dhi PERITI

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WORKSHOP ON BEACH AND COASTAL RESORT RISKS

MALTA - 24^{th} SEPTEMBER 2018

TSUNAMI Risks in Malta.

Normal Sea Wind driven Waves at the breakwater , entrance to Grand harbour

It is very improbable for wind driven waves to be higher than 12m, with boulders up to 15 tons weight being washed over sea walls 4m above sea level

Tsunami wave hitting sea wall in Phuket Thailand

Largest wave displaced boulders, with a mass of 2,000 Tons imply Tsunami surges of 30-40M depth

Velocities Gained in Flash Floods & Tsunami Wave flows

The aftermath of a Flash Flood in the low lying areas of Qormi

whilst noting that velocities of 10km/hr (2.5m/s) for a river is considered to be fast flowing. Highest Maltese storms intensity, 226mm Sept 2003, flow velocity 9km/hr (5km/hr person swept away)

Tsunami – This main thoroughfare in northern Japan is now a raging river

Tsunamis, although with rarely breaking waves, are very destructive because of the much higher water velocities, with onshore velocities for the 2004 Indian Ocean disaster having ranged from 18 to 47km/hr (5 -13m/s),

THE CHARACTERISTICS OF WAVES

- 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.
- Wind driven waves grow continuously under the action of wind and their maximum height reflects the average intensity of the wind along the fetch.

PHYSICS OF TSUNAMI

The disturbing forces and typical wavelengths for wind driven waves and tsunami

Wave Type	Typical Wavelength	Disturbing Force
Wind Wave	60-150m	Wind over ocean
Seismic sea wave (tsunami)	200 km	Faulting of sea floor, tsunamigenic low lying & generally M_s>6.5 – depth < 50km. Volcanic eruption. Landslide.

Thus noting the deepest ocean seas standing at 10,000m , whilst the deepest end of the Mediterranean at 4,000m the sea depth to wavelength ratio for a tsunami wave stands at:

200km/4km = 50 > 20, thus defined as a shallow wave.

Shallow water waves are defined as: **D/L > ½**

With **$V = (gD)^{½}$ but for Tsunami $V=2(gD)^{½}$** (Keuleugen)

WIND DRIVEN WAVES

Largest maximum waves of 6m or more are located in the Western Mediterranean and the Ionean Sea under the action of the Maestrale.

A 40-year analysis of Significant Water Heights shows wave heights in the Mediterranean Basin varying from a minimal effect up to 5m tending to 7m, although extraordinary storms with wave heights 10m – 11m have been recorded.

MEDITERREAN WAVE FETCH F & Bathymetry

Figure No.1: Mediterranean Basin and its Sea Fetch averaging: 3,700km X 1,785km

Source: Google earth with indication of shallow & deep seas in the Mediterranean

Malta's NNW Fetch - 1,226 km NE Fetch - 647km

H_{MAX} = > $0.336(F)^{0.5}$ (Thomas Stephenson)

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.

- Lands are surrounded by a 1º (1:55) gently sloping plain for an approximate 80km to a 130m depth called the Continental Shelf

BATHYMETRY DATA OF THE 72,850 sqm 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

