DESIGN OF UNDERGROUND EXCAVATIONS AND THE SIGNIFICANCE OF EUROCODE 7

Professor Bjørn Nilsen
Norwegian University of Science and Technology (NTNU)

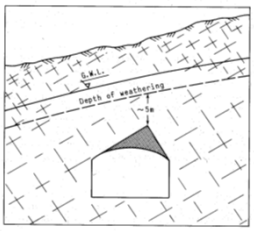
- SIGNIFICANCE OF STEPWISE INVESTIGATION AND DESIGN
- BASIC DESIGN APPROACH
  1) location
  2) orientation
  3) optimization of geometry/shape
  4) dimensioning
- SIGNIFICANCE OF EUROCODE 7

INVESTIGATION AND DESIGN STAGES AS RECOMMENDED BY IAEG

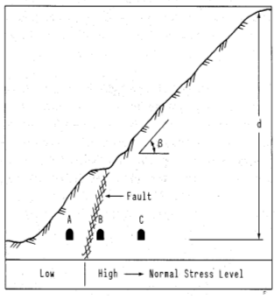
SITE INVESTIGATION STAGE	INVESTIGATION ACTIVITIES	DESIGN AND CONSTRUCTION PROGRESS
PROJECT CONCEPTION	*Recognition of need for project*	
	initial project conception	
	Basic knowledge of ground conditions	Basic project concept design
	Recognition major problems	
PRELIMINARY	Preliminary field investigations	Confirmation or amendment of design concept
	Design of main investigation	Preliminary detailed design
MAIN	Main investigation Information recovered during investigation	Modification to detailed design
	Report on main investigation	Final design of project
	CONSTRUCTION	
CONSTRUCTION	Recording ground conditions as found	Modifications to design
	Further investigation	Modifications to design
POST-CONSTRUCTION	COMPLETION OF CONSTRUCTION	
	Monitoring behaviour in operation	Maintenance works

Exchange of information

DESIGN STEP 1: LOCATION

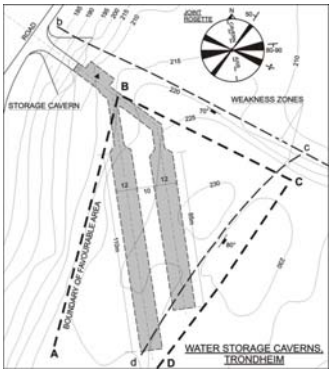


SHALLOW SEATED (SS) CASE:
- Best possible rock mass quality
- No intersecting faults
- Minimum rock cover?

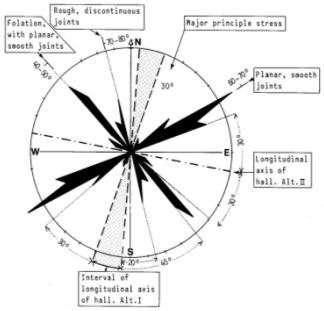


DEEP SEATED (DS) CASE:
- Also: any destressed areas?

DESIGN STEP 2: ORIENTATION



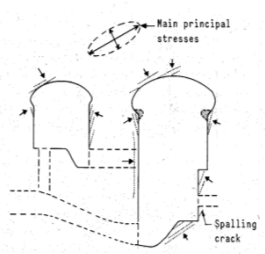
SS-CASE:
- Bisectional angle between main joint sets
- Perpendicular to any fault zones



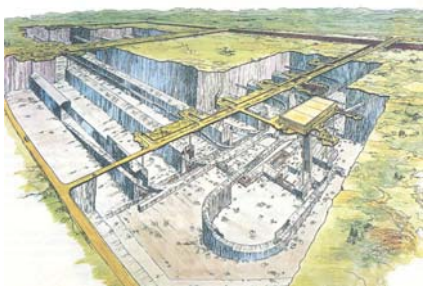
DS-CASE:
- Also: axis ~20-30° with σ_1

DESIGN STEP 3: OPTIMIZATION OF GEOMETRY/SHAPE

Main design principle: evenly distributed stresses, i.e.geometry as simple as possible



Protruding corners should be avoided - but not always possible!

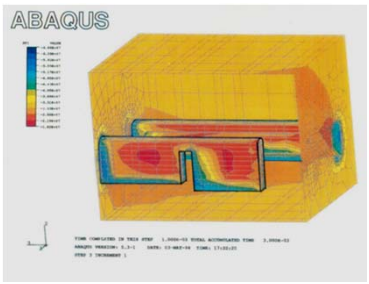


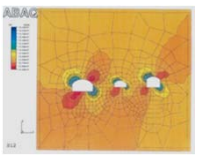
Several smaller caverns better than one/ few very large!

