English

つながる教材

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Differences Between Tsunamis and Storm Surges (1)

	Prediction	Protective Structures	Evacuation
Tsunami	Earthquakes are unpredictable. However, it may take time for a tsunami to reach the bay (**about 1 hour in the Mikawa Bay**).	Since it follows an earthquake, structures (such as levees and water gates, drainage pumps, their management structures, etc.) may not be functional.	Depending on the scale of road and building damage
Storm Surge	Typhoon's path and scale can be estimated to a certain accuracy.	Possible if the storm surge is predictable. However, in case of heavy rain, it may lead to multiple disasters in addition to river overflow.	Depending on the scale of river overflow

- A tsunami is unpredictable because it is generated by an earthquake (also unpredictable). However, there is time to evacuate, since it takes time for a tsunami to roll across the ocean and to reach the coast. The issue when an earthquake occurs first is that protective structures may be deteriorated by the time a tsunami strikes the coast.

- A storm surge is caused by a typhoon. Thanks to the high accuracy of Japanese predictions, storm surges can be estimated to a certain accuracy (path and scale). Moreover, astronomical tides (high and low tides) predictions are also highly accurate, which makes it possible to know beforehand whether a storm surge will lead to other disasters. What matters is to know when a disaster such as heavy rain or floods due to typhoons, will occur.

- A tsunami is caused by a water level change due to seismic activity. Wave height increases as it reaches the coast (where water is shallow).

- A storm surge is caused by water suction accompanied by low atmospheric pressure due to a typhoon, and a strong wind drift (a movement downwind). These two effects are what make sea surface level rise abnormally.

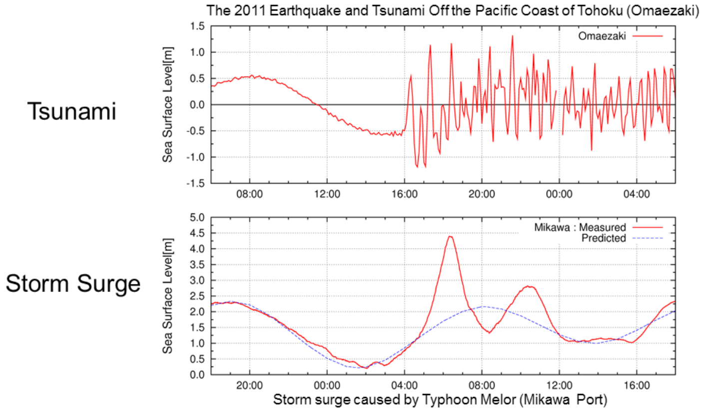
Both tsunamis and storm surges are dangerous when they strike the coast, since the quantity of water (≈ wave height) increases when it is displaced to shallow waters.

Differences Between Tsunamis and Storm Surges (2)

	Causes	Characteristics	Duration
Tsunami	Rise (or decline) in the sea level due to submarine earthquake → **Propagation of water level change**	Earthquakes are unpredictable. However, it may take time for a tsunami to reach the coast. Accompanied by earthquake damage	Up to 1 hour (but risk of multiple tsunamis)
Storm Surge	Low atmospheric pressure because of a typhoon (**suction effect**) and rise in the water level due to strong wind drift (**wind drift effect**)	Typhoon's path and scale can be estimated to a certain accuracy. Accompanied by high waves, floods, strong wind	Several hours

Both get stronger when they approach the coast (as water gets shallow).

Comparison of the Tsunami/Storm Surge Sea Level Change Over Time



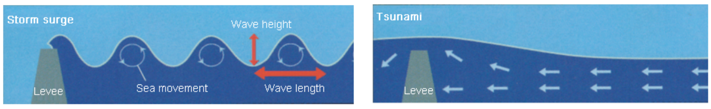
- The cycle of one tsunami wave takes 10 minutes to 1 hour.

- The cycle of a storm surge depends on the wind speed of typhoon and takes several hours in most cases. The difference between the two is pretty clear, by comparing the sea level change over time. Since both were accompanied by the astronomical tide (sea level change = astronomical tide + (tsunami or storm surge)), tide level at that time had a big influence on whether disasters occurred and on the scale of those that did occur.

Waves we usually see at the sea travel in cycles that last from a few seconds to dozens of seconds. However, this cycle takes more than 10 minutes for a tsunami, which is a pretty long cycle. To be more precise, "a long cycle" refers to "a long wave length (the length of one wave)." Waves of both tsunamis and storm surges are said to be "long" because of their unusual length.

Differences Between a Tsunami and (Normal) Waves

- Differences between waves and a tsunami
  - Wave length Waves of a few meters high cause a gentle wave
    A few m to hundreds of m / A few km to dozens or hundreds of km ↓
    Boats can **overcome** a tsunami
  - Movement
    Back and forth movement due to water level change /
    Water mass movement, **current**
  - Energy
    Wave energy, **repetitiveness** / Hydrodynamic energy due to the current, **uninterrupted movement** for some time



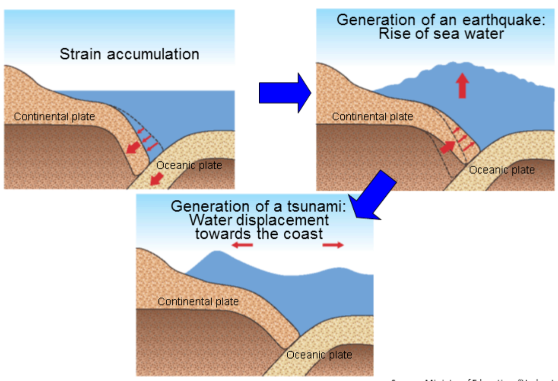
A normal wave measures between a few meters to a few hundred meters, whereas the wave of a tsunami can be measured in kilometers. Therefore, the waveform gradient (wave height/wave length) is extremely small, even for a tsunami of a few meters (for instance, if wave height H=10 m and wave length L=10 km, then H/L=0.001), so the water level will only rise a little (except for offshore tsunamis).

As far as water movement is concerned, normal waves usually go back and forth (which you can easily understand if you have ever bathed in the sea with a rubber ring). The cycle of a tsunami appears to be related to the same back and forth movement as normal waves, but its waves travel so far that what we can actually comprehend it is not its time scale (a few seconds to a few minutes or dozens of minutes), but the current caused by the movement of the water mass.

Normal waves usually dive into the surface sea and are not affected by the water mass, while during a tsunami, water is displaced from the surface to the bottom of the sea (since its strong energy reaches deep waters).

