Master Thesis

Topic:

Probabilistic assessment of tunnel lining stability by considering the uncertainty of design parameters and soil variability

Description:

The construction of tunnels and their design are complex tasks in the field of engineering. The challenges in the analysis of tunnel linings are dominated by non-linear effects, defining the overall load-bearing behaviour and the soil-structure interaction [1]. The responsibility of the engineer is to design a tunnel such that the safety requirements pertaining to the stability and serviceable of the structure are met while accounting for the complexity of the soil-tunnel interaction and variable geotechnical conditions. These factors make it a difficult task for engineers to ensure the economical design of tunnels whilst ensuring a low probability of failure. Additionally for tunnelling, no standardised design procedure is available.

With the implementation of the DIN EN 1997 (EC 7) [2], the limit state design approach from structural engineering was adopted in geotechnical engineering. In structural engineering, the application of partial safety factors for limit state design was found to be an objective and efficient way to ensure the stability and reliability of a structure. The concept of safety factors considers the statistical variability of the load and the resistance and effectively adds a safety margin to the design. This safety margin is achieved by increasing the characteristic load, while decreasing the characteristic resistance. The challenge in transferring this concept to geotechnical engineering, especially where soil-structure interactions play a crucial role, is the difficulty in separating the load from the resistance. In the case of a tunnel (and other geotechnical problems e.g. retaining walls), the soil acts not only as a load, but also as a supporting structure. The use of partial safety factors is not directly applicable for tunnel design without considering the uncertainty of soil parameters. The definition of the ultimate state (US) presents another difficulty for the design of a safety concept in tunnelling, as the definition of the point of ultimate failure for tunnel structures is not clearly defined. Different approaches are found in practise, such as the comparison of bending moments in the segments with the resistance of the reinforcement [3]. Though this approach is often used in practise, the conclusion that the first plastic hinge leads to a global failure is questionable. The non-linearity of the tunnel-ground interaction stands against this argument. The current procedures of tunnel design for the assessment of the serviceability and ultimate limit state have two major disadvantages: 1) the probability against failure is not sufficiently estimated and 2) the influence of the uncertainty of the geotechnical parameters are typically not quantified.

Besides the deterministic analysis with safety factors, DIN EN 1990 (EC 0) [4] gives the possibility to use probability-based methods for the analysis of limit state functions. The probability of failure can be estimated by different methods, e.g. FORM (First-Order Reliability Method), MCS (Monte Carlo Simulation). These probabilistic methods have been found to be quite conservative as they typically do not consider the spatial correlation of soil, i.e. that the soil behaviour of even a homogenous layer varies spatially. The Random Finite Element Method, which involves generating a number random fields of spatially correlated variables representing soil properties (e.g. friction angle or stiffness) for use in a numerical FE model and subsequently determining the probability of failure, has been gaining attention within geotechnical engineering,

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especially in the field of tunnelling (e.g. [6]). With this method, uncertainties relating to the variability of the soil can be considered in a finite element model within a probabilistic framework, whilst simultaneously considering the variability of factors relating to the tunnel (e.g. concrete strength; without spatial variability). Additionally, reliability analysis can help to understand the behaviour of a system and assess the traditional deterministic design method. Finite element models can be combined with the random field theory, to analyse the performance of a tunnel lining in a probabilistic framework. Within this framework, data from site investigations and in-situ measurement can be progressively included in the design to update the model.

According to Pells [5] a large amount of tunnel failures between 1964 and 2010 were found to be caused by unexpected geological or hydrogeological conditions. This thesis aims to investigate the influence of unexpected geological conditions on the assessment of the stability of a tunnel within a probabilistic framework with the aim of comparing the results to the deterministic approach, currently being used in practice.

Scope of work:

1. Selection of a tunnelling case study with a TBM or NATM method in homogenous soil conditions, where ideally measurement results as well as laboratory and/or field testing are available
2. Calibration of the chosen material model parameters based on the expected (average) ground properties
3. Quantification of the soil spatial variability by calculating the experimental variogram and selecting a suitable model

<u>Simplified structural model</u> (with a higher probability of failure due to varying the depth of cover and loading due to neighbouring buildings):

4. Structural design of the tunnel in accordance with EC 7 and/or other accepted design approaches (e.g. ZTV-ING)
5. Development of a 2D finite element model in ABAQUS for the assessment of the chosen case study; neighbouring buildings should be modelled as rigid surfaces with a uniform load
6. Determination of the factor of safety by use of either the load or material factored approach
7. Determination of the probability of failure of the tunnel through Monte Carlo Simulations:
    a. Without considering spatial variability i.e. constant geotechnical parameters for each simulation
    b. With considering spatial variability and the Random Finite Element Method based on an existing tool
8. Comparison of the factor of safety with the probability of failure
9. Undertaking of a sensitivity analysis considering the following factors:
    a. the variation of the material strength
    b. the variation of the soil properties
    c. the variation of the spatial variability

[Optional] Reference structural model:

10. Steps 5-8 considering the real boundary conditions of the tunnel (depth of cover, loading due to nearby buildings etc.); including calibration of the model based on measurement data

Prerequisites:

- Good knowledge of the mechanical behaviour of soil and tunnelling
- Well-founded knowledge in the concepts of statistics and risk analysis
- Knowledge of ABAQUS and at least one programming language

Date of formulation

Date of issue:

Issued to:

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Bibliography

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