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Underground storage experts

Normes et méthodologies de conception des ouvrages au rocher

ISRM WG Design Methodology

- Rock Engineering Design Methodology Book Structure *Introductory book material*
- C1: Describes the background to the subject
- C2:Explains the need for a modern methodology
- C3: Presents updated design guidance flowcharts
- C4: Describes the information required for design
- C5: Explains the procedure for technical auditing of the design
- C6:Application of the methodology to the design of a large rock slope
- C7;Application of the methodology to an underground cavern complex
- C8: Explanation of Protocol Sheets for using the new methodology
- C9: Application of the Protocol Sheets to the cavern complex design
- Color photographs of rock engineering projects Appendices on ISRM SMs and the BQ system References Index

SIMPLIFIED DESIGN CHART FOR ROCK ENGINEERING (BIENIAWSKY - 1987)

ENGINEERING CONSTRAINTS

Function , Size, Shape, Layout,
Method of Excavation

OBJECTIVES

Safety, Stability, Economy

DETERMINATION OF INPUT DATA

Geologic Structure
(engineering geological mapping and geotechnical core logging)
Rock and Rock Strata Properties
(strength, deformability and factors of influence)
Groundwater In situ Stress Field)
Applied Loads

DESIGN METHODS

Analytical
(numerical and
physical modeling,
failure criteria)

Empirical
(rock mass
classifications
and experience)

Observational
(field measurements)

