RQD
Slope stability classification
Weathering

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RQD

Rock Quality Designation

Drill core measures

Total Core Recovery

$$TCR = \frac{\sum total\ length\ of\ core}{total\ length\ drilled} * 100\,\%$$

Solid Core Recovery

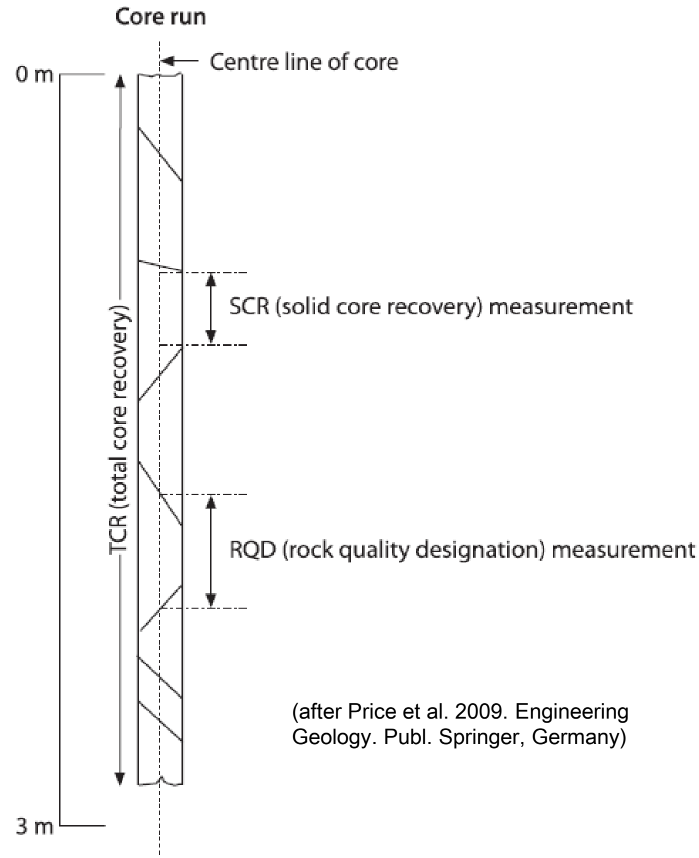
$$SCR = \frac{\sum length\ pieces\ of\ solid\ core}{total\ length\ drilled} * 100\,\%$$

Rock Quality Designation

$$RQD = \frac{\sum length\ pieces\ of\ intact\ core\ with\ length\ (*)\ > 10\ cm}{total\ length\ drilled} * 100\,\%$$

*) along centre line of core

SCR & RQD : Obvious drilling breaks to be excluded (pieces should be fitted together and counted as one piece)



(after Price et al. 2009. Engineering Geology. Publ. Springer, Germany)

RQD (Rock Quality Designation)

Originally:

A rock mass classification system (Deere, 1964)

- Depending on the RQD only a rock mass quality was assigned to a rock mass

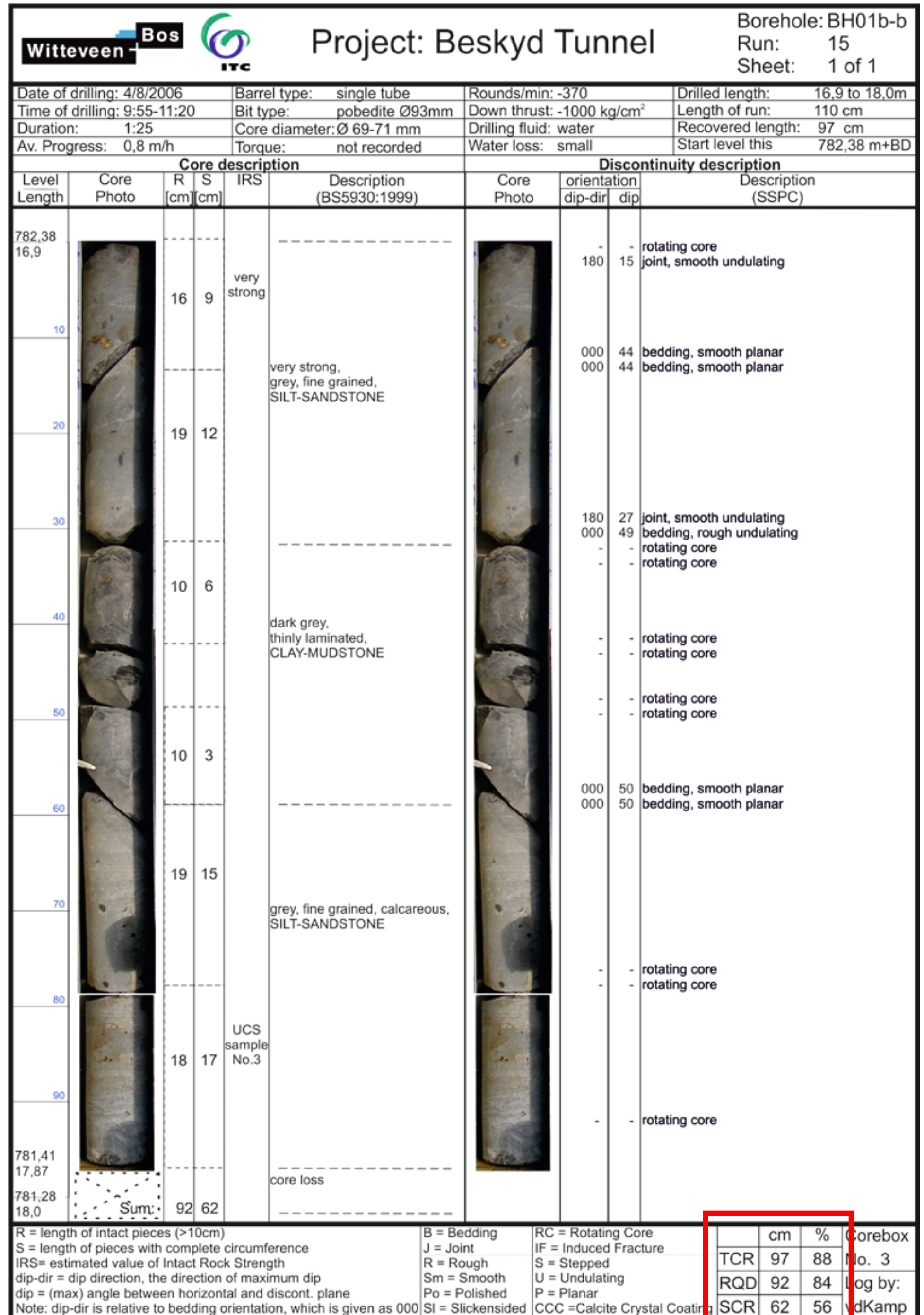
<25% - Very Poor; 25-50% - Poor; 50-75% - Fair; 75-90% - Good; 90-100% -Excellent

This function of the RQD is not used anymore

RQD at present:

A standard in borehole core description

RQD


Witteveen + Bos
ITC
Project: Beskyd Tunnel
Borehole: BH01b-b
Run: 15
Sheet: 1 of 1
Date of drilling: 4/8/2006
Time of drilling: 9:55-11:20
Duration: 1:25
Av. Progress: 0,8 m/h
Barrel type: single tube
Bit type: pobedite Ø93mm
Core diameter: Ø 69-71 mm
Torque: not recorded
Rounds/min: -370
Down thrust: -1000 kg/cm²
Drilling fluid: water
Water loss: small
Drilled length: 16,9 to 18,0m
Length of run: 110 cm
Recovered length: 97 cm
Start level this 782,38 m+BD
Core description
Level Length
Core Photo
R [cm]
S [cm]
IRS
Description (BS5930:1999)
Discontinuity description
Core Photo
orientation
dip-dir
dip
Description (SSPC)
782,38
16,9
16
9
very strong
19
12
very strong, grey, fine grained, SILT-SANDSTONE
10
6
dark grey, thinly laminated, CLAY-MUDSTONE
10
3
19
15
grey, fine grained, calcareous, SILT-SANDSTONE
18
17
UCS sample No.3
781,41
17,87
core loss
781,28
18,0
Sum:
92
62
rotating core
180 15 joint, smooth undulating
000 44 bedding, smooth planar
000 44 bedding, smooth planar
180 27 joint, smooth undulating
000 49 bedding, rough undulating
rotating core
rotating core
rotating core
rotating core
rotating core
rotating core
000 50 bedding, smooth planar
000 50 bedding, smooth planar
rotating core
rotating core
rotating core
R = length of intact pieces (>10cm)
S = length of pieces with complete circumference
IRS= estimated value of Intact Rock Strength
dip-dir = dip direction, the direction of maximum dip
dip = (max) angle between horizontal and discont. plane
Note: dip-dir is relative to bedding orientation, which is given as 000
B = Bedding
J = Joint
R = Rough
Sm = Smooth
Po = Polished
Sl = Slickensided
RC = Rotating Core
IF = Induced Fracture
S = Stepped
U = Undulating
P = Planar
CCC =Calcite Crystal Coating
cm %
TCR 97 88
RQD 92 84
SCR 62 56
Corebox No. 3
Log by: vdKamp

RQD (Rock Quality Designation)

RQD at present:

- A standard in borehole core description

And used in:

- rock mass classification schemes for tunnels, slopes, etc. (Q-system, RMR, SMR, etc)
- excavatability classifications
- rock mass strength (RMR)
- rock mass permeability
- etc., etc., etc.

RQD (Rock Quality Designation)

RQD at present:

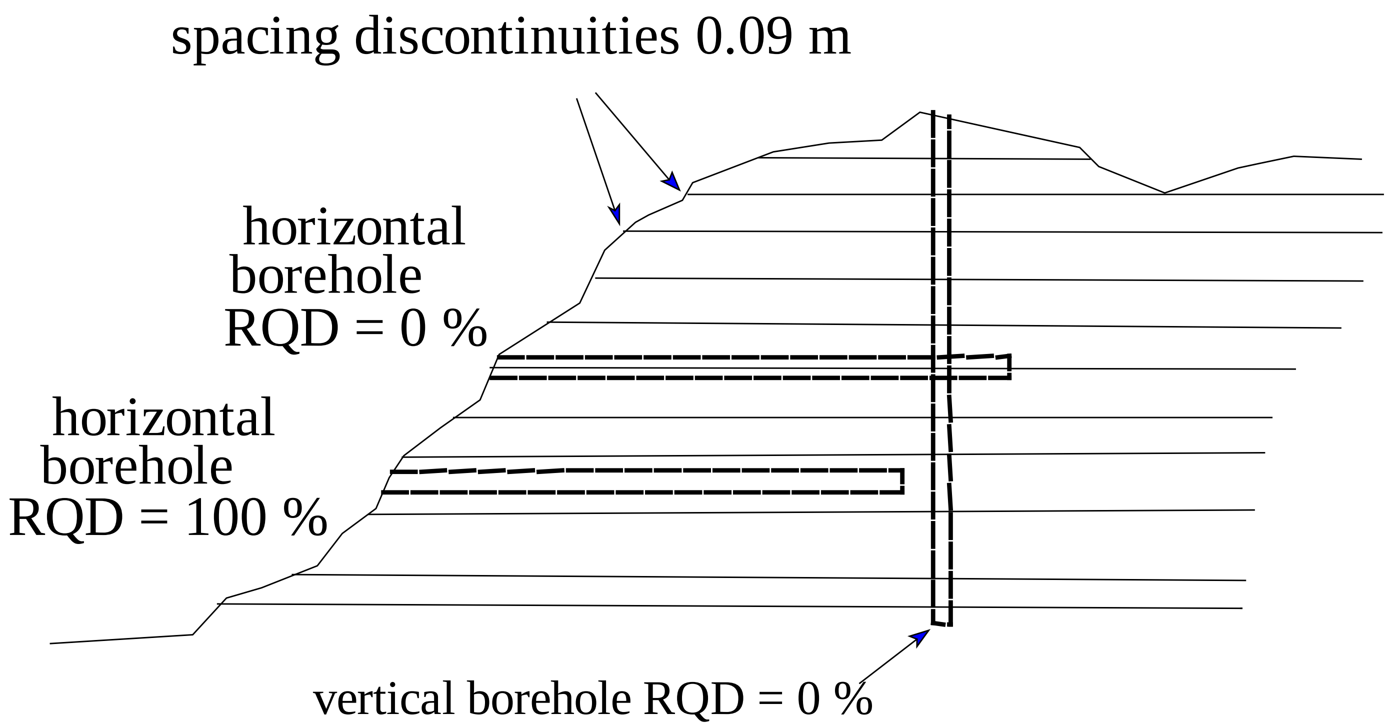
Probably the most popular rock mass parameter

Used for virtually everything

Is this justified…………………

Problems with RQD (1)

1. Arbitrary length of 10 cm
2. Orientation of borehole in relation with discontinuity spacing



Problems with RQD (2)

3. Weak rock pieces (weathered pieces of rock or infill material) that are not sound should not be considered for determining the RQD (Deere et al., 1967, 1988). To exclude infill material will usually not be too difficult; however, excluding pieces of weathered, not sound rock is fairly arbitrary.

