

Norwegian Tunnelling Technology and Practice Workshop Singapore February '09

"Planning and Pre-investigations"



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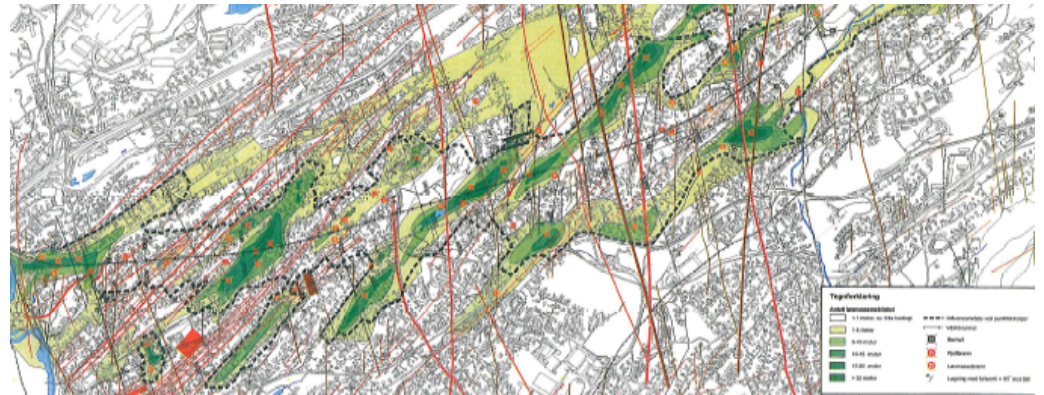
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Planning and Pre-investigations

Some key words

Focusing the back ground
for the investigation
schemes



- What kind of construction material do we deal with?
- Particular aspects related to the unlined tunnelling concept
- Why do pre-investigations?
- Risk sharing in sub surface projects; predictability
- Geological aspects that can influence the underground structures
- Main stages of pre-investigations and distribution of efforts made

But not very much about various methods

Planning and Pre-investigations



- Vulnerability associated with lack of knowledge and means of communication
- V.S. confidence through tested systems
- In information processing



Planning and Pre-investigations

Some special principles that we take into account in the Norwegian tunnelling

- Self supporting capacity of the rock mass
- The thermal capacity of the rock mass
- The impermeable capacity of the rock mass
- The drained concept



These are fundamental principles in Norwegian tunnelling and indeed the pre-investigations are taking these into account

