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Overview of 20 years of field measurements in the coastal zone and at the Petten sea dike in the Netherlands

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ABSTRACT

This paper intends to give an overview of almost 20 years (1994–2013) of field measurements at the Petten site in the Netherlands and to list the main research findings derived from these measurements. The main objectives of the Petten site were to obtain field data of (i) wave propagation from deep water through the surf zone to the dike, (ii) wave run-up against the dike, and (iii) (since 2006) wave overtopping. The paper describes the evolution of the site lay-out during its existence and discusses the data collection, processing and dissemination. The most important research findings based on Petten site data have been obtained in research projects like OPTICREST (1998–2001), CLASH (2002–2004) and WTI (2003–2013). The results of the WTI project (on wave overtopping, wave run-up, redundant wave measurements and rapid bathymetric changes) are described here in more detail, because these results have not gained widespread attention yet.

1. Introduction

1.1. Introduction

Field measurements have been undertaken under the responsibility of Rijkswaterstaat (a part of the Dutch Ministry of Infrastructure and Environment) at the Petten site in the Netherlands in the period 1994–2013. The main objectives of the Petten site, which was located at the Petten sea defense (dike), were to obtain field data of:

1. wave propagation from deep water through the surf zone to the dike,
2. wave run-up against the dike, and
3. wave overtopping.

Measurements to meet the first two objectives were carried out since the start of the measurement site in 1994. A wave overtopping device to meet the third objective was installed in 2006.

The Pettens sea defense had to be improved according to the Dutch safety standards and as a solution it was decided to place by large nourishment (35 million m^3 sand) a beach and dune area in front of the dike. As a consequence waves will not reach the dike anymore and the measurement site had to be removed in 2013. There have been discussions on re-erecting a similar site at another location in the Netherlands, but it was decided to not do that.

1.2. Background

In the assessment of the Dutch primary water defenses against flooding, knowledge of the wind field, water levels and wave conditions under extreme storm conditions is required. In this assessment, numerical and statistical models are used to determine the so-called Hydraulic Boundary Conditions. These consist of the water levels and wave conditions near the sea defenses (e.g., toe of the dike) under normative conditions, which in the case of Petten correspond to extreme storms with a return period of 10,000 years. In order to get confidence in these models and to improve them through validation, field measurement data are required. Given this purpose, field data obtained under storm conditions are relevant; when the models perform satisfactorily under these conditions, we have more trust in their performance under normative conditions. Because of the relative rare occurrence of storms (say, a few per year) and the desire to build statistics, this demands for a field measurement campaign over a relatively long period (say, a decade or more).

Statistics is used to extrapolate measured offshore (deep water) wind, water level and wave conditions to large return periods. To determine the safety given by the sea defense against flooding, processes like wave run-up or wave overtopping need to be considered. Given the dike geometry, they depend on the water level and wave conditions at the toe of the dike. In order to determine wave conditions at the toe of the dike under normative conditions, one needs to have a good understanding of the wave transformation from offshore to nearshore. Obtaining field data to gain such an understanding was the first objective to initiate the Petten site.

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Many dikes have historically been designed based on the expected wave run-up height. The dike was considered to fail if its crest height was too low compared to the run-up height, which would result in too much wave overtopping under normative conditions. Therefore, the process of run-up must be understood. Field measurements of run-up can provide information that laboratory measurements cannot, e.g., on possible wind and scale effects. Since run-up depends on the nearshore water levels and wave conditions, these need to be measured as well. Therefore, it was an obvious choice to combine wave measurements with run-up measurements at the same site (objective 2).

Since, say, the turn of the century, the design and safety assessment of dikes has shifted from assessing the run-up height to the allowable amount of overtopping. To acquire field data for this process, in 2006 an overtopping device has been installed on the Petten site to measure wave overtopping during storm conditions (objective 3). Again, field measurements can provide information on possible effects (e.g., of wind and scale) that cannot be studied in the laboratory.

Apart from wind and scaling effects, it must be noted that the reality in the field is different (often: more complicated) from the one in the laboratory. When interpreting field data, one should always be cautious of this.

