Shotcrete and Waterproofing for Operational Tunnels

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International Tunnelling Association
Working Group on Shotcrete Use

Basilica Cistern
Istanbul, 6th Century

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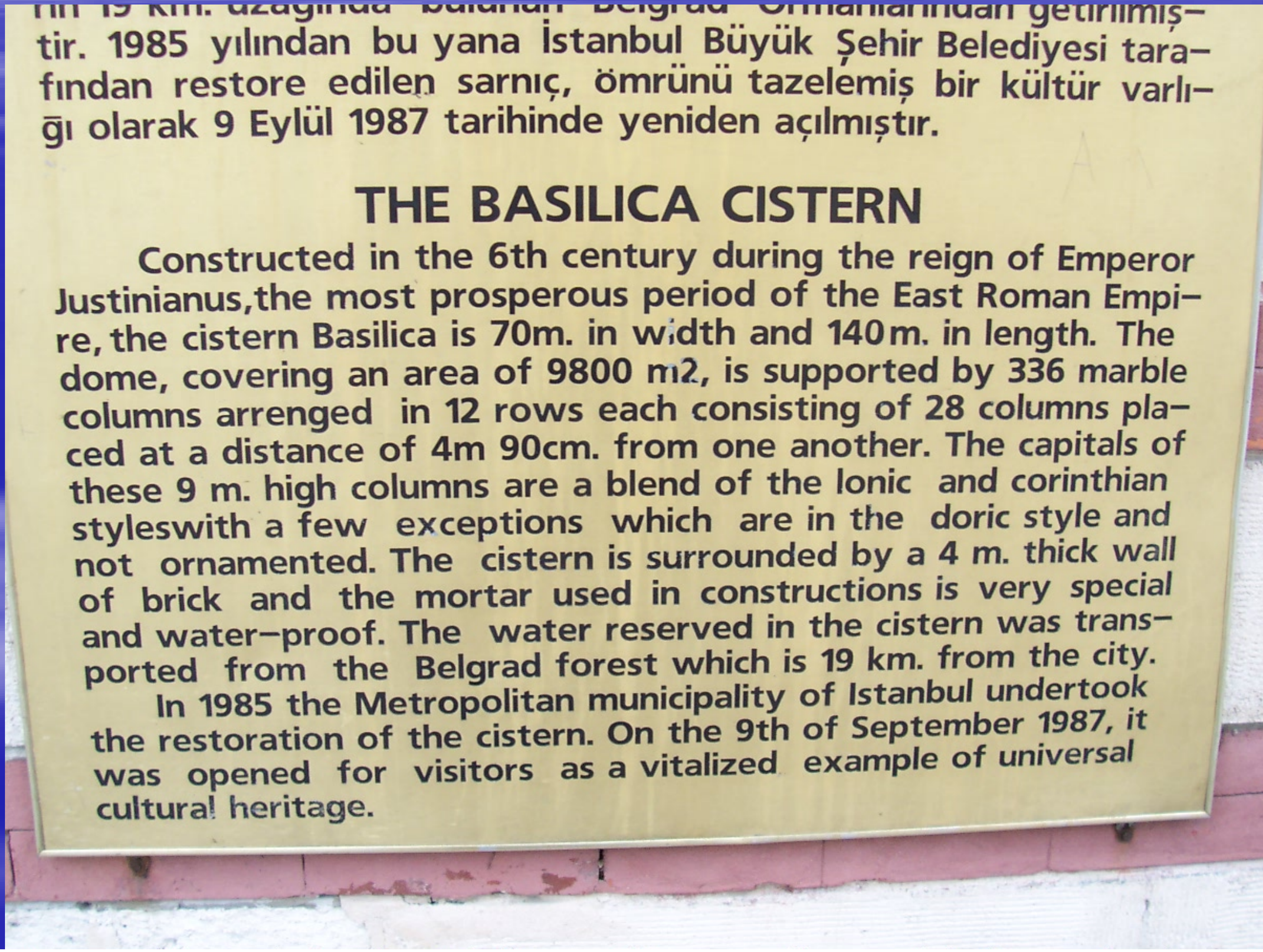

ITA Activities on Waterproofing

- WG 6 – Maintenance and Repair
- Wg 12 – Shotcrete Use

16,00 EUR

K 8266

Felsbau

Rock and Soil Engineering

3/2005

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INTERNATIONALE ERFAHRUNG IN DER TUNNELABDICHTUNG

Abdichtung Lötschberg-Basistunnel Nord
Bauabschnitt Mitholz

Waterproofing Requirements

- More sophisticated equipment underground
- More demanding public
- Psychological aspects of leakages
- Improvement of waterproofing techniques

On the other hand

- Increasing costs
- No general solution: functionality, durability, environment

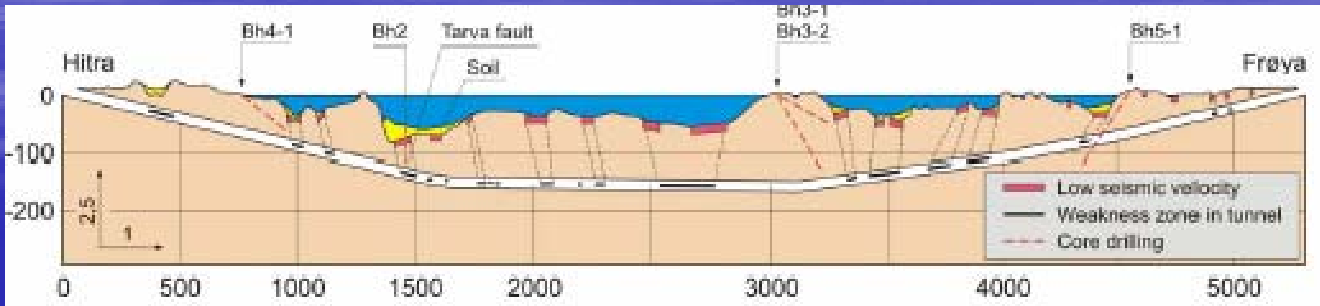
Different Criteria for infiltration

	$l/m^2.day$
Alp Transit: 39g/km.sec	0.13
Sweden: 2 l/min.100m	1.1
Norway (highway) 300 l/min.km	14
São Paulo Subway	1.0

