Seismic hazard and risk assessment - MSIIS-22 scale

Elaborated on the basis of the deliverable 5.3 and 5.4

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Introduction

The presentation is based on the results of the PostMinQuake project research presented in deliverable 5.3 titled „Seismic Hasard and risk assement” and deliverable 5.4 titled „Risk assessment of the impact of the induced seismicity , elaborated by:

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IGN	Institute of Geonics	Petr Konicek

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Seismic hazard

Seismic hazard describes phenomena generated by earthquakes that have potential to cause harm. Seismic hazard can be evaluated from instrumental, historical, geological observations and typology of buildings.

In order to describe the seismic hazard in post-mining areas , we should carry out the following studies:

- Characteristics of the earthquake event (magnitude and epicentre location);
- Collecting the ground-motion parameters (PGA / PGV) recorded by the monitoring stations in study area;
- Elaborating GMPE for PGV / PGA;
- Elaborating a map of site effects or amplification factors across the area of study;
- Calculating PGV and PGA shake maps;
- Elaborating intensity map in the area of study;
- Applied MSIIS-22 scale (or EMS-98) in order to generate a shake-map in terms of degrees of seismic instrumental intensity;
- Determining of harmfulness of post-mining earthquakes on buildings and on people;
- Determining the assessment of post-mining microseismicity on the risk of sinkholes.

Seismic hazard -seismic monitoring and metadata

In post-mining areas, we distinguish:

Regional seismic monitoring - conducted to determine the location of the post-mining earthquake, magnitude, engineering vibration parameters (PGV, PGA), and other. Data colection of ground motion parametrs used to elaborating GMPE (Ground Motion Prediction Equation)

Local seismic monitoring - carried out to track the development of seismicity in the area of the old shallow exploitation. Information about a specific zone of hazard of a sinkhole

Metadata:

A map of the thickness of Quaternary deposits (grid map) is recommended to elaborate on the study area

At each seismic station, the V_{S30} shear wave velocity should be recognized and the amplification factor should be calculated or the A, B, C, and D ground type according to Eurocode 8 is recommended to designate under each station .

Seismic hazard – testing sites

Basic seismic data on each testing site to study seismic hazard and GMPE:

Gardanne testing site:
3 200 post-mining-induced earthquakes in magnitude range from -3 to 3 and highest recorded on the BULL station PGV=4.9 mm/s and PGA=550 mm/s2 and for an event and frequency range of the main phase of GM from 1 to 20 Hz.

Kazimierz Juliusz testing site:
48 post-mining earthquakes in magnitude range from 0.7 to 2.1 and highest recorded PGV=0.96 mm/s (PGA=65 mm/s2) and frequency range of the main phase of the Ground Motion from 1 to 20 Hz.

Seismic hazard

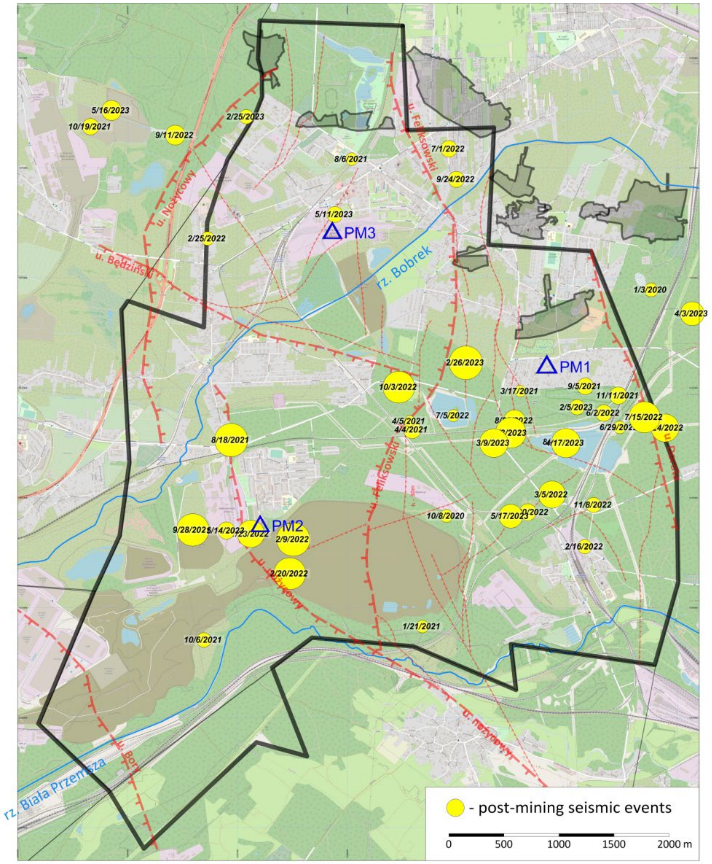
Kazimierz Juliusz testing site – seismicity (2020 – 06.2023)

48 post-mining seismic events (192 PGV data point)

Magnitude: from 0.7 to 2.1

location in tectonic faults area and mined areas.

Water level rised up during flooding process 70m (from 2020 to 06.2023)



Seismic hazard

GMPE (USCB-Kazimierz Juliusz)

The basic form of the attenuation relationship is as follows (Joyner and Boore 1993):

$$\log(GM) = c_1 M + c_2 M^2 - c_3 \log(R) - c_4 R + c_5 S + \varepsilon$$

GM - ground motion, ***M*** – magnitude (seismic energy), ***R*** - hipocentral distence, ***S*** - parameter related to amplification or soil class according to Eurocode 8, ***ε*** - standard error**,** ***c_1÷c_5-*** coefficients estimated through multiple regression analyses.
The hipocentral distance is calculated as ***R=√(r^2+h^2),*** where ***r*** - epicentral distance and ***h*** is the fixed/common depth factor (the depth is estimated)

The peak horizontal ground vibration velocity is calculated using the following formula

$$PGV_H = PGV_{hrock} W_f$$

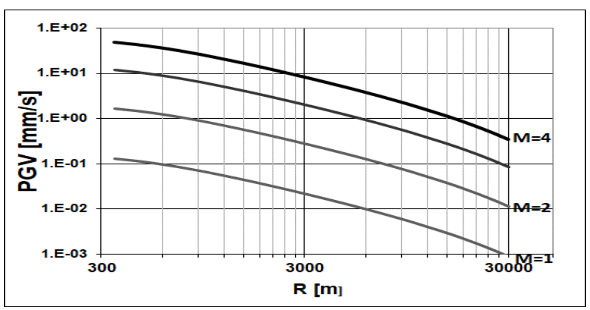
where: W_f - vibration amplification factor in the time domain for dominant bandwidth 2-8Hz - calculating as average values for the frequency range , PGV_{Hrock} - Seismic method - MASW
Thickness of QUOTERNARY deposits

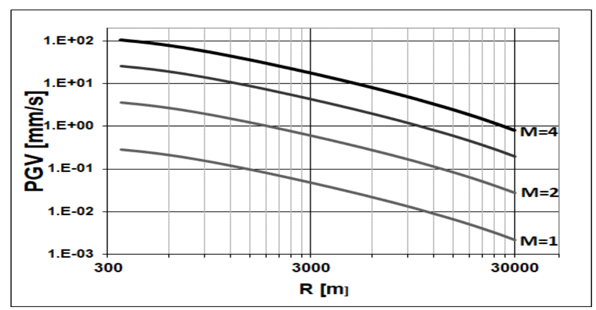
Seismic hazard

GMPE (USCB-Kazimierz Juliusz)

$$\log(PGV_H) = -1.005 + 0.9014 \log E - 0.03425 (\log E)^2$$

$$-0.00001435R - \log(R) + \sum_{i=1}^{n} c_{4i} S_i + 0.2029P$$



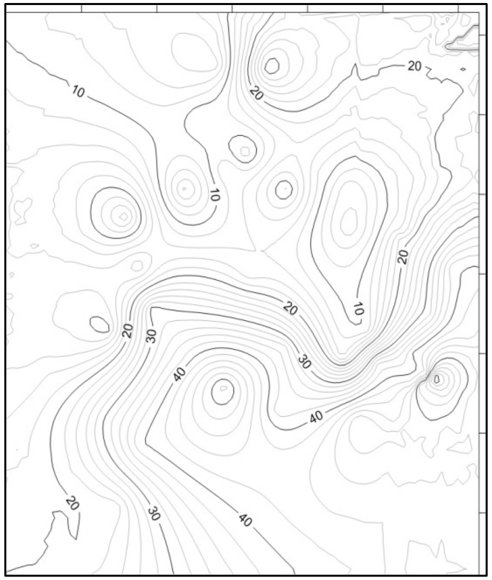


Predicted values of peak horizontal velocity PGV_H for the 50th (a) and 95th (b) percentiles as a function of local magnitude and distance

