Slope Failure Disasters and Countermeasures

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Typical site plannning countermeasures against slope failures at countryside
(Yamaguchi prefecture, western Japan)

Phenomena to Cause Sediment Disasters

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Debris Flow

This is a phenomenon in which soil and rock on the hillside or in the riverbed are carried downward at a dash under the influence of a continuous rain or a torrential rain.

Although the flow velocity differs by the scale of debris flow, it sometimes reaches 20-40 km/hr, thereby destroying houses and farmland in an instant.

Landslide

This is a phenomenon in which part of or all of the soil on a slope moves downward slowly under the influence of groundwater and gravity.

Since a large amount of soil mass usually moves, a serious damage can occur. If a slide has been started, it is extremely difficult to stop it.

Slope Failure (landslip, earth fall)

In this phenomenon, a slope abruptly collapses when the soil that has already been weakened by moisture in the ground loses its self-retainability under the influence of a rain or an earthquake.

Because of sudden collapse, many people fail to escape from it if it occurs near a residential area, thus leading to a higher rate of fatalities.

Law for Prevention of Sediment Disasters

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Sabo Law (Enacted in 1897)

■ Law for the purpose of so-called "flood-related erosion control

Prevention of interference with the normal flow of rivers

■ Landslide and Slope failre disaster <u>locations and implementation limited by the reading of the "Erosion Control Low"</u>

Landslide Prevention Law (Enacted in 1958)

■ Enacted to promote new measures for landslides in city areas, which could not be adopted in the Erosion Control Act.

* Impetus was the **July 1957** Western Kyushu landslide disaster which produced casualties

■ <u>Landslide measures separated</u> from erosion control measures

Law on Prevention of Disasters caused by Steep Slope Failure (Enacted in 1969)

■ Enacted based on public calls for the rapid development of landslide measures.

* Impetus was the frequent landslide damage caused by localized heavy rains in Nagasaki, Saga, Hiroshima and Hyogo (July), Niigata and Toyama (August), and Wakayama (October) in **1967**

■ <u>Steep slope measures separated</u> from erosion control and landslide measures

Sediment Disaster Prevention Law

(Enacted in 2000)

■ Newly enacted due to the recognized need for stronger soft measures such as the dissemination of information on risk areas for sediment disasters, the development of warning and evacuation systems, the restriction of development activities and the strengthening of building safety etc.

* Impetus was the **June 1999** Hiroshima and Kure landslide and debris flow disasters

(Amended in 2011)

■ Amended to provide necessary information for municipalities so that they can determine evacuation instructions for residents in the event of an imminent sediment disaster.

* Impetus was the river channel blockages resulting from the 2004 Niigata-Chuetsu Earthquake and the 2008 Iwate-Miyagi Inland Earthquake.

■ **Sediment Disaster**

<u>Soft Measure Enhancement</u>

Hard Measures | **Soft Measures**

An example of hazard map for sediment disasters

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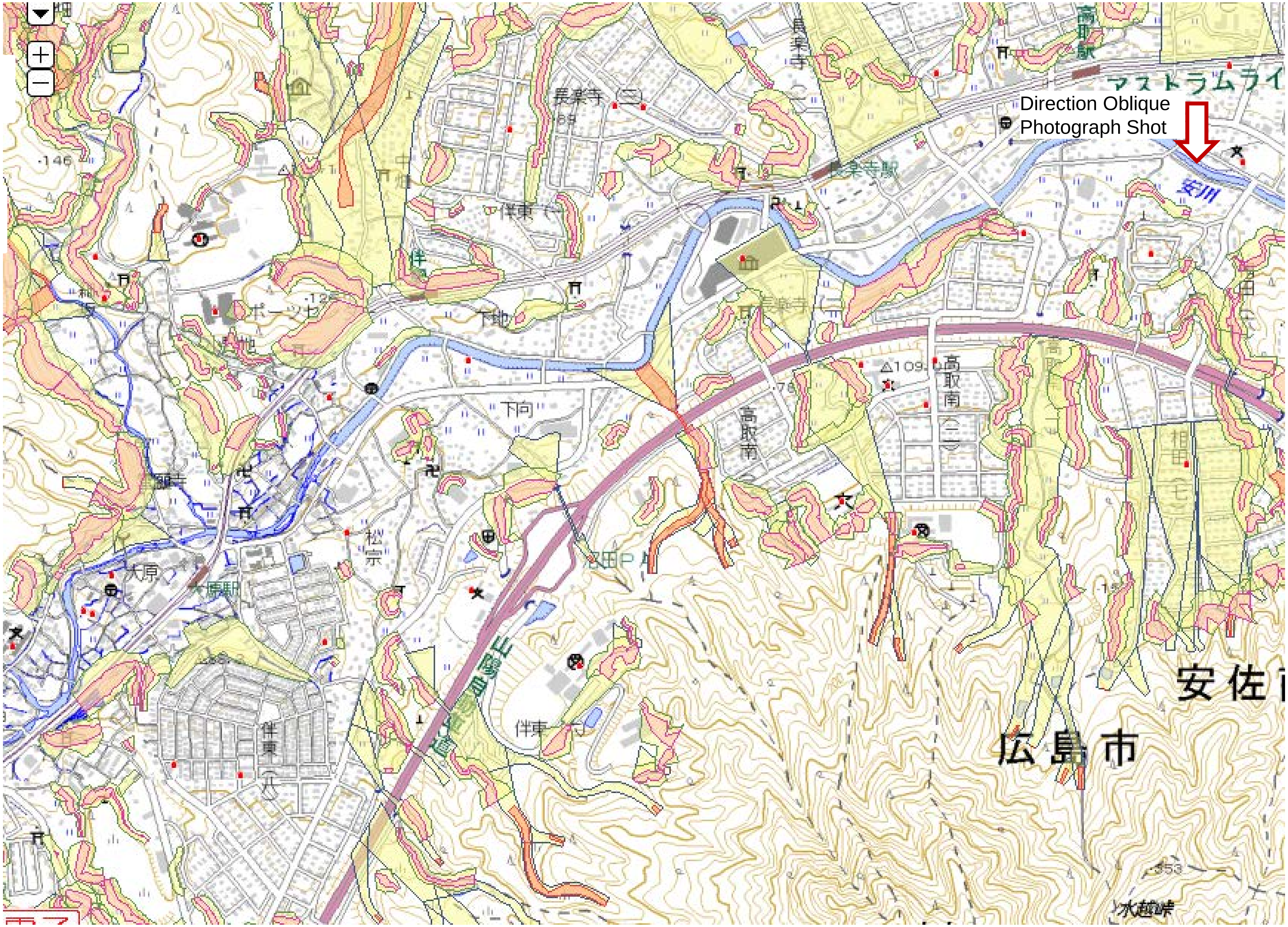
- Debris flows
  - Special Risk Area
  - Risk Area
- Slope failures
  - Special Risk Area
  - Risk Area



Slope Failure Disaster caused by Rainfall

Sept 2005 Kitamorokata, Miyazaki pref.

Aso city, Kumamoto prefecture, July 2012

Slope Failure Disaster caused by Rainfall

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Jun 2014 Yokosuka, Kanagawa pref.

Slope Failure Disaster caused by Earthquake

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Difference between Slope Failures and Landslides

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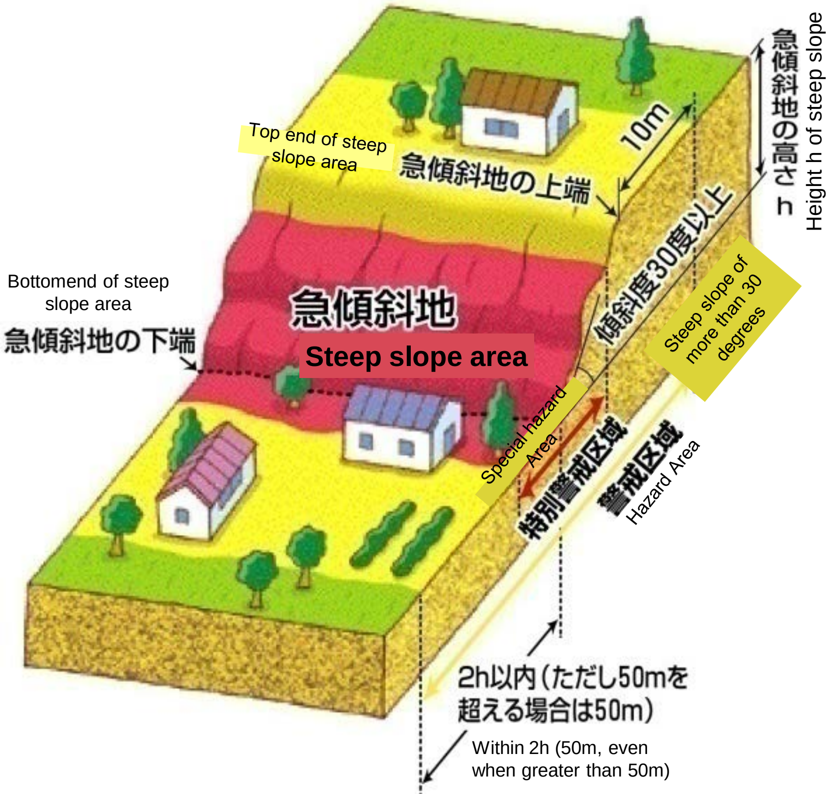
Diagrams of Location Prone to Slope Failures Disasters



Features of Slope Failures and Landslids

Item	Slope failures	Landslides
Geology	Almost no relation to geology	Occurs in specific geology and geological structure
Topography	Occurs at a steep slope	Occurs at a gentle slope in a so-called landslide topography
Depth of movement	Within 1-2m	Several meter to over 10 meter
Scale of movement	Small	Large
Speed of movement	Abrupt	Usually slow, sometimes abrupt
Warning signs	Hardly any warning signes almost always fail suddenly	Often developed cracks, depressions, upheavals, groundwater fluctuation
Causes, triggering mechanism	generally influenced by rainfall intensity	Generally infuluenced by excess groundwater, elevated groundwater table

Types of slope movement

<table>
<tr><td colspan="3" rowspan="3">TYPE OF MOVEMENT</td><td colspan="3">TYPE OF MATERIAL</td></tr>
<tr><td rowspan="2">BED ROCK</td><td colspan="2">ENGINEERING SOILS</td></tr>
<tr><td>Predominantly coarse</td><td>Predominantly fine</td></tr>
<tr><td colspan="3">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="3">TOPPLES</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="3">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">FEW UNITS</td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td rowspan="2">TRANSLATIONAL</td><td>Rock block slide</td><td>Debris block slide</td><td>Earth block slide</td></tr>
<tr><td>MANY UNITS</td><td>Rock slide</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td colspan="3">LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="3" rowspan="2">FLOWS</td><td rowspan="2">Rock flow
(deep creep)</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td colspan="2">(soil creep)</td></tr>
<tr><td colspan="3">COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

Varnes (1978)

Collecting Basic Data on Sediment Disasters

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- In order to obtain necessary basic data on sediment disaster measures in Japan, disaster data collection activities and sediment disaster risk location investigations have been implemented.

- The resulting data is used for a variety of other studies into required locations for sediment disaster measures, the study of technical criteria, the study of warning and evacuation system, policy reviews, and the study of responses following disasters.

- Prefectures carry out the investigations, on behalf of the national government. The details from the investigations are then presented to the prefectures by the national government

