TSUNAMIS: DISASTERS AND COUNTERMEASURES

SHUTO Nobuo, ARISH, NIHON UNIVERSITY
BANDA ACHE, INDONESIA
NOT A BIG ONE.
THE 1946 ALEUTIAN TSUNAMI 30m HIGH
THE LIGHT HOUSE WAS WASHED AWAY.

The light house was 18 m high.

It stood on the ground 10 m high above sea level.
THE 1946 ALEUTIAN TSUNAMI SPREAD OVER THE PACIFIC OCEAN

For a tsunami several 100 km long, the ocean 4 km deep is quite shallow.
THE TSUNAMI ARRIVED AT HAWAII.

School children saw a precedent abnormal tide and warned. No one listened to this warning. It was on April 1st.
FAILED TO EVACUATE.
159 DEATHS in Hawaii.

A waterside worker at the Hilo Harbor.
THE MAX. RUNUP OF
THE 2004 TSUNAMI as high as 49m

(Photo by Okayasu)

The two photos are from HP of Coastal Eng. Lab., Yokohama National U.

(Photo by Sasaki)
THREE TYPES OF TSUNAMI
IN THE SHALLOW SEA

RAPID TIDE

BREAKING BORE

SOLITONS

IN DEEP SEA

Original tsunami height
TSUNAMI HEIGHT
LOCALLY QUITE DIFFERENT

Measured in 1933.
A REASON OF LOCAL DIFFERENCE IN TSUNAMI HEIGHT (UNIC, FUJITU)
<table>
<thead>
<tr>
<th>DISASTERS BY TSUNAMIS IN THE PAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>• HUMAN LIFE</td>
</tr>
<tr>
<td>• BUILDINGS</td>
</tr>
<tr>
<td>• STRUCTURES SCOURING, OVERTURNED</td>
</tr>
<tr>
<td>• TRAFICS RAILWAYS, ROADS, HARBORS</td>
</tr>
<tr>
<td>• LIFELINES WATER SUPPLY, ELECTRICITY, TELEPHONE, SEWAGE</td>
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<tr>
<td>• FISHERIES BOATS, AQUACULTURE</td>
</tr>
<tr>
<td>• COM. &amp; INDUSRTY DETRACTION DUE TO SOAKAGE</td>
</tr>
<tr>
<td>• AGRICULTURE PRODUCTS, FARM LAND, IRRIGATION CHANNEL</td>
</tr>
<tr>
<td>• FOREST PHYSICAL, PHYSIOLOGICAL</td>
</tr>
<tr>
<td>• FIRE KITCHEN, HEATING, ELECTRIC LEAKAGE</td>
</tr>
<tr>
<td>• OIL SPILL SPREAD OF FIRE, POLLUTION</td>
</tr>
<tr>
<td>• TOPOGRAPHY EROSION, DEPOSITION</td>
</tr>
</tbody>
</table>
LOSS OF LIVES vs. DESTROYED HOUSES

The 1896 Meiji Great Sanriku Tsunami

A typical “tsunami earthquake”.

The 1933 Showa Great Sanriku Tsunami
KAWATA DIAGRAM
with Banda Ache data by Oya et al.

Three order difference, depending on an early evacuation or not.

No vertical evacuation in case of Banda Ache.
VERTICAL OR HORIZONTAL EVACUATION?

The 1983 Nihonkai-Chubu Earthquake Tsunami at the mouth of Iwaki River.

Nine people. None at all. Thickness of water=70 cm.

The last person.
RULE No. 1
AFTER A VIOLENT EARTHQUAKE, A TSUNAMI WILL COME.

TSUNAMI EARTHQUAKE!!!

Ten-percent exception.
RULE No. 2
A TSUNAMI BEGINS WITH AN EBB.

There is no rule but has exception.

(Photo by Mr. F. Sasaki)

This tsunami began with a sudden flood.
Wind effect on a wooden house in 1993

First wave

Second wave
DAMAGED BY WIND, IN 1993

Water depth: 25cm above the 1st floor.
DAMAGE TO WOODEN JAPANESE HOUSES

- **Destroyed**: No structure at all.
- **Heavily damaged**: Major portion of pillars and walls are destroyed or lost.
- **Partially damaged**: Pillars remain. A portion of walls is destroyed.
- **Slightly damaged**: Walls are not damaged. Windows are broken.
- **Inundated**: No mechanical damage.
A ROUGH ESTIMATE OF DAMAGE TO WOODEN HOUSE

DAMAGE BEGINS AT
\[ V = 4 \text{ m/s}, \quad \text{or Force} = 1.1 \text{t/m} \]

Water depth: 1 m  Partially damaged
Water depth: 2 m  Heavily damaged

Partially damaged
Heavily damaged
DAMAGE TO HOUSES IN TERMS OF TSUNAMI HEIGHT

Black: 1993 tsunami

RC. Bldg.