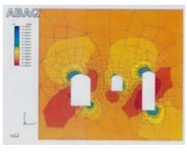
4) DIMENSIONING

TWO MAIN ALTERNATIVES:

- EMPIRICAL APPROACH
- NUMERICAL ANALYSIS

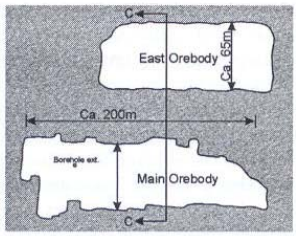


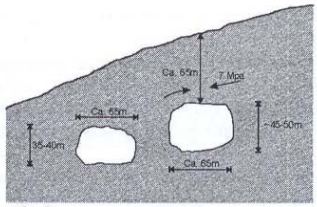




Max. span of cavern?
Empirical: 15-20 m no problem in good rock

EXAMPLES LARGE SPAN





IN BOTH CASES:

FAVOURABLY HIGH σ_h!

MINING:

SKOROVATN, SPAN 65m

CIVIL ENGINEERING:

GJØVIK OLYMPIC MOUNTAIN HALL, SPAN 61m

THE EUROCODES: NEW EUROPEAN BASIS FOR DESIGN
replacing national standards in Norway in 2010

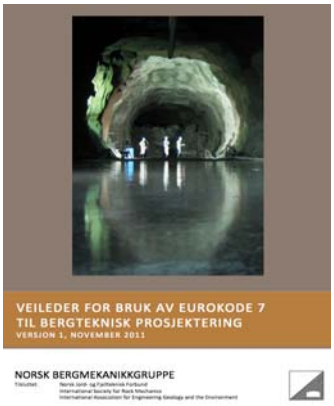
Part 2: Rules for site investigation and laboratory testing

EUROCODE 7

- FOCUSING MAILY ON SOIL, NOT AS MUCH ON ROCK
- TO BE APPLIED ALSO FOR ROCK ENGINEERING DESIGN
- NATIONAL APPENDIX (NA) INCLUDED
- NA CONTAINS NATIONAL DESIGN PARAMETERS (NDP)
- REPRESENTING A NEW CONCEPT FOR ROCK ENGINEERING!

RECOMMENDATIONS DEFINED BY NBG;
NORWEGIAN NATIONAL GROUP OF ISRM

- GUIDELINES FOR APPLICATION
- ADVISE FOR INTERPRETATION



EUROCODE 7

RELIABILITY CLASS (R1-R4):

Classification based on - risk for personell/users
- economical and other consequences

DEGREE OF DIFFICULTY (low, medium, high):

Classification based on - ground conditions/ground investigation
- parameter availability
- availability of design methods
- basis of experience

may change underway!

RELIABILITY CLASS + DEGREE OF DIFFICULTY
=> GEOTECHNICAL CATEGORY

GEOTECHNICAL CATEGORY BASED ON EUROCODE 7

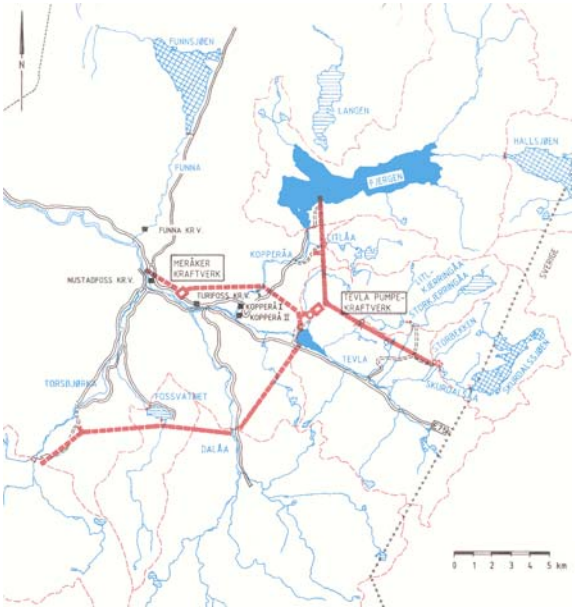
Reliability class	Degree of difficulty		
	Low	Medium	High
CC/RC 1	1	1	2
CC/RC 2	1	2	2/3
CC/RC 3	2	2/3	3
*CC/RC 4**	*	*	*