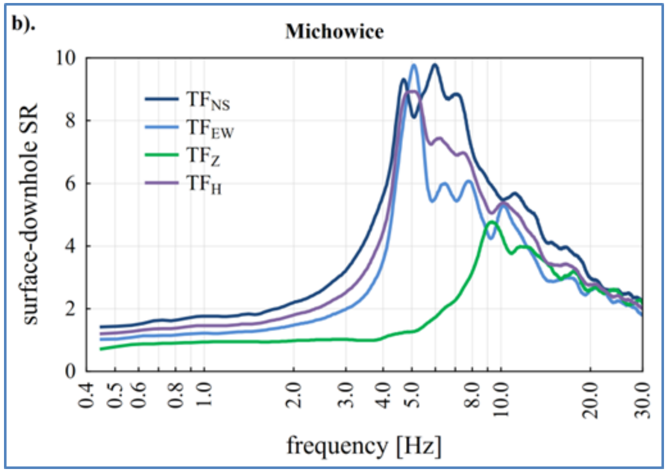
Seismic hazard

Amplification map at Kazimierz Juliusz testing site

Thickness of Quaternary series at Kazimierz Juliusz



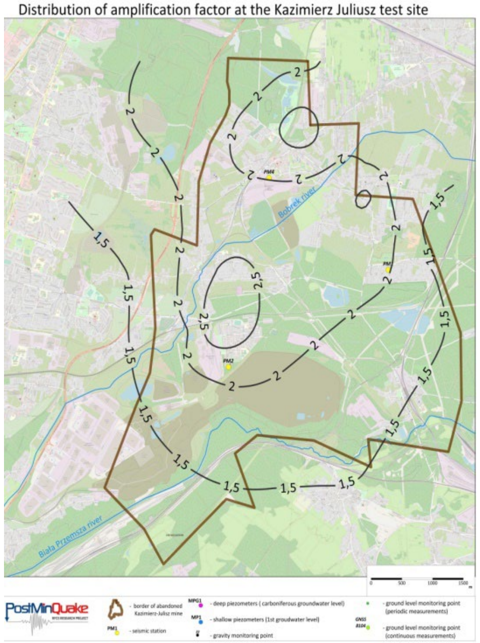
The high amplification effect for post-mining and mining-induced earthquakes is related mainly to quaternary overburden



$f_{rez1} = V/4H$

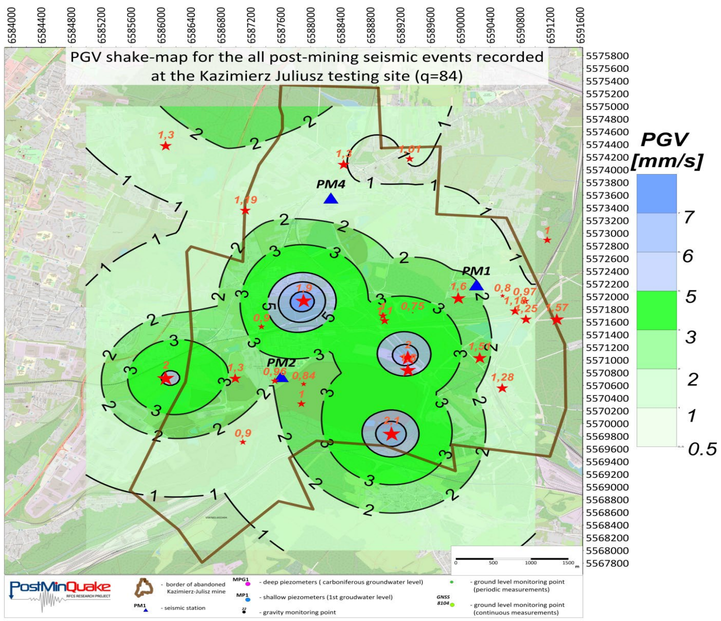
Map of amplification at Kazimierz Juliusz test site avaraged for vibration frequency (2Hz – 8 Hz)

Distribution of amplification factor at the Kazimierz Juliusz test site



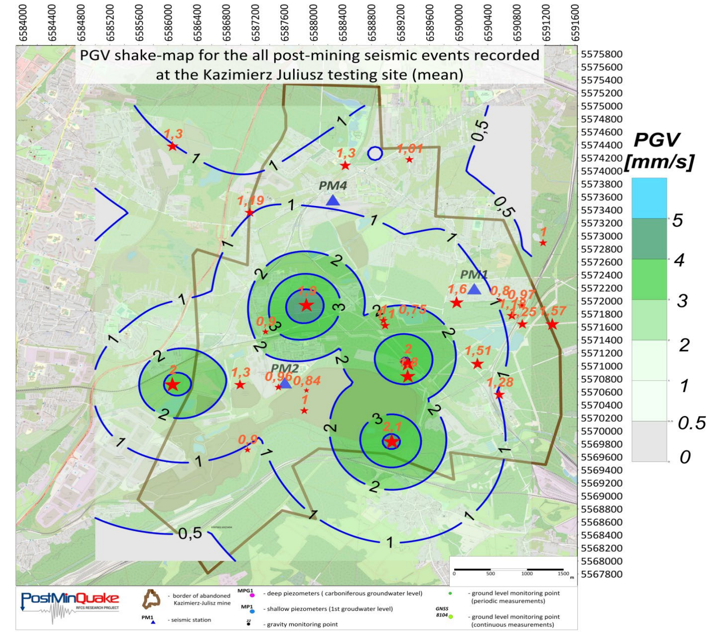
Seismic hazard

PGV shake-maps



Mean value (right):
PGV_H= 5 mm/s

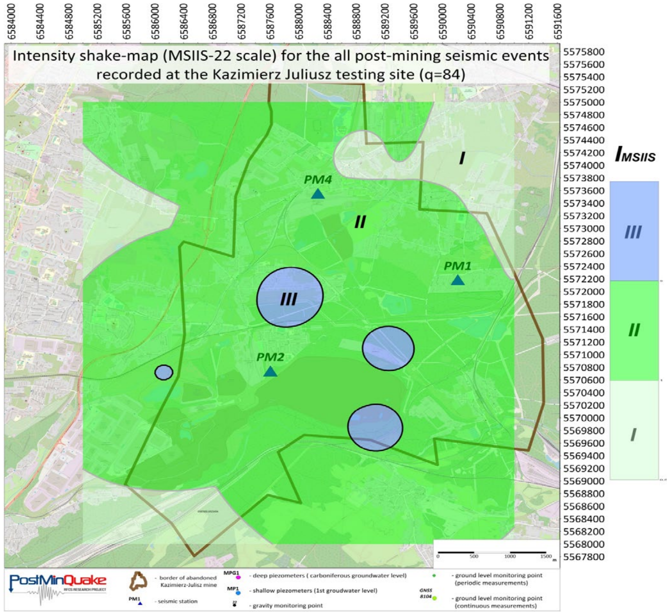
for 84th percentiles (left}:
PGV_H= 7 mm/s

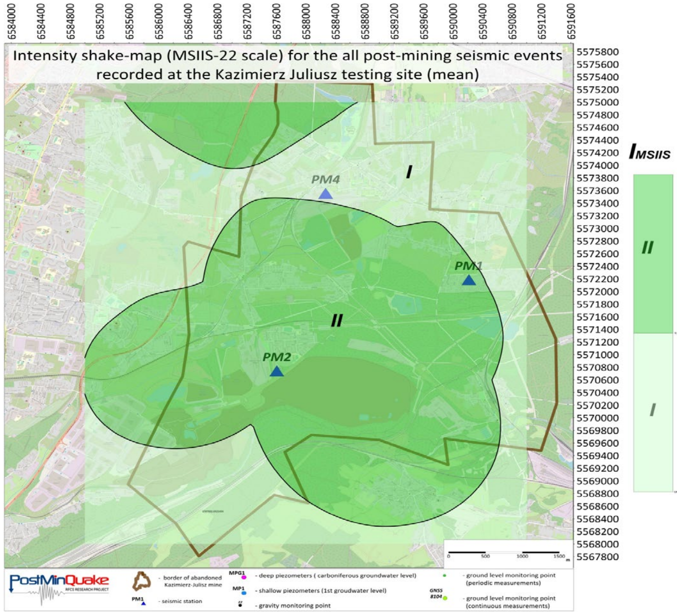


PGV shake-map caused by all post-mining seismic events recorded at the Kazimierz Juliusz testing site from January 2020 to July 2022, using the developed equation for hard soils (class A according to Eurocode 8) and the distribution of the amplification factor in the KJ testing site..