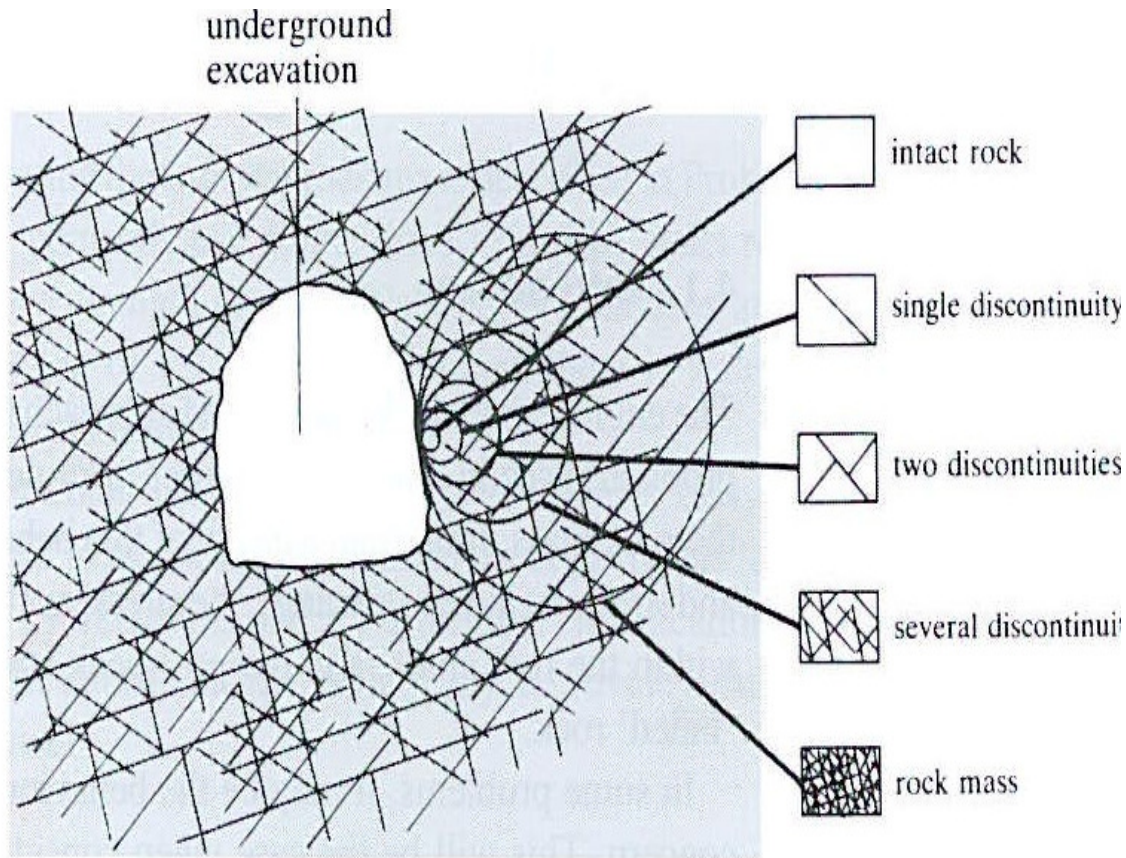
Planning and Pre-investigations

- The rock mass varies along the tunnel alignment
- The rock mass is anisotropic, in-homogenous and suffers from discontinuities
- The construction is a reversed process
- The remaining from the construction process constitute the material that shall take loads, absorb stresses and be tight
- As soon as the project site is decided the material is also given, no possibility of modifying or customizing the material, but can support it
- Consider it still as a construction material



Challenges: How to possibly identify the variation in capabilities, how to obtain sufficient knowledge of the rock mass, how to take these variations into account in design and construction?

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- Keep in mind:
- We do collect samples, specimen being intact rock
- Lab-tests are performed on specimen
- The rock is not an intact material but suffers from discontinuities
- The rock mass as the construction material constitutes it all

Planning and Pre-investigations

- The purposes of pre-investigations:
- "Pre-investigations are to be executed with methods and means to secure that decision makers have **sufficient basis** to **evaluate the consequences** of a sub surface project and establish **realistic cost and time estimates**"
- What is sufficient???
- All parties do have a risk limit (owners, contractors, designers)
- "Sufficient" has to be defined individually for each project!

A national
research effort

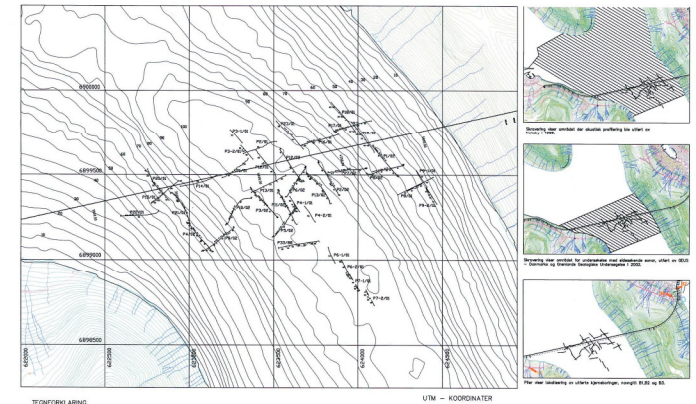


Planning and Pre-investigations

The goals of the pre-investigations are guidance for various parties:

- The client (pays, owns and operates the projects)
- The designer (needs input data and plans the investigations)
- The contractor and financing source (evaluates the risk)
- The bureaucrats and politicians (those who administer the interests of the society)
- Any project could be subject to revision and external control

“...have **sufficient basis to evaluate the consequences** of a sub surface project and establish **realistic cost and time estimates...**”



Planning and Pre-investigations

Various actors – various demands

- **The client;** needs pre-investigations to be able to judge the feasibility of a project and make assessments on time estimates, costs and consequences, prepare documentation for the politicians, the society and granting authorities, evaluate the risk aspects
- **The designer;** needs pre-investigations to decide the location and design of portals, choose geometry horizontally and vertically, evaluate handling of weakness zones and particular geological features, estimate quantities of support- and grouting measures, assess construction time and costs
- **The contractor,** needs pre-investigations to be able to cost estimate the project risk he takes on, to plan the equipment that is needed, establish and plan work progress and production, plan logistics and order materials.

