MECHANIZED EXCAVATION OF LONG TRANSPORT TUNNELS

Concrete Segments for Tunnel Linings – Field of Application and Design

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Content of this presentation

- Design Principles and Inputs
- Construction Systems
- Segment Lining Systems
- Ring Geometry
- Sealing Systems
- Requirements to Systems
- Influences
- Joint Configurations
- Bolts / Centering Tools
- Tolerances
Principles of Segmental Linings

- Approx. Length of tunnel with fixed diameter exceeding approx. 2,000 meter.

- Combine TBM- and segment designer immediately after fixing of method and before start of design work.

- Both designs should show minimum 10 years of relevant experience.

- Client to specify dual requirements of TBM and lining.

- Distribution of technical responsibilities at interface.
Basic Inputs for Design of Segmental Linings

• Minimum Radius of Tunnel alignment
• Maximum Diameter of Tunnel
• Dual requirements of TBM and lining (e.g. width of the ring, segments per ring, max. loadings of TBM thrusts)
• Geotechnical datas (e.g. max. overburden, max. ground water pressure)
• Other requirements (e.g. fire loadings, tunnel operation loadings, earth quake, minimum tolerances)
Thrusters of TBM
Master Ring

Master ring for checking of defined tolerance and segment details
Construction Systems (1)

- Segment Lining system with fixed diameter
  - Lining totally with segments
  - Closed longitudinal joints – fixed outer diameter
  - Filling of annular space with gap grouting material
Construction Systems (2)

- Expendet segment Lining with variable diameter
  - Lining totally with segments
  - Variable outer diameter
  - Segment system with compressing elements – Filling of annular space with gap grouting material
Construction Systems (3)

- **Lining Systems with invert segments**
  - Integration of purpose formed invert segments
  - Function: immediate fastening (invert, carriageway, drainage)
  - Invert segment part of final lining
Construction Systems (4)

- Lining system with conventional supporting elements and integrated invert segments
  - precast segments in invert only
  - Use of shotcrete, anchors and cast-in-place concrete
  - Carriageway with drainage
  - Part of final segment lining
Single lining system with invert segment

Regelprofil Sanierung 2002
Typical section Repair 2002

Ringbeton
Ring concrete

Fugenmörtel
Pointing mortar

Vorschle
Original invert

3.05m

2.286

2.65

2.05

R=1.45
Construction Systems (5)

- **Single-lining with segments**
  - Full support of excavation surface
  - Structural safety of tunnel
  - Serviceability of tunnel (water tightness, durability)
  - Quality requirements to tunnel lining surface
Construction Systems (6)

Double-lining systems with segments and final lining of cast in place concrete

- Sustainable final lining constructed as cast-in-place inner layer
- Absorbing of ground water loadings by final cast-in-place lining
- Segment lining will absorb all other geotechnical loadings
Construction Systems (7)

- Double-lining systems with segments and functional final lining

  - Function of final lining is limited (e.g. fire loading, sealing, collision protection, …)

  - Function or segment lining equal to single-lining system
Double Lining System

Technisches Schaubild Tübbingring

- Randbalken WDI C30/37
- Mittlere Schiplatte WDI
- Bituminöse Tragschicht 5cm
- Auffüllung mit zementstabilisiertem Kiessand
- Geotextil
- Drainenschicht
- Füllbeton
- Mittenterwässerung DN400

Schlussstein

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Construction Systems (8)

- **Double-lining system with invert segments**
  - Combination of invert segment with shotcrete final lining
  - Function of integrated invert segment
    - Immediate fastening
    - Protection of excavation intrados
    - Serviceability of tunnel construction (water tightness, durability)
Segment Systems

- Rectangle system
- Trapezoid system
- Rhomboid system
- Hexagonal system
Example for Trapezoid Segments
Rhomboid key stone segment
Example for Hexagonal Segments
Details of Segment Geometry

TYPICAL CHAMFER GEOMETRY

GASKET AT CHAMFER CORNER

SEGMENT WITH IMPROVED CORNER
Ring Geometry

- Parallel Ring system
- Parallel Ring system with corrections rings
- Left-Right-Systems
- Universal Ring Systems
Watertightness

**Membrane Systems**
- Installation between segment lining and cast-in-place concrete final lining
- Absorbing of ground water loadings by cast-in-place concrete final lining

**Gaskets**
- Installation in special grooves of the segment joints
- Absorbing of full ground water loadings by the segments
Ring Geometry Examples

