Knowledge FOr Resilient soCiEty

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(K-FORCE)

EARTHQUAKE GEOTECHNICAL RISKS WHAT WE KNOW, WHAT WE SHOULD KNOW LESSONS LEARNED

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1. INTRODUCTION

Earthquake destructive effects upon urban areas, buildings, economies, are huge challenges for each society located in a seismically prone region. The society should be very well prepared and organized to „survive" 60 seconds of ground trembling with minimum losses. Sank houses, overturned buildings, cut off pipelines, collapsed bridge-decks, uplifted manholes, blocked roads by soil mass and rock debris, huge area moved downwards, artificial dams formed instant water reservoirs, large ground subsidence are post-earthquake nightmares for each engineer caused by *geotechnical hazards*. Landslides and soil liquefaction are among the most destructive geotechnical phenomenon during an earthquake.

In recent times, urban development has spread into areas that were not used as construction sites before, like abandoned river channels, young alluvial deposits, human reclamation land, steep mountain terrain. These areas are characterized with high potential of geotechnical instabilities. The consequences of such rapid urbanization in earthquake prone regions cannot be hidden. Earthquakes and geotechnical hazards in particular, expose the urban development blunders in a very dramatic way: Darfield Earthquake 2010-2011 in New Zealand *"Widespread and severe liquefaction occurred in native soils covering nearly one third of the city area (Christchurch). The liquefaction was often accompanied with significant lateral spreading and caused tremendous damages to buildings and lifelines. ...A significant part of the network was still out of service even three months after the quake, and it is estimated that it will take at least two to three years to fully recover the wastewater system…."*. [Cubrinovski M. et al. 2012]. "*The 2011 Tohoku-Pacific Ocean earthquake caused severe liquefaction of the reclaimed lands along Tokyo Bay in Japan. The liquefied area was about 42 km^2, and the epicentral distance was about 380 km. About 12,000 houses settled and tilted due to the liquefaction. Many water, sewage, and gas pipes were severely damaged*" [Ishikawa et al., 2012]. "More than 800 of the landslides triggered by the earthquake blocked watercourses and impounded lakes…during the Wenchuan 2008 Earthquake" [Masahiro Chigira et al, 2013]

The economic losses induced by geotechnical instabilities during the earthquakes are enormous and are still under consideration for recent earthquakes. The data from past earthquakes show that liquefaction resulted in nearly $1 billion worth of damage during the 1964 Niigata Japan earthquake (NRC, 1985), $99 million damage in the 1989 Loma Prieta earthquake (Holzer, 1998), and over $11.8 billion in damage to ports and wharf facilities in the 1995 Kobe earthquake (EQE, 1995).

The paper is focused on geotechnical hazards during an earthquakes namely landslides and soil liquefaction. Geotechnical risks are often underestimated or even neglected and consequences upon that can be devastating. Short theoretical background is given in the first part and lessons learned from mid size earthquake is given. The mid Niigata earthquake 2004 is very good example of wide spread geotechnical instabilities occurred during this seismic event which rapidly increased the economic losses. Information and data from this earthquake are valuable lessons that should be shared not just among the engineers but also to everyone involved in earthquake preparedness system (decision makers, urban planners, crisis management team, risks analyst ...).

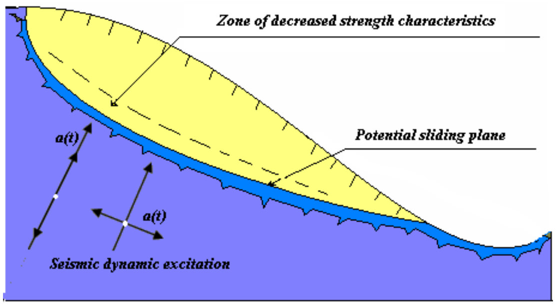
2. LANDSLIDES – BACKGROUND

The notion "landslide" refers to a wide range of processes resulting in motion of soil masses including rocks, soil, artificial embankments or their combination.

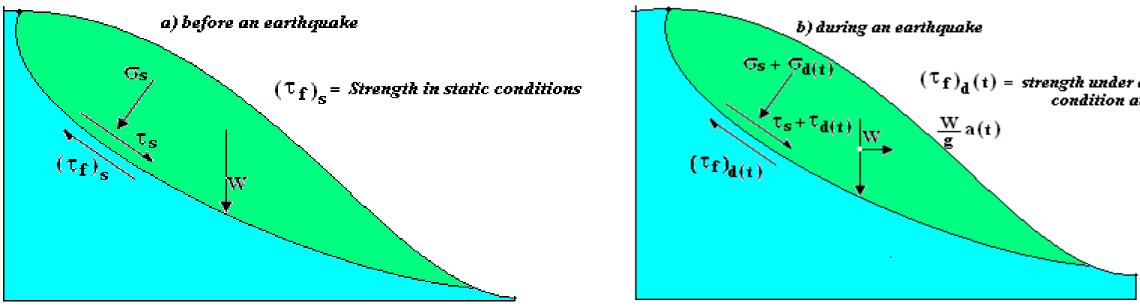
Landslides Caused by Earthquake

Numerous historic data and results from investigations of earthquake effects point out that landslides triggered by earthquakes are one of the most frequently and the most destructive geotechnical hazards.

The reason for soil instability due to earthquake effect is the additional dynamic force due to the earthquake. Under specific geological and geomorphological conditions, this dynamic force may exceed the shear strength of the soil material or the disturbed rock and may cause separation, sliding of smaller or larger soil blocks.