FUNDAMENTAL MODE OF THE CONTINENTAL SHELF

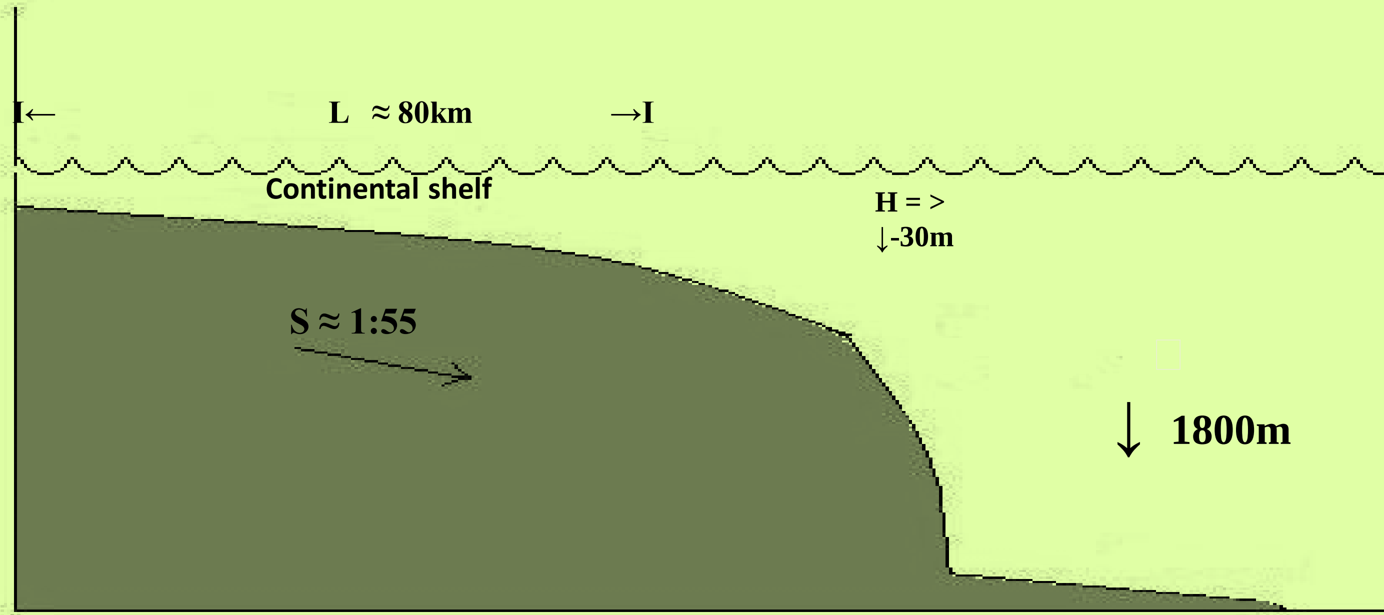


Figure No.2: Profile of the Continental Shelf

Shelf Resonance Periods
T=> $8(L/s.g)^{½}$ => $8L(gH)^{½}$ (Munk 1962)

T – period of the dominant mode, which is 4 times the travel time from the shore to the shelf edge

MEDITERRANEAN TSUNAMI CHARACTERISTICS

- In 365AD an M7.7 in Crete created a tsunami reaching Libya, Egypt, Calabria and as far as Spain – the 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
- Recently discovered geomorphological marine deposition evidence suggests that Malta's coastlines have been over washed up to elevations of 20m above sea level and distances inland, commonly up to 60m and exceptionally up to 120m. This by an exceptional event, such as in 365AD.
- Since only two events of this type separated by some 19,000 years have been identified, it is very difficult to estimate a return period with any confidence.

Source : Swiss Re 1992/Mottersherd et alia.

MEDITERRANEAN REGIONS TSUNAMI HAZARDS - 1

- W. Mediterranean is less prone (with 40 reliable events catalogued) than EAST, as opposed to 100 events in the East (Papadopoulos 2005)

- 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.

