



# つながる教材

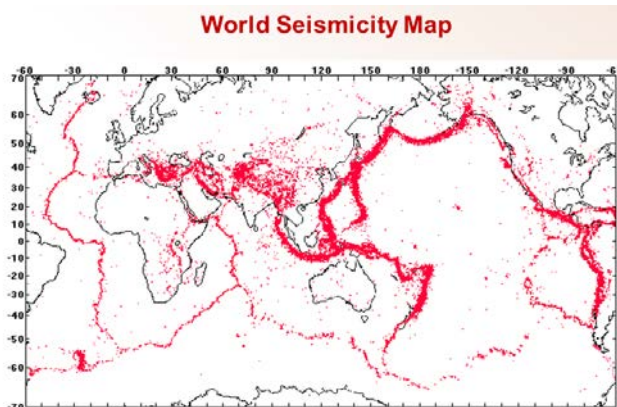
国立大学法人 豊橋技術科学大学  
安全安心地域共創リサーチセンター

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

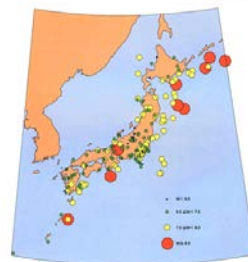
Earthquakes do not occur all over the world. Seismic activity is actually very limited to some areas. This reminds us that there are more people living on this planet who do not experience earthquakes.

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.

## Earthquakes that have caused major damage



Chronological Scientific Tables 2002

- 1891 The Great Nobi Earthquake, M8.4 (7,300)
- 1896 Meiji Sanriku Earthquake and Tsunami, M8.7 (27,000)
- 1923 Kanto Earthquake, M7.9 (140,000)
- 1927 Kita Tango Earthquake, M7.3 (2,900)
- 1933 Sanriku Earthquake and Tsunami, M8.1 (3,100)
- 1946 Nankaido Earthquake, M8.0 (1,400)
- 1948 Fukui Earthquake, M7.1 (3,800)
- 1964 Niigata Earthquake, M7.5 (28)
- 1968 Tokachi Offshore Earthquake, M7.9 (53)
- 1983 Middle Japan Sea Earthquake, M7.7 (104)
- 1993 Kuroshiro Offshore Earthquake, M7.8 (12)
- 1993 Southwest-off Hokkaido Earthquake, M7.8 (23)
- 1995 Southern Hyogo Prefecture Earthquake, M7.2 (6,427)
- 2004 Niigata Prefecture Chuetsu Earthquake, M6.8 (68)
- 2007 Niigata Prefecture Chuetsu Offshore Earthquake, M6.8 (15)
- 2011 The Earthquake Off the Pacific Coast of Tohoku Region, M8.4 (19,000)

### Overview of Natural Disasters in Japan

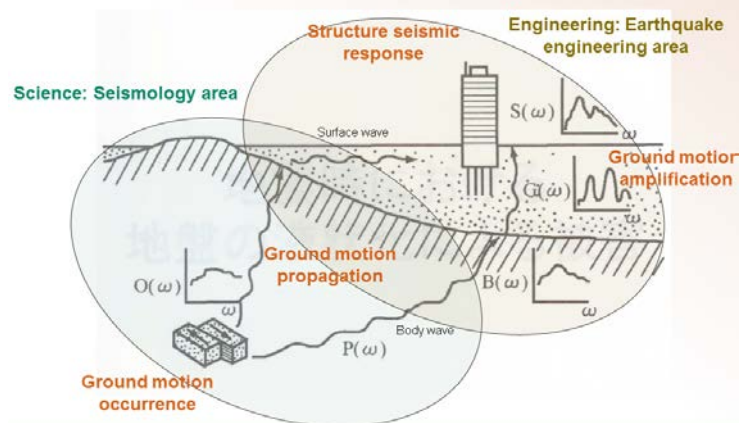
- Natural disasters that cause material and human damage
  - Earthquakes (fire, tsunami, landslides)
  - Cloudbursts (rains in the rainy season, heavy rainfalls in urban area, landslides)
  - Typhoons (floods, ocean waves, landslides)
  - Volcanic eruptions (pyroclastic flows, mudflows)
  - Strong wind (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

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.

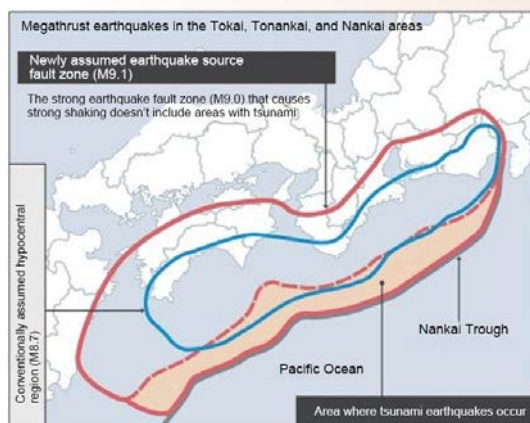
In recent years, there have been prominent initiatives transcending the academic frameworks, as major efforts have been made to further disseminate information on earthquakes and prepare shelter environments for temporary occupancy.

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 areas related to earthquakes



### Predicted Megathrust Earthquakes

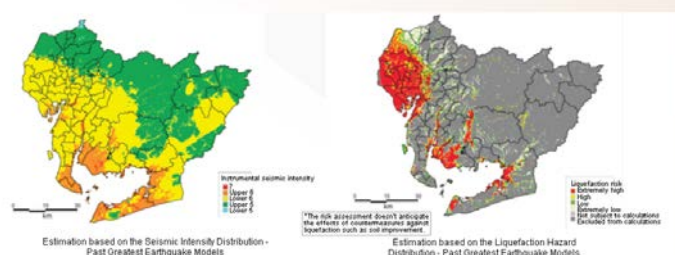


These are the study results on intensity and liquefaction potential due to “The Greatest Earthquake Models Ever” concerning the three interrelated quakes, which were announced in 2013 by Aichi Prefecture.