Sliding took place along well differentiated sliding planes and that these planes are located through zones having decreased strength characteristics of soil layers or degraded rock masses. The decreased strength in these zones which are usually located in the subsurface or ground waters, erosion processes, the tectonic deformations due to the presence of such zones on fault planes or along the contacts between rock masses. As general case, in static conditions, the soil mass of the slope, above the potential zone or a sliding plane is under the effects of the **gravity load (w)** in vertical direction. Under dynamic conditions caused by an earthquake, an additional effect is involved - the additional dynamic force proportional to the potentially unstable soil mass and the acceleration **(a(t))**.



a) before earthquake

(σ_s) - normal stress ; **(τ_s)** - shear stress ;

$(\tau_f)_s = f(\sigma, c, \phi)$; **$\tau_s < (\tau_f)_s$ - equilibrium**

b) during the earthquake

($\sigma_d(t)$) ; ($\tau_d(t)$) ; ($\tau_s+\tau_d(t)$)

$(\tau_f)_d(t) = f((\sigma_s + \sigma_d(t), c, \phi)$

$(\tau_s + \tau_d(t)) < (\tau_f)_d(t)$ stable

Depending upon the relation between

$(\tau_s + \tau_d(t))$ $(\tau_f)_d(t)$,

the soil mass remains stable for $(\tau_s + \tau_d(t)) < (\tau_f)_d(t)$

or it has a disturbed stability for $(\tau_s + \tau_d(t)) > (\tau_f)_d(t)$

Factor of safety Fsd

Fsd =Rsd / Asd

<u>R – resisting forces</u>
<u>A – active forces</u>

Factor of Safety is conventional concept ,
work well for static case, but outdated for dynamic case !!!

Concept of critical acceleration

It is a special interest to define acceleration which brings the potentially unstable part of the slope to point of failure. Acceleration ***'a'*** which resulted the factor of safety *FSd=1* is called *critical acceleration.*

$\mathbf{a}_{max} < \mathbf{a}_{cr}$ **; Fsd > 1**
$\mathbf{a}_{max} > \mathbf{a}_{cr}$ **; Fsd < 1**

good starting point , not enough why *?*

if $\mathbf{a}_{max} > \mathbf{a}_{cr}$ *soil will start to move*

do we have enough information to define stability of the slope? no !

- how much deformation will accumulate at the end of earthquake (residual) ?
- what is the volume of unstable and moving soil mass ?
- what does it mean that deformation for the integrity and performance of the earth structure

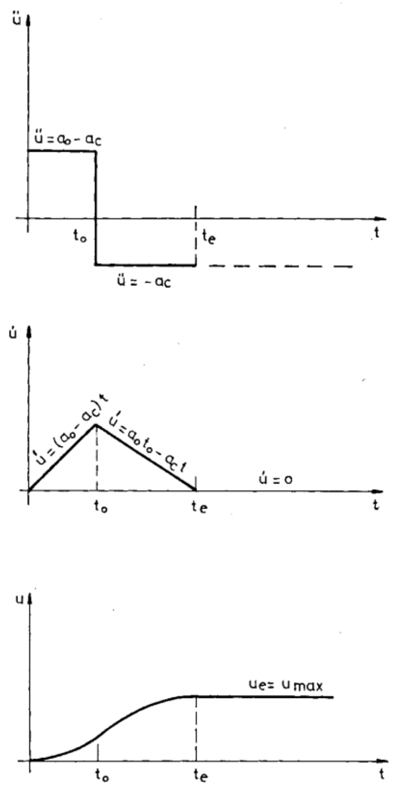
Calculation of permanent displacement

<u>Assumptions :</u>

Motion caused by the acceleration in the direction of the slope caused permanent displacement.

Excitation with opposite direction of the slope is considered as unable to move mass backwards.

Since the direction of accelerogram‟s amplitudes is alternative the procedure is repeated for the positive and negative part of accelerogram, separately.



Calculation of permanent displacement using Newmark model

Although landslides most frequently occur in mountainous regions, they also may occur in relatively low regions. In low regions, they occur in case of cuts (during construction of roads and alike), failure of river banks, horizontal widening of soil materials and other types of failire in conditions of mining and excavation. The kinematics of the landslides, i.e., the modes of distribution of motion through the sliding soil mass is one of the most important criteria for classification of the landslides. The knowledge about the failure mechanism is of a great importance for definition of a corresponding mode of management of landslides.

Socio-Economic Effects of Landslides

Soil instability has caused large-scale loss of human lives and enormous economic losses in many countries. The economic losses due to landslides are high and are exponentially increased, parallel with the expansion of populated areas toward instable slopes. Landslides not only cause loss of human lives and loss of animals but they inflict damage to entire residential and industrial settlements as well as agricultural and forest lands, affecting the quality of water in the rivers etc.

Today, the socio-economic effects (direct and indirect) in the USA, Japan, Italy and India seem to roughly range between 1 billion dollars to 6 billion dollars per year for each country. There are very few reliable national evaluations in the developing countries since there is limited research in the field of landslides. Still, landslides are frequently the cause of large scale damages in these countries as well. Despite the measures for improvement in recognition, anticipation, managing, osculation and warning systems worldwide, the activity of the landslides has an upward trend. The factors affecting this increase are:

1. The increased urbanization and development of regions of potential landslide hazard
2. Continuous desertification of regions susceptible to erosion and landslides.
3. Increased intensity of precipitation due to climatic changes.

Governmental agencies and those that develop the policies related to land use pattern have to have a greater understanding of the socio-economic effects of the landslides. In cooperation with experts and engineers, they could obtain the necessary knowledge for the purpose of making proper decisions for prevention and management of damage due to landslides.

The negative effects of the landslides may affect the environment or the urbanized surrounding. The structures near the landslides are strongly affected. The settlements built on instable slopes may experience considerable damage to their foundation, walls, the surrounding estate and underground structures.

The greatest vulnerability, i.e., the heaviest consequences of landslides are related to infrastructure facilities. The most frequent problems are the cuts, the embankments, failure of road due to weak soil material susceptible to loss of strength characteristics. The rock falls on the roads frequently cause loss of human lives. The consequences of burial of roads may exceed material damage (separation of entire towns, no access to information, no access to the injured, etc.)

