KAMRA TAL-PERITI

*To support members of the profession in achieving excellence in their practice of architecture and engineering in the interest of the community*

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# SUSTAINABLE DEVELOPMENT:
# CIVIL ENGINEERING AND THE BUILT ENVIRONMENT

## INTERNATIONAL CONFERENCE

**Malta**

**5th May 2011**

# Wave Forces: Tsunami And Sea Wind Driven in the Mediterranean: Malta's Scenario

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**Normal Sea 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

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**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 & BATHYMETRY DATA

Table 1: 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, volcanic eruption, landslide |

*Source: Brooks/Cole, a division of Thomson learning, Inc*

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=(gD)** ½ (Kevlevgen)

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# WIND DRIVEN WAVES

Waves grow continuously under the action of wind and their maximum height reflects the average intensity of the wind along the fetch. Once fully developed wind waves will not develop in size, no matter how long the wind blows.

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. Note that the Malta significant wave height is in figure 3 indicated at 3m.

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# MEDITERREAN WAVE FETCH & Bathymetry

**Figure 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

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# Conditions Necessary for a Fully Developed Sea at given Wind Speeds and the Parameters of the Resulting Waves

| Wind Conditions | | | Wave Size | | |
|---|---|---|---|---|---|
| Wind Speed in one Direction | Fetch | Wind Duration | Average Height | Average Wavelength | Average Period |
| 19km/hr (5.25m/s) | 19km | 2hr | 0.27m | 8.5m | 3.0 sec |
| 37km/hr (10.25m/s) | 139km | 10hr | 1.5m | 33.8m | 5.7 sec |
| 56km/hr (15.5m/s) | 518km | 23hr | 4.1m | 76.5m | 8.6 sec |
| 74km/hr (20.5m/s) | 1313km | 42hr | 8.5m | 136m | 11.4 sec |
| 92km/hr (25.5m/s) | 2627km | 69hr | 14.8m | 212.2m | 14.3 sec |

**Thomas Stephenson had developed the empirical formula, linking fetch and maximum height of wave.**

$$H_{max} = 0.336(F)^{½}$$

**The Stephenson equation for a wind fetch of 518km gives a wave height given by: 7.65m**

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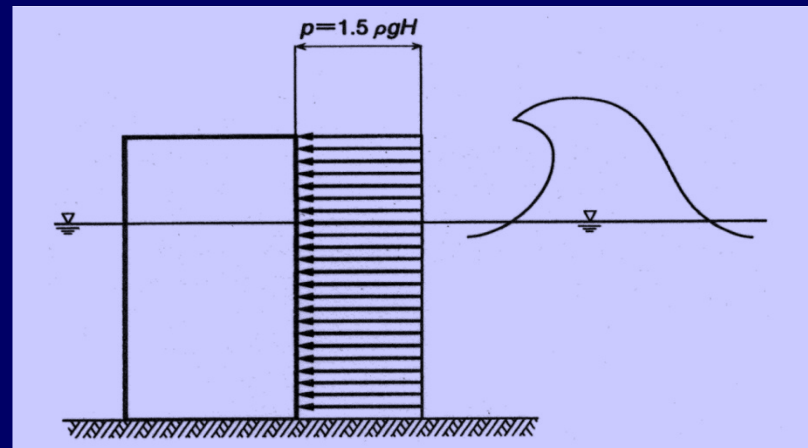
# SEAWAVE PRESSURES ON VERTICAL FACES

**The power of the wind driven waves has been established on whether the walls are subjected to non-breaking (or pulsating), impulsive breaking (impact) or broken wave impact.**