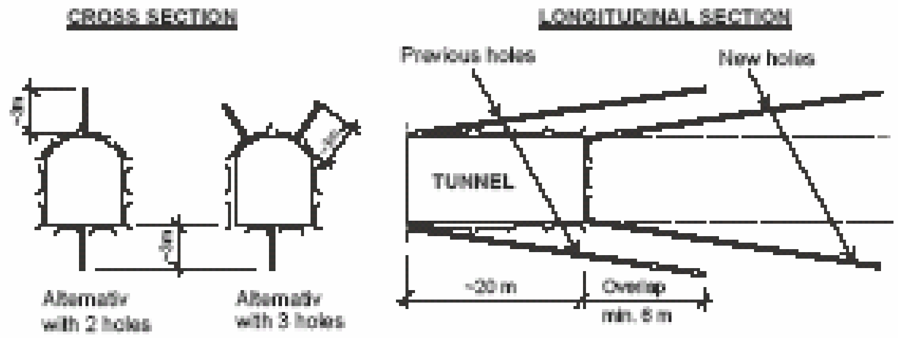
Underground Railway Systems
l/m^2.day (Haack, 1991)

	short	long
Washington, D.C.	10.7	0.9
San Francisco		0.9
Atlanta		0.9
Boston		1.8
Baltimore	5.3	0.7
Buffalo	0.4	0.2
Melbourne	0.25	0.1
Antwerp	0.25	0.1

