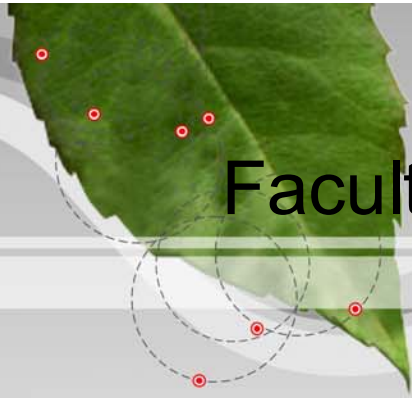




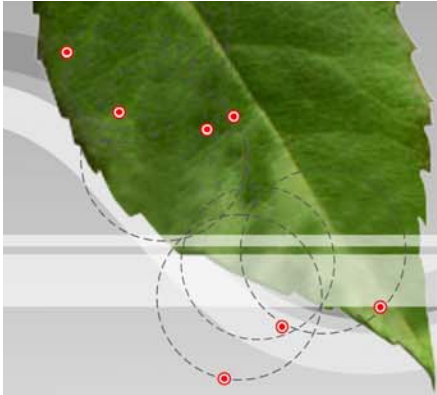
University of Ljubljana,
Faculty for Civil and Geodetic Engineering



Geotechnical analysis of recovery lot

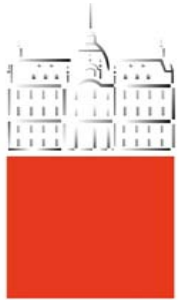
A. Petkovšek, J. Klopčič, B. Majes

Project ALPTER – Terraced landscapes of the Alpine arc.
Dobrovo, October 12th 2006

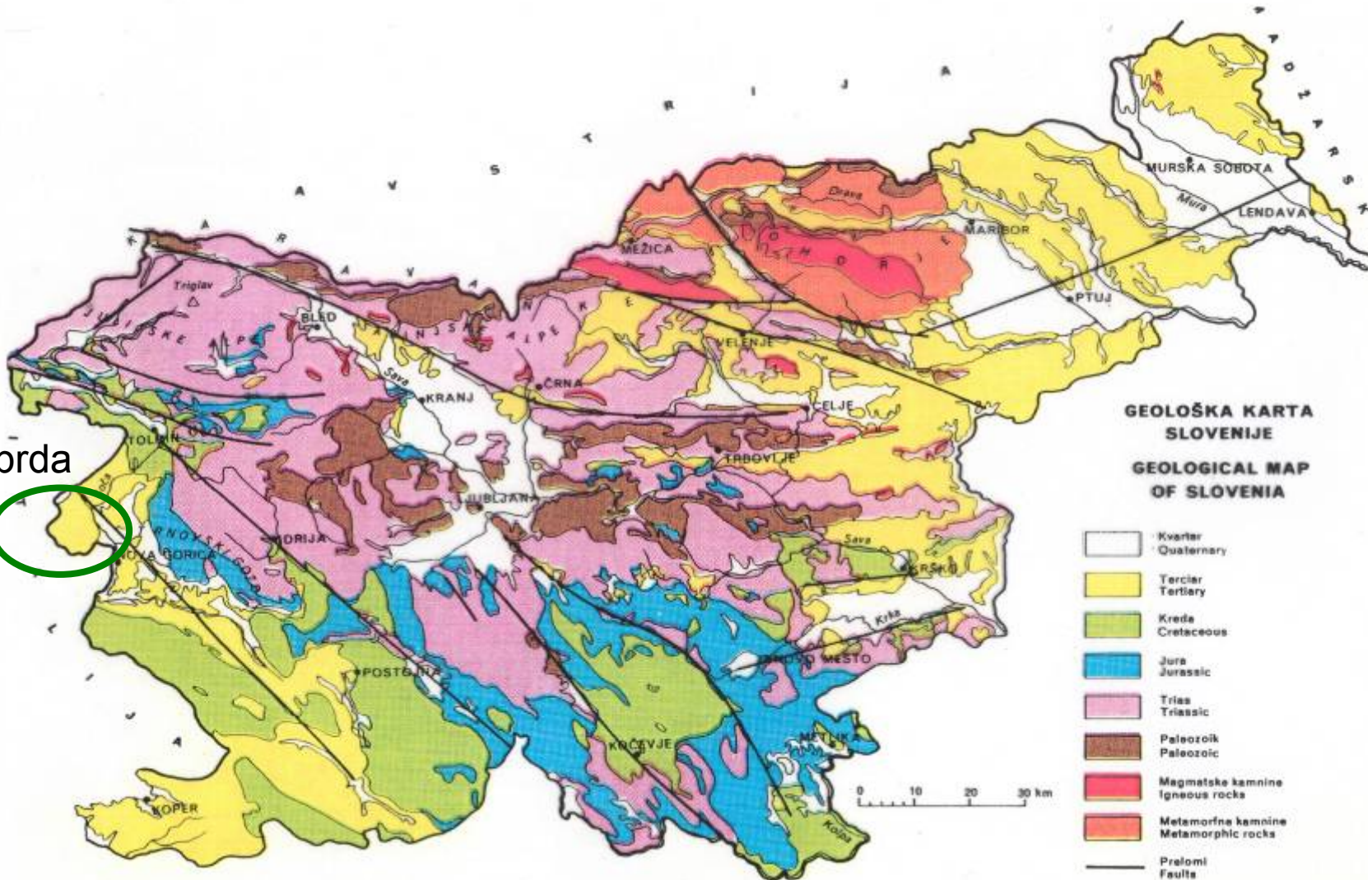


Content

- 1. Introduction***
- 2. Flysch rock properties and behaviour***
- 3. Influence of flysch deterioration to the long term slope stability***
- 4. Influence of slope inclination to stability***
- 5. Influence of underground water level to stability***
- 6. Conclusions and recommendations***



