Natural hazards in Slovenia: Regional settings, legislation, hazard assessment and prevention

Jošt Sodnik and Matjaž Mikoš,
University of Ljubljana, Faculty of Civil and Geodetic Engineering
Contents

• Slovenia
  – Regional settings
  – Maps and natural hazard related data

• Natural hazards in Slovenia (included in this presentation)
  – Floods
  – Landslides
  – Debris flows
  – Rockfall
  – Avalanches
Slovenia: basic data

- area of 20,273 km²
- population ~ 2 mio
- density ~ 99 per km²
- 1,200 km railways
- 19,800 km roads
- 0.014 % of our planet's land surface
- home to 2 % of all known species of plants and animals
Slovenia: Relief map

- Highest point: 2864 m Triglav
- Alpine climate
- Continental climate
- Sub-Mediterranean climate
- 42 km of coastline
Slovenia: Geological map (variety of rocks)

Geološka karta Slovenije

Copyright: Geološki zavod Slovenije

Legend:
- Kvarter Terciar
- Kreta Jura
- Trias Perms
- Karbon Devon
- Devon Silur
- Silur Ordovicij
- Kambrij
- Predkambrij
- Maematsko kamnlos

Paramount Post Graduate Course | Innsbruck | 23. – 25. Okt. 2012
jost.sodnik@gmail.com
Slovenia: precipitation map (annual height in mm)
Slovenia: Hydrographic map

25,000 km rivers; 8,000 km torrents
Channel density > 1.5 km/km²
Slovenia: erosion areas and torrential watersheds
Slovenia: Legislation

- New Water Act in 2002
- All water related activities
  - Water management
  - Hydro power production
- Defines endangered areas due to natural hazards
  - Floods
  - Erosion
  - Landslides (rainfall induced)
- Avalanches
Floods
Floods

- 30% of population in the potentially flooded area
- 3 massive floods in last 5 years
- Flood hazard map for Slovenia 1:250 000 (2007)
- New legislation adopted in 2007 and 2008
- Directions for hazard assessment
- Obligations for spatial planning
- In progress
- Defining important areas according to EU directive
- Detailed hazard maps (1:5000) (financial issues)
Floods: Flood warning map 1:250 000 (2007)
Floods: Flood hazard mapping (methodology)
Floods: Detailed hazard map (spatial planning)
Debris flows
Debris flows

- Log pod Mangartom (nov. 2000)
  - 7 casualties
  - Over 1,000,000 m$^3$ magnitude
- “Case study” type of research
- Mathematical modeling
- Hazard assessment
- Debris flow susceptibility map 1:250,000 in 2008
- No “special legislation”
  - Partly covered with flooding legislation (erosion)
  - Methodology for hazard assessment
  - Rheology and magnitude of the event
Debris flows: debris flow susceptibility map
Landslides
Landslides

- National cadastre and database of landslides
- Landslide susceptibility map 1:250 000 in 2004
- Established system for sanitation measures financing
- No “special legislation” for landslides
- Landslide hazard very poorly implemented into process of spatial planning
Landslides: National landslide database

~ 6602 landslides (database not active since 2005)

≈ 0.4 slide per 1 km²
Landslides: Landslide susceptibility map

GeoZS, 2006

Authors: M. Komac & M. Ribičič
Rockfall
Rockfall

- Mostly relevant for road and railway infrastructure

- Rockfall susceptibility map 1:250 000 in 2011

- No special „rockfall legislation“

- “Case to case” solutions by certificated engineers for rockfall protection on state road network
Slovenia: Rockfall susceptibility map
Rockfall - protection

Protection of roads

Protection of railways
Avalanches
Avalanches

- Mostly relevant for transport infrastructure, ski resorts and mountain huts
- Generally covered with Water Act, 2002
- No “special legislation” on methodology for detailed snow avalanche hazard mapping
- Avalanche cadastre for Slovenia (~1250 avalanches)
- Detailed avalanche hazard analysis are performed for designing protection measures in endangered areas (defined in cadastre)
Conclusions

- Natural hazards are relevant in Slovenia
  - Transport connections
  - Settlements
  - Infrastructure

- Necessary to adopt proper legislation
  - Methodology for hazard mapping
  - Obligations for spatial planning

- Necessary to finance research projects
  - National
  - European - transnational (ParaMount)
Thank you for your attention.
Koroška Bela: presentation of torrential testbed and debris flow phenomena research

Jošt Sodnik and Matjaž Mikoš,
University of Ljubljana, Faculty of Civil and Geodetic Engineering
Koroška Bela testbed location
Koroška Bela testbed data

- Fan area 1.02 km²
- 2200 residents
- International railway
- Regional road
- Watershed area 6.4 km²
- Active landslide in the watershed area
- Debris flow in 1789
Debris flow research

- Pre-ParaMount project research
- Torrential basin survey
- Research excavations on the fan
- Geological and geotechnical research
- Flo2D sensitivity analysis and modeling