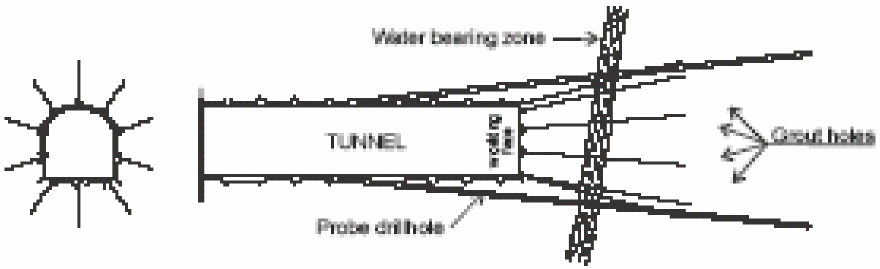
Norwegian Subsea Bored Tunnels



WATER CONTROL



1) PROBE DRILLING



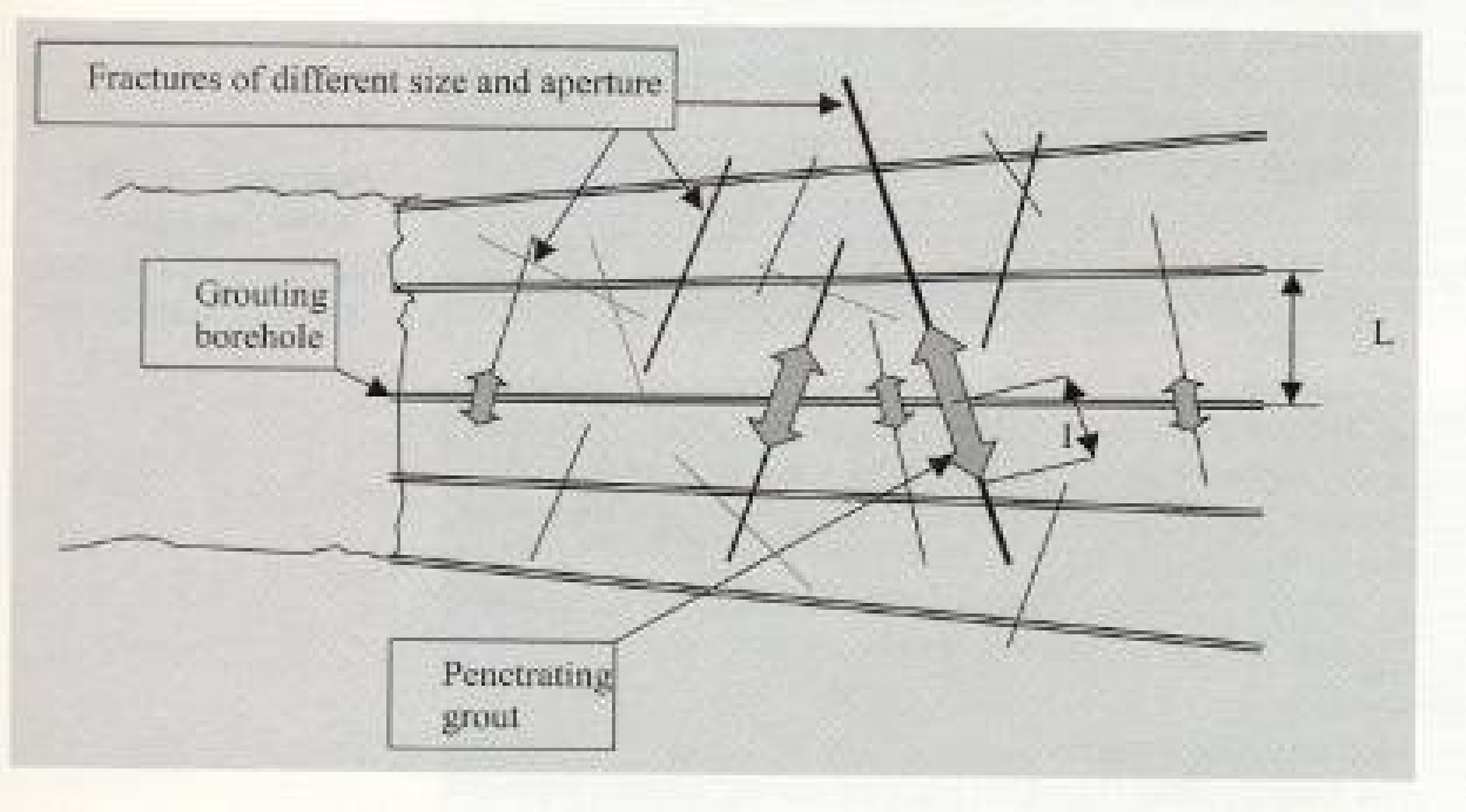
2) PRE-GROUTING

GROUTING PRESSURE UP TO 10 MPa

PRESET QUANTITY FOR ECONOMICAL PUMPING: ~300 l/min per km

ACHIEVED AT OPENING: 20-460 l/min per km

Stop Criteria for Cement Grouting (Gustafson & Stille, 2005)



Norwegian Operational Experience (ITA Open Session, 2005)

- Water ingress reduced by up to 50% (self-healing)
- Algae growth in some tunnels
- Periodical replacement of installations
- Yearly maintenance cost: 1 - 1.5% of investment
- Investment: US$ 6,000.00 – 10,000.00

  (2- or 3-lane tunnels)

Damaging Effects of Water on Tunnels (ITA WG 6)

17 types of defects and remedial measures

- Corrosion of internal fittings
- Frost damage
- Erosion of mortar
- Corrosion of reinforcement
- Degradation of concrete
- Swelling soil
- etc

(chemically aggressive water)

Water Inflow x Durability

- Flow rate
- Chemical aggressivity

Ex:

- – Kanmon Strait Tunnels (concrete, sea water; Miyaguchi, 1986)
- – Cast iron segmental lining

Shotcrete for Final Lining

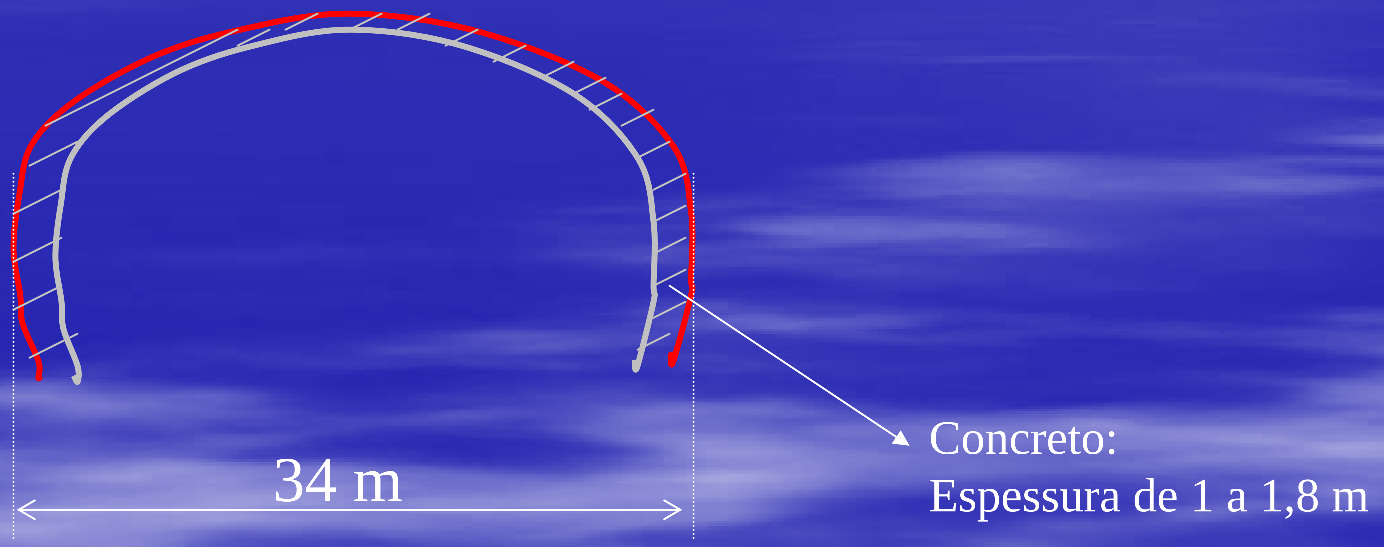
- Material requirements
- Less material
- Concept of rock reinforcement *vs* rock support
- “design attitude”

Design
ITA WG 12 “Shotcrete for Rock Support”, 2004

“The contributions from different countries illustrate well the widely different views on rock support design. This becomes especially evident when comparing sometimes the over-conservative cast in place concrete linings with what evidently is satisfactory support under similar conditions using shotcrete. There are many examples of thickness reduction from one meter down to 10 to 15 cm of shotcrete”