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3. SOIL LIQUEFACTION

Introduction

Soil liquefaction is a major geotechnical hazards which cause great damages during earthquakes. “Modern” engineering treatment of liquefaction related issues evolved initially in the wake of the two devastating earthquakes of 1964; the 1964 Niigata (Japan) and 1964 Great Alaskan Earthquakes. Seismically induced soil liquefaction produced spectacular and devastating effects in both of these events, thrusting the issue forcefully to the attention of engineers and researchers. The Niigata earthquake of 1964 is regarded in Japan as a milestone in that it led to public recognition of liquefaction phenomena and of the importance of measures to mitigate the damage caused by earthquakes in general. The city of Niigata had been reduced to ashes by a large fire in 1955, but as a result of extensive restoration works the urban area had been reshaped and reborn as a new city with modern facilities and installations. Thus, the 1964 earthquake was an enormous blow, and caused unprecedented damage, Fig.3.1.

Fig.3.1 Overturning of residential buildings, Niigata, 1964

The Niigata earthquake can be cited symbolically as the first event in the world where all kinds of modern infrastructure were destroyed (to the surprise of many) by what came to be well known later as soil liquefaction. Because of its engineering importance, the problems of liquefaction have received a great deal of attention among the geotechnical community and many efforts have been made to clarify the basic mechanism and various aspects of the associated problems.

Over the nearly four decades that have followed, significant progress has occurred. Initially, this progress was largely confined to improved ability to assess the likelihood of initiation (or “triggering”) of liquefaction in clean, sandy soils. As the years passed, and earthquakes continued to provide lessons and data, researchers and practitioners became increasingly aware of the additional potential problems associated with both silty and gravelly soils, and the important additional issues of post-liquefaction strength and stress deformation behavior also began to attract increased attention.

Cause of Liquefaction

The typical subsurface soil condition that is susceptible to liquefaction is a loose sand, which has been newly deposited or placed, with a ground water table near ground surface. During an earthquake, the application of cyclic shear stresses induced by the propagation of shear waves causes the loose sand to contract, resulting in an increase in pore water pressure. Because the seismic shaking occurs so quickly, the cohesionless soil is subjected to an undrained loading. The increase in pore water pressure causes an upward flow of water to the ground surface, where it emerges in the form of mud spouts or sand boils. The development of high pore water pressures due to the ground shaking and the upward flow of water may turn the sand into a liquefied condition, which has been termed liquefaction. For this state of liquefaction, the effective stress is zero, and the individual soil particles are released from any confinement, as if the soil particles were floating in water (Ishihara 1985).Structures on top of the loose sand deposit that has liquefied during an earthquake will sink or fall over, and buried tanks will float to the surface when the loose sand liquefies (Seed 1970). After the soil has liquefied, the excess pore water pressure will start to dissipate. The length of time that the soil will remain in a liquefied state depends on two main factors: (1) the duration of the seismic shaking from the earthquake and (2) the drainage conditions of the liquefied soil. The longer and the stronger the cyclic shear stress application from the earthquake, the longer the state of liquefaction persists. Likewise, if the liquefied soil is confined by an upper and a lower clay layer, then it will take longer for the excess pore water pressures to dissipate by the flow of water from the liquefied soil. After the liquefaction process is complete, the soil will be in a somewhat denser state.

Liquefaction-Related Phenomena

When the ground is subjected to strong shaking during an earthquake, several phenomena of engineering/significance can manifest themselves, from onset of liquefaction to subsequent ground settlements and sometimes flow failure involving extremely large movements of soil masses. The phenomena and problems associated with liquefaction can be put in perspective by considering two different conditions encountered in the field.

One is the level ground condition in which the phenomenon of cyclic softening or liquefaction is of prime concern; the other is the sloping ground condition where flow failure or large lateral displacement is of major importance in addition to the cyclic softening. Fig.3.2 shows the phenomena and problems of engineering significance for each of these conditions.

In the level ground condition, the major factor would be the occurrence of cyclic softening or liquefaction in sandy deposits in which the ground starts to move back and forth with large amplitude. The assessment of whether cyclic softening can or cannot occur in a given deposit would be the first important task in clarifying the level of safety of the ground against an earthquake with a given intensity of shaking. Under level ground conditions, the next problem would be the estimation of ground settlements resulting from dissipation of pore water pressures developed in liquefied sand deposits, which cause grave concerns for the integrity of lifelines buried at shallow depths where the deleterious effects of liquefaction are most predominant.

In sand deposits such as under sloping grounds, levees or embankments, checks should be made in the same way as for level ground to determine whether or not cyclic softening or liquefaction is triggered. If liquefaction is identified as being triggered, the ground will at least undergo large-amplitude motions causing settlement or breakage of overlying structures, as in the case of level ground. In the worst case, the ground will start to move largely in one horizontal direction, perhaps driven by a slightly persisting gravity-induced force, bringing about an intolerable amount of lateral deformation or flow-type failure. A second-step analysis is then necessary to determine whether the flow-type deformation will or will not occur, on the condition that cyclic softening or liquefaction has already occurred in the sand deposit being considered. This kind of evaluation is called post seismic stability analysis; the strength used in this analysis is termed residual strength or steady state strength. If the once-liquefied ground is identified by post-seismic stability analysis as being prone to flow-type failure, the consequences will be disastrous, involving extensive movement or complete slumping of soil masses forming the ground or embankments. However, if the post seismic stability analysis indicates that the flow type failure can be avoided, the consequent damage will remain below a tolerable level, although it may require some degree of repair work.

