An AI/IOT-based system of GEOsensor NETworks for real-time monitoring of unStablE tErrain and artificial structures

Activity 1.2 Webinar 2

Monitoring of unstable terrain and artificial structures in Montenegro (practice so far from geodetic and civil engineering point of view)

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CONTENT

- Landslide Monitoring (Slobodan Živaljević)
- Geodetic Monitoring (Radovan Đurović)
- Monitoring of Civil Engineering Structures (Nina Serdar)

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Slobodan Živaljević

Landslide monitoring

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Landslide monitoring

CONTENT

- Introduction.
- Geology and unstable terrains in the territory of Montenegro
- Landslide Ratac
- Landslide Markovići
- Landslide Sutomore

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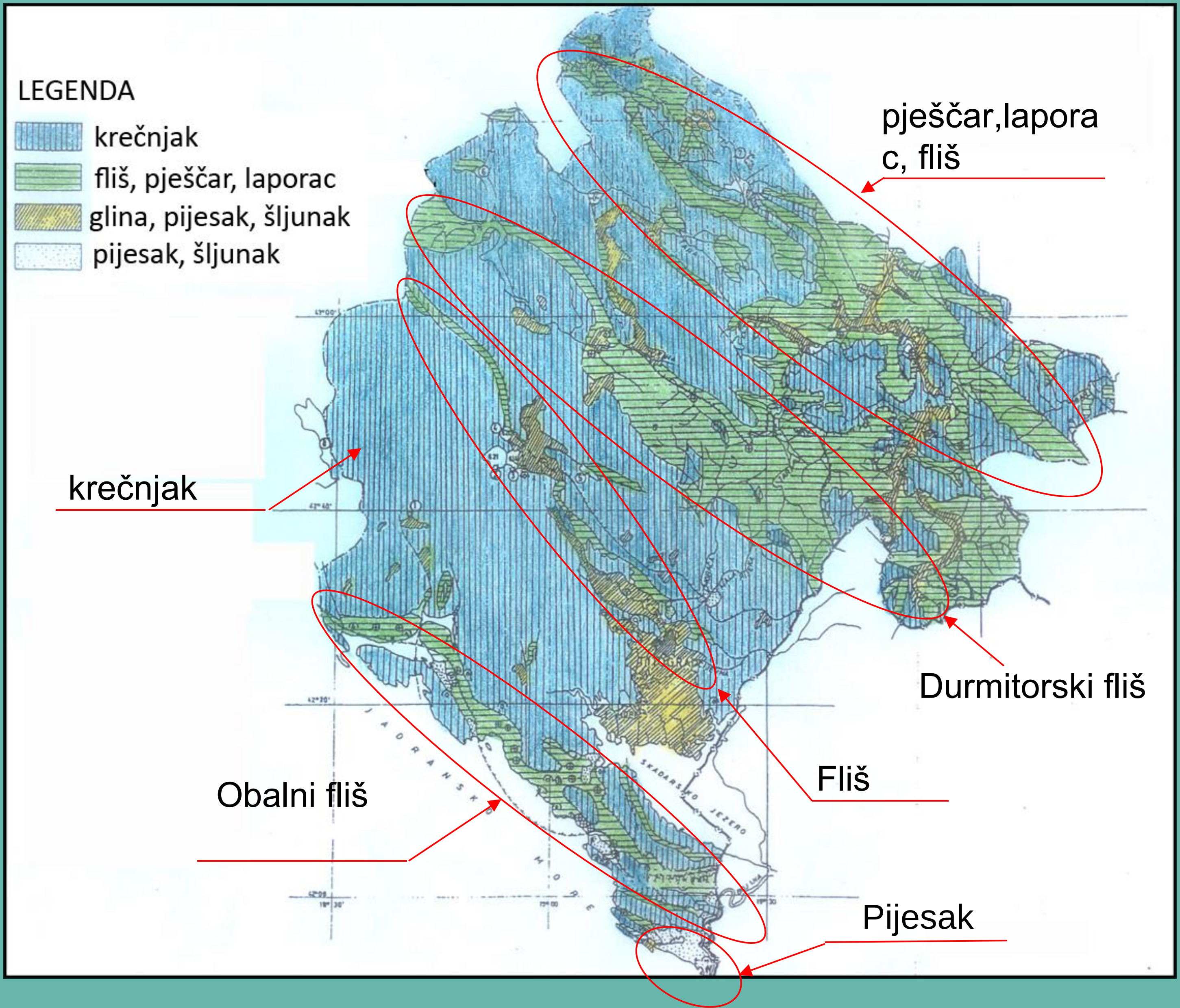
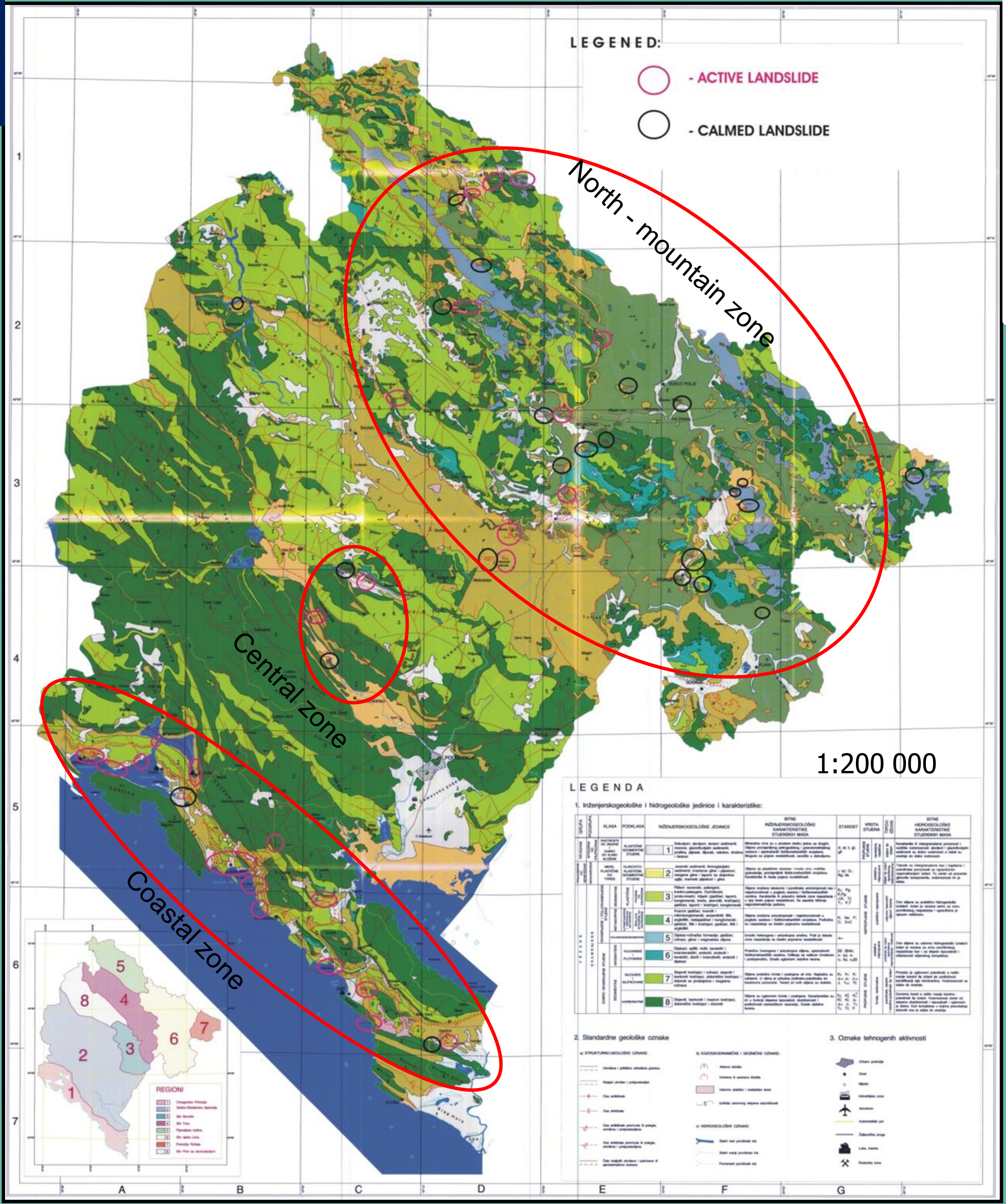

LEGENDA
krečnjak
fliš, pješčar, laporac
glina, pijesak, šljunak
pijesak, šljunak
pješčar,lapora
c, fliš
krečnjak
Durmitorski fliš
Fliš
Obalni fliš
Pijesak

Landslide map



This map was created in 2002 in the Institute of Geological Survey of Montenegro

There are three zones of the landslides:

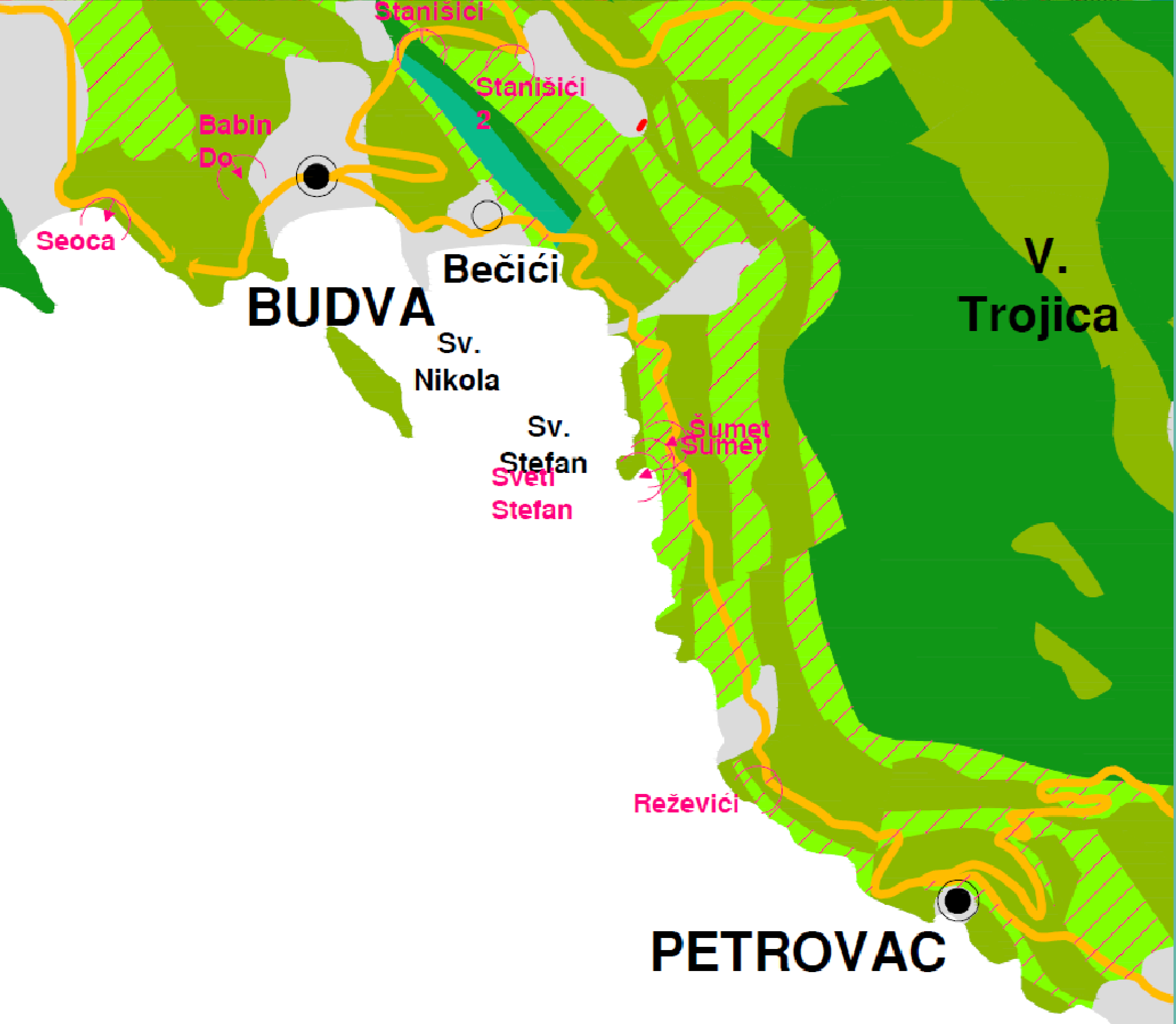
- Coastal zone
- Central zone
- North - mountain zone

Landslides along the coast (generally in flysch)

These are mostly landslides that formed on the mountain slopes, composed of flysch and Quaternary sediments, (deluvial-eluvial drift).

