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

Deliverables: D1, D3, D4 and D5

19-20 November 2014 RAPSODI meeting at PARI

RAPSODI – 1st year METU deliverables

- **D1 : Report on existing tools, data, and literature on tsunami impact, loads on structures, failure modes and vulnerability assessment provides :**

- Summary of the existing literature on numerical modelling tools
- Proposed formulas to calculate tsunami loads on structures
- Catalogue of failure modes based on observations of the 2011 Tohoku tsunami and existing knowledge
- Summary of vulnerability assessment models used in tsunami research

- **D3 : Report on the comparison of coastal structures in Europe and Japan :**

- Identifies the type of coastal protection structures against related hazards in Europe and Japan
- Compares the characteristics of these structures in both regions considering the types of coastal hazards they are designed against

- **D4 : Report on comparison of mitigation strategies in Europe and Japan :**

- Describes the existing measures against tsunami attack in Europe and Japan
- Discusses the hard and soft measures in both areas and evaluates the use of each of the methods
- Provides a comparative evaluation based on state-of-the-art overview of existing mitigation measures

- **D5 : Report on computed tsunami parameter values in shallow waters and around structures**

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D1 – PART 1 – Tsunami Numerical Modelling

- Models focus on the tsunami generation, propagation and inundation (eg. TUNAMI, NAMIDANCE, MOST)
- Some others for a wider range of applications such as near shore wave processes, advection-dispersion or sediment transport that can be used for tsunami modelling (eg. BOSZ, MIKE21, etc.)
- Almost all have the capability of modelling earthquake generated tsunamis
- After 2004 and 2011 events, the accuracy of inundation modelling including the velocity and fluxes through validation and verification emphasized

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D1 – PART 2 – Tsunami Impact and Loads on Structures

Principal forces associated with tsunami:

(1) hydrostatic force,
(2) hydrodynamic (drag) force,
(3) buoyant force,
(4) surge force and
(5) impact of debris.

Three essential parameters for defining the magnitude and application of these forces:

(1) inundation depth,
(2) minimum wave height
(3) flow velocity (flow direction),
(4) flow depth,
(5) momentum flux

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D1 – PART 2 – Tsunami Impact and Loads on Structures

Source	Type of Load	Formula
Mizutani and Imamura (2001)	Overflowing wave pressure	$\frac{p_{om}}{\rho g H'_d} = A \frac{V_m H_w}{L} \frac{t_0}{t} \sqrt{\frac{2}{g H'_d}} sin\theta_2$
Wiegel (1970)	Overtopping volume	$V = 0.287 \int_{t_1}^{t_2} (\frac{1}{2} h_s \cos\frac{2\pi t}{T} - h_w)^{3/2} dt$
Sumer et al (2007)	Tsunami force on sea walls	$Fwall = (1/2)\rho g b \eta 2(x_w, t) + C_f \rho b \eta(x_w, t) C^2$
Ramsden and Raichlen (1990)	Tsunami force on a vertical wall	$\frac{F_T}{\frac{1}{2}\gamma b(H_1 + d_w)^2} = (\frac{\eta + d_w}{H_1 + d_w})^2 + 2C_F N_F^2 \frac{\eta H_1}{(H_1 + d_w)^2}$

Source	Type of Load	Formula
City and County of Honolulu Building Code (CCH) Alternatively, FEMA 55	The hydrostatic force	$F_{HS} = \frac{1}{2}\rho g (ds + \frac{up^2}{2g})^2$
CCH (2000), FEMA 55 (2003)	The buoyant force	$F_B = \rho g V$
CCH (2000), FEMA 55 (2003)	The drag force	$F_D = \frac{\rho C_D A u^2}{2}$
FEMA 55 (2003)	Bore velocity	$u = C\sqrt{g d_s}$
Dames and Moore (1980), CCH (2000)	The surge force	$F_S = 4.5\rho g h^2$
Asakura et al. (2000),Okada et al., 2005	Tsunami wave pressure	$qx = \rho g(3h - z)$
FEMA 55 (2003) and CCH (2000)	Debris impact force	$Fi = m_b \frac{du_b}{dt} = m \frac{u_i}{\Delta t}$
Keulegan (1950)	Surge velocity	$u = \sqrt{2gh}$
Fukui (1963)	Surge velocity	$u = \sqrt{1.83(gh)}$
Nasu (1948)	Current velocity	$u^2 < \frac{h_v + 0.89b}{0.0358}$
Mizutani and Imamura (2001)	Maximum dynamic wave pressure	$\frac{p_{dm}}{\rho_w g h} = K \frac{c^4}{g^2 H h}$
Mizutani and Imamura (2001)	Sustained wave pressure	$\frac{p_{sm}}{p_{dm}} = 0.14(2 + \cos\theta_1)\frac{c^2}{gH}$
Mizutani and Imamura (2001)	Impact standing wave pressure	$\frac{p_{im}}{p_{dm} + p_{sm}} = 0.5 (\frac{g(h+H)cot\theta_1}{c^2} < 1.1)$

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- **D1 – PART 3 – Failure Modes**

- Overview of different failure modes with short examples, the source of information, and further details
- most of the structures surveyed in the field → overtopped and therefore functional failure occurred
- scour → most common failure mechanism among almost all types of coastal protection structures
- overturning, slope instability, soil instability and sliding → other common failures
- Mechanisms categorized according to the two tsunami induced loading conditions:

✓ the water level difference across the structure

✓ wave forcing

- D1 - PART – 3 – Failure Modes

COASTAL STRUCTURES FAILURE MECHANISMS			FAILURE MODES INDUCED BY TSUNAMI LOAD CONDITIONS												
			WATER LEVEL DIFFERENCE ACROSS THE STRUCTURE	Overflow (functional failure)	Scour - Foundation Undermining (Leeward)	Scour - Foundation Undermining (Seaward)	Sliding	Soil Failure (Settlement, Seepage, Liquefaction)	Slope Failure (Leeward)	WAVE FORCE	Slope Failure (Seaward)	Overturning	Parapet/Crown Wall failures due to tsunami runup&drawdown	Sliding	Scour
				A	B	C	D	E	F		G	H	I	J	K
COASTAL PROTECTION STRUCTURES	1	**Seawalls and Revetments**													
	1.1	Concrete Block		√	√							√		√	
	1.2	Composite (solid-concrete)		√	√	√		√				√			
	1.3	Mound		√	√			√							
	2	**Sea Dikes**													
	2.1	Mound													
	2.2	Concrete armored		√	√	√									
	3	**Breakwaters**													
	3.1	Block Type		√	√		√	√							
	3.2	Rubble Mound		√							√				
	3.3	Composite (caisson and mound)		√	√				√			√		√	
	4	**Walls**													
	4.1	Parapet/Crown Walls											√		
	4.2	Harbour Walls		√											
	4.3	Quay Wall						√							
	5	**Embankments**			√										
	6	**Sluices, Tsunami Gates**		√								√			

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- **D1 – PART 3 – Failure Modes**

- Failure mode matrix for buildings by analysing the model tests, observations and field data

- Similar to the coastal structures matrix, the failures are grouped into two according to the main driving processes:

✓impulsive tsunami loading

✓standing tsunami pressure

- Structures grouped according to:

✓available protection measures taken against tsunami impact

✓construction type

✓individual parts of the structures

- Note that the matrix is a preliminary result and requires additional work.

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- **D1 – PART 3 – Failure Modes**

		LAND STRUCTURES FAILURE MECHANISMS	**FAILURE MODES INDUCED BY TSUNAMI LOAD CONDITIONS**																	
			IMPULSIVE TSUNAMI LOADING	Total Failure (explosive)	Bending and/or punching shear failure	Overturning	Sliding	Debris Impact	1st story collapse	Pancake Collapse	**STANDING TSUNAMI PRESSURE**	Overturning	Sliding	Scour	Rebar Yielding	Rebar Fracture	Wash-away due to sustained force	Tilting and Drifting by scouring	Fracture of Wall (Opening)	Large residual deformation
				A	B	C	D	E	F	G		H	I	J	K	L	M	N	O	P
LAND STRUCTURES	**1**	**Structures with protection**																		
	1.1	**Walls**																		
	1.1.1	Concrete-Block Fence Wall												√		√				
	1.2	**Columns**																		
	1.2.1	RC Column						√								√				
	1.2.2	Concrete-Block Column														√				
	1.3	**Other**																		
	1.3.1	Stone Monuments										√								
	1.3.2	Railway Bridge												√		√				
	2	**Structures without protection**																		
	2.1	**Walls**																		
	2.1.1	Wooden Wall		√				√												
	2.1.2	Concrete Wall			√									√			√			
	2.1.3	Concrete-Block Wall												√		√				
	2.1.4	RC Fence Wall												√	√	√				
	2.1.5	Concrete-Block Fence Wall												√		√				
	2.2	**Columns**																		
	2.2.1	RC Column						√								√				
	2.2.2	Vertical Column (acrylic)																		
	2.3	**Buildings**													√					
	2.3.1	Circular Buildings						√												
	2.3.2	Rectangular / Square Shape Buildings				√		√						√						
	2.4	**Other**																		
	2.4.1	Stone Monuments										√	√							
	2.4.2	Wooden Structures						√												
	3	**Structures with no Information on Protection**																		
	3.1	**RC Buildings**						√	√	√				√				√	√	
	3.2	**Steel Buildings**						√				√		√			√			√

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- **D1 – PART 4 – Vulnerability Assessment**
- Tsunami vulnerability assessment approaches throughout the literature under topics of:

- general tsunami vulnerability assessment approaches (deterministic and probabilistic assessment)
- tsunami fragility
- social and ecological tsunami vulnerability

- Best approaches would combine quantitative and qualitative assessments

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- D1 - CONCLUDING REMARKS:

- Enhance numerical models such as NAMI-DANCE focusing on the modelling of tsunami parameters in high resolution geometries & accurate computation of flow patterns

- Through experiments, fill the gap on tsunami impact on rubble mound breakwaters

- Through experiments, understand the overflow impact on rubble mound structure

- Enhance the vulnerability assessment model developed by NGI by integrating building fragility curves and detailed socio-economic, environmental, and physical information collected after the 2011 tsunami in the model in order to improve a quantitative tsunami risk assessment

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D3 : Report on the comparison of coastal structures in Europe and Japan

- Structural measures in Japan due to:

- Tsunamis & Storm Surges

- Coastal protection structures in Europe against:

- Storm Surges & Coastal Erosion

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- Structural measures in Japan to control storm surges and tsunamis:

- 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

Tsunami and Storm Surge Hazard Map Manual” (2004)