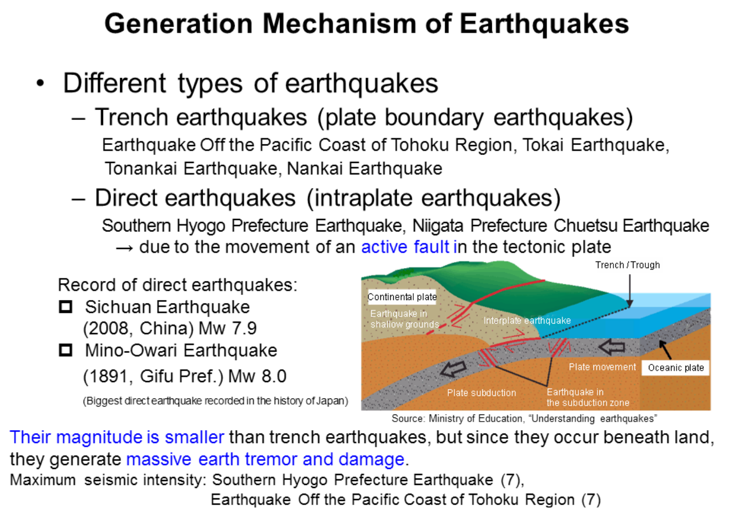
Learn more about: **Tsunamis**

- Generation mechanism



Source: Ministry of Education, "Understanding earthquakes"

As most of you may already know, a tsunami is the displacement of a substantial volume of water attributed to an earthquake at the bottom of the sea, increasing water level, which causes damage when striking the coast.

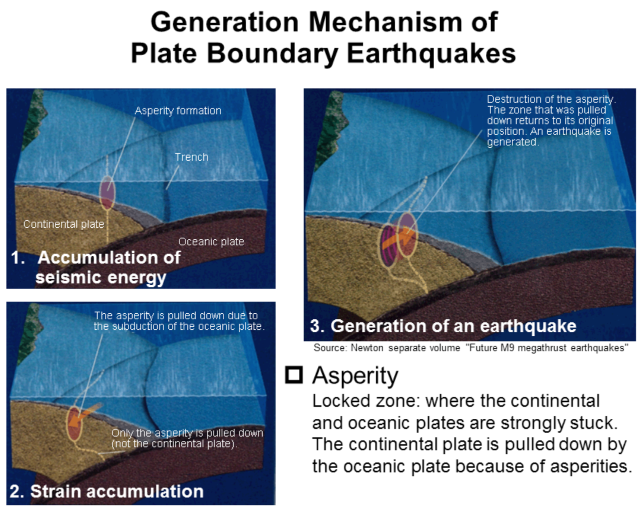


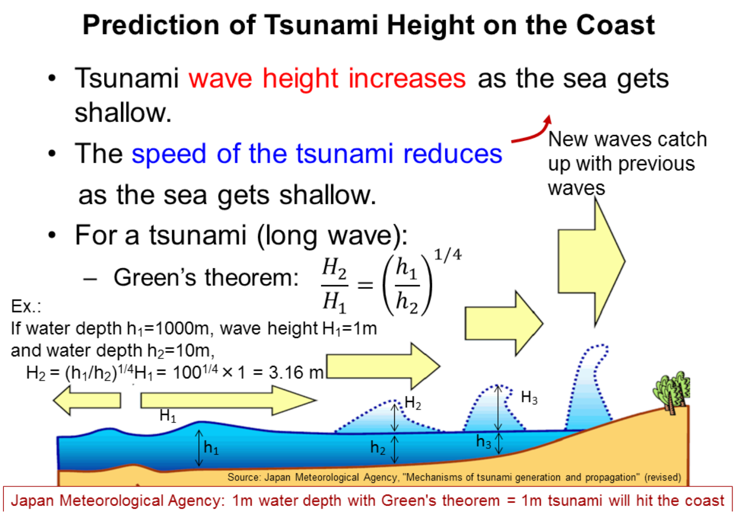
There are two types of earthquakes: plate boundary earthquakes generated at the boundary of continental plates, and intraplate earthquakes generated away from plate boundaries.

Plate boundary earthquakes are also called trench earthquakes since the deep trench at the bottom of the ocean, such as the Japan Trench, is located right next to the continental plate (hence forming a boundary).

Intraplate earthquakes are generated in a relatively shallow area, right under the land we live on, and are also called direct earthquakes. Plate boundaries are rather far away from the continent, so the seismic intensity (earth tremor) we feel on the ground is rather small, as opposed to direct earthquakes, because they are generated right under our feet. This is why damage caused by the tremor is important. In the event of a trench earthquake leading to a tsunami, its magnitude is bigger than the earth tremor, which I will talk about later on.

"Asperities"…This expression tends to be commonly used nowadays by the Central Disaster Management Council in its presentations concerning the hypocenter of Nankai megathrust earthquakes. Also called a "locked zone", it refers to the area where plates are strongly stuck to another. It does not merely make the continental plate curve down beneath the oceanic plate, since it also generates earthquakes that may differ depending on the size and geographical distribution of such asperities. The Central Disaster Management Council take the position of these asperities into consideration in the epicenter model.

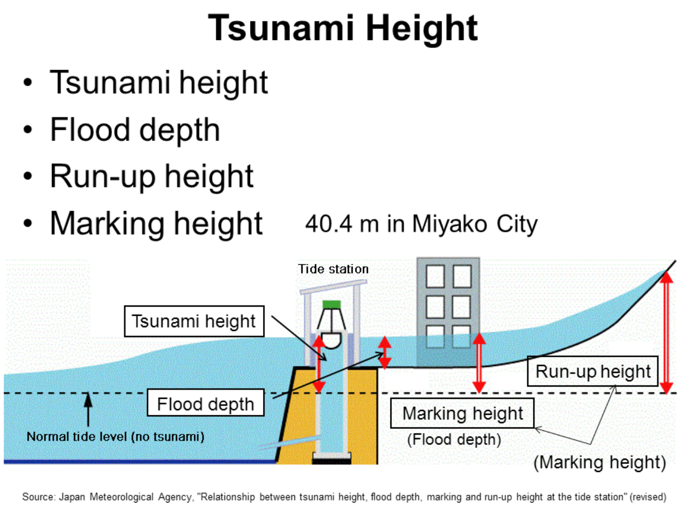




The particularity of a tsunami is that it gets higher as the sea gets shallow, while wave speed decreases. As the sea gets shallow, wave length decreases: at a specific point, the quantity of water carried in one wave equals the one of the sea, boosting tsunami height.