HIGH GEOTECHNICAL CATEGORY =>

- More investigation
- More thorough planning
- More control

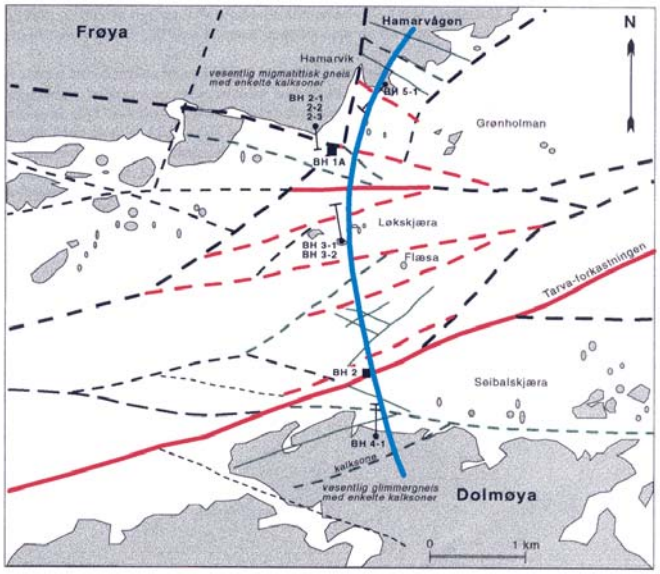
Extent of investigation to be decided by owner!

EXAMPLE: HYDROPOWER PROJECT IN REMOTE AREA



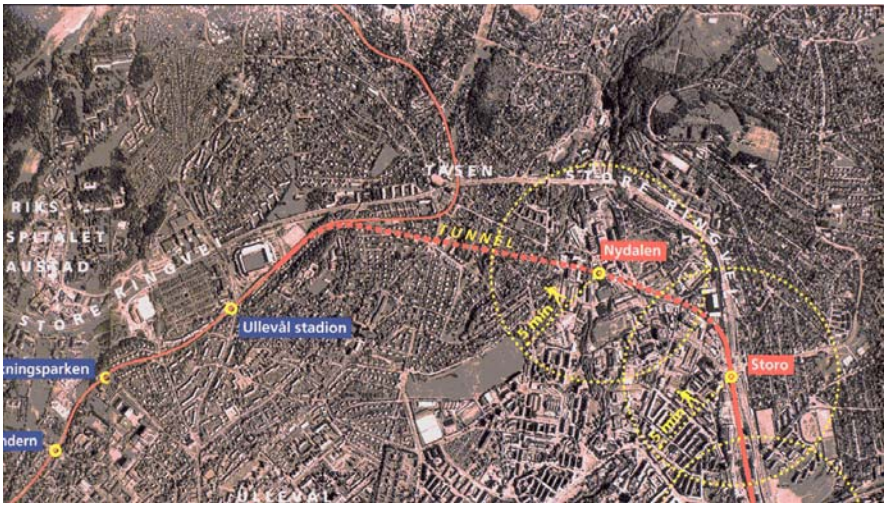
GEOTECHNICAL CATEGORY 1-2

EXAMPLE: SUBSEA TUNNEL IN COMPLEX GEOLOGY



GEOTECHNICAL CATEGORY 3

EXAMPLE: SUBWAY TUNNEL IN URBAN AREA



GEOTECHNICAL CATEGORY 3

EUROCODE 7 – BASIS OF GEOTECHNICAL DESIGN

EC7 ALLOWS 4 ALTERNATIVE DESIGN PRINCIPLES:

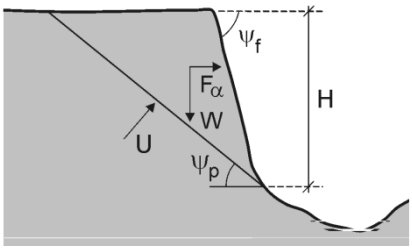
1) DESIGN BASED ON CALCULATION
   - analytical model; based on partial factor method (and not traditional factor of safety!)
   - "half-empirical" model; i.e. Q-method
   - numerical model; i.e. Phase^2, UDEC etc.

2) DESIGN BASED ON PRESCRIPTIVE MEASURES
   - based on experience for "simple conditions"

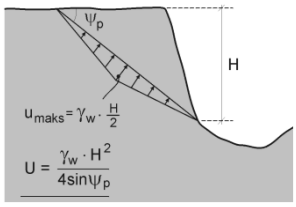
3) LOAD TESTS AND TESTS ON EXPERIMENTAL MODELS
   - not very relevant for rock masses

4) OBSERVATIONAL METHOD
   - assumptions and completed design to be verified by monitoring and observation during construction