Seismic hazard

MSIIS-22 intensity shake-maps at the Kazimierz Juliusz test site (2020-06.2023)



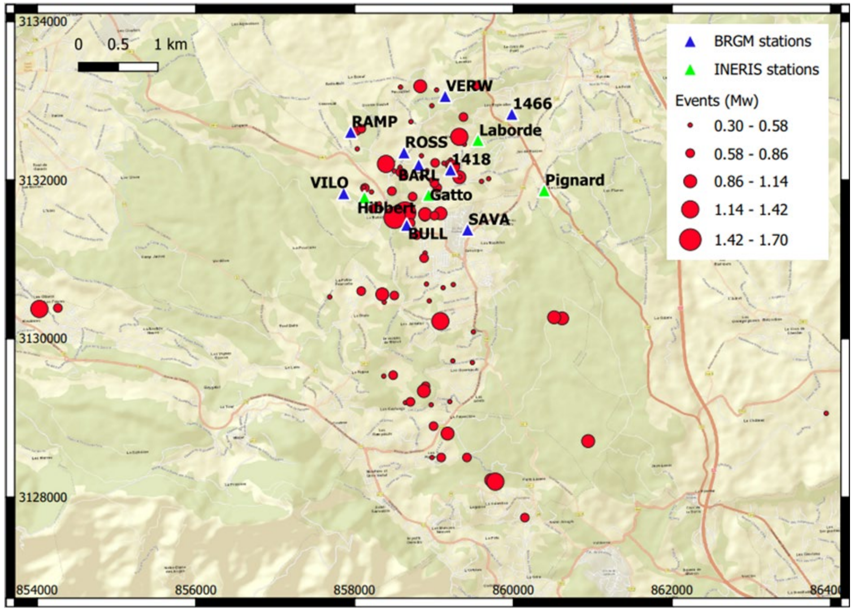


MSIIS intensity shake-maps for the all post-mining seismic events recorded at the Kazimierz Juliusz testing site from January 2020 to July 2022, using PGV$_H$ predicted for the 84th percentiles (left fig.) and 50th percentiles (right fig.)

Seismic hazard – GMPE Gardanne

The seismic data selected to calculation GMPE in Gardanne:

- period 2018-2022, total of 740 data points
- 95 seismic events, recorded by 13 stations



(max recorded PGV seismic station Gatto – 8.8 mm/s

Seismic hazard – GMPE Gardanne

- Regression perfomed with the Bayesian updating method by Kuehn & Abrahamson (2018)

- $$\log_{10} Y = c_1 + c_2 M_w + (c_3 + c_4 M_w) \log_{10} R_{hypo} + c_5 R_{hypo} + T_{site,i} + \eta_j + \varepsilon_{i,j}$$

Site term specific to each station, related to a standard-deviation $\boldsymbol{\sigma_{S2S}}$

Inter-event error ~$N(0,\boldsymbol{\tau})$

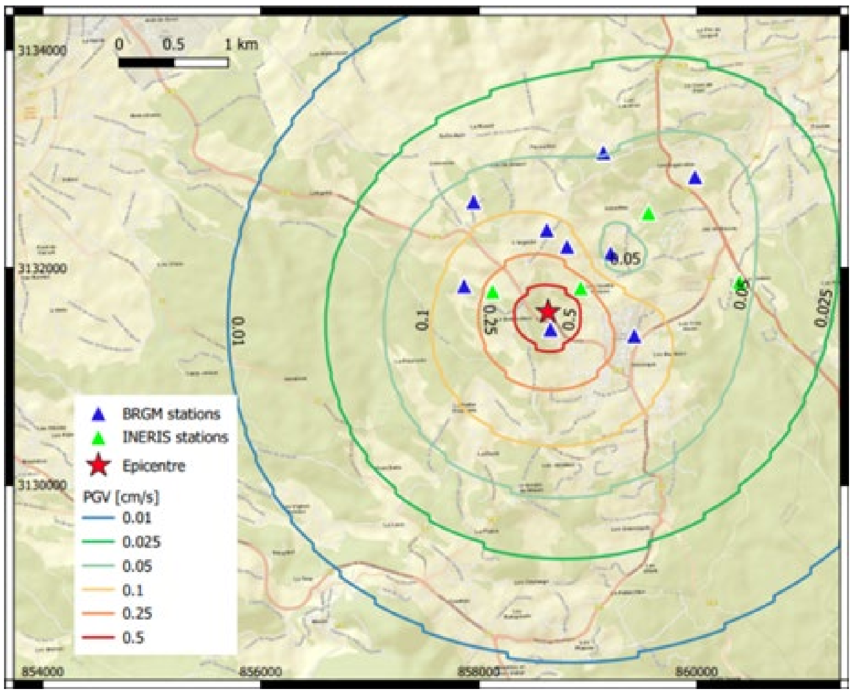
Within-event/within-site error ~$N(0, \boldsymbol{\sigma_{SS}})$

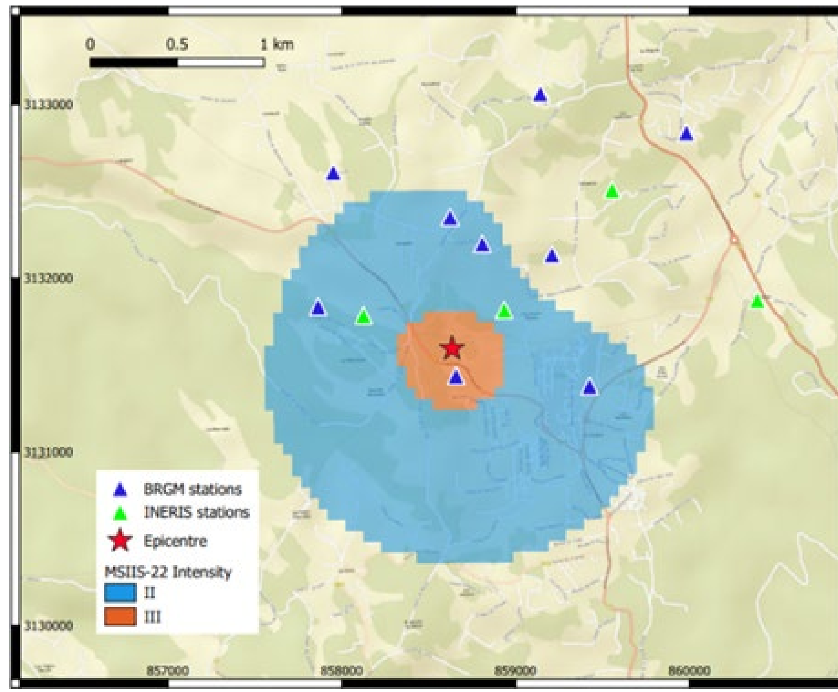
where Θ = [c1; c2; c3; c4; c5] and x = [Mw; Rhyp] are respectively the vectors of GMPE coefficients and predictor variables.

The Bayesian regression allows to estimates the posterior distribution of the predictor variables, as well as of the values of the standard deviations τ, σSS, and σS2S.

Seismic hazard

PGV shake-map , using observations from 13 stations and MSIIS-22 seismic intensity map for the M 1.7 induced earthquake in Gardanne post-mining area.
The method requires the high density of seismic stations in the study sites





PGV >5 mm/s (seismic station Gatto – 8.8 mm/s

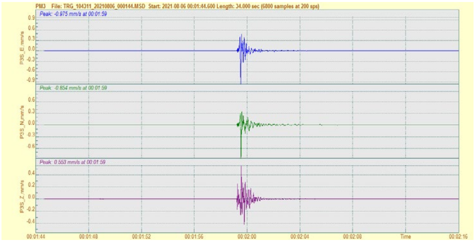
I_{MSIIS} = III (felt indoors by many people, potential damage of buidings - none

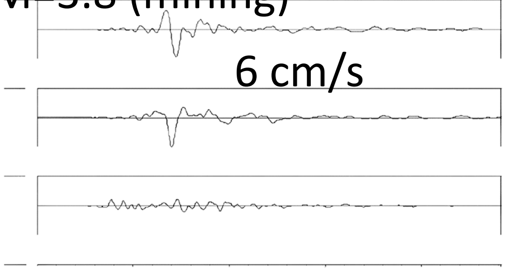
Mining and Post-Mining Seismic Instrumental Intensity scale - MSIIS-22

Characteristic of mining and post-mining induced earthquake

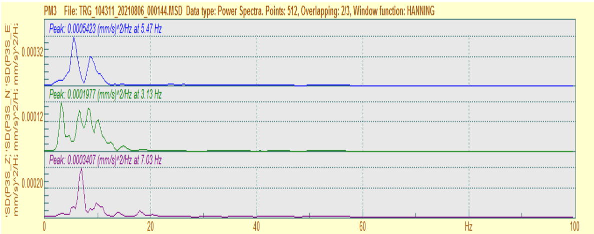
06.08.2021, M=1.3, Kazimierz Juliusz, PM3
(post-mining)