The change in tsunami wave height can be roughly estimated using Green's theorem. the change in wave height is given by the water depth ratio raised to the 1/4th power. Therefore, tsunami gets rapidly higher as the water depth decreases.

The formula to measure the speed C of the tsunami (as well as storm surge) wave length is $C=\sqrt{gh}$ (g: gravitational acceleration, h: water depth). Water depth h and speed C decrease while the wave approaches the coast. Therefore, since waves that follow a tsunami (waves going in the same direction as the tsunami after it approaches the coast) travel faster, they catch up with previous waves, increasing wave height.



Some of the expressions commonly used to refer to tsunami height are:

- Tsunami height (wave height)
- Flood depth
- Run-up height
- Marking height

etc.

Sometimes, however, these expressions are mixed up.

This is often the case with "tsunami height", as it can be used to refer to several concepts.

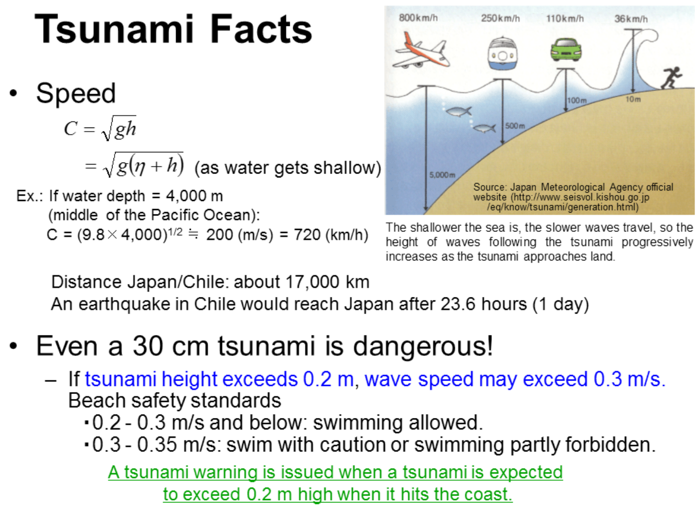
For instance, we often hear on the news about "a 30 m tsunami," however this is not referring to the "wave height" (from the bottom to the top of a wave), but to the run-up or marking height.

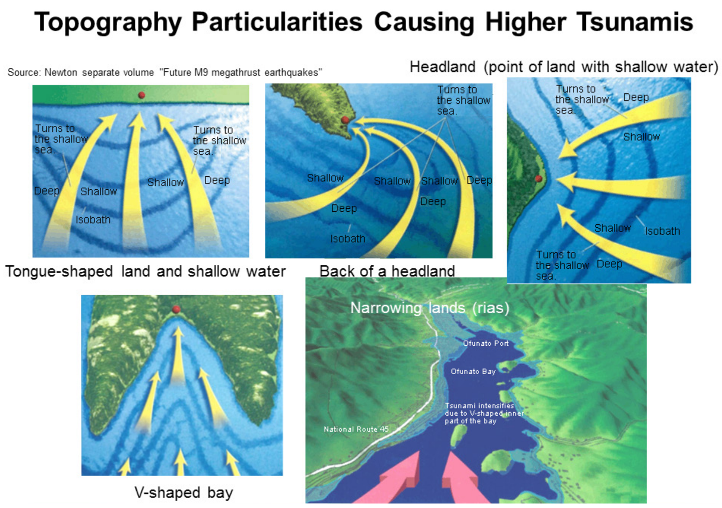
This is why you have to be particularly careful when you hear the expression "tsunami height".

As I have already said, the formula to calculate the speed C of a tsunami is $C=\sqrt{gh}$. A tsunami in the Pacific Ocean, which is about 4000 m deep, would propagate at 200 m/s = 720 km/h, an average speed. This is close to the speed of a jet. Therefore, supposing there was an earthquake on the other side of the planet, in Chile, located 17,000 km from Japan, it would reach the coast after 23.6 hours (about one day). If this earthquake generates a tsunami, this could be even 30 cm high.

Since tsunami is a long wave with a current traveling both at the surface of the water and at the bottom of the sea, this 30 cm tsunami could be compared to a 30 cm deep current (river).

In general, when a tsunami exceeds 20 cm high, its speed goes beyond 30 cm/s, thus having a high potential for putting lives at risk.





The propagation and form of a tsunami differ depending on the topography of the coast it is traveling to.

Tsunamis as well as normal waves travel while forming right angles with isobath (a line that connects all points having the same depth below a water surface, the same altitude on a topographic map, the same atmospheric pressure on a weather map). This is why the energy of a tsunami tends to concentrate on shallow grounds and headlands (= higher waves).

Besides, a tsunami that hits the mouth of a bay where land narrows, such as V-shaped bays and rias, concentrates its energy on the inner part of the bay, which causes considerable damage.

Tsunamis Hitting Ports and Coastal Areas

- Destructive breaking wave
  - Stronger wave power applied to structures
- Rivers flowing upstream (in waves or one breaking wave)
  - More damage due to tsunami hitting inland areas, damage to river structures, levee damage and overflow
- Ports
  - More damage to port infrastructure, vibrations (wave height increase), more ship damage, and negative consequences on fishery

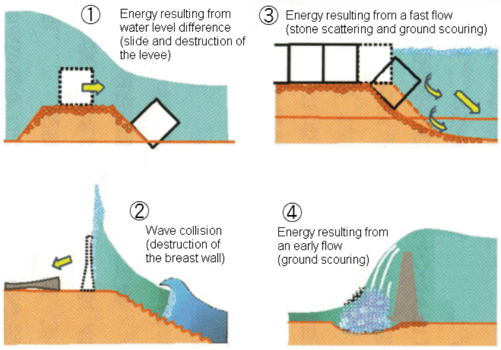
Source: "Photographic Report on the 1983 Nihonkai Chubu Earthquake", March 1984

When a tsunami strikes the coast, the depth of the sea decreases so much it generates a destructive breaking wave. It is possible to design structures, such as seawalls, to be hit by normal waves, by considering hydrostatic pressure ($p=\rho gh$), which can only be determined by water depth. However, in the case of a destructive breaking wave, extra energy is deployed by the water mass when struck on the wall, leading to an increase in the amount of energy that hits the structure. This is why these structures face a greater risk of damage. Moreover, a tsunami may strike river estuaries, and hit inland areas by flowing upstream. Damage to ports is inevitable.

Therefore, tsunamis can cause several kinds of damage in coastal areas.

