CONCERT-Japan
Research and Innovation Joint Call

Efficient Energy Storage and Distribution
Resilience against Disasters

RAPSODI Project

Risk Assessment and design of Prevention Structures fOr enhanced tsunami DIsaster resilience

Deliverable D3 – Comparison of coastal structures in Europe and Japan

1st year of funding

20120768-03-R
17 March 2014
Revision: 1 / February 2015

NGI
PARI
Middle East Technical University
Civil Engineering Department
Technische Universität Braunschweig

CONCERT JAPAN
Connecting and Coordinating European Research and Technology Development with Japan
www.concertjapan.eu

This work was supported by funding received from the
CONCERT–Japan Joint Call on Efficient Energy Storage
and Distribution/Resilience against Disasters

Project information

Name of the project:	RAPSODI
Start of the project:	01 July 2013
Duration (no. of months):	24
End of the project	01 July 2015
Name and country/region of each partner	NGI, Norway; PARI, Japan; TU-BS, Germany; METU, Turkey
Overall budget	383 k€

Client

Client:	CONCERT-Japan Joint Call Secretariat
Client's contact persons:	CONCERT-Japan Coordinator The Scientific and Technological Research Council of Turkey (TUBITAK) Ms. Filiz Hayirli (filiz.hayirli@tubitak.gov.tr) concertjapan@tubitak.gov.tr Phone: + 90 312 468 5300 (ext.1910) CONCERT-Japan Joint Call Secretariat Centre national de la recherche scientifique (CNRS) Ms. Lucie Durocher (lucie.durocher@cnrs-dir.fr) Phone: + 33 (0)1 44 96 47 14 Fax: + 33 (0)1 44 96 48 56 http://www.concertjapan.eu
Contract reference:	NGI 229578/H20; METU 113M556; TUBS 01DR13016;
Settlement numbers	PARI 2013 H25国際第1-33号 and for 2014 H26国際第1-17号

For NGI

Project manager:	C.B. Harbitz
Prepared by:	Dr. Gulizar Ozyurt, Dr.Ahmet Cevdet Yalciner, Gozde Guney Dogan
Reviewed by:	G. Kaiser and C.B. Harbitz

Publishable summary

The consortium of Risk Assessment and design of Prevention Structures fOr enhanced tsunami DIsaster resilience (RAPSODI) project aims to design tsunami mitigation structures to improve tsunami resilience. Prevention can be tackled by building coastal defenses to resist sea water inundation to the areas that are dry most of the time. In this regard, it is necessary to identify the existing coastal protection structures and their characteristics around the world. A comparison on those existing structures would also provide a way to specify the gaps and improve the existing knowledge on infrastructure and coastal protection. Therefore, Deliverable 3 - *Comparison of coastal structures in Europe and Japan,* describes coastal protection structures against related hazards in Europe and Japan and compares the characteristics of these structures in both regions considering the types of coastal hazards they are designed against.

Japan has constructed dikes for nearly 2,000 years against tsunamis. These dikes are designed considering the historical tsunami heights and predicted storm surge heights. They are mostly sloped on both the seaward and leeward sides containing an earthen core covered with precast concrete slabs, pavers, or stone. Breakwaters, tsunami seawalls and barriers, and water gates are the other main types of coastal structures built in Japan against tsunamis. Breakwaters are made of massive precast concrete caissons on top of a rubble mound foundation and the seaward slopes of the breakwaters are generally covered with precast concrete units. Breakwaters are also constructed to prevent overtopping of wind waves and to cope with overflowing storm surges. In addition to that, a considerable number of artificial reefs or detached breakwaters have been constructed mainly to reduce overtopping of waves and also to improve the stability of sandy beaches.

On the contrary, coastal structures in European countries are mainly designed considering storm surges and coastal erosion. Although Europe was hit by large tsunamis, tsunami is not considered in the design of coastal structures and information on European action against tsunamis is very limited. Only in Norway, structures against tsunamis are in place such as dikes. Seawalls which are either rock armoured or vertical seawalls constructed with concrete are the most frequently seen form of coastal protection in European countries against the storm surge. Sea dikes are also common in some countries such as Germany and Denmark which are mostly reinforced in Denmark due to significant storm surges experienced. Furthermore, the main categories of coastal structures against coastal erosion along the European Coasts can be listed as seawalls, revetments, groins and detached breakwaters in addition to beach nourishment which is an alternative soft engineering technique against coastal erosion and often used in combination with other protection in many countries.

All in all, different types of coastal hazards are common in Japan and Europe and this has been reflected in the type of coastal structures, design constraints and

the construction materials. The performances of different structures under tsunami loading especially in the case of European structures should be considered even if they are effective in case of storm surges. Although tsunami risk is low in many parts of Europe, there exists several historical tsunamis not due to earthquakes but due to landslides and volcanic eruptions as well. While research on tsunami generation risk in Europe could present the exposed coastal areas, research on the performance of European coastal structures under tsunami loading would help to determine the actual risk.

Contents

1 Introduction

Coastal structures built around the world can generally be divided into two groups which are 1) shore-parallel structures such as seawalls, sea dikes, revetments, detached breakwaters, artificial reefs, sea bottom protections (armouring of the shore) and 2) artificial islands and shore-normal structures such as groins, jetties, and harbour breakwaters.

Shore-parallel structures are mainly constructed as coastal protection structures although there are exceptions like near shore breakwaters. They can significantly reduce the amount of wave energy reaching a protected area whereas they have also been proven to serve as beach stabilization structures effective against erosion caused by both alongshore and offshore sand losses.

Artifical islands and shore-normal structures including groins, jetties and harbour breakwaters are other types of coastal structures. Jetties are commonly used for training navigation channels and stabilizing inlets whereas groins are the most common shore-connected structures for beach stabilization. A groin is an active structure extending from shore into sea, most often perpendicularly or slightly oblique to the shoreline. Constructed in a series to form a groin field, they help to create or widen beaches by capturing sand moving along the shoreline.

The consortium of Risk Assessment and design of Prevention Structures fOr enhanced tsunami DIsaster resilience (RAPSODI) project aims to design tsunami mitigation structures to improve tsunami resilience. Prevention can be tackled by building coastal defences to resist sea water inundation to the areas that are dry most of the time. In this regard, it is necessary to identify the existing coastal protection structures and their characteristics around the world. A comparison on those existing structures would also provide a way to specify the gaps and improve the existing knowledge on infrastructure and coastal protection. Moreover, a strong focus is put on the utilization of complementary expertise between Japan and the European partners in this project as the consortium is established as a Euro-Japan research.

Therefore, this report, Deliverable 3 - *Comparison of coastal structures in Europe and Japan*, describes coastal protection structures against related hazards in Europe and Japan whereas Deliverable 4 - *Report on the comparison of mitigation strategies in Europe and Japan* (http://www.ngi.no/en/Project-pages/RAPSODI/Reports-and-Publications/) describes the existing measures against tsunami attack in Europe and Japan. The key objective of this report is to identify the type of coastal protection structures in Europe and Japan, to compare the characteristics of these structures in both regions considering the types of coastal hazards they are designed against.

In chapter 2 of the report, coastal structures in Japan against tsunamis and storm surges together with brief information on coastal erosion are described and examples are provided, either by photographs, aerial views, or by cross sections of typical structures of the described types. Chapter 3 continues to describe coastal protection structures in Europe, mainly against storm surges and coastal erosion, and eventually against tsunamis, wherever the hazard has been considered relevant. Finally, in chapter 4, a comparison of all the structures is carried out to provide an overview of the existing situation.

2 Japan

2.1 *Introduction*

Structures in Japan to control storm surges and tsunamis are also given in “Tsunami and Storm Surge Hazard Map Manual” (2004) such as:

- Breakwaters against storm surges and tsunamis
- Tide embankments, banks, and revetments
- Water gates and land locks
- Seaside forest
- Reinforced concrete, and steel reinforced concrete, buildings

However, although the coastal impacts of storm surges and tsunamis are quite similar, they are dynamically very different. Tsunamis propagate through the deep oceans and strike the coastlines, whereas storm surges are present through the coasts and do not exist over the deeper part of the oceans. Although the prediction of tropical and extra-tropical cyclones that generate storm surges in terms of the exact location of the landfall is quite difficult and has possible errors, in terms of time it can be seen several days earlier. For tsunami case, no prediction can be given until the submarine earthquake actually happens and therefore, the warning time for tsunamis is generally substantially smaller than for storm surges. For example, in Japan, only few minutes of elapsed time is observed between the occurrence of the earthquake and the tsunami impact on the coastline in some cases. In such situations, no tsunami warning system would be effective, and the earthquake itself has to be used as early warning (Nirupama and Murty, nd). In the light of such information, the coastal protection structures against tsunamis and storm surges in Japan will be handled separately.

When it comes to coastal erosion in Japan, the sandy beaches are rapidly changing into artificial coasts, and man-made concrete structures is expanding day-by-day. Most long stretches of beach, characterized for a long time by white sandy beaches and pine tree forests, have disappeared. Because of port and dam constructions, fluvial sand supply has significantly reduced resulting in shoreline recession around the river mouths. The port breakwaters have also blocked continuous sand supply along the coastline. These breakwaters cause longshore sand transport by triggering formation of wave shelter zone and consequently leading to an accretion of large amount of sand in that zone and erosion in the surrounding area. Therefore, it can be said that almost all causes of the beach erosion in Japan are due to anthropogenic factors (Uda, 2010). Coastal problems, more specifically the issues of beach erosion, in Japan have not arisen only from the problems of coastal engineering, but they relate mainly to the social system including the legal system. The structures, seawall, concrete armor units and detached breakwaters are the ones generally installed against beach erosion. However, the point may be that while fundamental measures are difficult to adopt and, instead, stopgap measures of installing a seawall with concrete armor units are selected, this is also a way of rapidly producing an artificial coastline.