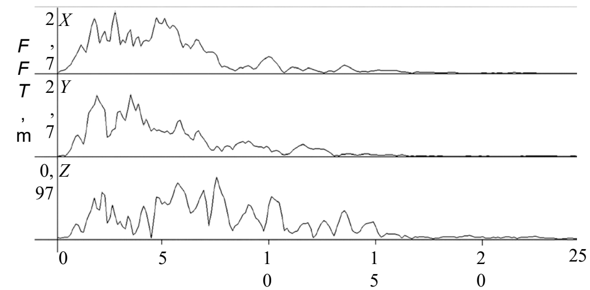
30.09.2015 mining induced sejsmic event,
Janina Mine, M=3.8 (mining)



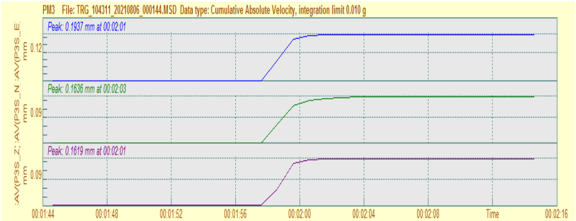


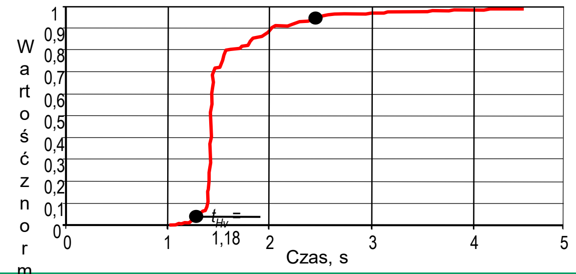
PGV - shear
wave in epicenter.
No surface waves
in epicentral area





Frequency of the
main phase of
ground motion 1-10Hz



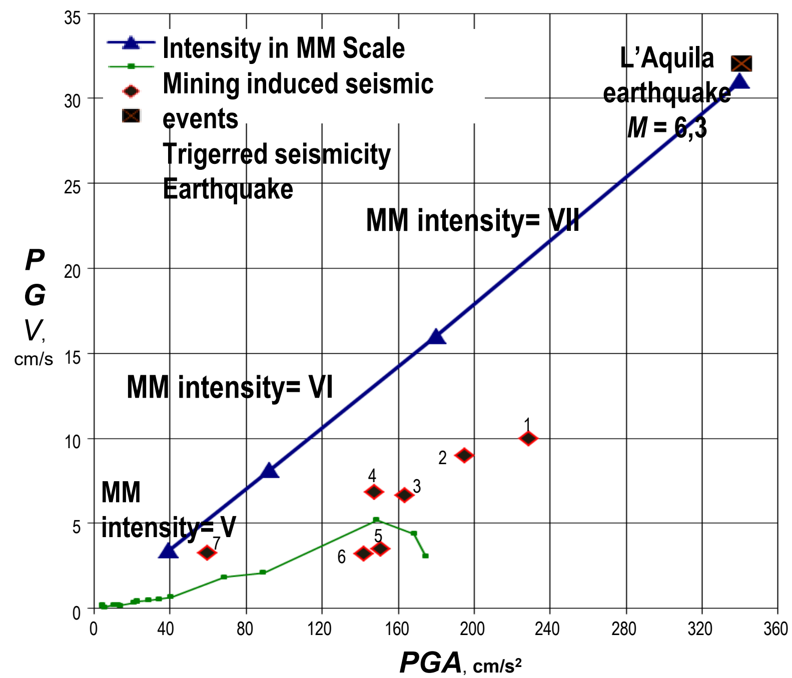


short time duration
- few second

Mining and Post-Mining Seismic Instrumental Intensity scale - MSIIS-22

Natural earthquakes –Induced earthquakes

Earthquake instrumental intensity scales (e.g. MMI), design for natural seismicity, are not suitable for assessing the effects of vibrations generated by induced seismic events in buildings, because they characterise by different engineering parameters (PGV /PGA, duration time of main vibration phase, frequency of the main phase, response spectra etc.)



Seismic energy of mining trigerred tremors

1 – KWK Śląsk, Panewniki 4E9 J
2 – KWK Bobrek, Bytom 9E8 J
3 – KWK Janina, Żarki 9E8 J
4 – ZG Rudna, Polkowice 1,9E9 J
5 – KWK Śląsk, Panewniki 8E7 J
6 – KWB Bełchatów, Szczerców 1,6E9 J
7 – KWK Piast, Chełm 3E9 J

Mining and Post-Mining Seismic Instrumental Intensity Scale -MSIIS-22

The MSIIS-22 scale was developed in the PostMinQuake project, but its construction and basis uses previously developed versions for induced seismicity developed for Polish coal mines at Central Mining Institute with the participation of Polska Grupa Węglowa (latest version of GSIS-2017) and for mines in Europe as part of the COMEX project (MSIS-15)

MSIIS-22 is applied to assess the impact of vibrations (PGV) caused by mining and post-mining induced earthquake on buildings, the perceptibility of vibrations by people, the nuisance level of using buildings and empirical dynamic resistance criterion for buildings.

The application of the instrumental intensity I_{MSIIS} requires determining two parameters:

- velocity of ground motion (PGV)
- duration of vibration

and to assess the degree of harmfulness vibrations in buildnigs for the instrumental measurement levels of the I_{MSIIS} seismic intensity:

- building typology
- building technical conditions

Mining and Post-Mining Seismic Instrumental Intensity scale - MSIIS-22

Short form of the Mining and PostMining Instrumental Intensity Scale MSIIS-22 (more details in Deliverable 5.3 of the PostMinQuake project)

MSIIS-22 Degrees of seismic instrumental intensity I_{MSIIS}	Vibration velocity (mm/s) for short time duration impact ($t \leq 1.5$ s)	Vibration velocity (mm/s) for long time duration impact ($t > 1.5$s)	Perceived shaking Subtitle	Potential damage of buidings	Degrees of harmfulness of vibrations in buildings S
I	<1	<1	Not felt or very weak felt	none	S_1
II	≤5	≤5	weakly felt or felt indoors	none	S_2
III	5 - 20	5 - 10	Felt indoors by many people, outdoors by few. Dishes rattle, hanging objects begin to swing.	none	S_3
IV	20 - 40	10 - 25	Felt strongly indoors by many people. Weak shaking of the whole building. Open windows and doors may close.	Intensification of existing damages	S_4
V	40 - 60	25 - 40	Felt strongly by most people. Many people are frightened and run outdoors. Furniture may be shifted. Rocking of the whole building.	Damage to decorative elements. Fall of pieces of plaster. Hair-line cracks in walls. Failure of partitions or gable walls	S_5
VI	60 - 90	40 - 60	Felt very strongly by most people. Most people are frightened and try to run outdoors. A few people lose balance. Objects fall from shelves in large number.	Slight single structural damages. Chimney fracture at the roof line. Large cracks in most walls, Failure of gable walls	S_6

Mining and Post-Mining Seismic Instrumental Intensity Scale - MSIIS-22

VII	90 - 160	60 - 100	Most people have a problem with balance. Fear and panic. In single cases, heavy objects, such as TV sets and furniture, can fall over. Objects fall from shelves in large number	Vibrations can damage structural elements of buildings. Collaps of chimney. Seismic event significantly reducing their dynamic resistance, when the low frequency range of the main phase of horizontal vibrations, f <5 Hz take place. The stability of buildings is not threatened.	S_7
VIII	> 160	>100	The entire building sways and creaks, and furniture can move, sway, and overturn. People are very scared and run outside, most of them lose their balance. There is a danger to people outside the building - falling tiles, cornices, bricks from chimneys, gable walls. Nuisance unacceptable for tenants of buildings.	Damage to structural elements threatening the stability of the structure. Ground motion can cause very large damage to the most severely stressed elements of building structures. Vibrations are particularly dangerous in the low frequency range of the main phase of horizontal vibrations, f <5 Hz.	S_8

Subtitle

The following types of buildings were distinguished in the observations:
Masonry buildings **(I)**

- simple stone masonry **(I-A)**
- unreinforced brick masonry **(I-B)**
- unreinforced brick masonry with RC floor **(I-C)**
- reinforced masonry **(I-D)**

Reinforced concrete wall structures buildings **(II)**
Reinforced concrete frame buildings **(III)**

Mining and Post-Mining Seismic Instrumental Intensity Scale - MSIIS-22

Levels of nuisance for used buildings.

