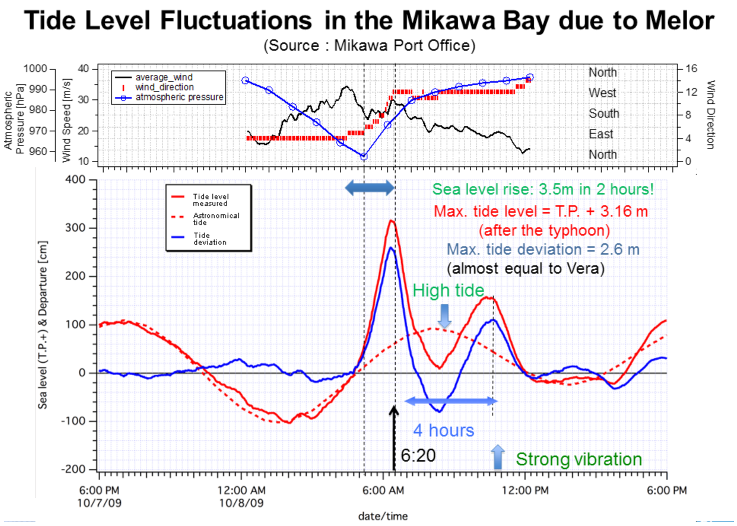
For Vera, the maximum level of water reached in the Mikawa Bay was T.P. 3.3 m, with a 2.6 m deviation. Judging only from the level of water, Melor caused the same storm surge as the second time Vera hit Japan.

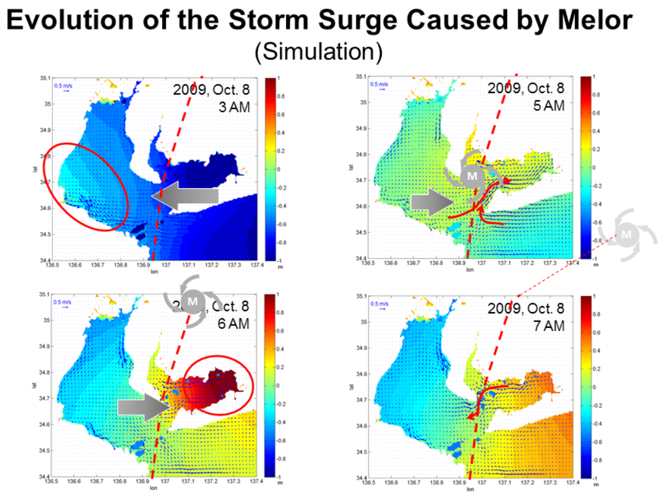
T.P. (Tokyo Pale): average Tokyo Bay sea level
Altitude: the height of something above sea level (often referring to the average sea level near ports and noted "... m above sea level")
Elevation: height measured from a reference point
Since the sea level is often chosen as the reference point, altitude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

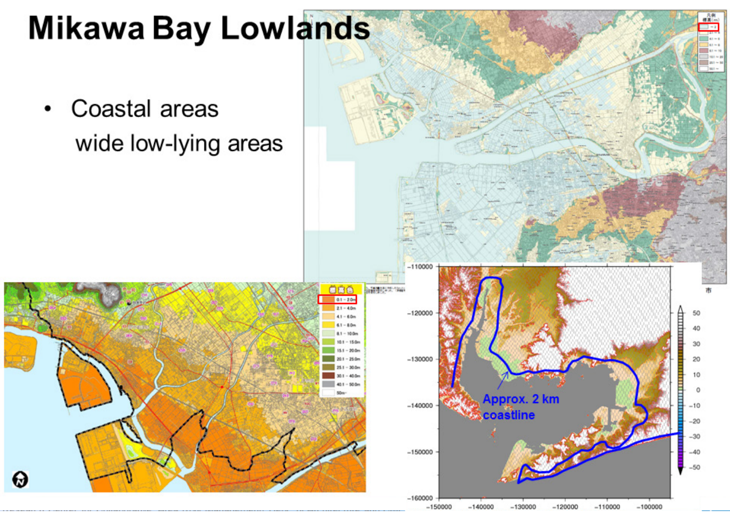


Here is a simulation of the storm surge caused by Melor. At the time the typhoon approached the Mikawa bay (3 AM), the east wind made the sea level rise in the Ise Bay. Once the typhoon was gone, the wind coming from it was blown in the opposite direction, which made a water mass that had remained in 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

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

English

つながる教材

三浦均也

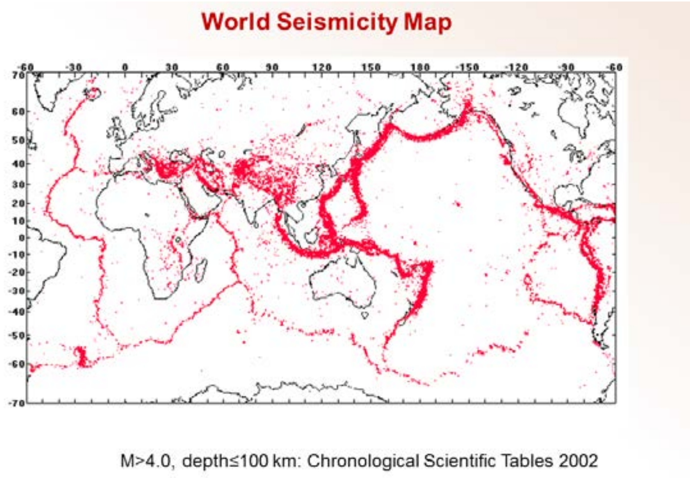
建築・都市システム学系教授

SOIL LIQUEFACTION: MECHANISM, DAMAGE AND COUNTERMEASURES

2014 “Regional Earthquake Disaster Prevention Course” Advanced Edition
Research Center for Collaborative Area Risk Management (CARM), Toyohashi University of Technology
October 9, Venue: Kamomeria (Port Information Center), Toyohashi City

Kinya MIURA

Toyohashi Univ. of Technology, Dept. of Architecture and Civil Engineering
Division of Geotechnology and Disaster Prevention, GeoMechanics Laboratory



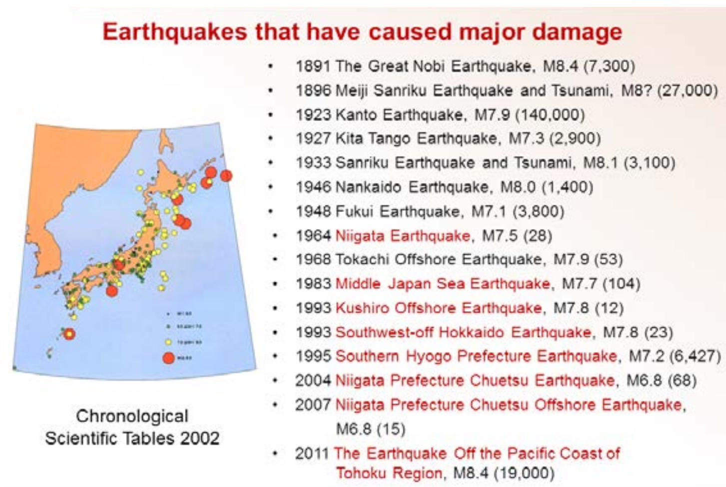
M>4.0, depth≤100 km: Chronological Scientific Tables 2002

Earthquakes do not occur all over the world. Seismic activity is actually very limited to some areas. This reminds us that there are more people living on this planet who do not experience earthquakes.

The mechanism causing earthquakes can be explained by plate tectonics. Japan lies along several areas with high seismicity. Therefore, earthquake disasters are of utmost concern in Japan where civil life and economic activities may be considerably affected. We need for construction engineers to be reminded once again how imperative is to always provide structures designed to withstand earthquakes.

This is a list of major seismic disasters (earthquakes with large intensity that have caused major damage). Numbers in parentheses give the number of deaths. These figures show the gravity of such disasters, as earthquakes are the only cause, excluding the war, for the death of so many people at once in Japan.

There are also some earthquakes in red that caused large damage due to liquefaction. Liquefaction-induced damage has been increasing in the recent years.



Chronological Scientific Tables 2002

Overview of Natural Disasters in Japan

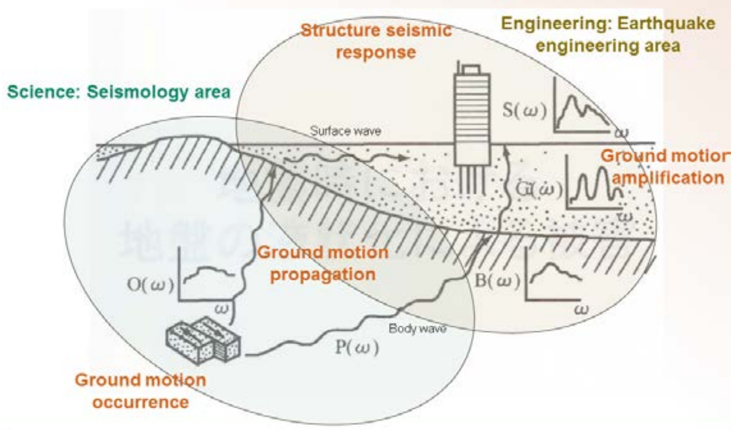
- Natural disasters that cause material and human damage
  - Earthquakes (fire, tsunami, landslides)
  - Cloudbursts (rains in the rainy season, heavy rainfalls in urban area, landslides)
  - Typhoons (floods, ocean waves, landslides)
  - Volcanic eruptions (pyroclastic flows, mudflows)
  - Strong wind (first spring gale, tornados)
  - Wildfires, heavy snowfalls, drift ice
  - Abnormal weather (cool summers, mild winters)
- Damage factors to structures and buildings
  - Earthquake impact >> rockfalls, soil liquefaction
  - Deep percolation

Earthquakes are the greatest natural disaster affecting Japan. Damage caused by the impact doesn't resume to collapsed houses, but it widely due to the earthquake collateral effects: fire, tsunami and landslides. If we consider also damage caused to structures, it can be said that earthquakes cause the greatest damage.

Research on earthquakes and seismic disasters extends to various disciplines. Ground motion occurrence and propagation are subjects mainly to geology and geophysical studies in the science field. On the other hand, ground motion amplification and structure seismic response according to alluvial grounds make the subject of studies of civil and construction engineering.

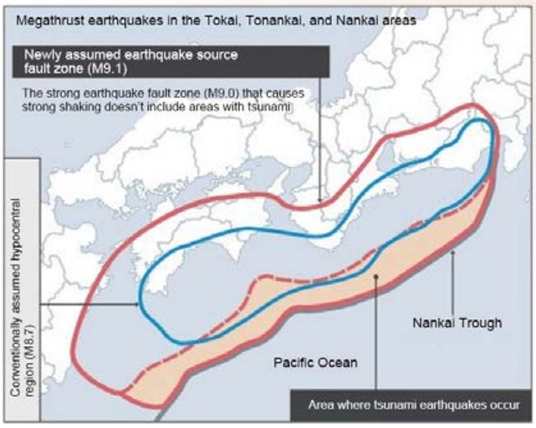
In recent years, there have been prominent initiatives transcending the academic frameworks, as major efforts have been made to further disseminate information on earthquakes and prepare shelter environments for temporary occupancy.

Research areas related to earthquakes



In 2003, the Central Disaster Prevention Council estimated that Tokai, Tonankai and Nankai would likely be the hypocentral areas for interrelated earthquakes occurring in the future, and made damage estimates. In 2013, following the 2011 Earthquake Off the Pacific Coast of Tohoku Region, a Nankai Trough Major Earthquake of a M9 class was predicted, and damages were estimated. Local governments are currently studying the prediction. This reaffirmed that the Tokai region was in a very serious situation.

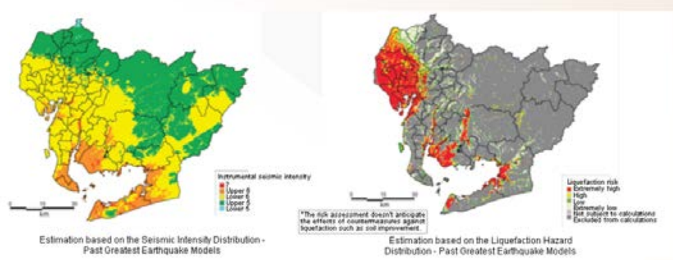
Predicted Megathrust Earthquakes



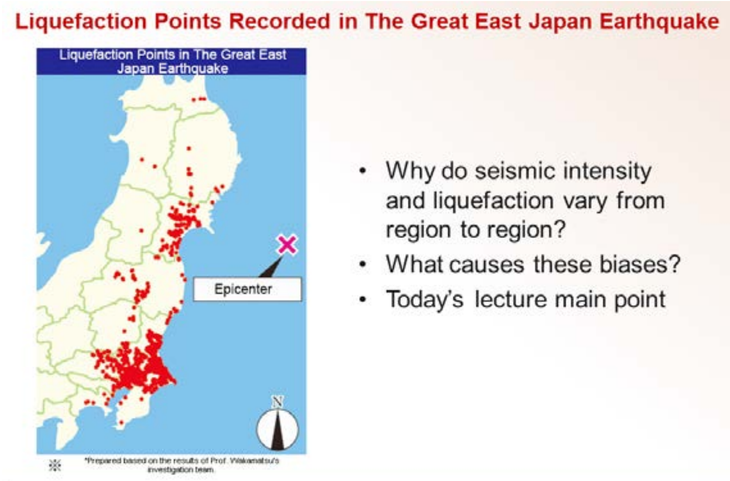
These are the study results on intensity and liquefaction potential due to "The Greatest Earthquake Models Ever" concerning the three interrelated quakes, which were announced in 2013 by Aichi Prefecture.