2.2 Tsunamis

The observations on the examples of five major categories of coastal structures are as the following:

Coastal dikes: Coastal dikes constructed in Japan along the Pacific Coasts are built parallel to shoreline protecting coastal areas from tsunamis, storm surges, typhoons and flood due to tsunamis along large river basins. The dikes are mostly sloped on both the seaward and leeward sides comprising an earthen core covered with precast concrete slabs, pavers, or stone. They have base widths ranging from approximately 5 m to 20 m. Generally an asphalt topping or a concrete deck exists at the structure crests.

Tsunami seawalls or walls (barriers): Tsunami seawalls are placed along the shoreline against tsunami overtopping of local coastal structures and flooding of highlands behind the coast (*Fig.* 2.1). They consist of concrete units having nearly 10 meters high. On the contrary, tsunami barriers are built onshore and usually functioning as a separation between the inner harbour facilities and the town structures further inland. The barriers are also made of concrete, having heights ranging from 5 m to 10 m. Furthermore, steel gates allow vehicular access between the inner harbours and towns whereas stairways over the walls provide pedestrian access. The steel gates are closed in case of a tsunami unless an operational error occurs.

Water gates: Tsunamis can often inundate long distances up a river valley, causing massive damage inland. Water gates are also coastal protection structures to prevent flood that pass over a river, near the river mouth. They are like dams or sluices having many lift gates. Water gates allow tidal exchange and flow of river water to the sea as they stay open during normal conditions. However, they are shut in case of a tsunami and they block the tsunami wave not to travel up the river system.

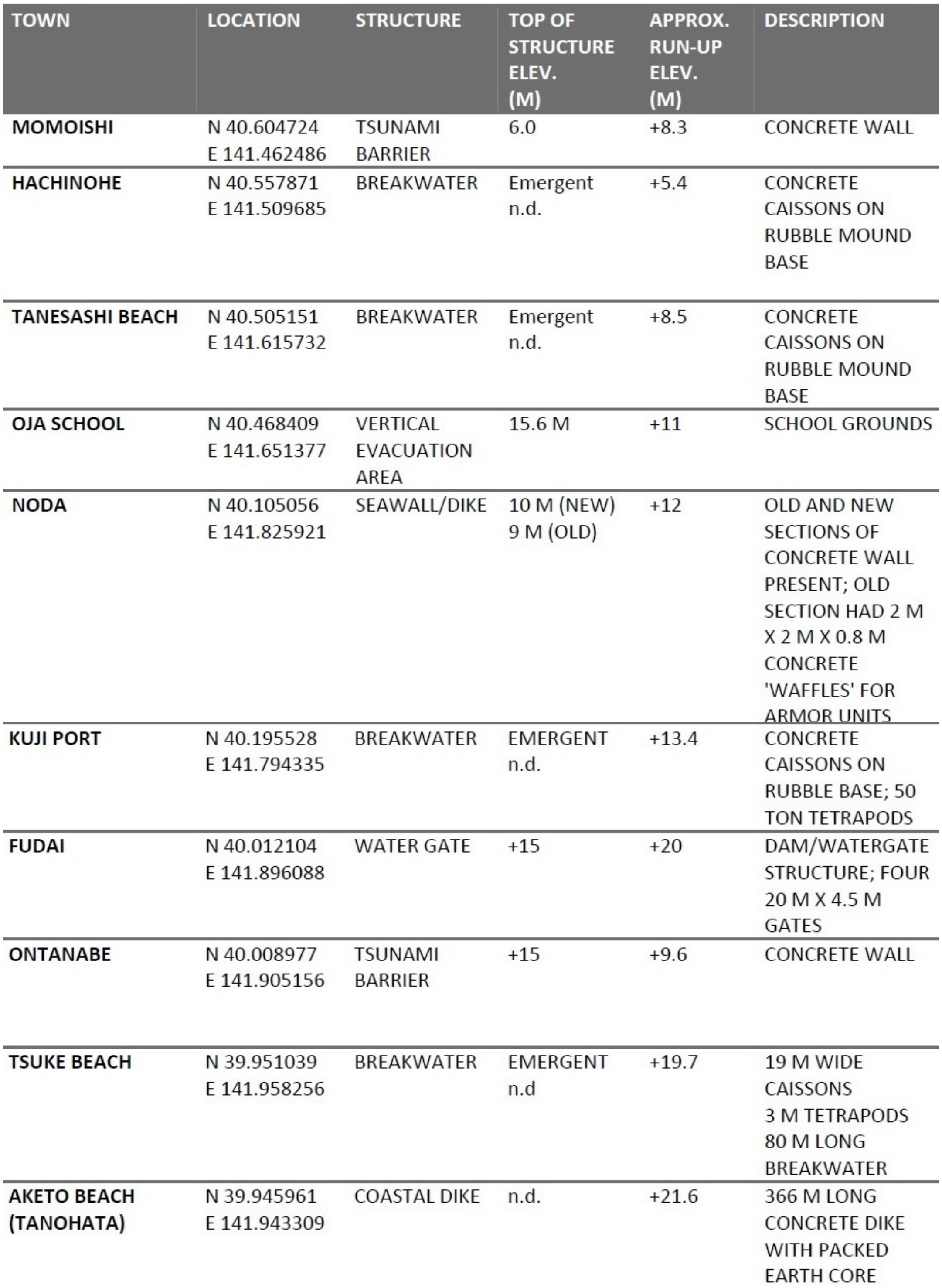
Fig. 2.1 12.8m Seawall at Funakoshi Bay in Yamada Town (Source: Takahashi, Tsunami Disaster Mitigation in Japan, 2012)

Breakwaters: Breakwaters are structures mainly constructed offshore a port or shoreline to protect the leeward area from extreme conditions such as high waves and storms. Typical breakwaters in Japan are made of massive precast concrete caissons on top of a rubble mound foundation. The seaward slopes of the breakwaters are generally covered with precast concrete units such as tetrapod, dolos, or other engineered concrete units. The ones constructed at harbour entrances are functioning as protection of the shoreward region of the port against a tsunami. Also, at many small fishing villages along the coast without natural protection, breakwaters form small artificial harbours.

Greenbelts: Along the coasts of Japan, greenbelts also referred to as vegetative barriers help to protect the highland areas behind them as a second or third line elements because they dissipate wave energy, reduce run-up and high velocity flows taking part after beaches, dikes and seawalls. Rows of tall trees mainly build up the greenbelts along with shrubs and green areas.

The list of these structures is also given with their locations, structure elevations and material types in *Table* 2.1.

Table 2.1 List of structures visited during reconnaissance survey of the ASCE/COPRI Coastal Structures Team. (Source: ASCE-COPRI-PARI Coastal Structures Field Survey Team, 2013.)



TOWN	LOCATION	STRUCTURE	TOP OF STRUCTURE ELEV. (M)	APPROX. RUN-UP ELEV. (M)	DESCRIPTION
MOMOISHI	N 40.604724 E 141.462486	TSUNAMI BARRIER	6.0	+8.3	CONCRETE WALL
HACHINOHE	N 40.557871 E 141.509685	BREAKWATER	Emergent n.d.	+5.4	CONCRETE CAISSONS ON RUBBLE MOUND BASE
TANESASHI BEACH	N 40.505151 E 141.615732	BREAKWATER	Emergent n.d.	+8.5	CONCRETE CAISSONS ON RUBBLE MOUND BASE
OJA SCHOOL	N 40.468409 E 141.651377	VERTICAL EVACUATION AREA	15.6 M	+11	SCHOOL GROUNDS
NODA	N 40.105056 E 141.825921	SEAWALL/DIKE	10 M (NEW) 9 M (OLD)	+12	OLD AND NEW SECTIONS OF CONCRETE WALL PRESENT; OLD SECTION HAD 2 M X 2 M X 0.8 M CONCRETE 'WAFFLES' FOR ARMOR UNITS
KUJI PORT	N 40.195528 E 141.794335	BREAKWATER	EMERGENT n.d.	+13.4	CONCRETE CAISSONS ON RUBBLE BASE; 50 TON TETRAPODS
FUDAI	N 40.012104 E 141.896088	WATER GATE	+15	+20	DAM/WATERGATE STRUCTURE; FOUR 20 M X 4.5 M GATES
ONTANABE	N 40.008977 E 141.905156	TSUNAMI BARRIER	+15	+9.6	CONCRETE WALL
TSUKE BEACH	N 39.951039 E 141.958256	BREAKWATER	EMERGENT n.d	+19.7	19 M WIDE CAISSONS 3 M TETRAPODS 80 M LONG BREAKWATER
AKETO BEACH (TANOHATA)	N 39.945961 E 141.943309	COASTAL DIKE	n.d.	+21.6	366 M LONG CONCRETE DIKE WITH PACKED EARTH CORE

Table 2.1 Continued

TOWN	LOCATION	STRUCTURE	TOP OF STRUCTURE ELEV. (M)	APPROX. RUN-UP ELEV. (M)	DESCRIPTION
OMOTO PORT	N 39.849190 E 141.973931	COASTAL DIKE AND BREAKWATER	n.d.	+20	315 M LONG X 13 M WIDE CONCRETE DIKE WITH PACKED EARTH CORE; 30 TON TETRAPODS
TARO	N 39.735192 E 141.971916	MIYATO BRIDGE (1969); TSUNAMI WALLS	+10	+20 (SOUTH) +28 (NORTH) +6 (INSIDE)	CONCRETE WALLS FORM AN "X" IN FRONT OF TOWN BRIDGE WAS 32 M LONG X 9 M WIDE WITH FOUR 0.3 M WIDE X 1 M DEEP STRINGERS
MIYAKO PORT	N 39.643819 E 141.968491	PORT AREA	n.a.	+8	PILE SUPPORTED PLATFORMS
KANEHAMA (TSUGARUISHI)	N 39.585581 E 141.944907	WATER GATE AND DIKE	+10	+12	FLOOD GATE LOCATED 10 KM FROM MOUTH OF BAY
OTSUCHI	N 39.352929 E 141.932572	TSUNAMI WALL	+5	+15 - +19 (OUTSIDE) +8 (INSIDE)	CONCRETE SEAWALL
RYOSHI STATION	N 39.307887 E 141.890466	BREAKWATER	EMERGENT n.d	+18	CONCRETE CAISSONS
KAMAISHI	N 39.261438 E 141.928520	BREAKWATER	+6	+10	CONCRETE CAISSONS ON RUBBLE MOUND BASE; 63 M DEEP; 670 M LONG NORTH B/W; 300 M GAP; 990 M SOUTH B/W
TONI BAY	N 39.208207 E 141.892534	BREAKWATER	EMERGENT n.d	+13.2	CONCRETE CAISSONS WITH ARMOR UNITS
KOJIRAHAMA	N 39.207000 E 141.867228	TSUNAMI WALL	+12.5	+17.8	12.5 M HIGH X 8.5 M WIDE CONCRETE WALL WITH ROADWAY INSIDE

