WEATHERING DETERIORATING AND SLOPE STABILITY CLASSIFICATION FOR THE FUTURE

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Namur, Belgium, 12 June 2008

ITC

Slopes in The Netherlands?

Jan van Goyen, View at Leiden, 1650 – Museum Lakenhal, Leiden

Dykes have slopes!

(Brouwersdam, The Netherlands)

Also real rock slopes in the Southern part of The Netherlands!

(ENCI quarry; photo: http://www.beeldexpressie.be/film/)

Other reasons to study slopes even if coming from a flat country

Slopes are an ideal study object for soil and rock mechanics in general because:

- Soil or rock in tunnels and foundations often not visible
- Failures in tunnels or foundations not or difficult to study
- Slopes often easily accessible
- Often many slopes in a relatively small area

and not very scientific, but highly important:

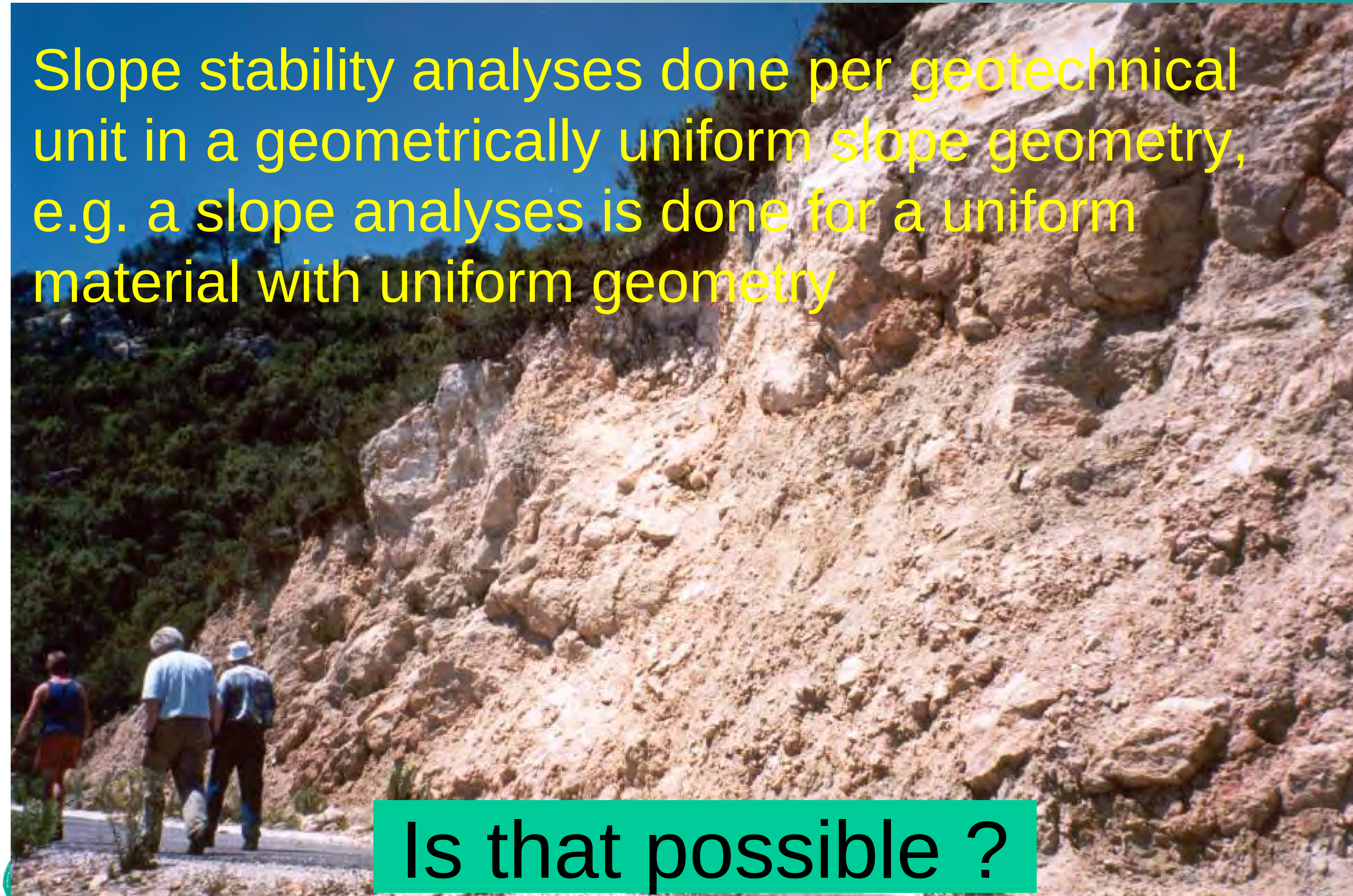
many Dutch civil engineering companies work worldwide with soil and rock slopes

Slope stability

What is required to analyse the stability of a slope ?

- soil and rock mass properties
- present and future geometry
- present and future geotechnical behaviour of soil or rock mass
- external influences such as earthquakes

Slope stability analyses done per geotechnical unit in a geometrically uniform slope geometry, e.g. a slope analyses is done for a uniform material with uniform geometry



Is that possible ?

Variation

Heterogeneity of mass causes:

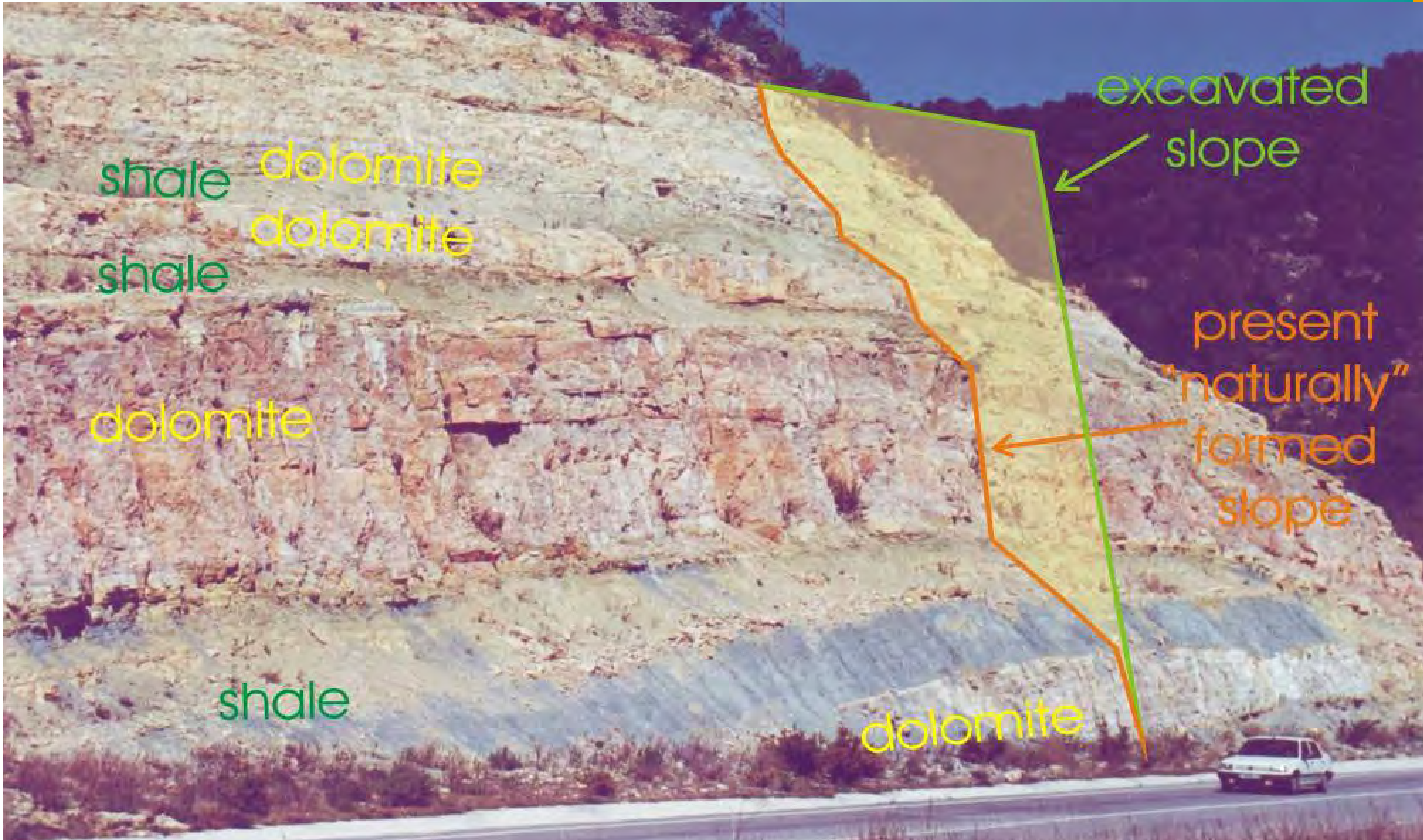
- variation in mass properties

Heterogeneity of slope geometry causes

- Variation in geometry

Original situation

design error




Example 2: Many discontinuity sets
with large variation in orientation
(too many for the design engineer?)

Example 3: Many discontinuity sets with large variation in orientation


Example 4: Variation in clay content in intact rock causes differential weathering
bedding planes
April 1990
Slightly higher clay content


Example 4: Variation in clay content in intact rock causes differential weathering
April 1992
mass slid

Uncertainty

- Uncertainty in properties
- Uncertainty (error) in measurements of properties
- Uncertainties in geometry
- Uncertainty (error) in measurements of geometry (often small)
- Uncertainty in failure mechanisms applicable
- Uncertainty in future environment (for example, weathering)

Options for analysing slope stability

Analytical

Numerical

Classification

Analysing slope stability

- analytical: only in relatively simple cases possible for a discontinuous rock mass
- numerical: difficult and often cumbersome, however, possible with discontinuous numerical rock mechanics programs such as UDEC

Hence, classification systems may be a good and simple alternative

Classification systems are empirical relations that relate rock mass properties either directly or via a rating system to an engineering application, e.g. a slope

Existing classification systems:

For underground tunnels:

Bieniawski (RMR)

Barton (Q)

Laubscher (MRMR)

etc.

For slopes:

Selby

Bieniawski (RMR)

Vecchia

Robertson (RMR)

Romana (SMR)

Haines

etc. etc.

Development of existing rock mass classification systems

- First developed for underground excavations
- Most slope systems are based on underground systems adjusted to be used for slopes

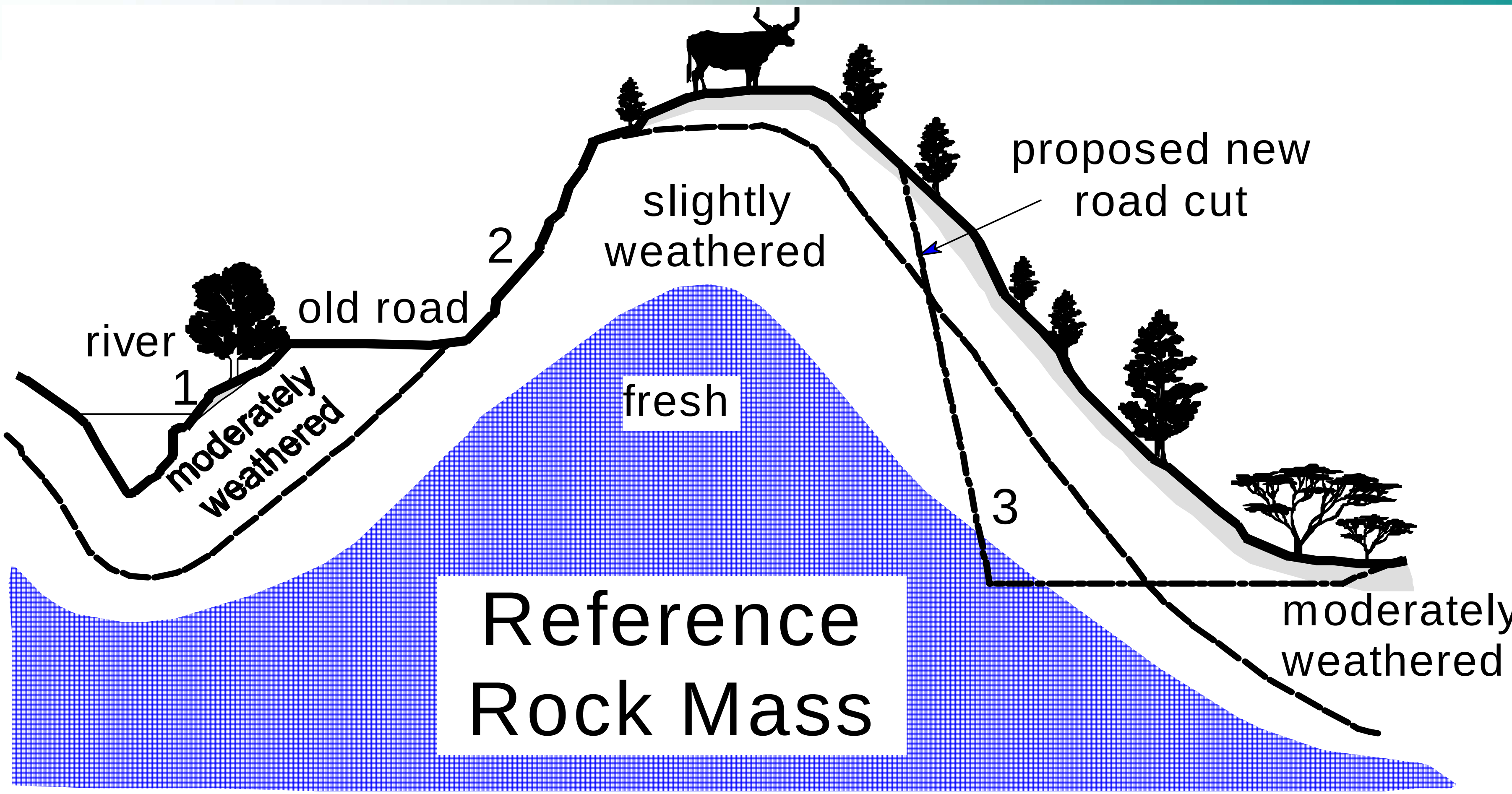
Existing systems did not give satisfactory results – hence development of a new system