Protective Structures in Ports and Coastal Areas

- Potential damage to coastal disaster prevention structures



Tsunami energy	① Hydraulic pressure (water level) before and beyond the structure
	② Impact of the breaking wave
	③ Drag caused by the current
	④ Scouring caused by the current

Source: JSCE Magazine, "Feature Issue on Disasters - Great East Japan Earthquake", July 2011

Many coastal structures are damaged by tsunamis, as was the case during the Great East Japan Earthquake. This damage can be divided into the 4 following patterns.

① Damage due to water level difference: when sea water overflows, the water level between the sea and land sides differ (sea side > land side), applying an excessive hydraulic pressure to structures, and damaging them.

② Damage due to wave impact: when the tsunami breaks onto structures, its water mass is applied on it, thus applying an excessive energy onto it (breaking wave pressure), and damaging these structures.

③ Damage due to drag: structures can be damaged (especially foundations) due to the powerful current accompanying a tsunami (speed and overflow).

④ Damage due to scouring: when sea water overflows, it generates a rapid current (supercritical flow) above structures which then falls down. Inland structure foundations end up scouring, damaging these structures (which frequently occurred during the Great East Japan Earthquake).

Relationship Between Magnitude M, Energy E and Tsunami Wave Height H

- $E = 10^{4.8+1.5M} = 10^{4.8} \cdot 10^{1.5M}$
- $M_t = \log_{10} H + \log_{10} D + 5.80$
  (D: propagation distance $\geq$ 100km)
- If magnitude M increases by 1 (ΔM=1),
  then energy E gets 32 times bigger ($10^{1.5\times\Delta M}$ times).
- If magnitude M_t increases by 0.3 (ΔM_t=0.3),
  then tsunami wave height H doubles ($10^{\Delta M}$ times).

Here are the formulas to determine the relationship between earthquake energy and magnitude on one hand, and tsunami wave height and magnitude (as well as propagation distance) on the other hand. To solve this equation briefly, when the magnitude increases by 1, the energy deployed by an earthquake gets 32 times bigger. If magnitude only increases by 0.3, the wave height of a tsunami caused by this earthquake would double.

In this slide, M_t refers to tsunami magnitude, a parameter indicating the scale of a tsunami. In the case of a distant tsunami, the earthquake magnitude M is roughly equal to the tsunami magnitude M_t.

Magnitude and earthquake energy, as well as the wave height of the tsunami the earthquake generates, do not have a linear relationship (that is to say, if one doubles, so does the other). Indeed, since they significantly increase compared to the rise in magnitude, it is important that everybody understands the level of danger through information given in news flashes mentioning earthquake magnitude.

Tsunami Damage

Mikawa Bay → (from 4 m) Ocean → (from 16 m)

Wave Height (m)	1	2	4	8	16	32
Wooden houses	Partly destroyed		Entirely destroyed			
Stone houses	OK		(no data)	Entirely destroyed		
Ferroconcrete buildings	OK			(no data)		Entirely destroyed
Fishing boats		Some damage	50% damaged	100% damaged		
Protection forests	Minor damage, smaller tsunami, no floating debris		Some damage, no floating debris	Entirely destroyed, no use		
Shellfish culture			Some damage			
Coastal villages		Some damage	50% damaged	100% damaged		

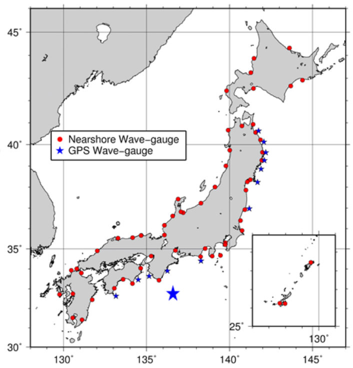
Source: Shuto, 1993

In 1993, Shuto and others established the correlation between tsunami wave height and damage done on houses and other structures, based on past surveys on tsunami damage. Furthermore, the Central Disaster Management Council recently released its tsunami predictions. In the event of a tsunami, a wave more than 20 m high is expected to hit the coast of the Aichi Prefecture, which should not exceed 4 m in the Mikawa Bay. When this kind of extremely high tsunami is predicted, considerable damage is to be expected, even in the Mikawa Bay.

The Ministry of Land, Infrastructure, Transport, and Tourism has created a wave information network called NOWPHAS (The Nationwide Ocean Wave information network for Ports and HArbourS) and installed a coastal wave monitoring system throughout Japan. Thanks to NOWPHAS, Japanese coasts are constantly monitored. Information obtained is posted on its official website as necessary. The GPS systems that were measuring waves on the coasts from the Aomori to the Fukushima Prefectures (located 100 to 400 m deep in the sea, 10 to 20 km off the coast) at the time of the 2011 tsunami monitored its shape, and transmitted important data, which helped analyzing the particularities of this tsunami and working on countermeasures.

Japanese Observation Network

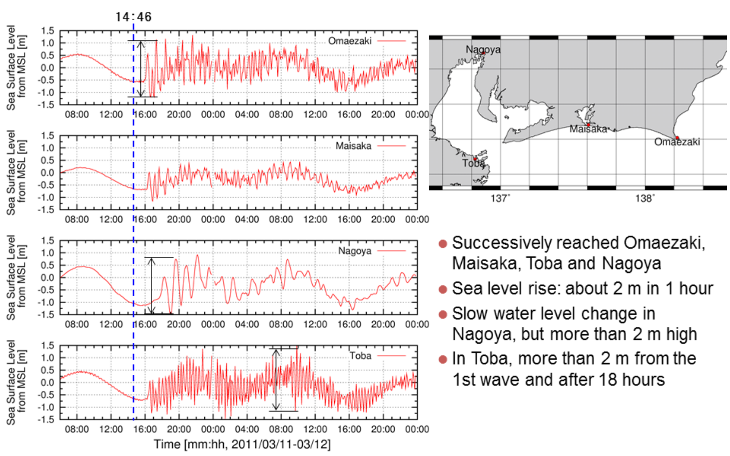
- NOWPHAS
  The Nationwide Ocean Wave information network for Ports and HArbourS
  http://nowphas.mlit.go.jp/index.html
  - Conducted by the Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport, and Tourism
  - Managed by the Port and Airport Research Institute
- Coastal wave monitoring, wave measurement by GPS
  - Understanding the particularities of the 2011 tsunami significantly contributes to future countermeasures



Installed in the Ise Bay since 2013

In June 2013, this monitoring system was installed off the mouth of the Ise Bay.