- ParaMount project
- Damage potential assessment
- TopRunDF sensitivity analysis
- Flo2D analysis with different DEMs
- Algorithms for torrential fans remote sensing
- Algorithms for LiDAR DEM improvements
Pre-ParaMount Project
Torrential basin survey
**Pre-ParaMount project**

**Excavations and geological/geotechnical research**

---

**Table:**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>Clay sediment</td>
</tr>
<tr>
<td>Layer 2</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Layer 3</td>
<td>Limestone</td>
</tr>
</tbody>
</table>

---

**Diagram:**

[Diagram showing geological layers and sediments]
Pre-ParaMount project
Flo2D model sensitivity analysis

- Computational grid cell size
- Position of input hydrograph
- Rheology parameters of debris flow
- Control parameters of the model
- Roughness parameters of the grid
- Influence of buildings
ParaMount project
Damage potential assessment

• Settlements
  – 251 houses and 19 apartment blocks (22 apartments)
  – Heavy steel industry facility

• 1 km of railway Ljubljana – Villach
  – 60 trains per day

• 1 km of regional road Moste - Jesenice
  – 16,000 vehicles per day
ParaMount project
TopRunDF sensitivity analysis

• Simple semi-empirical model
• Sensitivity analysis of input parameters
  – Mobility coefficient
  – Elevation step
  – Monte Carlo iteration number

• Promising results compared to Flo2D model
• Short computational times
• Some problems with numerical methods
ParaMount project

TopRunDF sensitivity analysis

Flo 2D

TopRunDF
ParaMount project
Testing different DEMs with Flo2D

• Different DEMs
  – Public available DEM5
  – Public available DEM12,5
  – LiDAR derived DEM0,5
  – DEM 0,5_5 (re-sampled DEM 0,5)

<table>
<thead>
<tr>
<th>Name (produced)</th>
<th>Accuracy (RMSE*)</th>
<th>Production method</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM12.5 (2001-2005)</td>
<td>3.8 m</td>
<td>fusion of existing geodetic datasets of different type/quality</td>
</tr>
<tr>
<td>DEM5 (2006-2007)</td>
<td>3.5 m</td>
<td>resampling of DEM12.5 + stereo photogrammetry and local adjusting with CAD-tools</td>
</tr>
<tr>
<td>DEM0.5 (2009-2010)</td>
<td>5-10 cm (in channels gross errors &gt; 1m)</td>
<td>datasets of 12 blocks (leaves &amp; snow): different approaches to filtering and interpolation</td>
</tr>
<tr>
<td>DEM5 from DEM0.5 (2010)</td>
<td>5-10 cm (in channels gross errors &gt; 1 m)</td>
<td>resampling of DEM0.5</td>
</tr>
</tbody>
</table>

* RMSE (Root Means Square Error)
ParaMount project
Testing different DEMs with Flo2D

DEM 5
DEM 12,5
DEM 0,5
DEM 0,5_5
ParaMount project
Testing different DEMs with Flo2D

<table>
<thead>
<tr>
<th>Model description</th>
<th>Maximum inundated area [m²]</th>
<th>Average flow depth [m]</th>
<th>Average flow velocity [m/s]</th>
<th>Computational time [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public DEM5</td>
<td>145,325</td>
<td>0.78</td>
<td>2.38</td>
<td>1.9</td>
</tr>
<tr>
<td>Public DEM12.5</td>
<td>118,675</td>
<td>1.18</td>
<td>2.37</td>
<td>2.8</td>
</tr>
<tr>
<td>LiDAR DEM0.5</td>
<td>131,200</td>
<td>0.80</td>
<td>1.84</td>
<td>32</td>
</tr>
<tr>
<td>LiDAR DEM5</td>
<td>131,325</td>
<td>0.71</td>
<td>2.40</td>
<td>26</td>
</tr>
</tbody>
</table>

- More accurate results with LiDAR DEMs
- LiDAR data has potential for further improvements
- Much longer computational times (32h for 15 min event)
- Large amount of data – could be problem when analyzing larger areas
- High price for LiDAR data
- -> Need for DEM improvements
ParaMount project

Algorithms for LiDAR DEMs improvements

- Improvement of LiDAR DEM0.5
- Algorithms for improvements:
  - Centered on torrential channel
  - New combinations of filtering “point cloud”
  - MCC (multiscale curvature classification) for channel banks
  - Manual filtering corrections for channel
  - Removing non-ground points
  - Natural neighbor method for main fan area

- Algorithms still under development
ParaMount project

Algorithms for LiDAR DEMs improvements

- Results of improvement

- Channel better expressed
- More accurate results on the floodplain area
- Bridge error eliminated
- Computational times decrease from 32h to 2,5h (15 min event)
ParaMount project

