Another Engineering Top Ten..
Cost-Effective Development of URL Facilities

Discussion Points for the 4th ISRM Underground Research Laboratory Workshop.

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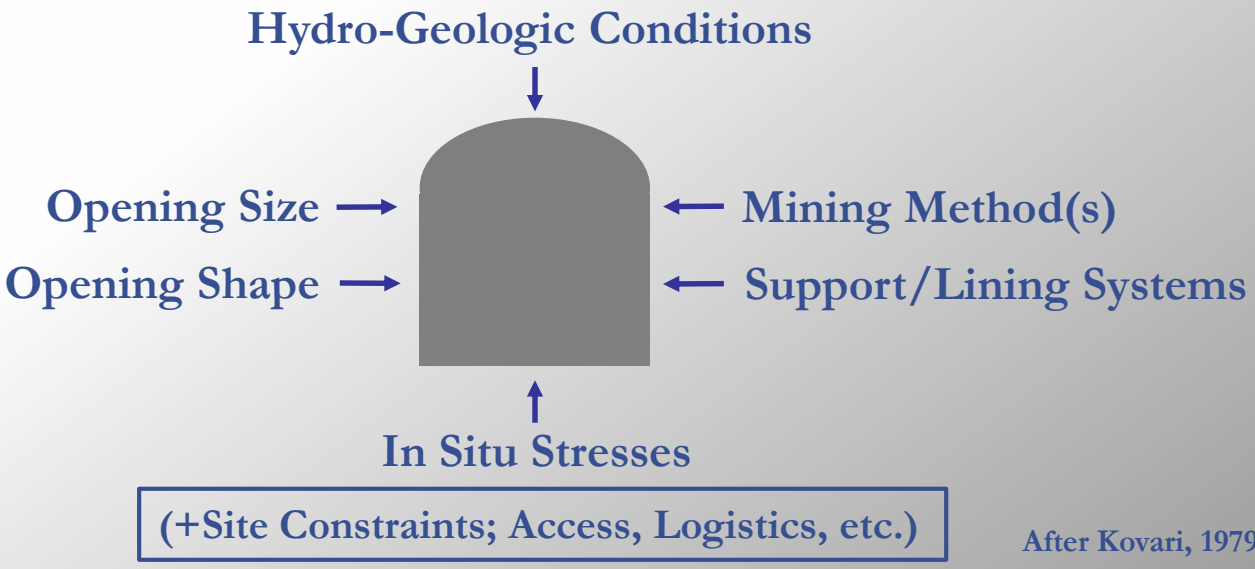
Discussion Points - Top Ten

- 1. Understand the Design Process
- 2. Investigate First
- 3. Actively Seek-Out Contractor Input
- 4. Think Safety
- 5. Mobilize the Rock Mass Strength
- 6. Simplify Construction Work
- 7. Innovate when Appropriate
- 8. Estimate Costs Accurately
- 9. Manage Risk
- 10. Streamline the Design-Build Process