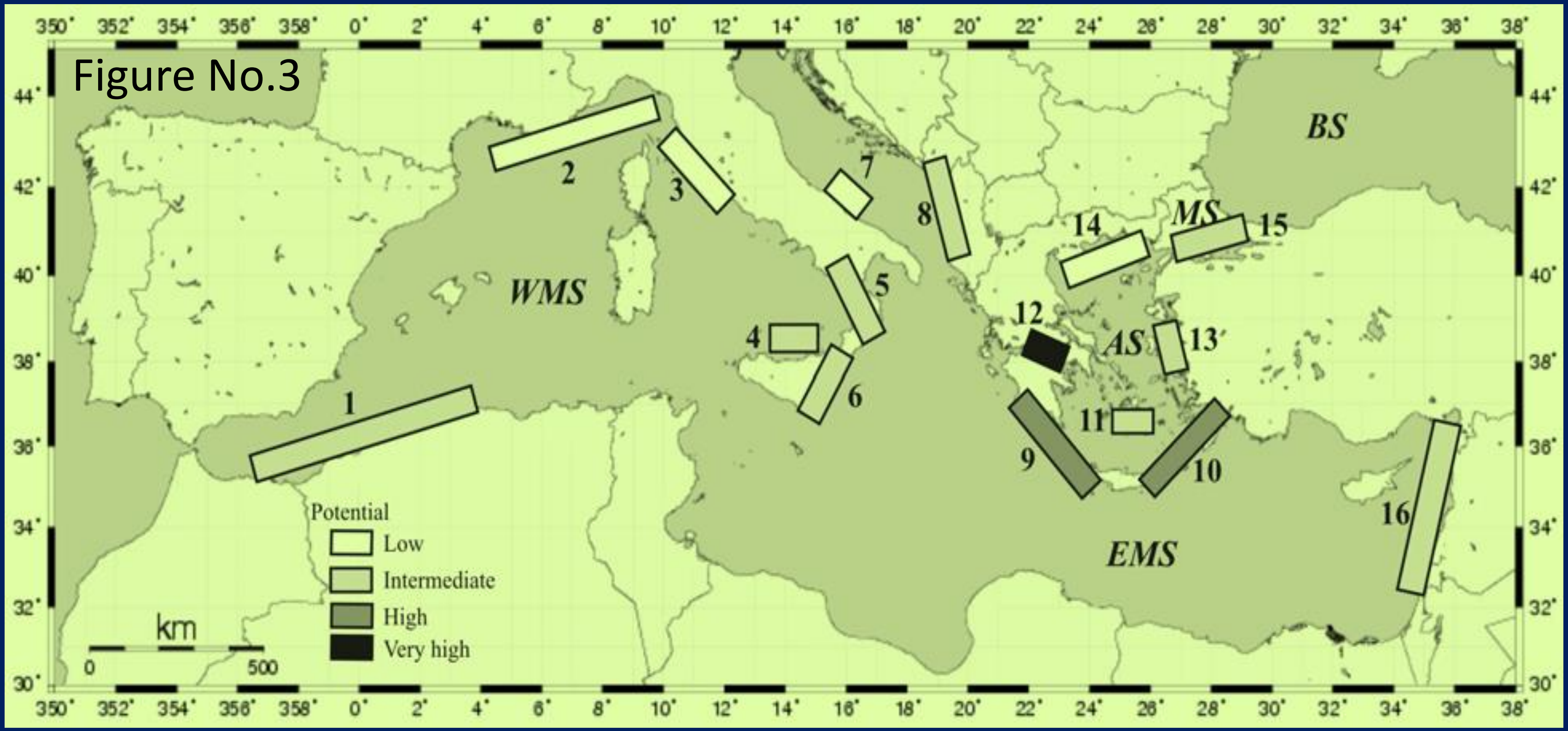
MEDITERRANEAN REGION
TSUNAMI HAZARDS - 2

- 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.

MEDITERRANEAN TSUNAMI POTENTIAL ZONING according to INTENSITY & OCCURRENCE (Papadopoulos 2005)



AS = Aegean Sea, MS = Marmara Sea, BS = Black Sea,
1 = Alboran Sea, 2 = Liguria and Cote d' Azur, 3 = Tuscany, 4 = Calabria,
5 = Aeolian islands, 6 = Messina straits, 7 = Gargano promontory,
8 = South-East Adriatic Sea, 9 = West Hellenic arc, 10 = East Hellenic arc,
11 = Cyclades, 12 = Corinth Gulf, 13 = East Aegean Sea,
14 = North Aegean Sea, 15 = Marmara Sea, 16 = Levantine Sea

TSUNAMI MAGNITUDE SCALES (Ambraseys 1962)