Algorithms for torrential fans remote sensing

• DEM based algorithms (DEM 12,5 and DEM 5)

• Used parameters (Podobnikar)
  – Relative relief
  – Curvature of the terrain
  – Slope of the terrain
  – Exposition (N,W,S,E)
  – Parameters defined using “local window”

• Algorithms still under development
ParaMount project
Algorithms for torrential fans remote sensing

First results of beta version of algorithms
ParaMount project
Main results and deliverables

- New tools for debris flow hazard assessment
- New algorithms
  - DEM improvement
  - Torrential fan remote sensing
- Hazard map for Koroška Bela torrential fan
- Possibility to implement developed methods to other areas
ParaMount project
Main results and deliverables

LEGEND:

Red (high hazard): 
H > 1m or v*h > 1m²/s

Orange (medium hazard): 
H > 0,5m or v*h > 0,5 m²/s

Yellow (low hazard): 
H > 0,2m or v*h > 0,2 m²/s
Thank you for your attention
Baška grapa: presentation of rockfall/avalanche testbed and snow avalanche risk assessment

Gašper Rak and prof. Franci Steinman,
University of Ljubljana, Faculty of Civil and Geodetic Engineering
Content:

- Testbed description
- Data and information
- Avalanche Hazard assessment on regional and local scale
- Assessment of damage potential in testbed
- Risk assessment for avalanche
- Conclusions
Testbed Posočje (Baška grapa):

- Bohinjska railway (Jesenice-Gorica-Kreplje-Trst)
- Austro-Hungarian monarchy build it in years 1902-1906 as a second railway connection of Austrian and Bavarian cities (Vienna, München, Prague) with Trieste (port city on the Adriatic Sea)
- Demanding construction with tunnels and bridges in difficult mountain terrain
- Till 1914 railway has an important role for economic development
- During WW1 it has been given a completely different, but still very important role

Technical data (Jesenice – Trieste)

- Opening year: 1906
- Length: 145km
- Tunnel: 48 (up to 6339m)
- Bridges: 62 (stone arch bridge with 85m span length)
- Max rail inclination: 2.6%
Railway Jesenice – Gorica today:

- Regional line (Decree on the categorization of railway lines, 2002)
- Additional rail connection of Koper port with Austria and Germany
- Passenger transport, car transport and freight transport
  - ~10000 passenger trains per year (~27 trains per day)
  - ~5000 freight trains per year (~13 trains per day)
- Museum train as tourist attraction
- It is still not electrified
Many natural hazards threat Bohinj railway

- Torrents & erosion, landslides, rock fall and avalanches
Input data and information

- Analyses of geological reports
- Collection of meteorological and hydrological data
- Past event documentation and field survey of silent witnesses
  - ~ 100 recorded events in last 10 years
  - Few data on exact number of events
- Data collection of railway infrastructure, passengers and cargo transport etc.
- Field survey of Protection systems & decision support system and their defect
- New field survey of topographic data for more detail rock fall and avalanches simulation with mathematical models
- Avalanche cadastre
- Information about forest stands and their functionality as protection forests
Field survey & Database of existing protection structures

- Slovenian railways has no evidence of existing protection structures and their state
- the Slovenian partners made an extensive field survey and prepared a database with all important data:
  - Location (GPS coordinates)
  - Distance from track and approximate railroad chainage
  - Altitude
  - Slope inclination
  - Year of construction (mostly unknown)
  - Type of structure
  - Structure dimensions (length, height)
  - State of structure (bad, sufficient, good, very good, perfect)
  - Suitability of structure for expected hazards (bad, sufficient, good, very good, perfect)
Field survey & Database of existing protection structures

- With losing importance in recent decades, railway and protection structures became neglected → major part of the structures are in bad condition
- Situation is slowly improving → in recent years SŽ installed some new modern structures

**State of protection structures**

- Bad: 3%
- Sufficient: 17%
- Good: 7%
- Very good: 5%
- Perfect: 68%

**Suitability of protection structures**

- Bad: 12%
- Sufficient: 17%
- Good: 31%
- Very good: 68%
- Perfect: 3%
Avalanche hazard assessment

• Avalanche cadastre
  (Cadastre made for the whole country registers 13 avalanche areas in the Baška grapa test bed. For each avalanche area, data included in the cadastre comprise of: area size, centroid coordinates, release area altitude, deposition area altitude, slope angle, shape of avalanche area, vegetation, soil stability, exposition and estimated recurrence interval)

• Avalanche hazard assessment on regional scale/hazard indication map
  (simulation with avalanche energy line model (simulation performed by Irstea, FRA) → determination of “hotspots”)

• Detailed simulation of avalanche hazard for the most endangered section
  – the most endangered sections defined on the basis of avalanche cadastre, results of simulation on regional scale and data on endangered sections of the railway, received from the Slovenian railways
  – In the study, the field survey results (orientation, existing protection structures and vegetation) and the modelling results (impact energy and deposition depth) for snow depths with different probability (return intervals of 10, 30 and 300 years) were the basis of an elaborate hazard assessment, which allowed the division of the railroad into hazard classes.
Avalanche hazard maps

