

GEO-HAZARDS DURING EARTHQUAKES AND MITIGATION MEASURES

- LESSONS AND RECOMMENDATIONS FROM THE 2011 GREAT EAST JAPAN EARTHQUAKE-

(Digest Version)



The Japanese Geotechnical Society

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The Japanese Geotechnical Society

2011 Committee for Geo-hazards during Earthquakes and Mitigation Measures

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Introduction

The Japanese Geotechnical Society (the JGS) is responsible to contribute to our society by mitigation of geo-disasters, as a majority of its members are engineers or researchers specializing in academic research and development of technologies to tackle those geo-disasters caused by earthquakes, heavy rainfall or floods etc. So far, the JGS has taken a variety of actions to mitigate geo-disasters.

As significant amounts of geo-disasters happened in the 2011 Great East Japan Earthquake, we decided to summarize the lessons learned from the relevant disasters and the recommendations for appropriate countermeasures for reconstruction and recovery. These recommendations aim to be effective not only to contribute to reconstruction and recovery from these devastating disasters, but also to prevent and mitigate possible damages of earthquakes that may happen nationwide in the future.

These recommendations have been formulated based on the following five perspectives.

- 1) Have the mechanisms and causes of the observed geo-hazards been determined?
- 2) Has geotechnical engineering contributed to mitigating the disaster caused by this earthquake by reducing geo-hazards?
- 3) What kind of geo-hazards has this earthquake caused due to inadequate or lack of damage prediction and countermeasures against damage?
- 4) At this point in time, which geotechnical technologies can be proposed for use in restoration, recovery, disaster prevention, and disaster mitigation?
- 5) In order to reduce geo-hazards in the future, what issues need to be resolved in geotechnical engineering surveys, design, implementation, and maintenance?

At the moment, the research work is currently underway in the JGS to summarize these lessons and recommendations with these perspectives stated above. Although the final report will be published in March 2012, the JGS has compiled this preliminary edition because it is urgent to suggest our recommendations in order to facilitate reconstruction and prevent or mitigate damages of upcoming earthquakes. This booklet is a summary of the preliminary edition, which discusses the important issues listed below.

- (1) Damage caused by soil liquefaction, focusing on private housings
- (2) Damage and restoration of developed housing lands on hills
- (3) Disaster by massive tsunami and restoration and reconstruction
- (4) Ground subsidence and ground settlement over a wide area and its countermeasures
- (5) Dealing with disaster wastes, tsunami deposits, and soils contaminated with salt and radioactivity
- (6) The restoration policy of the social infrastructures and application of geotechnical engineering technologies

(1) Damage Caused by Soil Liquefaction, Focusing on Private Housings

Damage caused by soil liquefaction and evaluation on precautionary measures

Soil liquefaction widely made significant damages on a great number of structures in Tohoku and Kanto areas. The range of distances from the epicenter to damaged areas is consistent with that in the experiences of the past earthquakes both at home and abroad. Yet, vast areas of recently reclaimed lands in the Tokyo Bay area were damaged by soil liquefaction, though these areas are as far as 380 km away from the epicenter (Fig. 1). In the Tokyo Bay waterfront areas, over ten thousands houses suffered from serious settlements or inclinations due to soil liquefaction. Lifelines such as sewage lines and roads were also damaged severely. In the alluvial lowland of the Kanto Plain, many similar damages were observed in recently reclaimed lands on lakes and former channels. Furthermore, soil liquefaction took place in some parts of the developed housing lands on hills in Tohoku area. In Tohoku and Kanto areas, many river dikes were also damaged seriously by soil liquefaction in foundation ground (mostly located in old river channels).



Fig. 1 (left) Estimated liquefied zones (delineated by red lines) along Tokyo Bay (Yasuda, S. & Harada, K.)

Fig. 2 (right) Damaged houses and road due to soil liquefaction (Yasuda, S.)

While residential area got serious damages, public facilities hardly got any damages of soil liquefaction even in The Tokyo Bay area where many liquefaction sites were reported. Elevated structures and bridges for highways and railways, major buildings (i.e., mid- to high-rise buildings), public utility conduits, important industrial facilities (i.e., oil tanks) and many others were rarely damaged by liquefaction of foundation ground.

The above is because those public structures are designed and constructed under the technical standards which consider influence of soil liquefaction. Having experienced the Niigata Earthquake in 1964, geotechnical engineers have recognized risk of soil liquefaction. And then, the relevant seismic design codes for public facilities have been revised to consider prediction and countermeasure of soil liquefaction (Fig. 3). These improved seismic design

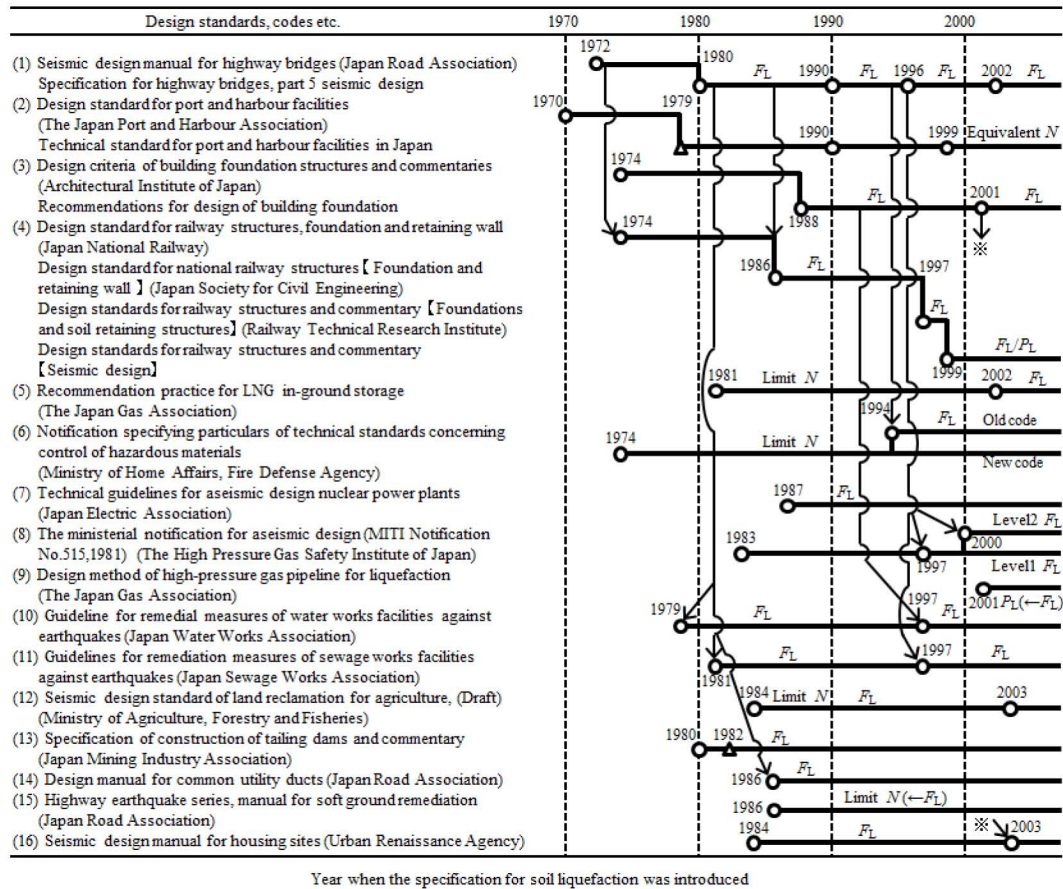


Fig. 3 History of introduction of the specifications for prediction of and countermeasures against soil liquefaction in Japanese design standards and codes for infrastructures

(Note)

F_L: the method to predict the safety factor against soil liquefaction of a soil element based on “the Liquefaction Resistance Factor (F_L)” of the soil element, which is obtained by dividing the "strength with respect to soil liquefaction" by the "liquefaction-inducing seismic load acting on the soil element."