Slope Stability probability Classification (SSPC)

SSPC

- three step classification system
- based on probabilities
- independent failure mechanism assessment

Three step classification system (1)



1: natural exposure made by scouring of river, moderately weathered; 2: old road, made by excavator, slightly weathered; 3: new to develop road cut, made by blasting, moderately weathered to fresh.

Excavation specific parameters for the excavation which is used to characterize the rock mass

- Degree of weathering
- Method of excavation

Rock mass Parameters

- Intact rock strength
- Spacing and persistence discontinuities
- Shear strength along discontinuity

- Roughness - large scale
  - small scale
  - tactile roughness
- Infill
- Karst

- Susceptibility to weathering

Slope specific parameters for the new slope to be made

- Expected degree of weathering at end of lifetime of the slope
- Method of excavation to be used for the new slope

Intact rock strength

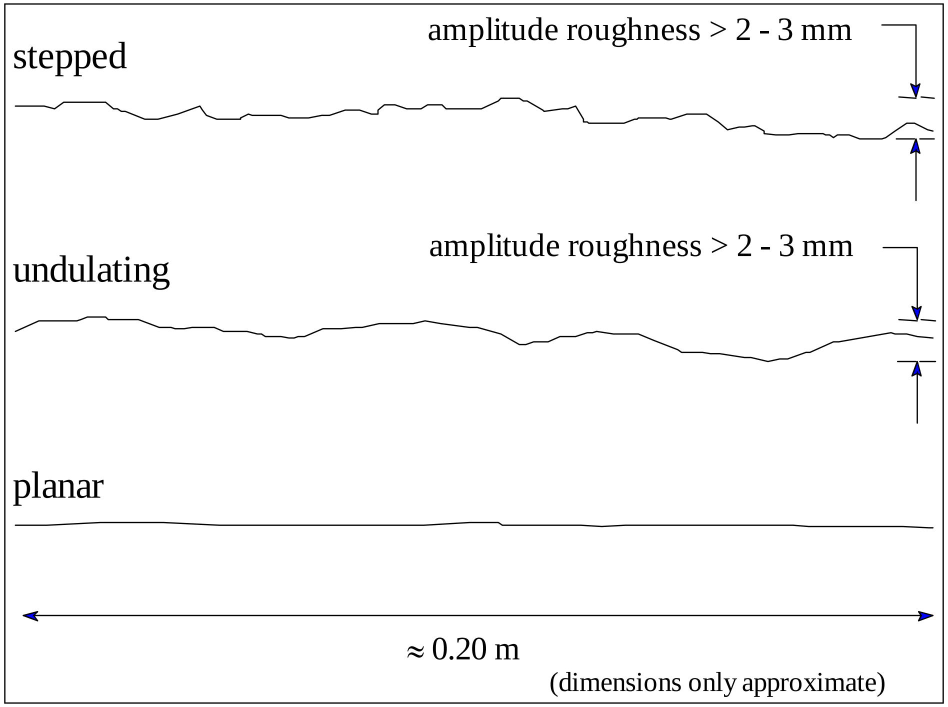
By simple means test - hammer blows, crushing by hand, etc.

Spacing and persistence of discontinuities

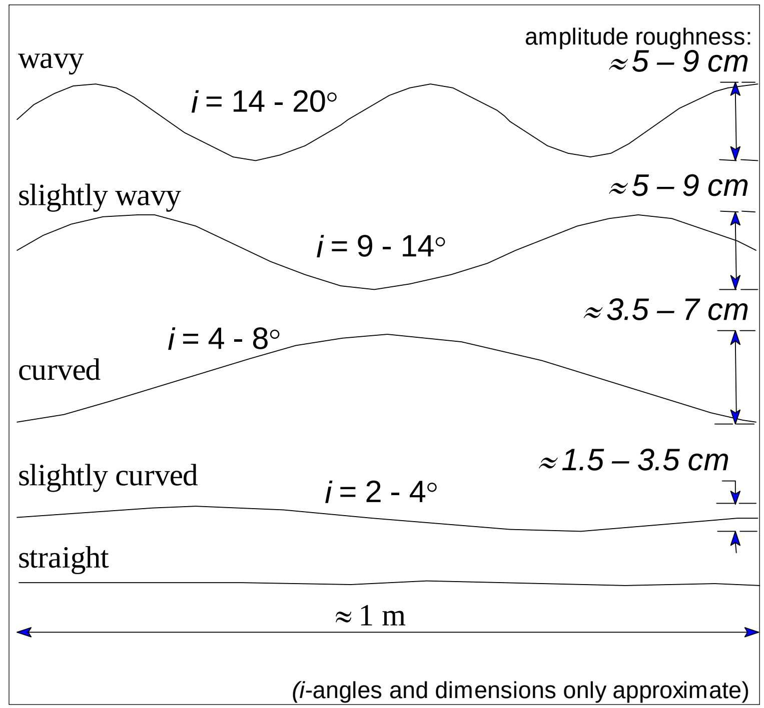
Based on the block size and block form by first visual assessment and then quantification of the characteristic spacing and orientation

roughness

small scale



large scale



Infill:

- cemented
- no infill
- non-softening (3 grain sizes)
- softening (3 grain sizes)
- gauge type (larger or smaller than roughness amplitude)
- flowing material

Shear strength - Infill

Orientation dependent stability

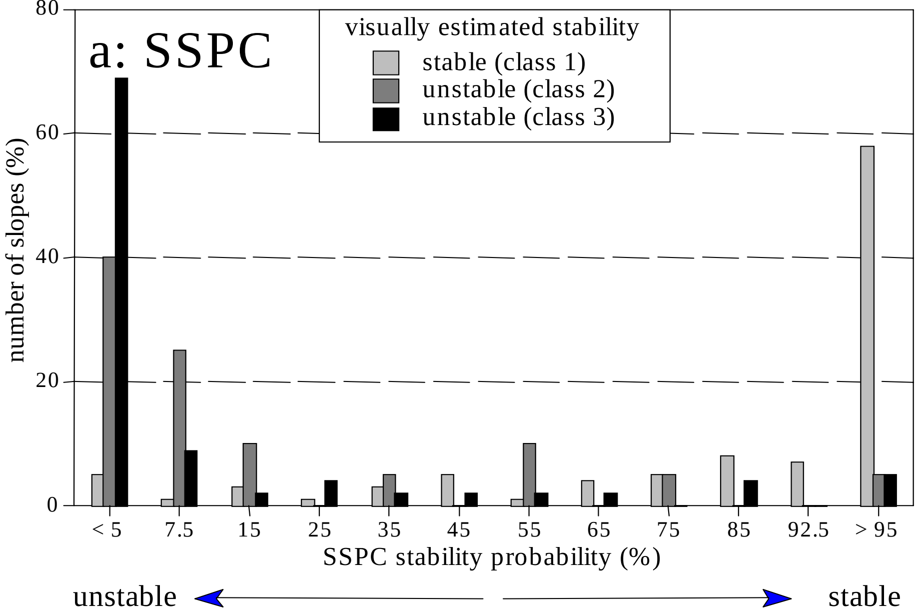
Stability depending on relation between slope and discontinuity orientation

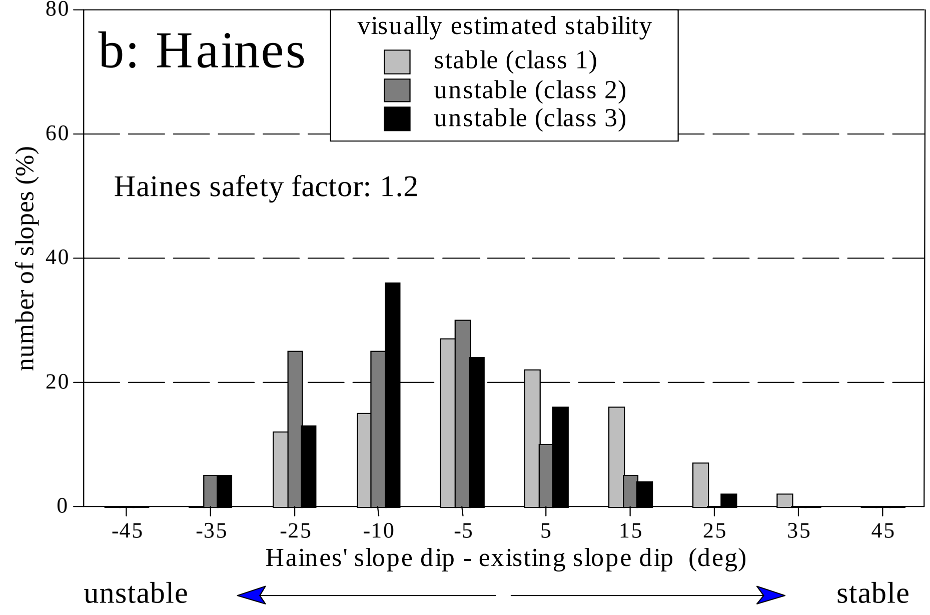
- Instability caused by discontinuities

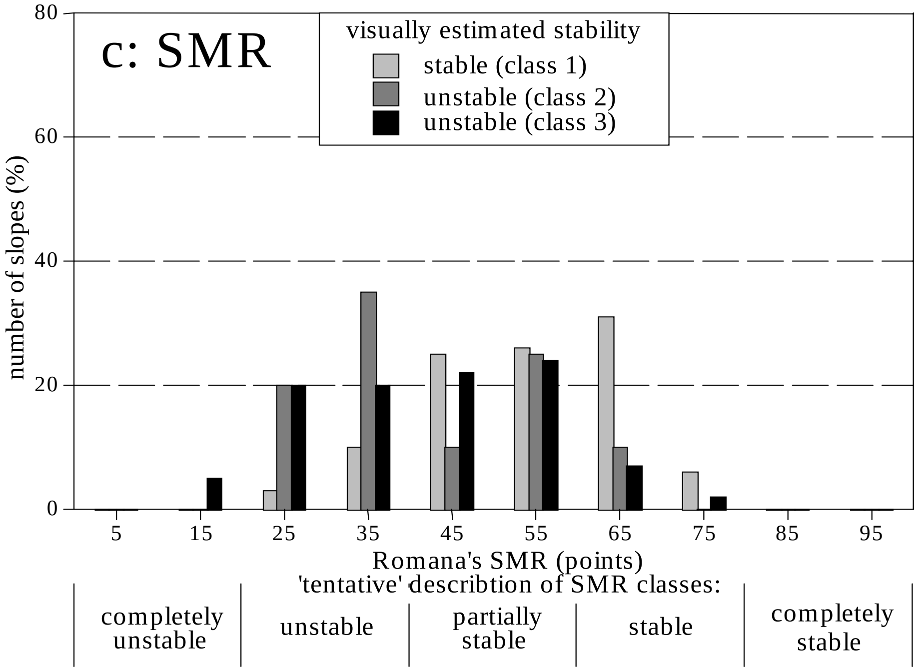
Orientation independent stability

Stability not depending on relation between slope and discontinuity orientation

- Instability not caused by discontinuities (for example, failure of intact rock, water run off moving blocks from the slope, etc.)







