STAKEHOLDER WORKSHOP ON TSUNAMI AWARENESS, MITIGATION AND PREPAREDNESS FOR TOURISM SECTOR, MARINA & YACHT CLUBS, SCHOOLS AND COMMUNITIES IN MALTA

Thursday 23rd – Friday 24th May 2013
University of Malta, Msida, Malta

Organized by

International Ocean Institute (IOI) & Institute of Earth Systems (IES), University of Malta

In Cooperation with

The Civil Protection Department (CPD)

Ministry for Home Affairs and National Security

Historical Records of Tsunamis in the Mediterranean Sea and Impact Forces on Built Structures.

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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

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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),

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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.

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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 **$V = (gD)^{1/2}$ but for Tsunami $V = 2(gD)^{1/2}$** (Keuleugen)

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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.

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MEDITERREAN WAVE FETCH F & Bathymetry

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

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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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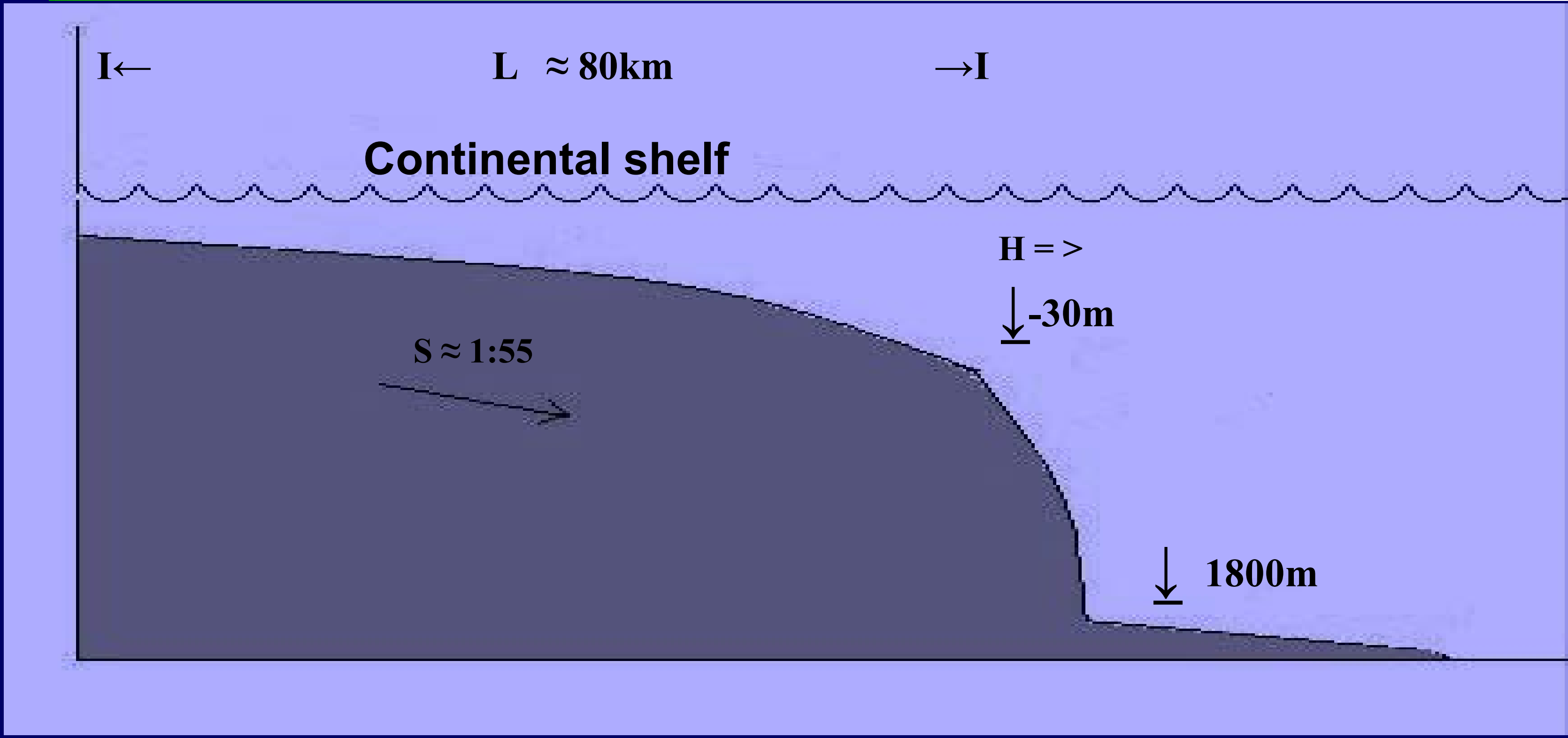
FUNDAMENTAL MODE OF THE CONTINENTAL SHELF



Shelf Resonance Periods

T=> 8(L/s.g) $^{1/2}$ => 8L(gH)$^{1/2}$ (Munk 1962)

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

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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 – 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

Source : Swiss Re 1992

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MEDITERRANEAN REGIONS TSUNAMI HAZARDS

•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.