4. The RQD value is influenced by drilling equipment, drilling operators and core handling. Especially RQD values of weak rocks can be considerably reduced due to inexperienced operators or poor drilling equipment.

Problems with RQD (3)

5. No standard core barrel - single, double, or triple barrel ?
6. Diameter of boreholes
7. Drilling fractures should be re-fitted, but what are drilling fractures?
8. RQD should be determined per lithology, but where is the lithology boundary if washed away?

RQD without borehole (Palmstrøm, 1)

J_v = the volumetric discontinuity count

= total number of discontinuities per m3

= the sum of the number of discontinuities per metre length of all discontinuity sets

RQD without borehole (Palmstrøm, 2)

$$IF \quad J_v \geq 4.5 \quad ===> \quad RQD = \left(115 - 3.3 * J_v \right)\%$$

$$IF \quad J_v < 4.5 \quad ===> \quad RQD = 100\,\%$$

$$J_v = total\ number\ of\ discontinuities\ per\ m^3$$

$$(= sum\ of\ number\ of\ discontinuities\ per\ metre$$

$$length\ of\ all\ discontinuity\ sets)$$

(ISRM, 1978, Palmstrøm,1975)


bedding planes: spacing 0.4 m
Joint 2: spacing 1.0 m
Joint 1: spacing 3.0 m

RQD without borehole (Palmstrøm, 3)

Example1:

Bedding spacing 0.4 m = 2.5 discontinuity per meter

Joint 1 spacing = 3.0 m = 0.33 discontinuity per meter

Joint 2 spacing = 1.0 m = 1 discontinuity per meter

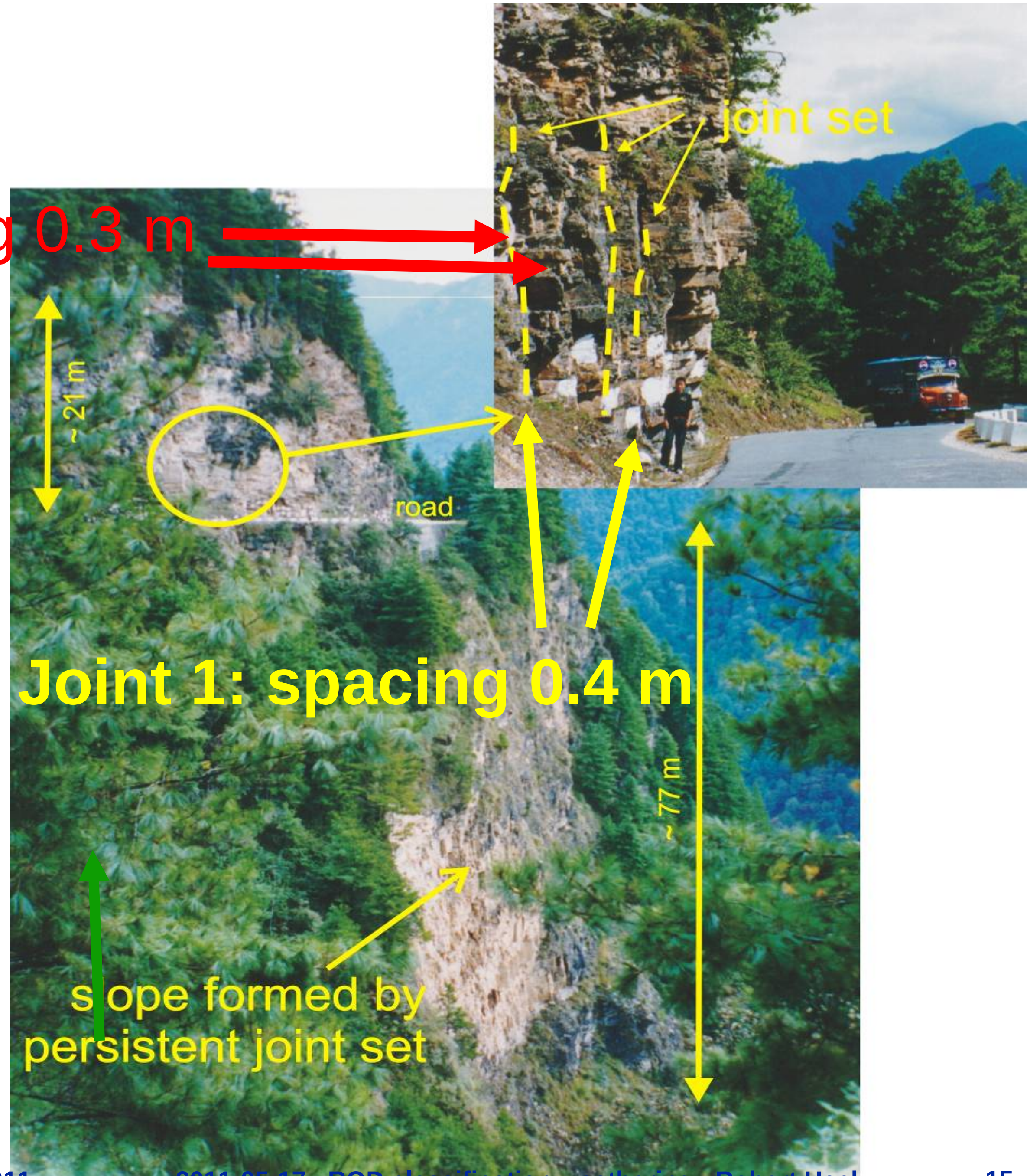
Jv = 2.5 + 0.33 + 1 = 3.83 discontinuities per m3

Jv < 4.5 → RQD = 100 %

foliation planes: spacing 0.3 m

Joint 2: spacing 0.4 m

(perpendicular to slope)



RQD without borehole (Palmstrøm, 3)

Example 2:

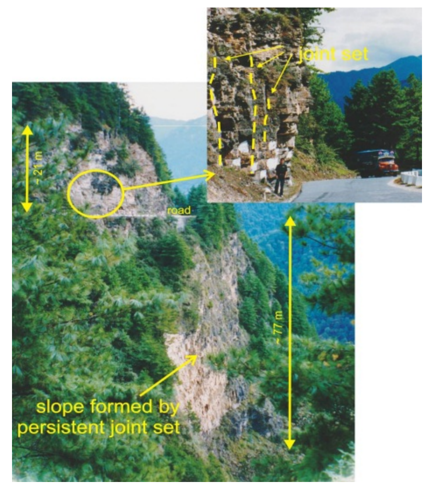
Foliation spacing 0.3 m = 2.5 discontinuity per meter

Joint 1 spacing = 0.4 m = 2.5 discontinuity per meter

Joint 2 spacing = 0.4 m = 3.3 discontinuity per meter

Jv = 2.5 + 2.5 + 3.3 = 8.3 discontinuities per m3

Jv > 4.5 ➔ RQD = (115 – 3.3 * Jv) = 88 %



RQD without borehole (Palmstrøm, 3)

More complicated and sophisticated relations exist for RQD without a bore hole

However: It will always be a simulation

RQD is inherent to the process of drilling

Without drilling some features determining the RQD are lost such as: washing out weak layers, fractures due to drilling, etc.

Rock mass classification systems

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

For example in the RMR system:

- properties (such as RQD, intact rock strength, spacing of discontinuities) of the rock mass are given point ratings
- the points are added to give the RMR rating

the RMR rating is related to:

- the stability of the tunnel
- support measures in the tunnel (e.g. shotcrete, rock bolts, steel sets)

RMR:

	parameter		range of values						
1	intact material strength – UCS (MPa)		> 250	100-250	50-100	25-50	5-25	1-5	< 1
	rating:		15	12	7	4	2	1	0
2	drill core quality – RQD (%) [(1)]		90-100	75-90	50-75	25-50	< 25		
	rating:		20	17	13	8	3		
3	discontinuity spacing (cm)		> 200	60-200	20-60	6-20	< 6		
	rating:		20	15	10	8	5		
4	condition of discontinuities		very rough surfaces not continuous no separation [(2)] unweathered wall rock	slightly rough surfaces separation < 1 mm slightly weathered walls	slightly rough surfaces separation < 1 mm highly weathered walls	slickensided [(3)] surfaces or gouge < 5 mm thick or separation 1-5 mm continuous	soft gouge > 5 mm thick or separation > 5 mm continuous		
	rating:		30	25	20	10	0		
5	groundwater	inflow per 10 m tunnel length (L/min)	none	< 10	10-25	25-125	> 125		
		ratio of joint water pressure over major principal stress	0	< 0.1	0.1-0.2	0.2-0.5	> 0.5		
		general conditions	completely dry	damp	wet	dripping	flowing		
	rating:		15	10	7	4	0		

Notes: 1) RQD expresses the quality of the core obtained from a borehole and depends on the quality of the rock mass; 0%: many discontinuities and weak zones; 100%: sound rock with few discontinuities. 2) Separation is the opening between the two discontinuity walls. 3) Slickensided is a striated smoothly polished surface created by frictional movement between the two sides of a discontinuity.

rating:	100 - 81	80 - 61	60 - 41	40 - 21	< 20
class no:	I	II	III	IV	V
description:	very good rock	good rock	fair rock	poor rock	very poor rock
average stand-up time:	20 year for 15 m span [(1)]	1 year for 10 m span	1 week for 5 m span	10 hours for 2-5 m span	30 minutes for 1 m span
cohesion of the rock mass (kPa):	> 400	300 - 400	200 - 300	100 - 200	< 100
friction angle of the rock mass (deg):	> 45°	35° - 45°	25° - 35°	15° – 25°	< 15°

Notes: 1) Span is the span of the excavation.

RMR example:

	parameter		range of values						
1	intact material strength – UCS (MPa)		> 250	100-250	50-100	25-50	5-25	1-5	< 1
	rating:		15	12	7	4	2	1	0
2	drill core quality – RQD (%) (1)		90-100	75-90	50-75	25-50		< 25	
	rating:		20	17	13	8		3	
3	discontinuity spacing (cm)		> 200	60-200	20-60	6-20		< 6	
	rating:		20	15	10	8		5	
4	condition of discontinuities		very rough surfaces not continuous no separation (2) unweathered wall rock	slightly rough surfaces separation < 1 mm slightly weathered walls	slightly rough surfaces separation < 1 mm highly weathered walls	slickensided (3) surfaces or gouge < 5 mm thick or separation 1-5 mm continuous		soft gouge > 5 mm thick or separation > 5 mm continuous	
	rating:		30	25	20	10		0	
5	groundwater	inflow per 10 m tunnel length (L/min)	none	< 10	10-25	25-125		> 125	
		ratio of joint water pressure over major principal stress	0	< 0.1	0.1-0.2	0.2-0.5		> 0.5	
		general conditions	completely dry	damp	wet	dripping		flowing	
	rating:		15	10	7	4		0	

Notes: 1) RQD expresses the quality of the core obtained from a borehole and depends on the quality of the rock mass; 0%: many discontinuities and weak zones; 100%: sound rock with few discontinuities. 2) Separation is the opening between the two discontinuity walls. 3) Slickensided is a striated smoothly polished surface created by frictional movement between the two sides of a discontinuity.

