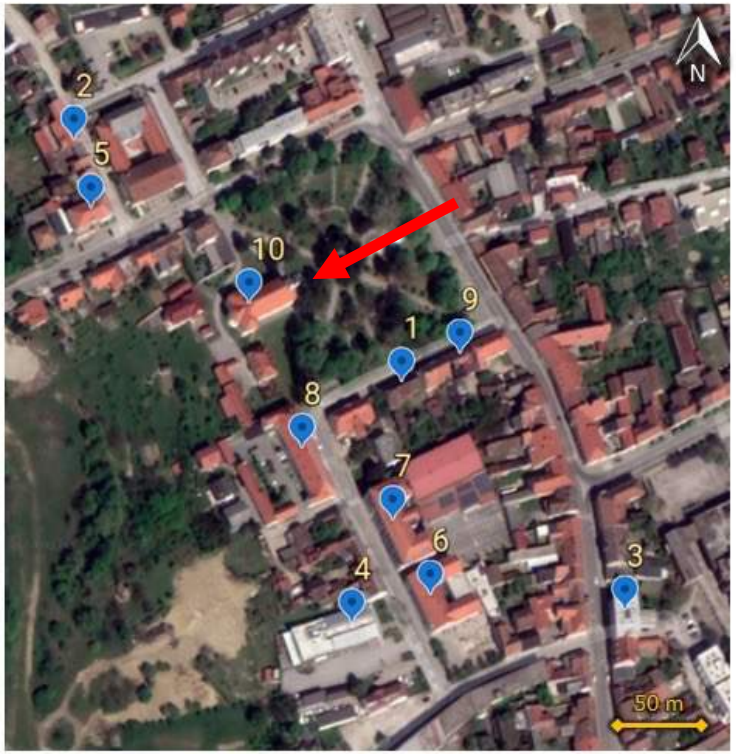


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Church of St. Lawrence

- Originating from the 18th century; destroyed in Croatian War of Independence in 1991.; re-built in 2004. → RC and confined masonry structure

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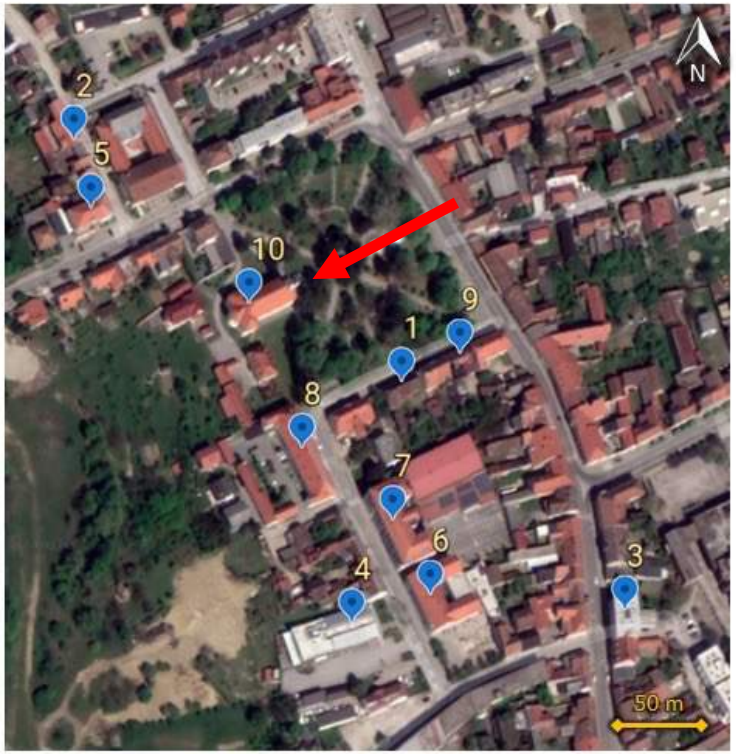

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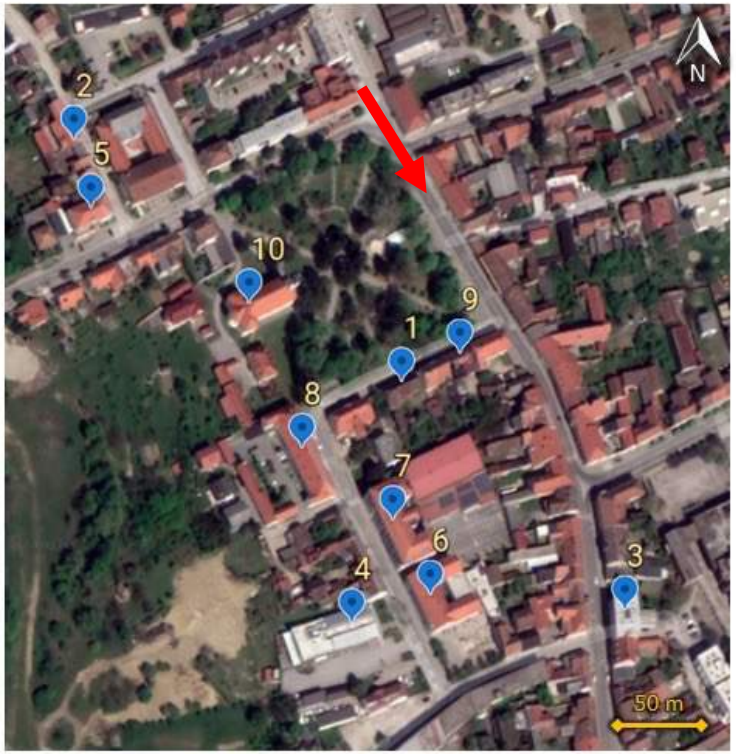