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

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.

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





### Liquefaction Points Recorded in The Great East Japan Earthquake



- Why do seismic intensity and liquefaction vary from region to region?
- What causes these biases?
- Today's lecture main point

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.

### Seismic Damage to Structures Not Directly Attributable to Liquefaction



### Seismic Damage to Structures Not Directly Attributable to Liquefaction



Tomakomai City:  
2003 Tokachi Offshore Earthquake



Sumatra Island:  
2004 Sumatra Earthquake

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 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.

#### Liquefaction phenomena recorded in ancient documents



“Ansei Kenbunroku - Part II”:  
The 1854 Ansei Tokai Earthquake (1854), Suruga Province

#### NHK program: the first recording ever to show structural damage caused by liquefaction phenomenon



1964 Niigata Earthquake: Sinking terminal building

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.

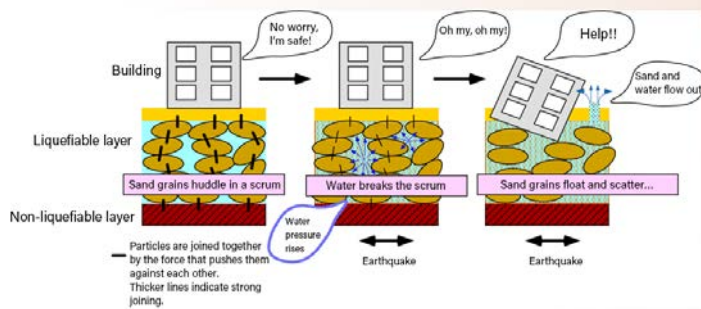
#### History of research on liquefaction led by Japan and the USA

- Research has gained full momentum in Japan and the USA since 1964 (Niigata Earthquake, Great Alaskan Earthquake)
  - “Liquefaction” was used for the first time as a technical term by Japanese researchers
  - Research follows the following steps:
    - Clarify the mechanism
    - Analyze of damage
    - Establish surveying methods
    - Develop preventive measures and earthquake-resistant design methods
  - Research results were verified when the Middle Japan Sea Earthquake hit in 1983
  - From this point on, *countermeasures against liquefaction* have been incorporated into many earthquake-resistant design methods

## MECHANISM OF LIQUEFACTION

- Mechanism of sand liquefaction (micro-level)
- Mechanism of sand liquefaction (micro-level)
- Conditions for onset of liquefaction

### Onset mechanism of liquefaction phenomenon



- Originally, sandy soil makes a good foundation for supporting buildings.
- Compared to clay soil, it presents almost no problem.
- However, once an earthquake occurs...

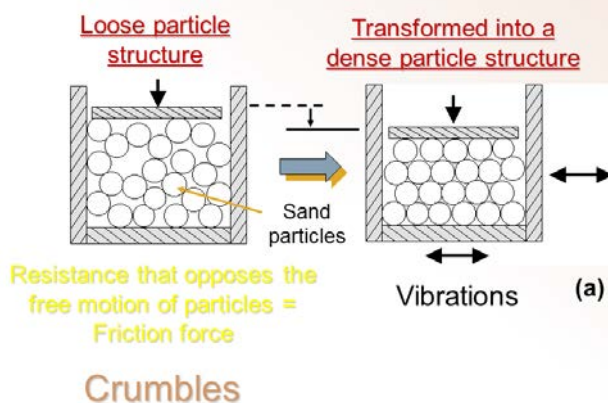
First, let's study the liquefaction phenomenon from a microscopic viewpoint.

- 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

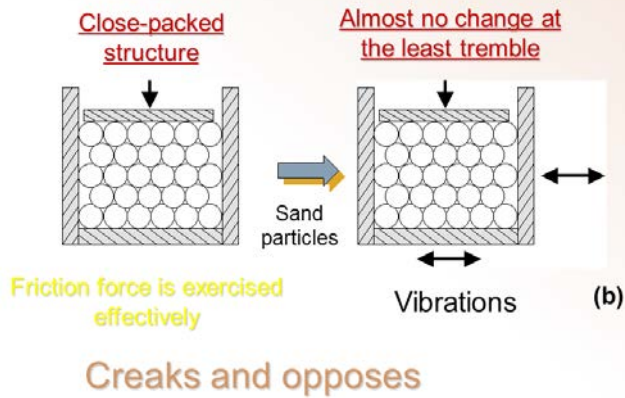
- Sand deformation
  - Changes in the structure of sand particle arrays
  - Soil particles don't break, they deform
- Sand particle motion in water
  - Settling velocity becomes slower as water's resistance acts on the particles
  - Particles will not re-stabilize until all of the water drains out
-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

### Vibration of loose particle structures



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.

### Vibration of dense particle structures



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.

### NHK program: microscopic study of particle structure using photoelasticity

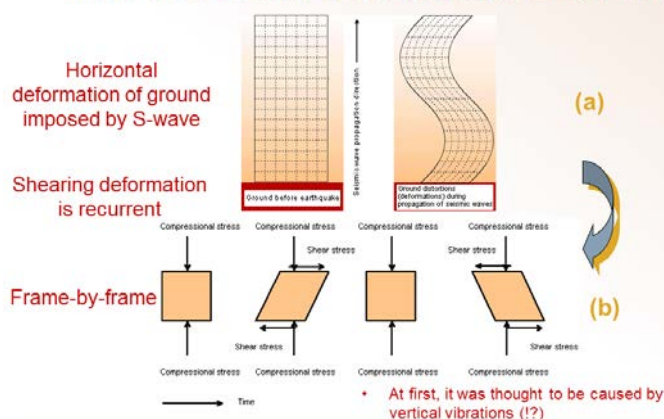


When a soil is saturated with groundwater, no matter the vibrations it is subjected to, its volume will not modify immediately. In this experiment, applying vibration while soil volume remains constant is causing peak shearing deformation.