The study reveals that it is not solely the distance from the epicenter, but also ground conditions have a considerable influence.

Seismic Intensity and Liquefaction Hazard Distribution Maps Based on Past Greatest Earthquake Models



FY2011 - FY2013: Study results on the estimated damage from Tokai, Tonankai, and Nankai earthquakes in Aichi Prefecture

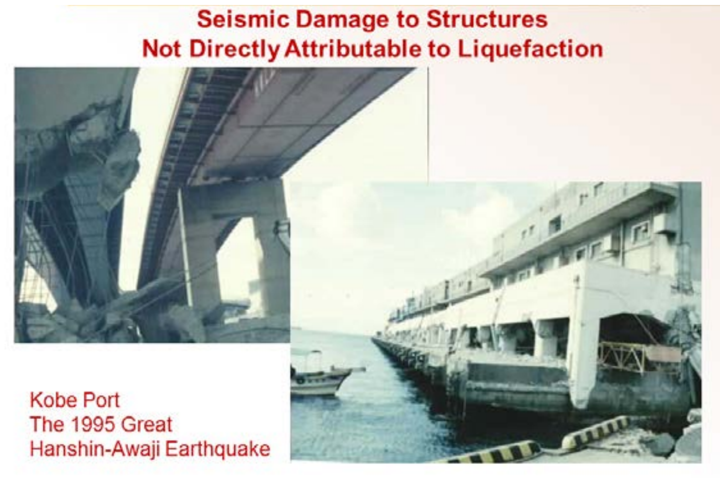


This map shows the distribution of liquefaction points recorded in The Great East Japan Earthquake. It shows the strong influence of ground conditions to the occurrence of liquefaction. What are the conditions for liquefaction to occur? This is one of the lecture's main points.

BACKGROUND AND HISTORY ON LIQUEFACTION

- Human and material damage
- From natural phenomena to natural disasters
- History of research on liquefaction
- Thoughts on liquefaction

These are examples of quake damage not directly related to liquefaction. During the Great Hanshin-Awaji Earthquake, the impact caused damage to reinforced concrete constructions such as bridges and buildings.



This is an example of quake damage not directly related to liquefaction. During the 2003 Tokachi Offshore Earthquake, fire broke out at an oil-related facility in response to a long oscillation period. During the 2004 Sumatra Earthquake, livelihood was destroyed and many human lives were lost due to tsunami.

Human damage is caused by collapsed houses, fire and tsunami, to name a few. Human damage induced by soil liquefaction is extremely small, while material damage is becoming relatively larger. Damage to public facilities (infrastructure, lifelines) is significant to such extent there are not few the cases when it accounts for more than half of the amount of economic damage. Due to its reduced rigidity, the liquefied soil has also a seismic isolation effect. This is why structures sink or tilt, although even in such cases the seismic impact often doesn't cause their collapse.

Characteristics of Damage in Soil Liquefaction Phenomenon

- Human damage factors
  - Collapsed houses
  - Fire
  - Tsunami
- Characteristics of liquefaction-induced damage
  - Material damage is overwhelmingly greater than human damage
  - Casualties caused directly by liquefaction phenomena are extremely rare
  - Suppressive effects on structural damage induced by reduced acceleration; are there base isolation effects?
  - Marked damage of public facilities by liquefaction
  - 80% of damage is caused by liquefaction...
  - A little over 60% of the disaster left by the 1995 Great Hanshin-Awaji Earthquake was caused by liquefaction
  - Liquefaction-induced damage in the 2011 Great East Japan Earthquake spread even to the Kanto region, which is far away from the quake's epicenter.

- Records of natural phenomena
  - Traces of sand boiling from Jomon and Yayoi periods
  - Ansei Tokai Earthquake (1854), Suruga Province
    - "Ansei Kenbunroku" (literally, *Ansei Chronicle*), Part II
  - The Great Earthquake of Tokyo (1923), Fukui Earthquake (1948)
    - Liquefaction was observed, but there was no remarkable damage directly related to the phenomenon.
- 1964: Great Alaskan Earthquake (March), Niigata Earthquake (June)
  - Modern facilities (infrastructure) suffered damage for the first time ever
  - Starting point for the research on liquefaction; the first year of liquefaction
  - 1986 Middle Japan Sea Earthquake, 1993 Southwest-off Hokkaido Earthquake, 1995 Southern Hyogo Prefecture Earthquake, 2011 Earthquake Off the Pacific Coast of Tohoku Region

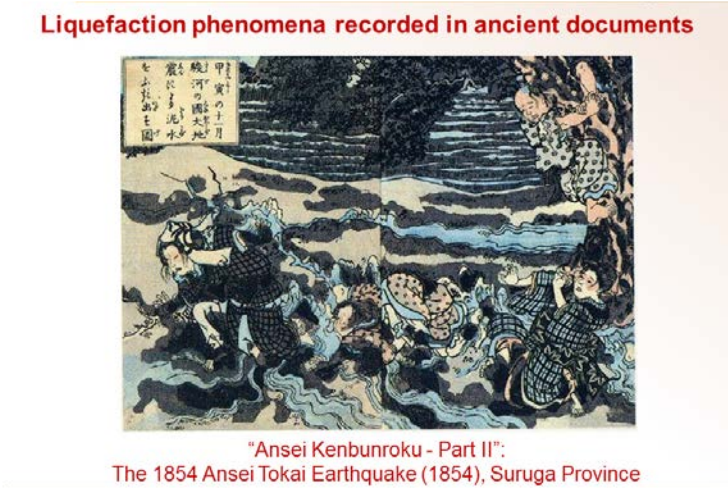
Liquefaction is a natural phenomenon, supposed to have been observed in earthquakes since ancient times. The phenomenon was recorded also in the 1923 Great Kanto Earthquake and 1948 Fukui Earthquake, but it is strongly perceived as a natural disaster ever since the 1964 Great Alaskan Earthquake and Niigata Earthquake. With these two quakes as a turning point, research on soil liquefaction has been conducted energetically by Japan and the USA as leaders. It is known as the starting point for research on liquefaction. Also during the 1986 Middle Japan Sea Earthquake, 1993 Southwest-off Hokkaido Earthquake, 1995 Great Hanshin-Awaji Earthquake, and the 2011 Tohoku Earthquake, liquefaction-induced material damage to infrastructure and houses has spread.

Trace of liquefaction discovered to be dating from the Middle Yayoi period

Uchisatohacho Site, Yawata City
Disaster Prevention Research Institute
(Kyoto University)

This is a trace of soil liquefaction discovered during excavations at at a site dating back to the Middle Yayoi period. Liquefaction is a natural phenomenon that has been occurring since ancient times if conditions were met.

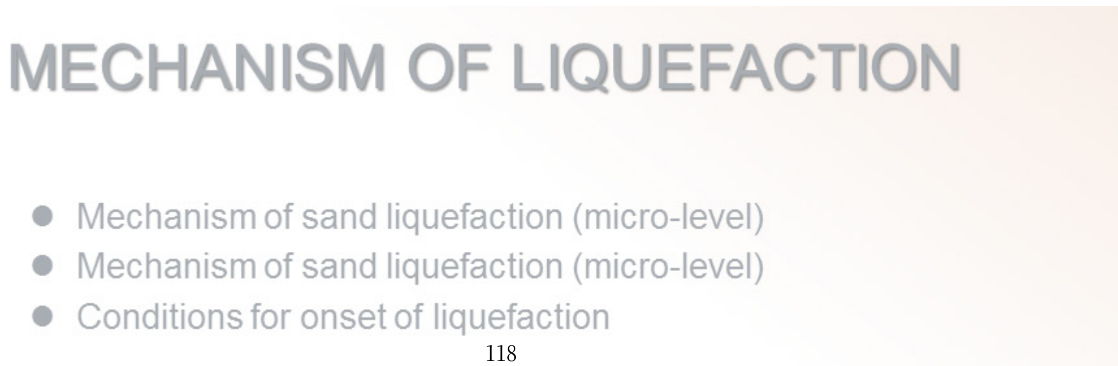
This part refers to the 1854 Ansei Tokai Earthquake recorded in the ancient chronicle “Ansei Kenbunroku - Part II”. It shows people running about trying to escape from the soil liquefaction occurred in the area that is today part of Shizuoka Prefecture.

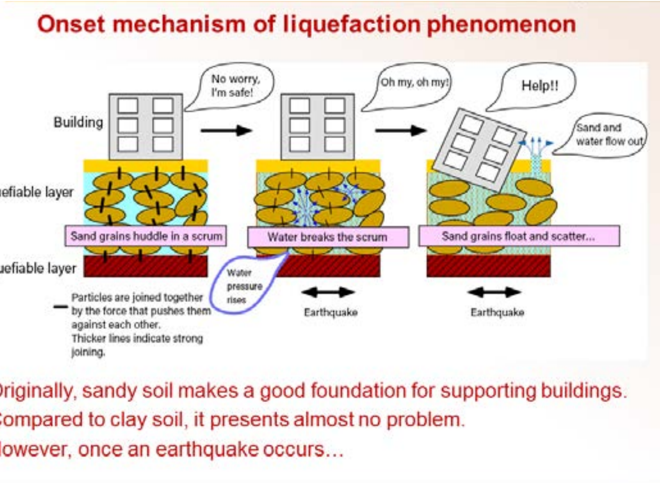


This is a video taken by Mr. Yuminamochi, a cameraman who happened to be in the terminal building of the Niigata Airport when the earthquake started (later known as the 1964 Niigata Earthquake). This is one of the most valuable materials for the study of geotechnical earthquake engineering since it made widely known how severe and important was the soil liquefaction phenomenon affecting modern facilities.

During the earthquake, muddy water spurted up, burst on the surface and completely covered the runway’s apron. The underlying liquefied soil lost its bearing capacity and caused the airport’s building to sink more than 1m.

Research on soil liquefaction has been conducted by Japan and the USA as leaders ever since 1964’s Great Alaskan Earthquake and Niigata Earthquake. Research has followed the following steps: “Clarify the mechanism,” “Analyze of damage,” “Establish surveying methods,” and “Develop preventive measures and earthquake-resistant design methods.” In Japan, liquefaction research results, which had been carried out since the Niigata Earthquake, were verified when the Middle Japan Sea Earthquake hit in 1983. From this point on, countermeasures against liquefaction have been incorporated into the earthquake-resistant design of many structures.





Sand is generally considered a good soil thanks to its small subsidence and high bearing capacity. That is because sand particles form stable array structures that ensure good transfer of load. However, once seismic motions occur, the array structure of sand particles becomes fragile, which indicates the onset of liquefaction phenomenon.

First, let's study the liquefaction phenomenon from a microscopic viewpoint.

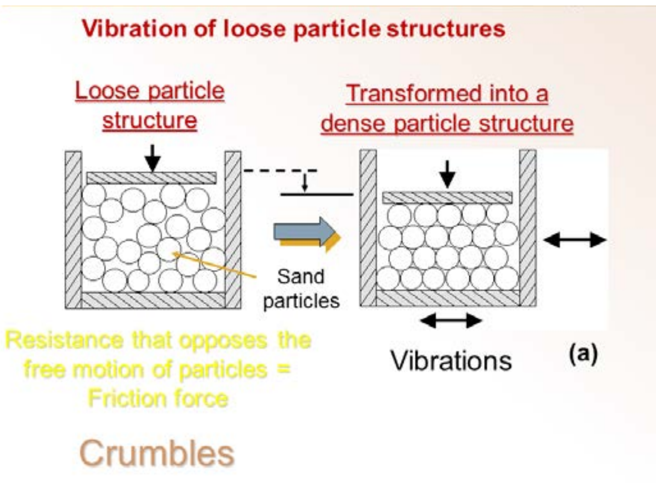
• Sand deformation … Sand particles neither break down, nor deform. This refers to changes in their arrays and sand inclusion.

• Sand particle motion in water … Sand particles fall down quickly in the air, but in water they move at a sluggish pace due to water's viscous resistance. Consequently, it takes longer time for sand particles to reorganize their array structure, which causes persistent liquefaction.

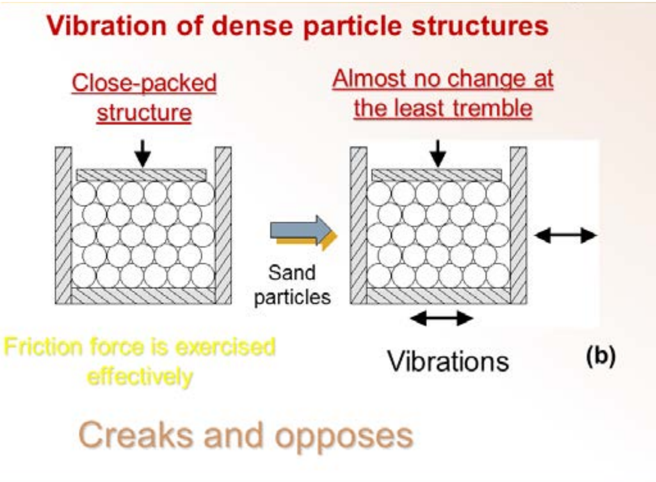
• Dilatancy … This is a phenomenon specific to some substances formed by grouping particles together (granular material), such as sand, but also granulated sugar, rice, beans, etc. Their volume changes when they are subjected to vibrations or deformation. This is a property that we don't see in such materials as metals in fluids or air. When loose grounds are subjected to vibrations, their volume shrinks and the liquefaction phenomenon occurs. This is why grounds sink due to liquefaction.