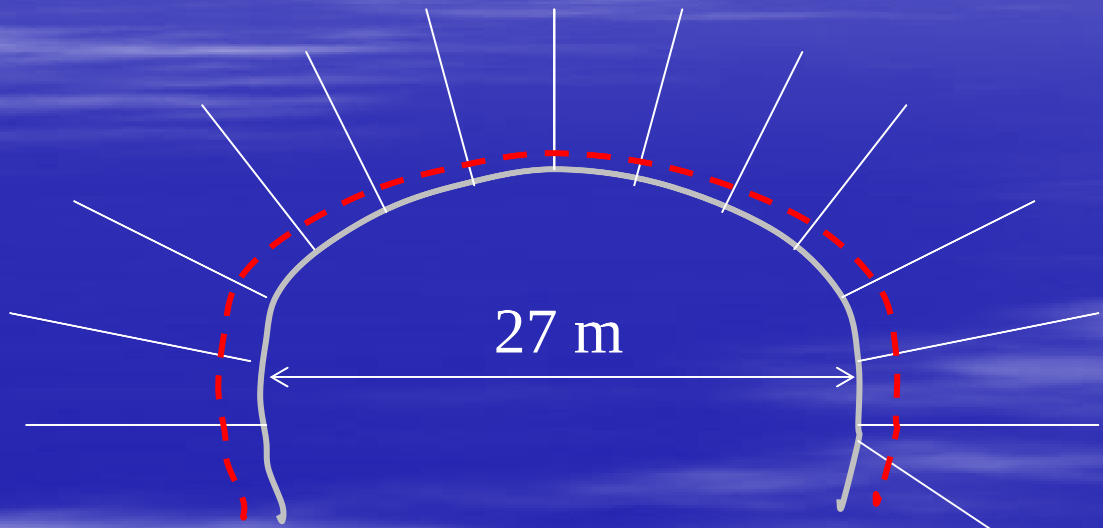
K. Garshol

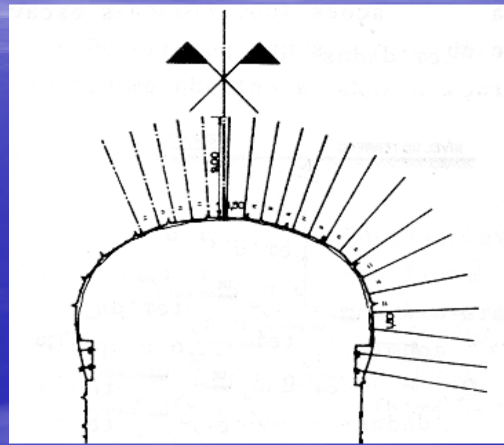
Paulo Afonso IV



Paulo Afonso IV

Re *et al.* (1982)

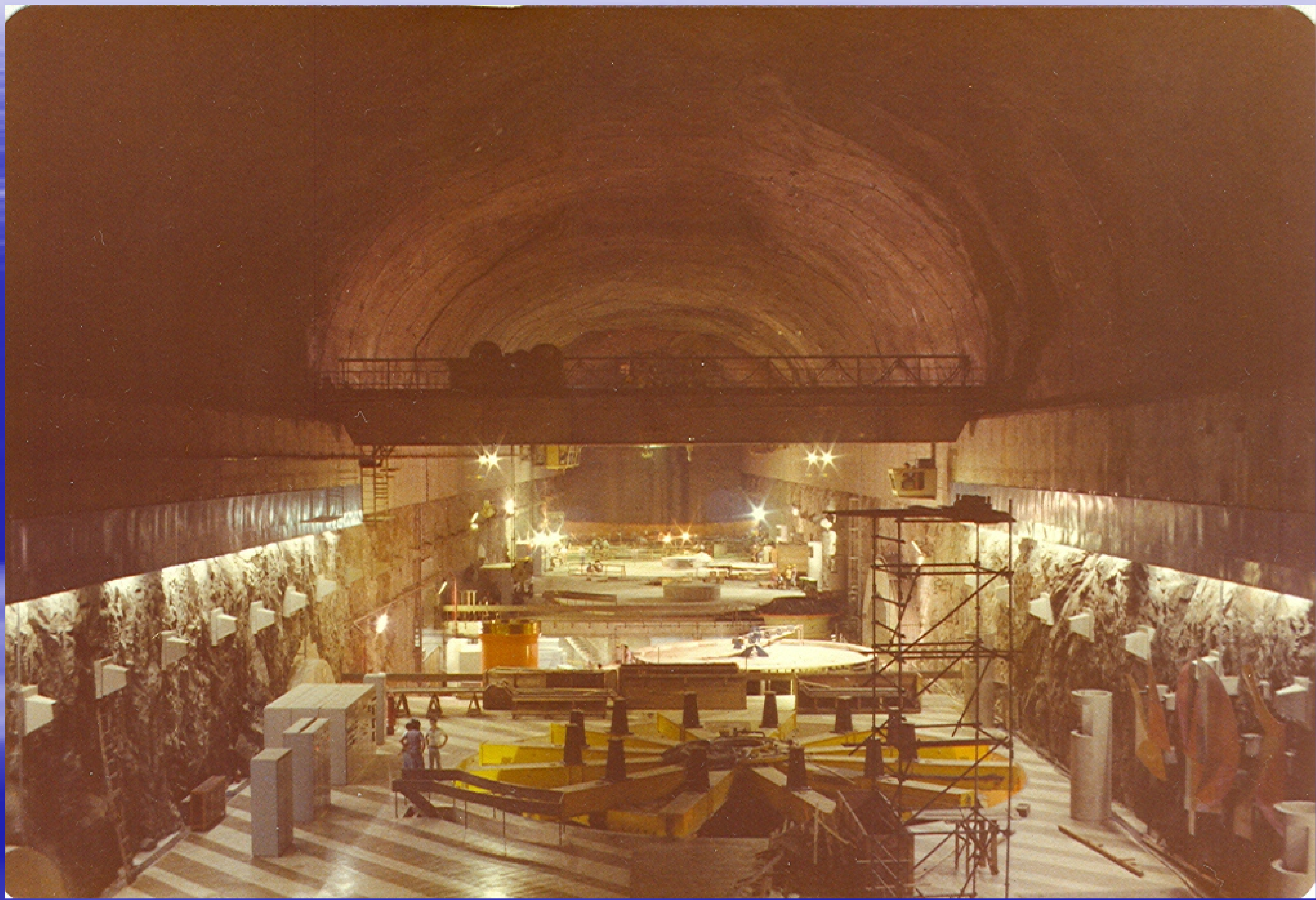




Shotcrete:
10 to15 cm
thickness

USINA DE PAULO AFONSO III

USINA DE PAULO AFONSO IV



Single shell lining in Germany

Single-track tunnels (Pöttler & Klapperich, 2001)