Geological map of Slovenia

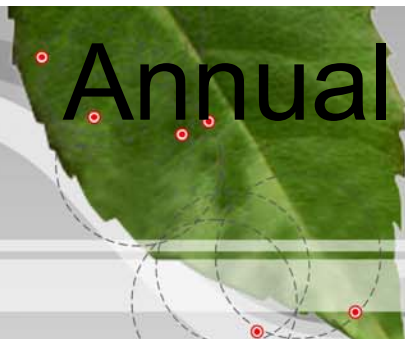


Goriška brda



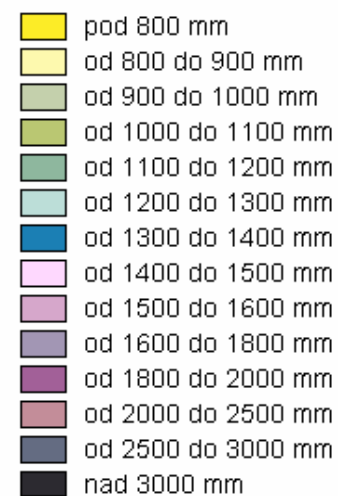


Annual precipitation, 1961 - 1990



Goriška brda

1500 - 1800 mm

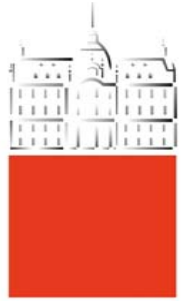






What we have to know about flysch bedrock

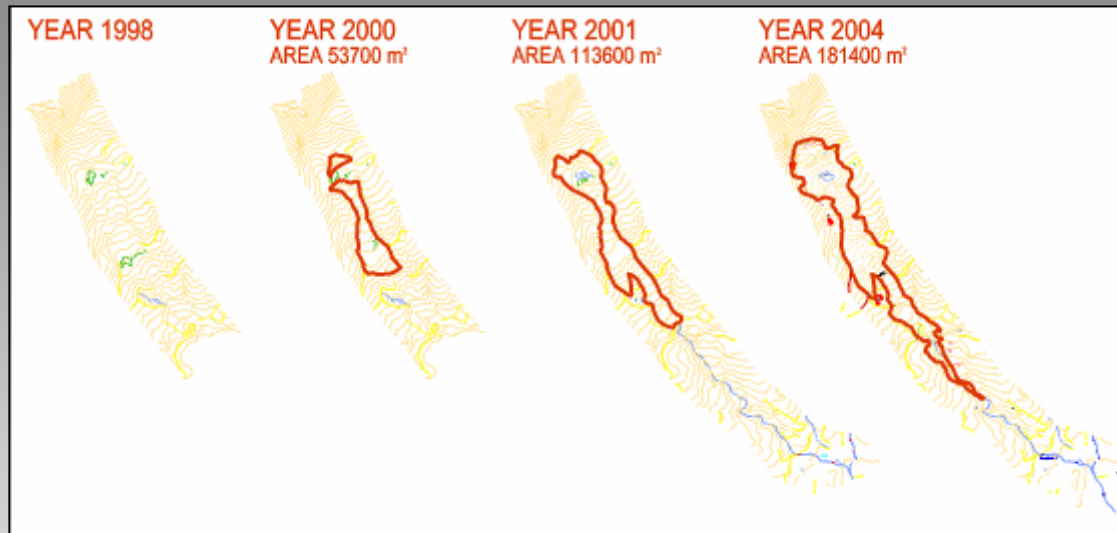
- Very heterogeneous, layered materials.
- Sandstones, siltstones, marls, clay shales, stiff clays and even calcarenites
- Very sensitive to water.
- They are intermediate in behaviour between rock and soil.
- Tend to transgress from rock-like to soil like materials in a relatively short time period.



Changes, changes...

- Changes: volume changes, lost of strength, sensitivity to water firstly increases and then equilibrates.
- Changes in the strength can be very drastic, commonly exhibit 40 – 80 % reduction in shear strength over periods from 1-70 years.
- Internal friction angles of 20 – 30⁰ in natural flysch are often reduced to extremely low values of < 15⁰
- Many engineering problems: landslides, premature failures of road embankments, pavements, terraces.

A “Slano Blato” large landslide case



Source of data: Majes (2006)





“Self-feeding” landslide Slano blato



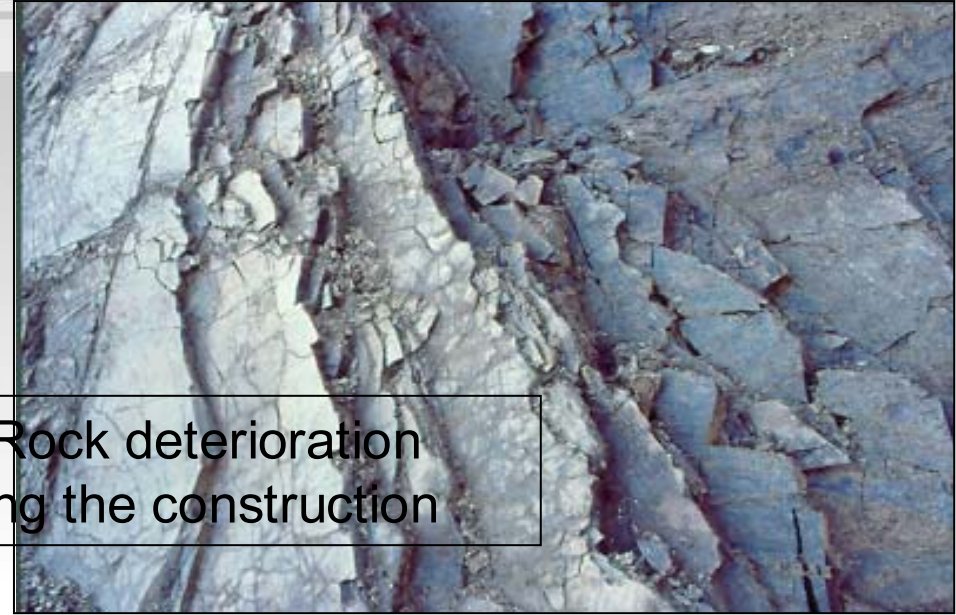


A motorway Razdrto case

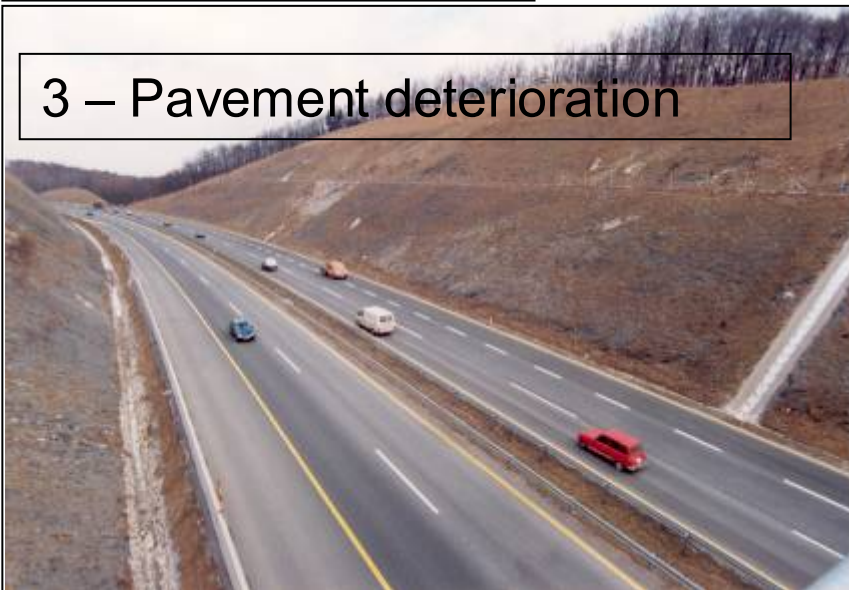
1 – Excavation in stiff rock



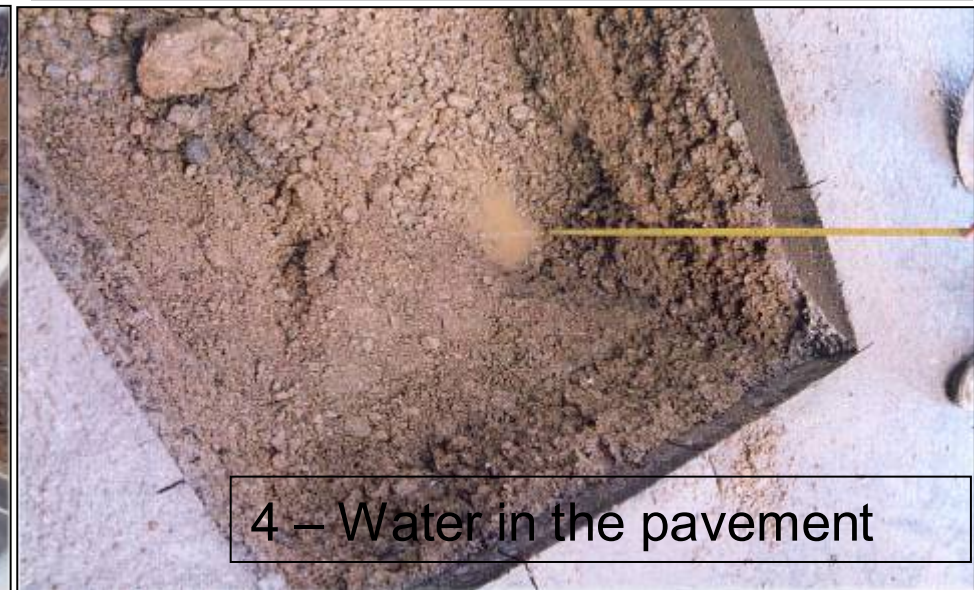
2 – Rock deterioration during the construction