Microscopic mechanism of liquefaction phenomenon

- Sand deformation
  - Changes in the structure of sand particle arrays
  - Soil particles don't break, they deform
- Sand particle motion in water
  - Settling velocity becomes slower as water's resistance acts on the particles
  - Particles will not re-stabilize until all of the water drains out
- Dilatancy
  - Volume change caused by shear deformations
  - Special property seen in granulated sugar, rice, beans, etc.
- Onset of liquefaction



When subjected to vibrations, loose soil particles easily change their array structure causing the soil volume to shrink. It is during this process that liquefaction occurs.



On the other hand, dense soil particles do not change their array structure regardless of the strong vibrations they're subjected to. Therefore, it can be said that liquefaction does not occur in dense soils

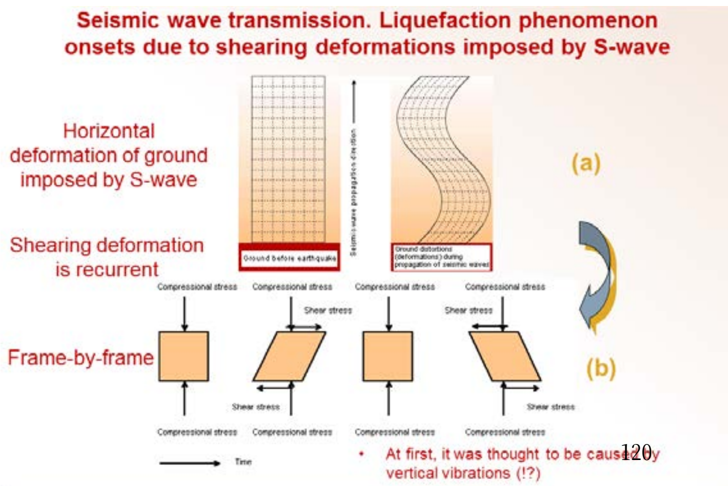
This video illustrates the photoelasticity experiment.

They used a cylinder made out of resin to resemble soil particles. You can see the array structure of soil particles and the modifications it suffers when stress is transmitted and the particles are subjected to vibrations. The translucent resin to which stress is applied becomes denser, which slows down the speed of light traveling along. This leads to monochromatic light interference that creates a striped pattern (alternating bright and dark bands). The linkage between these bands allows us to know the status of stress transmission. This kind of experiment has been used also in mechanical engineering, but nowadays, computer simulation has made more detailed analysis possible. This video shows how soil liquefaction mechanism is impressively visible now.

When a soil is saturated with groundwater, no matter the vibrations it is subjected to, its volume will not modify immediately. In this experiment, applying vibration while soil volume remains constant is causing peak shearing deformation.

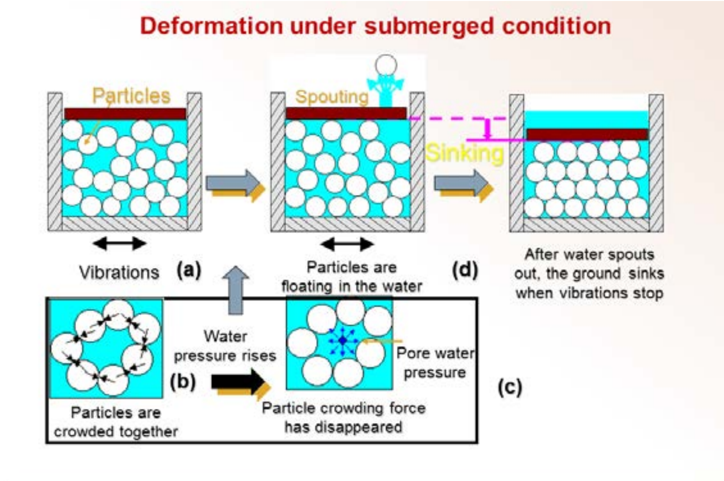
Particles in dense soils do not change they array structure regardless of repeated ground deformations, and thus such soils do not lose their stress transmission structure. Therefore, we learn that liquefaction is unlikely to occur in grounds with high density.

Now, if we extract several particles, the resulting loose ground experiences chain-reaction liquefaction from particles moving to fill in the voids. As a result, particle array structure suffers significant changes, and the ground loses its stress transmission structure. Properly understanding such mechanism is the first step toward analyzing damages and formulating preventive measures.



We have learned from the photoelasticity experiment that it is the horizontal peak shearing deformation, as illustrated here, that causes soil liquefaction. We thus understand now that a transverse wave (S-wave, principal shock) is a dangerous vibration mode also for structures, as dangerous as the horizontal peak vibration in soil liquefaction.

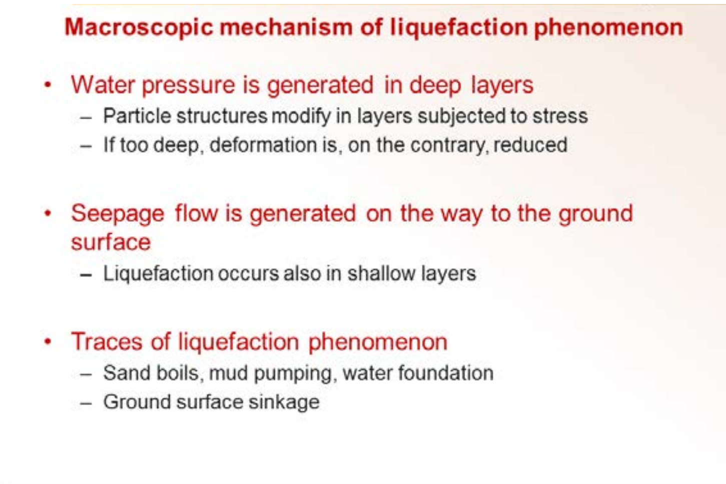
If sandy soil is saturated with groundwater, soil particles' array structure starts to change and the volume to shrink, during which water pressure rises and will eventually spurt to the ground surface. These are spurts of muddy water (water combined with sand) that can be observed in liquefied soils.



This video shows the characteristics of both liquefied and non-liquefied soils. We learn that soils with high risk of liquefaction are fine sands of uniform particle size.

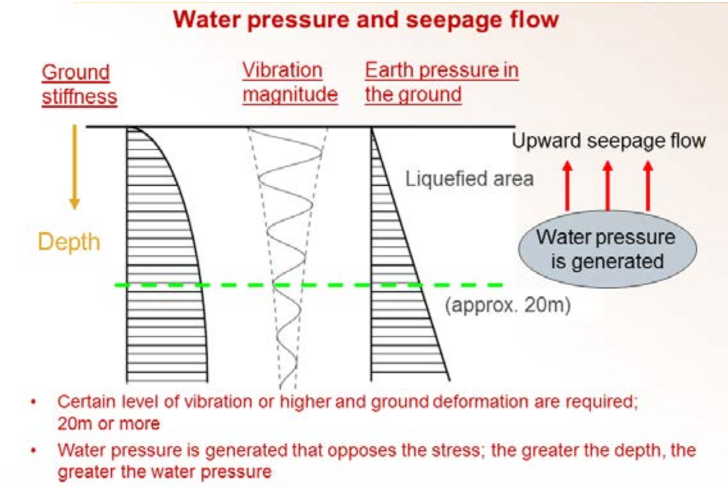
Next, we are about to study the liquefaction phenomenon from a macroscopic viewpoint.

• Water pressure is generated in deep layers … Particles must be exposed to stress from the surroundings in order to change their array structure. Therefore, soil particle structures modify due to vibrations at a certain level of depth. Yet, if the place is too deep, the very seismic motion is small, which complicates changing in soil particle array structures. Consequently, liquefaction phenomenon occurs in layers with certain depth at first, and the pore water pressure rises.



• Seepage flow is generated on the way to the ground surface … Water pressure generated in deep layers seeks a way out through the ground surface, which is why it transforms into seepage flows (groundwater flows) and eventually spurts to the ground surface.

• Traces of liquefaction phenomenon … Groundwater spouts up from cracks and weak points in the ground surface. This water is mixed up with sand and mud, which is why expressions like "sand boils," or "mud pumping" are used in this case. Being visible on the surface makes them evidence of the liquefaction phenomenon onset underground. By draining the groundwater, ground will sink the volume equivalent to the drained water.

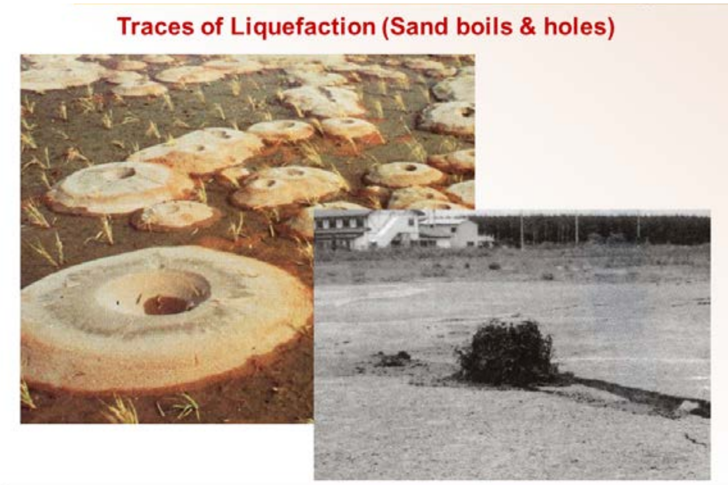


Generally, soils liquefy at a depth not greater than 20m. This means countermeasures must cover a range up to 20m in order to prevent liquefaction onsets. This is the main cause why countermeasures against liquefaction require huge costs.

The video is a recording of a simulation test of soil liquefaction phenomenon, which was conducted at the Research Institute of the Ministry of Transport (currently the Ministry of Land, Infrastructure, Transport and Tourism). Soil meeting all the requirements to undergo liquefaction is constructed on the shaking table, and various structures are disposed on top. The shaking table enables accurate reproduction of observed seismic motions.

Poles and heavy structures are drawn inside the ground and thus sink. Meanwhile, light structures float due to buoyancy effects. In either cases, damages are critical.

The test reveals that pore water pressure is generated in deep layers, which causes groundwater and soil to circulate towards the ground surface.



The images show a sand boiling and sand boil holes, which indicate traces (evidences) of liquefaction. These were observed in the Middle Japan Sea Earthquake.

The 1995 Great Hanshin-Awaji Earthquake: Central part of Port Island, Kobe City

During the Great Hanshin-Awaji Earthquake, Port Island underwent massive liquefaction, and great amount of groundwater gushed up through the ground surface. Immediately after that, the surroundings looked like they had been hit by floods.

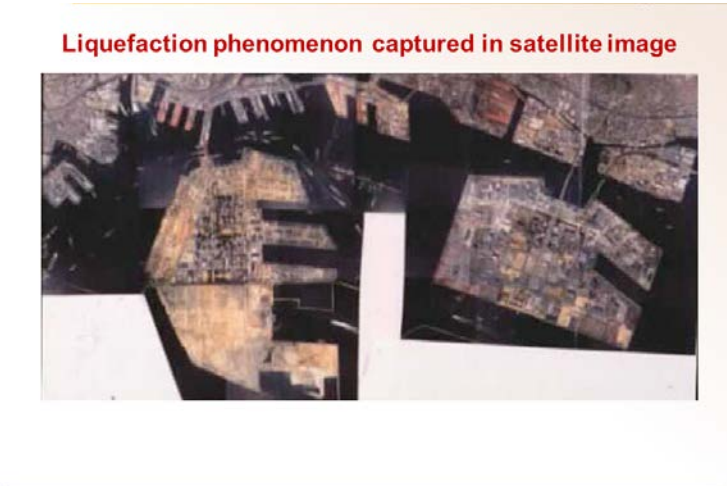
Liquefaction occurs when three conditions are met:

・Fine sands of uniform particle size
・Such sands with loose depositional packing
・Shallow groundwater level

Soils that meet these 3 conditions undergo liquefaction when subjected to a certain level of seismic motion.
It takes just one condition to overcome for liquefaction to be prevented.

