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Geotechnical and seismic microzonation map of the Bovec region

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Abstract

In 1998, the area of Upper Posočje in the north-west of Slovenia experienced the strongest earthquake in the 20th century in the Slovenian territory. There were no casualties, however, 4200 houses and other building were damaged. The Slovenian Government adopted an extensive plan of post-earthquake restoration, which was almost fully completed by 2003. In place of 160 buildings that suffered too much damage to be repaired new ones were constructed. A geotechnical map of wider Bovec area was produced to be used for planning, location selection and determination of foundation conditions. The geotechnical map was prepared on the basis of the existing geological map, which was additionally reviewed and supplemented on the field. This was added by the geotechnical field research data, including an overview of the existing documents on the foundation construction in the area concerned, engineering geological mapping and drilling of 20 boreholes in areas where the data on ground composition was insufficient. The geotechnical map was supplemented with GIS databases of the damage to buildings and the nature. For buildings for which foundation conditions were determined during restoration, a special database was additionally created. The data collected was also used for the preparation of the seismic microzonation map, which served as the basis for the static designing of seismically safe construction.

Kratka vsebina

Leta 1998 je bil na območju Gornjega Posočja v severnozahodni Sloveniji najmočnejši potres v dvajsetem stoletju na območju teritorija Slovenije. Smrtnih žrtev ni bilo, bilo pa je poškodovano 4200 hiš in drugih objektov. Vlada Slovenije je sprejela obsežen plan popotresne sanacije, ki je bil do leta 2003 skoraj v popolnosti zaključen. Namesto 160 objektov, ki so bili preveč poškodovani, da bi jih bilo mogoče popraviti, so se zgradili novi. Za planiranje, izbor lokacij in določitev pogojev temeljenja je bila izdelana geotehnična karta širšega območja mesta Bovec. Geotehnična karta je bila izdelana na osnovi obstoječe Geološke karte, ki pa je bila dodatno na terenu preverjena in dopolnjena. K temu so bili pridruženi podatki geotehničnih raziskav na terenu, ki so zajemali pregled obstoječe dokumentacije o izvajanju temeljenja na obravnavanem območju, inženirskogeološko kartiranje in vrtanje 20 vrtin na območjih, kjer je primanjkovalo podatkov o sestavi tal.

Postopek izdelave Geotehnične karte je bil naslednji. Najprej je bila digitalizirana geološka karta. Geološke enote na karti so bile nadalje združene ali deljene v inženirskogeološke enote, glede na geomehanske lastnosti tal. Drugi pomemben vhodni podatek za izdelavo Geotehnične karte so bili podatki o poškodbah objektov zaradi potresa. V alpskem svetu, kjer ni objektov so bile uporabljene ugtovljene poškodbe, ki so nastale v naravi zaradi potresa. Izdelana je bila karta poškodb, ki je v GIS aplikaciji združevala lokacije poškodovanih objektov z bazo popisa poškodb. Narejena je bila analiza velikosti poškodb v odvisnosti od sestave tal. Na osnovi korelacije med stopnjo velikosti poškodb in sestave tal so bili za inženirskogeološke enote dodatno opredeljene geomehanske lastnosti tal. Pri tem so bili posebno pomembni podatki o območjih, kjer teren gradijo slabo nosilna tla, ki so se ob potresu prikazala kot območja z najtežjimi poškodbami na hišah. Končno so bile inženirskogeološke enote s sorodnimi lastnostmi združene v nov sloj po podobnih geomehanskih lastnostih. Za vsako tako dobljeno združeno inženirskogeološko enoto posebej so bile določeni pogoji temeljenja. Rezultati GIS obdelave so bili pregledno prikazani v izrisih in izpisih: Karta velikosti stopnje poškodb na objektih in v naravi, Geološka karta, Inženirskogeološka karta Tabela pogojev temeljenja za inženirskogeološke enote in Karta seizmične mikrorajonizacije.

Introduction

For the presentation and processing of all data the GIS technology was used.

The inter-disciplinary data collected was primarily used for three purposes:

– the analysis of earthquake impact,

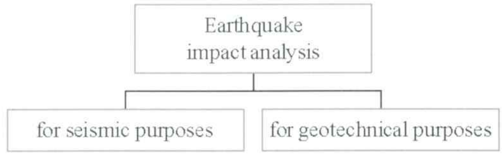
– the preparation of the basis for the restoration works on the damaged buildings, and

– the monitoring of restoration.

The analyses of earthquake impact were conducted for seismic and geotechnical purposes.