Inconvenience	***Disruption of normal use***	***Perceiving the mining tremors by people***	***$I_{MSIIS-22}$ intensity***
Imperceptible	Practically does not occur	Negligible	I - II
Small	Insignificant	Noticeable	III
Medium	Hinder the usage	Rising adverse reactions	IV - V
High	Interruptions in use may occur	Annoying and fear	VI - VIII

Mining and Post-Mining Seismic Instrumental Intensity Scale - MSIIS-22

Relation of the degrees of the instrumental measurement intensity **I_{MSIIS}** with the degrees of harmfulness **S** depending on the type of building structure and its technical condition

<table>
<tr><th rowspan="2">MSIIS-22
Degrees of seismic instrumental Intensity
I_{MSIIS}</th><th>Masonry buildings (I):
unreinforced brick masonry (I-B)
unreinforced brick masonry with RC floor (I-C)</th><th>Reinforced concrete wall structures buildings (II)
and
reinforced masonry (I-D)</th><th>- Reinforced concrete frame buildings (III)</th><th>Buildings in poor technical condition</th></tr>
<tr><th colspan="3">Buildings in good technical condition</th><th></th></tr>
<tr><td colspan="5">Degrees of harmfulness S corresponding to degrees of instrumental intensity I_{MSIIS}</td></tr>
<tr><td>I</td><td>S_1</td><td>S_1</td><td>S_1</td><td>S_1</td></tr>
<tr><td>II</td><td>S_2</td><td rowspan="2">S_2</td><td>S_2</td><td>S_2-S_3</td></tr>
<tr><td>III</td><td>S_3</td><td>S_3</td><td>S_4</td></tr>
<tr><td>IV</td><td>S_4</td><td>S_3</td><td>S_4</td><td>S_5</td></tr>
<tr><td>V</td><td>S_5</td><td>S_4</td><td>S_5</td><td>S_6</td></tr>
<tr><td>VI</td><td>S_6</td><td>S_5</td><td>S_6</td><td>S_7</td></tr>
<tr><td>VII</td><td>S_7</td><td>S_6</td><td>S_7</td><td>S_8</td></tr>
<tr><td>VIII</td><td>S_8</td><td>S_7</td><td>S_8</td><td>*Strong* S_8</td></tr>
</table>

Mining and Post-Mining Seismic Instrumental Intensity Scale - MSIIS-22

Dynamic resistance categorisation depending on building's type

	Buildings in good technical condition			
Degree of measured seismic intensity	Masonry buildings (I) unreinforced brick masonry (I-B) unreinforced brick masonry with RC floor (I-C)	Reinforced concrete wall structures buildings (II) and reinforced masonry (I-D)	Reinforced concrete frame buildings (III)	
	Dynamic resistance levels			
I	full	full	full	
II	full	full	full	No vibration destructive potential
III	**full**	full	**full**	
IV	**high**	**full**	**high**	
V	**acceptable**	**high**	**acceptable**	
VI	**conditional**	**acceptable**	**conditional**	Structural safety threshold
VII	**conditional**	**conditional**	**conditional**	
VIII	**unacceptable**	**unacceptable**	**unacceptable**	

Mining and Post-Mining Seismic Instrumental Intensity Scale (MSIIS-22)

Conclusions

The assessment of seismic hazards in post-mining areas is inextricably linked to the appropriate monitoring of induced seismicity

To determine the level and effects of post-mining earthquakes, it is necessary to know the vibration parameters at the assessed site. For this purpose, ground motion prediction equations (GMPE) and spatial variation of ground motions for sites were recommended (PGV and I_{MSIIS} shake maps)

To assess the intensity of mining and post-mining earthquakes, the MSIIS-22 instrumental intensity scale was developed in the PostMinQuake project, using the parameter of Horizontal Ground Motion Velocity PGVH, vibration duration, and vibration frequency.

The assessment of the effects of vibration harmfulness in buildings, the levels of nuisance for used buildings by people, affected by post-mining earthquakes was elaborated in the MSIIS-22 scale.

Mining and Post-Mining Seismic Instrumental Intensity Scale (MSIIS-22)

Conclusions

The MSIIS-22 intensity scale allows for an empirical assessment of the resistance of buildings to mining and post-mining earthquakes.

The observations on testing sites in Gardanne, Kazimierz Juliusz, and Ostrava -Petrvald positively verify the operation of the MSIIS-22 scale, according to which the vibrations were at maximum intensity level of degree III.

Seismic risk assessment

What is a risk ?

RISK = HAZARD X EXPOSURE X VULNERABILITY

Seismic risk assessment

What is a risk ?

RISK = HAZARD X EXPOSURE X VULNERABILITY

Earthquake characteristics

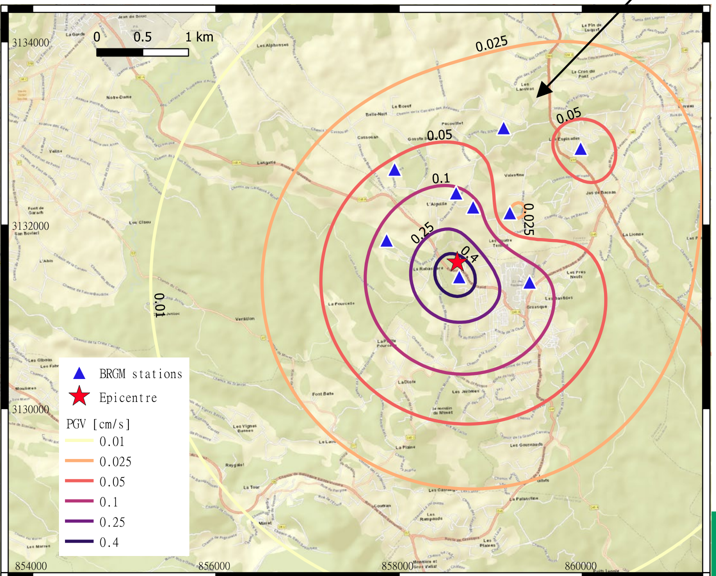
Magnitude
Intensities
Soil amplification
…

Seismic risk assessment

What is a risk ?

RISK = HAZARD X EXPOSURE X VULNERABILITY

PGV Shakemap

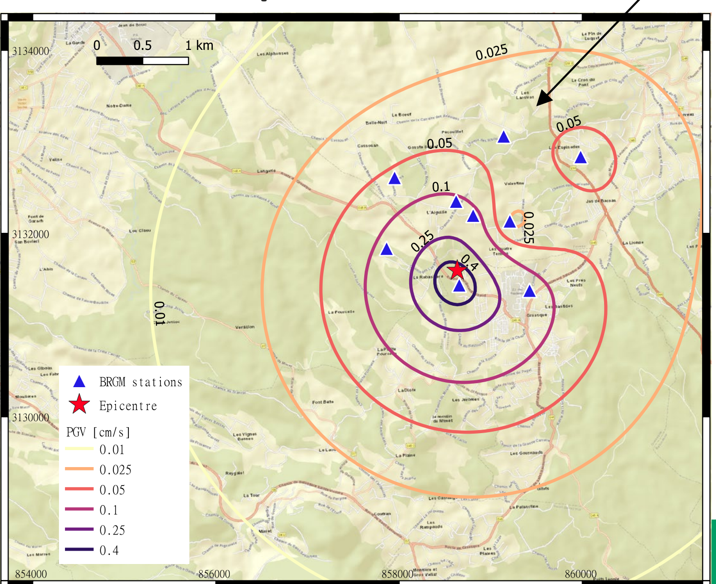


Seismic risk assessment

What is a risk ?

RISK = HAZARD X EXPOSURE X VULNERABILITY

PGV Shakemap



Exposed elements

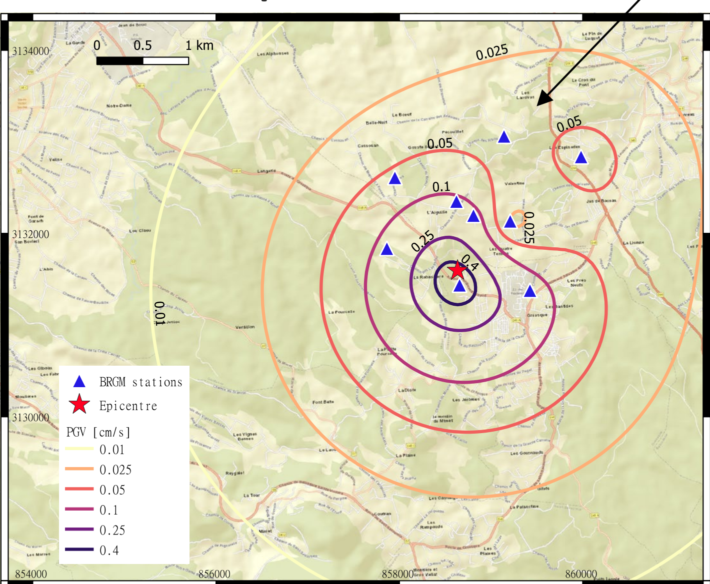
Population
Buildings
…

Seismic risk assessment

What is a risk ?

RISK = HAZARD X EXPOSURE X VULNERABILITY

PGV Shakemap



Exposed elements

Population
Buildings
...