3 – Pavement deterioration



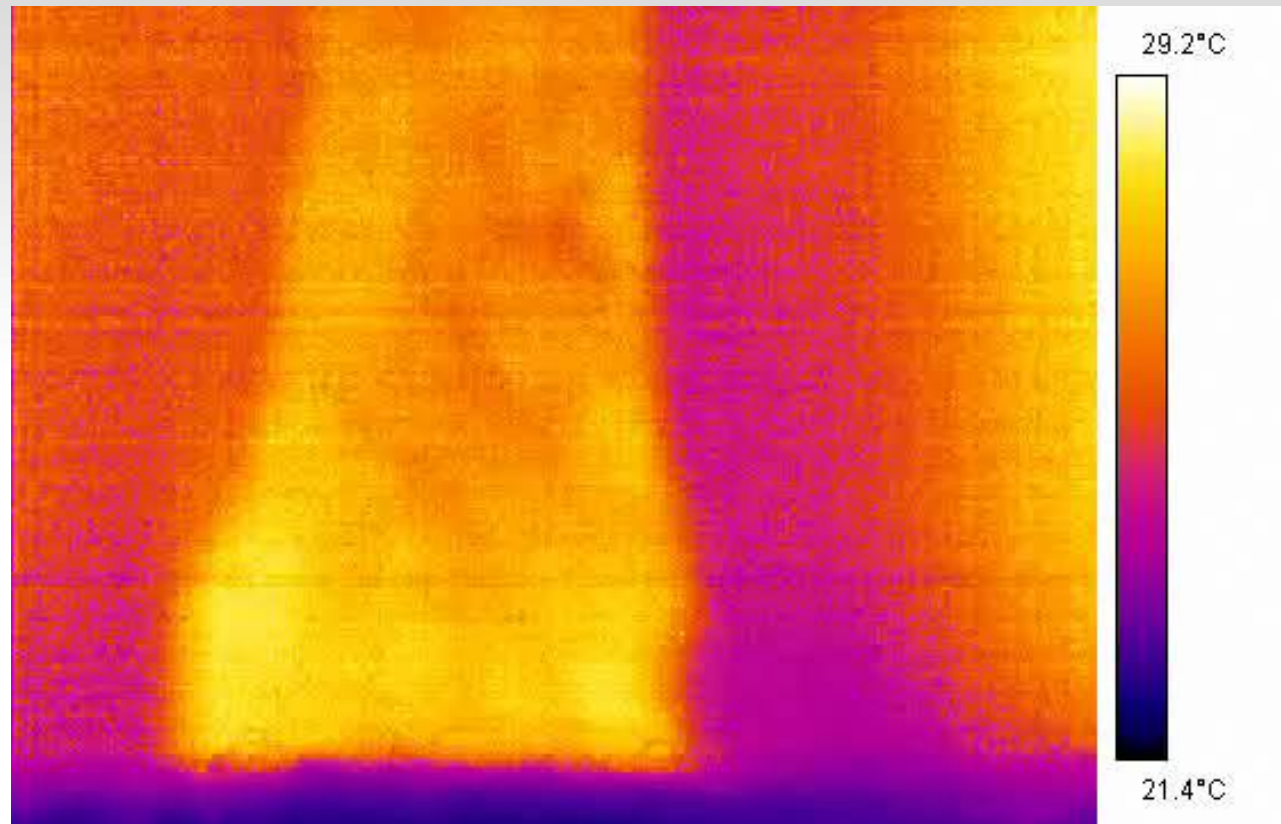
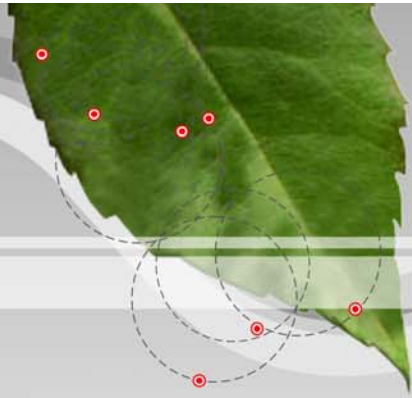
4 – Water in the pavement





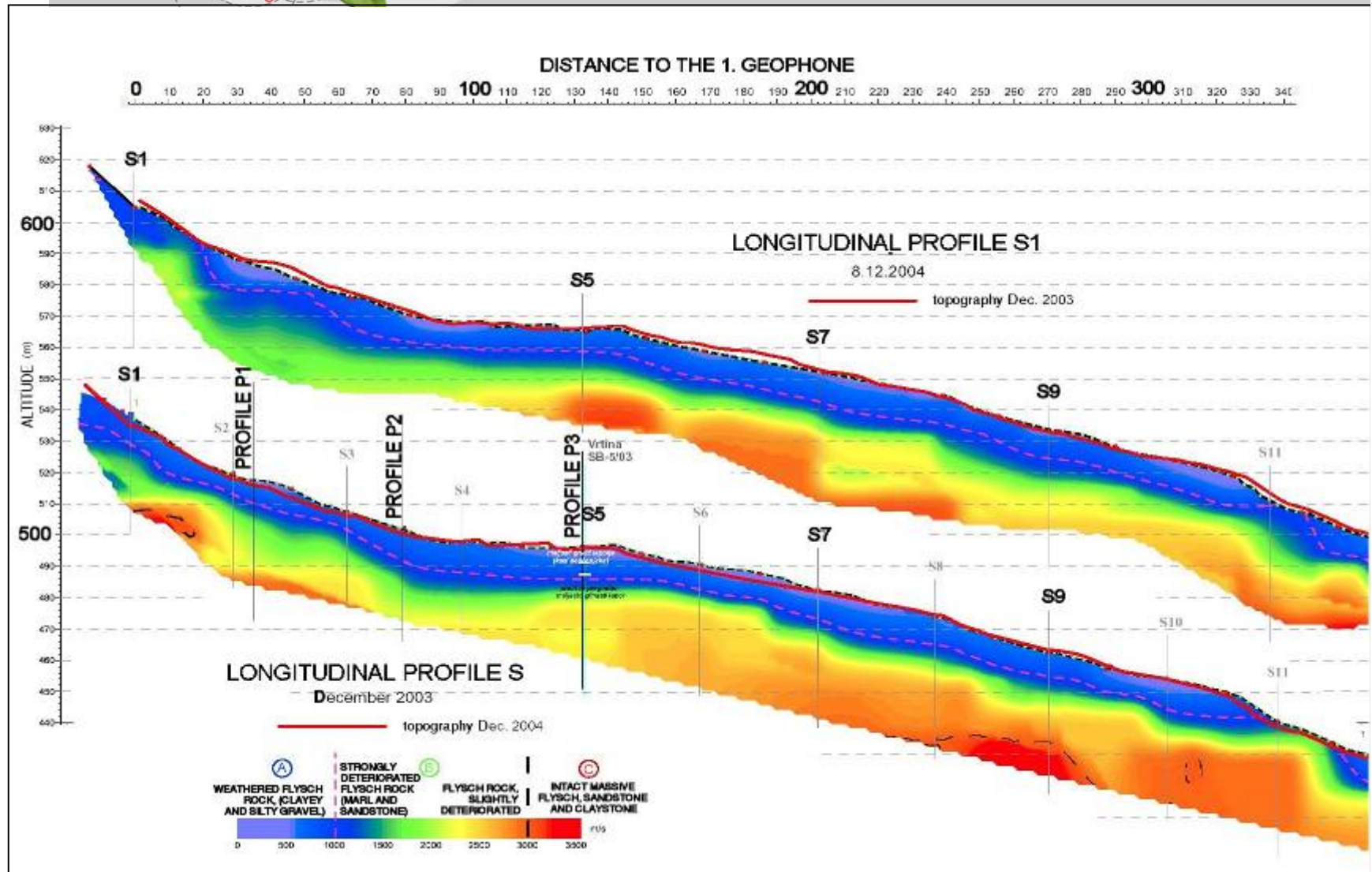
Factors, that control the magnitude of changes has not been well understood

- High suction. In case that the cloud of adsorbed water is not completed, the particles will tend to adsorb water from the surroundings. Flysch will deteriorate due to swelling.
- Softening along fissures also play an important role in the rapid loss of strength