Onset conditions of liquefaction

- **Sand of uniform particle size**
  - Clays particles are too small and sticky
  - Gravel moves fast even underwater
- **Loose sedimentation**
  - Changes in the structure of particle arrays
  - Volume reduction due to dilatancy
- **High groundwater level**
  - Persistent liquefaction
- **Strong seismic motion**

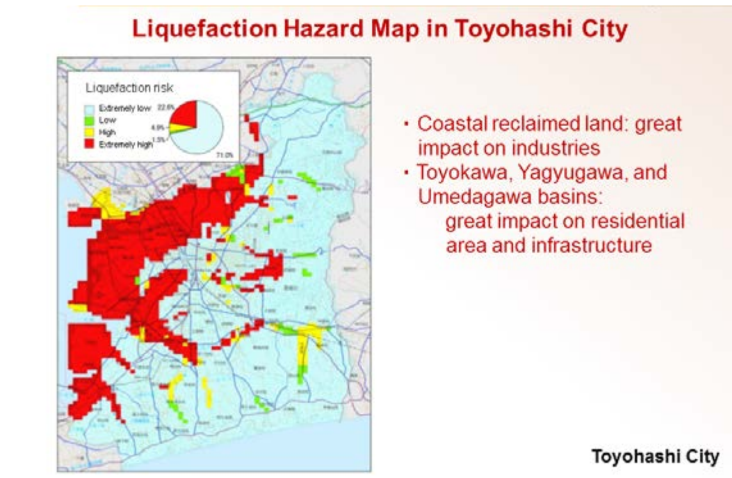


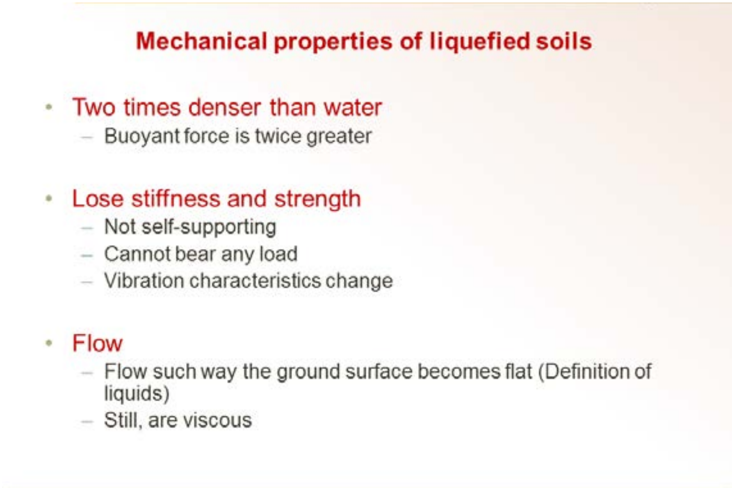
This is a satellite image taken just after the Great Hanshin-Awaji Earthquake. We can infer from the sand boilings shown in ocher that liquefaction onset extensively in Port Island and Rokko Island.

Soils meeting all the requirements to undergo liquefaction are widely distributed throughout Toyohashi City as well.

Liquefaction in coastal reclaimed land may seriously affect industrial activities.

Also, watersheds of Toyokawa, Yagyugawa, and Umedagawa rivers are also at a high risk of undergoing liquefaction, which would have a significant impact on the residential area, lifelines and infrastructure.





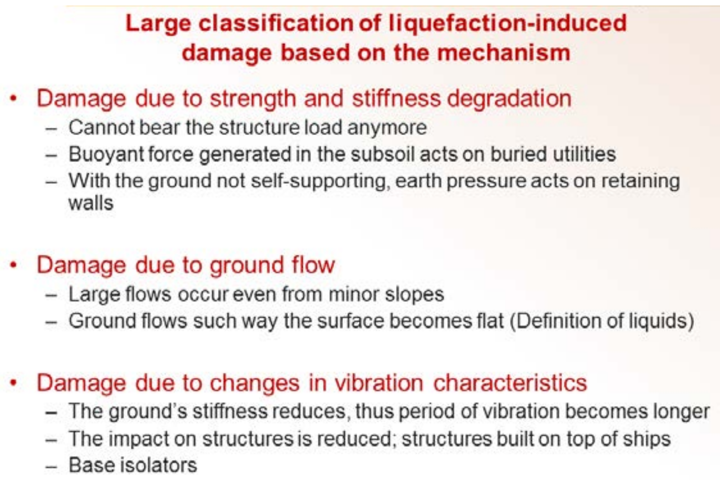
Liquefaction turns ground, which is normally in a solid state, into a liquid state.

- Two times denser than water … This means that the buoyant force of soil is twice greater and thus relatively lightweight underground structures and buried utilities are subjected to buoyancy twice as greater.

- Lose stiffness and strength … Soil structures such as embankments are not self-supporting. The ground cannot completely sustain the weight of structures. In short, its bearing capacity fails. While in solid state, the ground shows constant vibrations dependent on the velocity of elastic waves. However, once liquefied, the ground turns into a liquid state and thus shows large cycle vibration.

- Flow … Fluids flow due to gravity and tend to make the surface flat. Liquefied soils share the same property: if the surface tilts, the ground spreads laterally.

These three properties are the key points in considering the damage caused by liquefaction.



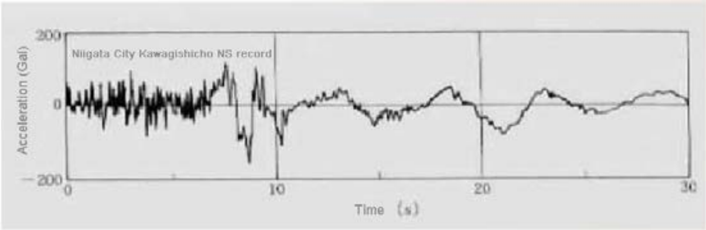
The damage induced by liquefaction can be classified into the following three categories:

- Damage due to strength and stiffness degradation … Heavy structures sink because the ground cannot bear the structure load anymore. Underground structures are lightweight so they float due to buoyancy effects.

- Damage due to ground flow … Also grounds tilted at relatively moderate angles experience lateral displacement of equivalent mass. The same occurs for embankments on flat surfaces. The tendency of surfaces to become flat is the basic nature of liquefaction phenomenon.

- Damage due to changes in vibration characteristics … Vibration period expands due to the ground's low stiffness (spring) as if the structures were built on a boat. As a result, another danger arises as structures, which originally have long vibration period, may resonate, although the impact forces acting on structures generally decrease.

Damage due to changes in vibration characteristics



- Ground acceleration recorded in Kawagishicho, Niigata City (1964 Niigata Earthquake)
- In the wake of the earthquake, soil liquefaction onset near the 8-second vibration frequency.
- The natural period afterwards was around 5 seconds.

This is the ground acceleration time history measured during the Niigata Earthquake with seismic intensity meters attached to the apartment buildings in Kawagishicho, Niigata. Kawagishicho is renown for the complex of apartments which sank considerably or collapsed due to soil liquefaction. This case is often introduced in school textbooks and other publications. The vibration characteristics vary greatly before and after the ground liquefies. At a vibration period near 8 seconds, soil liquefaction occurs, and it gets longer onwards to 5 seconds. Although the ground acceleration itself is reduced, damage is rather greater to structures with longer vibration period.

Classification of damage due to strength and stiffness degradation

- Bearing capacity loss: sinkage or collapse of structures
  - Buildings, poles, piers and abutments
- Buoyancy increase: buoyant buried structures
  - Storage tanks, sewage pipes, manholes
  - Buried pipelines
- Earth pressure increase: uplift of anti-earth pressure constructions
  - Quay walls, retaining walls

Classification of damage due to ground's strength and stiffness degradation

- Bearing capacity loss: sinkage or collapse of structures … Structures, poles and other constructions built on liquefied soil, which are not supported on piles, sink considerably and eventually are sucked into the soil. This is because liquefied soils lose their capacity to support the structure loads. During the Niigata Earthquake, several apartment buildings in Kawagishicho sank considerably or collapsed.

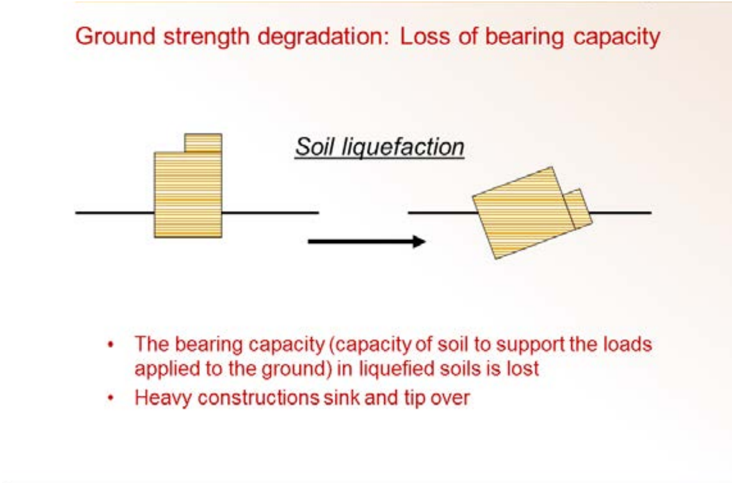
- Buoyancy increase: buoyant buried structures … Liquefaction causes soils to lose their bearing capacity and thus behave like liquids, by subjecting them to a buoyant force. This force is two times higher than that of water, which is why concrete water storage tanks and manholes, if empty, float upward.

- Earth pressure increase: Earth pressure increase: uplift of anti-earth pressure constructions … The earth pressure acting on retaining walls increases when the soil's shear stiffness and strength are either reduced or lost. Therefore, structures such as quay walls in ports and retaining walls in embankments are extruded by the earth pressure.

Subsidence and fall of structures: Kawagishicho apartment complex, Niigata City (1964 Niigata Earthquake)

- Several buildings tipped over
- However, there was no remarkable structural damage

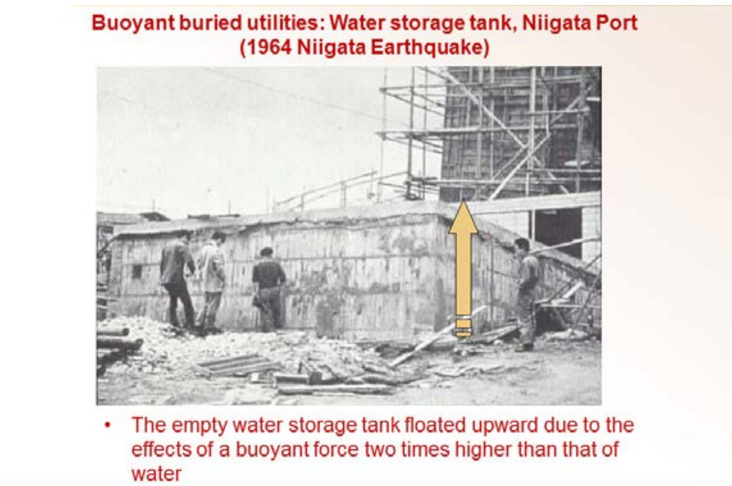
This is the complex of apartments in Kawagishicho hit by the Niigata Earthquake. This case is often introduced in school textbooks and other publications. Several apartment buildings sank considerably or collapsed.



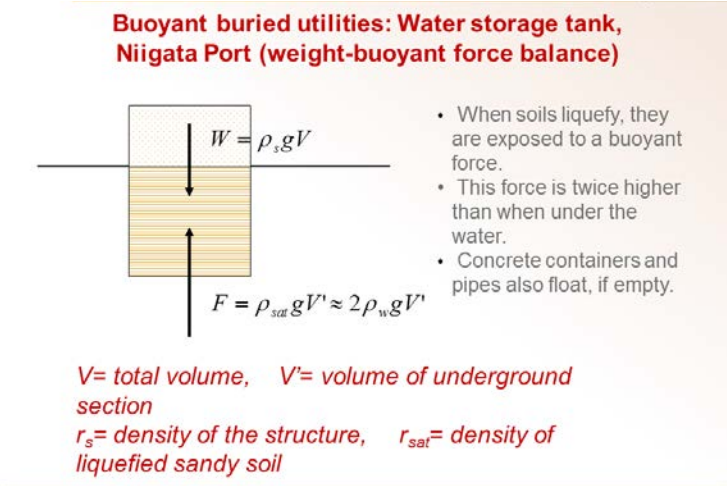
Because of reduced bearing capacity in liquefied soils, heavy constructions sink considerably, or in case of eccentric loading, they collapse.

This is the complex of apartments in Kawagishicho devastated by the Niigata Earthquake. The buildings had fell over to such extent their bases could be seen. Back then, liquefaction phenomenon wasn't yet perceived as a natural disaster. However, on that occasion, sandy soils were recognized as being constantly stable and relatively better ground in comparison with cohesive soils, and pile foundation weren't employed anymore. However, this is what happens once soil is liquefied.

Another notable thing here is the little damage observed in the superstructure that, even after so much damage was produced, it looked like windows were open post-fall. There was also few injured people. This shows us that liquefaction acted as damping device for the ground.

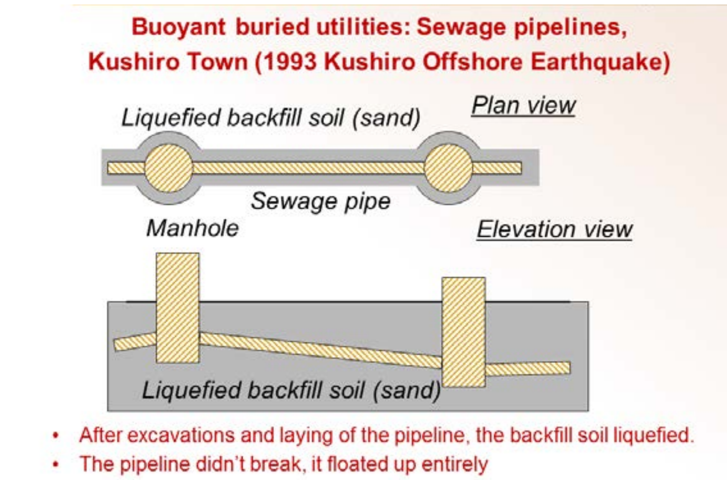


This is a water storage tank in Niigata Port damaged during the Niigata Earthquake. Although the tank was made of concrete, it had almost no water inside, which is why it floated upward at the effects of buoyant force. The floating height exceeds human height.