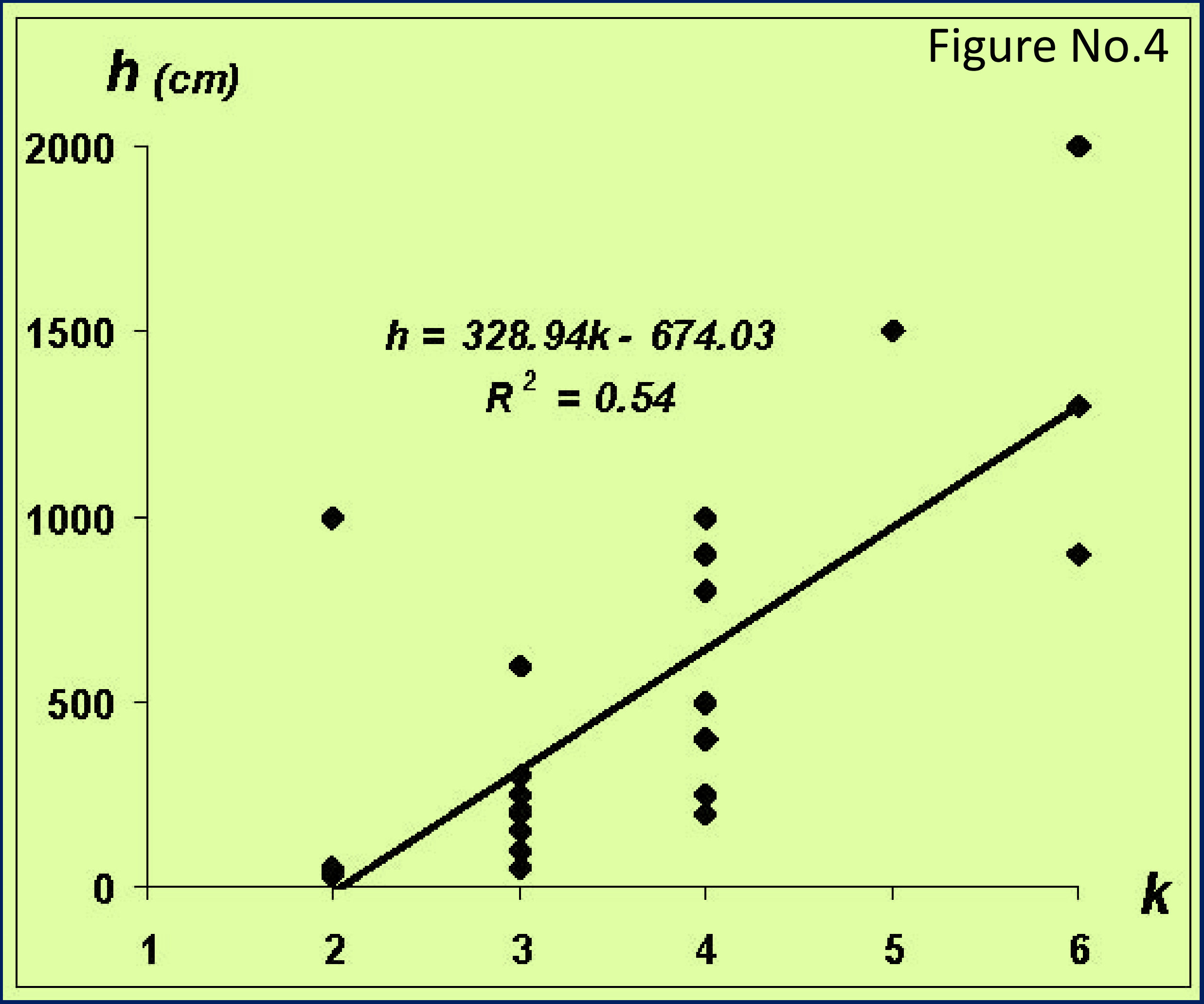
K_o=> $\log_2 H^{½}$	Runup m	Comments
I	0.25	Very light –Perceptible only on very sensitive tide gauges
II	1.00	Light – Noticed by those living along the flat shore
III	2.00	Rather strong – Generally noticed due to flooding of gently sloping coasts. Light sailing vessels carried away on shore.
IV	4.00	Strong – Flooding of the shore to some depth. Solid structures on the coast injured. Coasts littered with floating debris.
V	16.00	Very strong – General flooding of the shore to some depth. Harbour works damaged. People drowned. Wave accompanied by strong roar.
VI	64.00	Disastrous – Partial or complete destruction of man-made structures for some distance from the shore. Flooding of coasts to great depth. Big ships severely damaged. Trees uprooted or broken. Many casualties

Mediterranean Tsunami Vulnerability Assessment - 2

	Intensity - I				
Coastal Region	Average Recurrence (years)	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
Hellenic Island 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	VI	1511	-
Eastern Italy	52	3.2	V	1889	High
Calbria/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	III-IV	1860	High

D

Relations between wave height h and intensity K_o in the entire Mediterranean Sea



Source: Papadopoulos 2005

(K_O = tsunami intensity on the 6-point Sieberg-Ambraseys scale)

TSUNAMI FORCES

- ∑ horizontal force = hydrostatic + hydrodynamic + impulsive + inertial + debris impact.
- Tests show that the max wave loading on a wall on impact is 10-12 times the hydrostatic force
- For wave height < 5m & velocity < 5m/s, tsunami force exceeds 5000 kg/m^2 (50kN/m^2) with windows and masonry panels expected to fail at 10-20% of this level