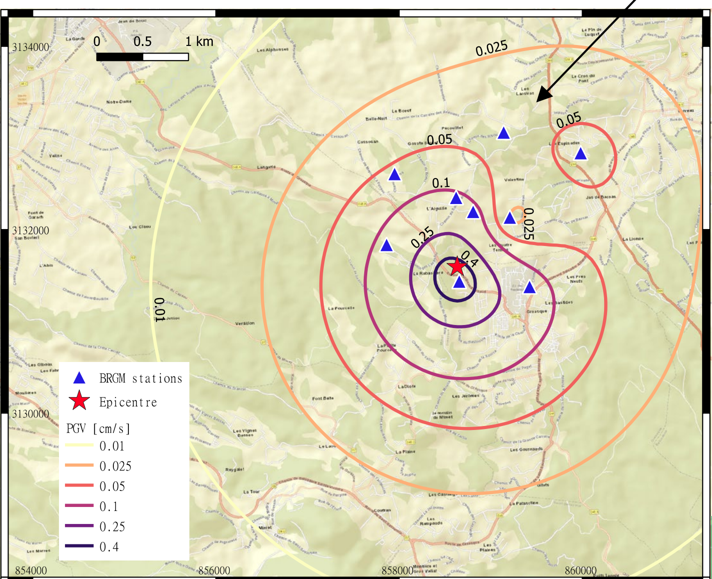
Level of fragility of elements exposed to a phenomenon

Seismic risk assessment

What is a risk ?

RISK = HAZARD X EXPOSURE X VULNERABILITY

PGV Shakemap



Exposed elements

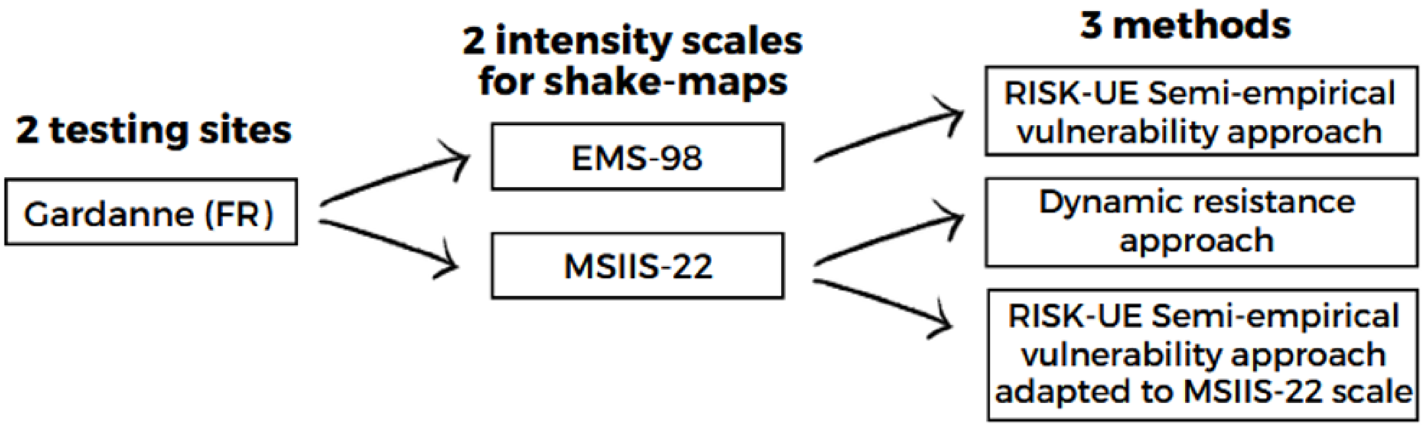
Population
Buildings
…

Building typology and associated vulnerability

Type	Type RISK-UE	Sous-type	Description	Période de construction	Photo	V^{min}	V*	V^{max}
		$T1_i$	Bâtiment en pierre **isolé**	**Avant 1970**		0.62	**0.76**	1.02
T1 : Pierre	M1.1	$T1_m$	Bâtiment en pierre **mitoyen**	**Avant 1970**		0.62	**0.88**	1.02
		$T1_{mc}$	Bâtiment en pierre **mitoyen** avec des **commerces au RDC**	**Avant 1970**		0.62	**0.92**	1.02

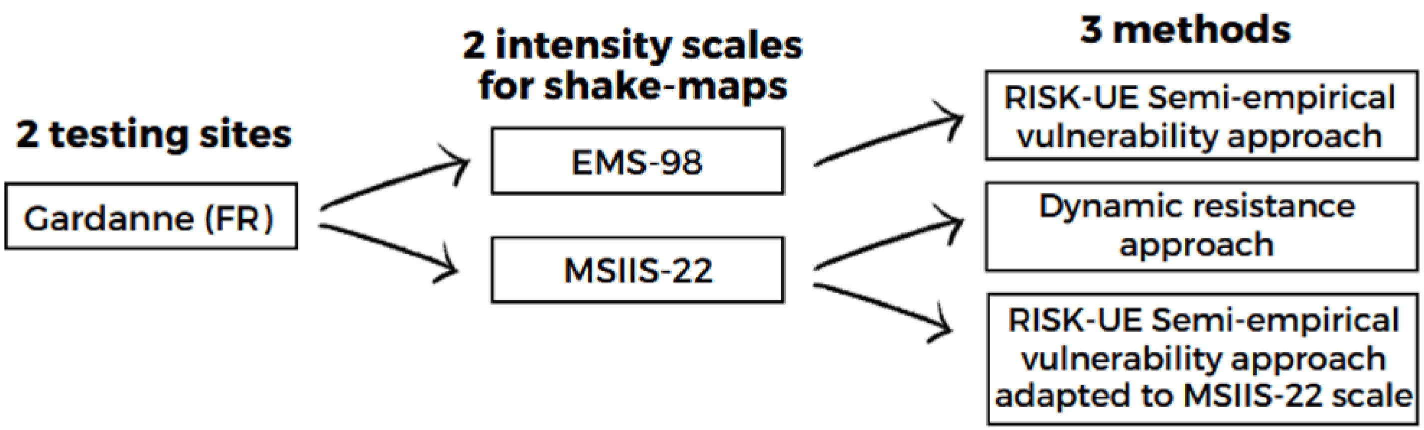
Seismic risk assessment

Methods developped to calculate risk assessment



Seismic risk assessment

Methods developped to calculate risk assessment

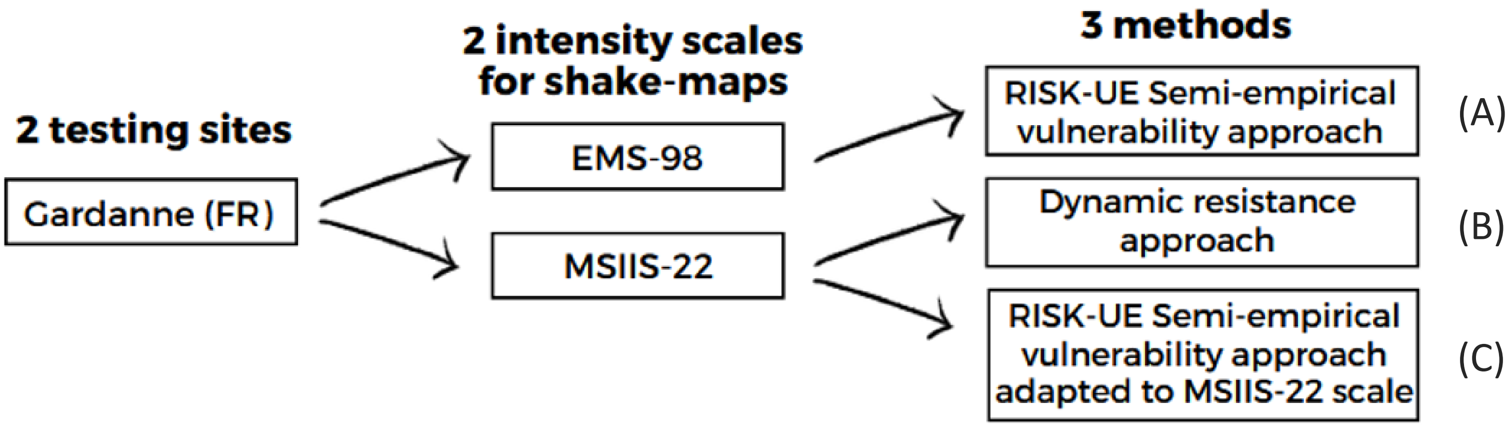


(A)

Method A – « Conventional » damage assessment (Risk-UE approach)

Seismic risk assessment

Methods developped to calculate risk assessment



Method A – « Conventional » damage assessment (Risk-UE approach)

