Geo-disasters in Japan in the Context of Climate Change

K. Yasuhara[1], S. Kawagoe[2] and K. Araki[3]
Institute for Global Change Adaptation Science (ICAS), Ibaraki University, Mito, Ibaraki, Japan
Fukushima University, Fukushima, Japan
Yamanashi University, Yamanashi, Japan
E-mail: kazuya.yasuhara.0927@vc.ibaraki.ac.jp

ABSTRACT: Japan is an area affected strongly by land surface upheaval and by climate change instability. Background evidence of increasing and magnifying geo-disasters includes the following: (i) frequent and extremely severe torrential rainfall; (ii) high and increasing frequency of strong earthquakes (5+ and 6- as the Japan Meteorological Agency seismic intensity scale); and (iii) typhoons with magnified damage effects. Based on a review of that information stated above, an attempt has been made to overview the present situation and future trends of geo-disasters in the context of climate change and to present possible adaptive measures against disasters. Particularly, emphasis is assigned to the importance of the combined effects of plural events, which increases the probability of extreme events, sometimes triggering devastating consequences. Adaptive measures against climate change-associated geo-disasters are presented by classification into software and hardware. Special emphasis is devoted to the availability of information and communication technology (ICT) and information, communication and robot technology (ICRT) involving devices such as IC-sensors and Un-crewed Aerial Vehicles (UAV, drones), which are useful in early warning systems and in simple monitoring systems.

KEYWORDS: Compound geo-disaster, Climate change, Adaptation, ICT

1. INTRODUCTION

Climate change in Intergovernmental Panel on Climate Change (IPCC) usage refers to change in the climate state that is identifiable (e.g. using statistical tests) by changes in the mean and/or the variation of its properties and which persist for an extended period, typically decades or longer. Included is any change in climate over time, whether caused by natural variation or by human activity. However, the United Nations Frameworks Convention on Climate Change (UNFCCC) uses climate change attributed solely to human activities: climate variation refers to changes attributable to fluctuation related to natural events.

In spite of the situation described above, this paper describes climate change-induced geo-disasters from the standpoint of IPCC and countermeasures for reducing damage caused by geo-disasters, which are divisible into two categories of mitigation and adaptation.

Climate variation – Degree to which climate fluctuates yearly above or below a long-term average value.

Climate change – Long-term continuous weather change (increase or decrease) to average weather condition or the range of weather.

Japan has an extremely bad set of circumstances, with land upheaval with climate change. Recently observed geo-disasters in Japan are characterized by the following (MLIT & JMA, 2012).

i) Occurrence of gigantic sediment disasters taking place as deep-seated slope failures on the Kii Peninsula in 2011 and massive debris flows in Hiroshima in 2014, resulting from torrential and extreme rainfall.
ii) Sediment disasters after earthquakes, which include movement of large soil masses during the Great Eastern Japan Earthquake in 2011 and failure of snow sediment after the Northern Nagano Earthquake in 2011.
iii) Sediment disasters during heavy snows such as soil mass movements and avalanches caused by melting after heavy snowfall, which occurred in many places in 2012.

Background evidence of increasing and magnifying geo-disasters is the following.

i) Often extremely severe torrential rainfall events
ii) Increasing frequency of earthquakes with 5+ and 6- on the Japan Meteorological Agency seismic intensity scale
iii) Typhoons with magnified damage effects

Based on the reviewed information presented above, an attempt has been made to overview the present situation and future trends of geo-disasters in the context of climate change and to present possible adaptive measures against disasters. Particularly, emphasis is assigned to the importance of combined effects of plural events, which increase the probability of extreme events, sometimes triggering devastating consequences. The necessity of adaptive measures against climate change-associated geo-disasters is emphasized by classification into software, hardware, human-ware, and command-ware.

2. RECENT SITUATIONS OF NATURAL DISASTERS CAUSED BY CLIMATE CHANGE

2.1 Brief Review of Asian Natural Disasters

From reviewing case histories of disasters caused by natural hazards in Asian regions, Kokusho (2005) showed the following: i) we might be continuing to overlook very extreme events that occurred in sparsely populated areas, especially in rural areas; ii) earthquakes, tsunami events, floods, slides, volcanoes, waves/surges, and wind storms will continue to be major causes of future catastrophes; iii) considering future extreme events, increasingly expanding areas of human activities are creating compound hazards of new types. Kokusho also pointed out that new compound hazards are expected to result from i) Asian population growth and economic development, ii) new urban facilities produced with little experience of severe disasters, and iii) other compound hazards such as land subsidence related flooding from increasingly vulnerable dykes.

From Kokusho's assertions, questions arose, such as "Have those extreme natural events been caused by climate change including global warming?" The answer to this question has been clarified since 2005, a decade ago. In fact, a recent IPCC report (2014) presents evidence that climate change might trigger extreme disasters. However, uncertainty related to this issue has persisted. Therefore, to date, a mode of explanation has existed: some events might result from climate change; others might not. For that reason, it is necessary to continue research efforts and information exchange through international cooperation of professionals and stakeholders from related fields, and particularly in Asia–Pacific regions.

2.2 Compound Disaster Importance

Special attention should be devoted to compound disaster effects because these magnify disaster loss and damage. To do so, the following are necessary: (i) clarifying climate change induced mechanisms of disasters caused by natural hazards; (ii) predicting future events and outcomes; (iii) estimating likely economic losses and costs for precautions and preparedness; and (iv) proposing adaptation techniques and strategies.

While referring to Figure 1, let us consider the nature of compound disasters. The following should be included: (i) a second disaster occurs immediately after or before a major disaster, generating catastrophic consequences; (ii) damage is compounded through a combination of the disaster with a vulnerable background or human and social situations (see Figure 2); and (iii) the psychological aftermath multiplies the damage. This classification accords well with that proposed by Kokusho (2005).