Disaster Report Form

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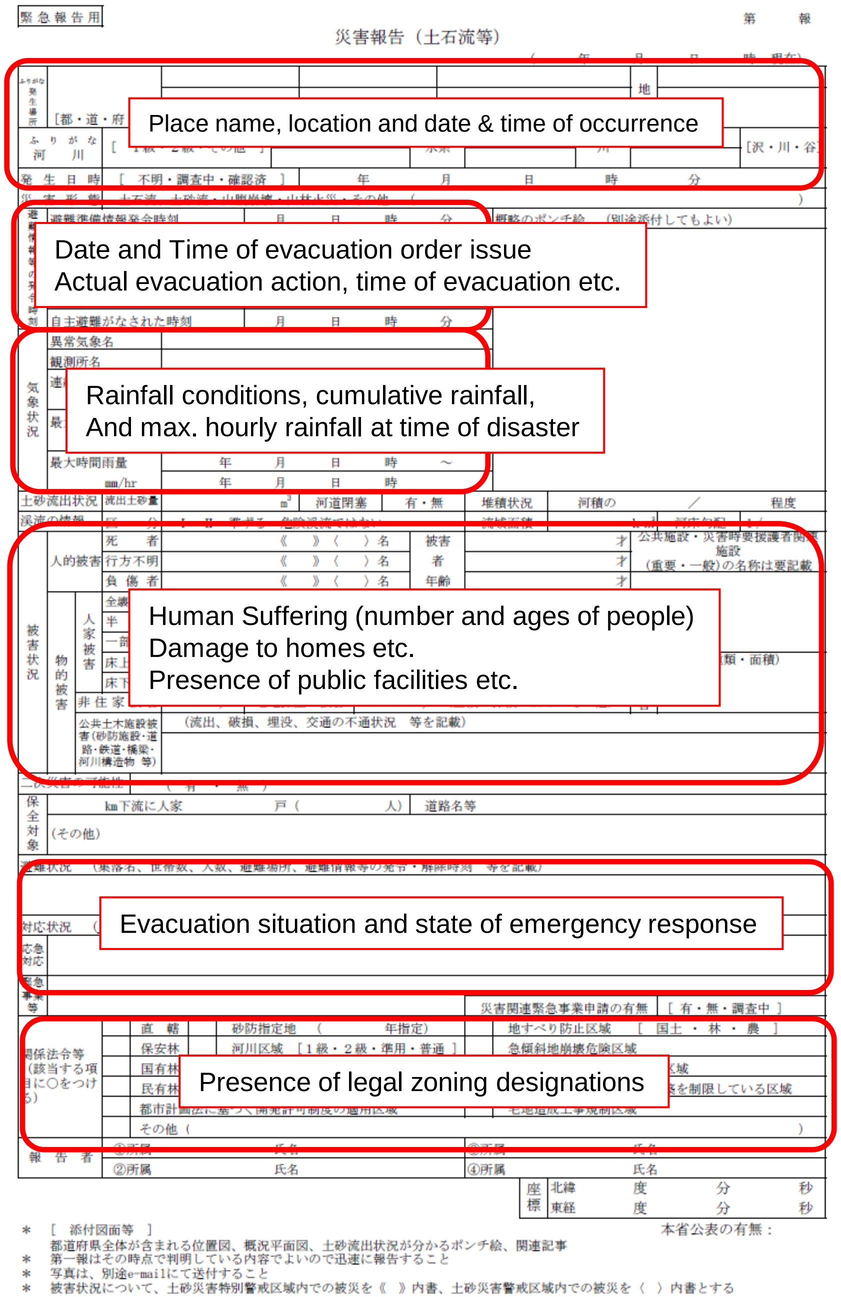
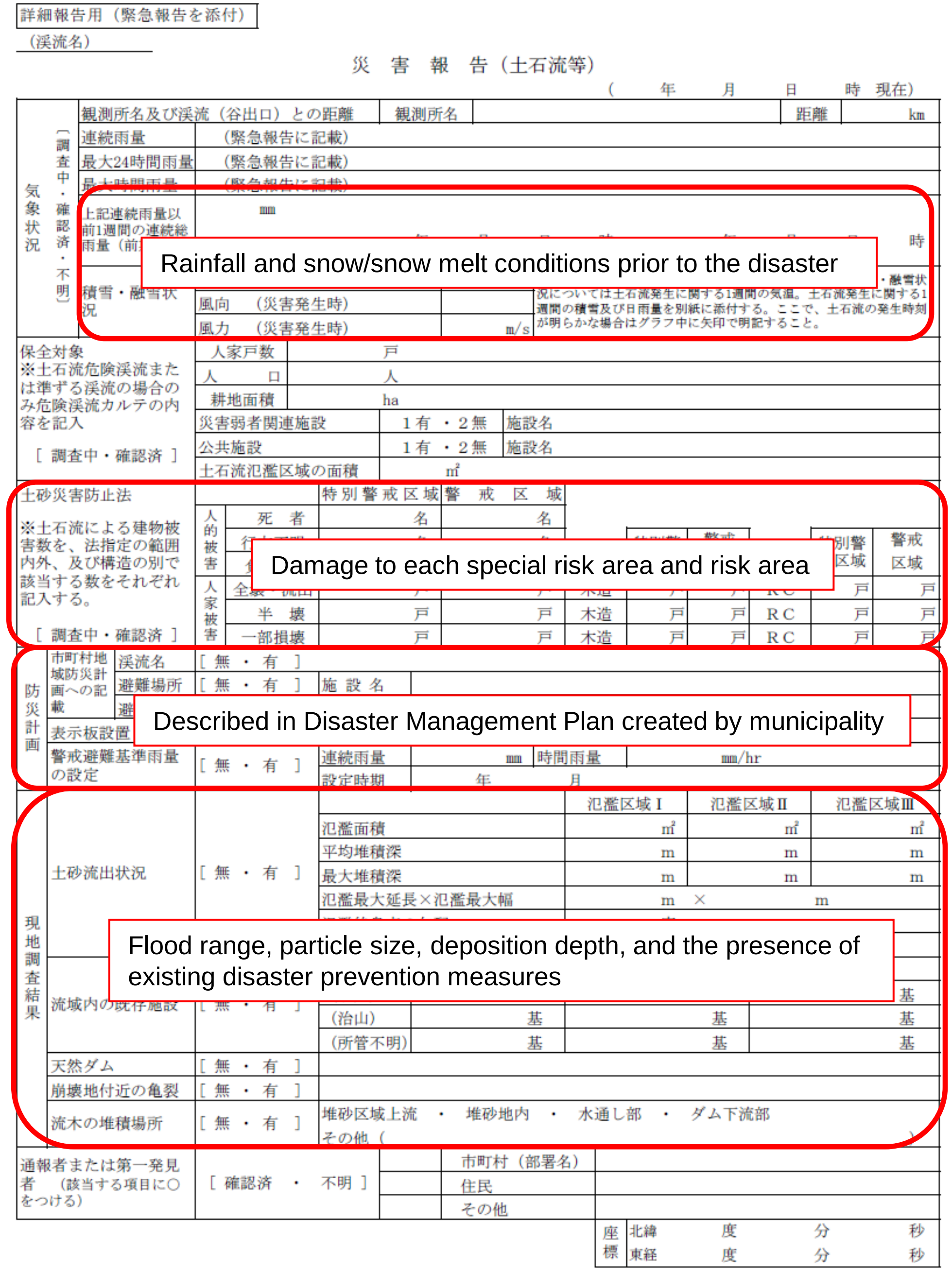
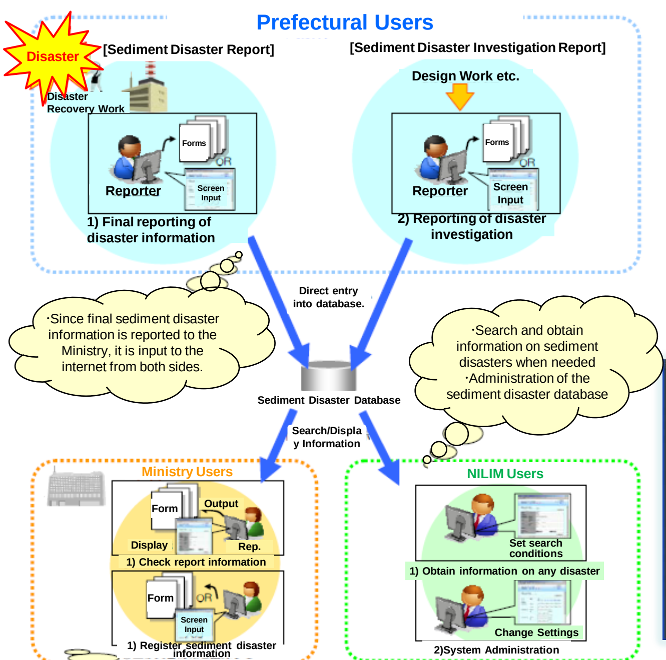
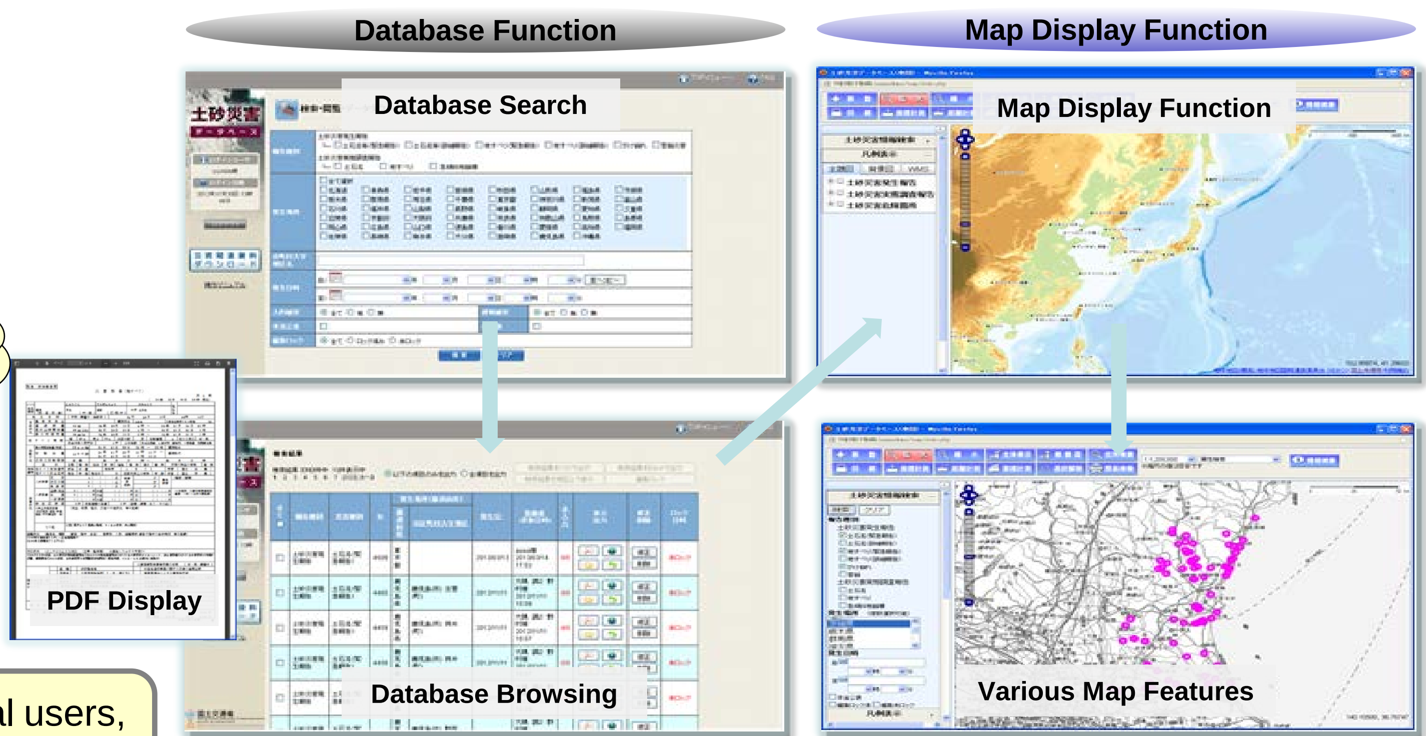




Sediment Disaster Data Collection System

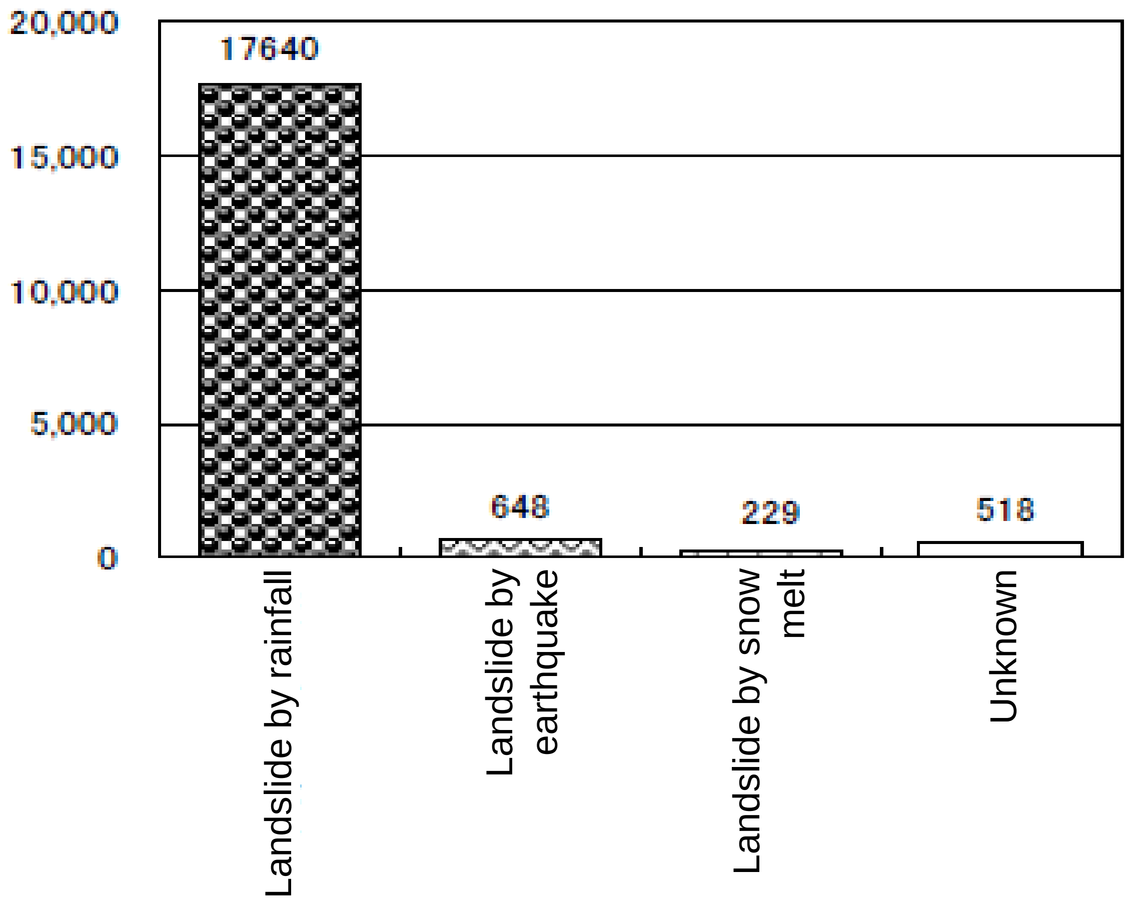
- In the event of a sediment disaster, there is a need for national and prefectural governments to share details of the disaster for the purpose of emergency response and recovery
- The database is shared between the national and prefectural governments over the internet





When there is a report from prefectural users, a web search is made to confirm the details.

Basic Characteristics of Slope Failure (Inducing Factors)



Basic Characteristics of Slope Failure (Topography)

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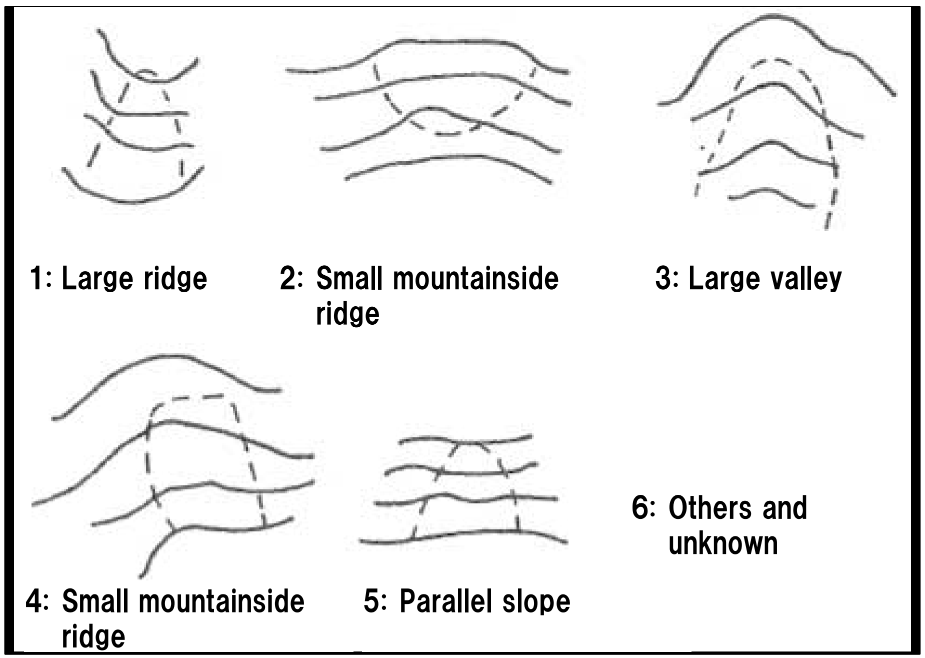
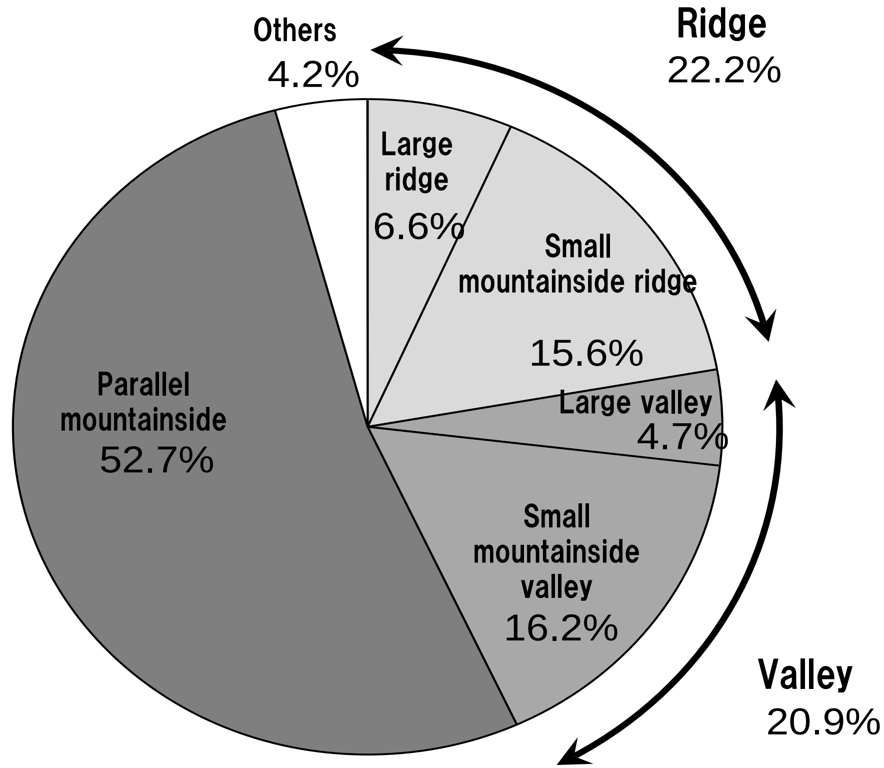
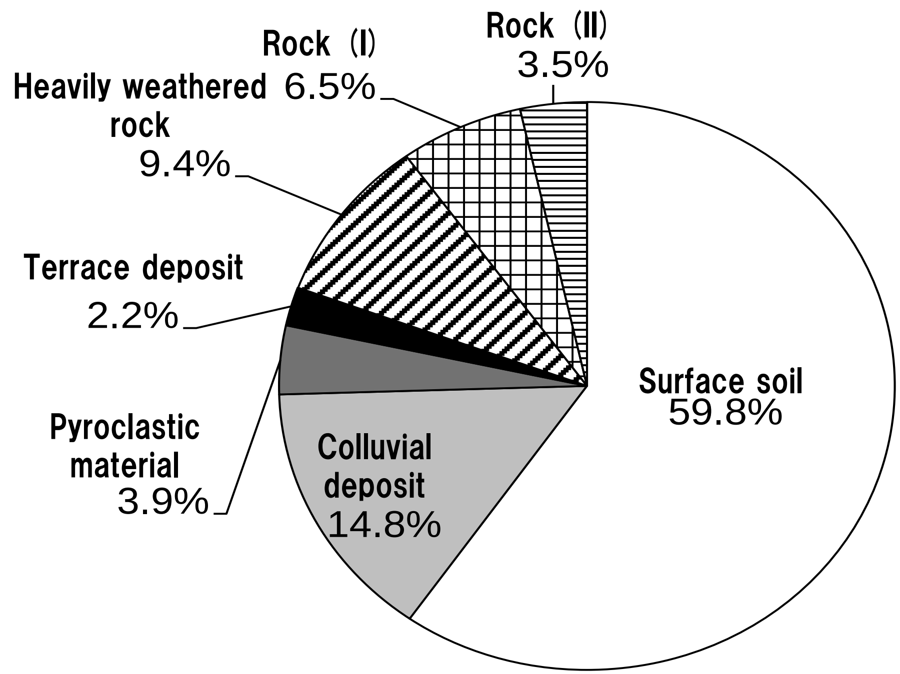