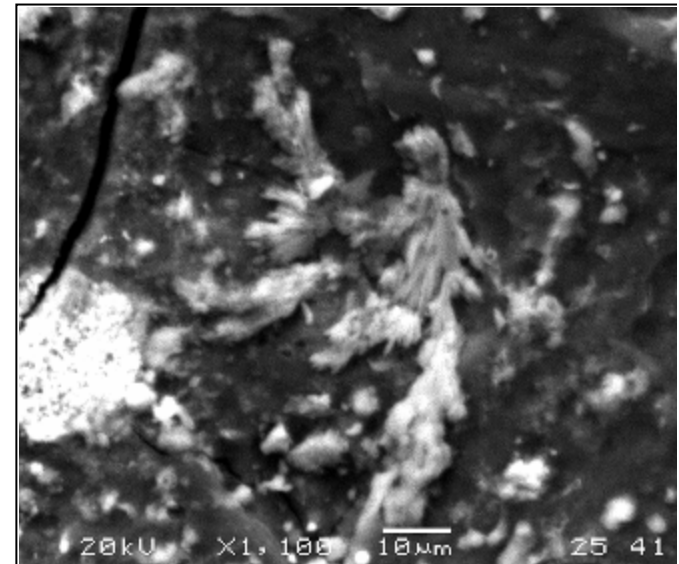
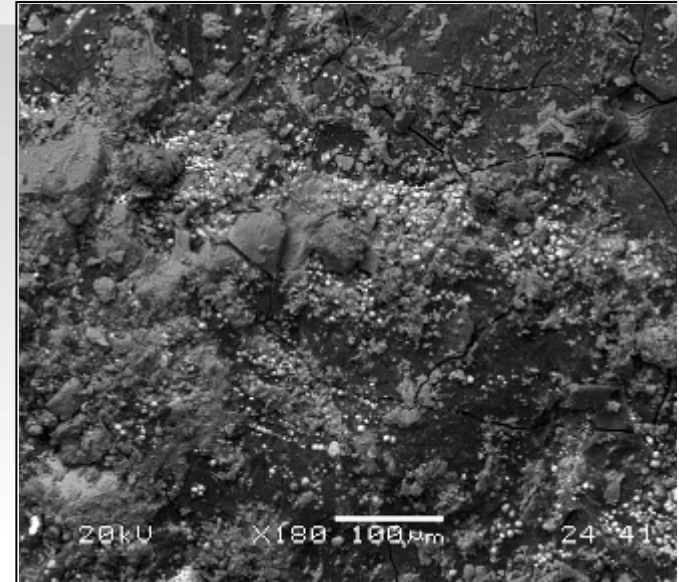


Geophysical investigation: (progressive deterioration into the depth)





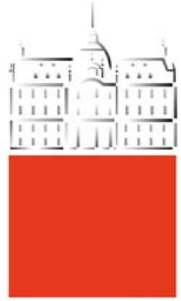
Fissures and Sulphate and Sulphide salts...





Flysch and water

- All other conditions being equal, the higher the moisture content, the lower the strength
- Moisture has three separate effects:
 1. it can affect the state of stress (suction/pore pressure; $\tau = c + (\sigma - u) \operatorname{tg} \phi$)
 2. it can affect the structure of the soil through the destruction of the “cementation” between flysch soil particles
 3. it works as an reactive component – sulphate and sulphide reactions with water and oxygen

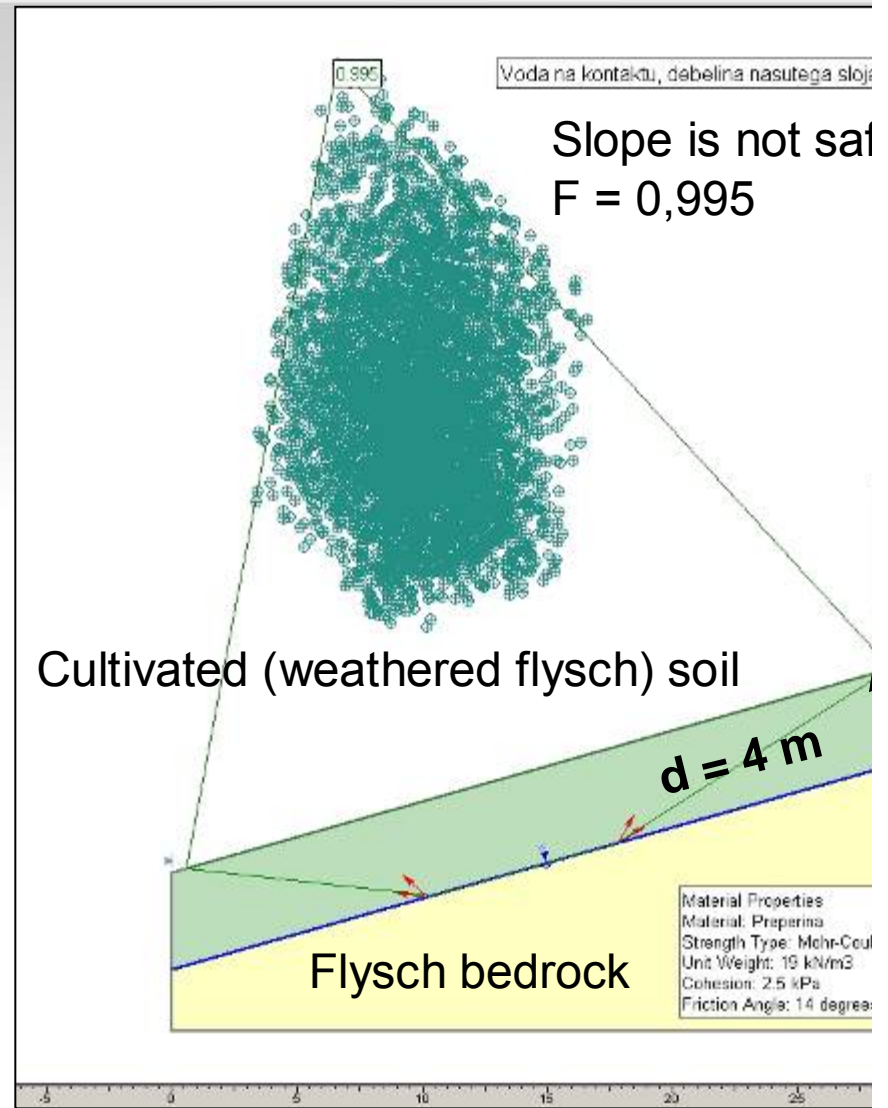
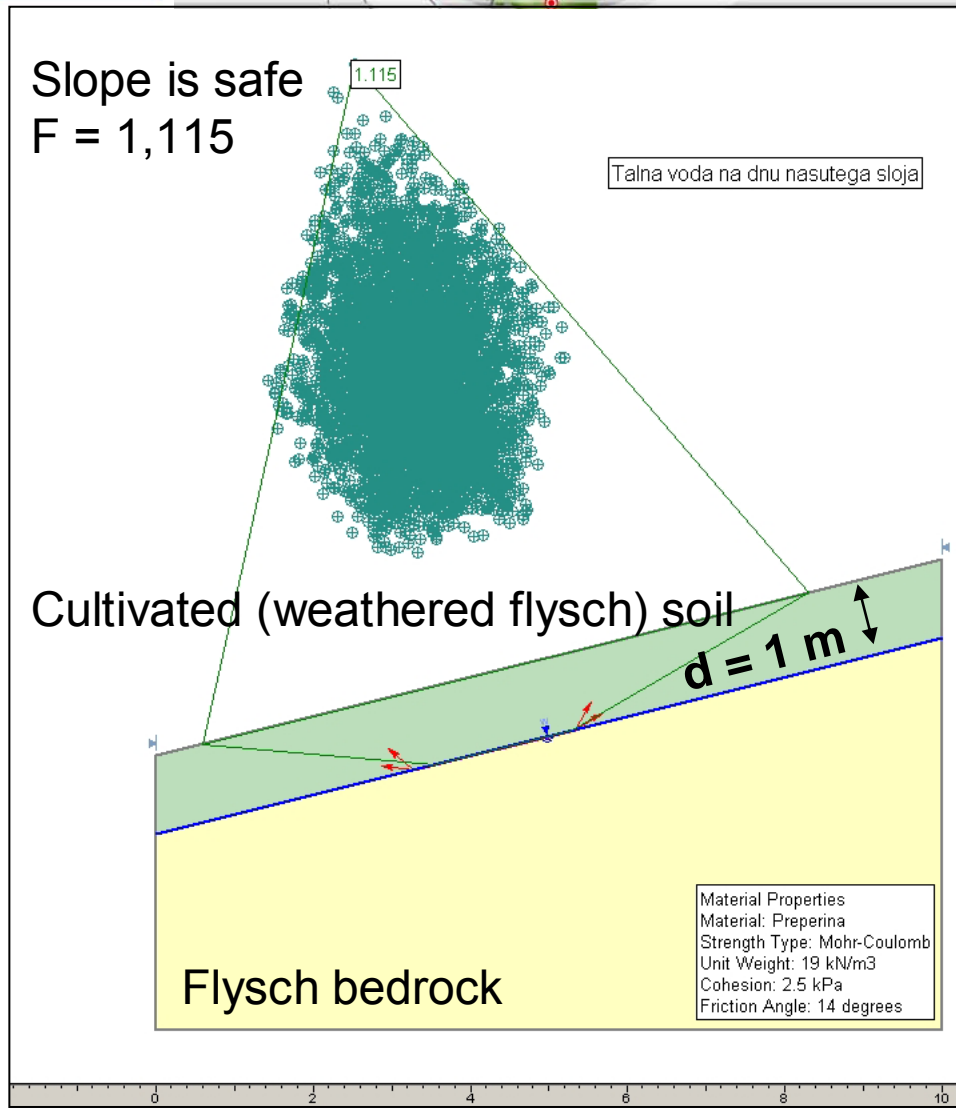


Intensive weathering

- Due to weathering, the thickness of the soil layer covering the flysch bedrock increases slowly on the natural slopes
- In case of tillage and land cultivation, the influence of water increases due to the soil loosening and the process of flysch weathering is accelerated.