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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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TSUNAMI MAGNITUDE SCALES (Ambraseys 1962)

K_o => $\log_2 H^{1/2}$	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

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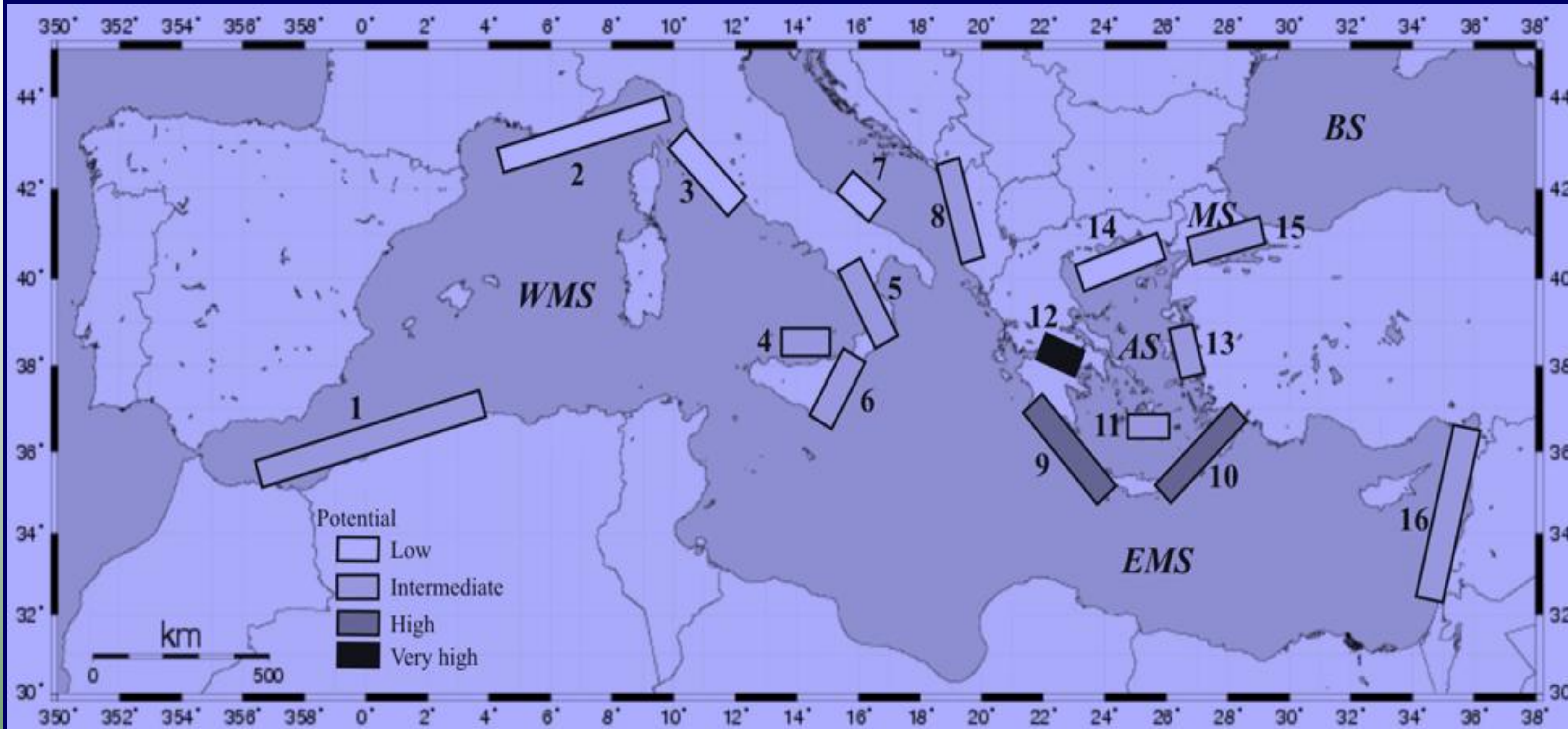
MEDITERRANEAN TSUNAMI POTENTIAL ZONING according to INTENSITY & OCCURRENCE (Papadopoulos 2005)