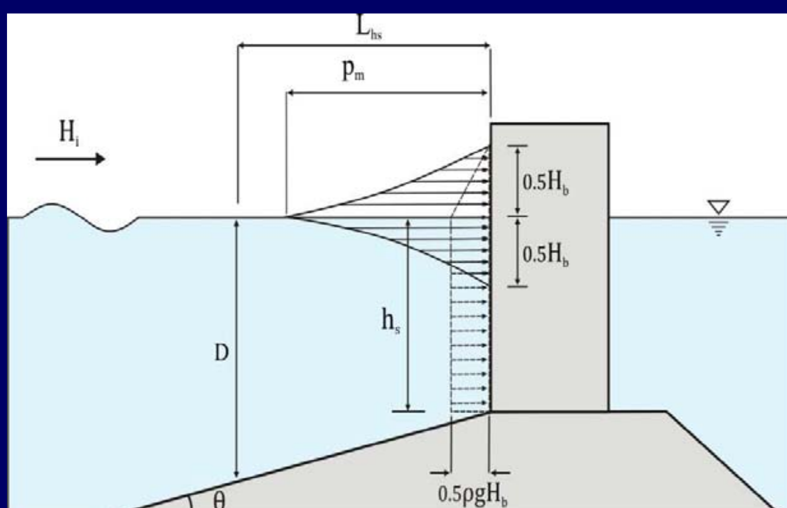
**The greatest force recorded was one of 3.5 tons per square foot (335kN/m$^2$ by Mr. Thomas Stevenson. One thing evident from Mr. Stevenson's experiments is that the larger the area of the exposed face the less is the pressure recorded, that very high pressures, possibly even exceeding the record of 3.5 tons, may occur on small areas.**

**The main methods used to estimate pulsating wave forces on upright breakwaters, include the work of Hiroi 1919, Ito 1971 and Goda 1985. Sanflou 1928 however, deals with walls in deep water, not subjected to impact forces. Minikin's method in the early 1950's, used for breaking waves was found to be too conservative, and has been overtaken by Goda's method used for both breaking and non-breaking waves.**

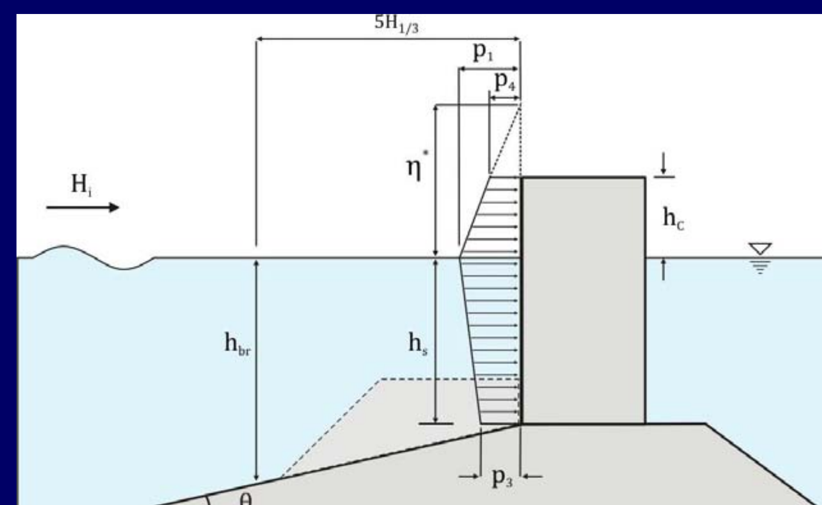
# PRESSURE DISTRIBUTION by BREAKWATER WIND WAVE DRIVEN WAVES




Heroi’s Formula




Minikin Method




Goda Method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# PRESSURE GENERATED BY WIND DRIVEN SEA WAVES

Comparison of wave forces on a 4.3m high wall as calculated by the Goda & Minikin methods

| | Goda method | | Minikin method | | Hiroi Method |
|---|---|---|---|---|---|
| Wave Period (sec) | 6 | 10 | 6 | 10 | |
| Pl (kN/m$^2$) | 26.6 | 36.4 | 336 | 176 | 65 |
| F (kN/m) | 99.6 | 142 | 309 | 194 | 278 |
| M (kN-m/m) | 204 | 289 | 772 | 485 | 598 |

*Source: Coastal Technical Note 1988*

Hiroi method gives a force F of **278kN/m**, which equates to 3 times the hydrostatic force developed Goda method, equates to 1.2 times the hydrostatic pressure developed.

Both these wave pressures are considerable, noting blast explosion loading to be taken at *35kN/m$^2$*. This peak value below the still water line decays rapidly with depth, although not being the case of the Hiroi method. A Ciria document notes that the average wave pressure on sea walls varies from **150kN/m$^2$** down to **50kN/m$^2$**, with the lower pressures adopted where the wall is very high.