Percentages are from total number of slopes per visually estimated stability class.

visually estimated stability:

class 1: stable; no signs of present or future slope failures (number of slopes: 109)
class 2: small problems; the slope presently shows signs of active small failures and has the potential for future small failures (number of slopes: 20)
class 3: large problems; The slope presently shows signs of active large failures and has the potential for future large failures (number of slopes: 55)

Comparison

ITC

Poorly blasted slope

Poorly blasted slope

New cut (in **1990**):
Visual assessed: extremely poor instable.
SSPC stability < 8% (13.8 m high, dip 70°, rock mass weathering: 'moderately' and 'dislodged blocks' due to blasting).

Forecast in **1996**: SSPC stability: slope dip 45°.

In **2002**: Slope dip about 55° (visually assessed unstable).

In **2005**: Slope dip about 52° (visually assessed unstable – big blocks in middle photo have fallen).

Plane sliding failure

40 year old road cut, Spain

Plane sliding failure (2)

- Laboratory test: ϕ=45°
- SSPC: ϕ≈35°
- Stability assessed using:
  - SSPC – 55% stability probability, failure imminent (ϕ≈35°)

Landslide in harbour – Saba – Dutch Antilles

SSPC results

Pyroclastic deposits	Calculated SSPC	Laboratory / field
Rock mass friction	35°	27° (measured)
Rock mass cohesion	39kPa	40kPa (measured)
Calculated maximum possible height on the slope	13m	15m (observed)

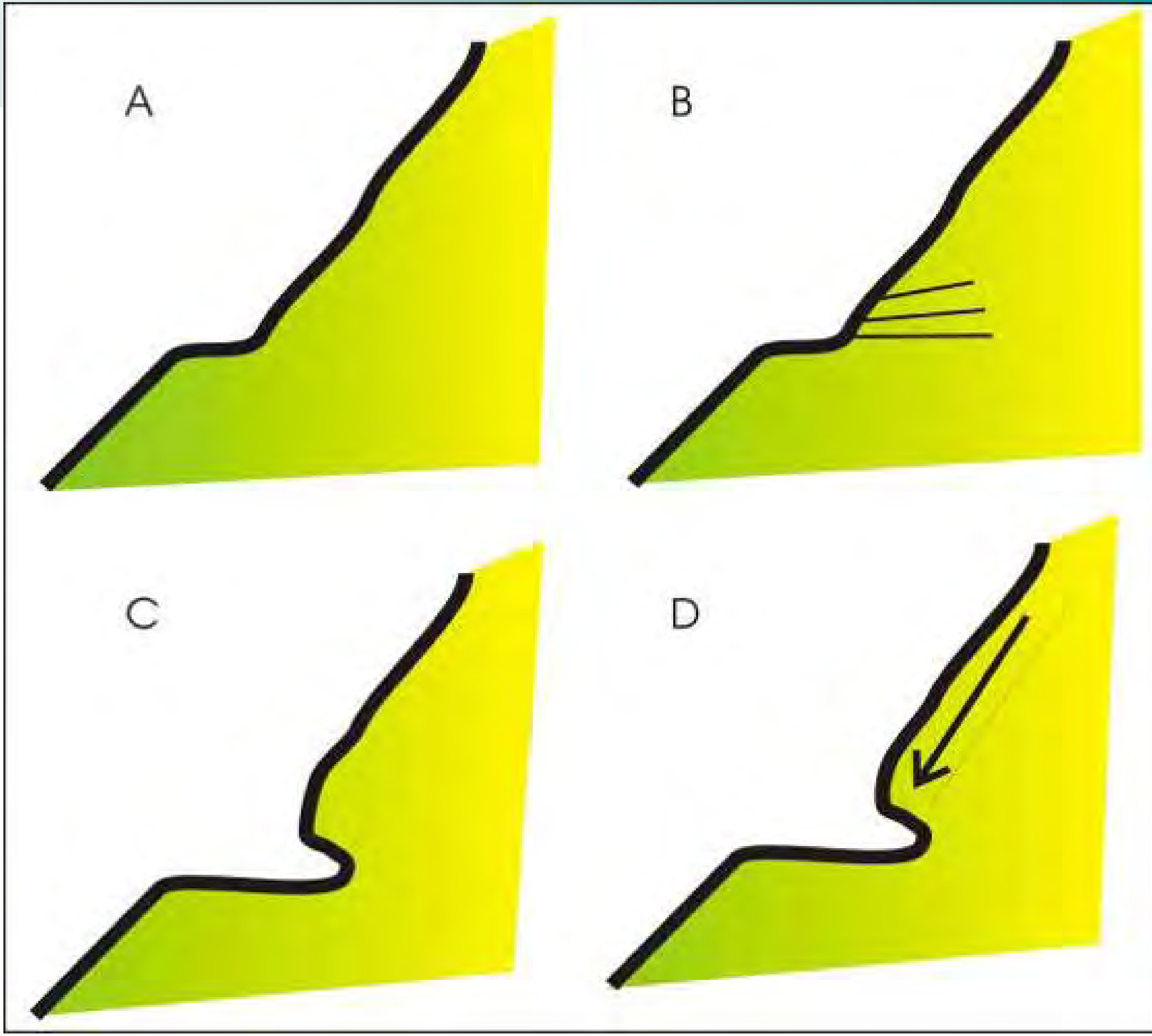
Failing slope in Manila, Philippines

Failing slope in Manila (2)