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

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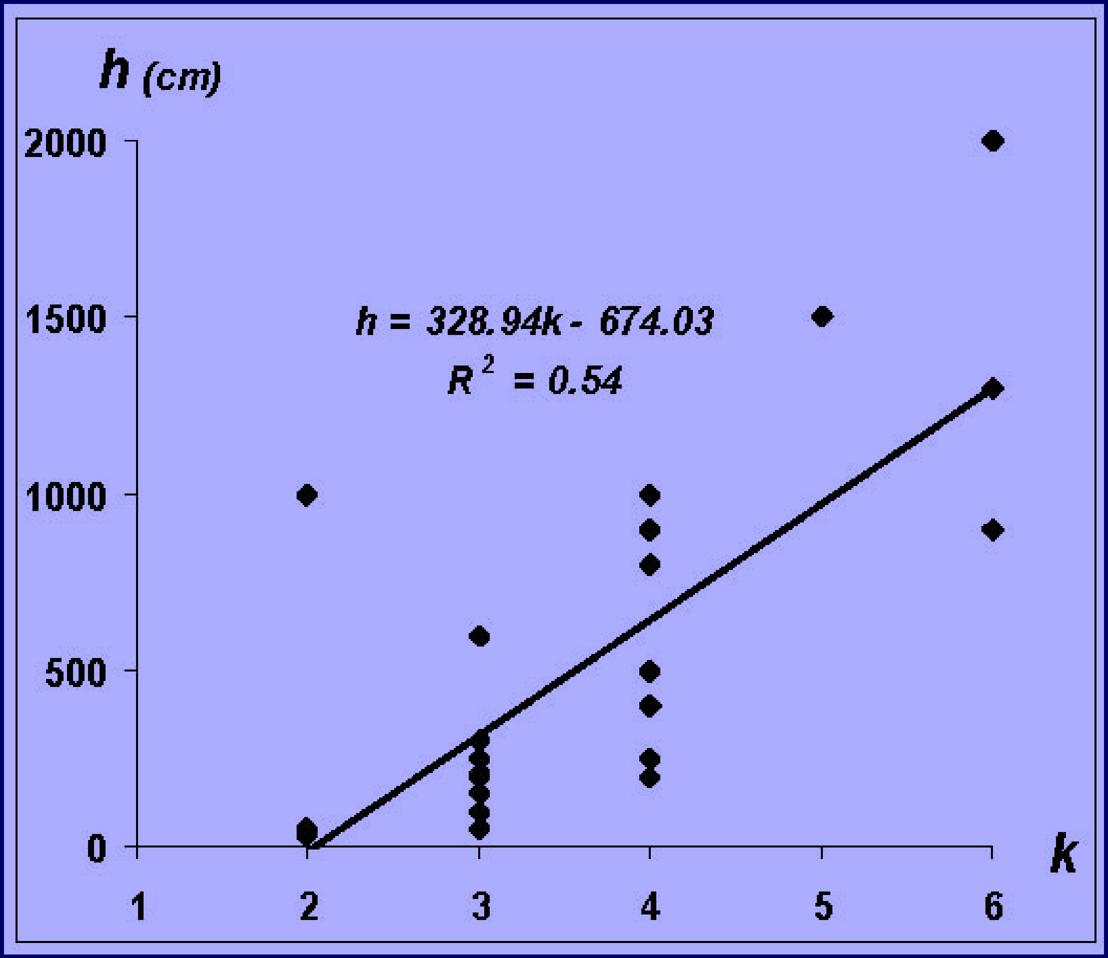
Relations between wave height *h* and intensity K_O in the entire Mediterranean Sea



Source: Papadopoulos 2005

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

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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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MALTA'S TSUNAMI RISKS

- The greatest tsunami damage with 7.00m ht run-off and a 1,500 year return period, is from the Aegean Sea with 90min warning.

- From Eastern Sicily only a 0.5m high run-off and a 75-year return period is expected with a 50min warning period. (Ruangrassamee 2008)

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Inundation of the Maltese Islands up to the 10m mark