Table 2.1. Continued

TOWN	LOCATION	STRUCTURE	TOP OF STRUCTURE ELEV. (M)	APPROX. RUN-UP ELEV. (M)	DESCRIPTION
RIKUZENTAKATA	N 39.005844 E 141.630776	TWO TSUNAMI WALLS W/ GREENBELT		+19	TWO CONCRETE SEAWALLS SEPARATED BY A 50 M WIDE GREENBELT/BEACH AREA
KESENNUMA	N 38.909945 E 141.581426	PORT	+2	+8	PORT AREA; CONCRETE SEAWALL
OYA KAIGAN STATION	N 38.813009 E 141.569268	COASTAL REVETMENTS	<3	+15.0	SCALLOPED PAVERS; 1/2 TON TETRAPODS; LONG JACKS IN FRONT OF CONCRETE SEAWALLS
KOIZUMIHAMA	N 38.774600 E 141.517337	SEAWALL AND GREENBELT	n.d.	+19.6	CONCRETE SEAWALL AND BEACH AREA
UTATSU	N 38.716313 E 141.523210	BRIDGE	n.a.	+14.8	CONCRETE BRIDGE
SHIZUGAWA BAY	N 38.674247 E 141.453670	TSUNAMI WALL	+8	+15.2	CONCRETE SEAWALLS
OKAWA SCHOOL	N 38.545820 E 141.428447	RIVER DIKE	n.d.	+6	SCHOOL GROUNDS LOCATED BESIDE CONCRETE RIVER DIKE
OGATSU	N 38.512688 E 141.463919	PORT AREA	n.a.	+14.7	
ONAGAWA	N 38.443412 E 141.446208	PORT AREA	n.a.	+18	50 MILES FROM EPICENTER
ISHINOMAKI	N 38.416713 E 141.274888	PORT AREA	n.d.	+4.9	MODERN PORT FACILITY; CONCRETE PLATFORMS
NOBIRU BEACH	N 38.374410 E 141.170683	COASTAL DIKE; JETTY	n.d.	+5.0	CONCRETE PAVERS WITH ASPHALT CREST
MATSUSHIMA BAY	N 38.364338 E 141.061313	SEVERAL ISLANDS	n.a.	+2.7	PROTECTED BAY; LOW SEAWALLS; WATER ACCESS
SENDAI NEW PORT	N 38.272001 E 141.013638	PORT AREA	n.d.	+6.4	CONCRETE PLATFORMS

Table 2.1 Continued

TOWN	LOCATION	STRUCTURE	TOP OF STRUCTURE ELEV. (M)	APPROX. RUN-UP ELEV. (M)	DESCRIPTION
SENDAI OLD PORT	N 38.267462 E 141.025955	PORT AREA	n.d.	+5.2	CONCRETE PLATFORMS
GAMO TIDAL FLATS	N 38.260648 E 141.018812	BEACH	n.d.	+6.1	BEACH AREA/OVERLOOK
ARAHAMA	N 38.218211 E 140.985163	COASTAL DIKE	n.d.	+12.2	CONCRETE DIKE WITH PACKED EARTH CORE
NATORI RIVER/IDO	N 38.182375 E 140.953125	GREENBELT	n.d.	+5.3	BEACH AREA WITH VEGETATED BUFFER
IGUNE	N 38.201126 E 140.950631	GREENBELT	n.d.	+2.5	YASHKIRIN OR "GREEN FENCE" OF THICK BAMBOO AND TREES SURROUNDING RESIDENCE
SENDAI BEACH/AIRPORT	N 38.134517 E 140.941704	COASTAL DIKE	n.d.	+6.4	FIGURE "8" UNITS (2 M X 2 M X 0.5 M)

2.3 Storm Surges

Storm surges caused by typhoons have also caused catastrophic damage by flooding in Japanese history. An average of 3 typhoons, out of 27 occurring each year, hit Japan directly due to the fact that Japan is located in the ordinary route of typhoon tracks (Shuto, 2007). Large storm surge disasters have occurred frequently until 1961. For example, in case of a typhoon with a storm surge namely Ise Bay Typhoon in 1959 caused about 5000 deaths. Although it is impossible to avoid the impacts of flooding and storm surges caused by these typhoons, the situation changed a bit after 1970's and extensive flood damage due to storm surges have been rare. (Torii and Kato, 2002). Torii and Kato state that one of the main factors of less number of severe storm surge floods in recent 40 years is construction of coastal dikes against storm surges. Most of coastal area in Japan is protected from storm surges and high waves by coastal dikes as also stated in the previous section. They are largely covered with concrete or asphalt units. After the 1959 Ise Bay Typhoon and the 1960 Chilean Tsunami, it has been the general trend to build coastal dikes having a length of 5-6 m as coastal defenses. The construction of storm surge breakwaters was also realized after the event. Breakwaters were constructed far offshore, allowing sufficient area behind breakwaters to prevent wind waves from entering through the narrow entrance of bays. To cope with overflowing storm surges and overtopping wind waves, the front, top, and rear side of coastal dikes were to be covered with concrete (Shuto, 2007). The design parameters are stated as the tide level, wave overtopping rate and evaluated return periods of them.

Saleh (nd) published the results of his site visits conducted along the Kagoshima Coastline, Japan to identify the coastal protection structures. He states that the revetments he discovered consists of small rocks and nicely arranged inside the gabions. The revetment is arranged into 3 different layers to cope with the different wave energy attacks in the area. The shoreline protections are built in such a way that they withstand the variable wave energy throughout the year because wave energy is higher during the typhoons of the peak of summer (June- August) compared to winter.

3 Europe

3.1 *Introduction*

European coasts have variable conditions and different defense schemes. Some coasts along the United Kingdom and Denmark have cold climate, strong waves and emergent detached structures whereas Mediterranean sites are characterized by low tidal excursion and moderate waves. Coastal structures in European countries are mainly related to storm surges and coastal erosion. Europe was hit by large tsunamis in the past and similar, or possibly larger, events may happen again (Louat and Baldassari, 1989; Soloviev, 1990, 2000; Tinti et al., 1996, 2004; Pelinovski et al., 2002; Lander et al., 2002; O'Loughlin and Lander, 2003; Sahal et al., 2010); however, most of the coastal protection structures are not designed considering tsunami. Therefore possible tsunamis may cause much larger destruction due to the increased occupation of the coasts (TRANSFER, 2009).

3.2 *Storm Surges*

To begin with, in the Baltic Sea Region, the storm surge risk mainly takes place in the southern part of the Baltic Sea region, i.e. Germany, Poland being in direct contrast to the northern Baltic coasts of Finland and Sweden which are mainly composed of hard rock. The tidal influence is negligible (tidal range < 0.25 m) and the coasts are wave dominated, while the wave climate is moderate (National Institute for Coastal and Marine Management, 2004). The North Sea Coasts of Germany, the North Sea islands, the Wadden Sea, as well as the big harbours of Hamburg and Bremen have also a severe storm surge risk. Water level heights related to storms can be more than two times higher along the North Sea Coasts of Germany than along the Baltic (*Fig.* 3.1a). Denmark is another country where storm surge generally are more severe at the North Sea Coast. In addition to these, the whole Dutch coasts have a severe storm surge risk (*Fig.* 3.1b).

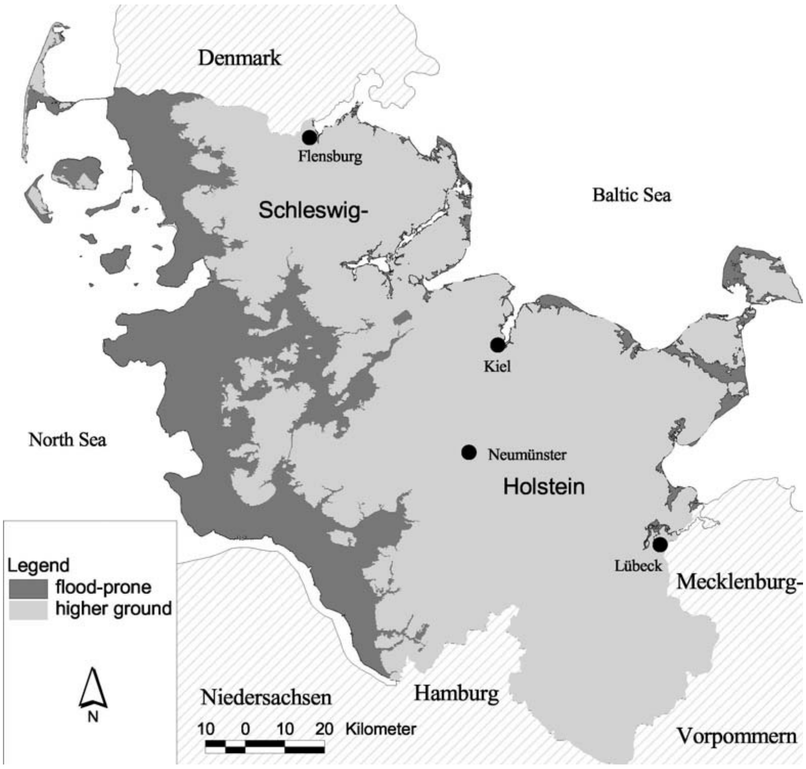


Fig 3.1a Coastal flood-prone lowlands in Schleswig-Holstein. (Germany North Sea and Baltic Sea Coasts) (<u>Source:</u> Jacobus H., A new coastal defence master plan for Schleswig-Holstein, 2004)

Fig. 3.1b Flood-Prone Coastal Areas North Sea. (<u>Source:</u> "Coastal Protection in Germany" Course Lecture Notes, Coastal Engineering Research Group, University of Rostock)

Belgium: The Belgian coast consists of mainly sandy beaches with sea walls in front of the coastal towns and dunes in between. The present coastal defence system can withstand a 100 years storm surge (Verwaest et al., 2008). The coastal structures such as quays, dikes and sluices function as a part of the coastal defence system. At several locations the height or the strength of these harbour structures is limited, resulting into breaching possibilities via the harbours. The criteria determined in the Integrated Master Plan for Coastal Safety initiated by Belgian Coastal Division for safety is to withstand extreme storm floods, providing a minimum safety standard of once in 1000 year. Storm return walls, erosion resistant slopes, storm surge barriers and an international dike in Zwin region are the proposed hard coastal protection works in the plan.