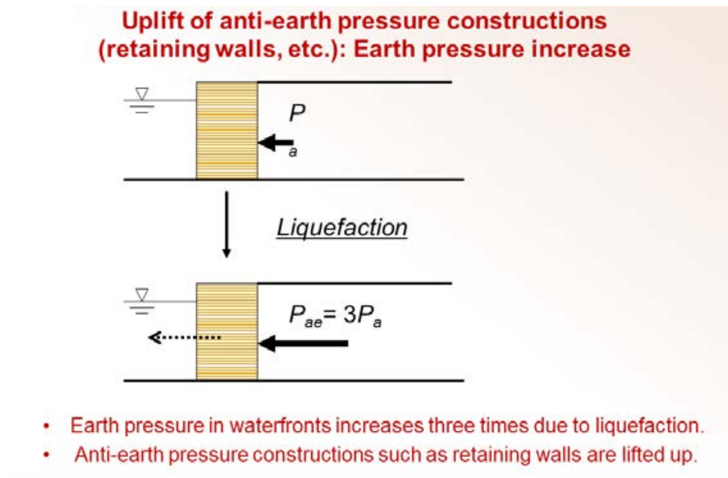
The floating height of structures buried in liquefied soils can be calculated in proportion to the buoyant force.

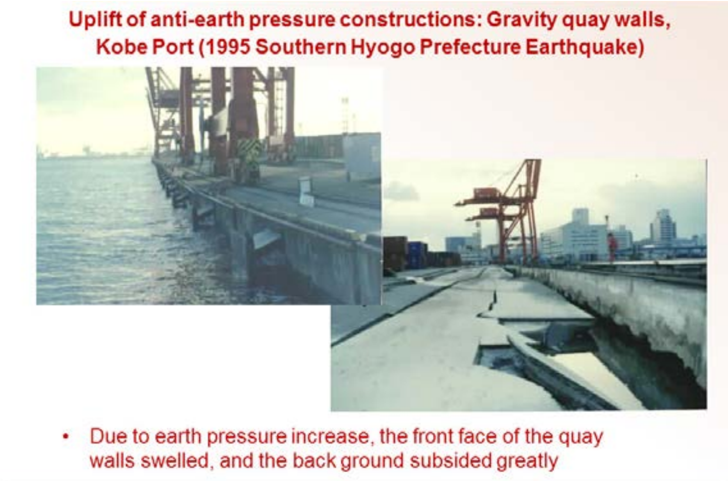
Illustrated here are a sewage pipe and manhole in Kushiro Town damaged during the Kushiro Offshore Earthquake. I was surprised to see how the manhole had floated up 1.4 meters. This is also a result of the buoyancy of liquefied soils.



At the time of restoration of this sewage pipe, the site was investigated in the current state. The surrounding soil was silty and didn't look like a liquefied one, so they used sandy soil for backfilling upon laying of the pipeline and manhole. Said soil was the one to liquefy.

This illustration shows how earth pressure changes after the liquefaction of soil. Consider quay walls in ports, by deducting water pressure acting on the outside, earth pressure reaches three times higher level after liquefaction.





These are Port Island's quay walls damaged during the Great Hanshin-Awaji Earthquake. These walls were greatly pushed out, and the back ground subsided. There remain rails (supported by piles) with loading cranes mounted on in critical condition.

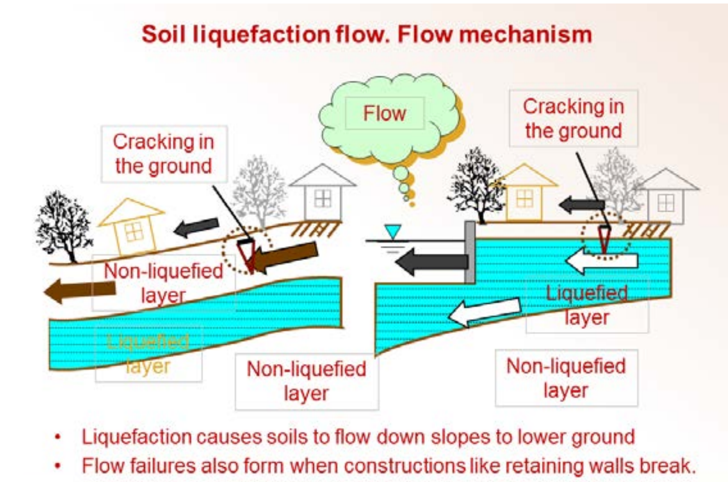
Classification of damage due to ground flow

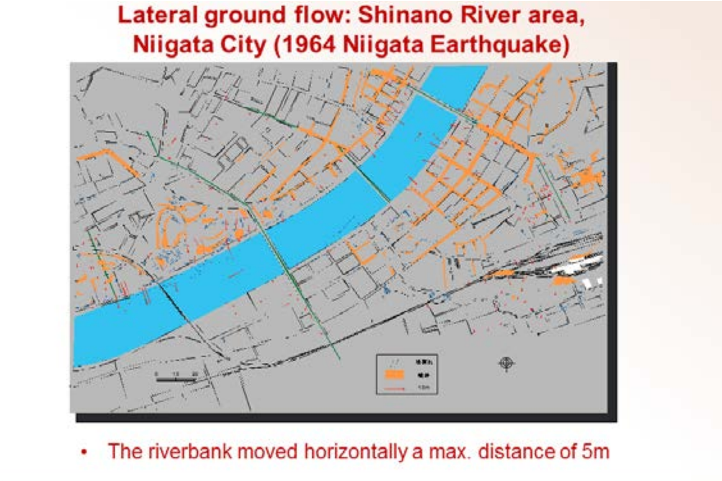
- Stiffness loss: lateral ground flow　… The liquefied ground is displaced laterally considerably on the backside of riverbank and quay walls. This causes buried pipes and pile foundations to fail at the effects of an horizontal force.

- Shear strength degradation: flow failure in embankments　… When embankments are not sufficiently compacted, they are subjected to liquefaction. The compacted soil fluidizes and spreads laterally.

- Foundation ground liquefaction-induced flow: fall or collapse of embankments　… Even when the embankment doesn't liquefy, if the foundation underneath liquefies, the whole block will break apart followed by the ground's subsidence.

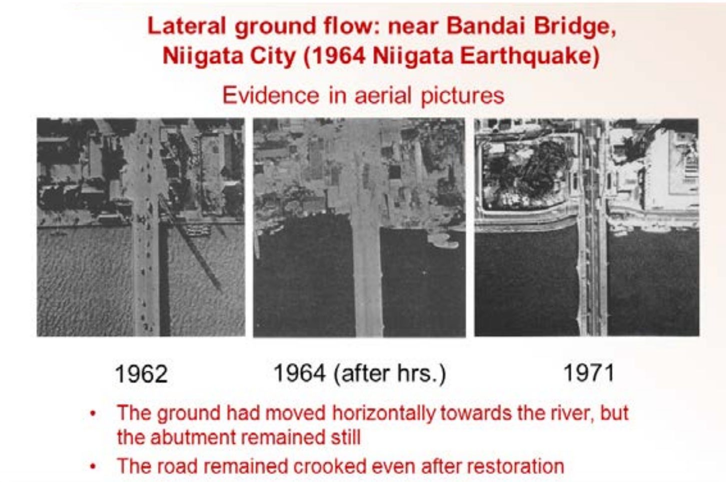
Liquefied soil in tilted areas flow down to lower ground. Even when the ground is flat, coastal and riverbank protection is displaced due to increased earth pressure. This causes the back ground subject to liquefaction to spread laterally.

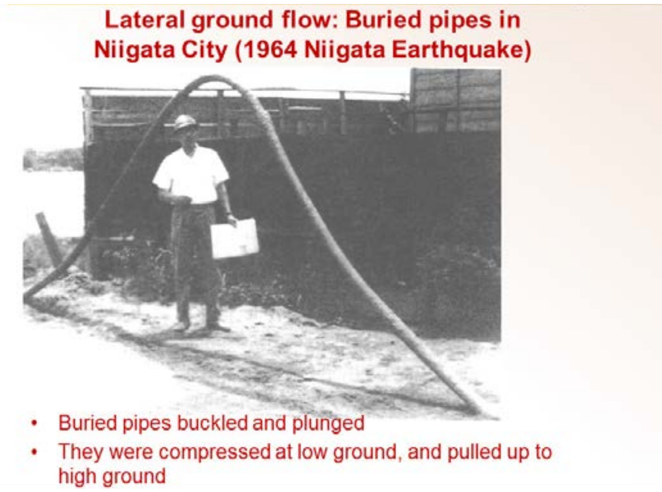




These are the amounts of displaced ground estimated based on aerial pictures taken before and after the Niigata Earthquake. It shows a maximum amount of 5 meters of ground displaced from the riverbank of Shinano River.

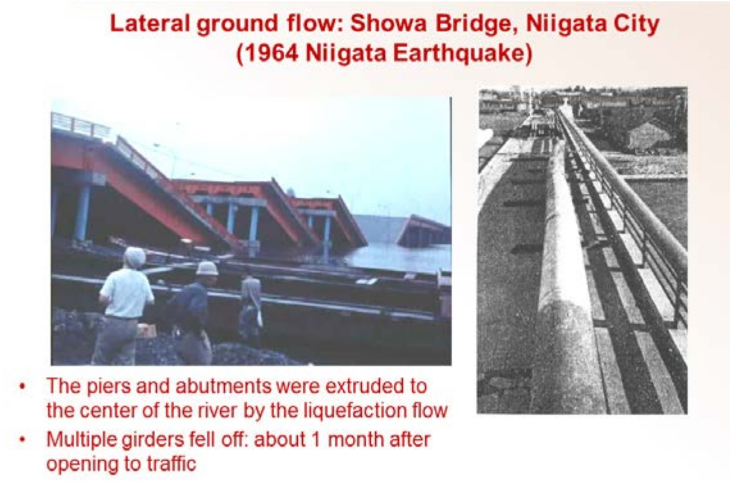
The lateral displacement of ground around Bandai Bridge can be observed in these aerial pictures taken before and after the Niigata Earthquake. Before the Niigata Earthquake, this was a straight road passing over the river. You can see that, when the earthquake hit the city, the road displaced considerably, including a part which collapsed into Shinano River. The bridge' s abutment had been built on pile foundation, which explains why there was little amount displaced. However, the restored road was greatly crooked, and horizontal displacement was visible at the road width.





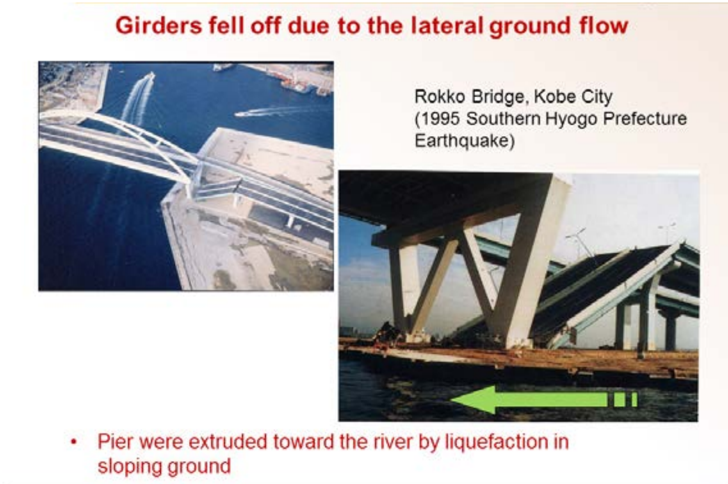
This is a buried pipe damaged during the Niigata Earthquake. The ground where the pipe had been buried into fluidized toward a depression, causing compressional stress to act on the buried pipe, which eventually buckled and plunged from the ground surface.

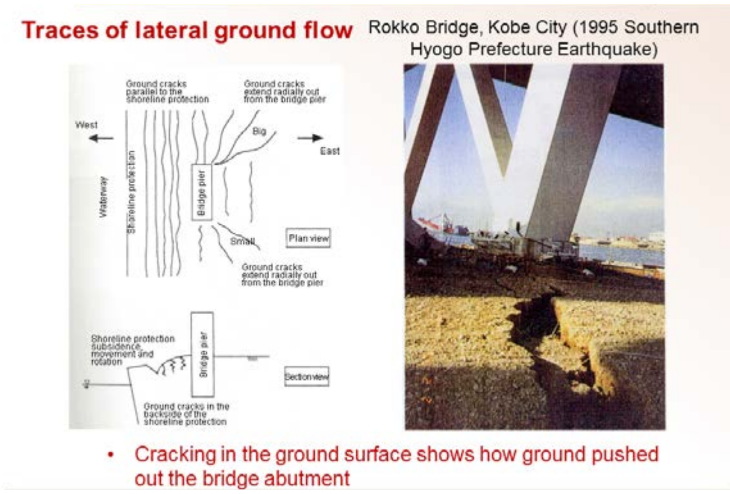
These pictures show lateral flow in the Shinano River bank. We learn that multiple crack appeared parallel to the river, and the bank spread toward the river due to soil liquefaction.