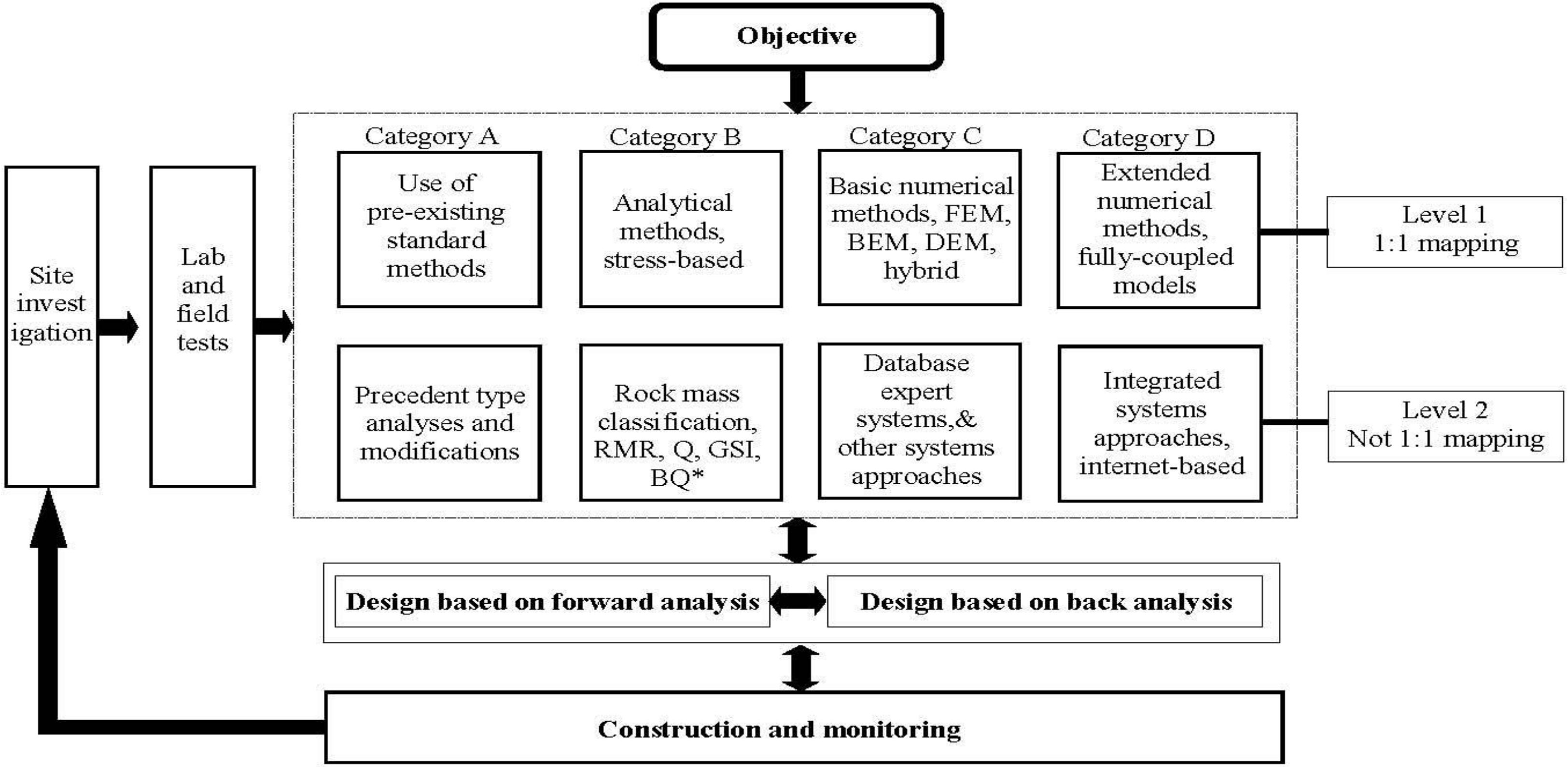
OUTPUT SPECIFICATIONS

For mines and tunnels :
Roof spans; stand-up time; support guidelines
For slopes and foundations :
Rock mass cohesion and friction; deformation modulus

FEEDBACK

Selection of Instrumentation for Performance Monitoring
Remedial Measures in Case of Instability

Fig. 2.1. Flowchart of rock mechanics modelling and rock engineering design approaches (Feng and Hudson, 2004).



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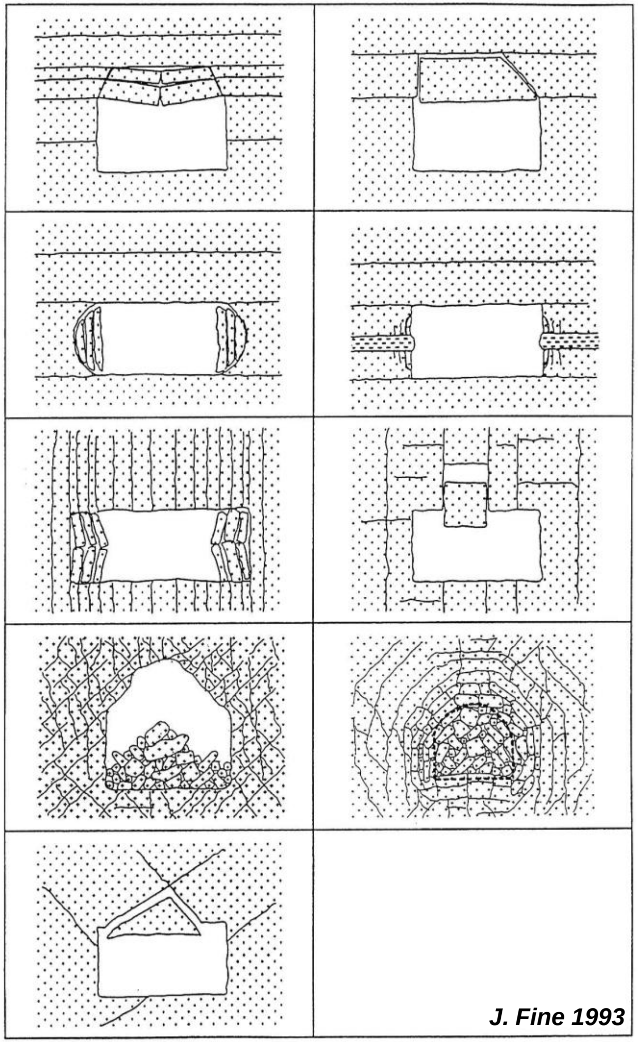
Typical mode of failure, rock falls