- Avalanche hazard very generally covered with Water Act from 2002
- No legislation on methodology for detailed snow avalanche hazard analysis and mapping
- The choice of 4 hazard classes was made according to Slovene flood mapping regulations, as was the choice of class markings

Energy line model results (IRSTEA)
Avalanche hazard assessment study (Sirk 2011)

Endangered sections (Slovenian railways)

4 hazard classes
- High hazard
- Medium hazard
- Low hazard
- Residual hazard

Post Graduate Course | Innsbruck | October 23rd to 25th, 2012
grak@fgg.uni-lj.si
Avalanche vulnerability map

• The method was comprised with the goal of its high simplicity and applicability to all Slovenian railroad lines.
• The basis for the vulnerability evaluation was once again the officially defined method used in flood management practice
• Measures for vulnerability classification were:
  – Railroad infrastructure vulnerability: a cadastre of railroad infrastructure elements (railroad track, switches, tunnels, culverts, bridges, switch houses, watchman’s houses, stops and stations)
  – Environmental vulnerability: the railway runs through different natural habitats and some of them are protected. The whole bed of the Bača watercourse is marked as “Ecologically significant area” and from the track kilometre 48.150 even protected by Natura 2000
  – Visibility: since the traveling speed is slow (60 to 70 km/h) there is a possibility, that the engine driver sees the obstacle (avalanche of rockfall deposits) on the track far enough and is able to stop the train or at least slow it down, so that the impact causes less damage. Visibility was estimated from the digital elevation model and orthophoto images.
  – Radial effect: if a collision occurs, the probability of derailment (higher damage) is higher if the collision takes place in a curve rather than on a straight track-line.
Avalanche vulnerability map

Enviromental vulnerability

Visibility

Radial effect

Railroad infrastructure vulnerability

4 vulnerability classes

- Very low vulnerability
- Low vulnerability
- Medium vulnerability
- High vulnerability

Part 1
Chainage: from 35.000 to 39.000

Part 2
Chainage: from 38.500 to 42.500

Post Graduate Course | Innsbruck | October 23\textsuperscript{th} to 25\textsuperscript{th}, 2012
grak@fgg.uni-lj.si
Avalanche risk map

- Risk is a combination of probability of a natural event and of the potential adverse consequences. Based on this definition risk for the railroad infrastructure was evaluated from hazard and vulnerability assessed according to the used method. Four risk classes were defined: high, medium, low and residual risk.
Avalanche risk map
Conclusions

• In Slovenia avalanches mainly threaten transport infrastructure, ski resorts and buildings in the mountains.
• Despite the presence of avalanche risk, there was a lack of regulations for avalanche risk management and resources for protection and decision support systems.
  • Avalanche hazard very generally covered with Water Act from 2002
  • No legislation on methodology for detailed snow avalanche hazards analysis and mapping
• For Slovenian test bed (Baška grapa) the Slovene partners of the PARAmount project made two important products: the database (cadastre) of protection structures and the risk evaluation (risk map).
• Results show the risk situation and consequently necessity for better risk management and decision support.
• The combination of the risk map and the database of protection structures provides an overview of possible future risk situations, if the structures continue to be neglected, as they have been for years.
• Results show also, where the risk situation can be improved by renovation of existing structures and where new structures are needed.
• Method used in testbed is convenient for other railway and roads, exposed to natural hazards.
Thank you for your attention
Rockfall risk assessment and concept of rockfall protection measures
(Slovenia railway test section – Baška grapa)

Jože Papež* and Franci Steinman**,

* M.Sc., Hidrotehnik
  Water Management Company
  (formerly PUH / partner PP8)
** Prof. Dr., University of Ljubljana,
  Faculty of Civil and Geodetic Engineering
Rockfall hazard – test bed Baška grapa

Contents

- **Rockfall hazard/risk assessment**
  - Methodology (analyses & field survey : modelling)
  - Hazard / risk map of test bed section

- **Concept of rockfall protection measures**
  - State of the art: protection of roads or railways (background and difference in development)
  - Planning (Founds), Design (EOTA!) and Installation (Quality!)

