Computational Wind Engineering simulations for design of Sand Mitigation Measures and performance assessment

Summary

The engineering interest about the windblown sand has been significantly growing in the last years. The large ongoing infrastructure projects in deserts require robust, cost-effective and high-performance solutions. This PhD Thesis deals with the application of the general Computational Wind Engineering design approach to developing new, innovative Sand Mitigation Measure (SMM) employed to protect desert railways. The Thesis is developed within the H2020-MSCA-ITN-2016 *"Sand Mitigation along Railway Tracks"* (SMaRT) European project under the Grant Agreement No 721798.

The scientifically based problem setting, design framework and the quantitative assessment of the sand mitigation measures are, at the present time, not sufficiently developed in the literature. The Thesis, at first, introduces an exhaustive problem setting in the form of the innovative classification of the problems sand is causing around railways, analogously to equivalent actions in civil engineering. Sand Serviceability Limit States involve railway partial loss of capacity and passenger discomfort. Conversely, Sand Ultimate Limit States involve service interruption and passengers unsafe conditions. Additionally, the new classification of sand mitigation measures is introduced, based on their relative position to the railway infrastructure and their working principle. Source-Path-Receiver categorization follows. The classifications are introduced to provide an orienting framework for the research and design activities within the Thesis.

Two innovative sand mitigation measures are developed. At first, the Path SMM called *Shield for Sand* is optimized in the sense of minimizing the cost-to-performance ratio with the Gradient-based and Genetic algorithm models. Additionally, an innovative Receiver SMM, called *Sand Blower* is designed from scratch. For the design, a deeper insight into the aerodynamic behavior of unmitigated railway systems is necessary. Therefore, a detailed numerical sensitivity analysis is carried out by varying the geometric parameters of the railway substructure, comprising of ballast and embankment. Moreover, typical conventional and non-conventional superstructure systems are tested. In particular, standard rails, tubular tracks, humped sleepers, and humped slab are considered. From the mentioned, humped sleepers applied on the most gentle ballast and embankment show the most promising results. In the light of this, the *Sand Blower* has been designed, applied

to that railway system.

This Thesis develops through the following chapters according to the objective methods and the applications mentioned above. The introduction to the study is presented in **Chapter 1**.

Chapter 2 is devoted to the state of art. In particular, this chapter starts with the definition of the sand action in analogy to other actions in civil engineering. After, the thorough description of the innovative classifications of sand limit states and the sand mitigation measures are given. The chapter finishes with the best practices and guidelines on sand mitigation strategy.

The description of the mathematical and numerical methods is given in **Chapter 3**. Briefly, the mathematical aspects of the Navier-Stokes equations are complemented by their numerical discretization in Finite Volume Method (FVM). The second part of the chapter deals with the description of Gradient-based optimization and the Genetic algorithm.

In **Chapter 4**, the design process of innovative sand mitigation measure *Shield for Sand* is given. The conceptual and preliminary design are briefly tackled, due to the fact they are not developed within the Thesis. They are followed by the detailed description of detailed design, optimization process and the verification of the optimized geometry by the higher fidelity numerical model.

Chapter 5 is devoted to the investigation of the aerodynamics of the unmitigated railway systems in the form of a thorough sensitivity study of both substructure and superstructure. The best performing combination is used in the conceptual and preliminary design of the *Sand Blower*.

In the final chapter, the conclusions and the future perspectives are detailed and critically discussed.

The Thesis aims at providing original contributions on four specific aspects. First, the innovative classification of sand limit states and sand mitigation measures is proposed to ground the design framework under which new mitigation measures can be designed in rationale-based approach. Previously, the most commonly adopted approach in sand mitigation has been an iterative heuristic approach based on trials and errors. Second, each individual stage of the design is covered by the application of the framework on two innovative sand mitigation measures. Third, a wide computational study of unmitigated railway systems is given, which is essential in the design of Receiver sand mitigation measures. Fourth, quantification of the aerodynamic performance is estimated by introducing the performance metrics based on the single-phase wind flow, to meet the engineering requirements during the early stages of the design process.