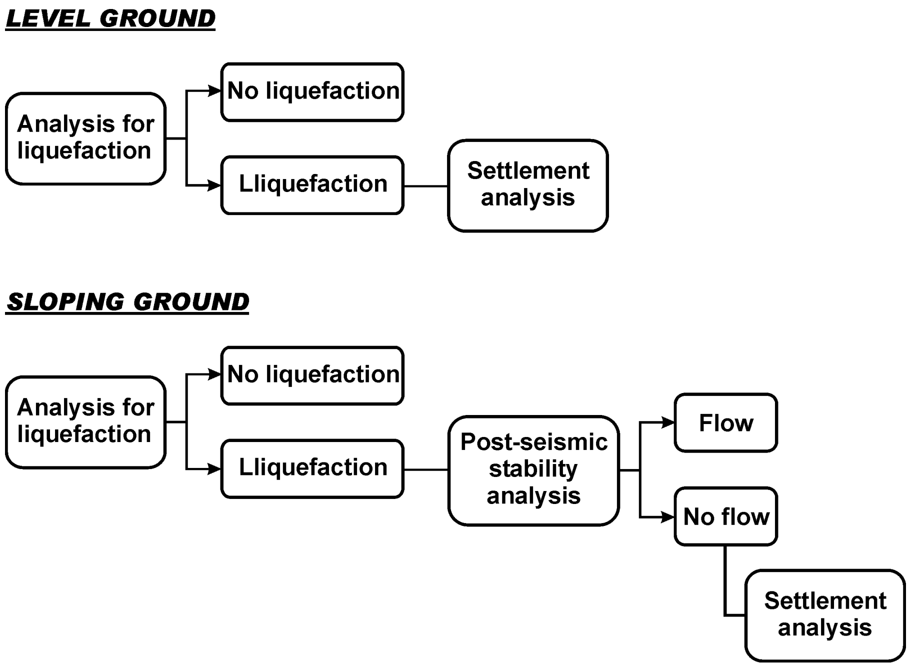

Fig.3.2 Flow chart of the problems associated with liquefaction (Ishihara, 1993)

Conditions for Liquefaction Occurrence

A great deal of information on liquefaction behavior has come from post-earthquake field investigations, which have shown that liquefaction often occurs at the same location when soil and groundwater conditions have remained unchanged. Thus liquefaction case histories can be used to identify specific sites or more general site conditions that may be susceptible to liquefaction in future earthquakes.
Not all soils are susceptible to liquefaction; consequently the first step in liquefaction hazard evaluation is usually the evaluation of liquefaction susceptibility. If the soil at particular site is not susceptible, liquefaction hazard evaluation can be ended. If the soil is susceptible, however, the matters of liquefaction initiation and effects must be addressed.
The occurrence of liquefaction is affected by various factors, which can be classified into three categories

- Ground motion characteristics
- Geological conditions
- Soil properties

These factors are summarized in Table 3.1

Table 3.1 Factors affecting the occurrence of liquefaction

Soil properties	Unit weight, grain size distribution, fines content, average grain size, clay content, plasticity index, relative density, structure of skeleton, shear modulus, damping ratio, coefficient of volume compressibility, degree of saturation, specific gravity of soil particle
Geological conditions	Water table, geological age, total stress, effective stress, over consolidation ratio, earth pressure at rest, initial static shear stress, deformation constraint condition, boundary condition against seepage: drainage conditions
Ground motion characteristics	Horizontal acceleration, magnitude of earthquake, intensity of seismic shear stress and number of cycles or duration, strain level, direction of shearing

Liquefaction induced damages

Effects on Built Environment

Liquefaction phenomenon by itself may not be particularly damaging or hazardous. Only when liquefaction is accompanied by some form of ground displacement or ground failure is it destructive to the built environment. For engineering purposes, it is not the occurrence of liquefaction that is of prime importance, but its severity or its capability to cause damage.

Flow Failures - Flow failures are the most catastrophic ground failures caused by liquefaction. These failures commonly displace large masses of soil laterally tens of meters and at times, large masses of soil have traveled tens of kilometers down long slopes at velocities ranging up to tens of kilometers per hour. Flows may be comprised of completely liquefied soil or blocks of intact material riding on a layer of liquefied soil. Flows develop in loose saturated sands or silts on relatively steep slopes, usually greater than 3 degrees (Figure 3.3).

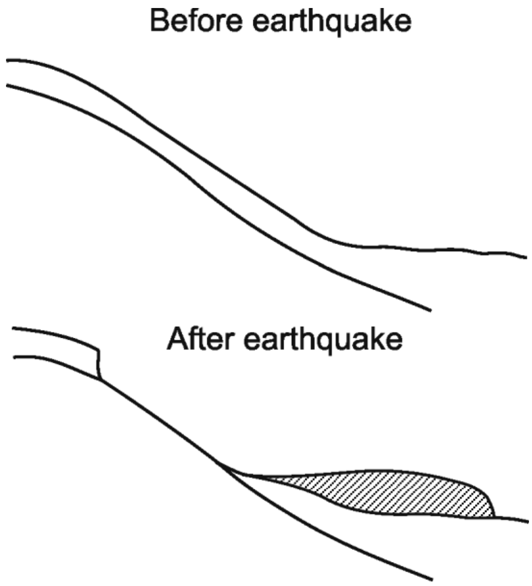

Figure 3.3 Diagram of flow failure caused by liquefaction and loss of strength of soils lying on steep slope. The strength loss creates instability and flow down the steep slope

Lateral Spreads. Lateral spreads involve lateral displacement of large, superficial blocks of soil as a result of liquefaction of a subsurface layer (Fig.3.4). Displacement occurs in response to the combination of gravitational forces and inertial forces generated by an earthquake. Lateral spreads generally develop on gentle slopes (most commonly less than 3 degrees) and move toward a free face such as an incised river channel. Horizontal displacements commonly range up to several meters. The displaced ground usually breaks up internally, causing fissures, scarps, horsts, to form on the failure surface. Lateral spreads commonly disrupt foundations of buildings built on or across the failure, sever pipelines and other utilities in the failure mass, and compress or buckle engineering structures, such as bridges, founded on the toe of the failure.