Year	1981-1983	1982	1984-1987	1987-1989
Ground	S/M	S/M	M	C
Pressure (bar)	0.5	0.5	0.5	0.6
Thickness (cm)	37	25	39	40

Year	1987-1989	1989-1990	1989-1992	1981	1991
Ground	C	M	M	M	G/M
Pressure (bar)	0.6	0	1.2	0.5	0
Thickness (cm)	25	40	55	30	35

C - claystone
M - marl
S - sandstone

Comments by Pöttler & Klapperich, 2001

- 10 - 15% savings due to single shell concept
- Scattered considerations about load on the second layer: full load to partial load
- Different design philosophy $\rightarrow$ even more significant savings

Single shell lining in São Paulo

Single track tunnels

Year: since 1981

Ground: stiff clay with water-bearing sand layers

Pressure: 0.5 to 2.0 bar

Total thickness: 20 to 25 cm

Shotcrete lining for the São Paulo Subway

t = 0.25 m

p = 2 bar

t = 0.25 m

p = 2 bar

t = 0.40 m

p = 0.7 bar

t = 0.25 m

p = 0.5 bar

Opinions from National Groups

- Conflicting opinions
- Different technical cultures
- Role of information exchange
- Technology property

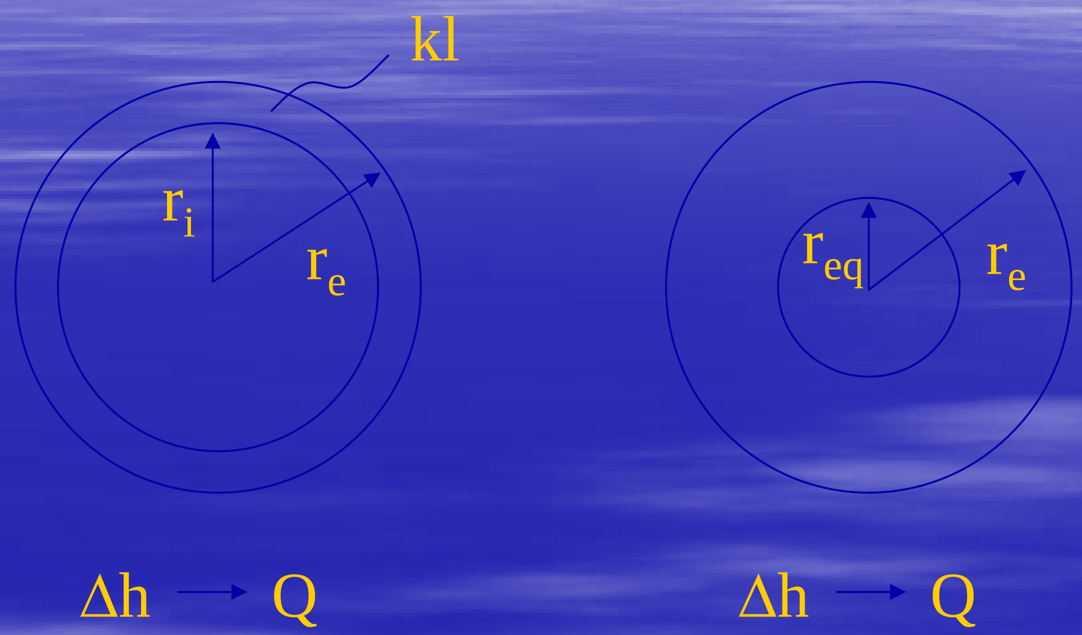
1988 ITA Congress on Tunnels and Water

Schryer (Germay): shotcrete shells not suitable for zones more than 10m below water

Astad & Heimli (Norway): shotcrete considered watertight for practical purposes

Current shotcrete technology: low hydration heal cement, additives for low porosity: k~10-^{14}m/s