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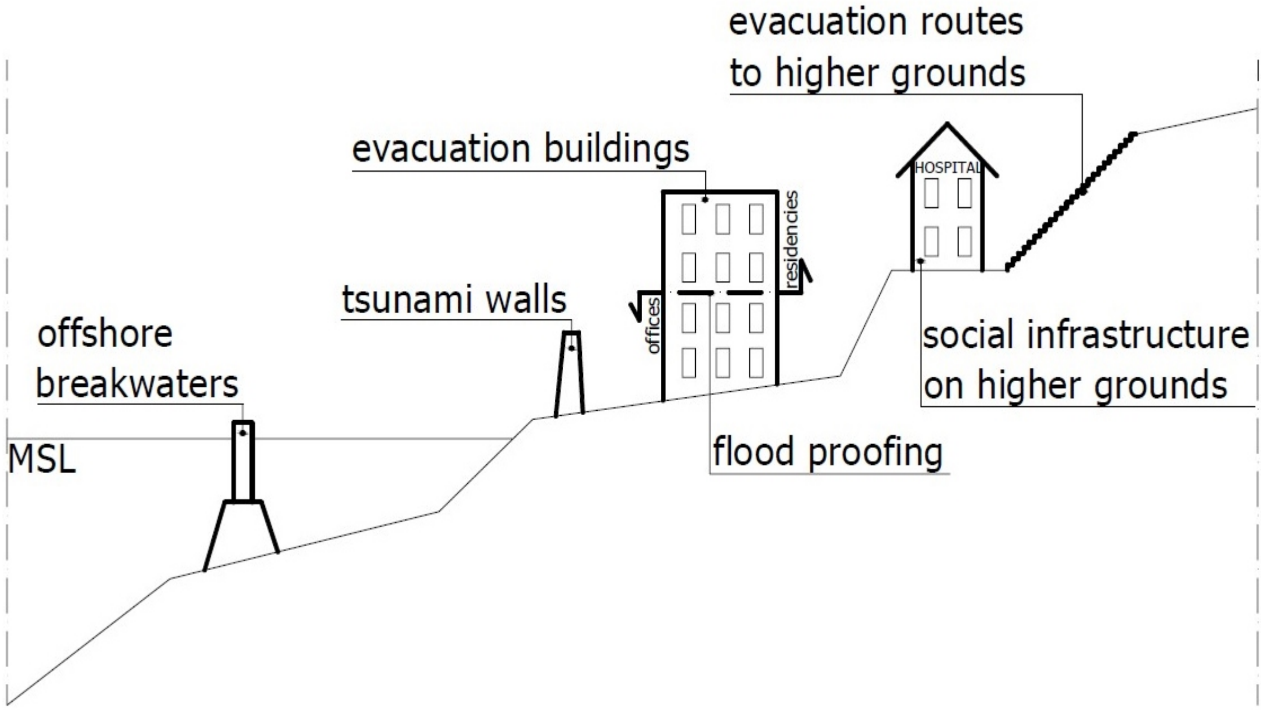
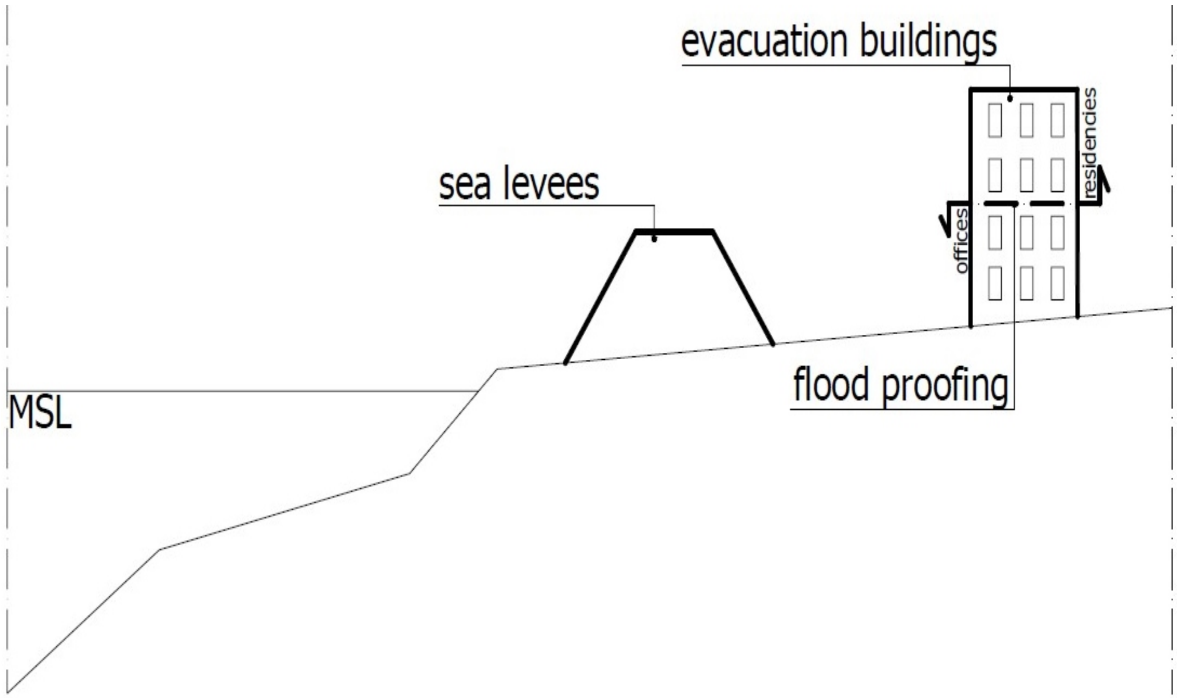
- Tsunami countermeasures in Tohoku region



Tsunami countermeasures in the rias (MSL=mean sea level). (<u>Source:</u> Tsimopoulou, V.,)



Flood risk countermeasures in flat plain region (MSL = mean sea level). (<u>Source:</u> Tsimopoulou, V.,)

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- Coastal structures in European countries are mainly related to storm surges and coastal erosion.

