LANDSLIDES IN JAPAN

(The Fifth Revision)

The Japan Landslide Society
National Conference of Landslide Control

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Preface

The Japanese archipelago is a part of the Circum Pacific Orogenic Belt and is geologically very unstable. The bedrock materials which comprise the mountain terrain have been severely fractured since its formation and have developed numerous fault fracture zones. The Japanese archipelago is often referred to as "scar-laden islands". The mountain region displays a wide variety of topography with steep terrain that often exhibits a stage of maturity. Furthermore, the islands are located within the monsoon zone and receive abundant rainfall. Coupled with early summer rainy spells and later typhoons, numerous landslides occur resulting in staggering damages.

Since 1960, Japan has experienced a high level of land utilization as part of the national policy. In particular, residential developments near and around large cities, reclamation of coastal regions, and construction of dams and highways have all severely altered the existing topography (which is one of the major contributing factors that cause landslides). Due in part to this relationship, citizens in general have a keen sense of awareness concerning landslide disasters.

Therefore, when a catastrophic disaster should occur around us, we try to understand the cause and effect relationship between the physical conditions and the type and nature of the disaster. Recent large scale disasters include: numerous debris flows in Nagasaki City and the surrounding region caused by the concentrated extremely heavy rainfall of July, 1982; the Jizuki-Yama Landslide of Nagano City of July, 1985; and the widespread disaster caused by the Hyogo Earthquake of January, 1995. All of these disasters claimed and affected many lives, and have demonstrated a close relationship between natural disasters and the lives of citizens living in the affected regions. The above incidents have also acted as a "wake-up" call for us to be aware of the urban types of disasters which have resulted in new problems.

In order to reduce the affects of natural disasters in the 21st century, the United Nations established the "International Decade of Natural Disaster Reduction" in 1990 (in which the decade is nearly one-half over). During the internationl conference held at Yokohama in 1994, the following objectives were adopted: 1) to increase the awareness of disaster prevention on an international level; and 2) to build up the regional mutual cooperation structure. Furthermore, it is important to realize that every effort is required in order to reduce the natural disaster, and to take a step forward to try to predict disasters.

Since establishment of the Japan Landslide Society in 1963, 34 annual meetings and numerous symposiums have been organized and over 120 issues of the journal "Landslides" have been published. Recently, the society published the annual newsletter "Landslide News" in English, and is distributed overseas and received well. The 5th revision of "Landslides in Japan" focuses on the current understanding of landslide origin, and discusses some of the problems concerning landslide investigations and research in Japan. It is our desire that this publication will be distributed not only among the professionals involved with landslide research and landslide mitigation, but also among the general public to increase public awareness and development of technology regarding disaster prevention. We sincerely hope that these efforts will contribute to the reduction of the damages.

中村三郎

Saburo Nakamura
President, The Japan Landslide Society

1. Japan and Its Nature (Landform, Geology and Climate)

Physiology of Japanese Archipelago (Composition and Topographic Division of the Island Arc)

The Japanese archipelago is comprised of five main island arcs extending approximately 3000 km in the north-south direction, and encompasses a total area of about 378, 000 square km. Seventy- five percent of the total land area consists of mountainous terrain **(Fig. 1)**. The five main island arcs are, from north to south, Kurile Arc, Northeast Honshu Arc, Izu-Mariana Arc, Southwest Honshu Arc and Ryukyu Arc. These arcs approximately represent plate boundaries of the North America Plate, Pacific Plate, Eurasian Plate, and Philippine Sea Plate. Because of this arc-plate relationship, Japan is located in an area of severe crustal movement, and is situated in one of the world's most seismically active regions. There are 77 active volcanoes in Japan, and represent approximately 10% of the world's active volcanoes. The deep-seated earthquakes around Japan are epicentered along the Kurile-Kamchatka Trench, Japan Trench, Izu-Ogasawara Trench, South Sea Trench, and Ryukyu Trench, which dip steeply into the continent along the Wadati-Benioff plane. Furthermore, a series of volcanic fronts are aligned between the trenches and the continent. Typically the volcanic belts are located about 100 to 200 km inward of the trenches **(Fig. 2)**. Based on the volcanic fronts, the five island arcs mentioned above are classified into volcanic inner arcs and non-volcanic outer arcs.

Based on the characteristic configuration and partial overlapping of the five island arcs, the Japanese archipelago is divided into 12 distinct physiographic zones **(Fig. 2)**. Landslides occur frequently within six provinces: Zone A_1, the main interior of Hokkaido (inner Kurile Island Arc) which exhibits medium to small scale landslides; Zone B_1, the inner Northeast Honshu Arc (the representative landslide zone); Zone D_1, the Northeast Kyushu Island within the inner Southwest Honshu Arc (the zone of high density landslide distribution); Zone D_2, the outer Southwest Honshu Arc and Zone DC_1, the Central Western Honshu (Chubu Mountains), represented by landslides of very slow movement and very large-scale, rapidly moving failures; and Zone DC_2, the Central Eastern Honshu (Kanto Mountains) which exhibits a high density landslide distribution within low-lying mountains.

Engineering Geologic Structure of the Japanese Archipelago

Based on the major geologic divisions and characteristics of the earth materials during slope movement, the Japanese archipelago is divided into 15 engineering geologic divisions **(Fig. 3)**. Furthermore, on the basis of plate tectonic research and assessment of slope movement, the 15 engineering geologic divisions are further subdivided into five distinct tectonic zones, discussed below.

Ⅰ. Pre-Tertiary Accretionary Terrain Zone: This zone represents Mesozoic and Paleozoic sedimentary rocks **(Division 4)** and metamorphic rocks **(Division 3)**, ultramafic and mafic intrusive rocks **(Division 2)**, Cretaceous marine deposits of turbidite facies **(Division 5)**, and Flysch type sedimentary rocks of Late Mesozoic to Early Miocene age **(Division 6)**. These divisions are typically distributed along the extensional direction of the narrow island arcs. The geologic divisions are juxtaposed against each other from the oldest formations (on the continental side) to the youngest formations (on the Pacific Ocean side). The contacts between the divisions are separated by shear zones including thrust faults.

Ⅱ. Plutonic Zone: This zone consists of plutonic rocks of mostly Cretaceous of Early Tertiary age **(Division 1)**. However, a few parts of this zone include Miocene and Quaternary age intrusive rocks. Plutonic rocks of pre-Tertiary age exhibit significant weathering.

Ⅲ. Tertiary Covering Sediments Zone: This zone represents the areas of the highest landslide occurrence within the Japanese archipelago, and consists mostly of Neogene (and some Paleogene) semi-consolidated clastic materials **(Divisions 8 and 10)** and volcanic rocks **(Division 9)** which overlie the Pre-tertiary Accretionary Terrain Zone and the Plutonic Zone. Non-siliceous mudstones easily weather or decay into clays due to increased water content and weathering. Alteration of the volcanic rocks changes the color to a greenish appearance, and thereafter they are called "green tuff". Tuffaceous mudstones contain abundant smectite clays, and contribute to one of the primary causative factors of landslides.

Ⅳ. Quaternary Volcanic Zone: Volcanoes consisting of lava, welded tuff and scoria beds **(Division 14)** often form very steep slopes. Furthermore, the volcanoes are often associated with hydrothermal alteration and volcano-induced earthquakes. The high relief of the volcanic regions also attracts heavy precipitation. All of these factors contribute to slope instability. Cap rock conditions exist when volcanic rocks overlie the clastic materials.

Ⅴ. Quaternary Regional Pyroclastics Zone: This zone consists of large scale eruptions of Late Quaternary acidic, welded and unwelded pyroclastic deposits **(Division 13)** that are distributed throughout much of Japan.

Climate of Japan

The Japanese archipelago is situated between North latitude 45 degrees and 20 degrees, facing the Pacific Ocean along the southeastern side and the Sea of Japan and Eurasian continent along the northern side. Due to the geographical position of Japan, the climate varies considerably.

During the winter months, continental cold masses (high pressure zone) are formed in the Siberian region due to radiation cooling. The cold seasonal winds that are generated from the cold air masses move through the Sea of Japan and absorb large quantities of moisture during Japans' winter months, which cause the dominating northwest winds. When the moist seasonal winds reach Japan, the cold air masses collide into the mountain regions. As the air masses rise with increasing elevation, a large quantity of moisture is precipitated as snow along the slopes facing the Sea of Japan, establishing one of the worlds' famous snowy regions **(Fig. 5)**.

In the spring, due to the low pressure zones moving west to northeast, the cold-warm cycles are repeated and gradual warming occurs. Numerous landslides have been triggered by the large quantity of snowmelt along the slopes facing the Sea of Japan. Cherry blossoms and budding from the southernmost island moves progressively northward. In early June, the Northern Pacific High Pressure Zones gradually

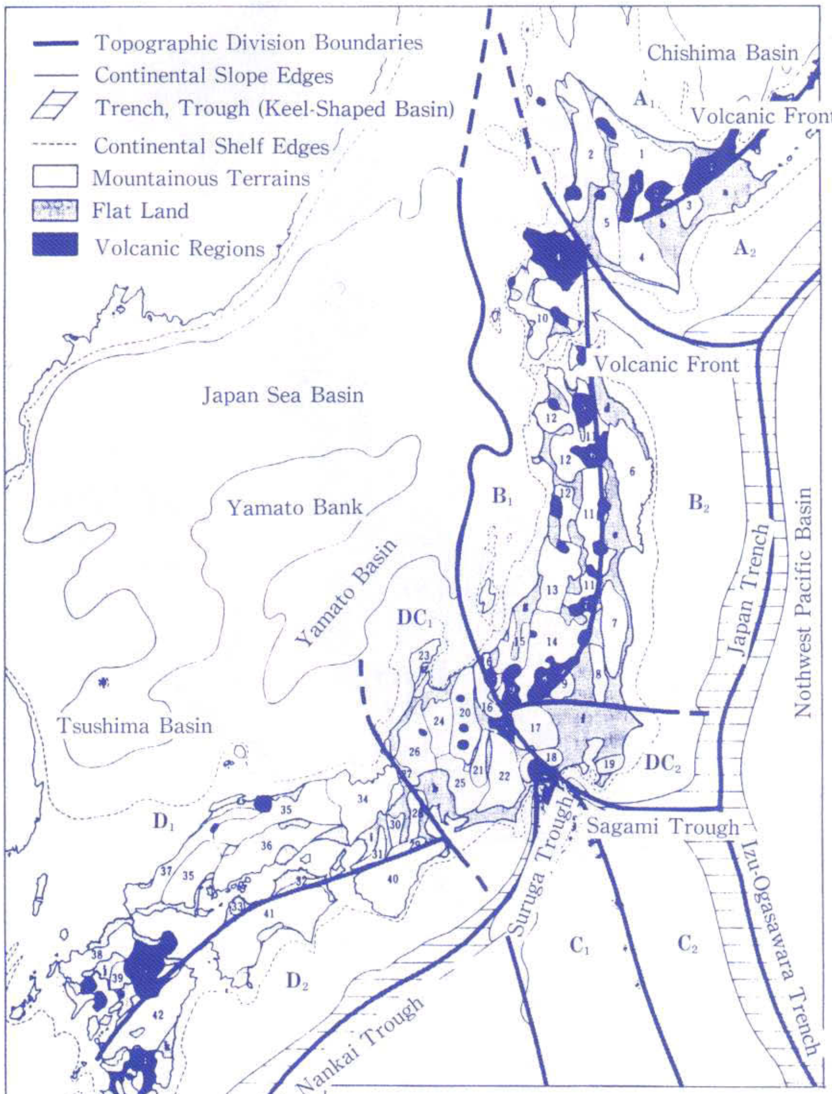
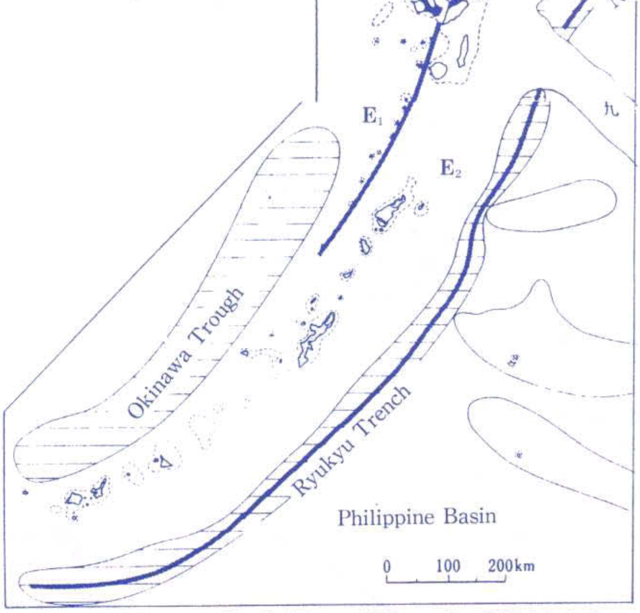



Fig. 2 Topographic divisions of Japan (by S.Kaizhuka)

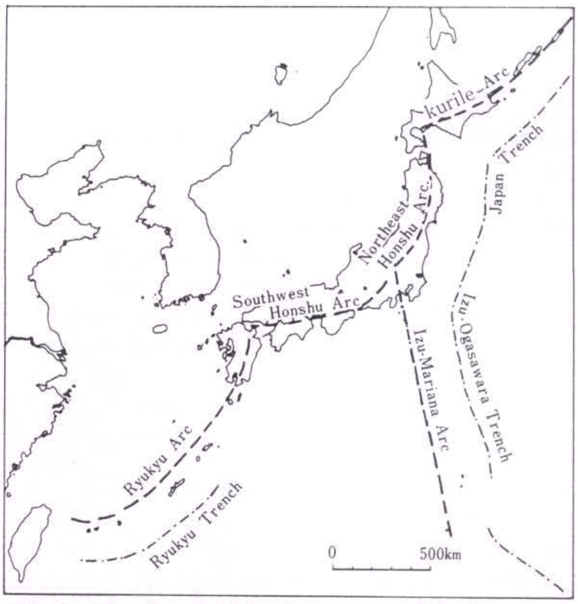


Fig. 1 Trenches and island arces around the Japanese Archipelago

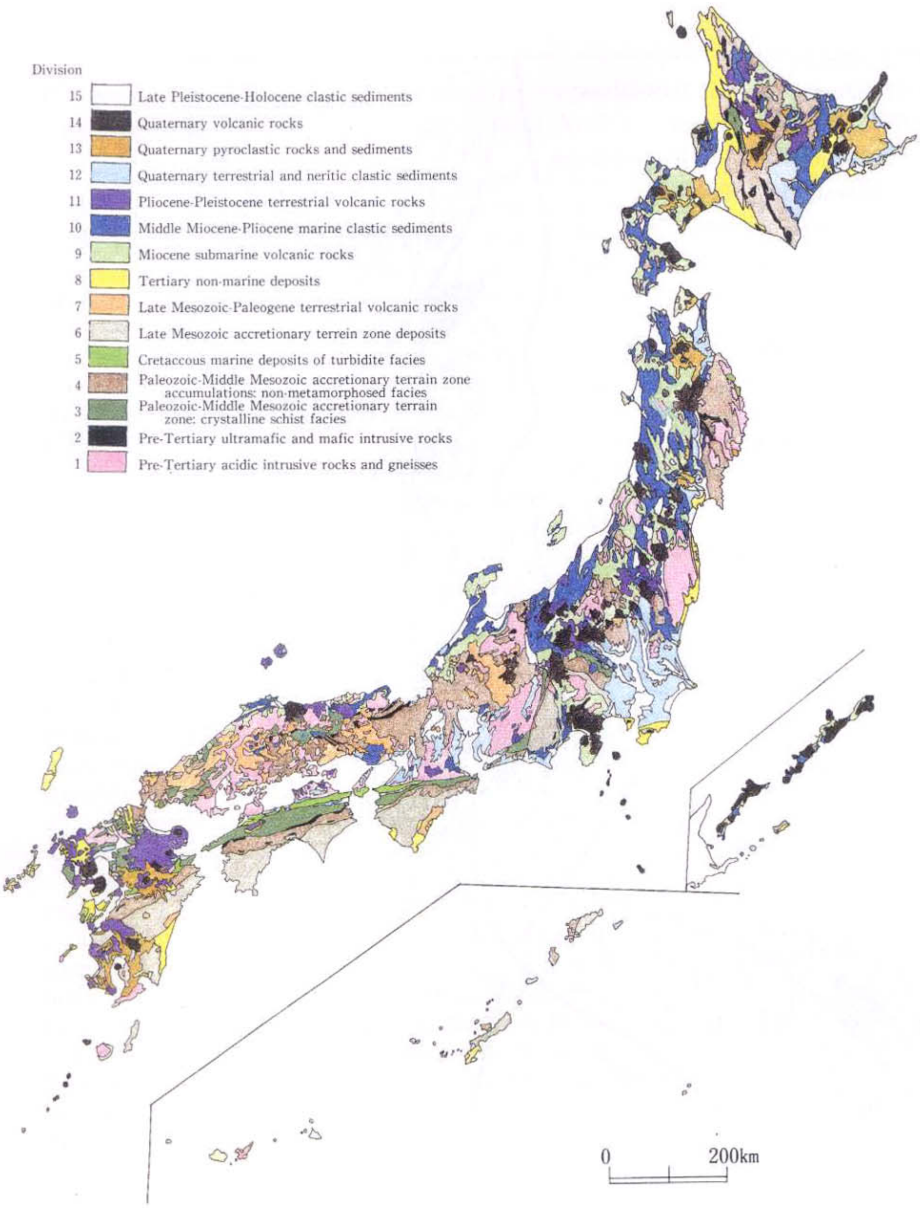


Fig. 3 Major engineering geologic divisions of Japan

Fig. 4 Landsides designated by the government for mitigation measures

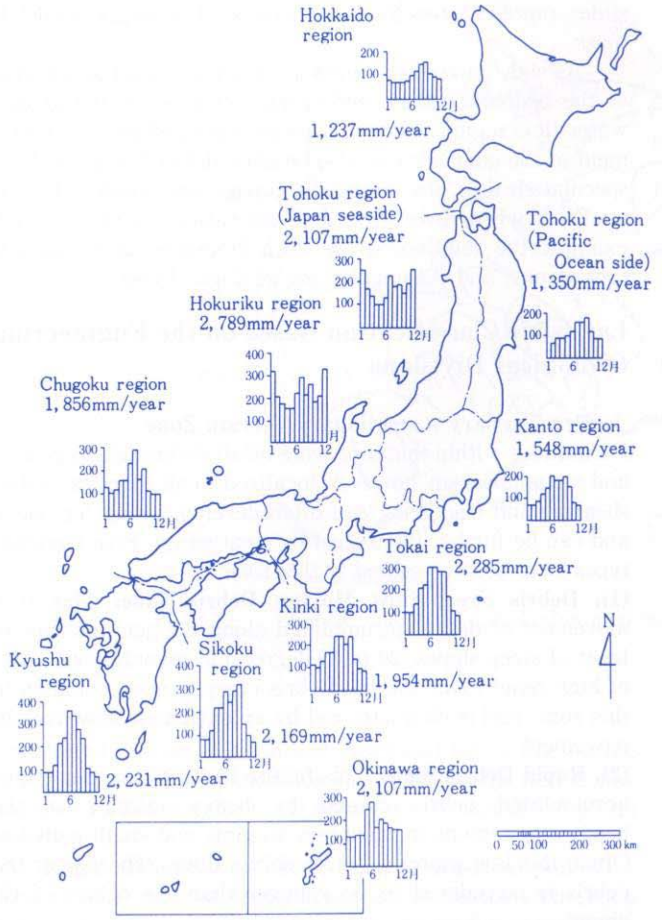


fig. 5 Regroval hyetgraph of precipitation

move from south, and the northern air masses move from the Sea of Ohhotsk since the springs and collide above Japan, froming a stationary seasonal rain front. Usually, this early summer stationary rain front (Baiu Front) lasts a couple of months, intermittently dropping large quantities of rain. These rains often create landslide and debris flow disasters.

In the summer months, Japan is a high temperature-high humidity region due to the Northern Pacific High Pressure Zones that cover most of Japan. In the fall, typhoons form in the low latitude regions of the Northern Pacific Ocean and move northward circling the westen rims of the Northern Pacific air masses that often land in Japan **(Fig. 6).** These typhoons usually generate very strong winds and very heavy rainfall, and cause frequent sedimentation disasters and flooding. The pressure distribution pattern in early autumn is very similar to the stationary rain of early summer. Late autumn (October-November) is generally clear and offers the beauty of the colored hills.

The annual precipitation in Tokyo (Pacific Ocean side) is 1405 mm. At Owase, however, the Kii Peninsula records 4002 mm while Takada (Sea of Japan side) records 2880 mm (of which one-half is snow).

Landslide Disasters in Japan

The natural conditions discussed above are multiple affects that create unique physical conditions susceptible to landsliding which cannot be seen any other place in the world

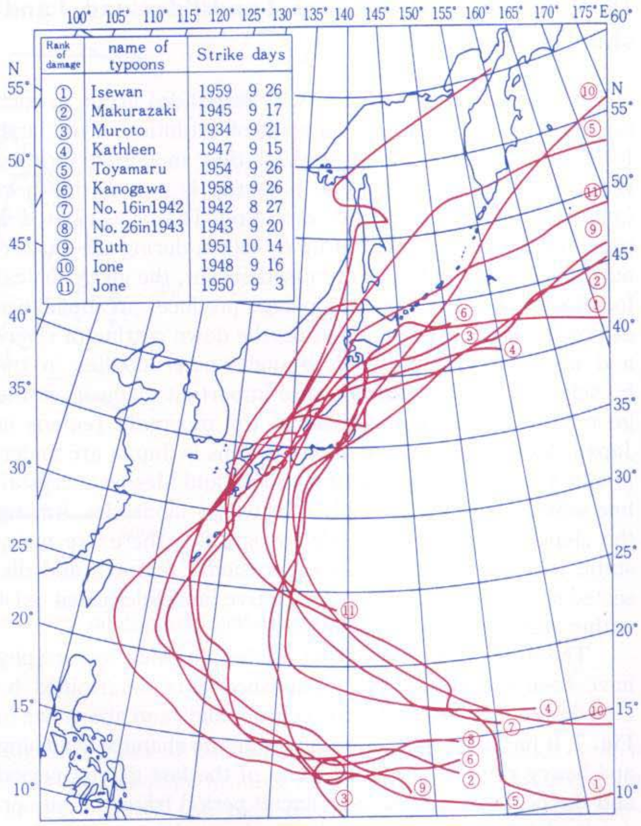


Fig. 6 Courses of typhoons

(Fig. 4). Since only 25% of Japans' land area is flat and low lying with plateaus, the Japanese people have suffered numerous landslide disasters since ancient times. For example, evidence of landslide failure has been unearthed from the site (Oshimo Shell Mound, Aso-Cho, Ibaragi Prefecture) of Jomon in the Middle to Late Period (3000-1000 BC). Nihon Shoki (720 literature) recorded numerous landslides and failures associated with the mega-earthquake (along the South Sea Trough) of November 29, 684. Recent disasters include torrential downpours around Kumamoto and Nagasaki in 1972; disasters from typhoon No. 17 in 1976; torrential downpours in Nagasaki in 1982, and many others. Human casualties from these disasters include 543 deaths in the 1972 event, 298 deaths in the 1976 event, and 493 deaths in the 1982 event. Disasters from single landslide events include a large scale failure of Ontake San, Nagano Prefecture in 1984 (volume: 3.4 $\times$ $10^7 m^3$, 15 deaths), Tamanoki Landslide of Ohmi-Cho, Niigata Prefecture in 1985 (10 deaths), Jizuki Yama Landslide, Nagano City in 1985 (26 deaths), and others. More than 300 landslides and slope failures have been reported since the Southern Hyogo Earthquake of January 17, 1995. The population density of Japan is $328/km^2$ (based on the 1994 census population of 124 million). However, the population density of the flat and low lying areas and plateaus of Japan is $1312/km^2$ indicating the severity of land use in Japan. Landslides generally occur along gently to moderately sloping ground which is also important as these areas include residential and agricultural use. Because of these conditions, an active effort must be developed to protect the slopes from future landsliding and failures in Japan.

2. Characteristics of Landslide Phenomena in Japan

Developmental Process of Landslides and Landslide Topography

By examining the reason why landslides occur in such high frequency from the standpoint of evolution of the landform, it must first be recognized that mountain-forming resulting in increased erosion potential is one of the most important factors in landslide evolution. That is attributed in part to crustal movement of up to 1500m during the Quaternary Period. Secondly, as discussed earlier, the geographical location of the Japanese archipelago produces an abundance of precipitation which accelerates the down cutting of rivers and also provides plentiful ground water supplies in the hillsides. As result, landslides are important elements in the geomorphological development in the mountain regions in Japan. Most of the mountainous regions in Japan are underlain by the Neogene sedimentary rocks and Mesozoic crystalline schist, which are strongly affected by landslides. Among the slopes that have landslide topography, there are many static landslides with advanced erosional features and dissected scarps and slump blocks. Active landslides often exist within static landslide topography.

The ages of the formation of the landslide topography have been established from published data determined by C-14 dating methods and tephra chronology, and are shown in **Fig. 7**. It has been speculated that climatic changes (warming and heavy rainfall) during the end of the last glacial period and the beginning of the postglacial period triggered numerous landslides. In particular Japan, located east of the Eurasian Continent and separated by the Sea of Japan, the Tsushina Current began to enter the Sea of Japan at that period causing heavy snowfall in the winters in regions facing the Sea of Japan. As a result, the region is highly susceptible to landslide occurrences.

Large scale landslide features can be formed by an aggregate of smaller landslide features **(Fig. 8)**. Following the formation of a large scale landslide cluster, it has been recognized that fissures and cracks could develop during landslide movement. That movement could facilitate infiltration of ground water into the head portion and flank of the landslide mass. Such conditions can cause localized instability and result in the formation of smaller landslides within the large landslide. Many of the currently existing active landslides represent reactivated portions of a larger landslide mass.

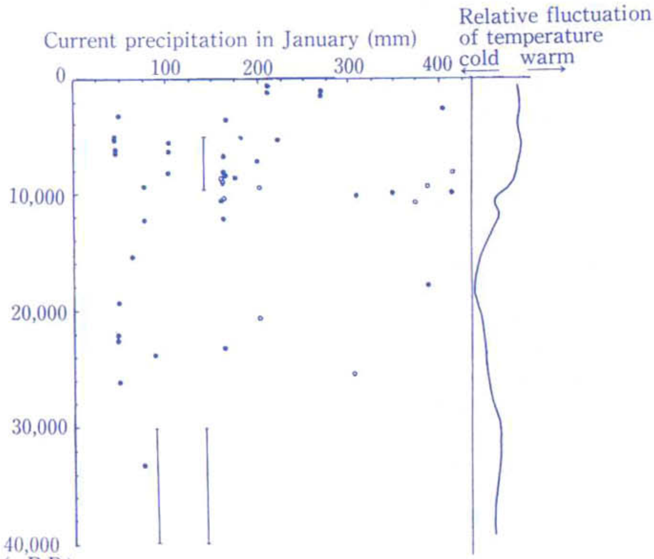


Fig. 7 ^{14}C age of landslides with respect to current rainfall total in January

As slide movement continues, fracturing and weathering of the bedrock occurs, and creates changes in the ground water flow regime. Material composition and mode of movement of the landslide can also be altered. Further, it has been speculated that the landslide topography could also be modified when associated with alteration. Next, we shall examine the relationship between landslides and landslide topography, and the engineering geologic divisions.

Landslide Classification Based on the Engineering Geological Divisions

I. Pre-Tertiary Accretionary Terrain Zone

Formations within this zone were lithified through diagenesis and metamorphism, however, localized weak zones caused by shearing and fracturing can often develop during tectonism and can be further intensified by weathering. Five landslide types have been classified in this zone.

(1). Debris Creep-Slow Moving Debris Slide: This is a movement of debris accumulated along the gentle slopes in front of steep slopes (20 to 35 degrees) in mountainous areas of high relief (over 300 m). Debris creep is most common in this zone, and is characterized by an extremely slow rate of movement.

(2). Rapid Debris Slide: This failure is a rapid movement of accumulated debris caused by heavy rainfall at the headwater regions in mountain streams and small canyons. Often, this is a source area for debris flows. The age of the debris is considered to be younger than the debris of **(1)** above.

(3). Rapid Rock Slide: This is a rock slide involving more than $10^8 m^3$ in volume, and is caused by seismic activity or torrential rains. It has been speculated that the majority of the failures had experienced a creep-type deformation prior to the catastrophic failure.