Seismologists used the data gathered to determine the seismic parameters of the earthquake (depth of earthquake, type of earthquake, definition of the tectonic structure in relation with the earthquake, seismic intensity, etc.).

The analysis of the geological-geotechnical data enabled the correlation of the impact of the damage to the nature and the buildings with the local geological conditions and geomechanical ground characteristics. The seismic and geotechnical analyses together were used for the preparation of a new seismic microzonation map.



Maps and Databases

The data were organised in three groups:

– NATURAL CHARACTERISTICS OR NATURAL CONDITIONS,

– EARTHQUAKE IMPACT DATA, AND

– RESTORATION DATA (GEOTECHNICAL PART).

The spatial data were shown on digital maps, while the descriptive data were given in databases. The connections between the graphical representations and databases were made by means of ID numbers or identifiers.

In order to determine the natural characteristics, we amended the existing geological map of the Bovec Basin in the scale of 1:10,000, and we also used a more general

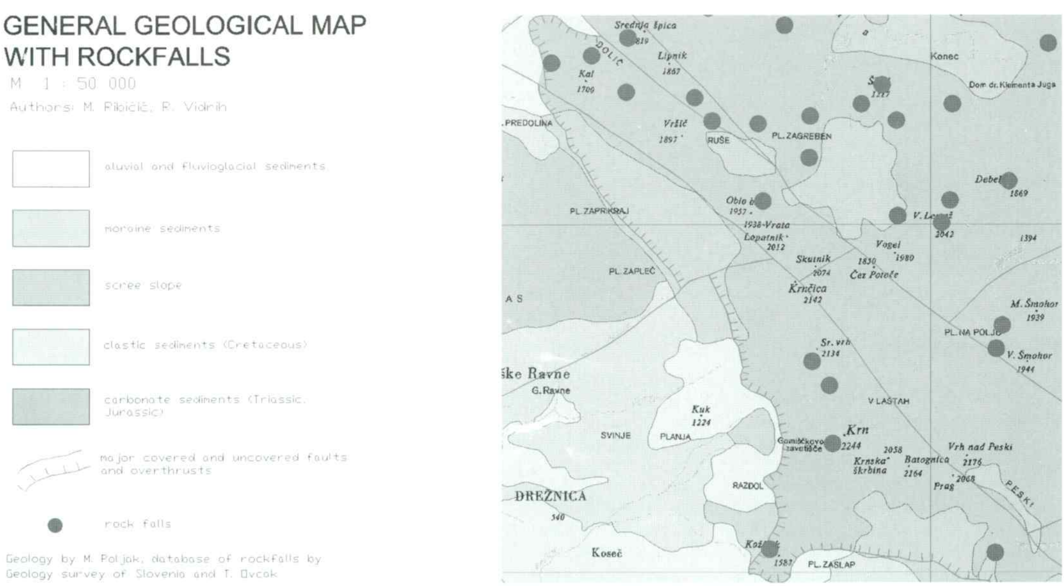


Fig 1. Section of Geological map of Upper Posočje in scale 1: 25,000.