Numerous water sources, which leaking at the tectonic contact of carbonate rock masses and the impermeable flysch formations contribute to the activation of the landslides.

- Depth 2-10m (15m)
- Area 2500-50000 m^2
- Creep



Aktivno klizište
Active landslide

Umireno ili sanirano klizište
Stabilized or dormant landslide

Uslovno stabilan i nestabilan teren
Conditionaly stable

1 Deluvium, alluvium, glacio-fluvial, debris, granular soil, silt

Slope stability problems

3 Flysch – marl, claystone, sanstone, conglomerates

Heterogenity, weathering, landslide prone

SEIZMO-GEOLOŠKE PODLOGE I
SEIZMIČKA MIKROREJONIZACIJA URBANOG PODRUČJA
SO BUDVA

KARTA STABILNOSTI TERENA

- **Budva municipality**
- **Seismic microzonation of urban area**
- **Map of terrain stability zones**

LEGENDA:

STABILAN TEREN
Stabile

TEREN NA KOME PRIRODNI ČINIOCI I DJELATNOST ČOVJEKA NE MOGU IZAZVATI POREMEĆAJ STABILNOSTI TERENA

USLOVNO STABILAN TEREN
Conditionaly stabile

TEREN STABILAN U PRIRODNIM USLOVIMA, ALI KOJI PRI IZVOĐENJU INŽ. RADOVA ILI PRI IZRAZITOJ PROMJENI PRIRODNIH ČINILACA MOŽE POSTATI NESTABILAN

Human activity could trigger landslide.
Natural triggers: rainfall and eartquake

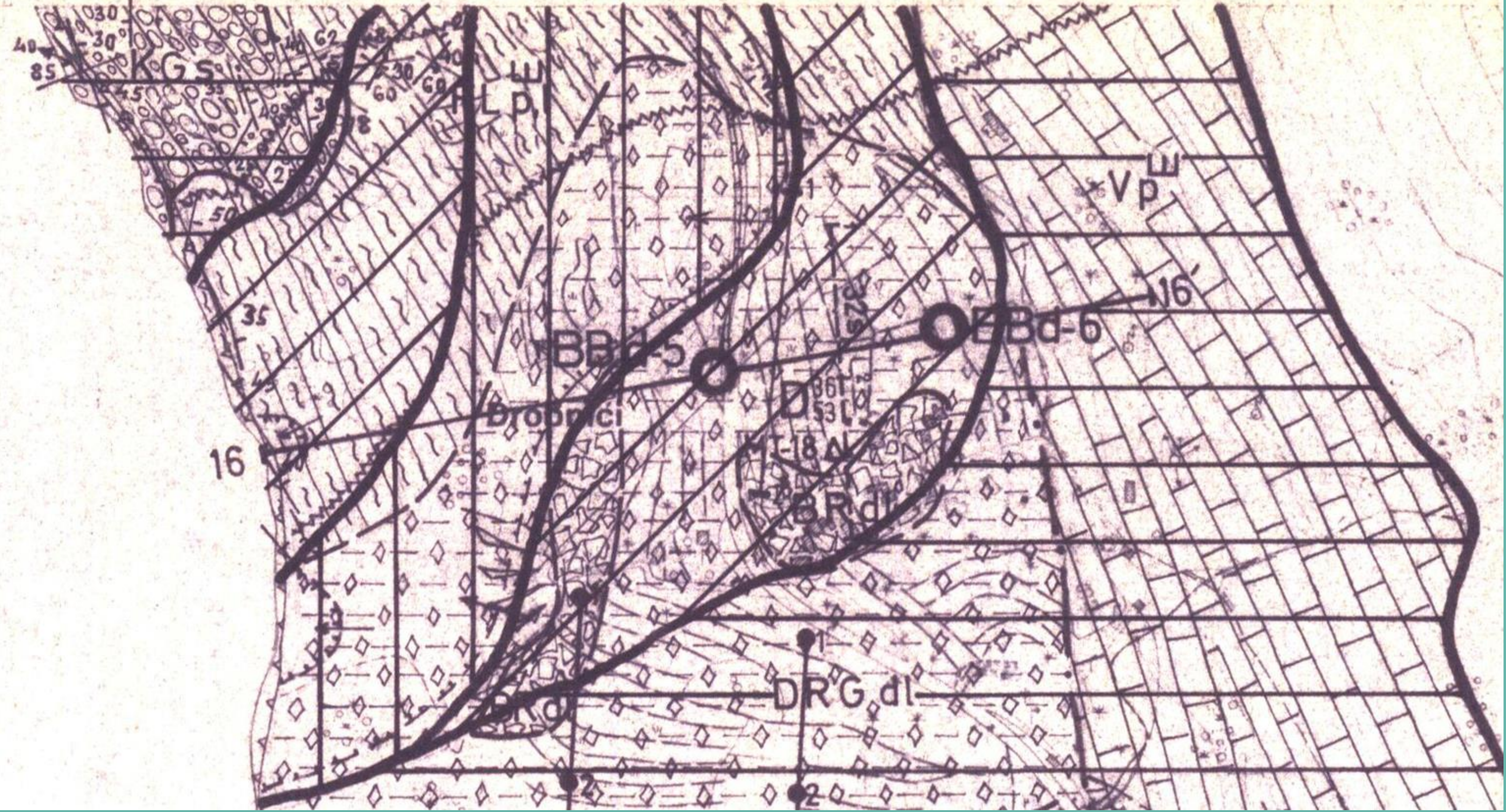
NESTABILAN TEREN A
Unstable type A

TEREN NESTABILAN U PRIRODNIM USLOVIMA, A PRI IZVOĐENJU INŽENJERSKIH RADOVA MAHOM SE INTEZIVIRAJU INŽENJERSKO-GEOLOŠKI I HIDROGEOLOŠKIH PROCESI KOJI SU I USLOVILI POMJERANJE TERENA

NESTABILAN TEREN B
Unstable type B

IZRAZITO NESTABILAN TEREN SA VRLO IZRAŽENOM INŽENJERSKO-GEOLOŠKIM I HIDROGEOLOŠKIM PROCESIMA KOJI USLOVLJAVAJU INTEZIVNO KLIZANJE I TEĆENJE TLA I BEZ IKAKVE LJUDSKE DJELATNOSTI.
OBIČNO SU TO PODRUČJA U NESTABILNIM TERENIMA.


ŠL,Pms
DRG dl
MT 15
DR O pr
V R p
FL p
V R s
Crvena glavica
DRG Ko
ŠL,Pms
3
DRG Ko
14
4
DRK o
V R s
FL p
V R s
15
5



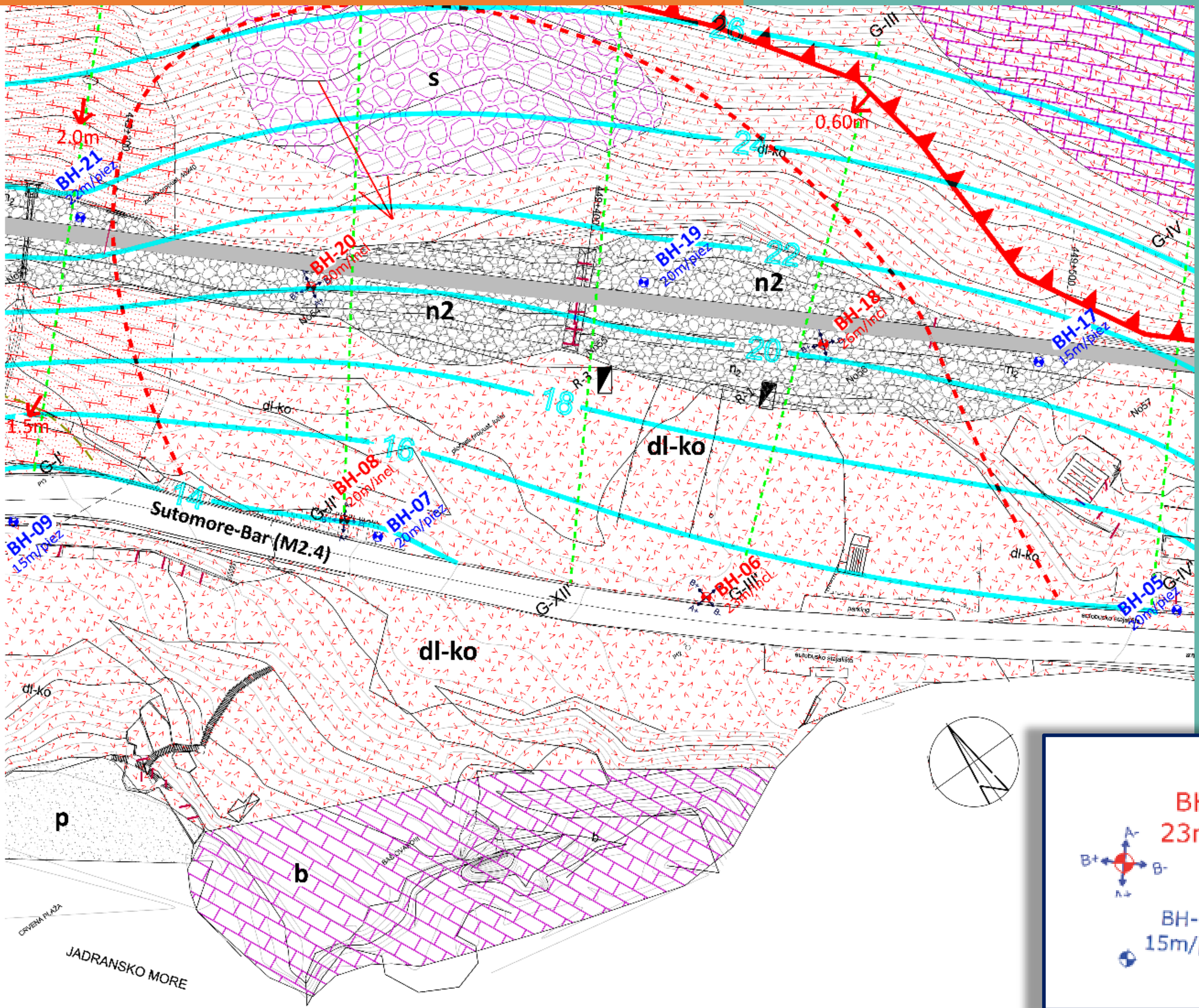
KGs
FLp
Vp
BBd-5
BBd-6
16
16
MT-18
BRd
DRG dl

Landslide Ratac

Section of the Belgrade-Bar railway from Sutomore station to Bar station, from km 449+309.00 to km 449+473.00, total length 164m.