(4). Slow Rock Slide: For crystalline schist, the slide plane is roughly parallel to the slope; for non-metamorphic rocks, the slide plane is sub-parallel to laminar-bedding planes and small low angle faults.

(5). Bedrock Creep: The characteristics of this landform include scarps facing towards the ridge lines accompanied by multiple scarps that are roughly parallel to the ridge lines. Bedrock creep generally occurs near the ridge lines of mountain regions of high relief. The lower slopes have bulges, and the slope as a whole exhibits a convex shape. This represents the early stage of deformation of the landform and slope dynamics. However, it is suspected that distinct slide planes or separation planes have not been recognized. Numerous examples have been identified through aerial photographic interpretation and in field reconnaissance.

II. Plutonic Zone

Although the intrusions occurred throughout geologic time, the type of landslides and modes of failure are similar to the landslides found within the Plutonic Zone.

(1). Rapid Surficial Slide: This involves failure of surficial soils, residual soils and colluvium triggered by intense rainfall. It is most common in the Granitic Zone. Failed debris moves further downstream while stripping surficial materials along the way. Depending on the amount of water available, this type of movement can often develop into debris flows.

(2). Rapid Debris Slide: This failure includes debris ac-

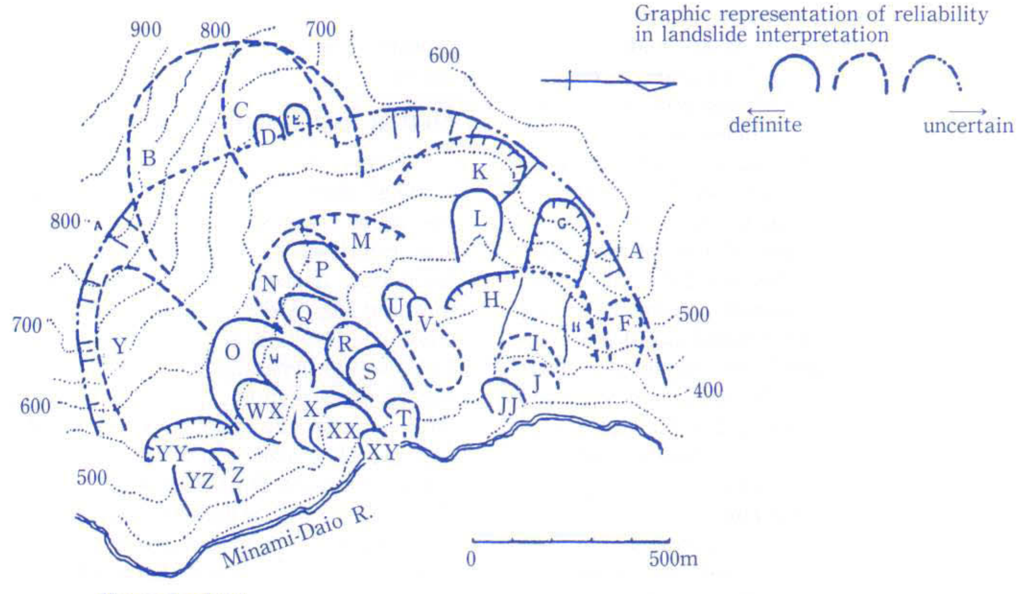


Fig. 8 Landslide distribution map based on aerial photographic interpretation

cumulated around the drainage head and knick line during the Pleistocene Epoch (perhaps during the glacial periods) by intense rainfall. Similar to **(1)** above, it can often develop into debris flows.

(3). Rapid Slide of Weathered Rock or Residual Soil: This type of slide involves deep and extremely weathered bedrock where the failure is generally triggered by intense rainfall. Slide planes are generally found within the weathered zone, and others are found along joint surfaces and dikes.

(4). Slow Moving Landslide: The slide planes in this group are found along faults and fractures within the granitic rocks and along the weathered zone within acidic plutonic rocks such as granodiorite. However, not many landslides are observed in areas underlain by plutonic rocks in Japan. Even though they do exist, they are generally small scale.

III. Tertiary Covering Sediments Zone

The clastic materials observed within this zone are semi-consolidated. Mudstones could easily turn to clay by hydration and weathering. Tuffaceous mudstones contain abundant smectite that contributes to sliding. The types of landslides observed within this zone are discussed below.

(1). Clayey Soil Creep-Slow Slide Movement: This type of slide often occurs in areas underlain by mudstone and colluvium along valleys of low relief. Depending on the velocity, the sliding can change to "mud flow". This type of movement is relatively small, and ranges in size measurements of width: 5-100 m; length: 100-500 m and depth: 5-20 m. The causes of initial movement include increased pore water pressure from snowmelt, stationary weather fronts of early summer (Baiu Front) and typhoons.

(2). Rapid Slide of Semi-Consolidated Sediments: This is a rapidly moving slide along very steep slopes triggered by snowmelt, intense rainfall or earthquakes with materials comprised of clastic materials such as gravels (conglomerate), sands (sandstone), and silts (siltstone) deposited during the Pleistocene and Upper Pliocene Epochs. In some cases the rapid slide changes to mud flows with an average velocity of up to 8 m/sec.

(3). Slow Slide of Consolidated Sediments: The basic composition of the slope-forming materials includes the overlying hard-competent cap rock formation with underlaying soft-incompetent formations. The competent formations include thick sandstone, silicified shale, and thick volcanic rocks, which the incompetent formations include unsilicified mudstone and altered tuff. The maximum dimensions of this type of slide could be on the order of width: 4 km; length: 5 km; and depth; 100 m.

(4). Bedrock creep: This is the same type of slope deformation defined in **I, (3)** above, and is also observed in the Green Tuff Zone.

IV. Quaternary Volcanic Zone

There are four types of slope movement that have been recognized within this volcanic zone.

(1). Large-Scale Rapid Failure of Volcanic Rocks / Debris Avalanche: This type of failure is involved only with composite volcanoes and lava domes of high relief. As new volcanic activities centered within the deeper portion of the volcano that contain upward-migrating magma, earthquakes and fluctuating ground water levels could induce a catastrophic collapse of the upper volcanic body. This type of failure often deposits relatively large, unbroken blocks as mudflow hills along the foothills and nearby low lying areas. The volume of the failure is on the order of 10^8 to $10^{10}m^3$. Most of the cases involve andesitic volcanoes (for example, Mayuyama at Shimabara and Bandai-San), but there is a case that involves basaltic volcanoes (Mt. Fuji, for example). Smaller scale failures ranging from 10^6 to 10^7m^3 triggered by earthquakes (for example, South Slope Ontake-San of 1984).

(2).Rapid Clay Slide in Hydrothermal Altered Zone: This type of landslide occurs within zones that receive severe hydrothermal and fumarolic alteration near the crater bottom which is an opening to the lower slope. Examples of this type of failure include Hakone Sounzan of 1953, Hakone Ohwakudani, Kirisima Volcanoes, and Myoko San.

(3). Slow Moving Slide of Sedimentary Rocks Underlain by Volcanic Deposits: This is a type of landslide formed along the foothills of volcanoes where terrains are underlain by sedimentary rocks in turn overlain by lava and pyroclastic rocks that protect the slope from erosion (cap rock structure). As localized active down cutting of channels proceeds, over-steepened and unstable areas transporting the volcanic bodies would fail. The scale of this failure type could be very large, measuring up to width: 2 km; and length: 4 km.

(4). Debris Flow: There are two types of debris flows. One type involves recently deposited volcanic ash that is subjected to rainfall which could flow downstream causing frequent debris flows (Yakedake, Sakurajima, UnzenFugendake, and others). The second type is associated with high temperature pyroclastic flows that melt the existing snow and ice, and flow downslope with the melted water. The flowing body erodes and consumes materials along the way, becoming a large scale mudflow-debris flow (Tokachidake).

V. Quaternary Regional Pyroclastic Zone

The slope movements within this zone are represented by the failure of unwelded pyroclastic flow deposits accompanied with intense rainfall. Furthermore, in this zone the failures are frequently induced by seismic activity. However, it is considered that the majority of these failures involve not only the rapid slide/topple/fall of the pyroclastic flow deposits, but also include the rapid slide of the tephra and surficial deposits underlain by the pyroclastic flow deposits.

Sliding and Rapid Failure

Among the slope movements discussed in the previous sections, there are significant differences in the mode of movement assigned "rapid" and "creep" or "slow". In Japan, it is traditional to classify slope movements into two broad categories; Jisuberi=sliding, and Hokai=rapid failure. As shown in **Fig. 9**, the areal extent of sliding is comparatively large (over 1000 square meters), gently sloping (less than 30 degrees, and generally between 5 to 20 degrees), and slow velocity (less than cm/minute) with a longer duration (over 100 hours). On the other hand, the rapid failure is quite the opposite. The size is less than 1000 m^2 occurs on slopes ranging between 30 to 60 degrees, and has a velocity faster than 1 m/sec with a duration that is less than one hour. The definite difference in damage is that sliding sustains large economic damages while the rapid failures are more of a threat to human casualties. Therefore, any measure for such slope movements have to be responded according to the characteristics of each type. In fact, the mitigation measures must be implemented according to the characteristics of the type of movement.

	Landslides	Slope Failures
Geology	Occur in places with particular geology or geological formation.	Slightly related to geology.
Soils	Are mainly active on cohesive soil such as slip surface.	Frequently occur even in sandy soils (decomposed granite, top soil, Shirasu, etc.)
Topography	Occur on gentle slopes of 5° to 20° and often have plateaushaped topography in the upper portions.	Frequently occur on the slopes steeper than 30°
Situation of activities	Continuous, or repetitive occurrences.	Occur suddenly.
Moving velocity	Speed is normally low at 0.01 to 10 mm/day.	Extremely high speed of more than 10 mm/day.
Masses	Have little disturbed masses and often move while maintaining original form.	Have greatly disturbed mass.
Provoking causes	Are greatly affected by groundwater.	Are affected by rainfall intensity during rainfall.
Scale	Have a large scale between 1 and 100 ha.	Have a small scale. Average volume of collapsed material is about 440 m^3 (18.8 m wide, 21.1 m long, 1.6 m deep).
Symptom	Have cracks, depressions, upheavals, groundwater fluctuation, etc. before the occurrence.	Have few symptoms and suddenly slip down.
Gradient	10° to 25°	35° to 60°

Fig. 9 Difference between landslide and slope failure

3. Landslide Investigation and Prediction

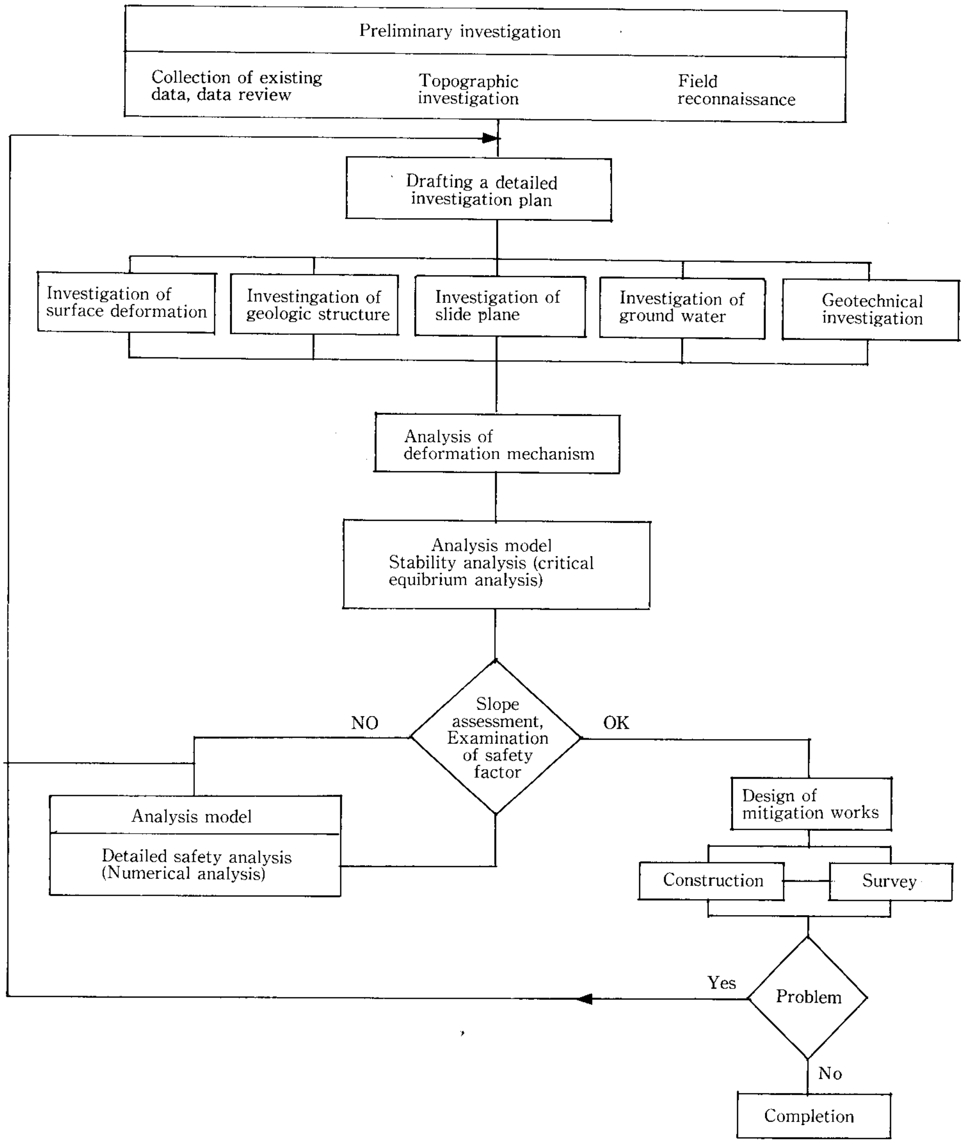


Fig. 10 Flow chart for landslide investigation and analysis

The flow chart shown in **Fig. 10** describes the general investigation procedures in an attempt to understand the mechanism of origination of disasters associated with slope movement and to predict the resulting deformation. Investigation items and investigation methods are shown on **Table 1**.

3.1 Preliminary Investigation

(1) Collection of Existing Data, Data Review

Landslides often occur at specific locations under certain topographic and geologic conditions. Therefore it is important to utilize existing data (history of the problem, records of restoration work, and data review) in order to understand the topography, geology, and properties of similar landslides. It is also important to understand their relationship with meteorologic factors, period of activity, existence of any warning sign, ground water conditions, chronology of topographic change or erosion by rivers, earthquakes, and other factors which may have a relationship with the slope deformation surrounding the investigation site area prior to the detailed investigation.

(2) Topographic Investigation

It is necessary to identify any changes in the site topography. That can be accomplished by recognizing; 1) the overall topographic feature of the site; 2) understanding the topographic characteristics of the site slopes; and 3) estimating the regional geologic structure of the site. Such methods include comparing the aerial photographs of the site and vicinity taken prior to and after the sliding , and interpreting the topographic maps and aerial photographs.

In Japan, aerial photographs are taken every few years over the entire country at a scale between 1/10000 to 1/40000. These photographs are used to understand the chronologic and topographic changes over the country. Furthemore, in order to be able to effectively interpret the phenomena related to microtopography and landslides, large scale aerial photographs with a scale of 1/8000 to 1/15000 are often taken.

By utilizing aerial photographs, it is possible to interpret landslide phenomena and warning signs, geology and geologic structure, topography and distribution of vegetation type. For landslide investigations, it is useful to identify and interpret the distribuoion and continuity of knick lines, gentle slopes, gullies and cracks in the photos to aid in preparing a photo interpretation map. The map can then be utilized during the field investigation.

The recent popularity of remote sensing using satellite photographs has been particularly useful for analysis utilizing the thermal infrared spectrum which is possible to estimate the distribution of slide areas and ground water, and live vegetation. Remote sensing can be used for analysis of topographic characteristics and topographic in terrain susceptible to landsliding.

(3) Field Investigation

With an approximate understanding of the overall topographic feature and knowledge of the distinction(s) of movement and aerial extent of the sliding block(s) (viewed from the opposite side), a detailed field investigation plan can be developed to delineate the aerial extent and a general direction of movement of th landslide zone, assess the geology and geologic structure, estimate the cause(s) of the sliding, and predict future movement. The field investigation should not include just the actual landslide area, but also extend to the surrounding areas where possible future sliding also exists. The field investigation should also include areas where aerial

Table. 1 Investigation items and investigation methods

	Investigation items \ Investigation method	Interpretation of aerial photographs	Literature research	Topographic survey	Topographic investigation	Surficial geologic investigation	Sabsurface exploration by borings	Test adit	Geophysical exploration	Soil tests	Ground water tests	Investigation of slide plane	Investigation of land difformation	Notes
Topography	slope form	○		◎	○									
	slope inclination			◎	○									
	slope height, location of safety objective	△		○	○									
	formational process of slope	○	△		△									
	landslide topography (areal extact, moving blocks, direction of movement)	◎		◎	◎									
	knick line (yes or no)	◎		○	○									
	micro topography of slope	△			◎									
Geology and geologic structre	rock type and rock quality	△	○			◎	◎	◎	○	△	△			composition of rocks and hardness
	degree of weathering and level of relaxation					△	○	◎	◎		△			
	densify of rock formation						△	◎		◎				
	distibutim of fault and fracture zones	○	△			◎	◎	◎	○					
	distributim and depths of slide plane	△				○	◎	◎	○			◎		continuity
	inclination of slide plane					○	◎	◎				◎		
	quality of slide mass, composition of slide plane materials					○	◎	◎			○			filling
	mechanical coefficieuft of slide plane									◎				
	deformation conditons of slide plane											◎		
Deformation condition of ground surface					△								◎	
Conditions of ground water and springs						△	○				○			
Estimation of pore water pressure							△				◎			
Existing conditions and warning signs	history of past disasters	○	◎		△									
	existence and conditions of scarps	○			◎									
	secondary failures and rock falls	△			○									
	conditions of toe area and uplift	○			◎									
	existence of extremely relax beds and rocks				△									
	diformation of structuers				◎									

◎ : very effective investigation method ○ : effective investigation method
△ : depending on the situation, may be an effective method

photographic interpretation is difficult or unclear, and in areas that could aid in the understanding of particular topographic features and characteristics.

3.2 Drafting a Detailed Investigation Plan

In order to examine the follow item, a detailed investigation which will satisfy the objectives under the listings in the investigation methods and observation instruments in the **Table 1**, should be planned.

(1) aerial extent of the slide, differentiation of moving blocks and identification of the direction of movement
(2) location and shape of slide plane(s)
(3) nature of landslide block(s)
(4) possibility of further or future movement on slopes above the existing slide
(5) possibility of further, future or accelerated sliding
(6) distribution of ground water

Survey lines can be established on each moving block on the ground where the slide mass is expected to be thickest and where the stability analysis and plan for control works will be emphasized. As a general rule, the main survey line should be placed where the width of the slide exceeds 100m with subsidiary survey lines established at approximately 50m intervals **(Fig. 11)**.

Exploratory borings should be drilled on the order of every 30-40m. At least three borings should be drilled along the main survey line with one boring drilled at least 5 to 10m below the slide plane. During the early stage of the investigation, it is particularly important to have an accurate estimate of the configuration and location of the slide plane(s) an adequate boring depth can be achieved **(Fig. 12)**.

Seismic survey lines should be placed at intervals between 50-100m, and electric survey and radioactivity survey lines should be placed at 20-50m intervals. A survey should be conducted along the main survey line as well as along the logitudinal survey lines that cross the main survey line and subsidiary survey lines. For the seismic survey, the survey points should be established at 5-10m intervals, 20-50m interval for the electric survey, and at 3-5m intervals for the radioactivity survey. Furthermore, to verify the results of the geophysical surveys it is important to drill borings at the survey line intersections.

3.3 Detailed Investigation

(1) Investigation of Surface Deformation

The investigation of surface deformation is conducted to define the boundaries of the landslide, size, level of activity and direction(s) of the movement, and to determine individual moving blocks of the main slide. The presence of scarps and transverse cracks are useful for determining whether the potential for future activity exists.

Instrumentation used for the surface deformation investigation includes extensometers, ground tiltmeters, movement determination by survey methods including transverse survey, grid survey, laser survey from the opposite bank, move ment determination by aerial photographs, and G. P. S. **(Fig. 13)**

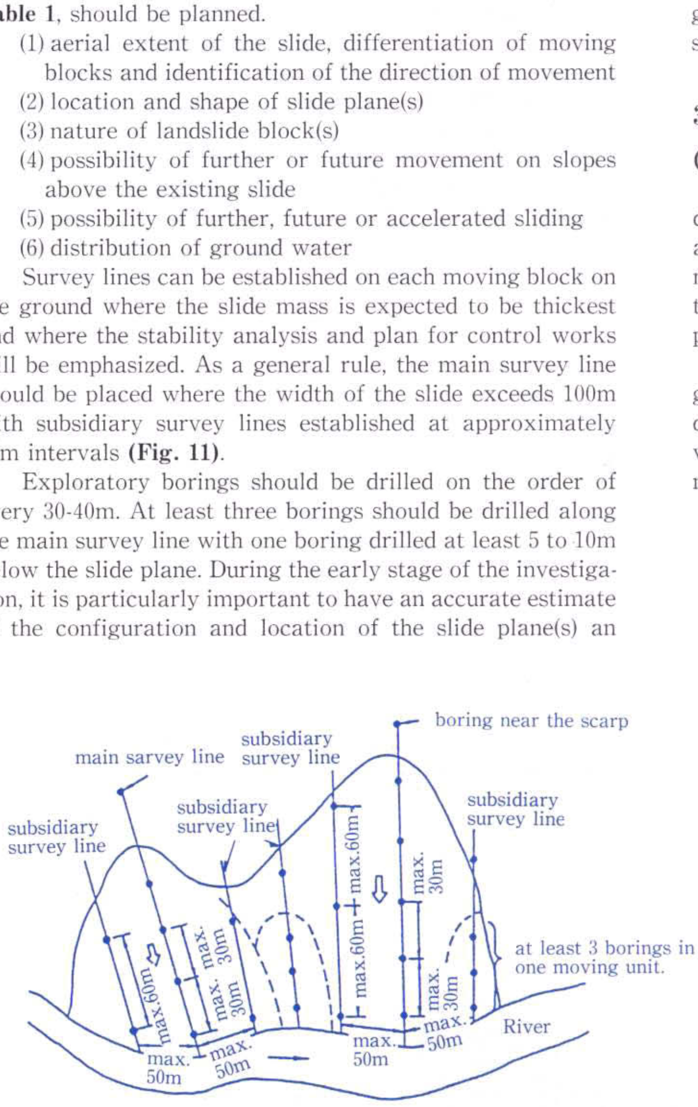


Fig. 11 Location of borings along survey lines

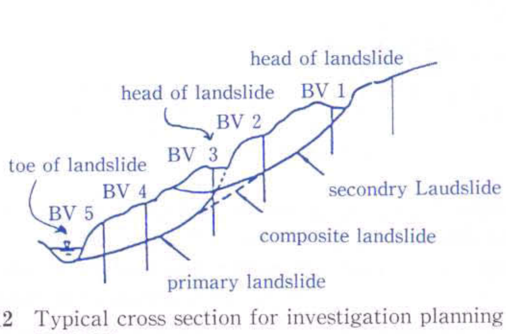


Fig. 12 Typical cross section for investigation planning purposes

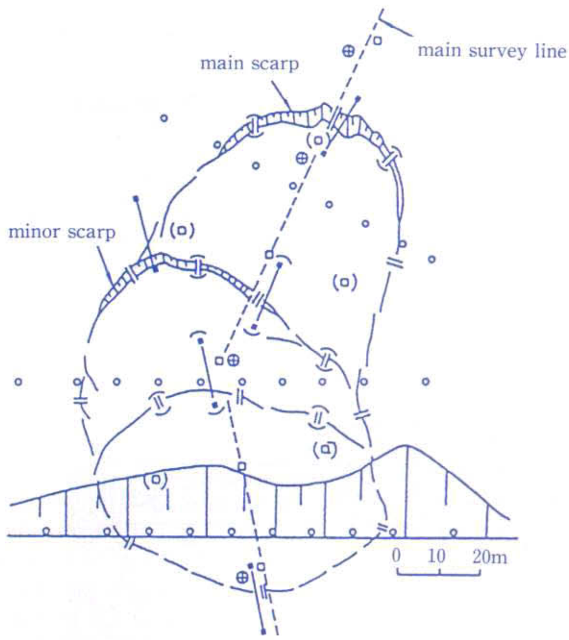


Fig. 13 Example of instrumentation

provides an example of instrumentation.

1) Extensometer

The extensometer is used to measure relative movement by comparing the extension of two points. The extensometers are generally installed across the main scarp, at transverse crack and transverse ridges near the toe or front portion of the slide and parallel to the suspected slide movement **(Fig. 14)**. By arranging a series of interconnecting extensometers from the main scarp to the toe of a complex landslide that has many moving slide blocks, the resulting data could aid in clearly delineating the individual slide blocks. Measurements should be accurate to within 0.2mm, and the magnitude of the movement and daily rainfall data should be included to establish the relationship between the measurable movement and the precipitation rate **(Fig. 15)**.

2) Tiltmeter

The ground tiltmeter is useful for determining the deformation at the head and toe portions and sometimes along the flanks of the landslide, or to assess the possibility of future deformation. A level type tiltmeter is most conventional. The tiltmeter is capable of measuring the N-S and E-W components **(Fig. 16)**. The magnitude of tilting and tilt directions can be determined directly from the instrument panel. Furthermore, in order to determine the characteristics of the deformation, the results are shown chronologically along with the daily rainfall totals. The relationship between the magnitude of tilting and the cumulative effect of tilting, rainfall totals and groundwater levels are shown on **Fig. 17**.

