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Mitigation measures against windblown sand along railways

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SUMMARY:
The engineering interest about windblown sand is dictated by the harmful interactions between sand and a number of structures and infrastructures in sandy coastal and arid environments. In particular, the planned and ongoing railway projects in the deserts of Far East, Middle East and North Africa regions require robust technical solutions to ensure the envisaged railway performance level. At present, the rationale conception, design, and performance assessment of sand mitigation measures are not sufficiently developed. The huge competences of the railway industry, traditionally developed in non-arid regions, should be developed and complemented to face these issues. The paper introduces original categorizations of both the windblown sand-induced performance deficiencies of the railway systems and the prevention techniques to mitigate windblown sand effects. The state of the art is reviewed in the attempt to present the classification as accurately as possible. The main goal is to provide an orienting framework for scholars, railway owners, designers, general contractors and operators.

Keywords: sand mitigation measures, windblown sand, railway infrastructures

1. INTRODUCTION

Windblown sand affects a number of structures and infrastructures in sandy coastal and arid environments. On the one hand, coastal infrastructures are experiencing the increased frequency of windstorms induced by climate change, giving rise to sand transport events from sandy coasts to urbanized areas. On the other hand, desert regions increasingly host human activities and built infrastructures given the increasing number of projects currently ongoing or planned across North Africa, Middle East, and Southeast Asia. In particular, the wind-induced accumulation of sand is one of the specific key design challenges threatening safety and affecting serviceability and maintenance of railways in sandy coastal and desert regions.

A growing demand for windblown sand mitigation design, building and maintenance has been observed in the last decade and it is expected to further increase in the next years. The increasing interest in windblown sand mitigation is testified by the growing number of published studies and filed patents in the last years. A non-exhaustive survey of studies cited in Bruno et al., 2018 versus year of publication is shown in Fig. 1 (a) while a non-exhaustive survey of patents about windblown sand mitigation measure versus filing year is shown in Fig. 1 (c). The considered technologies are classified by the International Patent Classification (IPC) codes E01F 7/02 “Snow fences or similar devices, e.g. devices affording protection against sand drifts or side-wind effects" and E04H 17/00 “Fencing, e.g. fences, enclosures, corrals".

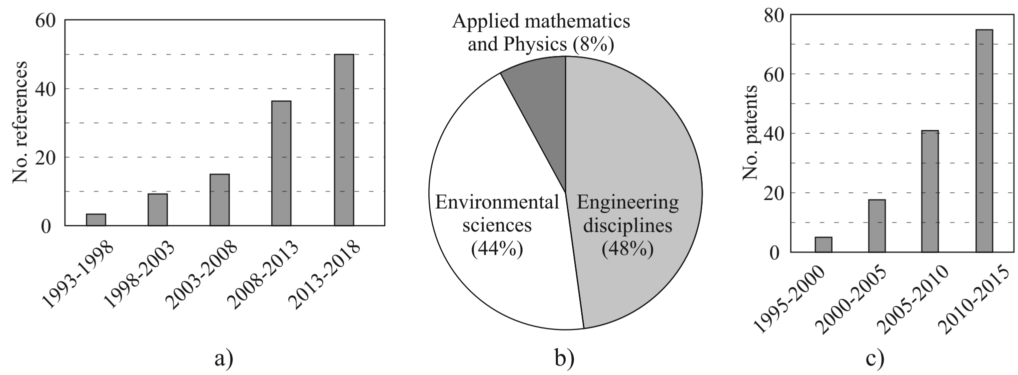

Figure 1. Number of cited references classified by year of publication (a), classification of references according to the research area (b), increasing trend of filed patents through years (c).

Multidisciplinarity in windblown sand mitigation is testified by the graph in Fig. 1 (b), showing the distribution of the cited peer-reviewed studies among the addressed research fields (Bruno et al., 2018). Given the high fragmentation in research fields, scientific affiliations are reduced to three main research area, i.e. engineering disciplines, environmental sciences, and applied mathematics and physics. Environmental sciences comprehend studies in Geology, Ecology, Geography. Engineering disciplines comprehend Structural, Mechanical, Geotechnical, and Transport engineering. Despite the development of ad-hoc studies for specific projects, a systematic and comprehensive problem setting and solving is still missing. In order to deal with these open issues, a problem-and-solution approach is proposed. First an original categorization of the windblown sand induced performance deficiencies is introduced. Then, the prevention techniques capable of mitigating windblown sand effects are arranged on the basis of a new proposed categorization. The resulting framework is addressed to scholars, railway owners, designers, general contractors and railway operators as a structured base to properly set up project terms of reference, most suited design solutions and plan maintenance practices.

2. WINDBLOWN SAND LIMIT STATES

In general terms, under a given incoming windblown sand drift the overall infrastructure is characterised by a resulting level of performance. From a structural design perspective, windblown sand effects have been categorized into Sand Limit States (SLS) as threshold performance levels, beyond which the railway no longer fulfills relevant design criteria. SLS are set in analogy to other safety formats in Structural Engineering (e.g. EN 1990, 2002). SLS are further classified into *Sand Ultimate Limit States* (SULS) and *Sand Serviceability Limit States* (SSLS).