Method B – Dynamic resistance approach : application of the MSIIS-22 Scale

Method C – Adaptation of the Risk-UE approach to the MSIIS-22 scale

Seismic risk assessment

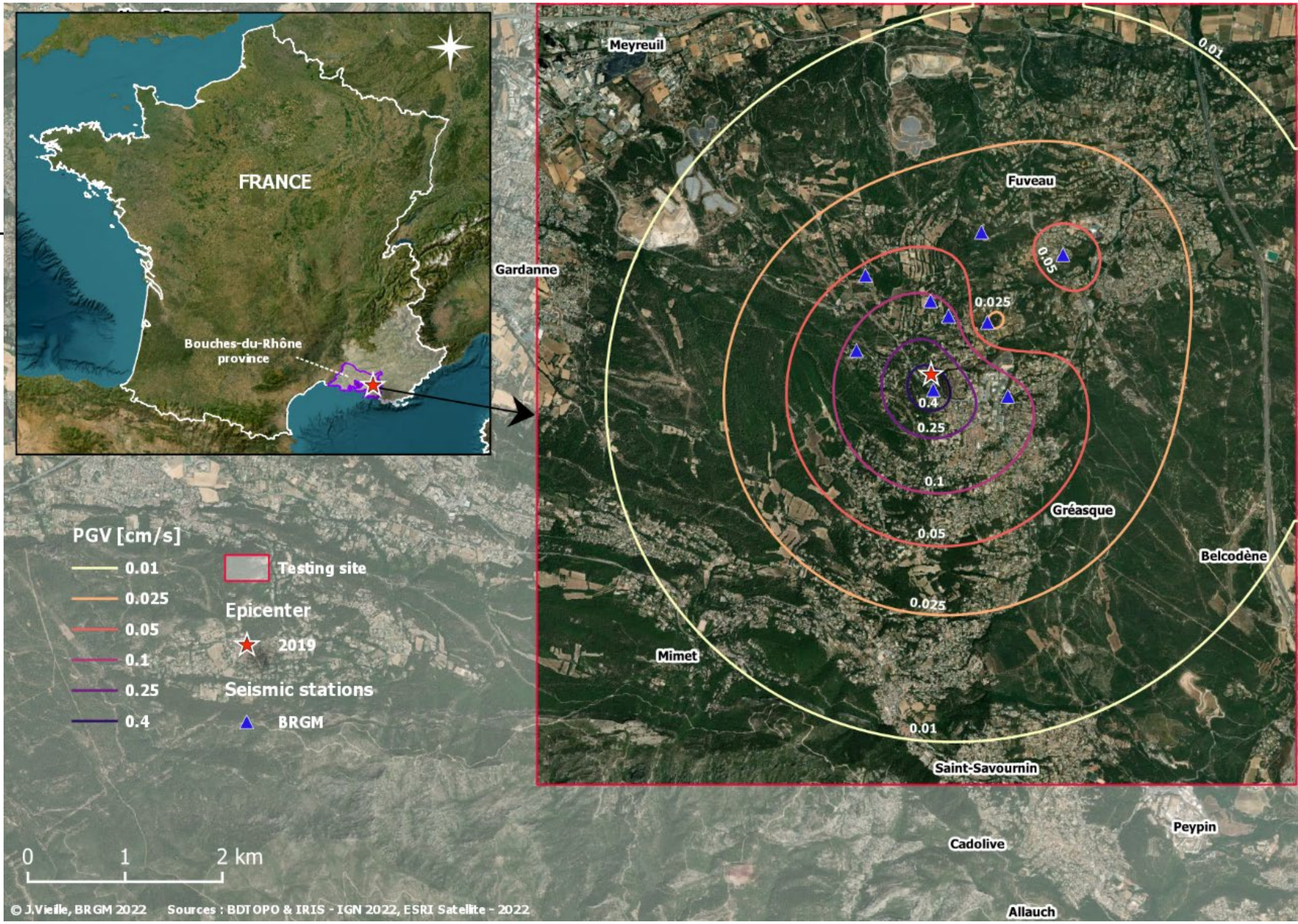
Input data

		Methods		
		1. Semi-empirical vulnerability approach (EMS98 intensities)	**2. Dynamic resistance approach (MSIIS intensities)**	**3. Semi-empirical vulnerability approach adapted to MSIIS-22 intensities**
Hazard (intensity maps)	-	Ground motion (GMPE) model converted in EMS98 intensities (PostMinQuake Report D5.3; Mutke et al., 2022)	Ground motion (GMPE) model converted in MSIIS-22 intensities (PostMinQuake Report D5.3; Mutke et al., 2022)	

Seismic risk assessment

Input data

Hazard (intensity maps)



Seismic risk assessment

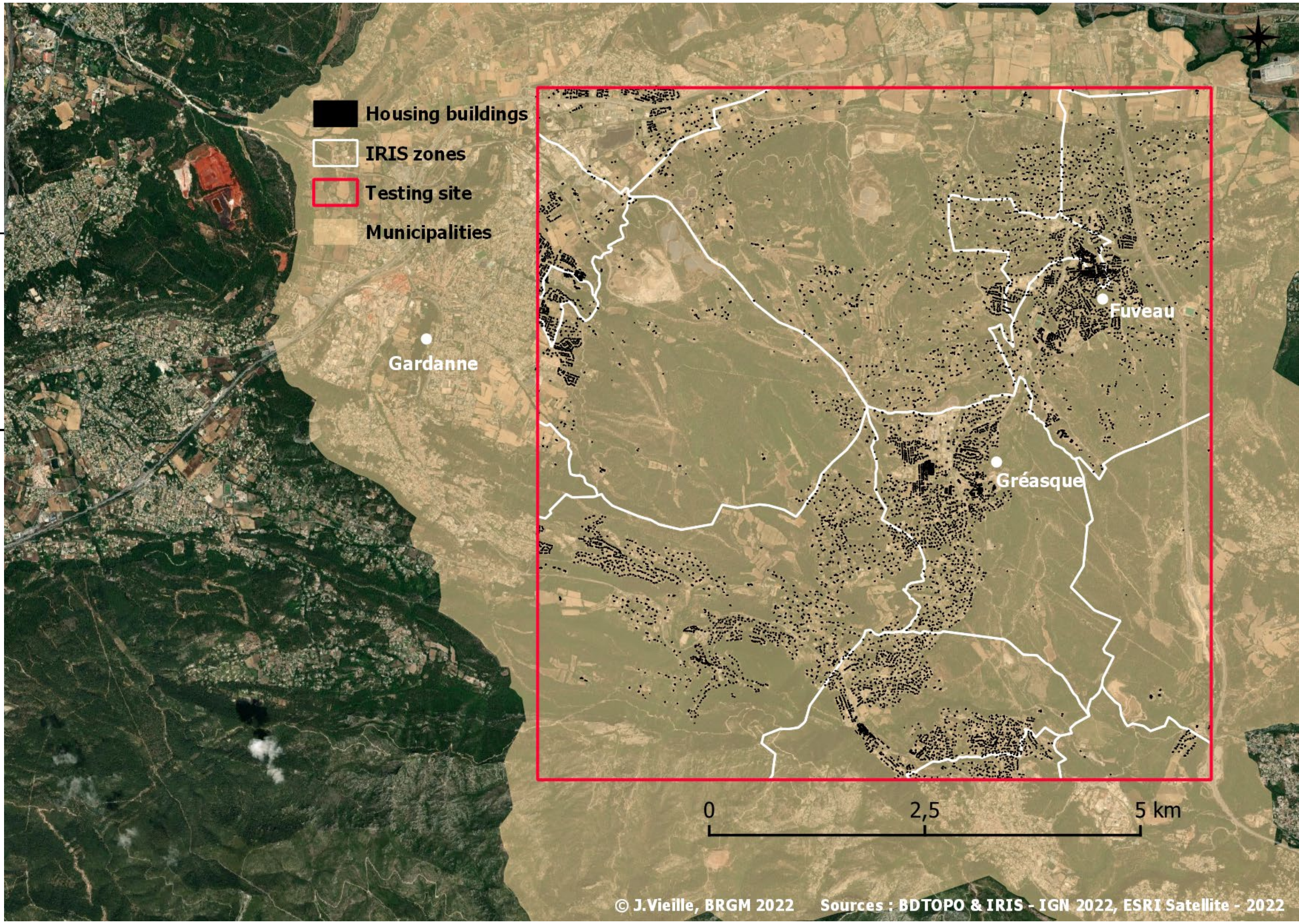
Input data

		Methods		
		1. Semi-empirical vulnerability approach (EMS98 intensities)	**2. Dynamic resistance approach (MSIIS intensities)**	**3. Semi-empirical vulnerability approach adapted to MSIIS-22 intensities**
Hazard (intensity maps)	-	Ground motion (GMPE) model converted in EMS98 intensities (PostMinQuake Report D5.3; Mutke et al., 2022)	Ground motion (GMPE) model converted in MSIIS-22 intensities (PostMinQuake Report D5.3; Mutke et al., 2022)	
Exposed elements (building)	*7.834 buildings*	Housing buildings from BDTOPO - IGN 2022 (French national database)		

Seismic risk assessment

Input data

Hazard (intensity maps)
Exposed elements (building)