- For the purposes of developing the Main Project, geodetic surveys and monitoring of landslide activity were carried out (2018),
- geotechnical and geological research,
- monitoring of displacement measuring devices (2018-2020),
- monitoring and assessment of installed piezometers and geophysical tests of the geological environment.

GEOOLOGICAL MAP



Sredina 1 - Antropogene formacije

n1	nasip pruge
n2	recentne tvorevine nasipa

Sredina 2 - Deluvijalni materijali

dl-ko	Deluvijalno-koluvijalni materijal
dl-el	Deluvijualno-eluvijalni materijal
dl	Deluvijum

Sredina 6 - Krečnjaci i rožnaci

Kr-R	Krečnjaci i rožnaci
Kr-R*	Krečnjaci i rožnaci sa površinskom zonom od blokova, drobine i crvenice
b	Blokovi višemetarskih dimenzija porijeklom od odrona

Sredina 5 - Flišna osnovna stijena

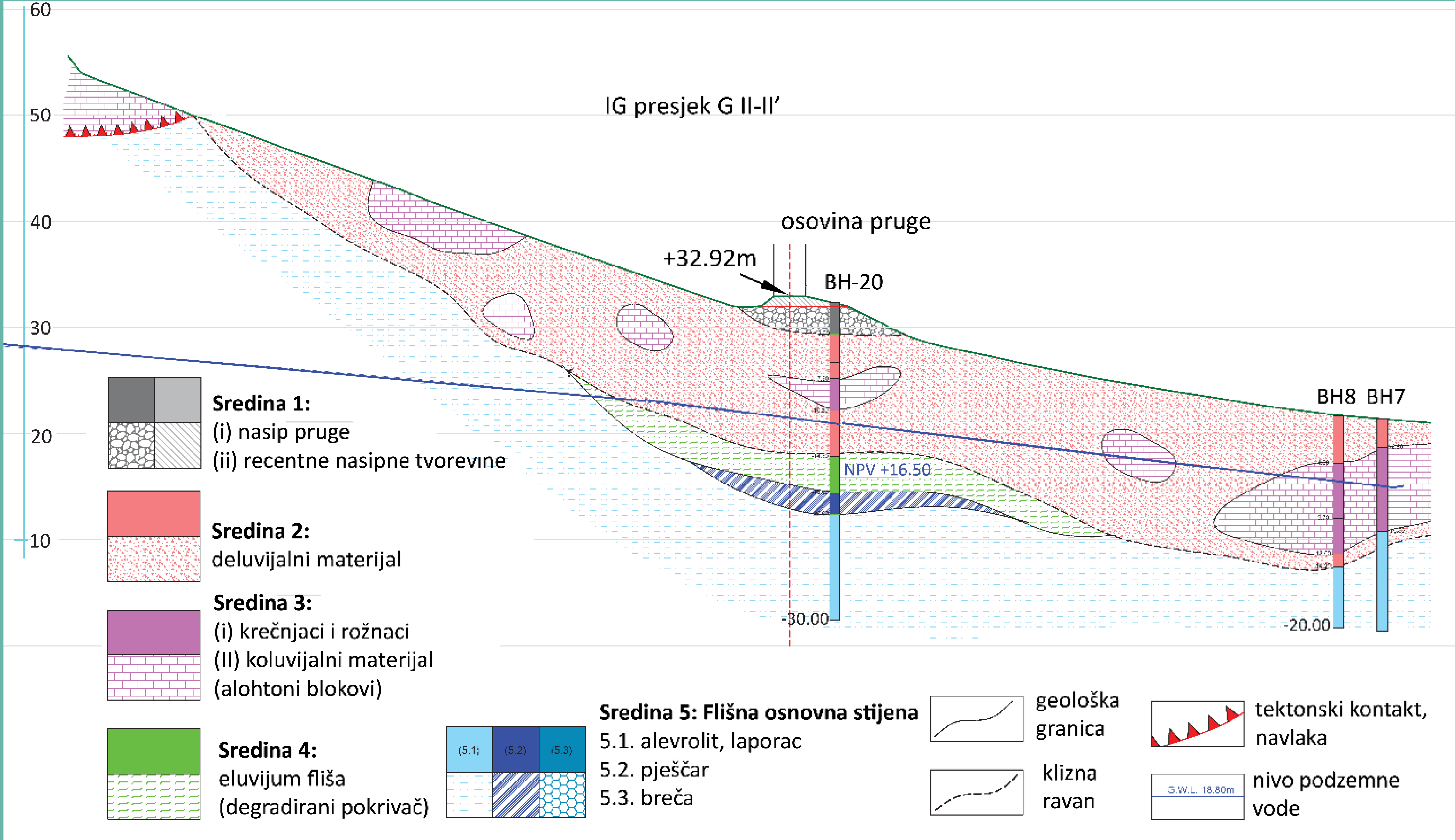
Fl*	flišna degradirana osnovna stijena gdje dominira alevrolit-laporac

Neklasifikovano u geotehničke sredine

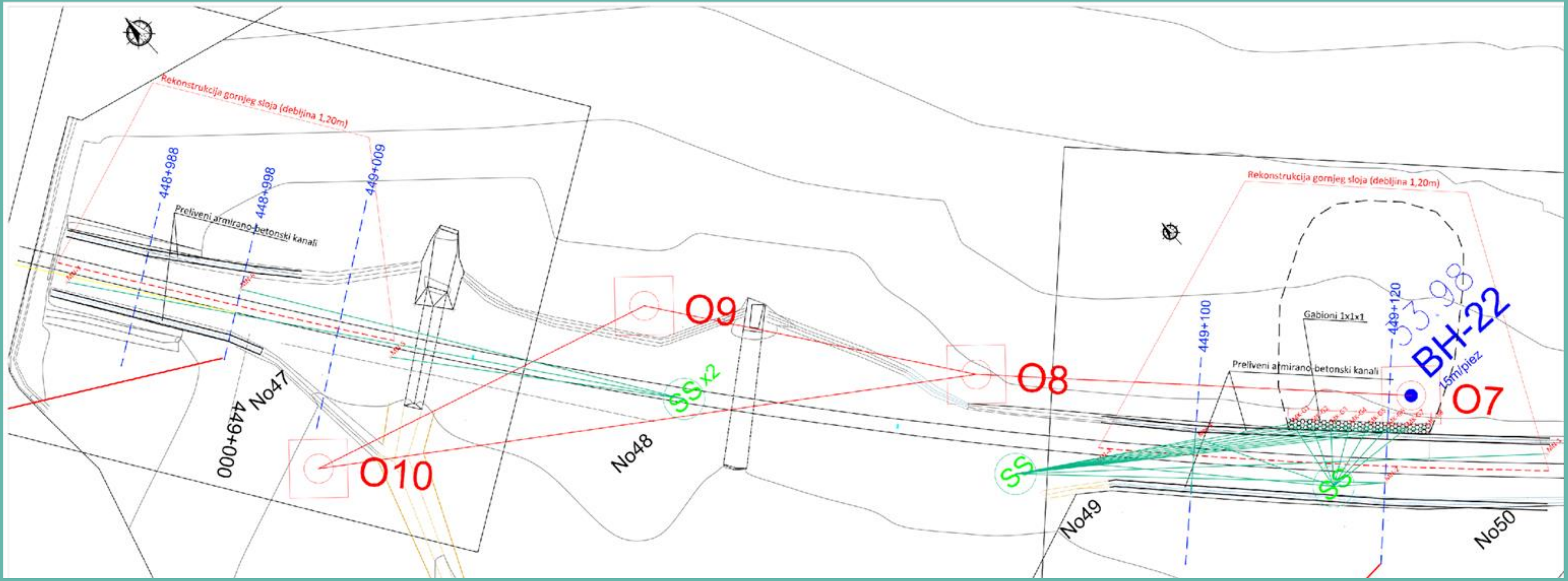
s	sipar
p	plažni pijesak
R	zona sa crvenim pločastim do škriljavim rožnacima

BH-06 23m/incl (A- A+ B+ B-)	izvedena istražno-inklinometarska bušotina sa dubinom i smjerovima inklinometarskih osa
BH-17 15m/piez	izvedena pijezometarska bušotina sa dubinom