# 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

# 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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# MEDITERRANEAN AREAS PRONE TO TSUNAMI RISK

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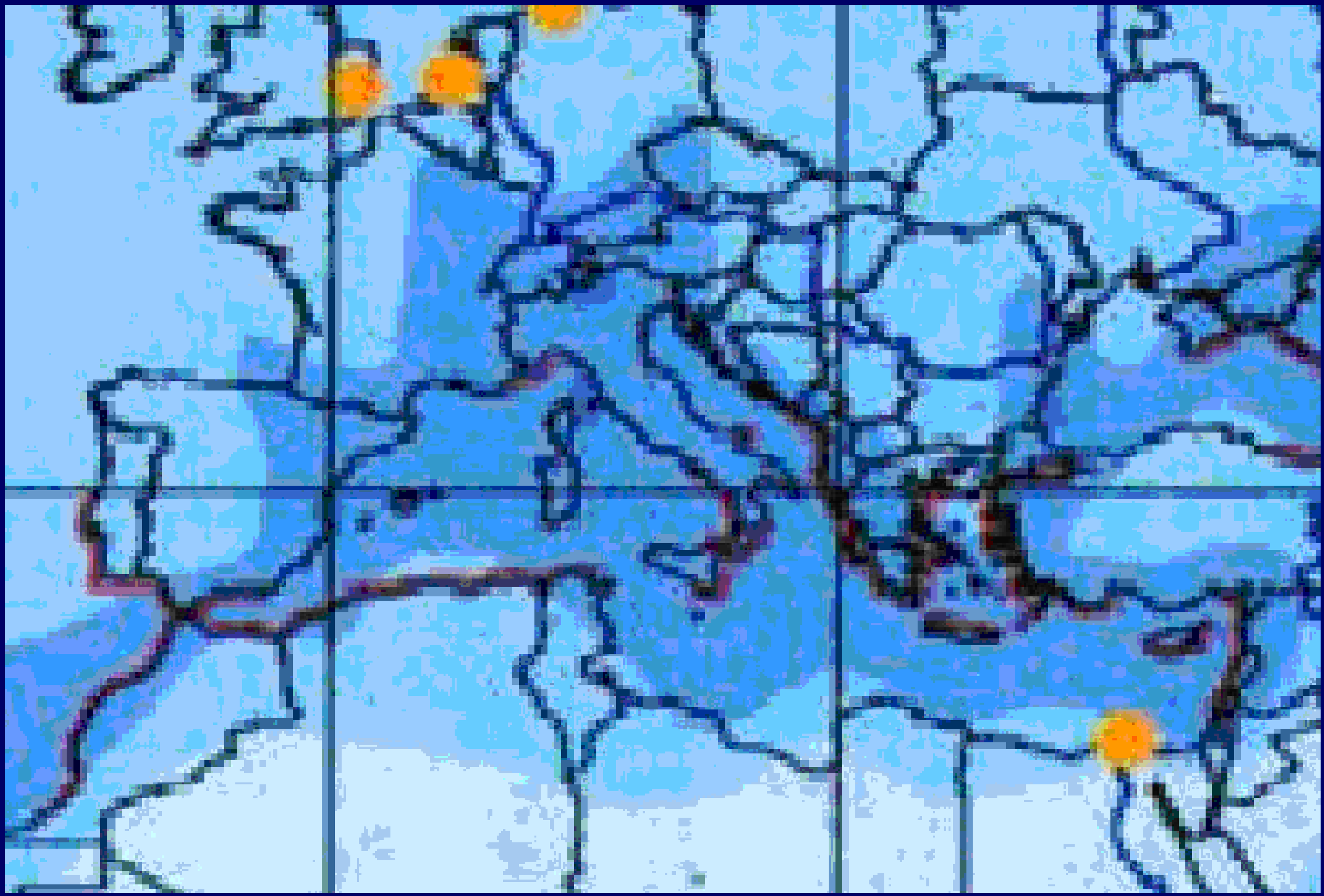

------------ Coasts exposed to tsunamis

Source: Munich Re, “Flooding and Insurance” 1997.