APPROXIMATE EQUIVALENT SYSTEM

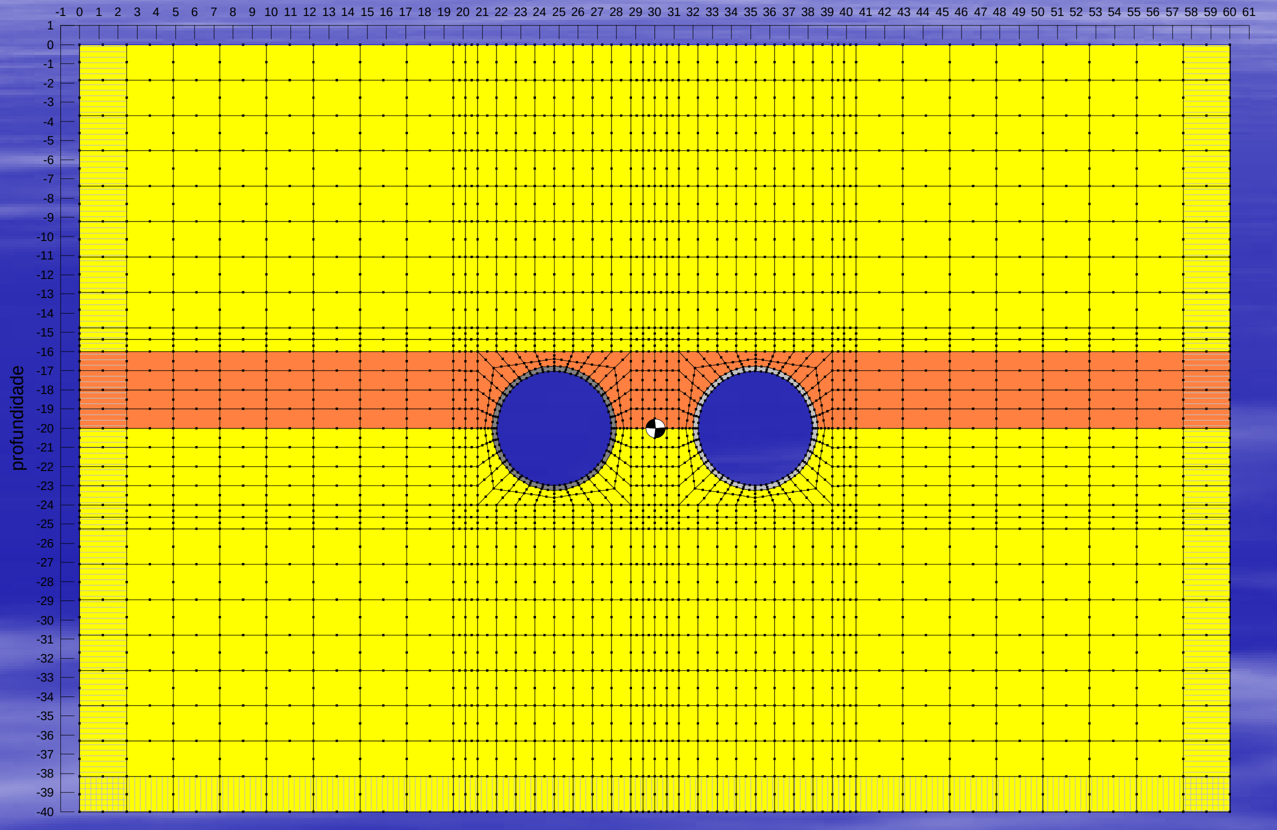


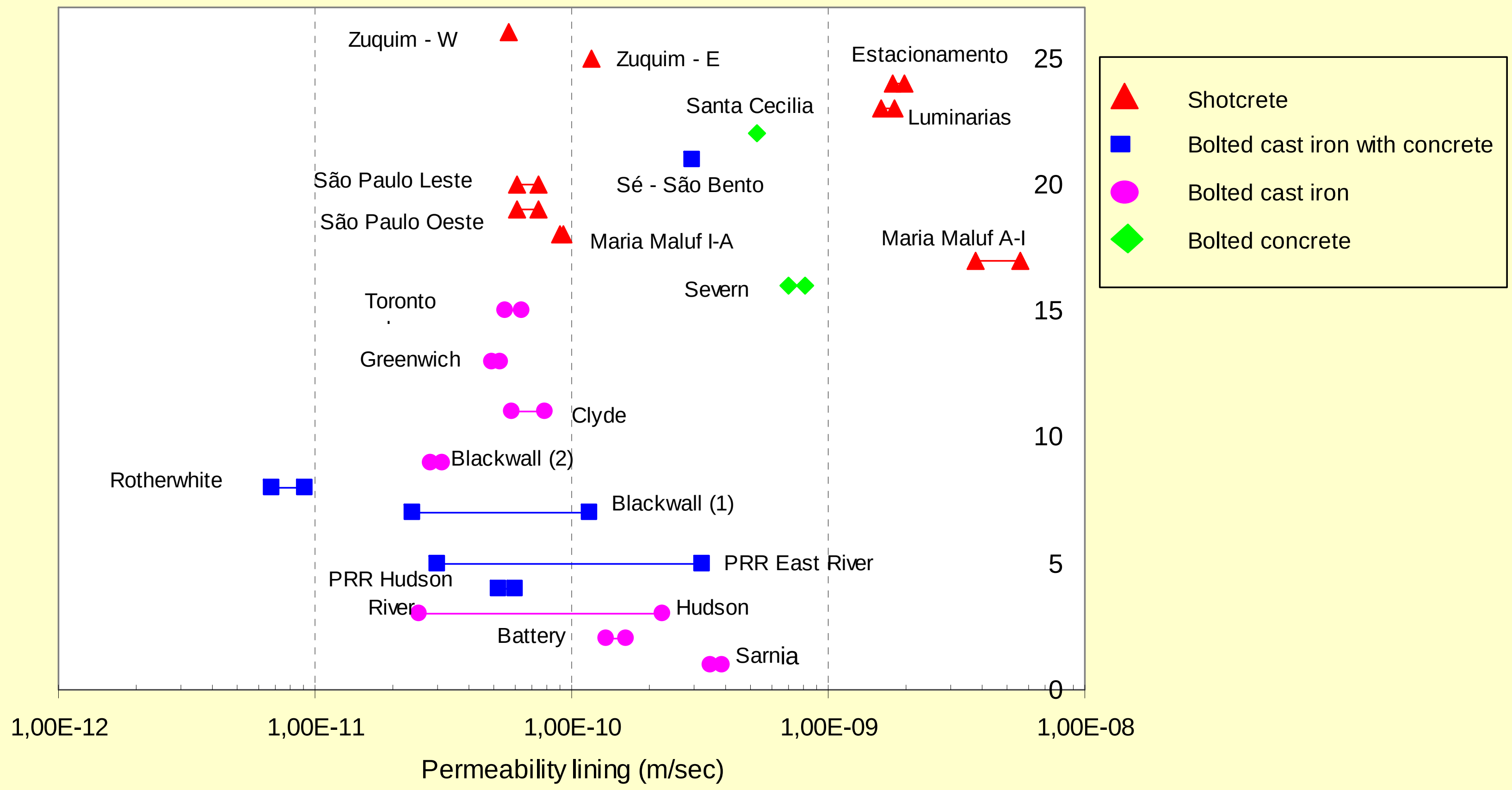
$$r_{eq} = r_e \left(\frac{r_e}{r_i} \right)^{-k_g / k_l}$$

