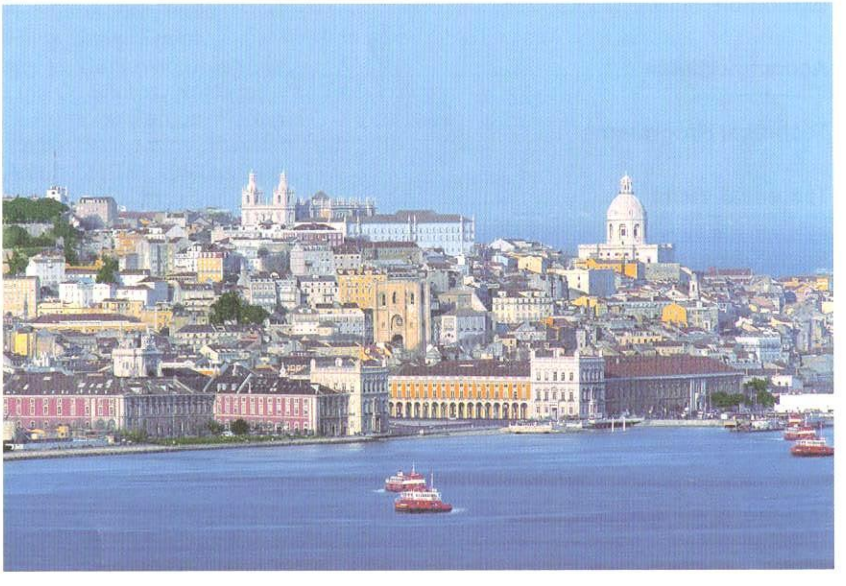
International Association for Bridge
and
Structural Engineering

Final Invitation
IABSE Symposium

Structures and Extreme Events

250 years after, in memory of the 1755 Lisbon earthquake and tsunami



Lisbon, Portugal **September 14-17, 2005**

Organized by

Portuguese Group of IABSE (APEE)

and

National Laboratory for Civil Engineering (LNEC)

TSUNAMI CONSTRUCTION RISKS IN THE MEDITERRANEAN - OUTLINING MALTA'S SCENARIO

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- The Mediterranean region is active with earthquakes and volcanoes, some of them generating tsunamis, 20% which have been damaging.

- Tsunamis reach local coasts soon after they have been generated, giving little time, 1 to 30 minutes for warning. The run-up height & inundation zones are important parameters to consider.

- Due to the vast development that has occurred around the Mediterranean shoreline over the past century, economic measures are now required to reduce in a reasonable manner the risks from a tsunami event.

PHYSICS OF TSUNAMI

- Tsunami waves are distinguished from ordinary ocean waves by long wavelength often exceeding 100km and time between crests ranging from 10mins to 1 hour

- Wind driven waves have a wavelength of 100m to 200m with time between crests varying from 5 sec to 20 sec

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BATHYMETRY DATA OF THE MEDITERRANEAN SEA

- Max. depths encountered in Ionian Sea exceeding 4000m
- This is to be compared to 10,000m in the Pacific
- In the Tyrrhenium & Ligurian Seas rarely exceeds 2,000m
- Malta plateau between Malta & Sicily & Tunisian Plateau reaching Lampedusa rarely exceeds 200m.
- Velocity for a 2,000m depth approximated to 504 km/hr & for a 200m to 159km/hr

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BATHYMETRY DATA OF THE 72,850 sq m CONTINENTAL SHELF OF MALTA

- **Varies from a gentle slope (1:35) along Pembroke-Salina stretch Marfa Ridge & Dahlet Qorrot to Marsalforn**
- **(1:20) slope Sliema – M'Scala stretch & Ghar Lapsi area**
- **(1:12.5) slope Comino all round**
- **(1:5) steep slope on the cliff S-W side of Malta & Gozo**
- **Deep waters of 10-18m encountered in 5-figured shape Grand Harbour**

