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Design requirement for mixed sand and gravel beach defences under scenarios of sea level rise

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ABSTRACT

Along many coastlines of the world, beaches provide the primary defence against flooding or erosion with their fate under rising sea levels still only poorly researched. This is particularly the case for the coastline of Southeast England, where ~190 km of shingle barriers protect low-lying hinterland or a coastal plain that is at or barely above the present reach of waves.

During the Holocene transgression, these beaches moved into their present position through longshore extension and cross-shore roll back. This process stopped more than a century ago with port developments affecting longshore transport and the construction of groynes to hold the beach in place. This was followed by beach recharge and recycling towards the end of the 20th century to build up and maintain beaches as coastal defences in their mid 19th century position.

This paper explores the design requirements for these beaches under future sea level rise scenarios of 1 to 5 m using recently developed tools.

It shows that the presently still semi-natural beaches have to increase in size with crest height elevations having to rise by at least up to 1.26 times the rate of sea level rise and that due to higher longshore wave power, especially during storm conditions in the future, higher and stronger groynes are needed to hold these larger beaches in place.

Future design requirements for beaches are sensitive to foreshore levels and orientation of the beach to the dominant waves with those presently characterised by shallow foreshores and oblique wave approach requiring the biggest adjustments. Required size increases will be difficult to implement due to the built-up nature of the hinterland.

The engineering alternative would be to replace beaches with hard structures, a process that has already started where maintaining a beach is no longer economically viable or the residual risk associated with overwashing and an eventual tidal breach has become unacceptable.

1. Introduction

Beaches containing sand and gravel exist along many coastlines worldwide where a mix of grain sizes is available from deposits of quaternary glacial processes, where local rock breaks down into differently sizes fractions (e.g. flint nodules in Chalk or conglomerates) or where mountain ranges close to the coast provide a sediment mix through rivers (e.g. the northern Mediterranean). These beaches can therefore be found in a wide range of tidal and wave environments, many of them forming the only (barriers) or primary (fronting seawalls – often in poor condition) defence against flooding or erosion of the hinterland. Pressure on these beaches to adapt their geometry and position to future increases in sea level is likely to lead to roll back [1] where this is possible and/or will require an increase in crest height and cross sectional area to maintain their ‘surface emergent cross section area’ [2] and resilience similar to the changes required for hard defences to adapt to sea level rise [3,4].

Along the coastline of Southeast England, ~190 km of drift aligned shingle beaches (for a definition of the term see Section 2) that developed during the Holocene transgression protect low lying areas or front a densely populated coastal plain at elevations around highest astronomical tide. The intent from Shoreline Management Plans for almost all of this length is to ‘Hold The Line’ over the next 100 years e.g. [5–8]. The implicit assumption, owing to the often significant amenity value of these beaches, is to achieve this through a continuation of the present beach management practice including beach recharge, beach recycling and structures that reduce longshore transport (groynes). However, with sea level rise continuing past this period, strategic considerations in relation to the design of these beaches given the difference in profile shape, tidal range and obliquity of wave

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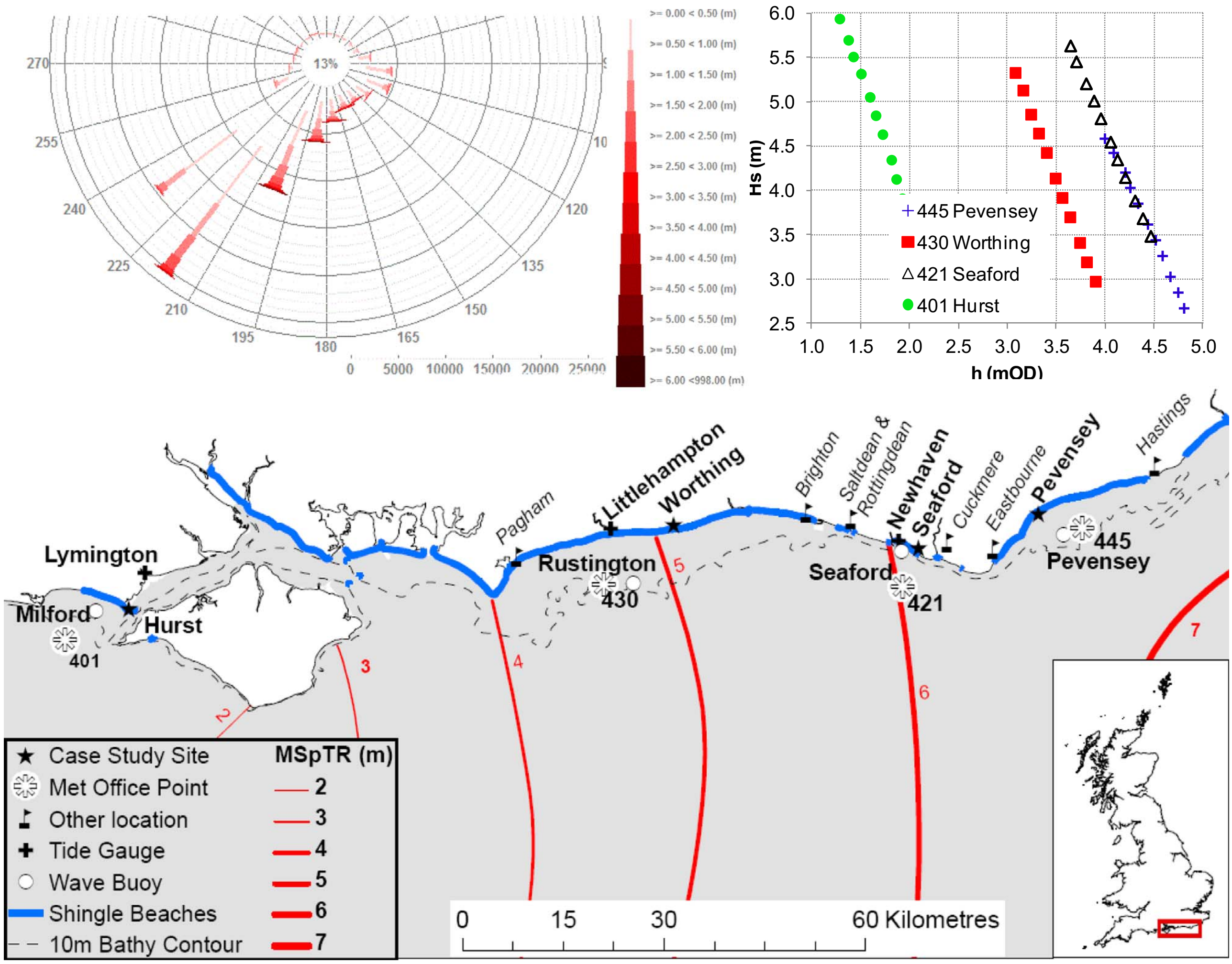