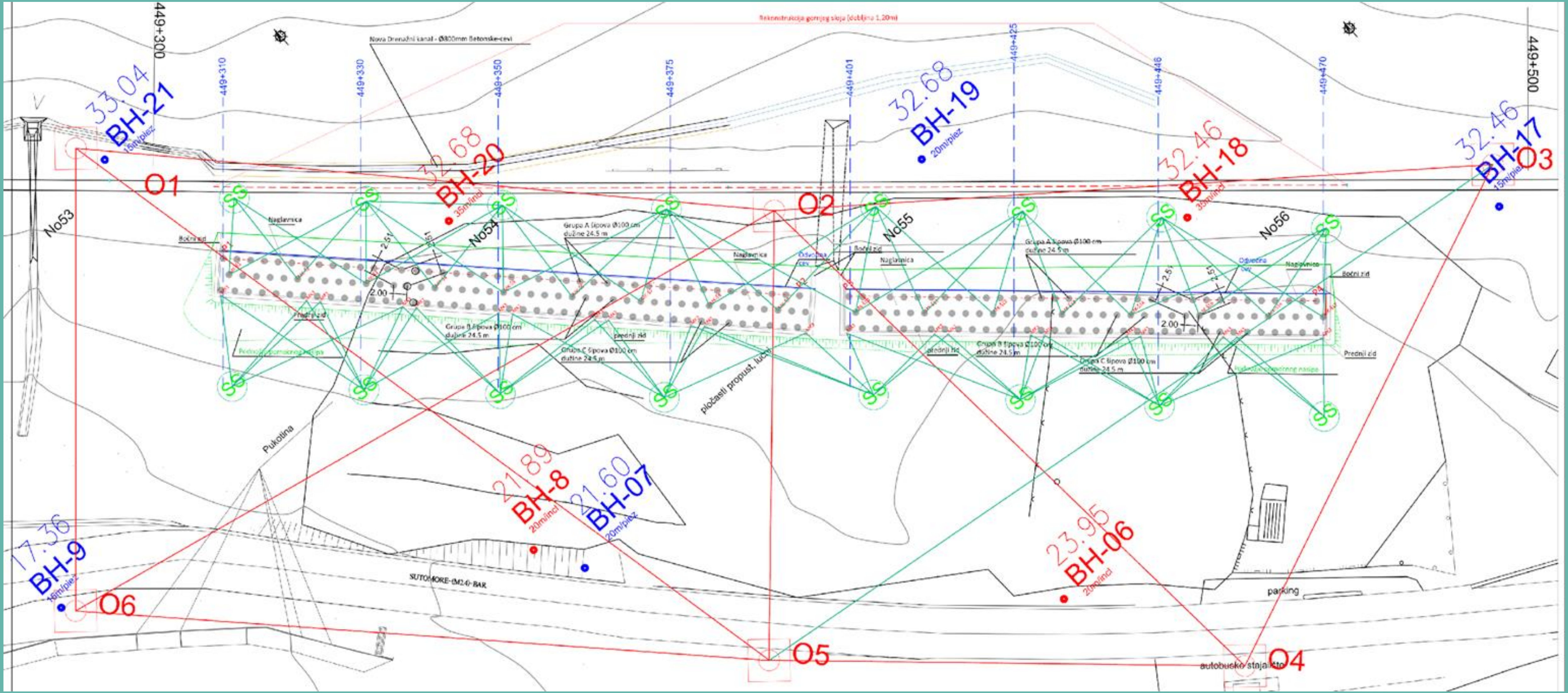
GEOLOGICAL SECTION



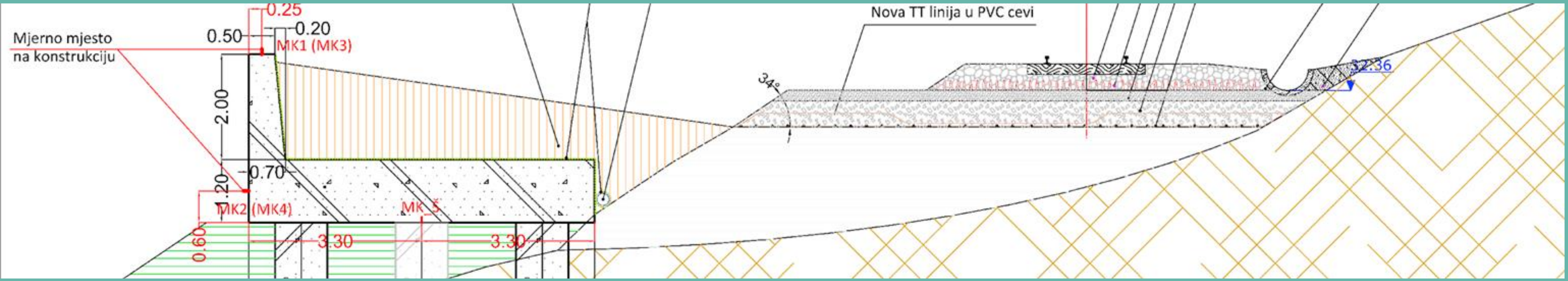
Basic and control net positions with monitoring layout

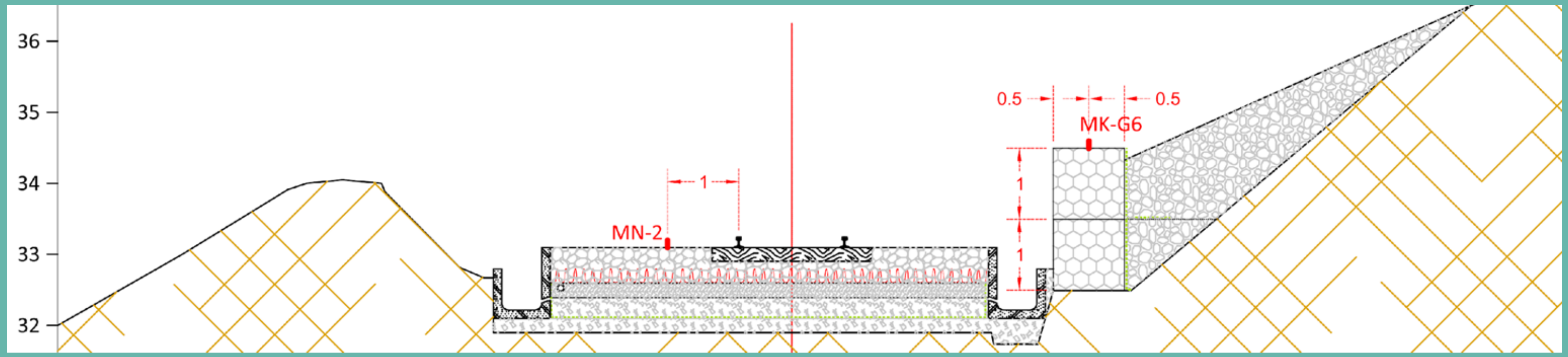


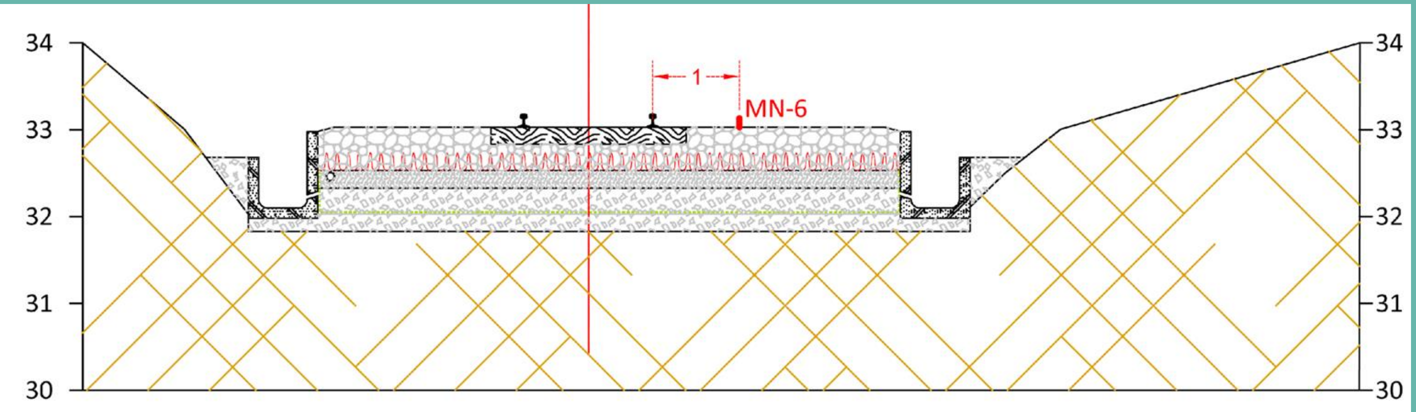
Basic and control net positions with monitoring layout