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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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# TSUNAMI RISKS

- **The greatest tsunami damage with 7.00m ht run-off is from the Aegean Sea with 90min warning.**

- **From Eastern Sicily only a 0.5m high run-off is expected with a 50min warning period.**

# Inundation of the Maltese Islands up to the 10m mark

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Source: dhi periti

# ST GEORGES BAY / ST JULIANS AREAS PRONE TO TSUNAMI RISK

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

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# TSUNAMI FORCES

- ∑ horizontal force = hydrostatic + hydrodynamic + impulsive + inertial.

- 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$^2$ with windows and masonry panels expected to fail at 10-20% of this level

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# JAPANESE DESIGN METHOD (Okada & al 2004)

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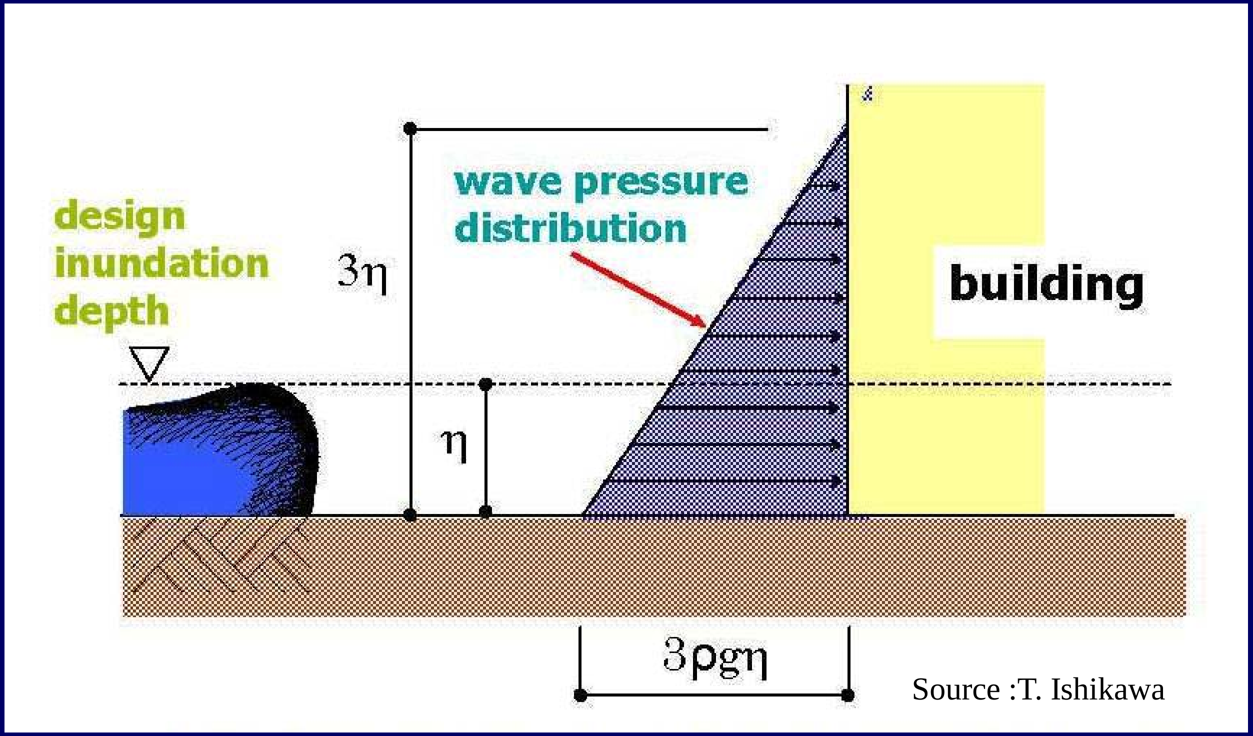
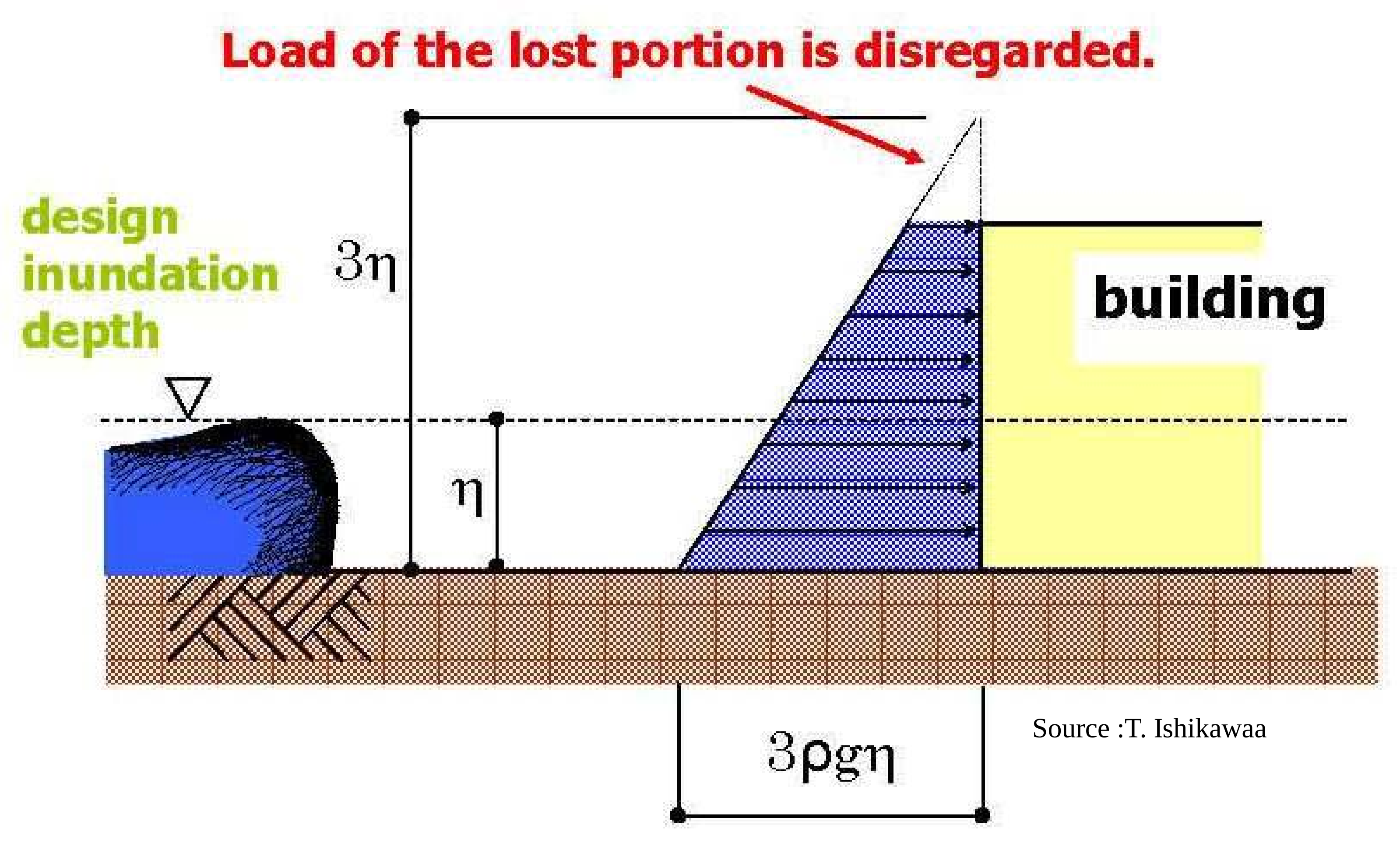



**The force per unit length of the wall is taken as an equivalent hydrostatic load with 3 times the inundation depth, H for a tsunami wave for no break up. This leads to a resultant force equal to 9 times the hydrostatic force. In the case of a wave break-up, an additional triangular pressure distribution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