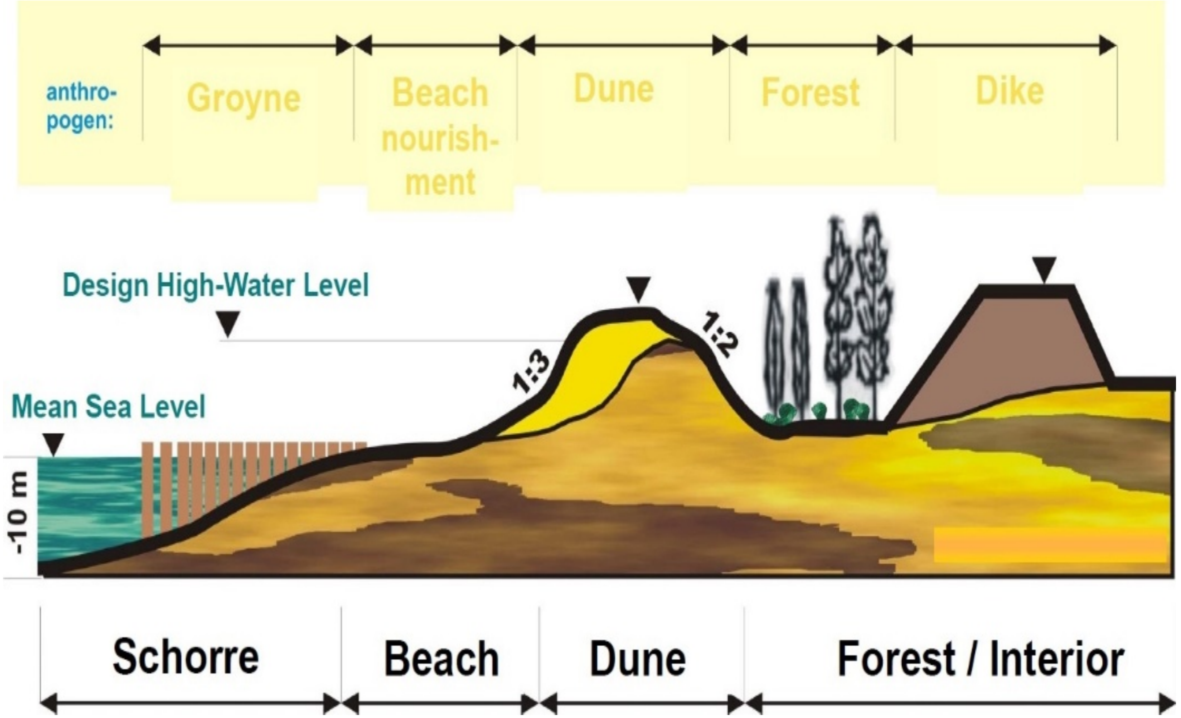
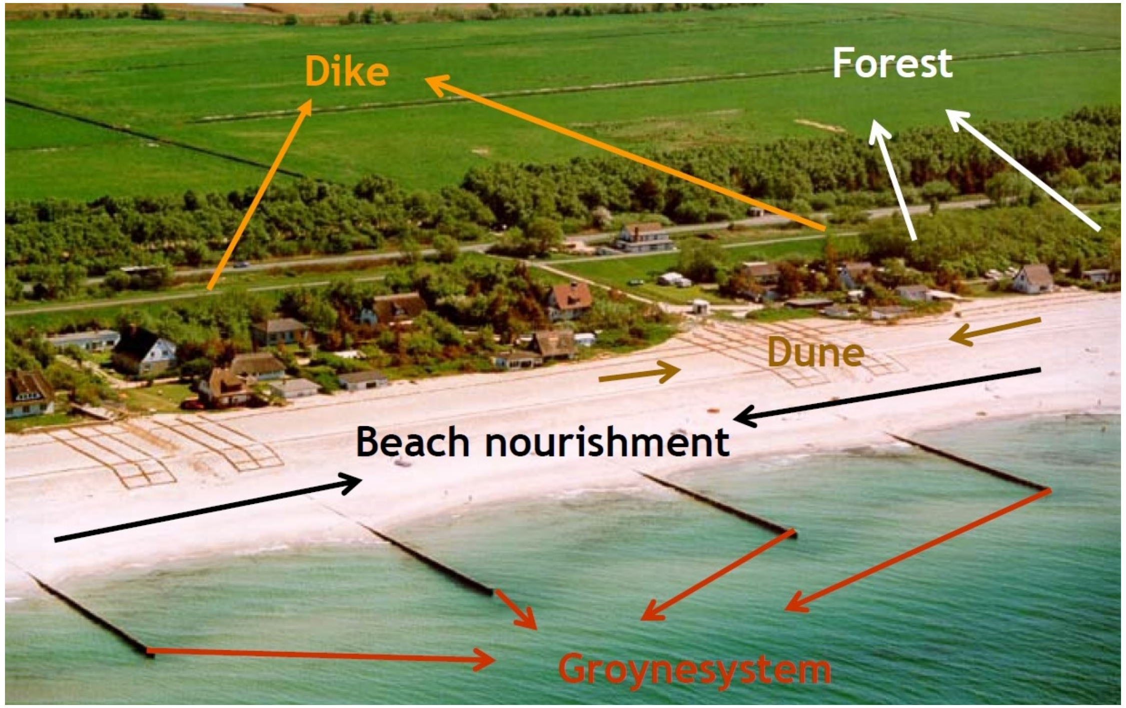


Illustration of Coastal and Flood Protection, Baltic Sea. Source: “Coastal Protection in Germany” Course Lecture Notes, Coastal Engineering Research Group, University of Rostock



Coastal and Flood Protection, Baltic Sea Source: “Coastal Protection in Germany” Course Lecture Notes, Coastal Engineering Research Group, University of Rostock

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- D3 - CONCLUDING REMARKS

- Both systems (typical defence systems in Europe and Japan) rely on different mitigation measures rather than just one.
- Large systems in Europe are natural defences like beaches and dunes which are maintained. In Japan, due to the high loadings of defences induced by tsunamis and storm surges, hard measures (e.g. concrete seawalls) in most cases
- Japan evacuation and the respective buildings is very often a part of the coastal defence strategy whereas in Europe coastal authorities often rely on natural or anthropogenic mitigation systems.