SULS are defined as the threshold performance level beyond which railway is no longer safe. Railways SULS are mainly induced by civil works, when the railway embankment or cutting are buried by sedimented sand. For instance, a desert dune encroaching a railway embankment (Fig. 2a). Once civil works attains SULS, the track superstructure attains SULS in turn. For instance, the sedimented sand may jam railroad switches, analogously to snow and ice accretion in cold environments (Fig. 2b). The full or partial covering of a railway segment, or of a component can finally induce the SULS of rolling stock, i.e. running train derailment.

Attaining SSLS involves railway partial loss of capacity and/or passenger discomfort. Given the large number of railway infrastructure components, there are many railway SSLS. Under SSLS, windblown sand affects only a single component of the railway. However, this can reverberate on the overall railway system performances. Among track superstructure SSLS, ballast contamination is the most common one (Fig. 2c). Ballast contamination leads in turn to a series of side effects identifiable as SSLS, e.g. increasing of the stiffness of ballast bed, decreasing of the damping of ballast bed and rail support modulus, rail corrugation (Fig. 2d).

(a) (b) (c) (d)

Figure 2. Windblown Sand Ultimate Limit States: full sand coverage of a railway due to encroaching sand dune in Namibia (a), railroad switch jammed by sedimented sand in Algeria (b). Windblown Sand Serviceability Limit States: ballast contamination in Algeria (c), rail corrugation in Jordan (d). Reprinted from Bruno et al., 2018.

3. SAND MITIGATION MEASURES

Sand Mitigation Measures (SMM) are categorized following their location with respect to the sand course. An innovative Source-Path-Receiver (SPR) scheme results (see Fig. 3):

1. *Source* SMM are directly located over the sand source (dunes or loose sand sheets) to prevent sand erosion. They are almost independent from the type of infrastructure (e.g. Guo et al., 2014).

2. *Path* SMM are located along the windblown sand path aiming at controlling sand transport by driving the wind flow and/or at promoting sand sedimentation around them. They depend on the overall geometry of the infrastructure (e.g. Raffaele, Beeck, et al., 2021).

3. *Receiver* SMM are directly located on the infrastructure (e.g. the railroad or its shoulder) to promote erosion of the sedimented sand. As a result, they strongly depend on the type of infrastructure (e.g. Horvat et al., 2022).

SPR categorization can be complemented by the recognized SMM working principles from the reviewed literature: i. Sand-modifying, where the mitigation is achieved by modifying the properties of sand; ii. Aerodynamic, where the mitigation is carried out by changing the local wind flow; iii. Sand-resistant, where the mitigation is achieved by improving the material properties of the infrastructure component to be protected. Such major differences in the working principles results from the multidisciplinarity in windblown sand mitigation. In this study, the focus is put on the aerodynamic-based SMMs.

Source and Path SMM are mainly addressed to mitigate massive sand erosion and transport upwind the infrastructure, i.e. reducing the sand flux responsible for SULS. However, even if such

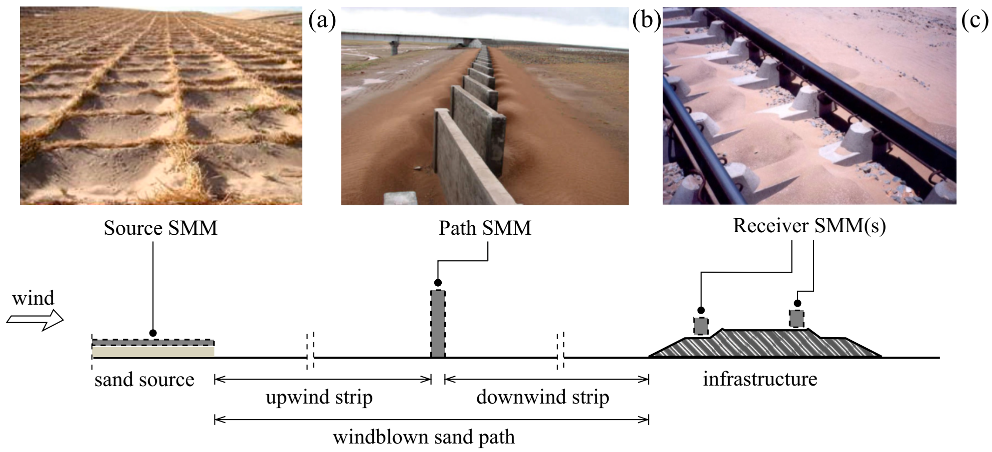

Figure 3. Conceptual scheme of the Source, Path and Receiver SMM classification. Straw checkerboard (a), straight vertical wall (b), humped sleepers (c). Reprinted from Raffaele and Bruno, 2020.

SMM exhibit high sand trapping performance, it is not likely that they completely trap the whole incoming windblown sand and cope with SSLS. Receiver SMM definitely cope with SSLS once the Path and Source SMM remove the threat of SULS. With this in mind, aerodynamic receiver SMM are addressed to avoid the local sedimentation on the railway body of small amount of of sand filtered by Source and Path SMM. The proposed classification also offers a new rationale to the combined use of complementary SMM, as proposed by e.g. Cheng et al., 2016.

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