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Introduction and historical background Handbook of Precast Segmental Tunnel Lining Systems

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Faculty of Civil Engineering

ITA AITES

ITACET Foundation

Bekaert

Segment Workshop, Warsaw 2025, May 27

Organized by Warsaw University of Technology and Polish Tunneling Association

Endorsed by ITA and ITACET

First Session starting at 9:00 AM

9:00 - 9:15	**Introduction and historical background,** Verya Nasri, PhD, PE, Chief Tunnel Engineer, AECOM, USA, 15 minutes
9:15 - 10:00	**Design fundamentals,** Verya Nasri, PhD, PE, Chief Tunnel Engineer, AECOM, USA, 45 minutes
10:00 - 10:30	**Concrete technology for fiber segment,** Barzin Mobasher, PhD, PE, Professor at Arizona State University, USA

Coffee Break, from 10:30 AM to 11:00 AM

Second Session starting at 11:00 AM

11:00 - 11:45	**Fiber segment,** Benoit De Rivaz, Global Technical Manager, Bekaert, France
11:45 - 12:30	**Connections and accessories,** Christophe Delus,Tunnel Division Director, Optimas, France

Lunch, from 12:30 PM to 1:30 PM

Third Session starting at 1:30 PM

13:30 - 14:15	**Sealing gaskets,** Andreas Diener, Product Manager Tunneling, Cordes, Germany
14:15 - 15:00	**Formwork systems,** Stefan Medel, Managing Director, Herrenknecht Formwork, Germany

Coffee Break, from 3:00 PM to 3:30 PM

Third Session starting at 3:30 PM

15:30 - 16:00	**SFRC segment production for IInd metro line in Warsaw,** Bartłomiej Dziuban, Gulermak Polska, Poland
16:00 - 16.45	**The use of SFRC for the segmental lining of the Świnoujście tunnel,** Wojciech Nowak, PORR Polska, Poland
16:45 - 17:00	**Concluding remarks,** Verya Nasri, PhD, PE, Chief Tunnel Engineer, AECOM, USA

End of Short Course 17:00 PM

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History and Technical Developments of Segmental Linings

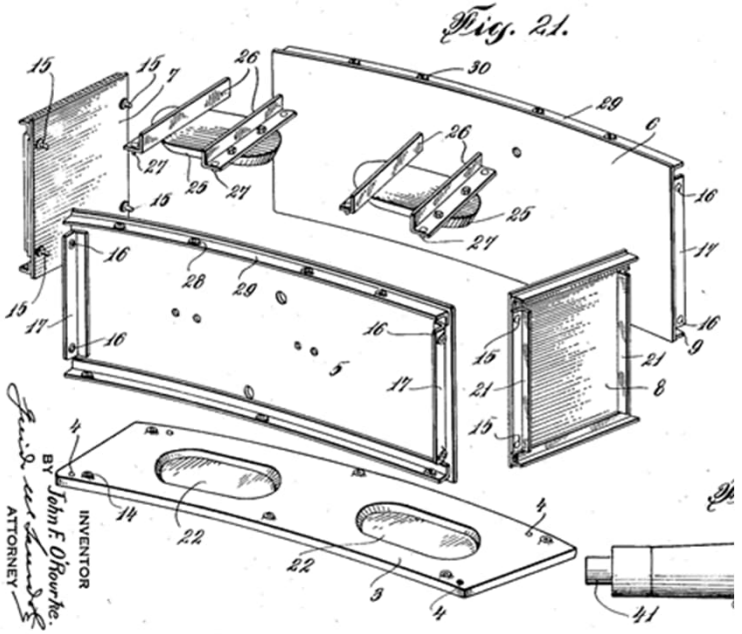
First 150 Years of Segmental Tunnel Linings

- First production in late 1800s…..then early 1900's (e.g. Parmley, O'Rourke, and others)
- Becoming more popular in last 50 years, due in part from much of the following improvements
  - Improved materials
  - Improved production facilities
  - Precision manufacturing and repeatability
  - Use of mechanized shields and TBMs
  - Systems approach to tunnel excavation and lining, often in more egregious ground conditions
  - Economies (life cycle cost) over other options

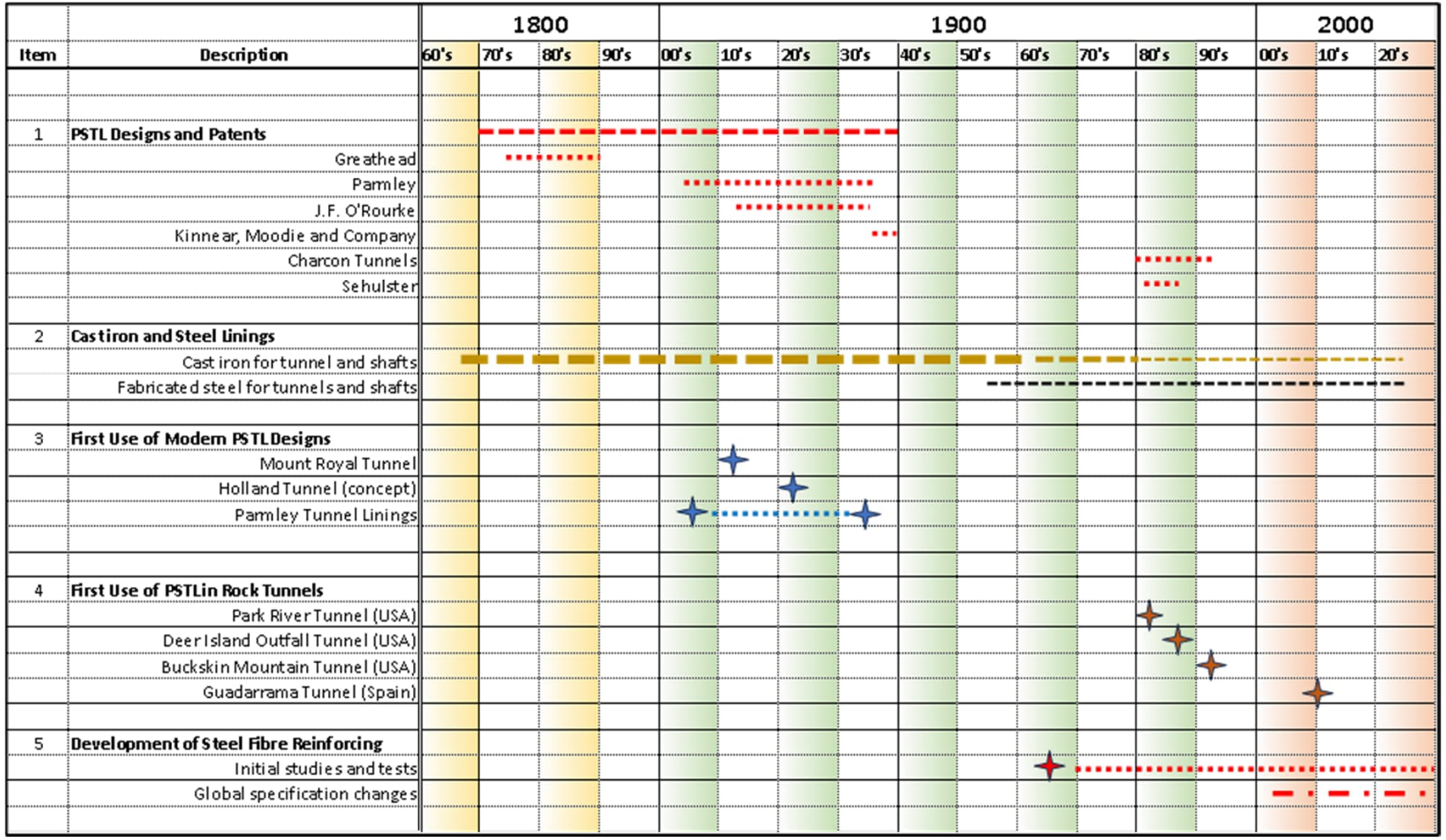
History and Technical Developments of Segmental Linings

TBM Developments and Lining Installation

- Tunnel Designers and Contractors called for changes in tunnel lining approaches and materials and required a “systems approach” to tunnelling operations; i.e. TBM excavation and lining, to improve overall economy.
- Single-pass tunnel linings became the preferred approach for soft ground tunnels (and some rock tunnels) using TBMs.
- Improvements in material properties, segment forms, connections, sealing and life cycle analyses made precast concrete more attractive than alternate materials.
- Precast concrete segments were also more economically attractive in most cases (but not all).