The 2011 Tsunami Observed in the Tokai Region



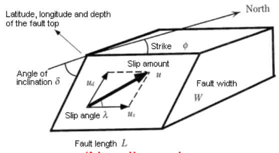
- Successively reached Omaezaki, Maisaka, Toba and Nagoya
- Sea level rise: about 2 m in 1 hour
- Slow water level change in Nagoya, but more than 2 m high
- In Toba, more than 2 m from the 1st wave and after 18 hours

Let me now talk about the tsunami of March 11, 2011, as recorded by tide stations of the Tokai region. The first wave successively reached Omaezaki, Maisaka, Toba, and then Nagoya. In Omaezaki and Toba, two cities facing the ocean, a very small vibration was measured.

In Maisaka, a small fluctuation was observed since the tide station is installed in the Lake Hamana, but the water level clearly differed from the ordinary tide level. Even the Nagoya tide station, located in the innermost part of the Ise Bay, recorded a slow fluctuation, and the water level increased more than 2 m higher than usual. After one day, the water level was still high, indicating how serious the scale (energy) of this tsunami was.

How to Predict Tsunamis (Simulations)

- Fault model
  - Prediction of the strength and scope of ground fluctuation by applying the following parameters.
  - The sea level fluctuation it triggers is the first tsunami wave.



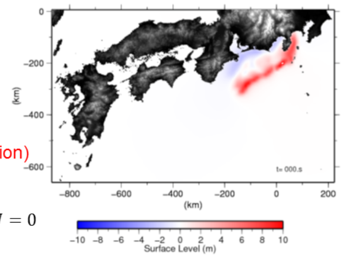
(Non-linear long wave equation)

$$\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial t}+\frac{\partial N}{\partial y}=0$$

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}\left(\frac{M^2}{D}\right)+\frac{\partial}{\partial y}\left(\frac{MN}{D}\right)+gD\frac{\partial \eta}{\partial x}+\frac{\tau_x}{\rho}-fN=0$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\left(\frac{MN}{D}\right)+\frac{\partial}{\partial y}\left(\frac{N^2}{D}\right)+gD\frac{\partial \eta}{\partial y}+\frac{\tau_y}{\rho}+fM=0$$

$$M=D\bar{u}, N=D\bar{v}, D=h+\eta$$



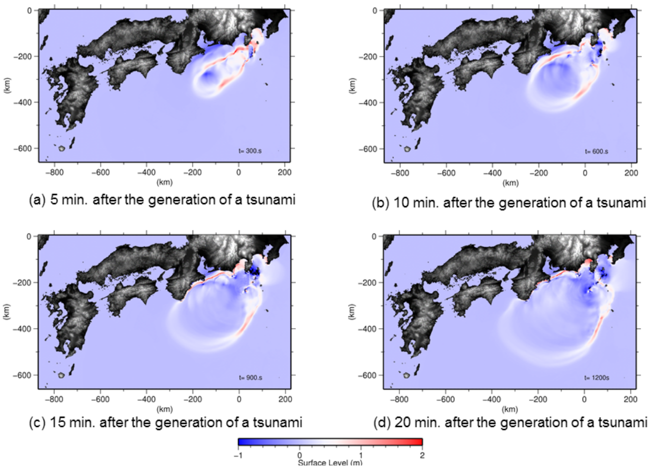
First wave of the 1944 Tokai-Tonankai interrelated earthquakes
(Aichi Prefecture Tokai and Tonankai Earthquakes Damage Prediction Research Report - 2002)

A tsunami simulation enables us to calculate the strength and scope of fluctuations at the bottom of the ocean with a fault model, and to measure their propagation by understanding the sea level change leading to the first tsunami wave. A non-linear long wave equation is used to simulate the propagation of a tsunami, whereas a simple linear long wave equation (which ignores non-linear elements) is used for seas deeper than 50 m (to put it simple).

The simulations you may often see on TV of a tsunami propagating on the Pacific Ocean (such as in anime) are often calculated with a linear long wave equation. It is a rather simple simulation, to the point you could do it at home with your computer. The only condition is for you to get information regarding submarine topography and the form of the first tsunami wave.

This is the result of a tsunami propagation simulation we did in our laboratory, for the 2002 Tokai-Tonankai interrelated earthquakes that were predicted and announced by the Aichi Prefecture. You can see in red the propagation of higher waves (= the tsunami), starting from the epicenters of the Tonankai Earthquake and of the Tokai Earthquake that reached the Suruga Bay to waters off the Kii Peninsula. This simulation enables us to understand that the first wave reached the tip of the Atsumi Peninsula in about 20 minutes.

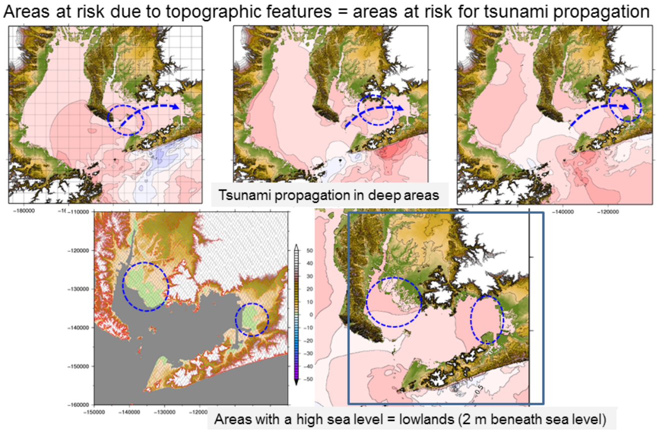
(Simulation Example)



(a) 5 min. after the generation of a tsunami
(b) 10 min. after the generation of a tsunami
(c) 15 min. after the generation of a tsunami
(d) 20 min. after the generation of a tsunami

Tsunami Propagation in the Mikawa Bay

- Propagation of a tsunami (areas with a high sea level) coming from the ocean to the Mikawa Bay after having entered the Ise Bay
- Areas at risk due to topographic features = areas at risk for tsunami propagation



Here is the result of a tsunami propagation simulation for the 2002 Tokai-Tonankai interrelated earthquakes that were predicted and announced by the Aichi Prefecture.

The tsunami, which hit the coast by entering the mouth of Ise Bay, traveled through a very narrow passage between the Chita and the Atsumi peninsulas (Nakayama Suido sea route), and then hit the Mikawa Bay. This simulation enables us to understand that the tsunami traveled clockwise, first hitting Ishiki, then Katahara and Toyohashi. If we compare wave propagation to topographic features of the Mikawa Bay coast, we notice that the tsunami started to spread to areas below sea level in the vicinity of Ishiki, and then reached other lowlands surrounding the Toyohashi Port.