The Netherlands:

Coastal protection in the Netherlands has been standardised and new designed after the 1953 storm flood disaster in the so-called “Deltawerken”. The new savety standards are shown in Fig. *3.2* (Sayers and Meadowcroft 2005).

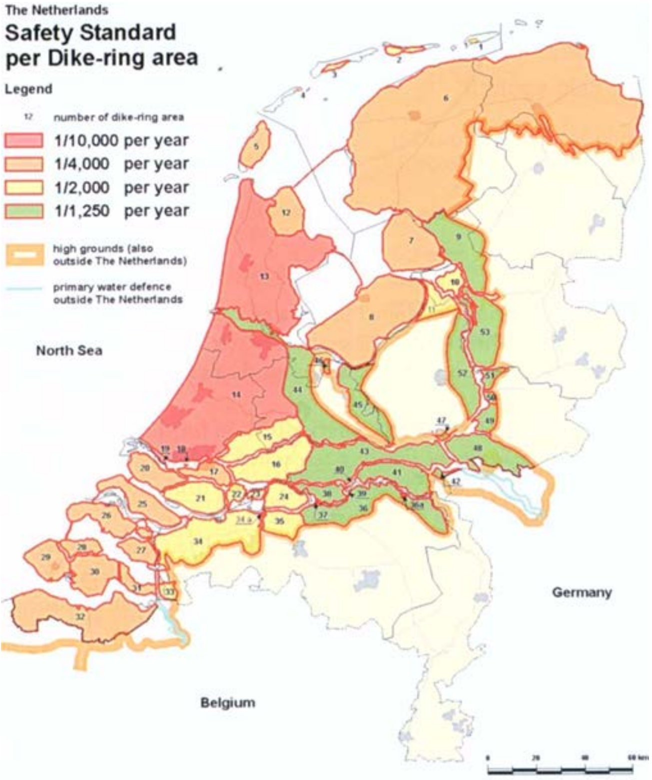


Fig. 3.2 Safety standards in the Netherlands (Sayers and Meadowcroft 2005)

The Dutch Wadden Sea islands generally have broad beaches and dunes. These present the most important element of coastal protection on the North Sea coast of these islands. Moreover, the whole Dutch Coast is divided into dike rings and protected by dikes, dunes and barriers to withstand a 1000 year water level, sometimes even up to a 10,000 year water level.

Primary flood defences in the Netherlands include dikes, dunes and hydraulic structures which provide direct protection against the sea, storm surge barriers and defences, which provide indirect protection against flood water - an example of these is the flood defences along the Noordzeekanaal- (The Netherlands National Report, 2006). Examples to these structures can be given as the quay walls and high grounds along the Nederrijn and by dikes in combination with high grounds along the river Ijssel in Arnhem (*Fig. 3.3* a and b), two-level quay walls in Doesburg (Fig. *3.4*) or alternative designs for the Dordrecht city flood defence (*Fig. 3.5*) (Voorendt, 2014).

Fig. 3.3 a) two-level quay wall *b) restaurant integrated in the flood defence*
(<u>Source:</u> Voorendt, 2014)

Fig. 3.4 a) two-level quay wall *b) relax stairs in the retaining wall*
(<u>Source:</u> Voorendt, 2014)

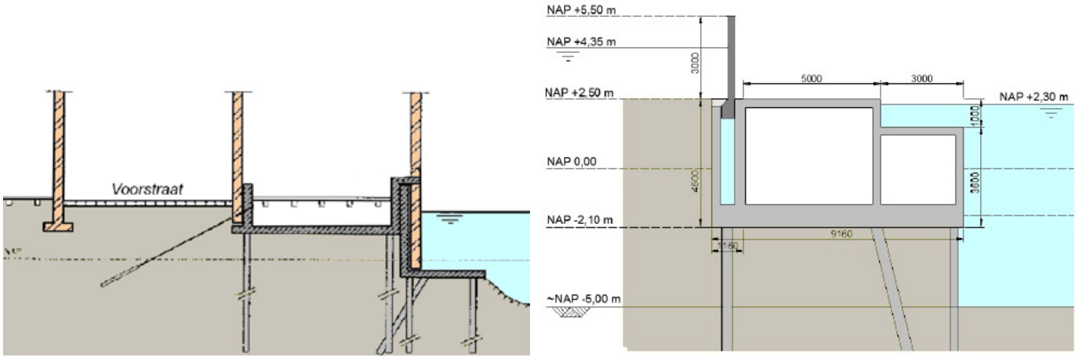


Fig. 3.5 Alternative designs for the Dordrecht city flood defence. (Source: Voorendt, 2014)

The storm surge barrier in the Rotterdam Waterway (1997) is also an example to the more centrally guided water management between 1798-2000 years in the Netherlands (van Leussen, 2008) (*Fig. 3.6*).

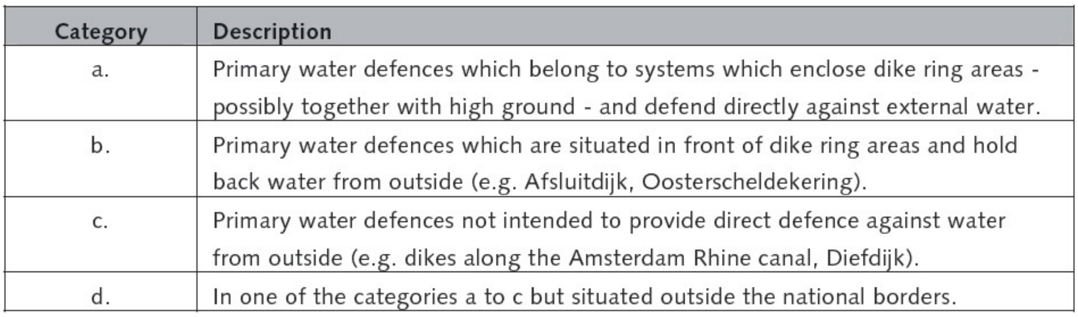
Fig. 3.6 Storm surge barrier in the Rotterdam Waterway (Source: Voorendt, 2014)

The safety of the Netherlands is dependent on reliable flood protection structures. Failure of flood defences could have serious devastating human and economic consequences as was proven by the damages caused during the North Sea flood of 1953 (European Commission Policiy Research Corporation, 2009).

The categorization of water defences in the Netherlands is given as four groups in Flood Risks and Safety in the Netherlands, FLORIS Study Report (2005). A 'primary' water defence is a water defence which protects against flooding either because it is part of the system that surrounds a dike ring area - possibly together with high ground

- or which is situated in front of a dike ring area. Under the present management regime four categories of primary water defences are defined, given in Table *3.1*.

Table 3.1 Overview of the four categories of flood defences (FLORIS Study Report, 2005)



Category	Description
a.	Primary water defences which belong to systems which enclose dike ring areas - possibly together with high ground - and defend directly against external water.
b.	Primary water defences which are situated in front of dike ring areas and hold back water from outside (e.g. Afsluitdijk, Oosterscheldekering).
c.	Primary water defences not intended to provide direct defence against water from outside (e.g. dikes along the Amsterdam Rhine canal, Diefdijk).
d.	In one of the categories a to c but situated outside the national borders.

<u>Germany:</u> The focus point of the Germn coastal protection strategy is the protection against flooding by means of dikes and other hard coastal defences such as storm surge barriers. The entire German North Sea coastline is protected by those coastal protection structures. Since about 1000 A. D. dikes function as the protection of the coastal areas against inundation (Niemeyer et al., 1996). Even the islands – if not surrounded by huge dune belts- are protected by hard structures. Dikes are constructed to withstand a 100 year storm surge and most of them are around 8 m high. As stated in the the most recent master plan for coastal defence (Schleswig-Holstein), for all primary dikes the design water level is needed to meet three basic requirements for a safety check; a return period of 1:100, being not lower than the highest water level recorded in the past, being not lower than the sum of the highest spring tides and the highest recorded surge (Policy Research Corporation, European Commission, 2009).

The 1872 storm surge event with its disastrous damage bases as a reference for determining the design water levels on the German Baltic Coast (with a set-up of about 3.5 m). Storm surge classification to get a measure for its severeness, a storm surge prediction in order to identify vulnerable or endangered coastal regions and observations of wave-induced set-up of water-levels are also the required steps in design concept (Niemeyer et al., 1996). Typical coastal protection structures are viewed in the following *Fig.* 3.7 and *Fig.* 3.8.