Basic Characteristics of Slope Failure (Soil Property)

Soil property	Collapse site	
	No. of sites	Component rate (%)
Surface soil	6038	59.8
Colluvial deposit	1494	14.8
Pyroclastic material	398	3.9
Terrace deposit	219	2.2
Heavily weathered rock	947	9.4
Rock (I)	654	6.5
Rock (II)	355	3.5
Total	10105	100



Basic Characteristics of Slope Failure (Geography)

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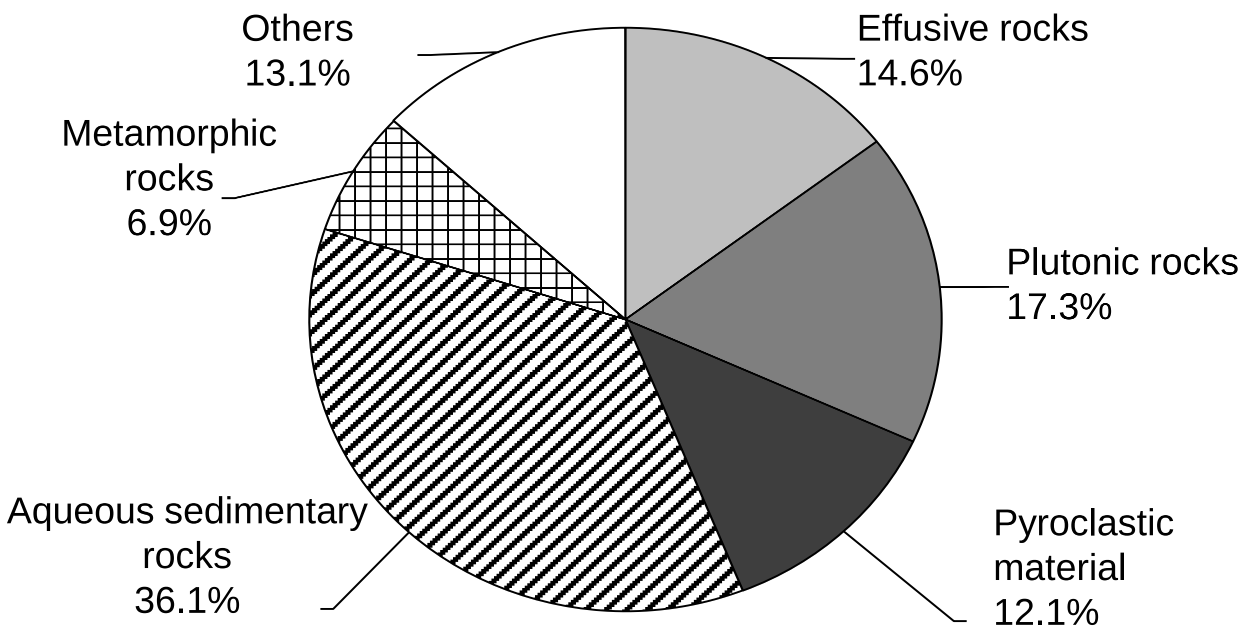
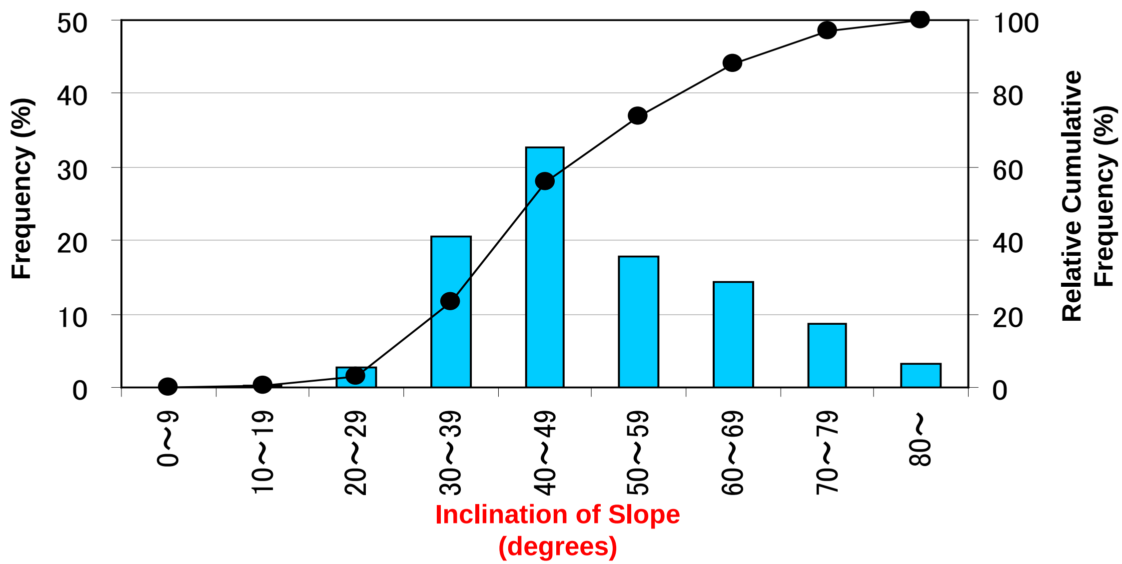
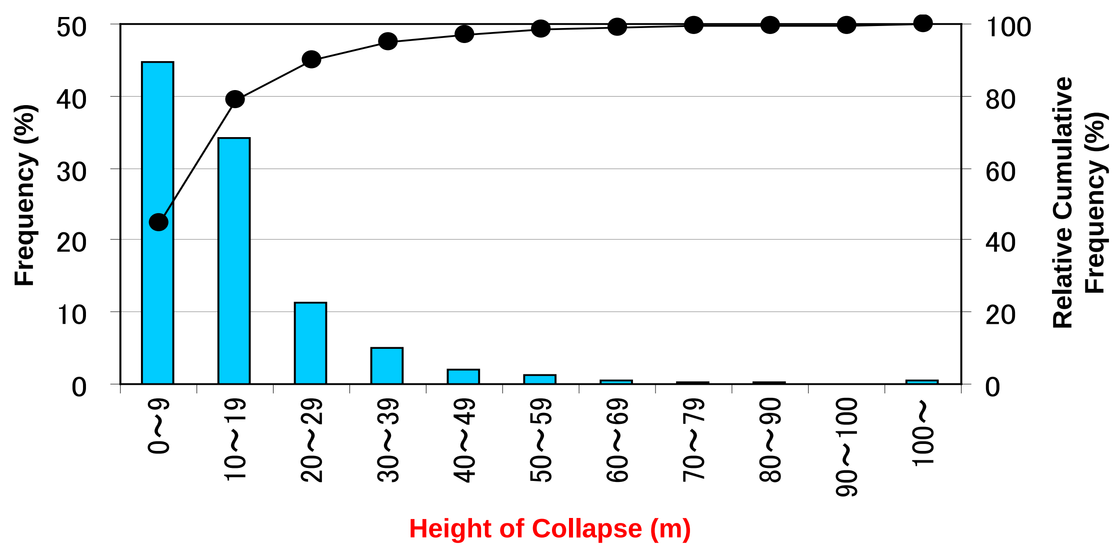
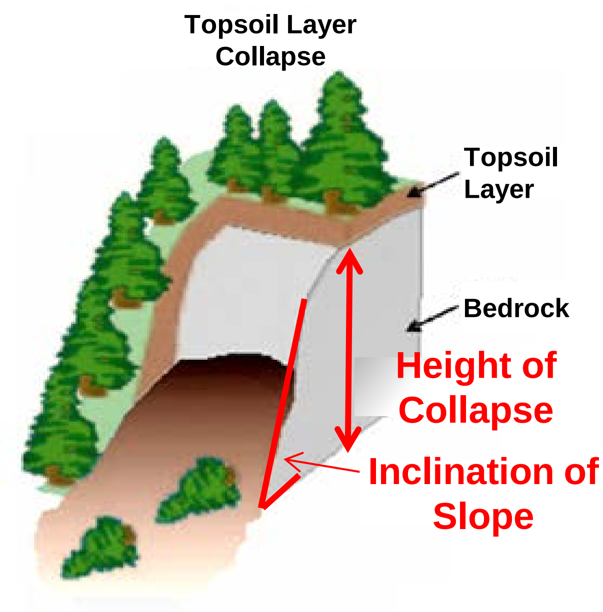
Geologic category	Typical rocks	Disasters from 1972 to 1997 (%): A	Distribution area (%): B	Collapse occurrence ratio A/B
Effusive rocks	Andesite, basalt, rhyolite, etc.	14.6	26.7	0.55
Plutonic rocks	Granite, diorite, quartz porphyry, etc.	17.3	11.8	1.47
Pyroclastic material	Agglomerate, tuff, etc.	12.1	55.3	0.87
Aqueous sedimentary rocks	Shale, sandstone, clayslate, etc.	36.1		
Metamorphic rocks	Schist, chert, etc.	6.9	4.6	1.50
Others		13.1	1.6	8.19



Basic Features of Slope failures (Inclination of slope and height of collapse)

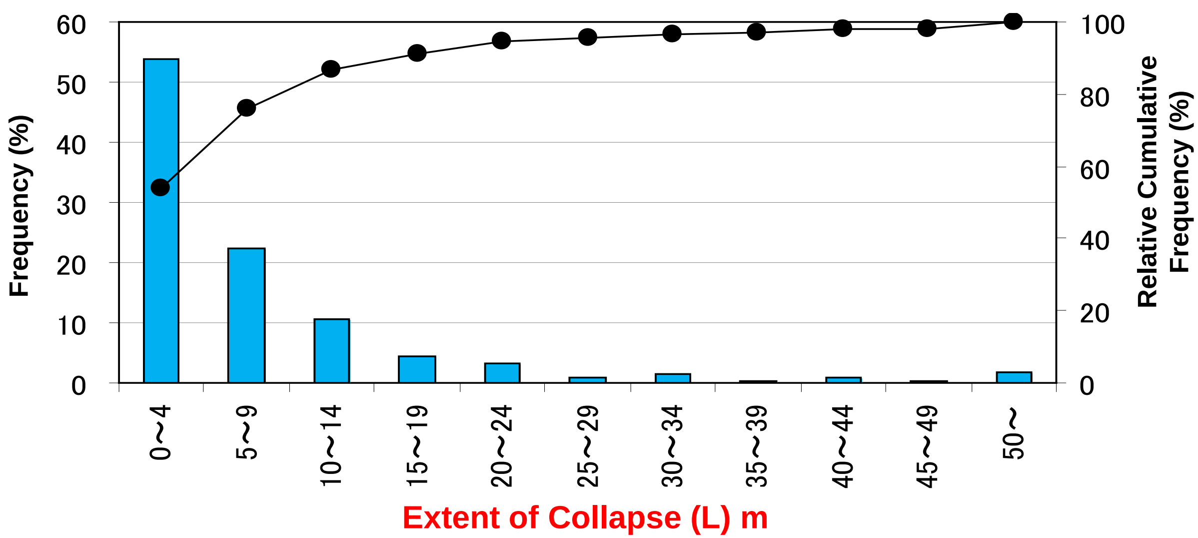


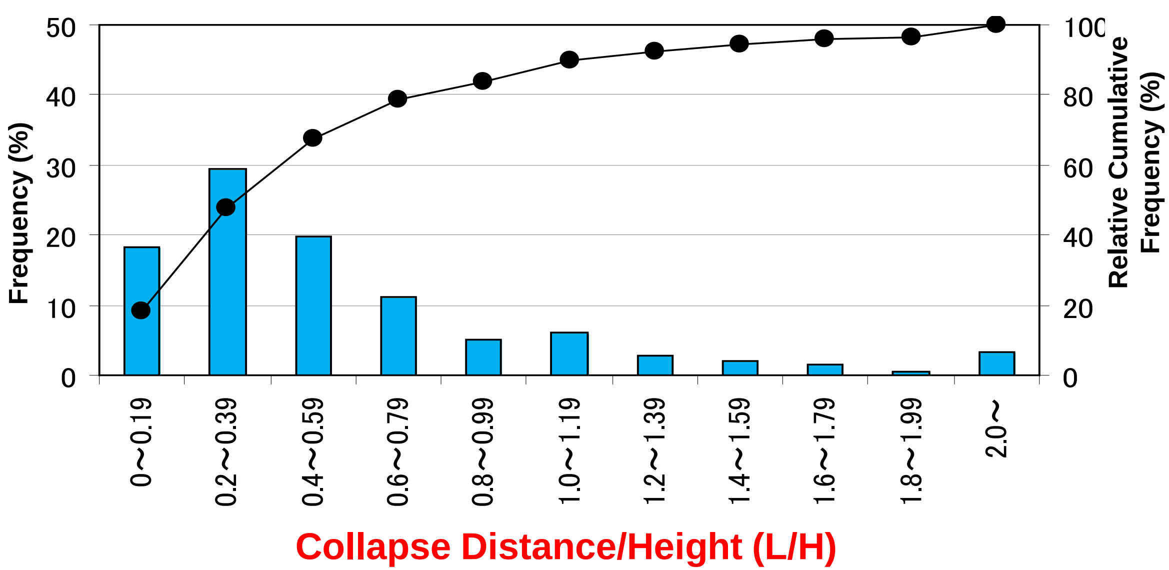


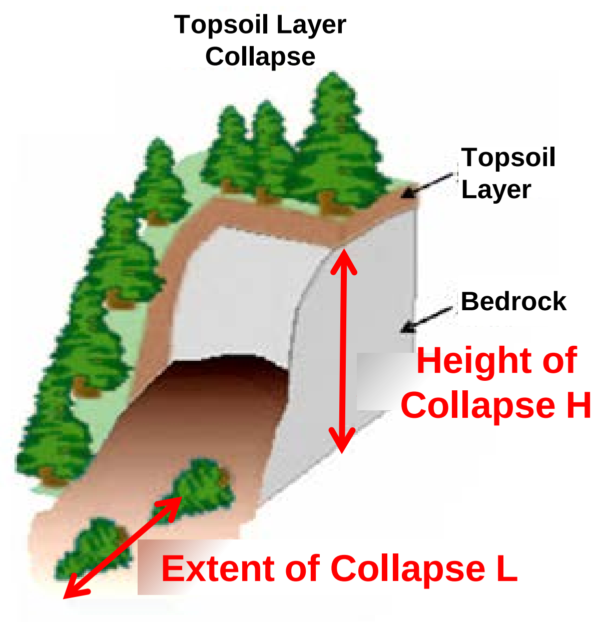


Basic Features of Slope failures

（Extent of Collapse and Relationship between Collapse Distance and Height）







Basic Characteristics of Slope Failure (Depth of Failure)