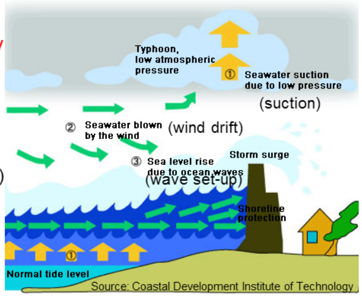
It is necessary to predict the consequences of such a disaster not only by taking into consideration the impact of a tsunami coming from the ocean on the coast (that is to say, what triggers a disaster), but also land factors (topographic features) of the areas it is supposed to hit. Some may think that the Mikawa Bay is less likely to be directly hit by a tsunami, because it is connected to the ocean by two narrow bay mouths (Ise and Mikawa). However, it is necessary to understand that some areas are potentially at risk for tsunamis (or other coast disasters such as storm surges).

Learn more about: **Storm Surges**

- Phenomenon during which the level of the sea in coastal areas exceeds the level of the astronomical tide, due to typhoons and low pressure
  → Japan Meteorological Agency
- Major factors that generate a storm surge:

(1) Seawater suction due to low pressure
(2) Seawater blown by the wind (wind drift)

⇒ The sea level rise generated propagates as a long wave, with the typhoon or low pressure.



Suction due to the atmospheric pressure: not connected to water depth.
Wind drift: strongly affected by water depth and coastal topography (inversely proportional to water depth).

A storm surge is a phenomenon during which the water level increases higher than it usually does during the astronomical tide.
The astronomical tide refers to global water level fluctuations due to celestial movements (centrifugal force, universal gravitation, etc.). Approximately 390 types of elements (tidal components) compose this tide, and the cycle of these elements range from 8 hours to 18.6 years. The sea level can be theoretically calculated, and the prediction results are posted online, such as on the Japan Meteorological Agency website. It is crucial to refer to water level fluctuations (tide difference) when designing coastal structures.

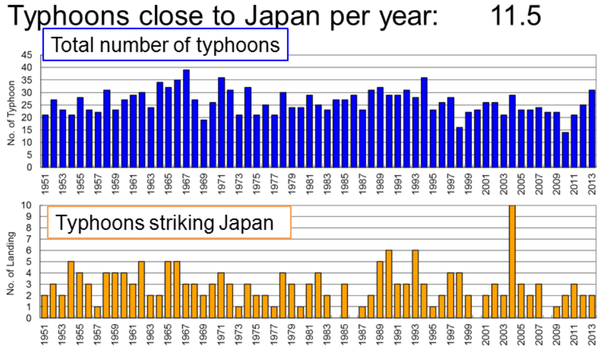
However, when a typhoon or very low atmospheric pressure are generated and approach the coast, 1) Seawater is sucked from the sea by low pressure (suction effect), 2) Seawater is blown downwind by a strong wind, and if there is an enclosed coastal sea in this same direction, the water level inevitably rises. This phenomenon can be compared to a long wave since it lasts for several hours, it occurs with a typhoon or low atmospheric pressure, in shallow seas. The water level rise due to the wind drift gets more dangerous in shallow waters, since it is inversely proportional to water depth.

$\Delta \eta = \tau\_s/\rho g h L$　$\Delta \eta$: water level rise, τ_s : sea shear stress due to sea wind, ρ : water density,
g : gravitational speed, h : average water depth, L : bay size (distance for sea wind to have an

Here is a summary of the Japan Meteorological Agency information on past typhoons. There are approximately 26 typhoons a year. Among which 3 strike Japan. In Japan, typhoons that cause damage are usually referred to with numbers from 10 to 20. In 2009, 18 was the number of the typhoon that hit the Mikawa Bay and generated a storm surge. In November 2013, the typhoon that hit the Philippines, which caused considerable damage, was number 30.

Typhoon Statistics (1951-2013)

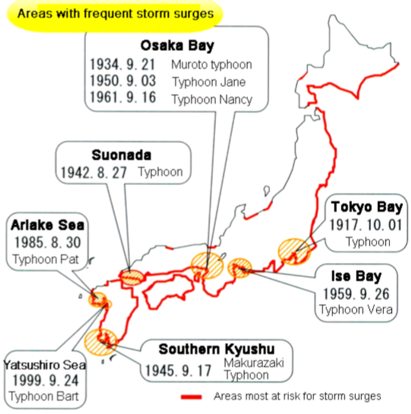
- Typhoons per year: 26.2
- Typhoons striking Japan per year: 2.8
- Typhoons close to Japan per year: 11.5



(Typhoons) The custom throughout the world is to give typhoons names. For instance,
Typhoon No.18, 2009: Melor; No.30, 2013: Haiyan, No.15, 1959 (Ise Bay Typhoon): Vera.
A tropical cyclone that reaches a wind speed of 34 knots (17 m/s) or above is called a typhoon. (Japan Meteorological Agency)

Areas at Risk for Storm Surges

- Bays and inland seas with a mouth oriented in the direction of the typhoon.
- For the Pacific Coast, when the typhoon's path strikes the west side of a bay (dangerous semicircle).
- When the axis of a bay = the typhoon's path (strong wind blowing towards the inner part of the bay).
- Areas with relatively shallow sea.



Here are the conditions for an area to be considered at risk for storm surges.
- When the mouth of a bay faces the typhoon's path.
- When the typhoon passes by the western side of a bay.
- When the axis of a bay coincides with the typhoon's path.
- When water is shallow.

When a typhoon comes from the south or southwest, all the Japanese bays on the Pacific Coast are at risk for a storm surge. This is especially the case with the three most important bays (Tokyo, Ise and Osaka), Ariake and Yatsushiro seas and the Seto Inland Sea.

A strong wind blows counterclockwise in the heart of a typhoon. When the path and wind direction of a typhoon are identical, the wind in its west side gets stronger, which is why it is called a dangerous semicircle. I have already said that shallow waters were particularly dangerous. Therefore, the route of a typhoon is a determining factor in storm surge generation.