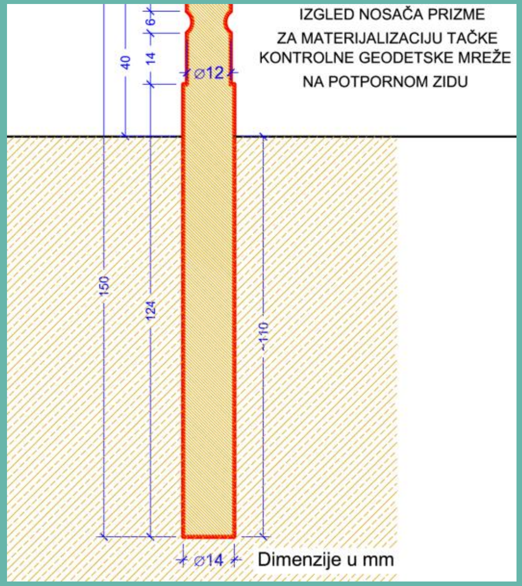


Measuring points locations









Landslide Markovići

CETINJE RAINFALL

5. March 115 l/m^2

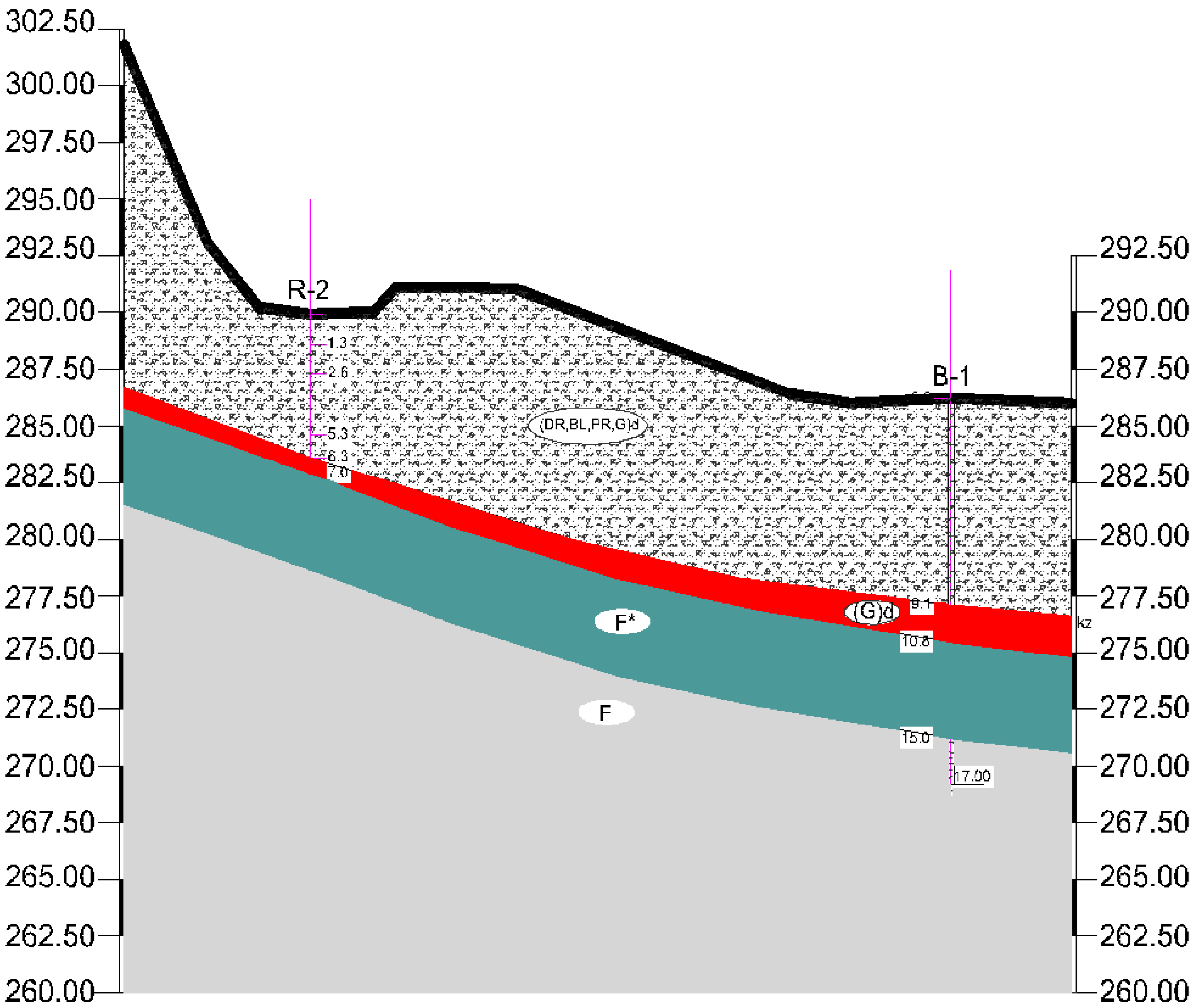
6. March 110 l/m^2

7. March 181 l/m^2

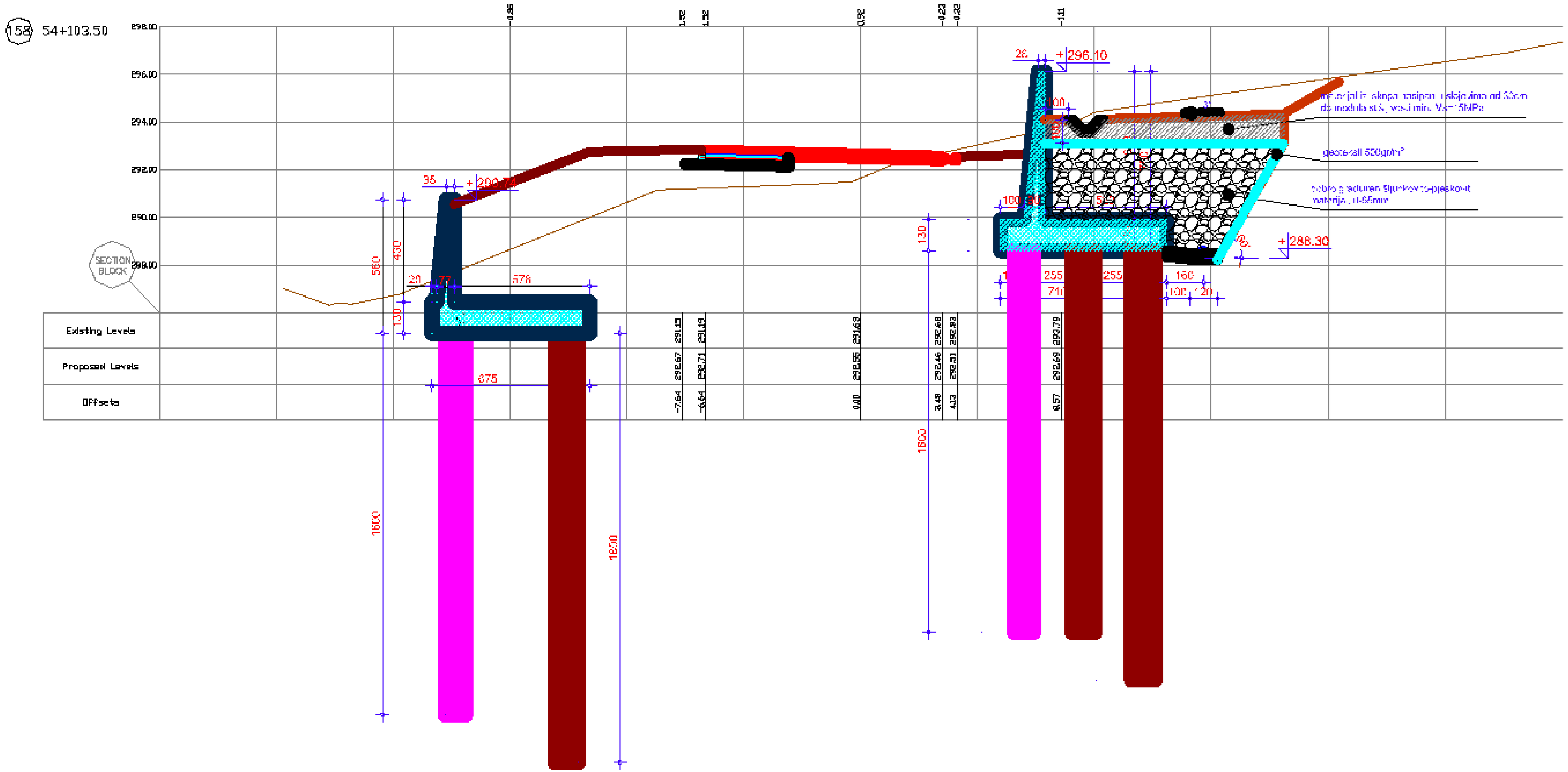
Average rainfall in Cetinje for March is 360 l/m^2, during 5,6 and 7th March average 135 l/m^2

- March 6, at evening the first cracks were observed on the roadway
- March 7, at 7 am the way has already been closed to traffic
- March 8, road was already seriously damage
- March 9, sliding was in maximum
- After March 10 began settling landslides

Geological section

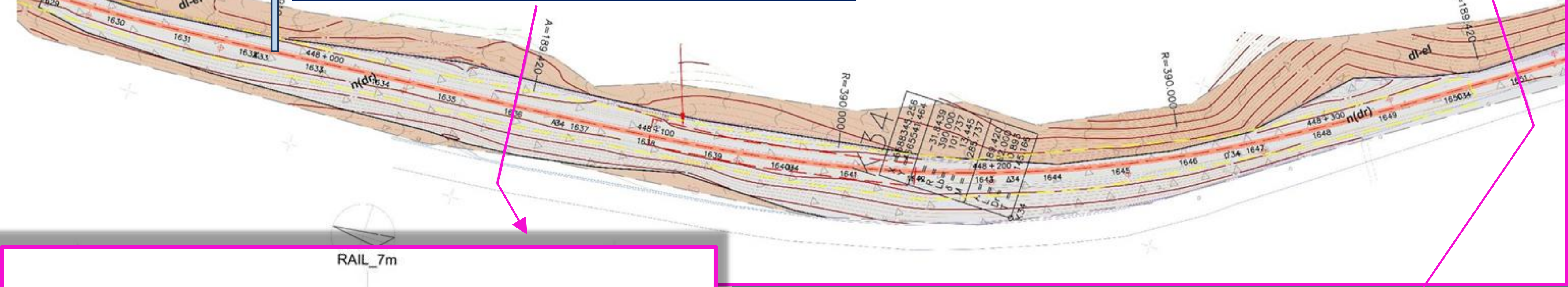


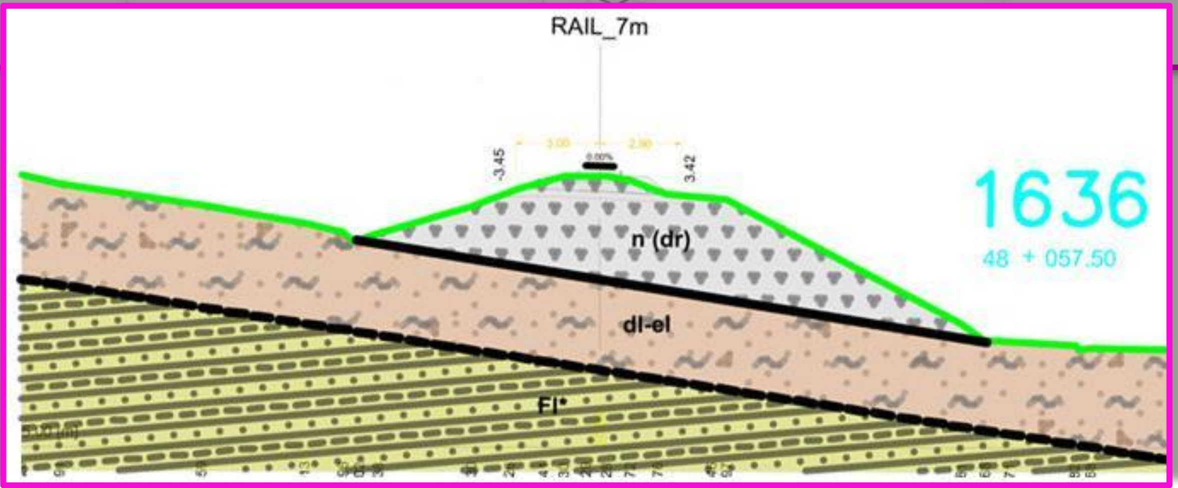
Remediation measures

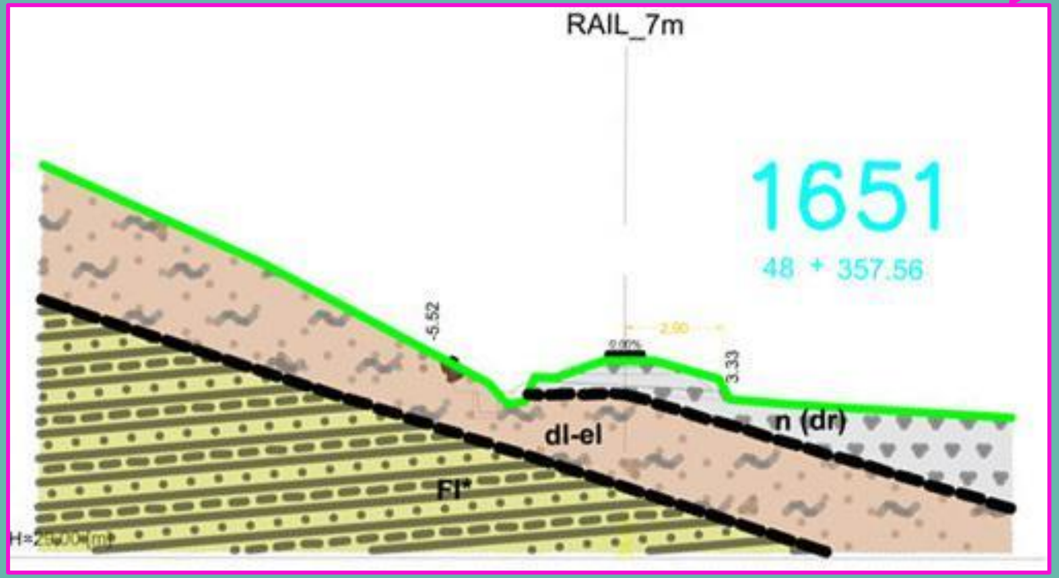


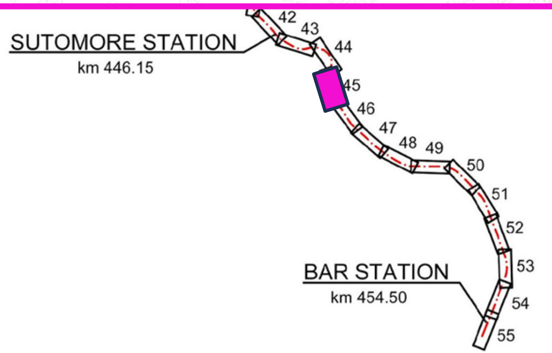
Landslide Sutomore

- Embankment on conditionally stable *dl-el* material
- Main road is wavy-stability problem in part under main road.
- recommendation: drainage+geodetic marks

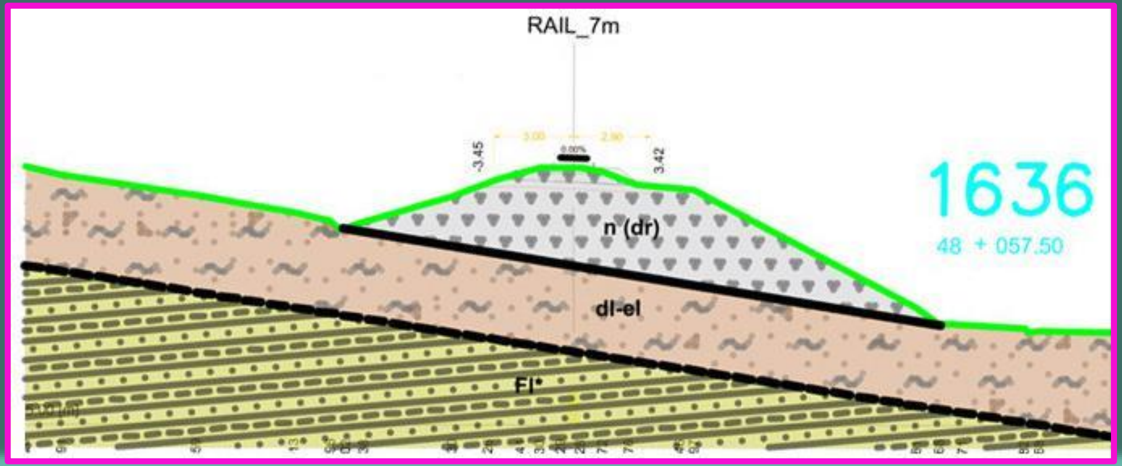








Landslide Sutomore



n (dr)	Embankment. Mostly well graded angular gravel with sand and with cobbles. Localy boulders. Also different percentage of fine grained particles. Material from limestone cuts. Generaly well compacted.
dl-el	Deluvial-elluvial sediments over flysch rock mass. Silty to sandy clay with angular small excerpts of sandstone, alevrolite and limestone, loccaly with angular cobbles blocks.
Fl*	Degraded flysch sediments. Surface area of the basic flysch rock mass dominated by alevrolite (soft marlstone). Loccaly thin layers of solid sandstones.