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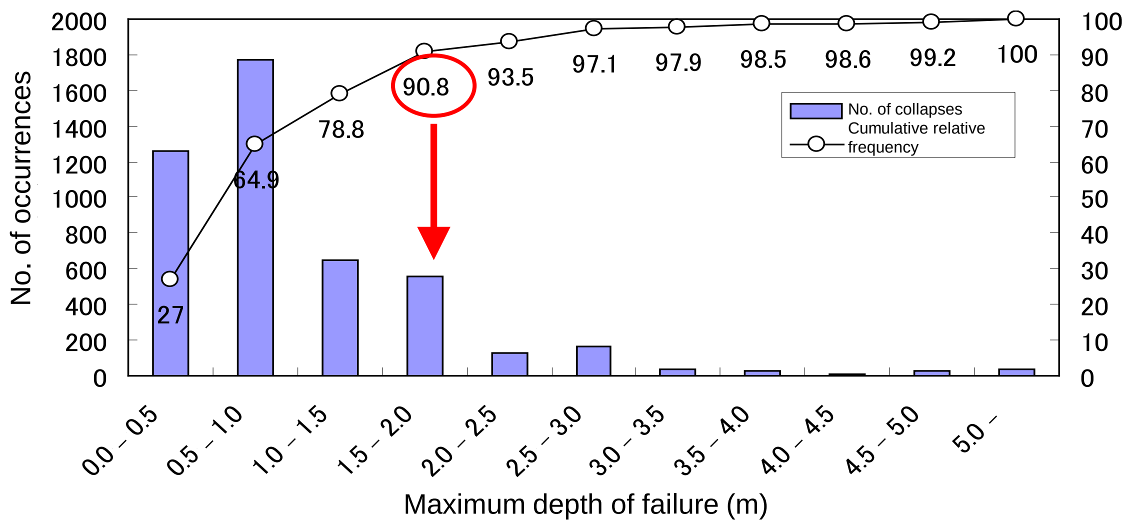
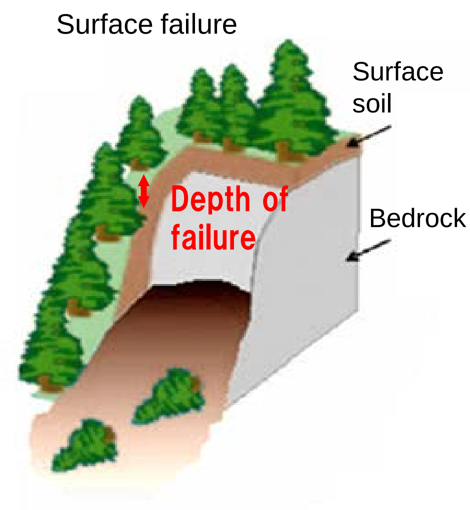
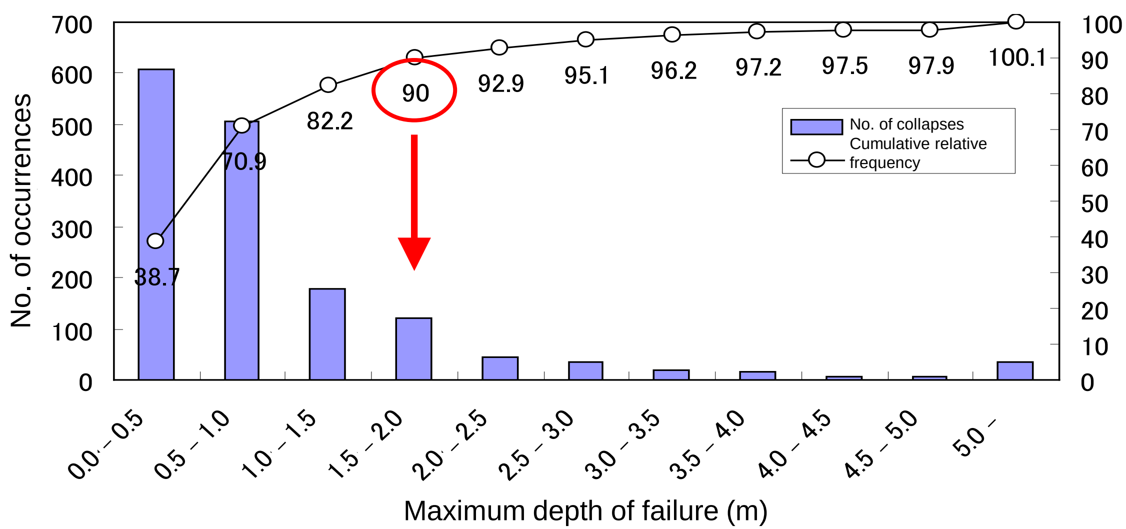
1982 to 1997

(4,671 data from 1982 to 1997)
—Used in the Act on Sediment Disaster Countermeasures for Sediment Disaster Prone Areas

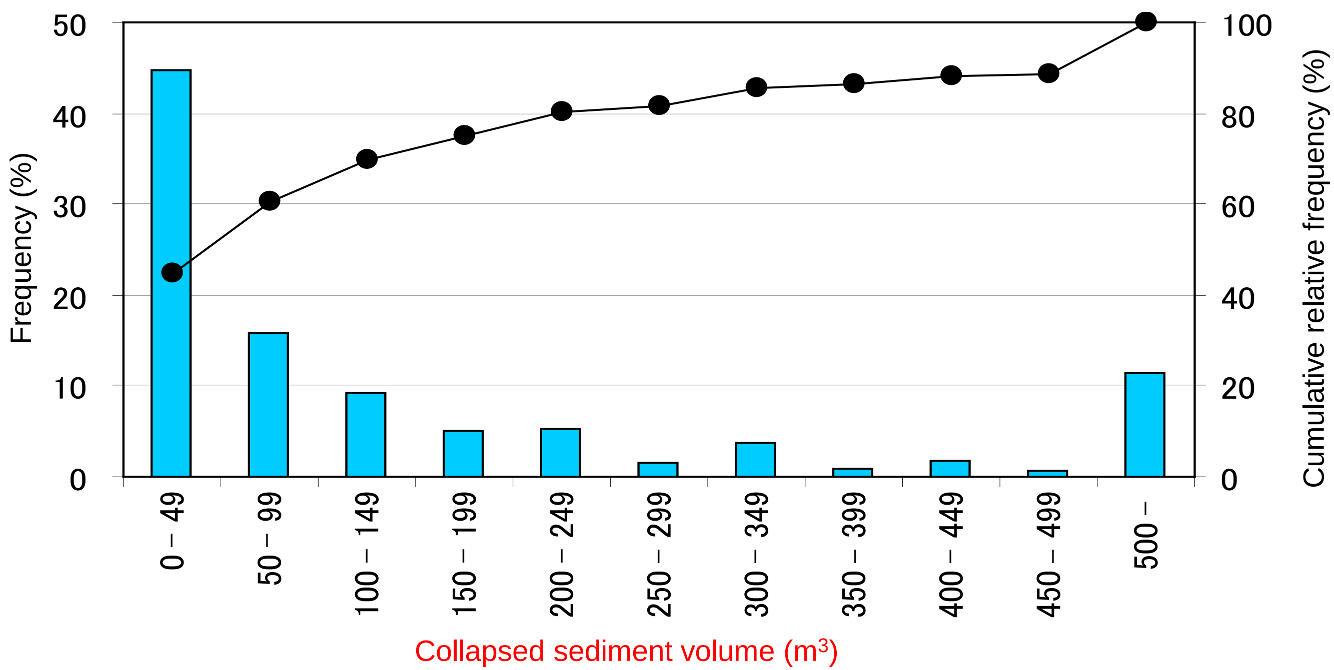


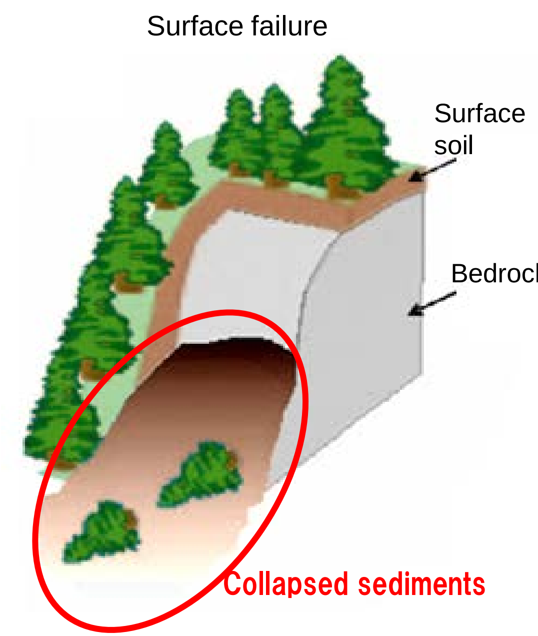


2001 to 2004



$H_d \leq$ 2m at 90%


Frequency (%)
Cumulative relative frequency (%)
0
10
20
30
40
50
0
20
40
60
80
100
0 – 49
50 – 99
100 – 149
150 – 199
200 – 249
250 – 299
300 – 349
350 – 399
400 – 449
450 – 499
500 –
Collapsed sediment volume (m3)


Surface failure
Surface soil
Bedrock
Collapsed sediments

土砂災害危険箇所調査

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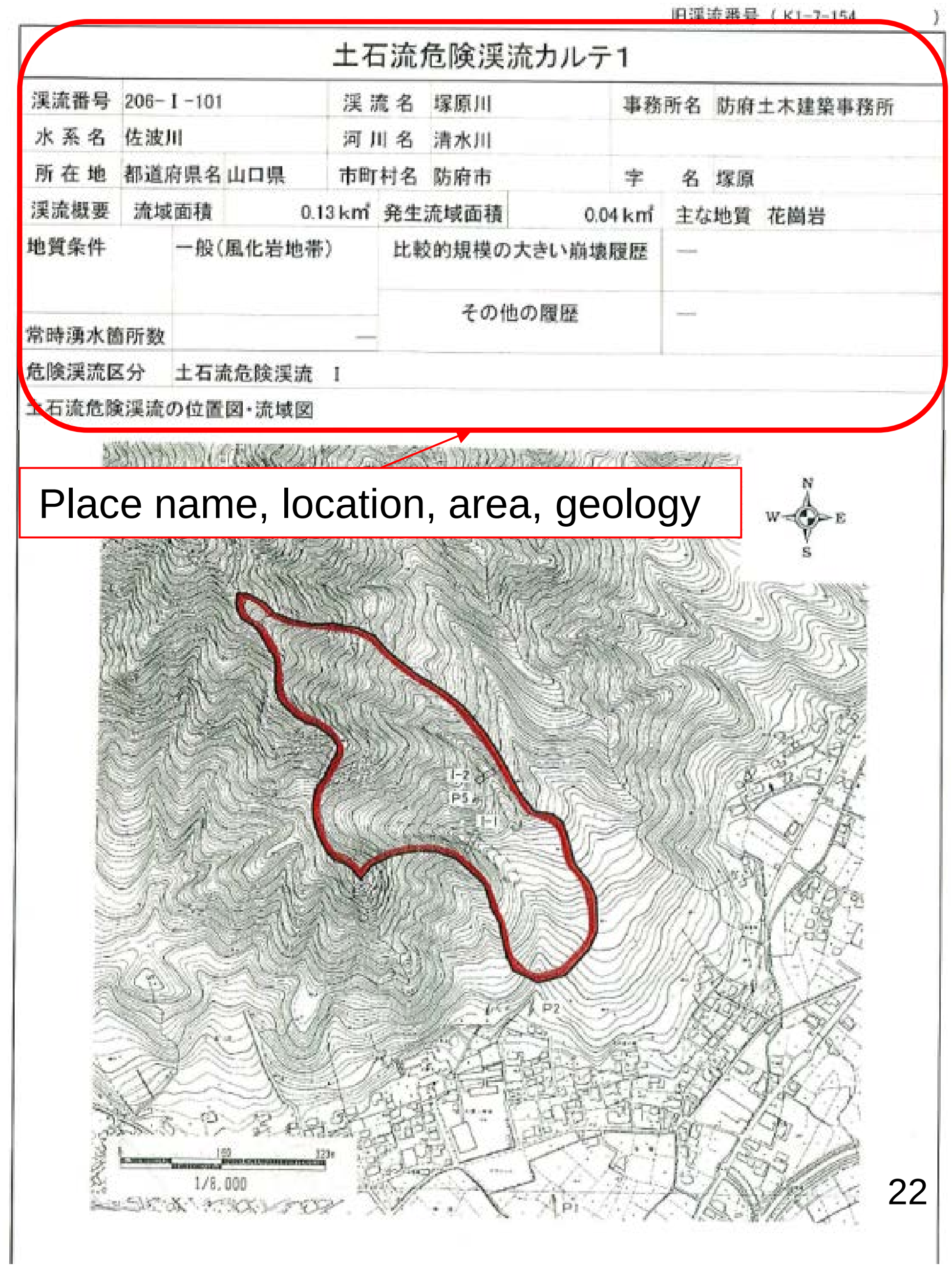
- Extract risk locations for each of debris flows, slope failure and landslides, based mainly on topographical features and the distribution of targets of protection such as homes and public facilities. Conduct field surveys, and investigate the position and spread, geology, range of possible damage and targets of protection, history of disasters, and current conditions (record with photos).
- Charts are created for each location, and held by the prefecture. Summary tables are then shared with national and prefectural governments.
- Based on the number of households within the areas where debris flow and land slippage damage is likely, designated the location as I (5 or more households), II (1-4 households), or III (likely to have a target for protection at a later time). For landslides, classify the landslide stability as A, B or C (relative evaluation based on score from survey items).



土石流危険渓流カルテ1

渓流番号	206-Ⅰ-101	渓流名	塚原川	事務所名	防府土木建築事務所
水系名	佐波川	河川名	清水川		
所在地	都道府県名 山口県	市町村名	防府市	字名	塚原
渓流概要	流域面積 0.13km²	発生流域面積	0.04km²	主な地質	花崗岩
地質条件	一般(風化岩地帯)	比較的規模の大きい崩壊履歴	—		
		その他の履歴	—		
常時湧水箇所数	—				
危険渓流区分	土石流危険渓流 Ⅰ				

土石流危険渓流の位置図・流域図

土砂災害危険箇所調査の一例（土石流危険渓流カルテ）

国土交通省

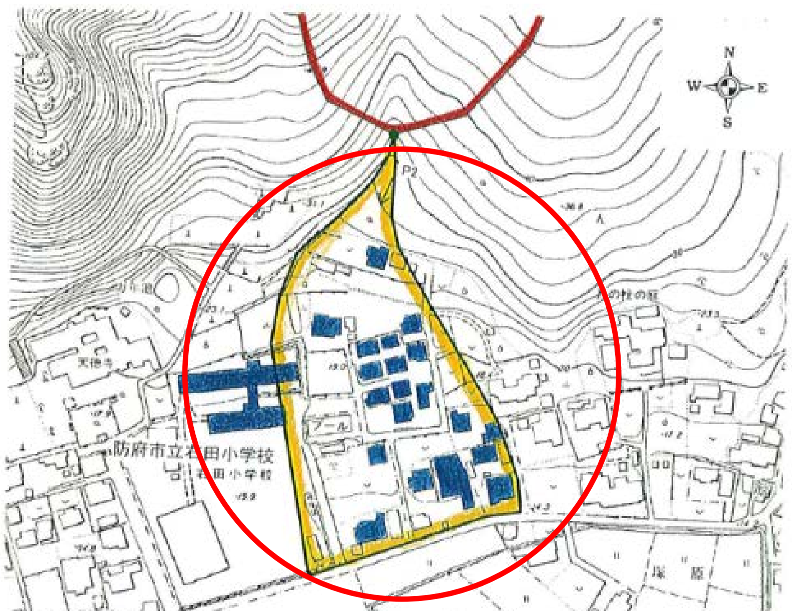
旧渓流番号（K1−7−154　　）

土石流危険渓流カルテ2

渓流番号	206−Ⅰ−101	渓流名	塚原川	事務所名	防府土木建築事務所
土石流危険区域設定の為の調査		調査日：	平成12年02月02日	（記入者：	冨士原　亮　　）
土石流危険区域の地形	扇状地形				
土石流氾濫開始点	条件	扇状地頂部		勾配	10°
土石流氾濫終息点	条件	勾配		勾配	3°
土石流氾濫開始点から土石流氾濫終息点までの距離					248 m
土石流氾濫区域の最大幅		130 m		土石流氾濫区域の面積	20,140 ㎡

土石流危険区域図

Topographical features of expected range of damage (gradient, area, width etc.)



Expected range of damage and homes that are targets of protection

旧渓流番号（K1−7−154　　）

土石流危険渓流カルテ3

[1/1]

渓流番号	206−Ⅰ−101	渓流名	塚原川	事務所名	防府土木建築事務所
保全対象	土石…				）
	人家…			事業所	0（　0）
	災害…数量				
	上記以外の公共施設種類・数量	公共施設：1（教育施設1）			
	田畑	耕地面積：　0.27 ha　（　0.27 ha）			
	交通網（道路・鉄道）	—			
渓床の状況	渓床堆積土砂の有無	Ⅰ-1	Ⅰ-2		
	存在する区間（m）	200	250		
	その厚さ（m）	1.5	1.5		
山腹の…	裸地の面積率	0.0 %			
	禿赭地の面積率	0.0 %			
	伐採跡地の面積率	0.0 %			
	新しい亀裂・滑落崖	亀裂： —	滑落崖： —		
砂防施設の効果	基数				
	未満砂量（総量）	0 m3			

No. of Targets of Protection

State of hills and mountain streams
Distribution of cracks and collapses
State of vegetation

名称	所管	ダムの諸元（計画値） 有効高	基礎長	計画…	元河床…	貯砂量	現地踏査結果 未満砂高	堆砂長	現況…	現況…量	未満砂量 V−V0 (m3)

Presence of target facilities
Specs for target facilities

計画流出土砂量	10,781 m3
調査所見	当渓流は、流域面積0.13k㎡、発生流域面積流域面積0.04k㎡を有する渓流で、渓床勾配は比較的急峻な地形を呈している。山腹斜面には主に、高木広葉樹が生育しており、顕著な崩壊は見られない。渓床にはφ=0.2～0.3mの小礫や中礫が点在し、土砂が、深さ1.5mほどで均一に堆積している。礫の表面にはコケの付着が見られる事から、近年、顕著な土砂移動は発生していないと考えられる。踏査の結果、現時点では比較的安定した渓… …崩壊の危険性があるとし…

Findings (disaster risk etc.)