- **Discussion/Conclusion**
  - How to deal with „today‘s“ major challenge („real life!“) : lack of funding ⬤ & increasing of risk ⬤?
  - Expert support by „Practical Approach“ by Decision making?
  - (Answer: rational but transparent regarding residual risks!)
Rockfall hazard – test bed Baška grapa
Rockfall hazards
Slovenia

- Manly endangered road and railway infrastructure
- Estimation (PUH, 2008, 2011) rockfall is a major hazard for:
  - 175 km i.e. 2.8% of the total of 6.215 km state roads
  - 59 km i.e. 4.8% of the total of 1.229 km railroads
- Rockfall susceptibility map 1:250 000 (already presented)
- No special legislation but „Design projects“ for rockfall protection on state road network (1993 - .. today start with EOTA standards)
Bled, 17. oktobra - Do nesreče je v soboto ob 6.37 prišlo zaradi skal, ki so se odkrilišne skalnate gmote kakšnih 30 metrov nad železniško progo in zgrmelo nanjo. Skala, ki je iztipila, je smerila dizelski motorni potniški vlak z dvema vagonoma, je merila 130-krat 60 centimeterov.

Vlak 42-43 z dvema vagonoma, ki je v soboto vozil na progo od Nove Gorice do Jesenic in nazaj, je bil dolg dobrih 44 tih metrov. Okrog 5.20 je prvič uspel peljali skozi blejski predor proti Jesenicam, kjer je čakal do načrtovanega izleta v 6.20, nato za z vsem oznanim potnikom "ritensko" spet krenil. Za potnike je bil mimo železniške robote postaje na Bledu, je zavil v 200 tolarjev. Poskodovan je prvi podstavni voziček, proga v
Rockfall hazard – test bed Baška grapa

Rockfall hazards assessment

PARAmaount activities in test bed Baška grapa

– Assessment of regional risk management
  
  • Output: Report of regional risk management of Bohinj railway ✓

– Rock-fall analyses (event documentation, field survey for silent witnesses, objects data base, computer simulating ...) & testing of "operative tools" for the simulation of rock-fall hazard processes (detailed test section)
  
  • Output: Hazard/risk map for test section of Bohinj railway ✓

– Evaluation and Recommendation for future risk management (rock-fall, snow avalanches protection management)
  
  • Output: Report of Evaluation and Recommendation for risk management regarding rock-fall and snow avalanches on test section of Bohinj railway ✓
Rockfall hazard – test bed Baška grapa
Rockfall hazards assessment
– Rockfall hazard analyses

• Analyses of existing documentation (reports, data in Excel sheets, ...):
  – Reports of SZ official commission about field survey of critical slopes
  – Analyses of geological reports
  – Collection of meteorological and hydrological data, forest stands (protection f.)
  – Analyses of event documentation (competition different „data bases“ of Event documentation in new d.b.(GIS))
  – Analyses of documentation about existing protection structures (competition different „data bases“ and field data captures in new d.b. (GIS))
  – Analyses of NOJP (alarm system) design plans & field data (placement in GIS)

• Site visits / Field survey („silent witnesses“ of rockfall events, measurements, objects data base ...) & preparation of expertises

• Preparation of „Input Data“ (DMR 2m, Railway line&stationary, forest ...)

• „Adaptation“ of methodology for rockfall and infrastructure needs

• Computer simulating (modelling)...; testing of "operative tools"

• Output: Hazard map for test section of Bohinj railway
Rockfall hazard – test bed Baška grapa
Rockfall protection – protection forest

Concept – positive influence of forest (also negative ?!)

Answers: Project MANFRED!
Rockfall hazard – test bed Baška grapa
Rockfall event documentation

Creation data base Event documentation (GIS)

- Date and time of the event
- Location (name of the railway line)
- Position (stationary)
- Location (X, Y)
- Rock type, it’s weight and volume (radius)
- Height above the railway line
- Transport area
- Action area
- Area of disposal
Rockfall hazard – test bed Baška grapa
Rockfall field survey

Initiation or rockfall source zones (dimension of design rock?)
Rockfall hazard – test bed Baška grapa
Rockfall field survey

Transit zone: record of addition data: under "green cover", are a lot of "clear path/trajectories, stopped rocks = dimension of design rock?"
Rockfall hazard – test bed Baška grapa
Rockfall field survey

Critical points (gorges, ...)

The wooden elements of rigid structures are mostly in bad conditions.
Rockfall hazard – test bed Baška grapa
Rockfall field survey

Existing protection structures - fulfillment of inventory forms

Condition of protection objects & systems

… in the literature can be found indications that such a barrier in very good condition retains 50-70 kJ of energy (?!).
Rockfall hazard – test bed Baška grapa

Existing protection structures - assessment of the state

Problematic

Insufficient

Critical

Condition of protection objects & systems

The many of old structures do not correspond to safety requirement regarding risk assessment.
Rockfall hazard – test bed Baška grapa

Rockfall field survey

Existing protection structures – rigid structures (rigid barriers and fences made of "palvis" nets)
Reinforcement of existing protection structure with additional lines of protection fences

Existing protection structures
Wooden barriers (Source: SVP Postojna, Nova Gorica 2008)

- Location (name of the railway line)
- Position (stationary)
- Length of the wooden rigid structure
- Height of the object (MIN, MAX)
- Distance from the railway
- The number of the post (of the one of barrier’s line)
- The number of wooden cross-ties (of the one of barrier's line)
- Year of the instalation of the object
- Year of the execution of reconstruction works (foundation, posts, wooden cross-ties)
- State of the object (palisade)
- Comments

