SEGMENT LINING
OR
INSTANT LINING

Prof. Eng. Sebastiano PELIZZA

GENERAL CONCEPTS
Segment lining or instant lining
TBM tunnelling lining is a continuous cylindrical structure of subsequent rings built within the tunnel by means of prefabricated strong reinforced concrete bricks installed at the rear of TBM. The single prefabricated brick is currently called segment: segment lining. The tube resists immediately to the ground loads: instant lining.
Each 1.4 – 2.0 m long ring consists of 5 to 10 according to the diameter “normal” segments plus one “key stone” element that enables the closure of the ring. A “universal” lock permits to adapt the ring to any kind of tunnel alignment radius, from the minimum to the linear one, by a simple rotation of every ring compared to the previous one along the tunnel axis at a given angle. The injection of mortar behind the segments, performed immediately at the beginning of the excavation procedures, ensures the reduction of superficial collapse and the correct confinement/bedding of the lining.
A “universal” ring permits to adapt the ring to any kind of tunnel alignment radius, from the minimum to the linear one, by a simple rotation of every ring compared to the previous one along the tunnel axis at a given angle.
Additional segment nomenclature
The reasons of the annulus
The injection of mortar behind the segments, performed immediately at the beginning of the excavation procedures, ensures the reduction of superficial collapse and the correct confinement/bedding of the lining.
Back filling. Grouting through the Tailskin.
Segment Design Steps
Generally, design steps for TBM tunnels could be as follows (ITA, 2000):

**Step 1: Define geometric parameters**
Alignment, excavation diameter, lining diameter, lining thickness, width of ring, segment system, joint connections

**Step 2: Determine geotechnical data**
Shear strength of soil, deformation modulus, earth pressure coefficient

**Step 3: Select critical sections**
Influence of overburden, surcharge, groundwater, adjacent structures

**Step 4: Determine mechanical data of TBM**
Confinement pressure, overcut, shield tail conicality, TBM length, total thrust pressure, number of thrusts, number of pads, pad dimensions, grouting pressure, space for installation. All these structural parameters associated with TBM characteristics may have potential impact on ring stress analysis.

**Step 5: Define material properties**
Concrete: compressive strength, modulus of elasticity
Reinforcement: type, tensile strength
Gasket: type, dimensions, allowable gap, elastic capacity

**Step 6: Design loads**
Soil pressure, water pressure, construction loads etc.

**Step 7: Design models**
Empirical model, analytical model, numerical model

**Step 8: Computational results**
Response: axial force, moment, shear
Deformation: deflection
Detailing: reinforcement, joints, groove
**Loading Conditions**

The tunnel lining behind the TBM must be capable of withstanding all loads/actions and combined actions without deforming, especially during ring erection and advance. Single-shell reinforced concrete segmental rings behind the TBM, can be designed to fulfill those demands. There are many loading cases for the segmental lining of tunnels driven by TBMs.

The following loads shall normally be considered in designing the lining of the shield tunnel (ISCE, 1996):

1. **Vertical and horizontal earth pressure**
2. Water pressure
3. Dead weight
4. Effects of surcharge
5. Soil reaction
6. Internal loads
7. Construction loads
8. Effects of earthquakes
9. Effects of two or more shield tunnels construction
10. Effects of working in the vicinity
11. Effects of ground subsidence
12. Others

Various combinations of the loads have to be considered according to the purpose of the tunnel usage.
**Thrust Jacking Loading**

The functions of the linings during tunnel construction are also to sustain jack thrust for advancing a shield machine and to withstand the back-fill grouting pressure. The tube has also the function as a tunnel lining structure immediately after the shield advanced. Thrust force of shield jacks is a temporary load which acts on the segments as a reaction force against it while advancement the shield machine and is the most influential load to the segment among the construction loads. Several verifications must be done for the jacking load effects on the segment, such as contact pressure, bursting forces in the radial direction, and bursting forces in the circumferential direction.
The Pushing Hydraulic:

- 16 Pairs of Cylinders
- Piston Dia: 220 mm
- Hydr. Pressure: 370 bar
- Max Pushing Force: 45000 kN
  → 4600 Tons
Screen display of the control parameters during excavation by EPBS.
Distribution of the tensile forces acting in the segment.
Tensile force defined by numerical analysis.
RILIEVI VISIVI E FOTOGRAFICI DELLE CONDIZIONI STRUTTURALI DEL RIVESTIMENTO

Progetto: Potenziamento itinerario Genova - Ventimiglia
Sottoprogetto: Raddoppio tratta S. Lorenzo - Andora
Lavoro: Esecuzioni di indagini strutturali nelle costruende gallerie Collecervo e Cagheiz
Comm.: 1354