- IRS = 75 MPa: → **7** points
- RQD = 80% → **17** points
- discontinuity spacing = 45 cm → **10** points
- condition: slightly rough, separation < 1 mm, slightly weathered walls → **25** points
- groundwater = dry → **15** points

RMR rating = 7 + 17+ 10 + 25 + 15 = 74 points

rating:	100 - 81	80 - 61	60 - 41	40 - 21	< 20
class no:	I	II	III	IV	V
description:	very good rock	good rock	fair rock	poor rock	very poor rock
average stand-up time:	20 year for 15 m span (1)	1 year for 10 m span	1 week for 5 m span	10 hours for 2-5 m span	30 minutes for 1 m span
cohesion of the rock mass (kPa):	> 400	300 - 400	200 - 300	100 - 200	< 100
friction angle of the rock mass (deg):	> 45°	35° - 45°	25° - 35°	15° – 25°	< 15°

Notes: 1) Span is the span of the excavation.

Classification systems:

- For underground (tunnel):
  - Bieniawski (RMR)
  - Barton (Q)
  - Laubscher (MRMR)
  - etcetera
- For slopes:
  - Selby
  - Bieniawski (RMR)
  - Vecchia
  - Robertson (RMR)
  - Romana (SMR)
  - Haines
  - SSPC
  - etcetera

Classification systems for slopes

- Romana's SMR
- Haines and Terbrugge
- SSPC

Romana’s SMR

$$SMR = RMR - (F_1 * F_2 * F_3) + F_4$$

SMR = Slope Mass Rating

RMR = Rock Mass Rating (same as Bieniawski's RMR)

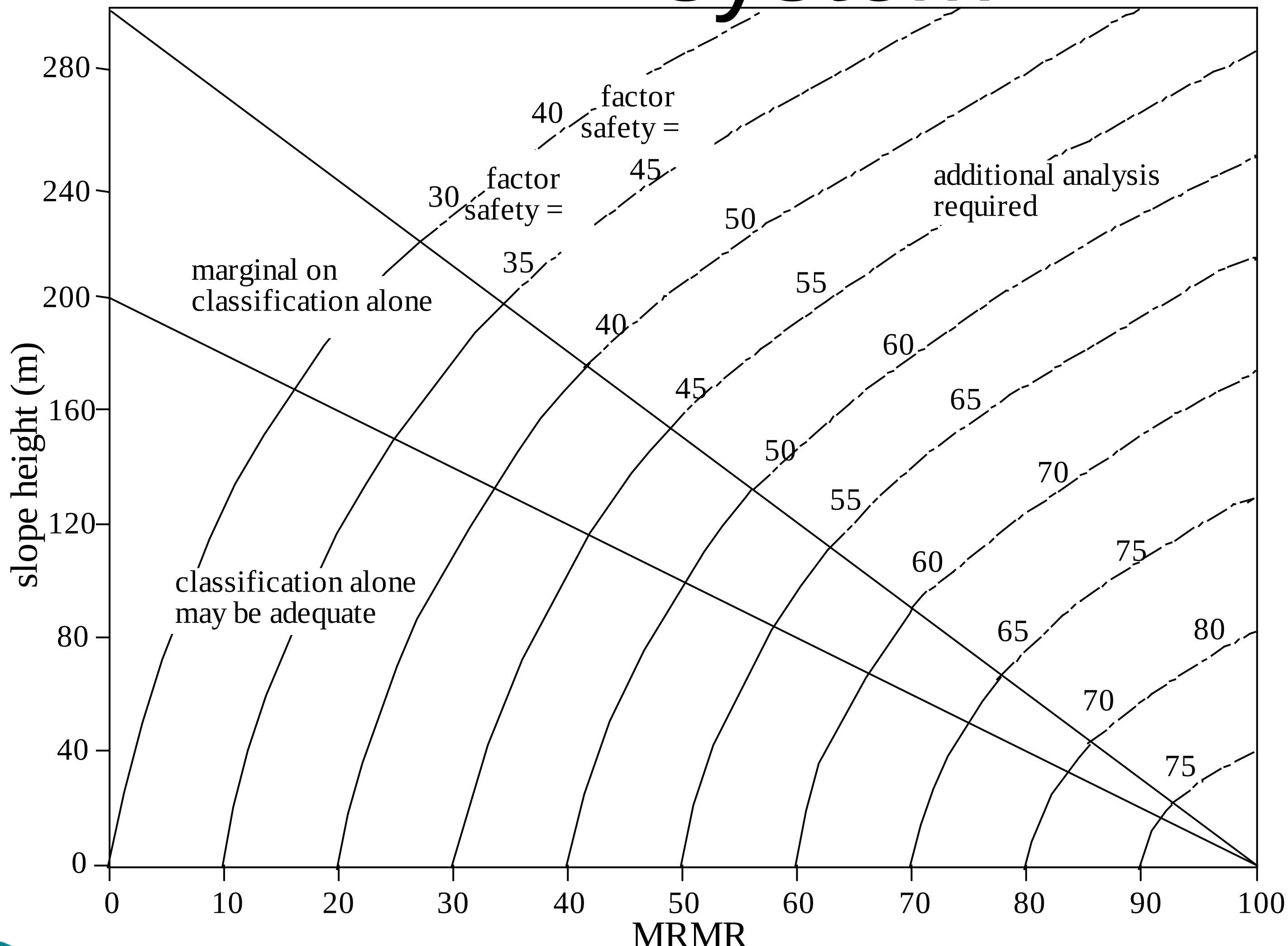
F_1 = factor for parallelism of the strikes of discontinuities and slope face

F_2 = factor for discontinuity dip angle

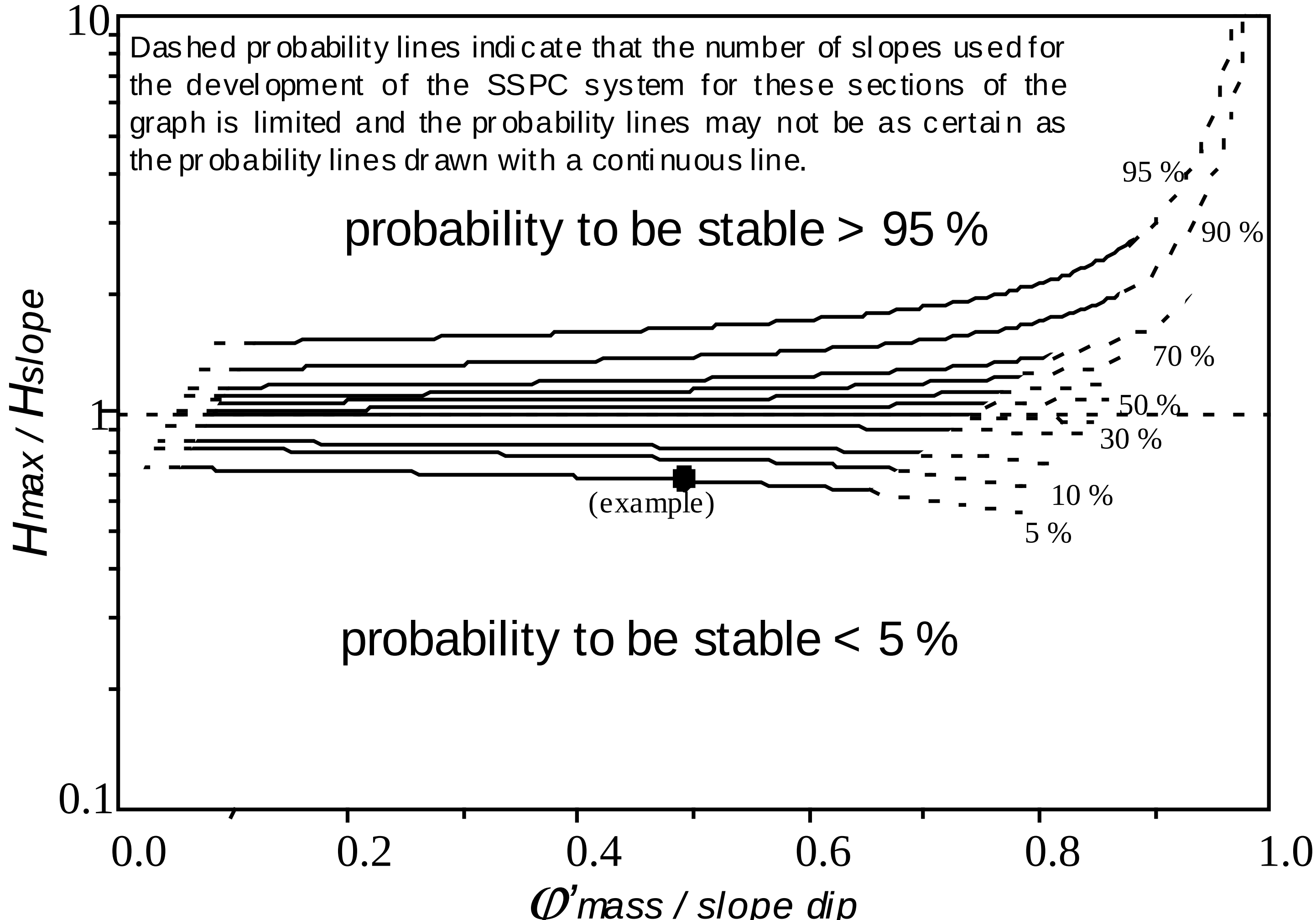
F_3 = factor for relation between slope face and discontinuity dip