<table>
<thead>
<tr>
<th>Župnija</th>
<th>Medpostajni odsek proge</th>
<th>Stacionaža odsek proge</th>
<th>Dolžina (m) palisade</th>
<th>Višina (m)</th>
<th>Oddaljenost od proge</th>
<th>Stevilo t timič</th>
<th>Stevilo pragov</th>
<th>Leto gradnje</th>
<th>Rekonstrukcija (leto)</th>
<th>Stanje palisade</th>
<th>Opomba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Podbrdo- Grahovo</td>
<td>37+000 - 37+300</td>
<td>300</td>
<td>1,50</td>
<td>2,50</td>
<td>60</td>
<td>143</td>
<td>v redu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Podbrdo- Grahovo</td>
<td>37+700 - 37+770</td>
<td>70</td>
<td>1,50</td>
<td>2,50</td>
<td>20</td>
<td>33</td>
<td>Zadovoljno</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Podbrdo- Grahovo</td>
<td>37+852 - 37+920</td>
<td>68</td>
<td>1,50</td>
<td>2,50</td>
<td>18</td>
<td>32</td>
<td>v redu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Podbrdo- Grahovo</td>
<td>39+350 - 39+400</td>
<td>50</td>
<td>1,50</td>
<td>2,50</td>
<td>35</td>
<td>23</td>
<td>Zelo slabo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grahovo-Most na Soči</td>
<td>41+900 - 42+050</td>
<td>150</td>
<td>1,50</td>
<td>2,50</td>
<td>150</td>
<td>70</td>
<td>v redu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grahovo-Most na Soči</td>
<td>54+390 - 54+410</td>
<td>20</td>
<td>1,50</td>
<td>2,50</td>
<td>30</td>
<td>9</td>
<td>Zadovoljno</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grahovo-Most na Soči</td>
<td>54+650 - 54+700</td>
<td>50</td>
<td>1,50</td>
<td>2,50</td>
<td>40</td>
<td>23</td>
<td>v redu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grahovo-Most na Soči</td>
<td>54+790 - 54+830</td>
<td>40</td>
<td>1,50</td>
<td>2,60</td>
<td>19</td>
<td>v redu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rockfall hazard – test bed Baška grapa

Rockfall field survey

Existing protection structures – rigid structures
(rigid barriers and fences made of "palvis" nets)
Rockfall hazard – test bed Baška grapa
Rockfall field survey

Data base about existing protection structures -
Development of new GIS data base with attribute date:

- Location (name of the railway line)
- Position (stationary)
- Object
- Material of the object
- Length of the object
- Height of the object
- Distance from the railway
- The number of the posts (of the object)

**State of the object**

- Suitability assessment
- Action (what to do: maintenance, replacement, ...)

E: joze.papez@hidrotehnik.si & franci.steinman@fgg.uni-lj.si
## Rockfall hazard – test bed Baška grapa

Tools for Hazard Assessment and Dimensioning of Measures (protection barriers/sistems) - SWOT

