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Windblown sand along railway infrastructures: A review of challenges and mitigation measures

Luca Bruno [a,b,*], Marko Horvat [a], Lorenzo Raffaele [a,b]

[a] Politecnico di Torino, Department of Architecture and Design, Viale Mattioli 39, I-10125, Torino, Italy
[b] Windblown Sand Modelling and Mitigation Joint Research Group, Italy

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ABSTRACT

The engineering interest about windblown sand is dictated by the harmful interactions between sand and a number of human infrastructures in arid environments. Particularly, the ongoing grand railway projects in the deserts of Far East, Middle East and North Africa regions require robust technical solutions to guarantee the efficient railway performance. The huge competences of the railway industry, traditionally developed in non-arid regions, should be developed and complemented to face mentioned challenges. The rationale problem setting, design, quantitative analysis and verification of sand mitigation measures are at present not sufficiently developed. The paper introduces original categorizations of both the windblown sand-induced performance deficiencies of the railway systems (windblown Sand Ultimate and Serviceability Limit States) and the prevention techniques to mitigate the windblown sand effects (Source-Path-Receiver categorization of the Sand Mitigation Measures). The state of the art is reviewed in the attempt to present the classification as accurately as possible. The main goal of the classification is to provide an orienting framework for scholars, railway owners, designers, general contractors and operators. We suggest the presented framework as a structured and organic base to properly set up future research activities, project terms of reference, most suited design solution, plan maintenance practices.

1. Introduction

The engineering interest about windblown sand is dictated by the harmful interactions that sand has with a number of structures and infrastructures in arid environments (Middleton and Sternberg, 2013), such as pipelines (Kerr and Nigra, 1952), industrial facilities (Alghamdi and Al-Kahtani, 2005), towns (Zhang et al., 2007), single buildings (Rizvi, 1989; Bofah and Al-Hinai, 1986), farms (Wang et al., 2010), roads (Redding and Lord, 1981), and railways (see Fig. 1). 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 arid 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 20–30 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 this review paper versus year of publication is shown in Fig. 2 (a) while a non-exhaustive survey of patents about windblown sand mitigation measure versus filing year is shown in Fig. 2 (c). The patents landscaping has been performed through Orbit© patent database. 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".

Multidisciplinarity in windblown sand mitigation is testified by the graph in Fig. 2 (b), showing the distribution of the cited peer-reviewed studies among the addressed research fields. Given the high fragmentation in research fields, scientific affiliations have been reduced to three main research area, i.e. engineering disciplines, environmental sciences, and applied mathematics and physics. Studies classified in environmental sciences come from Geology, Ecology, Geography. Engineering disciplines comprehend Structural, Mechanical, Geotechnical, and Transport engineering. It is worth stressing that several cited studies cross over more than one research area.

Despite the development of ad-hoc studies for specific projects, a

* Corresponding author. Politecnico di Torino, Department of Architecture and Design, Viale Mattioli 39, I-10125, Torino, Italy.
E-mail address: luca.bruno@polito.it (L. Bruno).
URL: http://www.polito.it/wsmm (L. Bruno).

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Nomenclature

ANR	Arab Network Railway
AR	Aspect Ratio
DP	Drift Potential
ETS	Erosion Transport Sedimentation
GCC	Gulf Co-operation Council
GR	Gulf Railway
IPC	International Patent Classification
KSA	Kingdom of Saudi Arabia
MENA	Middle East North Africa
PVC	Percentage Void Contamination
RDP	Resultant Drift Potential
S4S	Shield for Sand
SLS	Sand Limit State
SMM	Sand Mitigation Measure
SPR	Source-Path-Receiver
SRM	Sand Removal Machine,
SSLS	Sand Serviceability Limit State
SULS	Sand Ultimate Limit State
SVW	Straight Vertical Wall
UAE	United Arab Emirates
WD	Wheel Detector

systematic and comprehensive problem setting and solving is still missing. Furthermore, to our best knowledge, a common nomenclature about windblown sand induced effects on railways does not exist. Authors refer to these effects by using different nomenclature: e.g. “sand disasters” (Cheng et al., 2015; Shi et al., 2016), “sand damage” (Cheng and Xue, 2014), “aeolian hazard” (Boulghobra et al., 2016; Rizvi, 1989; Stipho, 1992), “sand risk” (Boulton et al., 2014), ”sand storm impact” (Pyrgidis et al., 2017), or combination of mentioned nomenclature (Behbahani, 2015).

