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Upgrade of coastal defence structures against increased loadings caused by climate change: A first methodological approach

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ABSTRACT

The paper presents a design exercise of upgrading a typical rock armoured revetment by modifying the structure profile and adding structure elements. Several concepts of upgrading are examined. A sea level rise corresponding to the mean of the IPCC 2007 predictions is used together with a slight increase in long-term wind/wave conditions as predicted for the North Sea by the Danish Coastal Authority. Both conditions of non-acceptable and acceptable increase in structure crest level are considered. Moreover, a scenario for steepening of the foreshore due to morphological changes caused by increased wave impacts is included. Only desk study tools are used for the upgrade designs. A simple comparative cost optimization analysis of the various upgrading solutions is presented, and conclusions are given for the preferred upgrading concept valid for the case study structure. A short discussion of the uncertainties related to upgrading design is included. The importance of physical model tests of the structures is underlined due to insufficient desk study tools for rubble mound upgrade design.

1. Introduction

Climate change might cause sea level rise and increase in the intensity of storms. Both phenomena will increase the risk of flooding of low lying areas, accelerate erosion of exposed soft beaches, and cause damage to existing coastal protection structures. This makes it necessary to upgrade the structures so they comply with the original design performance criteria. Upgrading can be done by modifying the structure profile and/or adding structure elements.

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) presents six scenarios with estimated sea level rises in the range 0.18–0.59 m, i.e. a mean value of 0.35 m, by the end of the 21st century.

Figures for increase in storm intensity are not given by IPCC but are dealt with regionally. As an example a 2% and a 5% increase in significant wave height are predicted for the North Sea for years 2050 and 2100 respectively, STOWASUS (2001). This is due to foreseen higher average wind velocities. However, related to storm wind velocities a 10% increase, which will add approximately 0.3 m to the wind generated set-up on a flat coast, is expected. On sandy coasts the higher water levels and the larger waves generally cause steepening of the coastal profile and subsequent accelerated retreat of the coastline.

The paper presents a design exercise of the upgrade of one of the most commonly used types of coastal protection structures, namely revetments with a sloping seaward front armoured with randomly placed quarry rocks. The structures are typically used in more shallow waters with depth limited design waves. The seabed can be both erodible and resistant.

The paper presents several concepts of upgrading for conditions of non-acceptable and acceptable increase in structure crest level. Specific upgrade design of a shallow water conventional revetment is performed assuming a sea level rise corresponding to the mean of the predictions by IPCC. The performance of the upgraded structure is assumed unchanged compared to the existing structure.

Desk study tools for the design of conventional revetment and breakwater structures are readily available but are not covering all performance aspects related to upgrading. An example is the effects of adding an extra armour layer. In the present design exercises are therefore used modifications of existing formulae. This introduces extra uncertainty for which reason it is stressed that performance of physical model tests is a necessity for the final evaluation of the proposed upgradings. Numerical models are not applied in the present paper because the available models, e.g. for armour stability, have not yet been sufficiently calibrated to cover the presented concepts of upgrading.

A simple comparative cost optimization analysis of the various upgrading solutions is presented. Finally safety aspects related to

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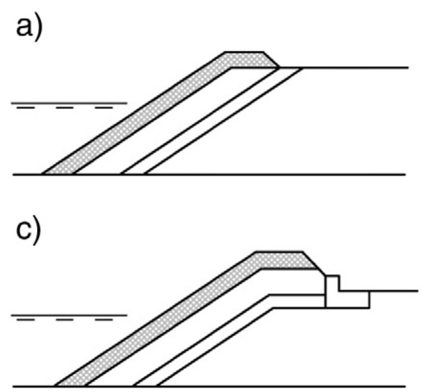

Fig. 1. Concepts of upgrading in which an increase in crest level is acceptable.

climate change motivated upgrading are discussed including the potential of application of Levels 1, 2 and 3 design procedures.

2. Concepts of upgrading

Increasing the crest level of the structure is an obvious measure for counteracting the increase in wave run-up and overtopping. However, in many places with promenades and restaurants this is not acceptable as the sea view will be blocked or reduced.

Fig. 1 illustrates concepts of upgrading in which an increase in crest level is acceptable. Strengthening of the main armour and reduction in overtopping are obtained by placing an extra layer of armour units on the front slope and on the crest. The related increase in pore volume improves the armour stability and reduces run-up and overtopping. Concepts in which a concrete superstructure is added or an existing superstructure is heightened and strengthened are also shown.

Fig. 2 illustrates concepts with no change in crest levels. Only armour units on the front are added in order to form a flatter slope or to form a berm. A flatter slope and a berm reduce the overtopping and increase armour stability. Solutions with a separate breakwater, a front reservoir or an artificial reef, all of which have the effect of reducing the wave impact on the existing structure, are also shown.

It should be noted that in order to ensure good connection, the adding of armour layers should preferably be done with the same type and size of armour units as in the existing structure. Even so, placement which ensures good interlocking can be very difficult to obtain for strongly interlocking complex types of armour units. In fact, complete replacement of the armour units might be a necessity.

3. Procedure and steps in upgrading-design of rubble mound structures

The procedure in upgrading design of a structure can be divided in the following steps:

1. Examination of the existing structure with respect to degradation of the structure elements and possible continuous use as parts of the upgraded structure.
2. Definition of the service lifetime of the upgraded structure.
3. Definition of geometrical and esthetical restrictions/limitations for the upgraded structure, as for example increase in crest level not allowed, concrete armour units not allowed, etc.
4. Definition of the performance criteria for the upgraded structure related to Serviceability Limit State (SLS) and Ultimate Limit State (ULS). Repairable Limit State (RLS) might be included as well

   a. Overtopping discharges and related exceedance probabilities
   b. Stability of structure elements. Types of damage, damage levels and related exceedance probabilities

   I Toe, front, crest and rear side (if relevant) armour displacements
   II Crown wall breakage, sliding and geotechnical slip failures
   III Geotechnical overall stability and settlements

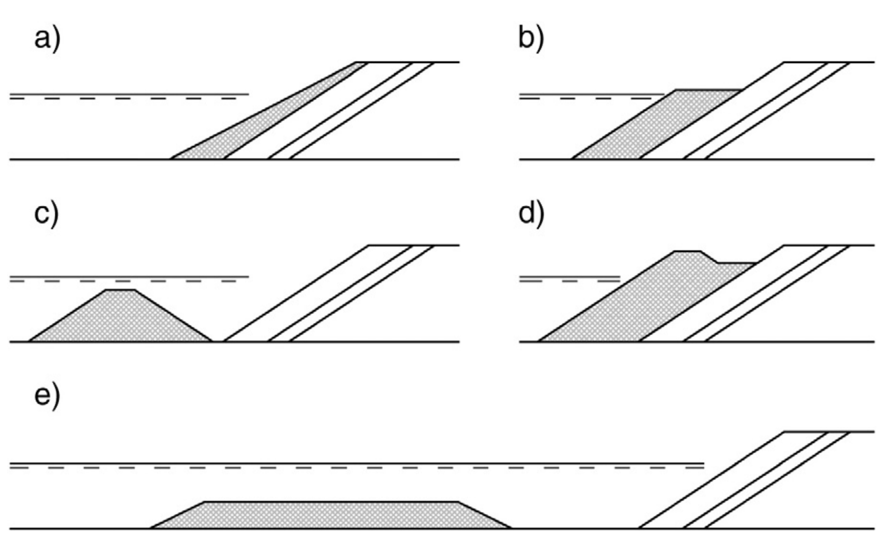

Fig. 2. Concepts of upgrading in which an increase in crest level is not acceptable.