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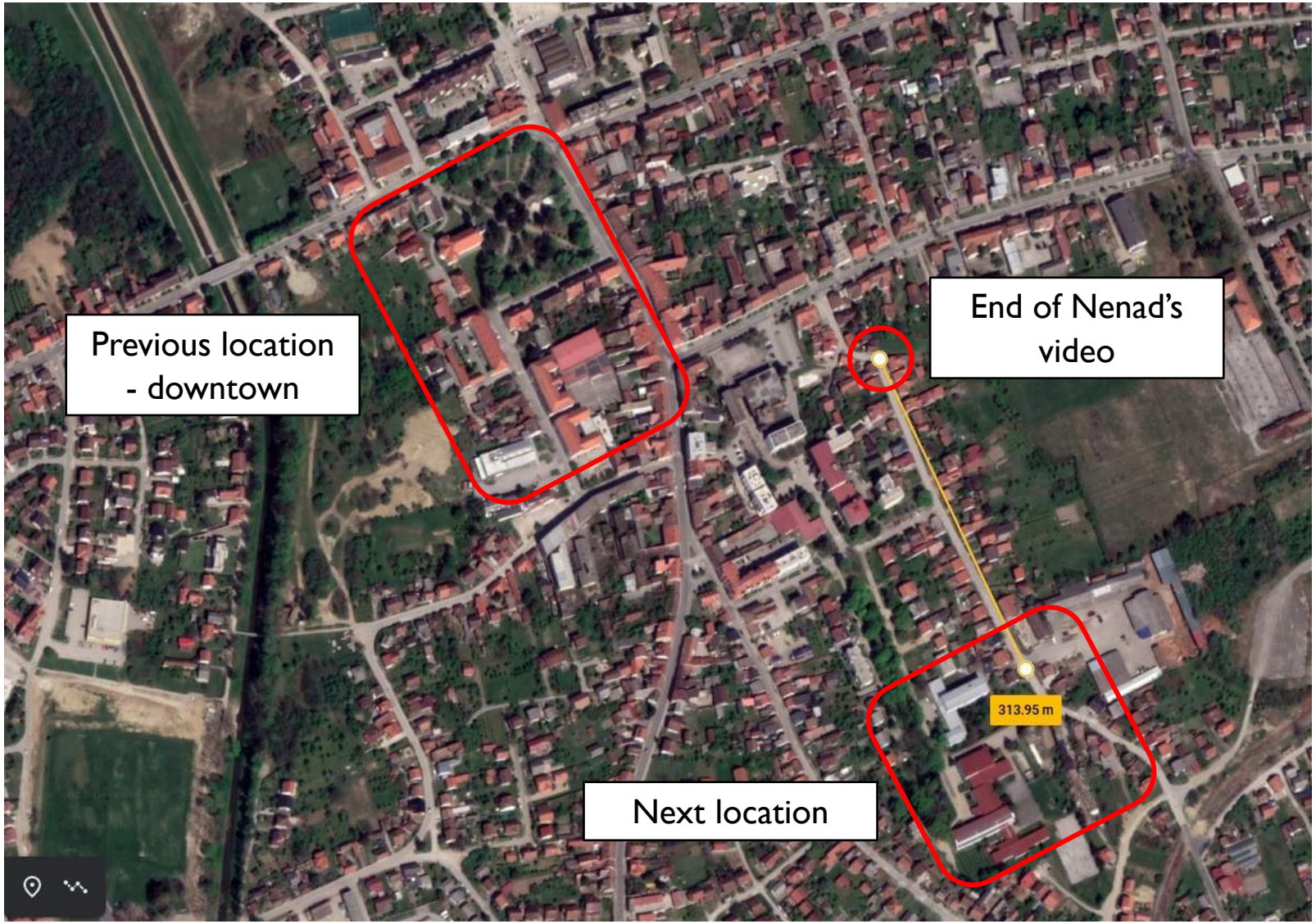
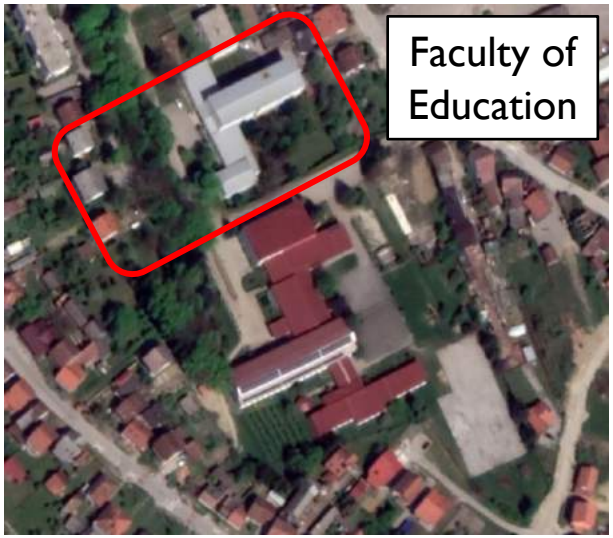
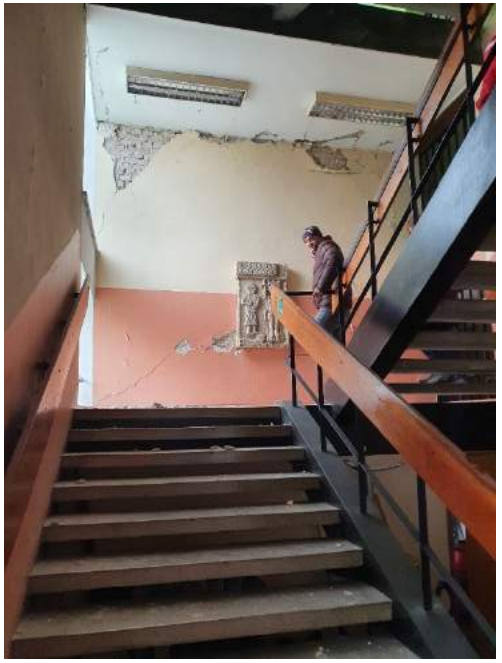
Ride through the epicenter – downtown

Walk through the epicenter – next location



Faculty of Education



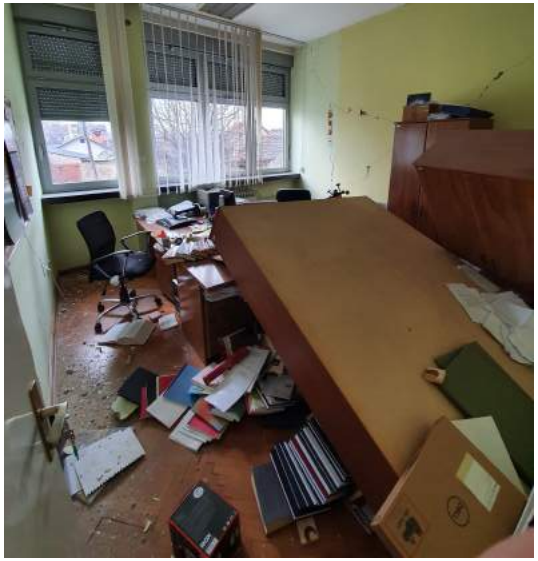


- Combination of confined and unconfined masonry.
- Significant damage observed.
- Recently performed energy efficiency renewal (façade).

Faculty of Education

- Possible OOP failure in case of stronger afterschocks!

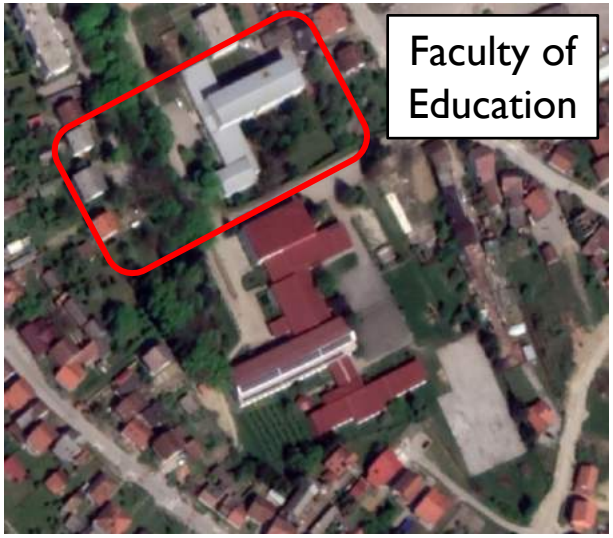
- Lots of overturned shelves and fallen items in the building.
- Sufficient anchorage in the library.



Faculty of Education

- Total collapse of the ceiling assembly in one of the classrooms.

