Coastal storm hazards, extreme loads and threats from tsunami

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Summary
Introduction
Coastal hazards
Wave loads
Tsunami risks to UK and Ireland
Tsunami analysis
Implications of Tohuku
Future?

Coastal hazards – key processes
- Beach movement / coastal erosion;
- Wave overtopping / flooding;
- Wave disturbance in harbours / ship motion;
- Armouring of soft frontages and rubble mounds;
- Loads on walls / decks.

Coastal vulnerability – industry
Infrastructure plant design – requires co-operation between Mechanical / Chemical / Civil Engineering and Hazard specialists, examples: power stations, refineries, re-gas etc.

Coastal vulnerability – housing
Images courtesy of HR Wallingford, Floods group.
Coastal vulnerability

The 10 cities with the largest population exposed to coastal flooding

Courtesy of Wolfgang Kron, Munich Re – presentation to ICCE 2008.

Coastal vulnerability

The 10 cities with the largest assets exposed to coastal flooding

Courtesy of Wolfgang Kron, Munich Re – presentation to ICCE 2008.

Storm damage

Italian marina breakwater under storm attack.

Image courtesy of Prof. Leo Franco.

Coastal vulnerability

Impulsive wave breaking against vertical or battered walls
⇒ high overtopping + high velocities + intense local pressures

Wave forces

Impulsive loads on vertical wall at Amlwch, small movements, about 1m at breakwater head.
Over-simple wave load formulae.
Ignored research on impulsive wave loadings.

Wave forces

Structural failure of crown wall, Motril, Spain.

Storm damage

Images courtesy of Prof. Vincente Negro Velez-Medrano.

Storm damage

Italian marina breakwater under storm attack.
Structural failure of crown wall, note limited size / length of rebar.

Images courtesy of Dr Keith Powell.

Damage from wave forces under deck

Images courtesy of Dr Matteo Tirindelli.

Images by Prof William Allsop.

Image by Prof William Allsop.

Southend water level (mODN) Wind speed (m/s)

Unaware Aware Aware & Evacuating Safe Toppled Deceased

No Road Closed 1 Road Closed 2 Roads Closed 3 Roads Closed

People [Log]

Consequence on People in Roads Closing

Life loss

Sea defences / flooding
Present day

**Sea defences / flooding**

- By Flood cell
- By Flood Area

**Expected Annual Damage**
- Upper Bound = 674,552
- Best Estimate = 539,361
- Lower Bound = 413,955

**Service conditions:** 1:1 to 1:10 year returns.
**Design conditions:** 1:50 to 1:500 year returns.
**Overload conditions:** 1:1000 to 1:10,000 year returns.

**Tsunami generation, subduction**

[Image: http://www.soest.hawaii.edu/tsunami/tsugen.html]

**Tsunami generation, slide**

**Earthquake Generated Tsunamis**

Okada, 1985

- The displacement of the free-surface is equal to that at the sea bottom.
- The bottom moves at the same time over the whole fault.
Submarine Landslides/Slumps

Watts et al. 1997

Numerical Modelling of Tsunamis

Generation
Vertical seafloor displacement (Okada)

Propagation
Most numerical studies: Shallow Water or Bousinesq models, reasonably well understood

Tsunami propagation


Tsunami propagation

Maximum computed tsunami amplitudes (in cm) in the Indian Ocean - (NOAA Center for Tsunami Research, http://nctr.pmel.noaa.gov/indo_1204.html)

Threat to UK and Ireland

FAR-FIELD TSUNAMI MODELLING
Max free surface at coast

- Arrival times are >4.5 hours
- Water levels rise to approx 100 year event levels
- Wave heights equivalent to severe winter storms
- Significant shelter afforded by continental shelf

Details on [http://www.defra.gov.uk/environment/studies/tsunami/default.htm](http://www.defra.gov.uk/environment/studies/tsunami/default.htm)

"Impact of a Lisbon-type tsunami on the UK coastline, and the implications for tsunami propagation over broad continental shelves" in Jo. Geophysical Research
NEAR-FIELD TSUNAMI MODELLING

> Flow depth
> Flow velocity

Building to resist tsunami

Modelling tsunami threats

> Gaps in knowledge – nearshore propagation of tsunami waves, across shoreline and inland
> Complex flow interactions with beaches, sediment, coastal defences, and around buildings
> Flow processes can be simulated in hydraulic models, but correct generation of the tsunami wave is essential:
  - Multiple waves
  - Preceding draw-down wave
  - Realistic time series of wave heights and wavelengths

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Physical modelling of tsunami

Since 1950s (Hall & Watts), flume experiments for the modelling of long waves on a sloping beach have been conducted

Solitary Wave

Paddle

Wave run-up

HRW Tsunami generator

Conceptual design
How does it work?

Theoretical waves often assumed to be representative of a tsunami

Solitary waves (Miles, 1980)

N-waves (Tadepalli & Synolakis, 1996)

December 2004 tsunami

Record from depth-sounder on "Mercator", approx 1 mile off Nai Ham beach, Phuket, Thailand. This record now inverted to give wave elevation.

Example test results

Model building under test, Mercator time series.
Tohoku tsunami, 11 March 2011

Data from DART 21418, on Pacific side of rupture zone, tide removed

Water level signals from TM1 and TM2. Note absence of trough-led, and 2-part nature of the time series

GPS buoy data, off Kamishi (left) and Kesennum (right)

An Extreme Mw9.0 Megaquake at Off Tohoku
Conclusions

The Next Tsunami Source?

Can future seismic displacements be predicted?

Conclusions

Number of loss events: 1860 – 2006
- Floods
- Earthquakes

Windstorms

Courtesy of Wolfgang Kron, Munich Re – presentation to ICCE 2008.