1. Understand the Design Process

Multiple input parameters - variability/geo-risk

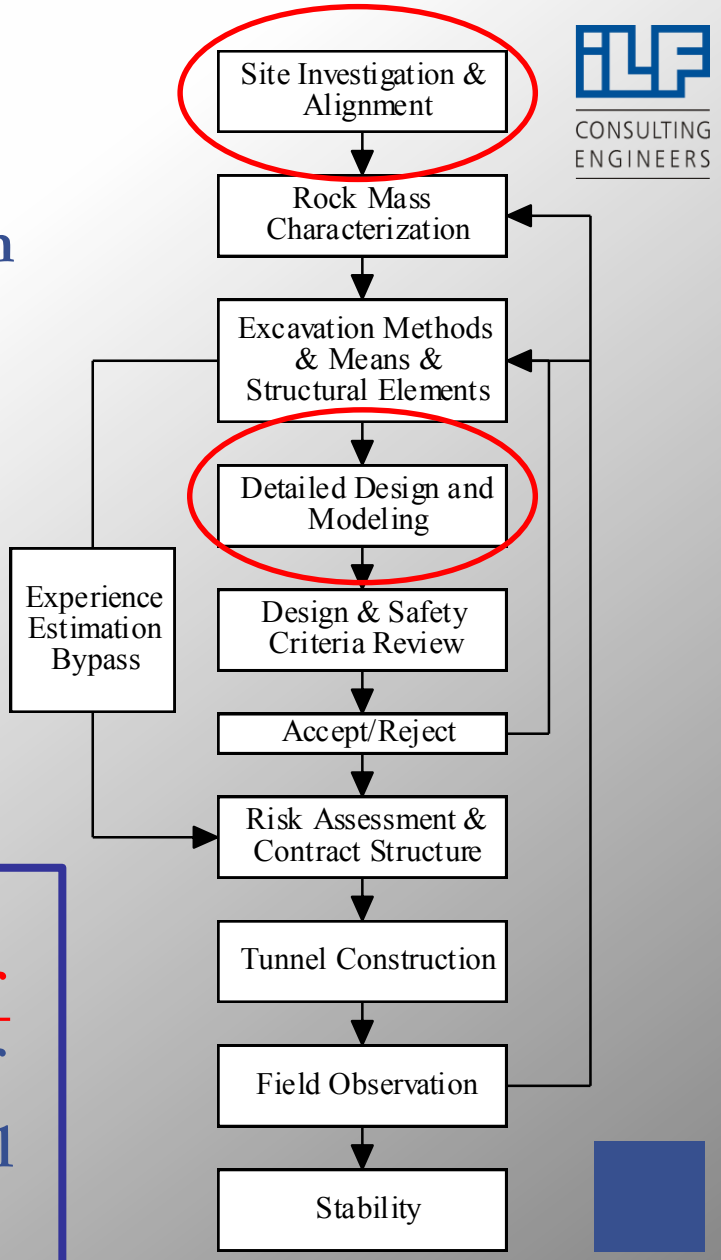
- Relatively hard to change the ground!
- Relatively easy to change mine/line methods
- Identify end-user flexibility early.. consider mine/line options that deliver lower cost/risk
- Expect Different Solutions at Different Sites



After Kovari, 1979

2. Investigate First

- Spend first dollars on site investigation.. avoid designs based on too much "geo-assumption".
- Geo-surprises lead to late changes, increased costs and/or CP delays.
- Start with questions (risks) - collect data - provide answers. Repeat, as needed, until all risks are addressed.



"Too many site investigations for tunnels comprise a regular pattern of boreholes, a conventional package of tests and a sigh of relief when it is all over." Muir Wood (1972).

3. Actively Seek-Out Contractor Input

Early Contractor Involvement - ask contractors how they would build it!

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Why are builders so often completely excluded from the design? They can often provide practical guidance on key($) design aspects.

- Requirements drive costs. stability demands (absolute - differential), water tightness, low dust/humidity
- Minimize surface/volume needs for clean, stable, dry
- Early constructability input on how to minimize cost/risk..

4. Think Safety

Working with large equipment in a dark, noisy environment is not intrinsically dangerous, but merits attention to detail

- Not only a question of the final structures being safe to occupy
- But also a question of ensuring that the facilities can be built, operated, maintained and decommissioned safely too..
- Proactive safety culture - don't wait for accidents to happen
- Job Hazard Analyses
- Daily Tool Boxes
- Near Miss Reports
- Safety Stand-downs
- Inspection Presence
- Management Buy-In
- No excuse for workers, managers, owners, sponsors..

