Mechanism of the Occurrence of Earthquakes and Tsunamis

Thank you, Mr. Chairman. Good morning, everybody.

Two years ago, at the end of 2004, a great earthquake with a magnitude of 9.0 happened near the south tip of Sumatra Island, Indonesia. Due to this earthquake, a great tsunami happened, and in total, nearly 250,000 people were killed. This is the biggest tsunami event in our history.

Today I will give a lecture on the mechanisms of the generation of earthquakes and tsunamis, and then we will consider how to survive from these natural disasters. The first slide please.

Mechanism of earthquakes and tsunamis

This figure shows a view of the 1896 Great Sanriku Earthquake Tsunami in the northern part of Honshu Island, Japan. You can see that once the tsunami happened, all peacefully living coastal people would have been killed by the covering sea water. As a result of this event, in total 22,000 people were killed due to the tsunami only, not the earthquake. Next slide please.

The earth's surface is covered with about 25 plates. These so-called plates are like conveyer belts. One plate is generated somewhere and sinks down like a belt conveyer below the neighboring plate. Here are the Japanese Islands, and here is the American coast, and the Pacific Plate is moving westward—9-cm pike here. And here the plate is sinking down because the plate boundaries have pushed into each other and accumulated stress, and once in 100 years on average a great earthquake will happen. Next slide please.

This is the configuration of the earth’s surface. You see here the Pacific Rim—the Japanese Islands, Taiwan, the Philippines, Indonesia, Papua New Guinea, and New Zealand—and the South American Continent are the plate boundaries. And here the Pacific Plate is running westward, 9cm per year, and sinking down below the Japanese Islands, Taiwan, the Philippines, and the Indonesian Archipelago. Once every 100 years or several hundred years, a great earthquake has happened near this rim area. Remember that the medical doctors have come here today from Pacific Rim countries. All our countries, all your countries, could possibly be attacked by a huge tsunami. This is because all the countries of the Pacific Rim are very close to the plate boundaries, and over 80% of tsunamis happen around the Pacific Rim. Next slide please.

This is a schematic drawing of plate motion. The plate was generated here and the magma flow is coming from deep within the earth and is like a belt conveyer sinking down at the Pacific Rim Archipelago. Here is the plate boundary, and stress is accumulated here; and finally, dislocation will happen on the surface of this boundary. That is the mechanism of gigantic plate bound-

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ary tsunamis, gigantic tsunamis. Next slide please.

This figure shows the distribution of earthquakes of magnitudes exceeding 6.0 in the 20th century up to now. As we can see, the black mark shows earthquakes generated at the plate boundary. We see here the Japanese Islands, Taiwan, the Philippines, Indonesia and Papua New Guinea—these countries facing the Pacific coast in particular have experienced a series of earthquakes. Another group of earthquakes happened on the south coast of the Indonesian Archipelago. This is another plate boundary where the Indian/Australia plate moves from south to north at a speed of 5 cm per year and sinks down below Sunda Island in the Indonesian Archipelago, and here another group of earthquakes occurred. Next slide please.

If a plate is sinking down underneath the neighboring plate, the stress will be accumulated, and finally the plate boundaries will shift. For example, once every 100 years, suddenly the upper plate will be pushed up and the sea bottom will suddenly move upward, then the sea water becomes disturbed, and a wave will be generated. Next slide please.

Once the plate boundaries have shifted—for example, 5 m or 9 m—then the sea bottom will be pushed up by 2 or 3 m at a depth of 4,000 to 6,000 m in the deep sea and a wave will be generated and it will begin to approach the coast line. At the coast, on the continental shelf, water depth is only 200 m. Here the depth is 4,000 m and here it is only 200 m. The energy of the wave is contained within 4,000 m of thickness; and then it will be condensed to only 200 m of water thickness. Therefore, the energy will be condensed and the amplitude of the wave will be amplified at the coast. Consequently, even if the wave height of the tsunami is only 2 m in the deep sea, it will be amplified three to four times at the coast, and here, say 6 or 8 m of water, a rising wave, will appear at the coast and the coastal town will be submerged by sea water. Next slide please.

