Coastal Engineering 133 (2018) 1–12

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Scarping of artificially-nourished mixed sand and gravel beaches: Sedimentological characteristics of Hayling Island beach, Southern England

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ARTICLE INFO

Keywords:
Beach cliffing
Gravel beach morphodynamics
Dredge emplacement
Coastal erosion
XRD clay minerals
Calcium silicate hydrates (CSH)

ABSTRACT

Beach cliffing is a wide-spread characteristic of artificially-replenished beaches, which has many undesirable engineering, environmental and economic consequences. A sedimentological study undertaken on the replenished mixed gravel and sand beach of Hayling Island (southern England) has shown that the persisting beach cliff consists typically of three distinct layers. The textural, geochemical and mineralogical analyses of the deposit showed that the development of the cliff, and particularly the formation of the intermediate, densely-packed layer, could be attributed to a series of processes. Firstly, the techniques used to emplace the recharge material on the beach (i.e. placement by heavy dumper trucks/bulldozers) result in a compaction and grain-fracture of the recharge material, and therefore a denser packing arrangement than that expected by its textural characteristics alone. Secondly, percolating water transfers medium- and fine-grained material to deeper parts of the deposit, resulting in the clogging of the interstices between the gravels and the formation of a densely-packed, poorly-sorted layer. The above processes promote the interactions between the clay minerals of the deposit with [Ca^{2+}] cations, resulting in the formation of particular cementing materials, such as Calcium Silicate Hydrates (CSH).

1. Introduction

Artificial beach nourishment has become an attractive alternative to hard coastal protection structures (Clayton, 1991; de Schipper et al., 2016; Payo et al., 2008; Trembanis and Pilkey, 1998). However, the morphological character and dynamics of artificial beaches can differ significantly from those of natural beaches, being controlled by the design beach profile, the recharge material grading/composition and, in the case of storm-dominated coasts, by particular characteristics of the extreme wave regime (Bonte and Levoy, 2015; Dean, 2002; Dean and Dalrymple, 2001; Whitcombe, 1996). Amongst the common characteristics observed in artificial mixed gravel and sand beaches are the higher proportion of sand (compared to the original beach), the greater compactness of the beach sediments than that expected for natural beaches of similar texture (Román-Sierra et al., 2014) and the presence of persisting cliff-like formations (Fig. 1) along the upper (dry under mean wave conditions) beach face appearing to consist of weakly-cemented recharge material (Halcrow, 2005; McFarland et al., 1994; Wilmington, 1983). However, a number of environmental issues have been associated with beach cliffing. These scarps can affect significantly the beach morphodynamics (Anfuso et al., 2001; Wright and Thom, 1977), as they may cause increased wave reflection at their bases (Kraus, 1988) and thus enforce beach erosion (Bonte and Levoy, 2015; Carter, 1988; McFarland et al., 1994; Quartel et al., 2008; Seymour et al., 2005). They have also been simultaneously considered to hinder, or even prevent, certain biological activities e.g. preventing female turtles from reaching their preferred nesting sites, resulting in eggs being laid dangerously close to the water line (Greene, 2002). On the other hand, cliffs can reduce the

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https://doi.org/10.1016/j.coastaleng.2017.12.003
Received 1 December 2016; Received in revised form 27 September 2017; Accepted 2 December 2017

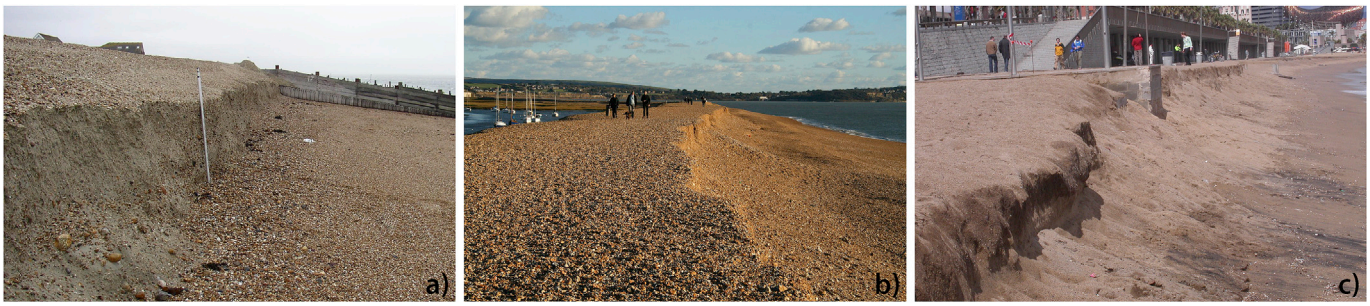

Fig. 1. Formation of beach cliffs in nourished beaches in different geographical locations and with different sediment size characteristics. In photos from left to right respectively are evident a) current working area Hayling Island beach, England, b) Hurst Spit, England and c) Barceloneta beach, Spain (with cliff angles far greater than the angle of repose).

recreational value of the beach, making it both unattractive and inconvenient to access.