5. Mobilize the Rock Mass Strength

If the rock mass is strong.. use the rock mass strength

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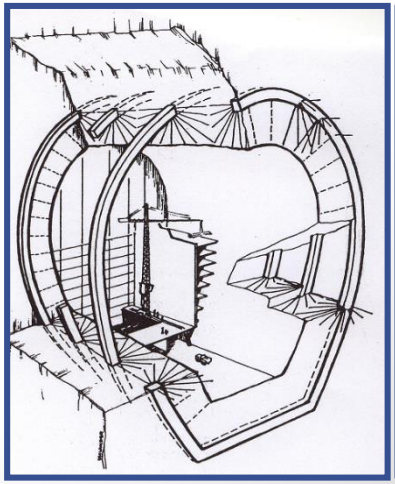
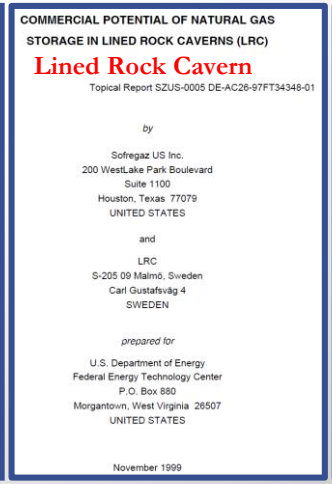
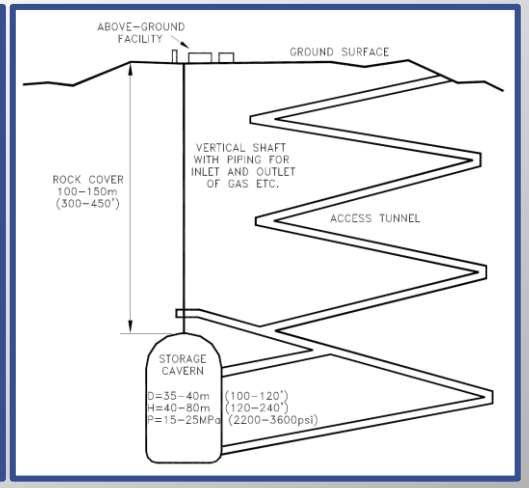
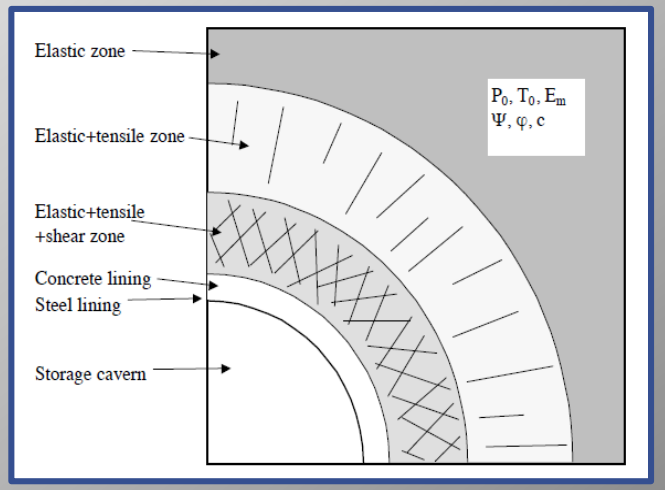
- Stable excavations can be created to meet challenging design requirements in many rock types. However, for URL's question is often cost, NOT feasibility.
- For URL's sited in hard rock, costs can be reduced by reducing the cost of reinforcement and liner work by mobilizing the strength of the rock mass that surrounds the opening.. e.g. "Sandwich Liner" for Lined Rock Cavern (LRC)..