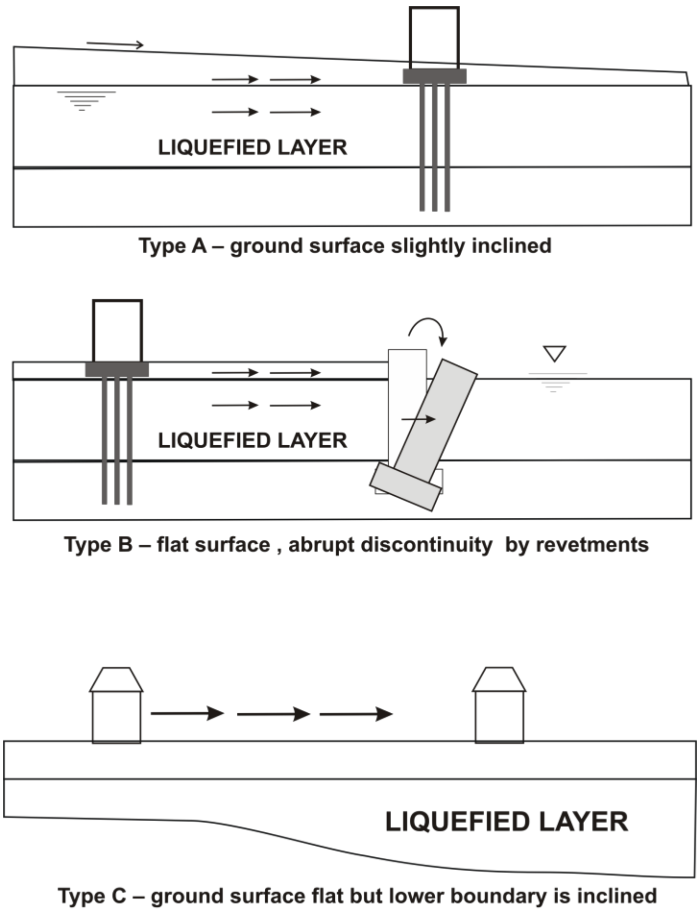

Fig. 3.4. Types of lateral ground displacements, after Hamada et al. 1986

Ground Oscillation. Where the ground is flat or the slope is too gentle to allow lateral displacement, liquefaction at depth may decouple overlying soil layers from the underlying ground, allowing the upper soil to oscillate back and forth and up and down in the form of ground waves (Figure 3.5). These oscillations are usually accompanied by opening and closing of fissures and fracture of rigid structures such as pavements and pipelines.

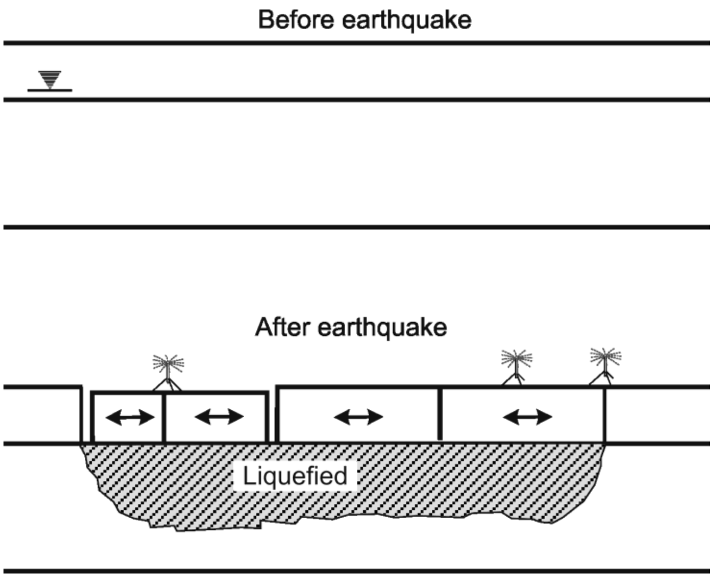

Fig.3.5. Diagram of horizontal ground ocsillation cause by liquefaction in the cross-hatced zone decoupling the surface layer from underlying ground

Loss of Bearing Strength. When the soil supporting a building or other structure liquefies and loses strength, largedeformations can occur within the soil which may allow the structure to settle and tip (Figure3.8). Conversely, buried tanks and piles may rise buoyantly through the liquefied soil. For example, many buildings settled and tipped during the 1964 Niigata, Japan Earthquake. The most spectacular bearing failures during that event were in the Kawagishi-cho apartment complex where several four-story buildings tipped as much as 60 degrees (Figure 3.6).Apparently, liquefaction first developed in a sand layer several meters below ground surface and then propagated upward through overlying sand layers. The rising wave of liquefaction weakened the soil supporting the buildings and allowed the structures to slowly settle and tip. Figure 3.7 shows typical example of loss of bearing capacity due to liquefaction during the Izmit Earthquake 1999, Turkey.

Fig. 3.6 Kawagishi-cho apartment complex, after the Niigata Earthqauke 1964

Fig. 3.7 Adapazari, Izmit Earthquake, Turkey 1999: August 17

Ground Settlement. In many cases, the weight of a structure will not be great enough to cause the large settlements associated with soil bearing capacity failures described above. However, smaller settlements may occur as soil pore-water pressures dissipate and the soil consolidates after the earthquake. These settlements may be damaging, although they would tend to be much less so than the large movements accompanying flow failures, lateral spreading, and bearing capacity failures. The eruption of sand boils (fountains of water and sediment emanating from the pressurized, liquefied sand) is a common manifestation of liquefaction that can also lead to localized differential settlements.