1.3. Overview of paper

In Section 2, the Petten measurement site is described: which instruments were located where and when. Collecting, processing and dissemination of the field data are discussed in Section 3. That section also includes an overview of the relevant storms that hit the Petten site during its lifetime. Section 4 is devoted to the results that large research projects (OPTICREST, CLASH and WTI) have derived from data measured at the Petten site. A discussion is given in Section 5. Acknowledgements follow the latter.

2. Description of the Petten site

This chapter starts with a description of the Petten sea dike (Section 2.1). An overview of the site (which instrument was placed where and when) is given in Section 2.2. Section 2.3 describes the 'standard' instruments, where 'standard' refers to instruments that were purchased from commercial parties and installed without serious additional manufacturing. Two non-standard instruments (the wave run-up gauge and the wave overtopping device) are discussed in Sections 2.4 and 2.5. Some remarks on the WESP (a vehicle to reach the measurement poles) and maintenance are given in Sections 2.6 and 2.7.

2.1. Description of the Petten sea dike

The Petten site was located off the coast of the province of North Holland near the town of Petten, where the Petten sea defense (see Figs. 1 and 2) gave local shelter to the coastline. The height of the sea dike was based on a run-up height safety level with a return period of 10,000 years. The Petten dike consisted of a 1:4.4 downslope, an 11 m long 1:20 gently sloping berm at extreme storm surge level (5.25 m + NAP) and finally a 1:3.2 upper slope until 12.75 m + NAP (NAP is the vertical reference level used in the Netherlands, which roughly corresponds to the mean sea level). In 2004, a small vertical sheet-pile wall of about 0.8 m was built upon the crest to reduce overtopping in case of extreme storm events. Over the years the adjacent dune areas have retreated, so that in comparison with the coastline the Petten sea defense extended slightly out into sea.

Due to the prevailing wind directions (see Fig. 3, top panel), most of the waves approach the coast from the south-west quadrant. Ocean swell waves can approach the Petten site only from the northern part of the North Sea. The wave climate at the Petten site is, therefore, dominated by wind waves. The majority of the waves have an offshore wave height (H_{m0}) between 0 and 2.5 m, and offshore wave periods

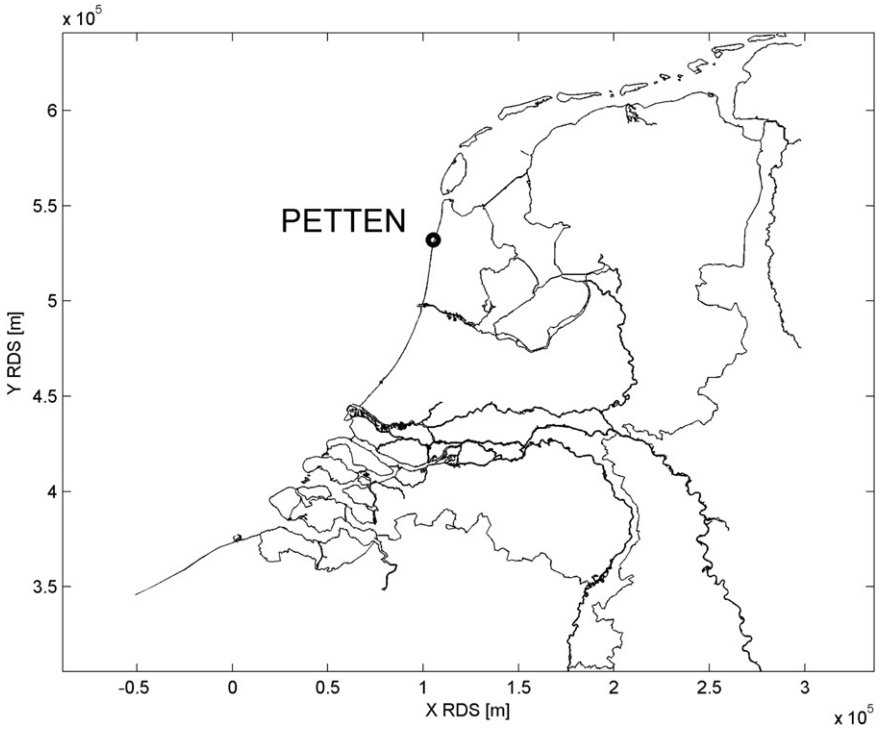

Fig. 1. Overview of the Netherlands, with the location of the Petten site indicated.