Elementary Schools Dragutin Tadijanovic and Mato Lovrak



Elementary Schools Dragutin Tadijanovic and Mato Lovrak

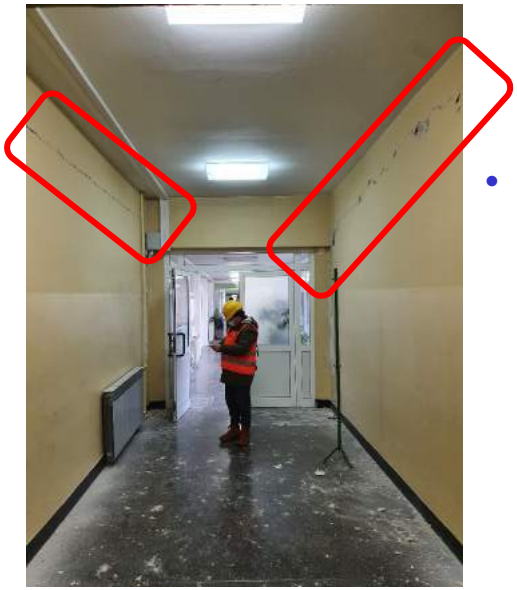
- Elementary School Dragutin Tadijanovic

- Elementary School Mato Lovrak

Elementary Schools Dragutin Tadijanovic and Mato Lovrak

- Elementary School Dragutin Tadijanovic
- RC moment-resisting frames with masonry infill walls

- Sports hall – RC frames with infill walls and steel joists roof structure – good performance.



- Cracks at the intersection of the masonry infill and the RC frame.

Elementary Schools Dragutin Tadijanovic and Mato Lovrak

- Elementary School Mato Lovrak

- RC structure
- Steel structure
- Timber structure

Very good performance.

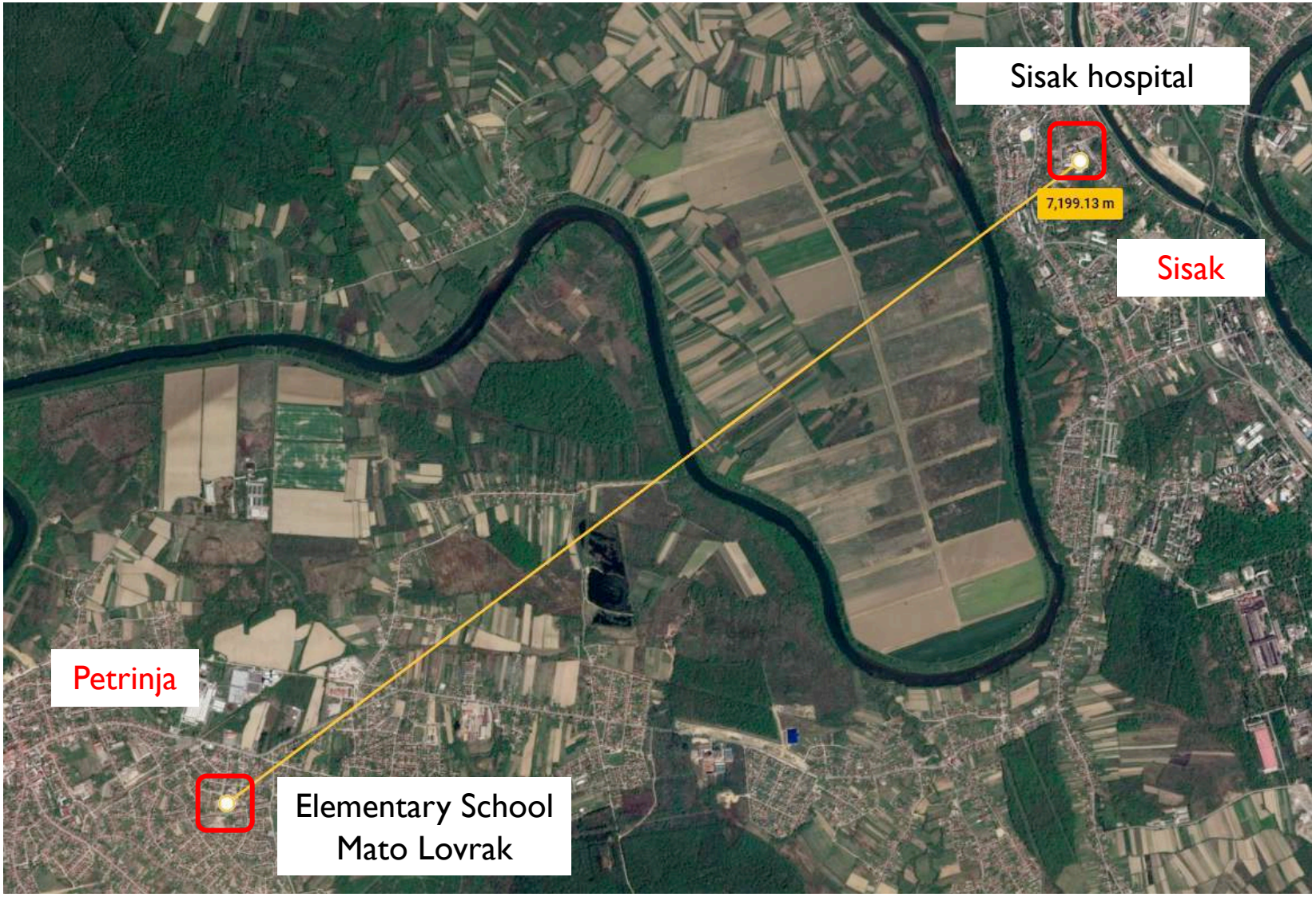
Elementary Schools Dragutin Tadijanovic and Mato Lovrak