土砂災害危険箇所調査の一例（土石流危険渓流カルテ）

国土交通省

旧渓流番号（K1-7-154　　）

土石流危険渓流カルテ4　[01/04]

渓流番号 206- I -101　渓流名 塚原川　事務所名 防府土木建築事務所

谷地形全景　写真番号: P1　平成12年02月26日

Panoramic view

保全対象状況　写真番号: P2　平成12年02月02日

State of targets of protection

旧渓流番号（K1-7-154　　）

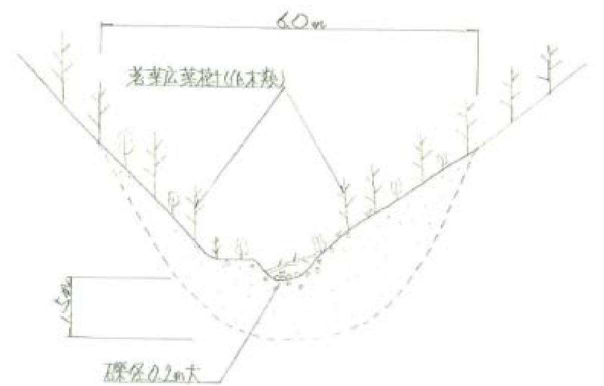
土石流危険渓流カルテ4　[02/04]

渓流番号 206- I -101　渓流名 塚原川　事務所名 防府土木建築事務所

横断調査地点(I-1)　写真番号: P3　平成12年02月26日

State of mountain stream

横断スケッチ(I-1)　写真番号:　平成12年02月26日



Side View
Thickness of deposited sediment,vegetation on top)

Human Suffering caused by Sediment Disasters

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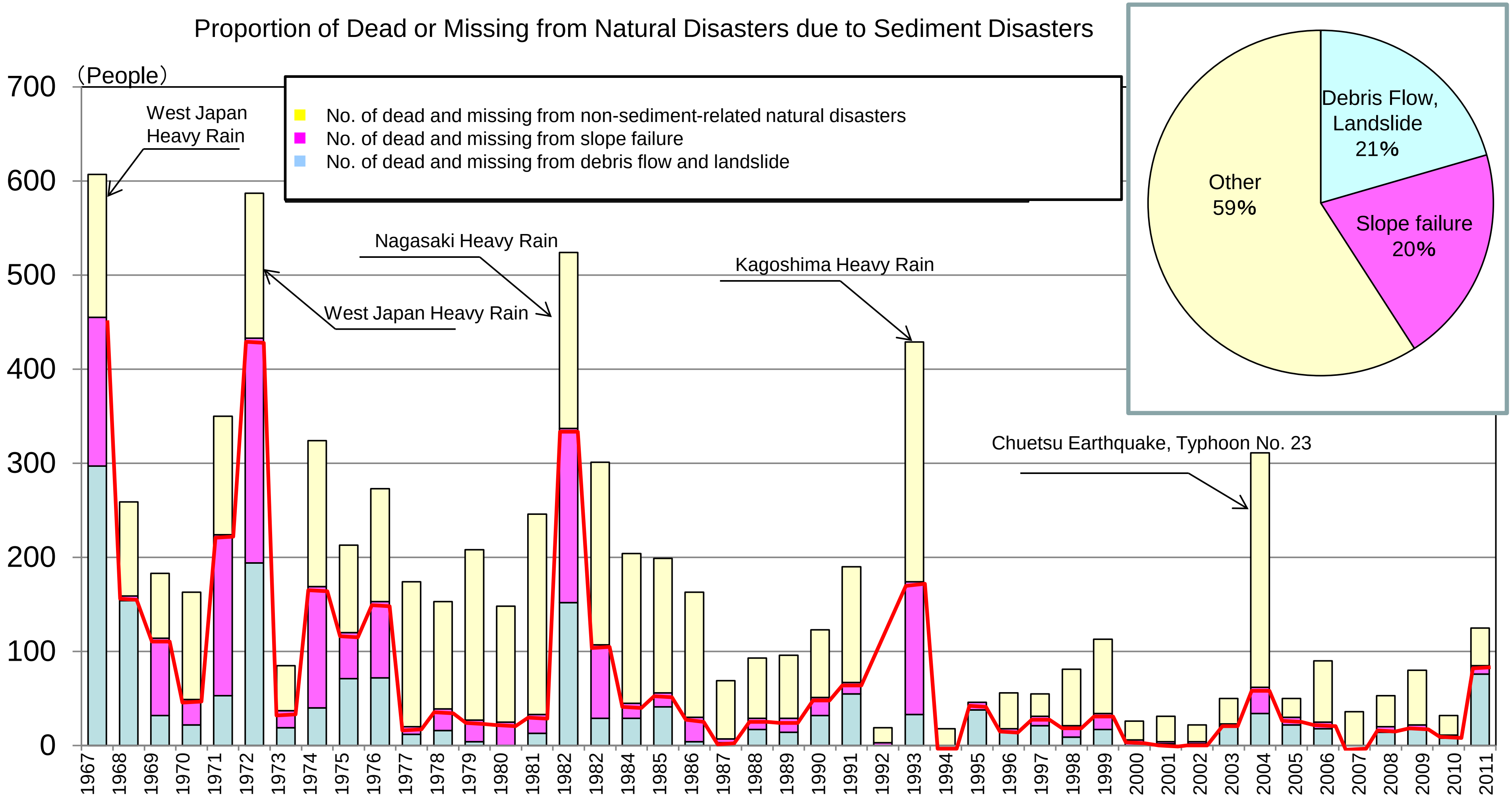
Sediment Disasters make up about half of the dead and missing from all natural disasters

Proportion of Dead or Missing from Natural Disasters due to Sediment Disasters



* **Excluding dead or missing persons from the Great Hanshin-Awaji Earthquake (1995) and the Great East Japan Earthquake (2011)**

For the number of dead and missing for each year, for all natural disasters, source is the Disaster White Paper, and for debris flows, land slippage, landslides and avalanches, source is the MLIT River Bureau Sabo Dept.

The number of dead and missing from non-sediment-related natural disasters, does not include snow damage, except for avalanches (from 1993).

Act on Prevention of Disasters Caused by Steep Slope Failure

- In July 1967, landslide disasters occurred in various parts of the western part of Japan. Hills, mountains, or cliffs located just behind or close to urban areas collapsed because of heavy rainfall, and a large number of people were killed.
- In those days, there were no clear institutional or organizational systems meant to prevent sediment disasters related to or caused by valley topography, such as regulations or measures to prevent collapsed sediments from entering mountain streams.
- In 1969, the national government established the Act on Prevention of Disasters Caused by Steep Slope Failure and started various projects to prevent collapse of steep slopes.

・Article 1

This Act aims to support stabilization of civil life and maintenance of national land by stipulating measures necessary to prevent collapse of steep slopes in order to protect lives of the general public from disasters caused by steep slope failure.

This act does not intend to directly protect assets or properties.

The primary purpose is to "eliminate or reduce human damage caused by steep slope failure."

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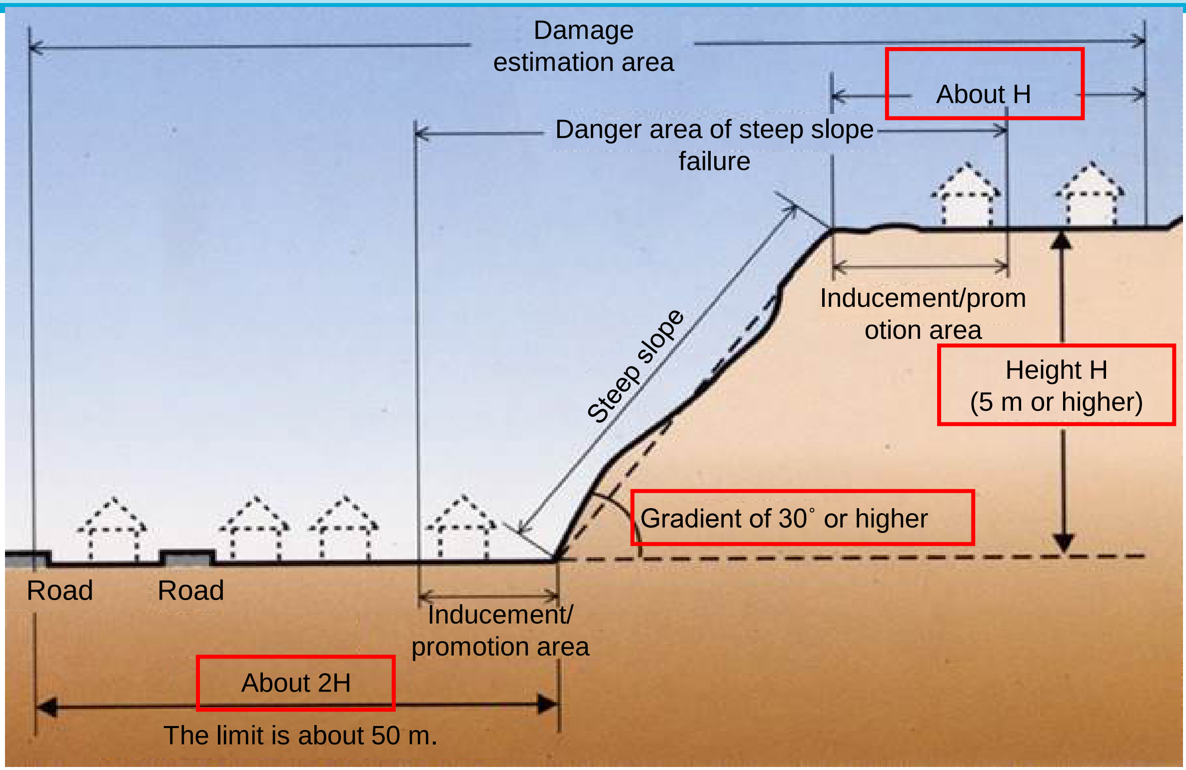
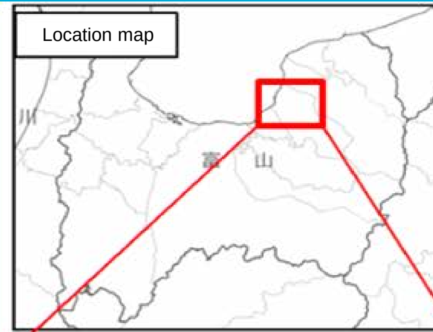


- Steep slope: land with a slope of 30 degrees or more
- Inducement/promotion area: Area where implementation of a restrictive action can induce or promote failure
- Damage estimation area: Area where failure of a steep slope can cause damage
- Danger area of steep slope failure: Area where the height of a steep slope is 5 m or more and five or more houses are located in the damage estimation area (governmental or administrative facilities, schools, hospitals, hotels or other public buildings may suffice the definition even if they are less than five in number).
- Steep slope failure prevention facility: facility located in a danger area of steep slope failure designed to prevent steep slope failure, such as retaining wall or drainage facility.

Case Examples of Positive Effects of Steep Slope Facilities

Disaster date:	July 19, 2014
Rainfall condition:	Continuous rainfall: 192 mm (1:00, July 19, to 9:00, July 20) Hourly maximum rainfall: 46 mm (21:00 to 22:00, July 19) * Otani Dam Observation Station
Occurrence site:	Amidado area, Kurobe city, Toyama prefecture
Failure condition:	Collapsed sediment volume of about 20 m^3
Condition:	Sediments that slid in a dangerous area of steep slope failure were captured by standby retaining walls. It helped mitigate the damage.



The standby retaining wall kept houses unharmed by collapsed sediments.

Concept of Method Selection (Example)

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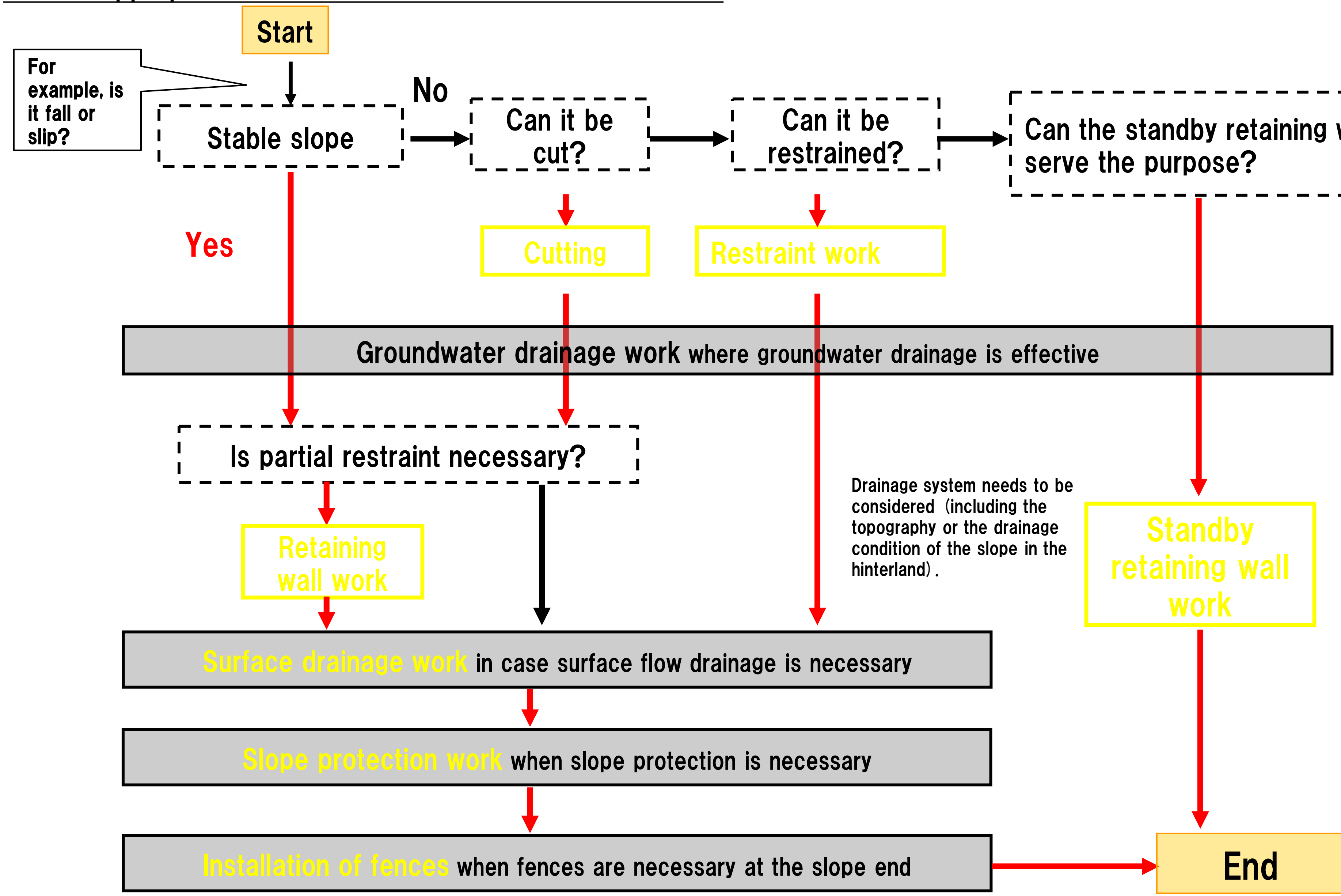
Where the topographic, geographic, or built-up condition is not uniform, a work section is generally subdivided by the type, and the appropriate method is selected for each subdivision.



Literature Survey

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- ## Major Purpose of Survey

To obtain a general understanding of the target slope including topographic and geologic characteristics

- ## Literature to Collect

Past disaster records, past slope inspection records, environmental records of the areas around steep slopes, meteorological records, earthquake records, geologic maps, topographic maps, land condition diagrams, land use diagrams, landslide distribution diagrams, aerial photos, literature and construction work records, geologic or soil survey reports, etc.

- ## Important Notes

✓ It is necessary to collect any materials that can be obtained as much as possible and apply them to field reconnaissance (reconnaissance survey) and major survey prior to conducting a field survey.

✓ Make full use of the collection of the basic surveys conducted based on the Act on Sediment Disaster Countermeasures for Sediment Disaster Prone Areas as they serve as useful data.

Field Reconnaissance

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- ## Major Purpose of Survey

  The purpose is to estimate the mechanism of failure and make qualitative evaluation of the scale and the degree of danger of postulated failure and to evaluate the necessity of ground survey and, when judged necessary, select locations of survey.