D.: destroyed
P.D.: partially destroyed
S.D.: slightly damaged

(Matsutomi & Shuto)
Time series of water level for a breaking bore at the fore- and rear-walls

(a) 分裂しない場合 (Matsutomi)
Damage to houses in terms of the water depth

\[ F \sim u^2 h \]

\( h \): measured or computed water depth
\( u \): computed current velocity \ (Hatori)

\[ F \sim h^2 \quad \text{if} \ u \sim (gh)^{1/2} \]

\[ F_D = 2.20 \ \rho \ C_D h_f^{2.21} B \] \quad (Matsutomi)

\( \rho \): density of water, \( C_D \): drag coefficient,
\( h_f \): water depth at the fore side wall, \( B \): width of building

Destruction condition

Wooden house: \( F_D = 1.06 \ tf/m, \ u = 4.2 \ m/s \)
Concrete block bldg. \( 16.9 \ tf/m, \ 10.2 \ m/s \)
Time series of water level for a cnoidal bore at the fore- and rear-walls

Fore side

Rear side

Current velocity

(Matsutomi)

$\alpha = 2.8 \text{ cm}$

$h_o = 10 \text{ cm}$

$z = 11 \text{ cm}$

$s = 1/20$
IMPACT OF SOLITONS
PRESSURE DISTRIBUTION FOR SOLITON-FRONT

eta/h = 0.3, hc/h = 0.7

図 ソリトン分裂波の最大波圧分布1(池谷ら, 2005)
FLOATED MATERIALS:
MORE DESTRUCTIVE THAN WATER.

Lumbers, once floated, changed to missiles.
DOMINO EFFECT

A boat “BETTER FORTUNE” brought misfortune.
Measured impact of a single log

(Matsutomi)
Impact formula for a single log by Matsutomi

Surging and breaking bore fronts

(a-1) Surging front

(a-2) Breaking bore front

(b) Quasi-steady flow

Quasi-steady flow
IMPACT OF FLOATED MATERIALS

D & L: diameter & length of a lumber
hr: water depth at the rear-wall

Water pressure of bore
Impact of lumber

図—18 流木の衝撃圧と段波の衝撃圧の比較例
AFTER THE 1896 TSUNAMI

A large quantity of tsunami deposit.
They are excavating the buried bodies.
The slide was sold in 1896.
A SANDY HIL 8 m HIGH built by THE 1853 TSUNAMI

Sand deposit above the red line

Iruma, Minami Izu.
<table>
<thead>
<tr>
<th>TSUNAMI INTENSITY</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSUNAMI HEIGHT (m)</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
<td>32</td>
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<tr>
<td>WAVE PROFILE</td>
<td></td>
<td></td>
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<tr>
<td>On a mild slope</td>
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<tr>
<td>Sudden rise near the shore.</td>
<td>Wall of water in the offing.</td>
<td>Wave front often breaks.</td>
<td>First wave may show plunging breakers.</td>
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<tr>
<td>On a steep slope</td>
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<tr>
<td>Rapid tide.</td>
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<tr>
<td>SOUND</td>
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<tr>
<td>Sudden big sound caused by plunging breaking on the beach.</td>
<td>Continuous sound caused by spilling breaking at wave front. (Like a sea roar, a storm, a locomotive or big trucks.)</td>
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<tr>
<td>Wooden house</td>
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<tr>
<td>Partial damage</td>
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<tr>
<td>Demolished</td>
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<tr>
<td>HOUSE</td>
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<tr>
<td>Stone house</td>
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<tr>
<td>Withstand</td>
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<td>(No data)</td>
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<tr>
<td>Demolished</td>
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<tr>
<td>R.C. building</td>
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<tr>
<td>Withstand</td>
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<td>(No data)</td>
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<tr>
<td>Demolished</td>
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<tr>
<td>FISHING BOAT</td>
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<tr>
<td>Damage begins</td>
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<td>Damage &gt; 50%</td>
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<tr>
<td>Damage = 100%</td>
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<tr>
<td>TSUNAMI CONTROL FOREST</td>
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<tr>
<td>AQUACULTURE RAFT</td>
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<tr>
<td>Damage begins.</td>
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</tbody>
</table>
DAMAGE TO FISHING BOAT

(1983 TSUNAMI)
Fig. 8. Surging wave (above) and abnormally low water (below) caused by the tsunami at the Noda fishing port (courtesy of Kuji Civil Engineering Office).
A LARGE EDDY OF
THE 1968 TOKACHI–OKI TSUNAMI
COASTAL DIKE