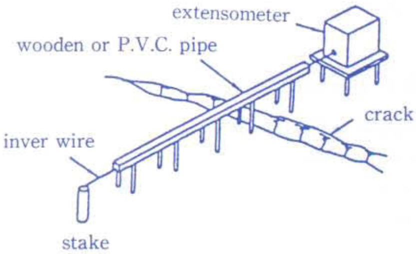


Fig. 14 Simplified diagram for extensometer installation

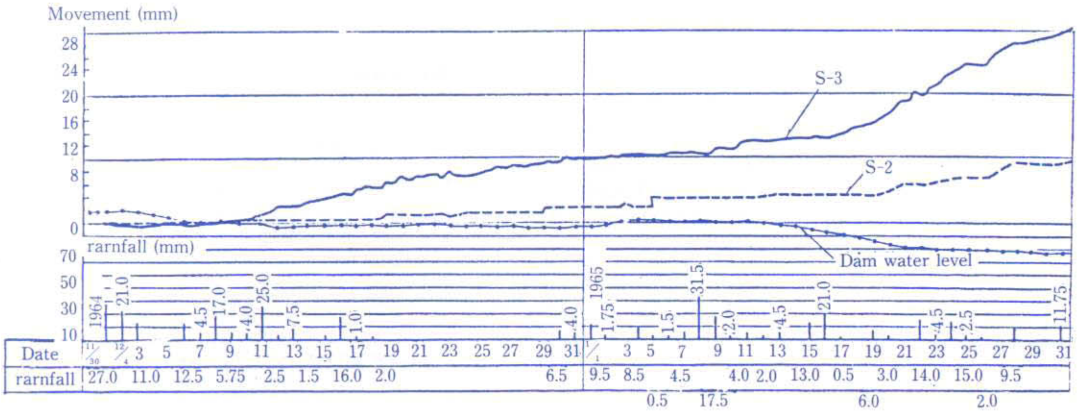
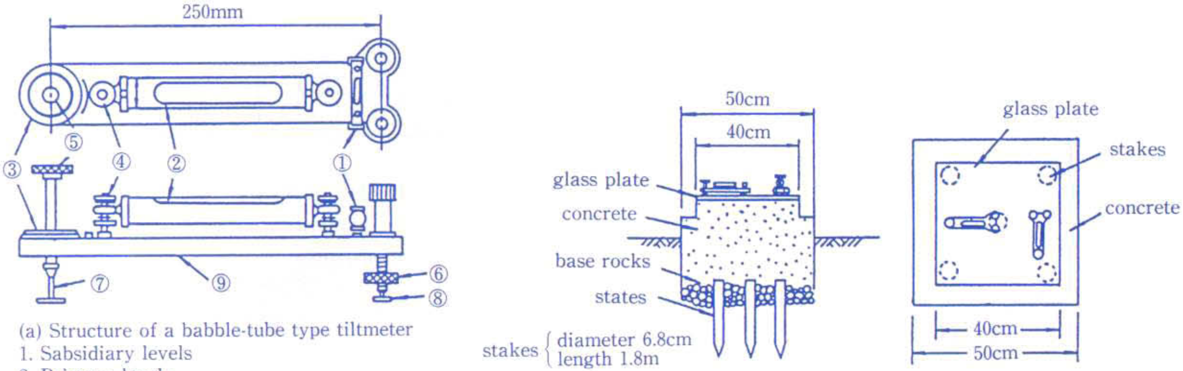


Fig. 15 Example of measurements by extensometer



(a) Structure of a babble-tube type tiltmeter
1. Sabsidiary levels
2. Primary levels
3. Panel
4. Level adjustment nuts
5. Primary legs turning nuts
6. Primary legs adjusting nuts
7. Main legs
8. Supporting legs
9. Level plate

b) Tiltmeter base

Fig. 16 Installation of tiltmeter

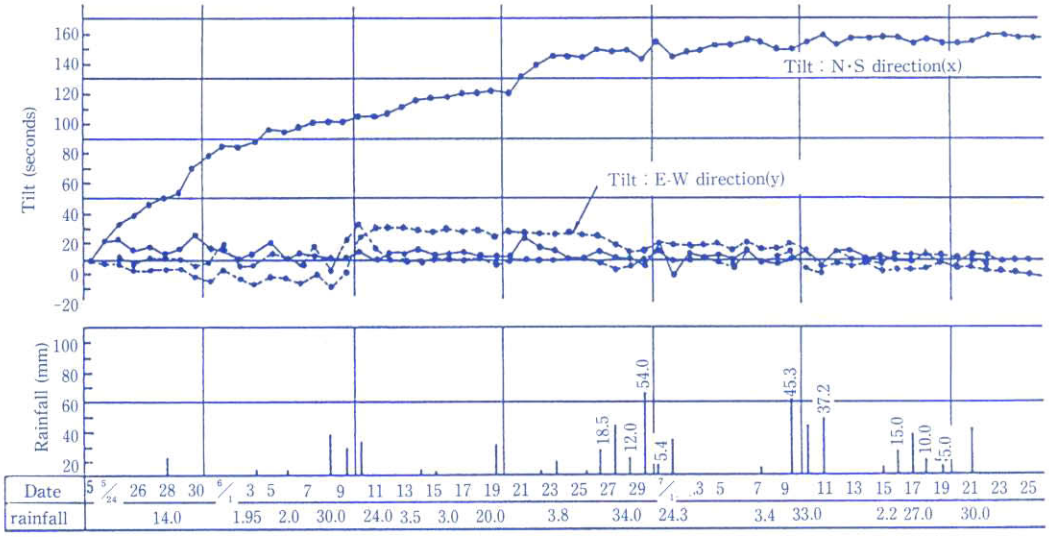


Fig. 17 Example of tiltmeter recordings

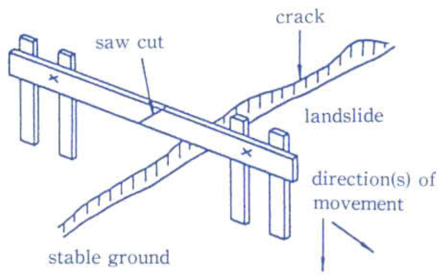


Fig. 18 Simple deformation deteltion method (Boards)

3) Simple Method to Measure Movements

One of the simplest methods to determine landslide movement is to drive wooden stakes across a tension crack along the direction of slide movement **(Fig. 18)**. Then attach horizontal boards to the stakes, and saw through the boards. Any movement across the tension crack can be determined by measuring the space between the sawed portions of the boards.

4) Determination of Movement by Surveying (Transverse Survey, Grid Survey, Laser Survey From the Opposite Bank, Movement Determination by Aerial Photographs, and G. P. S.).

Transverse Survey: This survey method establishes transverse survey lines across the landslide blocks with closely-spaced survey stakes. The survey stations should be established both within the slide and outside the slide on stable ground.

Grid Survey: This survey method involves constructing grid lines across the entire landslide as well as stable ground outside of the landslide. The survey stakes are driven at the intersection of the grid lines.

Laser Survey from the Opposite Bank; A control point is established along the opposite bank on stable ground, and survey stakes are positioned within the slide. It is most effective where the movement in large.

Movement Determination by Aerial Photographs: For landslides with a large component of movement, aerial photographic determination is the most useful. An accurate movement can be measured by annual or bi-annual flying.

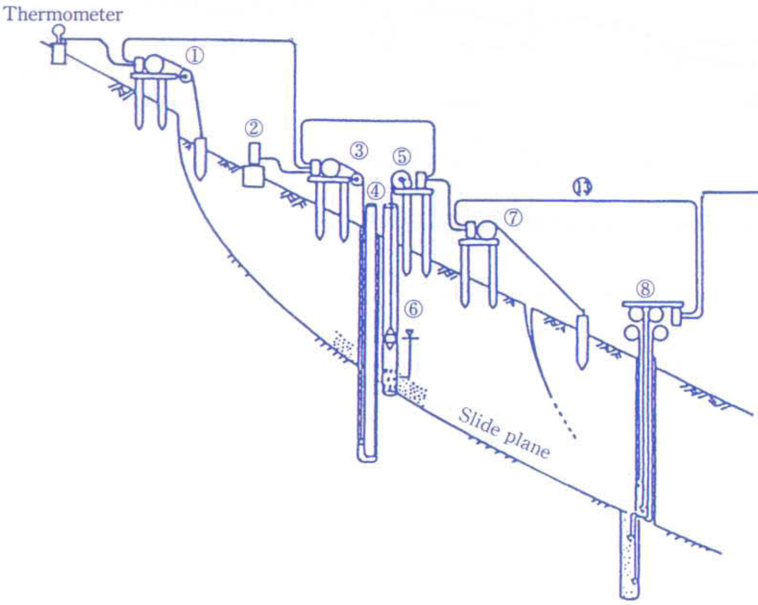
G. P. S.: Global Positioning System is the state of the art technology that uses signals from satellites to determine the three-dimensional positioning of the slide. G. P. S. has been used in recent landslide investigations where a high degree of success has been reported.

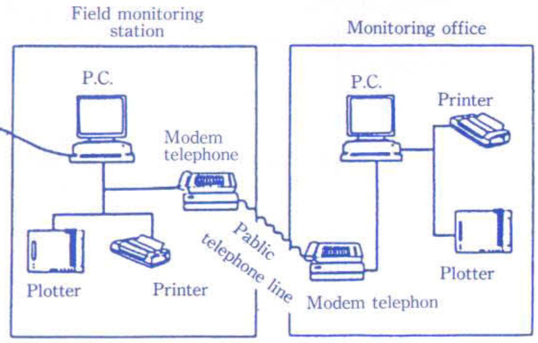
5) Automating Survey System

In the past, measurements of slope defomation have been performed manually. Recently, automatic survey systems using data loggers and computers have adopted **(Fig, 19)**. The instrument set-up in the field has been designed for easy installation, and is weatherproof, durable, maintenance-friendly and economical **(Fig. 20, 21, 22, 23)**. Through remote control in real time and rapid geographical data processing, it is possible to store long term data accurately and effetively and would provide an early warning of slide activity, thereby reducing landslide hazard. Furthermore, the recent development in the informationalized constructions systems and adopting the safety control at the construction site using the real time facilitates the planning through construction stage **(Fig. 24)**.

There are three main advantages in using the automating survey system.

1. Surveillance of the conditions of landslide failure: Issuance and cancellation of landslide watch and warning announcement based on the velocity of movement, piezometric pressure and variation in the rainfall





1. Ground surface diformation detection meter
2. Tipping bucket type rain gauge
3. Ground surface deformation detection meter (as subsurface extensometer) (wires of this instrument can also be connected to the guide pipes of inclinometer-④ or another instruments)
4. Inclinometer
5. Ground water level measurement meter
6. Boring specifically drilled for ground water level measurements.
7. Ground surface deformation detection meter
8. Subsurface deformation detection meter (Multi-layer movement meter)
9. Portable computer
10. Floppy disk driver
11. Interface adapter, batteries
12. Spare batteries
13. Tramsmission cables

Fig. 19 Typical construction of landslide automatic survey system

Fig. 20 Field conditions

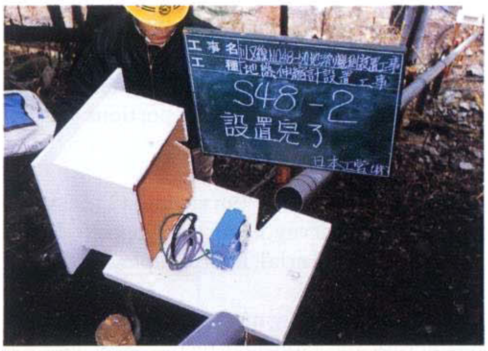


Fig. 21 Parts of sensor

Fig. 22 Data processing

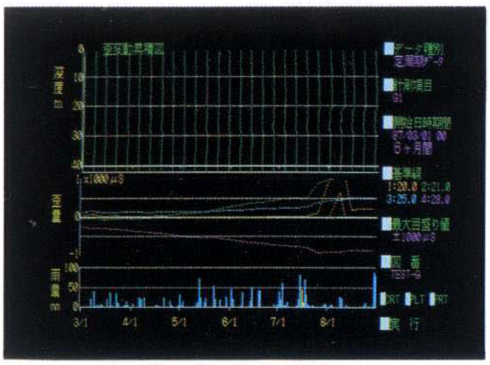


Fig. 23 Data (CRT)

amuonts. Prediction and forecasting of the landslide failure.

2. Understanding of the coditions of the landslide deformation: Chronological measurements of movement velocity. Determination of the slide plane depth. Determination of the relationship between the slope deformation and factors of slide occurrence (pore water pressure against the slide plane, critical pore water pressure related to the time of sliding, rainfall and snowmelt).

3. Effectiveness in determining landslide control works: Measurement of the amount of earth movement and pore water pressure. Measurement of the earth pressure affected by piles and collection wells. Determina-

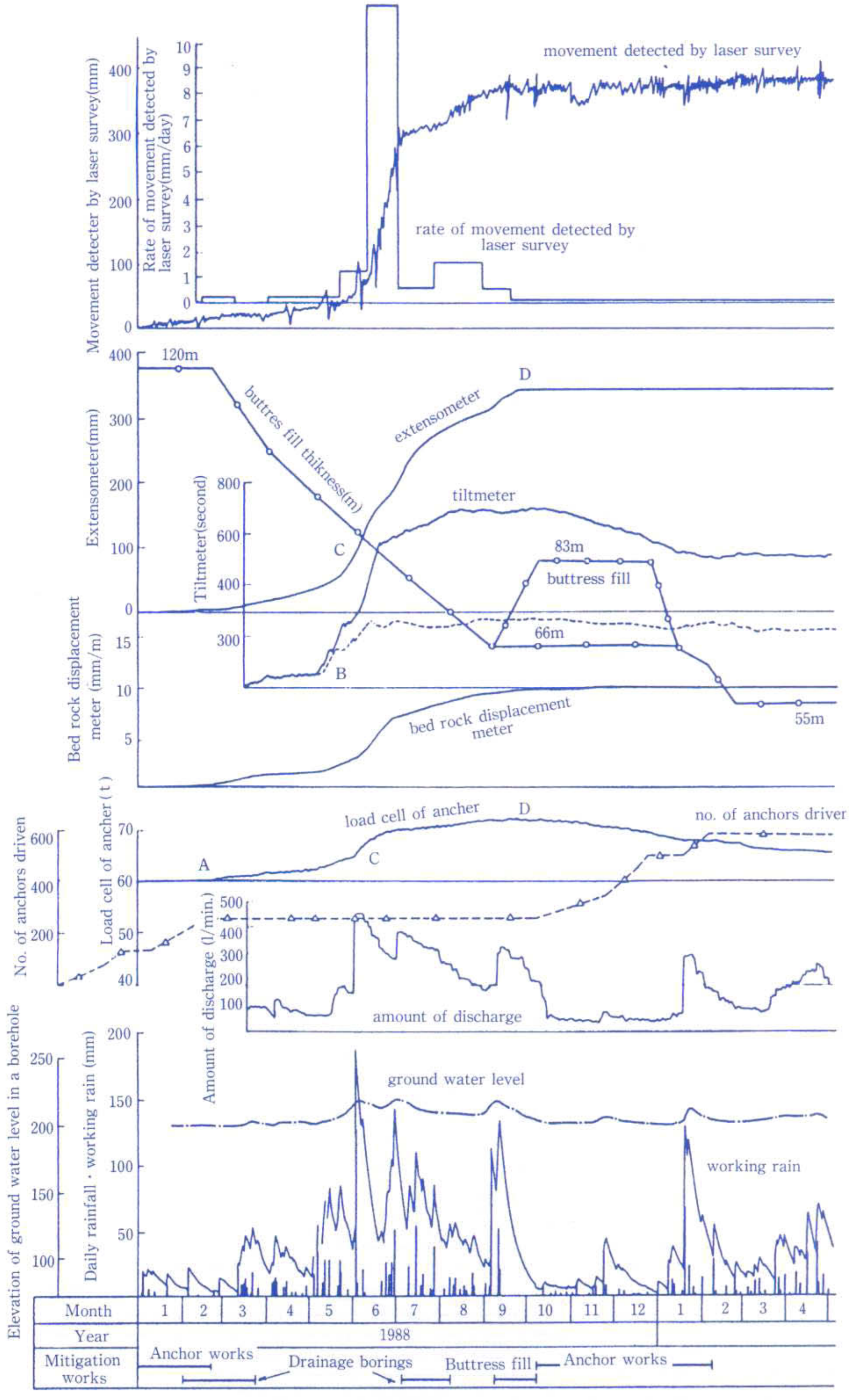


Fig. 24 Example of ground movement registered by various instruments

tion of the effectiveness of construction.

(2) Investigation of Geologic Structure

In most cases, the investigation of geologic structure relies on exploratory borings; however in cases where the bedrock distribution is ambiguous or a better understanding of the regional geologic structure is needed, then a geophysical exploration (seismic survey, electrical survey and radioactivity survey) is combined with the boring data.

1) Borings

The majority of the borings drilled are larger than 66mm. Core samples are recovered from the borings and are stored in core boxes. Boring logs should be prepared along with photographs of the core samples. The boring logs shall include such inforation as: geologic and soil description; color; hardness; lithologic description; degree of weathering; alterations and fractures; strike and dip of bedding joints; boring conditions; initial and stabilized ground water levels; and rate of core recovery.

Geologic assessment based on the boring data obtained from the drilling site should include a discussion regarding the differentiation of moving earth blocks, semi-moving earth, and stable ground. Clays within the slide plane generally have a high moisture cotent, are highly sticky and plastic and are often associated with abrasion scars and slickensides. During drilling, squeezed earth could occur near slide plane. Slopes where advanced relaxation of the bedrock formation has occurred will often exhibit gentler slopes than that of the unaffected bedrock zone. Formations can bend or form a kink bend near the lower limit of this zone, and could develop into a slide plane. In translational dip slope slides, the slide plane in many instances will develop along a thin, weak bed of mudstone, tuff bed or coal seam sandwiched between hard and competent beds. Borings can sometimes easily miss these thin beds. Therefore, the possible existence of slide planes along these weak beds typically consist of about 10cm, and must be cosidered even though the boring may not indicate they are actually present.

Furthermore, using the data from the borings, the follwing inforation must be assessed or determined.

1. Evaluation of slide plane
2. Ground water level measurements
3. Ground water logging
4. Ground water tracer tests
5. Standard penetration tests, Horizontal loading tests, In-situ tests such as in site permeability tests
6. Sampling for soil tests
7. Various geophysical logging.

2) Geophysical Surveys

Geophysical surveys (seismic survey, electric survey and radioactivity survey) are conducted to understand the approximate geophysical conditions of the slide itself and the surrounding area. P-wave refraction surveys are the most common seismic survey. Other methods, such as S-wave and P-wave shallow refraction, are seldom used. Electric survey is the specific resistance method and is applied to determime the distribution of aquifer(s) and to understand the geologic structure. These surveys include the development of the geotomography method. A natural radioactivity survey is used to determine the locations of small scale fracture zones and cracks.

(3) Evaluation of Slide Plane

Determining the slide plane for actively moving landslides utilize the fact that the rates of movement differ significantly along the slide plane. Depending on the requirements for surveying accuracy and magnitude of movement, the appropriate instrumentation shall be selected from the following representative instruments;

1. Pipe strain gauge
2. Inclinometer
3. Multi-layer movement meter

1) Pipe Strain Gauge

P.V.C. pipes with strain gauges are inserted into the boreholes, and the movement is estimated by the change in the strain as the P. V. C. pipe bends. The accuracy of the strain gauge increases as the intervals of the gauge narrows, however, it is acceptable to widen the space as much as 1m for investigations involving very thick slide materials and when it is difficult to handle the survey extension wires. Two of the lowest strain gauges must be anchored into the bedrock below the slide plane so that data from within the intact formation can be obtained. Furthermore, annular space

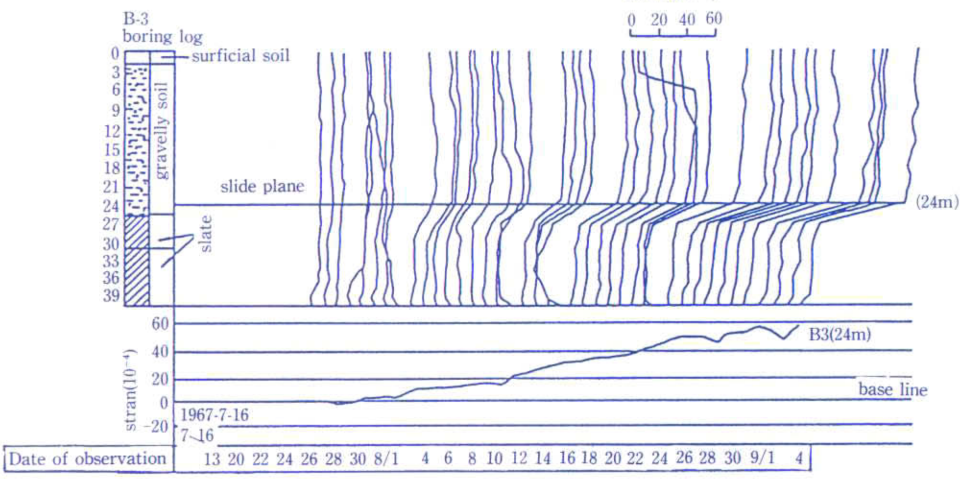


Fig. 25 Example of cumulative movement of pipe strain gaige

between the borehole and the pipe must be filled with concrete following the gauge installation. The instruments should last for one to two years **(Fig. 25)**.

2) Inclinometer

A grooved casing is inserted into the borehole extending into the bedrock foramtion, and have an adequate quality of grout placed into the borehole to assure a positive contact with the borehole. By lowering a probe equipped with a tilt sensor, deformation in the casing can be detected and movement of a landslide can be determined. An accurate measurement is possible where the deformation of a landslide is relatively small. As a landslide movement increases, the borehole and casing will bend making insertion of the probe difficult or will exceed the tilt detection limit of the instrument**(Fig. 26)**.

3) Multi-Layer Movement Meter

Several wires are anchored at different depths within a borehole with the attached wires extended to the ground surface. The magnitude of the displacement of each wire segment can be measured directly using a ruler. It is possible to install 20 to 30 wires per borehole. This method is not suitable for landslides with small displacement. This instrument is most effective where the slide movement is so large that some of the other instruments cannot be used. Applying the same principle, a vertical extensometer can be constructed by fixing a wire on the bedrock at the bottom of the

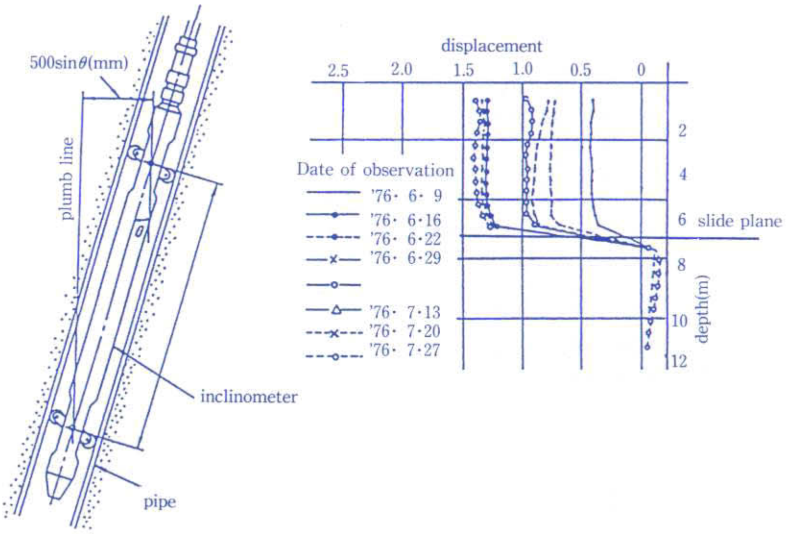


Fig. 26 Sensor of insersion type inclinometer (left) and interpretation of slide plane based on data

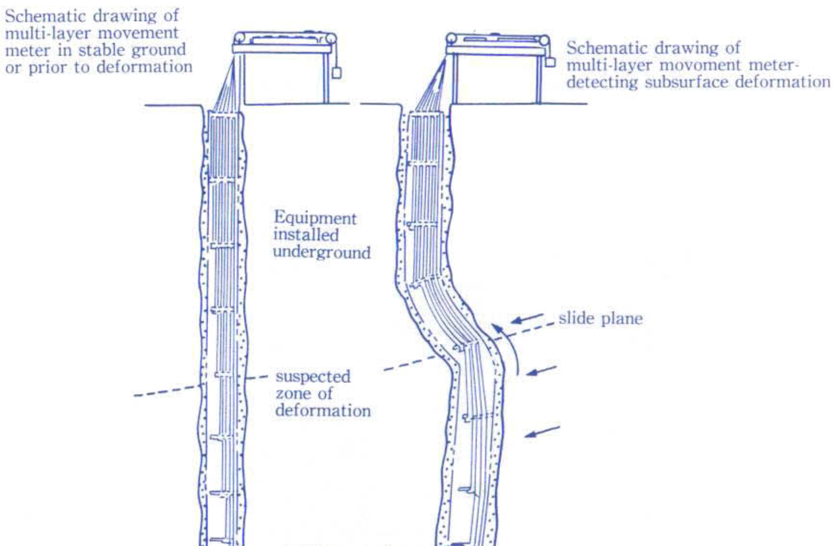


Fig. 27 Multi-layer movement meter

borehole **(Fig. 27)**.

4) Other Methods

Other methods to evaluate the slide plane include: slide plane detection probe; creep wells; and sounding penetration test.

(4) Ground Water Investigation

Investigation of ground water, which is a driving force of sliding, includes determining ground water level, pore water pressure, ground water logging, ground water tracing test, pumping test, water quality analysis, electricity survey, geothermal survey, and geophysical logging (electric logging and radioactive logging). Based on the results of the above measurements and tests, ground water control works can be planned and designed.

1) Ground Water Level Observation

As a genaral rule, ground water levels should be measured in all the boreholes. In some of the more important boreholes, continuous rainfall data will be kept by an automatic recorder to determine the correlation between the slide movement and rainfall and ground water level, and will collect data on the ground water distribution and movement regime.

2) Pore Water Pressure

Ground water levels in boreholes will often reflect seepage from highly fractured formations or indicate the water level of a predominant aquifer. Therefore, for stability analysis, it is best to measure pore water pressure along the slide plane. Sometimes it is difficult to accurately estimate the depth of the slide plane. In such cases it is desirable to install piezometers in the beds with low seepage or low shear strength. The standard piezometers that are used in landslide investigations must be durable, and open piezometer water level type.

3) Ground Water Logging

Locations of ground water flow and flow directions can be determined by measuring the increasing specific resistance of ground water in flow over time. The measurements will be continued often lowering specific resistance of ground water by injecting a salt solution into the borehele. There should be at least two borings for ground water logging at the head portion of the landslide where abundant ground water is expected. The measurement results should be recorded along with the boring logs, and the relationship between the location of ground water flow and bed, and magnitude and variation of specific resistance of ground water should be discussed. Furthermore, the results of the analysis should be recorded along with the cross sections in order to understand the overall ground water flow **(Fig. 28)**.

4) Ground Water Tracer Tests

Tracers such as a soluble dye, or inorganic chemicals(NaCl) are injected into a borehole. Water samples are then collected chronologically from springs, other boreholes, wells and ponds within or outside the landslied, and are analyzed for the tracer to estimate the ground water flow direction(s) and permeability. This data is used for basic information for the design of dewatering works.

5) Drawdown Test

In order to estimate the yield and to calculate the coefficient of permeability, water within a borehole is pumped to certain levels after raising the boring casing every 2 to 3m. A time-recovery curve can then be plotted using Jacob's and other formulas, and the coefficient of permeability can be determined.

6) Water Quality Tests

Water quality tests are an effective method to examine the distribution of the ground water regime and flow directions where the subject landslide is very large and the ground water system is expected to be complicated. Specific tests include determination of water temperature, Cl^-, SO_4^{2-}, HCO_3^-, Na^+, K^+, Ca^{++}, and Mg^{++} content, pH, alkalinity, electric conductivity, SiO_2, and others. The test results are classified according to the analytical data and composition.

7) Geothermal Investigation

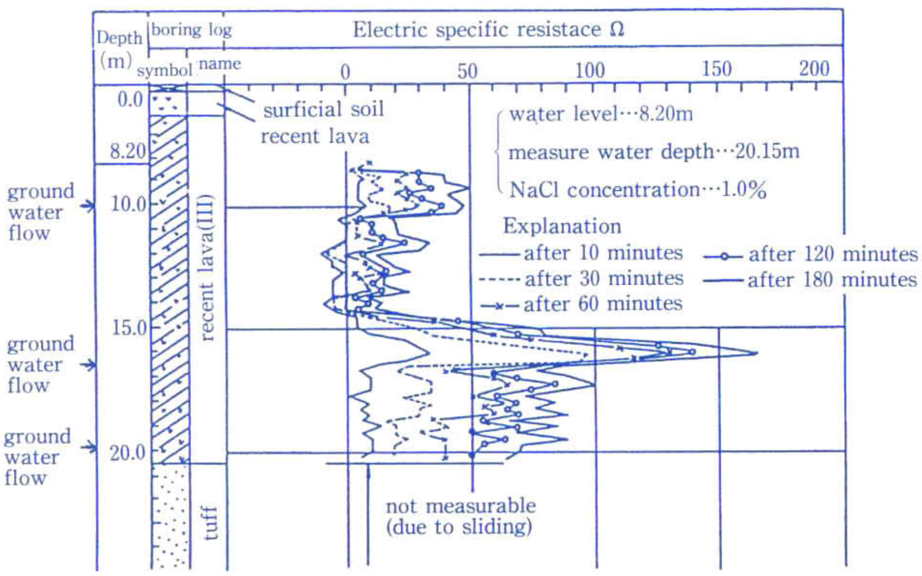
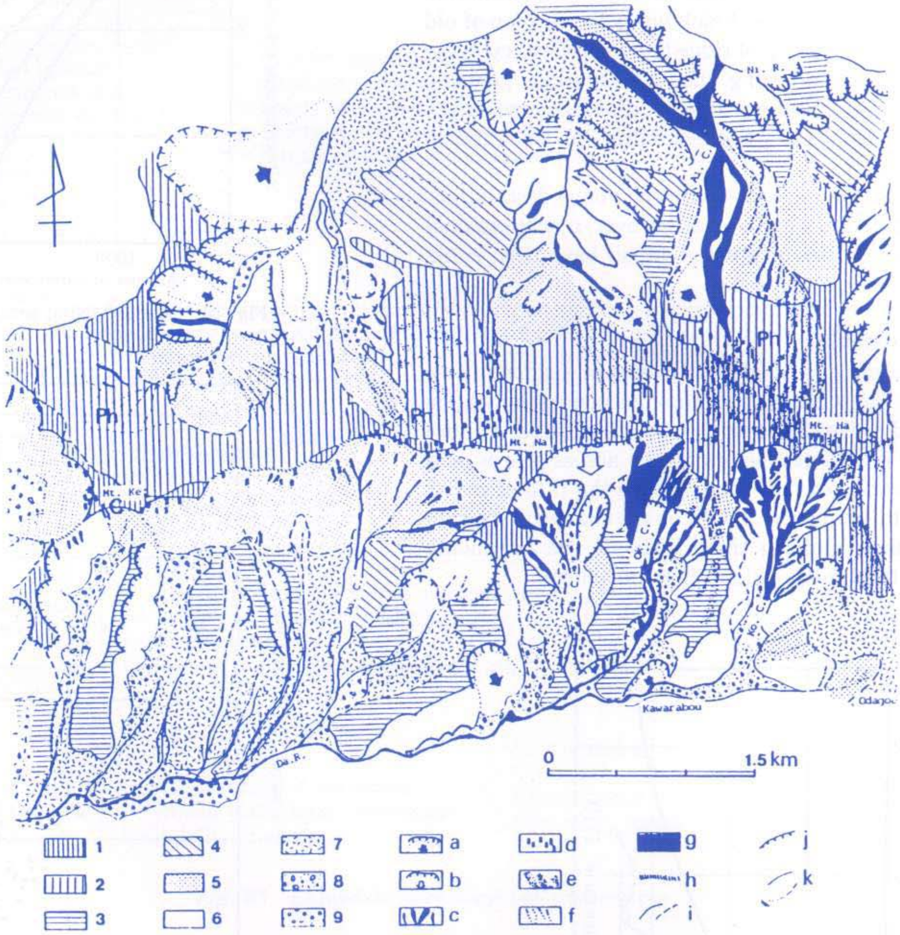


Fig. 28 An example of ground water logging

This procedure utilizes ground temperature measurements throughout the study area, including ground temperatures near the ground water veins. By measuring the temperature differences at non-ground water areas and near ground water veins, it is possible to isolate the ground water veins where the temperature difference between the two is large. By conducting the geothermal investigation in summer months or winter months where near surface ground temperature is influenced by air temperature, good results have been obtained for the isolation of relatively shallow ground water.