Planning and Pre-investigations

- The project locations in Norway changed
 - Moved closer to urbanized areas
 - Media is active and reviews projects
 - Opinion follows-up
 - Material is fixed when location is set
- These changed conditions imply that robust assessments need to be made
 - Planned construction time
 - Planned project cost
 - Planned efforts to minimize environmental impacts

Requirement to accuracy in cost estimates

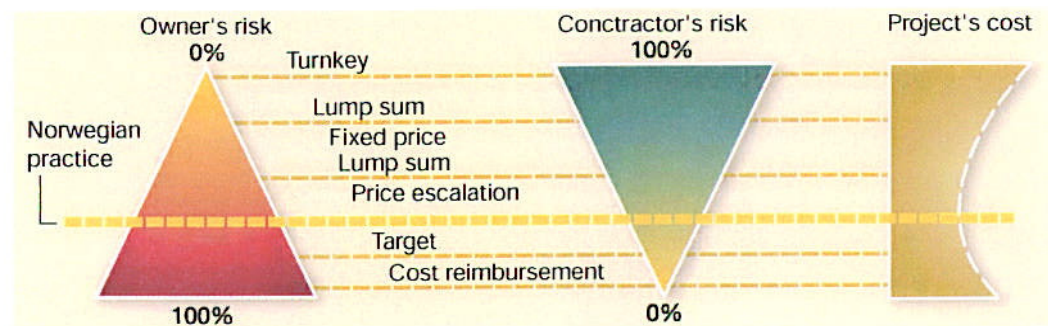
Project stage	Accuracy of cost estimate	Cost distribution investigations
Initial stage	?	1-5%
Feasibility study	+/- 30-40%	7-15%
Detailed feasibility study	+/- 25%	15-35%
Detailed design	+/- 10%	25-60
Construction plan, tender documents	+/- 10%	10-30%

⇒ It is strictly required to obtain a sufficient geotechnical basis to be able to establish such assessments. Then again we have to identify the level of sufficient

Planning and Pre-investigations

Risk aspects to take into account

- Establish contracts that secure proper transferring of information from the pre-investigations to tender and contract documents
- It is practically and economically impossible to reduce the risk to –nil–
- ITA claims; that all geological data, factual and interpretive shall be attached to the contract docs
- Confirm explicitly which information is factual and which is interpretive
- In Norway; "It's the owners ground" What does it mean?
- The contractor's risk and responsibility is related to construct the work acc. to agreed time and cost given the described geological conditions
- Project risks need to be carried by the party best fit
- The geological basis shall be subject to evaluation and comparison to the experienced conditions



Planning and Pre-investigations

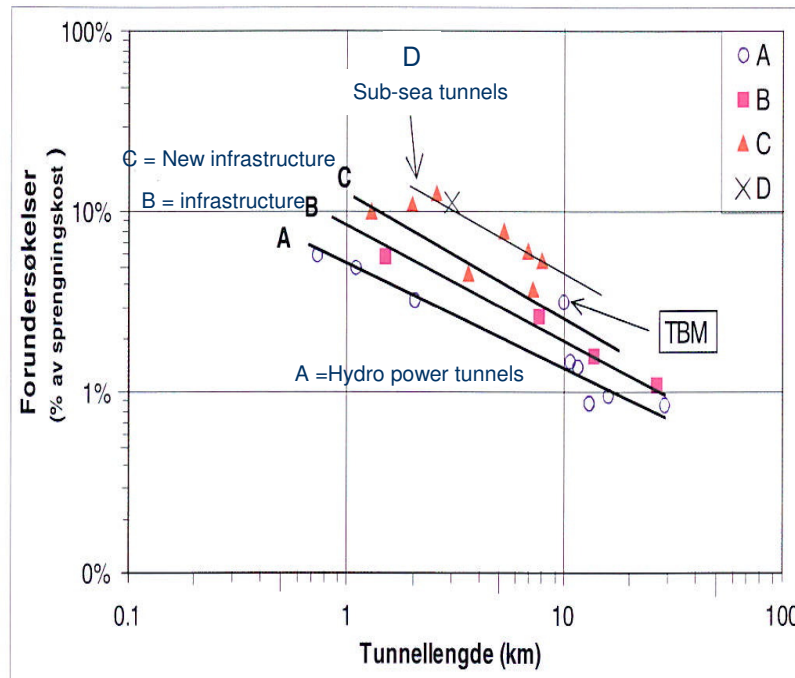
- Cost overrun and disputes have been shadowing the industry
- Changed geological conditions have been claimed
- Insufficient investigations were blamed to be the cause
- How to, if possible improve the predictability??
- Add more focus on pre-investigations
- Not necessarily by increasing the comprehensiveness but by improved understanding and quality