P_L: the method to predict the soil liquefaction potential of a given strata based on “the Liquefaction Potential Index (P_L)”, which represents the degree of liquefaction predicted for the whole of a given strata obtained from the vertical distribution of F_L value.

Limit N: the method of soil liquefaction prediction based on “the limit value of N (the number of blow count by the standard penetration test”.

(A) : Oil tanks designed following the design code established 1974

(B) : Oil tanks constructed before the year of 1974.

Level 1 and Level 2: Design seismic load levels for which soil liquefaction is predicted

codes have been applied to publicly-owned structures as well as private-owned structures such as mid- to high-rise buildings including apartments built by Urban Renaissance (UR) Agency, or industrial facilities owned by large organizations. Adding to the above, growing number of districts have introduced ground improvement to manage risk of soil liquefaction. Some districts such as Tokyo Disney Land in Urayasu city, Chiba, successfully mitigated damage of soil liquefaction by ground improvement; though it is located in the midst of the estimated liquefied zones.

One may say that it seems that soil liquefaction in recently reclaimed lands in the Tokyo Bay waterfront areas is unexpected, because very serious soil liquefaction was caused by rather small ground surface acceleration of similar magnitude of the Level I design seismic motion. However, it is justified to conclude that the risk of soil liquefaction has been predictable from the perspective of geotechnical engineering. It should be noted that, even before the introduction of the Level II design seismic motion, the seismic designs under the technical standards considering risk of soil liquefaction have successfully worked by using the Level I design seismic motion and necessary countermeasures have been taken. Furthermore, today, most of the technical standards estimate risk of soil liquefaction under the Level II design seismic motion which assumes even larger earthquake motion than the Level I. Then, the current technical standards can practically predict the risk of soil liquefaction in recently reclaimed lands despite that (1) the actual acceleration records at the ground surface in the Tokyo Bay areas were about the same magnitude of the Level I design seismic motion; and (2) they fail to consider the effect of very long duration of seismic motion which was observed in the March 11 Earthquake. Yet, it is also true that the current technical standards should be improved by more properly taking into account various factors, such as effect of duration of seismic motion or effect of aging of ground. Further research on these issues is necessary.

Adding to that, there are a number of old soil structures that may not satisfy current technical standards and societal requirements, even if those soil structures are under maintenance of public institutions. Those old soil structures (pipelines for sewage and irrigation, embankments for railways and roads, river dikes and etc.) and unexamined/untreated natural ground and slopes got serious damages due to soil liquefaction, which is discussed in Section (6).

Issues and recommendations on damage of private housings

Contrary to the public infrastructures and mid- to high-rise buildings, private housings have not been designed and constructed with consideration of soil liquefaction. The following is our views and recommendations to this issue.

- 1) Consideration to soil liquefaction, based on geotechnical investigations and soil tests, is necessary for design and construction of new houses and for countermeasures for existing

houses. The situation calls for more regulations for consideration of soil liquefaction to housing market. For newly built houses, the regulations should be applied at the point of either land reclamation or constructing house or both. Seeing insufficiency of the current regulations, it is needed to introduce further regulations into Building Standards Law, Act for Regulation of Residential Land Development and Housing Quality Assurance Act. The necessary requirements to be included in the regulations are; a) addition of assessment and disclosure of ground information including possibility of soil liquefaction to the criteria comprising the housing performance indication standards; and b) introduction of knowledge and skill of soil liquefaction into licensing examination for architect for wooden buildings. Also, it is desired to establish licensed experts who can evaluate the stability of ground for both in earthquake and in daily situation, considering severe disasters in developed housing lands on hilly district by the March 11 Earthquake. Finally, for reinforcement for existing houses, it is urgently needed to develop reliable and cost-effective construction methods for coping with soil liquefaction.

- 2) Development of standardized evaluation method for potentials of soil liquefaction for private houses
 - a) Preparation methodology for hazard maps should be standardized and the existing hazard maps need improvement on credibility, by including information of old river channels, former lakes, and history of reclamation. Improved hazard maps can be useful as initial screening for cases needing further detailed investigation.
 - b) Standardized seismic load is essential to assess risk of soil liquefaction in housing areas. In this respect, it is necessary to consider the duration of main earthquake motion and aftershocks. In the March 11 Earthquake, the extensive soil liquefaction in the Tokyo Bay areas despite relatively weak earthquake motion may be caused by the very long duration and the strong aftershock 29 minutes later. These areas experienced seismic intensity levels of five lower and upper and peak ground accelerations of 150 to 200 Gals. The effects of those factors of earthquake motion (i.e., a long duration of main shock and effects of aftershocks) are practically taken into account for the recent seismic design codes introducing the Level II design seismic motion. On the other hand, it is necessary to take into account those factors when assessing soil liquefaction at a given site for a given anticipated earthquake with the epicenter at a specified location (such the Tokai, Tonankai, and Nankai earthquakes anticipated in the future). It is considered that soil liquefaction may occur in recently reclaimed lands located in regions far distant from the epicenter (such as Seto Inland Sea and San-in regions).
 - c) The Swedish weight sounding test has been used generally to investigate the ground conditions for private housing ground. However, this test method is not reliable to evaluate resistance against soil liquefaction. This test is suitable for sorting out points which need further detailed investigation. As more advanced geotechnical investigation,

the standard penetration test and laboratory tests using retrieved samples are generally applied. It is in necessity to develop simple and economical ground investigation methods with reasonable accuracy.

- 3) The JGS has responsibility to familiarize knowledge of soil liquefaction and the relevant countermeasures. The JGS has made some achievement on spreading the expertise, but there are rooms for improvement.

(2) Damage and Restoration of Developed Housing Lands on Hills

The characteristic types of damage observed in the 2011 Great East Japan Earthquake

In many locations, there was severe damage to residential land developed by cut and fill in hilly areas. In Miyagi Prefecture, There were some damaged locations that had previously been damaged in the 1978 Miyagiken-oki Earthquake, as well as some newly damaged. One reason for damage occurring in new locations is considered to be the greater amplitude and longer duration of the earthquake motion than in the 1978 Miyagiken-oki Earthquake.