Particles in dense soils do not change their 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.

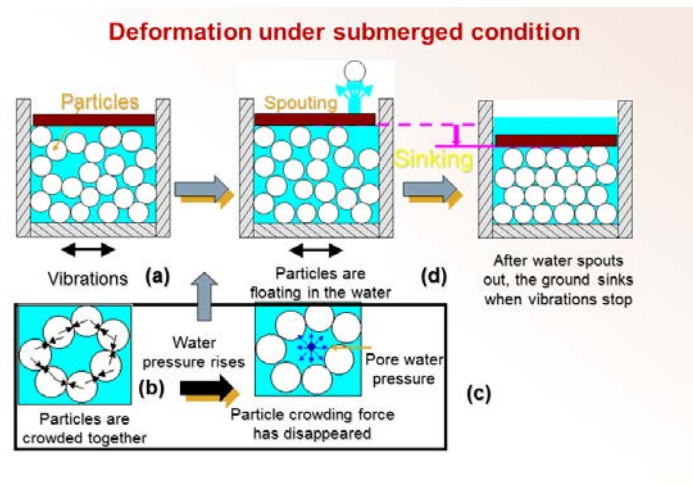
### Seismic wave transmission. Liquefaction phenomenon onsets due to shearing deformations imposed by S-wave



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.

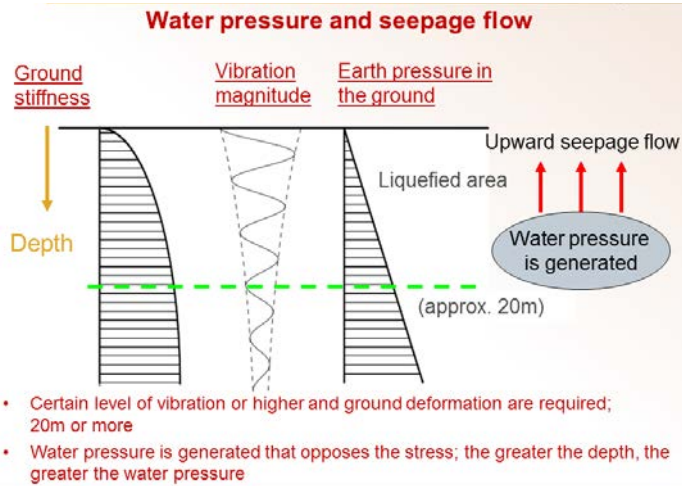
- Water pressure is generated in deep layers  
 ... Particles must be exposed to stress from the surroundings in order to change their array structure. Therefore, soil particle structures modify due to vibrations at a certain level of depth. Yet, if the place is too deep, the very seismic motion is small, 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 spurts 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.

#### Macroscopic mechanism of liquefaction phenomenon

- **Water pressure is generated in deep layers**
  - Particle structures modify in layers subjected to stress
  - If too deep, deformation is, on the contrary, reduced
- **Seepage flow is generated on the way to the ground surface**
  - Liquefaction occurs also in shallow layers
- **Traces of liquefaction phenomenon**
  - Sand boils, mud pumping, water foundation
  - Ground surface sinkage



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.

**NHK program: the process of liquefaction and types of disaster verified by shaking table test**



**Traces of Liquefaction (Sand boils & holes)**



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.

### Water fountain and ground sinkage in reclaimed lands

It looks completely like a flood area



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**

### Liquefaction phenomenon captured in satellite image



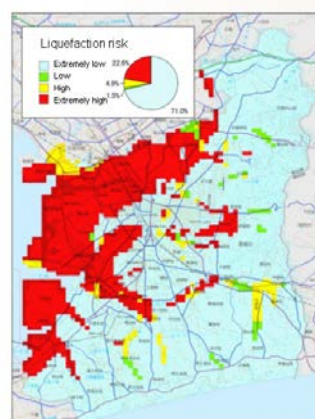
This is a satellite image taken just after the Great Hanshin-Awaji Earthquake. We can infer from the sand boils shown in other that liquefaction onset extensively in Port Island and Rokko Island.

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 Hazard Map in Toyohashi City



- Coastal reclaimed land: great impact on industries
- Toyokawa, Yagyugawa, and Umedagawa basins: great impact on residential area and infrastructure

Toyohashi City



# LIQUEFACTION-INDUCED DAMAGE CLASSIFICATION

- Liquefied soil properties
  - How do soil properties change
  - Properties of solids and liquids
- Damage classification
  - Damage due to strength and stiffness degradation
  - Damage due to ground flow
  - Damage due to natural frequency reduction

## Mechanical properties of liquefied soils

- **Two times denser than water**
  - Buoyant force is twice greater
- **Lose stiffness and strength**
  - Not self-supporting
  - Cannot bear any load
  - Vibration characteristics change
- **Flow**
  - Flow such way the ground surface becomes flat (Definition of liquids)
  - Still, are viscous

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.

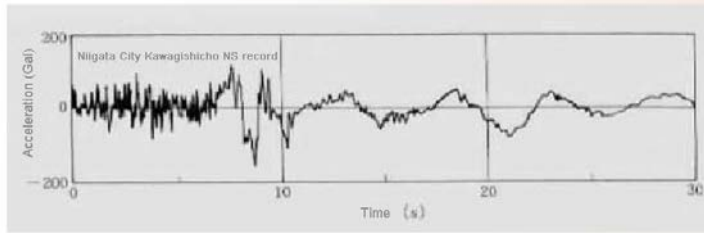
- Damage due to ground flow … Also grounds tilted at relatively moderate angles experience lateral displacement of equivalent mass. The same occurs for embankments on flat surfaces. The tendency of surfaces to become flat is the basic nature of liquefaction phenomenon.