- ## Survey Items

  Topographic survey, geologic survey, spring water survey, vegetation survey, and survey of the modes of slope failure of rock slops

- ## Important Notes

✓ Since rich experience often tells us what mode of failure will occur depending on the geology of the slope, clarify geologic and topographic interpretation of how the current slope has been formed.

✓ When there is any failure site nearby that slipped in the past, compare it with the target slope.

✓ Investigate where are discontinuities related to strength, water permeation, or water infiltration.

✓ When cracks are found on the upper part of the slope or the surface of the middle or lower part of the slope is swollen, such anomalies can often allow us to estimate the shape of the surface of rupture. Therefore, pay sufficient attention to the topography and slope shape.

Topographic Survey

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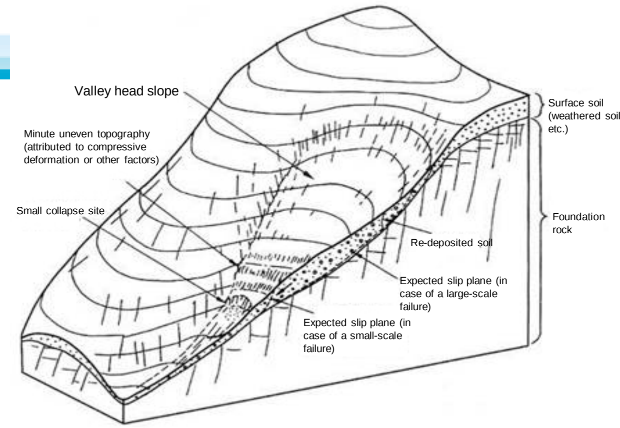
a. Valley head slope (zero-order basin)

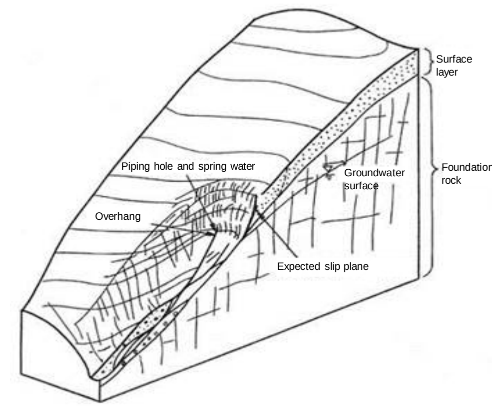
b. The waterhead of a stream or the water spring part

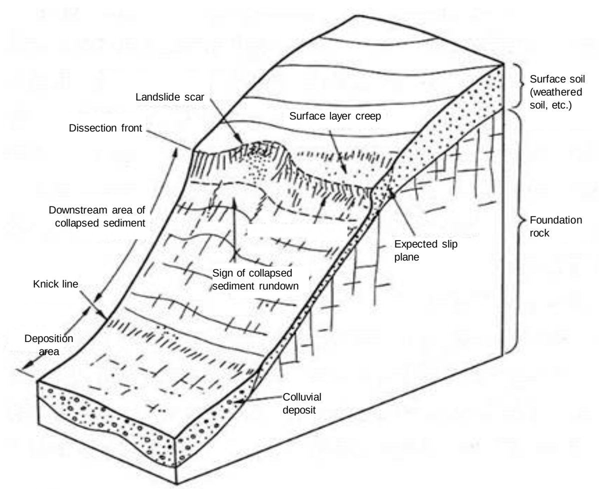
c. The vicinity of a dissection front (knick line) on the mountain slope (valley wall) or the upper part of the landslide scar

d. The periphery of a plateau or terrace scarp

e. Others include cases where deposits or volcanic ash layers thinly covering a mountain slope may slide down because of rainfall.







Classification of Failure Modes

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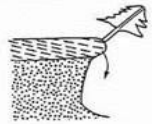
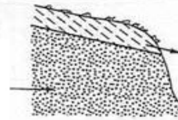
Surface soil

1-(1) Fall of surface soil



It occurs by wind, rain, or seismic force. The lower layer of the surface soil is gouged by erosion or any artificial force, and the exposed part causes failure.

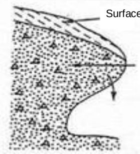
1-(2) Slip of surface soil



Only the surface soil slides down, and the slip plane is located in the boundary between the surface soil and the lower layer (assuming they will not slide simultaneously). This is the most frequent mode of failure.

Collapsed sediment

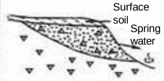
2-(1) Fall of colluvial deposit



This pattern occurs relatively less frequently. It is sometimes observed at the ends of a landslide.

2-(2) Slip of colluvial deposit

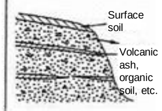
2-(2)-a Boundary with foundation rock



This type of slide occurs with the bedrock, or its weathered zone, whose lower layer is colluvial soil as the boundary surface. It may be treated as a small type of landslide.

Lower layers are often composed of sedimentary rocks with bedding (shale, sandstone, conglomerate, or schist). In generally, the entire slope slides down altogether. Spring water is often found at the foot of the slope.

2-(2)-b Discontinuity



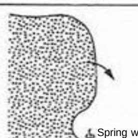
Sliding occurs over a discontinuity in the colluvial soil.

Soils of different grain sizes occur or volcanic ash or organic soil is sandwiched between layers while the colluvial soil is formed, and those discontinuities serve as the boundary surface that triggers failure.

Pyroclastic materials

3-(1) Fall of pyroclastic materials

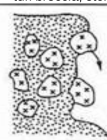
3-(1)-a Shirasu and loam



While the collapse of shirasu is the most typical example, the same phenomenon occurs even for loam layers when they have sandy layers in-between. This type of soil is particularly susceptible to earthquakes.

Spring water is generally seen at the foot of the slope either made of shirasu or loam, and spring water erodes the foot to cause failure. In some cases, flowing water also erodes the foot of the slope.

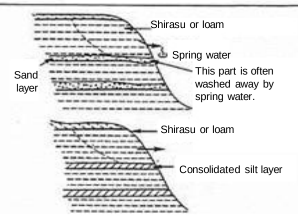
3-(1)-b Weathered agglomerate, tuff breccia, etc.



The soil other than the conglomerate is highly weathered or eroded, and the remaining conglomerate fails.

3-(2) Slip of pyroclastic materials

Shirasu or loam



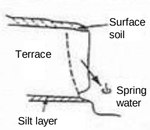
When a slope composed of shirasu or loam slides down, such soil is generally not entirely uniform or has spring water or permeable layer in the sandy soil, or has a relative impermeable layer such as consolidated silt layer.

When rain falls, piping or pore water pressure inside the shirasu or loam lying over the impermeable layer will rise to eventually induce sliding.

Terrace deposits

4-(1) Fall of terrace deposits

4-(1)-a Impermeable layer

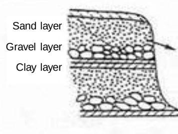


Although this very rarely occurs, it occurs when spring water exists around a layer with a high silty content.

4-(1)-b Pull-out of gravel

When the soils other than the gravel layer are eroded, the gravel alone remains and falls.

4-(2) Slip of terrace deposits

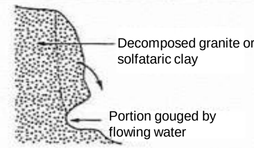


Since a round gravel layer serves as an aquifer, when the incoming water cannot be accommodated by this aquifer, then slip will occur. Topographically, it tends to occur where water is likely to collect.

Note: Based on a partial revision of the New Version of the Design and Actual Examples of Slope Failure Prevention Works

Heavily weathered rocks

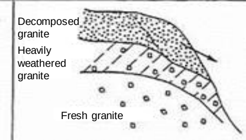
5-(1) Fall of heavily weathered rocks



Although this mode is very rare, it occurs when the foot of a cliff is eroded by flowing water.

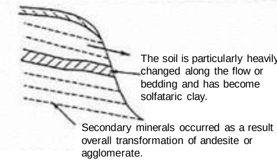
5-(2) Slip of heavily weathered rocks

5-(2)-a Decomposed granite



When decomposed granite slips, heavily weathered granite that became sandy slides on the boundary with the softly weathered granite. The thickness is generally 2 m or under at the thickest.

5-(2)-b Solfataric clay

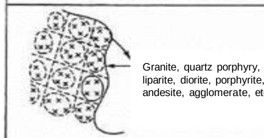


In an area with solfataric alteration, andesite or agglomerate undergoes transformation due to the reaction of hot water, heated air, or hot spring and becomes totally softened. When the soil along flows or bedding has particularly become clayey (solfataric clay), then it will slide down.

Rock (I) (hard rock)

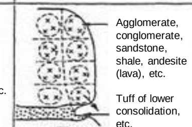
6-(1) Fall of rock (I)

6-(1)-a Grouped



When cracks loosen by rainfall or freezing, grouped rocks will fall (as rockfall). This often occurs when an earthquake occurs.

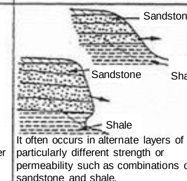
6-(1)-b Alternate layer



When layers are alternate, lower layers are weakly eroded, and upper layers remain.

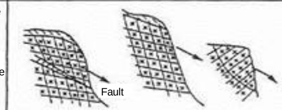
6-(2) Slip of rock (I)

6-(2)-a Boundary surface



It often occurs in alternate layers of particularly different strength or permeability such as combinations of sandstone and shale.

6-(2)-b Fault or crack

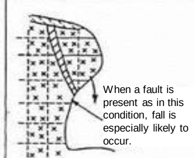


Directivity, density or condition of fault or crack (joint or crack) is major elements. These combinations form a variety of slip planes.

Rock (I) (hard rock)

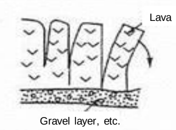
6-(1) Fall of (I)

6-(1)-c Fragile at the lower part



Of the layers belonging to the same strata, those with their bottom very susceptible to erosion and their top still remaining

6-(1)-d Lava



It frequently occurs at the ends of lava (particularly andesitic lava). Very high cliffs are often formed, and the soil along its joints (columnar joints) falls. This type of failure is seen in river banks or coasts in the volcanic zone.

6-(2) Slip of rock (I)

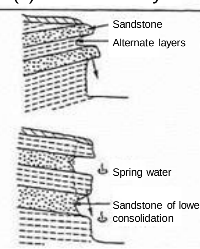
6-(2)-c Conglomerate or agglomerate

Slip occurs in slopes composed of conglomerate or agglomerate and specifically along the boundaries of glued parts of gravel with clay, limestone, or volcanic ash.

Rock (II)

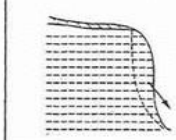
7-(1) Fall of rock (II)

7-(1)-a Alternate layers



Where layers are alternately formed, layers resistant to erosion remain and fall.

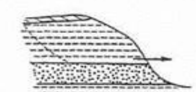
7-(1)-b Tertiary deposit



Cracks by surface drying occur near the surface (usually within 30 cm) in parallel, and fall occurs from that boundary.

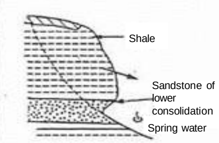
7-(2) Slip of rock (II)

7-(2)-a Shale or bedding plane



Shale in the tertiary layer is very weatherable. Weathering often progresses from the bedding plane, and the soil slips along that plane. When there is a highly permeable layer such as sandstone at the bottom, this tendency is actively promoted.

7-(2)-b Alternate layers of sandstone and shale



This type of slip often occurs in the Neogene layer where constituent sandstone has lower consolidation and is gouged as it is washed away by spring water.

- Purposes

✓ To make quantitative evaluation of the scale of failure including the amount of sediments to occur from a failure

✓ To obtain basic information for comparative review of methods and detailed design

- Focal Points and Important Notes

✓ It is important to conduct sounding or other tests to estimate the ground composition, slip surfaces, and strength in an objective manner.

Soil Survey Method—Check Items

・ Check Items in Soil Survey

- ✓ Soil composition of the slope and the strength of constituent soil
- ✓ Soil composition at the planned work site and strength constant for calculation of the bearing capacity of the structure

・ Important Notes

- ✓ Steep slope failure prevention is basically meant for surface failure and is not intended to understand the geologic condition in the depth of the slope.
- ✓ Therefore, it is important to consider the topographic or geologic conditions, minimize use of boring survey, compare simple survey methods such as sounding or geophysical exploration methods with boring, evaluate the balance of the resultant precision and cost for those options, and use the appropriate survey method.

Soil Survey—Sounding

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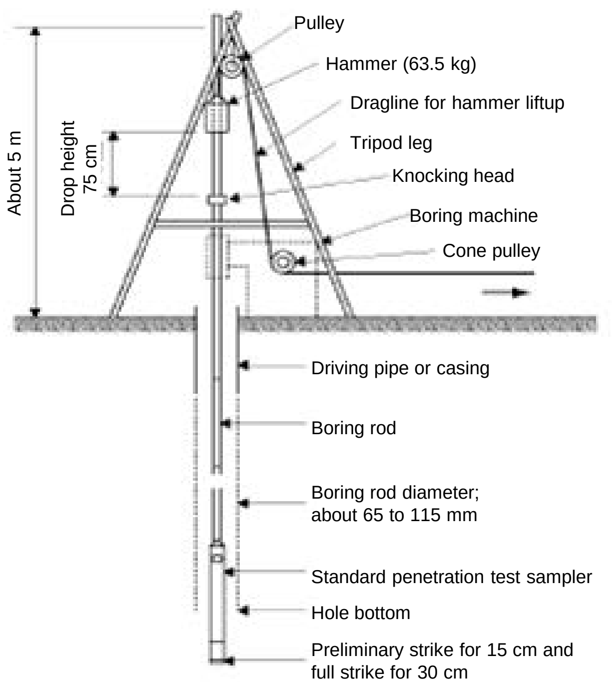
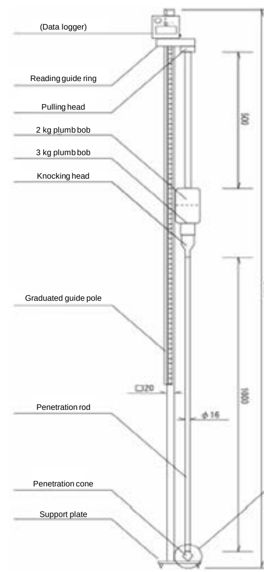
Name	Description	Remarks
Standard penetration test	• Freely drop a hammer with a mass of 63.5 kg ± 0.5 kg from a height of 76 ± 1 cm. After preliminary striking to penetrate the hammer 15 cm, the main striking is performed to penetrate 30 cm. Count the number of strikes (N value) when the depth of 30 cm is reached, and take the drilled sample. The effective depth is about 20 m. • Applicable soil: Soil excluding bedrock or cobble	Determination of N value or approximate bearing capacity, sampling of soil, or preparation of soil profile The machine needs to be brought to and set up at the site.
Cone penetrometer	• Statically penetrate a cone with a front end angle of 30° manually and measure the resistance the cone received with a force gauge. It calculates cohesive force or uniaxial compression strength approximately. • Applicable soil: cohesive soil	In reality, it is almost never used on steep slopes.
Swedish sounding	• Measure the static penetration resistance of the soil with a combined use of loaded (100 kg) penetration and rotational penetration. There are many proposed equations that convert the measured values into N value. • Effective depth: 5 to 10 m • Applicable soil: Soil excluding cobble or gravel	It may be judged applicable depending on the soil conditions although it poses some precision problem. There is no need to consider temporary installation.
Simple penetration test	• Freely drop a hammer with a mass of 5 kg from a height of 50 cm to determine the penetration resistance of the soil at the drop site. The obtained value is evaluated to be almost equal to N value. • Effective depth: 3 m • Applicable soil: Soil excluding hard cohesive soil or gravel	It is not widely applicable because of its shallow depth of penetration for testing. However, there is no need to consider transport or temporary installation.

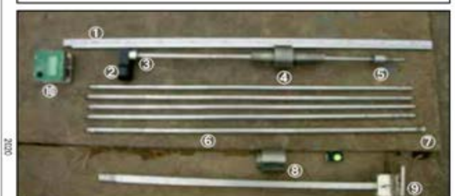
Reference—Various Types of Sounding Machines



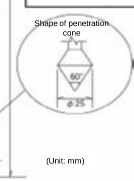
Standard penetration test

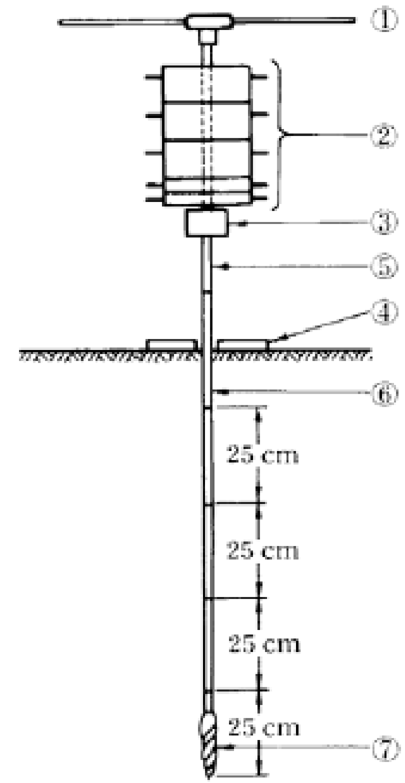


Penetration cone diameter: 25 mm
Penetration rod diameter: 16 mm
Penetration rod length: 100 cm
Weight of plumb bob: 3 kg + 2 kg (detachable)
Measurement: Measure penetration per strike.