Overflow depth
Height of dike

SCOUR AT THE REAR-TOE BY OVERFLOW OF WATER

Overflow depth vs. Height of embankment

UNDAMAGED BUT INEFFECTIVE
WASHED AWAY
UNDAMAGED

Funakoshi, Iwate, 1960

Fig. 17. Sea breaker broken down at the northern coast of Funakoshi, Iwate Pref. (Photo taken by K. Horikawa.)
DESTRUCTION OF QUAY WALLS, BY RECEDING TSUNAMI

SCORING DUE TO FALLING WATER THAT HITS THE TOE OF STRUCTURES, EXPOSED ON AIR OR COVERED WITH VERY THIN WATER.

Water fall of the receding tsunami, in 19690.
SCORING CAUSED BY TSUNAMI CURRENT

Hachinohe Harbor hit by the 1960 Tsunami

Max. ebb velocity: 13m/s. Max. flood velocity: 8m/s. The toe of a quay wall -3m was scoured to -9m.
The quay wall slowly subsided.
SCOUR DUE TO THE 1960 TSUNAMI

Tsunami height: 4m
Current velocity: 8~13 m/s.

Jetty

Water depth before (dotted line) and after (solid line).

Erosion depth along A-A’ line.
CURRENT INDUCED BY THE 1960 TSUNAMI, IN KESEN-NUMA BAY
8 m DEEP SCOUR
WATER LEVEL COMPARISON BETWEEN THE RECORDED AND COMPUTED

TSUNAMI AT KOGOSHIO

With topography before and after the tsunami.
Measured and simulated sea bottom in Kesen-numa Bay

(Measured)  (Simulated by Fujii et al.)
But the velocity .......?!!!
Protection is needed at the place of current concentration.

A reinforced concrete bridge remained but the road made of soil without cover was scoured by the 1960 tsunami.

An underpass of railroad damaged by the 1933 tsunami.
FIRE caused by TSUNAMI
TSUNAMI and FIRE assisted by IMFLAMABLE MATERIALS

Seward Whittier Valdez In Alaska

Crescent City In California

Niigata In Japan

Whittier in 1964
NIIGATA CASE

Burnt area

Flooded area
FIRST FIRE OUTSIDE THE TSUNAMI-AFFECTED AREA
Flooded area covered by the leaked oil
Five hours after the earthquake, the second fire started from unknown origin.

Other one hundred tanks caught fire and ignited.
This was the result.
TSUNAMI DEFENCE WORKS IN JAPAN

THE LARGEST TSUNAMI IN THE PAST OR TSUNAMI FOR THE LARGEST EARTHQUAKE PREDICTED BY SEISMO-TECHTONICS

COMBINATION OF DEFENCE STRUCTURES, TSUNAMI-RESISTANT TOWN DEVELOPMENT, AND SOFT-WARES
SELECTION OF DESIGN TSUNAMI

Those with numeral: past tsunami
Others: estimated with theories

INNER PLATE EARTHQUAKE
INTERPLATE EARTHQUAKE
We use **NUMERICAL SIMULATION** for planning, but it should be improved.

- **INITIAL VALUE**  INACCURATE SHORT- PERIOD COMPONENTS.  
- **DIFFERENTIAL EQ.**  PHYSICAL ERROR CONTROL.  
- **DIFFERENCE EQ.**  NUMERICAL ERROR CONTROL.  
- **TOPOGRAPHY**  INACCURATE SEA–BOTTOM.  
- **CALIBRATION**  FILTERED TIDE RECORDS.  
  MEASURED TRACE HEIGHTS ARE BIASED.
STABILITY & NUMERICAL ERROR CONTROL

CFL STABILITY

\[ \frac{\Delta X}{\Delta t} > (2gh_{\text{max}})^{1/2} \]

NUMERICAL C. \( \geq \) PHYSICAL C.

NUMERICAL ERROR CONTROL

20~30 GRIDS WITHIN ONE WAVE LENGTH.

STABILITY AT THE FRONT

\[ \frac{\Delta X}{\alpha gT^2} \leq 4 \times 10^{-4} \]
WITH THE FINER GRIDS, THE BETTER RESULTS?

The 1854 Tsunami at Shimoda.
REFRACTION IS GOVERNED BY THE GRID LENGTH.

Full line for $\Delta x = 1000 \text{ m}$
Dotted line for $\Delta x = 800 \text{ m}$

Fig. 5
Comparison of the wave ray for different grid sizes and computational region in near-sea.
Δx = 800m
Δx = 400m
Δx = 100m
DEFENCE STRUCTURES

SEA WALLS

TSUNAMI BREAKWATERS

TSUNAMI GATE

HIGHTENING OF RIVER DIKES
COASTAL DIKE CONSTRUCTED IN 1858. IT WORKED IN 1946.