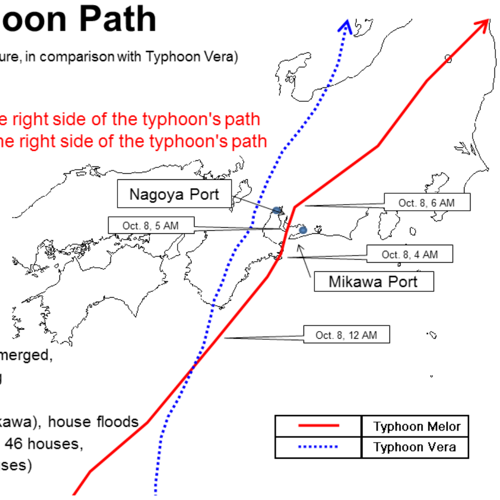
Here is a comparison of the paths of Typhoon Vera (1959) and Typhoon Melor (2009). Since Vera hit the tip of the Kii Peninsula by the Shiono Cape to travel through the Kii Peninsula, the Ise Bay happened to be in the east side of the typhoon (forming a dangerous semicircle), which caused considerable damage to the coast, and especially around the Nagoya Port in the inner part of the bay.

In 2009, Typhoon Melor traveled further east than Vera, and after having hit the east side of the Kii Peninsula, it hit the tip of the Atsumi and Chita peninsulas, and then traveled through the west side of the Mikawa Bay. At the time, the Ise Bay was on the west side of the typhoon, so there was no considerable damage in comparison to Vera. However, water level abnormally rose in the inner part of the Mikawa Bay, to the point cars got submerged and containers were floating in the sea. These two paths only differ a little, but such a difference is enough to generate a storm surge.

Typhoon Path

(Prepared by the Aichi Prefecture, in comparison with Typhoon Vera)

Common Elements
Vera: Nagoya Port on the right side of the typhoon's path
Melor: Mikawa Port on the right side of the typhoon's path

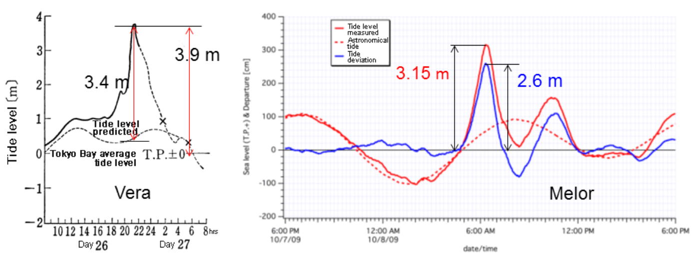


Main Damage
Mikawa Port
Cars for exportation submerged, empty containers floating
Tahara City
City river overflow (Shiokawa), house floods (floods above floor level: 46 houses, basement floods: 90 houses)

Major Storm Surge Damage in Japan (since Vera)

- Typhoon Vera (Sept. 26, 1959) (Mikawa Port, 3.30 m, 2.6 m)
  max. tide level T.P. 3.9 m, max. deviation 3.4 m (Nagoya)
- Typhoon Nancy (Osaka Bay, Sept. 16, 1961) 3.0 m, 2.5 m
- Typhoon Bart (Ariake Sea, Sept. 24, 1999) 4.2 m, 3.9 m
- Typhoon Melor (Mikawa Bay, Oct. 8, 2009) 3.15 m, 2.6 m

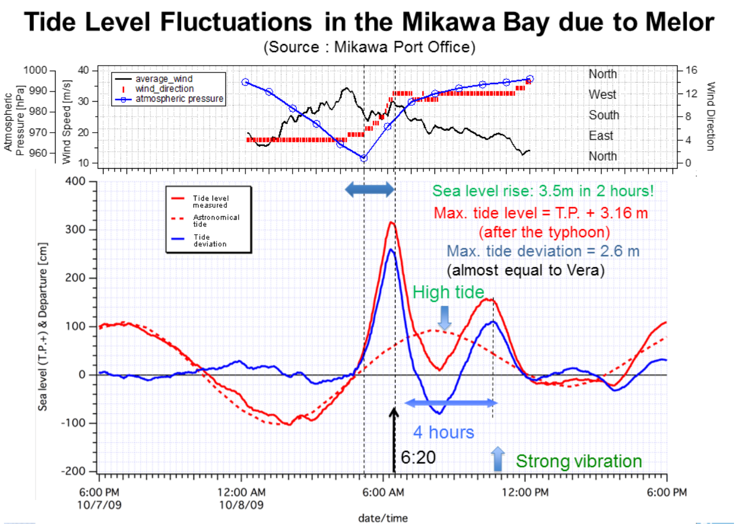
almost equal to Vera



Here I will present the particularities of the storm surges that hit the Mikawa Bay, such as the one caused by Typhoon Melor in 2009. Japan has faced a number of storm surges. However, Vera caused so considerable damage it made people think about preventive measures against other coastal disasters. The maximum level of water recorded for Vera was T.P. +3.9 m, with a 3.4 m deviation. In 2009, the maximum level of water recorded for Melor was T.P. 3.15 m, with a 2.6 m deviation (deviation in the Nagoya Port: approx. 1.0 m).

For Vera, the maximum level of water reached in the Mikawa Bay was T.P. 3.3 m, with a 2.6 m deviation. Judging only from the level of water, Melor caused the same storm surge as the second time Vera hit Japan.

T.P. (Tokyo Pale): average Tokyo Bay sea level
Altitude: the height of something above sea level (often referring to the average sea level near ports and noted "... m above sea level")
Elevation: height measured from a reference point
Since the sea level is often chosen as the reference point, altitude frequently means elevation.
If the average Tokyo Bay sea level is chosen as the reference point, altitude = T.P.

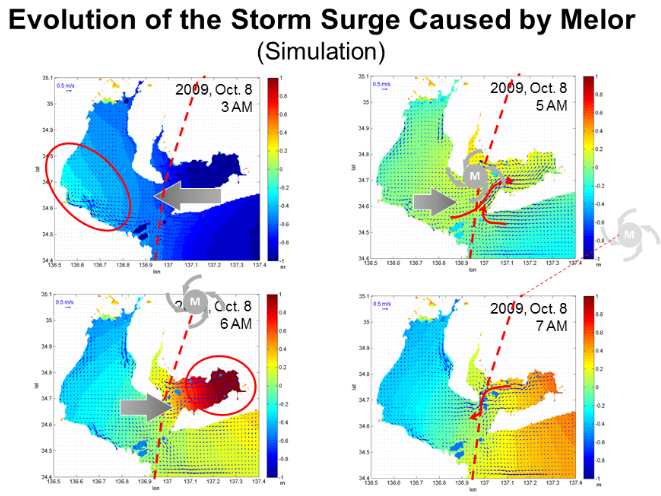


As you can see from the atmospheric pressure change, this storm surge was not generated when the typhoon was extremely close to the coast, but when the heart of the typhoon was passing through, which made wind direction change immediately (after the passage of the typhoon). At 5 AM, when the typhoon was the closest to the coast, there was no deviation (difference with the astronomical tide), but just 2 hours later, water rose by 3.5 m. The astronomical tide usually makes water rise by 0.6 cm/min (about 1 m in 3 hours), but this storm surge made water rise by 3 cm/min, which is extremely fast. Besides, 4 hours after the first rise in the water level, water rose again, though not as much as the first time. There was a deviation of more than 1 m.