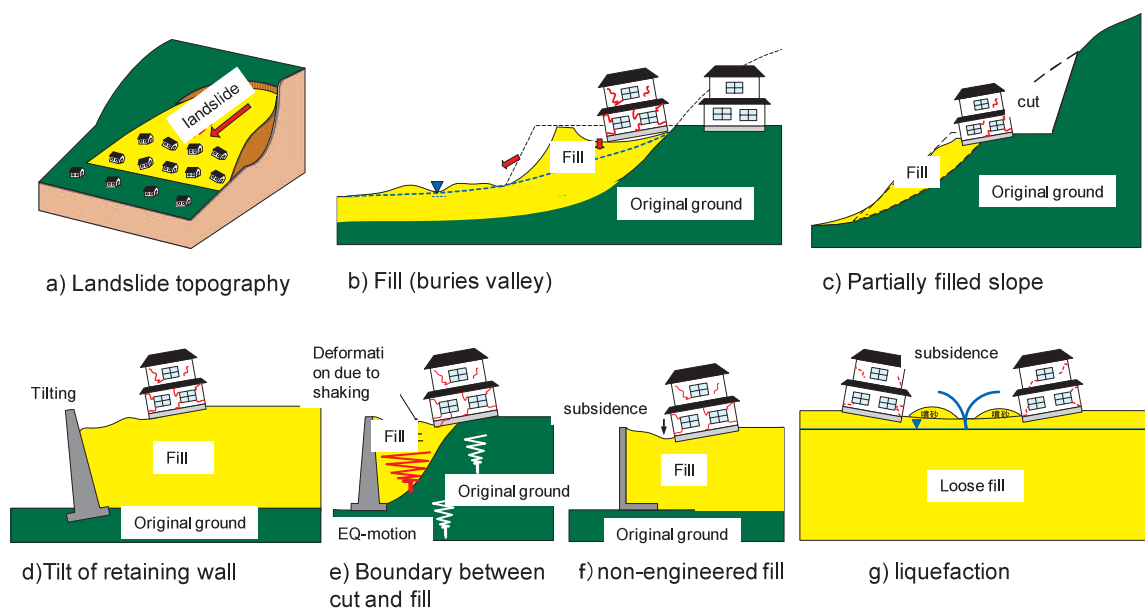
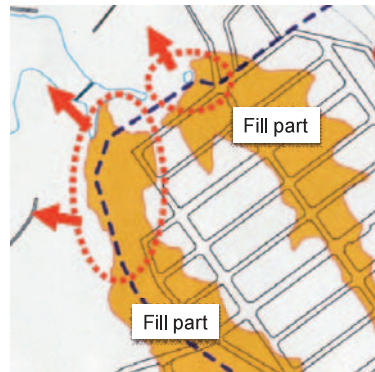


Fig. 4 Classification of damage mechanism of residential fill ground (Kazama, M.)

The earthquake damage mechanisms of residential fill ground can be classified into the types shown in Fig. 4. Of these, there was nearly no large-scale damage to residential land due to type (a), where slope failures are similar to landslide of natural grounds with sliding surface. On the other hand, there was a number of large-scale damage caused by type (b), where damage typically took place in the slopes of filled valleys. Differential settlements of houses are observed in many places on the boundary between cutting and filling as type (e) and on embankment as type (f). The last two types are thought to have resulted from the long duration of the earthquake motion. Fig. 5 is a photograph of typical case of type (b) damage.



- a) Re-damaged residential fill ground that had been damaged by the 1978 Miyagiken-oki Earthquake, Shiroishi City, Miyagi Prefecture
- b) Another typical damage case of embankment in narrow valleys, Yamamoto, Miyagi Prefecture
- c) Location of damage case shown in the middle figure in the plan view at the site

The challenges toward restoration and reconstruction

Central and local governments must support restoration and reconstruction of geo-disasters of developed housing lands (see Table 1). When foundation ground of houses gets damage, it takes much cost for homeowners to recover damage beyond reconstruction and repair of building. In the case of large-scale land damage which involves a dozen of houses, repair and reconstruction is beyond capability of each homeowner. In addition to damage of houses and ground including retaining structures, there may be damage to public infrastructures, such as roads etc. In order to ensure permanent stabilization of infrastructure and housing in the damaged area, reconstruction should aim at better performance than the previous structures by preventing sliding of whole embankment, rather than managing each house and structure. Involvement of governments can reduce burden on homeowners about soil stabilization and ground improvement to enhance seismic resistance of ground. As examples of such government assistance, there are the government-funded projects in the 1995 Hanshin-Awaji Great Earthquake, such as for reconstruction of retaining structures in private housing lands as special measures under reconstruction projects of damaged roads and

steep slope failure prevention projects. Moreover, during the restoration and reconstruction, it is required to prepare for second disaster caused by rain and for a difficulty of construction in a constrained space.

Table 1 Relationship between damage level and restoration method for developed housing lands

Classification of damage level	Classification of damage mechanism	(a)	(b)	(c)	(d)	(e)	(f)	(g)
1) Large-scale damage involving a dozen of house (exceeding the scale affordable by individual homeowners)		◎	◎	—	—	—	—	◎
2) Medium-scale damage involving several houses with influence to public infrastructures and neighboring areas		—	○	○	○	—	—	○
3) Small-scale damage for individual house, affordable by individual homeowners		—	—					
Damage to a large number of individual houses by a common cause		—	—	—	○	○	○	◎

Remarks for restoration works from damage: ◎ : cases that need full administrative support; ○ : cases that need administrative support; , Δ : cases that do not need administrative support

Our society has not fully recognized serious danger of geo-disasters especially those for private houses of individual asset. There are governmental support for seismic risk assessment and strengthening, but those measures have not been sufficiently carried out in practice. Consequently, there are a great number of sites of housing plots being left under dangerous state for a long time. It is called for identifying causes of the disaster, through investigation of embankments filling valleys and widened embankments in large-scale developed housing lands on hills. This is for raising consciousness on geotechnical risk of relevant housing lands and for development of technologies for earthquake-resistant soil structures. These investigations should cover those that suffered from earthquake damage as well as those that did not.

- 1) Similar to soil structures of public infrastructures maintained by government, it is necessary to establish a nation-level scheme for maintenance and technical management of drainage facilities, soil retaining walls and compaction control of embankments, etc. in housing lands in order to keep sufficiently high quality of design and construction of those structures.
- 2) It is necessary to establish a guideline for land use plans and disaster prevention plans that reflect precise historical characteristics of land and ground. It is necessary to develop such database containing history of land changes, information about the original topography, year of reclamation or embankment construction, past disaster history, etc. This database together with the current land use plan and disaster prevention plan should be made accessible for public with necessary legal adjustments.