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D4 : Report on comparison of mitigation strategies in Europe and Japan

- Tsunami mitigation strategies are discussed in two categories as the structural (hard) measures and non-structural (soft) techniques in Japan and Europe.
- Non-structural mitigation is a multi-element system consisting of:

- tsunami early warning system,
- community preparedness and education,
- land-use and evacuation root planning
- use of coastal vegetation

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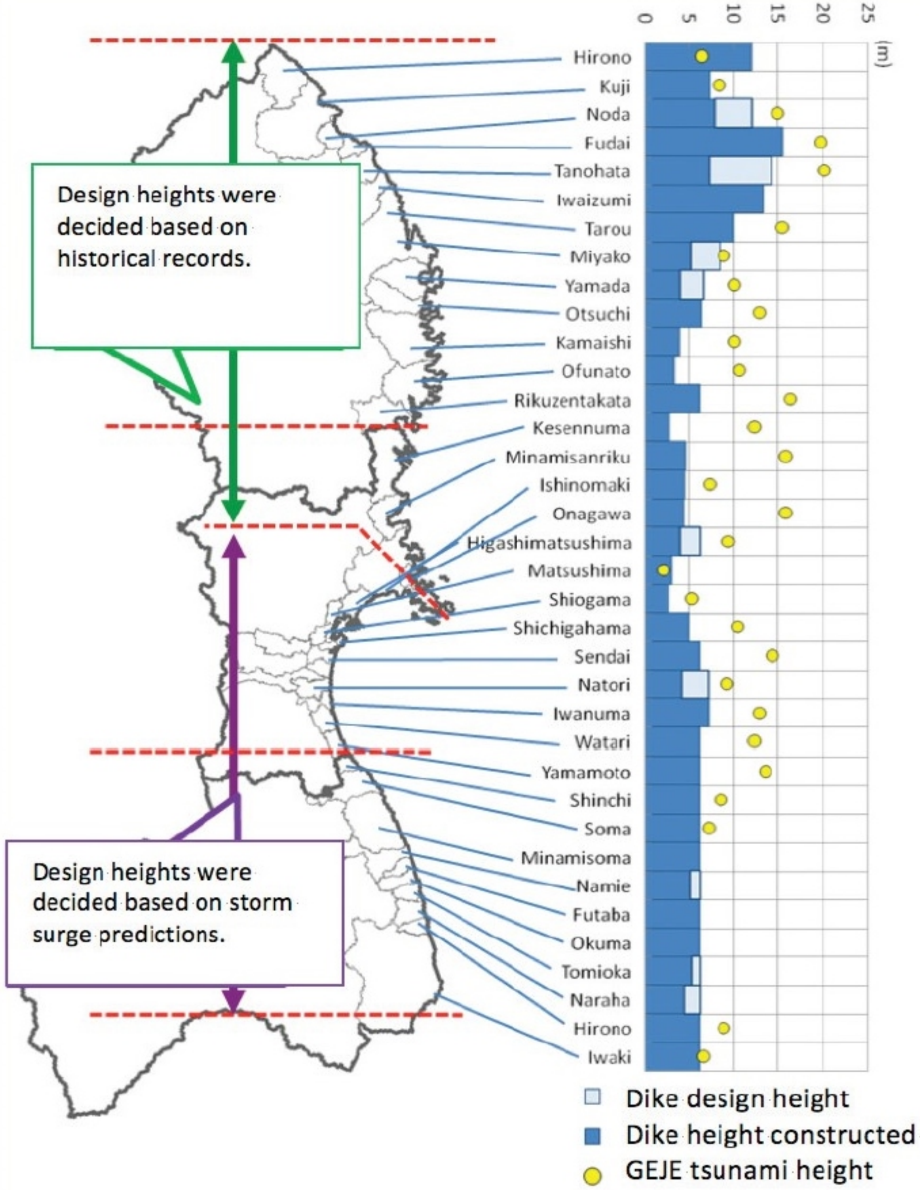
- JAPAN – HARD MEASURES

Coastal dykes against tsunamis for nearly 2,000 years

Dike in Hiro, Japan. Source: Ohta et al. 2005



Determining Dike Design Heights along the Pacific Coasts of Japan.
Source: Ishiwatari and Sagara, 2012

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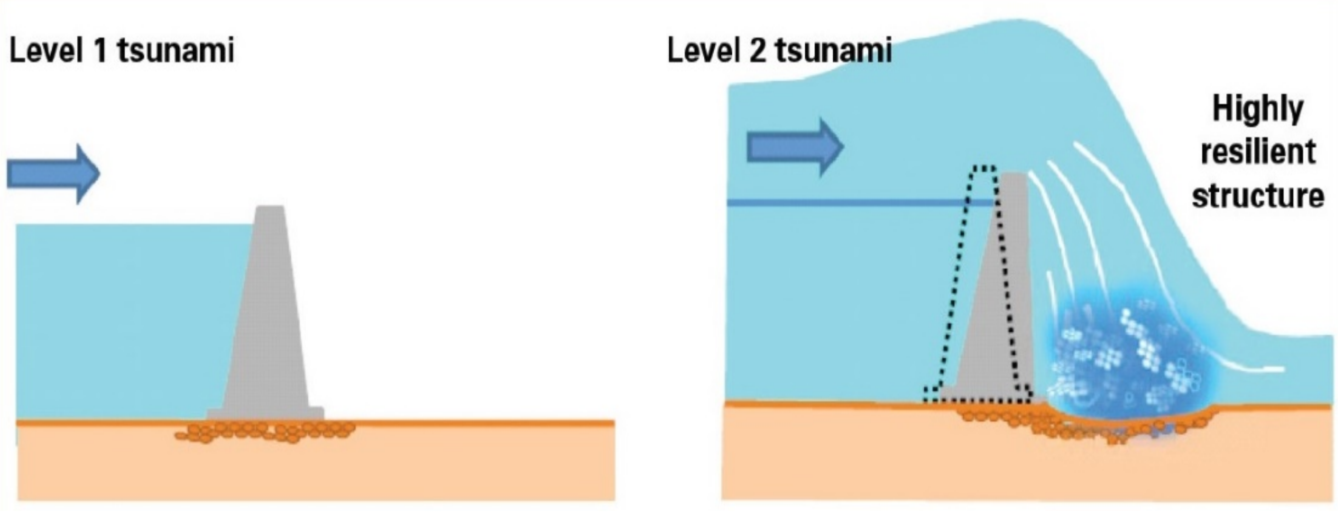
- JAPAN – HARD MEASURES