<table>
<thead>
<tr>
<th></th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Opportunities</th>
<th>Threats</th>
<th>Test bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP8, PP9</td>
<td><strong>Rockfall hazard map and method</strong>&lt;br&gt;Based on DEM and past events data. The latter exists for the whole Slovenian rail network. High precision (10 meter stretches) Enhanced with 1D and 2D numerical modelling. Danger zones set by the Slovenian Railways are considered.</td>
<td>Some of the employed vital data and studies are not available for all endangered railway sections in Slovenia. Difficult to apply to the whole Slovenian rail network. Hazard classes' thresholds should be verified with other methods or by representatives from the railway safety services.</td>
<td>Gives a good overview of hazard zones for the test bed, to be used by the railway management.</td>
<td>Possibility of hazard mismevaluation due to unforeseen influences.</td>
<td>Baška grapa – local</td>
</tr>
<tr>
<td>PP8, PP9</td>
<td><strong>Rocky For3D</strong>&lt;br&gt;The software provides good overview about spatial extension of rockfall hazard (good possibilities of different method of visualisation). Possibility of taking the actions of trees and forest stands into account. It allows the calculation of a large area, if detailed field data are available.</td>
<td>Back analysis with 2D rockfall models gives only an estimation of what happened. The quality of input data from field investigation very depends on expert experiences — a quite big differences are possible between different users (subjectivity).</td>
<td>The function of protection forest can be calculated as help for the forest management teams regarding silviculture works. The results can be imported into a GIS.</td>
<td>Results have to be properly checked on field, because of quite often defects of DEM input data — this applies to all 3D programs.</td>
<td>Baška grapa – local</td>
</tr>
<tr>
<td>PP8, PP9</td>
<td><strong>Rockfall (Dr. Spang)</strong>&lt;br&gt;A statistical calculation of energies, jump heights is possible. Positive response from expert designer / practitioner regarding dimensioning.</td>
<td>A lot of experience is needed to define the specific soil values. Only a range is given by the software.</td>
<td>Software could be even more user-friendly, especially regarding preparation of input data and possibility of saving different repeat experiments on the same spot.</td>
<td>Results should be checked for speed of falling rocks – this is very sensitive and highly dependent on the characteristics of the soil.</td>
<td>Baška grapa – local</td>
</tr>
<tr>
<td>PP8, PP9</td>
<td><strong>Past events cadastre – rockfall, snow avalanches</strong>&lt;br&gt;From good GIS data base are very good visible “hot spots/sections”. Consistent and comprehensive event documentation is a great help in assessing of hazard and designing protection measures.</td>
<td>Inconsistency in continuous documentation (proper records and descriptions of all cases) can lead to limited usability and to misleading conclusions.</td>
<td>Modern technological equipment (tablet computers, GPS devices, cameras equipped with GPS tracks, special binoculars, ..) can facilitate powerful help by capturing data and by formation of user-friendly and useful GIS data base.</td>
<td>Overvaluation of database of past events and the lack of attention to other potential dangerous sections.</td>
<td>Baška grapa – local</td>
</tr>
<tr>
<td>PP8, PP9</td>
<td><strong>Cadastre for rockfall mitigation structures</strong>&lt;br&gt;Possibility of comparing the data of the hot spots, past events, and behaviour of different protection measures. Essential data basis for planning of maintenance work.</td>
<td>In this area there is no Slovenian technical guidelines for the railways. It is not complete clear how to use this information in hazard and risk assessing. What is the weight of protective objects without known characteristics, plans, certificates ...</td>
<td>Because of common Europeans standards (e.g. EOTA guidelines) and experiences in neighbors countries could be such a already implemented solutions easy transferable in Slovene environment</td>
<td>Subjectivity in data entry regarding state of protection’s facilities / structures could lead to wrong conclusions.</td>
<td>Baška grapa – local</td>
</tr>
</tbody>
</table>
Rockfall hazard – test bed Baška grapa
Hazard assessment
Tools for Hazard Assessment and Dimensioning of Measures (protection barriers/sistems)
RockyforLINE RockyFor3D Rockfall (Spang)

RockyFor3D is a computer program for the 3D simulation of rockfall. It was developed by Luc Durren ...

RockforLine – energy line at 33° Rockyfor3D (result output: E_95) Rockfall 6.1 – most critical profile

Rockfall simulations as performed in PARAmount analysis are, despite state-of-the-art analysis, still an approximation of real events, so field investigation and incorporating of messages of “silent witnesses” in expert decision is obligatory to get more correct results.
Rockfall hazard – test bed Baška grapa

Hazard assessment

Tools for Hazard Assessment and Dimensioning of Measures (protection barriers/sistems)

Rockfall (Dr. Spang) - example

The program is based on the laws of motion and the collision theory. The path of a single rock block or of up to 10'000 blocks, can be calculated and interpreted by the same run. At each point within a profile (especially at the positions of planned interception structures or rockfall barriers) the kinetic energies and bounce heights can be calculated. The input data are varied by a random number generator within user defined boundaries. The results are presented in class and summation histogram.

- A statistical calculation of energies, jump heights is possible.
- Positive response from expert designer / practitioner regarding dimensioning.
Rockfall hazard – test bed Baška grapa
Hazard assessment

Hazard map

Public information, Surveying and Mapping Authority of the Republic of Slovenia,
Topographic data: digital orthophoto

Project:

ROCKFALL HAZARD MAP
Posočje test bed
Bača railroad section

Scale: 1 : 10 000
Date: August 2012

E: joze.papez@hidrotehnik.si & franci.steinman@fgg.uni-lj.si
Rockfall hazard – test bed Baška grapa
Risk assessment

Vulnerability map
Rockfall hazard – test bed Baška grapa

Risk assessment

Risk map
Rockfall hazard – test bed Baška grapa

Rockfall Protection

State of the art: protection of roads or railways

Protection of roads

“Less serious“ problems: simple light rigid mesh-fences
“More serious“ problems: … in last 15-20 years manly modern flexible and certificated rockfall protection barriers

Protection of railways

At the railways are dominated by
• rigid catching wooden-fences,
• simple light rigid mesh-fences and
• „old“ early warning systems.
Rockfall hazard – test bed Baška grapa
Rockfall Protection
State of the art: protection of railways
System for early warning and alerting called EAN / NOJP

On the most endangered 14 section there are installed early warning system called EAN in the length (sum) of 11.654 m. There exist also plans for additional 10.540 m of EAN.
The problems are solved with measures (hazard mitigation solutions) of:

- **active** (primary, secondary) and
- **passive** protection.