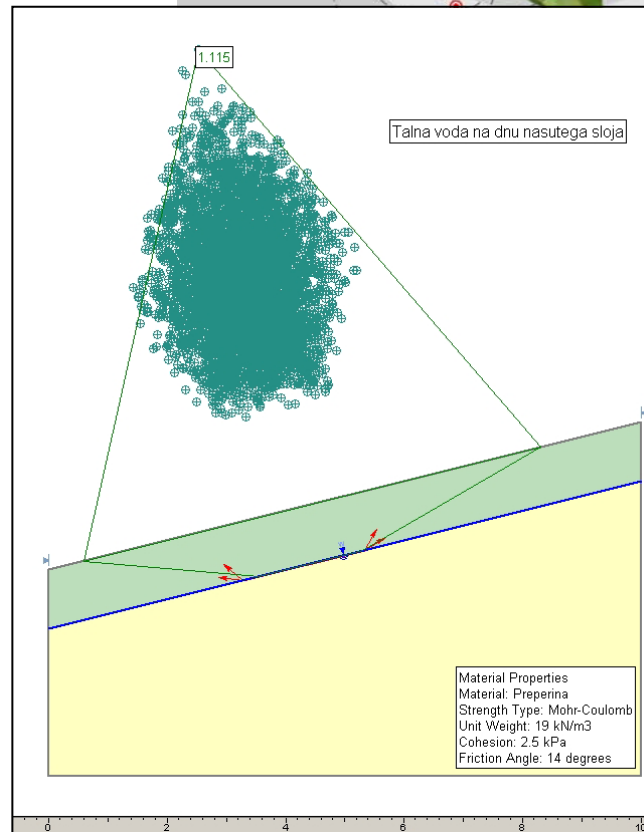


Influence of soil thickness to the stability

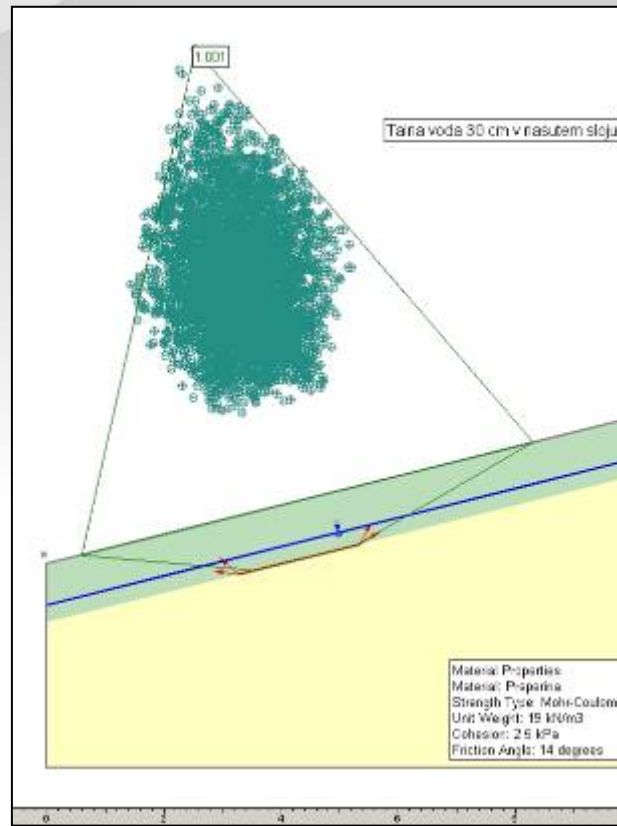




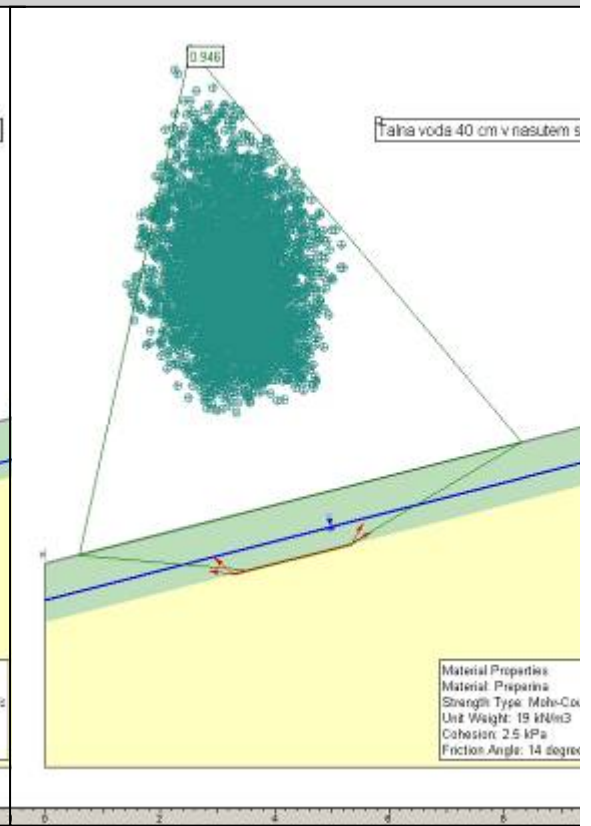
Influence of water table to the stability