Following the GEJE → two-level approach for the design parameters of structures

Level 1 events are the tsunamis that occur once in 100 years and cause serious damage

Level 2 includes the largest possible tsunami, which has a probability of occurrence once in every 1,000 years but results in devastating destruction

	Tsunami to be considered	*Required performance*
Level 1 tsunami	Largest in recent history (return period of approx. 100 yrs.)	Disaster prevention • Protect human lives • Protect properties/economic activities
Level 2 tsunami	Maximum level (return period of approx. 1000 yrs)	Disaster reduction • Protect human lives • Mitigate economic loss • Prevent major secondary disasters • Enable early recovery



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- EUROPE – HARD MEASURES
- Coastal structures in European countries are mainly designed to defend the hinterland against storm surges and the beaches and dunes against coastal erosion
- Only in Norway, structural measures against tsunamis are encountered.

Dike to protect from tsunamis in Årdalsvatn, Norway (Source: Årdal kommune)

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- JAPAN – SOFT MEASURES

- Tsunami and earthquake warning systems
- Community-based disaster risk management
- Practice of evacuation planning
- Land use planning
- Use of coastal vegetation

a) Tsunami evacuation route sign *b)* Sign showing the inundated level of previous Tsunami

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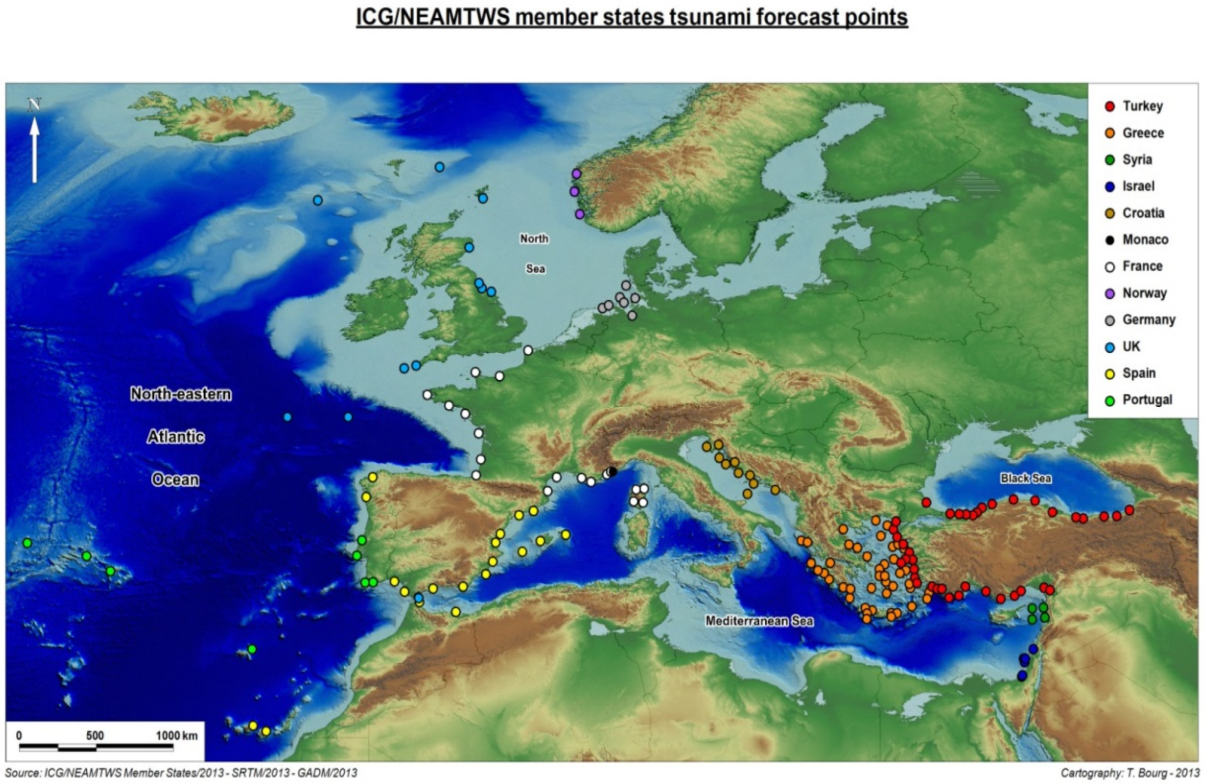
- EUROPE – SOFT MEASURES

Non-structural measures existing in Europe are limited.