Source: dhi periti

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ST GEORGES BAY / ST JULIANS AREAS PRONE TO TSUNAMI RISK

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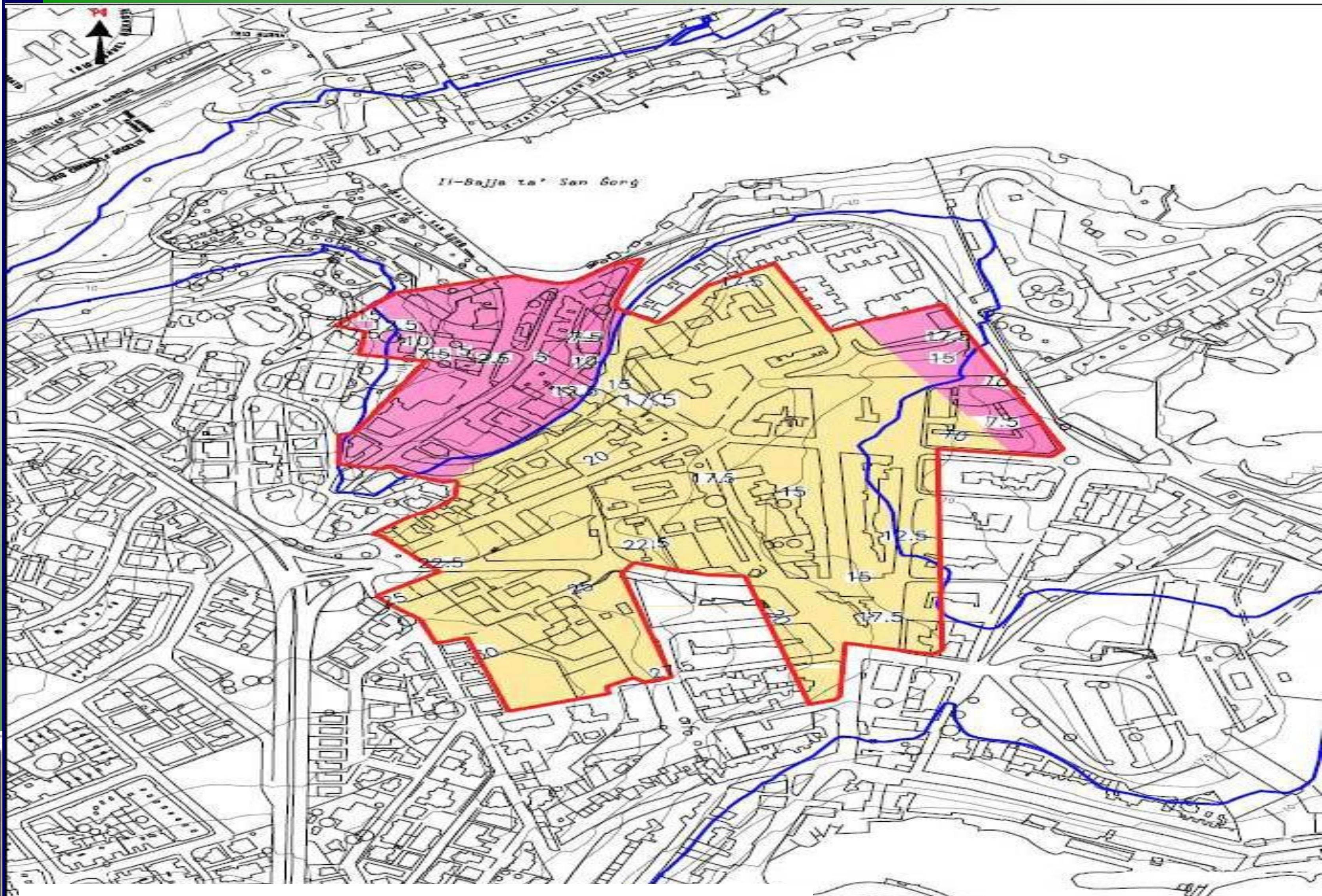

------------- 12.5 METRE ELEVATION MARK

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

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TSUNAMI FORCES

- $\sum$ 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

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TSUNAMI INDUCED FORCES defined by