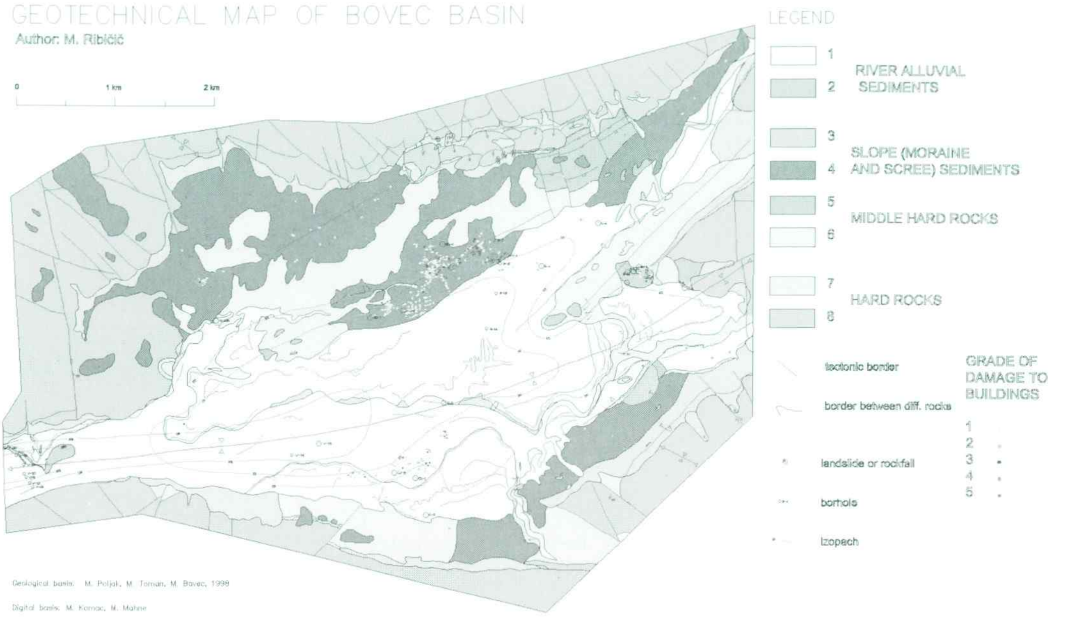


Fig. 2. Geotechnical map of Bovec basin

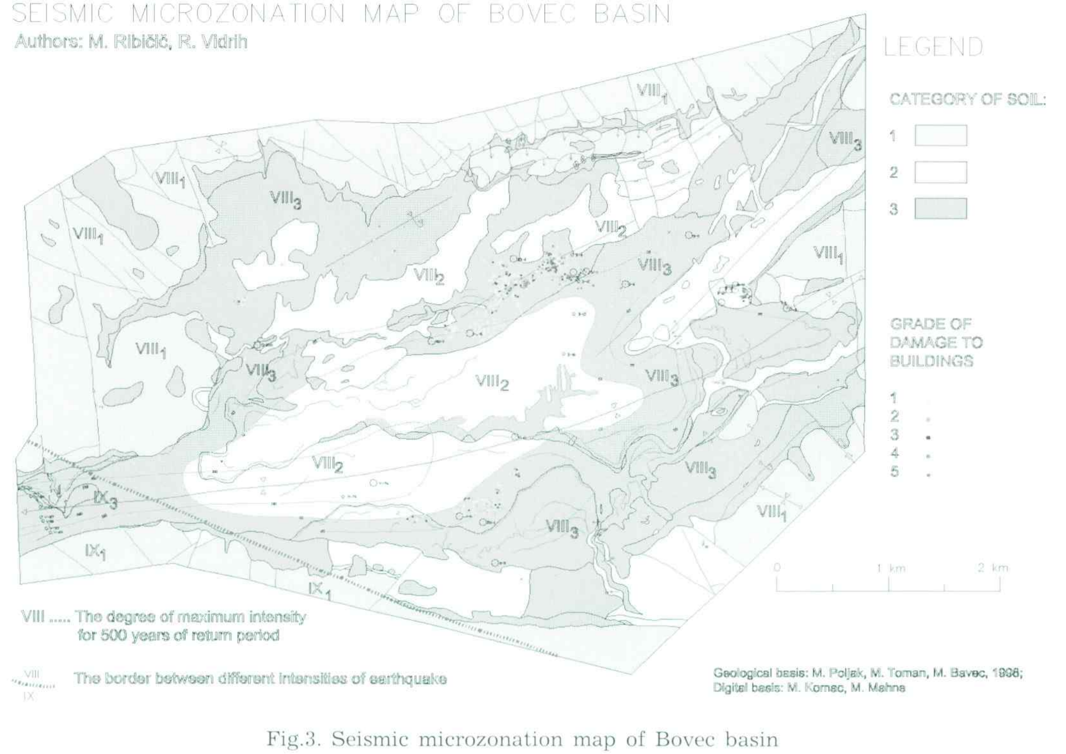
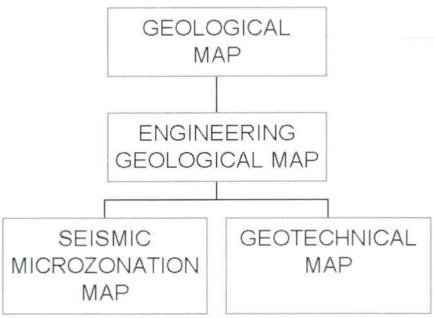


Fig.3. Seismic microzonation map of Bovec basin

map of the wider area in the scale of 1:25,000, added by the data on the probe boreholes and shallow excavations.

The procedure leading to the elaboration of the geotechnical map and seismic microzonation map as the final products was the following. First, the geological map was digitalised. Further, the geological units on the map were joined or divided to geological-engineering units according to the geomechanical and seismic characteristics of the ground. Another input data important for the preparation of both maps were the data on the damage to buildings due to the earthquake. In the Alpine region, where there are no buildings, the determined damage that the earthquake caused to the nature was used.



In the preparation of both maps, much aid was provided by the map of damage, joining the locations of the damaged buildings and the database of damage inventory. An analysis of the extent of damage in dependence on the ground composition was made.