(5) Geotechnical Investigation (Rock Mechanic Tests)

In order to conduct slope stability analyses and to design appropriate control measures for landslides, physical properties such as strength of slide plane, location and depth of slide plane and stable ground areas must be determined. The following tests are generally performed: physical tests, Standard Penetration Tests, soil mechanic tests (unconfined compression, tri-axial compression, box shear, ring shear, and in-situ shear (along the slide plane)). In order to obtain the earth reaction coefficient for the design of the restraint works, there is a current tendency to conduct more horizontal loading tests and plate loading tests to determine the modules of deformation. Furthermore, the intensity and degree of alteration of the slide plane clays are evaluated by X-ray diffraction methods. The results have also been applied to analyze the origin of the slide plane.



Topographical Units : 1. Gentle slopes on main ridges, 2. Periglacidl planation slopes, 3. Crest slope of brauch ridges · Terminal slopes of ridges, 4. Mountain-foot planation slopes, 5. Upper valley-shaped slope, 6. Lower valley-shaped slope, 7. Gentle slope of mountain shirt, 8. Talus, 9. Fluvill surface

Micro-geomorphology : a. Landslide topography (Recent), b. Landslide topography (Ancient), c. Slope failure, d. Tor, e. Rock mass slope, f. Gully, g. Snow niche, h. Knife ridge, i. Knick line between landform units, j. Cliff, k. Topographical boundary, C. Peak, Cs. U-Shaped gentle col, Ph. Shallow hollow

Fig. 29 An sample of geomorphological map near Mt. Hayachine (by Miyagi)

4-4 Prediction of Landslide

(1) Landslide Distribution Map

Most of the new landslide are reactivated old failures in landslide terrain, and unless there are special causes, it is extremely rare that non-landslide terrain fails. Those topographic characteristics can be interpreted from aerial photographs and topographic maps, and be verified through field reconnaissance.

Furthermore, bedrock landslides and weathered bedrock landslides with past movement at the time of sliding is small, and sheared bedrock and topographic features related to the early stages of sliding that were subjected to creep deformation in the deeper portions often do not exhibit clear landslide topographic characteristics. Because of these reasons, double ridge topography associated with mountain deformation, parting ridges, breaks-in-slope, knick lines, distribution of old and scarps, bulging at the tip of ridge lines, discrepancy in the geologic distribution following the investigation, geologic structure, degree of shearing, degree of creep and other factors must be considered when evaluating landslide topography.

Landslide distribution maps with the above descriptions are generally limited to small areas, however, recent regional maps covering the entire country of Japan have been published **(Fig. 29)**.

(2) Landslide Prediction

Now it is possible to predict the timing of a slope failure by interpreting the rate of deflection measured by extensometers placed across tension cracks of a slope. Failure predictions rely on extensometers placed across scarps, and areas will be considered "off-limits" when the rate of movement exceeds 2 to 4mm/hour. Based on the change in the rate of movement, the following three methods are commonly used to predict the timing of landslide movement.

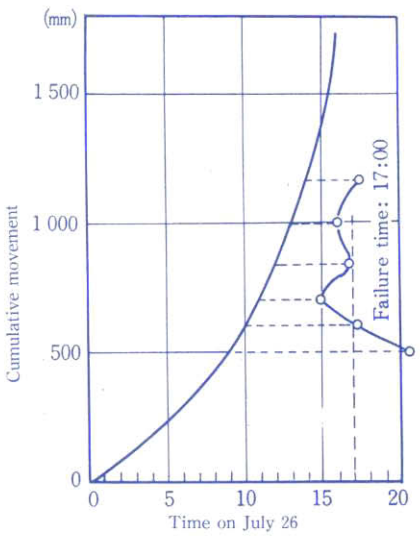


Fig. 30 Graphic solution of teriary creep curve

1) Graphic solution using the tertiary creep curve **(Fig. 30)**
2) Graphic solution of surplus time using semi-log paper **(Fig. 31)**
3) Method using a inverse number of rate of movement **(Fig. 32)**

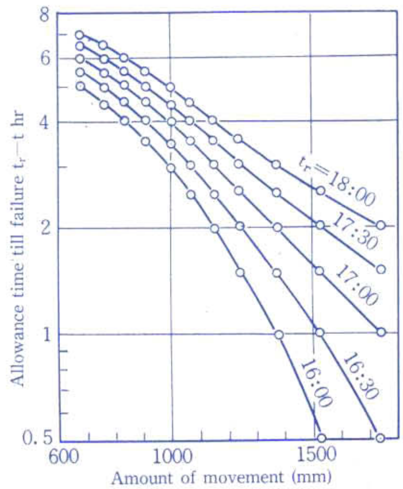


Fig. 31 Method using semi-logarithm

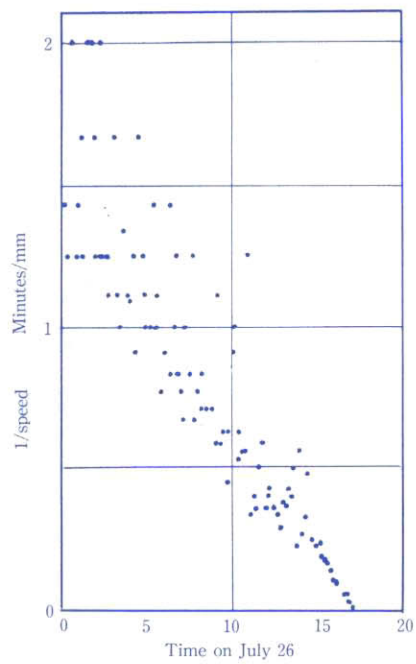


Fig. 32 Method using inverse number

4. Landslide Mitigation Works

Landslide mitigation works are conducted in order to stop or reduce the landslide movement so that the resulting damages can be minimized.

With a clear understanding of the causes and mechanics of the landslide, the landslide control works can be implemented according to the following flow chart **(Fig. 33)**.

The landslide mitigation works are broadly classified into two categories : 1) control works; and 2) restraint works. The control works involve modifications of the natural conditions of landslides such as topography, geology, ground water, and other conditions that indirectly control portions of the entire landslide movement. The restraint works rely directly on the construction of structural elements.

Specific measures included in the control works and restraint works are listed in **Fig. 34**.

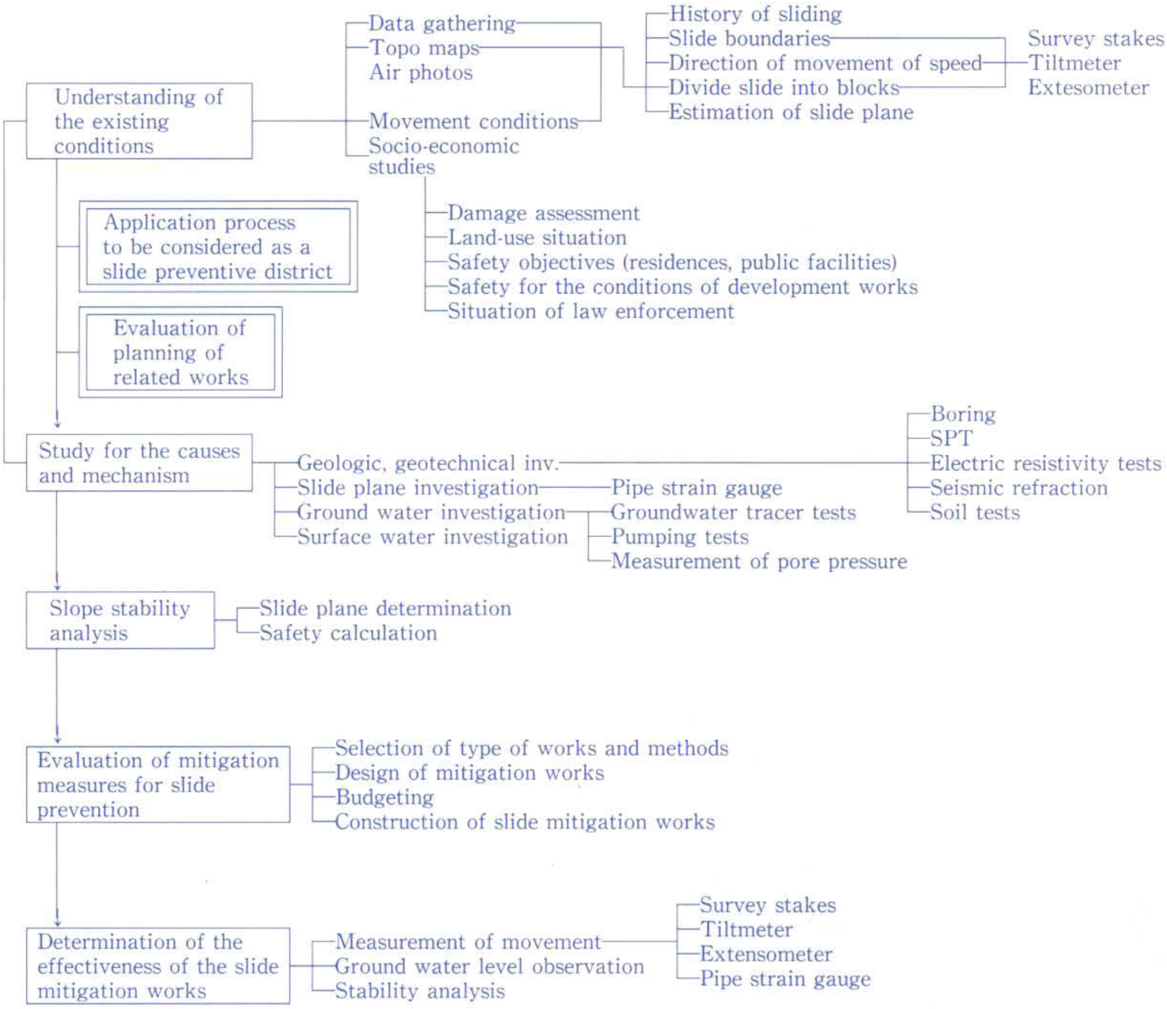


Fig. 33 Landslide investigation procedures

- Control Works
  - Surface Drainage Control Works
  - Subsurface Drainage Control Works
    - Shallow Subsurface Drainage Control Works
      (Interceptor Under Drains, Horizontal Gravity Drains, Interceptor Trench Drains)
    - Deep Subsurface Drainage Control Works
      (Horizontal Gravity Drains, Drainage Wells, Drainage Tunnels)
  - Soil Removal Works
  - Buttress Fill Works
  - River Structures
- Restraint Works
  - Pile Works
  - Large Diameter Cast-in-Place Pile Works
  - Anchor Works
  - Retaining Wall Works

Fig. 34 Landslide mitigation works

Landslide Control Works

a) Surface Drainage Control Works

The surface drainage control works are implemented to control the movement of landslides accompanied by infiltration of rain water and spring flows. The surface drainage control works include two major works : drainage collection works and drainage channel works. The drainage collection works are designed to collect surface flow by installing corrugated half pipes or lined U-ditches along the slopes, and then connected to the drainage channel. The drainage channel works are designed to remove the collected water out of the landslide zone as quickly as possible, and are constructed from the same materials as the drainage collection works. The surface drainage control works are often combined with the subsurface control works **(Fig. 35, 36, 37)**.

b) Subsurface Drainage Control Works

The purpose of the subsurface drainage control works is to remove the ground water within the landslide mass and to prevent the inflow of ground water into the landslide mass from outside sources. The subsurface drainage control works include shallow and deep subsurface drainage control works.

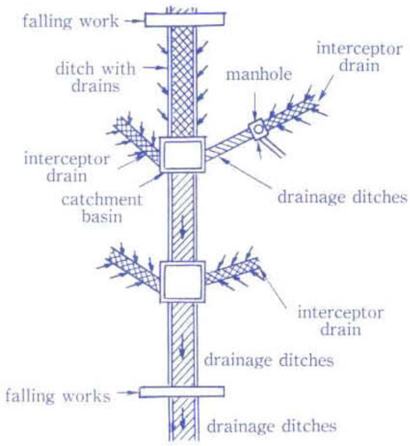


Fig. 35 Arrangement of ditches and interceptor drains

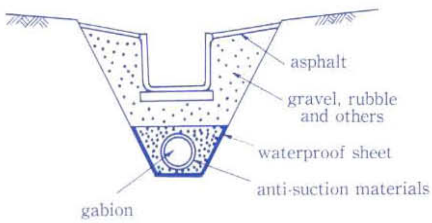


Fig. 36 An example of a drainage ditch with interceptor drain

Fig. 37 Surface drainage ditches

Fig. 38 Interceptor trench drains

Fig. 39 Drilling works for horizontal gravity drains

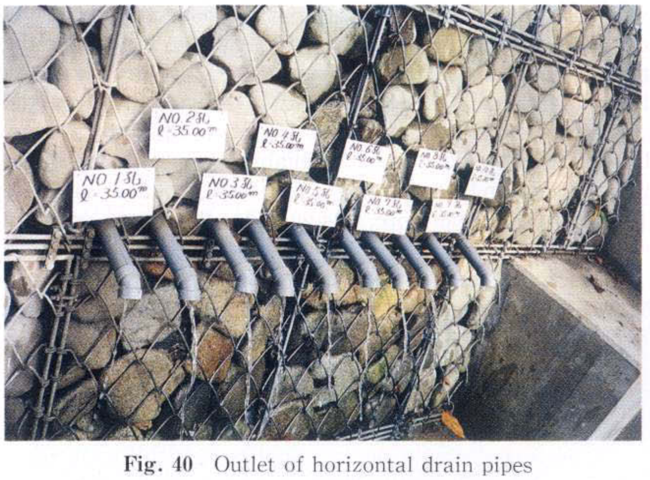


Fig. 40 Outlet of horizontal drain pipes

Fig. 41 A drainage well using steel segments

Intercept Under Drains and Interceptor Trench Drains

These systems are most useful to remove shallow ground water from up to 3m from the ground surface. The interceptor under drains contain impervious sheets at the bottom of the trench, and the gravels are wrapped with filter fabric and the drains are connected at groundsils and catch basins.

Structurally, the interceptor trench drain is a combination of the interceptor under drain and surface drainag control, and are commonly used **(Fig. 38)**.

Horizontal Gravity Drains

In order to remove the shallow groundwater within about 3m from ground surface, 30 to 50 m-long horizontal gravity drains are drilled. The pipes could be either perforated P. V. C. (polyvinyl chloride) or steel construction, and should be drilled at an angle of 10 to 15 degrees from the horizontal line **(Fig. 39, 40)**.

Fig. 42 A drainage well using reinforced concrete segments

Drainage Wells

Drainage wells of up to 25m deep and at least 3.5m in diameter are excaveted within areas of concetrated ground water. A series of radially-positioned horizontal gravity drains with multi-levels are drilled to collect the ground water into the drainage wells where the water can be removed through drainage tunnels. They are constructed of either steel or reinforced concrete segment, and concrets is used at the well bottoms and the upper portion of the well **(Fig. 41, 42, 43).**

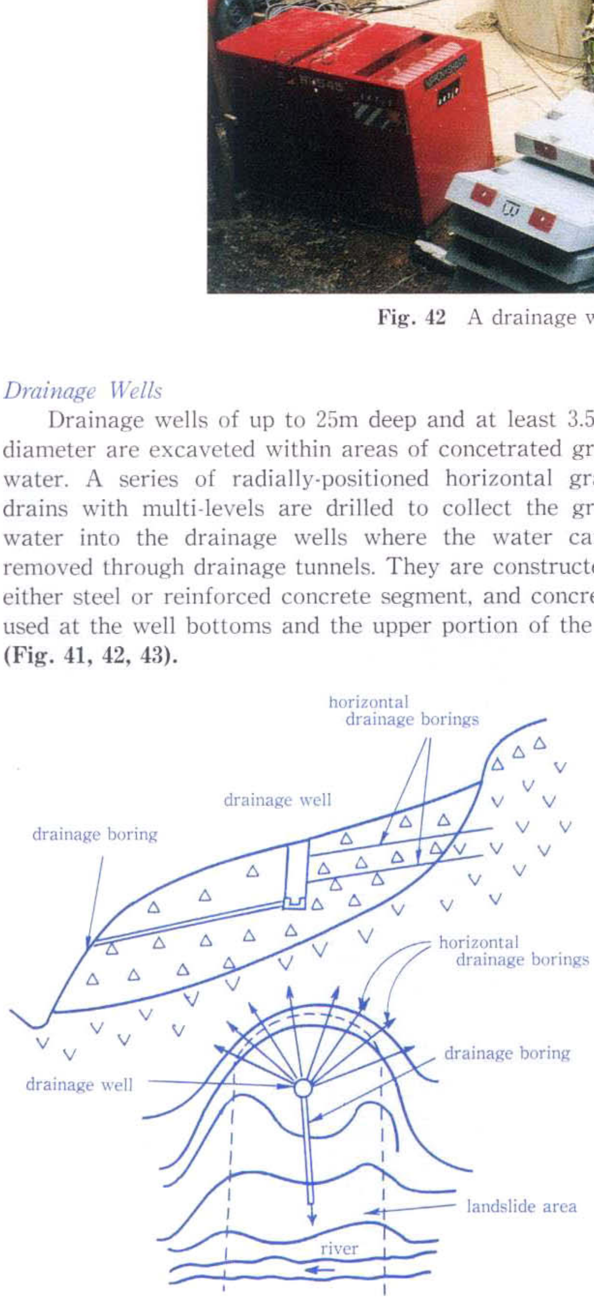


Fig. 43 Drainage well works

Drainage Tunnels

The primary purpose of the drainage tunnels (which are constructed below the slide plane) is to remove collected water out of the landslide mass by interconnecting the drainage wells. Instead of excavating the drainage wells from the ground surface, they can be constructed upward from the drainage tunnels. The series of gravity drains drilled from the tunnel tends to increase the effectiveness of the drain system. This is the most effective and reliable drainage work where numerous ground water veins exist within the landslide mass **(Fig. 44, 45)**. Furthermore, this work is effective to maintain existing facilities.

Generally, the diameter of the tunnel is between 1.8 and 2.5m, and the drainage channel is constructed along the invert.

c) Soil Removal Works

This is one of the methods where the most reliable results can be expected, and generally applies to small to medium sized landslides. Except for special cases, the soil removal is focused on the head portion of the slide **(Fig. 46)**.

d) Buttress Fill Works

The buttress fill is placed at the lower portions of the landslide in order to counterweight the landslide mass. It is most effective if the soils generated by the soil removal works are used **(Fig. 47)**.

e) River Structures

Degradation and channel bank erosion reduce earth stability and often tends to induce slide activity. In such cases, check dams, groundsils and bank protection can be constructed to prevent further erosion.

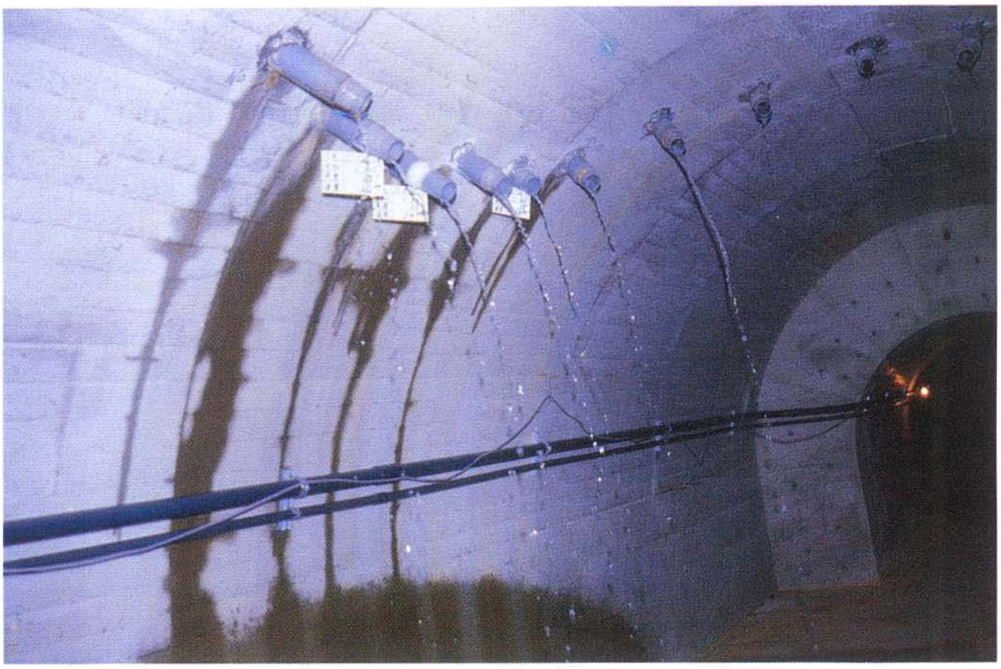


Fig. 44 Inside of a drainage tunnel

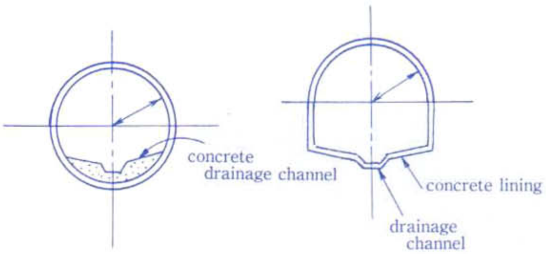


Fig. 45 Cross section of drainage tunnels

Fig. 47 Buttress fill works

Fig. 46 Earth removal works

Landslide Restraint Works

a) Pile Works

The pile works consist of driving piles as keys to tie together the moving landslide and the stable ground to restrain the movement. Generally, a thick walled steel pipe is used as the pile, and is then filled with concrete **(Fig. 48)**.

b) Large Diameter Cast-in-Place Pile Works

The large diameter cast-in-place works function similar to those of the pile works and are designed to tie the moving landslide and the stable ground together. However it involves much larger diameters. The construction is similar to the drainage well, and generally conists of pile of 1.5 to 6.5m in diameter and filed with reinforced concrete. Compared to the piles, the large diameter cast-in-place type are much more resistant to bending stresses **(Fig. 49)**.

c) Anchor Works

The anchor works utilize the tensile force of anchor bodies embedded through the slide mass and into stable earth, and are connected to thrust blocks located on the ground

Fig. 48 Pile works

Fig. 49 Under construction of the large diameter cast-in-place pile works

Fig. 50 Anchor works

Fig. 51 An example of crib walls

surface. The thrust blocks are anchored with a tendon that counteracts the driving forces of the landslide to restrain the slide movement. The advantage is that large restraint forces can be obtained from a relatively small cross sectional tendon **(Fig. 50)**.

d) Retaining Walls

Retaining walls are constructed to prevent smaller sized and secondary landslides that often occur along te toe portion of the larger landslides. Because of the large-scale earth-movement and numerous springs that are expected in land-slide terrain, crib walls are common instead of conventional reinforced concrete retaining walls **(Fig. 51)**.

5. Recent Landslides

Motochi Earth Flow

Location Rebun Island, Hokkaido, (45°18′N; 141°2′E).
Date of Slide October 11, 1994
Size of Slide Length: 550m; Width: 60 to 100 m; Depth: 5 to 10 m; Area: 4.0 ha; Volume: $2.8\times10^5 m^3$.
Damages One house destroyed, one house damaged, road was closed for long period of time.
Topographic and Geologic Conditions The Motochi District is located on the southwestern portion of the island, and exhibits old landslide topography (North and South Blocks). The site area is characterized by hills with flat ridges of about 250 m in relief and surrounded by monadnocks with steep peaks. Geologically, the hills consist of Upper Tertiary andesitic hyaloclastite, and form as a cap rocks overlying sandy tuff. The sandy tuff dips about 20 to 30 degrees to the west. The monadnocks are comprised of pyroxene andesite dikes and pyroxene porphyry.
Mechanism of Failure, Type of Movement and Rate of Movement During the month of September, 1994, there were a few days with daily rainfall exceeding 50 mm. By October 10, cumlative rainfall since early September reached 200 mm. It has beed concluded that the cumulative rainfall induced the earthflow, and it is speculated that the rainfall created an increase in the ground water level at the head area of South Block within the Motochi landslide area.

The Motochi earthflow originated within the South Landslide Block and consists of at least three units. The first and main flow originated along the road knocking down power poles and power lines (October 11, 2:55 AM). The failure started along the mid-portion of the South Landslide Block as a slump, then transformed into an earth flow that moved downward along a 10 to 20 degree slope. The earth flow then veered to the right at the steepest part at the slope, and terminated near the coast line. The scarp of the slump had receeded and eventually reached the head portion of the South Landslide Block. Both flanks of the slump block (upper portion of the earth flow) formed lateral scarps of 5 to 10 m high, while the foot (lower portions of the earth flow) contained transverse ridges of 3 to 6 m. Previously installed corrugated metal pipes and gabbion cages were pushed parallel to the side ridges (in the flow direction), while in the interior portion of the flow the pipes were pushed perpendicular to the flow direction and bent towards the direction of the flow. Small scale compression ridges were observed at the toe. It is also reported that some trees with their roots intact had been transported over 200 m.

The second earth flow originated below the knick point of the main earth flow. There are side ridges of about 1 m high along both sides of the flow within the interior of the side ridges of the main earth flow. Lastly, a small scale earth flow originated at the head section of the second earth flow, and terminated at the mid-portion of the slide. For the second flow, telephone poles were reportedly down at 8:15 AM, and the toe of the flow reached the residents at 3:30 PM. With the horizontal distance between the telephone poles and the residence being 75 m, the average movement rate is estimated to be about 10 m/hour. The main constituent within the earth flow consisted of white clayey soils with fragments of andesite breccia. The white clay is a smectite that is derived from the sandy tuff, and the andesite breccia is hyaloclastite and pyroxene porphyry.

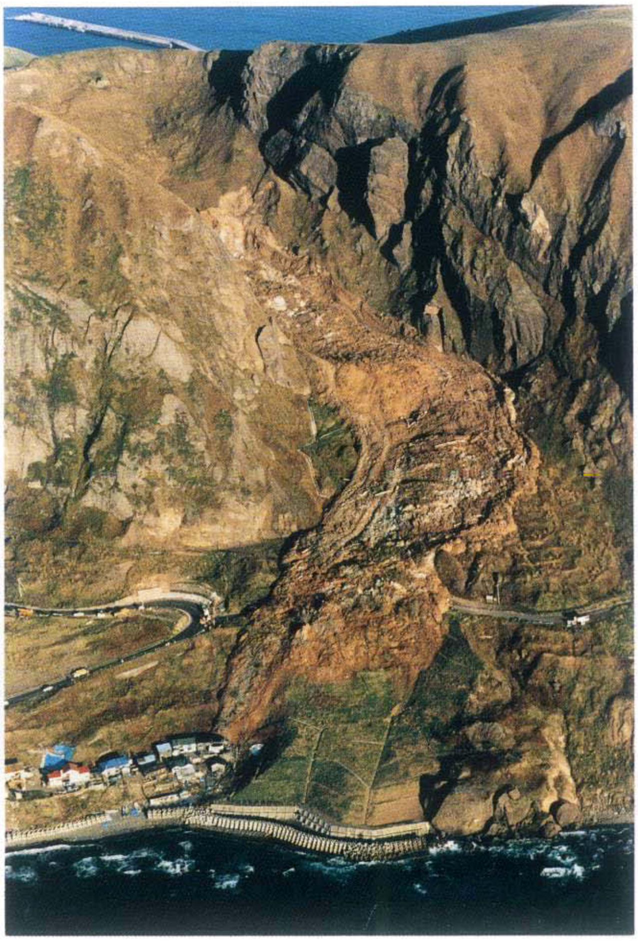


Photo. 1 Motochi Earth Flow, conditions immediately following the sliding (Photo courtesy of the Hokkaido Press).