Approximate expression for lining permeability

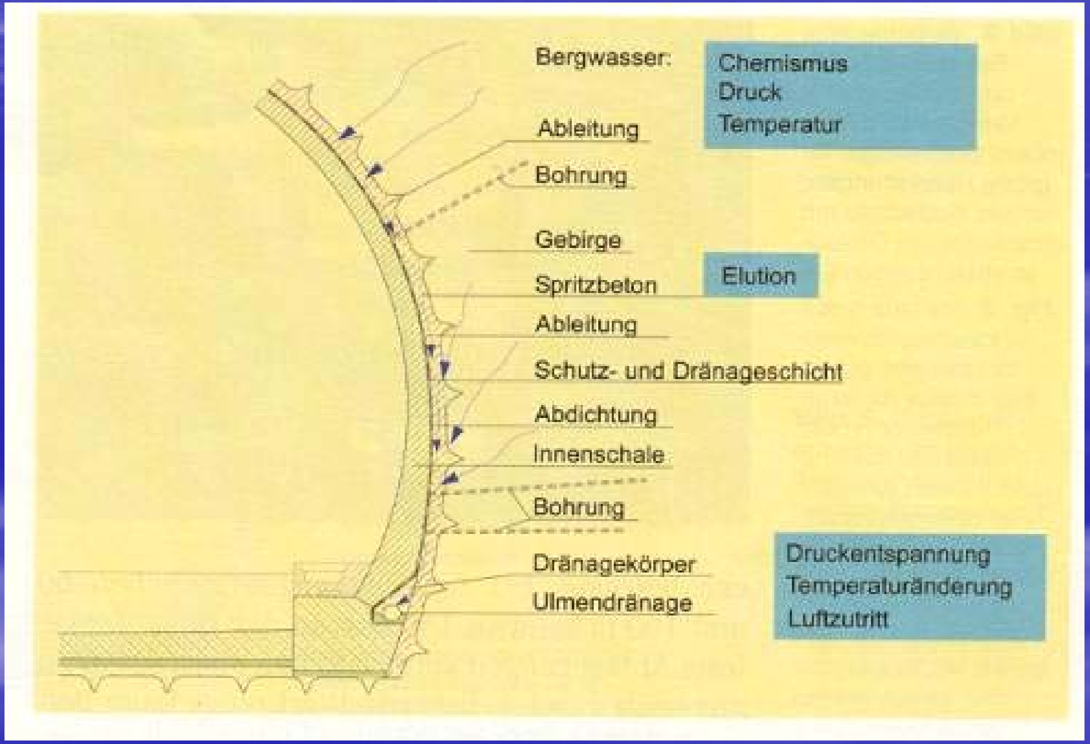
$$Q = 2\pi k_g h \frac{1 - 3\left(\frac{r_{eq}}{2h}\right)^2}{\left[1 - \left(\frac{r_{eq}}{2h}\right)^2\right]\ln\frac{2h}{r_{eq}} - \left(\frac{r_{eq}}{2h}\right)^2}$$