A. PARALLEL

B. TAPERED - SYMMETRICAL

A1. PARALLEL - HONEYCOMB SEGMENT

C. TAPERED - UNSYMMETRICAL
## Tailor-Made Gaskets

<table>
<thead>
<tr>
<th>Tunnel-Type</th>
<th>Challenge</th>
<th>Dätwyler solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metro &amp; Railway Tunnels</strong></td>
<td>Low to Medium Water Pressure, Low Reaction Forces</td>
<td>Soft Geometry, Soft Corner, Sliding Surface</td>
</tr>
<tr>
<td><strong>Mountain Basis Tunnels</strong></td>
<td>Tunnel Ovalization, Steps of Waterpressure, Very High Water Pressure</td>
<td>Specially Stable Geometry, Hydro-swelling top and lips</td>
</tr>
<tr>
<td><strong>Road Tunnels</strong></td>
<td>Big Diameters and offsets, Hydrocarbons, Fuels</td>
<td>Wide Profile, Protected surface or CR Rubber</td>
</tr>
<tr>
<td><strong>Water Supply Tunnels</strong></td>
<td>High Pressure, Potable Water Contact</td>
<td>Stable Geometry, Drinkwater Rubber Quality</td>
</tr>
<tr>
<td><strong>Combined Sewer Overflow Tunnels</strong></td>
<td>Big Diameters, Waste Water Contact</td>
<td>Hydro-swelling on top, EPDM Rubber</td>
</tr>
</tbody>
</table>
Gasket Details
Watertightening Capacity of Gaskets

![Graph showing watertightening capacity of gaskets with different gasket types and offset values.](image)

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Interaction Thrust Pressure
Gasket Relaxation

Stage 1
Gap Closed
(Thrust Pressure)

Stage 2
Gap Opened
(No Thrust Pressure)

Detail 1

Gasket Reaction

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Example of Longitudinal Joint

LONGITUDINAL JOINT
WITH GUIDING ROD

2.5 7.25 2.18

AXIS OF SEGMENT
AXIS OF THRUST SHOES
Example of Longitudinal Joint with Guiding Rod
Example of Joint including Gasket

RADIAL JOINT

M 2:1

Foam Tape 15x8

Gaskets system P 06-259
Supplier: D2 wyler or similar

BEVEL

Hardwood plate to be pressed from 3 mm to 2 mm by thruster load.
Joint formations - Shapings

- Flat partial area joints
- Groove-Tongue joints
- Conkave-Convex joints
Circumferential Flat Joint
Longitudinal Joint (Groove-Tongue)
Centering Tools and Fastening Elements

**Purpose**

- Connection of joints (temporary / permanent) through boltings and dowels
- For guaranting stability during implementation
- For prohibiting movements
- Allow a more precise and simple installation of segments
Inclined Bolt
Centering tools and fastening elements

**Methods**

- **Flexible tools**
  - Guiding rod (longitudinal joint), dowel (ring joint)

- **Dowels**
  - In longitudinal joints for absorption of traction and thrust
  - No additional bolting necessary

- **Bolts**
  - For temporary protection during assembling
  - In longitudinal and ring joints
  - Mostly inclined or curved
Joints

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Dowels

CONEX DOWEL  TIMBER DOWEL  ANEX DOWEL  SYNEX DOWEL

BUCLOCK RECESS COUPLER  "BICONO" DOWEL

FAST LOCK DOWEL SYSTEM  "BIBLOCK SYSTEM 60/200"  "SOF-CLIP"/"SOF-FIX" DOWEL
Shear capacity test curves of dowels

Dowel CONEX
- Capacity: 102,0 kN
- Max. def.: 15.6 mm

Dowel ANEX
- Capacity: 97,0 kN
- Max. def.: 15.0 mm

Dowel SOF-CLIP
- Capacity: 97.6 kN
- Max. def.: 23.0 mm

Dowel BUCLOCK (Standard)
- Capacity: 60,0 kN
- Max. def.: 20.0 mm

Dowel BUCLOCK (Heavy Duty)
- Capacity: 100,0 kN
- Max. def.: 20.0 mm

Deformation [mm]

Force [kN]

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Steel Dowel
Example for dowel hole in radial joint
Segment Tolerances
Tolerances

FRONT VIEW
CIRCUMFERENTIAL LENGTH +1mm

THICKNESS +3mm
RADIUS +2mm
SEGMENT PARTITION +0.02°
RADIUS +1mm
Tolerances

SEGMENT TOLERANCES

GROUND VIEW

LENGTH ±1mm
DIAGONAL CORD ±1mm
WIDTH ±1mm
MC DIRECTION IS PERPENDICULAR TO SEGMENT SIDE
LENGTH ±1mm
System requirements related to application and utilization

- **Segment systems for railway tunnels**
  - Single- and double-lining systems
  - All systems except „hexagonal system“ in use

- **Segment system for Metro tunnels**
  - Mostly single-lining sealed system
  - All systems except „hexagonal system“ in use
  - Basically universal ring and left-right-systems
System requirements related to application and utilization

- **Segment systems for road tunnels**
  - Single- and double-lining systems
  - All systems except „hexagonal system“ in use
  - Regarding sealing function all feasible

- **Segment system for water galleries and tunnels**
  - Mostly single-lining systems with open segment layer
  - Closure of joints ex post
  - Mostly parallel ring systems (with correction segments) and hexagonal segments in use
Thank you for your attention!