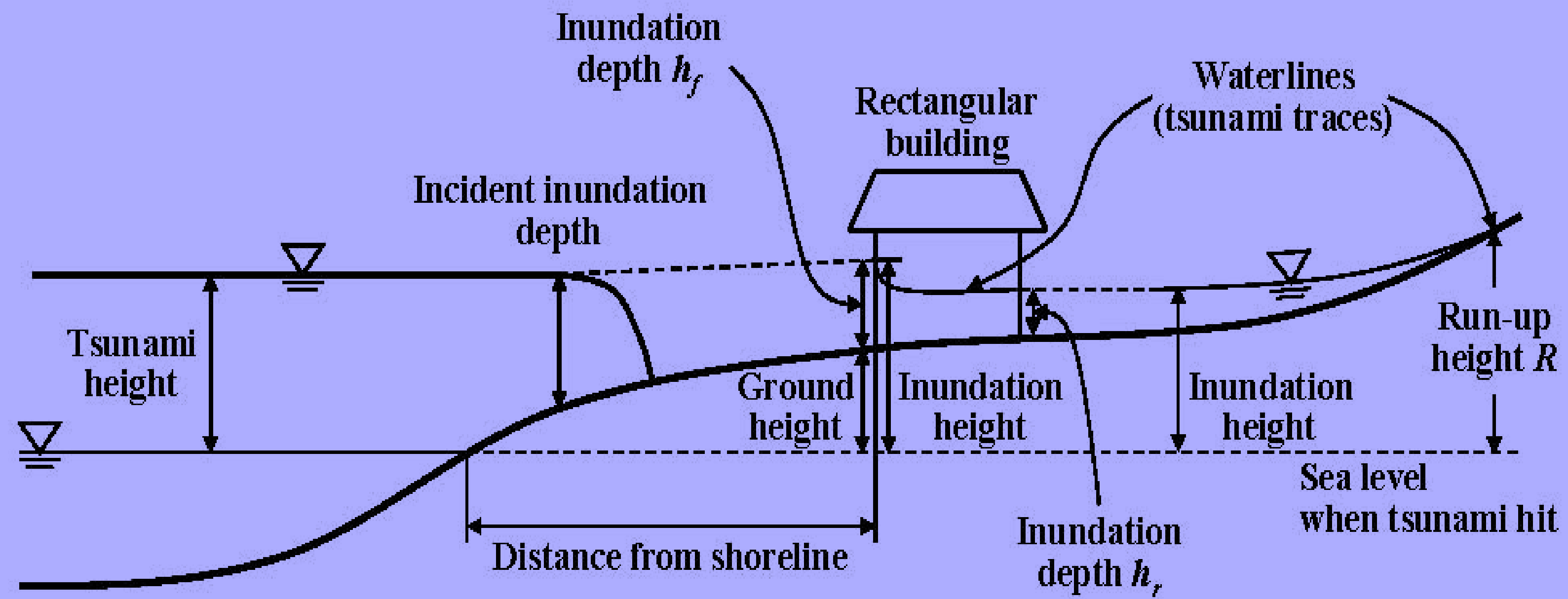

Figure 1. A process of tsunami run-up and definition of tsunami technical terms and parameters.

1. Inundation depth-h_r
2. Flow velocity $V=>1.2(gh_r)^{1/2}$
   Where h_r is the water mark on the building
3. Flow direction

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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) => $0.22\gamma_S C_D h^2_f W$ *as compared to* $5.5\rho g H^2$

$C_D = 1.1$ *to* 2.0

W *is the width of the width of the building*

JAPANESE DESIGN METHOD (Okada & al 2004)

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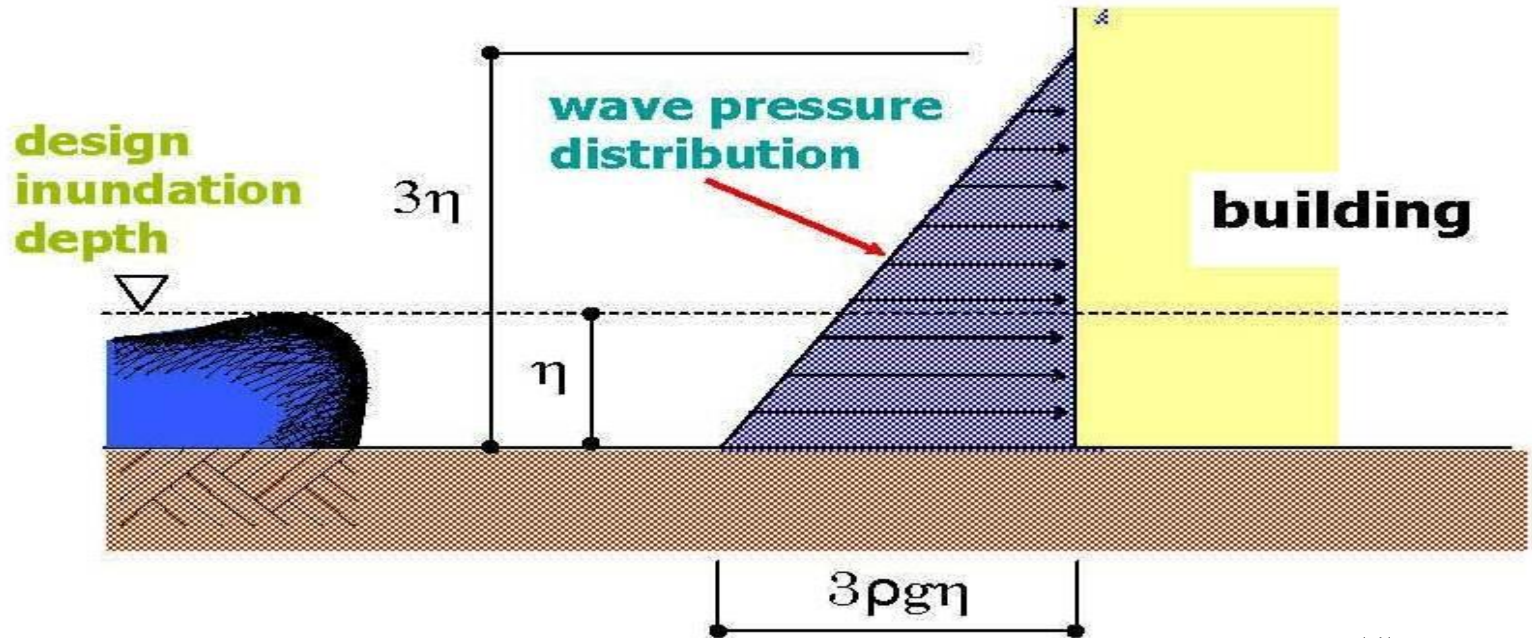

Source :T. Ishikawa

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.