# WAVE PRESSURE DISTRIBUTRION BASED ON BUILDING CONDITIONS




When pressure-resistant members are lower than 3η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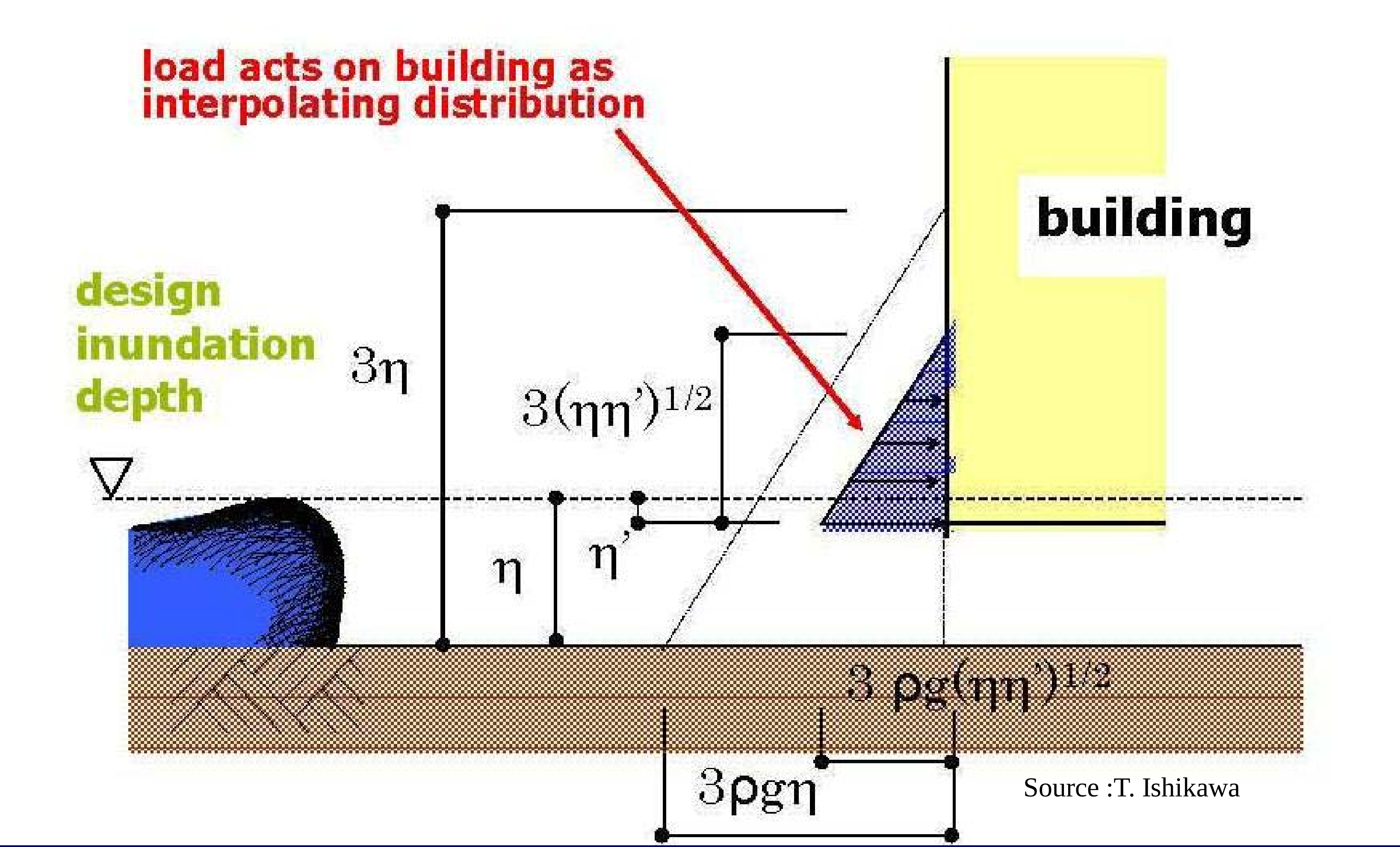