ZUQUIM TUNNELS

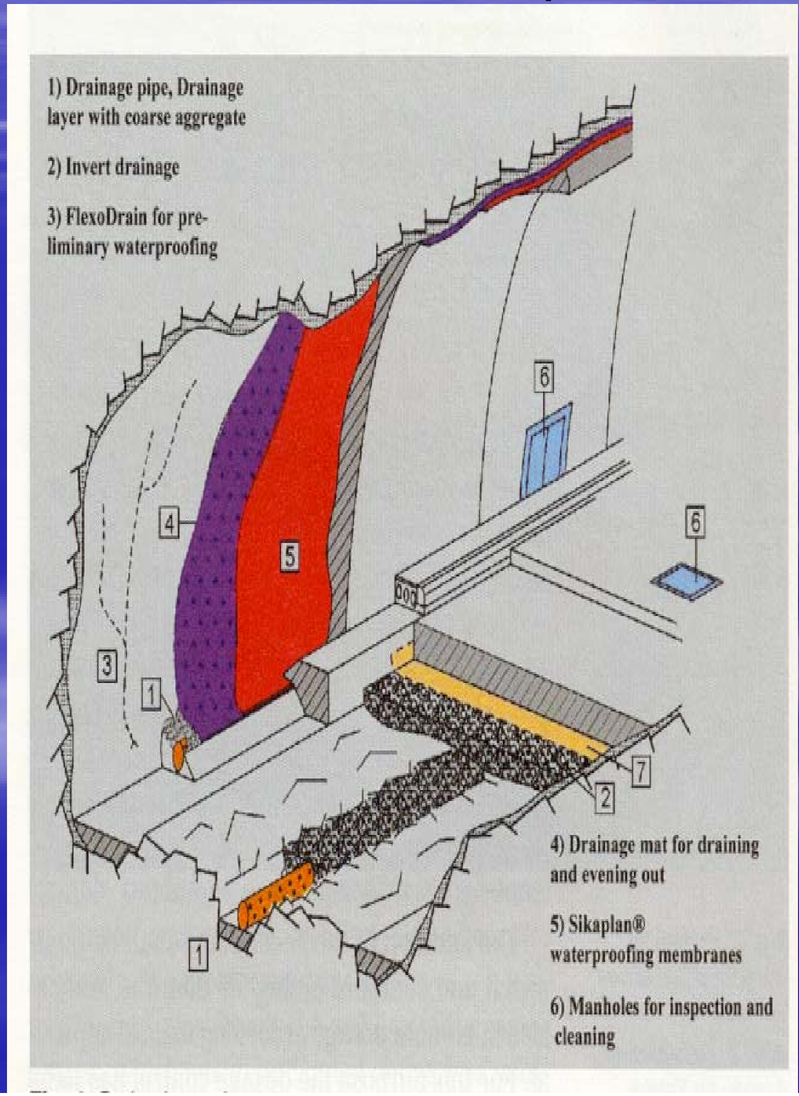



Zuquim - W
Zuquim - E
Estacionamento
Santa Cecilia
Luminarias
São Paulo Leste
Sé - São Bento
São Paulo Oeste
Maria Maluf I-A
Maria Maluf A-I
Severn
Toronto
Greenwich
Clyde
Blackwall (2)
Rotherwhite
Blackwall (1)
PRR East River
PRR Hudson
River
Hudson
Battery
Sarnia
25
20
15
10
5
0
1,00E-12
1,00E-11
1,00E-10
1,00E-09
1,00E-08
Permeability lining (m/sec)
Shotcrete
Bolted cast iron with concrete
Bolted cast iron
Bolted concrete

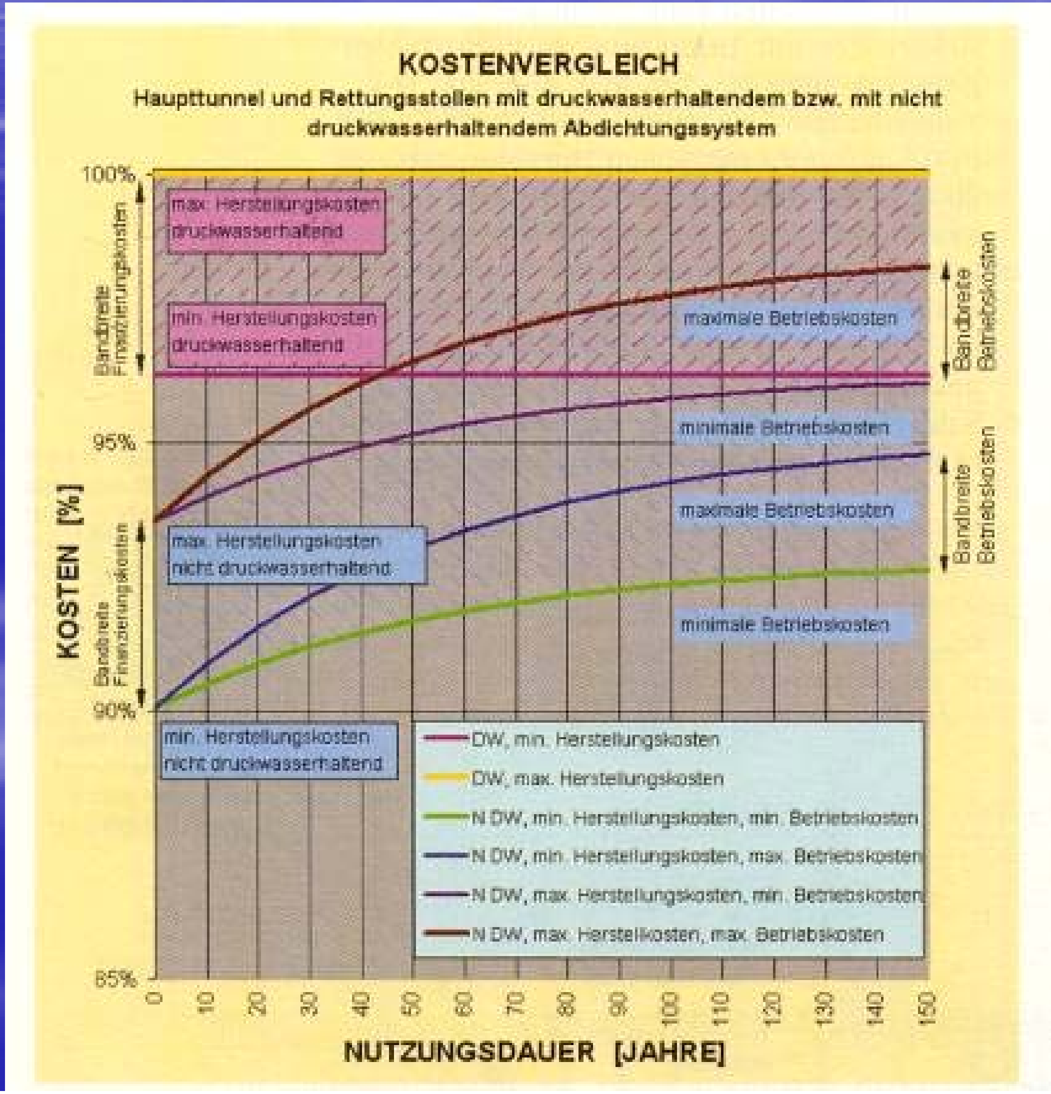
Drained Tunnels



Overview of Waterproofing Techniques: Drainage
Lemke *et al*., 2005



Cost of drained and watertight tunnel
(Stans/Terfens Tunnel, Insam *et al.*, 2005)



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