Timeline for Segmental Tunnel Linings

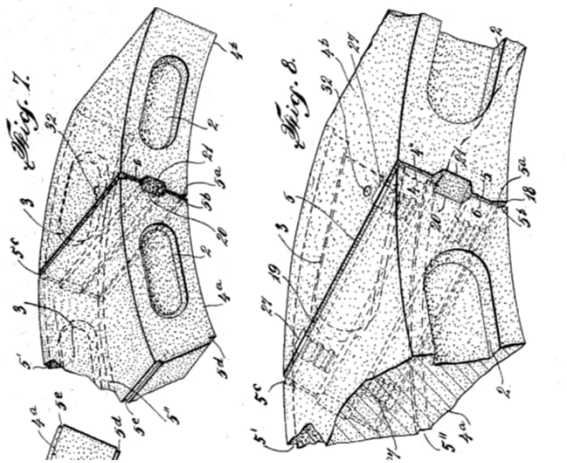


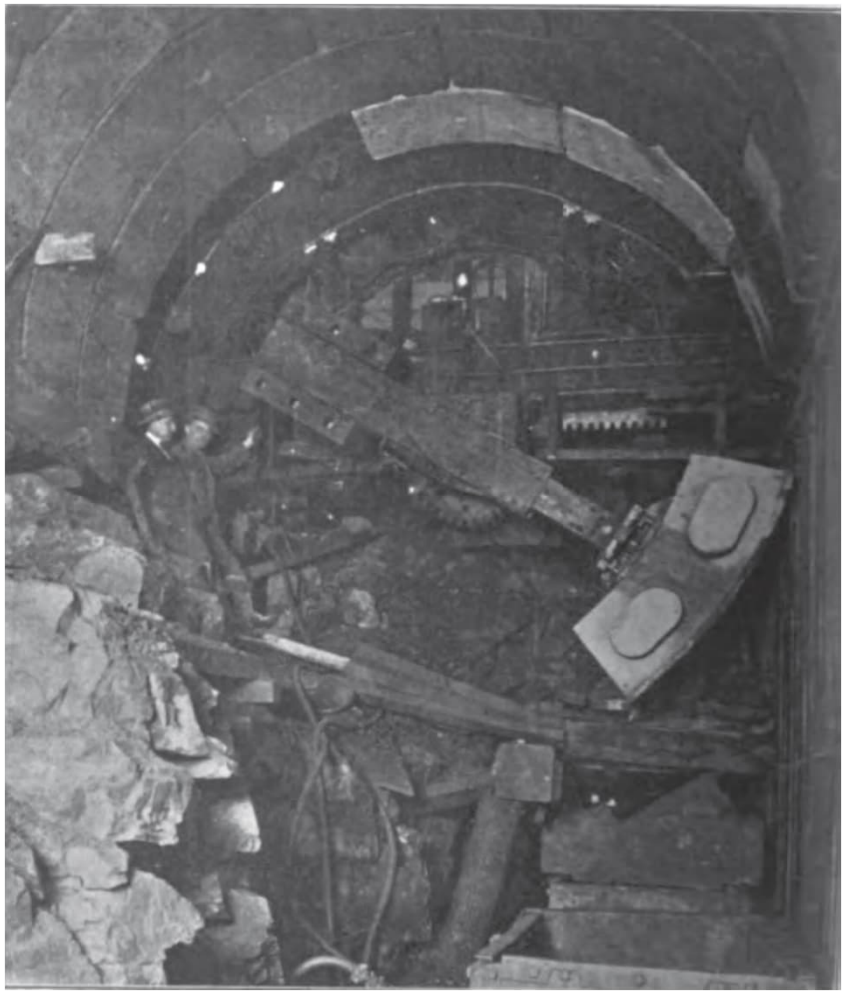
- From initial design concepts to mid-1900s
- Demise of preference for cast iron linings
- Early notable projects and innovative proposals
- Segmentally-lined rock tunnels

History and Technical Developments of Segmental Linings

O'Rourke "*Interlocking Tunnel Block*" Lining

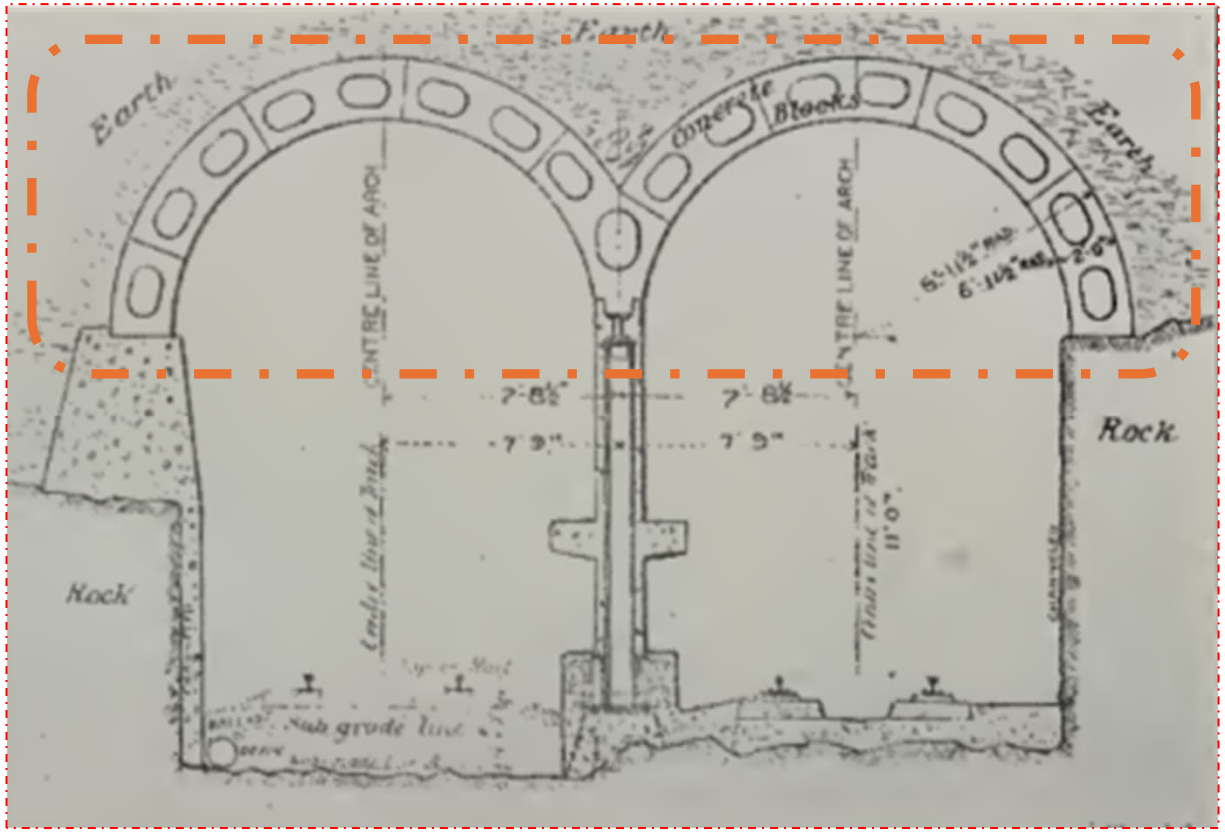
- Early Installation – Montreal, Quebec (1912)
  - Mount Royal Railway Tunnel (first major installation)
  - Twin parallel tunnels excavated concurrently
  - Mixed face tunnelling using PSTL for crown support
  - Tunnel in use for over 100 years until recently reconstructed and repurposed for metro