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TSUNAMI FORCES

- **As Tsunami approaches land, the wave slows down, height of wave increases.**
- **Deep water close to the shore hampers the build-up of a high wave**
- **Build-up may be 30m for tsunami waves near earthquake's epicentre or 15m for tsunamis of distant origin**
- **Boulders with masses around 200tons can be displaced by tsunami surges only 10m deep**
- **Wind-driven waves not higher than 12m with 15 tons boulders being washed over 4m sea-walls**
- **Flow velocity in recent tsunami ranged from 17- 47 km/hr as compared to 10km/hr for fast flowing river**

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TSUNAMI MAGNITUDE SCALES

m=> $\log_2 H$	K_o=> $\log_2 H^{1/2}$	Runup m	Comments
-2	i	0.25	*Very light* –perceptible only on very sensitive tide gauges
0	ii	1.00	*Light* – noticed by those living along the flat shore
1	iii	2.00	*Rather strong* – generally noticed due to flooding of gently sloping coasts. Light sailing vessels carried away on shore.
2	IV	4.00	*Strong* – flooding of the shore to some depth. Solid structures on the coast injured. Coasts littered with floating debris.
4	V	16.00	*Very strong* – general flooding of the shore to some depth. Harbour works damaged. People drowned. Wave accompanied by strong roar.

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RUNUPS IN METRES WITH THEIR RETURN PERIOD IN YEARS FOR VARIOUS SEAS

Run up-m	Mediterranean/New Zealand	Black Sea/Indian Ocean/North America/ Caribbean	South America /Hawaii/ South West Pacific
10	250	1000	200
15	1000	-	750
20	-	-	1000

For wave height < 5m & velocity < 5m/s, tsunami force exceeds 5000 kg/m^2 with windows & masonry panels expected to fail at 10-20% of this level

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MEDITERRANEAN TSUNAMI CHARACTERISTICS

In 365AD an M7.7 in Crete created a tsunami reaching Libya, Egypt, Calabria and as far as Spain – only tsunami to have propagated across entire Mediterranean

1.5m run up - return period 100 years

4.0m run up - return period 500 years

7.0m run up - return period 1000 years

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MEDITERRANEAN REGIONS TSUNAMI HAZARDS

- W. Mediterranean is less prone than EAST
- Strongest tsunamis are excited in the Aegean Sea, Hellenic & Calabrian areas
- Greece has had more than 160 events catalogued over 2000 years, although geological record suggests tsunami may have been smaller than described. Even for the 1956 Aegean Tsunami (V) scientific reports considered inaccurate.

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CENTRAL MEDITERRANEAN REGIONS TSUNAMI HAZARDS

- **1000AD – 1975AD**

  70 tsunamis (II – III)

  20 tsunamis (IV) return period 50 years

  7 tsunamis (V) return period 133 years

  3 tsunamis (VI) return period 350 years
- **78 triggered by earth quakes**

  20 triggered by volcanic eruptions

  2 triggered by slumps

The above has recently been revised with the 100 entries reduced to 70

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WESTERN MEDITERRANEAN REGION

- Tsunamis triggered by North African earthquakes with epicenies close to shoreline (especially Algerian)

Recent catalogue has

24 entries over period 220BC – 1980AD

In France

25 entries over period 200BC – 1991AD, with 21 recorded in the 19th Century

But all tsunami run-up heights do not measure 10's of cm.

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HISTORICAL TSUNAMI HAZARD - MALTA

- **Agius de Soldanis recounts how the sea at Xlendi rolled out to about 1 mile sweeping back “con grande impeto e mormorio” (MMXI) 1693**
- **1908 Messina (MMXI) flooding occurred an hour later in Msida & M’Xlokk, number of fishing boats damaged high sea level recorded in Grand Harbour.**
- **1973 a recession occurred in Salina bay lowering depth by 0.6m event accompanied with rumbling noise**
- **1983 sea in front of the Msida parish church flooded the road**

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Characteristics of the Principal Mediterranean Tsunamigenic Zones – Soloviev 1990