- RC structure
- Steel structure
- Timber structure

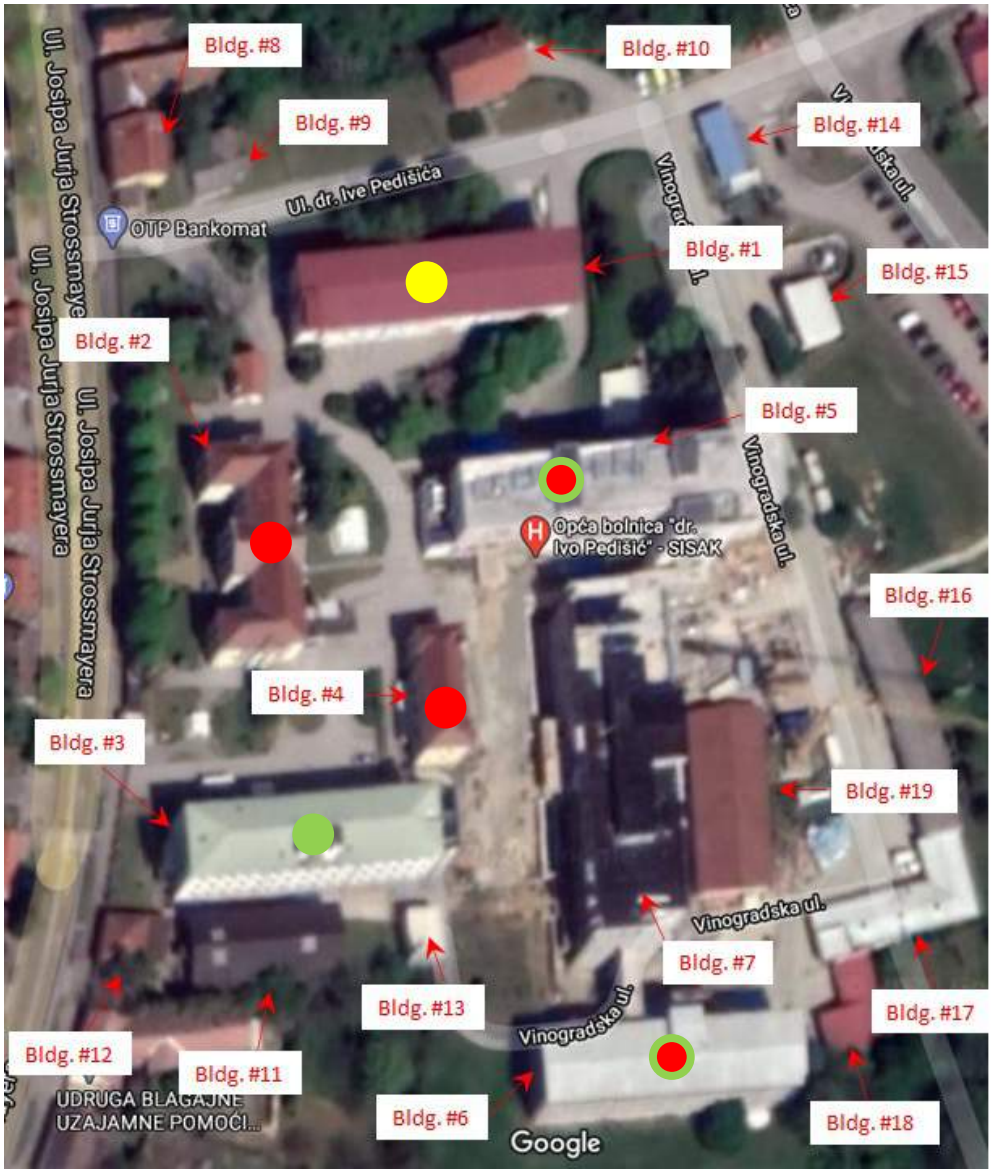
Very good performance.

(source of all photos in the bottom row: Suzana Ereiz)

Walk around the epicenter – Sisak



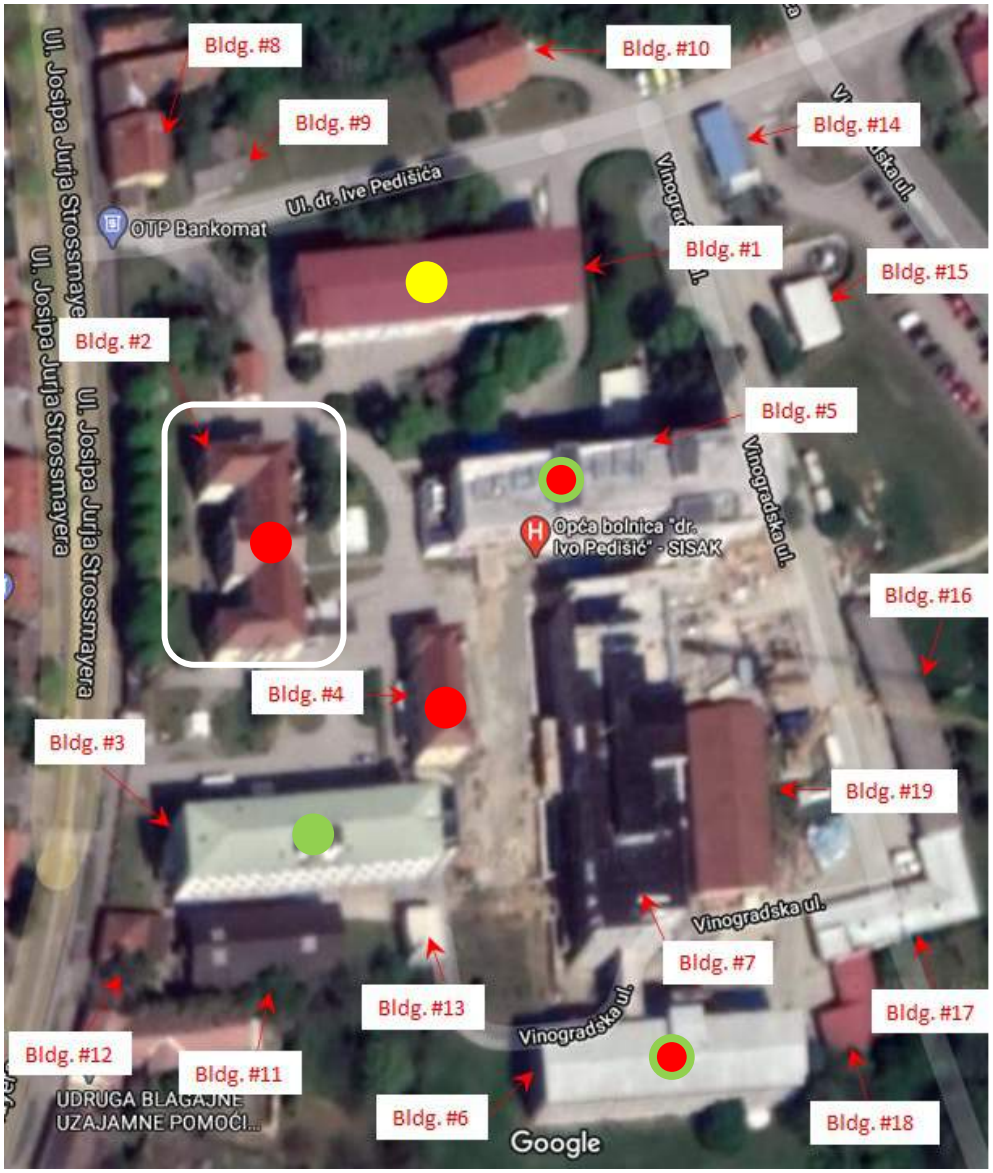
Sisak hospital



- The complex consists of buildings of different age and structure type.

- operational
- partially operational
- non - operational
- good condition but non - operational

Sisak hospital



- Building #2:
  - unreinforced masonry,
  - severly damaged.