Beach cliffs, sculptured by the interaction of the wave run-up with the beach sediments, are a common occurrence in sandy beaches nourished with material containing increased amounts of fine-grained sediments (de Alegria-Arzaburu et al., 2013; Payo et al., 2008). On the contrary, beach cliffs have been rarely found in artificial sandy beaches, whose recharge material originates from energetic environments (e.g. tidal inlet entrances), where finer particles have been winnowed by the strong flows from the bed sediments prior to extraction (Dean, 2002). Nevertheless, in the case of artificial coarse-grained beaches, even aggregates originating from energetic areas of the seabed are likely to contain medium/fine-grained material, which have been trapped within the coarse material interstices (Einstein, 1968). Cliff formation in such beaches has been previously attributed to the presence of a compacted layer within the sedimentary body, formed by a porosity decrease of the recharge material due to mechanical compaction during beach placement ('bulldozing') (McFarland et al., 1994).

Despite the environmental and economic significance of beach cliffs in nourished beaches, little research has been carried out on their formation mechanisms (de Alegria-Arzaburu et al., 2013) and in particular, on the sedimentary processes associated with the reduction of the permeability of the deposits that have been associated with their development (McFarland et al., 1994; She et al., 2007). Therefore, the objective of the present work is to improve our understanding of the processes involved in beach cliff formation and their dependence on the composition of the nourishment material. A better constrain of the factors that control the morphodynamic evolution of artificially replenished mixed

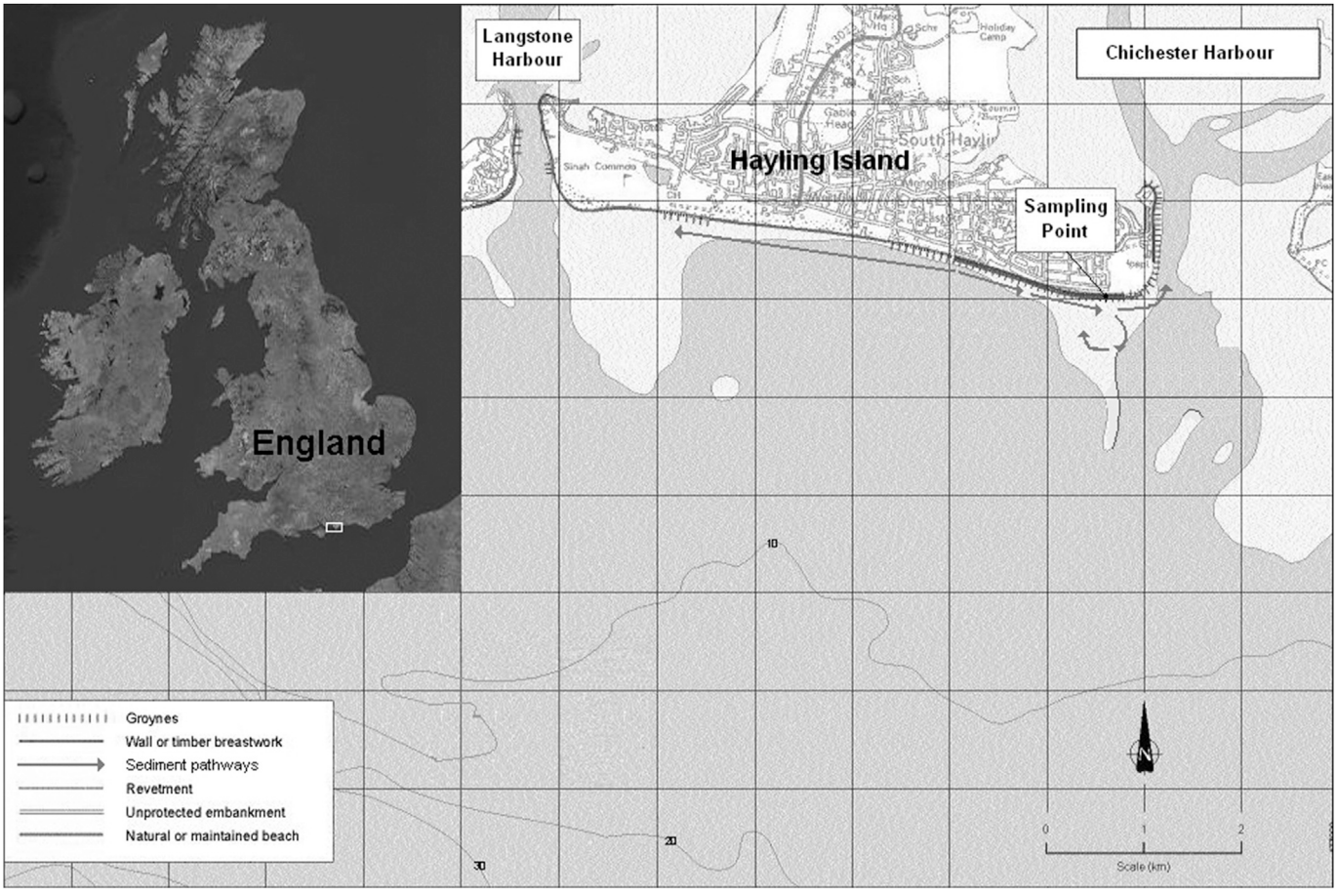

Fig. 2. Geographical setting of the study area. The area is protected from the Atlantic Ocean energy mainly by the island of Isle of Wight at the South coast of England. Note the littoral drift divergence.