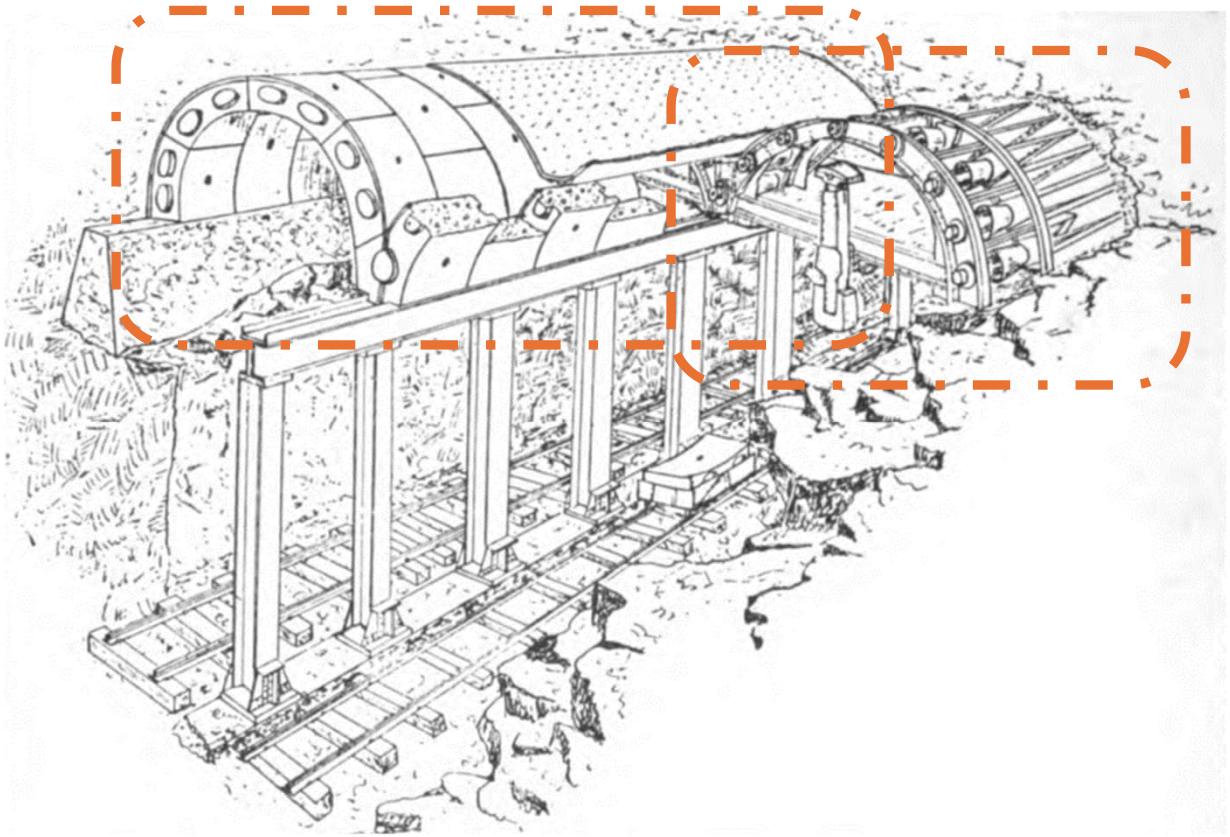




History and Technical Developments of Segmental Linings

Mount Royal Railway Tunnel – Montreal

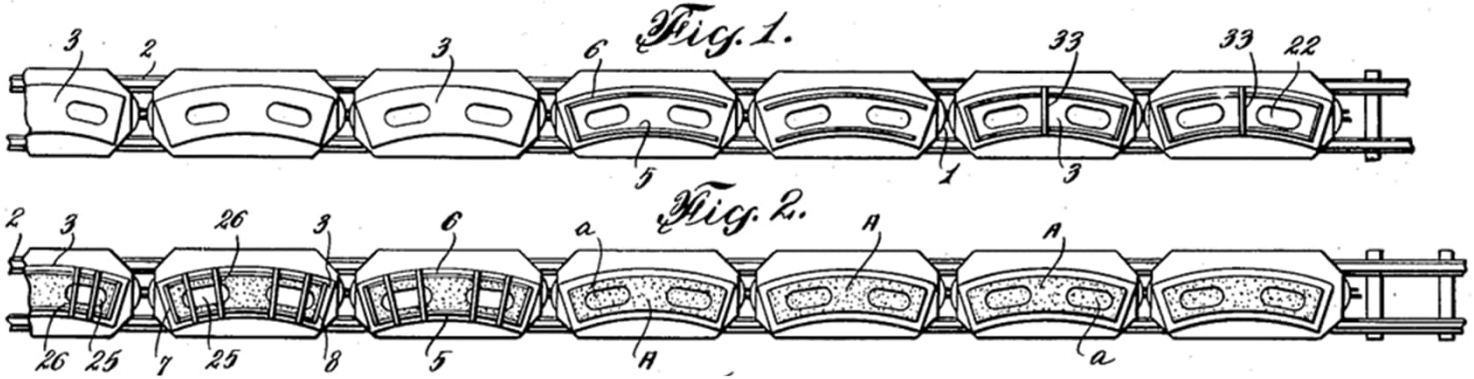


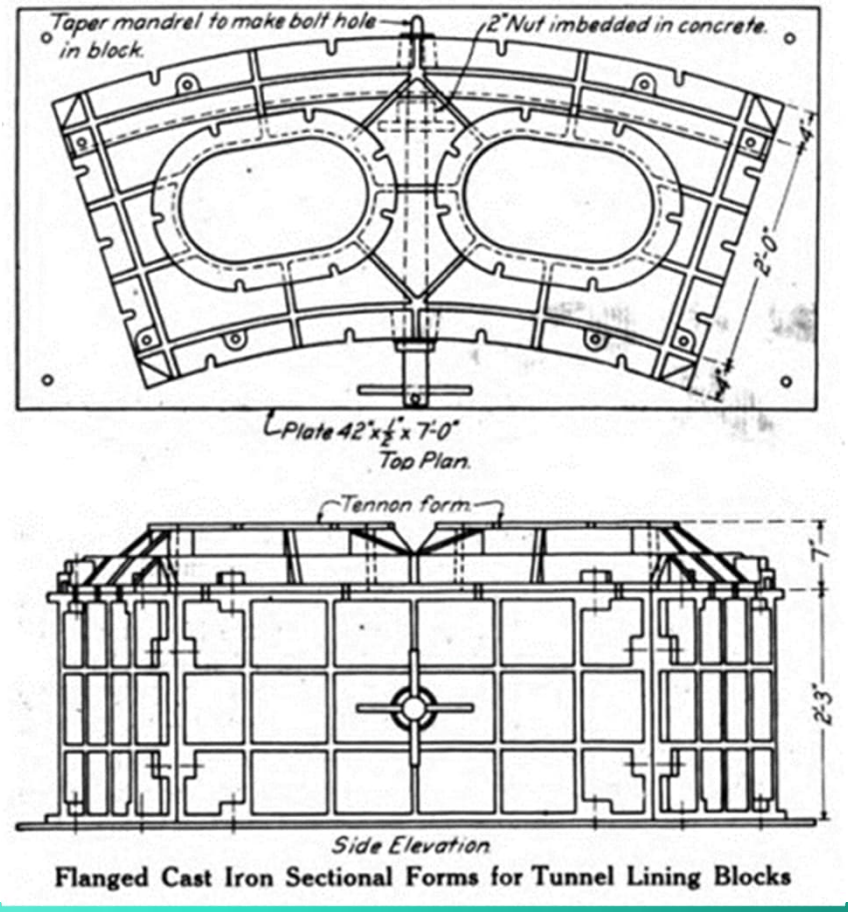


History and Technical Developments of Segmental Linings

Mount Royal Railway Tunnel – Montreal

- Segment Casting Methods and Materials
  - Machined cast iron molds were preferred
  - High tolerance on dimensions and repeatability
  - Carousel segment production facility on-site
  - Cast-in grooves and inserts

