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Implications of the 2011 Great East Japan Tsunami on sea defence design

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ABSTRACT

After the 2004 Boxing Day tsunami, much of the world's effort to defend against tsunami concentrated on tsunami warning and evacuation. The 2011 Great East Japan Earthquake and Tsunami led to direct and indirect losses as well as the deaths of many vulnerable members of Japan's coastal communities. This event has resulted in Japan rethinking and revising its design codes for sea defence structures. The new guidance emerging from this process is a valuable resource for other countries re-evaluating their own current mitigation strategies and this paper presents details of this process. The paper starts with the history of sea defence design standards in Japan and explains the process of revision of design guidelines since 2011. Examples of sea defences that failed and have since been rebuilt, observed during the two Earthquake Engineering Field Investigation Team (EEFIT) missions of 2011 and 2013, are also presented. The paper concludes with a discussion of international approaches and their application to nuclear power stations in Japan and the UK.

1. Introduction

In 2011 Japan was considered to be the best prepared nation on earth to withstand a large tsunami attack on its coasts, with sea defence structures (breakwaters, sea dikes and seawalls) specifically designed to afford sufficient protection to coastal settlements and critical infrastructure. Massive detached breakwaters were built in bays to defend great industrial ports and their populations; sea dikes were constructed along much of the coastal plain areas to protect low-lying agricultural land and towns from both tsunamis and storm surges; and seawalls, some of which were 10 m or more in height, were built as a result of previous tsunamis to provide protection for busy settlements. However, the size of the waves generated by the unexpectedly large magnitude of the 2011 Great East Japan Earthquake (Moment Magnitude 9) led to sea defences and other coastal structures being overwhelmed and in many cases completely or partially destroyed. Overtopping of the sea protection wall at the Fukushima Daiichi nuclear power station led to the loss of seawater pump facilities for the reactor cooling water causing a major release of radioactive material.

Due to the non-structural measures in place along Japan's vulnerable coastlines *i.e.* comprehensive warning systems and well-rehearsed evacuation plans, casualty figures were relatively low in comparison to the levels of devastation caused by the tsunami. However, this paper focuses on the structural measures to defend against tsunamis (though not the seismic considerations, see *e.g.* [46]) and charts the evolution of Japanese design guidelines and standards in the light of this catastrophic event. It describes the research that has been conducted into the failure mechanisms of key sea defence structures, explains the different levels to which sea defence structures must now be built and describes the detailed disaster scenario document that now exists for design considerations. Photographs and observations from two Earthquake Engineering Field Investigation Team (EEFIT) missions to Japan are included to illustrate the damage caused to defences and the reconstruction that has subsequently taken place in some locations. The paper then presents an overview of international approaches to sea defence design, where they exist, including the new American Society of Civil Engineers standard. It concludes by providing details of post-2011 sea defence structures built to protect an existing Japanese nuclear power station at Hamaoka, and the new Hinkley Point C power station in the UK.

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Notation

The following symbols are used in this paper:

a_I	incident tsunami height;
g	gravitational acceleration;
p_u	uplift pressure;
p_1	maximum value of pressure;
η^*	effective tsunami height; and
ρ_0	density of seawater.

2. Japanese Tsunami Design Procedures pre-2011

Before discussing Japanese guidance the terminology used to define such structures is given in Fig. 1. The underlined terminology is that which is used in this paper.

Japan has a rich history of guidance available to coastal engineers for the design of sea defence structures. In addition to the internationally renowned Yoshimi Goda who produced three editions of his book on the design of such structures over a nearly 30 year period [24] there are official *Technical Standards* that have been established under government acts. These prescribe the required technical criteria that should be applied in the construction, renovation or maintenance of facilities [65]. *Manuals* are also published as reference documents that provide detailed design guidance. The standards and manuals available for ports and harbour facilities prior to 2011 are shown in Fig. 2 and explained as follows.