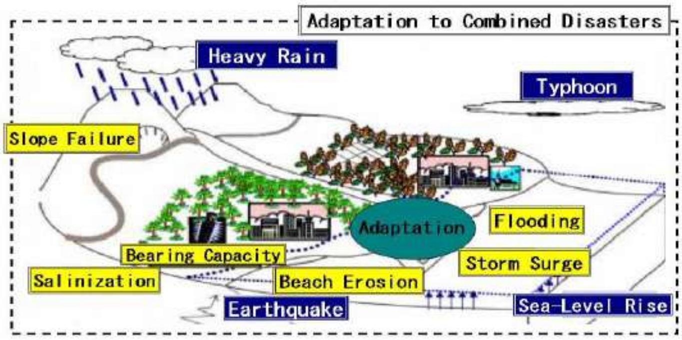


Figure 1 Examples of compound natural disasters (Yasuhara et al., 2012:2013)

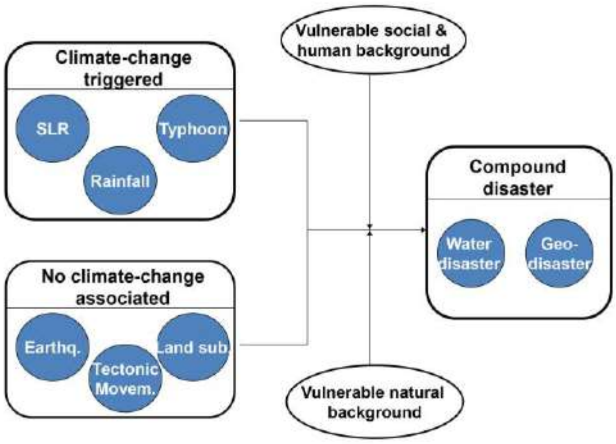


Figure 2 Backgrounds of compound natural disasters (Yasuhara et al., 2013: 2015)

3. RECENT TRENDS OF FACTORS TRIGGERING SEDIMENT DISASTERS

Before discussing appropriate preparation for previously occurring and possibly occurring sediment disasters and geo-disasters, we assess trends of events that might trigger tragic consequences.

3.1 Influences of Climate Change

As shown in Figure 3, it is assumed that climate change as defined in the *Introduction* produces (i) sea-level rise (SLR), (ii) magnification of and/or increase in the number of typhoons, (iii) variation of precipitation characteristics leading to torrential rainfall or extreme drought, and (iv) thermal variation of ground surfaces. This paper specifically addresses items (i)–(iii).

3.2 Sediment Disaster and Precipitation

Figure 4 depicts variations of sediment disaster occurrence over time during the 15 years of 1999–2014. Sediment disasters include slope failure, landslides, and debris flow. The yearly occurrence frequency of torrential rainfall of over 50 mm/yr. is shown for the last 35 years in Figure 5. Both figures show gradually increasing tendencies of both in recent years.

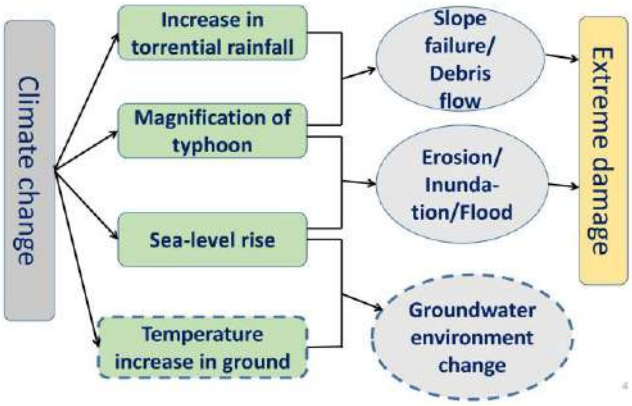


Figure 3 Influences of climate change on geotechnical events

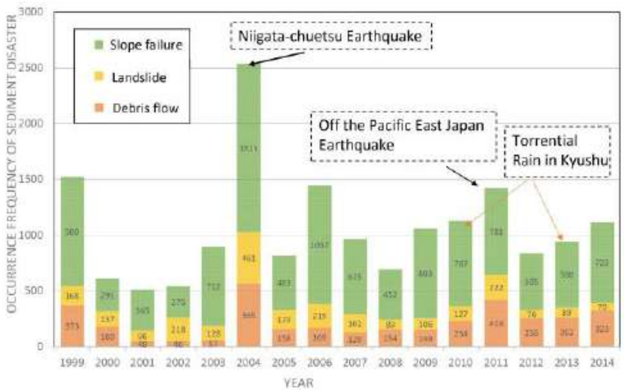


Figure 4 Sediment disasters occurring in various years (JMA, 2014)

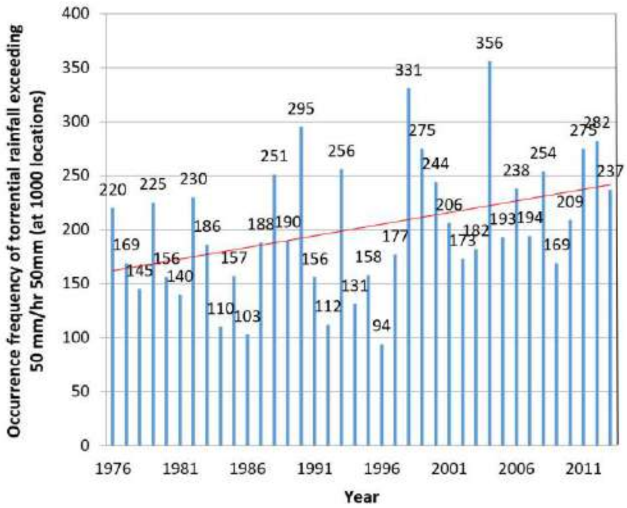


Figure 5 Variation of torrential rainfall frequency over time (JMA, 2014).

When the results of sediment disasters and torrential rainfalls are compared, we obtain Figure 6, which shows a tendency by which the frequency of sediment disasters increases nonlinearly over time.

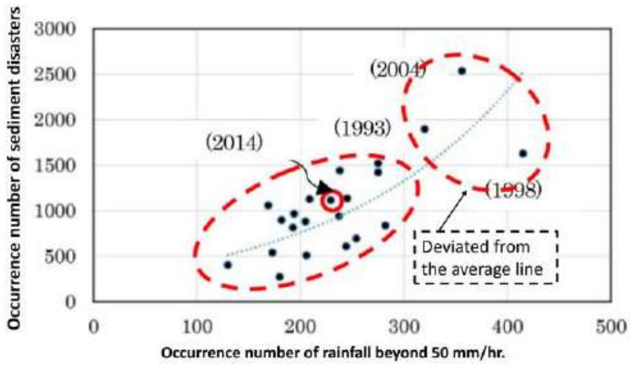


Figure 6 Sediment disaster and torrential rainfall frequencies

3.3 Earthquake Tendency

Earthquakes present another important factor triggering sediment disasters and geo-disasters. What would happen to human life if a great earthquake were to strike after a strong rainfall or rainfall? This worst-case scenario would be a climate-change-associated compound geo-disaster. We propose preparedness by answering the question posed above, although getting a correct answer is difficult.

For consideration of whether such a situation as that worst case scenario has actually occurred before, one can investigate the tendencies of large earthquakes over the last few decades. Figure 7 portrays variations of occurrence frequency of earthquakes with an intensity of lower 6 over time from 1960 to the present. All data are those of the Japan Meteorological Agency. Figure 7 clarifies that the frequency of earthquakes with intensity of lower 6 has been increasing over time, particularly since 1995. For that reason, we should take precautions for large earthquakes and heavy rainfalls. Preparation must be made for the worst case in which climate change-induced heavy rainfall and a great earthquake might occur simultaneously or nearly simultaneously, although this worst case might be extremely rare.