J. Fine 1993

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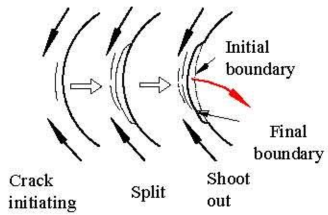
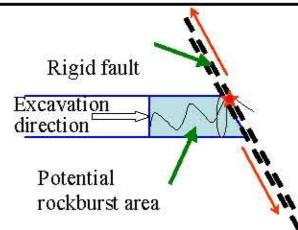
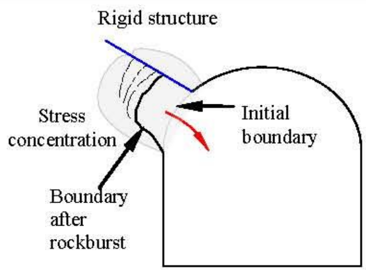
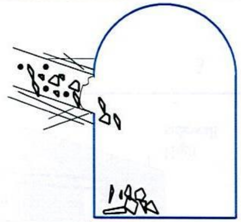
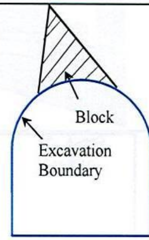
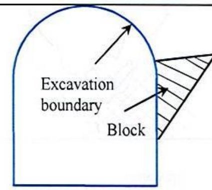
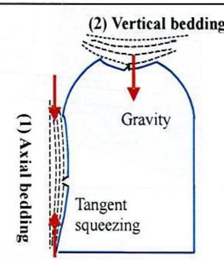
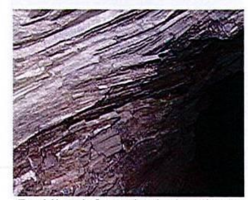
Table 7 Typical failure modes of large underground cavern group and its related tunnels

Failure modes			conditions	Sketches	Picture	Engineering analysis methods	Excavation and support strategies
Main type	Secondly type	types					
Stress control-failure	Rockburst	Strain-rockburst	High stress, hard/brittle rock		 Moderate rockburst at water drainage tunnel of a underground powerhouse	Energy release rate analysis, local energy release rate analysis, rockburst tendency index, expert system, neural networks	Optimal excavation scheme such as short advance rate, weak blasting, small section to reduce high stress concentration, stress release before main excavation, Support: high energy absorbing rock bolt, support in advance, shot concrete and meshing immediately
		Fault-rockburst	High stress and hard rock with a rigid fault at the place ahead of working face		 Severe rockburst at busdar tunnel of a underground powerhouse	Excess shear stress analysis, expert system, neural networks	Excavation: voiding large fault during cavern excavation, recognizing location of fault or geological structure adequately, stress release at the high stress concentration, etc. Support: high energy absorbing rockbolt
		Structure-rockburst	High stress concentration at the place with a geological structure		 Severe structure plane- rockburst occurred after several strain rockbursts at a deep tunnel	Energy release rate analysis, local energy release rate analysis, rockburst tendency index, expert system, neural networks	Optimal excavation scheme such as short advance rate, weak blasting, small section to reduce high stress concentration, stress release before main excavation, Support: high energy absorbing rock bolt, support in advance, shot concrete and meshing immediately

		Collapse at fault and fractured zone	Developed fault of joints with weak properties		 Collapse at a underground powerhouse	Discontinuous deformation analysis method such as discrete element method, DDA, continuous media analysis with reduction of mechanics parameters for the weak strata	Excavation: reasonable axis location and excavation direction to have a large angle with fault, fractured zone, weak blasting to reduce disturbance Support: shot concrete and mesh immediately, grouting or rock bolt in advance, or pre-stressed rock bolt
	Instability of rock block	Rock fall	Probable rock block at roof of arch formed by two or more structures with a excavation face	 	 Rock fall at roof of arch of a underground powerhouse	Key Block theory, rigid limit equilibrium, Hemispherical projection to recognize probable rock block	Excavation: weak blasting to reduce disturbance to structures Support: shot concrete and mesh immediately, pre-stressed rock bolt or reinforcement in advance
		Rock sliding	Probable rock block at sidewall formed by two or more structures with a excavation face	 	 Wedge sliding at a underground powerhouse		Excavation: weak blasting to reduce disturbance to structures. Support: shot concrete and mesh immediately, pre-stressed rock bolt or cable anchor reinforcement in advance, anchor pile to resistant sliding of large rock block.
Stress-rock structural control-failure	Buckling	Buckling deformation by bending	High tangential stress concentration and severe unloading at radial direction, thin strata	 	 Buckling deformation by bending at exploration tunnel of a underground powerhouse	Bending analysis based on beam or thin plate theory, discontinuous deformation (e.g. discrete element) analysis or continuous method considering anisortropy for complicated cases	Excavation: reasonable axis location of cavern to avoid it has large angle with preponderantly steep structures, weak blasting. Support: reinforcement immediately after excavation to enhance rigidity of strata against buckling, e.g., rockbolt at small spacing, rock bolt and steel bar pile, steel frame, or grouting