- monitoring systems, well organized early warning systems, and capacity building activities for the population, evacuation planning and land use planning (in Norway)

- Tsunami Early Warning and Mitigation System in the North Eastern Atlantic, the Mediterranean and Connected Seas, NEAMTWS

ICG/NEAMTWS member states tsunami forecast points



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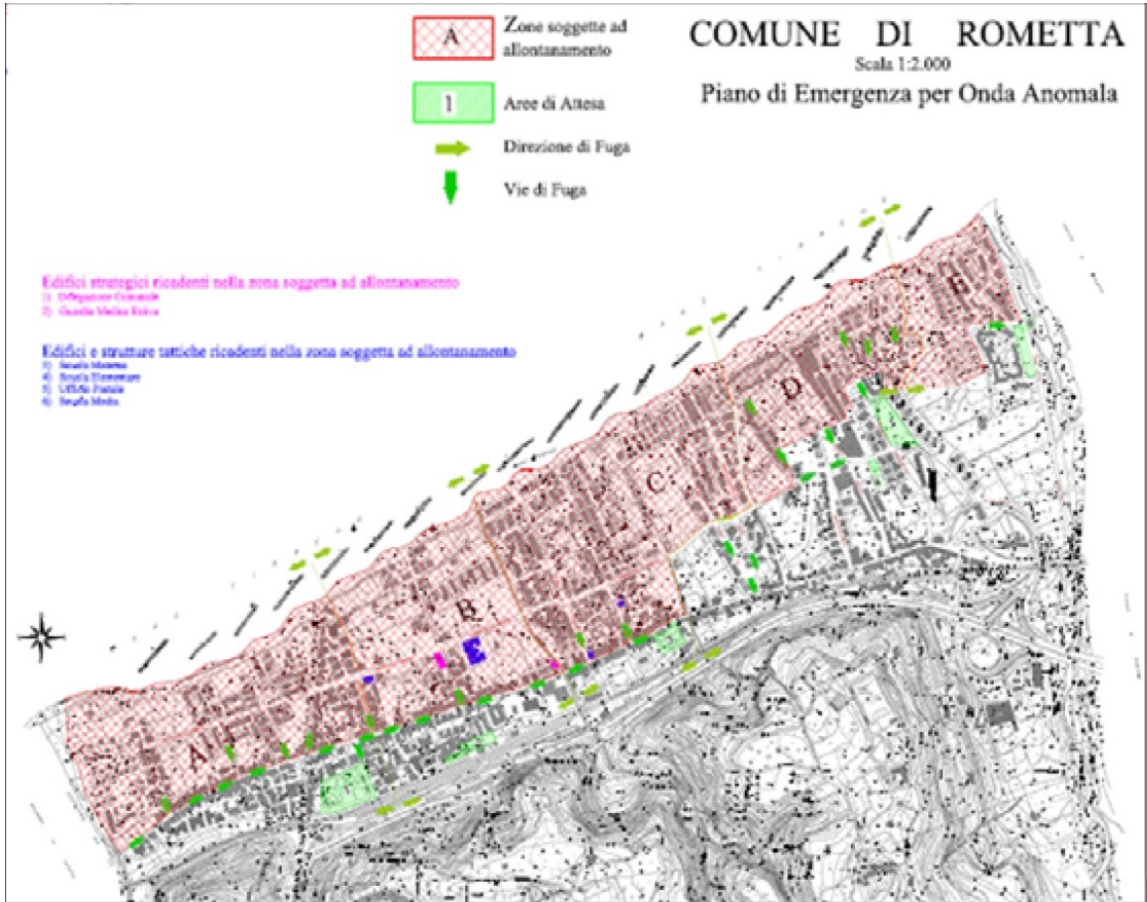
- EUROPE – SOFT MEASURES

\- Practice of evacuation and planning in Europe



Emergency scenario elements map in Sicily
(Source: Scheer et al., 2011)

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- D4 - CONCLUDING REMARKS

- Structural and non-structural tsunami mitigation measures differ greatly in Japan and Europe due to the difference in existence and perception of the tsunami risk
- There is a great variety of measures in Japan extending from constructing coastal dikes of advanced design to community preparedness and protection by coastal vegetation.
- In Europe, tsunami mitigation is rare and limited to a few types of actions.

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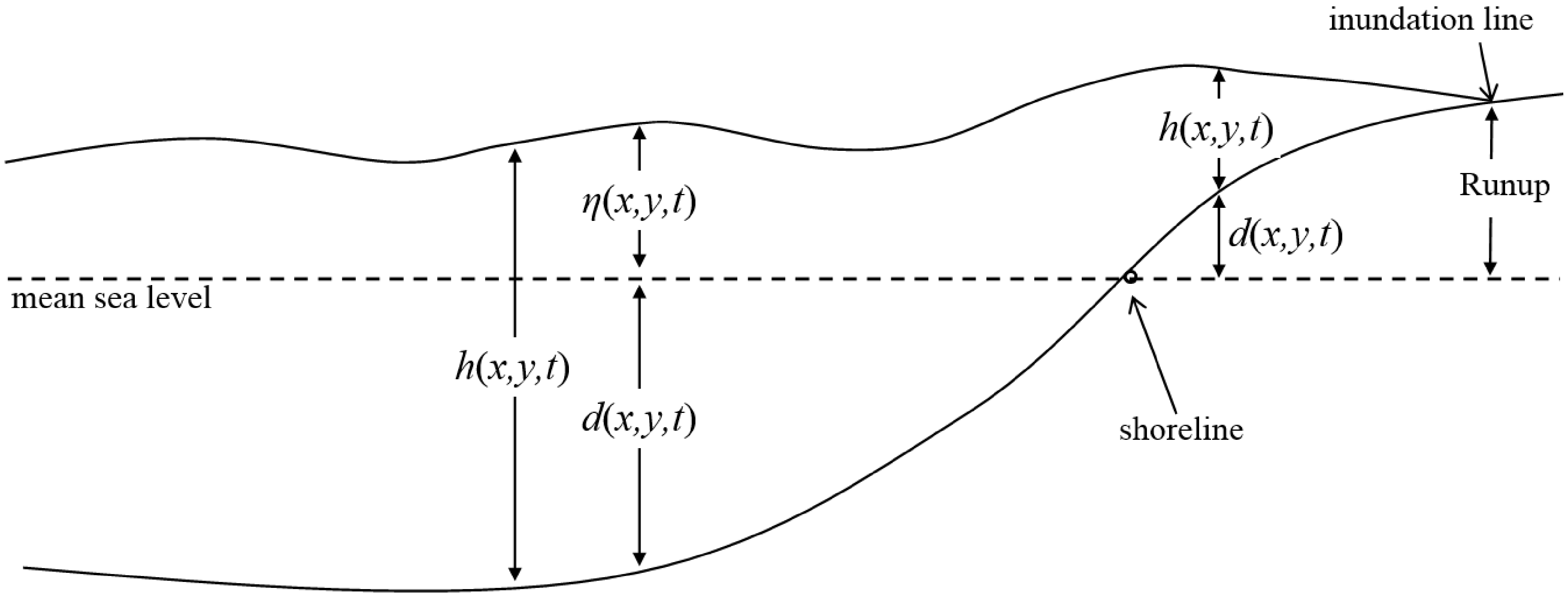
- **D4 - Report on computed tsunami parameter values in shallow waters and around structures**