(1) Graduated guide pole, (2) Reading guide ring, (3) Pulling head, (4) 3 kg plumb bob, (5) Knocking head, (6) Penetration rod, (7) Penetration cone, (8) 2 kg plumb bob, (9) Support plate, (10) Data logger





Swedish sounding

Simple penetration test—top: PWRI type; down: SH type

	Simple penetration test machine	Standard penetration test (boring)	Swedish sounding test machine
Resolution power	Every 10 cm Every strike	Every 30 cm	Every one cm (penetration stop depth) Every 25 cm (for rotary penetration)
No. of workers required	2	2	2
Weight of machine proper	15 to 17 kg (for 5 m long section of rod)	About 400 kg	Over 110 kg (for 5 m long section of rod)

Failure Modes and Survey Methods

Collapse category		Sign	Boring	Sounding: Standard penetration test	Sounding: Cone penetrometer	Sounding: Swedish sounding	Sounding: Simple penetration test	Geophysical exploration: Elastic wave exploration	Geophysical exploration: Electric exploration	Geophysical exploration: Underground radar exploration	Groundwater survey: Groundwater level survey	Groundwater survey: Groundwater tracking	Groundwater survey: Groundwater well logging	Groundwater survey: Permeability test	Surface water survey	Soil constant strength test: Soil mechanical test	Soil constant strength test: Soil physical test	Soil constant strength test: Rock test	Slope displacement survey (inclinometer, strain gauge, extensometer)
Surface soil	Fall	1 -(1)					△								△				
Surface soil	Slip	1 -(2)			○	○	◎	○	◎			○		○	○	○	○		△
Colluvial deposit	Fall	2 -(1)																	
Colluvial deposit	Slip	2 -(2)-a	◎	◎	△	◎	◎	◎	○	○	◎	◎	○	○		○	○		△
Colluvial deposit	Slip	2 -(2)-b	◎	△	△	○	○		△	△	◎	○	△	○		○	○		△
Pyroclastic material	Fall	3 -(1)-a																	
Pyroclastic material	Fall	3 -(1)-b																	
Pyroclastic material	Slip	3 -(2)	◎	△	△	△	○	△	△	△	◎	○	△	○		○	○		△
Terrace deposit	Fall	4 -(1)-a	○																
Terrace deposit	Fall	4 -(1)-b	○																
Terrace deposit	Slip	4 -(2)	◎	△			○	○	○		◎	○	○	○		△	△		△
Heavily weathered rock	Fall	5 -(1)																	
Heavily weathered rock	Slip	5 -(2)-a	◎	○	△	△	◎	◎	△		◎	○	△	△		○	○		△
Heavily weathered rock	Slip	5 -(2)-b	◎	○	○	○	△	○	○		◎	○	△	△		○	○		△
Rock (I)	Fall	6 -(1)-a	△					△		○								△	
Rock (I)	Fall	6 -(1)-b	△					△	△									△	
Rock (I)	Fall	6 -(1)-c	△					△	△									△	
Rock (I)	Fall	6 -(1)-d	△					△	△	△		△						△	
Rock (I)	Slip	6 -(2)-a	◎	△				◎	△	△	△	△	△					△	△
Rock (I)	Slip	6 -(2)-b	◎					○	○	△	△	△						△	△
Rock (I)	Slip	6 -(2)-c	◎	△				△				△							△
Rock (II)	Fall	7 -(1)-a	△					△	△										
Rock (II)	Fall	7 -(1)-b																	
Rock (II)	Slip	7 -(2)-a	◎	○			△	○	△		○	△						△	△
Rock (II)	Slip	7 -(2)-b	◎	○				○	△		○	△						△	△

(Red box) Soil survey method

Measurement with Simple Penetration Test Machine

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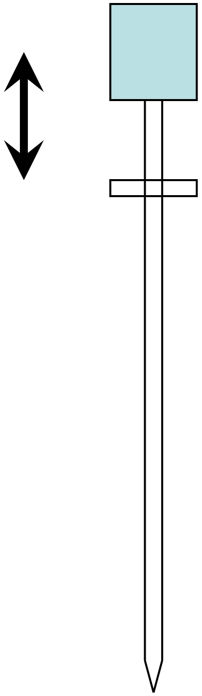
- The conventional test machine is designed to measure the number of strikes for every 10 cm penetration. SH type, however, can automatically record the penetration for every strike. Operated by two operators.

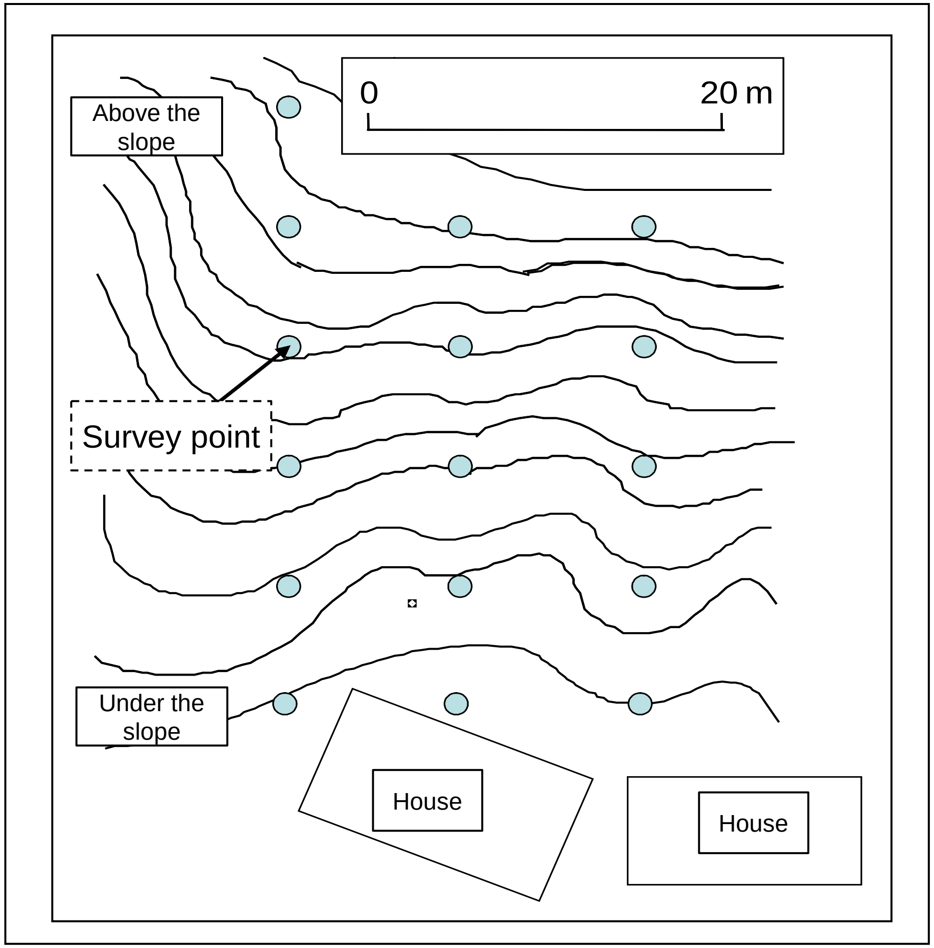


<u>References</u>
Technical Note of National Institute for Land and Infrastructure Management No. 261
Research on a method of estimating the potential depth of slope failure using a knocking pole test

Simple Penetration Test—Survey Density

- Arrangement of survey points

✓ It is recommended that the survey be conducted in a grid-like pattern at an interval of 5 to 10 m by considering the scale of slope.



Simple Penetration Test—Organization of Results

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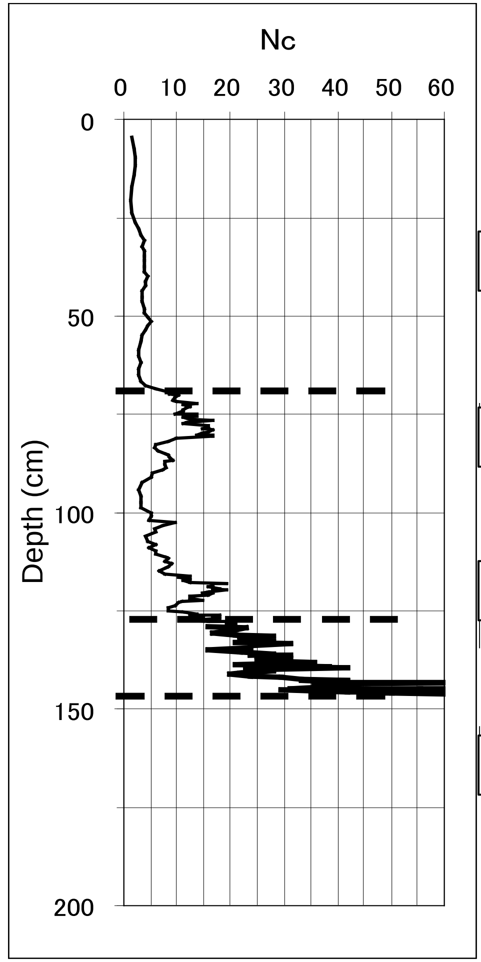
- Check if the characteristics determined by the test result based on the soil category roughly match those of the soil structure identified in the vicinity.

- When such similarity is confirmed as above, categorize the soil properties according to the soil structure identified in the vicinity. Then, identify a location where a slip plane is considered to occur and estimate the thickness of a layer that is likely to fail.



I layer

Nc value is 5 or under, and changes in Nc value in the depth direction are extremely small.

II layer

Nc value changes between 5 and 20.

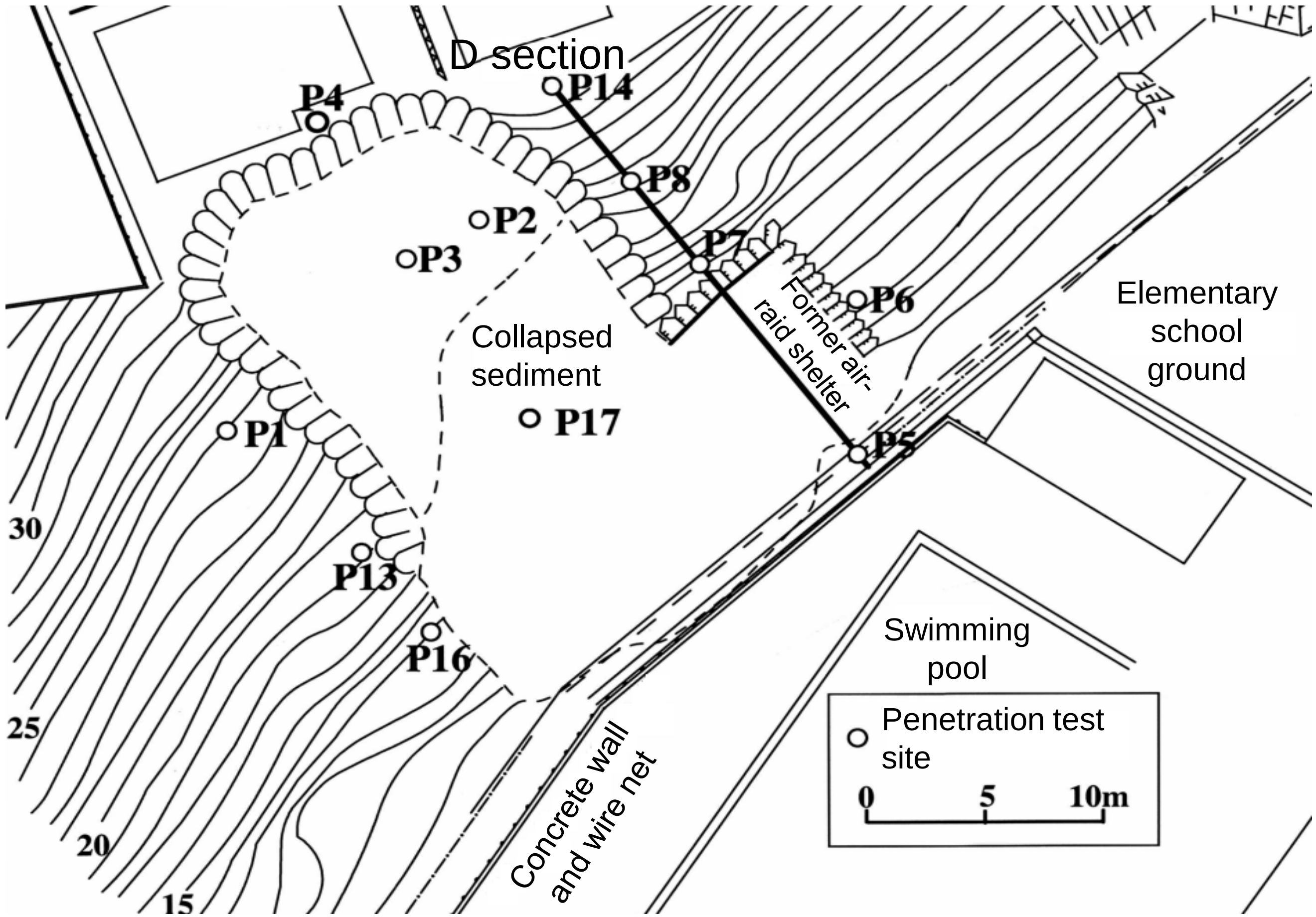
III layer

Nc value changes between 20 and 50, and the value changes greatly in the depth direction.

IV layer

Nc value is 50 or more.

Example of Simple Penetration Test



- Purpose

✓ To capture sediments with a standby retaining wall

- Design Conditions

✓ The retaining wall shall be structurally stable against the expected failure.

- It shall satisfy three conditions, or sliding, tumbling, and bearing capacity.
- It shall have a sediment pocket that can resist the impact force F by an expected failure and capture the amount of collapsed sediments V.

✓ Strength verification of members

Flow Chart of Standby Retaining Wall Design

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Selection of structural type and section

↓

Assumption of the location of retaining wall and clearance height

↓

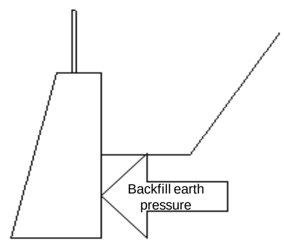
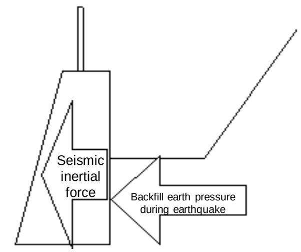
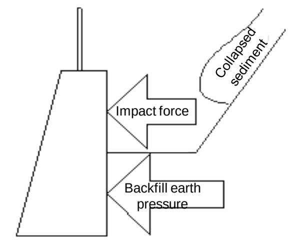
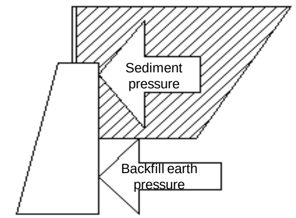
Can the amount of collapsed sediments be captured?

No → Necessity of measures against overflowing sediments and review of the measures

↓ Yes

Verification of stability → Review of measures

Combination of Loads of Standby Retaining Wall and Safety Factor

Combination of loads		In the peacetime	During earthquake	Under impact force	During deposition of collapsed sediments
State diagram					
External force		(1) Backfill earth pressure	(1) Backfill earth pressure (2) Seismic inertial force	(1) Backfill earth pressure (2) Impact force of collapsed sediments	(1) Backfill earth pressure (2) Sediment pressure of collapsed sediments
Safety factor	Sliding	Fs ≥ 1.5	Fs ≥ 1.2	Fs > 1.0	Fs ≥ 1.2
	Overturning	$\lvert e \rvert \leq B/6$	$\lvert e \rvert \leq B/3$	$\lvert e \rvert \leq B/3$	$\lvert e \rvert \leq B/3$
	Bearing capacity of the foundation ground	$q \leq qa = qu/Fs$ $Fs = 3.0$	$q \leq qa = qu/Fs$ $Fs = 2.0$	$q \leq qa = qu/Fs$ $Fs = 1.0$	$q \leq qa = qu/Fs$ $Fs = 2.0$

Note 1: Those with the height of 8 m or higher will be reviewed.
Where, e: eccentric distance of the working position of resultant force from the center of the bottom slab
B: Width of the bottom slab of retaining wall
q: Subgrade reaction intensity
qa: Allowable subgrade bearing unit capacity
qu: Ultimate subgrade bearing unit capacity

Relationship with Vegetation

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- Vegetation on slopes is divided into six, and the occurrence frequency with the number of landslides and the vegetation categories taken into consideration is shown in Table 1.3-3 and Fig. 1.3-5. Analysis of the relationship between the vegetation categories and the collapse frequency revealed that collapse occurred in spite of vegetation such as trees, indicating the difficulty in plainly judging the frequency of collapse by vegetation.