- 3) In order to assure earthquake-resistance of existing housing lands, it is essential to figure out construction history and present status (backfill materials, degree of compaction, standard penetration test results (*N*-values), deformation state, condition of groundwater and surface water, etc.). Development of cost-effective reinforcement method is also needed.
- 4) Amendment of the laws concerning property insurance system is necessary, introduction of such a system as the insurance premium reduction in case that appropriate mitigation measures are taken for the geo-hazards, for example.
- 5) The sellers of new houses should be obliged to provide necessary information of the housing land so that the buyers can examine the quality of foundation ground.
- 6) To establish the supporting system for rehabilitation of the disaster-stricken areas, the JGS will provide technical guidelines for restoration and reconstruction. It will also establish a cooperative framework and a technical support system between local governments or other sectors and geotechnical engineers.
- 7) The JGS will, in addition to other projects such as publication of "Geotechnical Information in Kanto" in 2010, collect geotechnical information from all over Japan and will make it available for public. In order to achieve the goal, the JGS promotes
 - a) disclosure of geotechnical information held by national and local governments,
 - b) cooperation on disclosure of geotechnical information held by private companies responsible for maintenance and management of public infrastructure, including roads, railways, electricity, communication networks, gas, etc.
- 8) The JGS will explain its achievement of research and technical development for public on earthquake-resistance of housing lands, and will carry out disaster mitigation projects.

(3) Disaster by Massive Tsunami and Restoration and Reconstruction

Geo-disaster caused by massive tsunami

The 9.0-magnitude (M_w) undersea megathrust earthquake occurred on 11 March, 2011, as subduction-zone earthquake with its epicenter approximately 72 km east of the Oshika Peninsula. Being different from disasters caused by inland earthquake, massive tsunami brought destruction along the Pacific coastline of east Japan. Seawalls could not work enough and fully. Fishery facilities, roads and railways, industrial facilities, and power plants got damages which were related to failures of various soil structures and foundation ground. There are other various types of geo-disasters such as salted farmland, disaster wastes, management and disposal of toxic materials, radioactive soils, and tsunami deposits. This point is explained in Section (5).

Two geotechnical challenges

- 1) *The design, construction, and maintenance of tsunami defense facilities:* Most tsunami defense facilities (breakwaters, tidal barriers, coastal dikes, river dikes in the vicinity of river mouths, etc.) functioned adequately until the tsunami exceeded their anticipated heights. Thereafter, most defense facilities including their foundation ground were washed out by erosion and scouring associated with the overflowing water, and then most lost their functions completely. It is necessary to identify the mechanism of embankment failures caused by tsunami force, overflow, erosion, and scouring, and of those by scouring of foundation ground, to evaluate the effectiveness of conventional slope protection works on seawalls of embankment forms, and to develop seawalls or breakwaters with improved tsunami resistance.
- 2) *Ensuring tsunami-resistance of various public infrastructures other than tsunami defense facilities:*
 - i) Development of port facilities, evacuation shelters, river dikes and their ancillary facilities (such as sluices, sluice gates, and pumping stations) with tsunami-resistance.
 - ii) Development of roads and railways with tsunami-resistance
 - Bridges: bridge girders, abutments, backfills and foundations (scour-resistant foundations)
 - Embankments: prevention of erosion, scouring, and piping (i.e., embankment with soil-reinforcing technologies to resist overflow)
 - Route selection and suitable structural measures in harmony with tsunami-resistant town planning (i.e., embankments of high-standard highways or high-speed railways)

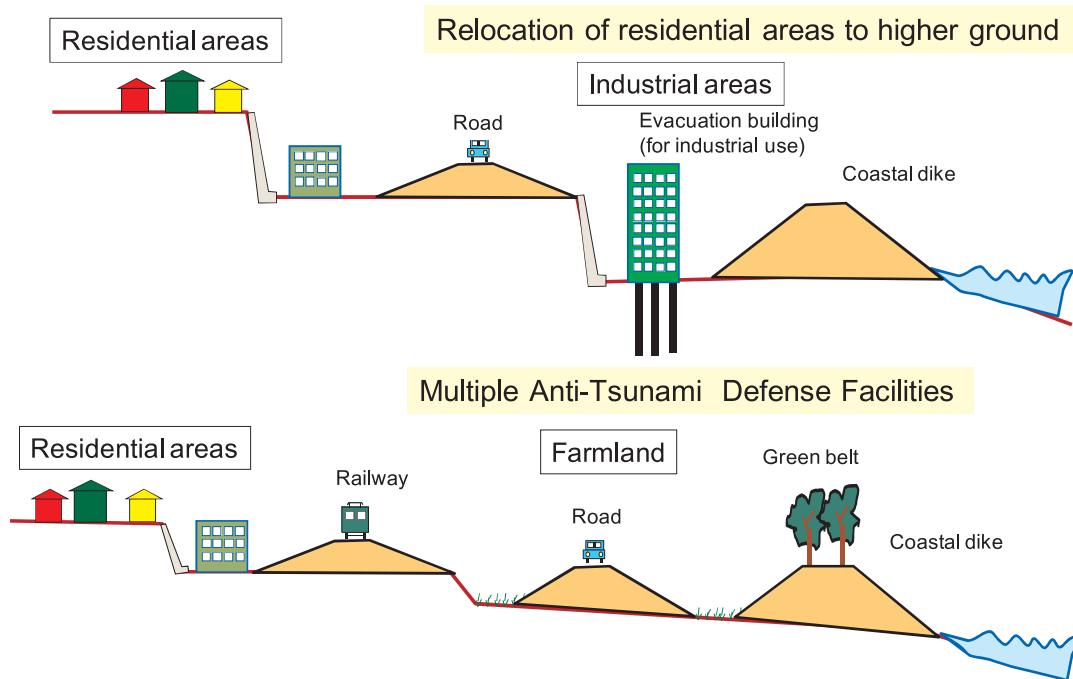


Fig. 6 Schematic diagrams showing applications of conventional geotechnical technologies to the restoration program (the first version) of Miyagi Prefecture (Asahi Newspaper, morning paper, 4th June, 2011)

How geotechnical engineering can be applied to construction of multiple tsunami defense facilities and relocation of residential areas to higher ground

There are visions of construction of multiple tsunami defense facilities and relocation of residential areas to higher ground in order to minimize casualty of massive tsunami, adding to a major single tsunami barrier and evacuation plan. Some geotechnical challenges to realize these visions are described below.

- 1) For reinforced concrete seawalls, their foundations (e.g., pile foundations) should be designed to have very strong shear resistance and pull-out resistance in order to prevent sliding and overturning by tsunami force. There might be cases that require consideration on soil liquefaction.
- 2) Conventional embankment-type seawalls cannot effectively resist erosion and scouring caused by overflow of tsunami. Thus, these embankments for roads and railways cannot stand against overflow, though these structures are supposed to be the second barrier to tsunami.
- 3) Conventional embankment-type seawalls with gentle slopes must have very large widths and amounts of earthworks when they have substantial heights to block tsunami (Fig. 6). For example, embankment must be 85 meters wide in bottom, when it is 15 meters tall, 10 meters wide in top, and has a slope ratio (height/width) of 1/2.5.