Source :T. Ishikawa

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

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

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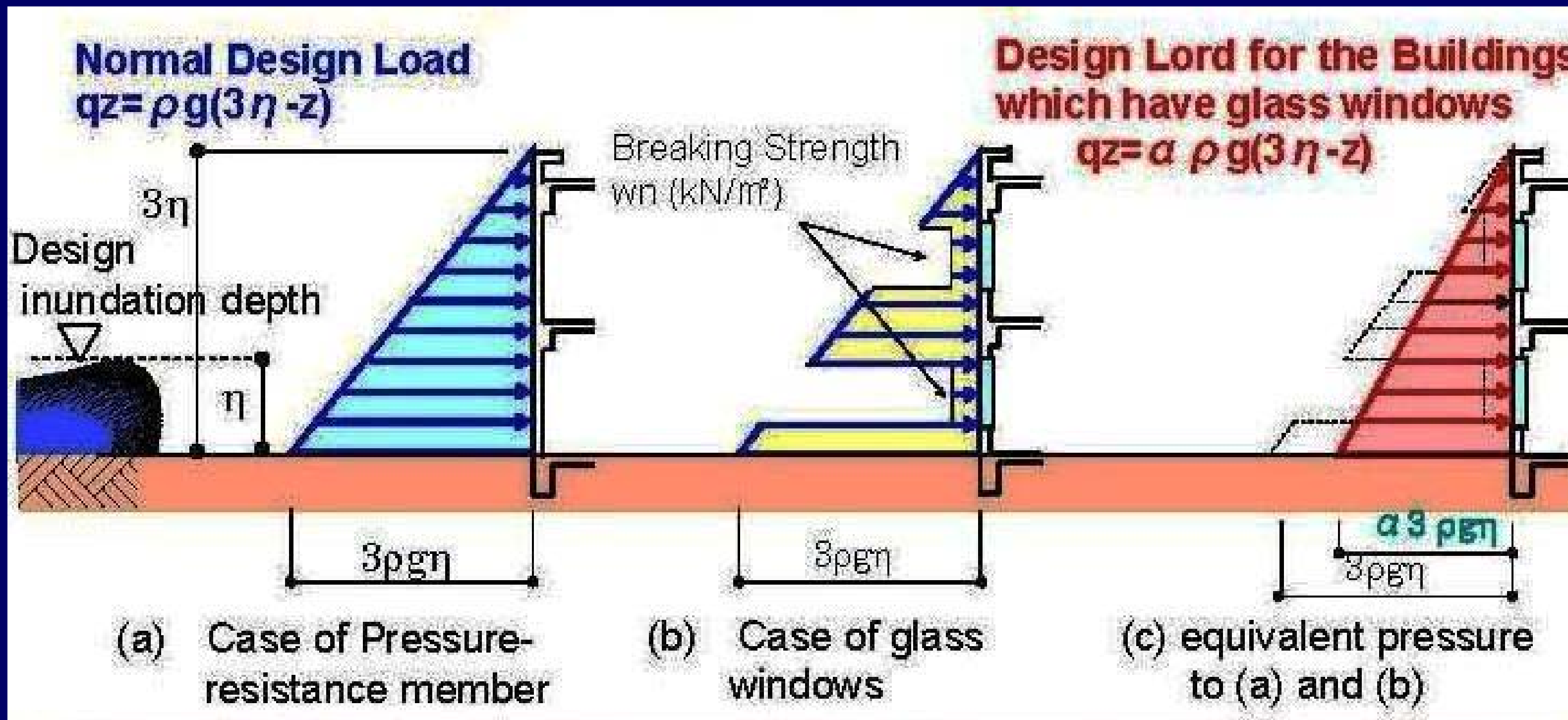


Source :T. Ishikawa

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 ½ ρg(H) $^2$ = 11 × (4.3m × (4.3m× 10.05KN/m$^3$ ) /2 = 1,022kN/m.**

**The average tsunami wave pressure works out at: 1,022KN/m / 4.3m = 238kN/m$^2$**

Comparison of Wind Driven and Tsunami Waves on a 4.3m high wall

| | Impact Force | % of Tsunami impact |
|---|---|---|
| Tsunami | 1022kN/m | 100% |
| Hiroi | 278kN/m | 27%. |
| Minikin | 309kN/m/194kN/m | 25% |
| Goda | 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$^2$**

# TSUNAMI – SEA WAVE FORCES
# for the Maltese Islands

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

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

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