TSUNAMI INDUCED FORCES defined by

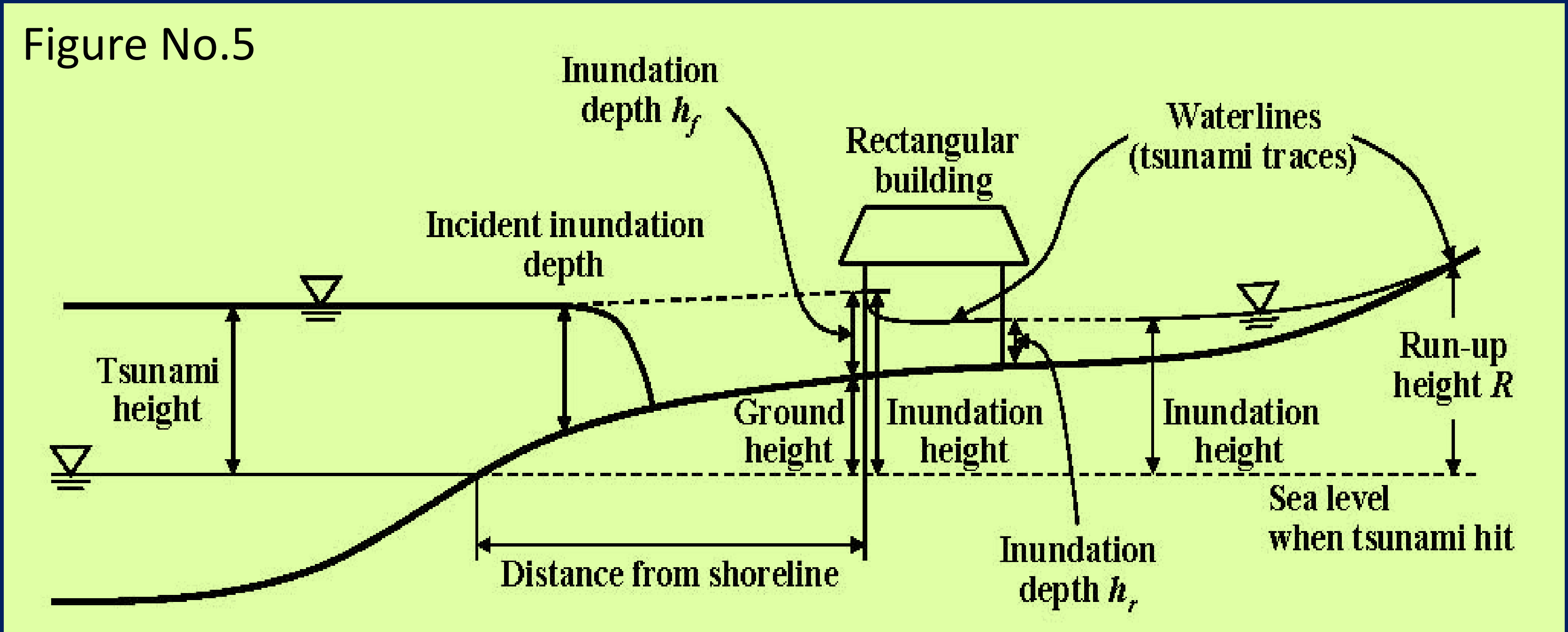


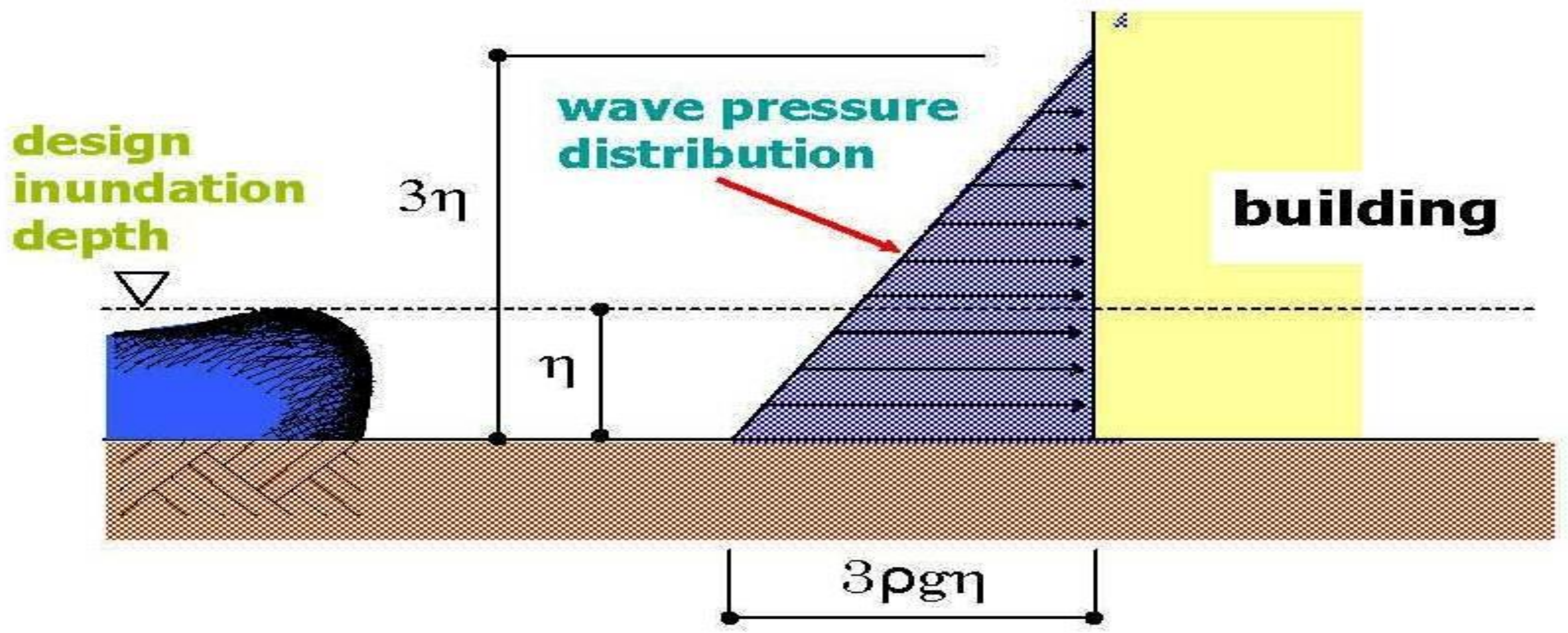
Figure 1. A process of tsunami run-up and definition of tsunami technical terms and parameters.

1. Inundation depth-h_r
2. Flow velocity $V \Rightarrow 1.2(gh_f)^{½}$

   Where h_f is the water mark on the building
3. Flow direction

JAPANESE DESIGN METHOD (Okada & al 2004)

Figure No.6



Source :T. Ishikawa

- The force per unit length of the wall is taken as an equivalent hydrostatic load with 3 times the inundation depth, H for a tsunami wave for no break up. This leads to a resultant force equal to 9 times the hydrostatic force.
- In the case of a wave break-up, an additional triangular pressure distribution to a height of 0.8H with base pressure of 2.4ρgH, where ρ is the seawater density is superimposed.

New judgment criterion for the degree of damage to buildings.

Type of building	Partially Damaged			Destroyed		
	h_f (m)	u (m/s)	F_D (kN/m)	h_f (m)	u (m/s)	F_D (kN/m)
Reinforced Concrete	-	-	-	>8.0	>5.8	>155~281
Stone, Bricks, Concrete Block	3.0	3.6	21.8~39.6	7.0	5.5	118~215
Wood	1.5	2.5	5.4~9.9	2.0	2.9	9.7~17.6
Degree of Damage	Most pillars withstand tsunami, but parts of walls are damaged. Restoration is possible.			Walls and most of pillars are damaged. Restoration is not possible.		

Source : Paper: **INUNDATION FLOW VELOCITY OF TSUNAMI ON LAND AND ITS PRACTICAL USE - 2010**