4) For relocation of residential areas to higher ground, earthworks of cutting and filling are inevitable. The grounds might be vulnerable against future earthquakes when conventional construction methods are used, as evident from the March 11 Earthquake. Some examples are poorly compacted embankments with insufficient drainage facilities, retaining structures of low earthquake-resistance, and steep cut slopes without appropriate reinforcement and soil stabilization treatments.

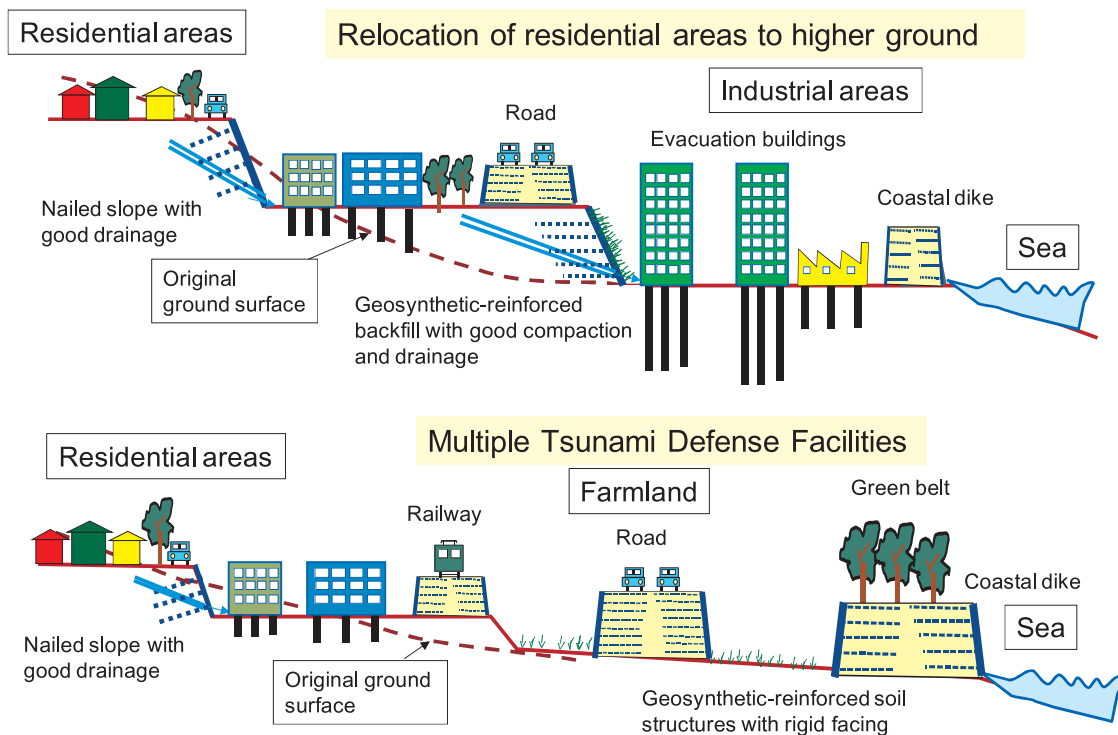


Fig. 7 Schematic diagrams showing applications of recent geotechnical technologies to the restoration program (the first version) of Miyagi Prefecture

Geotechnical engineering can certainly contribute for realization of the tsunami-proof visions. The following solutions can be proposed regarding the above issues.

- 1) Tsunami deposits can be utilized as filling materials, after removing salt, for embankments such as seawalls.
- 2) For embankment-type seawalls, it is effective to apply suitable compaction technologies, installation of drainage facilities and/or other ground improvement methods for keeping resistance against tsunami forces and erosion or scouring by overflowing. Seismic resistant design can be guaranteed also by these processes. For steep cut slopes, it is effective to use suitable drainage, and to apply appropriate soil-reinforcing technologies such as soil-nailing by inserting steel reinforcement or rock-bolts and other techniques (Fig. 7).
- 3) Some areas can hardly keep enough space for construction of stable seawalls and embankments of conventional type for roads, railways and houses, because of narrow flat

areas surrounded by mountains and shoreline. In this case, stabilization by geosynthetic-reinforced soil technologies is useful for a high earthquake-resistance while steep reinforced slopes can save space (Fig.7). Seawall embankments can be strengthened by covering their walls with reinforced concrete facings connected to reinforcement layers arranged inside the embankments to resist against wave forces and erosion or scouring by overflowing.

- 4) With measurements stated above, houses and important facilities must be located on the stabilized cut areas as much as possible, and it is better to locate roads and parks on stabilized embankments.

(4) Ground Subsidence and Ground Settlement over a Wide Area and Its Countermeasures

During the March 11 Earthquake, the ground subsided or rose in accordance with the crustal movements, while poorly compacted or loose ground also settled due to the shaking and due to dissipation of excess pore water pressure after soil liquefaction.



Fig. 8 (left) Inundated areas, Sendai Plain (by the courtesy of Geospatial Information Agency of Japan)

Fig. 9 (right) Inundation by ground subsidence, two days after the earthquake, Ishinomaki City, Miyagi Prefecture (by the courtesy of Tohoku Regional Bureau of MLIT)

A brief overview of ground subsidence and response in the future

Ground subsidence occurred over an extremely wide area along the Pacific coast from the Tohoku region to the Kanto region. This was not a consequence of ground contraction, but was associated with crustal movements. Subsidence reached several tens of centimeters in many locations, while it was as large as 1.2 meters on the Oshika Peninsula. On the Sendai Plain, the area lying below sea level increased by a factor of 5.3 from 3 km² prior to the earthquake to 16 km² afterwards (Fig. 8). As a result of ground subsidence, houses and farmland in many places have been inundated as shown in Fig. 9, which hindered recovery efforts in the disaster-stricken areas by the tsunami. Coastal dikes completely collapsed or left with insufficient height have hampered work to drain the flooded water. Inundation damage will continue until restoration of the coastal dikes, which will take a long time. As a result, groundwater is becoming progressively saline, which is causing additional serious problems for the restoration effort.

In many coastal areas, port facilities, agricultural land and urban areas, this ground subsidence over a wide area has caused serious inundation and flooding damages due to a lack of sufficient drainage. These areas are exposed to the future danger of submergence. The effect of ground subsidence is similar to the one by the expected rise in sea level due to global warming, so problems of inundation damages due to high tides, tsunamis, severe rains, and flooding as well as salination of groundwater will become more serious in the long term. In particular, where the ground has subsided in coastal areas, the relative difference between ground level within the dikes and the tide level outside has increased. As a result, the hydraulic gradients and amounts of seawater permeating into the dikes and the foundation ground have risen. In order to deal with the instability of the dikes and to prevent salination of

the ground within the dikes (in particular lands used for agriculture), it is necessary to widen the dikes or to build cut-off walls. Knowledge of geotechnical engineering is indispensable to this task.



Fig. 10 (left) Ground subsidence and heaving (in meter) by the 1946 Nankai Earthquake (Kawasumi, H.)