F_4 = factor for method of excavation

Haines and Terbrugge slope system



SSPC failure probabilities for orientation independent failure

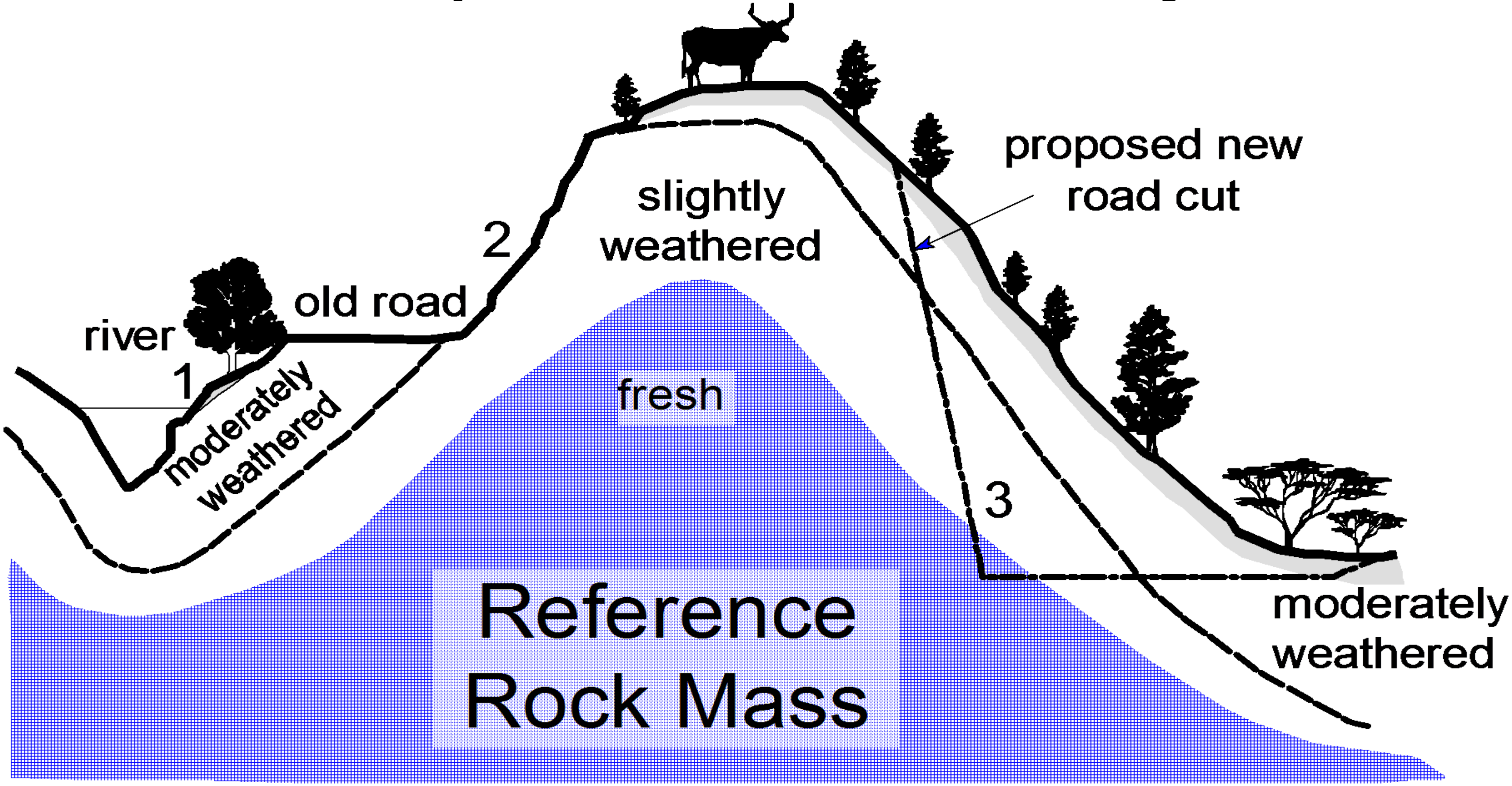


Slope Stability probability Classification (SSPC)

SSPC

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

Three step classification system



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.

Three step classification system (2)

EXPOSURE ROCK MASS (ERM)

Exposure rock mass parameters significant for slope stability:

- Material properties: strength, susceptibility to weathering
- Discontinuities: orientation and sets (spacing) or single
- Discontinuity properties: roughness, infill, karst

Exposure specific parameters:

- Method of excavation
- Degree of weathering

Factor used to remove the influence of the method excavation and degree of weathering

REFERENCE ROCK MASS (RRM)

Reference rock mass parameters significant for slope stability:

- Material properties: strength, susceptibility to weathering
- Discontinuities: orientation and sets (spacing) or single
- Discontinuity properties: roughness, infill, karst

Slope specific parameters:

- Method of excavation to be used
- Expected degree of weathering at end of engineering life-time of slope

Factor used to assess the influence of the method excavation and future weathering

SLOPE ROCK MASS (SRM)

Slope rock mass parameters significant for slope stability:

- Material properties: strength, susceptibility to weathering
- Discontinuities: orientation and sets (spacing) or single
- Discontinuity properties: roughness, infill, karst

SLOPE GEOMETRY
Orientation
Height

SLOPE STABILITY ASSESSMENT

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

- Degree of weathering
- Method of excavation

Slope specific parameters for the new slope to be made

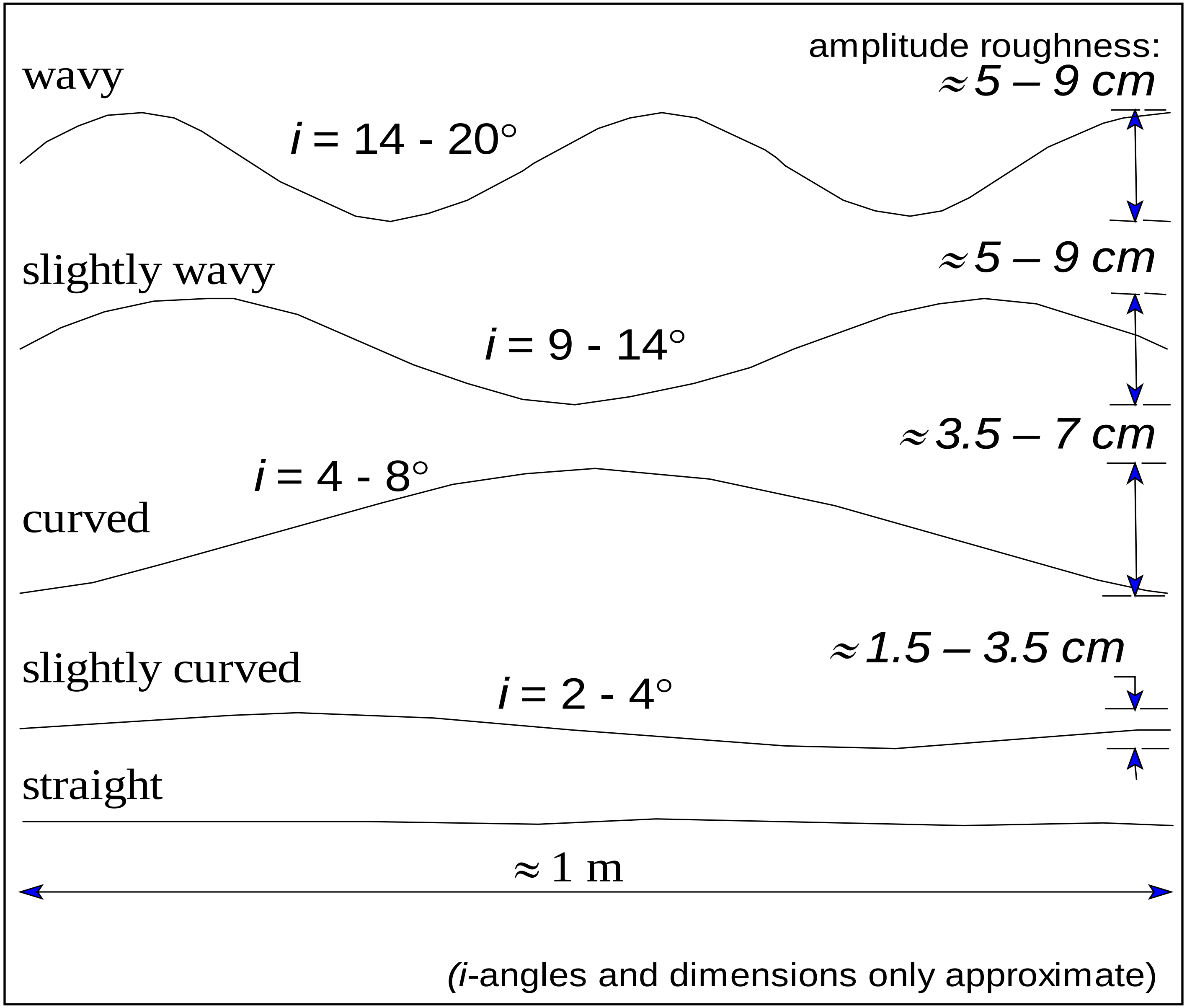
- Expected degree of weathering at end of lifetime of the slope
- Method of excavation to be used for the new slope

Intact rock strength

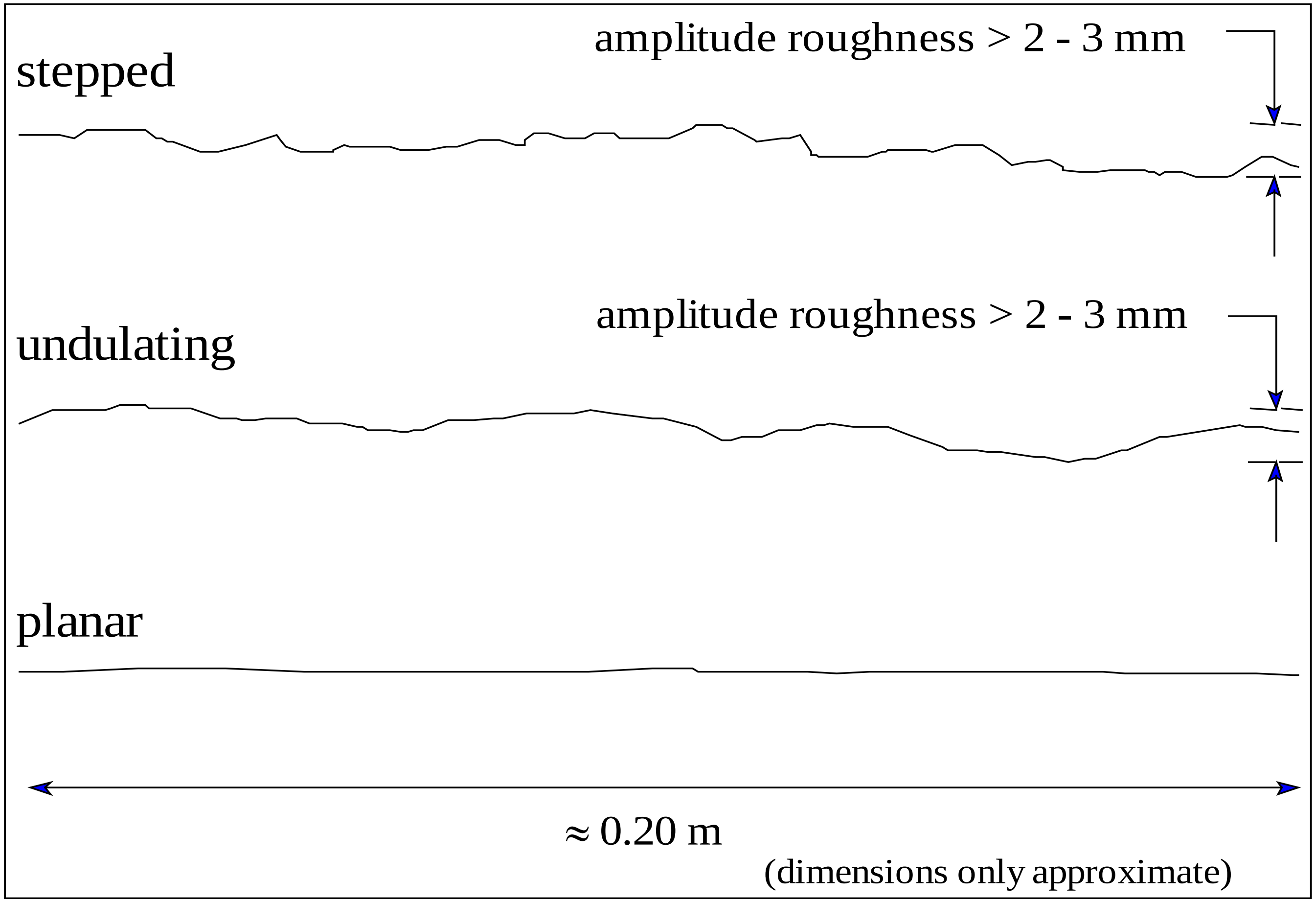
By simple means test - hammer blows, crushing by hand, etc.