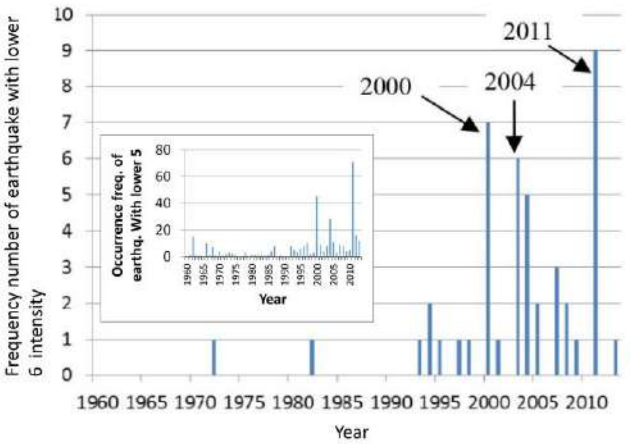


Figure 7 Earthquakes with intensity of 6 lower/5 lower over time

In the same manner as that used for Figure 5, influences of earthquakes with intensity of 5 lower on the frequency of sediment disasters is shown in Figure 8. Comparison with the result in Figure 5 shows no mutual relation.

Comparison of Figures 6 and 8 suggests that the sediment disaster frequency is influenced more strongly by torrential rainfall than by large earthquakes.

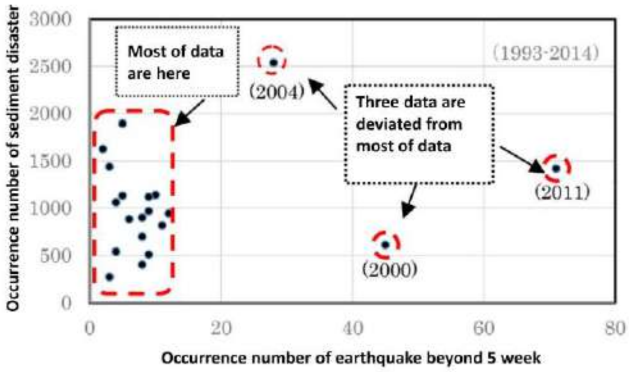


Figure 8 Earthquake influence on sediment disaster occurrence

3.4 Prediction of Future Sediment Disasters

The study has described the future prediction of climate change-induced sediment disasters and their economic loss.

Figure 9 exhibits predicted results of sediment disasters, indicating that the probability of sediment disaster occurrence increases concomitantly with increasing duration of the return period of rainfall. This tendency is more marked in western than in eastern Japan. However, the predicted economic loss shown in Figure 10 is more eminent in western areas than in eastern areas and the economic loss amount at the end of the twenty-first century is almost twice that of the present day. Figure 9 and Figure 10 results are mutually consistent.

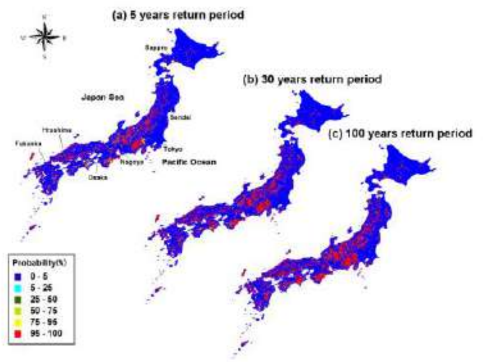


Figure 9 Prediction of probability of sediment disasters

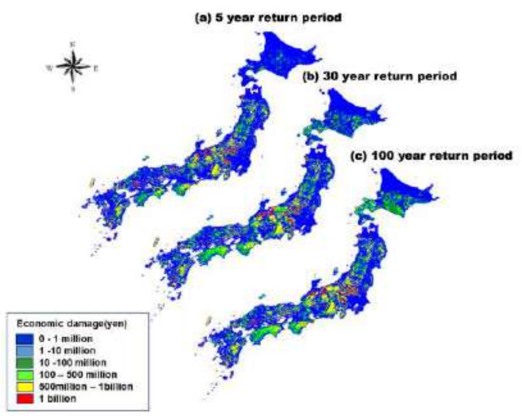


Figure 10 Predicting sediment disaster related economic loss

4. CASE STUDIES OF COMPOUND DISASTERS

Along with the tendency shown in Figure 4, geo-disasters with great scale have frequently occurred as shown in Figure 11. Sediment disasters tend to occur in western areas. This point shows agreement with predicted results in Figure 9 and Figure 10. Some disasters are regarded as compound disasters. Therefore, some case histories are introduced here. They belong to compound disasters based on classification in Figure 3.

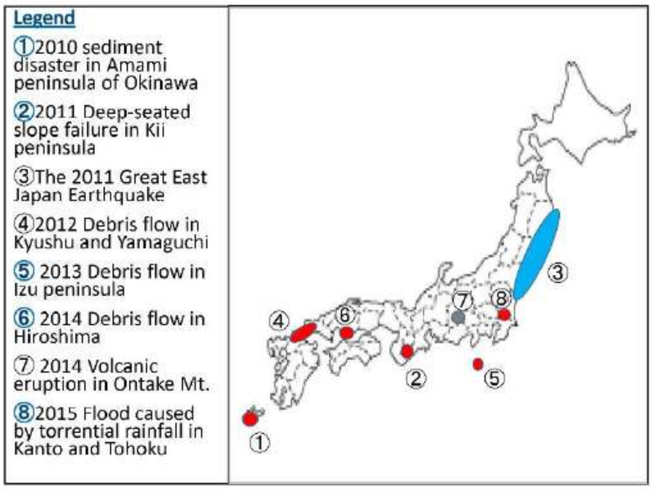


Figure 11 Recent natural disasters with the great scale

4.1 Geo-disasters Triggered by Compound of Abnormal Rainfall with Large-scale Earthquake

Extensive slope failure damage occurred in Niigata in 2004 because a great earthquake with magnitude 6.8 followed by long-term rainfall of longer than one month is counted as a typical compound geo-disaster. As shown in Photo 1, this disaster induced the collapse of highways and derailment of the *Shinkansen*, its first such accident, completely leading to slope failure at around 4000 locations. Many slope failures are caused mainly by the following:

i) Saturation from unsaturated soils undergoing long-term rainfall
ii) Frequent occurrence of strong aftershocks (see Figure 12)

Another feature of damage from this earthquake was to induce the secondary sediment disaster caused by melting heavy snow after the earthquake.