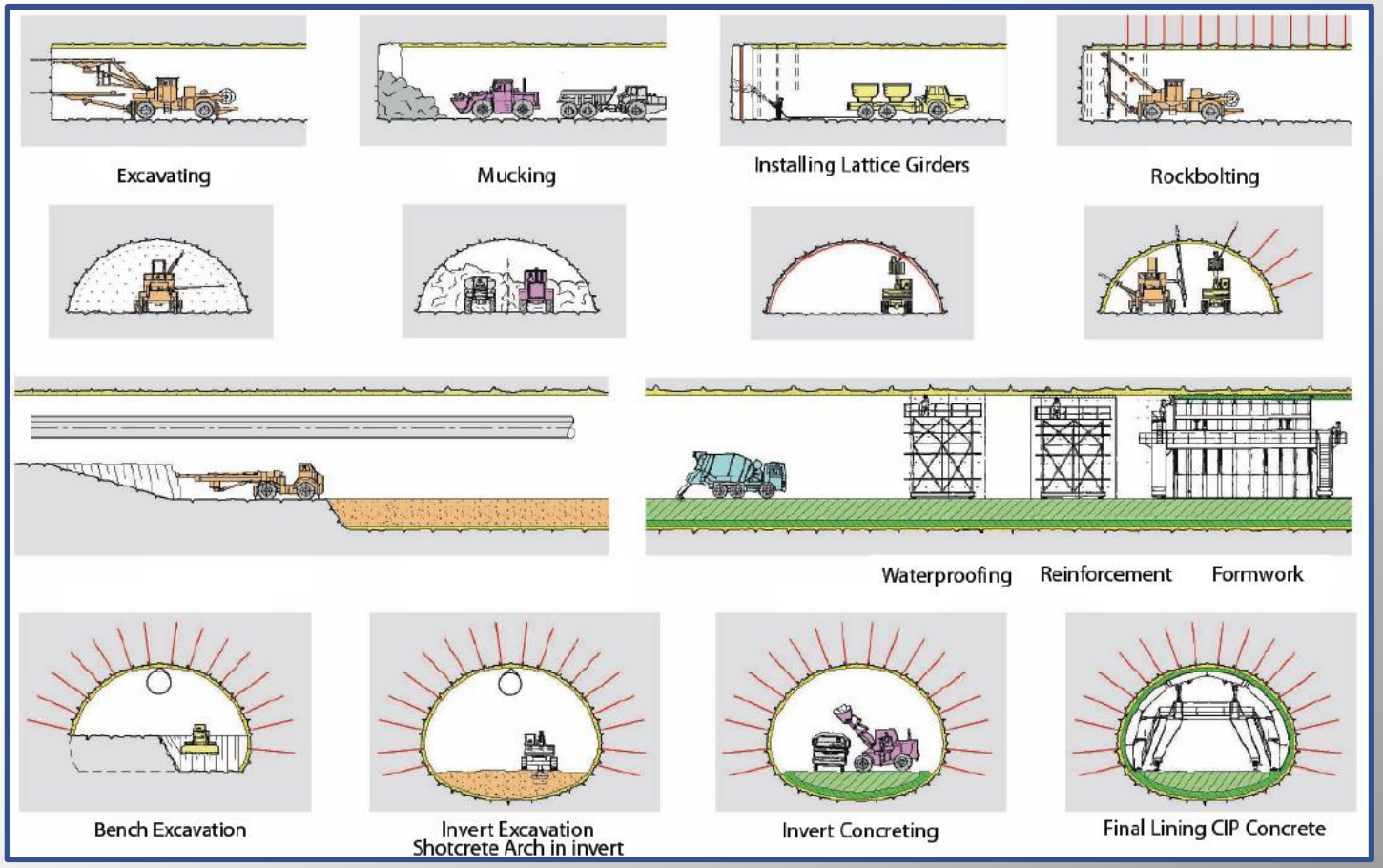


"Rib-in-Rock Reinforcement

Source: http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/Natural%20Gas/other/34348_final.pdf

6. Simplify Construction Work

- Don't make the construction cycle more complicated than it has to be.



- Simpler cycles are generally safer, faster, cheaper, less risky.

