Hybrid performance assessment of sand mitigation measures for coastal and desert applications

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1. INTRODUCTION

Windblown sand hazard affects both building environment and human activities (such as transport infrastructures, buildings, urban areas) and ecological system (such as coastal dunes and desert oasis) in sandy coastal and desert environments. On the one hand, ongoing climatic changes have increased the frequency and magnitude of wind storms along coastal regions in extra tropical regions, Europe included. On the other hand, desert regions are increasingly hosting human activities and built structures. In light of this, windblown sand interacts with ground-mounted obstacles of any kind inducing sand erosion and sedimentation around them and detrimental effects, such as transport infrastructure loss of capacity, but also destructive failures (Raffaele and Bruno 2019).

Several Sand Mitigation Measures (SMMs) design solutions to mitigate windblown sand effects have been proposed so far (Bruno et al. 2018). They aim to prevent sand from reaching the protected system. Most of them are located between the sand source and the protected system, and they are intended to trap incoming sand by promoting wind speed lowering and sand sedimentation (Path SMMs). SMMs usually translates into nature-based solutions, such as earthen berms, ditches, porous vegetation belts, or artificial obstacles, such as man-made porous and solid barriers.

However, with some remarkable exceptions, the rigorous design and performance assessment of SMMs remain at their early stage in the engineering literature, while they are mostly based on trial- and-error approaches in the technical practice. According to the authors, this is due to the multidisciplinary and multiphysics/multiscale nature of the phenomenon coupling fluid dynamics and aeolian processes. As a result, on one hand, research should benefit from disciplines adjacent and partially overlapping, e.g. fluid dynamics, wind engineering and aeolian geomorphology. On the other hand, experimental and numerical approaches should be mutually supporting to model multiphase windblown sand processes.

Physical experiments usually translate into full-scale or wind tunnel scale tests. In-situ full scale tests reflects real world environmental conditions but they are expensive, time-consuming, and subject to environmental setup conditions difficult to control. WST testing is almost entirely carried out by scaling the characteristic length L of the surface-mounted obstacle for both economic and practicality reasons. Conversely, sand grain diameter d can hardly be scaled to avoid switching from sand to dust particles and underlying physics. This opens the door to physical similitude theory based on dimensionless numbers (e.g. Re or Fr numbers) referred to the whole multiphase/multiscale flow (Raffaele et al. 2021).

The numerical simulation of windblown sand flow, herein called Erosion-Transport-Deposition (ETD) simulation, is mainly carried out through the resolution of fully Eulerian models coupling wind flow aerodynamics and aeolian processes resulting in in-air sand concentration ϕs and the morphodynamic evolution of the sand bed. Among them, Eulerian ETD simulations adapt well to the engineering needs of modelling large-scale processes and cutting costs with respect to WST and full- scale tests (Lo Giudice and Preziosi, 2020). However, ETD simulations have to be always calibrated and validated on physical measurements.

In this study, the authors take advantage of both WST tests and ETD simulations to assess the performance of a sinusoidal berm SMM. WST tests are carried out in the Wind Tunnel L-1B of von Karman Institute to characterize the sand flux in open-field conditions and around the SMM. The SMM performance is assessed by taking into account the progressive loss of performance of the SMM caused by the gradual accumulation of sand around it. WST measurements are adopted to properly tune and validate ETD simulations carried out with the same scaling of the WST tests. Finally, a full- scale ETD simulation is performed in order to quantify the performance under real-world conditions and quantify the experimental distortion resulting from non-compliance of physical similitude.

The complementary combination of WST and ETD provides deep insight into the scaling effects to SMM performance, lowering the costs with respect to in-situ full scale testing. Furthermore, it constitutes a promising approach to design SMMs and shorten the time required to evaluate in-field efficiency.

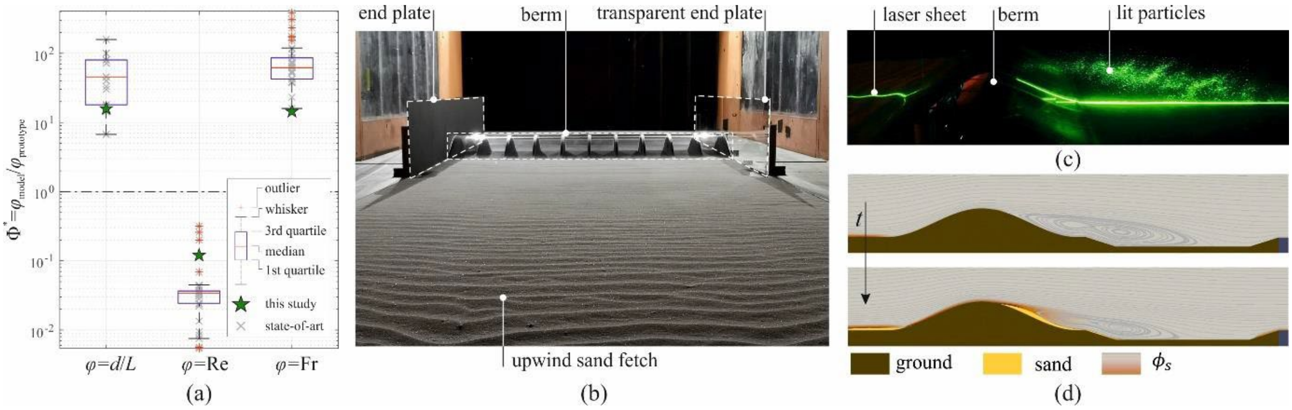

Figure 1: WST setup dimensionless numbers (a), front view of the tested sinusoidal berm SMM (b), laser sheet for PTV grain counting and morphodynamic evolution (c), full-scale ETD simulation for varying time t (d)

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