Contact water
F = 1,115



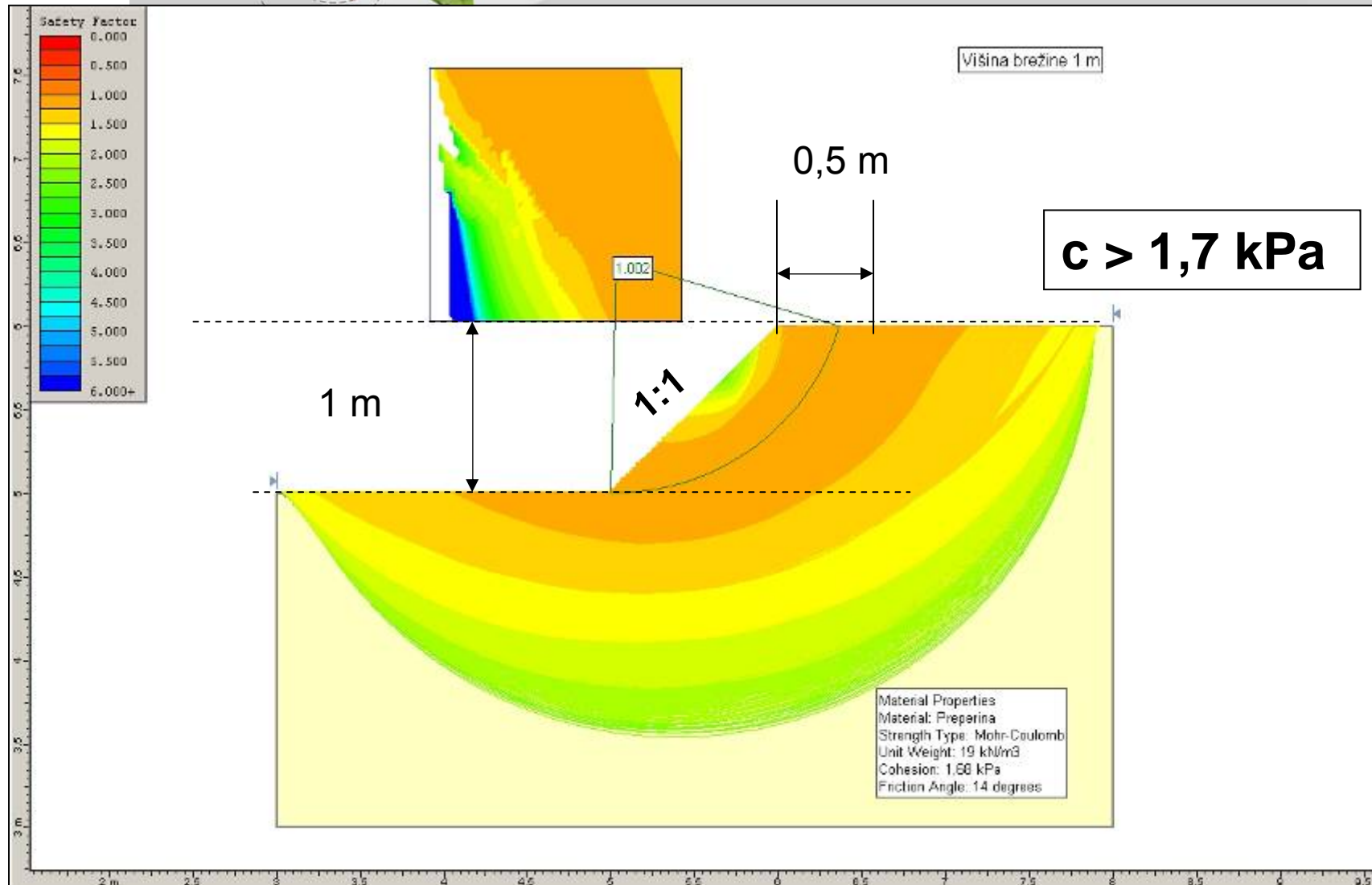
+ 30 cm water
F = 1,001



+ 40 cm water
F = 0,848

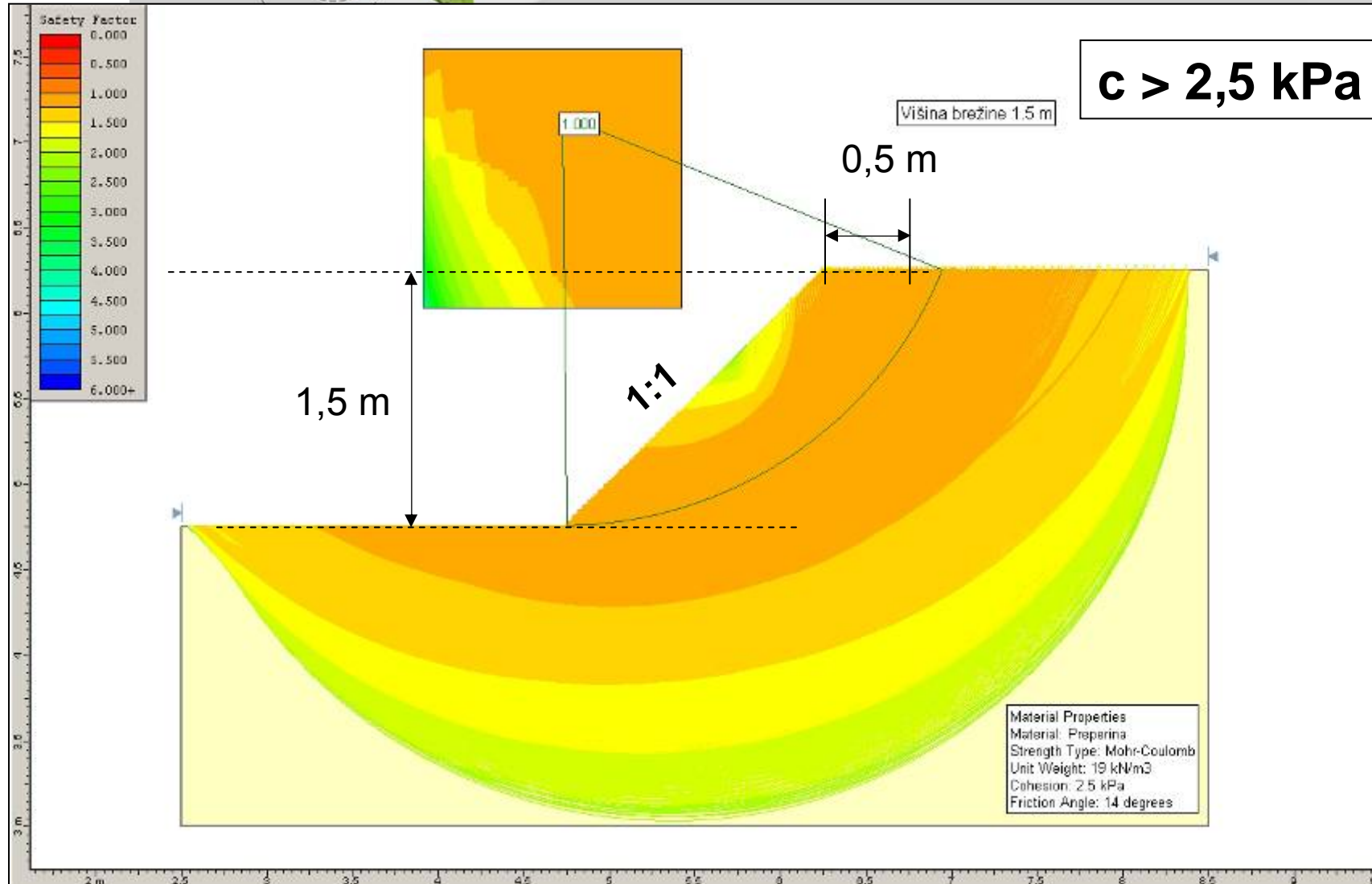


“Internal” stability of a single terrace



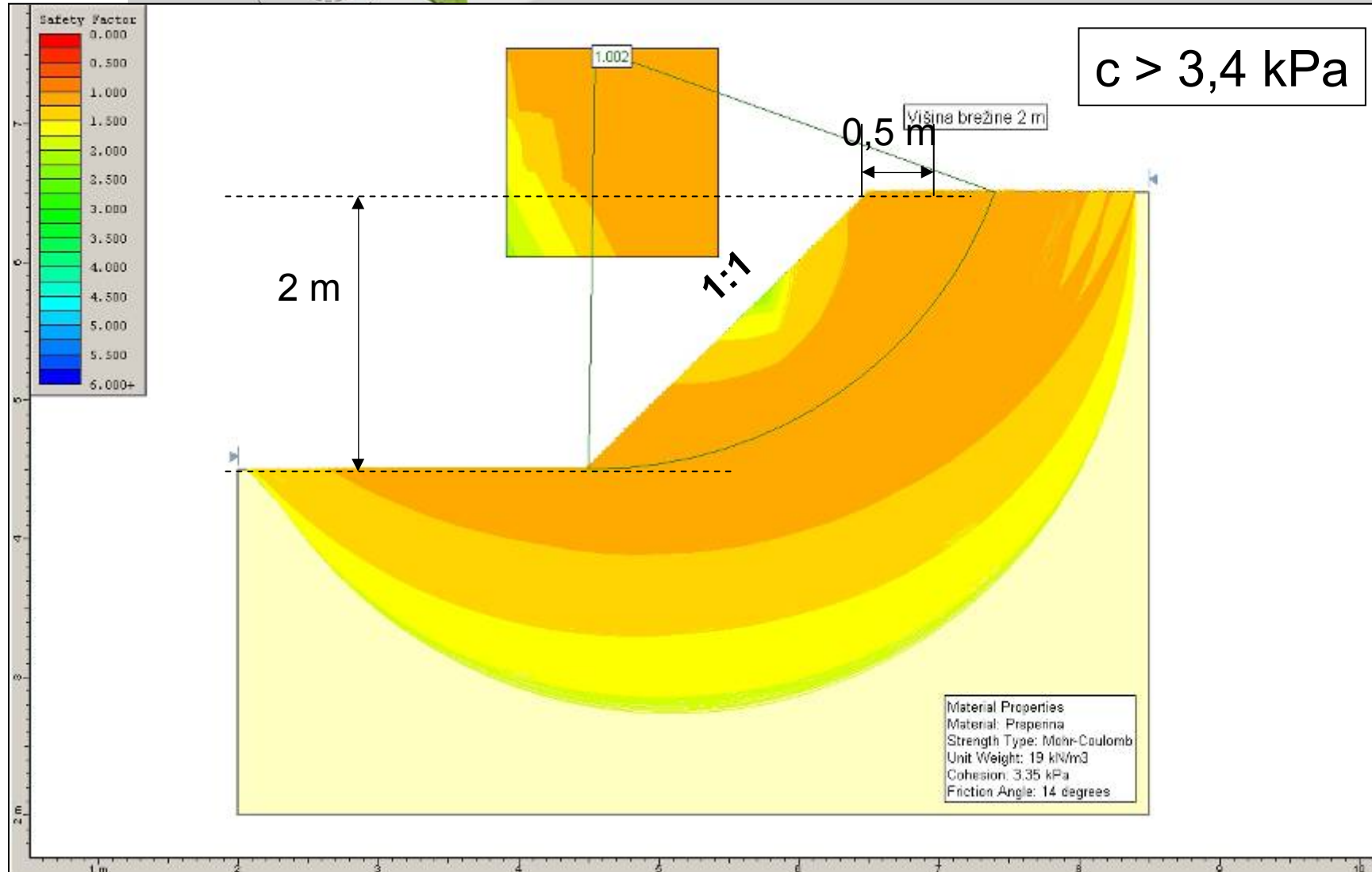


“Internal” stability of a single terrace



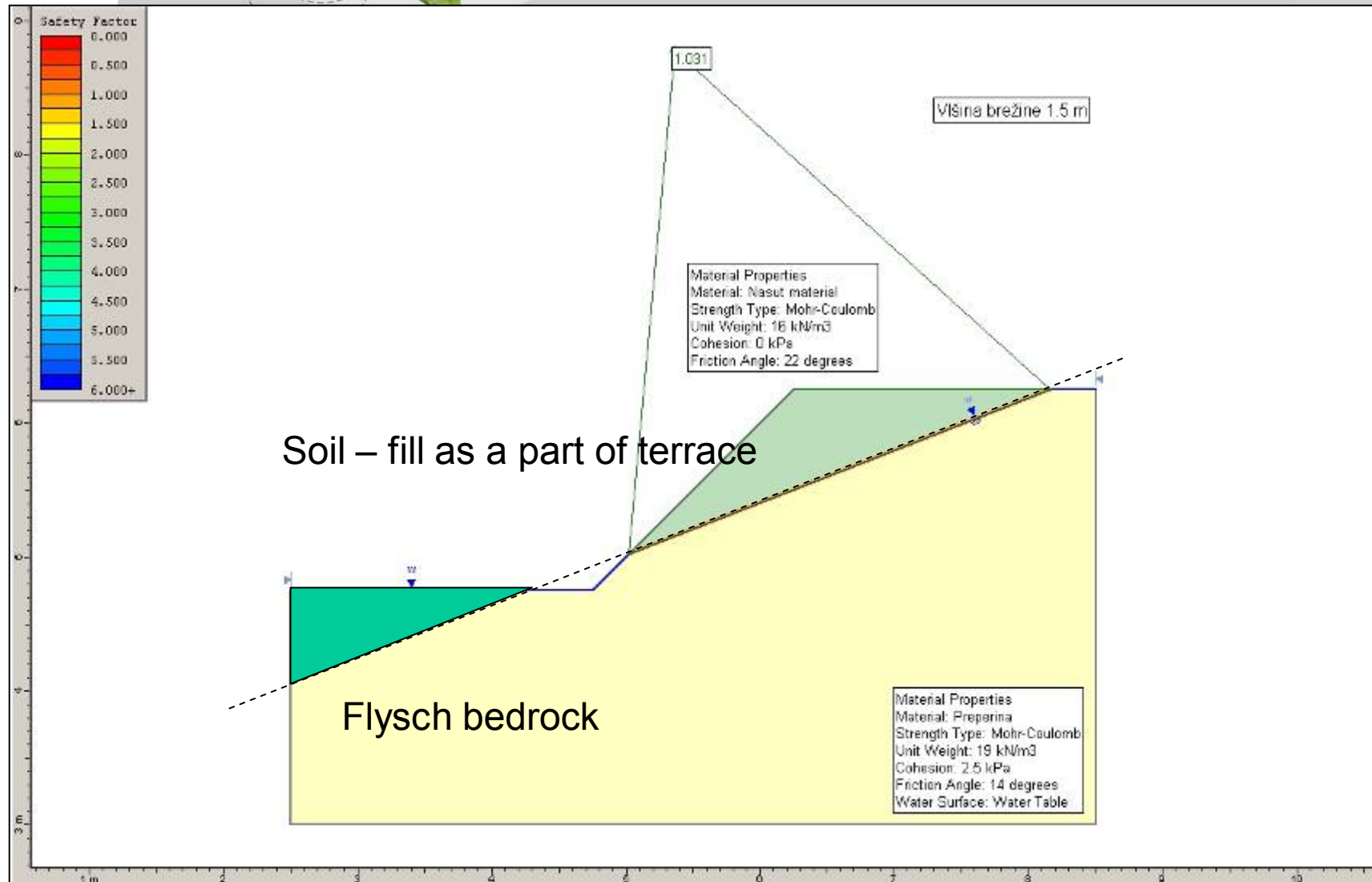


“Internal” stability of a single terrace



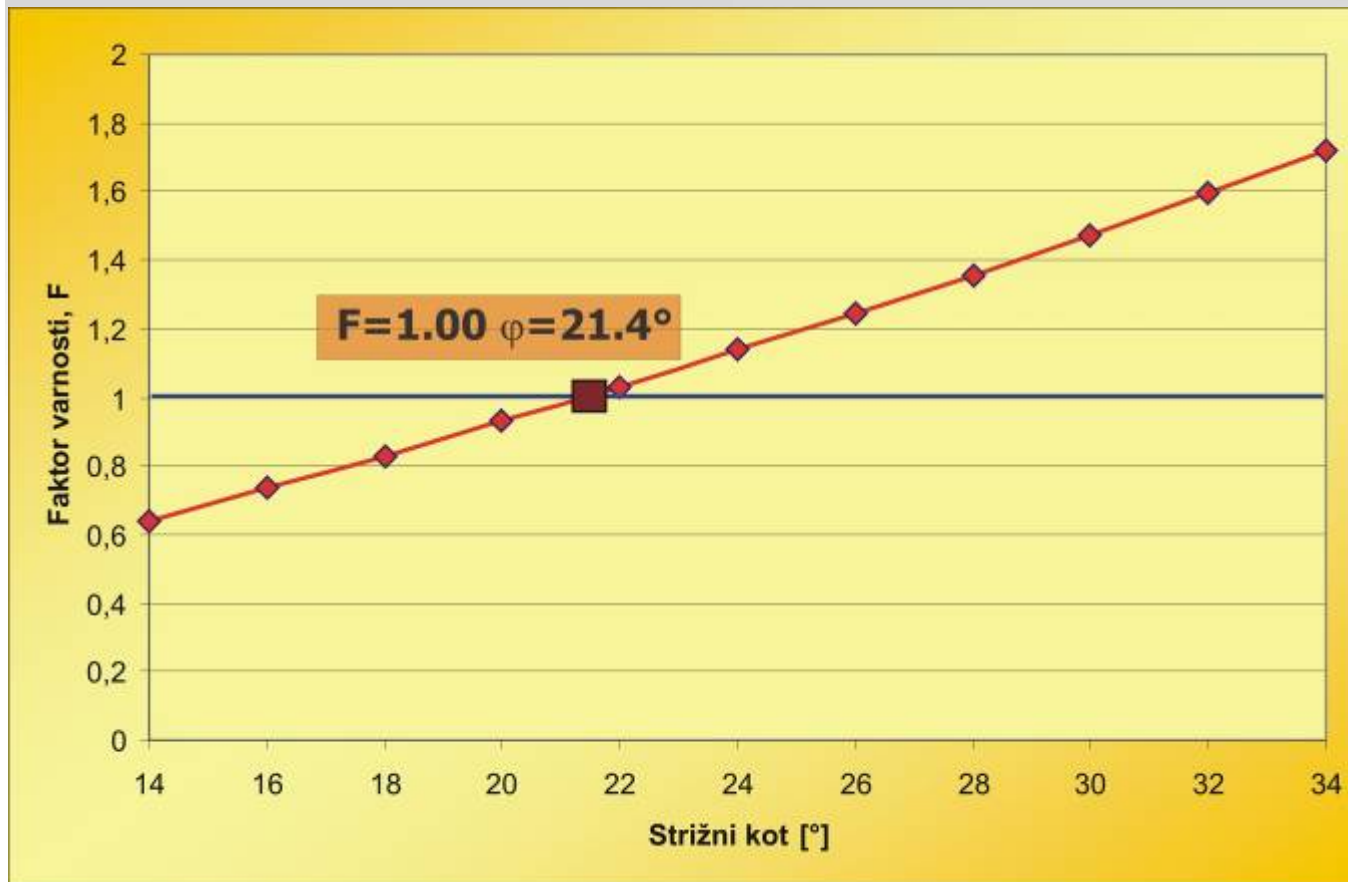


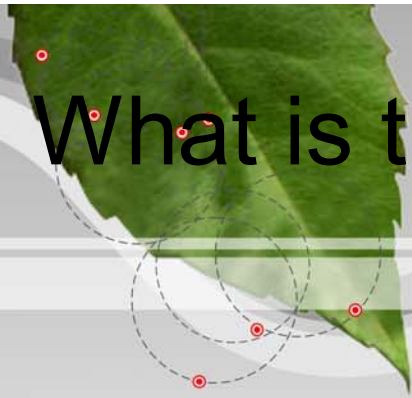
“Internal” stability of a single terrace



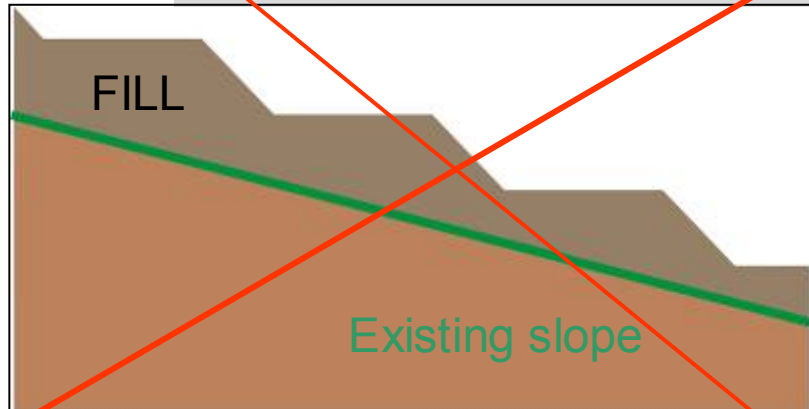


Influence of shear angle to the terrace safety

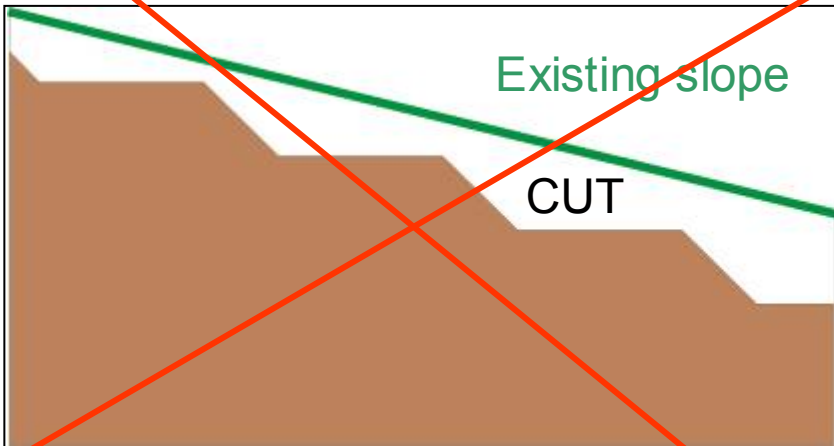




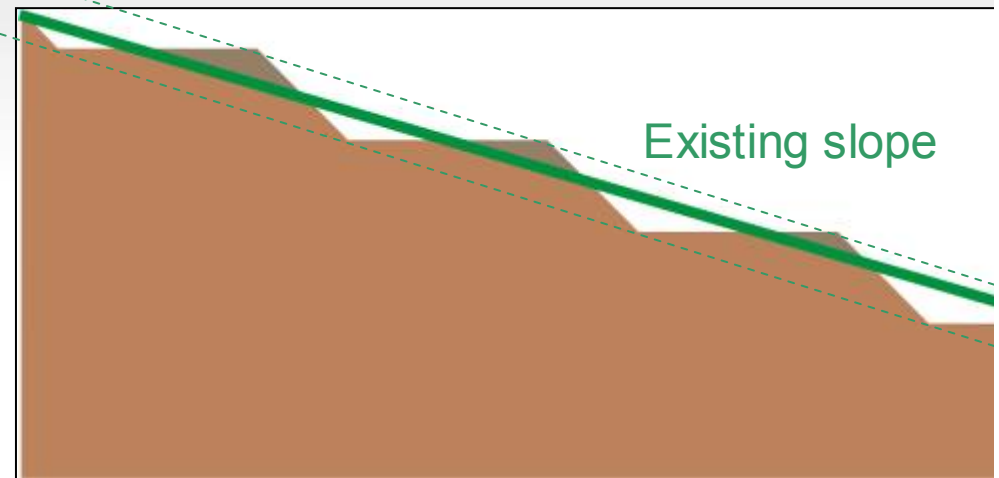