operational

partially operational

non - operational

good condition but non - operational

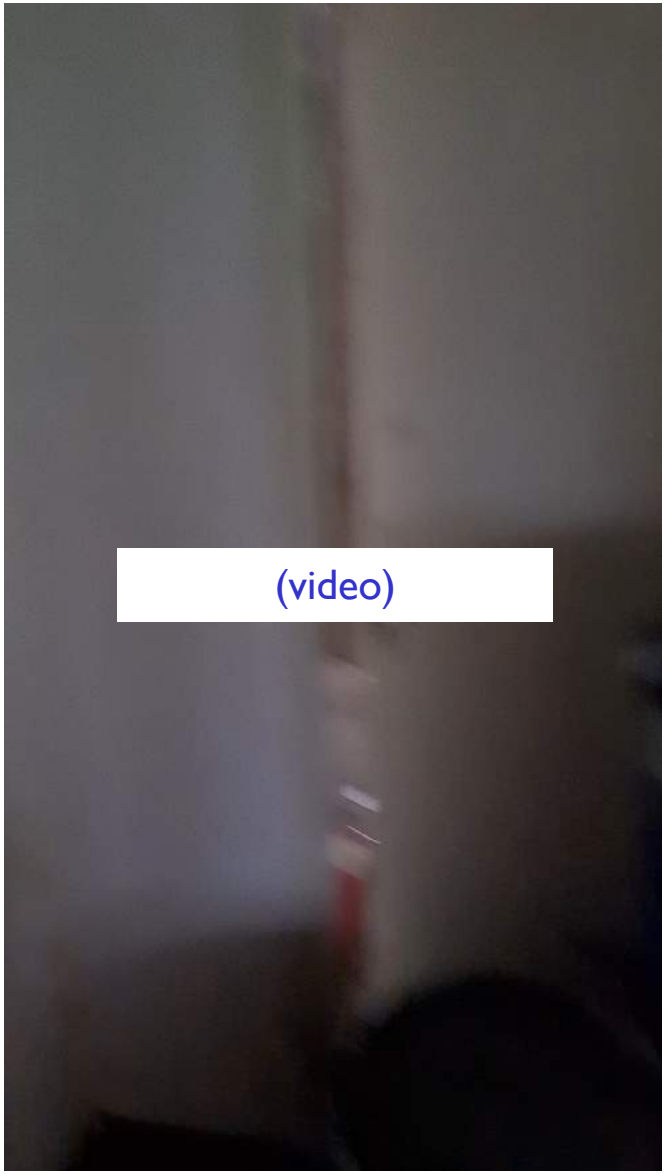
Sisak hospital

- Building #2:

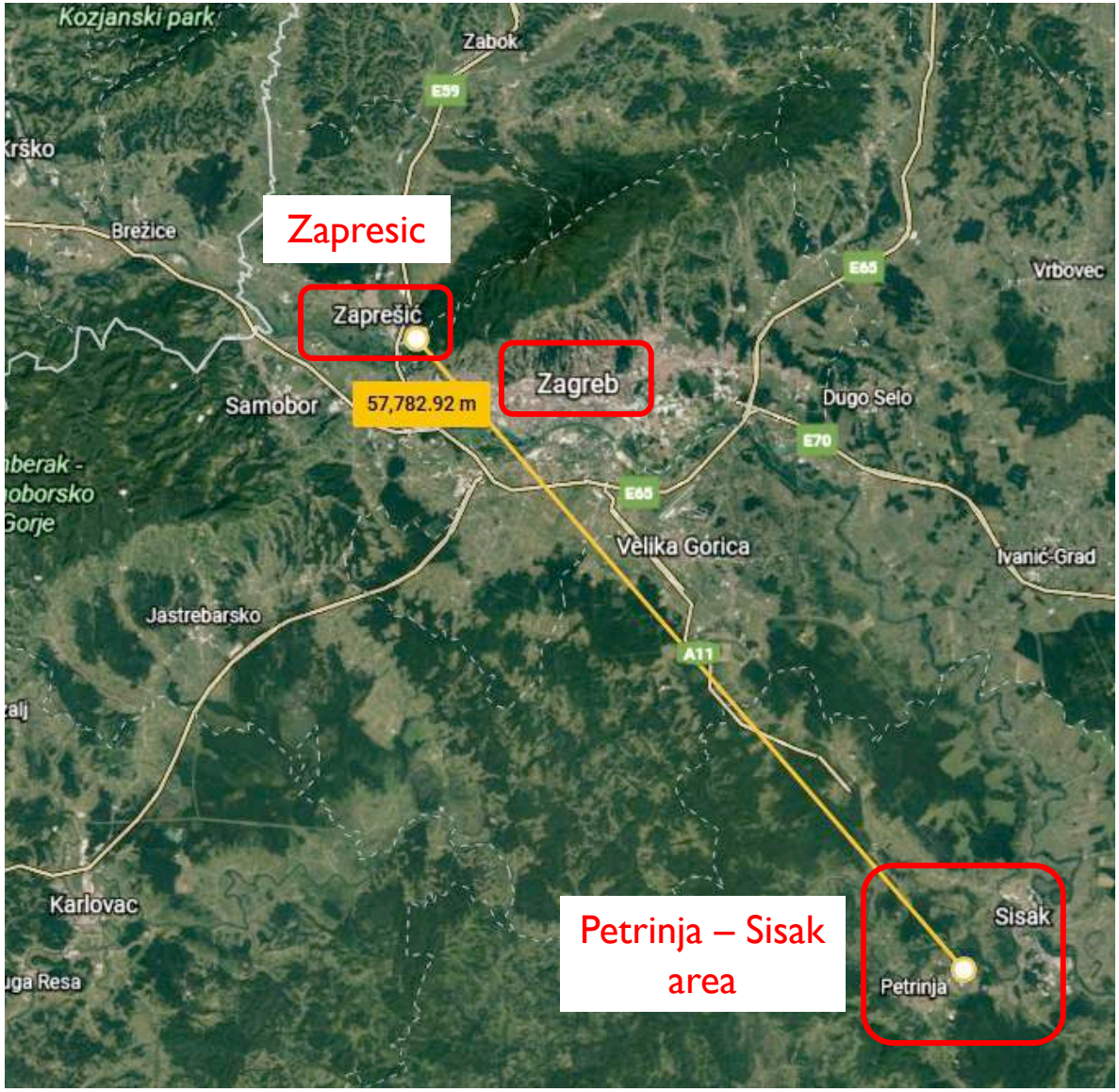
  - wide shear cracks observed from both the inside and the outside,
  - failure of gabel walls,
  - failure of chimneys.