Mitigation Measures Ground water drainage control works; Surface drainage control works; surface soil removal works

Raiden Coast Rock Block Slide

Location Raiden Kaigan, Katanakake Iwanai-Cho, Hokkaido, (42°55′N; 140°24′E).
Date of Slide July 12, 1993
Size of Slide Size of failed block; Height: 25 m; Width: 10 m; Depth: 11 m; Volume: $2.9\times10^3m^3$.
Damages Although no lining was damaged by the failure, National Highway Route 229 was closed for one month because of the hanging rock block.
Topographic and Geologic Conditions The Raiden coastal area consists of a continuation of steep eroded sea cliffs up to 200 m high, and is composed of Pliocene volcanic breccia beds. These beds consist of hyaloclastite, pyroclastic breccia and massive lava flows. Rocks near the failure consist mainly of breccia and subrounded pebbles of volcanic conglomerate within a sandstone matrix. This volcanic conglomerate dips gently to the north with vertical joints of several meters apart.
Mechanism of Faiure and Type of Movement A rock block glide occurred along the vertical joint and bedding plane slide. However, the 25×10^8 m rock block remained hanging on the steep slope.
Causes of Failure Off shore Southwest Hokkaido Earthquake of July 12, 1993 (Magnitude 7.8).
Mitigation Measures The mitigation measures include reinforcement of the lining below the hanging rock block with H-beams. On October 7, 1993, the hanginng rock block was blasted off. Later, additional rocks were removed and wire mesh was applied over the exposed rocks.

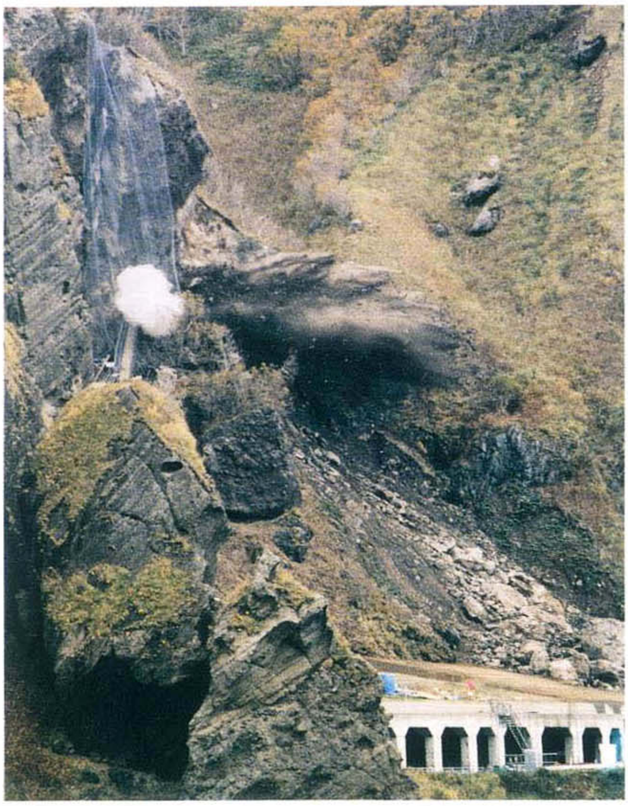


Photo. 2 Blasting of the hanging rock blocks (Photo courtesy of the Hokkaido Shinbun Press)

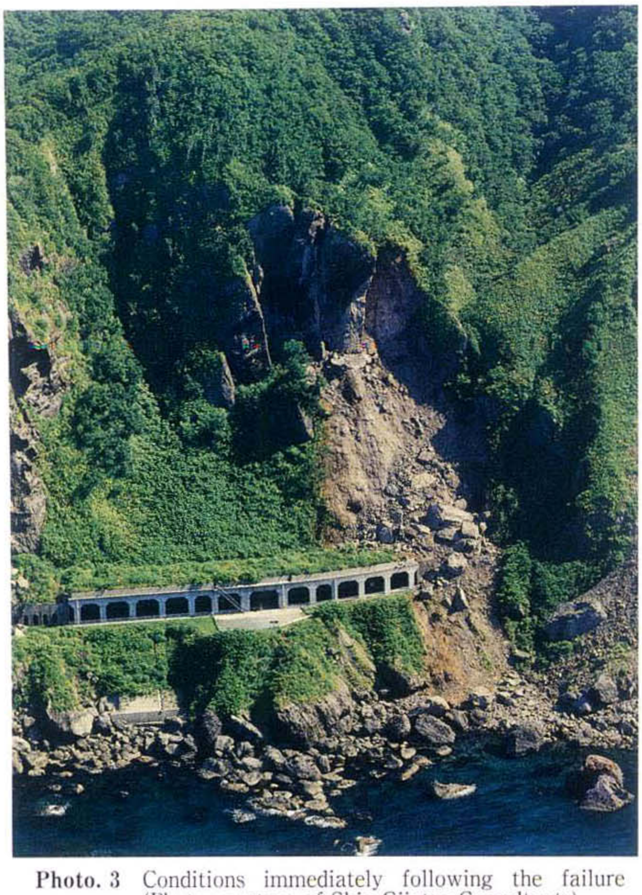


Photo. 3 Conditions immediately following the failure (Photo courtesy of Shin Gijutsu Consultants)

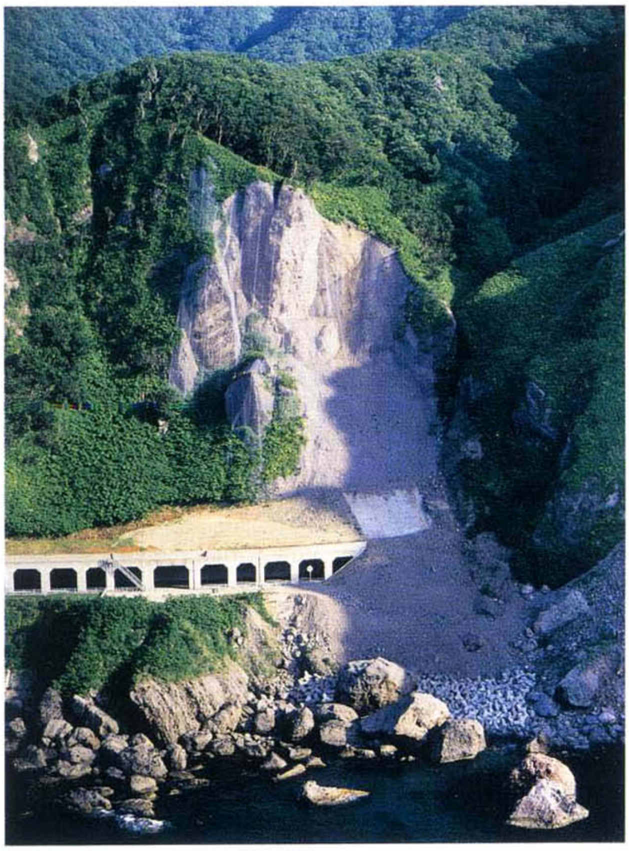


Photo. 4 Conditions following the completion of the mitigation works (Photo courtesy of Koken Enjineering)

Okushiri Harbor Landslide

Photo. 5 Conditions immediately following the slides (Photo courtesy of the Bhosai Chishitu Kogyo)

Location Okushiri Island, Hokkaido, (42°10′N; 139°31′E).
Date of Slide July 2, 1993
Size of Slide Height: 120 m: Width: 200m; Depth: 20 to 30 m; Volume: $1.5 \times 10^5 m^3$.
Damages Hotel Yhoyhoso and restaurant at Okushiri Harbor were destroyed, and included 29 deaths.
Topographic and Geologic Conditions The geology of the Okushiri Harbor area consists of Upper Tertiary, Pliocene sandstones and pyroclastic rocks and marine terrace deposits overlying the Pliocene sediments. The terrace deposits are about 120 m high and form a cliff slope angle of 45 degrees. The geology along the scarp area consists of loose sandstone dipping to the southwest, and is overlain by volcanic breccia, tuff and tuffaceous sandstone, and volcanic conglomerate.
Mechanism of Failure and Type of Movement Based on the aerial photographic analysis, it is possible to interpret two separate failures: 1) bedrock slide-avalanche, and 2) debris slide. The first failure was a vertical fall and occurred at the north side. Following immediately was the second failure, which had some inclination and occurred at the south side. The direction of the second failure was verified from the orientation of the slickensides at the main scarp. Finally, rock debris that was accumulated along the way failed as a secondary slide along the northern slope. Above the main scarp, the slide plane was formed along the contact between the sandstone and the overlying pyroclastic rocks.
Causes of the Slide Off shore Southwest Hokkaido Earthquake—Magnitude: 7.8; Epicenter: 42°47′N; 139°12′E; Depth of epicenter: 34 km. It was estimated that the Earthquake Intensity (Japanese) was a VI at Okushiri Island; however, the earthquake had two separate main shocks. The initial main shock occurred northwest of the island and lasted for 20 seconds, then the second main shock moved about 100 km southward and occurred west of the island and lasted for 35 seconds. Therefore, it is possible that the first and second failures may correspond to each of the main shocks.
Mitigation Measures Grading works; concrete retaining works; concrete crib retaining works; and grass planting works.

Photo. 6 Conditions after the mitigation works (Photo courtesy of Shin Gijutsu Consultants)

Dozangawa Landslide

Location Minamiyama, Ohkura-Mura, Mogami-Gun, Yamagata Prefecture, (38°38′N; 140°12′E).
Date of Slide Slide 1) June 28, 1966; Slide 2) April 1981; Slide 3) May 1994
Size of Slide Slide 1):?, Slide 2): Length: 400 m; Width: 200 m; Area: 10 ha; Slide 3): Slope Length: 50 m; Width: 130 m; Area: 0.6 ha.
Damages In recent years, Slide 1) resulted in 25 deaths.
Geology, Mechanism of Failure and Causes The site area is underlain by Upper Tertiary (Miocene to Pliocene Epoch) black to dark gray mudstone in turn overlain by alternating beds of gray sandy siltstone and sandstone. Further, the entire region is overlain by up to 80 m of Quaternary volcanic eruptive materials (the eruption was from the Hiziori Caldera about 10,000 years ago, and is located 4 km southwest of the site). The eruption resulted in plateaulike topography. The north-south running Dozan River dissects the plateau forming very steep cliffs along both sides of the river.

This region receives a large volume of precipitation (2700 mm annually) with snow fall in excess of 3 m. The thick accumulation of volcanic materials functions as a ground water recharge area, causing numerous landslides during the snowmelt seasons and early summer rainy spells.

Based on the site topographic characteristics, the Dozangawa Landslide is grouped into three areas: Sabuta Area, Minamiyama Area, and Yunotai Area. However, the date of the sliding of each area is unknown.

The Sabuta Area is a very large landslide and comprises 79.19 ha. The slide moves as a block with an average depth of 70 m.

The Minamiyama Area is a secondary landslide that occurred within the slide debris (GL=10 to 20 m) of the primary landslide (Sabuta). The movement as a whole is very slow, however, portions of the slide could move rather fast during the snowmelt seasons.

The Yunotai Area represents the typical plateau topography underlain by the volcanic eruptive materials. The plateaus are flat-topped with very steep scarps. Scarp failures are repeated during the snowmelt seasons. The slide planes are formed at GL=12 to 18 m. It is possible that the accelerated activity is due to erosion at the toe and by the Furumizu River.

Mitigation Measures

1) Sabuta Area: Because of the depth of the slide plane (up to 70 m), ground water removal works were considered with a combination of drainage tunnels and drainage wells.
2) Minamiyama Area: Due to the high groundwater table, a combination of drainage wells and drainage borings were planned, and pile works and anchor works have been implemented.
3) Yunotai Area: In order to protect the toe area from erosion, dams and bank protection works have been constructed. For future works, a combination of drainage wells and drainage borings and pile works have been planned.

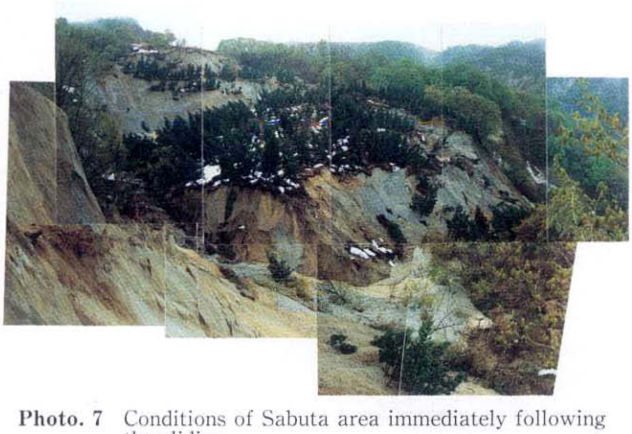
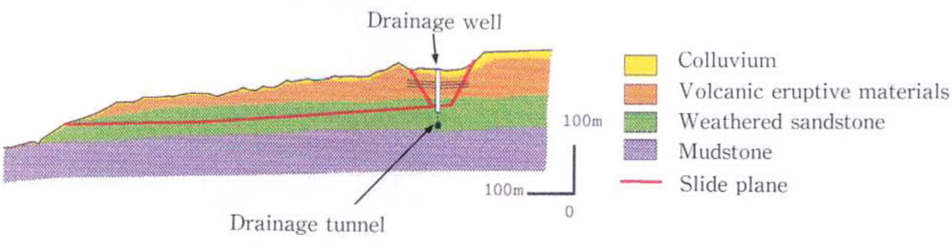


Photo. 7 Conditions of Sabuta area immediately following the sliding

Photo. 8 Panoramic view of the Dozangawa Landslide



Cross section of the Sabuta Landslide

Takisaka Landslide

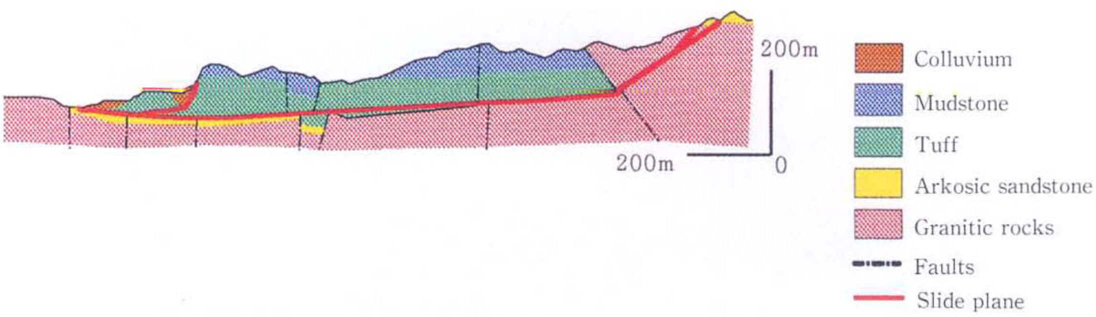
Location Shingo Toyosu, Nishi Aizu-Cho, Yama-Gun, Fukushima Prefecture, (37°38′N; 139°39′E).

Size of Slide Length: 2100 m; Width: 1300 m; Area: 150.25ha; Volume: $4.8 \times 10^7 m^3$.

Damages Since the landslide originally occurred in 1888, the area has been suffering numerous episodes of landslide disaster. Recently, landslides have been induced by the snowmelt and inflicted damages such as sediment discharge into Aga River and cracks along the roadways.

Geology, Mechanism of Failure and Type of Movement The Takisaka Landslide is divided into two blocks along Seki Creek: the northern block and the southern block. Geology of the site consists of pre-Tertiary granitic rocks (basement complex) and includes from bottom to top: lithified to non-lithified arkosic sandstone; green tuff; mudstone; and overlying terrace deposits consisting of sands and gravels and colluvium. The factors associated with the cause of sliding are: 1) the green tuff weathered into a plastic clay; 2) existence of a fault fracture zone to depth. Because of these factors, this landslide is one of the largest bedrock slides in Japan where the depth to the slide plane is in excess of 100 m. Because of the increased slide movement during the snowmelt, it has been concluded that ground water inflow by snowmelt and river bank erosion from the increased Aga River flow are driving forces of the movement.

Mitigation Measures The mitigation works started in 1958. By 1982, partial surface drainage control works and drainage well works had been completed. Since 1983, in order to reduce the flow of ground water from the faults, a series of connected large-diameter drainage wells were constructed. As a result, the average annual movement of the landslide was reduced from 1 m prior to 1985 to about 10 cm after 1985. However, portions of the slide resumed activity during the snowmelt season of 1994, and subsequently drainage tunnel works have been implemented.



Cross section of the Takisaka Landslide

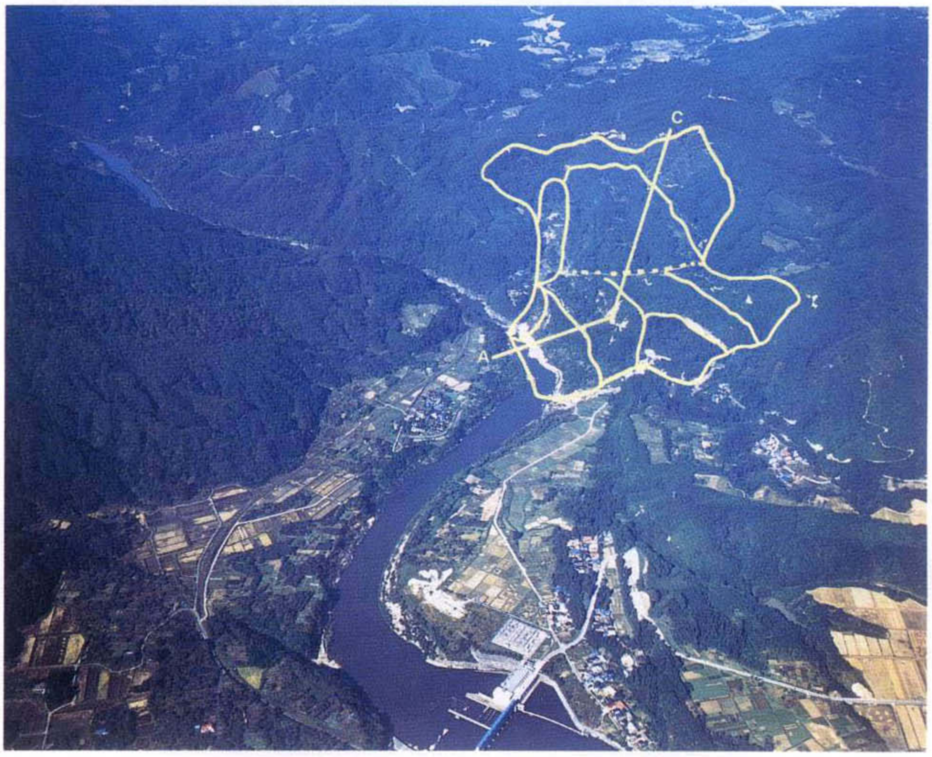
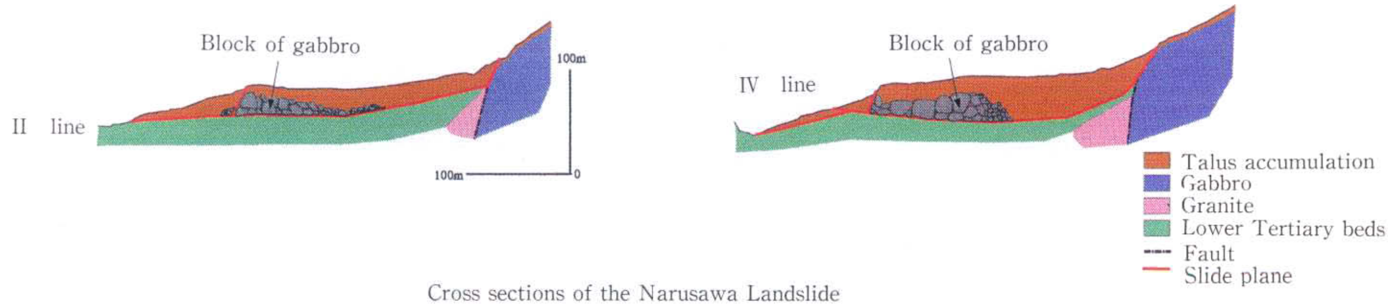


Photo. 9 Panoramic view of the landslide

Narusawa Landslide

Location Ohori, Narusawa, Kohma-Cho, Iwaki City, Fukushima Prefecture, (37°05′N: 140°48′E).
Size of Slide Length: 500 to 700 m; Width: 650 m: Area: 45 ha: Volume: $1.1 \times 10^7 m^3$.
Damages The failure occurred on August 12, 1988, and caused the destruction of one residential structure and closing of a city street.
Geology, Mechanism of Failure and Type of Movement The geology of the area consists of Lower Tertiary sandstone, mudstone, conglomerate and coal overlying the granitic rock basement complex. The areas behind the slide are separated by the Akai Fault and are underlain by gabbro. Early sliding of the Narusuwa Landslide could be quite old as fragments of lacustrine deposits (indicating the low energy environment) and large blocks of gabbro, thought to have toppled or failed rapidy from the higher elevations, are incorporated into the slide mass. The causative factors of sliding include: 1) the existence of the fault at the scarp area, which acted as the plane of separation; 2) the presence of tuffaceous siltstones, which acted as the lubricant; and 3) drag folds that were formed within the Lower Tertiary beds near the fault as a result of faulting. The inclination of the tuffaceous siltstone which became the slide plane is about 20 degrees. The contributing factors of slide movement include the increased water pressure from infiltration into the open cracks along the fault separation plane, and slope instability near the toe of the slide due to erosion.
Mitigation Measures The landslide control works include large scale soil removal at the head area, installation of a 3-dimensional dewatering system (tunnel conduit and drainage wells) to drain the depression at the head area, and construction of dams to prevent sediment discharge at the toe area. The restraint works included installation of piers and anchors along the cut slopes and the toe area.

Photo. 10 Panoramic view of the Narusawa Landslide



Cross sections of the Narusawa Landslide

Jinmyono Landslide

Location Tanokuchi, Tochio City, Niigata Prefecture, (37° 25′N; 139°39′E).
Date of Slide December 26, 1989.
Size of Slide Length: 300 m, Width: 120 m; Depth: 25 m; Area: $3.6\times10^5 m^2$; Volume: $4.0\times10^6 m^3$.
Damages 1.5 ha of cultivated field, 790 m of roadways, and 5 reservoirs.
Geology and Mechanism of Failure The site region is underlain by alternating beds of muddy sandstone and mudstone. Outcrops around the slide area expose mostly gray mudstone, and around the Mizushirizawa River, located near the northeastern corner of the slide, expose gray mudstone of relatively high lithification. Moderately weathered grayish brown mudstone interbedded with thin tuffs are observed in the head portion of the slide, and shows the development of joints that are oriented perpendicular to the bedding planes.

The primary causes of landsliding include: 1) the bedrock is composed of mudstone with high swelling potential; and 2) due to tectonic movement the bedrock is highly jointed and easily weathered. The contributing cause of landsliding is infiltration of prolonged rain water prior to the addition of snowfall and snowmelt.

The past history of slide activity is unknown, however, there has been some erosion during every snowmelt season. Although it has been very slow, the slide has showed signs of instability since 1985. The current landslide was initiated near the head portion of the slide at the ridge areas where scattered reservoirs are located. The sliding debris reached the Mizushirizawa River, temporary ponding the upstream areas. There are 7 reservoirs of various size within the slide that have lost water storage capacity due to the development of cracks. Also, the growing capacity for rice paddies has been completely lost.
Mitigation Measures Drainage channel works including drainage wells, drainage borings and interceptor under drains as have been constructed. Two years after the completion of the mitigation works, some leaks have been noticed in the head portion of the slide. However, it is assessed that the drainage control works are functioning effectively as a large discharge of ground water has taken place in the drainage borings. Furthermore, the results of the movement detection instrumentation indicate that stability has been achieved.

Photo. 11 Conditions immediately following the slide

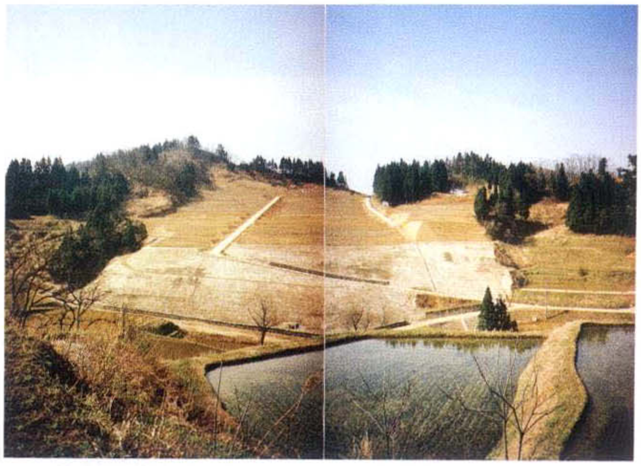
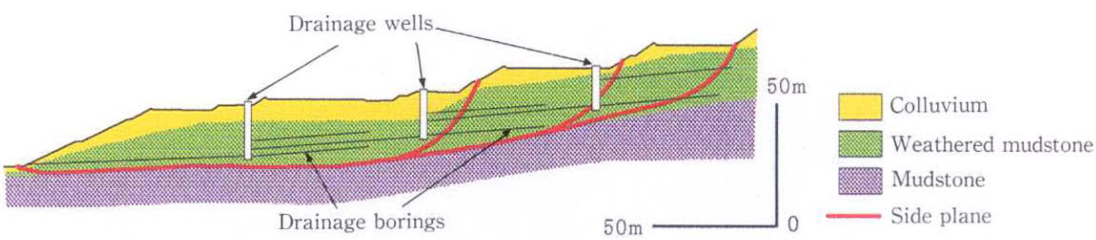


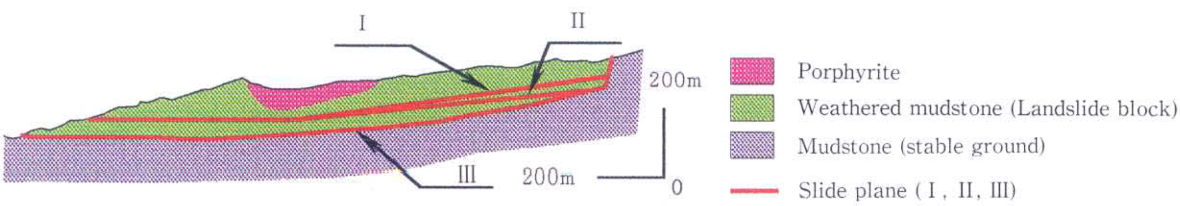
Photo. 12 Conditions following the completion of the mitigation works



Cross section of the Jinmyono Landslide

Dangosashi Landslide

Location Itakura-Machi, Nakakubiki-Gun, Niigata Prefecture, (37°10′N; 138°19′E).
Date of Slide Unknown.
Size of Slide Length: 1,800 m; Width: 1,600; Average Depth: 70 m; Area: 200 ha; Volume: $1.4\times10^8 m^3$.
Damages Active secondary sliding at the toe and flanks of the landslide caused damage to the cultivated fields and roadway almost every year.
Geology, Mechanism of Failure and Type of Movement This large scale landslide is located in the southern portion of a hilly region within a highly-concentrated landslide zone. The landslide zone is underlain by Upper Tertiary Miocene marine mudstone. The region is situated within a NNE to SSW-trending structure exhibiting a fold axis (anticline and syncline axis) and faults. Due to the deformation from folding and faulting, the strength of the bedrock is low. The mountain is comprised of an andesitic intrusive body situated upslope of the slide, and functions as the source area for ground water. It is apparent that these factors contributed to sliding. Based on boring data, three slide planes have been identified: the slide plane I is about 70 m deep; the slide plane II is about 100 m deep; and slide plane III is about 135 m deep. Measurements taken over the past several years has revealed no movement along all three slide plane. However, the slope stability analysis indicates that slide plane I has the lowest factor safety. Therefore, the potential for slope instability still exists. Furthermore, ground water moving near slide plane I is the contributing factor for secondary sliding at the toe area. Because of the above reasons, the mitigation measures have oriented towards controlling slide plane I.
Mitigation Measures Serious effort for mitigation works commenced in 1988. The primary concerns for this large scale landslide are: 1) the slide planes are very deep; and 2) ground water supplied from the andesite body upslope of the slide increases the possibility of movement of the slide. Therefore, subsurface drainage control works (including three drainage tunnels) and installation of drainage wells at the head portion of the slide is the main thrust of mitigation works. Drainage tunnel No. 1 was completed in 1994, and pile works have been executed to control the active secondary landslide.