4.2 Geo-disasters Triggered by Abnormal Rainfall and Geomorphologic Characteristics

4.2.1 2010 Sediment disaster on the Amami Peninsula

Amami Peninsula in Kagoshima (location ① in Figure 11) was attacked by Typhoon No. 13, with accompanying heavy rainfall with maximum intensity for that year (137 mm/hr) and total amount of rainfall (977 mm) which was almost twice as large as that in the Nagasaki great flood damage in 1982. This rainfall led to sediment disasters at 55 locations, which include 20 cases of debris flow, 4 of landslides, and 31 of cliff failure. Soils undergoing sediment disasters had well-graded distribution of soil particles, although some were sandy gravel and others were gravelly sandy soil, particularly at the slope surface because of weathering.

Through analysis of the precipitation characteristics observed in the sediment disasters in Amami Peninsula, Yasufuku et al. (2011) pointed out that the rainfall pattern is divided into single-peak and dual-peak torrential rainfalls. Figure 13 presents an example observed on October 20, 2010 which belongs to the single-peak in Figure 13(a) and the dual-peak in Figure 13(b).

Photo 1 Damage to a railway and a highway

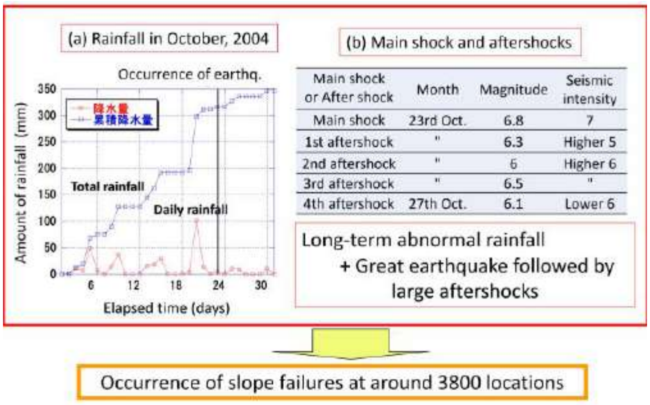


Figure 12 Mechanism of slope failure caused by earthquake

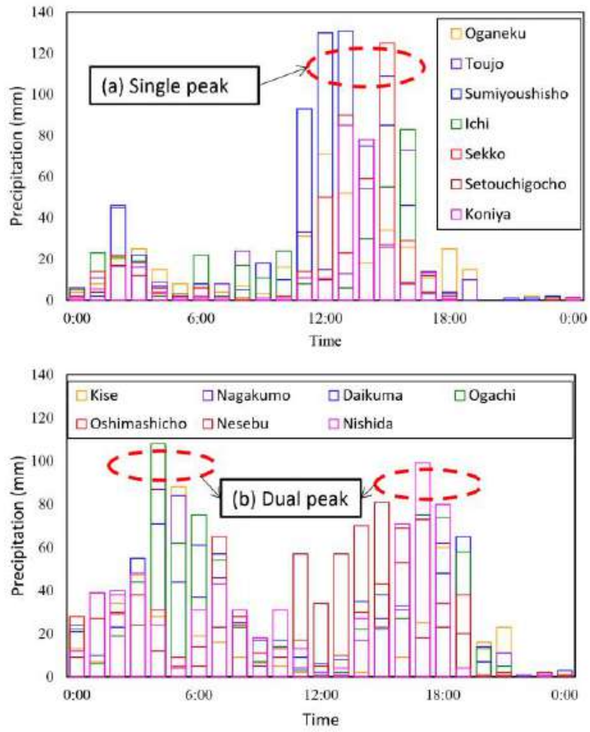
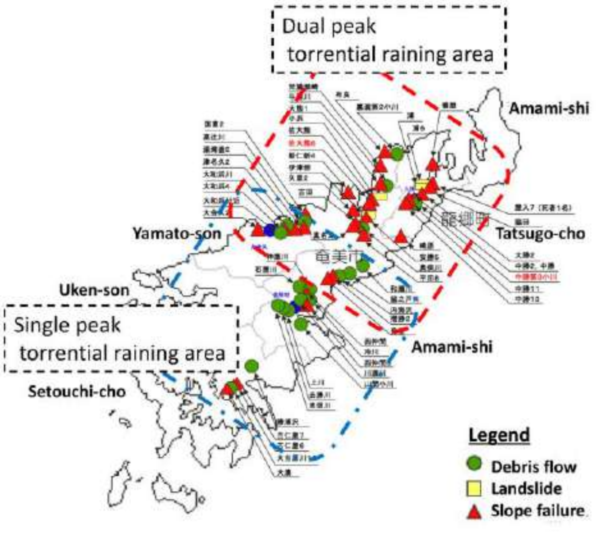


Figure 13 Two-precipitation patterns triggering sediment disasters

Subsequently, Araki and Ishii (2015) noticed that there was a boundary line that can be used to divide single-peak and the dual-peak patterns, as shown in Figure 14. They also found that cliff failure and debris flows were respectively predominant in the northeast and in the southwest of the peninsula, which implies that precipitation with the single-peak pattern is associated with debris flow and precipitation with the dual-peak pattern is associated with landslides and cliff failure. However, they concluded that this tendency had nothing to do with the geological situation and that sediment disasters occurred only at the surface parts of slopes.

(a) Observation locations and boundary line of rainfall patterns



(b) Sediment disasters and boundary line of rainfall patterns (Kagoshima prefectural government, 2015)

Figure 14 Rainfall pattern and sediment disasters as determined from measurements and investigations.

4.2.2 2013 Debris flow in Izu Peninsula

Typhoon No. 26 of October 11, 2013 called *"Wipha"* brought about unexpectedly strong torrential rainfall with total amount of 824 mm/24 hr, the greatest in observed history. Particularly as a result of devastating sediment disasters such as sediment discharge followed by driftwood flows, human casualties came to 40, including fatalities and the missing. The abnormal rainfall resulted from a linearly localized weather front formed by both warm and cold air and its stagnation beyond Izu-Oshima Island for a long period (Meteorological Research Institute, 2013).

Figure 15 presents variations of hourly amounts and accumulated amounts of precipitation with elapsed time from 9:00 on October 15, 2013 through 7:00 on October 16, which indicates that precipitation increased gradually up to the peak at around 3:00 to 4:00 on October 15. Therefore, the unexpected single-peak rainfall induced the massive debris flows; seepage forces derived from the long-term precipitation induced the surface slide.