Hideo Matsutomi, Kensuke Okamoto2and Kenji Harada

F_D (drag force) => $0.22\gamma_S C_D h^2{}_f\, W$

$C_D = 1.1 \text{ to } 2.0$

W *is the width of the building*

Vulnerability of the built environment - 1

Due to the utilisation of the Mediterranean coastal zones, the potential impacts of future tsunamis are likely to be much greater than in the past. New vulnerability assessments are to incorporate parameters such as:

A. The presence of on & off-shore protective barriers,
B. The distance from the shore,
C. Depth of flood water,
D. Building construction standards,
E. Preparedness activities,
F. Socio-economic status and amount of warning and ability to move away from the flood zone.

Vulnerability of the built environment - 2

A. Building surroundings – no barrier, high vulnerability, low/narrow earth embankment (high vulnerability), low/narrow masonry wall (moderate vulnerability), high concrete wall (low vulnerability).

B. Land vegetation cover – no cover (high vulnerability), scrub cover (moderate vulnerability), trees (low vulnerability), on the other hand large engineered coastal barriers could have a negative environmental impact.

C. Flood management systems such as diversion canals, dams and tide gates.

D. Number of stories in each floor – only one floor, vertical evacuation impossible, more than one floor vertical evacuation possible, leading to a lower vulnerability.