Source: Tunnel Operations, Maintenance, Inspection & Evaluation Manual

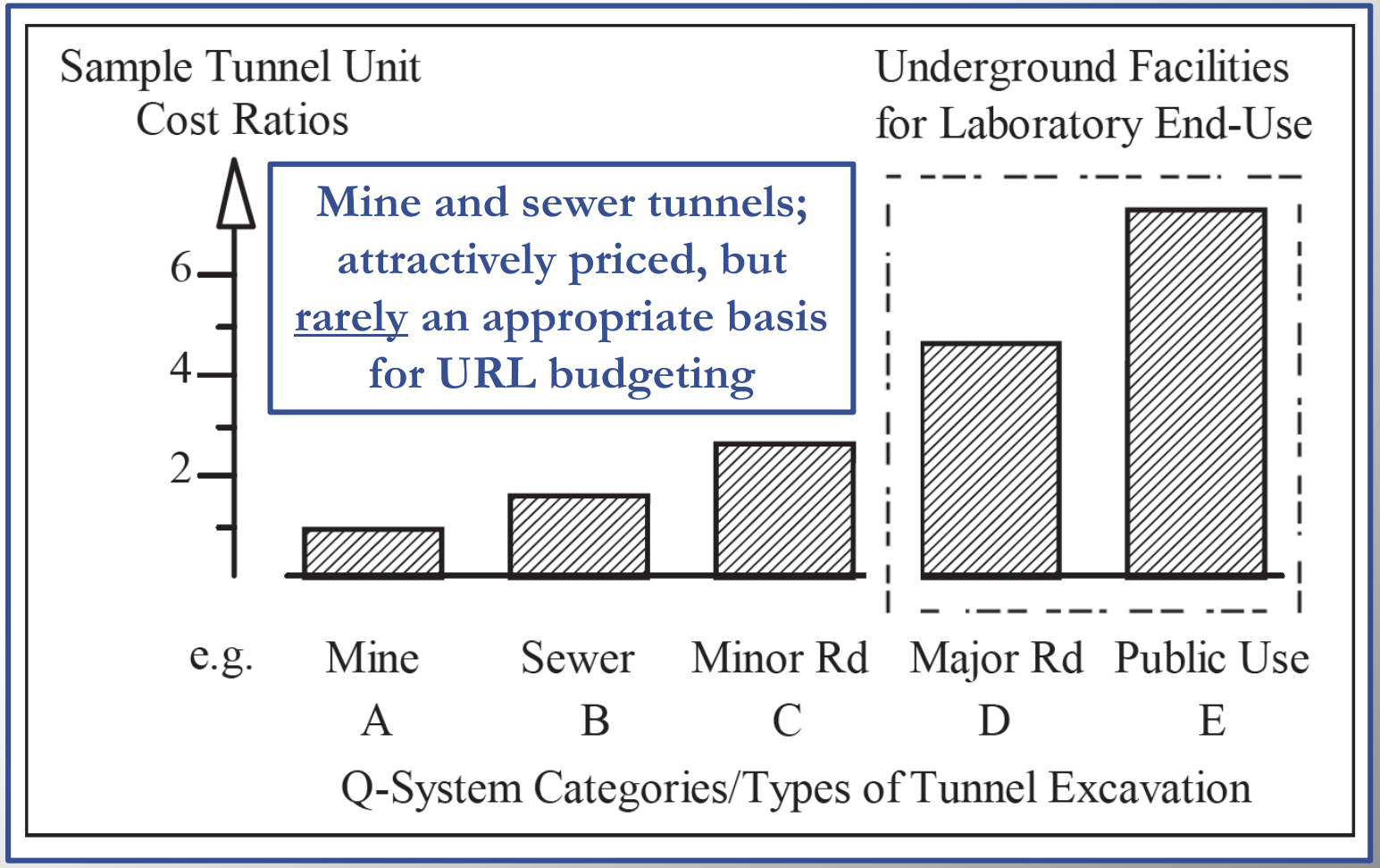
7. Innovate when Appropriate

Mining Companies are Investing in New Technologies

- Track new advances in methods, equipment, materials (TSL's)..
  - "Future Smart" - Anglo American
  - Mine of the Future" - RioTinto Aker Wirth and Atlas Copco will individually work with Rio Tinto to develop two new tunnelling concepts and Herrenknecht will work with the Group on the development of a new shaft boring machine.

8. Estimate Costs Accurately

Needs for human occupancy (and emergency egress), stability, dryness have a very strong influence on cost



8. Estimate Costs Accurately

Geology, construction method(s), site constraints, and location strongly influence cost..

Investment Cost Comparison Lined Rock Cavern - U.S. vs. Scandinavia

Item	US Cost	Scandinavia Cost	Ratio US to Scandinavia
Preconstruction	5,800	5,800	1.0
Below Ground	125,550	54,600	2.3
Above Ground	31,000	34,000	0.9
Total	162,350	94,400	1.7

Investment Cost Comparison Lined Rock Cavern - Underground Works

Underground Excavation Type	Cost Ratio US:Scandinavia
Tunnels	3.2
Caverns	3.4
Shafts	1.7

..also reference G. Nuijten talk NNN14. Paris, Dec. 2014.

"The cost differences are caused mainly by different union rules in the United States compared to Scandinavia." LRC Study

Source: http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/Natural%20Gas/other/34348_final.pdf