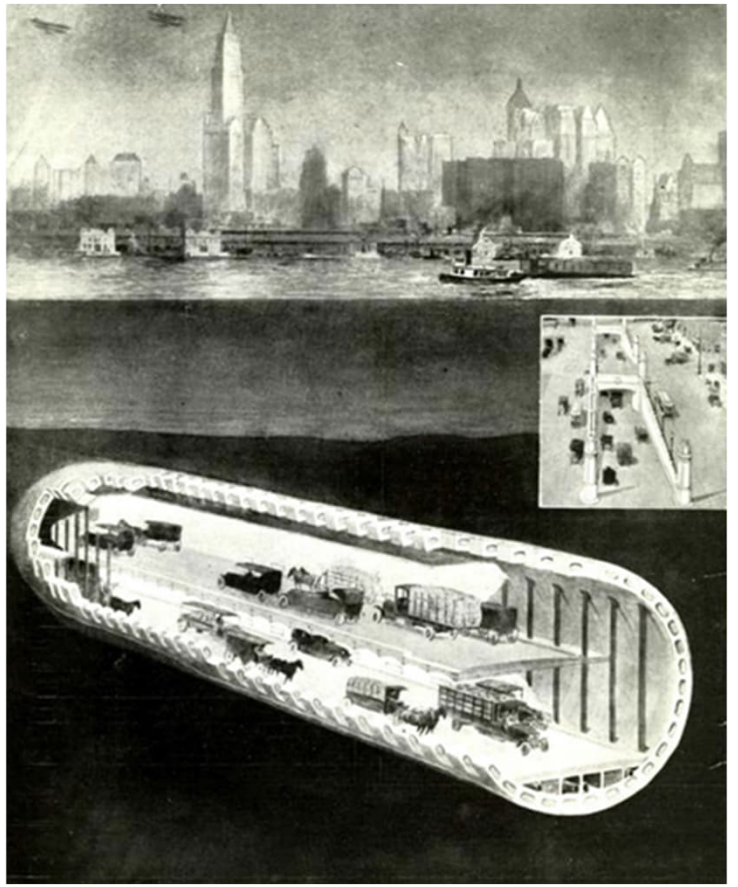




Flanged Cast Iron Sectional Forms for Tunnel Lining Blocks

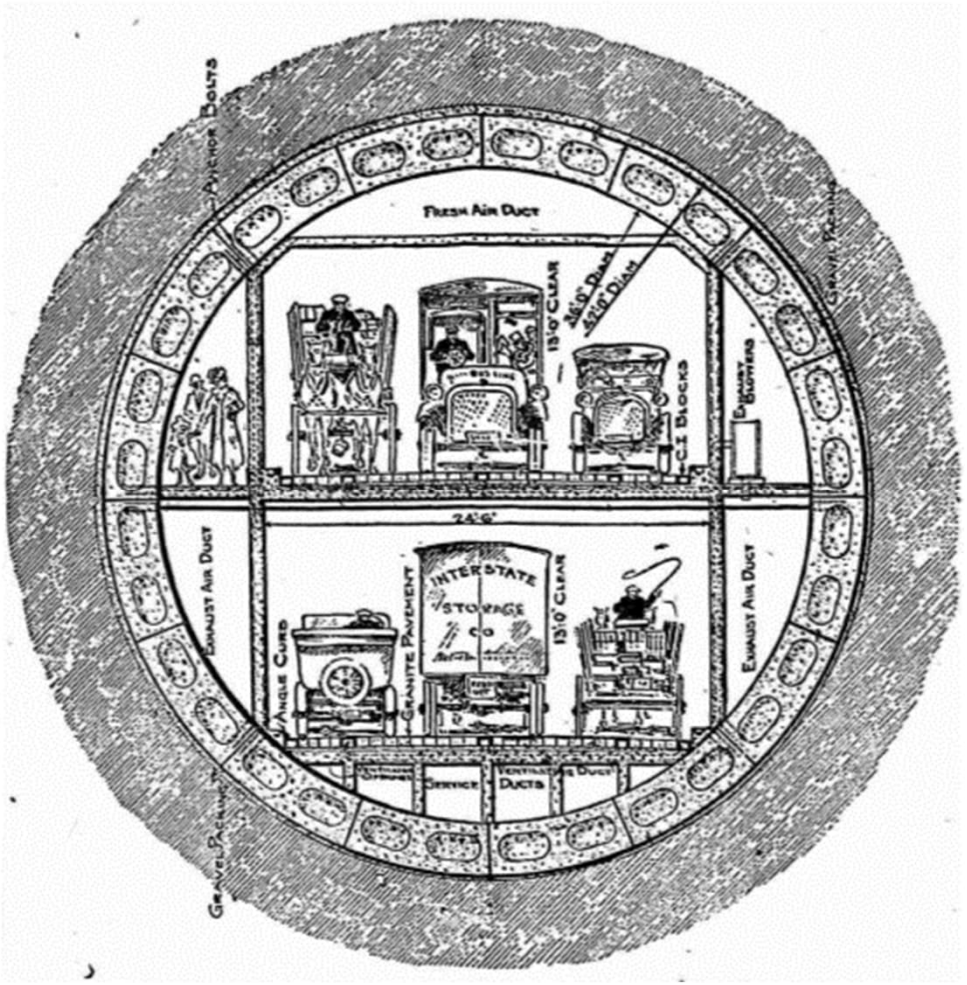
Holland Tunnel (New York City) – Concept

- Early Concept for a tunnel under the Hudson River ay New York City (1919);
  - Initially proposed by O'Rourke and Goethals (Panama Canal fame). Not constructed since a twin-bore tunnel arrangement was preferred.
  - First vehicle tunnel proposed under the Hudson River. Existing tunnels were dedicated to railroads (only).
  - Approx 12.8m (42 ft) bore diameter and possibly requiring the largest tunnelling shield ever considered….*extending the shield technology in its time*.



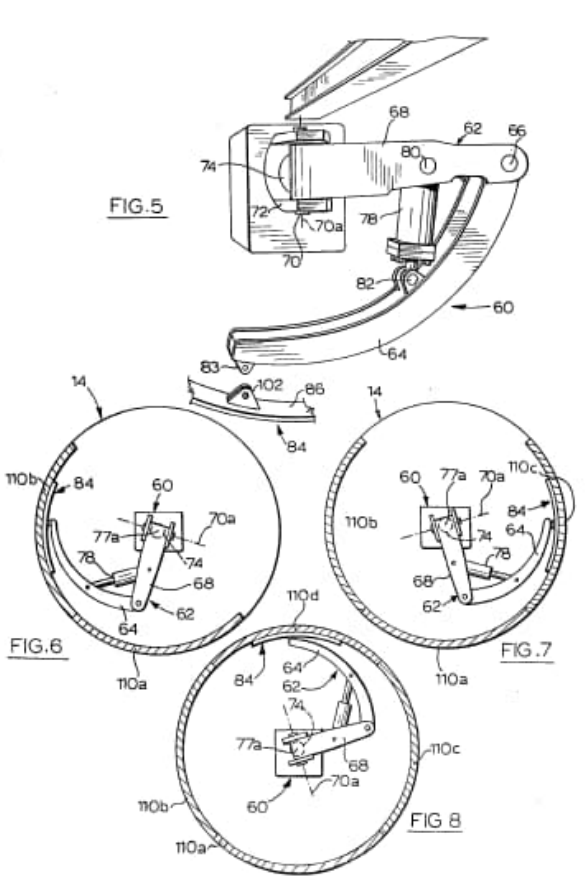
Holland Tunnel (New York City) – Concept

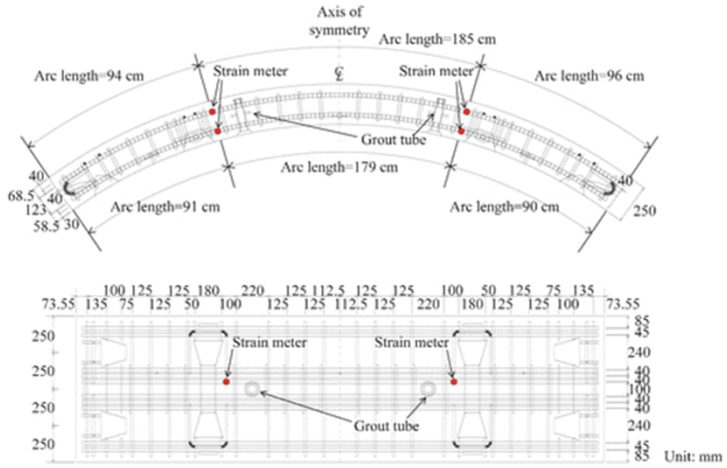
- Early Concept for a tunnel under the Hudson River at New York City (1919)
  - Three-foot thick precast "*interlocking tunnel blocks*" were proposed as the initial tunnel lining for ground support and groundwater control.
  - Over and under twin roadway decks, possibly the first of this configuration ever considered.
  - This concept was not constructed; instead, twin tunnels using cast iron segmental liners.