Vegetation category	Collapse site	
	No. of site	Component rate (%)
Bare land	637	6.3
Grassland	3207	31.5
Bamboo	657	6.5
Coniferous trees	1085	10.7
Broad-leaved trees	2537	24.9
Mixed forest with coniferous and broad-leaved species	1567	15.4
Others	494	4.9

Table 1.3-3 Slope vegetation and the number of collapses

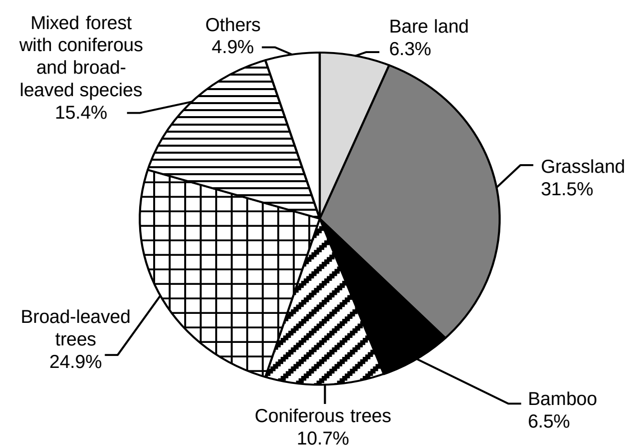

Fig. 1.3-5 Slope vegetation and collapse occurrence frequency

Relationship between Landslide and Rainfall

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- The most influential cause of landslide is rainfall. The relationships among the continuous rainfall from the start of raining to the occurrence of a landslide, the maximum hourly rainfall, the hourly rainfall when the landslide occurred, and the number of landslides are shown in Figs. 1.3-13 to 15.
- It is necessary to consider cases where a landslide site is distant from a rainfall observatory or the time of occurrence is estimation are also included (actual rainfall is expected to increase). However, there are cases where landslides occur even under small rainfall, and the number of landslides increases until the continuous rainfall or rainfall intensity reaches a certain value (100 mm or 30 mm, respectively) and decreases when they exceed the said value.

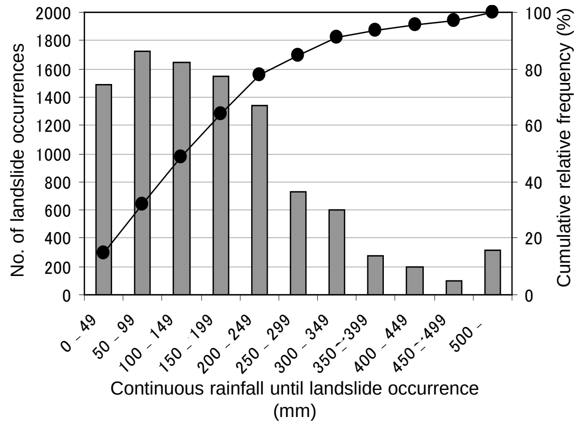

Fig. 1.3-13 Continuous rainfall until occurrence

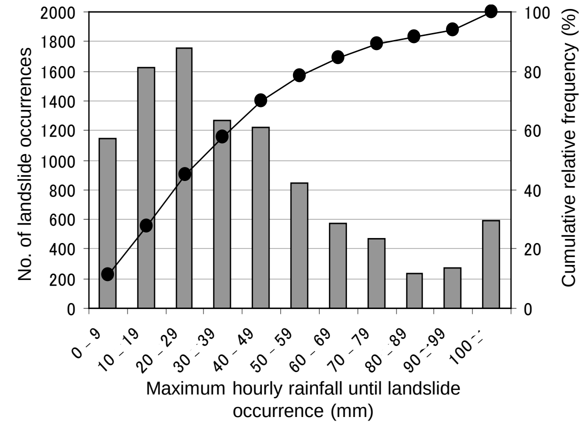

Fig. 1.3-14 Maximum hourly rainfall until occurrence

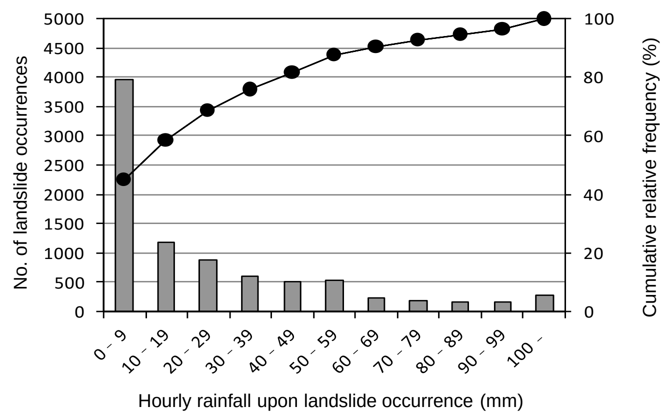

Fig. 1.3-15 Hourly rainfall at the time of occurrence

- While the most influential cause of landslide is rainfall, there are still many landslides that were caused by earthquakes. The data of landslides caused by earthquakes are extracted from the landslide disaster data including those related to the Izu Peninsula earthquake in 1974 and the Southern Hyogo prefecture earthquake in 1995 （149 cases）. The data are analyzed for comparison with the characteristics of rainfall-induced landslides.

Sectional Profile of Slope

- The sectional profiles of the collapse sites are compared by the cause with respect to landslides caused by earthquakes and those by rainfall (Fig. 1.3-16). More collapses by earthquakes occur on large ridges or small mountainside ridges than those by rainfall. It is also revealed that more collapses occur by rainfall than earthquakes in small mountainside valleys where instable sediments exist and surface water and groundwater tend to collect or on parallel mountainside slopes.

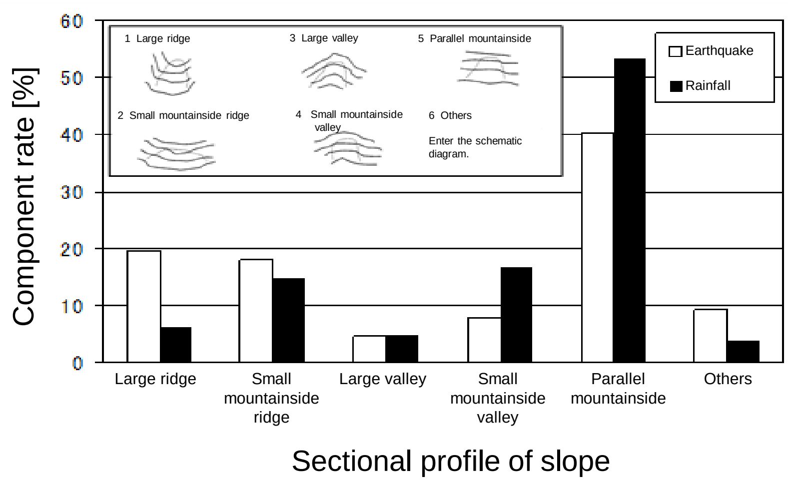

Fig. 1.3-16 Comparison of sectional profiles of collapse sites

- Unlike sectional profiles, no particular differences between collapses by earthquake and those by rainfall are observed with respect to the longitudinal profile（Fig. 1.3-17）.

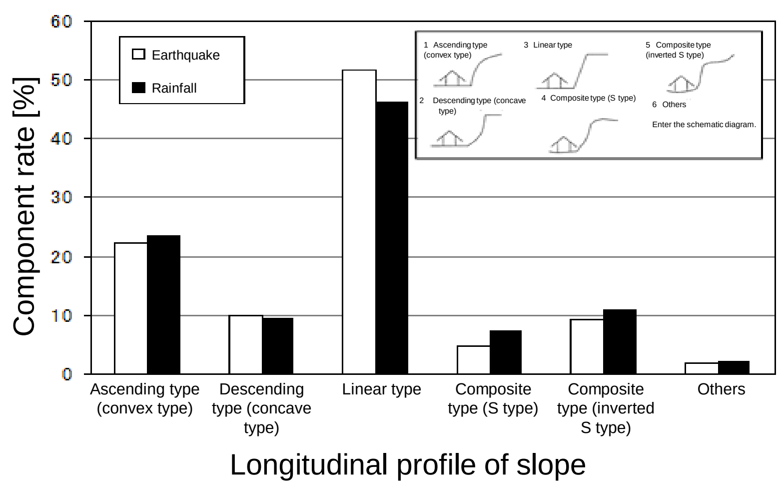

Fig. 1.3-17 Comparison of longitudinal profiles of collapse sites

Angle of Slope

- When a slope is between 31° and 50° in gradient, more collapses occur by earthquake than by rainfall (Fig. 1.3-18).

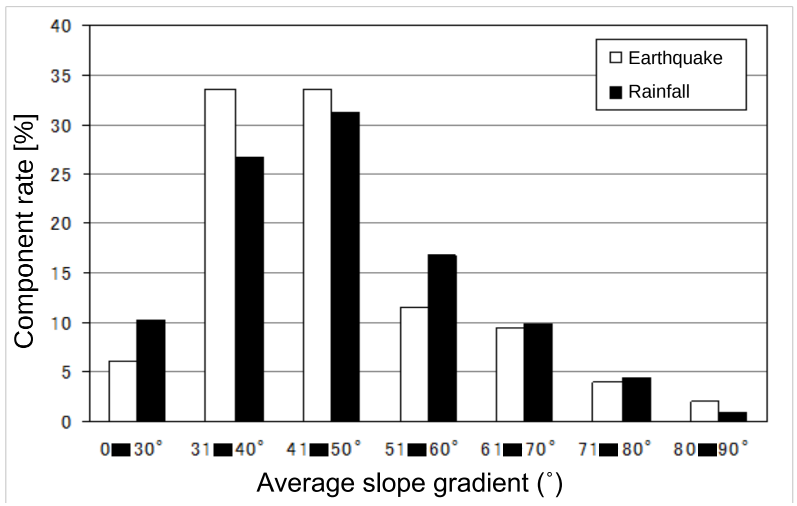

Fig. 1.3-18 Average slope at collapse sites

Scale of Collapse

- Collapses by earthquake are characterized by the collapsed sediment volume that exceeds 500 m^3 compared with those by rainfall (Fig. 1.3-19).

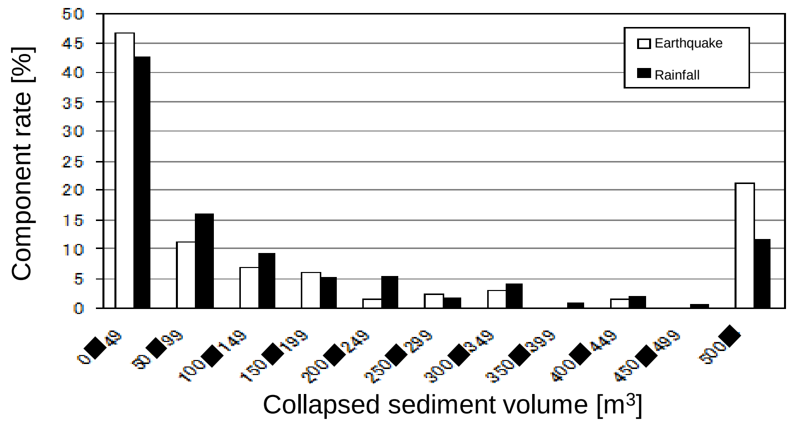

Fig. 1.3-19 Collapsed sediment volume

Travel Distance of Collapsed Sediments

- Fig. 1.3-20 shows the travel distance of the collapsed sediment, while Fig. 1.3-21 shows the ratio of the travel distance of the sediment to the height of the collapse. The travel distance of the collapse is 0 to 15 m in many cases. Some exceed 50 m as there are data of large-scale earthquake-induced collapses. Analysis of the ratio of the travel distance of the sediment to the height of the collapse indicates that the ratio of not more than 0.19 is greater for the collapses by earthquake than by rainfall and that the ratio of the travel distance of collapse by earthquake to the height is smaller than by rainfall. This suggests that earthquake-induced collapses are characterized by smaller soil water content and drier soil condition than rainfall-induced ones as causal factors.

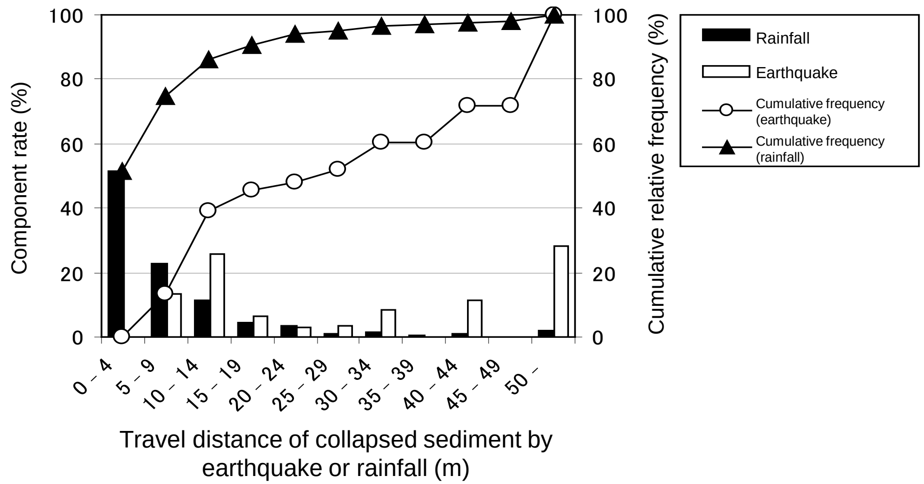

Fig. 1.3-20 Travel distance of collapsed sediments caused by earthquake and rainfall

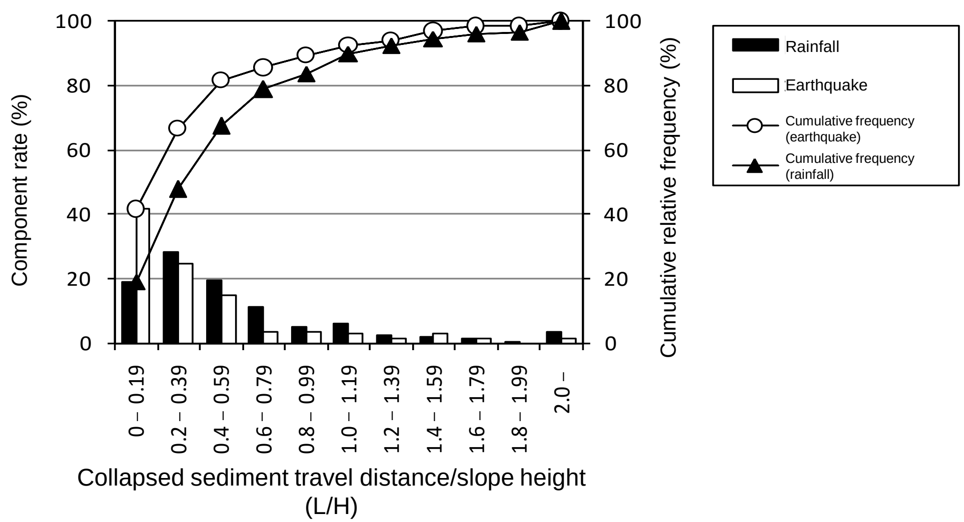

Fig. 1.3-21 Ratio of the travel distance of collapsed sediments to the slope height

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- The differences in the characteristics of landslides depending on the causal factor are summarized in Table 1.3-5.

Table 1.3-5 Characteristics of landslides caused by rainfall and earthquake

	Rainfall-induced collapses	Earthquake-induced collapses
Elevation or specific height	Frequent on mountain side	Frequent at the upper part of slope
Gradient	Frequent between 30° and 40°	Frequent between 35° and 55°
Slope profile	• Rarely seen on ridge lines • Many collapses in depressed topography	• Many near the knick line • Many on parallel slopes or ridge slopes