Predictability!



Planning and Pre-investigations

Experienced cost and amount of investigations for various projects as % of cost for blasting and mucking out included rig costs and relative to tunnel length (km)



As can be seen on the figure:

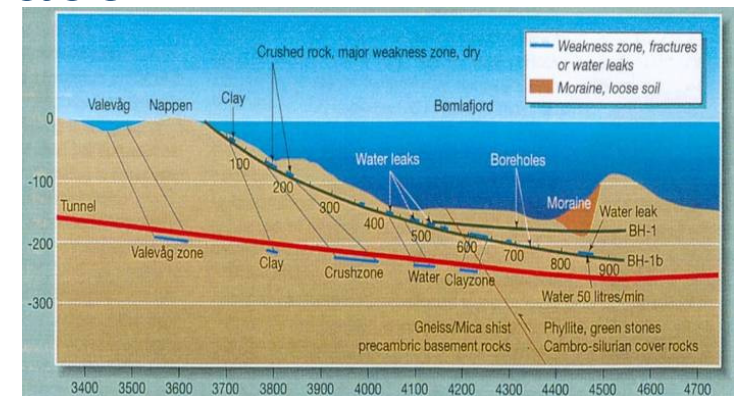
- Projects far away from urban areas have less costs with pre-investigations (A)
- New projects in urbane areas face stricter demands and are more costly with respctc to investigations (C)
- Sub sea tunnels are special (D)
- TBM-projects are often associated with higher cost for investigations

Urban projects are restricted, less rock cover etc. increasing the need of investigations to document feasibility and costs

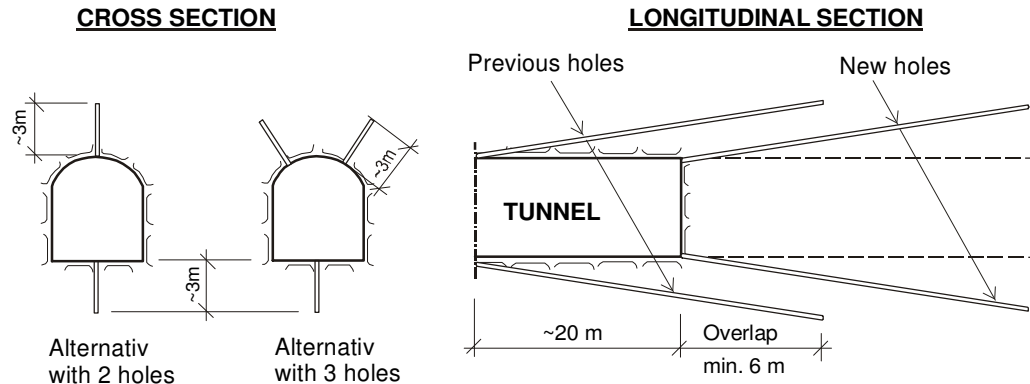
Planning and Pre-investigations

Anything special with Norwegian investigations?