Advancements in Mechanization & Monitoring

- Mechanization and Automation
  - Mechanical and vacuum handling devices; plant and tunnel
  - Manufacturing automation - plant
  - Segment selection and positioning in tunnel
- Measurement and monitoring
  - Ring orientation selection
  - Instrumentation – loads and deflections
  - Gas sealing and watertightness



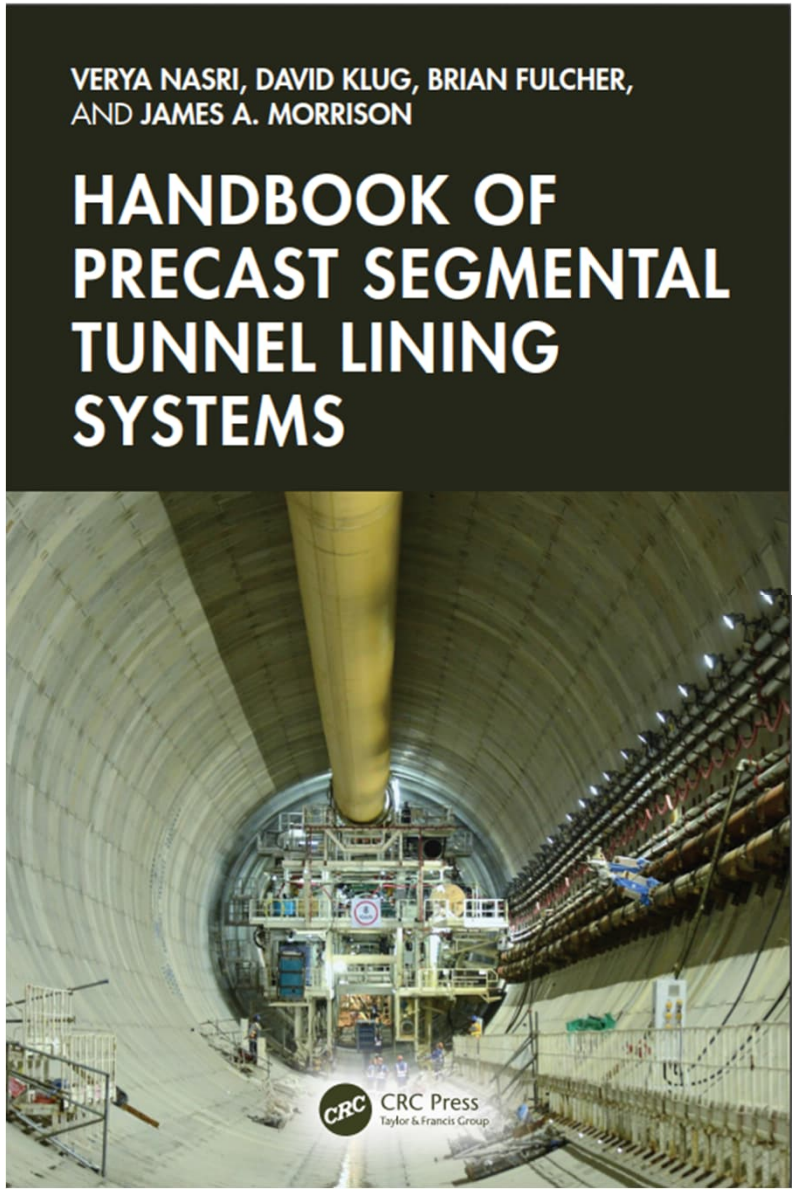


Summary

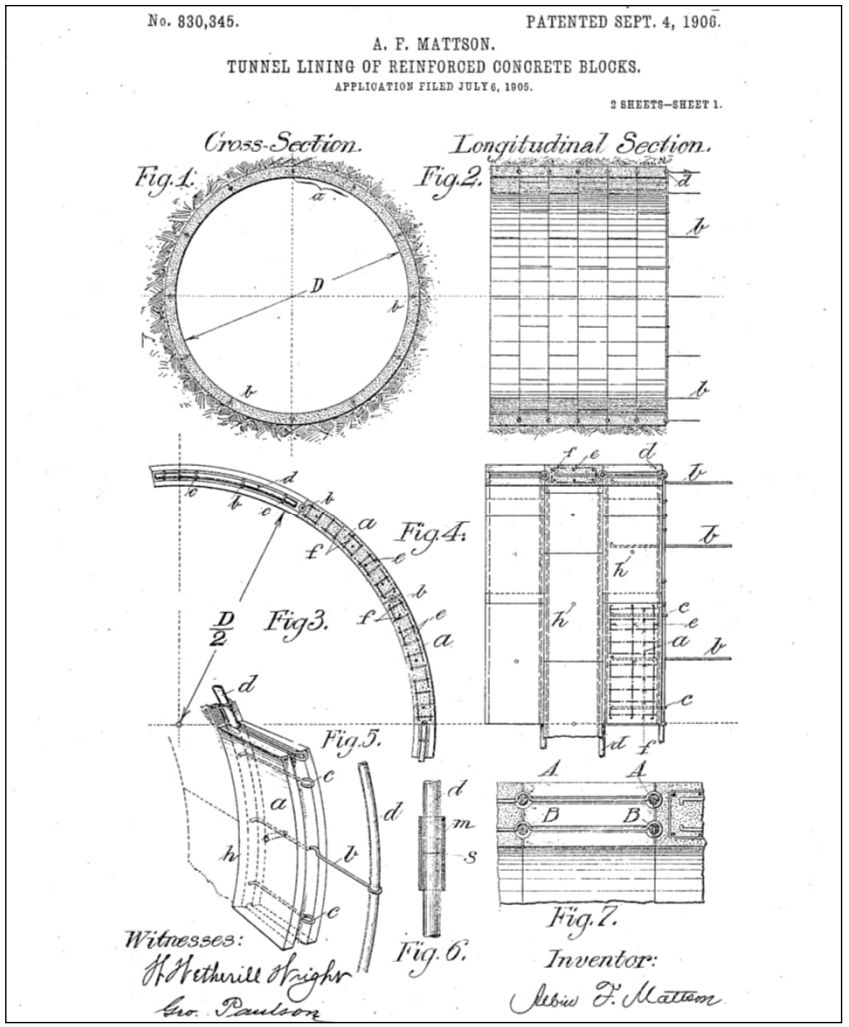
- Tunnel demand (i.e. quantities and loads)
- Tunnel location and function influenced design
- Tunnel durability (life cycle) & design innovations
- Material developments (including sustainability)
- Economic analyses and approach to constructing the work
- Mechanization, power and control for segment handling and installation
- Skilled labor force and Health and Safety considerations

Handbook Content

- Chapter 1 Introduction and History of Technical Developments
- Chapter 2 Geotechnical Design Considerations
- Chapter 3 Analysis and Design of Precast Segmental Tunnel Linings
- Chapter 4 Concrete Technology
- Chapter 5 Fiber Reinforcement
- Chapter 6 Connections and Accessories
- Chapter 7 Gasket Sealing Systems
- Chapter 8 Formwork Systems
- Chapter 9 Production
- Chapter 10 Handling, Transportation and Installation
- Chapter 11 Backfill Grouting of the Tunnel Liner
- Chapter 12 Durability and Service Life
- Chapter 13 Innovative Products and Applications



Chapter 1 Introduction and History of Technical Developments


No. 830,345. PATENTED SEPT. 4, 1906.

A. F. MATTSON.

TUNNEL LINING OF REINFORCED CONCRETE BLOCKS.

APPLICATION FILED JULY 6, 1905.

2 SHEETS—SHEET 1.

Cross-Section. Fig.1.

Longitudinal Section. Fig.2.

Fig.3.

Fig.4.

Fig.5.

Fig.6.