- 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.

## Large classification of liquefaction-induced damage based on the mechanism

- **Damage due to strength and stiffness degradation**
  - Cannot bear the structure load anymore
  - Buoyant force generated in the subsoil acts on buried utilities
  - With the ground not self-supporting, earth pressure acts on retaining walls
- **Damage due to ground flow**
  - Large flows occur even from minor slopes
  - Ground flows such way the surface becomes flat (Definition of liquids)
- **Damage due to changes in vibration characteristics**
  - The ground's stiffness reduces, thus period of vibration becomes longer
  - The impact on structures is reduced; structures built on top of ships
  - Base isolators

### 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 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.

### Classification of damage due to strength and stiffness degradation

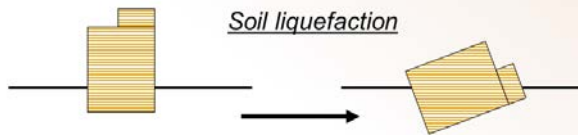
- **Bearing capacity loss: sinkage or collapse of structures**
  - Buildings, poles, piers and abutments
- **Buoyancy increase: buoyant buried structures**
  - Storage tanks, sewage pipes, manholes
  - Buried pipelines
- **Earth pressure increase: uplift of anti-earth pressure constructions**
  - Quay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

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.

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



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

**Ground strength degradation: Loss of bearing capacity**

- The bearing capacity (capacity of soil to support the loads applied to the ground) in liquefied soils is lost
- Heavy constructions sink and tip over

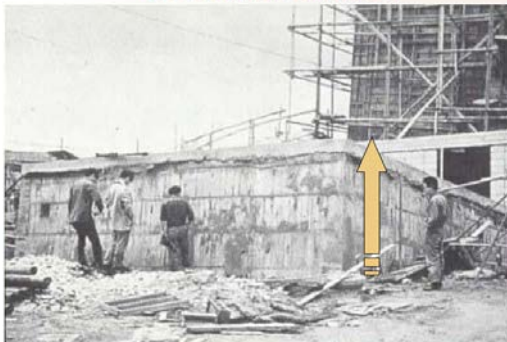
Because of reduced bearing capacity in liquefied soils, heavy constructions sink considerably, or in case of eccentric loading, they collapse.

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.

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

- Spread foundation (strip foundation) with no piers to support them
- The superstructure was almost intact; there was also little human damage

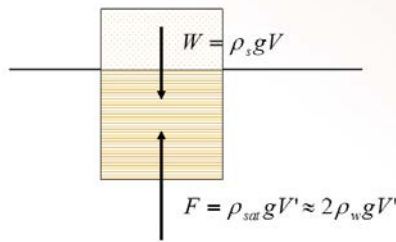
**Buoyant buried utilities: Water storage tank, Niigata Port (1964 Niigata Earthquake)**

- The empty water storage tank floated upward due to the effects of a buoyant force two times higher than that of water

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.



### Buoyant buried utilities: Water storage tank, Niigata Port (weight-buoyant force balance)



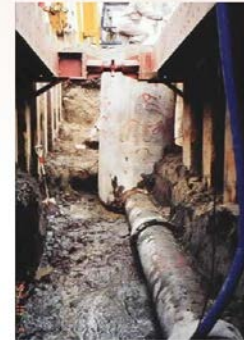
- When soils liquefy, they are exposed to a buoyant force.
- This force is twice higher than when under the water.
- Concrete containers and pipes also float, if empty.

$V$ = total volume,  $V'$ = volume of underground section

$\rho_s$ = density of the structure,  $\rho_{sat}$ = density of liquefied sandy soil

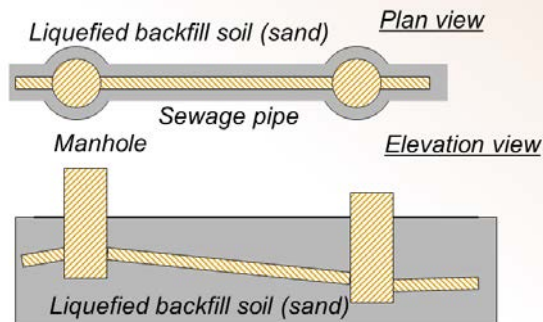
Illustrated here are a sewage pipe and manhole in Kushiro Town damaged during the Kushiro Offshore Earthquake. I was surprised to see how the manhole had floated up 1.4 meters. This is also a result of the buoyancy of liquefied soils.

### Buoyant buried utilities: Sewage pipelines, Kushiro Town (1993 Kushiro Offshore Earthquake)



- Manholes floated up 1.4m
- No liquefaction observed in the surrounding ground

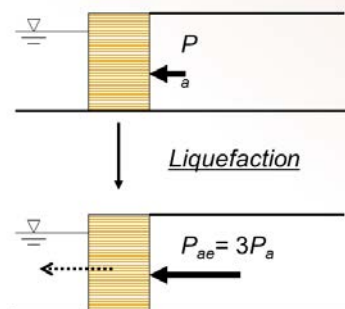
### Buoyant buried utilities: Sewage pipelines, Kushiro Town (1993 Kushiro Offshore Earthquake)



- After excavations and laying of the pipeline, the backfill soil liquefied.
- The pipeline didn't break, it floated up entirely

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.