There is one example of the Philippines Archipelago, with Fiji on the plate boundary, and here a group of earthquakes happened in this century, up here, in the sea west of Mindanao Island; and near the Philippines there is a plate boundary around here that crosses to the East China Sea, and here another group of earthquakes happened. And here there is a sunken trench and the plate boundary. On this back side another group of earthquakes happened. We call this group of earthquakes “backed-up earthquakes”, but their frequency is not as frequent as this kind of earthquake, say a ratio of four-to-one. Next please.

To the north of Papua New Guinea, the Pacific Plate moves down from the north, and here a group of earthquakes happened, and here—the Irian Jaya area of Indonesia—is very unstable, and several times huge earthquakes have happened, and these have been accompanied by tsunami attacks on this coast. Here the plate boundary is very close to the coast, and once an earthquake has happened, a tsunami attacks this coast very rapidly. For example, a tsunami will attack this coast within ten minutes or so—only 10 minutes or so. Next slide please.

Past earthquakes and tsunamis in Indonesia

Next we’ll look at the size of earthquake/tsunamis in Indonesia. Around Indonesia, not the Philippine sea plate but the Indian/Australian plate is sinking down at the Sunda Bench, and the great earthquake of 2004 took place here, and the most recent event, in 2005, took place here, and on July 17th of 2006—this year—another earthquake happened here in the central part of Java Island, here, off Chillachapel Port, and a tsunami was generated and around 500 people were killed due to the tsunami. In 1994, a serious group of earthquakes, gigantic earthquakes, took place at the plate boundary and the trench is here. Another exceptional case was in 1992, the Flores Island event, which was a backed-up event here.

In the Indonesian case, the epicentral area of the earthquakes was a distance from the mainland of Java Island or Sunda Island, of course, and there was enough time after the earthquake in this case, the East Java event of 1994. A tsunami attacked the coast 14 minutes or 15 minutes after the earthquake. In 2006, the tsunami struck after 15 minutes, and in the Sunda event, it struck nearly one hour after the earthquake—enough time for people to escape to a higher place. But in backed-up earthquake types, such as the 1992 Flores event, the epicentral area is very close to the coast, and once it has happened, the tsunami attacks the coast in only two minutes or three minutes.

Now, the meteorological agency of Indonesia has made efforts to establish a system for the issuance of tsunami warnings. Therefore, in the
near future they will be able to successfully broadcast tsunami warnings through television programs to the people as the earthquake happens and the objective information about a tsunami attack will be successfully broadcast. But for backed-up event, the warning may not reach people in time. Next slide please.

2004 Sumatra earthquake (Banda Aceh)
Here we see the 2004 Sumatra earthquake event. The simultaneous damage to places in Banda Aceh city at the north point of Sumatra Island. OK. Next slide please.

Banda Aceh city is here at the north point of Sumatra Island. Next slide please.

Banda Aceh city: the population is 25,000 people, and about 60,000 people were killed in that tsunami. On the western coast of the northern most point of Sumatra Island, we conducted a survey three weeks after the earthquake/tsunami. Next slide please.

The epicenter of the earthquake was concentrated here. Within two days, aftershocks took place up to here. This shows that the epicentral area was from 3 north latitude to 13 north latitude, and therefore in a distant area. The size of the epicentral area was 1,200 km north-south. Next please.

This is a city map of Banda Aceh. The sea water came to the blue line, about 4 km from the coastline; and between the shoreline and this red line almost all buildings were swept away. Between this red line and the blue line, the buildings were not swept away, only inundated. Next please.

We took photographs three weeks after the event. You can see that no house was left due to the strong current of the tsunami. The ground was seriously eroded. Next please.