What is the right type of landscaping

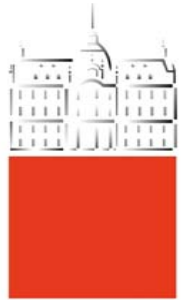


NO



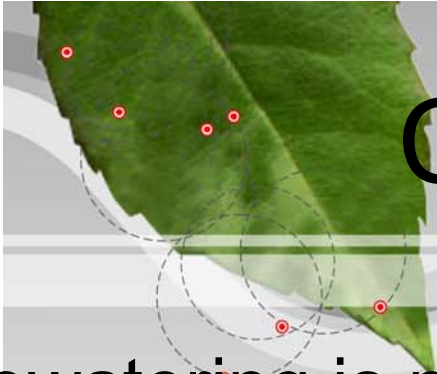
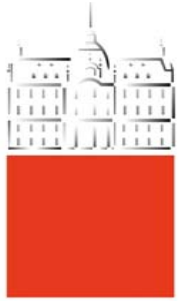
YES – keep and maintain the natural slope inclination





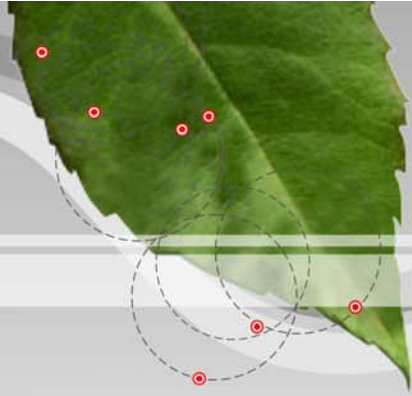
Conclusions

- It is important to keep and maintain the natural slope angle - inclination when planning and preparing new terraces,
- It is important to avoid additional fillings as well as additional cuttings into the natural flysch slope,
- It is important to understand and accept the fact, that due to the natural processes of flysch deterioration, the safety factor of the terraced and cultivated slopes will slowly reduce and that from time to time, additional supporting or maintaining earth works will be needed
- To maintain the slope stability, it is important to keep the dewatering system in good condition and to maintain the root systems on the terraced slopes



Conclusions

- Dewatering is necessary not only to collect the water from the springs, but also to control the effective dewatering during the rainy period and during the unusual climatic events
- In all situations in which the new terraced slope inclinations are steeper than the natural slope, it is important to design additional supporting and reinforcing structures such as: supporting stone walls, stone ribs or deep dewatering drainages.



Thank you very much!