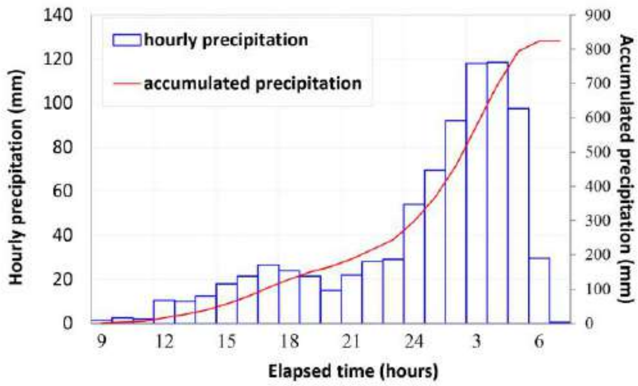


Figure 15 Hourly and cumulative precipitation amounts over time for 9:00 on Oct. 15, 2013 to 7:00 on Oct. 16 (Ohshima Observatory (JMA, 2015))

Sediment transportation from debris flow is shown in Photo 2 with slope failure. Slope failures led to debris flow, which is closely correlated to the single-peak precipitation pattern as found for the sediment disaster in the Amami Ohshima. Some similarities are apparent for Amami Ohshima and Izu Ohshima sediment disasters:

i) Both were disasters on an isolated island
ii) Disasters occurred in October, perhaps in a typhoon season
iii) Both were caused by a typhoon and the autumn rain front

Photo 2 Slope failure and damage (November 9, 2013)

One discrepancy exists for soil types with different properties. Izu Ohshima slopes consisted of volcanic ash sand in the upper layers and loess in the lower layers, whereas slopes in Amami Ohshima constitute gravelly sandy soils in the upper and sandy gravels in the lower layers with a well graded particle size distribution.

4.2.3 2013 Wide-ranged Sediment Disasters in Yamagata

This case study was spurred by unexpectedly abnormal precipitation over wide areas with steep geomorphological topology where several facilities for flood control and erosion control were prepared. The disaster in this area is characterized by magnification of disasters from geo-disasters to water disasters.

Disasters were induced by rain-front-type torrential precipitation during July 17–18, 2013 over wide areas of Yamagata Prefecture.

Particularly near the Oizawa Observatory where the largest amount of rainfall (212 mm/day) observed since the start of recorded observations in 1979. Frequent slope failure caused the disruption of roads and subsequently led to the isolation of numerous locations in town and villages, as shown in Photo 3. This was one reason preventing transportation of water resources to residents.

Photo 3 Sediments transported by slope failure

The Oizawa district, which sustained the greatest damage, is in the upper region of Sagae Dam, a multi-purpose dam managed by MLIT, forms a part of the water resource. This district also has the following geomorphologic characteristics.

i) The up-stream district of the Sagae Dam is in a heavy snowfall area. Therefore, marked development of accumulated and transported collapse materials follows snow melting.
ii) In addition to the steep slope (40 degree as an average gradient), the up-stream district is rich in surface water and groundwater. Consequently, outflow sediments reach the river channel easily and directly.

Those characteristics enable the collapsed sediments to move to the river channel followed actively by outflow of surface water, which brought about pollution of dam lake water to be used as potable drinking water by approximately 500 thousand residents. This water pollution exceeds the potential of remediation by the water purification plant. This chain of events from slope failure to pollution of water resources has caused suspension of water supply, as depicted in Figure 16.

As presented in Figure 17, this disaster represents compounded triggering factors, which produced a chain of disasters from geo-disasters to complex and difficult water disasters also involving environmental aspects.

4.2.4 2014 Hiroshima Debris Flow Disaster

Unexpected and locally torrential rainfall struck the mountainous slopes leading to production of debris flows that severely damaged the residences at the foot of mountains (Figure 18).

Photo 4 is a scene from the mountain stream outlet to residences in the Asa-minami district, showing that both are very close. This evidence shows that residents have no choice but to live close to the dangerous area for their convenience. A typical scene of damaged residences is shown in Photo 5.

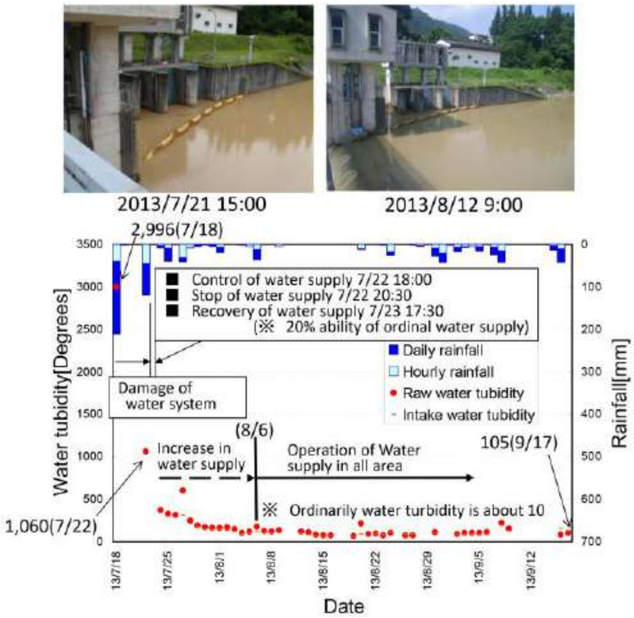


Figure 16 Pollution caused suspension of the water supply

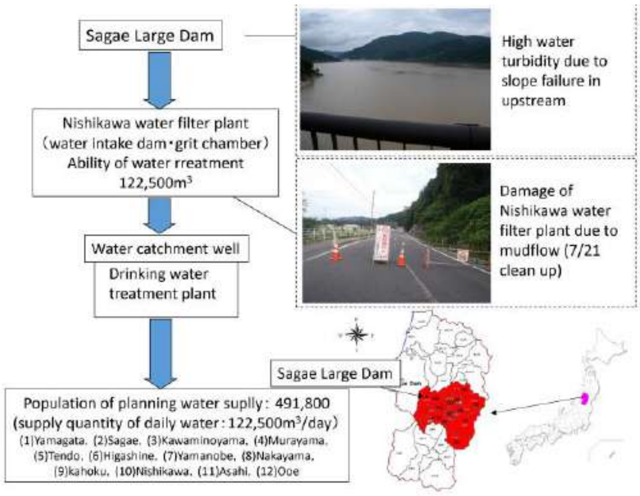


Figure 17 Chain from geo-disasters to water disasters

(a) Before disaster (b) After disaster

Figure 18 Damaged site (Asa-minami district in Hiroshima city (Yomiuri shimbun, 2014)

Photo 4 Relation between mountain stream outlet and residences in debris flow in Hiroshima

Photo 5 Damaged residences in debris flow in Hiroshima

Fatalities and the completely collapsed residences were, respectively, as many as 74 and 133. The main causes of devastating damage from debris flow are the following:

i) Abnormal precipitation called back-building phenomena, which produced linear rainbands and which were brought about by torrential downpours with maximum hourly rainfall intensity were around 101 mm/hr and up to 217.5 mm for 3 hr. This precipitation is similar to that encountered with the Izu Ohshima debris flow.

ii) Collapsed slopes constitute granite rocks at the base and masa soils weathered from granite rocks at the surface, which are prone to slope failure leading to debris flows caused by torrential downpours.