Coastal Region	Average recurrence (years)	Intensity-I Average	Maximal	Year of last Tsunami	Probability of next tsunami
N. Aegean	22	2.4	III	1978	Low
Eastern Greece	26	3.1	IV	1956	High
S. Turkey	18	2.6	III	1961	High
Aegean Sea	9	3.7	X	1968	High
HellenicIsland arc	21	3.5	VI	1948	High
Cyprus	17?	3.5	V?	1979	Low
E Mediterranean	106	3.2	V	1870	Medium
W. Greece	14	-	VI	1953	High
Corinthian Gulf	20	-	V	1981	Low
Albania	31	3.2	IV	1920	High
Yugoslavia	20	3.3	V	1979	Low
Venetian Gulf	180?	3.0	VI	1511	-
Eastern Italy	52	3.2	V	1889	High
Calabria/Sicily	12	3.8	VI	1954	High
W. Italy	46	3.5	V	1870	High
Ligurian Sea	17	2.8	IV	1914	High
Spain	100	3.0	III-IV	1860	High

MEDITERRANEAN TSUNAMI VULNERABILITY ASSESSMENT

- Disaster and emergency planners will be interested in determining maximum wave run-ups, horizontal inundation and their effect on wave flooding in terms of numbers of deaths and injuries, the need for response, recovery and rehabilitation activities. This type of flooding disaster would require antidiarrhoeals and antibiotics treatment, together with splints and plaster of Paris for fractures and cuts.
- Site specific evaluations to tsunami hazard should be drawn up for large and important risks situated in low-lying coastal areas. These might be defined as <3-5m above sea-level or 7-10m in the case of the most hazardous regions.
- It is of vital importance that disaster managers have detailed information on which buildings, infrastructural works and groups of people are particularly vulnerable to tsunami impacts. When such data is available, cost effective mitigation measures may be developed and applied. This is to be used as a tool for local planning and to determine post-tsunami emergency disaster response.

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VULNERABILITY OF THE BUILT ENVIRONMENT

- **Number of storeys on each building**
- **Description of ground floor**
- **Building material age, design**
- **Building surroundings**
- **Moveable objects**
- **Sociological data**
- **Economic land use data**
- **Land vegetation cover**

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ANTICIPATED TSUNAMI DAMAGE - MALTA

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- Touristic beach concessions & watersports facilities
- Yacht marinas
- Agricultural land – Pwales/Burmarrad villages with a shoreline bathymetry slope of 1:100 soil erosion & increase in salinity
- Infrastructural power stations harbour works Grand Harbour & M'Xlokk – tieing down of equipment important
- Sea craft in bays more at risk than out at sea

RISK ASSESSMENT FOR MEDITERRANEAN (MALTA) TSUNAMI EXPOSURE

As an example, consider a shed next to a quay storing electronic equipment. The height of the quay above the sea level is 1.5m. It is assumed the shed will resist the impact, but the sea water will enter and cause damage which is practically total.

The damage will be calculated for waves at 4m and 7m high, with the return period for Mediterranean estimated at 500 (600) and 1,000 (1,500) years respectively. The damage for a 4m high wave is assumed at 50% and 100% for 7m high.

Gross annualized damage rate for a single event X=∑MDR.v/R

Where MDR is the mean damage ratio as assumed above, v is the variance factor (safety factor), covering the uncertainty in the determination of the return period R/expected loss combination.

X = 50*2/500 + 100 * 2.5/1,000 = 0.45% (Mediterranean overall)

X = 50 x 2/600 + 100 X 2.5/1500 = 0.33% (Malta)

This alarming rate level achieved shows that sensitive goods should be stored outside tsunami reach.

TSUNAMI CONSTRUCTION RISKS IN THE MEDITERRANEAN (MALTA)

- **Tsunami vulnerability assessments are now to incorporate parameters relating to on and off-shore protective barriers, distance from the shore, depth of flood water, building construction standards, preparedness activities and amount of warning & ability to move away from flood zone**

- **A Risk Assessment has shown an annualised damage rate of 0.45% (0.33%) for goods stored within a Mediterranean tsunami reach region**

- **Noting the societal loss for the recent Indian Ocean tsunami tragedy to have reached $600 billion, this stresses the importance of installing early warning systems costed at $300 million, noting the considerable amount of lives to be saved.**

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