Galleria: Collecervo
Anello: 797
Concilio: SSL-1

NOTE:
1. $a=0.1\text{mm}$, $L=170\text{cm}$, Microfessura
2. $a=0.1\text{mm}$, $L=170\text{cm}$, Microfessura
3. $a=0.1\text{mm}$, $L=170\text{cm}$, Microfessura
4. $a=0.1\text{mm}$, $L=40\text{cm}$, Microfessura
5. $a=0.1\text{mm}$, $L=100\text{cm}$, Microfessura
6. $a=0.1\text{mm}$, $L=170\text{cm}$, Microfessura
7. $a=0.1\text{mm}$, $L=170\text{cm}$, Microfessura
8. $a=0.1\text{mm}$, $L=85\text{cm}$, Microfessura
9. $a=0.1\text{mm}$, $L=120\text{cm}$, Fessura
10. $a=0.1\text{mm}$, $L=70\text{cm}$, Microfessura
11. $a=0.1\text{mm}$, $L=125\text{cm}$, Microfessura
12. $a=0.1\text{mm}$, $L=75\text{cm}$, Microfessura
13. $a=0.1\text{mm}$, $L=75\text{cm}$, Microfessura
14. $a=0.1\text{mm}$, $L=170\text{cm}$, Microfessura
15. $a=0.1\text{mm}$, $L=120\text{cm}$, Microfessura
16. $a=0.1\text{mm}$, $L=70\text{cm}$, Microfessura

Posizione del concilio nell'anello

Misure di contatto in profondità tra due conci
RILIEVI VISIVI E FOTOGRAFICI DELLE CONDIZIONI STRUTTURALI DEL RIVESTIMENTO

Progetto: Potenziamento itinerario Genova - Ventimiglia
Sottoprogetto: Raddoppio tratta S.Lorenzo - Andora
Lavoro: Esecuzioni di indagini strutturali nelle costruende gallerie Collecervo e Caghel

Galleria Collecervo
Anello: 1634
Concetto: S5L-3

VENTIMIGLIA

NOTE:
1. a<0.1mm L<175cm Microfessura
2. a<0.1mm L>175cm Microfessura
3. a=0.6mm L=90cm Fessura
4. a=1.9mm L>170cm Fessura aperta
5. a=0.3mm L=40cm Fessura
6. a=0.3mm L>120cm Fessura
7. a<0.1mm L=35cm Fessura
8. a<0.3mm L>35cm Fessura
9. a<0.3mm L=45cm Fessura
10. a<0.1mm L=120cm Microfessura
11. a<0.1mm L=95cm Microfessura
12. a<0.1mm L=102cm Microfessura
13. a=3.5mm L=60cm Spaccatura
Experience has shown that the casting of the linings is always a very delicate operation because due to the small construction tolerances of the linings: this operation is in truth crude and inevitably leads to numerous, albeit small, errors in positioning. Errors in positioning the segments to the formation of small “steps” along the circumferential contact of the thrust/reaction faces.

In addition to this, and especially dueing the phase of casting linings form the ring, specific situations may arise which alter the regularity of the contact between the segments in a longitudinal direction and between the new ring with the previous one ring on the transversal plane in the tunnel: the ring may become oval due to its own weight and the poor filling in of the outside annulus: connected segments may be offset, the key stone may be inserted improperly and may stick too much or be set too deep, although only by a few millimeters. Not regular contact can lead to several kinds of segment cracks.
Grouting Loads

Primary grouting pressure applied to fill up the tail void behind the TBM is believed to govern both deformations and internal lining forces, as well as affect surface settlements. The grouting pressure acting on the outer surface (extrados) when the ring leaves the shield. For normal conditions, when a highly flowable mortar is used, the grouting pressure can be calculated constant around the ring. The annular grouting of the ring, with a grouting pressure minimum one bar (1 bar) higher than the surrounding water pressure, prestresses the ring and the enclosing ground.

Longitudinal grout injection through the tail of slurry shield (Gruebl, 2006)

Key segment is pushed out by excessive grouting pressure (Dul Negro, 2006)
**Storage Loads**

After mould stripping, segments are set down and stacked on supports. Timber blocks are usually placed between segments taking care that they are aligned with the supports. Storage and handling (e.g. turning, packing and then loading-out operations, supply to the workface…) influence the bending moment.
Handling Loads

During erection, the lining is subjected to a number of loads such as: forces resulting from segments overhanging during ring assembly; possible bumping impact loads; loads applied by the assembly systems retained (bolts, anchor bolts or plugs) it is necessary to consider the increasing in the mass forces due to dynamic effects.
Possible future excavations next to structures

Possible future buildings must be considered in the analysis, assuming some restrictions. As an example (zone 4B):

- **Vertical restrictions** - Excavations shall not exceed a total depth of 8 m.
- **Lateral restrictions** - No future excavations shall take place within an area of 5 m above the tunnel crown and 17 m on either side of the tunnel centre line.
**Trailer Loading**

Trailer chassis and other service loads can be applied on lining, including main bearing loads, divided by number of wheels. The loads induced by the trailer and by any fixations in the segments normally do not influence the reinforcement. During discussions with TBM manufacturer, it is necessary to state whether "Main Bearing Load" will be included in this type of analysis or not.
Fire load
Concrete tunnels are vulnerable to elevated temperatures caused by fire. Tests have shown that when the temperature of the reinforcement reaches 300°C, the bond between the rebar and concrete will be significantly reduced, leading to irreparable sagging and possible collapse of the total structure. Moreover, when concrete is exposed to fire temperatures as experienced in tunnels, concrete spalling often occurs. Tunnel cross-sections must be analyzed to consider fire loading.