This is a mosque at the court of Banda Aceh; only this building remained mostly intact, but all other buildings were entirely destroyed or swept away. And next please.

This is a photograph taken from the second floor of the mosque. In the first wave, the sea water rose up to the yellow line. The height of this level is 12 m above mean sea level; this green line is the level of the second wave. The sea water rose up to this level—this is 8.5 m above mean sea level. Next please.

The walls were entirely swept away. Next please.

This is a reinforced concrete building. You can see the columns of this building were reinforced steel. Not a weak building, but a strong building, but even this strong building was broken at the root of this column. Next please.

This is a high school, Banda Aceh Fifth Middle High School. You can see that before the tsunami, the second floor of the building was here, but due to the tsunami, this part—the second floor of a concrete building—was carried away. The sea water was up to 56 m above the ceiling of the second floor, 8.8 m above mean sea level. Next please.

We measured the tsunami height at the court—12.2 m. Under the innermost area, the height was about 5 m. Next.

We checked the distribution of washed-away houses by using satellite images taken before and after the tsunami, and along this street—the main street—the port, and the central most pier, and each of the three areas had a length of 1 km, 3 km in total. Next please.

This is the first area, the second area, and the third area. The white marks show the washed away houses, and the black ones are houses not washed away and kept safe. We can see that up to 2 km from the coast, almost all the houses disappeared, and then in some places, suddenly all the houses were safe. Suddenly. Here, almost all the houses were washed away, and here almost all the houses were safe. Very clearly it’s a boundary. Next.

We conducted a survey on the western coast, and here in the central part of Banda Aceh city, and here on the western coast. These images show before the tsunami and after the tsunami. We can see the eroded area due to the tsunami clearly in these images. You can see a yellow, chocolate colored line which means that before the tsunami it was a green forest approaching the coast, but after the tsunami, all the trees disappeared. We checked this coast. Next please.

This is a village where all the houses were swept away. As a result, almost all the people were killed. Mortality, the percentage of persons killed by the tsunami, was nearly one 100%. Nobody survived. Next please.

The tsunami height is thought to have been more than 20 m and up to 30 m on this coast. In the central part of the city, not only at one point, but here at many places you can see the 30 m mark. Next please.

As some plates come together here, sea water
rose up to 34.9 m here—29.8 m. We checked this. Next please.

This is a photograph of sea water that rose up to 30.4 m. Here a village had existed, and the people—about 350 people—were killed. Nobody survived. Next please.

The camera was set at 30.5 m, the inundation limit. We see here seawater. Seawater rose up to here, for 1.5 km—very unpredictable, but a reality. Next please.

Seawater also rose up here, the tsunami height was 27.9 m above mean sea level. Here there had existed one village that disappeared and nobody survived, and here you’ll see a human, and then the tsunami came. No way to survive. Next.

Past earthquakes and tsunamis in Japan
Near the Japanese Islands, four plates gather. From the east the Pacific plate comes together with the Philippines plate, moving from south to north 2.5 m per year and sinking down below the western part of the Japanese Islands. One group of earthquakes happened here and another group happened here. Next please.

One group of earthquakes happened on the south of Hokkaido, another on the east coast of the northern part of Honshu Island, another on the Sanriku Coast, and another group happened here—the Tokai earthquake and the Nankai earthquake. Next.

For the Tokai area, here, and the Nankai area, here, and in this area, at an average of 100 year intervals, gigantic Tokai earthquakes and Nankai earthquakes have taken place here. The size covered by these earthquakes was 300 km; 400 km. Next please.

These lines show earthquakes in the 20th century, 19th century, 17th century, and before, and the tsunami damage is shown historically. You can see there is a trend whereby once one earthquake happened in the Tokai area, then Nankai earthquakes followed after short intervals. For example, two years after the Tokai Earthquake of 1944, the Showa Nankai Earthquake of 1946 took place; and the day after the Ansei Tokai Earthquake of 1854, only 32 hours later, the Ansei Nankai earthquake of 1854 took place in this region. The Hoei Earthquake of 1707 took place together with a huge earthquake in the Bosei area. Next please.