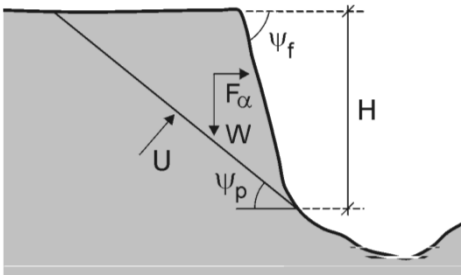
DESIGN BASED ON CALCULATION - EXAMPLE



H = slope height = 35 m
ψ_f = slope angle = 80°
ψ_p = inclination of potential sliding plane = 40°
γ_r = specific gravity of rock mass = 26 kN/m^3
γ_w = specific gravity of water = 10 kN/m^3
$W = (\gamma_r H^2/2)\cdot(1/\tan\psi_p - 1/\tan\psi_f) = 16{,}173$ kN/m
= weight of potential slide material
U = water pressure (kN/m)
α = seismic acceleration as fraction of g (m/s^2)
$F_\alpha = m\alpha$ = seismic force (kN/m)
$\sigma_n = (W\cos\psi_p - U - F_\alpha \sin\psi_p)/(H/\sin\psi_p)$
ϕ_a = arctan $\tau/\sigma_n' = \varphi_r + JRC \log(JCS/\sigma_n')$ [Barton-Bandis]



"OLD PRINCIPLE": FACTOR OF SAFETY, FS (deterministic method)



$FS = (W\cos\psi_p - U - F_\alpha \sin\psi_p) \tan\varphi_a / (W\sin\psi_p + F_\alpha \cos\psi_p)$

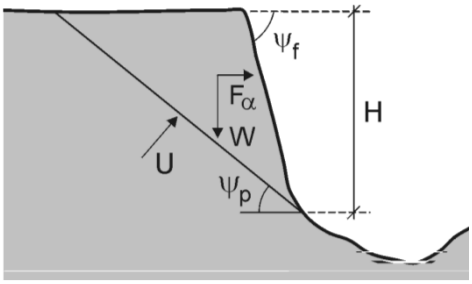
REQUIREMENT FOR SAFETY: FS > 1.0

Situation	Worst case	Best case	Earthquake/ no water	Water/no earthquake
U (kN/m)	4766	0	0	4766
α (in g)	0.25	0	0.25	0
F_α (kN/m)	4043	0	4043	0
σ_n (kN/m²)	92	228	180	140
φ_a (degrees)	71	56	58	64
FS	1.08	1.77	1.16	1.50

"NEW PRINCIPLE": PARTIAL FACTOR METHOD

load factor γ_f

material factor γ_m



$F_d = F_k \cdot \gamma_f$

$M_d = M_k / \gamma_m$

γ_f = 1.0 for W and U, 1.3 for F_α

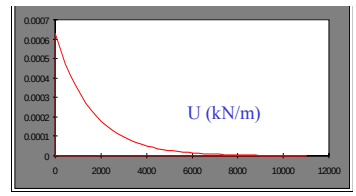
γ_m = 1.2 for $\tan\varphi_a$

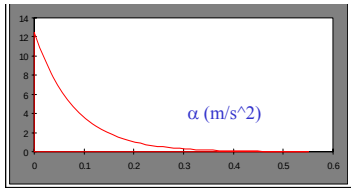
REQUIREMENT: $M_d > F_d$

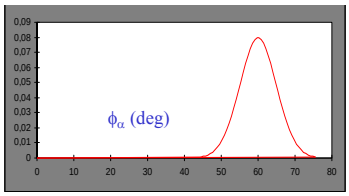
$F_{stab} > F_{driv}$

Situation	Worst case	Best case	Earthquake/ no water	Water/no earthquake
$F_\alpha \cdot \gamma_f$	5256	0	5256	0
σ_n	78	228	166	140
φ_a	74	56	61	64
F_{stab} (kN/m)	12318	15294	13536	13011
F_{driv} (kN/m)	14419	10391	14419	10391
F_{stab}/F_{driv}	0.85	1.47	0.94	1.25

ALTERNATIVE METHOD: PROBABILISTIC ANALYSIS







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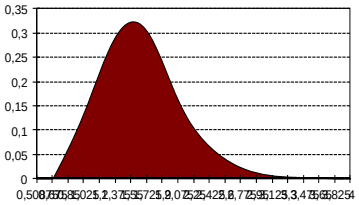
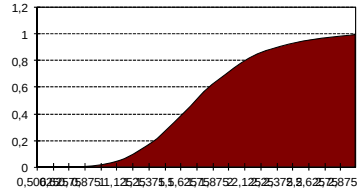


Probability of FS=x



Probability of FS=x

P (sliding) = P (FS<1.0) = 0.046

EUROCODE 7 / GEOTECHNICAL CATEGORY

PROVIDES GUIDELINES FOR METHODOLOGY AND EFFORT ON:

- obtaining background material
- planning and design (including investigation)
- control - at all stages
- analysis and calculation
- report preparation

Does not define the exact extent of investigation

When design is according to EC7, all requirements of the Norwegian Planning and Building Law are considered fulfilled