Tunnel Losses: Causes, Impact, Trends and Risk Engineering Management

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I. INTRODUCTION

Tunneling and Underground Works are unequivocally subject to a diversity of inherent uncertainties associated with the geotechnical, hydro-geological and environmental conditions that surrounds them.
With the noteworthy increase in the construction activities of major worldwide infrastructure works and their particularities (e.g. completion time and budget constraints and limitations), substantial pressure is being exerted upon insurance industry subject to increased failure probabilities and failure events.

- **In this work we demonstrate the key factors that are persistently involved in tunnel losses.**
- **These losses are considered and analysed on a quantitative basis referencing cost and time implications, construction methodology and developed failure type**
- **A number of Insurance related matters illustrating some of the underlying potential pitfalls and limitations are presented herein, highlighting the importance of early expert's input and feedback.**
- **Recommendations are given on the basis of a pro-active & focused risk engineering management.**

II. TUNNEL HAZARDS & RISKS

The present contribution is based upon documented and publicly available data on tunnel failure incidents worldwide. Comprehensive lists of major and noticeable tunnel failures were retrieved from the following sources:

- Engineering & Development Department (CEED), April 2015, Catalogue of Notable Tunnel Failures – Case Histories (up to April 2015)
- Reiner H, Developments in the Tunneling Industry following introduction of the Tunneling Code of Practice, IMIA Annual Conference, Amsterdam September 2011.
- IMIA WGP 48 (06) ALOP/DSU coverage for tunneling risks, 39th Annual Conference, Boston 2006
- MunichRe, The Code of Practice for Risk Management of Tunnel works Future Tunneling Insurance from the Insurers' point of view, ITA Conference Seoul April 2006

The main hazard sources of Tunnel and Underground Works are as follows:

i. Geology – Geotechnical Conditions
Influence of physical & mechanical ground properties / their "realistic" estimation / impact of ground water

ii. Tunnel Construction Methodology
Based on factors such as ground conditions, tunnel depth, contractor's experience, machinery availability, etc various construction methods can be selected (standalone or combined), like: TBM – NATM/D&B – C&C – etc.

iii. Design Approach
Importance predominately related to the profound knowledge of ground conditions, in-house experience

iv. Construction Execution & Workmanship
Importance of well-established and project-specific Construction Management Plan – Adherence to the approved design concept – Applicable Work Specifications

III. TUNNEL LOSSES ANALYSIS

The main objective is the analysis and evaluation of the available tunnel failure incidents and corresponding Insurance industry losses.

A. TUNNEL FAILURES

The analysis showed that the Soil-like ground types are more prone to instigate a tunnel failure (Figure 1 below).

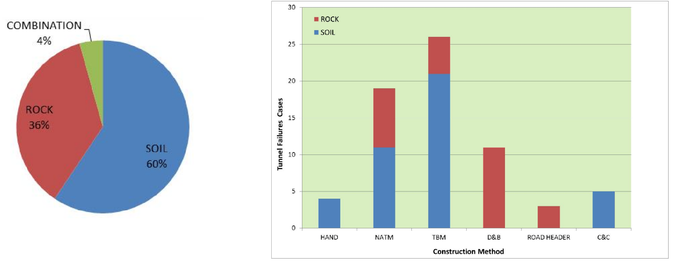

Figure 1: Tunnel Failures vs Ground Conditions and Construction Methodology

- TBM tunneling method is marginally outpacing NATM method but overall 'Conventional' tunneling prevails by counting almost two thirds of examined cases.
- Face instability stands out as the most frequent failure mode counting for almost half of the examined cases

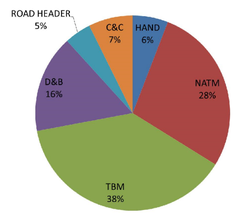

Figure 2: Tunnel Failures vs Construction Methodology

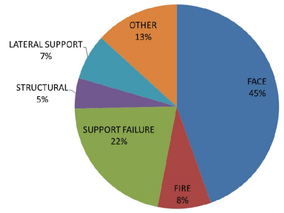

Figure 3: Tunnel Failures Types

B. TUNNEL INSURANCE LOSSES

Insurance related financial losses span over a wide range of values but exhibit a denser (arguably normal) distribution to values up to 50mUSD, which is in good agreement with most insurance policies tunnel limits.