### Uplift of anti-earth pressure constructions (retaining walls, etc.): Earth pressure increase



- Earth pressure in waterfronts increases three times due to liquefaction.
- Anti-earth pressure constructions such as retaining walls are lifted up.

### Uplift of anti-earth pressure constructions: Gravity quay walls, Kobe Port (1995 Southern Hyogo Prefecture Earthquake)



- Due to earth pressure increase, the front face of the quay walls swelled, and the back ground subsided greatly

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.

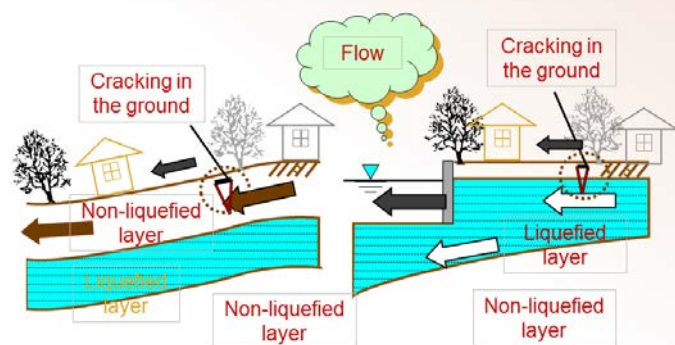
- Foundation ground liquefaction-induced flow: fall or collapse of embankments ... Even when the embankment doesn't liquefy, if the foundation underneath liquefies, the whole block will break apart followed by the ground's subsidence.

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.

### Damage due to ground flow

- **Stiffness loss: lateral ground flow**
  - Buried pipes, pile foundations
- **Shear strength degradation: flow failure in embankments**
  - Housing, road and railway embankments
  - Dams
- **Foundation ground liquefaction: fall or collapse of embankments**
  - Road and railway embankments, river levees

### Soil liquefaction flow. Flow mechanism



- Liquefaction causes soils to flow down slopes to lower ground
- Flow failures also form when constructions like retaining walls break.



### Lateral ground flow: Shinano River area, Niigata City (1964 Niigata Earthquake)

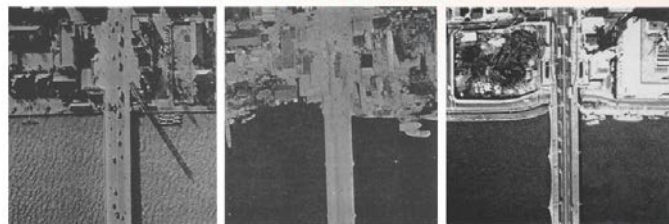


- The riverbank moved horizontally a max. distance of 5m

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.

### Lateral ground flow: near Bandai Bridge, Niigata City (1964 Niigata Earthquake)

#### Evidence in aerial pictures



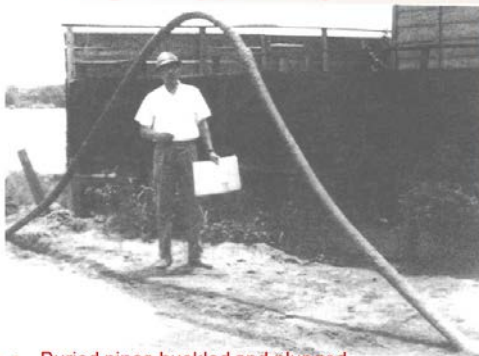
1962

1964 (after hrs.)

1971

- The ground had moved horizontally towards the river, but the abutment remained still
- The road remained crooked even after restoration

### Lateral ground flow: Buried pipes in Niigata City (1964 Niigata Earthquake)



- Buried pipes buckled and plunged
- They were compressed at low ground, and pulled up to high ground

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

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.

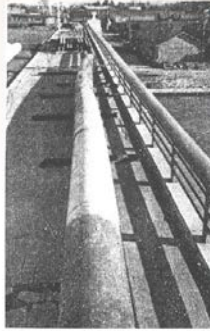
### Lateral ground flow: Shinano River bank, Niigata City (1964 Niigata Earthquake)



- Multiple cracks appeared parallel to the river
- The riverbank submerged into the water



### Lateral ground flow: Showa Bridge, Niigata City (1964 Niigata Earthquake)



- The piers and abutments were extruded to the center of the river by the liquefaction flow
- Multiple girders fell off: about 1 month after opening to traffic

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.

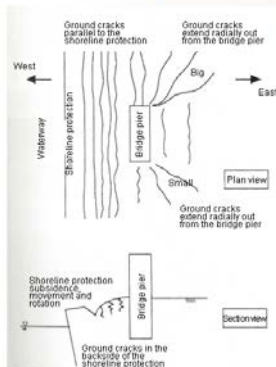
### Girders fell off due to the lateral ground flow



Rokko Bridge, Kobe City  
(1995 Southern Hyogo Prefecture Earthquake)

- Pier were extruded toward the river by liquefaction in sloping ground

### Traces of lateral ground flow Rokko Bridge, Kobe City (1995 Southern Hyogo Prefecture Earthquake)



- Cracking in the ground surface shows how ground pushed out the bridge abutment

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.