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



Shear strength - roughness large scale



Shear strength - roughness small scale

Shear strength - Infill

Infill:

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

Orientation dependent stability

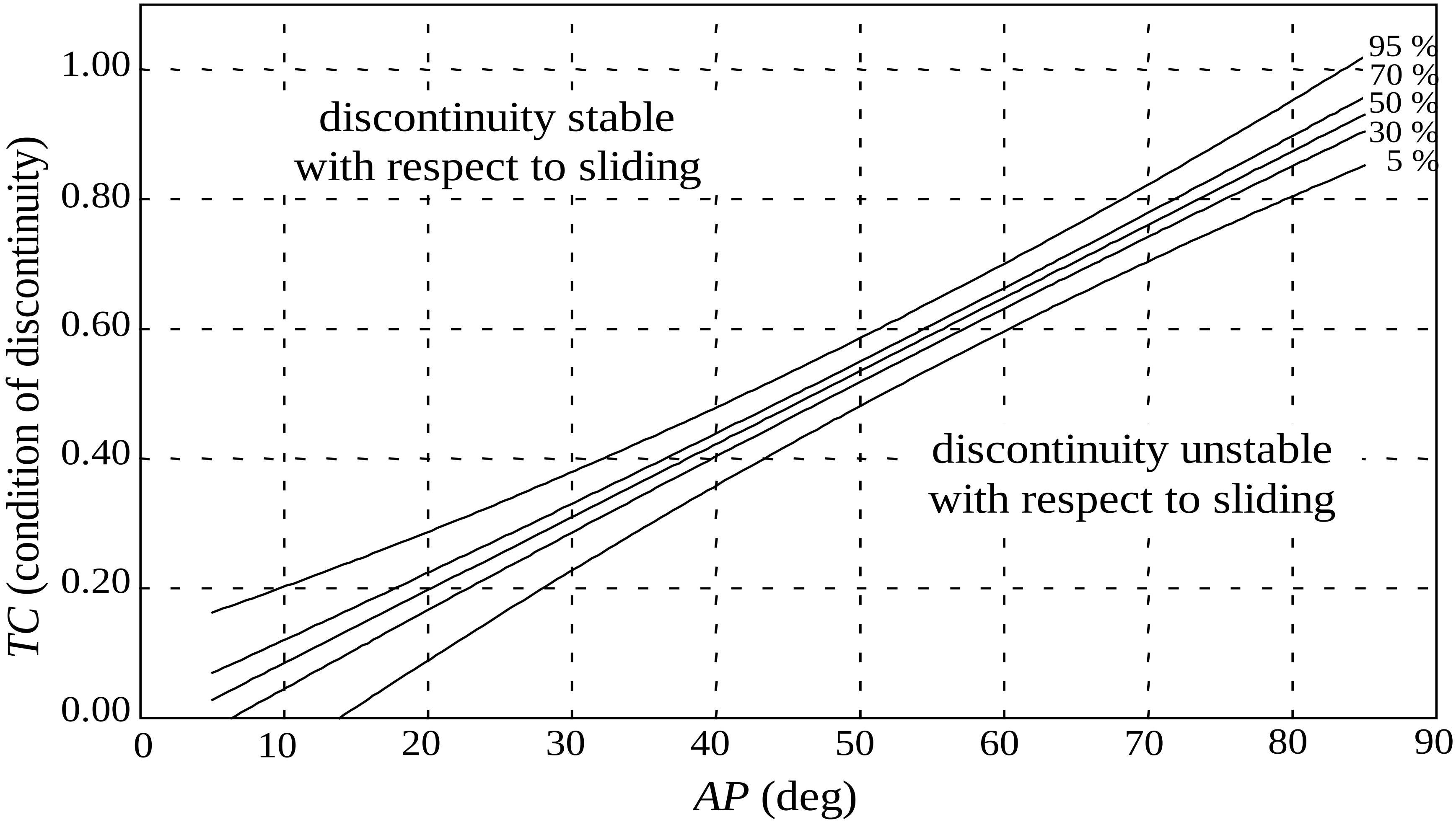
Stability depending on relation between slope and discontinuity orientation

Sliding criterion

sliding occurs if :

$$TC < 0.0113 * AP$$

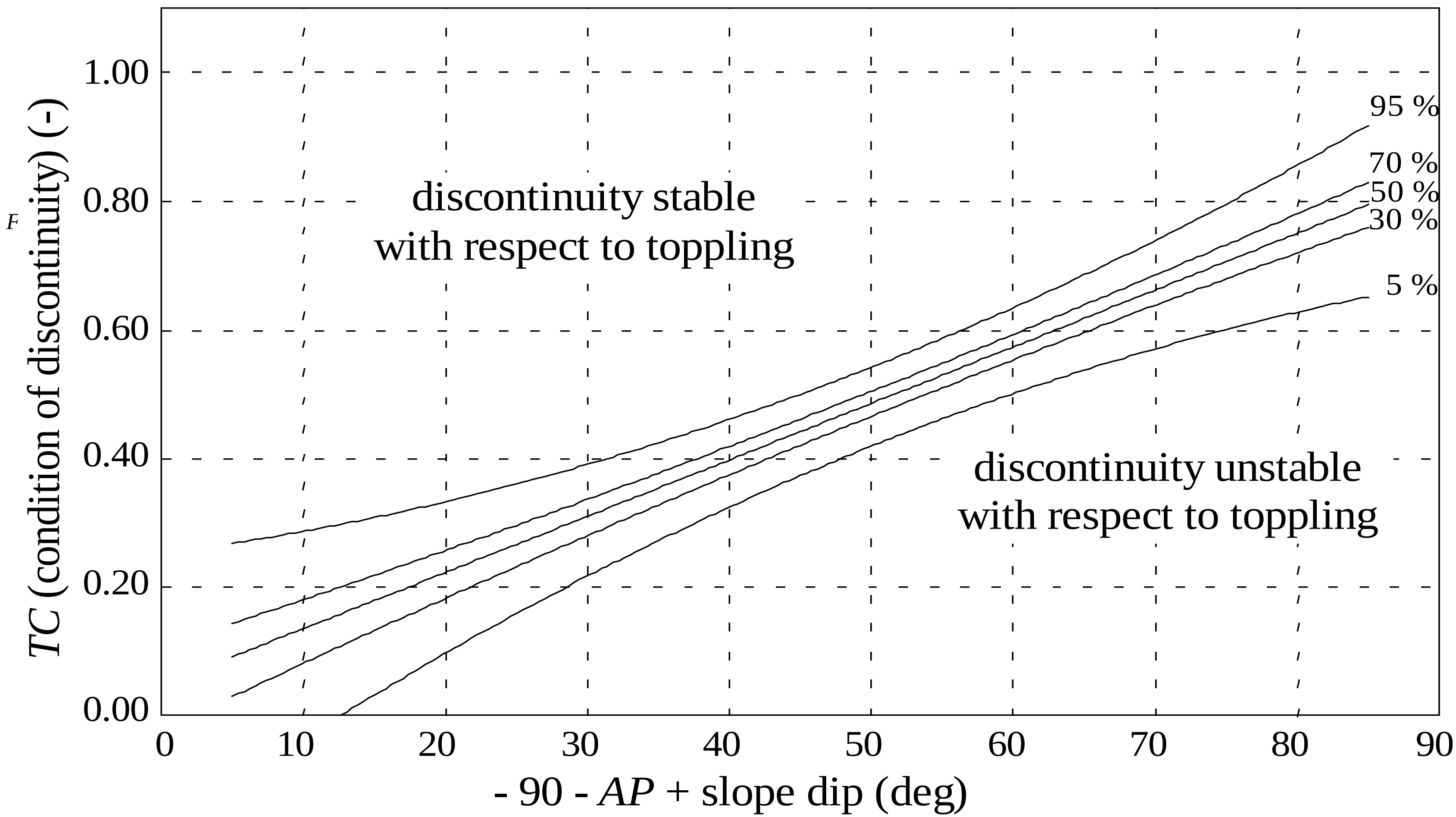
Sliding probability



Toppling criterion

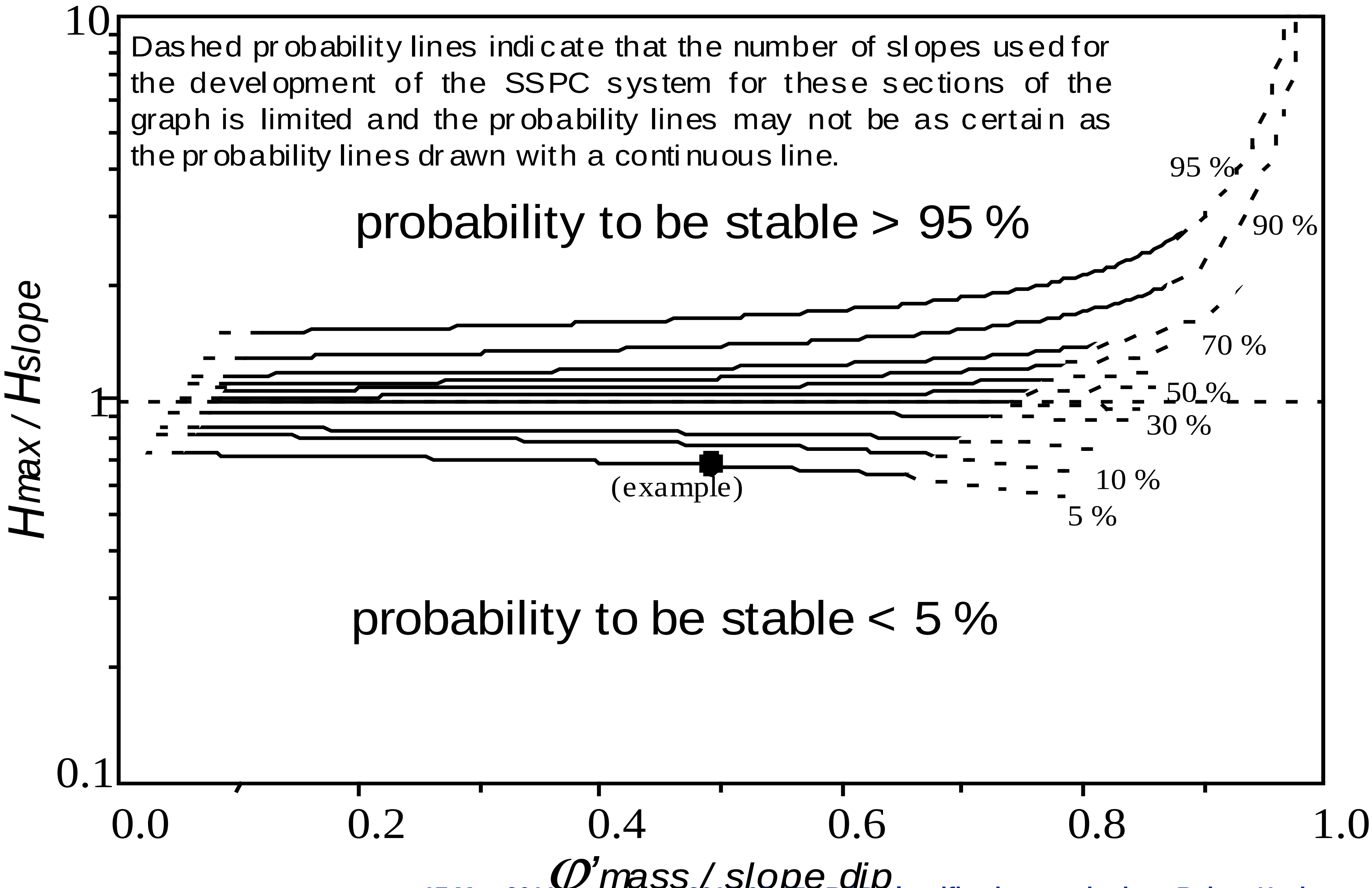
$$TC < 0.0087 * \left(-90^\circ - AP + dip_{discontinuity} \right)$$