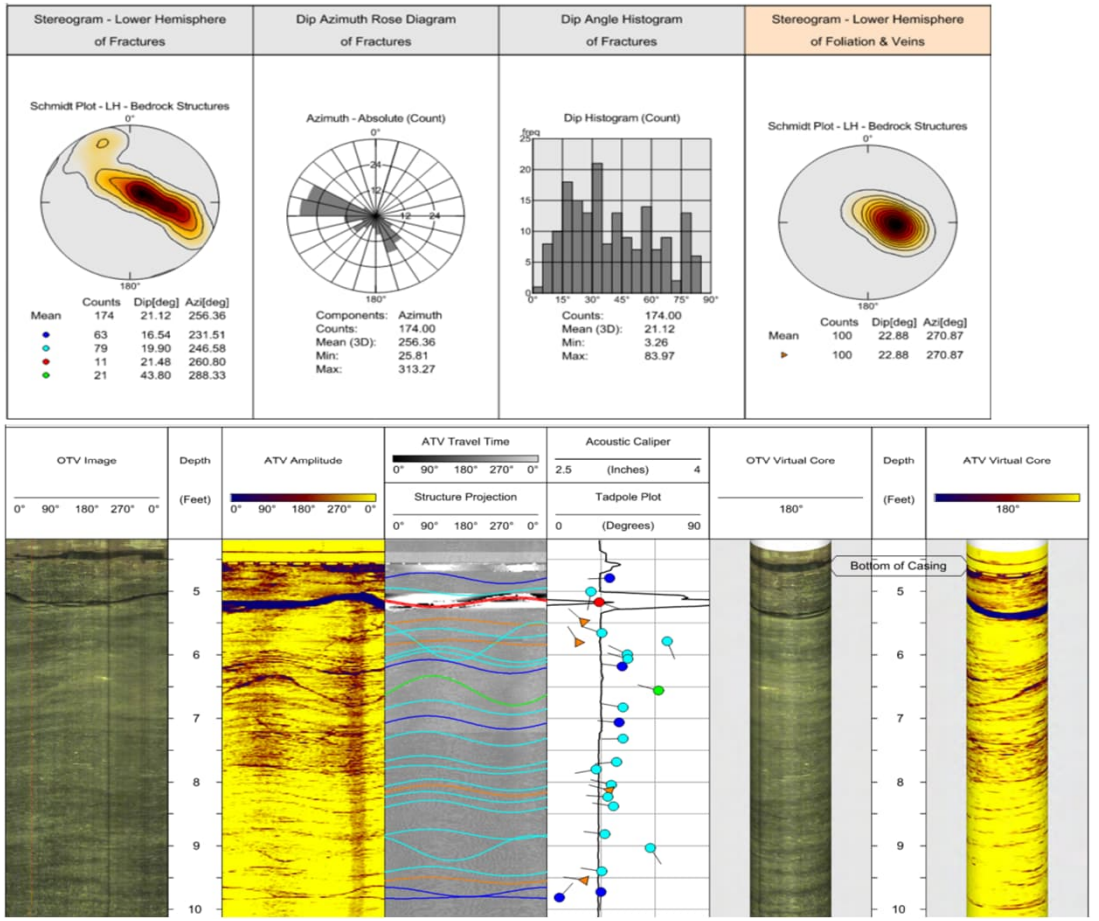
Fig.7.

Witnesses:

Inventor:

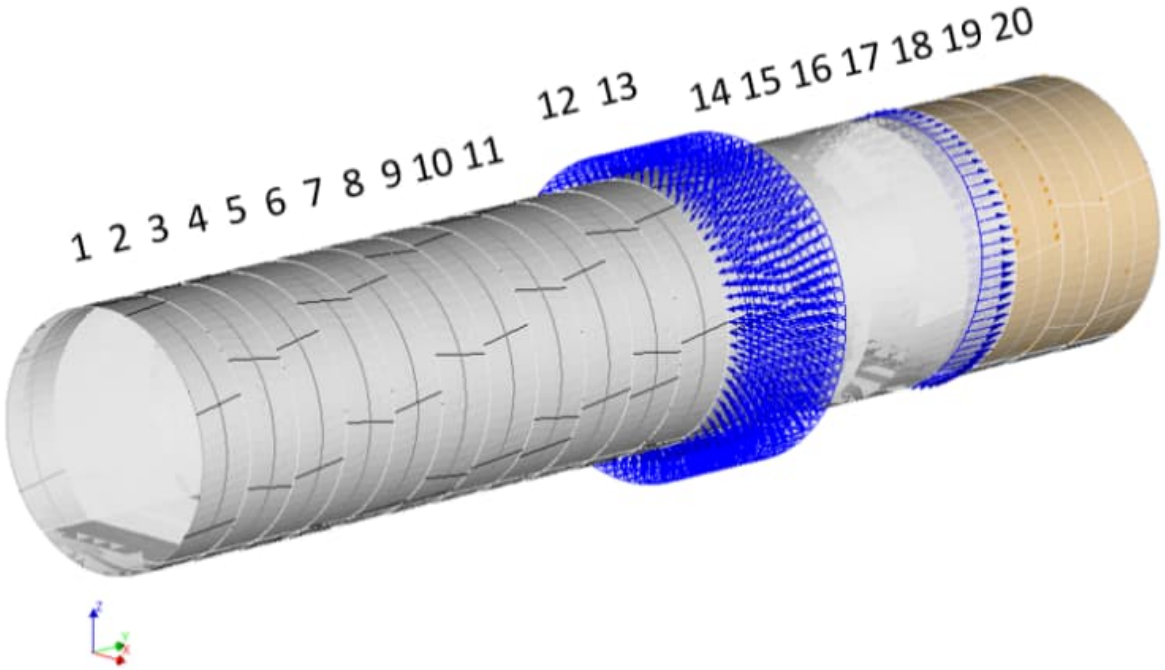
A.F. Mattson 1906, US Patent No.830,345 for Precast Tunnel Lining Segments

Chapter 2 – Geotechnical Investigations for Segmental Tunnel Lining Design



Typical OTV/ATV Borehole Logging Output

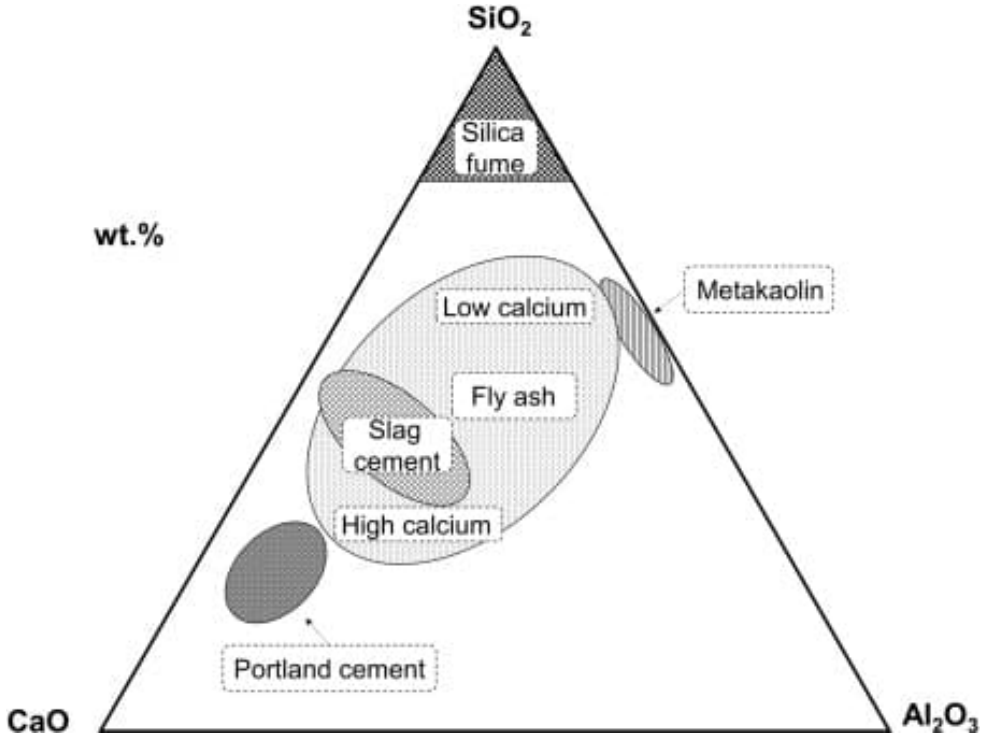
Chapter 3 Analysis and Design of Precast Segmental Linings