Cross section of the Dangosashi Landslide

Photo. 13 Panoramic view of the Dangosashi Landslide

Tochiyama Landslide

Location Nishi-Tobiyama, Noh-Machi, Nishi Kubiki-Gun, Niigata Prefecture, (37°01′N; 138°04′E).
Size of Slide Length: 2000 m; Width: 500 to 1100 m; Average Depth: 50 m; Area: 150 ha; Volume: $7.5\times10^{7}m^{3}$.
Damages The landslide activity can be divided into two parts. The Early Period landslide occurred between 25,000 to 46,000 years ago, and the Late Period landslide speculated to be occurred prior to the year 1311. The Late Period landslide was at the same depth as the Early Period and the creep type sliding has been continued. The triangulation survey station located at the head portion of the slide dropped 3.3 m between 1907 and 1983. Although the rate of deformation is extremely slow, cracks were visible along the roadway and structures and minor repair works have been performed repeatedly.
Geology, Mechanism of Failure and Causes of Failure Geology consists mainly of Miocene mudstone beds with interbedded sandstone of less than 10 m thick. For the Upper Tertiary formation, it is relatively well lithified, and slump structures have developed within the formation. Bodies of porphyrite intruded along the bedding planes of the mudstone beds at the upper portion of the landslide zone. The sliding had developed joint and consists of jointed shale or fractured shale. The surficial material consists of debris flow deposits containing mostly of gravelly soil. The mudstone beds dip 10 to 30 degree approximately parallel to the topography forming a dip slope condition. Occasional presence of severely fractured beds which are interbedded within the mudstone forming a weak zone and weakening of the rock by the development of joint system from the tectonic movement is one of the primary causes of the Early Period landslides. The reason for the continuation of the current activity which was suspected to be originated during the Late Period movement is assumed the increased pore water pressure from snowmelt and snow load.
Mitigation Measures The mitigation plan includes the instllation of drainage wells over the slope. Currently, the plan has been implemented starting from the upper portion of the slide.

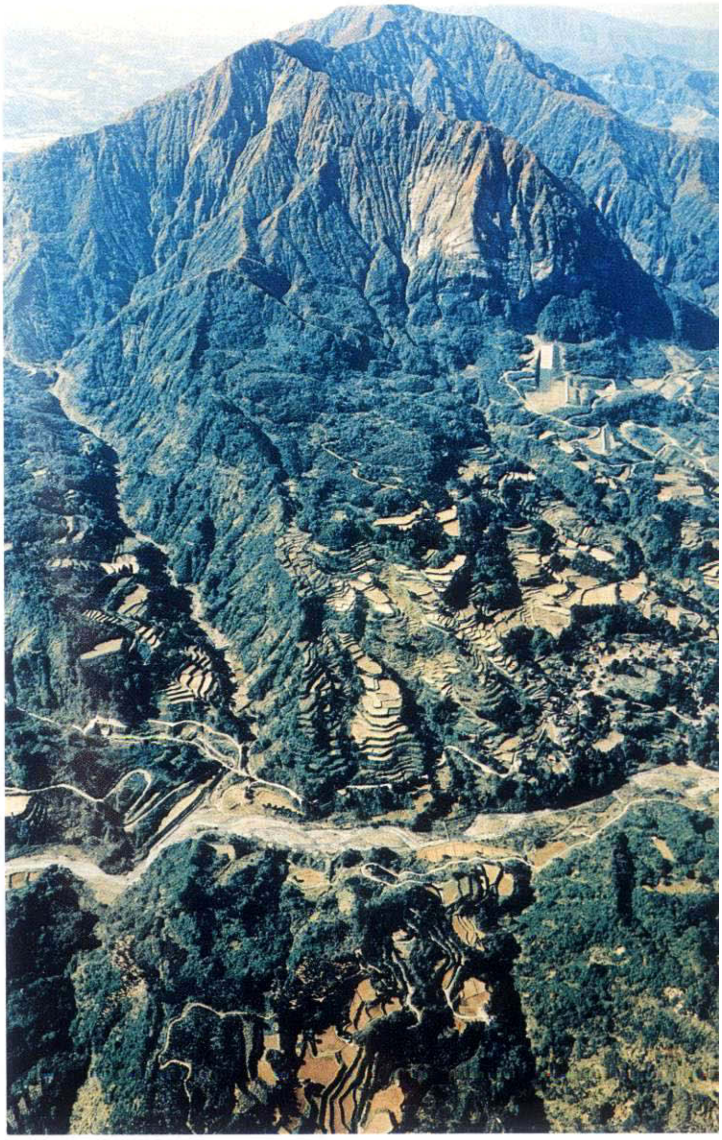
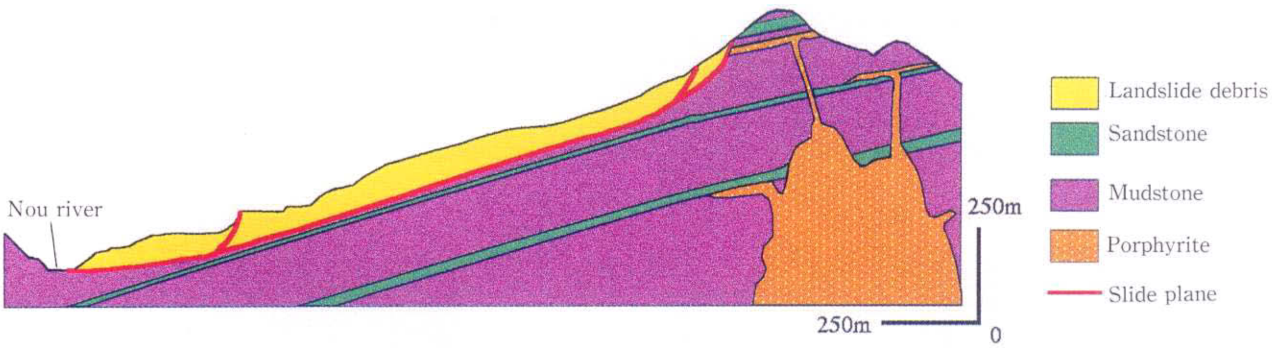


Photo. 14 Obligue areal view of the Tochiyama Landslide



Cross section of the Tochiyama Landslide

Ohdokoro Landslide

Location Kijiya, Ohdokoro, Itoigawa City, Niigata Prefectuzre, (36°52′N; 137°51′E).
Size of Slide Length: 1400 m; Width: 250 to 320 m; Average depth: 48 m; Area: 42 ha; Volume: $2.0 \times 10^7 m^3$.
Damages The slide initiated in April of 1974, and although it is relatively minor, the movement continues to date. Damages within the landslide include 800 m of Prefecture Highway, Irino Daira-Shirouma Road, 8 residential structures, 2 check dams, numrous cracks and deformation of transmission towers and telephone poles.
Geology, Mechanism and Causes of Failure The Ohdokoro River drainage is situated at Western Fossa Magna. From the upper drainage, the region is underlain by crystalline schist and Mesozoic and Paleozoic nonmetamorphosed sedimentary rocks. There are numerous intrusive serpentine bodies forming a serpentine melange zone. Two sets of recent pronounced lineaments traverse through the melange structure. One set is oriented in NW to SE, NNW to SEE direction, and the other set is oriented diagonally and intersects the first set in a NEE to SWW direction. Further, these basement complex materials are overlain by Quaternary Period volcanic clastic rocks originated in Kazahuki-Dake located at the southern end of the drainage. The landslide involves the clastic materials. As for the mechanism of sliding, it has been assessed that mud flow deposits had deposited in a depression of about 800 m in diameter, and the slide plane was formed within the basal portion of the depression which contains abundant clay derived from the serpentine. Surficial landslides have formed on the colluvium (which contains serpentine fragments) where the materials had been supplied from alluvial fan deposits and the slopes above. These smaller surface landslides are concentrated at the tension zone along the right side of Ohdokoro Landslide. Topographically, this area represents a conicle shape which tends to collect water. Furthermore, the higher region of the drainage basin is connected by mudflow deposits, thereby supplying a large volume of ground water to this area.
Mitigation Measures The focus of the mitigation measures was to control the surficial landslides, and to construct drainage wells near Kijiya Village.

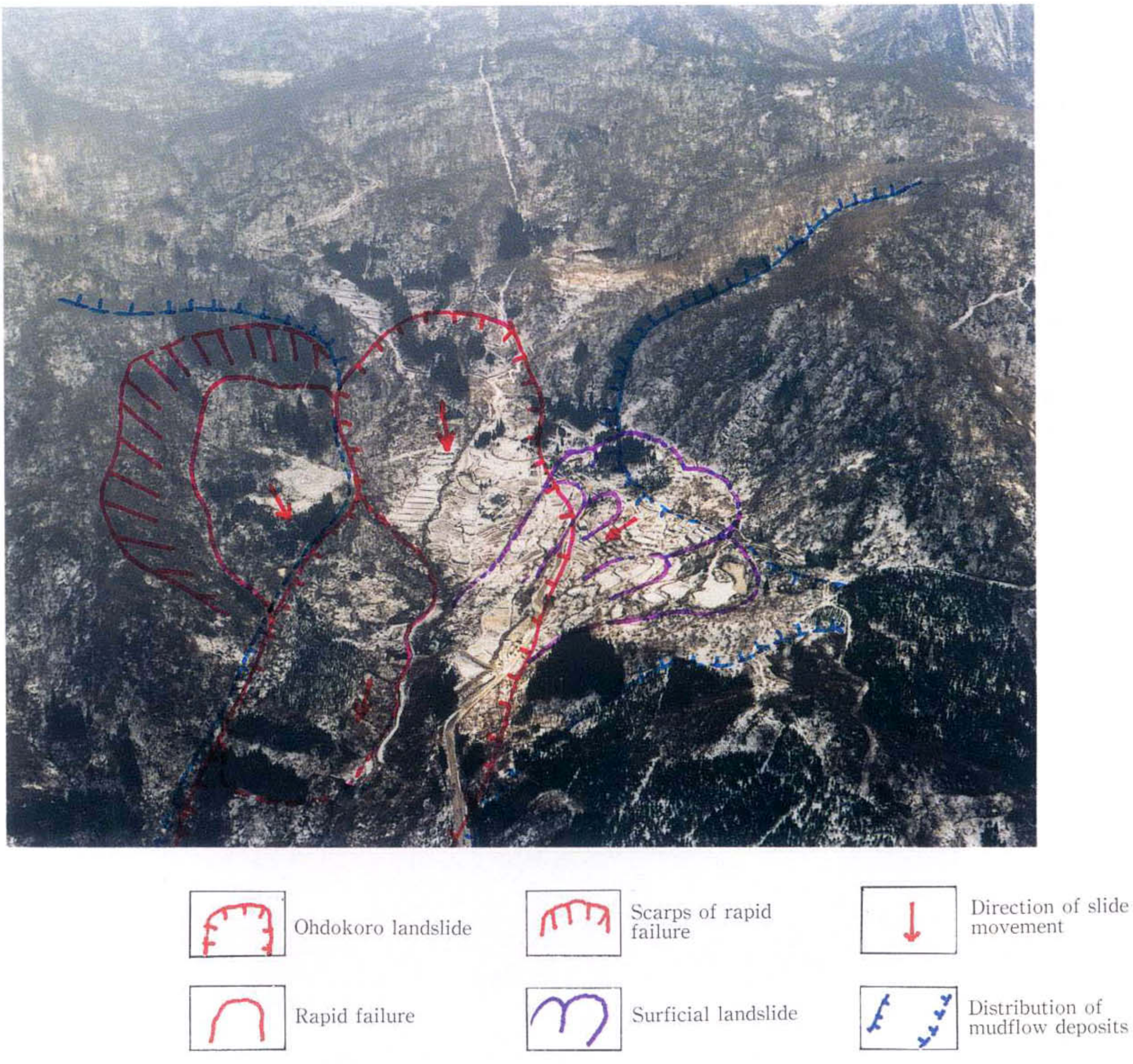
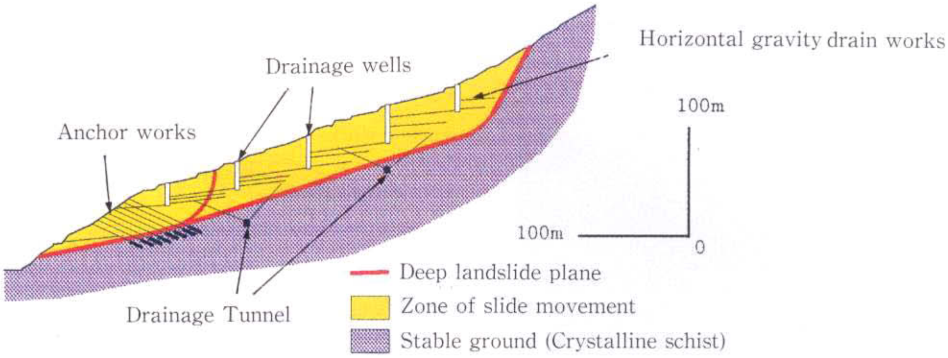


Photo. 15 Panoramic view of the landslide

Yuzurihara Landslide

Location Yuzurihara, Onishi-Cho, Tano-Gun, Gunma Prefecture,(36°08′N; 139°02′E).
Size of Slide Length: 600 m, Width: 1700 m; Depth: 40-50 m; Area: 100 ha; Volume: $1.96 \times 10^7 m^3$.
Damages There had been landslide activities prior to 1940 and residents have been evacuated from the affected areas. Recently, slide was reactivated October 16, 1991 due to rainfall and cracks and steps were formed along the National Highway Route 462 and local roads, residential and other structures.
Geology and Mechanism of Failure The basement rocks of the landslide is crystalline rocks belonging to the Sanbagawa Belt. Furthermore the Sanbagawa Belt is found throughout the drainage basin, and landslide is wide spread. Today, recognized landslides include large scale bedrock landslide (depth 40 to 50 m) having the slide plane within the crystalline schist. The crystalline schist exhibits a dip slope structure along the schistosity surfaces, joint surfaces and fault planes and develops cracks which promotes deep chemical weathering and over all weakening of the rocks creating the factors for the easy formation of the slide plane. Beside the rock quality, geologic structure and othe internal factors, it has been concluded that the sliding was induced by heavy rainfall (daily rainfall of 137 mm).
Mitigation Measures The prefectural government has been responsible for the mitigation works until 1994 which included the installation of 10 drainage wells for the ground water removal. However, the National Government took over the responsibility in 1995 and selected as nations 12th landslide mitigation works under the jurisdiction of the Ministry of Construction. For the immediate mitigation works, it has been decided to continue emphasis on the ground water removal works (drainage well and drainage tunnel works as the past dewatering system is not adequate.



Cross section of Kayakabu downstream block.

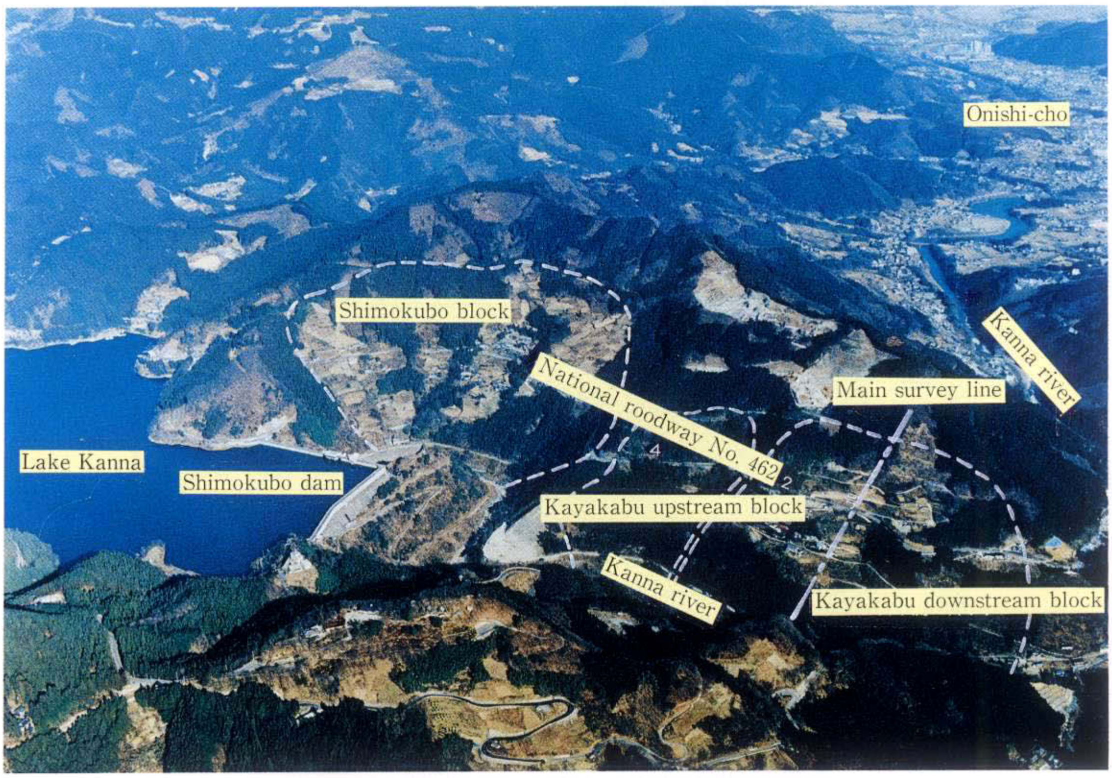
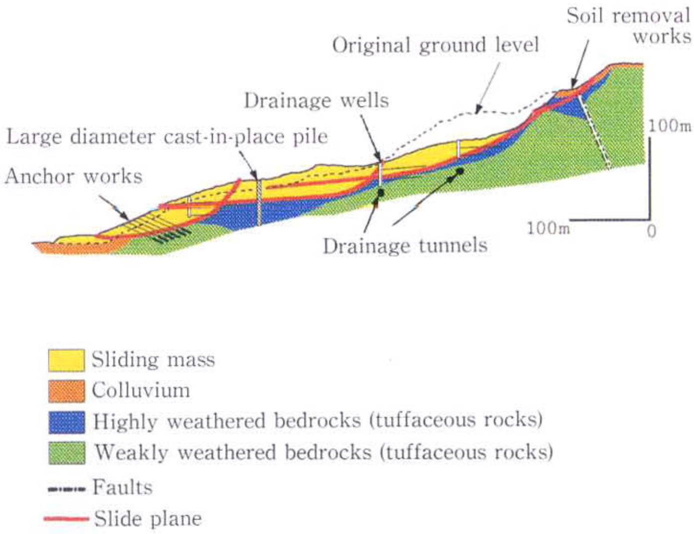


Photo. 16 Panoramic view of the Yuzurihara Landslide

Jizukiyama Landslide

Location Nagano-City, Nagano Prefecture, (36°40′N; 138°14′ E).
Size of Slide Length: 700 m; Width: 500 m; Depth: about 60 m; Area: 25 ha; Volume: $3.5 \times 10^6 m^3$.
Date of Slide July 26, 1985; around 5 P.M.
Damages 25 deaths, 4 serious injury, 50 residential structures destroyed, 5 half destroyed, 9 partially destroyed. Other damages include destruction of forest, roadways, water distribution system and other infra structures.
Geology, Mechanism of Failure and Type of Movement The site area is underlain by the Upper Tertiary, Late Miocene rhyolitic tuff and the investigations following the sliding revealed that the rock has unique characteristics of alteration and rupturing. As for the history of slide movement, a small movement was observed in 1981 and investigation has been conducted by Nagano Prefecture Enterprises Bureau which administer the tall road in the area. The slide movement has been accelerated by an early summer rainy spell of 1985 which produced unusually heavy rainfall. Finally, in the early evening of July 26 the large scale landslide occurred. The slide mass maintaining the unity failed rapidly. The debris flowed to the Yuya Subdivision located to southeastern direction and Shojuso, a home for aged and Bogakudai Subdivision located to south.
Mitigation Measures Immediately following the sliding, landslide mitigation measures and restoration works have been implemented. The mitigation measures included large diameter cast-in-place pile works, anchor works, pile works as the control measures; and construction of drainage wells and drainage tunnels as restraint measures. The works were started in 1986 and completed in 1987.

Photo. 17 Panoramic view of the Jizukiyama Landslide following the completion of the mitigation measures.

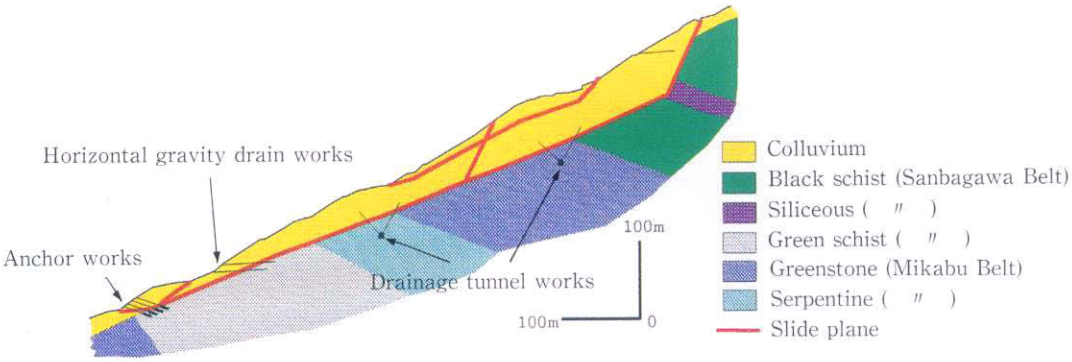


Cross Section of the Jizukiyama Landslide (mitigation measure construction drawing)

Photo. 18 Panoramic view of the Jizukiyama Landslide immediately following the sliding

Koshio Landslide

Location Kashio, Ohshika-Mura, Shimoina-Gun, Nagano Prefecture, (35°37′N; 138°05′E).
Size of Slide Length: 800 m; Width: 350 m; Area of Landslide Prevention Zone: 149.12 ha; Volume: over $6.0 \times 10^7 m^3$.
Damages There has been landslide movement in past history however, activity has increased in recent years. Accelerated movement occurred after torrential rains in June, 1992. Immediate damage included destruction of a small check dam, deformation of 8 small check dams, and tension cracks that developed along the slope. Further movement of the slide mass damaged residential structures and the National Highways, and buried the Kashio River which created the potential for a large scale debris flow on the central area of Ohshika Village (located downstream of the slide area).
Geology, Mechanism of Failure and Type of Movement The Median Tectonic Line traverses along the west side of the landslide. A fragmented synclinical axis extends along the regional structure on the upper slopes where the bedding dips into the slope. The site area is underlain by high pressure metamorphic rocks while the lower slopes of the hillside are underlain by muddy schists, basic schists, and siliceous schists of the Sanbagama Belt with intrusive bodies of serpentine. The upper slopes are underlain by geenstone, peridotite and serpentine of the Mikabu Belt. As whole, the schistose rocks are severely fractured and create favorable coditions for argilization. The currently active landslides consist of multiple slide blocks, and the slide planes of the overall blocks coincide with the deep seated slide plane of the Upper Block. The slide plane has a maximum depth of 70 m. The extension of this slide plane is connected to the slide plane of the Lower Block. The maximum depths to the slide planes of the Upper Block and the Lower Block are 30 m and 50 m, respectively.
Mitigation Measures By 1994, the slide movement has slowed down due to the effective mitigation measures. However, the Upper Block shows an annual movement of 300 mm, therefore mitigation works must be continued.



Cross Section

Photo. 19 Panoramic view of the Koshio Landslide

Sounzan Landslide

Location Hakone-machi, Kanagawa Prefecture, (35°14′N; 139°02′E).
Date of Slide July 26, 1953
Size of Slide (Landslide Hazard Zone) Length: 900 m; Width: 380 m; Area: 3.5 ha; Volume: $8.0\times10^5m^3$.
Damages Debris slide from a landslide turned into debris flow, flowing at speed of 7 m/sec. and buried a temple, roadway including 13 deaths and 15 injury.
Geology and Mechanism of Failure The Hakone Volcano was active during the Late to Middle Quaternary about 0.4 million years ago, and during that process a large scale caldera was formed. About 40,000 years ago a central crater hill (Kamiyama) was formed within the crater. The crater hill is composed of volcanic eruptive materials of andesite and tuff breccia and the Sounzan Landslide originated at the head position of the eroded canyon. In this region, the surficial materials up to 25 m from the ground surface had been altered to weak clay containing montmorillonite, kaorinite and alumite by high geothermal and volcanic gas. The cause of the slide has been attributed to the landslide area is covered with unstable talus deposits which had fell from the steep slopes above, and the active erosion along the canyon decreased the stability of the slopes above. The immediate triggering mechanism of the 1953 landslide was suspected to be the torrential rain which measured 432 mm in 10 days prior to the event.
Mitigation Measures Down stream areas of the Sounzan Landslide is one of the most representative and important hot spring resorts in Japan, therfore the disaster prevention has been very important. Consequently, erosion and sedimentation control and landslide mitigation works have been implemented since slide occurrence. In order to control the sediment discharge and to prevent erosion, 25 check dams, drainage channels and training levees were constructed along Suzawa between 1954 and 1984. Furthermore, numrous venting boreholes to relieve the volcanic gas have been drilled to control the hydrothermal alteration which is one of the causes of the sliding. In order to protect the resort area, six steel check dams and associated training levees have been constructed between 1986 and 1993 for the expected debris flow caused by the future expansion of landslide. As results of the mitigation measures, no noticeable landslide has occurred since the 1953 disaster.

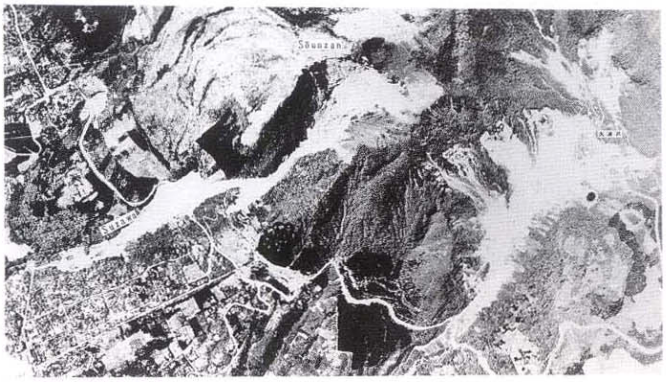


Photo. 20 Sounzan and Suzawa prior to the failure

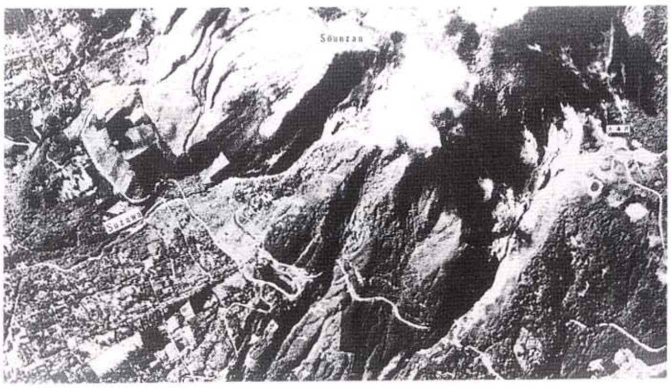
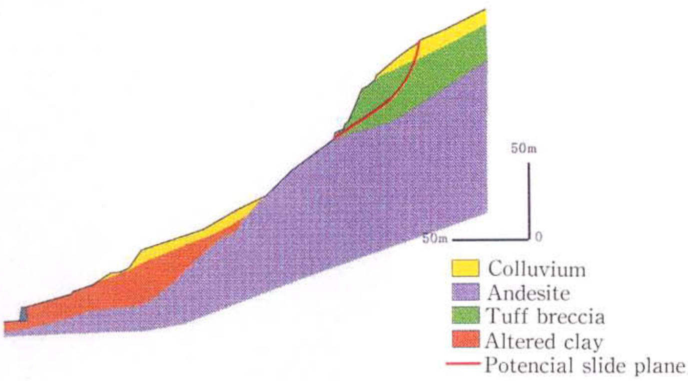


Photo. 21 Oblique areal view of the Sounzan Landslide showing steel form check dams and training levees.