On the basis of the correlation between the level of damage and the ground composition, the geomechanical and seismic properties of the ground were additionally determined for the geological-engineering units. Here, the especially important data were those referring to the low bearing capacity ground areas which the earthquake revealed as the areas with the worst damage to houses. At the end, the geological-engineering units with related properties were joined into a new layer according to their similar geomechanical or seismic characteristics. For each joined geological-engineering unit obtained in this way, the foundation conditions and the increase in the seismic level due to ground composition were determined.

Each map was added by a database describing the data captured.

DATABASES TO MAPS
database to the geological map database to the engineering geological map database to the geotechnical map database to the sesmic microzonation map

The attributes of the database to the geological map and the attributes of the key to the geotechnical map are given as examples: The structure of the descriptive data base to the geological map:

Geological units (polygon) – geological unit identifier – description of the mapped geological unit – age of rock – type of rock
Layer stike and dip (point) – layer strike and dip identifier – type of layer strike and dip – dip (angle) – strike (angle)
Geological boundaries (lines) – geological boundary identifier – type of geological boundary
Structure units (lines) – structure unit identifier – type of structure unit o axis of a normal large fold o axis of a toppled fold o axis of a metre fold o axis of a covered fold o axis of a plunging fold o fault o thrust o cracks
Large landslide (polygon)
Rockfall – older (point)
Rockfall appearing during the earthquake (point)
Isolines of equal thickness of quaternary sediments (line)

The maps were added by special databases formed within the data capture on the field:

FIELDWORK DATABASES
database of damage to buildings database of damage to the nature database of boreholes database of probe shafts database of geotechnical foundation conditions

The first database contained the inventory of the damage to buildings and the sec-

The database of the geotechnical key contained the following attributes. The right column shows descriptions for the geotechnical unit chosen as examples of the data contained in the database:

Attribute	Example
ROCK CLASSIFICATION	cohesionless soil; slope sediments (moraine and scree)
ROCK FORMATION	glacier sediments
ROCK DESCRIPTION	till (loose moraine) appears as scree of poorly-rounded boulders of limestone
MORPHOLOGY	gentle to medium dip of slopes
PHYSICO-GEOLOGICAL PHENOMENA	subject to strong slope erosion; landslides on steeper slopes
WEATHERED MATERIAL	
thickness	0.5 to 1.5 m
type	clayed gravel to clay with pebbles
USCS	GC – CL
EXCAVATION CATEGORY	
weathered material	II
rock	III
ASSESSMENT OF FOUNDATION AND CONSTRUCTION CONDITIONS	
description	ground of medium bearing capacity; requiring careful location selection and foundation
bearing capacity allowed	200 to 250 kN/m^2
adequacy assessment	less adequate; where possible, on larger area
groundwater	permeable to water; temporary groundwater above impermeable layers
slope inclination	1 : 2
applicability for building in	conditionally applicable

The database of the damage to buildings:

ATTRIBUTE	Example
ID NO.	1745
TYPE	residential buildings
ADDRESS	BOVEC, TRENTA, TRENTA 63
OWNER	RUDOLF ANA
YEAR OF CONSTRUCTION	1941
YEAR OF RESTORATION	1987
NO. OF FLOORS	ground floor + 1
FOUNDATION	no foundation
WALLS	stone
CEILING	wooden
ROOF	wooden
ROOFING	other
DESCRIPTION OF DAMAGE	The structure of the building has suffered much damage, partly due to the earthquake and partly because of its poor state and inappropriate construction method.
CATEGORY	4
DAMAGE LEVEL	65.0
Y	403860
X	139619

ond one the inventory of the damage to the nature. In order to connect the database concerning the inventory of the damage to buildings with the abovementioned maps, we used the national house records, which contain the basic information on buildings, in particular spatial co-ordinates.

The database of the damage to the nature included the damage to the nature found after the earthquake, with the information being gathered by mapping in the field:

ATTRIBUTE	Example
ID No. of the phenomena	3
Name	Mali Lemež – Šija
Time of triggering	12.4.1998
Place	LEPENA
Municipality	BOVEC
Y co-ordinate	398130
X co-ordinate	128020
Surveyed by	Beguš, Kočevar
Description and extension of the phenomenon	large rockfall

The research on the field involved a large number of boreholes and probe shafts made next to the buildings. The following are two examples of records contained in the database of boreholes and shafts.