Fig. 11 (middle) Submerged area in Gölcük due to ground subsidence during the 1999 Kocaeli, Turkey Earthquake (Yasuda, S.)

Fig. 12 (right) A typical case of ground settlement by soil liquefaction in Urayasu City (Yasuda, S.)

There have been many reported cases of ground subsidence in wide areas during the past earthquakes in Japan and abroad. At the time of the 1946 Nankai Earthquake, there was about 1-1.5 m of subsidence around Kochi City, as shown in Fig. 10, and the city suffered flood damage. There is a high possibility of the same type of ground subsidence occurring in the future due to the anticipated Nankai, Tonankai, and Tokai earthquakes. In the 1999 Kocaeli Earthquake in Turkey, ground subsidence occurred over a wide area along the Izmit coast, including subsidence of about 1.5 m at Gölcük (Fig. 11), where an area of 1 km² was inundated. The JGS dispatched a survey team to carry out a detailed investigation of the damage.

The followings are recommendations for countermeasures against earthquake-induced subsidence.

- 1) Carry out long-term monitoring of relative elevations as the sum of long-term ground subsidence and the rise in the sea level associated with global warming
- 2) Examine the effects of ground subsidence on the society by compiling examples of the March 11 Earthquake
- 3) Investigate the mechanisms of ground subsidence over a wide area in cooperation with other related academic societies, by carrying out digital mapping of changes in topography and other survey or exploration techniques
- 4) Use of disaster wastes, tsunami deposits, and excavated soils to raise urban areas, to construct breakwaters and seawalls, and also for land reclamation.

Ground settlement and its countermeasures in the future

Although there were fortunately no inundated areas in Urayasu City, as indicated in Fig. 12, the whole ground settled due to soil liquefaction by around 50 cm at the maximum over a wide area. Hence, a serious issue has been posed over how to restore the sewer that adopts gravity flow system.

In this manner, when the ground level settles or subsides over a wide area, it not only makes life difficult, but it makes the land vulnerable to disasters by floods or inundation by heavy rainfalls or high tides. In the lowland areas below sea level in Tokyo, danger of flooding is gradually decreasing with the implementation of aseismic strengthening work on seawalls, coastal dikes or river banks. Although, fortunately, there were no inundation damage to seawalls and dikes by the March 11 Earthquake, danger of the inundation still remains, and therefore the continuation of seismic risk assessment and aseismic strengthening work are urgently needed. In addition, the lowlands throughout the nation are vulnerable to such disasters as becoming high inundation potential zones. From now, it is required to examine the risk and take necessary measures for those areas.

In the densely populated areas below sea level in Tokyo, Nagoya and Osaka, the inundation caused by a tsunami at the time of an earthquake and failures of breakwaters, coastal dikes, or river bank can be a serious problem that is fatal to humans. Especially, the damage could be enormous when underground shopping malls, subways, or other underground structures of trains or roads are flooded. At such places, measures to prevent inundation and preparation to set shelters are urgent matters. In addition, when developing a tsunami-proof town, it is necessary to select suitable road or train routes and also to adopt suitable structural types for embankments and/or RC elevated flyovers according to the selection of routes. In these cases, the disaster prevention plan is necessary with the measures mentioned above, including control and evacuation of trains or cars.

(5) Dealing with disaster wastes, tsunami deposits, and soils contaminated with salt and radioactivity

Geo-environmental issues associated with the earthquake

The March 11 Earthquake brought about various forms of geo-environmental issues in many different places. The issues include: 1) safe and effective processing of enormous quantities of disaster wastes and tsunami deposits, or salinity of ground caused by the inundation over a wide area of agricultural lands due to the massive tsunami; and 2) soil contamination caused by the leak of toxic substances or radioactive materials from the damaged nuclear power plant.

Safe and effective processing of disaster wastes and tsunami deposits and their effective utilization as resources

The earthquake and tsunami have generated enormous quantities of disaster wastes, estimated at 24.9 million tons, and tsunami deposits, estimated at over 10 million m³, and have posed serious issues over their disposal. It is desirable that they can be effectively utilized as much as possible for restoration and rehabilitation effort. In particular, earthquake-generated wastes with no potential environmental hazards and any tsunami deposits that are mainly sand can be easily and effectively used as the fill material for soil structures. These materials should be classified and/or separated at the time of collection and temporary storage. To do this, it is necessary:

- a) to establish evaluation and processing methods for the re-use of resources;
 - b) to establish a policy of ‘effective utilization under risk management’ for dealing with materials that possibly contain harmful substances based on an appropriate risk assessment in order to promote the use of such materials that have extremely low environmental risk depending on their kinds or quantities;
 - c) to establish an evaluation method of salination on disaster wastes of tsunami, and to investigate its long-term effects when used as resources;
 - d) to evaluate its suitability, from a view point of geotechnical engineering, as the fill materials for construction of residential lands on higher ground, embankments for tsunami barriers;
 - e) to determine what kind of recycled fill materials can be used how and in which location;
 - f) to establish methods of estimating the amount and the characteristics of tsunami deposits.
- Knowledge of geotechnical engineering should contribute especially to a), b), d), and e) (Fig. 13 1. & 2.).