- Cost effective methods are applied to gain information about the variety of the rock mass
- Critical areas will have special attention
- Probe-drilling ahead of tunnel face is an established method for investigations



Planning and Pre-investigations



Probe drilling ahead
of tunnel face

- Pre-defined in tenders, contract documents and included in contractors procedures
- Typically applied intensively in sub sea tunnels
- Extensively applied in areas of expected adverse ground
- In on-shore tunnels typically local application
- Increased use in areas with tight requirements on water inflow criteria
- Content and application to be detail designed for dedicated purposes

Planning and Pre-investigations

- We have a set of normally applied investigation methods
- A project concluded that it might not be necessary to develop more methods but to learn to extract more information from existing methods
- Combination of existing methods need to be project specific
- Every method has a dedicated purpose
- Various professionals involved need to communicate the results: geophysics, geologists, rock mechanics, hydro-geologists, geographers etc
- Pre-investigations need to be gathered, systematized and presented.
- Knowledge and information to be transferred to the next party
- The importance of such transfer of knowledge is a must and should not be compromised!

Planning and Pre-investigations

- A list of the most applied and suitable methods
- Be aware that suitability may vary from one geological province to another
- Various methods give yield different parameters

Application Methods	Depth to rock surface	Rock mass quality	Weakness zones	In-situ stress	Ground water conditions
”Traditional methods”					
Review of base material	-	(x)	(x)	(x)	(x)
Mapping of nearby openings	(x)	x	x	(x)	x
Surface walk over survey	(x)	x	x	-	(x)
Refraction seismic	x	(x)	x	-	(x)
Core drilling	(x)	x	x	-	x
Vertical shallow drilling	x	-	-	-	-
Seismic tomography	(x)	x	x	-	-
Stress measurements	-	-	-	x	-
Laboratory analysis	-	x	(x)	-	-
Investigations during drilling	(x)	x	x	x	x
“New technologies”					
2D-resistivity measurements	x	(x)	x	-	x
Georadar	x	(x)	(x)	-	-
Optical tele-viewer	-	x	x	-	x
Seismic tomo. ahead of face	(x)	(x)	x	-	-
Measurements while drilling	-	x	x	-	-
x = well suited, (x) = can be applied, - = not suitable					

Identify the specific need of the actual project with respect to demands of parameters and choose from the list above

Planning and Pre-investigations

Type of sub surface construction	Part of site/specific conditions	Comments Pre-investigations / during construction
Hydro electric power scheme	Pressurized unlined tunnels and shafts	Increased evaluations / particular in-situ stress measurements
	Air cushion chambers (unlined)	Increased evaluations / particular in-situ stress measurements
	Underwater piercing	Increased per-investigations / increased pre-investigations, probing ahead of face
Shore-approaches	Underwater piercing and as sub sea tunnels	Increased number of evaluations and increased use of probing ahead of tunnel face
All types of sub surface facilities	Difficult portal area	Increased pre-investigations / More evaluations
	Shallow cover, in urban area	Increased pre-investigations / More evaluations
	High rock cover	Increased uncertainty, special methods / special methods
	Particular weakness zones	Increased uncertainty / special methods and increased extent
Large rock caverns	Large span	Increased pre-investigations / close follow-up, stress measurements, particular considerations
Sub sea tunnels	Significant part of tunnel is below water	Increased uncertainty, more pre-investigations, special methods/increased probing ahead of face
	Weakness zones	Increased uncertainty, more pre-investigations, special methods/increased probing ahead of face