Showa Bridge over Shinano River was another structure that suffered great damage during the Niigata Earthquake. Ten years before the quake, a devastating fire destroyed much of the downtown area, and money was invested in social infrastructure for the city's recovery. This included the Showa Bridge, which was hit by the quake shortly after the completion of its construction. The girders of the Showa Bridge fell into the river because of the piers' lateral displacement caused by the flow of liquefied soil at the site of the bridge, including the riverbed. Today, this form of girders is not used anymore.

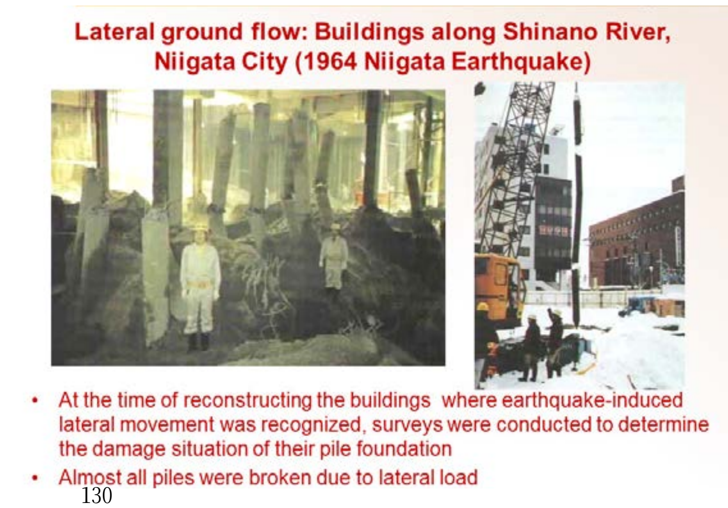
During the Great Hanshin-Awaji Earthquake, Rokko Bridge was damaged and girders fell. This was caused by the lateral displacement following liquefaction of soil near the bridge piers.

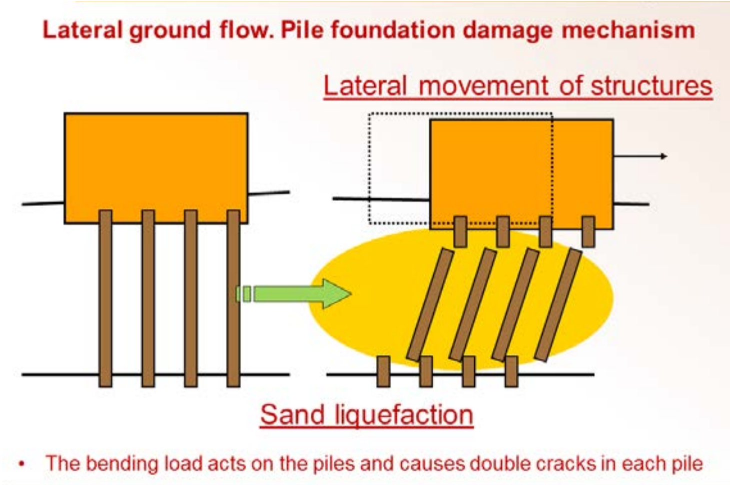




Cracking nearby the piers of the Rokko Bridge shows the damage mechanism. The piers were pushed toward the sea by a horizontal force generated by the displacement of the liquefied soil. This is considered to have caused girders to fall off.

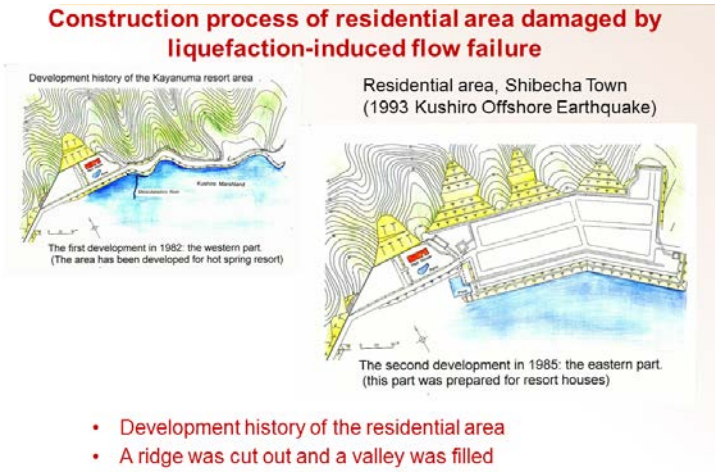
Foundation piles of buildings were also damaged during the Niigata Earthquake. These photos were taken during the investigation on foundations at the time reconstructing the affected buildings almost 30 years since the quake. The buildings were confirmed to have displaced more than 1 meter during the earthquake. Then, the embedded pile tips and heads benefited the horizontal displacement that caused piles to bend and crack in two places.





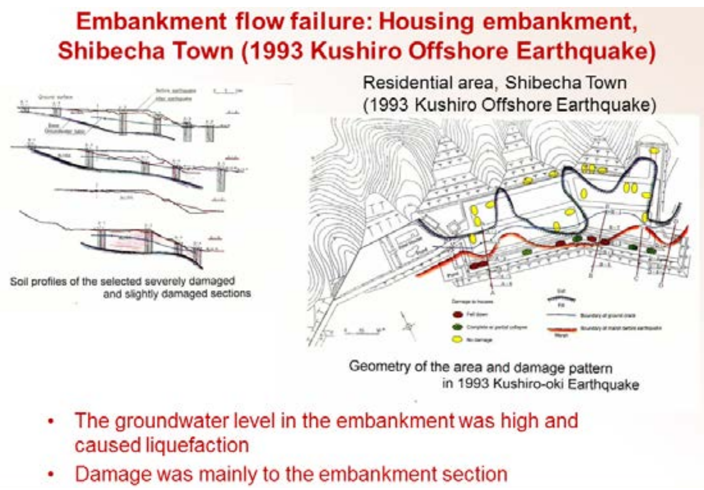
This shows the damage mechanism of foundation piles in liquefied ground that has displaced horizontally due to flow. Because of the condition that pile tips and heads must be embedded, the bending moment increases near both ends, causing piles to bend and crack in two places.

The residential area developed in the town of Shibecha was also damaged by liquefaction during the Kushiro Offshore Earthquake. The housing embankment collapsed, and several houses were damaged.

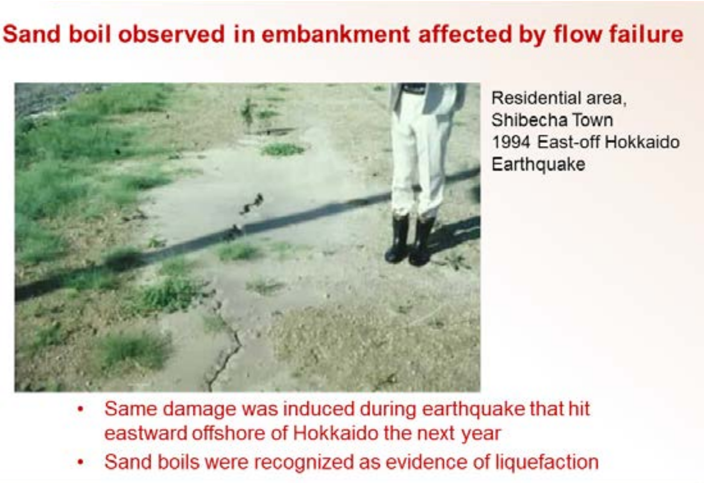


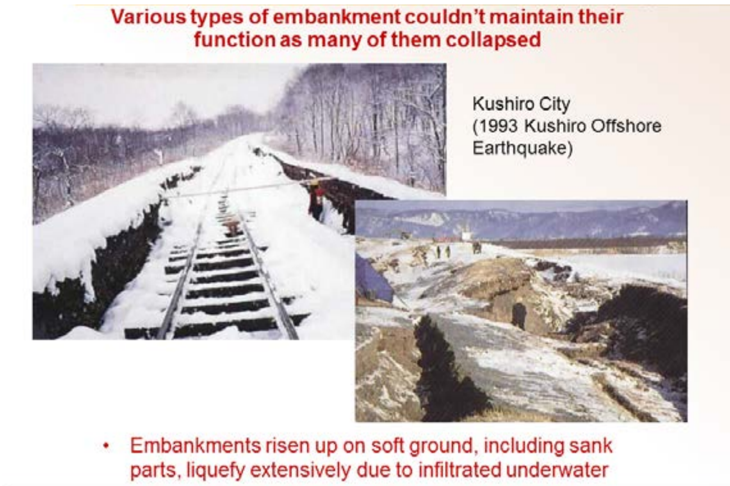
This is the development history of the damaged residential area. This area faced a swamp at the outer edge of the plateau. The residential area was built with the usual construction methods on the flat land resulted from earthmoving and embankment, as illustrated. The embankment was constructed by filling the valley.

The housing damage degree is plotted at the top of the cross-sectional and plan views of this planning drawing. It seems like they learned about it through a soil survey. Groundwater streaming in through the valley had infiltrated the embankment soil and was maintained at a relatively high level. Moreover, since almost all damaged houses had been built on the embankment, the cut section including lifelines suffered minor damage. The embankment soil liquefied, and a lateral flow was observed.

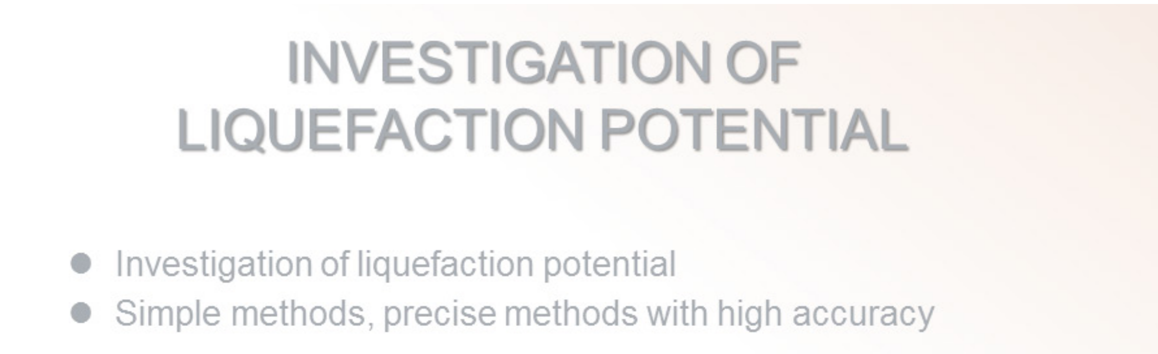


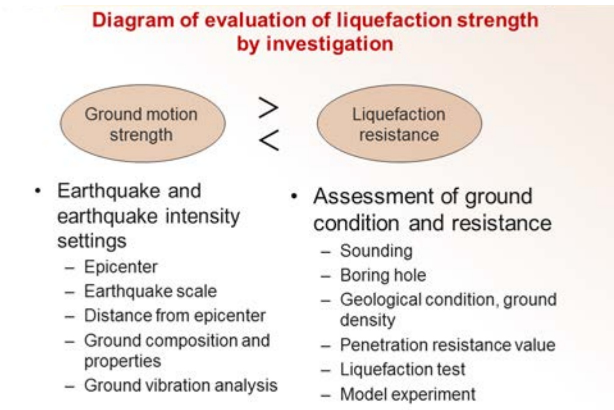
This region was hit again by earthquake eastward offshore of Hokkaido the following year, but this time the surface wasn't covered by snow, making the traces of sand boils, which are thought to be signs of liquefaction, visible on the surface of the embankment.

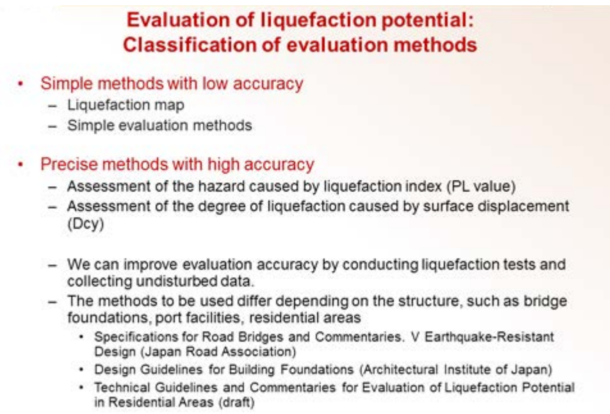




Several embankments on liquefied soil were also damaged during the Kushiro Offshore Earthquake, It was built on soft ground.