- **Below, a longer zone was separated in the embankment that was placed in the middle of dl-el (zone from 1629 to 1650).**
- **This zone is marked as problematic from the aspect of stability of the dl-el material below embankment.**
- **It is considered that this embankment is conditionally stable and that due to the characteristics of the dl-el material and due to water saturation in periods of heavy rainfall.**
- **For now, most of this zone is a stable but undulating highway the road and the landslides that occurred under the railroad in the settlement zone are associated with possible problems.**
- **In part from 1638 to 1642, a depression was visible in the central part of the embankment.**

Proposed measures

- **On this entire stretch, it is recommended to build a drainage ditch on the left (upper) side of railway line 3 to 4 m, the depth of which will be partly defined during the execution of the works after a direct inspection of the excavation.**
- **The drainage trench can be filled with well-permeable gravel and buffer material installation of geosynthetics. A plastic perforated pipe can be installed at the bottom, which will collect water and lead outside the railway zone.**
- **In any case, geodetic markers should be installed in this zone to monitor movement terrain in order to react in time in the event of a landslide.**

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Radovan Đurović

Geodetic monitoring

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Geodetic monitoring

- Two different geodetic approaches to monitoring:
- Classical deformation analysis
- Geosensor tec

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Bar Boljare Highway section Smokovac Mateševo.

- This section is part of the Bar-Boljare Highway, which is part of the "Trans European Motorway" route through Montenegro. It connects the main route of the TEM (from Gdańsk to Athens and Istanbul) with the Adriatic Sea and is part of the corridor of the Belgrade - South Adriatic Highway via the Trans-European Highway, of which it is part of the arm, which provides both the European orientation, and via the Port of Bar also the Mediterranean orientation of Montenegro, that is, it connects the Danube with the Mediterranean.

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GEODETIC DEFORMATION MEASUREMENTS AND DEFORMATION ANALYSIS

- METHODS OF DEFORMATION ANALYSIS:

- Pelzer method, Karlsruhe method, IWST method, Welsh method.

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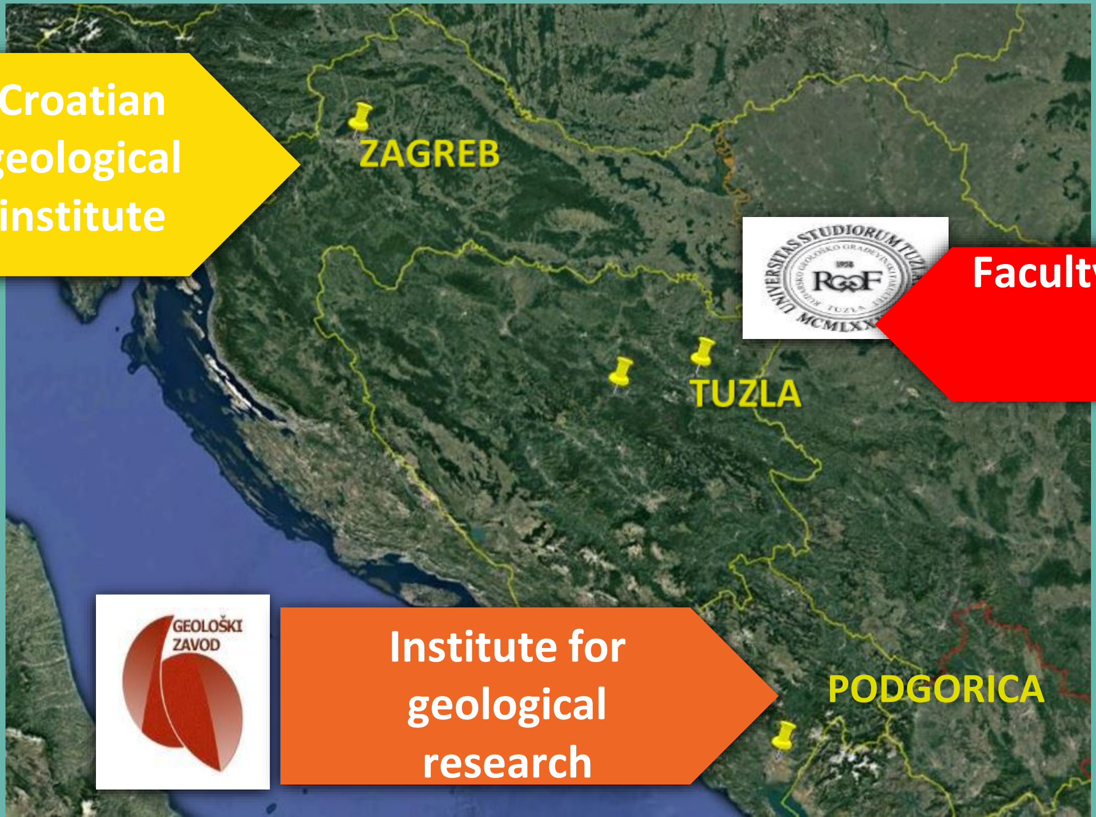
Topliš landfill above Budva - landslide

The second call of the EU program INTERREG IPA CBC Croatia-Bosnia and Herzegovina-Montenegro 2014-2020, the RESPONS project started in October 2020.

PROJECT PARTNERS

Croatian geological institute



Faculty of Mining, Geology Civil Engineering University of Tuzla

Institute for geological research

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Locations of boreholes in the field

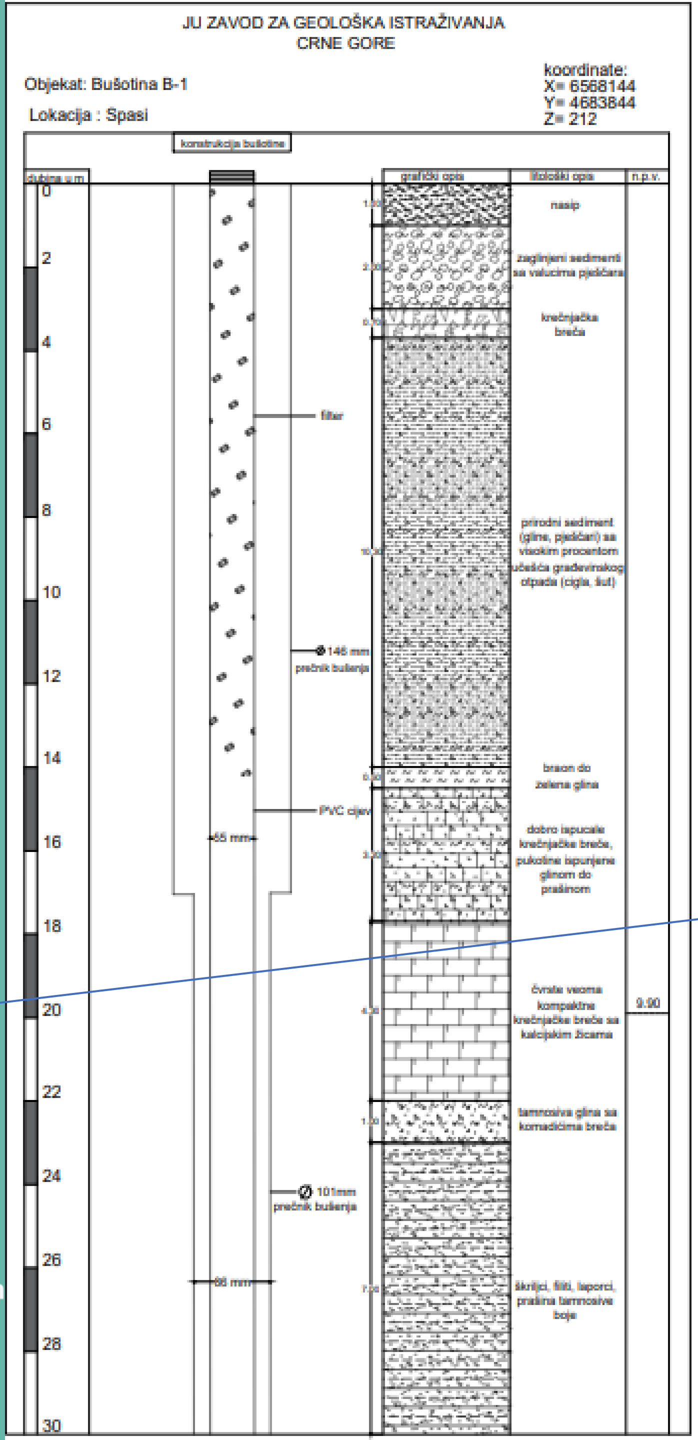
Inclinometer measurements were performed on the pilot training ground.

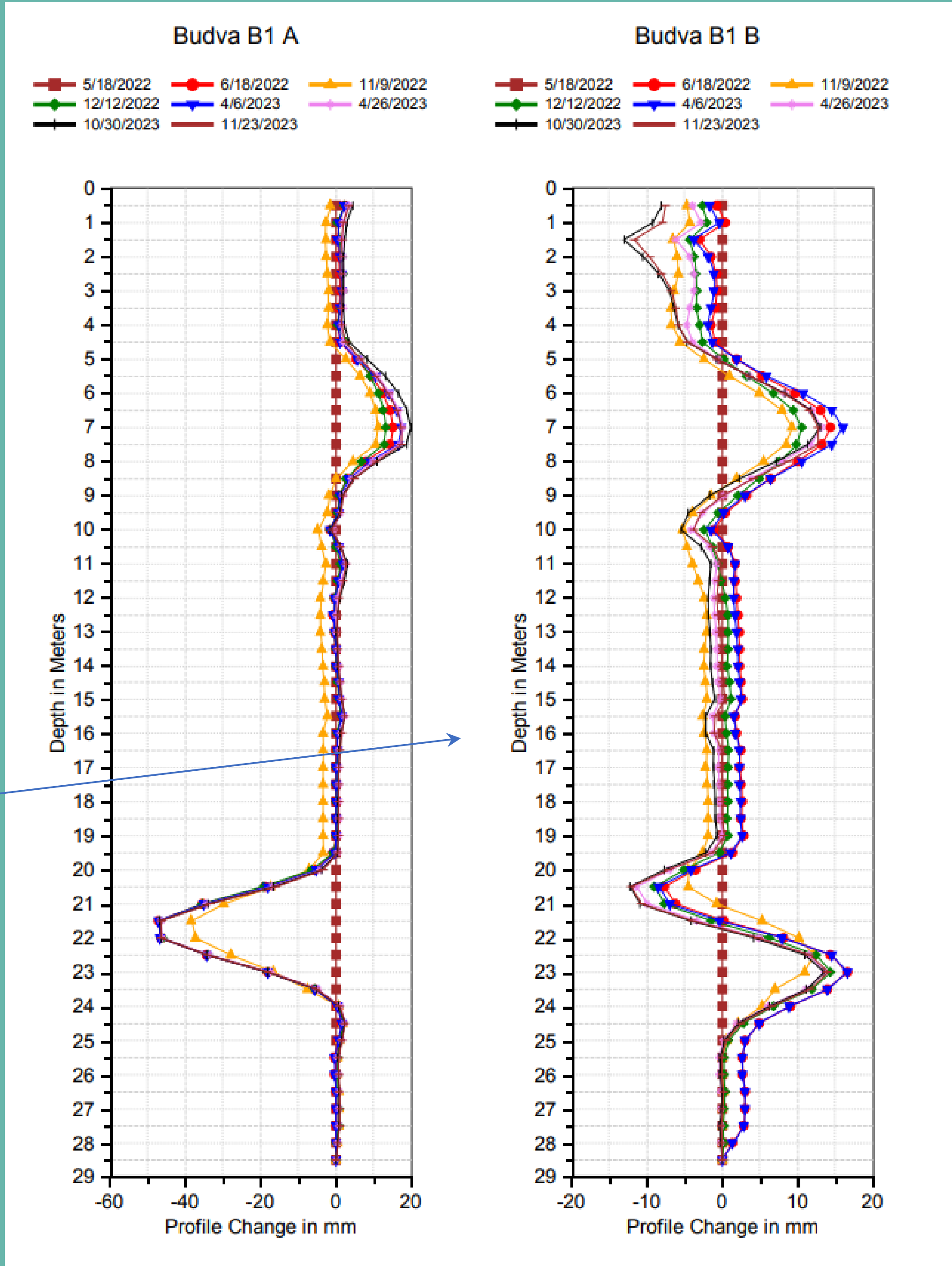
The location was chosen based on previous research, field tours - potential landslides in the region of the municipality of Budva.