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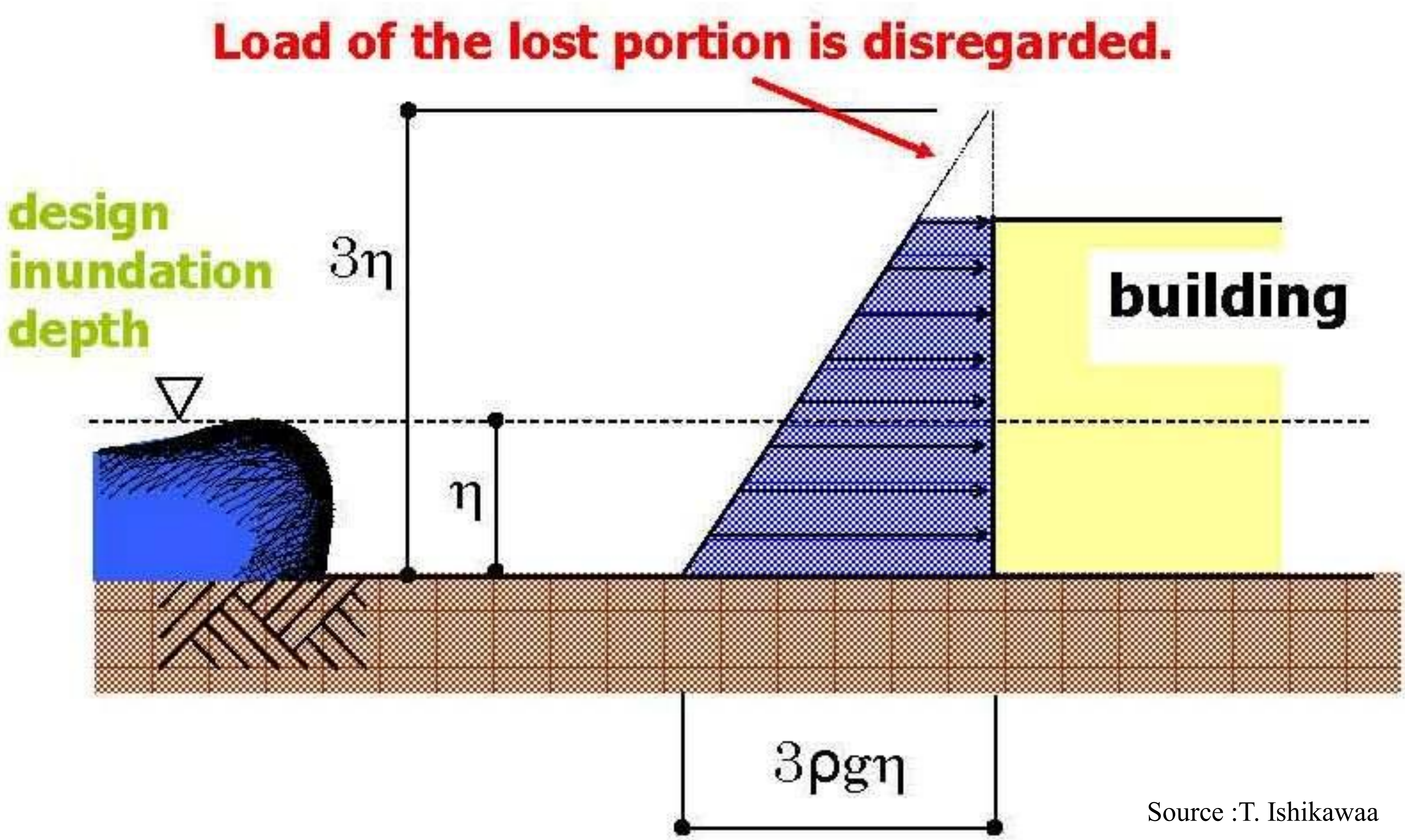
WAVE PRESSURE DISTRIBUTRION BASED ON BUILDING CONDITIONS