Buoyant rise of buried structures. Soil liquefaction can also induce buoyant rise of underground structure. Normally, the uplift of the buried structure is prevented by resistance from the adjacent soil. However, when soil liquefies, the soil loses its resistance and starts to behave like liquid with unit weight almost twice that of water. When the unit weight of the buried structure is less than that of the liquefied soil, floating of underground structures can occur. Figure 3.8 has been taken four day after Mid Niigata Earthquake 2004.

Fig. 3.8 A manhole uplifted during the 2004 Mid Niigata Earthquake

Increased lateral pressure on retaining walls. If the soil behind a retaining wall liquefies, the lateral pressures on the wall may greatly increase. As a result, retaining walls may be laterally displaced, tilt, or structurally fail, as has been observed for waterfront walls retaining loose saturated sand in a number of earthquakes.

Sand Boils. Although not strictly a form of ground failure because they alone do not cause ground deformation, sand boils are diagnostic evidence of elevated pore water pressure at depth and are indications that liquefaction has occurred. During earthquakes, sand boils are formed by water venting to the ground surface from zones of high pressure generated at shallow depth by the compaction of granular soils during seismic shaking. The water, which may flow violently, usually transports considerable suspended sediment that settles and forms a conically shaped sand boil deposit around the vent.

Fig. 3.9 Sand boil, during the Loma Prieta Earthqauke ， *USA* (1989, M = 7.1)

Variation in natural period of ground

The natural period, Tg, of a surface deposit is given by

$$T_g = \frac{4H}{V_s}$$

where H is the thickness of the deposit and Vs the shear-wave velocity;

$$V_s = \sqrt{\frac{G}{\rho}}$$

in which ρ is the mass density of sand.

The shear modulus of sand, G, decreases as excess pore pressure rises during shaking, elongating the natural period Tg. Thus, the surface deposit functions as a wave filter; the seismic-motion component of elongated period = Tg is amplified by resonance.

The acceleration record at a site of liquefaction (Fig. 3.10) indicates a long period motion after around 8 seconds. This' is probably because Vs was reduced by liquefaction and Tg was elongated.

For a given magnitude of acceleration, a low frequency motion is associated with a large amplitude of displacement. Thus, even when the magnitude of soil distortion is small, structures vulnerable to large displacement amplitude and slow rate of motion can be affected due to resonance by such a motion as in Figure 5.7; causing, for example, sloshing in oil storage tanks.

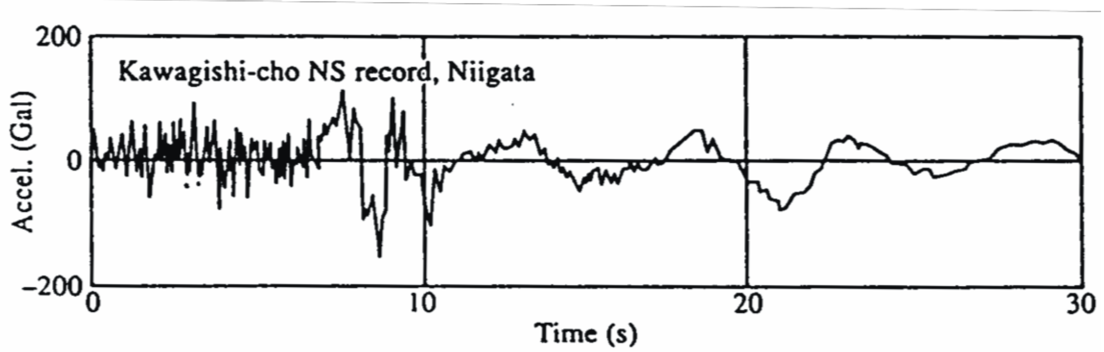

Fig.3.10 Niigata earthquake motion on liquefied ground; probably affected by soil softening after 8 seconds

4. LESSONS LEARNED

GEOTECHNICAL HAZARDS
THE 2004 MID NIIGATA EARTHQUAKE

REPORT BY THE RECONNAISSANCE TEAM

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SUMMARY

Seismic activity started on October 23, 2004 with strong earthquake which struck Mid Niigata Prefecture, central Japan. Main shock M=6.8 (according JMA) occurred at 5:56 PM JST on October 23, 2004 and it was followed by many aftershocks including M=6 seismic events. The intensity was estimated as 6+ on the 7-grade Japanese intensity scale, Figure 1. Maximum intensity was estimated to 7 (JMA) and maximum recorded acceleration of 1700 cm/sec^2 was registered.

Reconnaissance team was formed one day after the earthquake at the Geotechnical Laboratory, University of Tokyo lead by Professor Ikuo Towhata, Associate Professor Taro Uchimura, Researcher Vlatko Sesov and master student Masanori Mizuhasi. The team"s primary interest were geotechnical instabilities occurred after the earthquake and related damages.

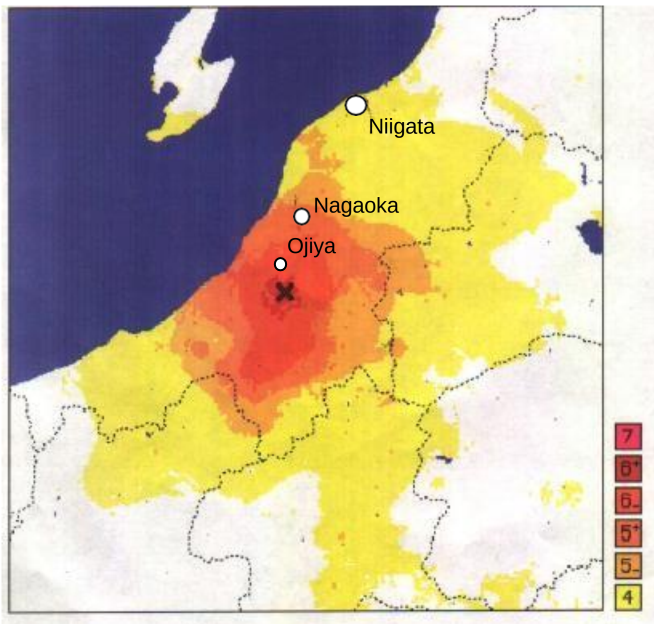


Figure 1. Intensity distribution of the October 23, 2004 Earthquake, 17:56 pm JST (JMA)

GENERAL OBSERVATIONS

This report is a result of visual observations, simple in-situ measurements and discussion with the local people of the affected area during three day visit from October 26 to 28, 2004. Comments and photos presented herein are limited to the visited area around Ojiya-city and Nagaoka-City. Many of the damaged sites were still unreachable by car during our visit due to heavily damaged roads and many landslides which blocked the roads.