Based on the facts described above, sediment disasters can be regarded as typical compound disasters, although conclusions are left for additional consideration of whether the event is associated with global warming.

4.3 Geo-disasters Associated with Snowfall Followed by Melting

An example of geo-disasters associated with heavy snow and its melting are introduced into 3.2.3. We should devote attention to tendencies of rapidly decreasing snowfall and a possible early snowmelt season in the context of climate change because snowfall, snow accumulation, and melting snow characteristics are expected to affect human life strongly in regions sustaining heavy snows. The Ministry of Environment and JMA (2012) estimate that the maximum decrease of the snowfall amount will be up to 146 cm by the end of this century. These changes of snowfall characteristics are expected to influence not only human life but also slope failure characteristics.

4.4 Characteristics of Recent Geo-disasters in Japan

Table 1 presents a description of typical geo-disasters that occurred during the last decade in Japan. Overall tendencies related to compound geo-disasters presented in Table 1 are presented below:

i) Extreme geo-disasters were exacerbated by great earthquakes and heavily torrential rains and anomalies in the amount and the intensity of rainfall precipitation

ii) A key word in precipitation is the linear rain band, which is probably brought about by rain fronts and typhoon phenomena, but it how this linear rain band is associated with global warming and climate change remains unclear.

iii) Generally speaking, soil types related to severe geo-disasters are sandy or gravelly soils, sometimes containing fine materials. Among them, some are so-called local soils including volcanic origin soils and weathered soils

Table 1 Compound geo-disasters of the last decade in Japan

Name of geo-disaster	Occurrence period	Soil type & soil properties	Magnitude of disaster	Factors causing disasters	Scientific and engineering characteristics & significances
Mid. Niigata Prefectural Earthquake (M6.8, & max. seismic intensity 7)	Oct.23,2004		No. of fatality: 68 No. of casualty: 4805	･Large earthquake (Mw: 6.8) folllowed by many aftershock ･Slope failure:caused by one month continuous rainfall before earthquake ･Avalanches: caused by heavy snowfall after earthquake	･A typical compound disaster where great earthquake was combined by a long-term rainfall
Sediment disaster in Amami Peninsula	Oct. 20, 2010	･Well-graded soil ･Sandy gravel and gravelly sandy soil	No. of fatality: 3 No. of damaged residences:24 Economical loss: 123 billion yen	Combined fall rain front and Typhoon No. 13 produced the maximum amount of precipita-tion with 691 mm	･The rainfall pattern causing geo-disasters is divided into the one-peak and the two-peak torrential rainfall.
Debris flow in Izu peninsula (Typhoon No. 26)	Oct.11, 2013	･Volcanic ash sandy soil ･Leoss soil (predominantly silt-sized sediment formed by the accumulation of wind-blown dust)	No. of fatality & missing: 40 No. of damaged residences:86	･Superimposing the typhoon and the autumn rain front followed by the linear rainband ･Total amount of precipitation: 824 mm/24hrs	･The one-peak rainfall produced mud flow and seepage forces caused by a long-term rainfall did sliding failure of slopes. ･Driftwoods were followed by mud flow.
Wide-ranged Sediment Disasters in Yamagata	17 to 18 July, 2013		･Isolation of villages and town ･Water suply to 500 thousands citizens was prevented	Geomorphological situation combined with abnormal rainfall with maximum intensity of 212 mm/day produced a chain of disaster from geo-disasters to water disasters	･Contamination of lake water was followed by sediment disasters. This is an evidence showing that disastrous and environmental issues are closely correlated.
Hiroshima Debris Flow Disaster	Aug. 20, 2014	Masa soil weathered from granite	No. of fatality: 74 No. of casualty: 44 No. of damaged residences: 255	Localized torrential rainfall attaked the vulnerable slopes consisting of weathered granite soils which are in general vulnrable to rainfall.	Back-building phenomena induced the linear rainband and thus localized torrential rainfall leading to devastating disasters.

4.5 Geotechnical Similarities and Discrepancies

An attempt was made to ascertain whether common fundamental geotechnical characteristics exist among soils related to previously stated geo-disasters. Figure 19 presents a summary of grain size distribution curves of soils from four geo-disasters in Amami (2010) (Kyushu University's Amami Oshima heavy rain disaster survey team, 2011), Izu (2013) (JSCE, JGS, JSEG and JLS (2014)) and Hiroshima (2014) (Araki et al., 2015).

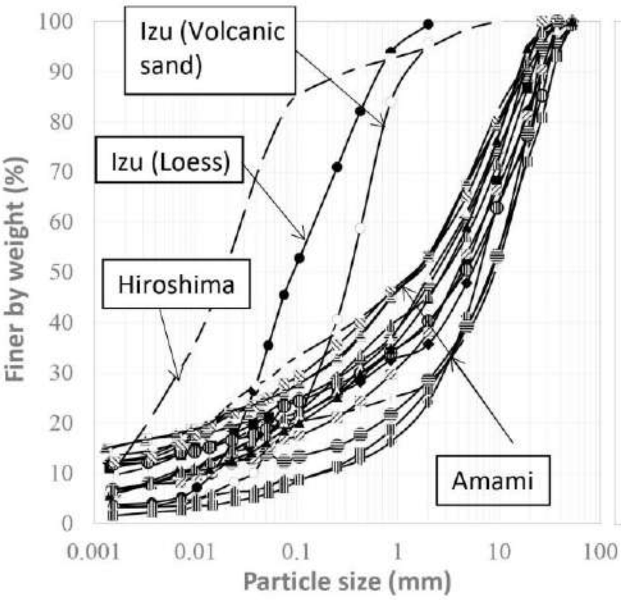


Figure 19 Grain size distribution curves of soils in heavily geo-disaster damaged regions

Soils at Izu and Hiroshima are silt-rich, whereas soils at Amami are sand-rich, which suggests that torrential rainfall induces devastating sediment disasters independently of the soil type on natural slopes.

However, Figure 20 presents the relation between coefficients of curvature and uniformity, U_c and U_c' determined from Figure 19. Figure 20 shows that the coefficient of curvature U_c' is roughly below one-tenth the coefficient of uniformity U_c. Particularly, there are tendencies by which U_c' approximately equals one-tenth of U_c for U_c below 100; U_c' is below one-tenth for U_c beyond 100.

The coefficient of curvature becomes smaller in comparison with the coefficient of uniformity, implying that the feasible grain size range widens by increased rock weathering and soil mass production.