Hamaguci, hero of the story, “Fire in the Haystacks”, constructed this dike.
TARO TOWN BEFORE AND AFTER
THE 1933 SHOWA GREAT SANRIKU TSUNAMI

LOSS OF HOUSE  4 2 8
DEAD          5 4 8
MISSED        3 6 3
INJURED       1 2 2
The Town of Taro, protected by SEA WALLS.

Photo in 1934.
TARO TOWN NOW, SURROUNDED BY SEA-WALLS 10 m HIGH.
MAINTAINNCE OF THE DIKE FOR A LONG TIME
If the Town of Taro is hit by the 1896 tsunami, (Iwate Prefecture)
TSUNAMI BREAKWATERS AT THE ENTRANCE OF OFUNATO BAY

Tsunami amplification in 1968, by Horikawa and Nishimura.
TSUNAMI GATE
AT THE RIVER MOUTH
TSUNAMI GATE AT A HARBOR ENTRANCE

Completed in 2004
Width: 40 m
Height: 9.3 m
Weight: 406 ton

Automatic closure within 5 minutes, triggered by a seismograph.
The 1968 tsunami reflected by sea-walls.
SEA-WALLS DID NOT WORK.

The 1993 tsunami was higher than the sea-walls by 5 m.
Movement of Village

New residence area

Original village
ORIGINAL AND MOVED VILLAGE IN 1960.
RELOCATED VILLAGE, PAST AND PRESENT

In 1933, just after movement

In 2001.

People are moving to low land, driven by the increase of population density.
ARTIFICIALLY-ELEVATED GROUND
Messina, Italy in 1908. Tsunami height=2.9m
TWO BUILDINGS IN AONAE, 1993

Before

During

After
THE TWO BUILDINGS THAT REMAINED.

This building stopped a house and boats.
TSUNAMI CONTROL FOREST, AT HILO, HAWAII

(Urban Regional Research)

(Bay Front hwy.)
TSUNAMI CONTROL FOREST

Ineffective

3 m

(Shuto)
<table>
<thead>
<tr>
<th>Area of the first kind</th>
<th>Structure</th>
<th>Height of Ground</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterproof structure excluding wooden structures</td>
<td>NP (+) 4 meters and over</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exceptions: Total floor area of waterproof structure is 100 m² or less without habitable room

<table>
<thead>
<tr>
<th>Area of the second kind</th>
<th>Structure</th>
<th>Height of Ground</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterproof structure Height of one habitable room or more</td>
<td>NP (+) 2 meters and over</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example: A wooden structure with a total floor area of 100 m² or less

In the case of (a) or (b), height of ground, NP (+) 1 meter and over

<table>
<thead>
<tr>
<th>Area of the third kind</th>
<th>Structure</th>
<th>Height of Ground</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same as above</td>
<td>NP (+) 1 meter and over</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exceptions: Foundation with NP (+) 1 meter and over

<table>
<thead>
<tr>
<th>Area of the fourth kind</th>
<th>Structure</th>
<th>Height of Ground</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterproof structure</td>
<td>Same as above</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area of the fifth kind</th>
<th>Structure</th>
<th>Height of Ground</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterproof structure</td>
<td>NP (+) 2 meters and more</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exceptions: Foundation with NP (+) 2 meters and over

1 habitable room or more

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Regulations on land use based on Nagoya municipal ordinance.
SOFT COUNTERMEASURES
FORECASTING AND WARNING
EVACUATION DRILLS
PUBLIC EDUCATION
RESCUE OPERATION
The data-base was made by the 100,000-case simulation.

Only two minutes after an earthquake, JMA issues warning.
THROUGH LONG CABLE, JAPAN

(JMA)
This GPS tsunami gauge recorded a tsunami generated by the Off-Kii Peninsula earthquake on November 5, 2004.
HAZARD MAP AND EVACUATION BUILDINGS
SHELTER TOWER

4th & 5th: Shelter
3rd: Tsunami museum
2nd: Meeting room
1st: Warehouse

Wat Ban Nyan, Khao Lak
AN ELEVATED SHELTER AT
SHIRAHAMA SEA-BATHING RESORT,
TOKUSHIMA PREF.
SOLAR BATTERY FOR EVACUATION SIGN BOARD
A TRAGEDY OF FOREIGN TOURIST WHO COULD NOT UNDERSTAND WARNING

Her last position
REMEMBER THE PAST

Tsunami parade at Hiro.

Tsunami monument

Storm surge trace
A tsunami has its individuality.

Disaster evolves.