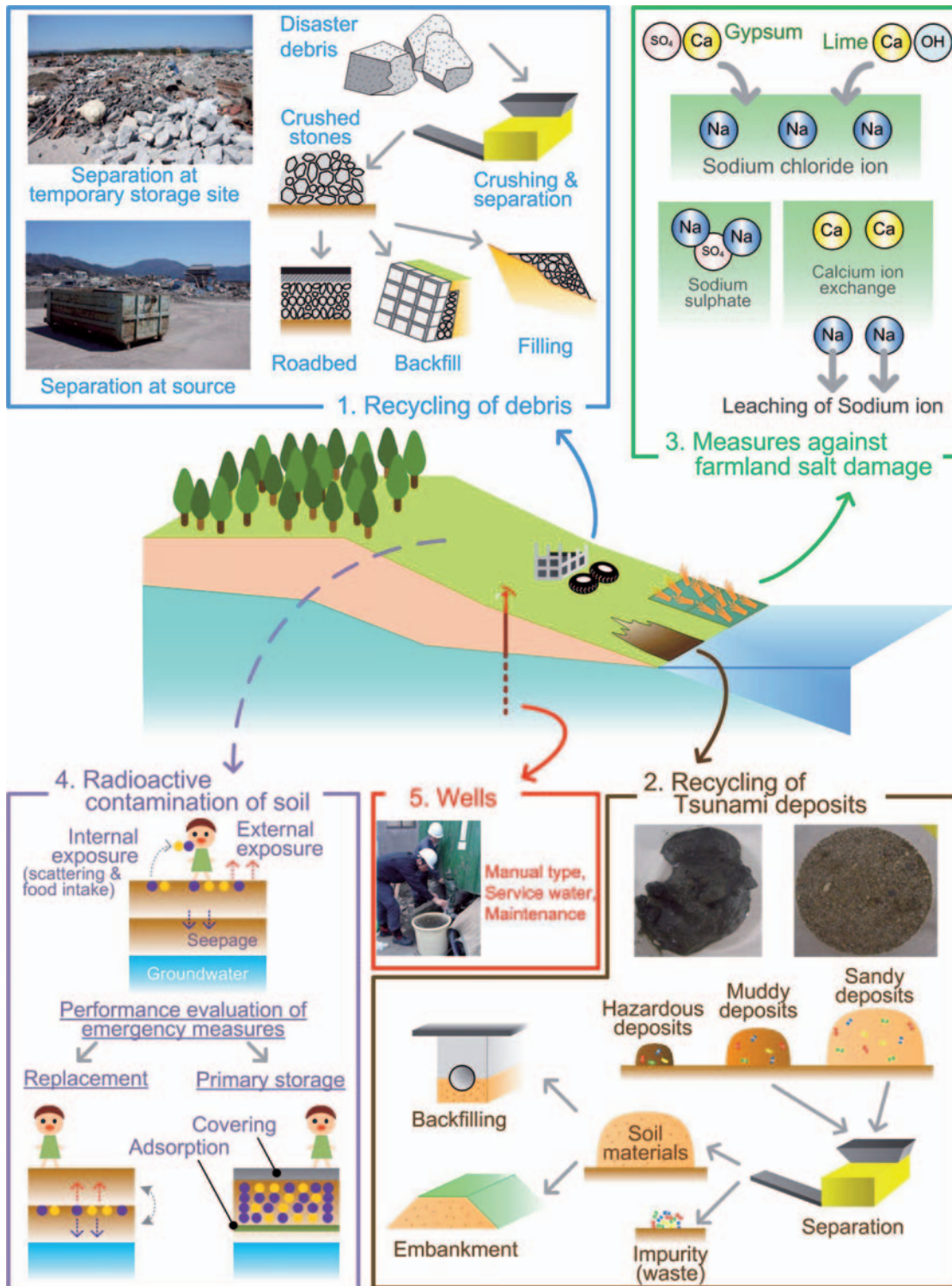


Fig. 13 Treatment of disaster wastes, tsunami deposits, and soil contaminated with salt and radioactivity (Endo, K.)

Geo-environmental impact assessment and appropriate countermeasures

The earthquake and tsunami damaged factories, oil-storage facilities, and storage facilities for other toxic substances. As a result, there is a serious concern about possible leakage and resulting soil contamination. There is also a serious concern that some deposits

left by the tsunami may contain fluorine and/or arsenic of natural origin, as well as other toxic substances that leaked from damaged industrial facilities and offices. Since the areas where soil contamination is concerned about is vast, it is necessary to carry out geo-environmental impact assessment and to take appropriate countermeasures effectively and rationally. In order to do this, it is required: a) to carry out efficient surveys for implementation of rapid and strategic countermeasures; b) to evaluate various geo-environmental effects such as soil contamination, groundwater contamination, airborne dust, bad smells, etc. and to implement countermeasures; c) to assess geo-environmental impact concerning disposal process and earth filling of debris, disaster wastes and to implement countermeasures against the relevant contamination; and d) to establish methods of estimating the quantity and the characteristics of tsunami deposits. The effective use of geotechnical engineering is also highly expected.

Countermeasures against salination of agricultural lands

To deal with salination of agricultural lands, some proven methods of salt removal are practical and effective (Fig. 13-3.). Also, the prevention of further salination requires multiple tsunami defense facilities as well as area-wide infrastructures, including tidal barriers, drainage systems, etc.

Countermeasures against radiation-contaminated soils

Management and processing of the radiation-contaminated soils is a long-term issue. The followings are activities which geotechnical engineering needs to contribute to (Fig. 13 -4.).

- a) Geo-environmental impact assessment on in-situ management of contaminated soils (i.e., replacement method of surface layers currently adopted), and suggestions about the appropriate management technology
- b) Development of appropriate methods of removing radioactive substances from the contaminated soils
- c) Technology evaluation for processing and isolating soils and wastes contaminated with radioactivity

The role of wells in disaster recovery

Although not suitable for drinking from a water quality point of view, this water from wells was extremely effective helping people in disaster-hit areas continue their daily life and maintain public sanitation (Fig. 13 -5.). This indicates a need for a positive approach to the use of groundwater at the time of disasters, such as by promoting the drilling of wells.

(6) The Restoration Policy of the Public Infrastructures and Application of Geotechnical Engineering Technologies

Effectiveness of the latest geotechnical engineering technologies

The gigantic earthquake of March 11, 2011, brought about no or minor damages to public infrastructures, mid- to high-rise buildings, major industrial facilities and their foundations that have been constructed and maintained by public agencies and large-scale private organizations following the recent seismic design codes. Earthquake-resistant soil structures with appropriate seismic risk assessment and strengthening also had no or minor damage (e.g., reinforced soil retaining walls built for high-speed railways and highways, modern rock-fill dams or some river dikes). This clearly demonstrated that the current seismic designs in the construction technologies including the geotechnical engineering technologies worked successfully.

Old soil structures that may not satisfy current technical standards and societal requirements and unexamined/untreated natural ground and slopes

Generally, soil structures, such as embankments or soil retaining walls, can be constructed at a reasonable price as well as in a short period of time in most cases. Also, embankment construction which uses soils from nearby excavation of cut slopes or tunnels is economical and least influential to the natural environments. Furthermore, their deterioration is generally slow and they are easily restored when damaged. For those reasons, enormous quantities of those soil structures have been built from ancient times, and they will be built in the future as well. With improvement of the construction technology and rising level of social demands for safety and functionality, today there exist huge amounts of soil structures that are characterized as follows;

1) Old soil structures that may not satisfy current technical standards and societal requirements:

Old soil structures were generally designed and constructed with the old technologies and standards, and thus they may not meet the criteria of performance that the current technical standards require. Among them are such soil structures as embankments or soil retaining walls for roads, railways, housing lands, and dams of reservoirs, river/coastal dikes, reclaimed lands, facilities for drainage such as manholes or sewers, and undergrounding structures such as pipelines for agriculture.

2) unexamined/unprocessed natural ground and slopes:

There is a great amount of natural ground and slopes that have been left without any risk assessments, thus no countermeasures have been taken despite having great impact on society in case of failure.