Photo. 22 Sounzan and Suzawa immediately following the failure



Cross section of the Sounzan Landslide

Kuchisakamoto Landslide

Location Kuchisakamoto, Shizuoka City, Shizuoka Prefecture, (35°10′N; 138°15′E).
Size of Slide Length: 1100 m; Width: 1500 m; Depth: about 50 m; Area: 180 ha; Volume: $1.5 \times 10^7 m^3$.
Date of Slide This region is underlain by numerous very large and old landslides. In the Area-A, the torrential rain associated with the early summer rainy spell in June 1988 reactivated a slide measuring the length, about 700 m, the width about 300, and area, about 21 ha. A large failure occurred at the base of the slope burring check dams. The torrential rain associated with the early summer rainy spell of July, 1993 accelerated the movement of the block measuring the length, 120 m, the width, 250 m, and the area, 3 ha. Furthermore, on July 1993, large scale steps were formed along the Prefecture Highway, South Alps Park Road located at the upper portion of the slide area. In the Area-B, a concentrated heavy rain in February 1989 reactivated a slide measuring the length 700 m, the width, 150 m, and area 11.8 ha creating a numerous stepped cracks on the slope. The maximum movement of that day, recorded about 200 mm at the head area and 400 mm at the toe area.
Geology Mechanism of Failure, and Type Movement The Kuchisakamoto Landslide is located along the eastern face of the drainage divide between the Ohigawa drainage basin and Abegawa drainage basin at ellevation between 1300 to 1500 m. The Sasayama Tectonic Line with large scale faults runs adjacent to the eastern flank of the slope exhibiting a stepped topography which has been suspected to be structurally controlled. The geology includes marine sediments, predominantly of sandstone and shale of Mesozoic Era, Gretaceous Period to Cenozoic Era, Lower Tertiary. The shale beds are deeply weathered and severely fractured and the slide planes are formed along the shale beds which were altered to weak clay. The slide movement is very active with larger movement during the rain, therefore it is assumed that the increase in pore water pressure from rainfall is a contributing cause the movement.
Mitigation Measures Because of the large size and the movement of the groundwater contributes to the landslide activity, the main thrust of the mitigation measure has been the ground water removal works including horizontal gravity drainage works, drainage well works and drainage tunnel works. In order to remove the ground water from the landslide efficiently, the dewatering system has been designed in three-dimension, i.e. multiple layers of horizontal vertical drains are drilled from the drainage wells and drainage wells are connected through the drainage tunnels.

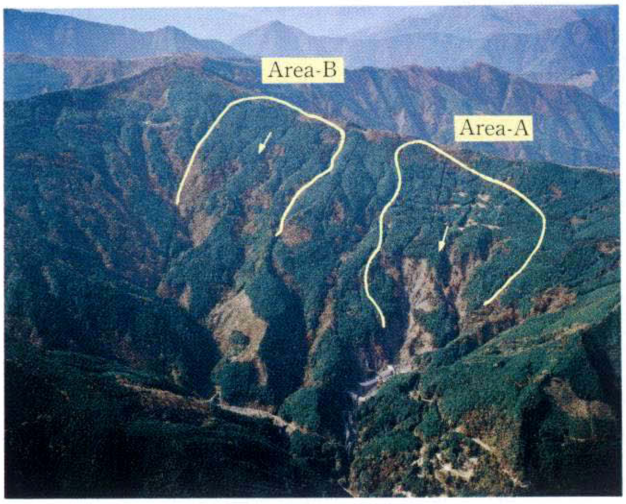
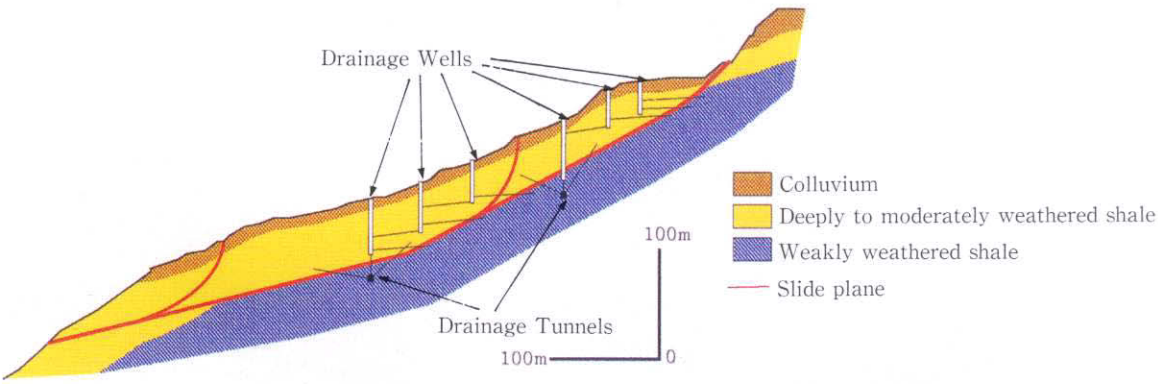


Photo. 23 Panoramic view of the Kuchisakamoto Landslide.

Photo. 24 Bird's-eye view of the Area-A



Cross section of the Kuchisakamoto Landslide-Area-A

Yui Landslide

Location Yui-Cho, Shizuoka Prefecture, (35°05′N; 138°33′E).
Date of Slide 1781
Size of Slide Length: 3 km; width: 1 km, Area: 264 ha.
Damages The Yui landslide has been divided into 26 distinct blocks. Since the initial sliding in 1781, the slide has been continuously active. The size of the slide is increasing due to the formation of a new slide immediately adjacent to the failed areas. The recent failures include the Terao Block in 1961, and the Nigorisawa Block in 1974. These slides inflicted damages to the Tokaido Line of the Japan Railroad, Natural Highway Route 1 and many residential structures.
Geology, Mechanism of Failure and Type of Movement The site area is located east of the Itoigawa-Shizuoka Tectonic Line, and southwest of the Fossa Magna and Iriyama Thrust Faults that extend in a north-south direction along the Yui River. The geology of the site area includes the Miocene Okouchi Formation, and the Pleistocene Hamaishidake Conglomerate.

The upper slopes are locally underlain by alternating beds of conglomerate mixed with agglomerate, sandstone and mudstone. The surface area of the mid-slope and up to the summit is covered with sandy to gravelly loam layers and loam layers, while in the lower half of the slope the mudstone beds are overlain by loam layers and deposits of sand and gravel.
Mitigation Measures The design criteria of the mitigation works is based on the Tokai Earthquake, and the torrential rains of July, 1974 (amount of rainfall: 546 mm/day and 78 mm/hr).

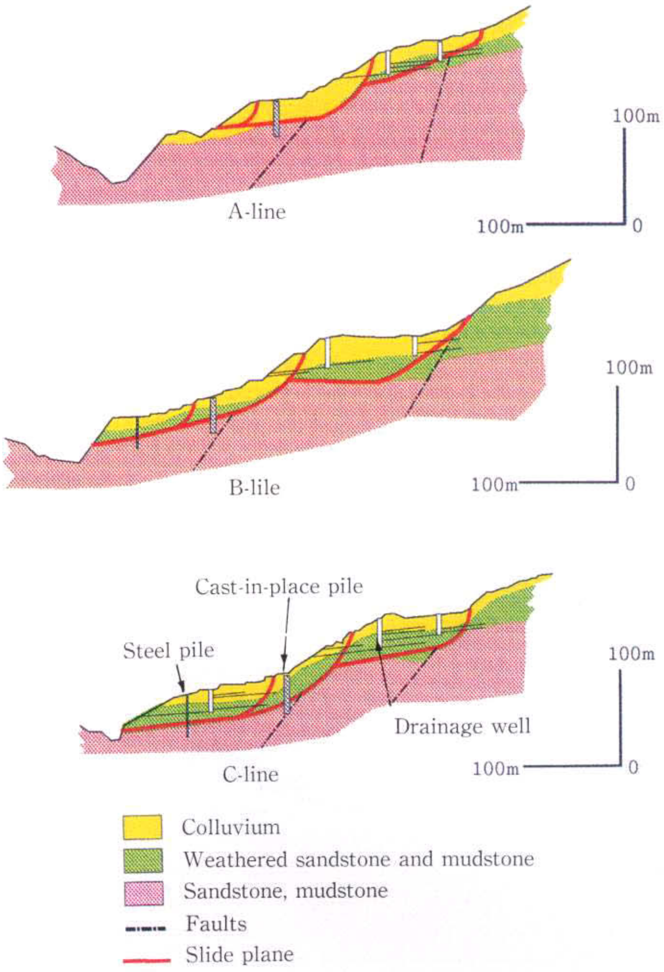
In the past, the mitigation measures were implented on an individual slide block basis. At the same time, earthquake resistance was incorporated as a special mitigation measure to maintain the integrity of the structures, and to prevent secondary landsliding along the toe areas.

The mitigation measures implemented to date include soil removal works, erosion prevention works, surface drainage control works, subsurface drainage works (culvert, horizontal gravity and vertical drains, drainage wells and interceptor under drains), steel pile works, anchor works and revegetation. Since 1987, large diameter cast-in-place pile works have been constructed.

Photo. 25 Obligue areal view of the Yui Landslide

Otoshi Landslide

Photo. 26 Panoramic view of the Otoshi Landslide



Cross sections of the landslide

Otoshi Landslide

Location Otoshi, Shogawa-Cho, Higashitonami-Gun, Toyama Prefecture, (36°34′N; 137°0′E).

Size of Slide Length: 430 m; Width: 250 m Depth: 30 to 40 m; Area: 11 ha; Volume: $20 \times 10^6 m^3$.

Damages Intermittent rains from June through August, 1993 (totaling 919 mm), triggered the landslide causing complete destruction of one, half destruction of two and partial destruction of seven residential structures; cracks on the roadways at nine locations; cracks on stone masonry and retaining walls at five locations; and a ground failure behind a residential structure.

Gelogy, Mechanism of Failure and Type of Movement The Otoshi Landslide is located along the northwestern slopes of Takao Mountain (elevation: 544.1 m). The mountain is underlain by alternating beds of sandstone and mudstone of Upper Tertiary (Miocene) age. The average strike of bedding in the region is NNW to SSE, and dipping at about 15 degrees NEE into the slope. The region is also underlain by an old, very large scale landslide. The Otoshi Landslide represents reactivation of old landslide deposits. The slide planens of the current landslide are located along the interface between the old slide deposits and the bedrock (sandstone and mudstone). The failure propagated headword as the lower slope failed.

Mitigation Measures As emergency measures, horizontal gravity drains were installed for dewatering the shallow ground water, and drainage wells were constructed for dewatering the deep ground water. Large diameter cast-in-place pilles were constructed due to the presence of a large thrust (about 3,500 tf/m). Steel piles were also installed to secure the passive pressure zone of the deep foundations.

Kamenose Landslide

Location Kamenose, Kashiwara City, Ohsaka-Fu, (34°35′N; 135°39′E).

Size of Slide Relief: 175 m; Average slope: 20 degrees; Area: 87.2 ha. The Kamenose Landslide consists of two areas, the Toge area and the Shimizudani area. Each slide directly influences the other.

Damages In recent years, large scale landslide movement occurred in 1903, 1931 and 1967, resulting in the clogging and flooding of the Yamato River, destruction of the National Rail tunnel, closing of the National Highway, and destruction of structures.

Among the slides that have occurred in the Toge area (which covers about 32 ha) between 1932 and 1982, damages included uplifting of the river bed of the Yamato River, and the National Rail tunnel which passes through the landslide area was crushed.

In 1967, a landslide measuring 15 ha, 800 m long and 200 to 300 m wide, occurred in the Shimizudani area. This failure in turn triggered sliding in the Toge area. Finally, the sliding developed into a large scale landslide covering the entire Kamenose region.

Geology, Mechanism of Failure and Type of Movement The geologic structure of this region includes two formations, the granitic basement rocks and volcanic deposits and lava (andesite). Surface deposits blanket both of the formations. Generally, the depth of the surface slide mass, on average, is 30 to 40 m with the deepest part of the slide exceeding 80 m. Most of the slide planes consist of thin tuff beds with intrusive tuff breccia above the tuff and andesite beds.

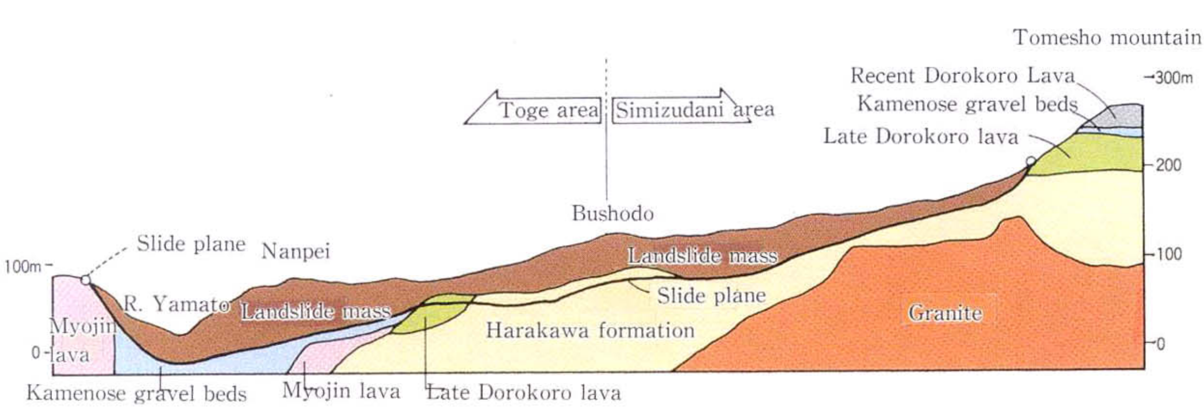
Mitigation Measures The early stages of mitigation works have been implemented by the Ohsaka-Fu governmet. The comprecensive mitigation works began in 1962 under the jurisdiction of the National Government. It should be noted that almost all of the mitigation measures developed in Japan have been utilized at this site.

The major landslide mitigation measures began under the jurisdiction of the National Government in 1962, and included soil removal works, drainage tunnel works, horizontal gravity and vertical drain works, drainage wells, surface drainage control works and steel pile works. The major mitigation measures were finally completed in 1986.

Current Conditions A total of 18.5 billion yen (U.S. $176 million, based on the January, 1996 exchange rate) has been spent up to 1986. The mitigation works in the Shimizudani area have been progressing well and is nearing completion. The stability of the upper slopes (the Toge area) has been significantly improved, and appeared to be in a stable state. However, some areas in the lower slopes indicated signs of movement and warranted that mitigation measures were needed. The mitigation (now in progress) includes installing gigantic cast-in-place pilles, which had never been tried in Japan. The cast-in-place piles have a maximum diameter of 6. 5 m and a total length of 1100 m.

Considering the social and economical importance of the Kamenose Landslide, the actual mitigation measures that were implemented include hardware type measures, and software type measures which consisted of an automatic monitoring system that was introduced to the local construcoion office in 1986. The system was designed to obtain real time data from instruments such as the tiltmeter, extensometer, rain gauge and other instruments that are strategically positioned on the landslide so that the behavior of the slide can be understood in a timely manner.

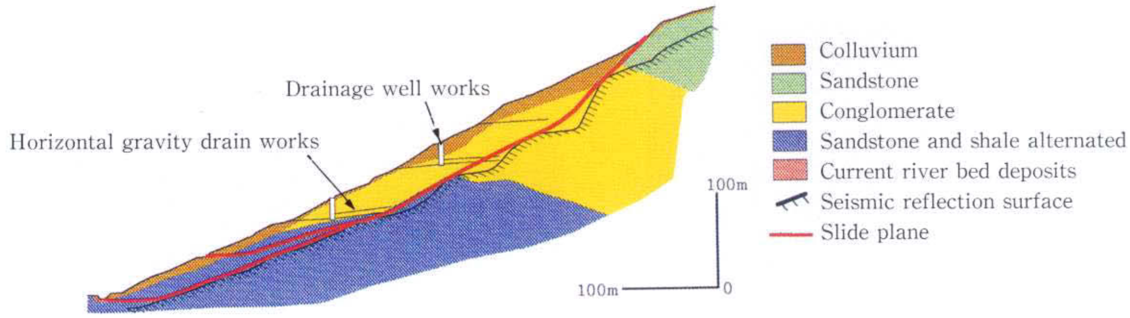
Photo. 27 Panoramic view of the Kamenose Landslide



Cross section of the Kamenose Landslide.

Nishitani Landslide

Location Nishitani, Nakaheji-machi Nishi Muro-Gun, Wakayama Prefecture, (33°46′N; 135°29′E).
Size of Slide Langth: 570 m; Maximum Width: 400 m; Depth: 50 m; Area: 14.6 ha.
Damages Records indicate this slide has undergone movement since 1889. Recent large scale landslide damages occurred on June 8, 1992 due to torrential rains associated with the early summer rainy spell. A 400 m section of the Prefecture Highway was closed down into a one way road, and a bridge abutment was destroyed at the toe of the landslide. Six residental strucures within the slide show some tilt, and numerous cracks found along the local roadway that made it difficult to drive upon.
Geology, Mechanism of Failure and Type of Movement The Nishitani region is situated on the southwestern portion of the Kii Mountains along steep slopes. Numerous landslides, including the subject landslide, are concentrated along the southern side of the Hongu Fault. The steep slopes are underlain by Late Tertiary alternating beds of sandstone and shale. The slide is undergoing creep type movement and is characterized by very slow movement. The Nishitani Landslide originated at the ridge slope, and based on the disturbed micro-topography along the ridge and activity status of the slide, has been broadly classified into three zones: 1) old landslide area near the summit; 2) current landslide area including secondary scarps; and 3) areas that have been severely eroded by the Nishitani River. The depths to the slide plane range to about 45 m from the top to the mid-portion, and to about 30 to 40 m from the mid-portion to the bottom. The slide plane is classified as a "keel-shape slide plane". Although the movement is slow, the slide is currently active. A strong good correlation exisis between the level of activity and rainfall rates. There appears to be abundant paths and avenues for ground water migration into the deep portions of the mountain. It has been suggested that the primary causes for slide movement include fault fractures and dip slope conditions, and erosion of the toe of the slide by the river and lowering of the river bed. The influence of increased deep ground water by rainfall is suggested to be the primary cause.
Mitigation Measures Because it was clear that the main cause of the 1992 disaster was increased ground water associated with rainfall, the mitigation works were oriented towards ground water removal, and have been continuously implemented to date.



Cross Section of the landslide

Photo. 28 Panoramic view of the Nishitani Landslide

Landslides associated with South Hyogo Earthquake

Location Nojima, Hokutan-Cho, Tsuna-Gun, Hyogo Prefecture, (34°34′N; 134°58′E).

Size of Slide and Damages Many landslides occurred adjacent to the active Nojima Fault which ruptured during the South Hyogo Earthquake on January 17, 1995.

One of the landslides that occurred was the Nojima Ohkawa Landslide measuring, length: 160 m; average width: 370 m; average thickness: 15 m; area: 6 ha; volume: 8.0 x 10^6 m^3. Residential structures, chicken coops and other structures were damaged by the slide, and the other damages included the complete destruction of one water tank.

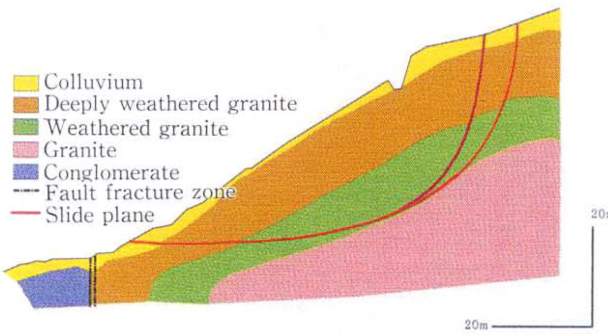
One of the other landslides to occur was the Todoroki Landslide measuring, length: 80 m; maximum width: 150 m; average width: 100 m; area: 5 ha; volume: $7.0 \times 10^5 m^3$. There are very few structures within the landslide area, and therefore no direct damage was inflicted.

Geology, Mechanism of Failure and Type of Movement Granitic rocks of the Mesozoic Era, Cretaceous Period are widely distributed on the northern portion of Awaji Island. The northwest side of the Nojima Fault (where the landslide occurred) is underlain by Upper Tertiary sandstones and siltstones that form a gentle dip slope that faces the ocean. The Nojima Fault is a relatively active fault that runs through the northwest portion of Awaji Island, and extends to the Akashi region of the main Honshu. The rupture along a segment of this fault caused the South Hyogo Earthquake, and exhibits a disinct right-lateral movement at the site area. The landslide deposits consist of the highly weathered granite while the Todoroki Landslide consists of partly weathered sandstone that was deposited over Tertiary sandstone. Further, the basement rocks near the fault have been severely fractured by past fault activity, forming numerous splinter faults. It is suspected that the fracture zone was caused by continuous seismic activity, and subsequently created avenues for liberal ground water movement. It is speculated that the landslide was caused by relaxing of the bedrock in the region due to activity along the active trace of the Nojima Fault, and a resulting change in the ground water flow directions and characteristics caused the influx of a large volumes of ground water along the bedding planes and/or joint surfaces.

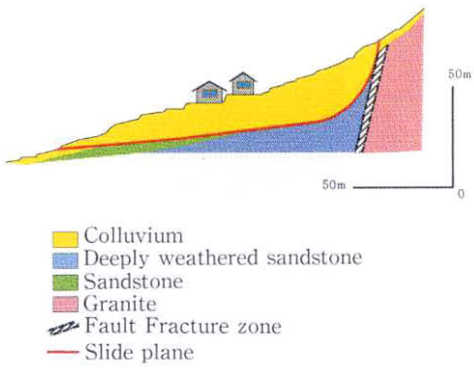
Mitigation Measures To reduce the pore water pressure around the slide plane, installation of horizontal gravity drains, drainage wells and drainage borings have been installed and more are planned. Furthermore, in oredr to augment the deficiency of the design safety factor, steel pile works for the Nojima Ohkawa Landslide and soil removal at the head area for the Todoroki landslide are also planned.

Photo. 29 Nojima Ohkawa Landslide

Photo. 30 Todoroki Landslide



Cross section of the Nojima Ohkawa Landslide:



Cross section of the Todoroki Landslide:

Kita-Kobe District Landslide

Location Miki City and Yokawa-Cho, Minou-Gun, Kobe City, Hyogo Prefecture.

Date of Slide Past records indicate a large scale landslide occurred is 1879. Since 1879, several large scale landslides have occurred.

Size of Slide There are 32 designated landslide districts with numerous landslide blocks of varying size. Larger blocks measure up to: Length: 800 m; Width: 520 m; and Depth: 30 m.

Damages The recent slide occurred in September, 1941, and damaged 8 residential structures.

Geology, Mechanism of Failure and Type of Movement The site area is located along the north side of Rokko-San at an elevation between 100 to 250 m. The site is underlain by the Upper Tertiary Kobe Group. Active tectonic movement in the region uplifted Rokko-San (called the Rokko-San Uplift), resulting in the majority of the beds to dip towards the west. The site area has been subjected to severe deformation including folding, faulting and flexuring and is one of the primary causes of sliding.

Geology of the site area consists of highly weathered mudstone, and fine grained tuff that shows a high level of argillization (to montmorillonite). The slide planes developed due to infiltration of rain water and ground water.

Mitigation Measures In order to remove the ground water (the primary cause of the sliding), drainage tunnels, a drainage well and drainage borings were installed as well as the control and restraint of the continually active slide. Surface drainage control works and steel pile works have also been implemented.

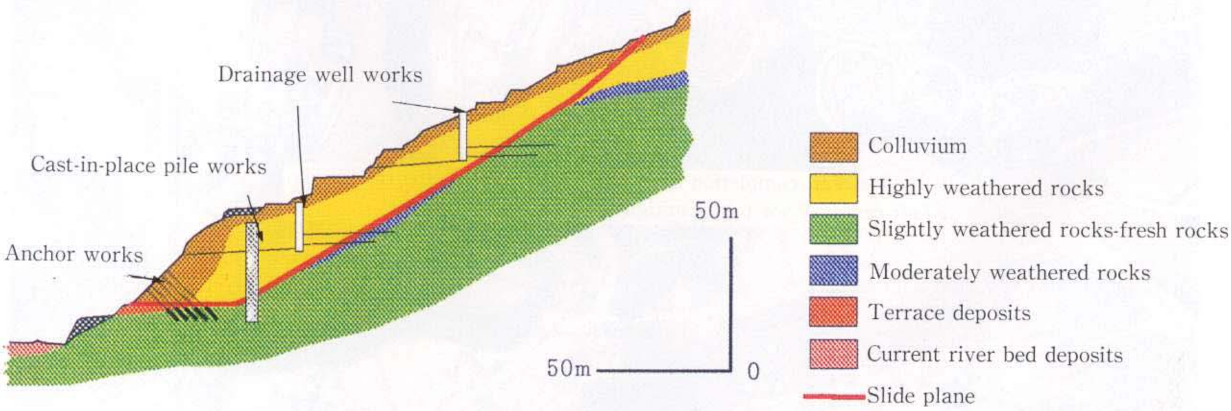
Photo. 31 Aerial photograph of the Kita-Kobe District Landslide

Zentoku Landslide

Location Zentoku, Nishiiyayama-mura, Miyoshi-Gun, Tokushima Prefecture, (33°52′N; 133°50′E).
Size of Slide Maximum Length: 900 m; Maximum Width: 2000 m; Landslide Prevention Area: 220 ha.
Damages It is speculated that the Ansei Earthquake of 1854 may have triggered the Zentoku Landslide. The Taniara Block (Z-6 Block) started to slide in the early 1870' s, and continued to move after 1945. Prefecture Highways suffered significant damages, as did residential structures, retaining walls and agricultural fields.
Geology, Mechanism of Failure and Type of Movement Geologically, the site area is comprised of the Sanbagawa crystalline schist and is sandwiches between the Median Tectonic Line and Mikabu Tectonic Line. The Sanbagawa Zone near Zentoku consists of argillaceous schist and sandy schist. Due to large scale tectonic movement, the rocks are severely fractured and highly weathered. Furthermore, the site area is in a dip slope condition facing the Iya River, which is the primary cause of sliding. Abundant ground water flows are supplied by heavy annual rainfall rates (2000 to 2500 mm annually). The landslide triggering mechanism was attributed to rapidly increased ground water levels from torrential downpour associated with typhoons.
Mitigation Measures Based on the topography, the Zentoku Landslide is divided into 7 large blocks. From 1992 to 1994, 20 cast-in-place piles, 280 anchors, and 5 drainage wells have been constructed on Block Z-1 (the largest amount of mitigation measures among all 7 blocks). Although less in scape, the adjacent Black Z-2 also received anchor works and drainage well works in 1988 and 1989. For Block Z-6, located near the upper reaches of the river, control measures that have been implemented include surface drainage control works, drainage wells and horizontal gravity drain works. Today, comprehensive future mitigation plan is an important subject.