The Technical Standards comprise a brief summary of each standard with an accompanying commentary which is divided into written notes on the standard followed by reference information with pertinent equations [65]; this information may be in the form of academic articles, design manuals, technical notes *etc*. The standards are prepared by bureaus within the respective ministries. Revisions to standards are introduced when there have been major changes *e.g.* the Technical Standards for Port and Harbour Facilities, moved from designing for regular to irregular waves in 1978 or the incorporation of performance-based design in 2007 (following pressure from the Technical Barriers to Trade Agreement [51]).

The production of the 2007 edition of the Port and Harbour Facilities technical standards was a collaboration involving:

- the Ports and Harbours Bureau (PHB) of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT);
- the National Institute for Land and Infrastructure Management (NILIM) of the MLIT; and
- the Port and Airport Research Institute (PARI).

An English translation of these 2007 technical standards was released by the Overseas Coastal Area Development Institute of Japan in 2009; this translation will be the document referred to in this paper as PHB [51].

The last Design Manual was released in 2000 [7]. This was prepared by the Committee on Coastal Engineering of the Japanese Society of Civil Engineering, a neutral body that had representation across different Ministries and from academics and practicing engineers (Mizuguchi and Iwata, 1999).

The design process in Japan might typically involve a national

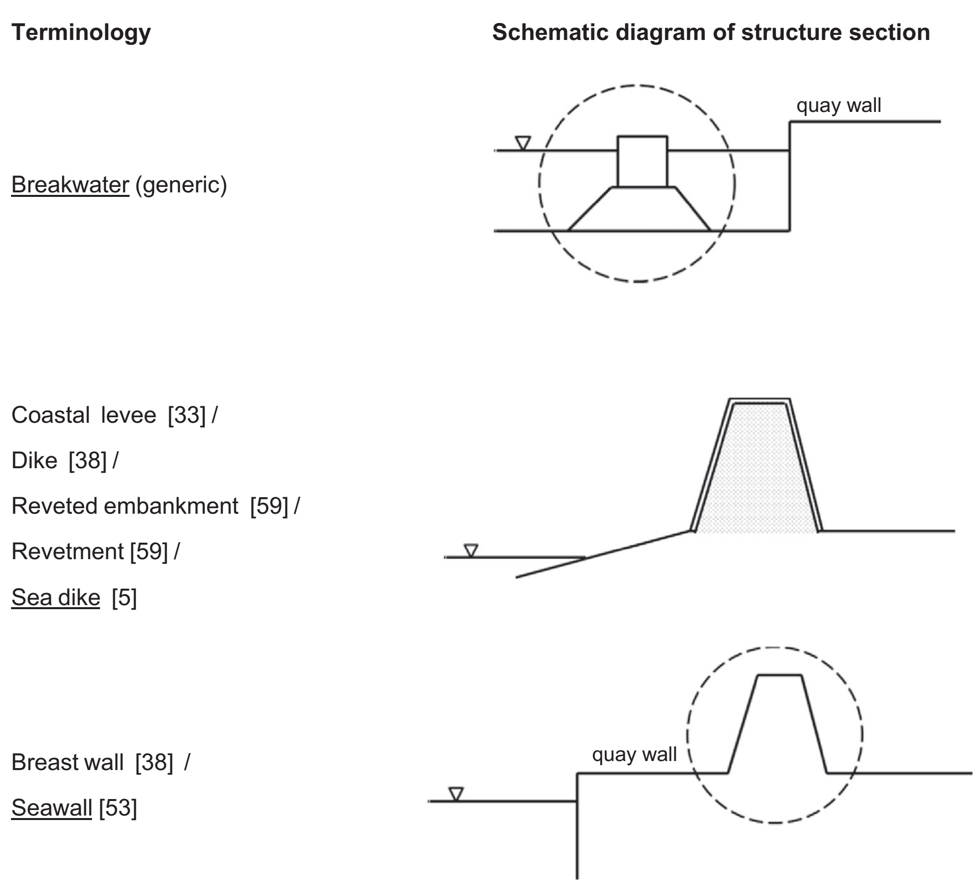

Fig. 1. Sea defence structure terminology [5,33,38,53,59].

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