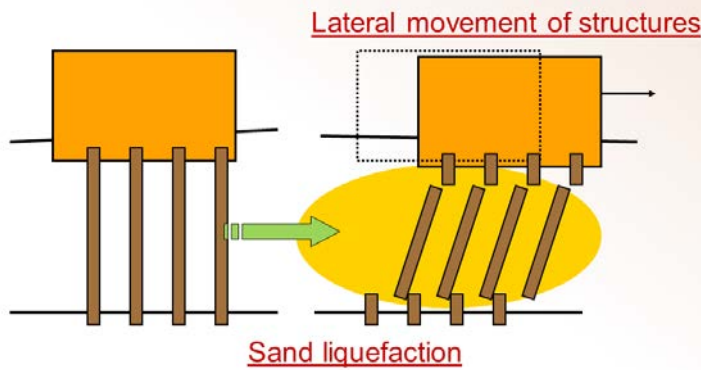
Foundation piles of buildings were also damaged during the Niigata Earthquake. These photos were taken during the investigation on foundations at the time reconstructing the affected buildings almost 30 years since the quake. The buildings were confirmed to have displaced more than 1 meter during the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

### Lateral ground flow: Buildings along Shinano River, Niigata City (1964 Niigata Earthquake)



- At the time of reconstructing the buildings where earthquake-induced lateral movement was recognized, surveys were conducted to determine the damage situation of their pile foundation
- Almost all piles were broken due to lateral load

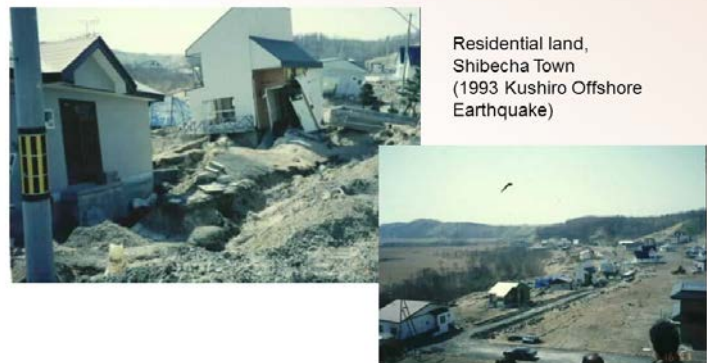
### Lateral ground flow. Pile foundation damage mechanism



- The bending load acts on the piles and causes double cracks in each pile

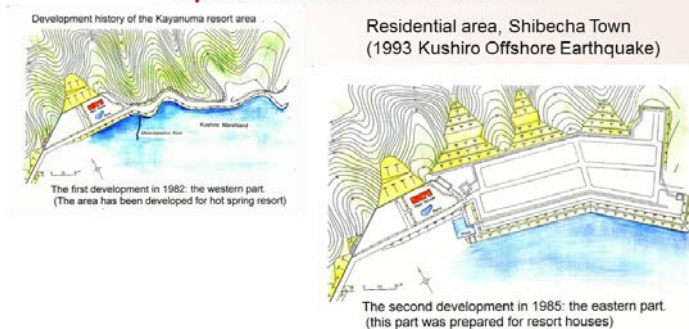
The residential area developed in the town of Shibecha was also damaged by liquefaction during the Kushiro Offshore Earthquake. The housing embankment collapsed, and several houses were damaged.

### Many houses were damaged by embankment flow



- Dozen houses built on embankment were all partially destroyed

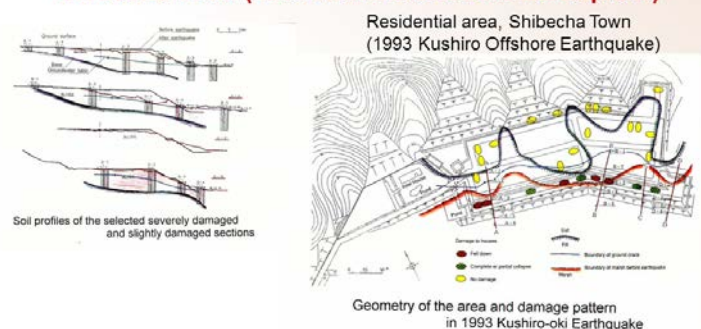
### Construction process of residential area damaged by liquefaction-induced flow failure



- Development history of the residential area
- A ridge was cut out and a valley was filled

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.

### Embankment flow failure: Housing embankment, Shibecha Town (1993 Kushiro Offshore Earthquake)



- The groundwater level in the embankment was high and caused liquefaction
- Damage was mainly to the embankment section



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.

### Sand boil observed in embankment affected by flow failure



Residential area,  
Shibecha Town  
1994 East-off Hokkaido  
Earthquake

- Same damage was induced during earthquake that hit eastward offshore of Hokkaido the next year
- Sand boils were recognized as evidence of liquefaction

### Various types of embankment couldn't maintain their function as many of them collapsed



Kushiro City  
(1993 Kushiro Offshore  
Earthquake)



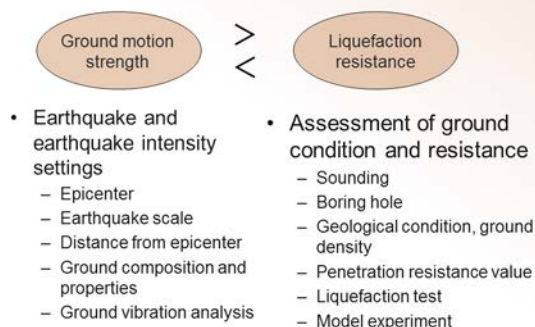
- Embankments risen up on soft ground, including sank parts, liquefy extensively due to infiltrated underwater

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

## INVESTIGATION OF LIQUEFACTION POTENTIAL

- Investigation of liquefaction potential
- Simple methods, precise methods with high accuracy

### Diagram of evaluation of liquefaction strength by investigation



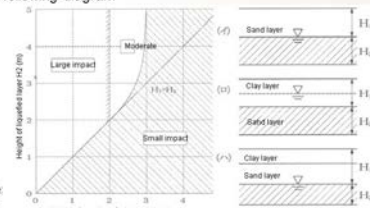
### Evaluation of liquefaction potential: Classification of evaluation methods