This red mark shows a time elapse for 2000, 150,000 A.D. and the earthquake magnitude. This red mark shows Tokai and Nankai earthquakes—for example, the 1944 and 1946 Nankai Earthquakes, the Ansei Tokai Earthquake and Ansei Nankai Earthquake of 1854, the Hoei Earthquake 1707—occurred in intervals of about 100 years. In an earthquake in the Kinki area—Kyoto or Osaka—another group of middle-sized earthquakes took place. This gigantic earthquake correlates with the middle-size earthquakes. For example, 40 years before, the first top runner of this earthquake happened; their number grows, and then a gigantic earthquake, the Nankai earthquake, took place. Ten years after the last runner finished, a calm period with no earth- quakes begins. Forty years before the top runner comes, and then the Nankai earthquake comes, and then 10 years after it the last runner comes, and then a no-earthquake period of nearly 50 years comes. Therefore inland earthquakes, middle-sized earthquakes, and Nankai earthquakes correlate with each other. The Hanshin-Awaji earthquakes in 1995 and 2001 happened around this area. We consider that these may have been the top runner for the next event. Forty years after the top runner appears, the next Nankai earthquake will happen. Therefore, the next Nankai earthquake will be 40 years after this one, maybe in 2035, 2030—around 2038—, the next Nankai earthquake will occur. Next please.

Here we see the Hoei earthquake of 1707, the Ansei of 1854, and the Showa Nankai of 1946. The sizes of these three earthquakes are not the same. For example, this is Shikoku Island, Osaka and Kyoto and the south coast of the Japanese Islands. This graph shows the tsunami height. This cross indicates the event of 1946, the Showa Nankai tsunami; this black one is the Ansei Nankai tsunami of 1854; and the white one is the Hoei tsunami of 1707. We can clearly see that the Showa Nankai Earthquake tsunami was smaller—at most, 6 m. For the Ansei Nankai tsunami of 1854, the maximum tsunami height was 9 m. But for the Hoei Earthquake, the tsunami was 21 m or 24 m. Comparing the Showa Nankai, Ansei Nankai, and Hoei, the tsunamis were not the same size and the Hoei event was the biggest event, and the Showa Nankai was the smallest event. Next please.

Here we consider that, if Tokai earthquake and Nankai earthquake happened independently like the Showa Nankai and Ansei Nankai,
the size of the Tokai Earthquake would be 300 km and the size of the Nankai Earthquake would be 400 km. But the size of the Hoei Earthquake, which happened in both areas, was 700 km. The Hoei Earthquake is comparable to the 2004 Sumatra Earthquake. The size of the Sumatra earthquake was 1,200 km, so if the Tokai Earthquake and Nankai Earthquake happened independently, they would be too small to compare. But the Hoei Earthquake of 1707 is comparable to the Sumatra event. The size of the Sumatra earthquake was 1,200 km, so if the Tokai Earthquake and Nankai Earthquake happened independently, they would be too small to compare. But the Hoei Earthquake of 1707 is comparable to the Sumatra event. The tsunami height exceeded 20 m and the same scene would have occurred on the coast of Kochi on the south coast of Shikoku Island. Next please.

Every big earthquake event in this area happened every time at the top of Cape Muroto; the south coast of Shikoku Island is uplifted and a sea terrace appears. For the Showa Nankai Earthquake, the amount of uplifting was 19 cm. At Muroto Cape, on average the plate is sinking down 9 cm per year. After 100 years have passed, 19 cm will have been compensated for—even if the Showa Nankai Earthquake uplifted 19 cm, over the next 100 years 70 cm will be cancelled out, and so no terrace remains. For the Ansei Earthquake also, even if 1.3 m was uplifted, after 100 years, 70 cm will be cancelled out and no sea terrace will remain. But in the gigantic Hoei Earthquake, 2.5 m was uplifted, and even if over the next 100 years 70 cm is compensated, 1.2 m remain and the sea terrace will remain. Next please.