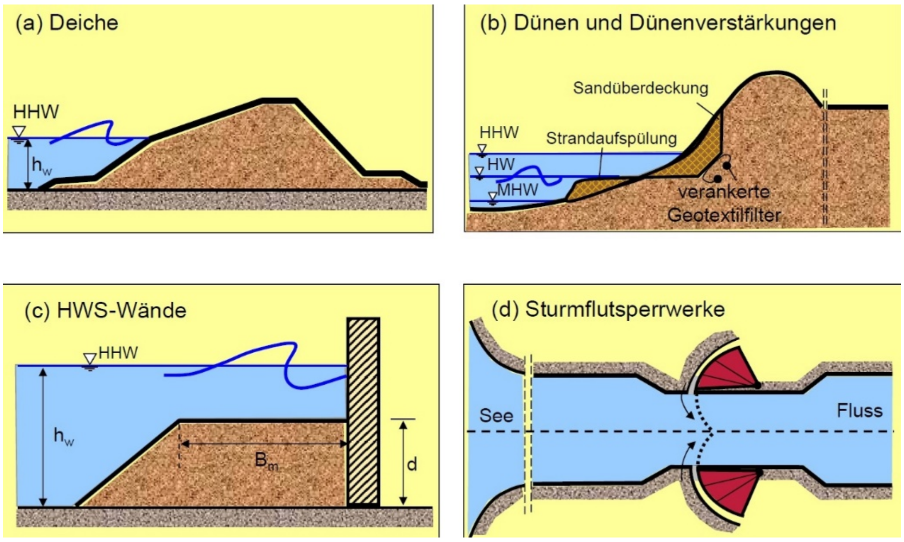


Fig. 3.7 Flood protection works in the German Coastal Zone (Overview), a) Dikes b) Dunes and Dune Reinforcements c) Flood Protection Walls d) Storm Surge Barriers. (<u>Source:</u> H. Oumeraci, "Coastal Engineering" Lecture Notes, TU-BS)

Fig. 3.8 Emssperrwerk (storm surge protection / storage function). (<u>Source:</u> H. Oumeraci, "Coastal Engineering" Lecture Notes, TU-BS)

<u>*Denmark:*</u> Coastal protection has been carried out in Denmark since around 1000 A.D. (the date of first dike construction in the Wadden Sea). The current performance of coastal protection along many Danish Coasts against storm surge flooding can be summarized according to a survey carried out between 1996-1999 as 900 km of dikes and 700 km of revetments (Danish Coastal Authority Database, 2013a). It should be

noted, that it is in general the landowner's responsibility of protecting their land against the impacts from the sea. The dikes along the Wadden sea are mostly reinforced as a result of the significant storm surges experienced in Denmark in 1976 and 1981. The dikes along Ribe and Tønder regions (cf. Fig. 3.9) are constructed to withstand a storm surge occuring every 200 years statistically, whereas the others are built for storm surges that statistically occur every 50 years (Danish Coastal Authority Database, 2013b).

Fig. 3.9 The Wadden Sea Dikes (<u>Source:</u> Danish Coastal Authority Database)

<u>The United Kingdom:</u> Sea defence frame of the United Kingdom against storm surges consists of temporary sea or tidal flooding incidents protection. However, most of the coastline of the UK can be described by erosion patterns, followed with stable segments and areas subject to accretion. Therefore, although breakwaters, seawalls,

jetties, revetments and groins are typically seen structures along the British Coasts, they are constructed mainly to stop coastal erosion.

Ireland: Ireland is one of the countries which is vulnerable to both coastal flooding and erosion resulting into different degrees of risk along its coastline. A collage of coastal protection structures along the Irish Coasts is given in *Fig.* 3.10.

Fig. 3.10. A collage of typical coastal protection structures in Ireland. a) rubble protecting private houses b) precast concrete structure protecting footpath c) gabions protecting footpath d) urban seafront with several generations of walls e) rubble protecting caravan site f) rock armour protecting coastal roads. (_Redrawn from:_ Pranzini E., and Williams A., "Coastal Erosion and Protection in Europe", 2013)

France: The earliest forms of coastal protection in France are rock armouring and seawalls. Rock armouring is still widely used in France, but in many areas it has been replaced by masoned seawalls. Masoned or stone seawalls are presently the most frequently seen form of coastal protection. Vertical seawalls also exist, sometimes alongside inclined walls of various slope forms. Seawalls have become much more popular than rock armouring because they are found as more aesthetic.

Fig. 3.11 Rock armour protection of cliff base in Normandy. (Redrawn from: Pranzini E., and Williams A., "Coastal Erosion and Protection in Europe", 2013)

Greece: Greece has the most extensive coastline among Mediterranean countries, the shoreline length exceeding 15,000 km. In Greece, vertical seawalls are usually constructed with concrete or rock material to protect coastal roads (e.g. the coastal road at Nea Makri (Chatzieleftheriou et al., 2007). Rock armouring is employed to many of the walls to protect the structure toe against scouring. The most common structural measure applied to protect private facilities and infrastructure of low importance is walls and revetments designed and constructed as parts of rocks having a rather uniform size. They can also be comprised of precast concrete blocks which are more commonly used as protection structures against coastal forms of more importance such as regions having higher aesthetic value. The seawall and breakwater in front of the "Peace and Friendship" Stadium and the Olympic Beach Volley Stadium at Faliron Bay (Attica) are some examples.

Turkey: Most of the Black Sea Coast of Turkey (from Sinop to Hopa, Artvin) is protected by rubble mound revetments against destruction of the Black Sea coastal road due to excess overtopping and wave effects since the road is a low-lying area.

Fig. 3.12 Coastal Roadside Rubble Mound Revetment in Black Sea

Many small rubble mound breakwaters having relative large crest widths are also observed along the entire Black Sea coast to provide a sheltered zone against wave action for fishery ports. Rubble mound breakwaters for port/harbour protection are the most common coastal structures in Turkey.

Fig. 3.13 A Rubble Mound Breakwater in the Black Sea Coast of Turkey

Fig. 3.14a A collage of scenes from Giresun Port under wave attack in the Black Sea Coast of Turkey


14:11
20. 2.1999


14:11
20. 2.1999

Fig. 3.14b A collage of scenes from Giresun Port under wave attack in the Black Sea Coast of Turkey

3.3 Coastal Erosion

Coastal erosion is the most common natural phenomenon along European Coasts that has always existed throughout the history. It results from a combination of various factors including natural ones as waves, winds, tides, near shore currents and sea level rise as well as the human-induced factors such as coastal structures, land reclamation, vegetation clearing or dredging operations.

Almost all European countries suffer from coastal erosion due to some combinations of those factors in combination with their coastal geomorphology, coastal hydrodynamics, and meteorological characteristics of the regions as well. For example, storm surge waves with high energies from the Northern Atlantic and the medium macro-tidal range of 2-4 m (maximum up to 15 m in Bay of Mont Saint-Michel, France), are the main drags of erosion along the Atlantic Coasts.

However, geomorphological features of each different area along the Mediterranean Coast vary considerably and erosion is mainly a result of winter storms when beach material is transported offshore, also to deeper water (National Institute of Coastal and Marine Management of the Netherlands, 2004).

In the Baltic Sea region, the coasts vulnerable to coastal erosion are those of Germany, Poland, Denmark and southern Sweden whereas along the remaining parts of the Swedish coast and along the Finnish coast erosion problems are very uncommon due to the prevailing land uplift. However, in spite of all those varieties in terms of causes of the problem or locations it is observed, the phenomenon is common and the engineering solutions in terms of structural measures against the issue do not show great differences. It does not mean that each region is taking similar actions; there are obviously variations according to the characteristics of each region.

As stated at the very beginning of the report, the RAPSODI Project focuses on coastal hazards and protection to increase resilience against those hazards specific to tsunamis. Therefore, the coastal erosion concept will not be analysed in much detail. The common-uncommon features of the structures against erosion will be given in a grouped way of the structures trying to also include the material properties, design parameters and the observed regions if possible.

The main categories of coastal structures against coastal erosion along the European Coasts can be listed as seawalls, revetments, groins and detached breakwaters and will be described in more detail in the following.

Seawalls: Almost all European regions employ seawalls except Lithuania (Pranzini and Williams, 2013). They are constructed as shore parallel massive structures being either gravity- or pile-supported structures. Common construction materials are artificial concrete units and stones, where stone walls performed a lot better to date. There are also gabion alternatives but not a common approach except Ukraine, Poland and Russia. These structures are often supported with sheet pile cutoff walls at their toe to prevent scouring. Ripraps are also generally used as additional rock toe protection. The seaward faces are generally sloped and/or stepped but vertical ones are also possible.

Revetments: These structures are also popular shore parallel measures made of erosion resistant materials, such as natural stone, concrete or geotextiles. They are constructed to protect a scarp, embankment, or other coastal property against erosion. However, the Eastern Adriatic Countries do not support using these structures. A revetment is commonly comprised of three parts as the armour layer, filter layer, and the toe part. Toe protection is also generally used to block displacement of the seaward slope of the revetment due to scour.

Groins: These are relatively narrow, shore perpendicular structures mostly made of rubble-mound or sheet-pile construction. Therefore, wood and stone are the preferred materials. They are very common; Estonia and Latvia are the only exceptions not to use groins. In Turkey also, groins (linear and T-shaped ones) are commonly applied against erosion along the Black Sea Coast. These structures are generally built as not permeable and linear, T-shaped or fishtail types are the three most common shapes. Ukraine is the only country in the European region that utilizes L shaped groins. Groins are used for several reasons such as a) stabilization of shores exposed to severe storms or exposed to seasonal shoreline recession by reducing the longshore transport rate, b) constructing or widening of a beach by catching the longshore drift, c) prevention of erosion or accretion in an inlet or at a harbour by functioning as a barrier to longshore transport.