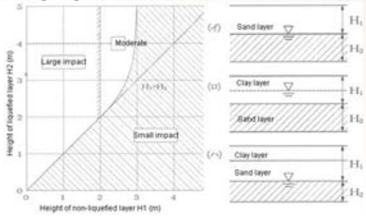






Evaluation of liquefaction potential: Simple and low accuracy methods

- Conduct the Swedish weight sounding test (SWS test)
- Search for the soil fine fraction content
- Identify non-liquefied and liquefied layers based on the soil fine fraction content
- Set the non-liquefied layer (H1) and liquefied layer (H2) to no more than 5m high
- Examine liquefaction from the following diagram



Source: Something Co.,Ltd. Official Website
http://www.s-thing.co.jp/jiban_ekijoka_kento/

Evaluation of liquefaction potential: Precise and high accuracy methods

- Use the electric static cone penetration test (CPT) or boring survey to search for soil liquefaction resistance based on soil properties, peripheral surface resistance, point resistance, and pore water pressure
- The extent of the exterior damage (PL) and ground surface displacement (Dcy)
- Identify the degree of liquefaction risk based on the PL value, and the level of liquefaction based on the Dcy value

Source: Architectural Institute of Japan Official Website
http://www.s-thing.co.jp/jiban_ekijoka_kento/

Liquefaction survey: FL method

- Calculates the soil's resistance ratio against liquefaction (FL value) in every depth

$$FL = R / L$$

where
R: liquefaction resistance L: peak shear stress ratio

- The liquefaction index (PL value) is calculated by integrating the FL value

$$PL = \sum_{k=1}^{n} (F_k \cdot W(z_k) \cdot \Delta z_k)$$

$$F_k = \begin{cases} 1 - FL_k & FL_k < 1.0 \\ 0 & FL_k \geq 1.0 \end{cases}, \quad W(z_k) = 10 - 0.5 z_k$$

FL_k; FL value of k-th layer
z_k; Depth from the center of k-th layer (m)
Δz_k; Thickness of k-th layer (m)

Evaluation of liquefaction potential: FL method

Relationship between PL value and degree of liquefaction
(Osaka Prefecture, 1997)

PL value	Degree of liquefaction
0 - 5	Almost no liquefaction and no damage
5 - 10	Small-scale liquefaction with almost no impact no structures
10 - 20	Moderate liquefaction with potential effect on structures
20 - 35	Severe liquefaction with many sand boils and cases of tilting spread foundation structures
≥ 35	Extremely severe liquefaction with large-scale sand boils and damaged structures

Evaluation of liquefaction potential: Dcy method

- Ground surface displacement (Dcy)

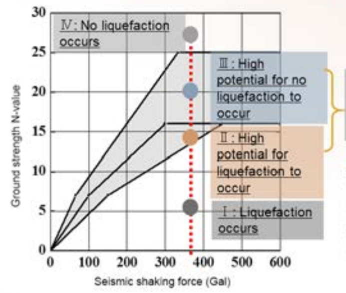
$$Dcy = \sum (\gamma_{cy} \cdot H)$$

where
γ_{cy}: peak shearing strain H: thickness of every layer

- Relation between ground surface displacement (Dcy) and degree of liquefaction

Dcy (cm)	Degree of liquefaction
0	None
≥ 5	Minor
> 5, ≤ 10	Low
> 10, ≤ 20	Moderate
> 20, ≤ 40	Major
> 40	Severe

Comparison of ground vibration and liquefaction resistance



Gray zone:
conditions are not cleared out

At seismic intensity IV or low, chances for liquefaction to occur are considerably reduced

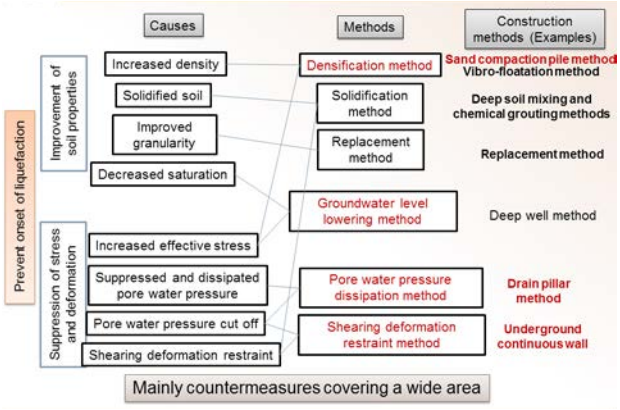
- The risk is higher when quake intensity exceeds the ground strength
- Cannot improve accuracy of analysis due to the large gray zone

Grounds and structures with great potential for suffering damage from liquefaction

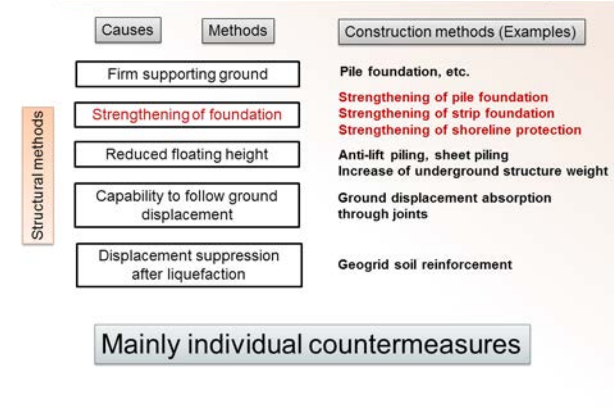
- Sands with loose depositional packing
  - River zone, floodplains, water routes; coastal and lake shores
  - Areas which names in Japanese include "water" kanji radical
    - Meikai, Ikemi, Enoshima, Oitsu, Shimizu, Shirakawa, Takasu, Akazawa, Minatomachi
    - Ushikawa, Shimoji, Funamachi, Kitajima, Funahara
- Reclaimed lands in the port area
  - Artificial grounds lack in density
  - Grounds subject to countermeasures can easily suffer repeated damages
- All sorts of embankment with high groundwater level
  - Housing, road and railway embankments over valleys
  - River levees, dams

COUNTERMEASURES AGAINST LIQUEFACTION

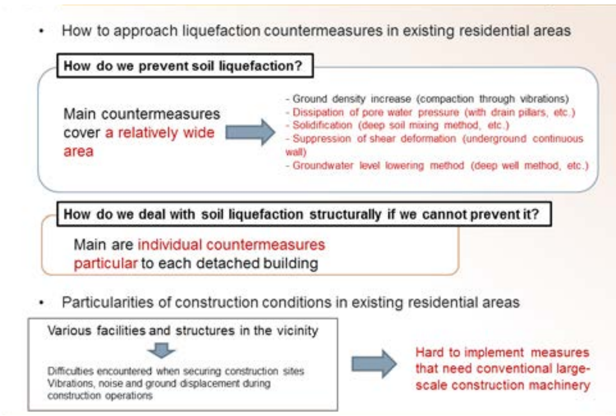
- Prevent soil liquefaction
  - Protect foundations and soil structures
  - Remove the causes (conditions) of liquefaction onset
- Protect structures from liquefaction
  - Although we cannot prevent soil liquefaction...
  - Make structures stay in place (never move)
  - Make structures that do not break apart even when moving



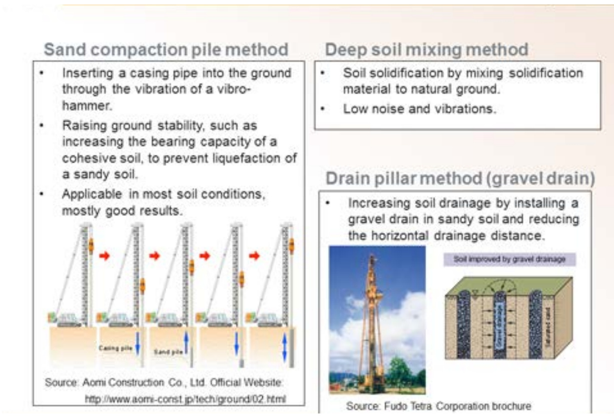
Causes
Methods
Construction methods (Examples)
Prevent onset of liquefaction
Improvement of soil properties
Increased density
Solidified soil
Improved granularity
Decreased saturation
Suppression of stress and deformation
Increased effective stress
Suppressed and dissipated pore water pressure
Pore water pressure cut off
Shearing deformation restraint
Densification method
Solidification method
Replacement method
Groundwater level lowering method
Pore water pressure dissipation method
Shearing deformation restraint method
Sand compaction pile method
Vibro-floatation method
Deep soil mixing and chemical grouting methods
Replacement method
Deep well method
Drain pillar method
Underground continuous wall
Mainly countermeasures covering a wide area



Causes
Methods
Construction methods (Examples)
Structural methods
Firm supporting ground
Strengthening of foundation
Reduced floating height
Capability to follow ground displacement
Displacement suppression after liquefaction
Pile foundation, etc.
Strengthening of pile foundation
Strengthening of strip foundation
Strengthening of shoreline protection
Anti-lift piling, sheet piling
Increase of underground structure weight
Ground displacement absorption through joints
Geogrid soil reinforcement
Mainly individual countermeasures

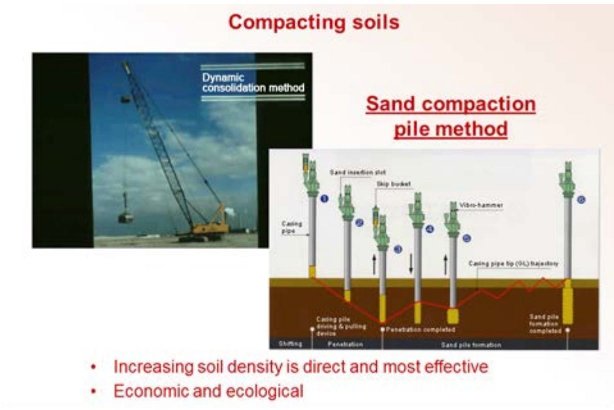


• How to approach liquefaction countermeasures in existing residential areas
How do we prevent soil liquefaction?
Main countermeasures cover a relatively wide area
- Ground density increase (compaction through vibrations)
- Dissipation of pore water pressure (with drain pillars, etc.)
- Solidification (deep soil mixing method, etc.)
- Suppression of shear deformation (underground continuous wall)
- Groundwater level lowering method (deep well method, etc.)
How do we deal with soil liquefaction structurally if we cannot prevent it?
Main are individual countermeasures particular to each detached building
• Particularities of construction conditions in existing residential areas
Various facilities and structures in the vicinity
Difficulties encountered when securing construction sites
Vibrations, noise and ground displacement during construction operations
Hard to implement measures that need conventional large-scale construction machinery

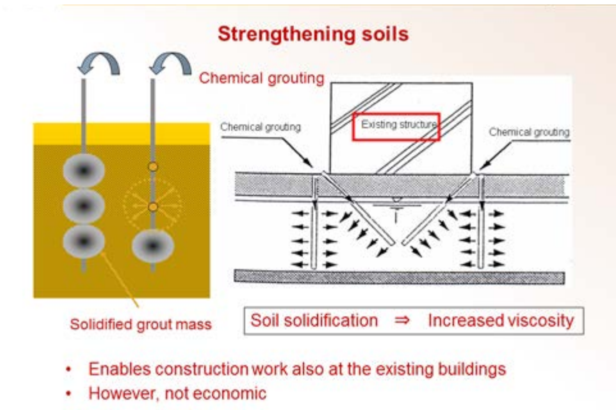


Sand compaction pile method
• Inserting a casing pipe into the ground through the vibration of a vibro-hammer.
• Raising ground stability, such as increasing the bearing capacity of a cohesive soil, to prevent liquefaction of a sandy soil.
• Applicable in most soil conditions, mostly good results.
Source: Aomi Construction Co., Ltd. Official Website: http://www.aomi-const.jp/tech/ground/02.html
Deep soil mixing method
• Soil solidification by mixing solidification material to natural ground.
• Low noise and vibrations.
Drain pillar method (gravel drain)
• Increasing soil drainage by installing a gravel drain in sandy soil and reducing the horizontal drainage distance.
Soil improved by gravel drainage
Source: Fudo Tetra Corporation brochure

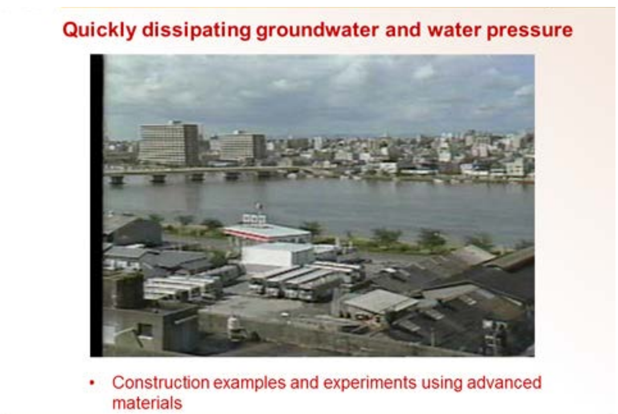
Countermeasures for embankment liquefaction with soil compaction
D-5
• We can prevent structural deformation of embankments by increasing soil density.