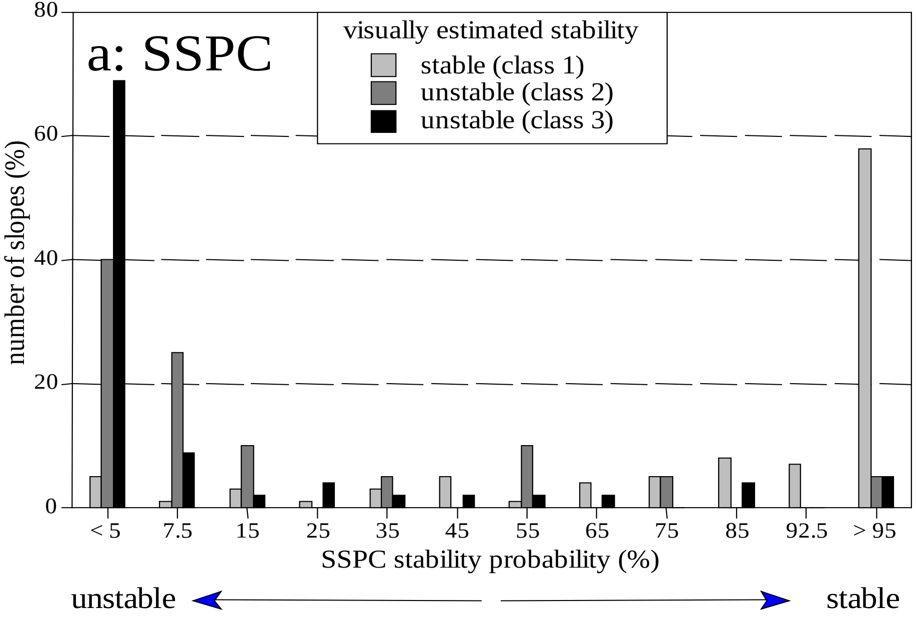
Toppling probability

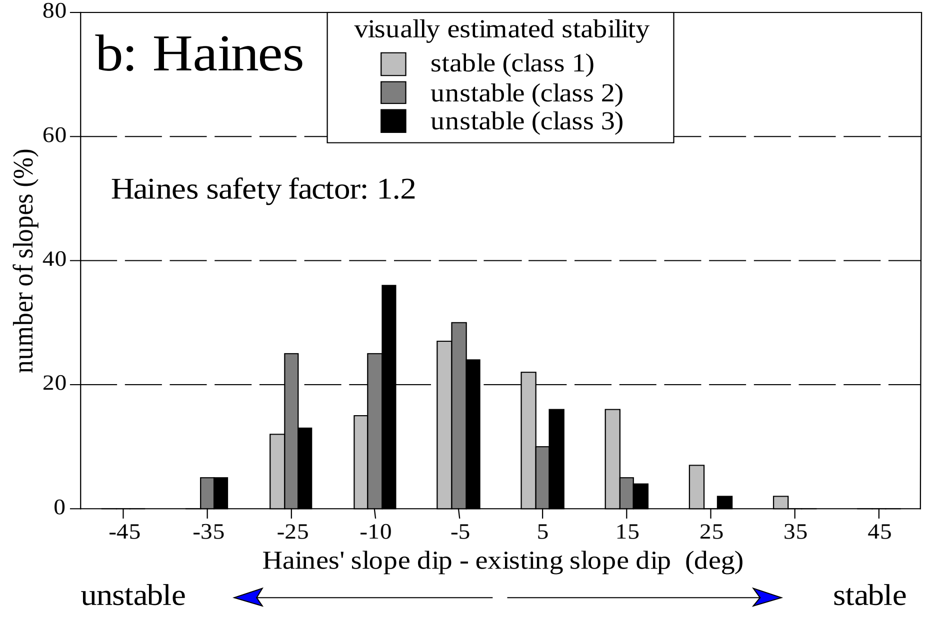


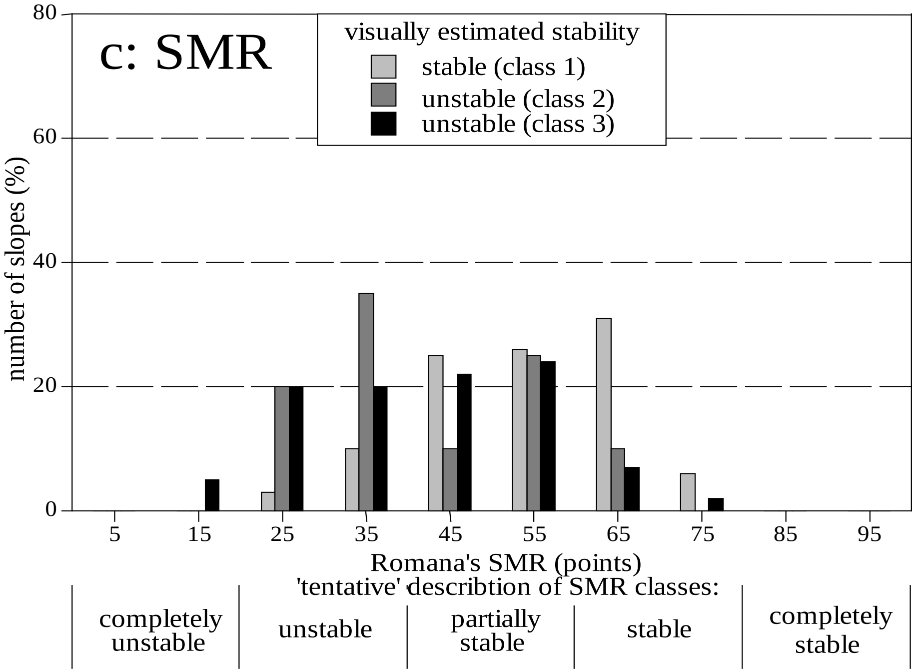
Orientation independent stability

Probability orientation independent failure









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)

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).

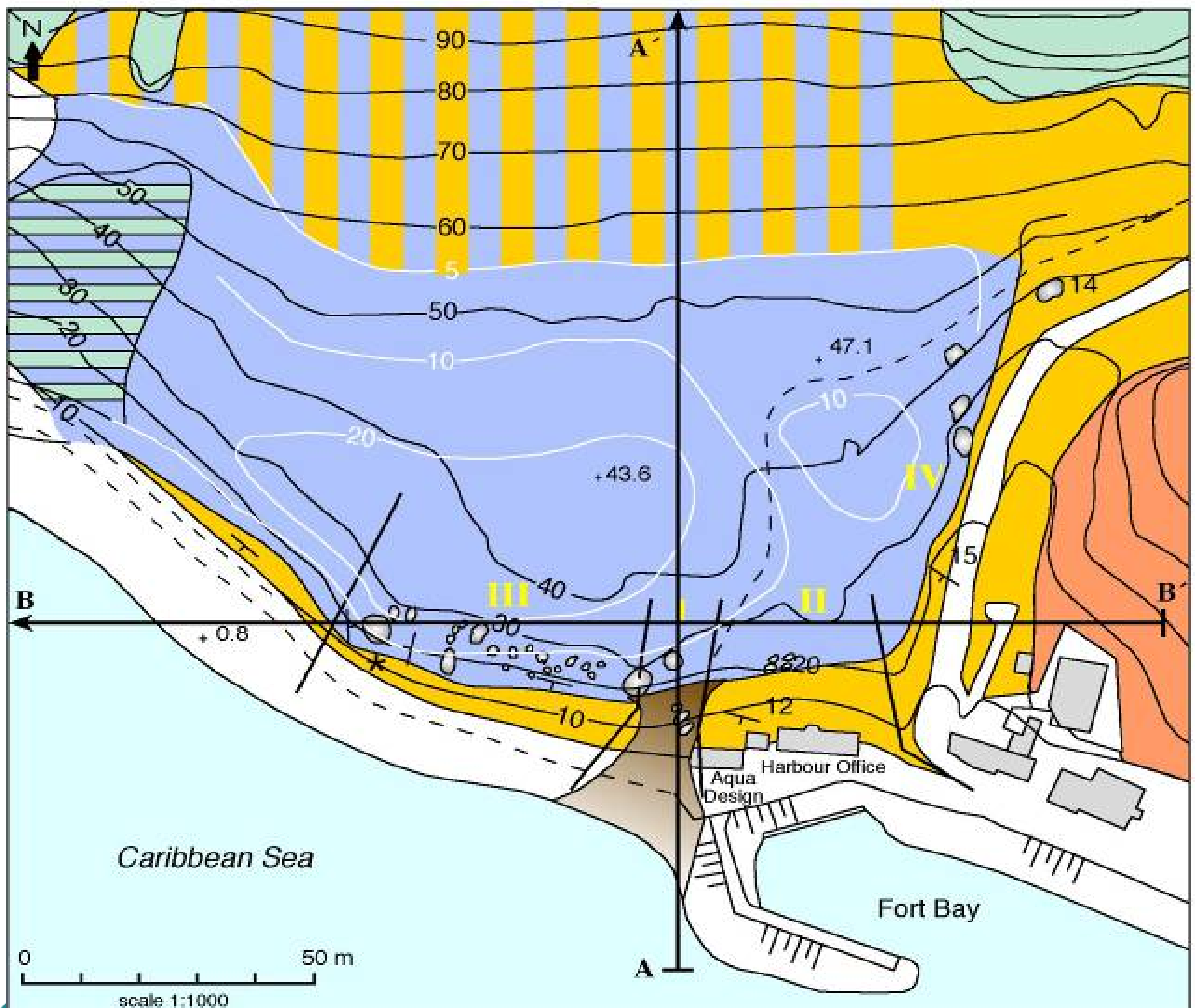
In 2005: Slope dip about 52° (visually assessed unstable – big blocks in middle photo have fallen).

Slope Stability probability Classification (SSPC)

Saba case - Dutch Antilles

Landslide in harbour

Geotechnical zoning



SSPC results

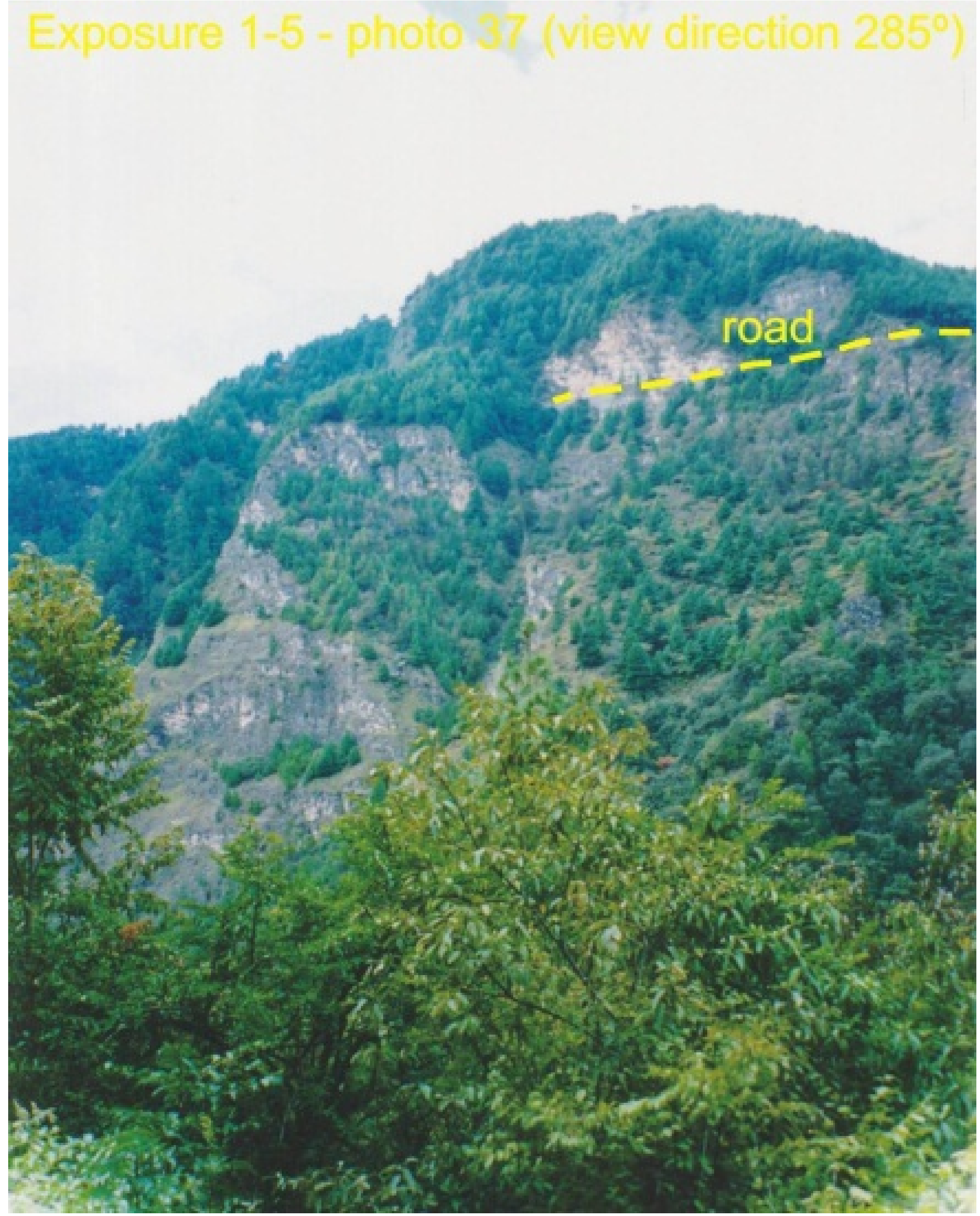
Pyroclastic deposits	Calculated SSPC	Laboratory / field
Rock mass friction	35°	27° (measured)
Rock mass cohesion	39kPa	40kPa (measured)
Calculated maximum possible height on the slope	13m	15m (observed)