Detached breakwaters: These breakwaters are also constructed as shore-parallel for beach stabilization in a way of reducing the wave energy and thus the sediment carrying capacity of the waves reaching the shoreline. They are designed either to prevent the erosion of an existing beach or to help creation of a new beach providing accretion. Although Italy has a frequent use of these structures along with groins, it cannot be said that this type of structures is very common throughout Europe because few countries (Italy, Romania and the Ukraine) construct these ones. In Russia and the Ukraine, concrete units are commonly used to build detached breakwaters (Pranzini and Williams, 2013). Also in Turkey, nearshore breakwaters are rarely seen along the Black Sea Coast.

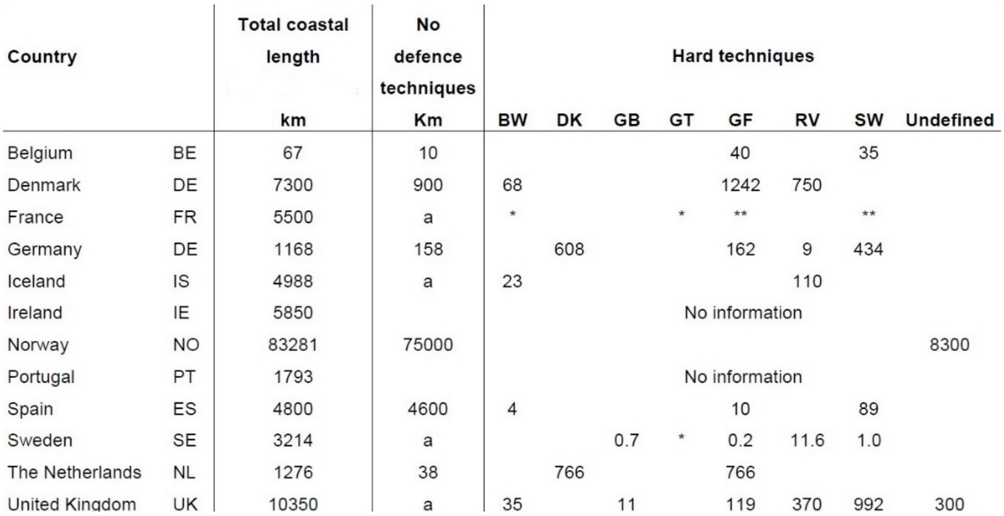
In addition to these, island platforms are not common features against beach erosion because the Great Britain, France, Italy, Romania and Spain are a handful of countries having such kind of formations. Also, slope protections similar to revetments are possible formations even though uncommon consisting of an enforced toe of a dune or cliff, usually in the form of piled stones or boulders.

4 Comparative Analysis

Accessible literature on the coastal structures against related coastal hazards in Japan and the European Region is reviewed, analysed and the information obtained based on the analysis is presented. As can be understood from the provided information, different types of coastal hazards are common in Japan and Europe. While tsunami issues are present very commonly in Japan, the European countries are mainly dealing with coastal erosion problems. As a consequence of that situation, types and characteristics of the coastal structures in these two regions differ significantly. While most of the European countries do not consider tsunami risk, Japan seems to gradually improve their design methodologies to protect from tsunamis. Structures against storm surges also differ significantly where more detailed information on a country basis is available in Europe and only very limited information was found for Japan in this respect. When coastal erosion phenomena and protection by coastal structures are concerned, this is not of a big concern in Japan, but it is very common on the European side.

Some of the available information on the coastal protection structures throughout Europe are given in Table *4.1* and *Figure 4.1-4.2* are provided as follows.

Table 4.1 Overview of coastal defence categories and their relative importance expressed in terms of kilometres of defended coast. (<u>Redrawn from:</u> Govarets and Lauwerts, "Assessment of the impact of coastal defence structures", OSPAR COMMISSION, 2009)



Country		Total coastal length	No defence techniques	Hard techniques							
		km	Km	BW	DK	GB	GT	GF	RV	SW	Undefined
Belgium	BE	67	10					40		35	
Denmark	DE	7300	900	68				1242	750		
France	FR	5500	a	*			*	**		**	
Germany	DE	1168	158		608			162	9	434	
Iceland	IS	4988	a	23					110		
Ireland	IE	5850		No information							
Norway	NO	83281	75000								8300
Portugal	PT	1793		No information							
Spain	ES	4800	4600	4				10		89	
Sweden	SE	3214	a			0.7	*	0.2	11.6	1.0	
The Netherlands	NL	1276	38		766			766			
United Kingdom	UK	10350	a	35		11		119	370	992	300

* Occurs in some points
**Occurs in a substantial portion of the coast
"a" Unprotected length not passed on

- BW: Breakwater, DK: Dike, GB: Gabion, GT: Geotextile, GF: Groin, RV: Revetment, SW: Seawall
- Total coastal lengths are also shown within so-called OSPAR Maritime Area in *Figure 4.1*.

Fig. 4.1 Coastal defence techniques used along the coastline of the OSPAR Maritime Area. (Redrawn from: Govarets and Lauwerts, "Assessment of the impact of coastal defence structures", OSPAR COMMISSION, 2009)

- No colour on the map indicates that there is no information available.

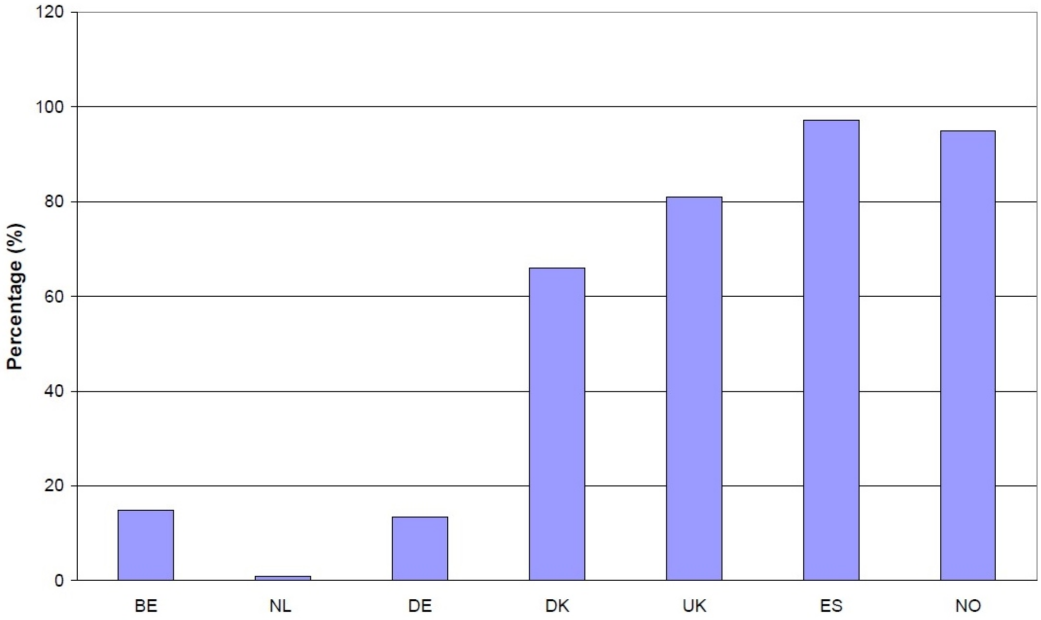


Fig. 4.2 Percentage of unprotected coastline in Belgium, the Netherlands, Germany, the United Kingdom, Denmark, Spain and Norway. (Redrawn from: Govarets and Lauwerts, "Assessment of the impact of coastal defence structures", OSPAR COMMISSION, 2009)

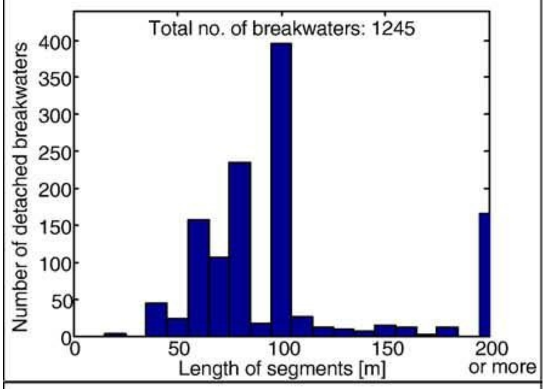
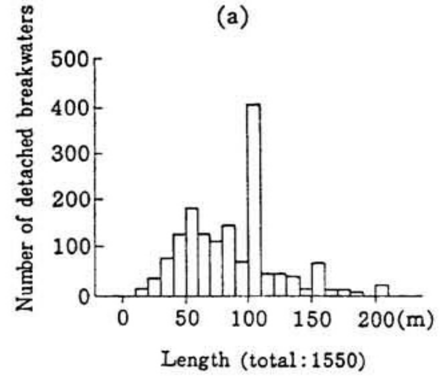
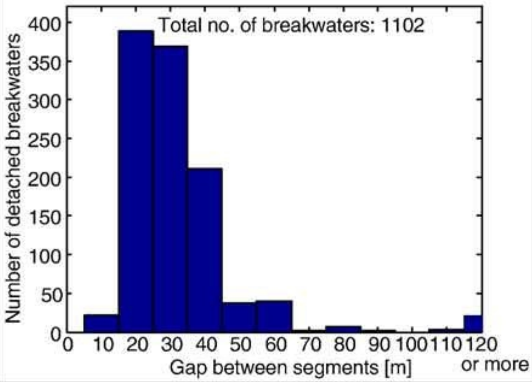
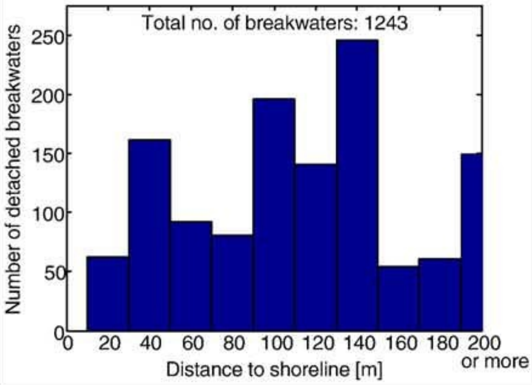
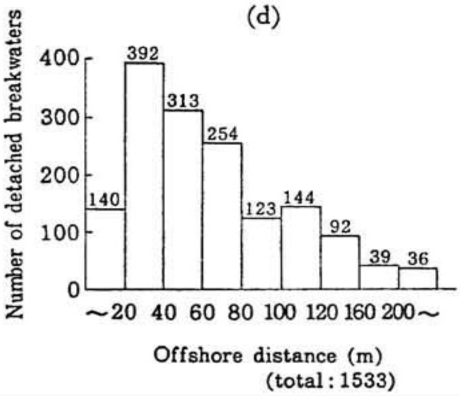
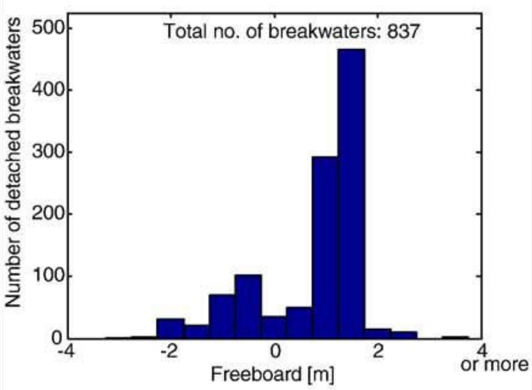
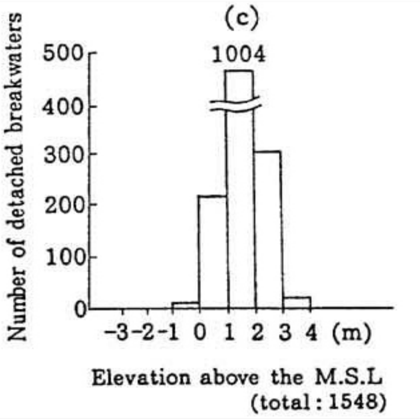
This information indicates that several countries such as Belgium, Denmark and Germany has protected their coastlines with hard techniques and most of their coastlines can be considered as artificial coastlines. On the other hand, some of the countries (eg Spain) have much less protection structures. Soft measures and combination of soft and hard measures are also seen along the European coasts. Once again, the importance of local characteristics of the region and the type of hazards are being distinguished as significant parameters on the choice of coastal protection method.