Description of ground floor – open plan with movable objects (high vulnerability) open plan without movable objects (moderate vulnerability)

Building material, age, design – buildings of fieldstone, crumbling and/or deserted (high vulnerability) ordinary brick/masonry (moderate vulnerability), pre-cast/reinforced concrete (low vulnerability).

Movable objects can cause injury to persons, damage to buildings or block evacuation routes.

E. Tsunami evacuation drills for school/local businesses/governmental offices evacuation.

F. Sociological data – population density during the night, the day, the summer and winter. Touristic centres will have high variations during the seasons, with the beaches vacant in mid-winter and most of the people keeping inland.

Economic land use data – business (shops, restaurants, hotels), residential, services (schools, hospitals, power stations, marine works).

HISTORICAL TSUNAMI HAZARD–MALTA 1

- Agius de Soldanis recounts how the sea at Xlendi rolled out to about 1 mile sweeping back “con grande impeto e mormorio” (MMXI) 1693
- It is, however, possible to make a reasonable scientific interpretation based on information on hydrographic charts. From the shoreline at Xlendi, an enclosed, elongated (0.5 km)bay of shallow depth extends seawards beyond the Ras il Badja Point at its entrance, where the depth is still a modest 4m.
- It is reasonable, therefore, to suggest that a drawdown to 4 m may have taken place, implying a withdrawal of upwards of 0.5 km prior to the tsunami arrival. (Mottersherd)

HISTORICAL TSUNAMI HAZARD–MALTA 2

- 1908 Messina (MMXI) flooding occurred an hour later in Msida & an estimated maximum of ~2.8m a.s.l. at Marsaxlokk. A number of fishing boats damaged by 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. These last 2 events The last could be waves excited by meteorological perturbations.

MALTA'S TSUNAMI RISKS 1

- The greatest tsunami damage is expected from high seismic activity in the Aegean Sea.

  This could excite wave run-ups of 7.0m height in the Marsaxlokk bay, decreasing to 2m to 3m height along the Sliema–Valletta shoreline.

  The arrival time of this tsunamic strike is expected to be 90 minutes after commencement of seismic activity.

- On the other hand the same seismic activity from Eastern Sicily would only induce run-up heights of 0.5m in Marsaxlokk Bay and 0.4m along the Sliema – Valletta shoreline. However a tsunami crest height for 5–10m for Malta can be created by a debris avalanche on Mt.Etna (Mottershead et alia).

  The arrival time of this tsunamic strike is expected to be 50 minutes after commencement of seismic activity (Ruangrassamee 2008).

MALTA'S TSUNAMI RISKS 2

In the case of a tsunami strike it is best to go *on* foot, not by car to the safest evacuation position. These have been worked out for 3 locations, mainly Ghadira, St. Julians & M'Xlokk.

- For Ghadira the travelling distance measures 300m, which at an average travelling speed of 1.5m/s takes 7½ minutes to undertake.
- For St. Julians the travelling distance measures 250m, which at an average travelling speed of 1.5m/s takes 6¼ minutes to undertake.
- For M'Xlokk the travelling distance measures 500m, which at an average travelling speed of 1.5m/s takes 12½ minutes to undertake (Morrison).

Inundation of the Maltese Islands up to the 10m mark

Figure No.7

Source: dhi periti

From the above it is noted that from earthquakes in the vicinity tsunami waves higher than 6m may be propagated. Studies undertaken suggest that the extreme is slightly higher, hence the zone of safety is taken at 10m.