Shield-Driven TBM Processes Simulated in a Finite Element Model

Chapter 4 Precast Concrete Technologies

4.1 Introduction
4.2 Design of Concrete materials for Serviceability and Sustainability Requirements
4.3 Concrete Constituents and Cement Hydration Aspects
4.4 Aggregates
4.5 Water
4.6 Chemical Admixtures
4.7 Fiber Reinforced Concrete
4.8 Characterization of Ductility in Fiber-reinforced Concrete
4.9 Material testing levels and Backcalculation Approaches
4.10 Full-Scale Tunnel Segment Testing
4.11 Application of Statistical Process Control for QC
4.12 Fresh State, Rheology Tests and Workability
4.13 Durability Parameters and aspects of Service Life
4.14 Diffusivity Based Approaches for Control of Service Life
4.15 Fire Protection and damage Control
4.16 Pre-Construction Testing for Selecting Optimum Concrete Mixture
4.17 Authored Documents



Ternary Diagram of Portland Cement and Supplementary Cementing Materials

Chapter 5 Fiber Reinforcement in Precast Concrete Segments

5.1 Introduction – Fiber Reinforcement in Precast Segments

5.2 Testing Procedures and Performance Criteria

5.3 Quality Control During Construction

5.4 Passive Fire Protection (PFP) with Micro-PP Fibers

5.5 Sustainability

5.6 Combined Solutions

5.7 New Types of Fibers – Macro Synthetic / Polymers

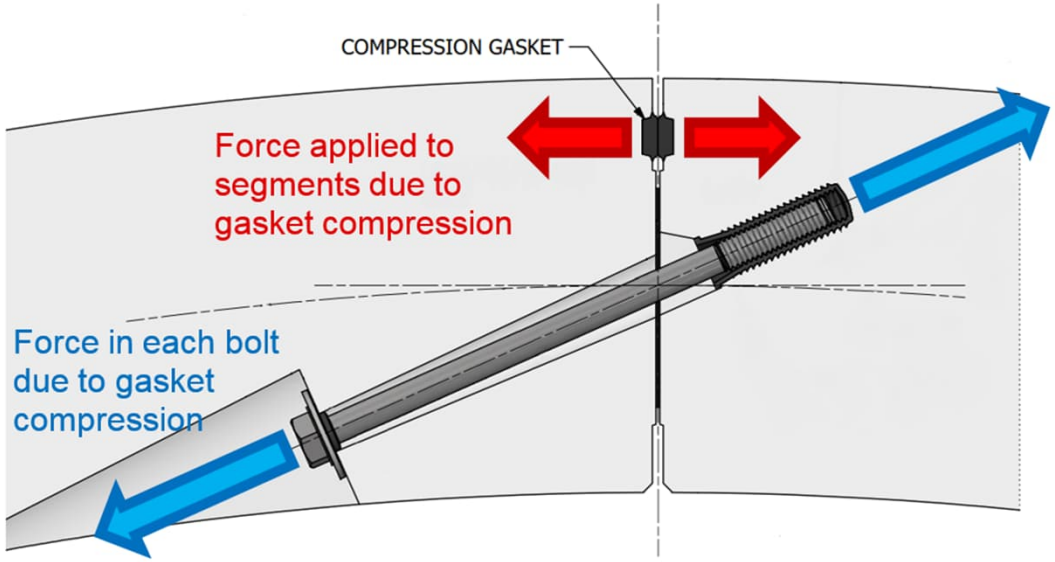
5.8 Tunnel Lining References Using FRC Precast Segments

5.9 References and Additional Reading Materials

Various Types of Fibers in Use Today

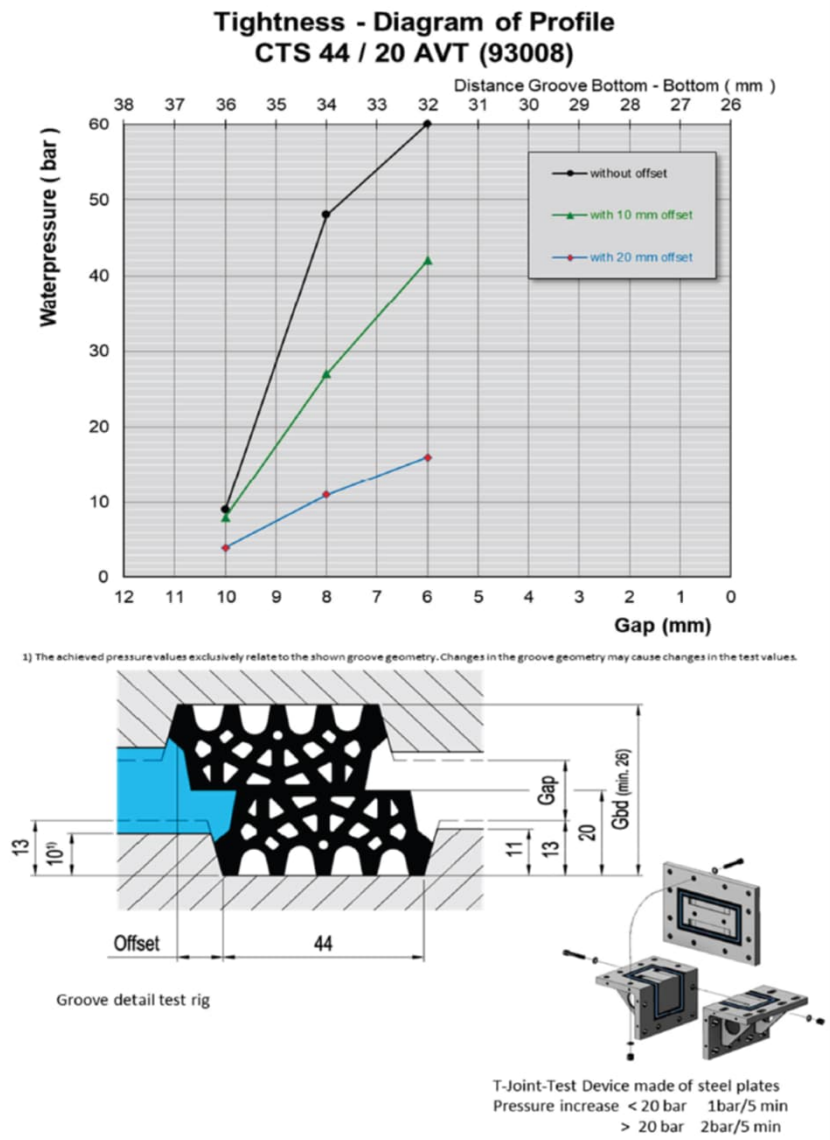
Chapter 6 Connections and Accessories for Segmental Tunnel Linings

6. Introduction
6.1 Connecting Bolts
6.2 Dowels and Bicones
6.3 Guide Rods
6.4 Grouting and Lifting Inserts
6.5 Joint Packing Materials
6.6 Testing of Connection Systems and Accessories
6.7 Design of Connection Systems and Accessories for Specific Loads
6.8 Design of Connectors at Cross-Passage Break-Out Areas
6.9 Through Segment Bolting / Dowel Systems for Seismic Applications
6.10 Recent Developments in Segment Joint Connection Systems
6.11 Fastening Systems for Tunnel Segments
6.12 Case Histories of Interesting Projects



Force Exerted by the Gasket on the Bolting System

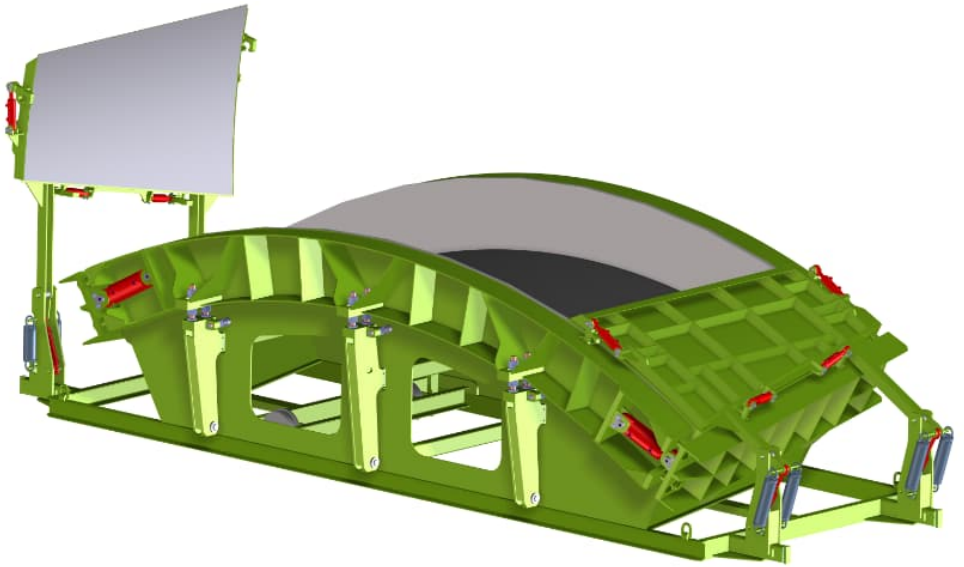
Chapter 7 Gasket Systems for Sealing Segmental Tunnel Linings