A wide variety of structures have been built in Japan with the express purpose of preserving coastal areas against the storm surges, tsunamis, and slow coastal erosion. The coastal protection structures such as detached (offshore) breakwaters, breakwaters, seawalls, dikes and gates cover almost 40% of the shoreline. These structures were designed to resist the critical condition of highest historical tsunami height or a 50-year-return wave on a storm surge. On the other hand, in Europe, probabilistic approach is used where at least 100 year return waves are considered and tsunami is not included in the design process.

Although the types of structures used in Japan and Europe are similar in general, they are widely different when the material of construction is considered. Breakwaters in Japan are almost always built as concrete caissons located on rubble mound bases whereas in Europe, most breakwaters are built as rubble mound structures with smaller concrete crown walls. Although the function of both type is the same, the reaction to hazards especially tsunami can be very different as discussed in Deliverable 1 of RAPSODI project (http://www.ngi.no/en/Project-pages/RAPSODI/Reports-and-Publications/).

Dikes are also constructed with different materials in Japan and in Europe. In Japan, most dike structures are covered with concrete blocks or asphalt on both sides of the structure. In Europe, one common practice is to use coastal vegetation especially on the leeward side. Once again, although the functional properties are the same, under tsunami conditions, European version would be much more vulnerable due to the scour effect under overflow. Concrete covers of the Japanese dikes were not as resistant as expected in 2011 GEJE event however, these can be considered as more resilient to tsunami loadings.

Another particular structure that can be compared is the case of detached breakwaters. Most detached breakwaters are designed as low crested structures where the main body is submerged and located offshore. A comparison analysis of characteristics of detached breakwaters in Europe and Japan was carried out within the scope of the DELOS project (Lamberti et al, 2005). The comparison shows that detached breakwaters with low crests are very common in Japan and similar characteristics such as length, depth and spacing of segments are being used at both locations. Some statistical differences are worth mentioning such as offshore distances of these structures are much less than the European cases. Additionally Japanese structures usually have larger crown widths of around 5 meters and more (*Fig 4.3*). These differences and similarities could be attributed to the different functional purposes combined (erosion, waves or tsunami) in one structure as well as site specific characteristics of two regions. How these differences in terms of resilience to tsunami loading affects the performance of the structures should be investigated for mitigation purposes.

EU	Japan
 Total no. of breakwaters: 1245 Number of detached breakwaters 0 50 100 150 200 250 300 350 400 0 50 100 150 200 or more Length of segments [m]	 (a) Number of detached breakwaters 0 100 200 300 400 500 0 50 100 150 200(m) Length (total:1550)
 Total no. of breakwaters: 1102 Number of detached breakwaters 0 50 100 150 200 250 300 350 400 0 10 20 30 40 50 60 70 80 90 100 110 120 or more Gap between segments [m]	
 Total no. of breakwaters: 1243 Number of detached breakwaters 0 50 100 150 200 250 0 20 40 60 80 100 120 140 160 180 200 or more Distance to shoreline [m]	 (d) Number of detached breakwaters 0 100 200 300 400 140 392 313 254 123 144 92 39 36 ~20 40 60 80 100 120 160 200~ Offshore distance (m) (total:1533)
 Total no. of breakwaters: 837 Number of detached breakwaters 0 100 200 300 400 500 -4 -2 0 2 4 or more Freeboard [m]	 (c) Number of detached breakwaters 1004 0 100 200 300 400 500 -3 -2 -1 0 1 2 3 4 (m) Elevation above the M.S.L (total:1548)

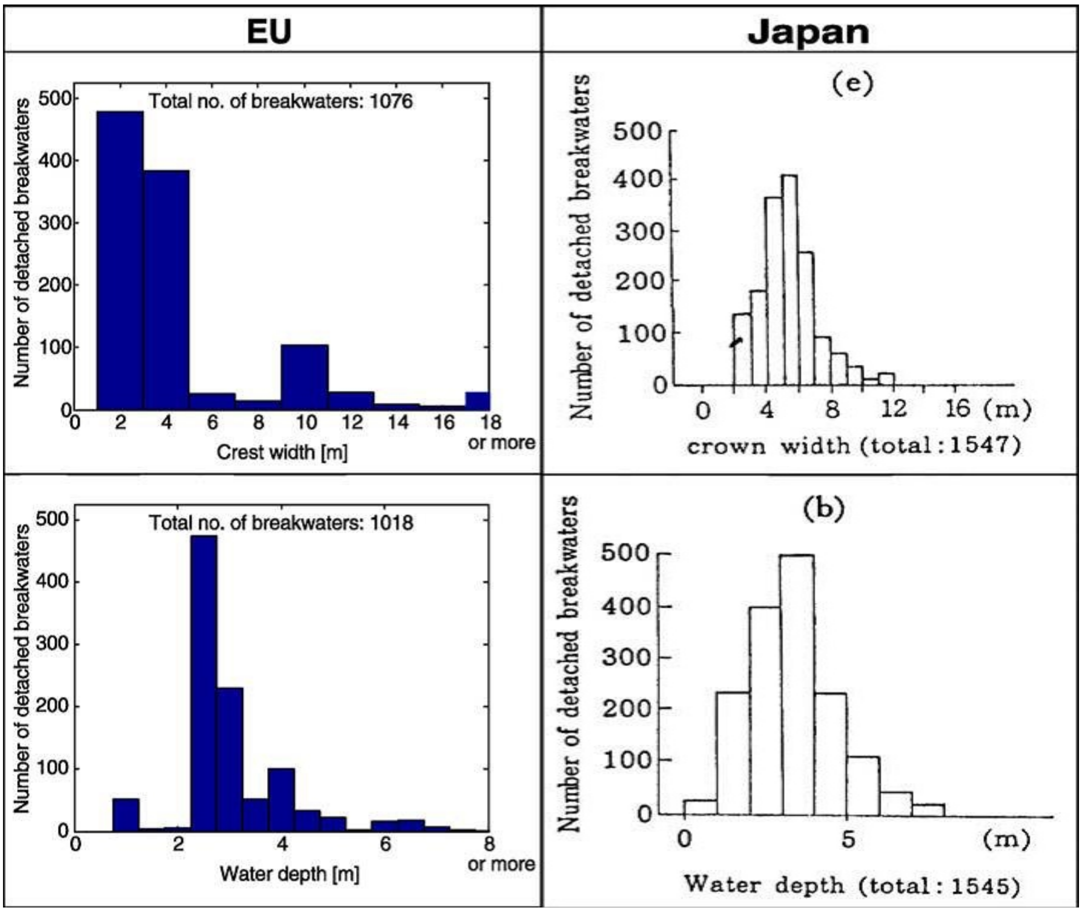


Fig. 4.3 Histograms showing the distribution of LCSs for each investigated parameter for the Europe and Japan. (Redrawn from: Lamberti et al., European experience of low crested structures for coastal management, 2005)

5 Summary and Concluding Remarks

Coastal protection structures have been the first line of defence against many of the coastal hazards and problems all around the world. There is a variety of protection structures that can be implemented in terms of hazard mitigation. The functionality, design, and construction of these structures depend significantly on the type of hazard they are built against as well as the site specific conditions. Therefore, different types of structures perform well under different hazard conditions. So, although similar structure types are constructed all around the world, not every location that has a protection structure is resilient against all types of hazards.

In Europe, the type of coastal hazards that are considered in the management strategies are storm surges and coastal erosion. Although storm surges result in flooding and the type of structures designed for protection aims to prevent the overtopping phenomena, the progress of the flooding event as well as the scale of loadings is very different than the case of tsunamis which are significantly considered in Japan.