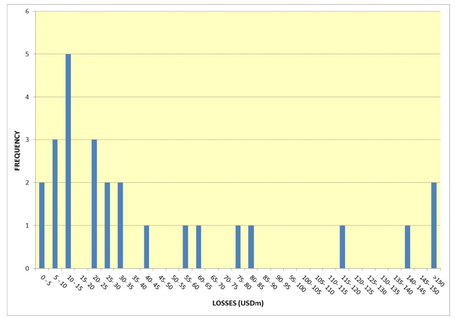

Figure 4: Insurance Financial Losses Frequency Distribution

The corresponding incurred project Time Delays also vary significantly but demonstrate likewise a rather 'normal' distribution for values up to 24 months.

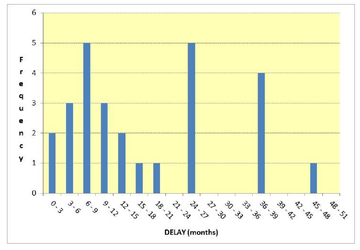

Figure 5: Project Delays Frequency Distribution

A correlation between Insurance Financial cost and corresponding Time Delays can be established which demonstrates the hysteresis of cost relative to time.

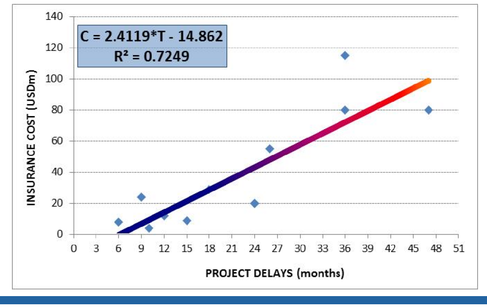

Figure 6: Relationship between Insurance Cost and Time Delays

IV. RISK ENGINEERING MANAGEMENT

- Early and Continuous active involvement of experienced Risk Engineering Management Consultants
- Due consideration of the project's life cycle, from conceptual stages to construction and operational phases
- Client's Role & Responsibilities of utmost importance to ensure smooth execution of the project
- Risk Registers are significantly important to timely identify project risk mitigation measures and opportunities
- Comprehensive Risk Management Toolkit, including among others:
  - "A Code of Practice for Risk Management OF Tunnel Works" (ITIG 2012)
  - "ITA WG2 – Guidelines for Tunneling Risk Assessment" (ITA – AITES 2006)
- Continuous risk engineering review of the tunneling project through:
  - Benchmarking against the Tunneling Code of Practice
  - Risk Engineering Site Surveys at regular intervals to confirm continuing compliance with the "Code"
- Sufficient Tunnel Works Limit included in the Insurance Policy meticulously deduced from a PML analysis

MOST INFLUENTIAL FACTORS RELATED TO A TUNNEL FAILURE

- **Geology / Hydrogeology**
  - i. Knowledge shortage directly attributed to Ground Investigation Schemes
  - ii. Identification of Weak Ground Zones and Prominent Features (e.g faults)
  - iii. Stratification – Low bearing formations located at the tunnel's crown can cause significant surface subsistence, especially in shallow tunnels

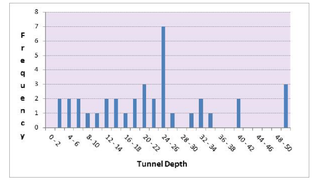

Figure 7: Failed Tunnels Depth Distribution

- **Design**
  - i. Tunnel Face Stability and Support Measures under uncertainty
  - ii. Proposed Instrumentation & Monitoring coupled with 'realistic' trigger levels.
  - iii. 'Realistic' estimation and simulation of overall exerted stresses on the tunneling profile
- **Construction Execution & Workmanship**
  - i. Robust Construction Management Plan
  - ii. Adherence to the approved design and Method Statements
  - iii. Composition and Qualification of the key project personnel and workforce

V. CONCLUSIONS

- **Tunnel Failures can cause substantial insurance related financial loss and significant project delays.**
- **We have analysed existing, publicly and commercially available, tunnel failures identifying the most influential factors contributing to a tunnel failure incident.**
- **Insurance Cost and Time Delays have been examined on a statistical-based process delineating their Frequency Distribution.**
- **We establish a linear relationship between insurance cost and corresponding time delays.**
- **We highlight the benefits of a pro-active Risk Engineering Management with the early involvement of experienced consultants and the use of worldwide recognised guidelines, such as TCoP and ITA.**

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