This is a marine terrace at Cape Muroto, at the southern tip of Shikoku Island. One professor from Hiroshima University, Dr. Maemoku, reported observing six sea terraces using carbon dating methods. Carbon dating showed that the ledge of the terrace was formed here; the age was estimated and it was found that the lowest ledge was formed about 300 years ago. The second one was formed about 800 years ago, the third one was formed nearly 1,200 years ago, and the fourth one was formed 2,000 years ago. The last one was apparently formed 300 years ago. Naturally, we can assume that this sea terrace was formed by the 1707 Hoei Earthquake, and therefore a big earthquake, like the Hoei Earthquake, was generated three times in every 2,000 years. Nankai Earthquake occurred every 100 years, but three times every 2,000 years a gigantic earthquake, like the Sumatra event, took place. Next please.

Study of paleo-tsunamis

I will shortly show you traces of lagoon bed layers, pre-historical tsunamis. Next please.

Here, near the Kii Peninsular, a lagoon is separated from the open ocean. Only at the time of a tsunami will outside sea water with sand rush into this lagoon. We checked the lagoon bed using geological methods—collecting piston coring. Next please.

We call the equipment pulling up the piston coring the “Ninja”. Next please.

We found a total of nine layers. These are the first three: the upper three are historical events, but the lower seven are pre-historical, paleo events resulting from Tokai Earthquake tsunamis. The lowest one is about 250 years ago. This mark shows that Tokai events or Nankai events happened periodically on this coast. Next please.

The earthquake and tsunami size were correlated to each other. Around the Japanese Island area, if the magnitude does not exceed 6.3, there is no tsunami. If the magnitude of the earthquake exceeds 7.5, then a huge tsunami may be generated. Next please.

Issuance of tsunami warnings

The Japan Meteorological Agency has a seismograph network for the issuance of tsunami warnings. In total, the network has about 200 points. They send meteorological observations to Tokyo or other branches in real time. Next please.

They can make judgements using P-S time and the seismic record amplitude. They can identify if there will be a tsunami, a big tsunami, or no tsunami. Within two minutes after the observance of an earthquake, they have the ability to announcement a tsunami warning. Tsunami; big tsunami; or no tsunami—such information will be broadcast via television within two-three minutes. Next please.

Fast tsunami detection

Other towns or coastal towns have tsunami sensors, like ultra-sonic ones that have been set up in the past several years. Next please.

Here the ultra-sonic sensors are trained on the sea surface, on sea water, and when the first initial wave comes to the coast, they’ll detect that the first tsunami has come. That is their judgment, we think. Next please.

Such information is transmitted through tele-
communications via the Internet or land lines to fire stations and announced to the people. Next.

For example, in Kesennuma City, they installed an ultra-sonic sensor at the bay mouth and inside the bay. Next please.

They successfully announced the event of 1996, where this small climb occurred. At the bay mouth they caught the first tsunami wave event at 23 o’clock, 40 minutes before midnight, and 15 minutes later the tsunami attacked the inland most point of the central city. The firemen announced that the tsunami would be coming 10 minutes later. They were able to warn the city people. Next please.

Such an ultrasonic tsunami protection network was installed on the Sanriku Coast around here, and we recommend to the establishment of this kind of ultrasonic tsunami network, for example, on the coasts of other countries on the Pacific Rim. I also want to advise countries and regions to exchange information about the first tsunami arriving through the Internet. Exchange information. Next please.

Here we have city planning; this building is near Fujisawa city, about 50 km south of Tokyo. It has been designated by the local government as a tsunami escape building. In the event of a tsunami warning or a tsunami coming, citizens can freely go up to the top floor of this building. Next please.

