PRECAST CONCRETE LINING TUNNEL

FIRST TARGET:

• Research on standard design of concrete lining precast segments, with reference to normal loading conditions (metro tunnels);

• Give metro lining tunnel design (soil type Milano) as “benchmark” for further developments in research topics (blast and fire engineering);

⇒ METRO OF PALERMO
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FURTHER DEVELOPMENTS:

• Awareness that only one design example is not enough for complete and deep understanding of concrete segment lining tunnel design;

• Need for “conceptual design” to investigate more variables pertaining standard design of concrete segment lining tunnel: not only about geometry of one only segment but with reference to all kind of details in geometry and joints.

⇒ NEED OF DESIGN DATABASE
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FURTHER DEVELOPMENTS:

01 DATABASE - PRECAST CONCRETE TUNNEL LINING

02 DATABASE - JOINTS DETAILS

BIBLIOGRAPHY
01 DATABASE - PRECAST CONCRETE TUNNEL LINING

- Collect and catalogue detail projects or “as build” of precast concrete lining tunnels, including all type of function roads/railways/hydraulics.
- Characterize main parameters: geometric ratios, mechanicals and structural ratios, geotechnical ad functional context.
- Deduce correlations between parameters to assess design trend under ordinary loads conditions.
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FURTHER DEVELOPMENTS ...

02 DATABASE - JOINTS DETAILS

• Catalogue of segments joints type and constitutive laws.
• Catalogue of type of gasket in segments.
• Type of concrete admix applied outside concrete ri
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FURTHER DEVELOPMENTS …

BIBLIOGRAPHY

• BLAST ENGINEERING….
  ✓ FEMA 426 Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings
  ✓ FEMA 459 Incremental Protection for Existing Commercial Buildings from Terrorist Attack

• PRECAST CONCRETE LINING TUNNEL ….
  ✓ PAST EXPERIENCES: PASSANTE MILANO, METRO BARCELLONA
  ✓ NORMS & STANDARD: AFTES 1997 Precast concrete segments, Calcestruzzo extrusionato-rivestimento per tunnel
  ✓ LITTERATURE REVIEW: 20 PAPERS & 3 THESIS
01 DATABASE - PRECAST CONCRETE TUNNEL LINING LINING

List of main parameters:

a) Tunnel type. ⇒ Roads/Railways/Hydraulics
b) Geological and geotechnical context.
   i. Soil type ⇒ [-]
   ii. H max/min soil overburden ⇒ [m]
   iii. Geotechnical parameters ⇒ γφ-c’ / cu
c) Excavation diameter. ⇒ Ds [mm]
d) External lining diameter ⇒ De [mm]
e) Lining average length (circular) ⇒ La [mm]
PRECAST CONCRETE LINING TUNNEL

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List of main parameters:

f) Segments thickness. ⇒ s [mm]
g) N segments/ring. ⇒ n [-]
h) Type of ring. ⇒ universal/straight...
i) Segment thickness/ring diameter ratio ⇒ s / D_e [-]
j) Reinforcement density. ⇒ p_{tot} [kg/mc]
   i. Longitudinal reinforcement ⇒ \rho_l = A_{sl}/A_c [%]
   ii. Transversal reinforcement ⇒ \rho_t = A_{st}/A_c [%]
   iii. % principal and secondary reinforcement. ⇒ p_1/p_{tot} e p_2/p_{tot} [%]
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List of main parameters:

k) Concrete volume / tunnel unitary length ratio. ⇒ [mq]
l) Comp. segment concrete strength $R_{ck}$. ⇒ [MPa]
m) Compressive strength ratio. ⇒ $N/(A_cxf_{ck})$ [-]
n) Presence of additional inner lining. ⇒ [-]
o) Filling behind segments.
   i. Type ⇒ [-]
   ii. Thickness ⇒ $s_e$ [mm]
p) Presence of seal band ⇒ [-]
q) Tension strength ⇒ [-]
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List of main parameters:

r) Gaskets ⇒ [-]
s) Max design pressure ⇒ [kPa]
t) Type of longitudinal joints.
   i. N/segment ⇒ [-]
   ii. Diameter ⇒ \(d_i\) [mm]
u) Type of transversal joints.
   i. N/segment ⇒ [-]
   ii. Diameter ⇒ \(d_t\) [mm]
v) Type of TBM. ⇒ [-]
01 DATABASE - PRECAST CONCRETE TUNNEL LINING