Gasket Water Tightness Diagram

Chapter 8 Formwork Systems for Precast Segmental Tunnel Linings

8.1 Segment Mold Design
8.2 Segment Mold Manufacturing
8.3 Design of Segment Plant Layout and Main Components
8.4 Carrousel and Stationary Production
8.5 Segment Handling Equipment
8.6 Three-Dimensional Measurement of Segment Molds and Segments
8.7 Master Ring Erection and Virtual Ring Build
8.8 Tolerances of Segment Molds and Segments
8.9 Segment Tracking and Quality Documentation System
8.10 Segment Mold Quality Control
8.11 Innovation in Tunnel Segment Production
8.12 Case Histories of Segment Production
8.13 References and Additional Reading Lists



Hydraulically Operated Mold

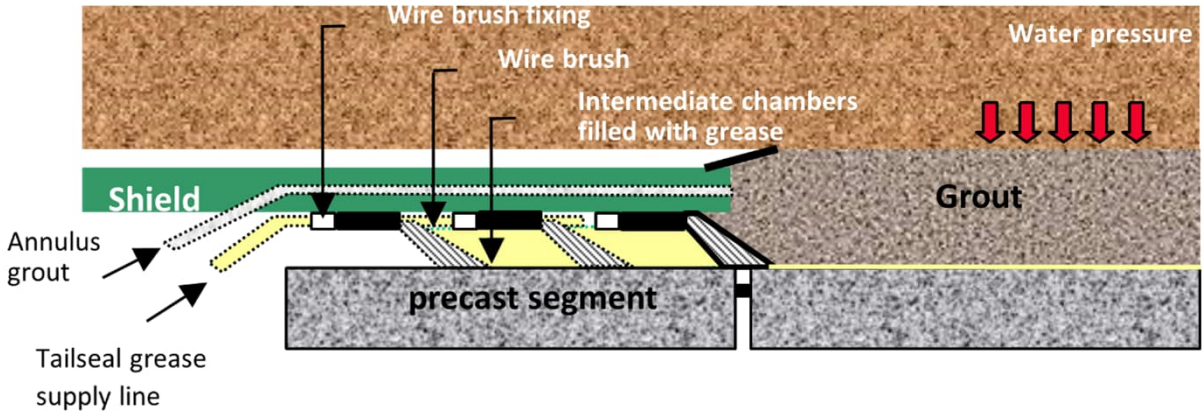
Chapter 9 Fabrication of Precast Segmental Tunnel Linings

Fiber Dosing and Metering System

Chapter 10 Transportation, Handling, and Installation of Precast Segmental Tunnel Linings

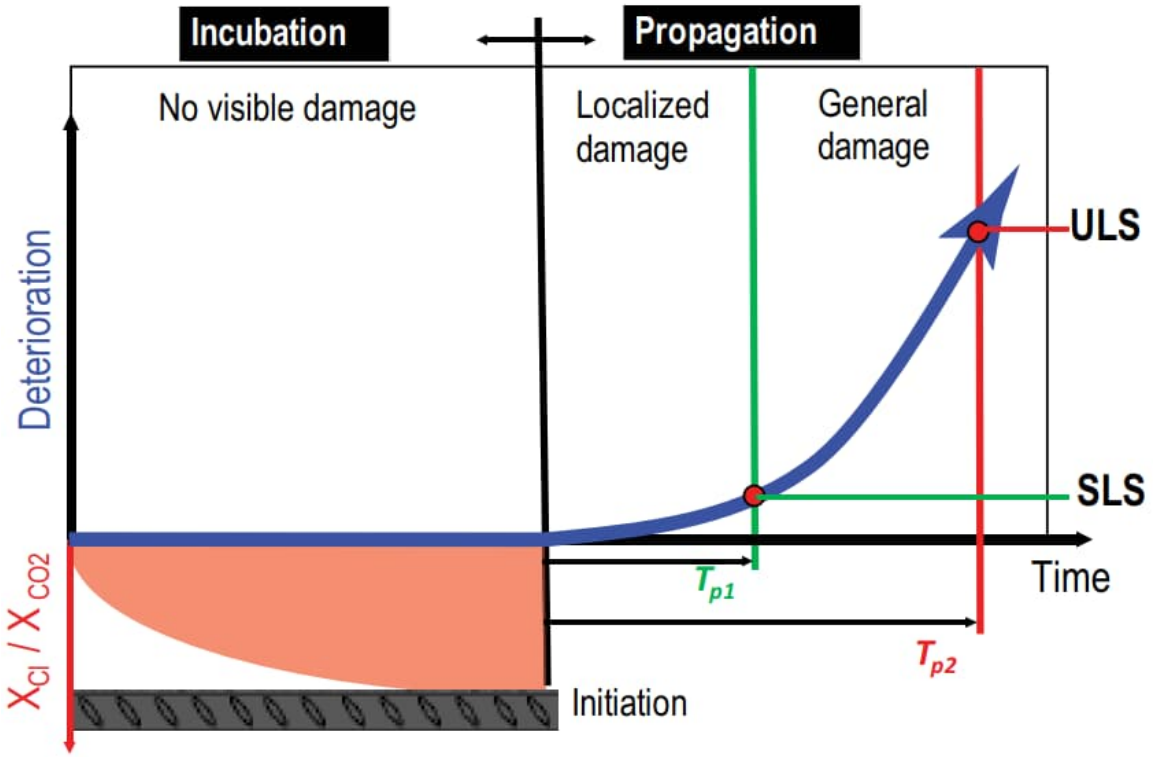
Robotic Arm at Segment Unloading Station

Chapter 11 Backfill Grouting of Precast Segmental Linings



Injecting Grout Through TBM Tail Shield

Chapter 12 Durability and Service Life of Precast Segmental Linings



Reinforced Concrete Deterioration Model

Chapter 13 Innovative Products and Applications

13.0 Current Position of Precast Segmental tunnel Linings in Tunnel Industry
13.1 Major Innovation that Impacted Precast Segmental Tunnel Linings Market Worldwide
13.2 Innovations in Segment Connector Componentry Systems
13.3 Innovations in Precast Segmental Tunnel Linings Sealing Systems
13.4 Innovations in Precast Segmental Tunnel Linings Reinforcement Systems
13.5 Innovations in Precast Segmental Tunnel Linings Corrosion Resistance
13.6 Innovations in Precast Segmental Tunnel Linings Design
13.7 Innovative Applications for Precast Segmental Tunnel Linings
13.8 Precast Segmental Tunnel Linings Applications in Shaft Construction
13.9 Utility Corridor Tunnel Construction Using Precast Segmental Tunnel Linings
13.10 Gas and Oil Industry Pipeline Tunnels
13.11 Innovations in Precast Segmental Tunnel Linings Casting Plant Technology
13.12 Innovative Permanent Identification Systems for Each Precast Segmental Tunnel Linings Segment
13.13 Innovations in Precast Segmental Tunnel Linings Materials
13.14 Future Needs for Innovation in Precast Segmental Tunnel Linings Project Materials and Design
13.15 Future Innovative Needs
13.16 Innovative Future Applications for Precast Segmental Tunnel Linings
13.17 Geothermal Energy Recovery Using Precast Segmental Tunnel Linings
13.18 Innovations in Mechanized Tunneling for Cross-Passage Construction

Shanghai Metro Double-O Tunnel

FRC Precast Segmental Lining of TBM Tunnels

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Thank you!

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