Landslide monitoring was carried out at the selected location, by monitoring the horizontal movements of the soil in the borehole in.

During the execution of the inclinometer borehole, the mapping of the borehole was done

Obtained measurement data by boreholes in epochs





Geosensor technology for monitoring the movement of landslides at the Topliš location

- The company MoDrone Ltd. and the Faculty of Civil Eng

Cadastral Municipality of Maine, Municipality of Budva, plot number

1.

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Placement of geosensors at the site

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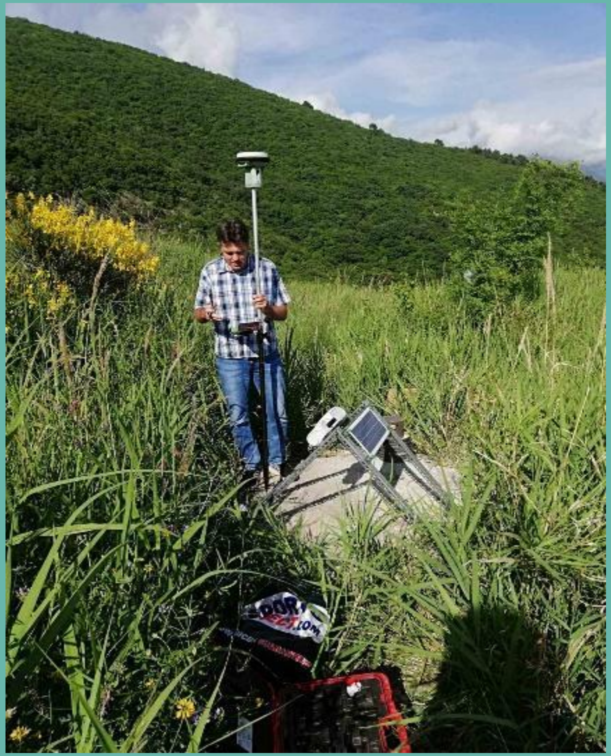
Geodetic measurement using GNSS technology



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Measurement results

Decoding results

Time	14:39:19 UTC
Fix quality	2 - DGPS
Position	42.295634°N 18.821512°E
Sats in use	12
HDOP	0.56
Geoid	36.7 m
Altitude	217.2 m
Close to	Budva, Montenegro

+ Options

	mjerenjeID	senzoriSenzorskiCvorID	senzoriMjernaVelicinaID	vrijednost	datumVrijeme
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	P11.1	P11.2	P11.3	P11
Y	6568149,789	6568149,784	6568149,786	6568149,786
X	4683835,951	4683835,949	4683835,948	4683835,949
Z	214,705	214,701	214,708	214,705

	P11.1	P11.2	P11.3	P11
ϑ	42°17'44,27009"	42°17'44,27005"	42°17'44,26999"	42°17'44,27004"
λ	18°49'17,46761"	18°49'17,46738"	18°49'17,46745"	18°49'17,46748"
H	253,48	253,476	253,483	253,480

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Analysis of the obtained results

	φ	λ	H
Mean value, MoDrone	42.29562956	18.82150203	214.42857143
Mean value, Faculty	42.29563057	18.82151875	253.47975000

Short time period of observation.

Expected results - geologically stable terrain.

Geosensors - an excellent method for monitoring of movements.

Possible to infiltrate into the future observations.

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Nina Serdar

Monitoring of Civil Engineering Structures

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What can be monitored in Civil structures

- Loads
- Deformation
- Displacement
- Carbonation front
- Corrosion potential
- Humidity
- Temperature

Independent of the type of the structure to be monitored, the assessment of critical weak points is one of the most important task.

Weak points: areas of the structure which are prone to damages or where possible damages cause non tolerable consequences.

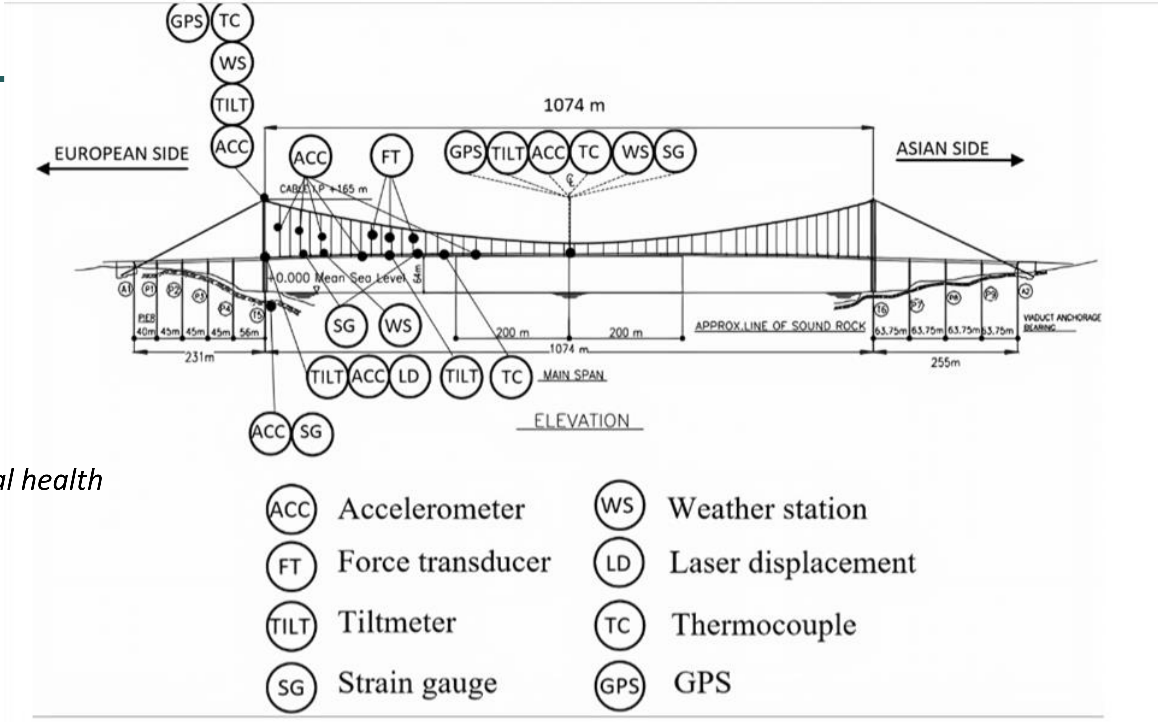


Fig. 4 Sensors arrangement for the SHM system of the First Bosphorus Bridge

Source:
Seismic assessment of bridges through structural health monitoring: a state-of-the-art review

Most common structures to be monitored and motivation for monitoring

Bridges:modern long-span bridges (often have a good maintenance programmes), so that significant local damage and deterioration is likely to be detected **visually** (otherwise very dense network of sensors is needed).

It is probably that only **global changes** such as foundation settlement, bearing failure or major defects (loss of main cable tension or rupture of deck element), are detectable by global SHM procedures with a minimum number of optimally located sensors.

Buildings and towers:monitoring of buildings is motivated mostly by the need to understand building performance during **earthquakes and storms**. Mostly global changes of structural behaviour is inspected as well as loads.

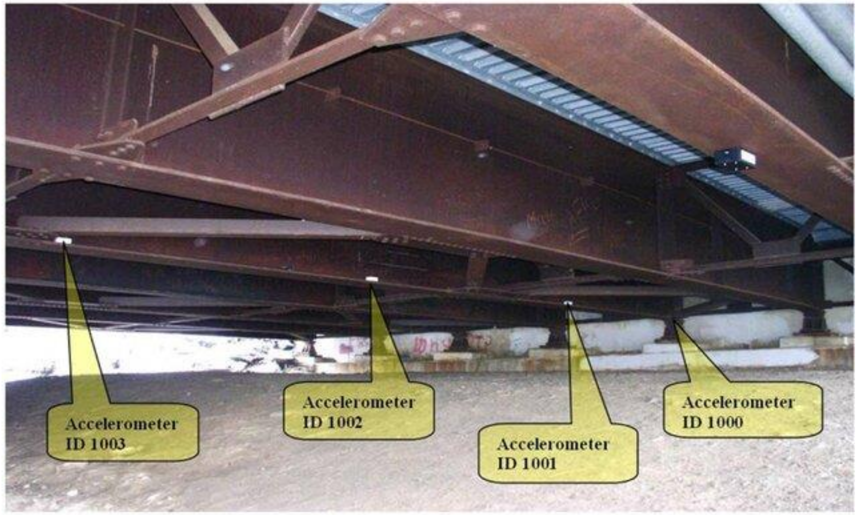
Tunnels and excavations: Tunnel monitoring is aimed at ensuring whether tunnel deformation is within limits in terms of stability and detection of effects on or from close structures. Stresses and strains may be measured, the emphasis is on **deflections**.

Example Bridges:
Vibration-based Monitoring

based on the concept that any change in physical properties of a bridge, whether local or distributed, will be captured by change in its dynamic properties: such as **natural frequencies and mode shapes**

the vibration response of the structure should be measured under controlled or ambient excitation. Most of the vibration-based monitoring methods mainly use data obtained from accelerometers for monitoring the bridge response at global level. The accelerometers are commonly used to measure vertical and/or horizontal accelerations of the bridge components at specific locations.