Source :T. Ishikawaa

When pressure-resistant members are lower than 3η

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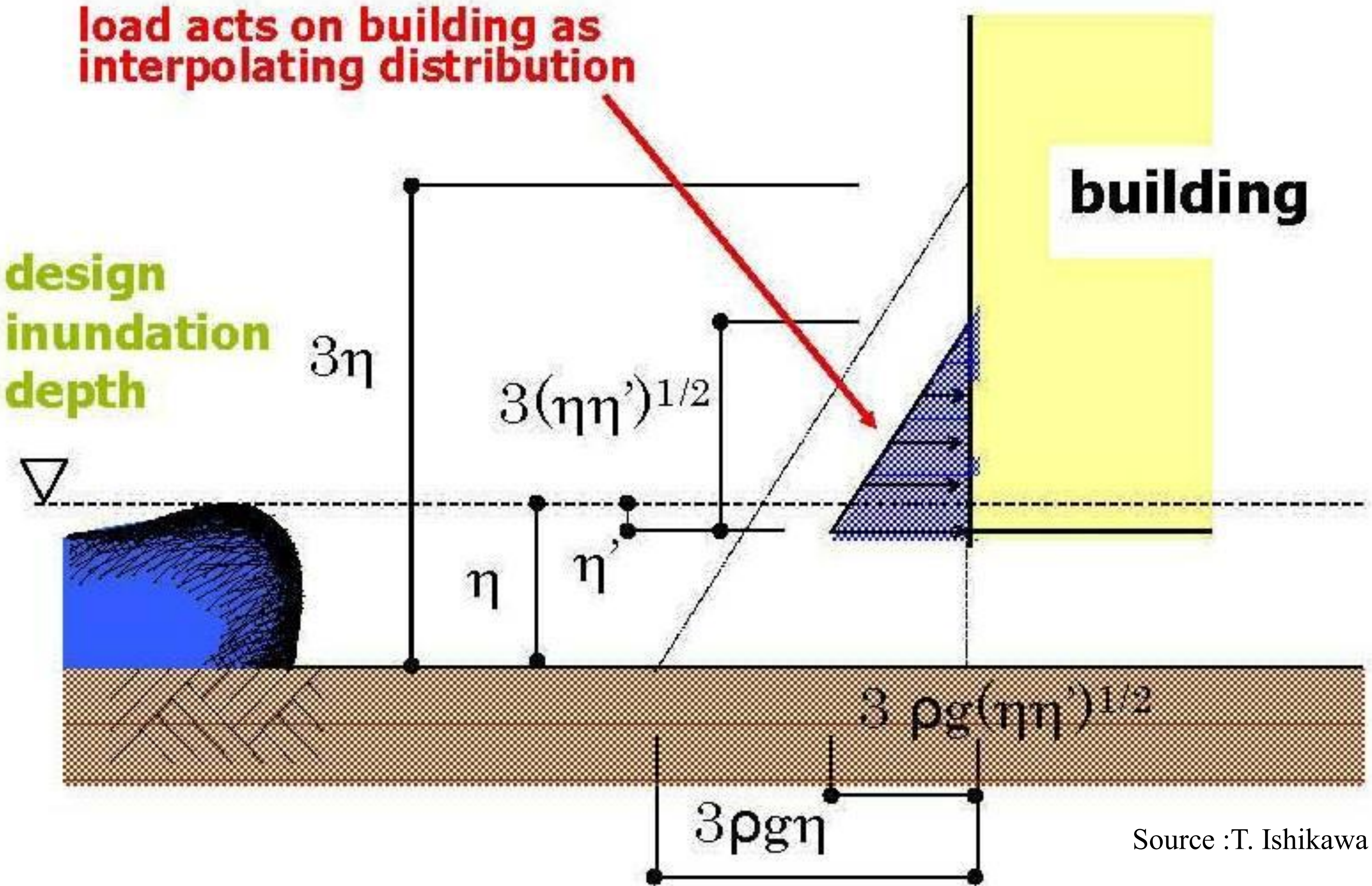

Source :T. Ishikawa

When pressure-resistant members are missing between 0 and η ¯ η '

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Setting of Tsunami design load for the buildings which have glass windows