Seismic risk assessment

Input data

		Methods		
		1. Semi-empirical vulnerability approach (EMS98 intensities)	**2. Dynamic resistance approach (MSIIS intensities)**	**3. Semi-empirical vulnerability approach adapted to MSIIS-22 intensities**
Hazard (intensity maps)	-	Ground motion (GMPE) model converted in EMS98 intensities (PostMinQuake Report D5.3; Mutke et al., 2022)	Ground motion (GMPE) model converted in MSIIS-22 intensities (PostMinQuake Report D5.3; Mutke et al., 2022)	
Exposed elements (building)	*7.834 buildings*	Housing buildings from BDTOPO - IGN 2022 (French national database)		
Building characteristics and associated vulnerability (index, dynamic resistance)	*7.834 buildings*	RISK-EU typologies - statistical distribution (Monfort & Roullé, 2016) and field work	RISK-EU typologies adapted to Polish typologies	RISK-EU typologies - statistical distribution (Monfort & Roullé, 2016) and field work

Seismic risk assessment

Input data

Methods		
1. Semi-empirical vulnerability	2. Dynamic resistance	3. Semi-empirical vulnerability approach

Hazard (intensity maps)

Exposed elements (building)

Building characteristics and associated vulnerability (index, dynamic resistance)

Type	Type RISK-UE	Sous-type	Description	Période de construction	Photo	V^{min}	V*	V^{max}	Justification de l'indice de vulnérabilité
T1 : Pierre	M1.1	$T1_i$	Bâtiment en pierre **isolé**	**Avant 1970**		0.62	**0.76**	1.02	Indice de base, type M1.2 : 0.74 Nombre d'étages (1 ou 2) : -0 .02 Irrégularité en plan : +0.04 Indice : 0.74-0.02+0.04=0.76
		$T1_m$	Bâtiment en pierre **mitoyen**	**Avant 1970**		0.62	**0.88**	1.02	Indice de base, type M1.2 : 0.74 Nombre d'étages (3 à 5) : +0 .02 Irrégularité en plan : +0.04 Mitoyenneté : +0.04 Plancher à différents niveaux : +0.04 Indice : 0.74+0.02+0.04+0.04+0 .04=0.88
		$T1_{mc}$	Bâtiment en pierre **mitoyen** avec des **commerces au RDC**	**Avant 1970**		0.62	**0.92**	1.02	Indice de base, type M1.2 : 0.74 Nombre d'étages (3 à 5) : +0 .02 Irrégularité en plan : +0.04 Mitoyenneté : +0.04 Plancher à différents niveaux : +0.04 Transparence : +0.04 Indice : 0.74+0.02+0.04+0.04+0 .04+0.04=0.92
Bâtiments en pierre, selon les techniques traditionnelles sans renforcement avec des planchers légers ou ma liaisonnés au mur. En zones dense les bâtiments sont construits à différentes époques, les planchers sont de niveaux différents, et il n'y a pas de joint parasismique. Les commerces aménagés au RDC créent des niveaux transparents. Les formes en plan irrégulières sont courantes (pas de joint).									
T2 : Maçonnerie non chainée	M3.1	$T2_i$	Bâtiment en maçonnerie, **non chaîné isolé**	**Avant 1970**		0.46	**0.74**	1.02	Indice de base, type M3.1 : 0.74 Nombre d'étages (1 ou 2) : -0 .02 Irrégularité en élévation : +0.02 Indice : 0.74-0.02+0.02=0.74
		$T2_m$	Bâtiment en maçonnerie, **non chainé, mitoyen**	**Avant 1970**		0.46	**0.80**	1.02	Indice de base, type M3.1 : 0.74 Nombre d'étages (3 à 5) : +0 .02 Mitoyenneté : +0.04 Indice : 0.74+0.02+0.04=0.80

Seismic risk assessment

Results

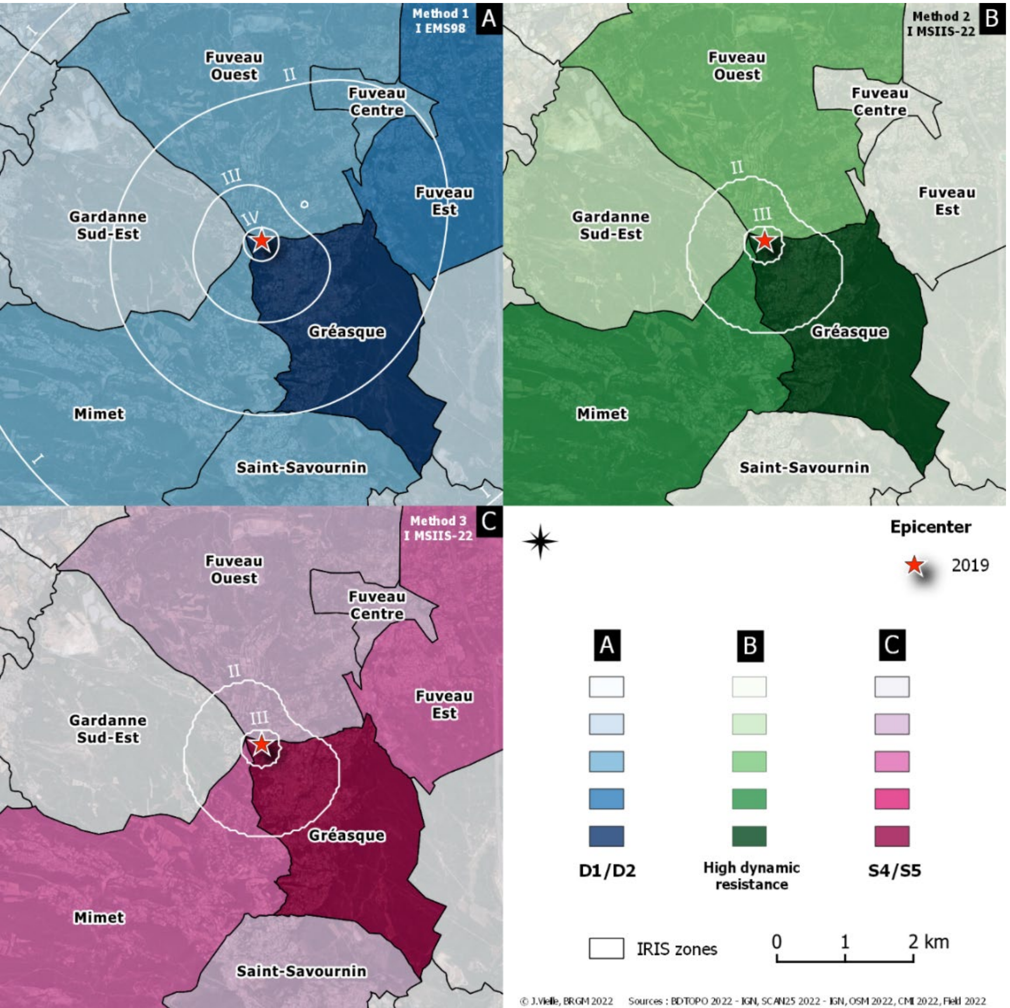
Gardanne site (France)									
Methods	*EMS-98 intensity scale - Level of damages*								
		Epicentral intensity	**Building number**	**D0 - No damage**	**D1 - Negligible to slight damages**	**D2 - Moderate damages**	**D3 - Substantial to heavy damages**	**D4 - Very heavy damages**	**D5 - Destructions**
	1. Semi-empirical vulnerability approach (EMS98 intensities)	4.1	7834	7798	32	4	0	0	0
	MSIIS-22 intensity scale - Level of dynamic resistance								
		Epicentral intensity	**Building number**	**Full**	**High**	**Acceptable**	**Conditional**	**Unacceptable**	
	2. Dynamic resistance approach (MSIIS intensities)	3	7834	7322	512	0	0	0	
	MSIIS-22 intensity scale - Adapted level of damages for post-mining seismic events								
		Epicentral intensity	**Building number**	**S1,2,3 - No damage**	**S4 - Intensification of existing damages**	**S5 - Damage to decorative elements**	**S6 - Slight single structural damages**	**S7,8 - Damage to structural elements**	
	3. Semi-empirical vulnerability approach adapted to MSIIS-22 intensities	3	7834	7756	74	5	0	0	

Post-mining event of April 19th, 2019 (Mw 1.7):

➔ No damage recorded in the area

Seismic risk assessment

Results



Post-mining event of April 19th, 2019 (Mw 1.7):

➔ No damage recorded in the area

Seismic risk assessment

Conclusions

- **Implementation of two new workflows in the VIGIRISKS platform (https://vigirisks.fr/):**
    - Direct application of MSIIS-22 scale (with the use of dynamic resistance as damage indicator)
    - Adaptation of the RISK-EU approach to the MSIIS-22 scale (from empirical data)

- **Need for more empirical data for a consolidation of the MSIIS-22 approaches**
- **No recorded damaging event in the Gardanne basin for a proper validation**

Thank you

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Géosciences pour une Terre durable