The principles of rockfall protection are determined by the **extent** and **location** of hazard. Base for decision about protection measures are:

- Hazard and risk assessment (including Rockfall simulation analysis)
- Preliminary Design Proposal for Rockfall Protection & Slope Stabilization
  - Has to already include demands and conditions regarding: standards, technical possibilities, up-to date types of solutions, reliability, durability, rationality and environmental acceptance of control measures
  - Prepared by Competent Natural Hazards Experts (certificated engineers)
Rockfall protection – test bed Baška grapa

Discussion / Conclusions

Key message: Take decision:
Passive or active measures or … combination of measures?

1. Passive …
Not to influence on process, only early warning?!

2. Active …
Influence on the process on the source, transport, deposition area?

Main message:
Transparent regarding residual risk!!!

<table>
<thead>
<tr>
<th>positive</th>
<th>negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop the traffic when something occur on observed section</td>
<td>Depend on electricity and proper working of all devices; false alarms,</td>
</tr>
<tr>
<td></td>
<td>the situations of direct impacts are not solved (rocks are not stopped)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>positive</th>
<th>negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active protection - stopping the rocks on the slopes</td>
<td>Questions of residual risk (remaining working height ...): depends on the</td>
</tr>
<tr>
<td></td>
<td>type and size of events? The maintenance?</td>
</tr>
</tbody>
</table>

Recommendation (proposal): Probably are the most adequate solutions the measures, which combine this two approach. But, the most critical sections „has to“ be in the future „covered“ with active measures (Decision 2).

E: joze.papez@hidrotehnik.si & franci.steinman@fkg.uni-lj.si
Rockfall protection – test bed Baška grapa

Discussion / Conclusions

Recommendation: protection of roads or railways

Active : Passive? Combination of measures (example)!
Rockfall hazard – test bed Baška grapa

Rockfall Protection - concept

Concept of protection measures – decision:
Primary or secondary active protection measures?

**Primary active measures**

Primary protection is carried out on the areas where rockfall phenomena occur.

Standard rockfall control was carried out with plain or reinforced mesh drape, with which the falling rocks were restrained.

**Secondary active measures**

Secondary protection is used when rocks have already been released.

… up to date rockfall barriers can retain falling rocks and boulders from 75 kJ up to over 8000 kJ of dynamic pressure. The rockfall barriers can be combined with avalanche protection measures.

**Decision – recommendation for slovene railways:**

Where is possible is more adequate to stabilize slopes on the source area (primary), but based on preliminary assessment of the slope conditions will prevail secondary measures. These structures (rockfall barriers) can serve their purpose only when they are regularly checked, cleaned and maintained. Provision must be taken to mitigate the residual risk.
Rockfall protection – test bed Baška grapa

Discussion / Conclusions

Key message: Take decision regarding active secundary measures:
How to tackle lack of funding 💲 & increasing of risk 🕵️‍♂️ (possibility?)

1. To protect more sections (m') of railroads with lighter simple structures?

2. To protect less sections (m') of railroads with high-tech flexible, certificated protection systems?

Main massage:
Transparent regarding residual risk!!!

<table>
<thead>
<tr>
<th>positive</th>
<th>negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>inexpensive, successful protection of large stretches for small rockfall events</td>
<td>Not known the level of protection and the residual risk</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>positive</th>
<th>negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>High protection for knowing hazard</td>
<td>Expensive, still remain residual risk</td>
</tr>
</tbody>
</table>

Recommendation (proposal): Decision 1 is in some way exceptable and reasonable: successful mitigation the hazard of falling small rocks, which is also dangerous for railway traffic. But, this actions has to be accompanied by hazard assessment, which will show remaining/residual risk & with settled goals, plans, how will be in the future adequate solved the most critical sections (Decision 2).
Rockfall protection – test bed Baška grapa
Discussion / Conclusions

Key message: Design & Installation: standards and control of quality!

PARAmount Post Graduate Course | Innsbruck | 23. – 25. Okt. 2012
E: joze.papez@hidrotehnik.si & franci.steinman@fgg.uni-lj.si
Rockfall protection – test bed Baška grapa
Discusion / Conclusions

Key message: Importance of regular inspection and maintenance!
Installation of first flexible high-tech protection barrier on Slovene railways in the year 2011 (also thanks to influence of PARAmount project?)

A complete protection against natural disasters does not exist, but we can important mitigate risk!

Take Action!

Thank you!
Thank you!

Additional informations:

Jože Papež  
(joze.papez@hidrotehnik.si)

Hidrotehnik  
Water Management Company  
Slovenčeva 97,  
Ljubljana, Slovenija

Additional informations:

Franci Steinman  
(franci.steinman@fgg.uni-lj.si)

University of Ljubljana (UL)  
Faculty of Civil and Geodetic Engineering (FGG)  
Ljubljana, Slovenija