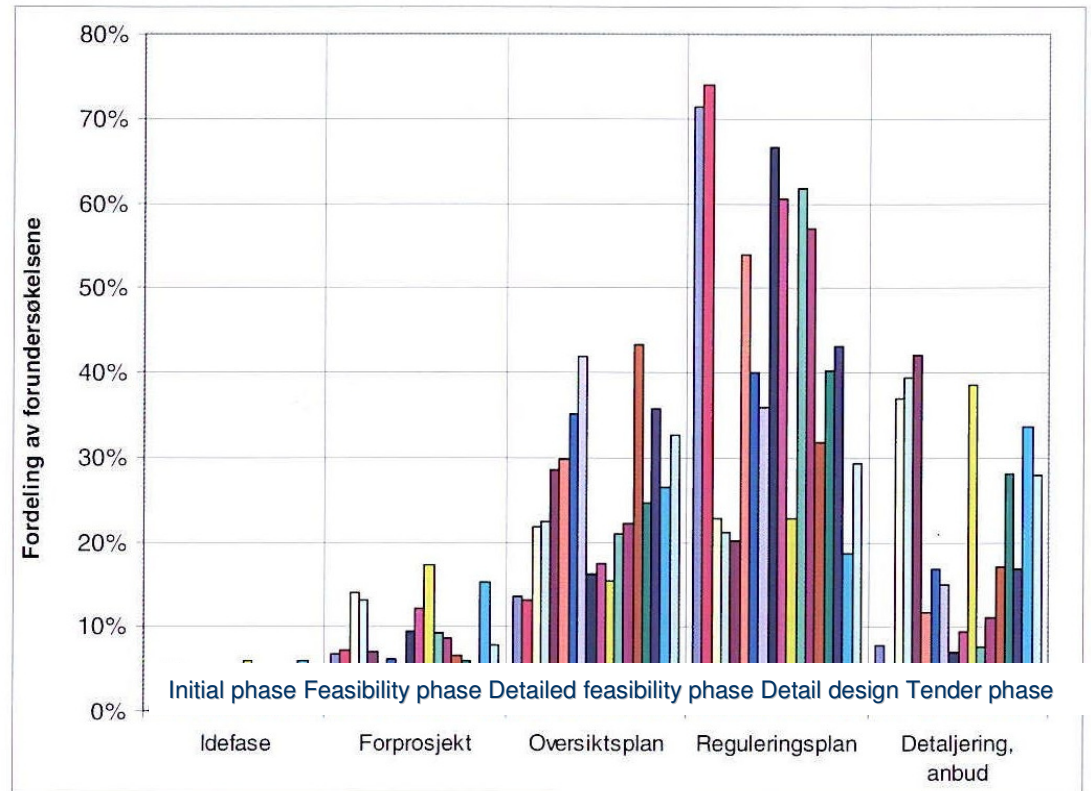
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- Rock mass quality incl. rock types and jointing; strength parameters, abrasiveness, DRI/BWI, from specimen to rock mass, jointing parameters, joint frequency → geometry and stability, choice of equipment, wear of cutters.....
- Weakness zones; major discontinuities, identify location and characteristics (origin like fault) → tunnel alignment, expected support, grouting, mitigative measures and monitoring
- In-situ stress; presence of stresses could be hell or heaven, magnitudes and orientation, anisotropy → geometry, choice of concept, support, mitigation during excavation
- Ground water; permeability, storage capacity, ground water level, influence zones, sensitive surface installation and flora/fauna. The rock mass is a jointed aquifer. → acceptable inflow levels, grouting criteria and design, mitigative measures, monitoring system

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- At various phases the need of accuracy varies with respect to cost, time etc
- Increased extent of pre-investigations as design becomes more detailed
- Experience show wide variety from project to project, major difference but clear trend

Distribution of inv. costs VS planning stage



Conclusion: Hard to say which is right and which is wrong. The truth surfaces when excavation is completed. Hindsight is a concrete science

Planning and Pre-investigations

”Summary Geological report”

- All Norwegian tenders include a Summary Geological Report
- It does not have the same status and content as a Geological Base Line Report
- It's purpose is to gather all available investigation results or make references thereto.
- It discloses all geological/geotechnical data collected by the Owner during the planning and pre-investigations
- ITA recommends full disclosure, separate factual data and interpretive data
- It is a mean to communicate information from the owner to the tenderers and the successful winner of the contract
- Enable the contractors to make up their own understanding of the geological model, and judge the consequences