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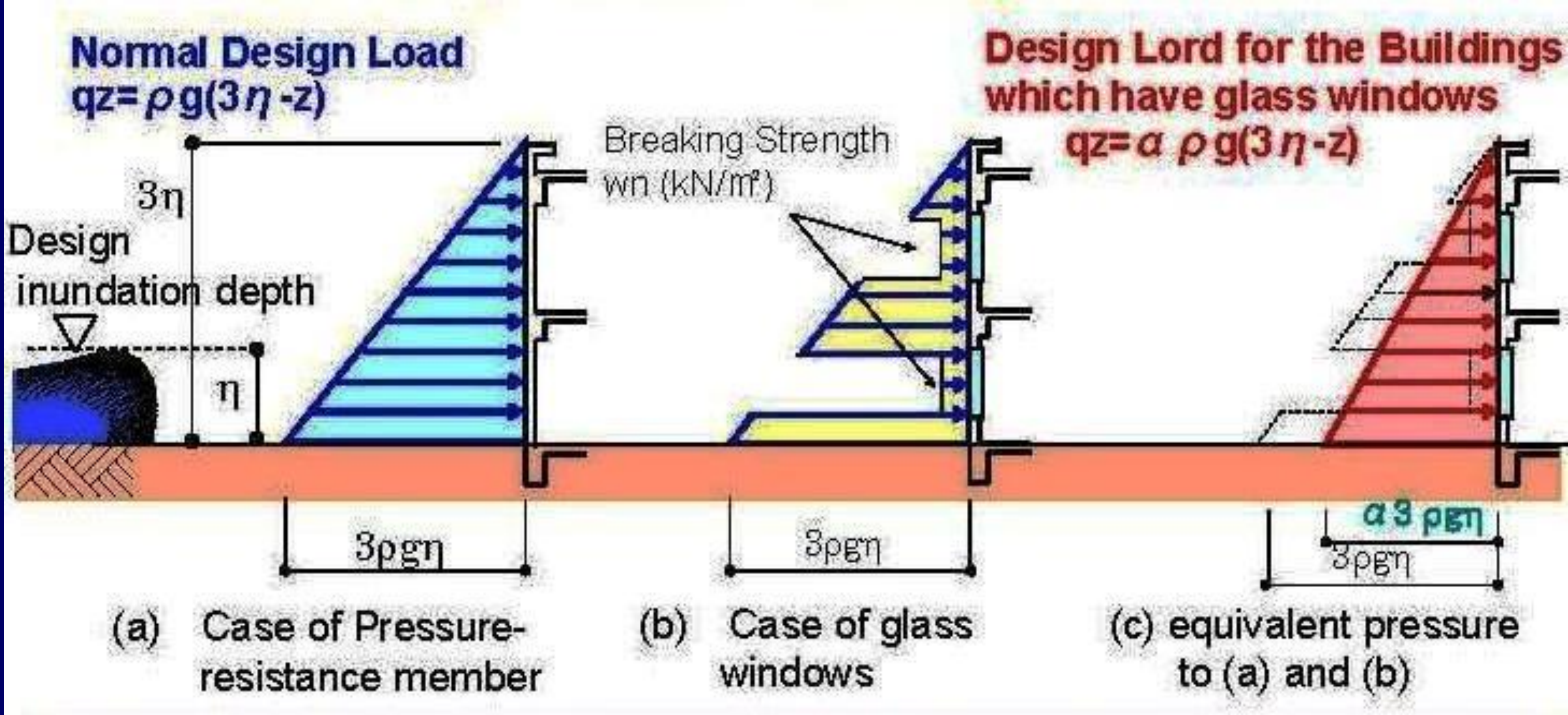

Source :T. Ishikawa

The tsunami wave pressures generated with wall openings of 25% and 50%. Reductions noted in the 15% - 25% and 30% - 40% respectively.

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WAVE FORCES as compared to HYDROSTATIC FORCE

Hydrostatic pressures developed for a 4.3m wall height with corresponding equivalent uniform pressures developed *(WD-wind-driven)*

	Tsunami	Hiroi (WD)	Minikin (WD)	Goda (WD)
Equivalent Hydrostatic impact force	×11	×3	×2.7	×1.3
Average pressure kN/m^2	238	65	58	28

The table above demonstrates the maximum average wave pressure developed at $238kN/m^2$ for a tsunami wave, with the minimum of $28kN/m^2$ by the Goda method for wind-driven. For a 7.0m high tsunami wave this pressure increases to $387kN/m^2$

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RECOMMENDATION on WAVE FORCES for Structural Engineers

Thus for a 4.3m high tsunami Malta breaking wave the force impact at 11 times the hydrostatic force is calculated at:

11times $\frac{1}{2}\rho g(H)^2 \approx 5.5_{es}H^2 = 11 \times (4.3\text{m} \times (4.3\text{m} \times 10.05\text{kN/m}^3)\ /2$

$= 1{,}022\text{kN/m}$.

The average tsunami wave pressure works out at: 1,022kN/m / 4.3m

$= 238\text{kN/m}^2$

Comparison of Wind Driven - WD and Tsunami Waves on a 4.3m high wall		
	Impact Force	% of Tsunami impact
Tsunami	1022kN/m	100%
Hiroi - WD	278kN/m	27%.
Minikin - WD	309kN/m/194kN/m	25%
Goda - WD	100kN/m/142kN/m	12%

Wind driven sea wave pressures vary by a 2.25 factor, noting the short duration of the impact wave.

If this is the case of a Tsunami wave, this will vary the pressure from 238kN/m^2 down to 108kN/m^2

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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 250kN/m² and for wind driven waves is limited to 75kN//m²

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