Compacting soils
Dynamic consolidation method
Sand compaction pile method
• Increasing soil density is direct and most effective
• Economic and ecological

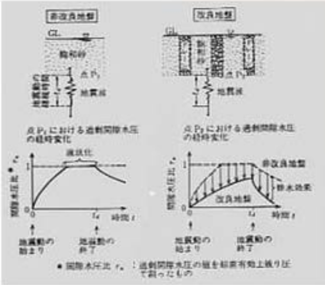


Strengthening soils
Chemical grouting
Chemical grouting
Existing structure
Chemical grouting
Solidified grout mass
Soil solidification ⇒ Increased viscosity
• Enables construction work also at the existing buildings
• However, not economic



Quickly dissipating groundwater and water pressure
• Construction examples and experiments using advanced materials

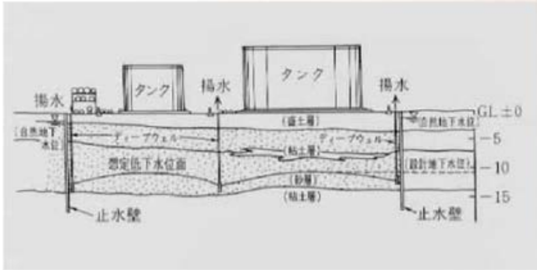
Quickly dissipating groundwater and water pressure



Gravel drain method

- Used for existing buildings, it's effective when vibration is not applied
- Largely used on quay walls in ports

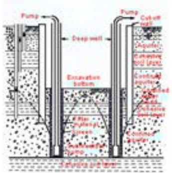
Lowering the groundwater level



- Also available for existing buildings
- Maintenance cost required -> not economic

Deep well method

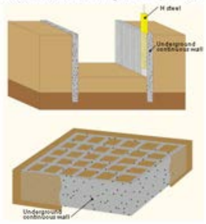
- Enclosed by a cut-off wall, these wells are used to lower groundwater level within the excavation.
- Used where countermeasures cannot be applied right beneath the structure.
- Lowering the groundwater level may cause the ground to sink.



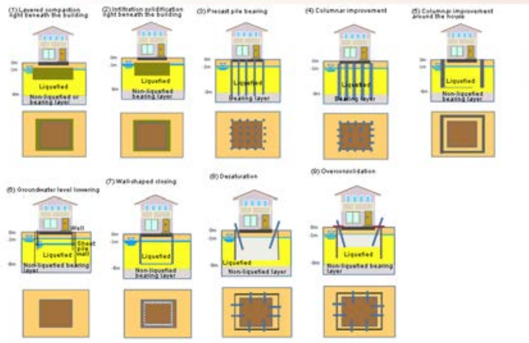
Source: Ikeda Kogyo Co., Ltd. Official Website
http://well-ikeda.com/?page_id=5

Underground continuous wall

- A highly rigid underground continuous wall is installed in the outer perimeter of the building to restrain shearing deformation.
- Together with the piles, it suppresses deformartion during earthquakes.

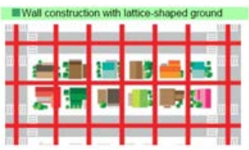


Source: CCC Association Official Website
http://ccc-kyokai.com/use-kouhou.html



Source: *How to deal with liquefaction in residential areas*, The Japanese Geotechnical Society (JGS)
http://www.jiban.or.jp/organi/bu/chousabu/20130722WS/002_OBAYASHI-130722WS.pdf

- Countermeasures to integrated liquefaction of roads and residential areas in Urayasu City
- Planning on a lattice-shaped wall construction method
  - This method partly prevents soil liquefaction, through the construction of an underground wall that surrounds residential areas (as a grid), with a cement-based solidifying agent to be inserted in the underground sand that easily liquefies.



Source: Liquefaction data, Urayasu City
http://www.city.urayasu.chiba.jp/secure/37768/shiryo.pdf

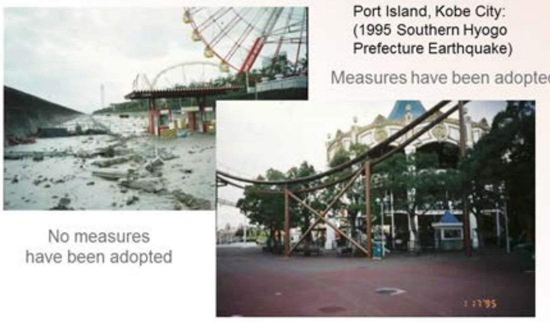
However, its cost is an issue.
If countermeasures are implemented with certain specifications, one can expect liquefaction damage to be reduced.

Are countermeasures against liquefaction effective?

- The effect is impressive
  - Damage can be entirely prevented
  - Numerous examples so far
- Why isn't this method adopted?
  - Financial issues
  - Its application depends on priorities: evacuation, support, reconstruction
    - Access to evacuation centers and hospitals, providing relief supplies and reconstruction materials
    - Emergency evacuation routes, ports, airports
  - Application according to financial productivity:
    - Highways, Shinkansen, precision machines, amusement parks

Examples of countermeasures against liquefaction

Port Island, Kobe City:
(1995 Southern Hyogo Prefecture Earthquake)



Measures have been adopted

No measures have been adopted

- The sand compaction pile method was used inside to protect the precise and costly facilities

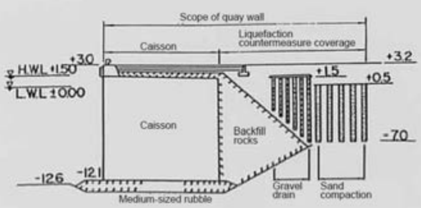
Effects of anti-liquefaction measures: West District of Kushiro Port (1993 Kushiro Offshore Earthquake)

No measures have been adopted (3-A quay wall)

Measures have been adopted (3-B quay wall)

- Countermeasures have been taken since the 1986 Middle Japan Sea Earthquake
- The difference between effects was undeniable; served as the driving force behind the restoration works

Examples of countermeasures against liquefaction for port facilities

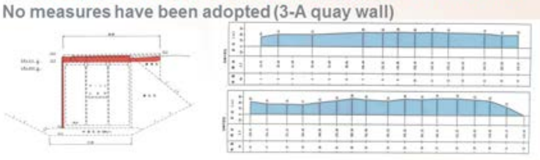


Conceptual diagram of the coverage of liquefaction countermeasures for a gravity quay wall and the scope of said wall

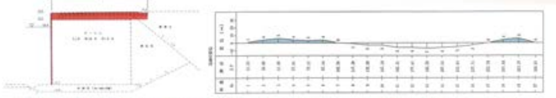
- Basically, the sand compaction pile method was applied
- Gravel drainage was used near the caisson

Effective anti-liquefaction measures: West District of Kushiro Port (1993 Kushiro Offshore Earthquake)

No measures have been adopted (3-A quay wall)



Measures have been adopted (3-B quay wall)



- The results of the quay wall displacement measurement showed the adopted measures were effective
- Facilities such as cranes were well-functioning

Comparison of anti-liquefaction measures cost

- Cost of countermeasures against liquefaction (Example)
  - Hotels (Yokohama): 10% of construction cost
  - Quay walls in ports: 35% of construction cost
  - 500 m airport runway: hundreds of millions to billions of yen
- Reconstruction cost
  - More than twice the cost of countermeasures
- For common detached housing
  - Soil improvement is unrealistic (several times the building expenses)
  - Reconstruction by consolidating building foundations after disaster is feasible

Should countermeasures against liquefaction be adopted or not?

- Cost comparison
  - Expenses necessary for countermeasures
  - Expenses necessary for reconstruction
- Earthquake-resistant design is an economic force function
  - Public and private facilities
  - Developed and developing countries
- Importance and economic efficiency of structures
  - Strategic and selective seismic strengthening
  - Important facilities; Maintaining security and safety
    - Emergency evacuation routes, evacuation facilities, medical facilities, anti-disaster centers
  - Facilities important for the economy and productivity; expenses related to economic losses and reconstruction
    - Highways, Shinkansen, trade ports
    - Is Tokyo Disneyland smarter?

Buildings and facilities of Tokyo Disneyland and Tokyo DisneySea (as of March 28)

State of the buildings and facilities of Tokyo Disneyland and Tokyo DisneySea

Buildings and facilities of both Tokyo Disneyland and Tokyo DisneySea did not suffer major damage after the 2011 earthquake. Some parts of the roads that had suffered minor cracks are being repaired, but gates are open all the same since these cracks did not hinder the safety of the amusement park.

Furthermore, liquefaction occurred in some parts of the parking lot, but visitors can park normally since it was fixed with gravel. Buildings and facilities of Disney Hotels, Ikspiari (R), Cirque du Soleil (R) Theater Tokyo and Disney Resort Line did not suffer major damage (Ikspiari will reopen on March 28).

Countermeasures against liquefaction: Tokyo Disneyland Sea

- State of liquefaction

  Liquefaction only occurred in the parking lot, not in the amusement park

Source: hochi.yomiuri.co.jp

Source: www.47news.jp

Source: www.yomiuri.co.jp

Countermeasures against liquefaction: Tokyo Disneyland Sea

- State of the amusement park (one part of it)

Westernland

Some bare rocks of Big Thunder Mountain are currently under repair, but other buildings and facilities did not suffer major damage.

Repair of some bare rocks of Big Thunder Mountain

No major damage except a few cracks

Critter Country

Buildings and facilities did not suffer major damage.

Source: Tokyo Disney Resort Official Website
http://www.olc.co.jp/wpmu/wp-content/blogs.dir/2/files/2011/03/20110328_01.pdf

Countermeasures against liquefaction: Tokyo Disneyland Sea

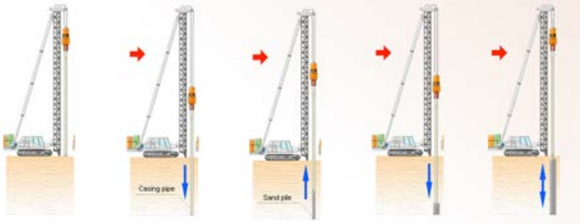
- Sand compaction pile method

This method is used to prevent soil liquefaction by solidifying the ground in compacting it. It prepares the ground through the insertion of sand compaction piles into the ground, by inserting and extracting a casing pipe repeatedly with a vibro-hammer.

Source: Aomi Construction Co., Ltd. Official Website
http://www.aomi-const.jp/tech/ground/02.html

Countermeasures against liquefaction: Tokyo Disneyland Sea

Source: Aomi Construction Co., Ltd. Official Website
http://www.aomi-const.jp/tech/ground/02.html



1) Positioning
The casing pipe is positioned.

2) Insertion
The casing pipe is driven into the ground using a vibro-hammer, until it reaches the required depth.

3) Insertion completed
The sand pile is discharged from the tip of the casing pipe, while extracting this casing pipe.

4) Pile formation
The sand pile is compacted by driving the pipe back down into the sand.

5) Pile formation completed
The pipe-raising and compaction procedure are repeated numerous times, forming a sand pile to the ground.

Status of liquefaction mitigation implementation around Disneyland Sea

- No measures have been adopted in the parking area
- No measures have been either adopted in the residential area

Residents whose houses were damaged due to liquefaction lost a trial for "unpredictable liquefaction"

Thirty-six residents of Urayasu City (Chiba Prefecture), whose houses were damaged due to liquefaction after the Great East Japan Earthquake, sued Mitsui Fudosan (Tokyo) to which they had bought the houses. The Tokyo District Court pronounced its judgment on the 8th to reject the claim of a compensation amounting to about 840 million yen.

Mr. Toshiyuki Matsumoto, Presiding Judge, pointed out that "it was complicated to estimate if any damage caused by liquefaction would occur when selling these houses."

The suit was filed by the owners of 30 three-story houses located on a land fill that Mitsui Fusosan had sold to the city between 1981 and 1982. The earthquake of March 2011 caused soil liquefaction of the lots for sales and houses suffered damage such as house leaning.

The plaintiffs argued that the fact that soil improvement was not carried out, though the risk of liquefaction was widely known (1964 Niigata Earthquake, etc.), was against the law. However, this argument was rejected since "an earthquake as important as the Great East Japan Earthquake could not have been predicted, so there was no obligation of soil improvement."

- YOMIURI ONLINE 2014.10.08 12:12

Abiko City giving up on countermeasures against liquefaction

On the 30th, Abiko City (Chiba Prefecture) announced that implementing countermeasures on soil improvement was difficult in the eastern part of Fusa District, which had suffered from liquefaction damage after the Great East Japan Earthquake.

Only 20% of land owners interrogated agreed on the "groundwater level lowering method," which consists in reducing underground water by pumping it. The decision to give up on countermeasures was eventually taken at an information session for the residents held in November. The city plans on looking for financial support for works to be done independently.

In the 1950s, this same district suffered from liquefaction damage on a land of about 12.5 hectares, where a swamp used to be filled. About 120 houses and shops were completely destroyed.

The city has been looking for a construction method to carry out soil improvement works in areas affected by disasters, thanks to a reconstruction subsidy received from the Government. The sand compaction pile method, in which sand and mortar are inserted into the ground, was initially considered, but the city decided to adopt the groundwater level lowering method, since no agreement could be reached with the residents due to the expensive amount of money they had to pay. (...)

Some of the reasons given for this disapproval (multiple answers possible) were: "Cannot afford the cost" (54%), "Do not have the intention to use the residential area" (29%), "Cannot install a well in the residential area" (23%). According to the city, the cost for this construction method was expected to be between 9,000 yen to 18,000 yen per year, but since this cost is permanent, some said that "it is complicated to make future generations pay for this." Besides, many lands are vacant since buildings were demolished.(...)

YOMIURI ONLINE 2014.10.02 09:00

平成 28-29 年度東三河地域防災協議会研究テーマ

Web サイト「つながる防災」を通じた防災コミュニティ形成（報告書）

代表者　斉藤大樹（豊橋技術科学大学 安全安心地域共創リサーチセンター長）

編さん　安全安心地域共創リサーチセンター

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国立大学法人 豊橋技術科学大学 安全安心地域共創リサーチセンター CARM

〒441-8580 愛知県豊橋市天伯町雲雀ヶ丘 1-1 環境防災実験棟 201　(Tel.0532-81-5157)