What we can learn from this is:

1. The peak of a typhoon differs from the peak of a storm surge. Since a storm surge occurs when the heart of a typhoon has come and gone, there is a risk for a secondary disaster in addition to floods.
2. A storm surge is not generated when the wind is the strongest, but when wind direction changes suddenly. This mechanism is a characteristic feature of Mikawa Bay storm surges, and cannot only be explained by a normal and strong wind drift.
3. The fact that a few hours after the first storm surge the water level rose for a second time also seems to be a characteristic feature of Mikawa Bay storm surges.
4. The time of the storm surge (first and second peaks) and of the high tide differed, but more serious damage would have been observed if that difference would have exceeded 2 hours.

Here is a simulation of the storm surge caused by Melor. At the time the typhoon approached the Mikawa bay (3 AM), the east wind made the sea level rise in the Ise Bay. Once the typhoon was gone, the wind coming from it was blown in the opposite direction, which made a water mass that had remained in the Ise Bay flow to the Mikawa Bay. This bay is only 9 m deep (the central part of the Ise Bay is more than 30 m deep), so the sea level rose immediately when the huge water mass flowed in. This explains why an unusual level of water was measured there.



Besides, an exchange of water mass was observed between the Atsumi Bay (inner part of the Mikawa Bay) and the northern Kinuura Bay. However, the water mass in the Kinuura Bay that had caused a rise in the water level when the typhoon was getting closer (before 5 AM) could not flow out, due to the flow of water coming from the Ise Bay, even after the wind had changed direction. This is why the level of the water remained high. Once water started flowing out from the Ise Bay and wind started drifting by being blown in the opposite direction, the level of the water in the Mikawa Port decreased simultaneously.

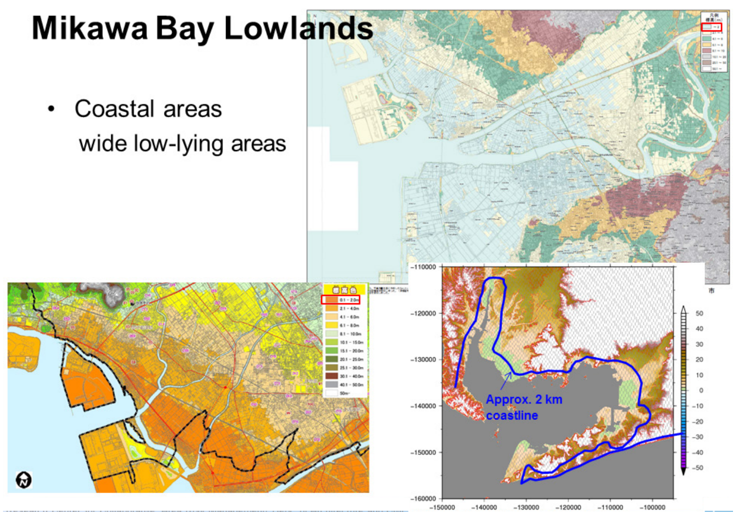
This storm surge was particular to the Mikawa Bay because of its topographic features and of the seawater exchange between the Ise and the Mikawa bays.

It is important to understand the topographic particularities of these phenomena to think about countermeasures to coastal disaster.

These are altitude maps released by the Toyohashi and Toyokawa cities. They help us to understand how wide this lowland is. It is necessary to fully understand that the risk of floods caused by tsunamis or storm surges does not only concern coastal areas, but also inland areas where towns are spreading. We have to be conscious that there are many areas potentially at risk.

- On this map, 30% of lands are 10 m below sea level.

- Most of the inner bay is 10 m below sea level (within 2 km from the coastline).



Issues Regarding Coastal Disaster Prevention

- Concentration of people, social properties, assets
- Seawater flowing upstream, leading to water overflow, floods in inland areas
- Coastal and dunes erosion (reduction of buffer zones)
- Securing evacuation routes and safe places to gather (+ evacuation methods and means)
- Road and railway damage (securing roads for the transportation of goods)
- Nuclear power plants
- Ensuring the safety of people spending time outside
- Levee damage (due to earthquakes or ancientness > maintenance needed)
- Floods beyond the levee (Mikawa Bay)

The issues presented in this slide raise a few questions.

- Should the priority be to protect people or material things, in areas hit by disasters?

- Obviously, the priority is to protect people, but how can we do so for people visiting the region or enjoying time outside?

- Not all material things can be protected. Which should be prioritized?

- How can we prevent more damage and secondary disasters?

- How can we speed up reconstruction?

There may not be model answers or correct answers to these questions. I think that each and every person should first think concretely about what they would do if they were the victim of a disaster.

For instance,

- What would we do if an earthquake occurred right now?
- Once the earthquake was over, what would we do next? etc.

Modern Cities Protected by Levees


Shiokawa


Maeshiba


Mitocho


Mitocho


Maeshiba


Akabane Fishing Harbor

Today, our cities are protected by levees. We often see residential areas spreading right next to levees.

We tend to think that they are functioning well, that they are protecting us, but maybe we do just because we didn't experience any disaster since they were built.

When Levees Can't Protect an Area...

Pictures: "Lessons learned from the Great East Japan Earthquake, Civil Engineering Special. Details of Damage to Infrastructures"

Levees that cannot protect cities lead to catastrophes. Many people experienced this tragedy during the 2011 Great East Japan Earthquake, which is something we all witnessed.

How to Handle Minor and Major Coastal Disasters

- Major disaster prevention = Preventing disasters with structures
  - Overhaul of seawalls and levees for rivers and coasts
  - Resistance to earthquakes, countermeasures to ancientness (= maintenance)
  - Overhaul of new structures for disaster prevention

Work to be done by the administration

Working on one of these 2 scenarios is not enough.
We have to **work on both** to be effectively **prepared in the event of an unexpected disaster.**

- Minor disaster prevention = Reducing damage without relying on structures
  - Raise of awareness of disaster prevention
  - Evacuation exercises
  - Preparation of information on disaster prevention
  (hazard map, means of transmitting information)
  - Development of cooperation systems to reduce disaster damage, and of evacuation facilities.

Disaster prevention education

Work to be done by the administration + citizens