Similarly, a plan of disaster prevention policies and strategies should be made if soil particle characteristics are correlated with other parameters such as peculiarity of precipitation, occurrence of surface water, seepage potential, and the scale of soil mass collapse.

5. GEOTECHNICAL ADAPTATION TO GEO-DISASTERS IN THE CONTEXT OF CLIMATE CHANGE

5.1 General

Generally speaking, less attention has been devoted to geo-disasters in the context of climate change in the field of global environmental science and engineering. Therefore, no systematic adaption to geo-disasters has been proposed in the context of climate change such as that described in the IPCC recent report in 2014. Very recently, however, Yasuhara et al. (2012: 2013) summarized possible geotechnical adaptations as classified into three categories in accordance with the philosophy raised in IPCC AR4 (2007).

The current paper explains some geotechnical adaptations as presented in Table 2, with discussion of their availability to reduce coastal and riverine damage in the context of climate change by division into hard and soft adaptive measures.

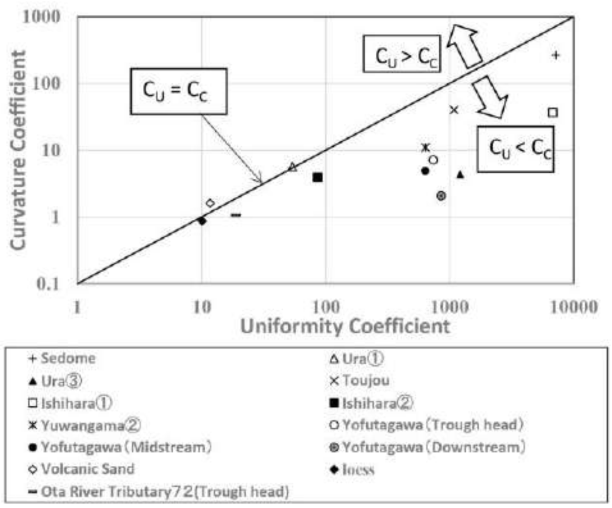


Figure 20 Relation between coefficients of curvature and uniformity

5.2 Vulnerability to Natural Disasters

Responsive measures to events caused by climate change are divisible into mitigation and adaptation, as shown in Table 2. Mitigation includes measures for reducing greenhouse gas (GHG) emissions while adaptation makes any arrangement for protection and reduction of damage to impacts by climate change or makes use of beneficial opportunities. In other words, measures for reducing exposure and measures for increasing the resilience to disasters can be called mitigation and adaptation, respectively, as Figure 21 shows, where the vulnerability of disasters is defined as presented below.

$$\text{Vulnerability: } V = E - (M + A) - R \quad (1)$$

Therein, E stands for exposure, M signifies mitigation, A denotes adaptation, and R represents resilience. Adaptation can contribute to decrease in vulnerability to natural disasters.

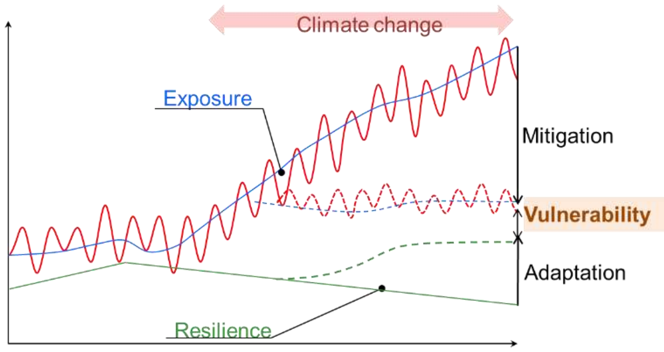


Figure 21 Definition of vulnerability to disasters caused by natural hazards (Komatsu et al., 2013)

5.3 Monitoring System as Adaptation to Geo-disasters

One important adaptive measure to sediment disasters and geo-disasters are monitoring systems used before, during, and after the disaster. Monitoring can be divided into pre-disaster (proactive) monitoring for early warning, post-disaster (reactive) monitoring for prediction of secondary disasters and precautions for them.

Representative examples of each are, respectively, utilization of sensors and Un-crewed Aerial Vehicles (UAVs).

As presented in Figure 22, early warning for sediment disasters should involve monitoring of variations of precipitation, surface displacement, and pore water pressures or water content in sloping grounds over time. Ideally, for issuing precise warnings, the optimum decision must be made using information stated above, although this is extremely difficult, as presented in Figure 22.

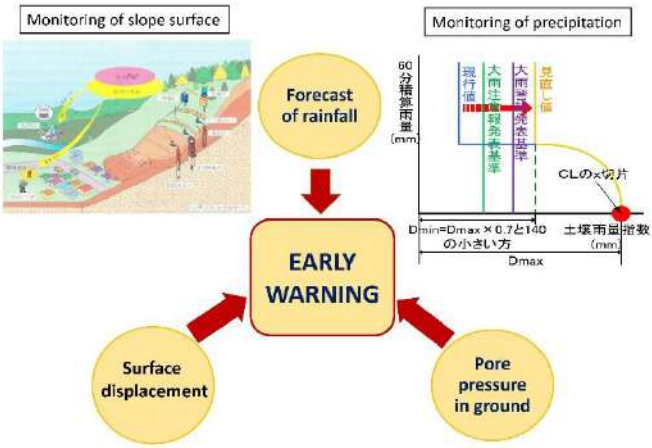


Figure 22 Integrated monitoring system for early warning of sediment disasters

5.4 Possible Installation of Acceleration Sensor

Large-scale model tests for slope failure caused by rainfall were conducted at the National Research Institute for Earth Science and Disaster Prevention (NIED) (Dairaku et al., 2014). Figure 23 shows a slope outline with 30 degrees for a gradient, which consists of masa soil with initial water content of around 7.9%. Masa soils used for the model tests closely resemble soils constituting debris flow that occurred in Hiroshima in August 2014. To ascertain how variation of acceleration in sloping ground with intensity of rainfall is correlated with slope failure, sensing IC-tags called MEMS were installed as shown in Figure 24 together with equipment to measure variations of volume moisture content.