- Simple methods with low accuracy
  - Liquefaction map
  - Simple evaluation methods
- Precise methods with high accuracy
  - Assessment of the hazard caused by liquefaction index (PL value)
  - Assessment of the degree of liquefaction caused by surface displacement (Dcy)
  - We can improve evaluation accuracy by conducting liquefaction tests and collecting undisturbed data.
  - The methods to be used differ depending on the structure, such as bridge foundations, port facilities, residential areas
    - Specifications for Road Bridges and Commentaries, V Earthquake-Resistant Design (Japan Road Association)
    - Design Guidelines for Building Foundations (Architectural Institute of Japan)
    - Technical Guidelines and Commentaries for Evaluation of Liquefaction Potential in Residential Areas (draft)



### Evaluation of liquefaction potential: Simple and low accuracy methods

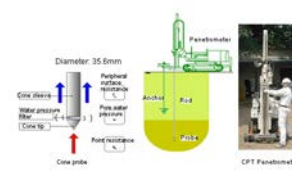
- Conduct the Swedish weight sounding test (SWS test)
- Search for the soil fine fraction content
- Identify non-liquefied and liquefied layers based on the soil fine fraction content
- Set the non-liquefied layer (H1) and liquefied layer (H2) to no more than 5m high
- Examine liquefaction from the following 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
- The liquefaction index (PL value) is calculated by integrating the FL value

$$FL = R / L$$

where

R: liquefaction resistance L: peak shear stress ratio

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

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

$FL_k$ : FL value of k-th layer

$z_k$ : Depth from the center of k-th layer (m)

$\Delta z_k$ : Thickness of k-th layer (m)

### Evaluation of liquefaction potential: FL method

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

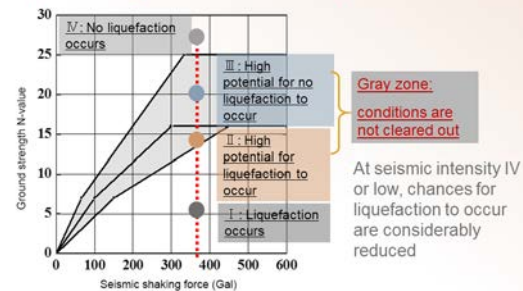
PL value	Degree of liquefaction
0 - 5	Almost no liquefaction and no damage
5 - 10	Small-scale liquefaction with almost no impact on structures
10 - 20	Moderate liquefaction with potential effect on structures
20 - 35	Severe liquefaction with many sand boils and cases of tilting spread foundation structures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

### Evaluation of liquefaction potential: Dcy method

- Ground surface displacement (Dcy)
 
$$Dcy = \sum (V_{cy} \cdot H)$$
 where  
 $V_{cy}$ : 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
$\geq 5$	Minor
$> 5, \leq 10$	Low
$> 10, \leq 20$	Moderate
$> 20, \leq 40$	Major
$> 40$	Severe

### Comparison of ground vibration and liquefaction resistance



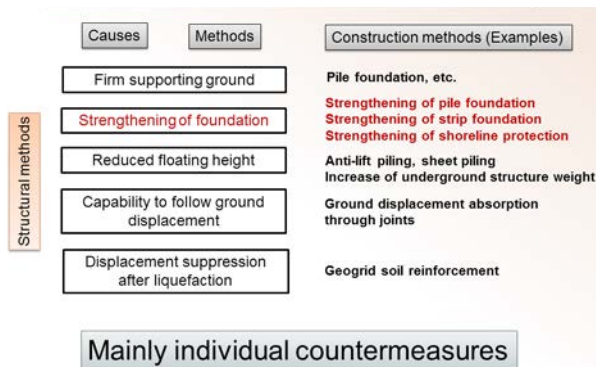
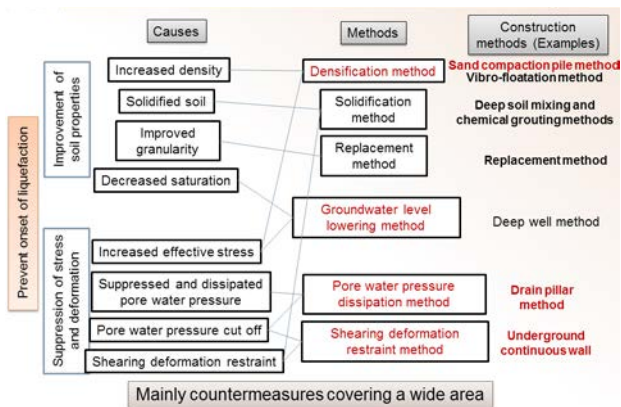
- The risk is higher when quake intensity exceeds the ground strength
- Cannot improve accuracy of analysis due to the large gray zone

### 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



- How to approach liquefaction countermeasures in existing residential areas
- How do we prevent soil liquefaction?**

Main countermeasures cover a relatively wide area

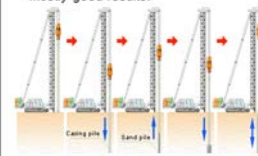
  - Ground density increase (compaction through vibrations)
  - Dissipation of pore water pressure (with drain pillars, etc.)
  - Solidification (deep soil mixing method, etc.)
  - Suppression of shear deformation (underground continuous wall)
  - Groundwater level lowering method (deep well method, etc.)
- 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.



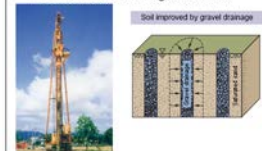
Source: Aom Construction Co., Ltd. Official Website: <http://www.aom-const.jp/tech/ground02.html>

#### 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.



Source: Fudo Tetra Corporation brochure

#### Countermeasures for embankment liquefaction with soil compaction

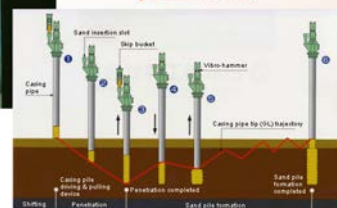


- We can prevent structural deformation of embankments by increasing soil density.