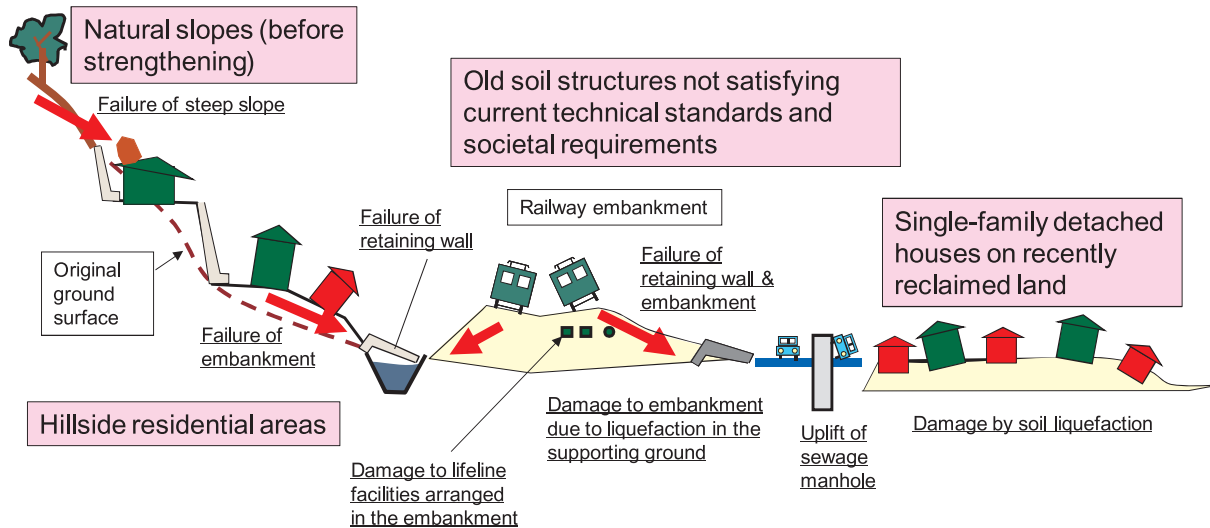


Fig. 14 Schematic diagram illustrating seismic damage in general in inland area



Fig. 15 (left) Damage to a main agricultural pipeline for a length of about 1.4 km due to uplift caused by liquefaction of backfill soil. The largest depth of opening was about 1.6 m (Mohri, H.)

Fig. 16 (right) Failure of a natural slope, Hanokidaira, Shirakawa City (Yasuda, S.)

Although this situation is unavoidable historically, it has been promoted to a certain extent to introduce the seismic design, seismic risk assessment and strengthening of the soil structures as parts of public infrastructures. Yet, the current conditions were still far insufficient. In fact, the recent earthquakes damaged a great number of ‘old soil structures that may not satisfy current technical standards and societal requirements’ (i.e., embankments or soil retaining walls for roads, railways, housing lands, and dams of reservoirs, river/coastal dikes, reclaimed lands, facilities for drainage such as manholes or sewers, and undergrounding structures such as pipelines for agriculture), and ‘unexamined/untreated natural ground and slopes’. Failure of those soil structures made a serious impact on society. (Figs. 14, 15, and 16)

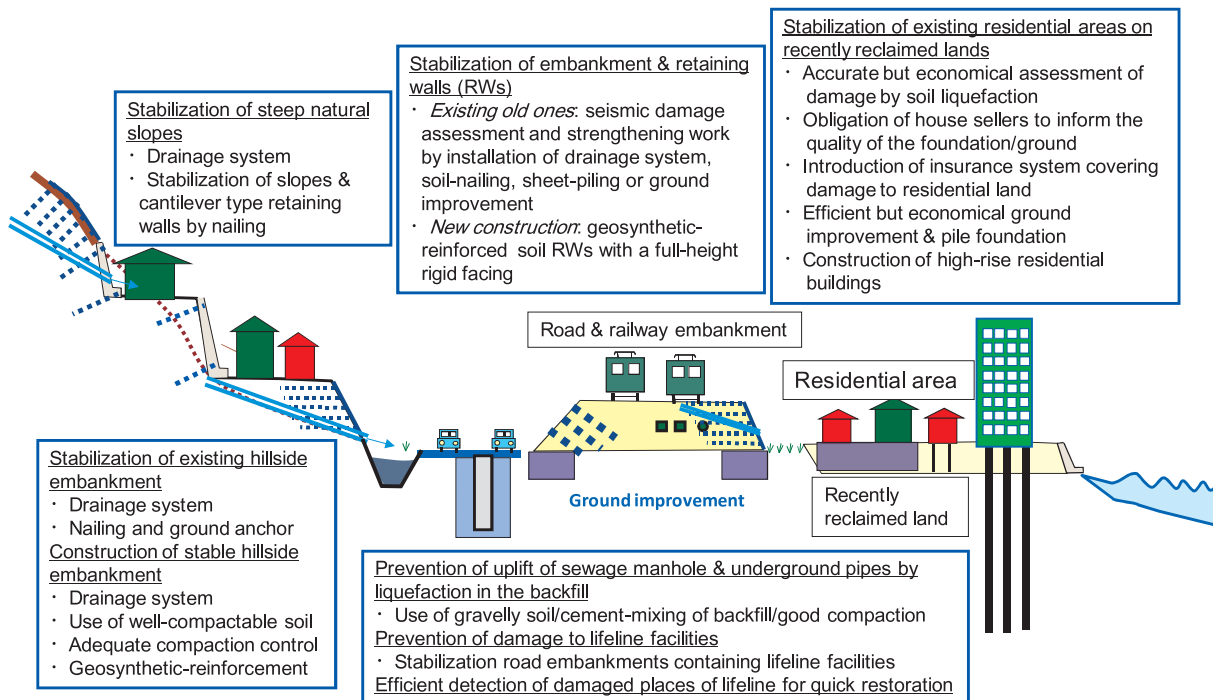


Fig. 17 Various examples of geotechnical engineering technologies to prevent geo-disasters

Seismic design, seismic risk assessment and strengthening, structurally better restoration that are prepared for a large number of damage in a wide area

Since ‘old soil structures that may not satisfy current technical standards and societal requirements’ and ‘unexamined/untreated natural ground and slopes’ are great in number, it has been a persistent and endless challenge to continue the seismic risk assessment and strengthening of such old soil structures. We cannot reduce our efforts for those works to achieve safe and secure Japan.

The conventional policy has been such that “failed soil structures (i.e., embankments, soil retaining walls, natural ground and slopes) should be restored quickly to their previous states.” This means that restored soil structures may fail again by similar earthquakes in the future. However, it will be difficult to cope with a large number of damages in a wide area like the recent case, and thus will cause a serious delay in restoration and reconstruction. It is required to change the above policy to more precautionary one that “the seismic risk of ‘old soil structures that may not satisfy current technical standards and societal requirements’ and ‘unexamined/untreated natural ground and slopes’ is to be assessed and cost-effective aseismic strengthening works are applied when necessary, especially for soil structures at such crucial points for emergency transportation or basic lifelines for life immediately after big earthquakes.

Also, it is always appropriate that the damaged soil structures, such as embankments and soil retaining walls and collapsed natural slopes need to restore their functions and securities as early as possible. At the same time, it is necessary to reinforce and reconstruct these

damaged soil structures / slopes to have a higher earthquake-resistance by using cost-effective methods, rather than restore these structures to their previous states that do not meet the today's standards. To this end, as shown in Fig. 17, it is necessary to utilize the latest geotechnical engineering, such as various ground improvement technologies or soil-reinforcing technologies, adding to basic technologies of appropriate compaction control of embankments, installation of drainage facilities and etc.