9. Manage Risk Early

Define Risks while there are more Mitigation Options

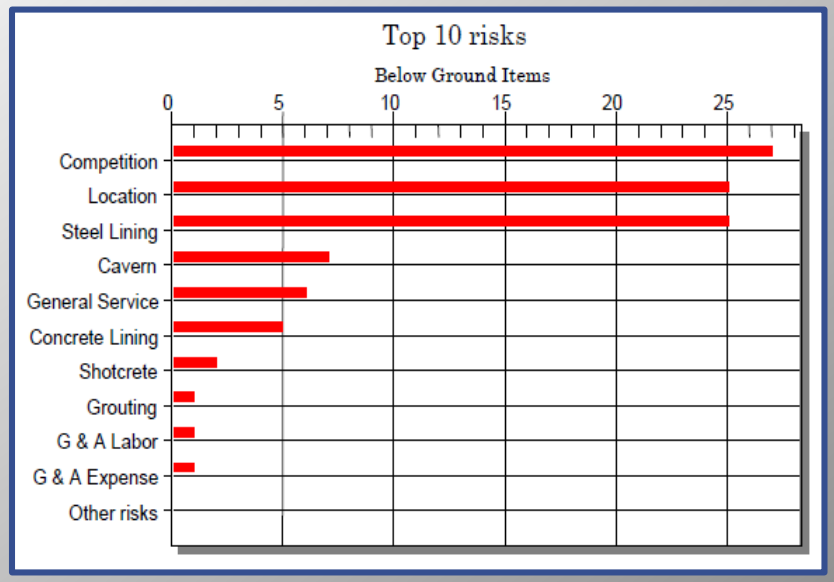
- It is critical that proactive steps are taken in a timely manner to predict and mitigate adverse conditions BEFORE design is detailed/contract is signed.
- Site conditions that differ from those described in the contract cause major construction problems, delays, cost overruns and legal fees..
- Define site-specific risks while more mitigation options are possible, see 1.

TABLE 7.3 Problems and Claims* Reported for Mined Tunnels

	Problems (% of tunnels)	Claims (% of tunnels)
Blocky/slabby rock, overbreak, cave-ins	38	16
Running ground	27	9
Flowing ground	5	4
Squeezing ground	19	8
Spalling, rock bursts	6	4
Groundwater inflow	33	6
Noxious fluids	6	4
Methane gas	7	2
Existing utilities	1	0
Soft bottom in rock	2	2
Soft zones in rock	4	2
Hard, abrasive rock (TBMs)	5	2
Face instability, rock	5	1
Roof slabbing	4	1
Pressure binding (equipment)	4	4
Mucking	5	2
Surface subsidence	9	2
Face instability, soil	11	5
Obstructions (boulders, piles, high rock in invert, cemented sand)	12	11
Steering problems	4	0
Air slaking	1	0

*As noted earlier, in this report the word "claim" is a shorthand expression that encompasses all requests for extras as a result of an unexpected subsurface situation.

Common Tunnel Problems & Claims



Lined Rock Cavern Risks

9. Manage Risk Systematically

Use a Disciplined, Industry-Specific Approach

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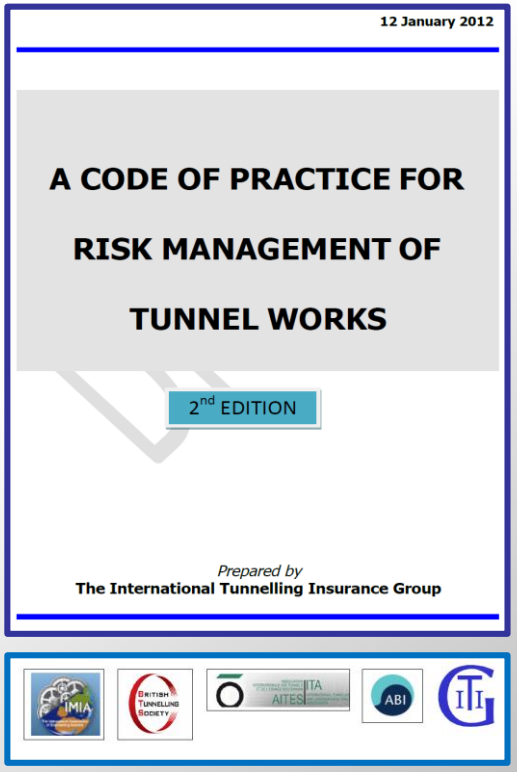
Where this Code of Practice uses the words 'shall' and 'must', the procedure to which it applies is compulsory. Where the word 'should' is used then the procedure is recommended best practice.