Sisak hospital

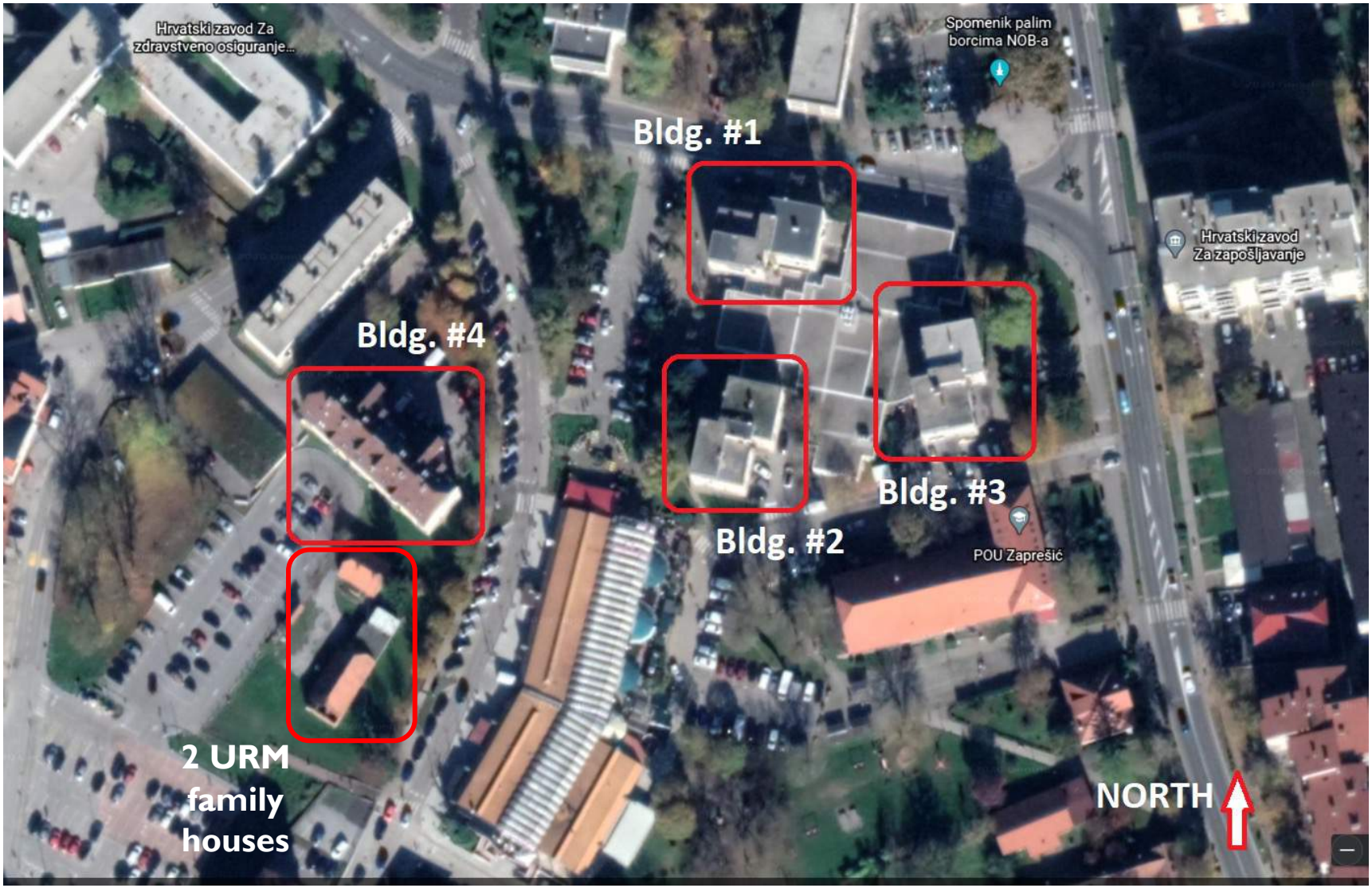
- Building #2 – ground floor.



Walk a bit further from the epicenter - Zapresic



Walk a bit further from the epicenter - Zapresic



Walk a bit further from the epicenter - Zapresic

- Building #4 and a single family URM 10 m away.

- Shear cracks on the ground floor.

- Crushed brick on the ground floor.

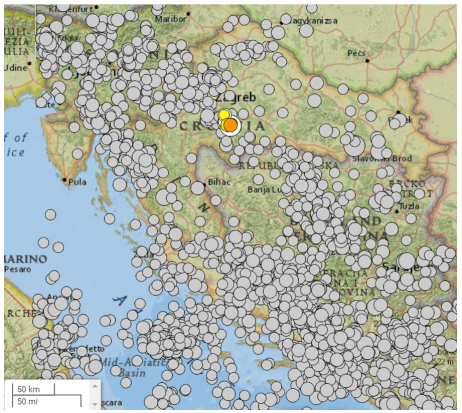
- Undamaged single family URM 10 m away from Building #4.

Walk a bit further from the epicenter - Zapresic

- Building #2: shear cracks on the ground floor, significant cracks throught the building.