Important aspect

It should be pointed that Niigata prefecture was seriously affected by Typhoon No.23 which pass through this region three days before earthquake. The Typhoon No.23 brought a lot of rain and made the ground heavily saturated and very soft at the time when strong earthquake occurred. Such soil condition additionally affected by strong ground shaking produced a lot of geotechnical instabilities.

On the basis of our observations geotechnical instabilities of the 23 October Mid Niigata Earthquake herein are classified in two categories:

2) Geotechnical instabilities related to man made ground structures

- *Lateral displacements and soil subsidence.* These types of damages were widely spread through all area struck by the earthquake. The local roads suffer significant damages due to settlement of the road embankment causing numerous cracks and subsidence of asphalt pavement. Crest settlements of the road embankment frequently occurred with lateral movement of the fill material which produced damages on the retaining wall at the toe of the embankment. Also buried water pipelines located in the middle of the roads were separated from the asphalt pavements.

Connection between the roads and the culverts also between roads and the bridges were particularly damaged by the subsidence of fill material of the road embankment. We observed large crest subsidence on the road approaching the bridge steel structure. The bridge itself performed well during the earthquake no visual damaged could be observe on the steel structure.

Large lateral displacements and ground subsidence we observed at Nagaoka National College of Technology which is located on small hill terrace in Nagaoka city. Large cracks in the ground could be seen all over the campus area. Also soil subsidence varied from tens of centimeters to nearly one meter and soil lateral displacement more then one meter occurred within the Campus area. Three and four stories reinforced concrete buildings founded on pile foundations at this College generally performed well during the strong shaking with limited damages on structural elements. Many of the embedded pipe lines were severe damaged due to large ground deformations.

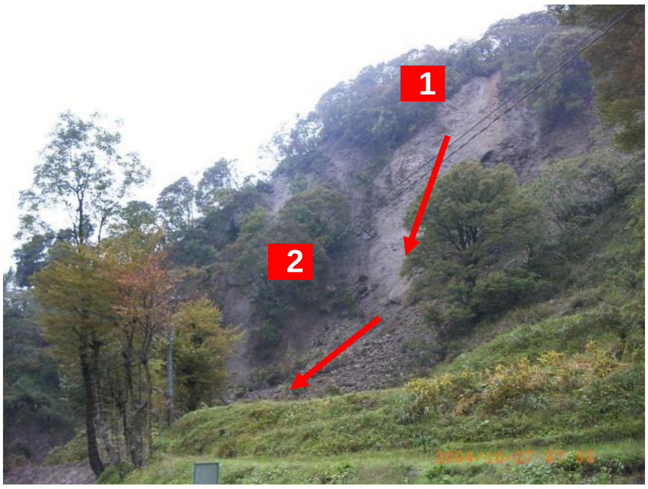
Finally, we would like to express our sincere condolences to the families who have lost their love ones, their homes, and experienced hard time during the last earthquake.

1) LANDSLIDES IN NATURAL SLOPES

Photos taken on October 26 to 28, 2004

Landslides have been one of the dominant geotechnical instabilities occurred during this earthquake. Saturated soil condition due to the past rainy days and very steep inclination of the natural slope made these slopes very vulnerable to earthquake shaking. There were a lot of landslides where subsurface soil layers from the top of the slope were sliding toward toe of the slope. Sometimes small rocks and mud stones with various dimensions have been seen in the landslide deposit. Landslides in the natural slopes we observed were small to mid sized landslides affecting nearby houses, buried road and railways and blocked small rivers with slide debris.

Photo 1- 1. Landslide in mild steep natural slope – due to ground topography sliding of the soil mass had different directions downward the hill. Red arrows indicate directions of sliding of the soil mass



Photos 1-2 & 1-3 Middle sized landslide in natural slope occurred at this place and temporary blocked the local road and small river. Numbers indicate the steps of the soil movements

Photo 1- 4. Landslide mass temporary blocked the local road, emergency measures had been taken, landslide mass was removed from the road and traffic was enabled again. Place: Nigorisawa

2) GEOTECHNICAL INSTABILITIES RELATED TO MAN MADE GROUND STRUCTURES

Photos taken on October 26 to 28, 2004

These types of geotechnical instabilities were connected with previous human activities which changed the initial natural ground condition. Based on our observations these instabilities could be classified as:

- *Landslide in manmade slopes.* Many of the local roads and railways connecting the villages in the mountain area east of Ojiya-city were built by cutting the natural slopes. Some of these manmade slopes were affected by earthquake triggered landslides and slide debris blocked the traffic. We observed mid sized landslide in Nigorisawa village that destroyed several houses and blocked the local road. The biggest landslide we observed took place near to Uragara bridge, Myoken, Ojiya-city. Huge rocks and mud stones completely blocked and destroyed the road in length of more than hundreds meters. Several landslides also took place in residential area in Takamachi. Ring road which was passing at the edge othis this residential area was destroyed by several landslides which took place during the earthquake.