PROTOCOL SHEET 2.2 *In Situ* Stress	
Have the regional stress circumstances at the site been established from stress maps or other sources?	Yes.
Has the rock stress been measured at the site?	Yes.
What type of method has been used for in-situ measurement?	"Overcoring" and "hydraulic fracturing" methods
How many locations are measured for in-situ stress?	14 locations at depth of 163m to 463m respectively, see Table 7.2.
Is the major principal stress orientated vertically or horizontally?	The major principal stress orientated horizontally due to tectonics
In what azimuth direction is the major horizontal stress?	Dip angle about 30 - 55° with S50 -75°E
What are the magnitudes and orientations of the three principal stresses? – show stereogram	Fig.7.8
What are the principal stress ratios: σ_1/σ_2 , σ_1/σ_3 , σ_2/σ_3 ?	The measured principal stress ratios: σ_1/σ_2 , σ_1/σ_3 , σ_2/σ_3 are 1.2-1.8, 1.5-2.5, and 1.1-1.7 respectively
Does the rock overburden vary above the anticipated project location?	Yes
Is there any reason to expect that the stress values may vary across the site because of, e.g. varying surface topography, effect of major faults, etc.?	High tectonics area
Have the four ISRM Suggested Methods on rock stress estimation been studied?	Yes.
Give the location of the complete rock stress estimation for the project site	Table 7.2
Have any difficulties been encountered in estimating the *in situ* stress?	Due to high tectonics action at different direction and deeply valley terrain
Give the name of the person completing this sheet	Dr. Jiang Quan and Mr. Xiang Tianbing
Give the name of the person checking the contents of the completed sheet	Prof. Feng Xia-Ting
Date of completing this form	30 May 2010
Location of electronic storage of this Protocol Sheet	Personnel computer and USB at Institute of Rock and Soil Mechanics, Chinese Academy of Sciences
Location of back-up electronic storage of this Protocol Sheet	scientific archives at Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

PROTOCOL SHEET 2.6 Hydrogeological Properties	
What information can the knowledge of the geological setting provide about the rock mass hydrogeological properties?	Permeability, and water flow on the surface of rocks.
Is water flow through the rock mass occurring main through the intact rock or through the rock fractures?	Water flows through the rock fractures
Have the rock mass hydraulic conductivity and/or rock fracture transmissivities been estimated by any means?	(1) There was large water flow at the fractured zone of the exploration tunnels, e.g.,water flow of 20l/s at working face at 136.5m from the exploration tunnel no.1 (2) In situ borehole water pressure tests.
Have the rock mass hydraulic conductivity and/or rock fracture transmissivities been measured directly?	The results of in situ water pressure indicate that the permeability at 6MPa pressure was about lest than 1Lu.
What are the likely water head pressures to be encountered in the project?	200～300m.
What are the likely fracture transmissivity values?	
Are high water pressures likely to be present when faults are intersected by the rock excavation?	Yes. For example, during the excavation of f_{30} at the exploration tunnels no.1-2, the fault at left side was closed and the fault at right side was open about 10 -20cm, with initial water flow of 80l/s.
Have any difficulties been encountered in specifying the rock mass hydrogeological characteristics?	The large difference at development of fractures resulted in difference of permeability.
Where is the hydrogeological information?	East China Investigation and Design Institute under CHECC
Give the name of the person completing this sheet	Dr. Jiang Quan and Mr. Xiang Tianbing
Give the name of the person checking the contents of the completed sheet	Prof. Feng Xia-Ting
Date of completion of this sheet	30 May 2010
Location of electronic storage of this Protocol Sheet	Personnel computer and USB at Institute of Rock and Soil Mechanics, Chinese Academy of Sciences
Location of back-up electronic storage of this Protocol Sheet	scientific archives at Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

Conclusions

- Les avancées méthodologiques peuvent nous protéger et nous feront progresser.
- Nous avons encore beaucoup à apprendre!
- Les retours d'expériences et les validations in-situ demeurent essentielles.
- "No theory can be considered satisfactory until it has been adequately checked by actual observations". "If something is discovered that does not agree with the hypothesis, rejoice! You can then really learn something new. You are on your way to an understanding of the problem".
  Prof. Ralf B. Peck.