Presentation roadmap

The setting & seismicity

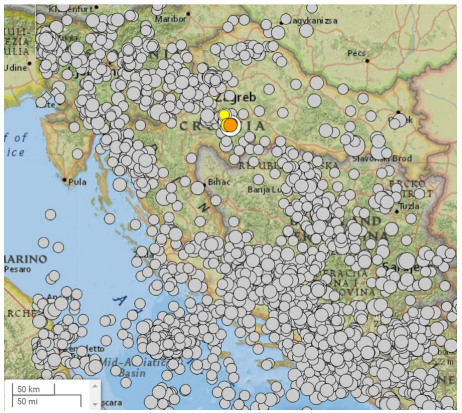


Walk through the epicenter – structural aspects

Walk through the epicenter – geotech aspects

Presentation roadmap

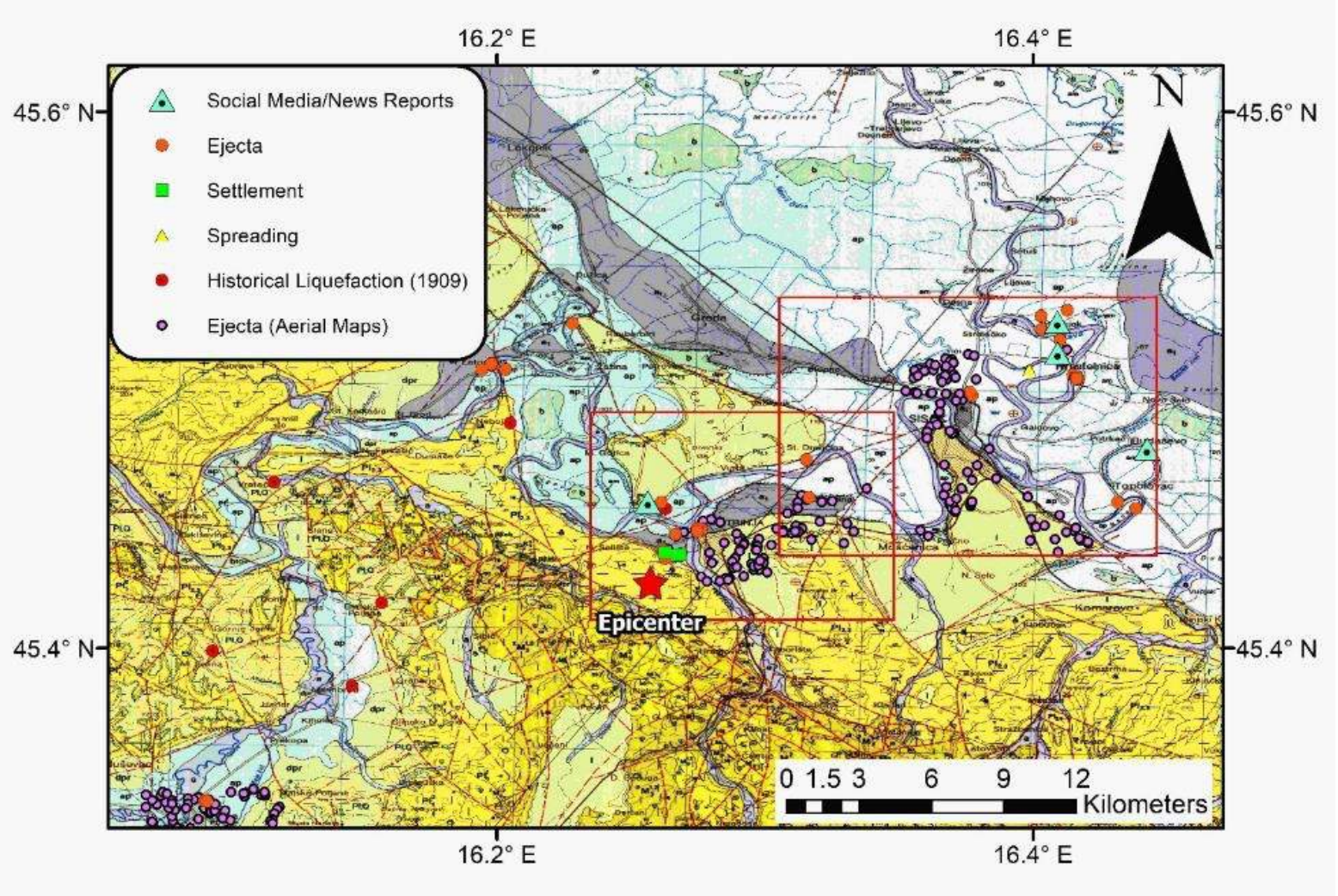
The setting & seismicity



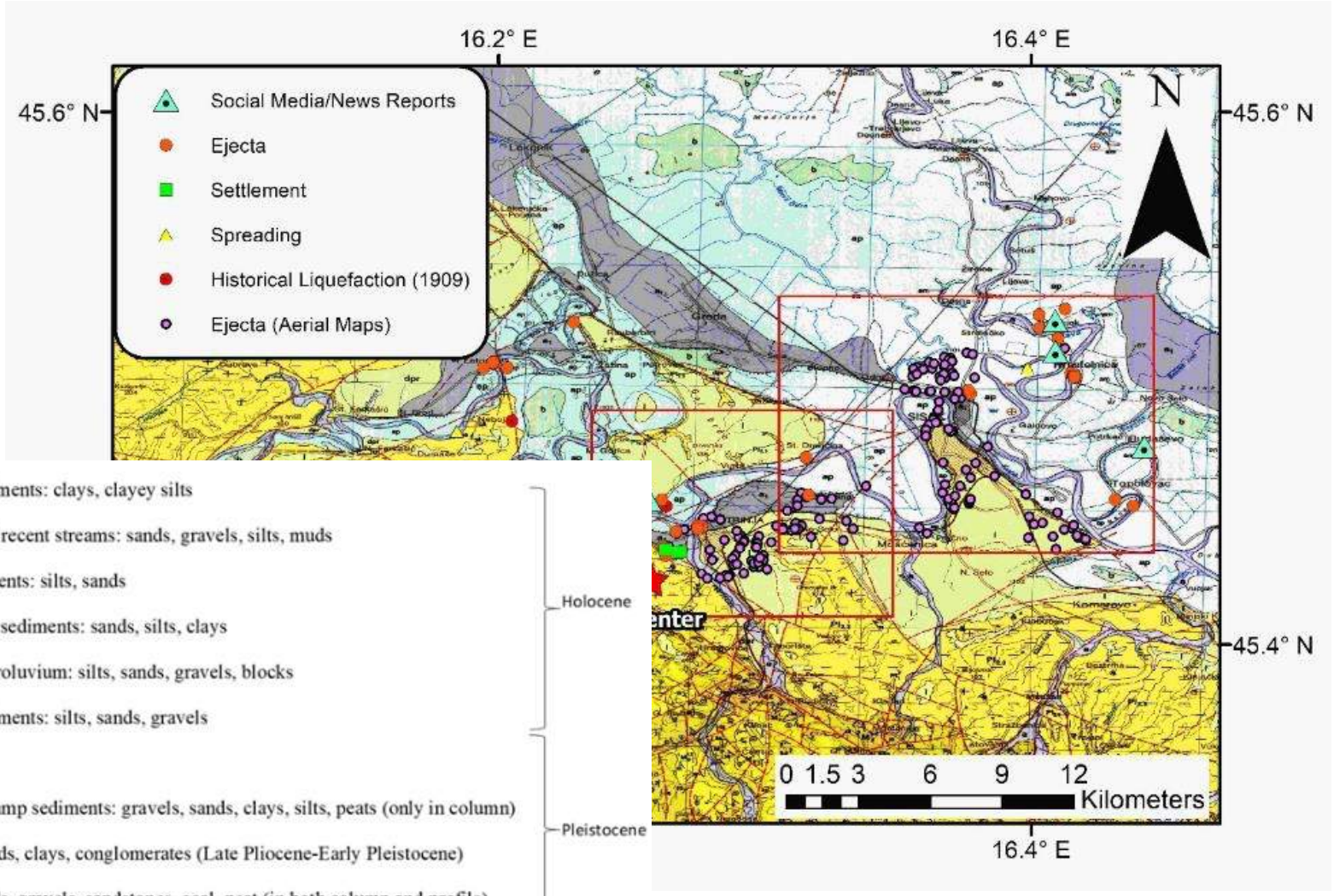
Walk through the epicenter – structural aspects

Walk through the epicenter – geotech aspects

Field and Infrastructure Liquefaction Damage



Field and Infrastructure Liquefaction Damage



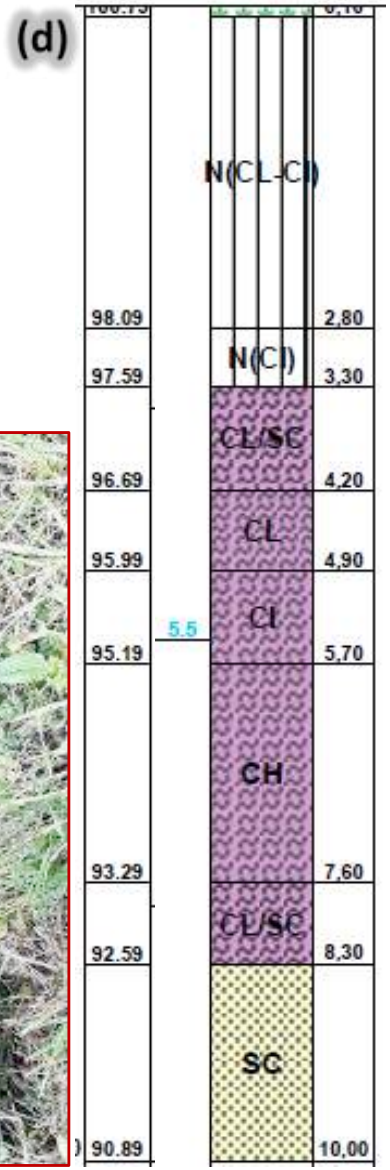
Field and Infrastructure Liquefaction Damage

Ejecta in an agricultural field near Hrastelnica (45.5009N, 16.4166E)

Drenačka Street in Petrinja
(45.4560936N,16.3173009E)