ST GEORGES BAY / ST JULIANS AREAS PRONE TO TSUNAMI RISK

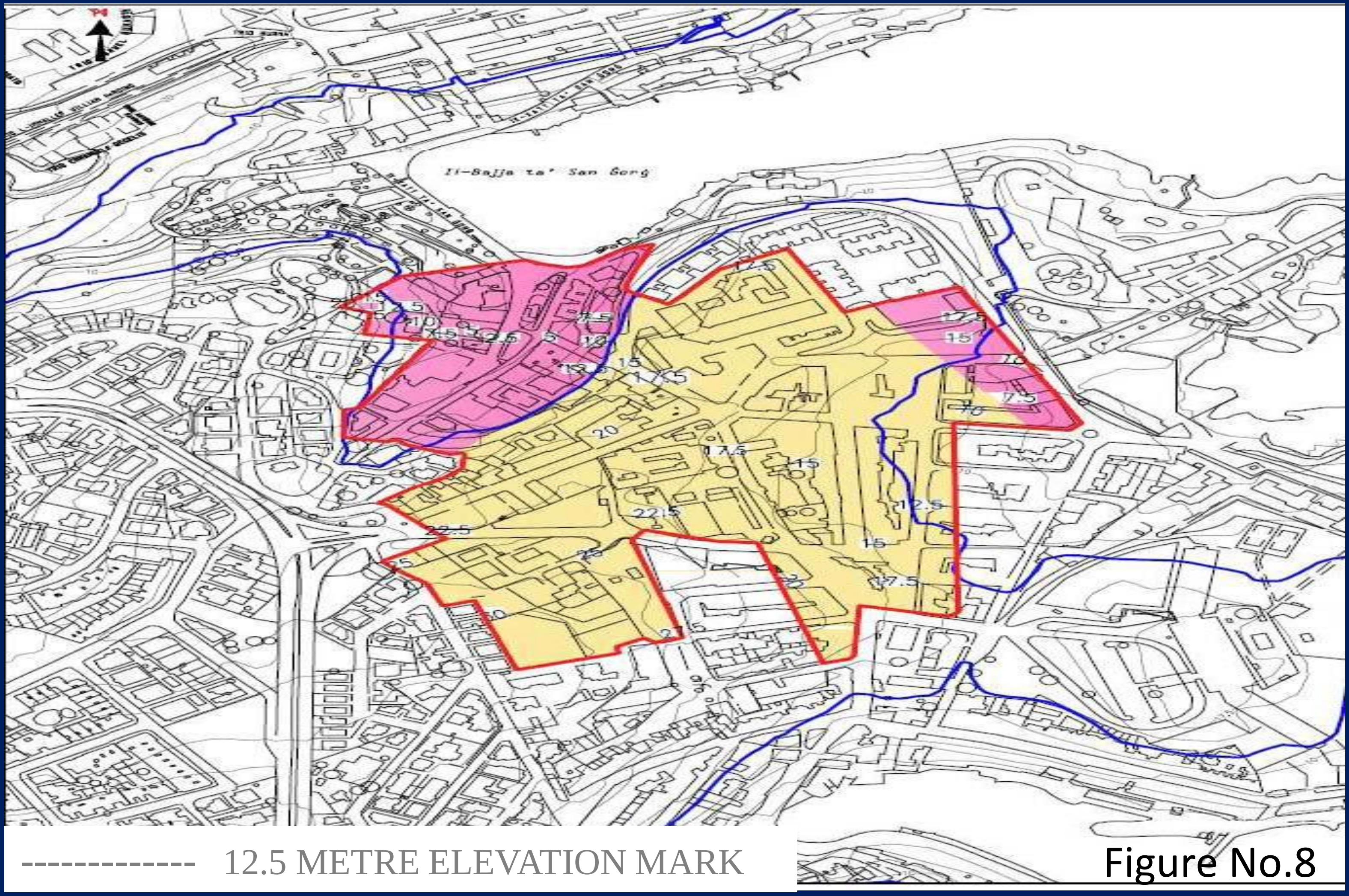


Figure No.8

Tourists are generally considered more vulnerable than locals, as they do not know the area, the potential risk or where it is best to go to – hence increasing their vulnerability.

ST GEORGES BAY / ST JULIANS AREAS PRONE TO TSUNAMI RISK

12.5 METRE ELEVATION MARK ASSUMED – above which tsunami inundation would have no effect

TSUNAMI – SEA WAVE FORCES for the Maltese Islands

- SEA WIND damage is greater from the NW (max wind speed 22 knots) with 5.2m high waves developing than from the NE (max wind speed 16 knots) with 3m high waves developing.

- Greater Tsunami damage however may occur from the Eastern side, with 5m tsunami waves developing and 0.5m tsunami waves developing from Eastern Sicily.

- Tsunami wave pressure is given at $250 kN/m^2$ and for wind driven waves is limited to $75 kN/m^2$. These are to be compared to blast pressures at $34 kN/m^2$.

THANK YOU

FOR YOUR ATTENTION

Tsunami construction risks in the Mediterranean – outlining Malta's scenario - Camilleri:
Disaster Prevention and Management Vol. 15 No. 1, 2006

Tsunami and wind-driven wave forces in the Mediterranean Sea – Camilleri:
Maritime Engineering Volume 165 Issue MA2, 2012.