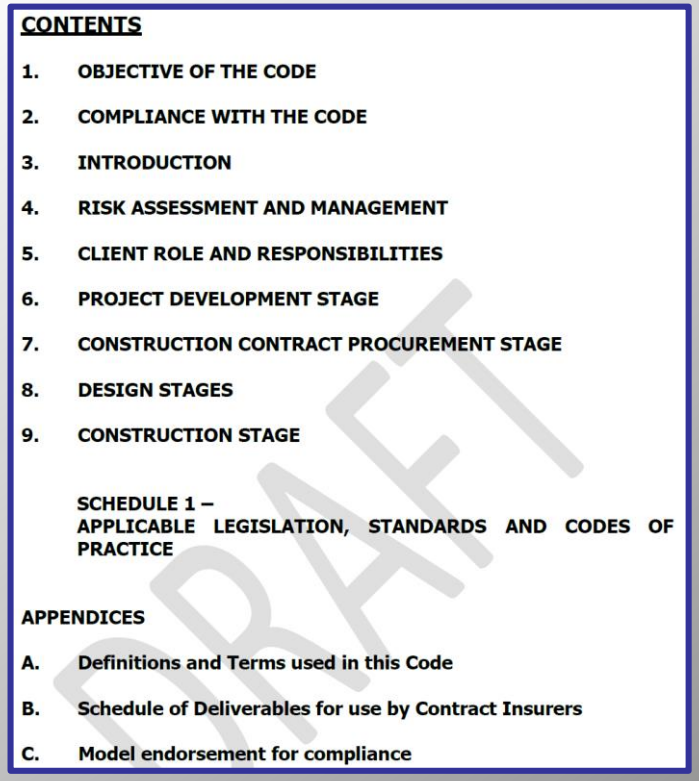
Benefit from the collective experience of others


12 January 2012

A CODE OF PRACTICE FOR RISK MANAGEMENT OF TUNNEL WORKS

2nd EDITION

Prepared by
The International Tunnelling Insurance Group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5. CLIENT ROLE AND RESPONSIBILITIES
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7. CONSTRUCTION CONTRACT PROCUREMENT STAGE
8. DESIGN STAGES
9. CONSTRUCTION STAGE

SCHEDULE 1 – APPLICABLE LEGISLATION, STANDARDS AND CODES OF PRACTICE

APPENDICES

A. Definitions and Terms used in this Code
B. Schedule of Deliverables for use by Contract Insurers
C. Model endorsement for compliance