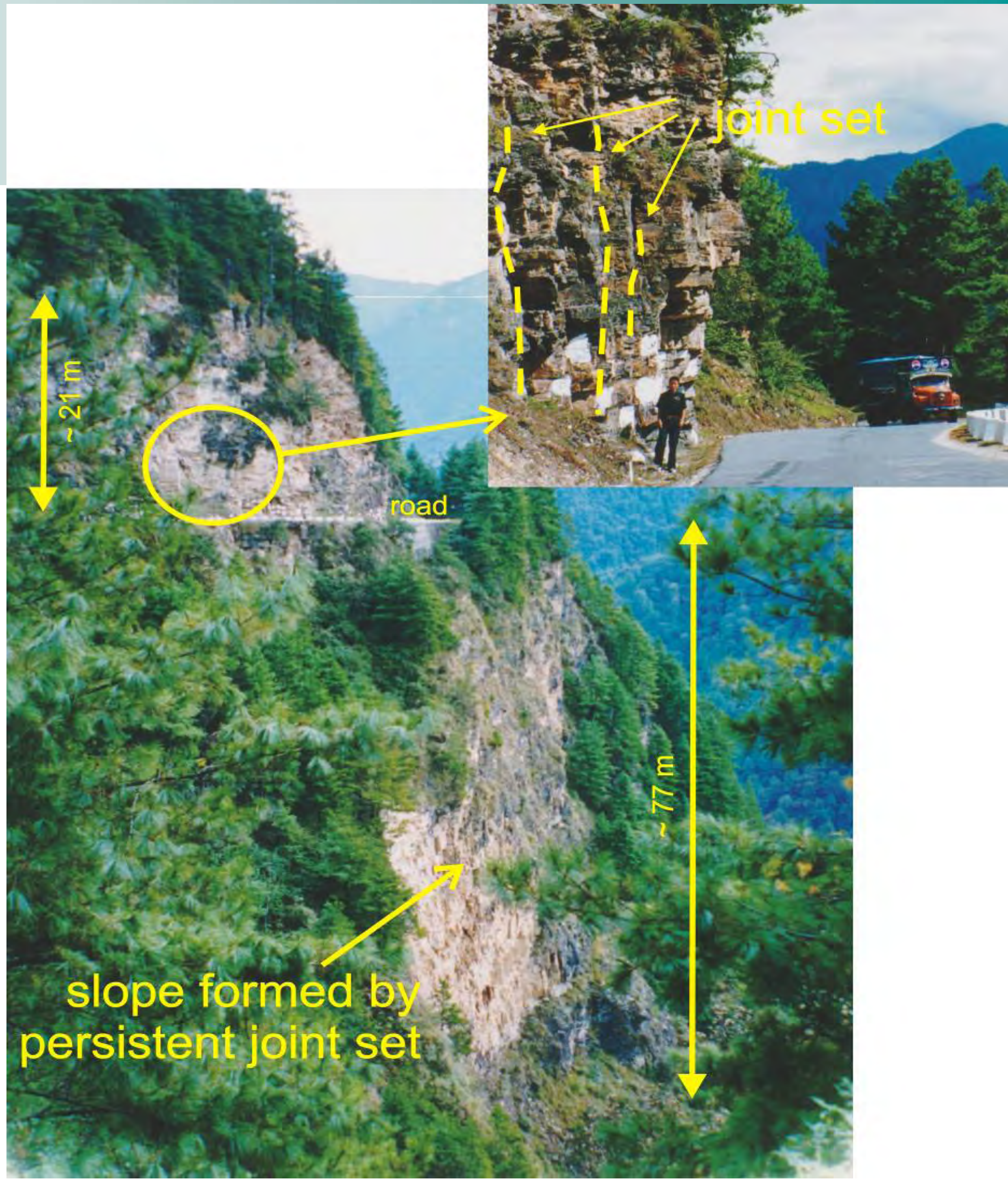
- tuff layers with near horizontal weathering horizons (about every 2-3 m)
- slope height is about 5 m
- SSPC non-orientation dependent stability about 50% for 7 m slope height
- unfavourable stress configuration due to corner

Widening existing road in Bhutan (Himalayas)

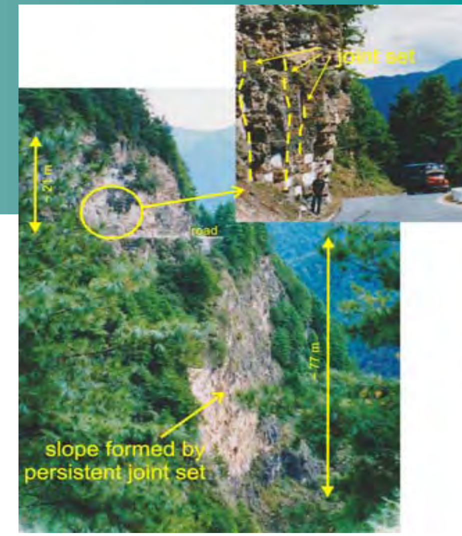
Bhutan (5) Method of excavation



Widening existing road in Bhutan (Himalayas) (2)



Widening existing road in Bhutan (Himalayas) (4)



Above road level:

- Following SSPC system about 12 – 27 m for a 75° slope (depending on unit) (orientation independent stability 85%)

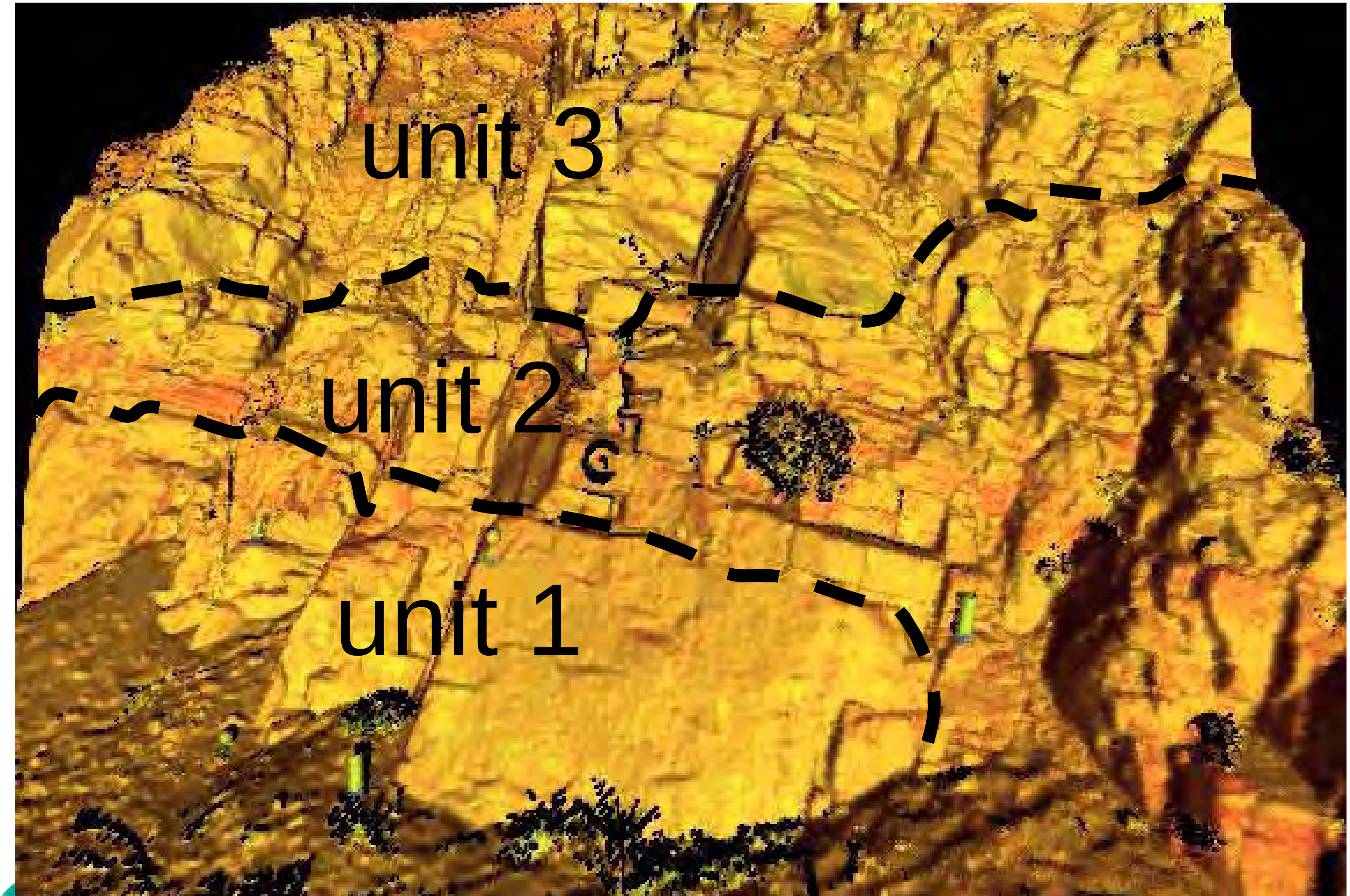
Below road level:

- Inaccessible – different unit ? – and not disturbed by excavation method

Heterogeneity

- even if uncertainty is included this is only up to a certain extend – what extend is to the discretion of the engineer
- can heterogeneity be defined by an automatic procedure , e.g. for example Lidar

Heterogeneity – Lidar imagery



(modified after Slob et al, 2002)

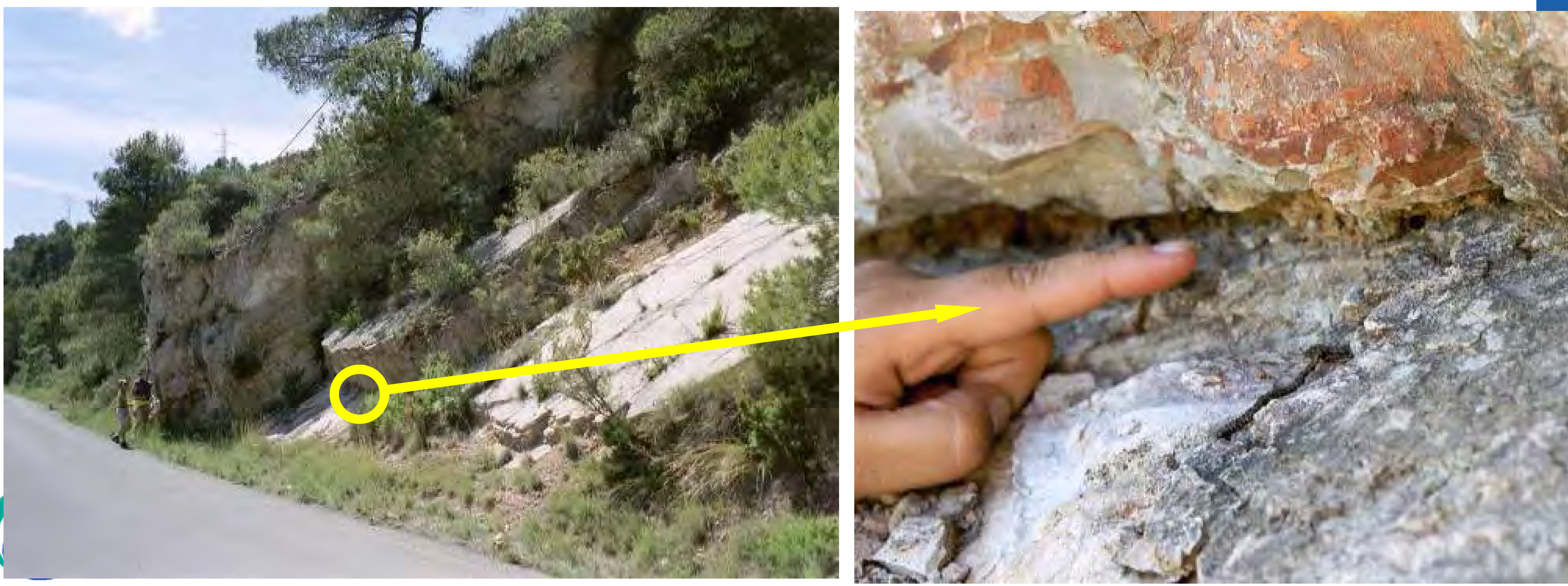
Degradation processes

Main processes involved in degradation:

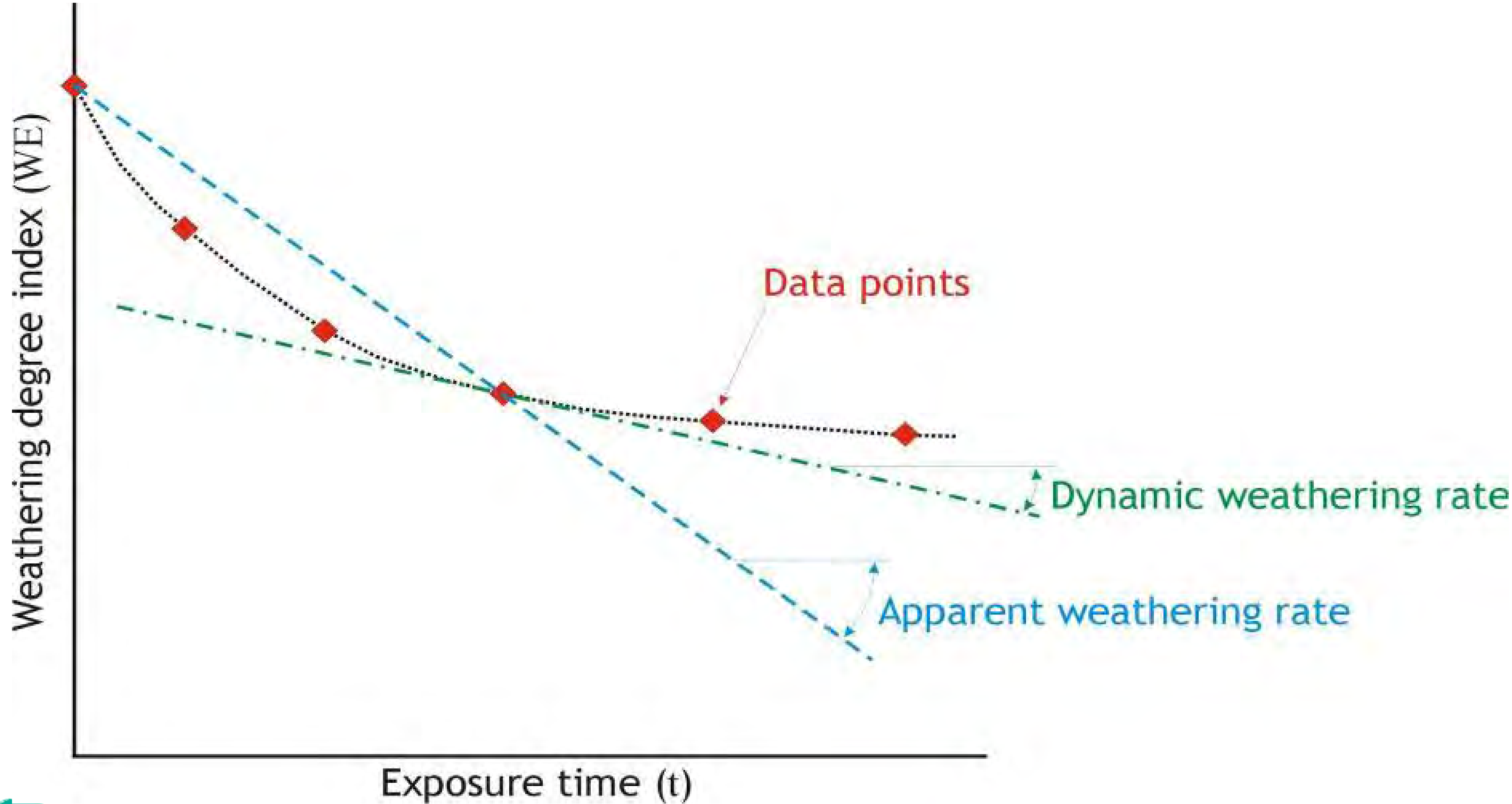
- Loss of structure due to stress release
- **Weathering** (In-situ change by inside or outside influences)
- **Erosion** (Material transport with no chemical or structural changes)

Significance in engineering

- When rock masses degrade in time, slopes and other works that are stable at present may become unstable



Weathering rates



Weathering rates

$$WE(t) = WE_{init} - R_{WE}^{app} \log(1+t)$$

$WE(t)$ = degree of weathering at time t

WE_{init} = *(initial) degree of weathering at time* $t = 0$

R^{app}_{WE} = *weathering intensity rate*

WE as function of time, initial weathering and the weathering intensity rate

Weathering rates

- Material:
  Gypsum layers
  Gypsum cemented siltstone layers

Middle Muschelkalk near Vandellos (Spain)

Weathering intensity rate

SSPC system with applying weathering intensity rate:

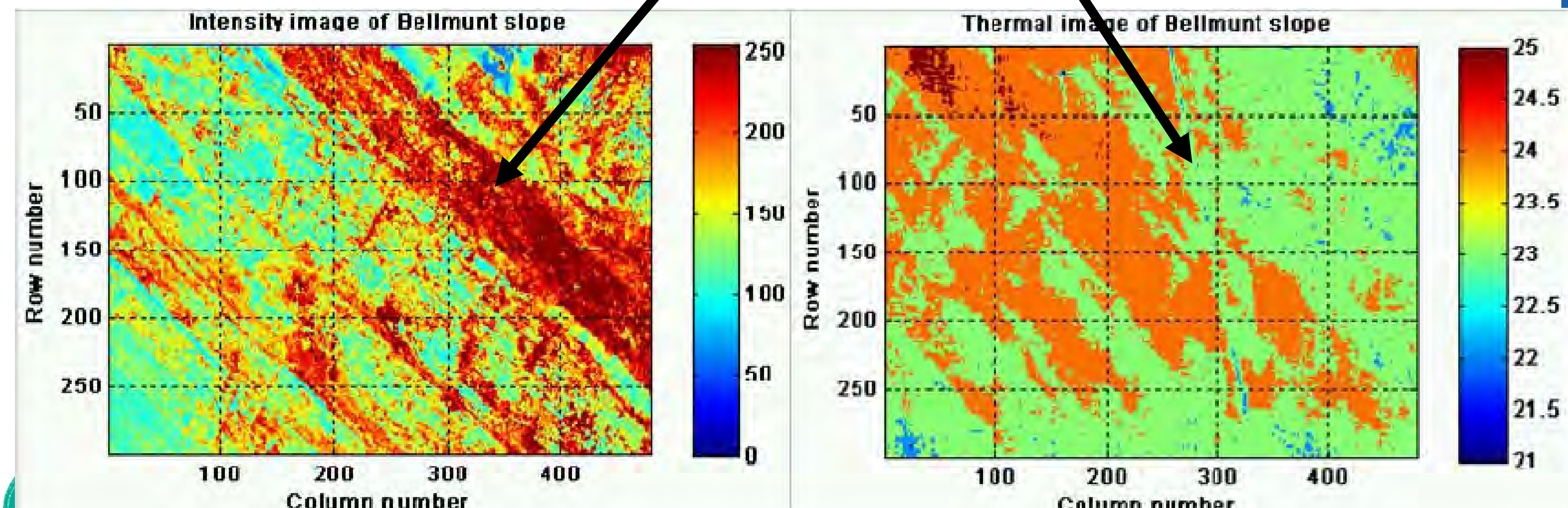
- original slope cut about 50º (**1998**)
- now around 44º (**2007**)
- in 15 years decrease to 35º (**2013**)

New developments - Future

Remote sensing for assessing "degree of weathering"

Lidar intensity

thermal



Conclusions

- SSPC classification works for slope stability
- Classification can incorporate uncertainty
- Rates of weathering can likely be quantified

- be not afraid to abandon inherited methodologies and parameters

Future

- more objective (remote sensing) tools to determine heterogeneity and degree of weathering
- classification systems for earthquake areas
- influence of snow and ice
- submersed marine slopes ?