Planning and Pre-investigations

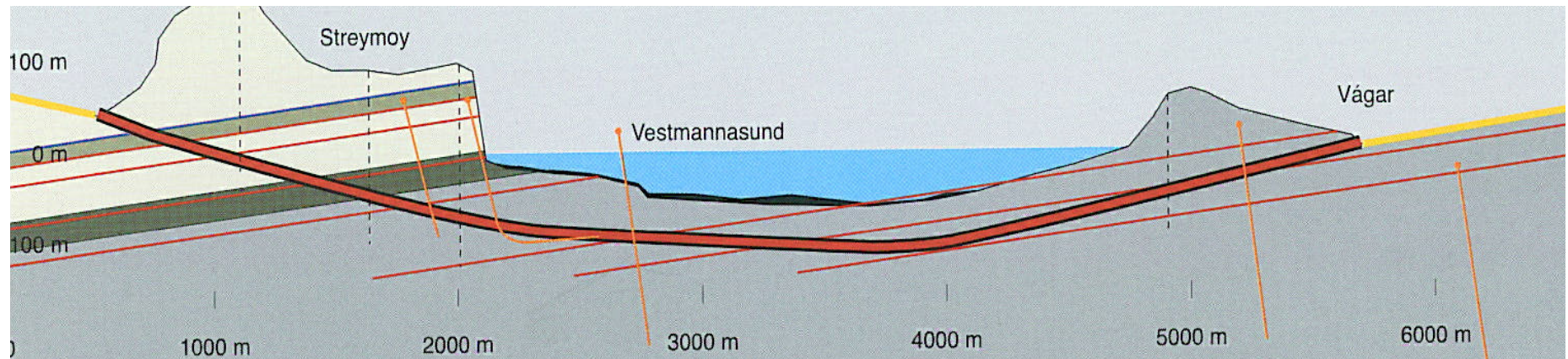
From "Summary Geological report" to instructions to contractor

- Normal contract format is based on Unit rate contracts
- All expected elements to be used for e.g. rock support are listed in the BoQ
- The specified quantities in the BoQ represent the best guess or expected quantities provided by the Owner or his representative, that is the designer
- The basis for the assessment of expected quantities would of course be the
- It is thus important that there is transparency and links between the Summary Geological Report and the quantities and units in the BoQ.

Planning and Pre-investigations

The role of the geological model

- The results from the pre-investigations need to be organized in a model
- The model is not static, but is continuously evaluated and further developed as new information is gained, before and after opening of the
- Geological information and tunnelling knowledge is incorporated into the model
- Visualized through complicated 3D-models or simple longitudinal sections or plan views, whatever fits best to the actual project
- The model communicates knowledge to the implicated parties
- The model constitutes a basis for prognosis for the planning and construction

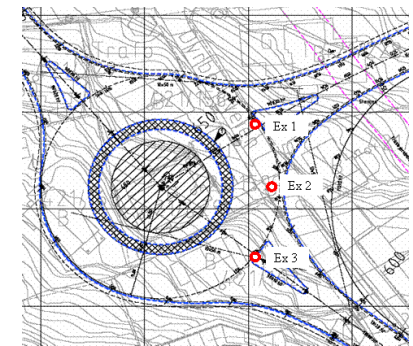
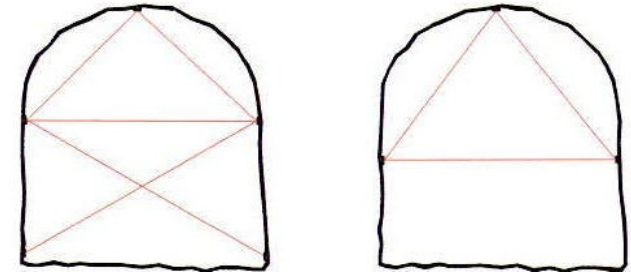


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Investigations during construction

- In-situ stress measurements
- Sampling for laboratory testing
- Deformation monitoring
 - Convergence
 - Ekstensometers
 - Measuring rock bolts
- Probing ahead of face
- Measurement while drilling
- Geological mapping and recording

Purpose: monitor tunnel behavior, confirm design and design assumptions, update geological model, check and update time & cost estimates, check and re-do scheduling and programming, make forecasts



Planning and Pre-investigations

Pre-investigations, extent and methods depend on the following, but not limited to:

- Tunnel concept to be applied
- Risk willingness of involved parties
- Contract format to be applied
- Location, type and complexity of the project
- Geological circumstances
- Excavation method to be employed
- Requirements from government

The right level is indeed project specific!

Planning and Pre-investigations

Tunnel excavation is a peculiar construction method, the material remaining is the constructive element!



Thank you!