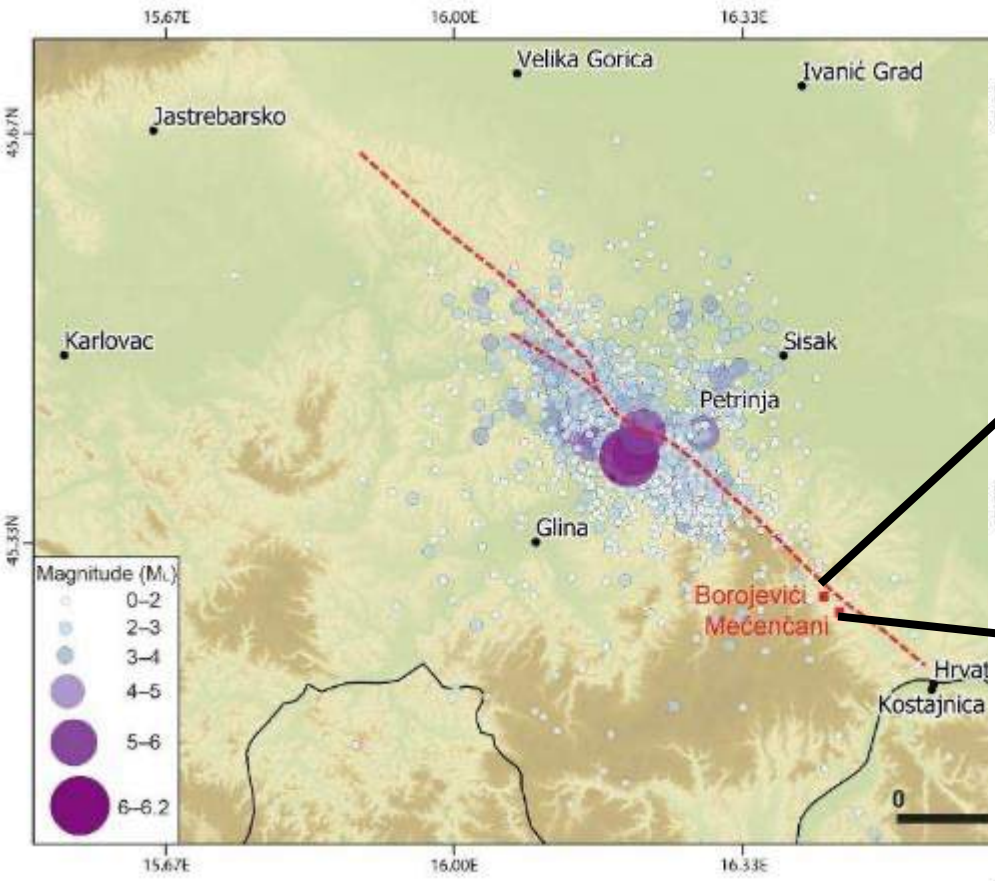
Ejecta in a football field near Letovanić (45.506095N, 16.198165E)

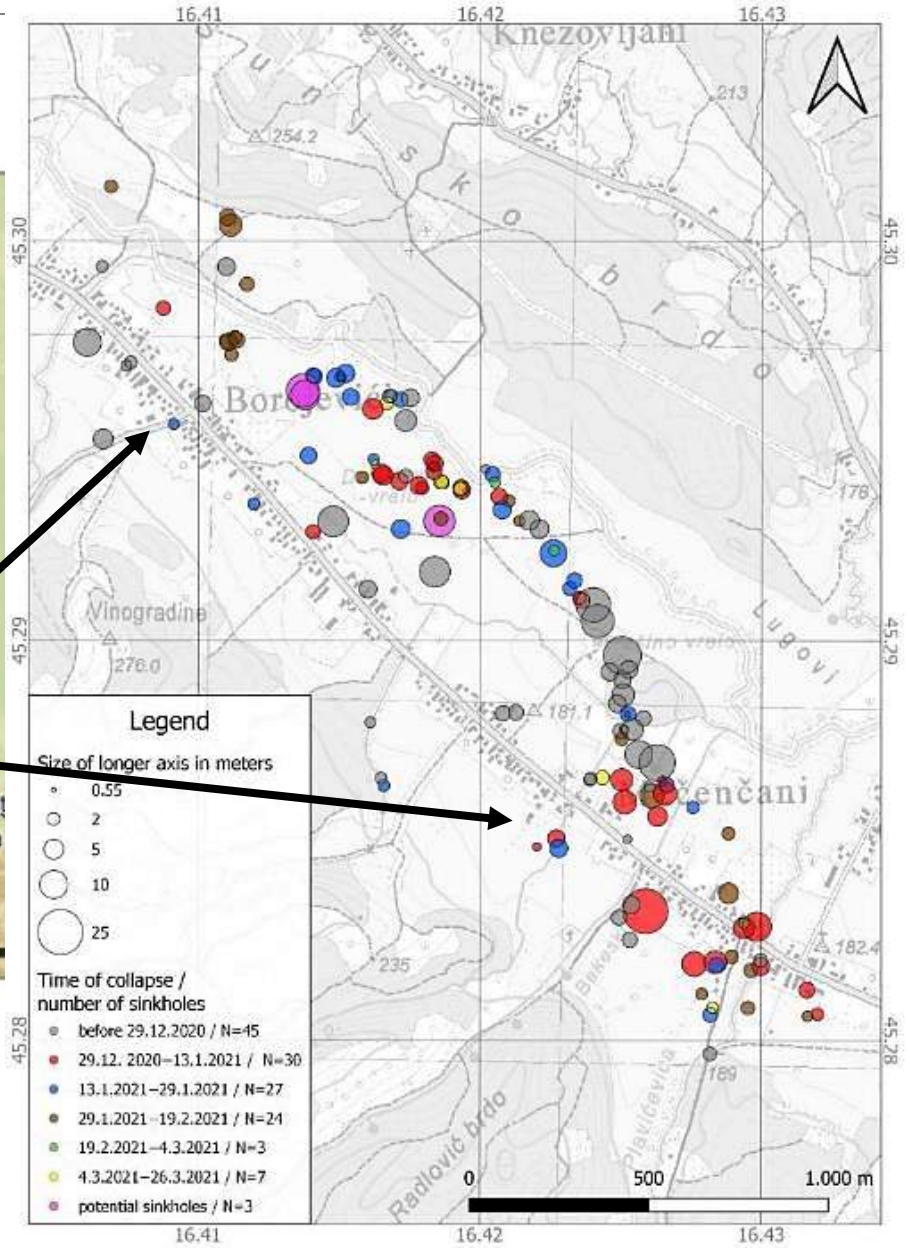
Levee Damage



Unexpected and Rare Post-Seismic Sinkholes

Total of 107 new sinkholes, and 49 fossil sinkholes, were identified in the 4 km^2 area of two villages Mečenčani and Borojevići





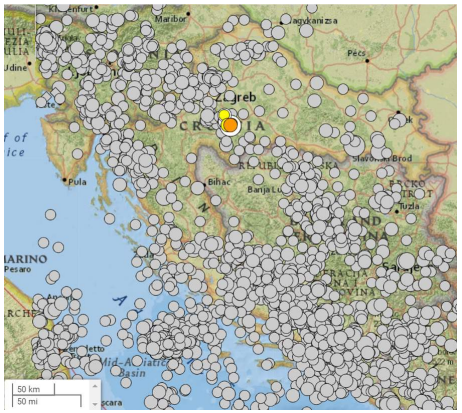
Cover-Collapse Post-Seismic Sinkholes

S001 the largest (45.280618N, 16.431644E)

S015 (45.282859N, 16.429841E)

Presentation roadmap

The setting & seismicity



Walk through the epicenter – structural aspects

Walk through the epicenter – geotech aspects

Summary

The human side – deda (grandpa) Nikola

The human side – deda (grandpa) Nikola

Red tag used by HCPI during their post-earthquake safety evaluations

(HCPI – Croatian Center for Earthquake Engineering)

The human side – deda (grandpa) Nikola's rakija

The best rakija ever

Quick Quake Quote

"Earthquakes never happen at the right time."
Prof. Eduardo Miranda

- March 22, 2020 M5.5 Zagreb
- December 29, 2020 M6.4 Petrinja

+ the pandemic

Vielen Dank!

Questions?

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