Schematic representation of the basic parameters used to calculate the damage metrics

Recommended damage metrics

- The water elevation (above the undisturbed mean sea level) and maximum/minimum water elevation

$$\eta(x, y, t) \qquad \eta_{\max}(x, y) := \max_t \eta(x, y, t) \qquad \eta_{\min}(x, y) := \min_t \eta(x, y, t)$$

- The flow depth (time dependent) and maximum flow depth

$$h(x, y, t) := \eta(x, y, t) + d(x, y) \qquad h_{\max}(x, y) := \max_t h(x, y, t)$$

- The velocity and maximum flow velocity

$$V(x, y, t) := \sqrt{u^2(x, y, t) + v^2(x, y, t)} \qquad V_{\max}(x, y) := \max_t V(x, y, t) = \max_t \left\{ \sqrt{u^2(x, y, t) + v^2(x, y, t)} \right\}$$

- The coefficient to compute the inertial component $h\, d\vec{V}/dt$

Recommended damage metrics

- The maximum momentum flux

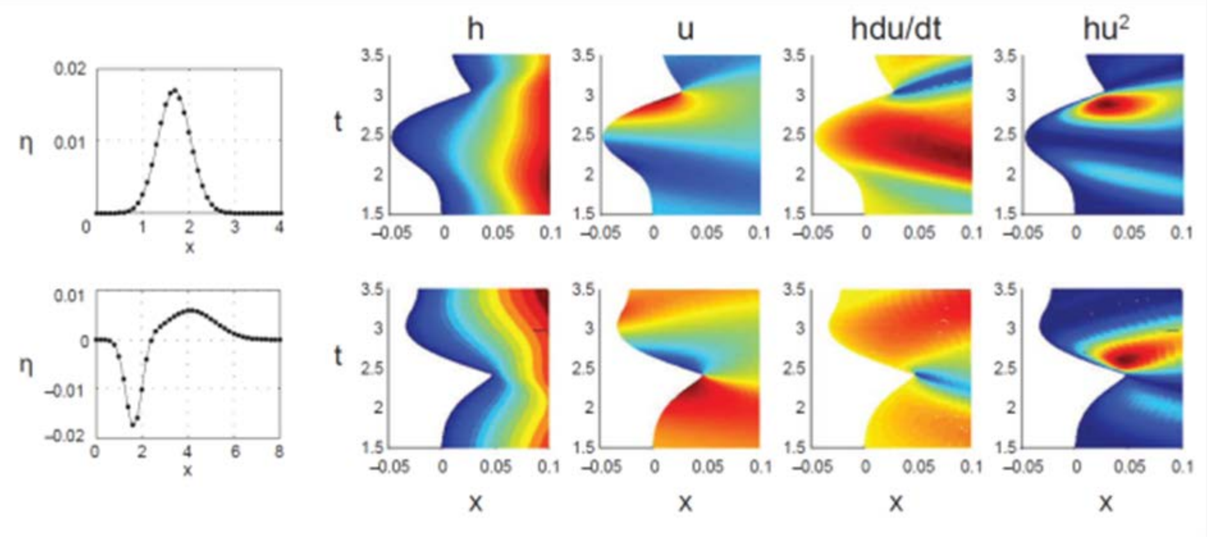
$$M_{\max}(x,y) := \max_t \{h(x,y,t)\cdot V^2(x,y,t)\}$$

- The Froude number
  - The normalization of drag force by hydrostatic force gives

$$HD = \frac{F_D}{F_h} = \frac{\frac{1}{2} C_D\, \rho_w\, A u^2}{\frac{1}{2}\rho_w\, g\, d\, A}$$

$$= C_D \frac{u^2}{g\, d} \quad \Rightarrow \quad HD = C_D * F_R^{\ 2}$$

- The drag coefficient mainly depends on
  - structure shape
  - secondarily on the flow conditions



Reference	Structure Type	C_D value
CCM in Synolakis (2003)	Piles	1.2 for non-breaking waves 1.75 for breaking waves
CCM in Synolakis (2003)	All Type of Coastal structures	1.25 for $b/d_s < 12$ 2.0 for $b/d_s > 12$
Arnason (2004) in Yeh (2006)	All Type of Coastal structures	1.0 – 2.0
Yalciner and Synolakis in Sümer et al. (2007)	All Type of Coastal structures	less than 2

Recommended damage metrics

- The front velocity
- In the evolution of the front of the solitary wave