Fig. 1. Map of the southern part of Southeast England showing location of places mentioned in the text, field sites, wave buoys, tide gauges and Met Office wave hindcast points together with contours of the 10 m depth and Mean Spring Tide range. The wave rose is for Met Office point 430 based on the period 1980 to 2014. Graph shows 1 in 200 JRP water level (h) and wave height (Hs) for the four Met Office points.

approach on the Southeast coast of England have to start now. Ideas about the conceptual behaviour of coastal environments under sea level rise scenarios of more than 1 m exist e.g. [9], but systematic approaches to this question are just evolving for sandy beaches [10] and are still missing for shingle beaches.

Considerations of the fate of beaches under scenarios of rising sea level are not new. Titus [11] provided two alternative scenarios for natural sandy barrier islands: “washing over landward and remaining intact, or breaking up and drowning in place.” (page 67) together with possible interventions for developed barriers. This is a different concept from the Bruun-rule that sees landward translation of the equilibrium profile together with seaward sediment transfer and which has recently been adapted to account for landward sediment transfer by Rosati et al. [12]. In a further development, Houston [13] offers a different response of beaches to sea level rise in the form of progradation if enough sediment is available. Most of the work is associated with sandy, low-lying coasts. Trenhaile [14] considers beaches on shore platforms fronting cliffs. Seawalls are similar to hard rock cliffs and therefore this model has application for such beaches that are restricted in their landward movement. This is acknowledged by Taborda & Ribeiro [15] who apply their work to sandy beaches fronting seawalls in Portugal. Finally, Dean & Houston [10: 8] have linked beach volume requirements under future sea level rise scenarios to engineering interventions like nourishment, suggesting that “it is an effective adaptation strategy to supply sand to raise active profiles with rising sea level”.

The historic response of natural shingle and gravel beach ridges has been investigated for some time e.g. [16,17] with an emphasis on response to sea level rise for example in Orford et al. [1]. Examples of roll back and overstepping during transgression in Southeast England are given by Mellet et al. [18] for the middle Holocene and by Allen et al. [19] for the Bronze Age period. Based on modern examples, Orford et al. [1] conclude that there is a relationship between the rate of retreat of a swash aligned barrier and the rate of sea level rise, which is modulated by a barrier's ‘inertia’ as defined by its cross section area. The inertia concept was refined and expanded by Bradbury [2] to also include crest level. With sea level rise, a beach will attempt to move vertically up under a dynamic equilibrium [20], but whether this coincides with recession or progradation [21] depends on the amount of available sediment. In the absence of additional sediment inputs to maintain the surface emergent cross section area, in particular with a flat topography behind the present day beach, drowning of a barrier is almost inevitable [20]. Where the hinterland is gently sloping upwards though, a simple translation of the existing cross section landwards is likely to be sufficient to adapt to sea level rise.

Historically in the Southeast of England, attempts to hold the existing beach in place or capture beach material moving along the coast using shore perpendicular structures (groynes) started at a larger scale in the mid to late 19th century; evidence of beach recycling goes back to 1900, but did not become a common practice until the 1970s/1980s [22]. Similarly, beach recharge from land based quarries has