- Need to define database with uniform and standard parameters that may be extended to more design offices, to improve database content.

- Anonymous source (with ©), data coded: X-YYY-N
  
  X = S (roads), T (railways), H (hydraulics)
  
  YYY = design office (origin of data), ex. LOM
  
  N = progressive number
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Ring slenderness

\[ y = 0.0399x + 29.644 \]

\( s \) (segment thickness) [mm] vs. \( \phi_{\text{ext}} \) (outer diameter) [mm]

Design data
Linear interp.
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AFTES 1997 Precast concrete segments
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Segment area aspect ratio

$y = 2.5307x - 797.35$

Design data
Linear interp.
Ring segments number vs. Tunnel diameter

\[ y = 0.0003x + 4.8194 \]

- Design data
- Linear interp.
Concrete lining volume vs. Tunnel diameter

\[ y = 2.3584x - 8.5708 \]

- \( \varnothing_{\text{ext}} \) (outer diameter) [m]
- Concrete volume [m\(^3\)]/ tunnel unitary length [m]

Design data

Linear interp.
Segment longitudinal % reinf. vs. thickness

$y = 9E-06x + 0.0051$
Segment transverse % reinf. vs. thickness

\[ y = 2 \times 10^{-7}x + 0.0006 \]

- Design data
- Linear interp.
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Segments reinf. principal+secondary

- Secondary reinf.
- Principal reinf.

<table>
<thead>
<tr>
<th>$\varnothing_{\text{ext}}$ (outer diameter) [m]</th>
<th>Principal/Secondary reinf. [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.20</td>
<td>100%</td>
</tr>
<tr>
<td>9.50</td>
<td>80% 20%</td>
</tr>
<tr>
<td>5.90</td>
<td>60% 40%</td>
</tr>
<tr>
<td>3.44</td>
<td>40% 60%</td>
</tr>
<tr>
<td>6.80</td>
<td>80% 20%</td>
</tr>
<tr>
<td>4.78</td>
<td>60% 40%</td>
</tr>
</tbody>
</table>
Concrete comp. strength vs. segment thickness

**Equation:**

\[ y = 0.0323x + 34.658 \]

**Graph:**

- **X-axis:** s (thickness) [mm]
- **Y-axis:** Concrete comp. strength [N/mm²]
- **Data Points:** Design data
- **Line:** Linear interp.
Reinforcement volumetric ratio vs. Tunnel diameter

\[ y = 0.7253x + 127.61 \]

- **Design data**
- **Linear interp.**
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![Graph showing the relationship between reinforcement volumetric ratio vs. s/Ø ext ratio](image)

- **Equation:** \( y = -466.02x + 154.87 \)
- **Axes:**
  - Y-axis: Reinforcement volumetric ratio [kg/m³]
  - X-axis: s/Ø ext [-]

Legend:
- Design data
- Linear interp.
PRECAST CONCRETE LINING TUNNEL

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N. longitudinal connectors vs. segment length

\[ y = 0.7253x + 127.61 \]

Design data
Linear interp.
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N. transversal connectors vs. segment width

Design data
Linear interp.

\[ y = 0.7253x + 127.61 \]
PRECAST CONCRETE LINING TUNNEL

01 DATABASE - PRECAST CONCRETE TUNNEL LINING

N. longitudinal connectors vs. segment weight

\[ y = 0.7253x + 127.61 \]

Design data
Linear interp.
THANK YOU!