The database of boreholes:

ATTRIBUTE		Example
ID No. of borehole		9
DEPTH		20 m
BOREHOLE		G-3
PLACE		Žičnica
DATE		August 1998
PROCESSED BY		M. Bavec
subreport – inventory of the borehole:		
depth	AC	Description of soil
0.2		humus
1.8	CI-CH	brown firm clay of intermediate to high plasticity
2.1	GC	brown clayey gravel
9.1		borehole compacted lime breccia
10.5		boulder of limestone
10.6		boulder of sandstone
14		grey marl (flysch)

The database of shafts:

Building ID No.	17
Place	BOVEC
Street	TRG GOLOBARSKIH ŽRTEV
House No.	16
Owner	Lilič L., Sivec F.
Depth	
0.0 – 0.60	man-made mound (GP, CL)
0.6 – 1.00	slightly silty gravel (GP)
Bearing capacity	200
Foundation	The building is founded shallowly, on strip footing 0.6 m under the height of the terrain, in incoherent soil
Structure	The foundation structure is made of 0.6-m strip footing, constructed of a composition of large rock singlets, poorly bound with concrete or fine sand
Assessment	The building has shallow foundations. The allowed bearing capacity of the ground corresponds to the freezing criterion. The foundation structure is of poor quality.

During the restoration, the geomechanical foundation conditions were determined for all new buildings. The above database of shafts was used for recording the data on the foundation conditions at individual locations.

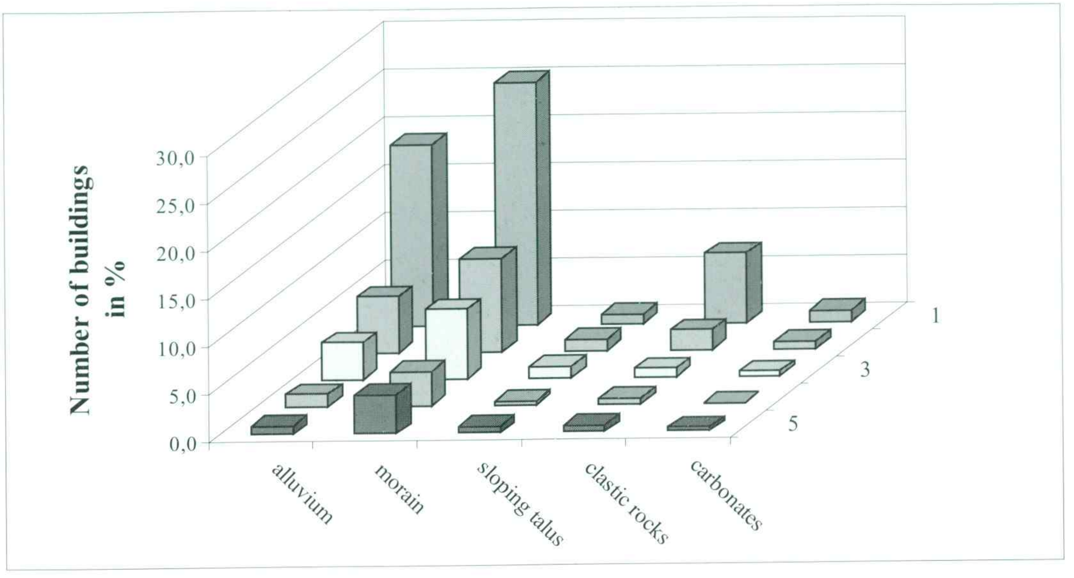
The results and applicability of GIS in post-earthquake restoration

The results of the collected information on the geological structure and of the seismic and geotechnical conditions, produced by means of GIS technology (ArcInfo software) were useful during the whole period of restoration, both in the construction planning and in the restoration or construction of new substitute buildings. The geotechnical map was used for envisaging the foundation conditions for building.

During the restoration, the seismic microzonation map served as a means of determining the basic seismic level and the impact of the ground composition on its increase or decrease, which is the basis for an expert in statics to be able to design seismically safe buildings.

We also created a GIS application which produced the foundation conditions and the seismic properties of the ground from the geotechnical and seismic map of the area of a selected building, i.e. of the location defined by the Y and X co-ordinates.

Besides, it was possible to make many useful analyses by means of GIS. Let us only present one of them. The chart below shows the number of damaged buildings in depen-



dence on the ground composition. It can be seen that the percentage of damaged buildings is the highest on the ground with the poorest geotechnical properties.

One can conclude that the use of GIS in post-earthquake research and restoration works proved to be successful, since at the beginning it required a clear and long-term concept of approach, and during the work it enabled a quick supply of information, much of which would have otherwise needed long processing, while with GIS it was immediately accessible.

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