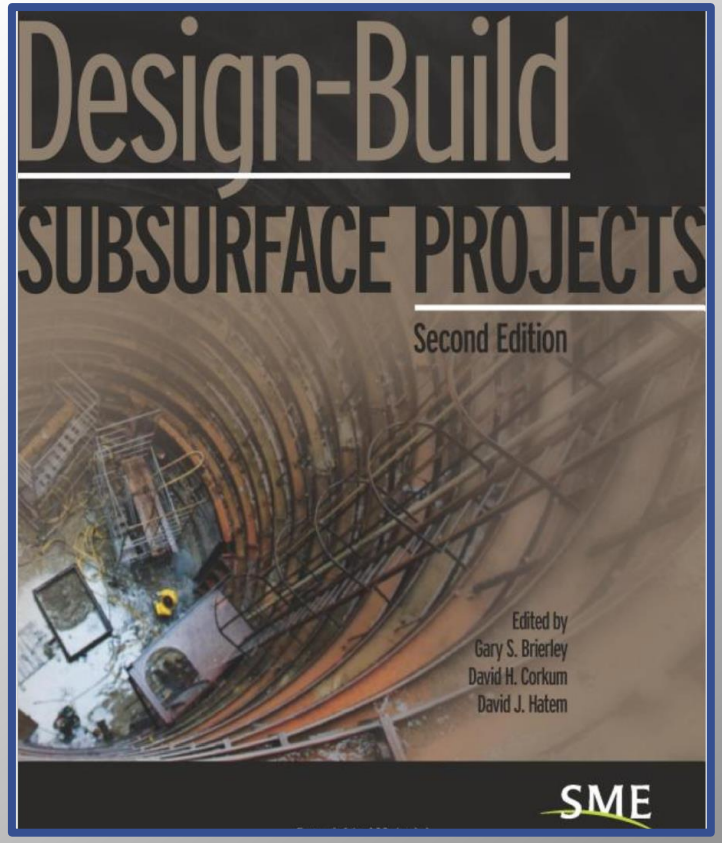
DRAFT

Insurers expect the insured to follow Best Practice

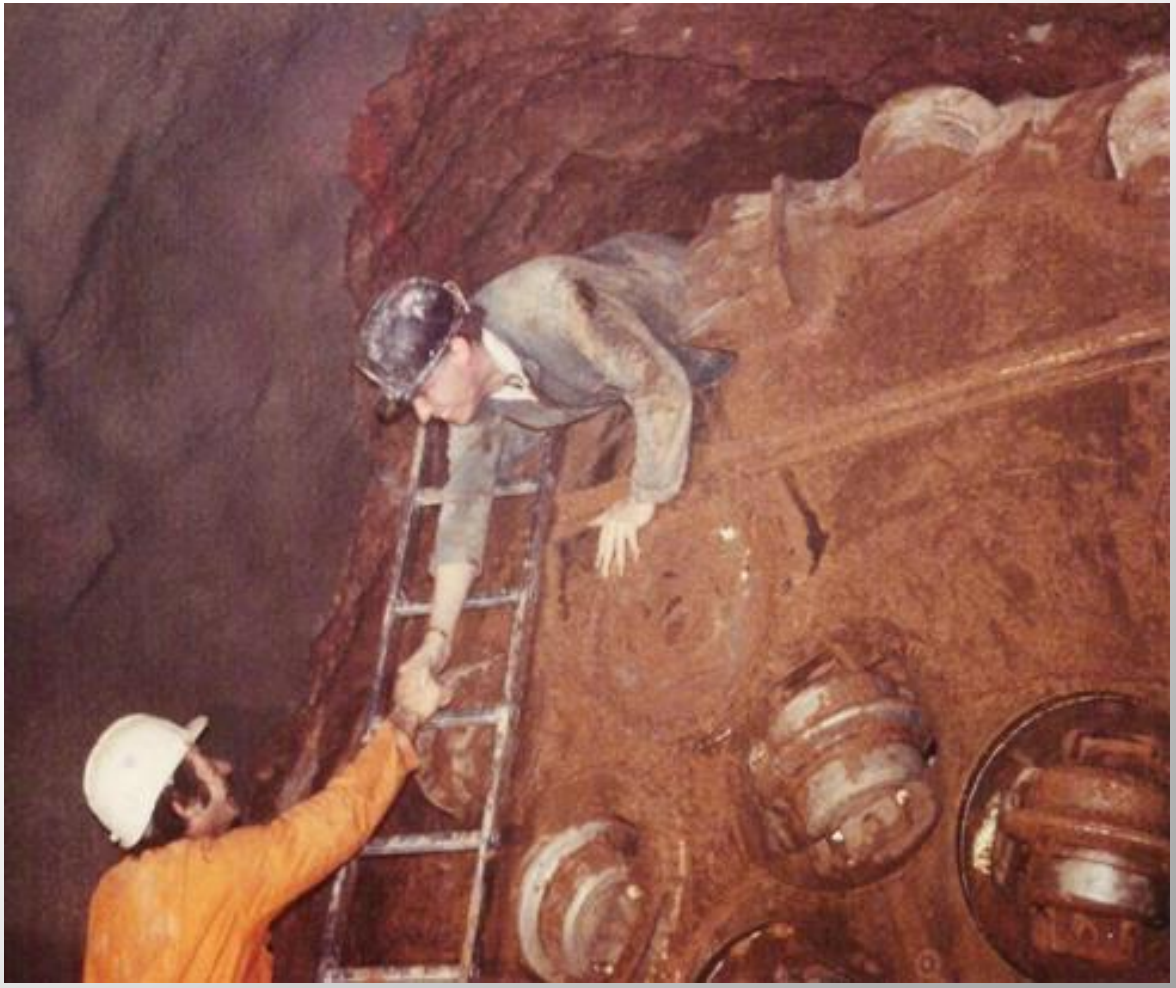
Tunneling has repeatedly proven to be a "Risky Business"

10. Streamline the Design-Build Process

- Design input window closes earlier - need to fix key dimensions, spatial functions, and performance, and limit prescriptive detail!
- Leave opportunities for Design/Builder to innovate and deliver an optimized product.
- Each Contractor can develop a solution to match their preferences;
  - Methods and means
  - Materials (temporary/permanent)
  - Sequencing of work activities
- Can reduce cost/time/risk, but needs owner to focus on performance and freeze requirements early in design cycle.



Thanks for your attention..



Questions?

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- US web-link: www.ilf-usa.com