#### Compacting soils

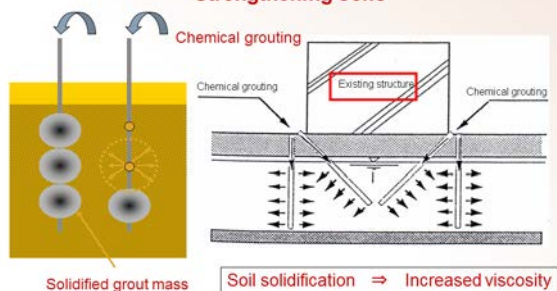


#### Sand compaction pile method



- Increasing soil density is direct and most effective
- Economic and ecological

#### Strengthening soils



- Enables construction work also at the existing buildings
- However, not economic

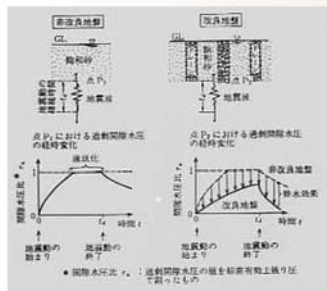
#### Quickly dissipating groundwater and water pressure



- Construction examples and experiments using advanced materials



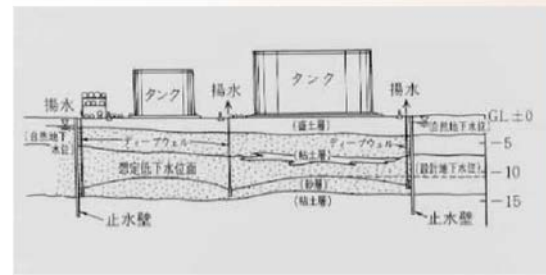
## Quickly dissipating groundwater and water pressure



## Gravel drain method

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

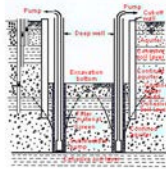
## Lowering the groundwater level



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

## Deep well method

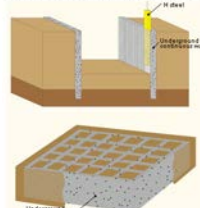
- Enclosed by a cut-off wall, these wells are used to lower groundwater level within the excavation.
- Used where countermeasures cannot be applied right beneath the structure.
- Lowering the groundwater level may cause the ground to sink.



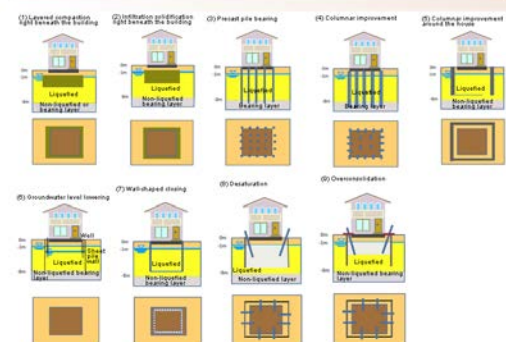
Source: Ikeda Kogyo Co. Ltd. Official Website  
[http://well-ikeda.com/?page\\_id=5](http://well-ikeda.com/?page_id=5)

## 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 deformation 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.jban.or.jp/organs/bu/chousabur/20130722VS-002\\_OBAYASHI-130722VS.pdf](http://www.jban.or.jp/organs/bu/chousabur/20130722VS-002_OBAYASHI-130722VS.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



- 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)



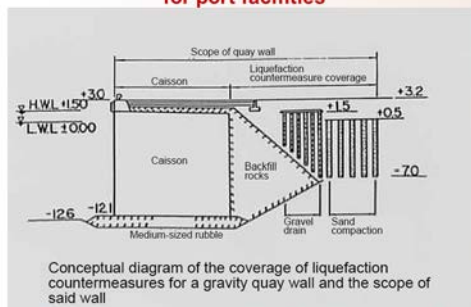
Measures have been adopted (3-B quay wall)



- 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



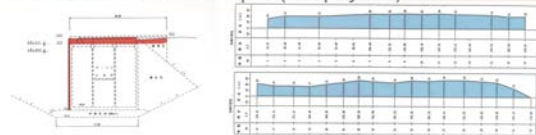
## Examples of countermeasures against liquefaction for port facilities



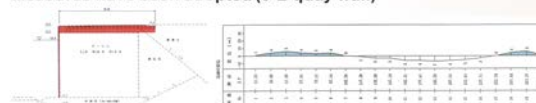
- Basically, the sand compaction pile method was applied
- Gravel drainage was used near the caisson

## 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, Ikspan (R), Cirque du Soleil (R) Theater Tokyo and Disney Resort Line did not suffer major damage (Ikspan 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)



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

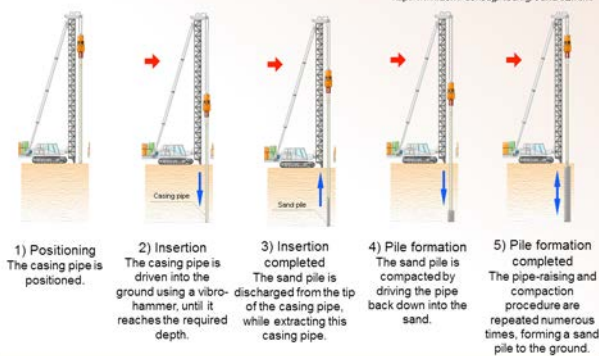
This method is used to prevent soil liquefaction by solidifying the ground in compacting it. It prepares the ground through the insertion of sand compaction piles into the ground, by inserting and extracting a casing pipe repeatedly with a vibro-hammer.



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/ground02.html>



## 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 Fudosan 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. (...)

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