These differences in functionality are reflected in the materials and the design process of the protection structures. While Japanese structures are mostly based on concrete and vertical structures, European structures usually depend on rock armouring and sloped structures with sea walls normally designed for erosion mitigation. The performances of different structures under tsunami loading, especially in the case of European structures, should be considered even if they are considered efficient in case of storm surges. Although tsunami risk is low in many parts of Europe, several historical tsunamis occurred, not due to earthquakes, but due to landslides. While research on landslide generated tsunami risk in Europe could present the exposed coastal areas, research on the performance of European coastal structures under tsunami loading would help to determine the actual risk.

6 References

- Álvarez-Gómez, J.A., et al. (2011): Tsunami hazard at the Western Mediterranean Spanish coast from seismic sources. Natural Hazards & Earth System Sciences 11.1.
- ASCE-COPRI-PARI Coastal Structures Field Survey Team (2013): Tohoku, Japan, Earthquake and Tsunami of 2011: Survey of Coastal Structures. ASCE Publications.
- The Netherlands National Report (2006).
- Balas, C. E., and Ergin, A. (2003): Rubble Mound Breakwaters Under Tsunami Attack. Submarine Landslides and Tsunamis. Springer Netherlands, 293-302.
- Cardineau, C.A. (2011): Analysis of Tsunami Hazards in Spain, eTraverse, Vol. II No. 2.
- Chatzieleftheriou, M., Alexandrakis, G., Poulos, S., Gaki-Papanastassiou, K. & H. Maroukian (2007): Assessment of vulnerability to a future sea-level rise of the E and NE coast of Attica. Proceedings of the 8th Pan-Hellenic Geographical Conference vol. 1, 298-305.
- Dababneh, A., Ferguson, B., and Barton, D.J. (2012): Probable Maximum Tsunami along the Dutch Coastline." The Twenty-second International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers.
- Danish Coastal Authority Database (2013a): http://eng.kyst.dk/the-wadden-sea-dikes.html
- Danish Coastal Authority Database (2013b): http://eng.kyst.dk/coastal-protection-in-denmark.html
- European Commission, Directorate-General for Maritime Affairs and Fisheries, Policy Research Corporation (2009): The economics of climate change adaptation in EU coastal areas', May 2009.

- Flood Risks and Safety in the Netherlands (Floris) (2005): Floris study - Full report, November 2005.
- Govarets A., Lauwerts B. (2009): Assessment of the impact of coastal defence structures, OSPAR COMMISSION, Technical Report - Biodiversity Series.
- Hofstede, J. (2004): A new coastal defense master plan for Schleswig-Holstein. Geographie der Meere und Küsten. Coastline Reports 1.2004, 109-117.
- Hsu, J.R.C., Uda, T., and Silvester, R. (2000): Shoreline protection methods—Japanese experience. Handbook of Coastal Engineering 9-1.
- Ishiwatari, M., and Sagara, J. (2012): Structural Measures against Tsunamis." WorldBank Knowledge Notes 1-1.
- Hofstede, Jacobus (2004): A new coastal defence master plan for Schleswig-Holstein. Geographie der Meere und Küsten. Coastline Reports 1.2004, 109-117.
- Kawata Y., Isobe M., Imamura F., Katada T, Nakano S., Hiroi O., Fujiyoshi Y., Yamada T. (2004): Tsunami and Storm Surge Hazard Map Manual.
- Lambert, J., and Terrier, M. (2011): Historical tsunami database for France and its overseas territories." Natural Hazards & Earth System Sciences 11.4.
- Lamberti, A., et al. (2005): European experience of low crested structures for coastal management. Coastal Engineering 52.10, 841-866.
- Lander, J.-F., Whiteside, L.-S., and Lockridge, P.-A. (2002): A brief history of tsunamis in the Caribbean Sea, Science of Tsunamis Hazards, 20, 57–94, 2002.
- Louat, R. and Baldassari, C. (1989): Chronologie des s´eismes et des tsunamis ressentis dans la r´egion Vanuatu Nouvelle-Cal´edonie (1729–1989). Rapports scientifiques et techniques. Sciences de la Terre, G´eophysique, ORSTOM, Noum´ea, 1, 47 pp. (in French).
- Mertens, T. et al. (2008): An integrated master plan for Flanders future coastal safety." Proceedings of the 31st International Conference on Coastal Engineering. Vol. 31.
- National Institute of Coastal and Marine Management of the Netherlands (2004): A guide to coastal erosion management practices in Europe, Eurosion.
- Niemeyer, H.D., Eiben, H., and Rohde, H. (1996): History and heritage of German Coastal engineering. History and heritage of coastal engineering. ASCE.
- Nirupama, N., and T. S. Murty (n.d.): Similarities and differences in tsunami and storm surge mitigation.
- O'Loughlin, K.-F. and Lander, J.-F. (2003): Caribbean tsunamis, A 500-Year History from 1498–1998. Advance in Natural and Technological Hazards Research, 263 pp.
- Ohta, H., Pipatpongsa, T., and Omori, T. (2005): Public education of tsunami disaster mitigation and rehabilitation performed in Japanese primary schools,

paper to the International Conference on Geotechnical Engineering for Disaster Mitigation & Rehabilitation.

- Oumeraci H.: "Coastal Engineering” Lecture Notes, Technische Universität Braunschweig
- Pelinovski, E., Kharif, C., Riabov, I., and Francius, M. (2002): Modelling of tsunami propagation in the vicinity of the French Coast of Mediterranean Sea. Naturals Hazards 25, 135–159.
- Policy Research Corporation (in association with MRAG) (2009): The economics of climate change adaptation in EU coastal areas - Socio-economic studies in the field of the Integrated Maritime Policy for the European Union. European Commission Directorate-General for Maritime Affairs and Fisheries.
- Pranzini, E., and Williams, A. (eds.) (2013): Coastal erosion and protection in Europe. Routledge.
- Sahal, A., Pelletier, B., Chatelier, J., Lavigne, F., and Schindel´e, F. (2010): A catalog of tsunamis in New Caledonia from 28 March 1875 to 30 september 2009, C. R. Geosci., 342, 434–447.
- Saleh, E.B. (n.d.): Coastal Structures in Kagoshima Coastline, Japan.
- Sayer, P. and Meadowcroft, I. (2005): Strategic Planning in Coastal Risk Management. Comrisk Subproject 2, Die Küste 70, 19-31.
- Shuto N. (2007): Review: A Century of Countermeasures Against Storm Surges and Tsunamis in Japan. Journal of Disaster Research Vol.2 No.1.
- Soloviev, S. L., Solovieva, O.-N., Go, Ch.-N., Kirn, K.-S., and Shchetnikov, N.-A. (2000): Tsunamis in the Mediterranean Sea: 2000 B.C. – 2000 A.D. Translation from Russian to English by Gil B. Pontecorvo and Vasiiy I-Tropin, Dordrecht, 237 pp. (about 300 descriptions).
- Soloviev, S.-L. (1990): Tsunamigenic Zones in the Mediterranean Sea, Natural Hazards, 3, 183–202.
- Suppasri, A., et al. (2013): Lessons learned from the 2011 Great East Japan tsunami: performance of tsunami countermeasures, coastal buildings, and tsunami evacuation in Japan. Pure and Applied Geophysics 170.6-8, 993-1018.
- Takahashi S. (2012): Tsunami Disaster Mitigation in Japan. National Conference on Disaster Risk Reduction: Assessing and Managing Risks in Lebanon.
- Tinti, S. and Maramai, A. (1996): Catalog of tsunamis generated in Italy and in Cˆote d’Azur, France: A step towards a unified catalogue of tsunamis in Europe, Annali di Geofisica, 39, 1253–1299.
- Tinti, S., Maramai A., and Graziani, L. (2004): The new catalogue of the Italian tsunamis, Natural Hazards, 33, 439–465.
- Torii, Ken’ichi, and Fuminori Kato (2002): Risk assessment on storm surge flood. Nist Special Publication SP, 315-324.
- Tsimopoulou, V. (2012): The Great Eastern Japan Earthquake and Tsunami: Facts and implications for flood risk management.

- Tsunami Risk ANd Strategies For the European Region, TRANSFER, www.transferproject.eu/
- Uda, T., et al. (2005): Beach erosion in Japan as a structural problem. Proc. 14th Biennial Coastal Zone Conf..
- Uda, T. (2010): Japan’s Beach Erosion – Reality and Future Measures. World Scientific, Advanced Series on Ocean Engineering Vol. 31.
- Van Leussen W. (2008): Flood Management in the Netherlands: Coping with Risks. 4th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability. Toronto, Ontario, Canada.
- Verwaest, Van Poucke, Reyns, Van der Biest, Vanderkimpen, Peeters, Kellens, Vanneuville (2008): SAFECoast: comparison between different flood risk methodologies: action 3B report, SAFECoast Interreg IIIb North Sea project, Flanders Hydraulics Research, Belgium.
- Voorendt, M. (2014): Examples of Multifunctional Flood Defences.

Review and reference page

Document information		
Document title Deliverable D3 - Comparison of coastal structures in Europe and Japan		***Document No.*** 20120768-03-R
Type of document Report	***Distribution*** Limited	***Date*** 17 March 2014
		Rev. No & date 1 / February 2015
Client CONCERT-Japan Joint Call Secretariat		
Keywords		
Geographical information		
Country, County		***Offshore area***
Municipality		***Field name***
Location		***Location***
Map		***Field, Block No.***
UTM-coordinates		

Document control									
Quality assurance according to NS-EN ISO9001									
Rev.	Reason for revision	Self review by:		Colleague review by:		Independent review by:		Inter-disciplinary review by:	
0	Original document								

Document approved for release	Date	Sign. Project Manager
	1 February 2015	Carl B. harbitz

NGI

PARI

Middle East
Technical University
Civil Engineering
Department

Technische
Universität
Braunschweig

CONCERT JAPAN
Connecting and Coordinating
European Research and Technology Development with Japan

concertjapan.eu