Failing slope in Manila, Philippines

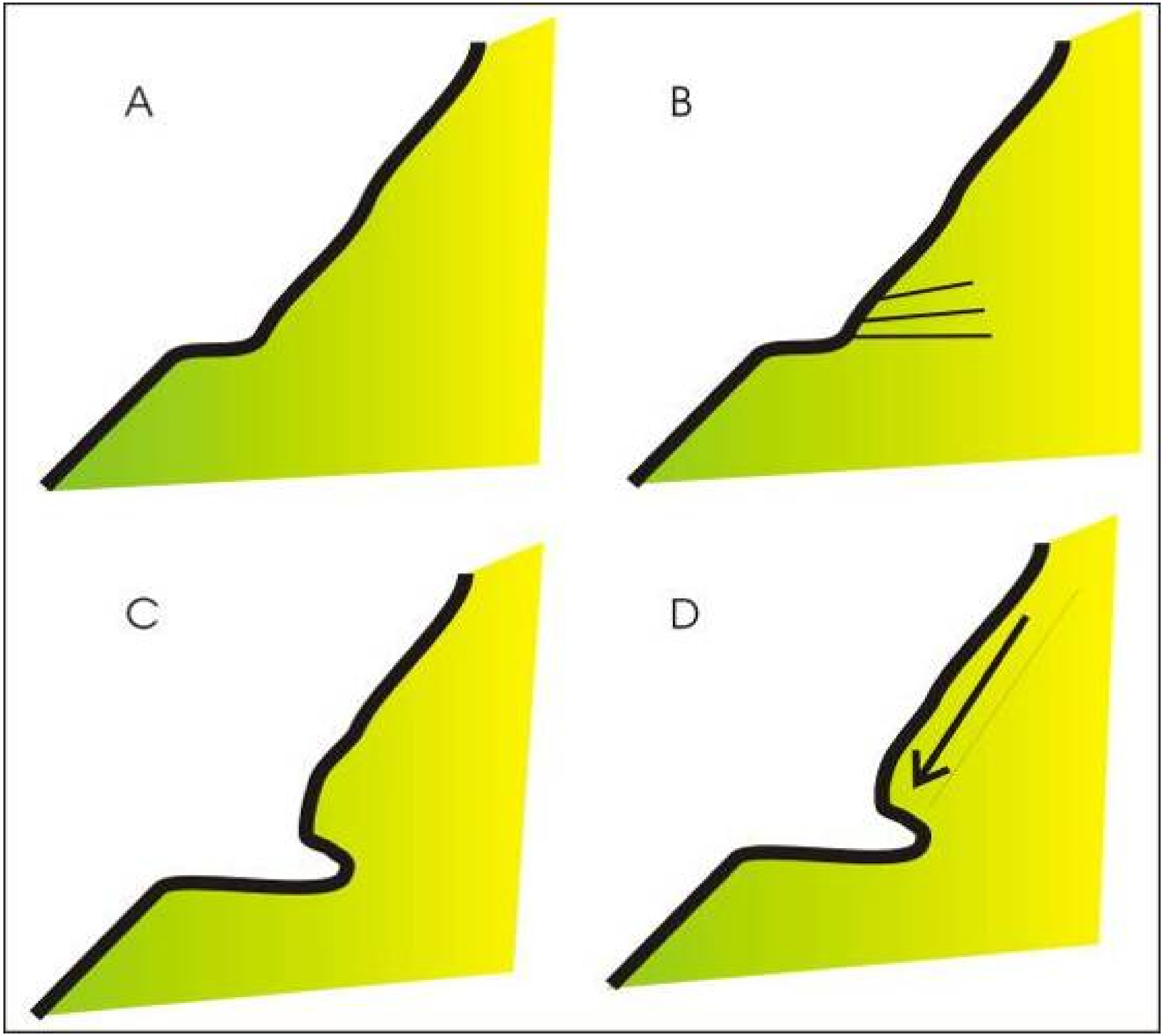
Failing slope in Manila (2)

- 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

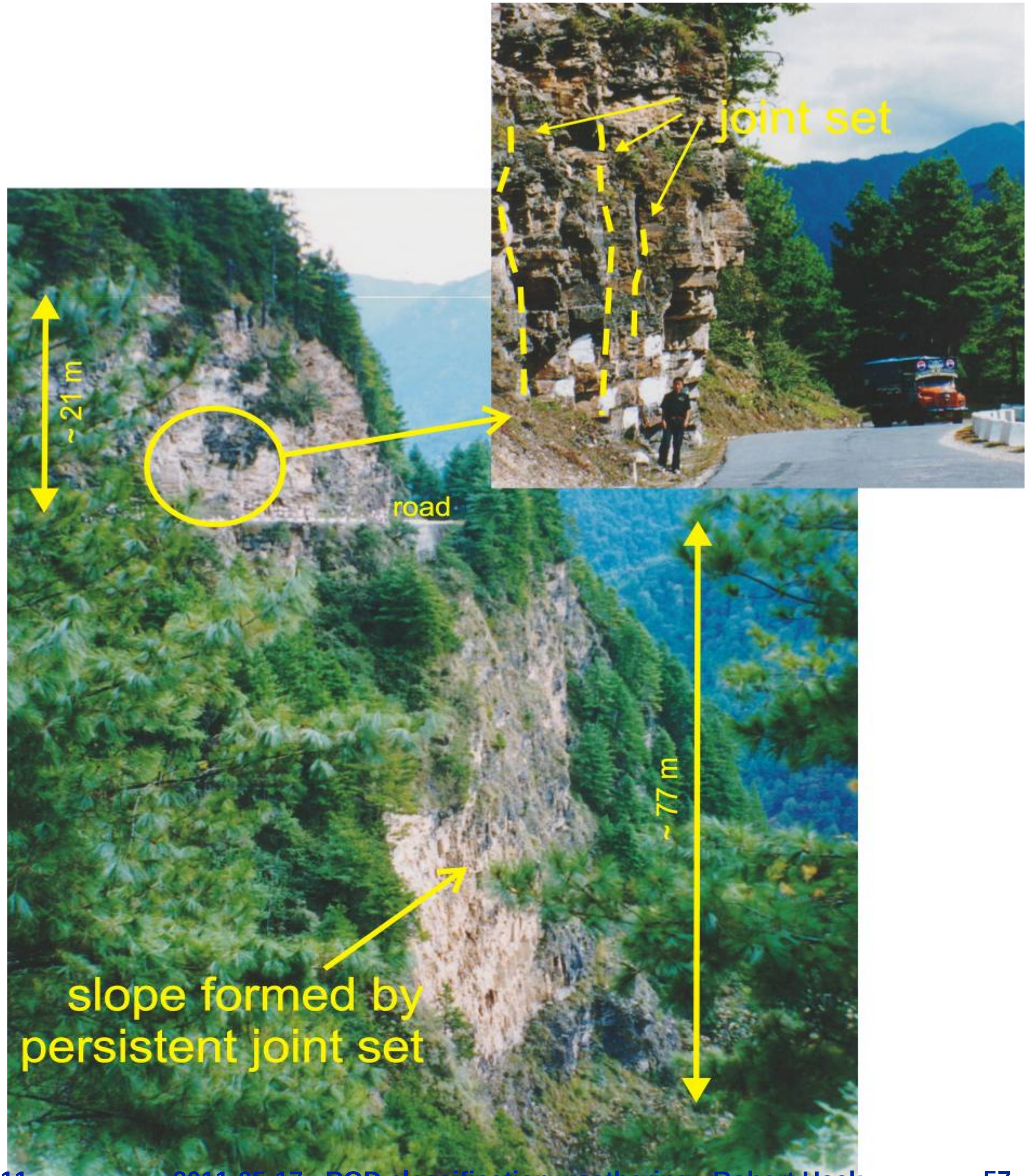
Widening existing road in Bhutan (Himalayas)



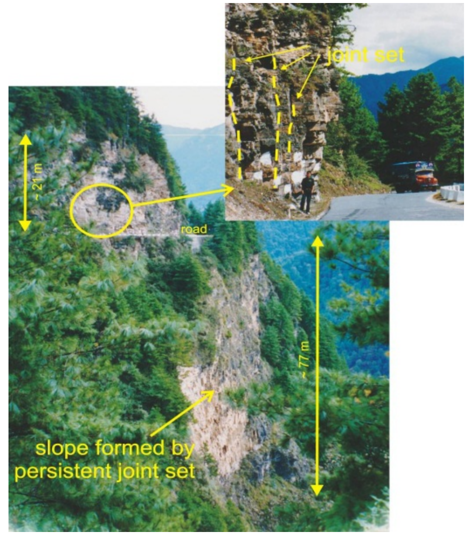
Bhutan (5) Method of excavation



Widening existing road in Bhutan (Himalayas) (2)



Widening existing road in Bhutan (Himalayas) (3)



Above road level:

Visual assessment:

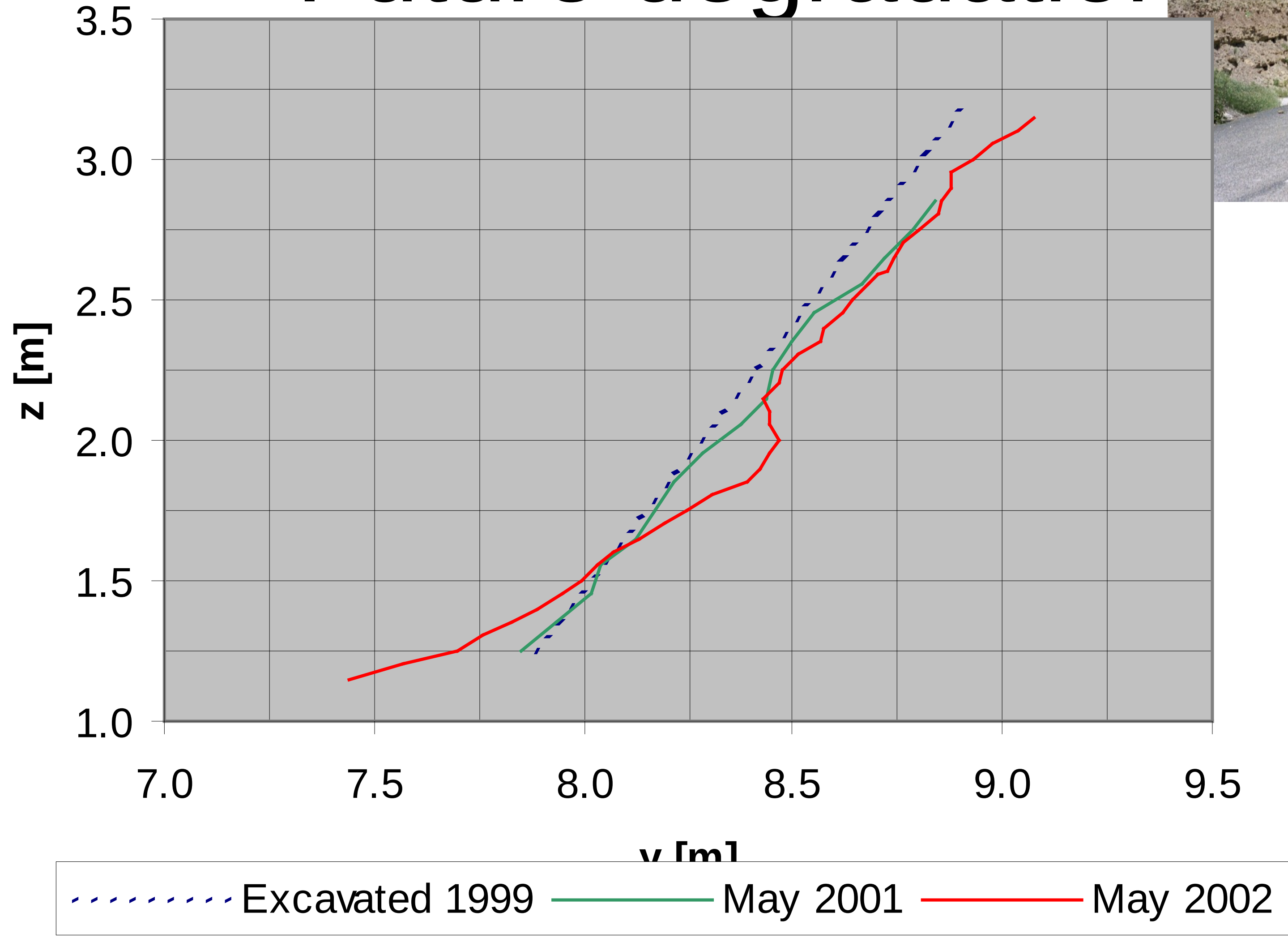
- Joint systems (sub-) vertical
- Present slope about 21 m high, about 90° or overhanging (!)
- Present situation above road highly unstable (visual assessment)

Following SSPC system:

- highly instable
- stability for: 27 m slope with 75° slope dip (orientation independent stability 85%)

Future degradation (2)

Future degradation



Reduction in slope angle due to weathering, erosion and ravelling (after Huisman)

Weathering rate

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

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

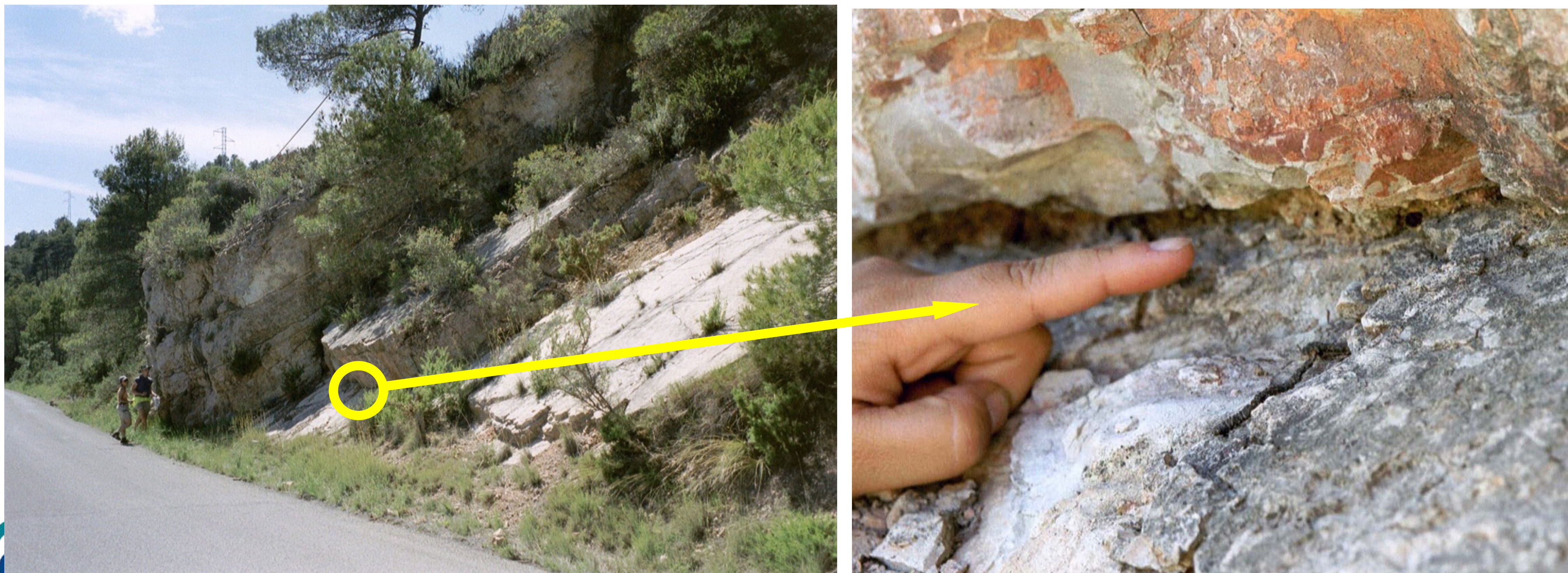
Degradation processes

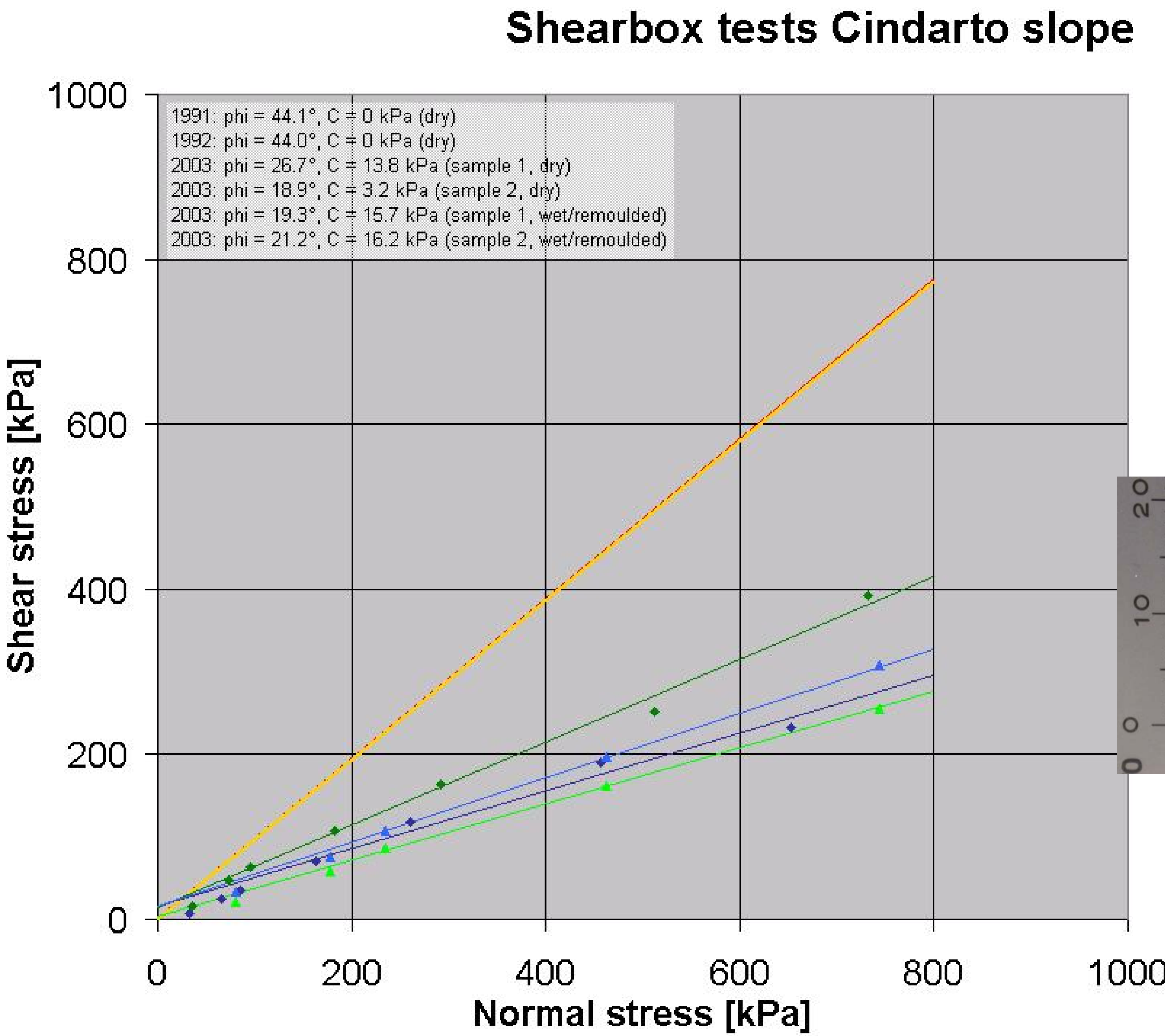
Main processes involved in degradation:

- 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




Shearbox tests Cindarto slope
1991: phi = 44.1°, C = 0 kPa (dry)
1992: phi = 44.0°, C = 0 kPa (dry)
2003: phi = 26.7°, C = 13.8 kPa (sample 1, dry)
2003: phi = 18.9°, C = 3.2 kPa (sample 2, dry)
2003: phi = 19.3°, C = 15.7 kPa (sample 1, wet/remoulded)
2003: phi = 21.2°, C = 16.2 kPa (sample 2, wet/remoulded)
Tests Cindarto, 1991 (dry)
Tests Cindarto, 1992 (dry)
Sample 1 (data), 2003 (dry)
Sample 1 (fit), 2003 (dry)
Sample 2 (data), 2003 (dry)
Sample 2 (fit), 2003 (dry)
Sample 1 (data), 2003 (wet/remoulded)
Sample 1 (fit), 2003 (wet/remoulded)
Sample 2 (data), 2003 (wet/remoulded)
Sample 2 (fit), 2003 (wet/remoulded)
Shear stress [kPa]
Normal stress [kPa]
0
200
400
600
800
1000


•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)

- in 15 years decrease to 35º

Kota Kinabalu, Malaysia

Main road: 10 years old

moderately weathered

SSPC

stability:

Sandstone:

stable

Shale:

ravelling

Kota Kinabalu, Malaysia

Kota Kinabalu, Malaysia

Side road: 5 years
slightly weathered
SSPC
stability:
Sandstone:
stable
Shale:
unstable

Kota Kinabalu, Malaysia

SSPC friction & cohesion:

	friction (deg)	cohesion (kPa)
shale		
slightly (5 years)	4	2.4
moderately (10 years)	2	1.1
sandstone		
slightly (5 years)	20	10.0
moderately (10 years)	11	6.3

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