Figure 23 Outline of model tests on slope failure caused by rainfall

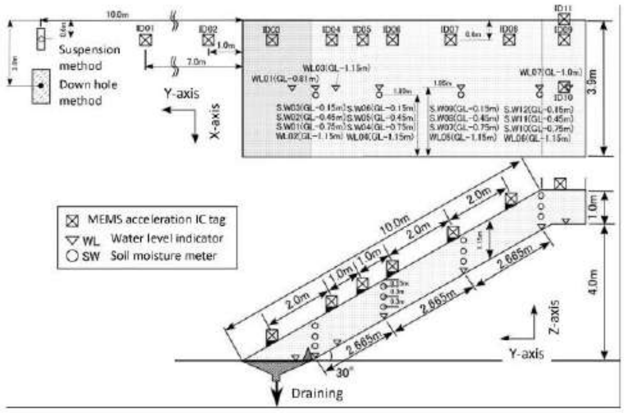


Figure 24 Sectional view of the model testing slope

Figure 25 and Figure 26 portray the variations of natural frequency measured from the IC-tags and the variations of volume moisture content with elapsed time starting from falling rain water above from the model testing equipment under the rainfall intensity of 15 mm/hr to 40 mm/hr. Results of both figures show that the predominant frequency decreases concomitantly with increasing volume moisture content in the sloping ground. This tendency suggests that either or both of the parameters should be clues for determination of when we should give alarms to citizens.

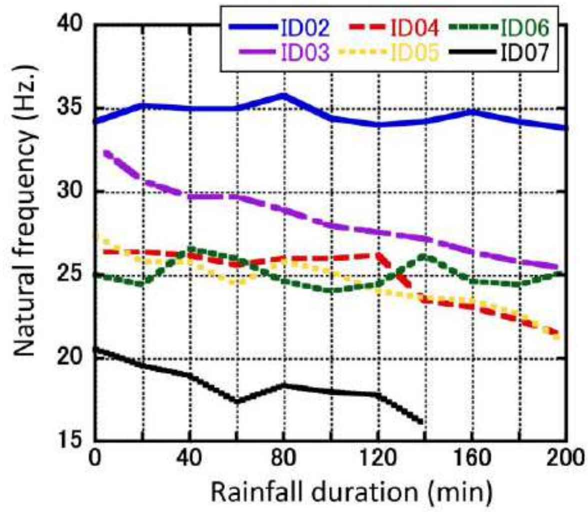


Figure 25 Variation of natural frequency with rainfall duration.

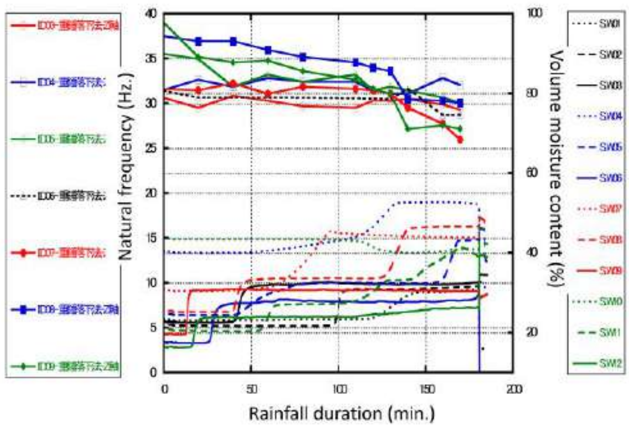


Figure 26 Variation of volume moisture content with rainfall duration.

A design chart like that depicted in Figure 27 can assist local governments to establish early warning systems following the instructions. Differences of thresholds of natural frequency or critical volume moisture content in Figure 28 are ascribed to differences of sensitivity to rainfall and water retention depending on the kind of soil: sand, silt, or clay.

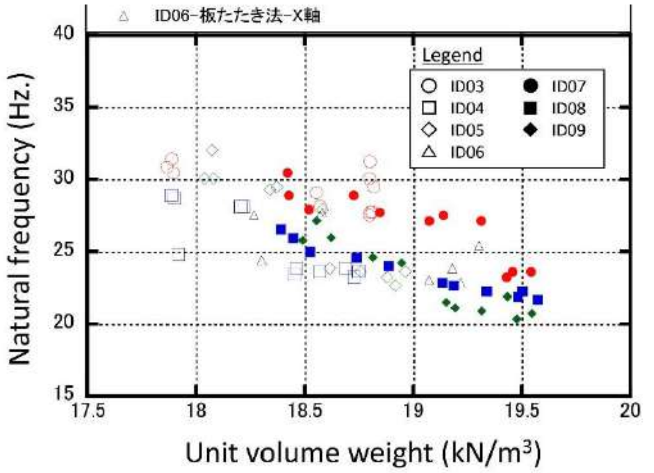


Figure 27 Relationship between natural frequency and unit volume weight of soils measured at large-scaled model tests (Dairaku et al., 2014)

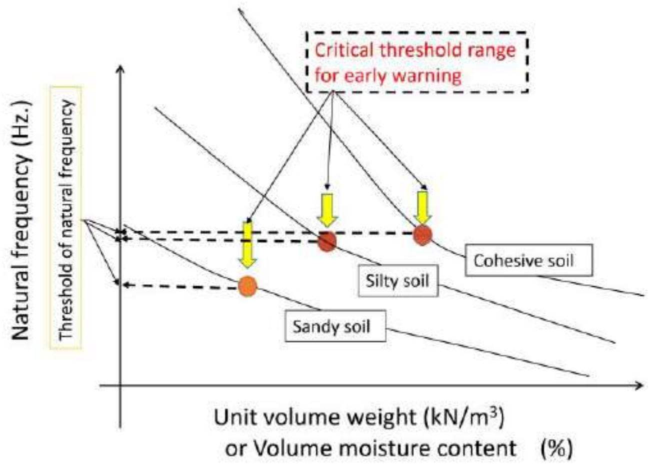


Figure 28 A key sketch for determining the critical value of natural frequency and volume moisture content.

6. CONCLUSION

Japan must confront its extremely bad location, combining land upheaval with climate change effects. Background evidence of increasing and magnifying geo-disasters was presented at the beginning of this paper, which is an overview of the present situation and future trends of geo-disasters in the context of climate change. Moreover, this paper presents possible adaptive measures against geo-disasters. Particularly, the importance of combined effects of plural events is emphasized. They increase the probability of extreme events, sometimes triggering devastating consequences. Specifically, the following were introduced as new findings:

i) The possibility exists that torrential rainfalls lead to slope failure and to debris flow. Therefore, such disasters are an issue spanning fields of geotechnical engineering and hydraulics.
ii) In regions with heavy snows, snow melting produces extreme sediment disasters, although the amount of snow accumulation has decreased because of global warming.
iii) Once rainfall becomes severe, sediment disasters become devastating, independently of the soil type. In such cases, no countermeasures can be effective except evacuation. Therefore, early warning is most required.
iv) Rainfall patterns are divisible into single-peak and dual-peak torrential rainfall. Aside from this, precipitation with the single-peak pattern should be associated with debris flows. Precipitation should be associated with the dual-peak pattern and with landslide and cliff failure.
v) Adaptive measures against climate change-associated geo-disasters are presented by classification into software and hardware. Special emphasis is given to the availability of information and communication technology (ICT) such as IC-sensors, which are useful for local governments to construct early warning systems.

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