This is a sea wall against tsunamis. This is one example on the Sanriku Coast, and the height of this wall is 10 m above mean sea level. They call this the “Great Wall of China”. Next.

Lock gate system. Next.

This is an example on a Hawaiian Island, Hilo. The people are prohibited from constructing houses close to the coast, within 1 km from the coast, so that they can have enough time to escape from a tsunami.

That’s all. Thank you very much. Tsunamis and earthquakes are common natural hazards that hit people in Pacific Rim countries. We want to join together with seismologists and other disaster protection experts and medical doctors to escape from this kind of natural hazard. Thank you very much.
MECHANISM OF THE OCCURRENCE OF EARTHQUAKES AND TSUNAMIS

Plate Configuration on the Earth’s Surface

Mantle Convection of Plates

Distribution of Epicenters in the Western Pacific Coasts

Mechanism of Generation of a Tsunami

Amplification of a Tsunami
2. Past Tsunamis in Indonesia and Japan

2.1 Indonesia topic: the 2004 Sumatra Tsunami
2.2 Japan topic: the Nankai Gigantic Earthquakes

The 2004 Sumatra Earthquake
Report of Tsunami damage in Banda Aceh City, Sumatra Island, Indonesia

Yoshinobu TSUJI
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The Port Mosque
Water Mark on the wall shows the tsunami water
height was 12.2m

Jr. high school No.5 of Banda Aceh 8.8m

Tsunami Heights in Banda Aceh

We made a survey of the Distribution of
Washed Away Houses

○ washed away house ● house not washed away
MECHANISM OF THE OCCURRENCE OF EARTHQUAKES AND TSUNAMIS

Survey of the western Coast of Banda Aceh City
Satellite Image

Before Tsunami  After Tsunami

No house left on the sand dune of Lhoknga village, height: 10 meters above the mean sea level

Tsunami Heights Distribution in Banda Aceh Area

Water inundation height on the western coast
Red: water traces on trees
Green: run-up height on slope

34.9m Valley

At the top of the tsunami limit of the 34.5m valley
2.2 Tsunamis in Japan

Nankai Gigantic Earthquakes

Plate Configuration around the Japanese Islands

Source Areas of the Tokai and the Nankai Gigantic Earthquakes

Pairs of the Tokai and Nankai Earthquakes
MECHANISM OF THE OCCURRENCE OF EARTHQUAKES AND TSUNAMIS


Formed Ages of Marine Terraces of the Cape Muroto, Shikoku Island
Hoei-sized earthquakes occurred 3 times in the recent 2000 years

Marine terraces at the Cape Muroto, Shikoku Island tell

Crustal upheaval
Showa Nankai 1946
0.9m
Amsei Nankai, 1854
1.2m
Hoei, 1707
2.5m
Marine terrace was formed only by the 1707 Hoei Earthquake

Swarm Earthquakes accompanied with the Nankai Earthquakes

Comparable to the 2004 Sumatra Earthquake
Location of “Oo-ike Lagoon”

Piston Core Sampling of lagoon bed sediment layers at Oiske pond, Owase City, Kii Peninsula

Working Deck “Ninja”

Traces of Pre-Historical Tsunamis of Takai Earthquakes in the Lagoon bed sediment layer of Oiske Lake, Owase City Kii Peninsula

4. The Method of Issuance of Tsunami Warning by Japan Meteorological Agency

日本気象庁による津波警報の発令方法

Relationship between Earthquake Magnitude and Tsunami Magnitude

Relationship between magnitudes of earthquakes and tsunamis for the world
5. Fast Tsunami Detection and Protection of Coastal Residents from tsunami hazards

Ultra-Sonic Tsunami Sensor in Taro Town
MECHANISM OF THE OCCURRENCE OF EARTHQUAKES AND TSUNAMIS

Tsunami Protection Wall in Fudai Town

Lock Gate System of Taro Town

City Planning of Hilo City, Hawaii