LANDSLIDE IN THE MANMADE SLOPES

Photos 2-1 & 2-2. Large landslide took place destroying retaining wall and several houses. Soil mass moved more than 50 meters downwards. Place: Nigorisawa

LANDSLIDES AT TAKAMACHI RESIDENTIAL AREA

Photo 2-3 & 2-4 Several landslides took place in Takamachi residential area. Large cracks were formed due to soil movement within this area, varied from tens of centimeters to more than one meter. Roads and pipe lines were heavily damaged.

Photo 2-5 & 2-6. This residential area was located on small hill terrace. A ring road at the edge of this terrace was wiped off by the landslides on several places. The landslide mass scarped the surface layer just at the edge of the houses, left photo. The right photo also showed retaining wall which was destroyed by landslide.

3. SOIL LIQUEFACTION

- *Liquefaction.* There were no significant liquefaction induced damages. Up-lifted manholes in Ojiya city and small sand boils in their vicinity were the evidence that liquefaction took place. Also small sand boils could be observed in the rice fields.

Photo 3-1 & 3-2 Manhole uplifted by buoyancy force due to liquefaction. Sand ejected from the ground was observed in the vicinity of the manhole

- Derailed Shinkansen (Super Express Train) near Tokamachi Town.

The Super Express Train (Shinkansen) derailed due to the strong shaking. There were some damages on the piers located 10 to 100m away in the north direction from the derailed point. Liquefaction occurred at the foot of the piers which were 10 to 20m away in the north direction from the above-mentioned piers, and the boiled sand reached 70 to 90cm. The gap between the pier and the ground indicates the large displacement the pier experienced. (Honda Riki et al)

Photo 3-3 Derailment of Shinkasen**,**

Photo 3-4 Rigid RC elevated railroad

Photo 3-5 Sand boils next to pier

Photo 3-6 Open gap between pier and ground

4. LATERAL DISPLACEMENTS AND SETTLEMENTS AT NAGAOKA NATIONAL COLLEGE OF TECHNOLOGY

Photo 4-1 Nagaoka National College of Technology – aerial view. Red arrows indicate directions of the observed soil displacements. Blue circles indicate the places where the following photos have bee taken.

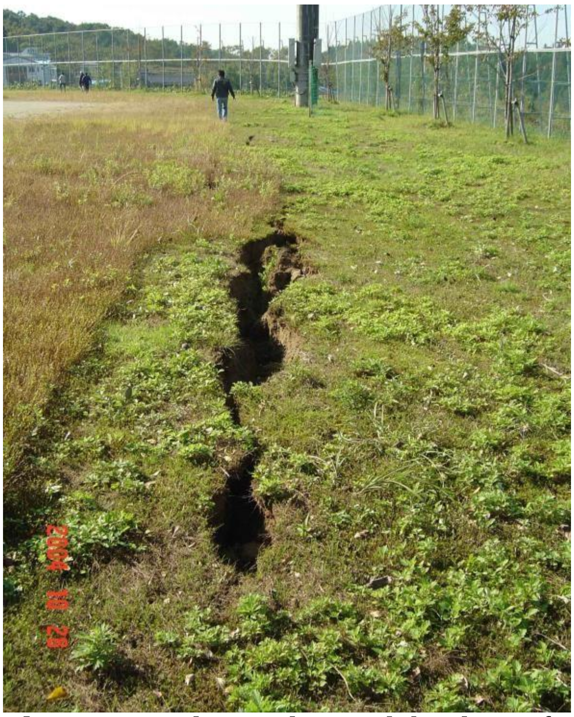


Photo 4-2. Soil moved toward the slope of the hill terrace and large cracks appeared at the ground surface. Place: N1, see Photo 4-1.

Photo 4-3. Ground subsidence of nearly 1 m at the college playground. Place: N2, see Photo 4-1.

Photo 4-4. Fill material separated from underground concrete structure due to large permanent soil displacement. Place : N3, see Photo 4-1

Photo 4-5 & 4-6. Large ground deformation was observed between two buildings. RC building which is shown at the left side of the Photos, lay on pile foundation and we didn"t observed any significant visual damages. Surrounding soil was completely deformed with large soil displacement and settlements heavily damaging the embedded pipe lines. Place: N4

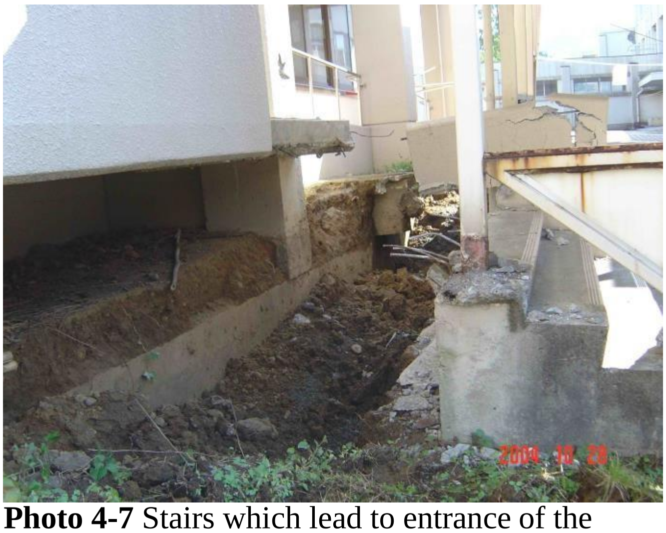


Photo 4-7 Stairs which lead to entrance of the building (Photo 2-17) were break apart and separated from the building. Place: N5

Photo 4-8 Asphalt pavements and embedded pipe lines were heavily damaged due to ground deformation. Place: N6

Photo 4-9. Soil settlements up to one meter were observed near to this three stories building which is founded on pile foundation. Place: N7

Photo 4-10. Tennis courts, were built on small terrace where lateral soil displacements took place toward gymnasium. Place : N8