In order to deal with these open issues, we adopt a problem-and-solution approach: 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 the new categorization we propose. The evolving state-of-art is reviewed in light of such categorizations. 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. Historical review of desert railways

2.1. Past railways across deserts

Historically, the first railways along deserts have been built by colonial countries. The British military railway was built at the end of the 19th century (1897–1899) from Wadi Halfa to Abu Hamed over the Nubian desert (Sudan, Winchester and Allen, 1935a, b). The French railway form Mecheria to Ain Sefra in Algeria was opened in 1887 (Belkacemi, 1984) across the norther part of the Kenadsa desert, and then extended to Beni Ounif in 1903, and to Colomb-Bechar in 1906 (Winchester and Allen, 1935b), in the framework of the never finished *Trans*-Saharan Railway project (1870–1941 Heffernan, 2010). The best example of a German railway is the line from Aus to Lüderitz built in 1906 over the Namib desert (Namibia, Dierks, 2004). The Hejaz Railway was built from Damascus to Medina, through the arid Hejaz region of Saudi Arabia and was a part of the Ottoman railway network built from 1900 to 1908 with German advice and support (Nicholson, 2005). At the present time, most of the mentioned lines are partially or totally decommissioned, and their remains buried by accumulated windblown

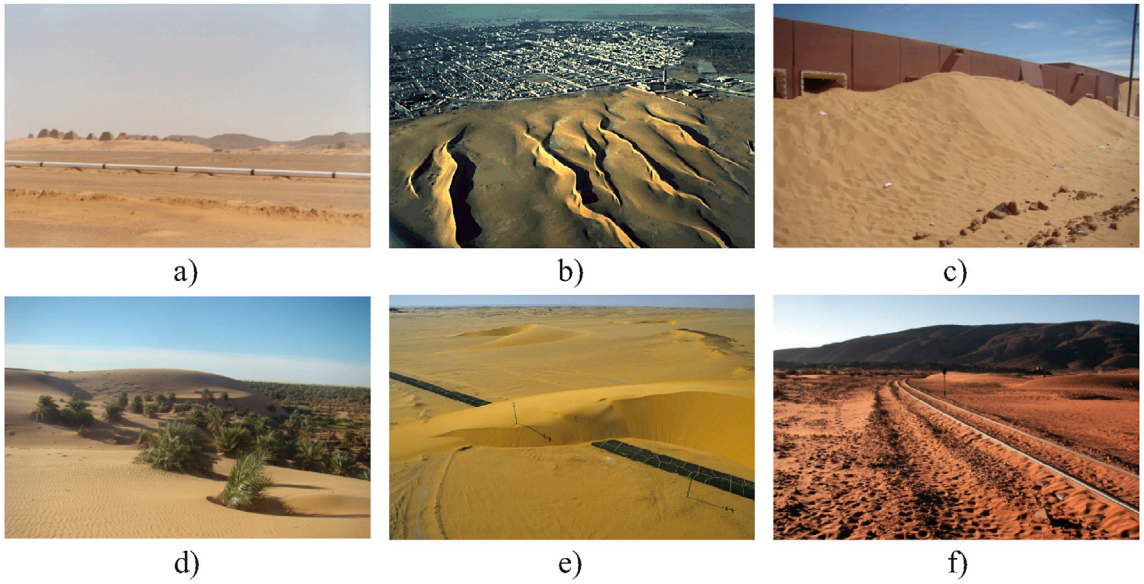

Fig. 1. General windblown sand induced problems: a) pipeline in the desert (explicit publishing permission from the owner of the photo: gordontour@Flickr), b) invading sand dunes in front of a city (reprinted from: Preziosi et al., 2015, with the permission from Elsevier), c) encroached single building (explicit publishing permission from the owner of the photo: Nouar Boulghobra), d) sand-invaded palm plantation (explicit publishing permission from the owner of the photo: Nouar Boulghobra), e) sand covered road (explicit publishing permission from the owner of the photo: Yann Arthus-Bertrand), f) railway in the desert (courtesy of Astaldi).