(a)



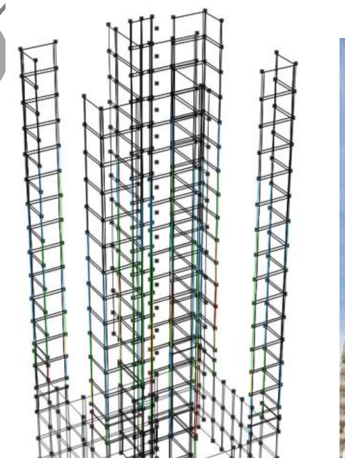
(b)

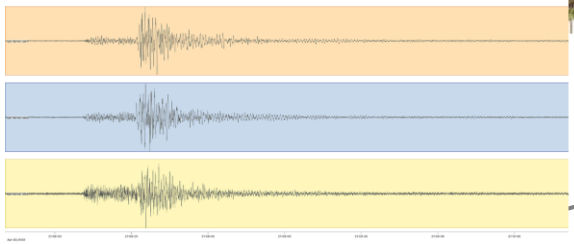
Source: Self-Powered Sensors for Monitoring of Highway Bridges

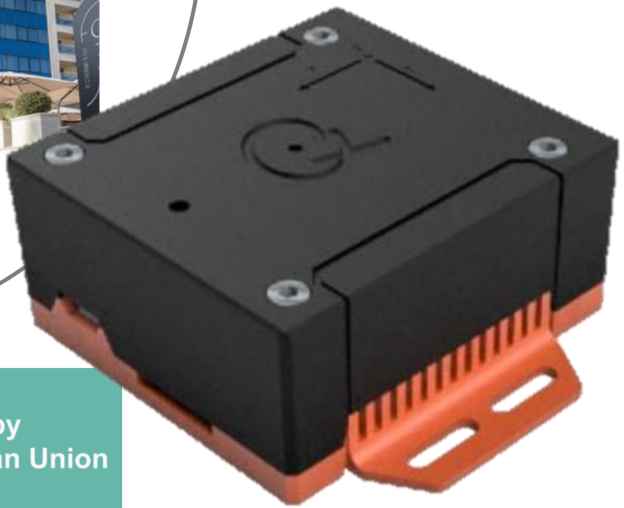
Example Bridges:
Strain-Based Monitoring

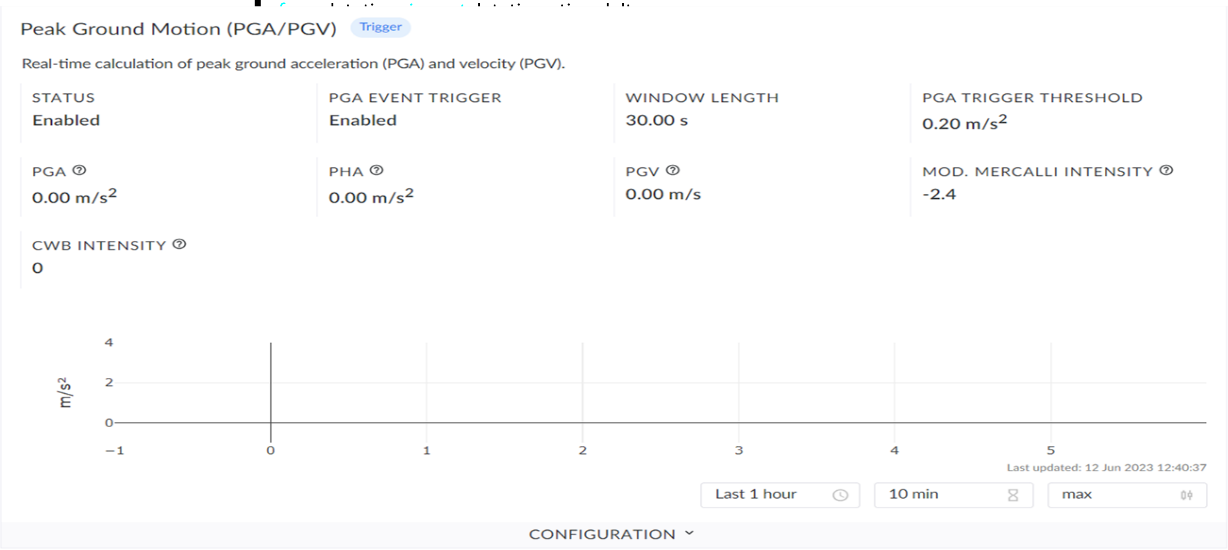
Since damage is usually occur at local level, strain monitoring methods can be used as a means to locally monitor key bridge elements at critical locations. **Fiber optic sensors and strain gauges** are among the most popular sensors used for strain monitoring.

Example Buildings:
RISE H 2020: Smart buildings for seismically resilient Monetenegro

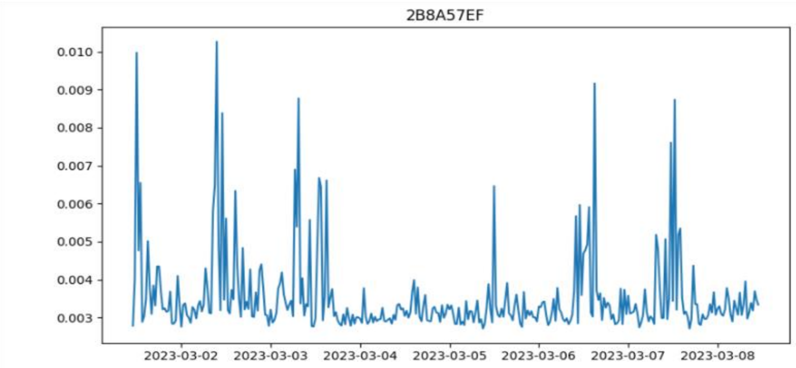









```
# Setup a time window e.g. of the last 7 days
end_time = datetime.utcnow()
start_time = end_time - timedelta(days=7)
# Create a query with the time range and a rolling max of 30 minutes
query = MeasurementQuery(
  start_
  end_
  inter
  aggre
)
result =
plt.plo
plt.title(result.sensor_uid)
plt.show()
```



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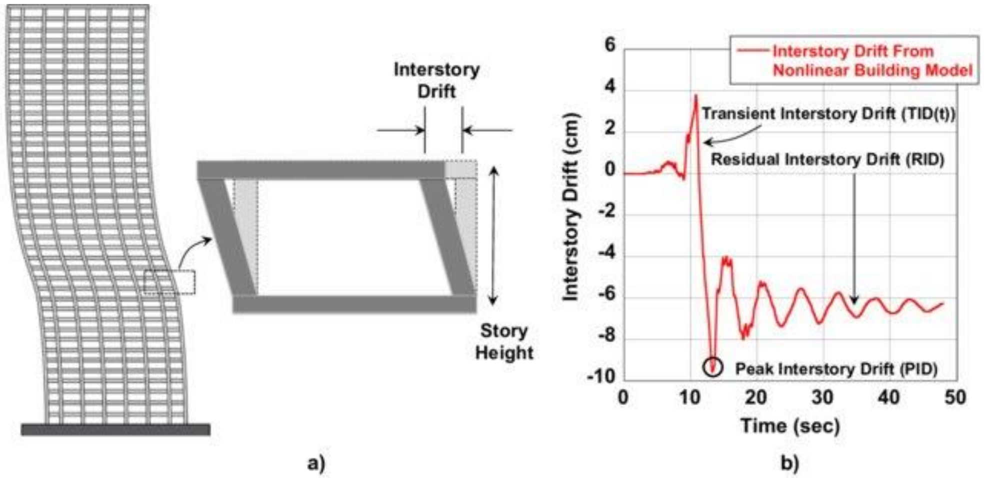
Limiting values to be measured according to standards

Standard/ Reference	Effect	Type	Inter-storey Drift Ratio Limit	Top Deflection Limit
Eurocode				
Eurocode 3 ENV 1993-1-1:2005:	Wind	Steel	No guidance	No guidance
Eurocode 8 EN 1998-1-2004	Seismic (approx 95 year)	Steel / Concrete (limits depend on finishes)	1/200 – 1/100	No guidance
Japanese Code				
Building Codes of Japan and Recommendations from the Special Approval Process by a Selected Expert Review Panel (applies to any building over 60m)	Seismic	Steel	Typically: (100yr): 1/200 (500yr): 1/75 - 1/100	No guidance
		Concrete	Typically: (100yr): 1/500 (500yr): 1/200	No guidance
Guidelines for the Evaluation of Habitability to Building Vibration	Wind	Steel	Same as above	No guidance
American Standards				
ASCE 7-05 – Minimum design loads for buildings and other structures	Wind		No guidance	No guidance
	Seismic (2/3 of 2475 event)	Steel / Concrete	1/100 – 1/200	No guidance
Los Angeles Tall Building Structural Design Council, An alternative procedure for Seismic analysis and design of Tall buildings located in the Los Angeles region (2008)	Seismic (MCE)	All	1/33	No guidance



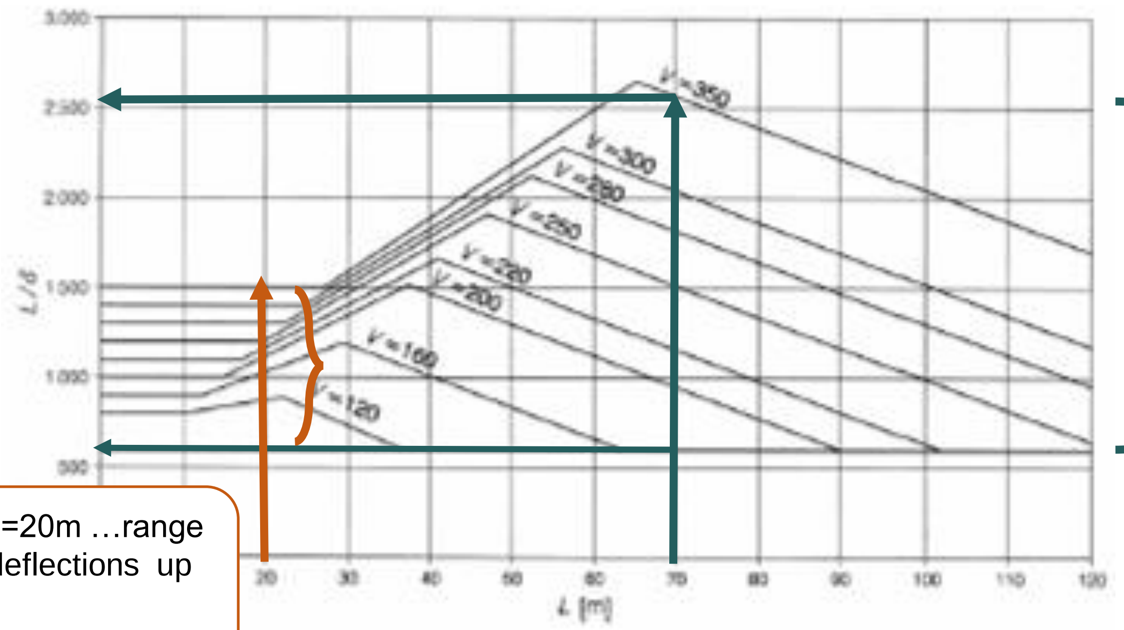
Source: An Advanced Biaxial Optical Sensor System for Post-Earthquake Assessment of DOE Critical Facilities

Buildings: drifts

Table 2. Eurocodes Vibration Serviceability Vertical Acceleration Limits

Level of comfort	Vertical acceleration(m/s^2)
Acceptable	2.0
Good	1.3
Very Good	1.0

Bridges: accelerations



Example L=70m …range of limited deflections up to
11.6 cm to 2.8 cm depending on train speed

Example L=20m …range of limited deflections up to
3.3 cm to 1.33 cm depending on train speed

Bridges: deflections

Problems and limitations in the development of civil infrastructure monitoring system

1. Inappropriate instrumentation and sensor overload
over-instrumentation: so an understanding of expected performance and critical locations is helpful

2. Environmental factors and noise VBDD (vibration-based damage detection) using accelerometer signals work well in controlled conditions, but changes in modal properties due to environmental conditions are significant

3. Communications: Wireless or land links are a necessity for remote control

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