Photo. 32 Panoramic view of the Zuntoku Landslide

Photo. 33 Conditions following the completion of the mitigation measures for Block Z-1



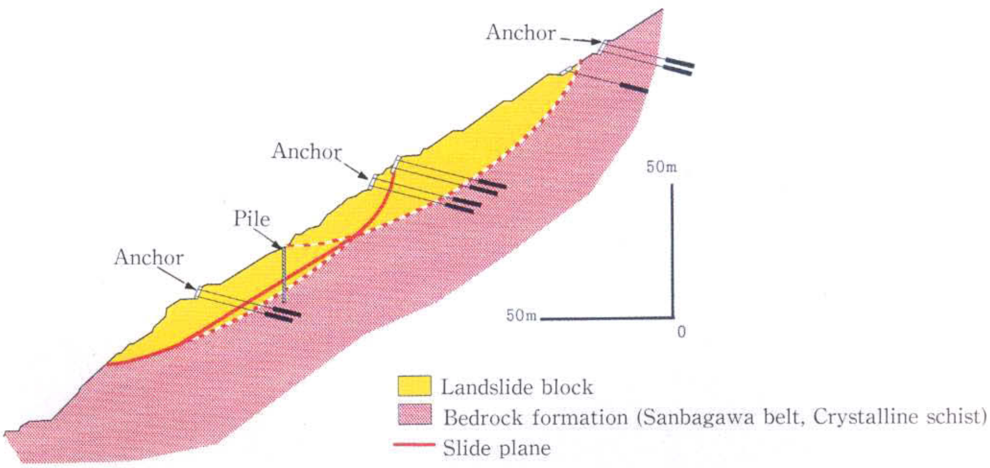
Cross section of Block Z-1

Shinano Landslide

Location Shinano, Misato-Son, Oe-Gun, Tokushima Prefecture, (34°01′N; 134°15′E).
Size of Slide Slope Length: about 300 m; Width: 200 m; Depth: 20-30 m.
Damages The slide consists of three blocks. The initial failure occurred within the Block-B in 1949, and intermittently further cracking and failures developed. In particular, Block-A reactivated in 1971, follwed by movement of Block-C in 1974. Block-C is located along the upper slopes of the slide, and has resulted in damages to 5 residential structures (one was completely destroyed, and two have been moved). In 1989, sediment runoff from failures near the foot portion of the slide caused damages to the local roadways. Slide activioy increased in 1994, were numerous tension cracks developed near the upper slope area causing differential settlement along the local road.
Geology, Mechanism of Failure and Type of Movement Geology at the site area consists of crystalline schist of the Sanbagawa Belt, and includes muddy schists and basic schists. The slide planes of the Shinano District Landslide are typically found within the weathered zone of relatively stable-appearing beds. The slide planes are not necessarily in the clay beds, but rather they are found in the upper portions of the moderately fractured and mildly weathered beds. As far as the morphology of the landslide development is concerned, the slide is a retracting-type landslide that originated along the north-flowing Kawada River, located about 500 m east (relief of about 300 m) of the site area. However, the boundaries where the mitigation measures wrer implemented are located on the slopes with higher elevations than 300 m, and are limited to the area where active movement has occurred since 1949. The contributing cause of sliding suspected to be ground water, however, due to the quickly severed exploratory boreholes by the slide the movement, and the nature of the ground water movement within the bedrock formation, the movement is not clearly understood yet.
Mitigation Measures This slide is very large, and because of its headward migration, it is considered very active. Consequently, the mitigation measures required an immediate effect, and therefore soil removal works and anchor works were implemented.

Photo. 34 Conditions immediately following the sliding

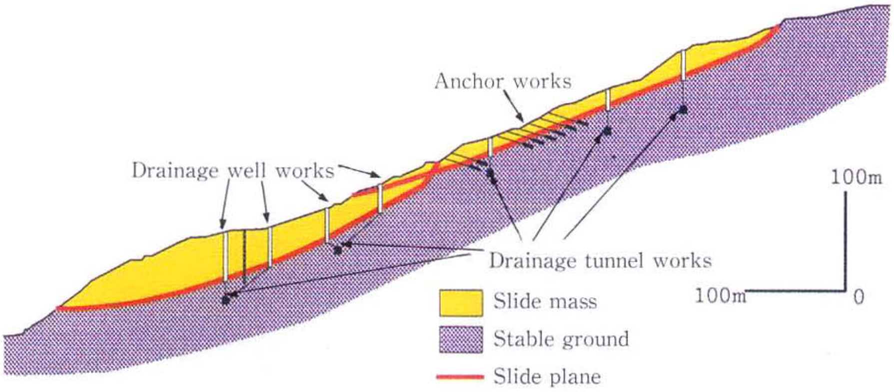
Photo. 35 Conditions following the completion of the mitigation works



Cross section of the Shinano Landslide

Kashio Lanislide

Location Kashio, Higashiiyayama -mura, Miyoshi-Gun, Tokushima Prefecture, (33°50′N; 133°53′E).
Size of Slide Depth: 30 m; Area 50.0 ha, Volume: $1.5\times10^7 m^3$.
Damages This slide is thought to have originated at least in the B.C. Although this slide has maintained a relatively slow rate of movement in recent years, activity has somewhat accelerated since 1988 with an average annual movement of 30 cm/year, causing seriouns damage to the residential structures and roadways.
Geology, Mechanism of Failure and Type of Movement Geologically, the region is locatjd within the Sanbagawa crystalline schist zone which is sandwiched between the Median Tectonic Line and the Mikabu Tectonic Line, and basic schist of the Sanbagawa Belt. Due to large scale tectonic activity, the rocks are highly fractured and weathered. The slide occurred on a dip slope where the average slope is 24 degrees. The head of the slide is located at 950 m above sea level, and the toe is located at 650 m above sea level near the Kashiodani river bed. The slide is divided into two blocks; the upper block, and the lower block. The upper block slide is structurally controlled, and occurred within the unweathered muddy schist. The lower block slide occurred within deeply weathered muddy schist with advanced argillation. The slide occurred due to pore water pressures acting on the slide planes. The slide planes are located at depths of 10 to 20 m deep for the upper block, and 20 to 30 m deep for the lower block.
Mitigation Measures Because of the size and high degree of slide activity, the initial phases of the mitigation works were concentrated on groundwater removal follwed by planned restraint works.



Cross Section of the Kashio Landslide

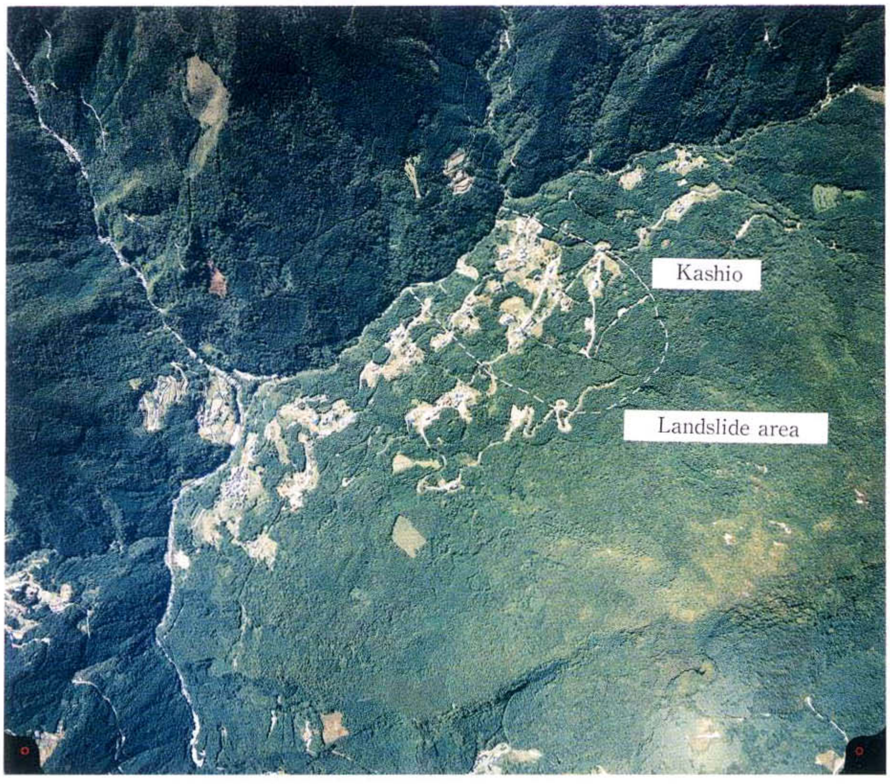


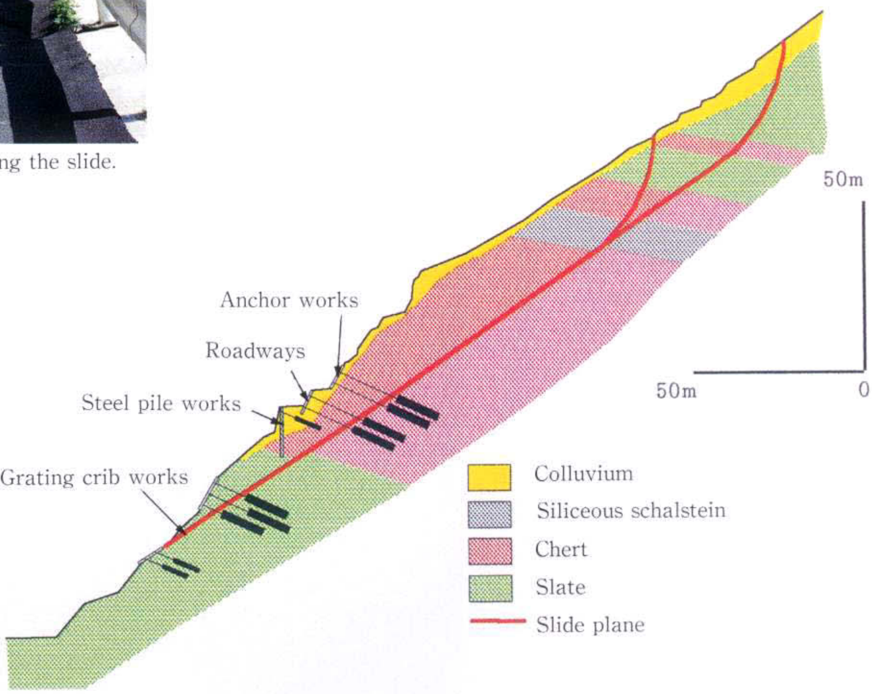
Photo. 36 Panoramic view of the Kashio Landslide

Ohdo Dam Landslide

Location Tosaki, Niyodo-mura, Takaoka-Gun, Kochi Prefecture, (33°32′N; 133°15′E).
Size of Slide Length: 170 m; Width: 150 m.
Damages A relocated local roadway was closed due ot 0.5 to 2 m high cracks caused by the landslide. The slide occurred on April 19, 1982.
Geology, Mechanism of Failure and Type of Movement The area above the relocated local roadway is underlain by chert interbedded with slate. The slopes below the road are underlain by siliceous schalstein interbedded with dolomite. The siliceous schalstein was fractured by tectonic activity, and further weakened by infiltration of water. It has been suggested that the rock slide occurred following the rapid failure of the lower slopes due to saturation during the early stages of the infiltration process. The rapid failure of the lower slopes acted as a triggering mechanism for the rock slide, which occurred along fault planes situated along the upper portion of the slope.
Mitigation Measures Since the failure of the lower slopes was close to the triggering mechanism of the main slide, the mitigation measures on the lower slopes is very important. Anchor works and grating crib works were implemented on the lower slopes as well as anchor works on the upper slopes.

Photo. 38 Conditions following the completion of mitigation works.

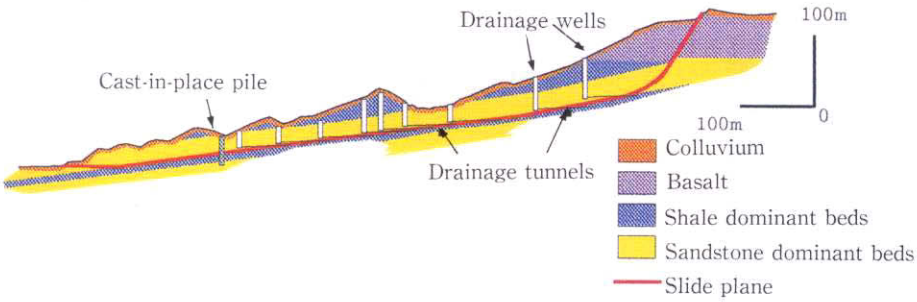
Photo. 37 Conditions immediately follywing the slide.



Cross section of the Ohdo Dam-Tosaki Landslide

Washiodake Landslide

Location Shitonoji-men, Emukae-Cho, Kitamatsuura-Gun, Nagasaki Prefecture, (33°17′N; 129°40E′).
Size of Slide Length: 1000 m; Width: 500 m; Maximum depth: 90 m; Area: 42.8 ha.
Damages The landslide was suspected to have occurred around 1945. In the spring of 1950, tension cracks along the forest roads up to the ridge area were observed, and appeared to expanding. An investigation was initiated, and by the summer of 1950, the tension cracks along the head area were confirmed. Today, the main scarp is about 15 m high. Additional investigations have been conducted as the slide movement continues, and the complete outline of the slide mass was established by 1995. Associated with the sediment movement of the toe area to the Emukae River, movement of the slide mass also resulted in deformation of the railroad alignment, and damages such as shifting to fields and rice paddies. Cracks in residential structures were also reported. The landslide area encompasses 33 residential structures, one public hall, 500 m of rail, one rail station, 11.2 ha of cultivated fields, 17.3 ha of forests, and 500 m of class II Emukae River. Furthermore, if a massive failure were to occur it would result in substantial damages to the downstream areas of the Emukae River.
Geology, Mechanism of Failure and Type of Movement The slide area is underlain by Tertiary sedimentary rocks consisting mainly of sandstone and mudstone, and structurally form a dip-slope condition. Near the summit, these sediments are overlain by basalt of Pliocene age. The Tertiary sediments repeat a rhythmic cycle consisting of a coarse to medium grained sandstone, sandy mudstone, and siltstone to shale with a coal seam between the clay beds derived from tuff at the top of each cycle. These coal seams act as conduits for main ground water flow. The type of landslide above is called Hokusho-Type, and is a translational rock slide. At the site, it is characterized by basaltic cap rocks that cover the ridge area (also the source of ground water). Since the coal seams along the monocline structure act as a slide plane, the overlying sandstone and mudstone beds fail as rock blocks.
Mitigation Measures The mitigation measures implemented between 1952 and 1989 consisted mainly of control works to reduce the annual movement to about 6 cm/yr. However, due to heavy rains in 1990 and 1992, the rate of movement has increased. As an emergency measure, drainage well works have been implemented along with partial restraint works.



Cross section of the landslide

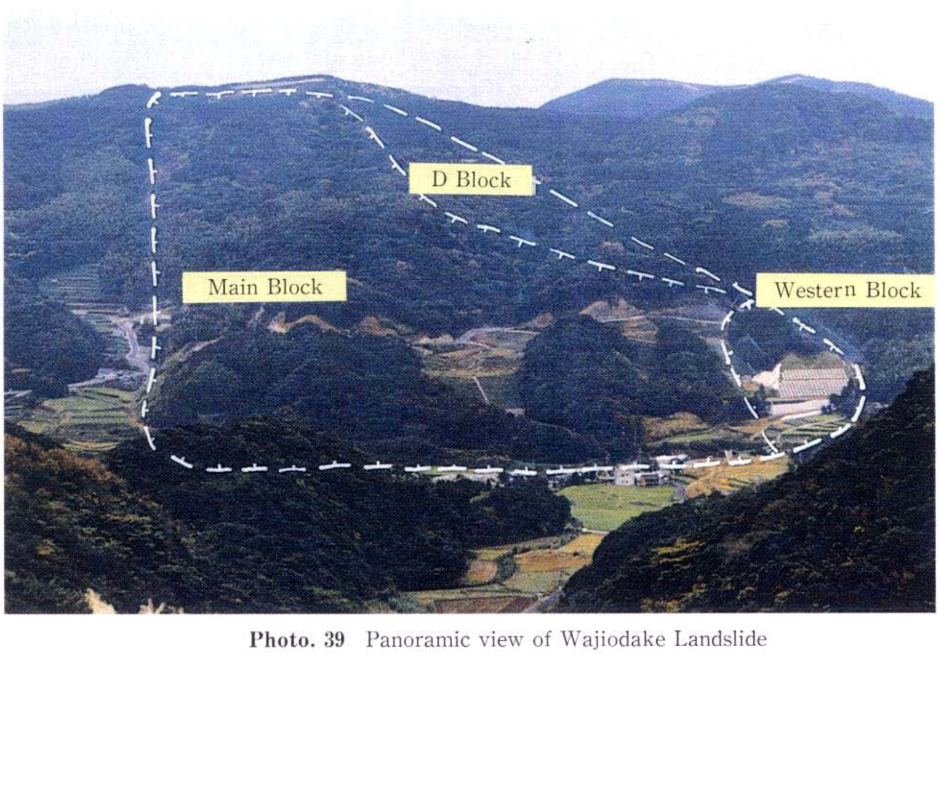
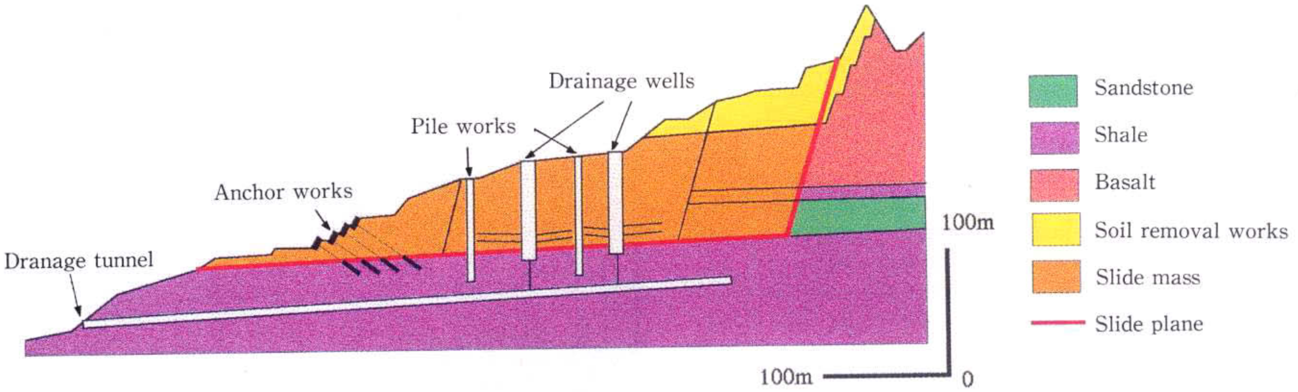


Photo. 39 Panoramic view of Wajiodake Landslide

Ishikura Landslide

Location Imafuku-Cho, Matsuura City, Nagasaki Prefecture, (33°20′N; 129°47′E).
Size of Slide Length: 500m m; Width: 350 m; Area: 22 ha; Volume: $3.0 \times 10^6 m^3$.
Damages Tension cracks were observed prior to the major failure of July 4, 1990. The heavy rainfall preceding the sliding (235.4 mm from July 1-2) rapidly raised the ground water level to 4 to 5 m, which in turn lubricated the slide plane along a zone of weakness and induced the failure. The damages included breach of one reservoir, toppling of one check dam, numerous damages to roadways, disturbance of 1042 m of irrigation channels, 5.8 ha of rice paddies, 1.6 ha of cultivated field, and 1.4 ha of forest.
Geology, Mechanism of Failure and Type of Movement The majority of the slide area is underlain by Upper Tertiary (Early to Middle Miocene) rocks, and by Lower Tertiary rocks on the upslope areas. These Tertiary rocks are in turn overlain by basaltic volcanic rocks forming a cap rock structure. The slide plane was found to be near the bedding plane between sandstone and coal-bearing shale. The angle of the slide plane ranges between 3 and 5 degrees.
Mitigation Measures After the initial sliding, numerous tension cracks developed within the body of the slide mass. The open tension cracks promoted easier infiltration of rain water. Due to this increase in pore water pressure the possibility of renewed activity within the slide mass increased significantly. Consequently, a 3-dimensional dewatering system combined with drainage wells and drainage tunnels were constructed. Additionally, soil removal works were implemented at the head area, and steel pile works and anchor works were implemented at the toe area.



Cross section of the Ishikura Landslide

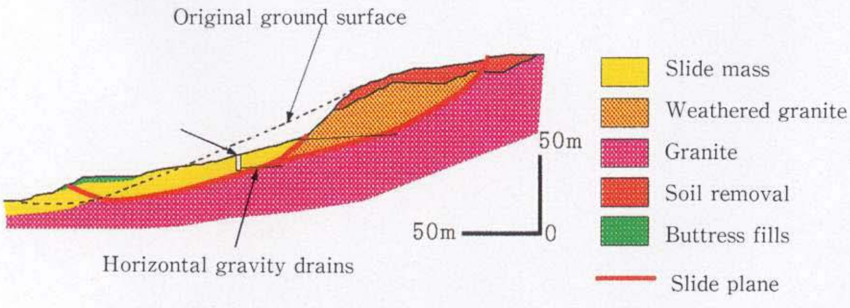
Photo. 40 Conditions immediately following the Ishikura Landslide

Bishamon Landslide

Location Hiyoshi-Cho, Hioki-Gun, Kagoshima Prefecture, (31°36′N; 130°23′E).
Size of Slide Length: 250 m ; Width: 300 m; Area: 6 ha; Volume: 1.0 x 10^6m³.
Damages The landslide occurred on September 20, 1994, resulting in 2 deaths, 3 injuries, destruction of 2 residential structures, and affecting 436 m of roadway and 2.3 ha of cultivated field.
Geology, Mechanism of Failure and Type of Movement The slide area is underlain by sedimentary rocks of the Mesozoic Period (Cretaceous Epoch) with granitic intrusions located along the western slopes of Yahazudake. The upper portions of the slope are underlain by sedimentary rocks and the lower portions are underlain by granite where the landslides occur. The granitic rock is deeply weathered to argillite at about 40 m deep, and has a particularly welldeveloped clay seam that exists parallel to the granitic intrusion. Deeply and completely weathered granitic rocks contain abundant clay of form an impervious zone. It is possible that pore water pressure within the slope underlain by granitic rocks could remain stable for a long period of time after the ground water level is raised by rainfall. It has been concluded that the primary cause of the sliding was a reduction in shear strength within the argillaceous granitic rocks by increased residual pore water pressure. The failure occurred along the weak beds (such as clay seams) where alteration is highest.
Mitigation Measures Due to the large scale of the sliding mass, the mitigation measures were oriented towards increasing the stability factor mainly by control works combined with the selected constraint works where positive results can be expected. Specifically, mitigation measures included soil removal works at the head portion of the landslide and buttress fill along the toe portion of the slide. Attempts were also made to control the sliding force by ground water removal by installing drainage wells, and horizontal gravity drains. Finally, restraint by piles were implemented to complete the mitigation efforts.

Photo. 41 Conditions immediately following the Bishamon Landslide

Photo. 42 Conditions following the completion of the mitigation measures



Cross section of the Bishamon Landslide

6. Professional Organizations Engaging in Landslide Study and Control Works

Japan Landslide Society

The Society was established in 1964, with a current membership of about 2,300 composed mostly of scientists and engineers working in the fields of geology, geomorphology, geophysics, civil engineering, erosion control, forestry, agricultural engineering, and other fields concerning landslides and related phenomena. Many of the members are affiliated with universities and colleges, research institutes, public agencies, consulting firms and other private sectors. The society has five sections representing five geographical regions of Japan.

The journal "Landslide" is published quarterly with over 120 published issues. To date, the journal contains mainly research papers printed mostly in Japanese and accompanied with English subtitles and abstracts.

Annual meetings are held in accordance with the bylaw of the society, and generally attract about 1,200 participants and 100 to 110 papers are presented. In addition, the Society and its sections sponsor symposiums and workshops in various cities annually throughout Japan.

As for international activities, in 1972 the Society organized the first International Symposium on Landslide Control in Kyoto. The 2nd International Symposium was organized in Tokyo in 1977, with the 3rd symposium in New Delhi in 1980. Thereafter, the symposium has been held once every four years, and in 1996 the 7th International Symposium on Landslides will be held in Trondheim.

The Society also joined and organized the "Landslide Field Conference" with American colleagues in 1979 and 1983 (in U.S.A.), 1980 and 1985 (in Japan) to exchange experiences, and the conference developed into an organization of International Conference and Field Workshop on Landslides (ICFL), which was supported by the United Nations, the U. S. National Research Council and other organizations. For the International Conference held in Tokyo in 1985, over 200 professionals participated and 81 papers were published in proceedings. This conference was continued and resulted in the 5th ICFL in Australia and New Zealand, 1987, the 6th ICFL in Swiss, Austria and Italy, 1990, and the 7th ICFL in Czech and Slovak, 1993. The 8th ICFL conference will be held in Spain in 1996. The Society also organized many International Workshops on Landslieds with China and other countries of East Asia.

The annual international newsletter "Landslide News" has been published by the Japan Landslide Society to promote the exchange and opinion on landslides on a worldwide basis since 1987. The latest issue (No. 9) was published in August 1996. Each issue contains "Recent Landslide Research", "Landslide Research Organization", "News/ Reports of Meetings", and "Information", About 2,000 copies of "Landslide News" are distributed free of charge to overseas landslide researchers, government officials, and consulting firms. "Landslide News" and its Japanese translation are also distributed to the members of Japan Landslide Society. If anyone wishes to inquire or learn more about the society, or to be on the "Landslide News" mailing list, requests should be directed to:

President: Saburo Nakamura
Address; Kaga Bldg., 5-50-7, Shinbashi, Minato-ku,
Tokyo 105 Japan
Phone: (03) 3432-1878
Fax: (03) 3432-1878

National Conference of Landslide Control

The Conference is composed of the governors of the 47 Prefectures of Japan. It is intended to contribute to improvement to the techniques of the member prefectures through investigation and study and disclosure of landslide records every year.

Chairman: Governor of Niigata
Address; 4-1, Shinko-cho, Niigata 950 Japan
Phone: (025) 285-5511

Forest Conservation Engineering Research Association

The Association was established in 1956 with forest conservation engineers as its members for enhancing forest conservation technology and developing business activities through the exchange of technical infomations and the meetings for reading research papers.

The Association comprises the president served by the Director of Forest Conservation Division of the Forestry Agency and about 7,500 members with 8 branch offices located across the country.

Activities of the Association include the publication of its journal for presenting research papers and exchanging view as well as the holding of meeting for reading research papers once a year. In addition, each branch office independently publishes journals and holds meeting for reading reserch papers.

President: Director, Forest Conservation Division
Address; c/o Forest Conservation Division, Forestry Agency, 1-2-1, Kasumigaseki, Chiyoda-ku, Tokyo 100
Phone: (03) 3502-8111

The Japan Association of Landslide Control Technigues

The Association was organized in 1974 by consultants and contractors engaged in landslide mitigation works and the manufacturers and dealers of materials, machines and instruments related to the mitigation works. The Association publishes a technical journal "Landslide Control Techniques", holds lecture meetings, and is increasing their efforts of mitigating landslide techniques, to study new control methods and develop new instruments.

President: Shigenobu Sakano
Address; 5-3-7, Shinbashi, Minato-ku,
Tokyo 105 Japan
Phone: (03) 3483-0493

Universities and Colleges

Academic studies of landslide are being conducted by researchers in the universities and colleges individually or jointly.

Public Agencies

1) Ministry of Agriculture, Forestry and Fisheries-Conduct investigations and implement the control work of landslides related to the conservation of farm and forest land.

2) Ministry of Construction-Conduct investigations and implement the control works of landslides and along rivers, highways, dams and residential areas.
3) Japanese National Railways-Control of landslides for the protecion of railways.
4) The Japan Highway Public Corporation-Control of landslides along highways
5) Local Governments-Control of landslides under the jurisdiction of the respective local governments.

Research Institutes

1) National Research Institute for Earth Science and Disaster Prevention
Address: 3-1, Tennodai, Tsukuba-city, Ibaraki 305
2) National Research Institute of Agricultural Engineering
Address: 2-1-2, Tennodai, Tsukuba-city, Ibaraki 305
3) Forestry and Forest Products Research Institute
Address: Matsunosato-1, Kukisaki-Machi, Inashiki-Gun, Ibaraki 305
4) Geological Survey of Japan
Address: Higashi 1-1-3, Tsukuba-city, Ibaraki 305
5) Public Works Research Institute
Address: Asahi-1, Tsukuba-city, Ibaraki 305
6) Geographical Survey Institute
Address: Kitazo-1, Tsukuba-city, Ibaraki 305
7) Railway Technical Research Institute
Address: 2-8-38, Hikari-cho, Kokubunji-city, Tokyo 185
8) Central Research Institute of Electric Power Industry
Address: Abiko 1646, Abiko-city, Chiba 270-11
9) Geological Survey of Hokkaido
Address: Kita 19 jo, Nishi 12 Chome, Kita-ku, Sapporo
10) Sabo Technical Center (STC)
Address: Yamawaki Bldg., 4-8-21, Kudan-Minami Chiyoda-ku, Tokyo 160
11) Fukada Geological Institute
Address: Honkomagome 2-13-12, Bunkyo-ku, Tokyo 113

Other Professional Organizations

1) Erosion Control Engeneering Society
2) The Japanese Geotechnical Society
3) Japan Society of Civil Engineers
4) The Geological Society of Japan
5) Japan Society of Engineering Geology
6) The Japanese Forestry Society
7) The Association of Japanese Geographers
8) The Japanese Society of Irrigation, Drainage and Reclamation Engineering
9) The Japan Society of Photogrammetry
10) The Japanese Geomorphological Union

7. Index Map of Landslides Illustrated