LANDSLIDES IN JAPAN

(The Sixth Revision)

Japan Landslide Society
National Conference of Landslide Control

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Contents

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PREFACE

Landslide investigation and mitigation measures in Japan have advanced since the Maseguchi landslide that occurred in Niigata Prefecture in 1947. Serious research in landslide and related phenomena began about 50 years ago. The "Landslide Prevention Law" designed to prevent and mitigate landslides, the first of its kind in the world, was enacted in 1958. This law is the foundation for the advancement in landslide control technology in Japan. Since that time, landslide investigation methods and various mitigation measures have been developed and continuously improved. It appears that the techniques for landslide mitigation, including investigation, analysis and design of mitigation measures, as well as the maintenance and administration of the completed works, have been nearly completed. Based on such advancements, it is now possible to stabilize slopes that had been actively moving and to prevent further movement of landslides caused by highway and dam construction and housing developments.

The Japan Landslide Society and the active involvement of its members have contributed to the advancement of landslide research and technical development of landslide mitigation measures. The society was established in 1963, and has grown continuously to its current membership of 2500. The Society offers the opportunity for publication, presentation and exchange of ideas to researchers and engineers studying landslides and related fields.

It is my great pleasure to present "Landslides in Japan, 6th Revision". This book reflects a milestone of the advancement and the development of landslide research and technical development in Japan. In this issue, the previously published five issues are included in a CD-ROM so the reader can appreciate our advancement in landslide research and development of mitigation technology in the past 30 years. Descriptions of numerous landslides which occurred during that period are also included.

In Japan, we are at a turning point in landslide research and development. In addition to the conventional landslide mitigation measures which focus on the stabilization of an active landslide, prediction of landslide hazard zones, the development of "soft" or non-structural measures involving landslide hazard avoidance, rock falls and large-scale failures which will have a much larger social implication have been an important topic.

One of the objectives of the "Landslides in Japan, 6th Revision" is to introduce landslide phenomena in Japan to landslide researchers and engineers overseas, but we also hope this will facilitate and promote free exchange of research results and technology for advancement in the field.

We sincerely hope that advancement in research efforts will aid in the reduction and avoidance of landslide related disasters worldwide.

中村浩之

Hiroyuki Nakamura
President, Japan Landslide Society

1. JAPAN AND ITS NATURE (LANDFORM, GEOLOGY AND CLIMATE)

1.1 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 (Fig. 1-1), and encompasses a total area of about 378,000 square km. Seventy-five percent of the total land area consists of mountainous terrain. 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 within one of the world's most seismically active regions. There are 86 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, Nankai Trough, 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. 1-2). 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. 1-2). Landslides occur frequently within six of the zones : Zone A1, the main interior of Hokkaido (inner Kurile Island Arc) which exhibits medium to small scale landslides ; Zone B1, the inner Northeast Honshu Arc (the representative landslide zone) ; Zone D1, the Northwest Kyushu Island located within the inner Southwest Honshu Arc (the zone of high density landslide distribution) ; Zone D2, the outer Southwest Honshu Arc (Shikoku Mountains) and Zone DC1, the Central Western Honshu (Chubu Mountains), represented by landslides of very slow movement and very large-scale, rapidly moving failures ; and Zone DC2, the Central Eastern Honshu (Kanto Mountains) which exhibits a high density landslide distribution within low-lying mountains.

1.2 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. 1-3). 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 Zone : This zone represents Mesozoic and Paleozoic sedimentary rocks (Division 4) and metamorphic rocks (Division 3), ultrabasic rocks (Division 2), Cretaceous sedimentary rocks (Division 5), and Late Mesozoic to Early Miocene age Flysch-type sedimentary rocks (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 Rock Zone : This zone consists of plutonic rocks of mostly Cretaceous to 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 Rock Mantle Zone : This zone represents the areas of highest landslide occurrence within the Japanese archipelago, and consists mostly of Upper Tertiary (and some Lower Tertiary) semi-consolidated clastic materials (Division 8 and 10) and volcanic rocks (Division 9) which overlie the Pre-Tertiary Rock Mantle Zone and the Plutonic Rock 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 Pyroclastic Flow 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.

1.3 CLIMATE OF JAPAN

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

During the winter months, continental cold air 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. 1-5).

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 begins from the southernmost island and moves progressively northward. In early June, the Northern Pacific High Pressure Zones gradually move from the south, and the northern air masses move from the Sea of Okhotsk since early springs and collide above Japan, forming a stationary seasonal rain front. Usually, this early summer stationary rain front (Baiu Front) lasts a couple of months and intermittently drops large quantities of rain. These rains often create sedimentation 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 that form in the low lati-

A_1 Interior regions of Hokkaido
A_2 Outer regions of Hokkaido
B_1 Inner Northeast Honshu Arc
B_2 Outer Northeast Honshu Arc
C_1 Inner Izu-Mariana Arc
C_2 Outer Izu-Mariana Arc
D_1 Inner Southwest Honshu Arc
D_2 Outer Southwest Honshu Arc
DC_1 Central Western Honshu
DC_2 Central Eastern Honshu
E_1 Inner Ryukyu Arc
E_2 Outer Ryukyu Arc

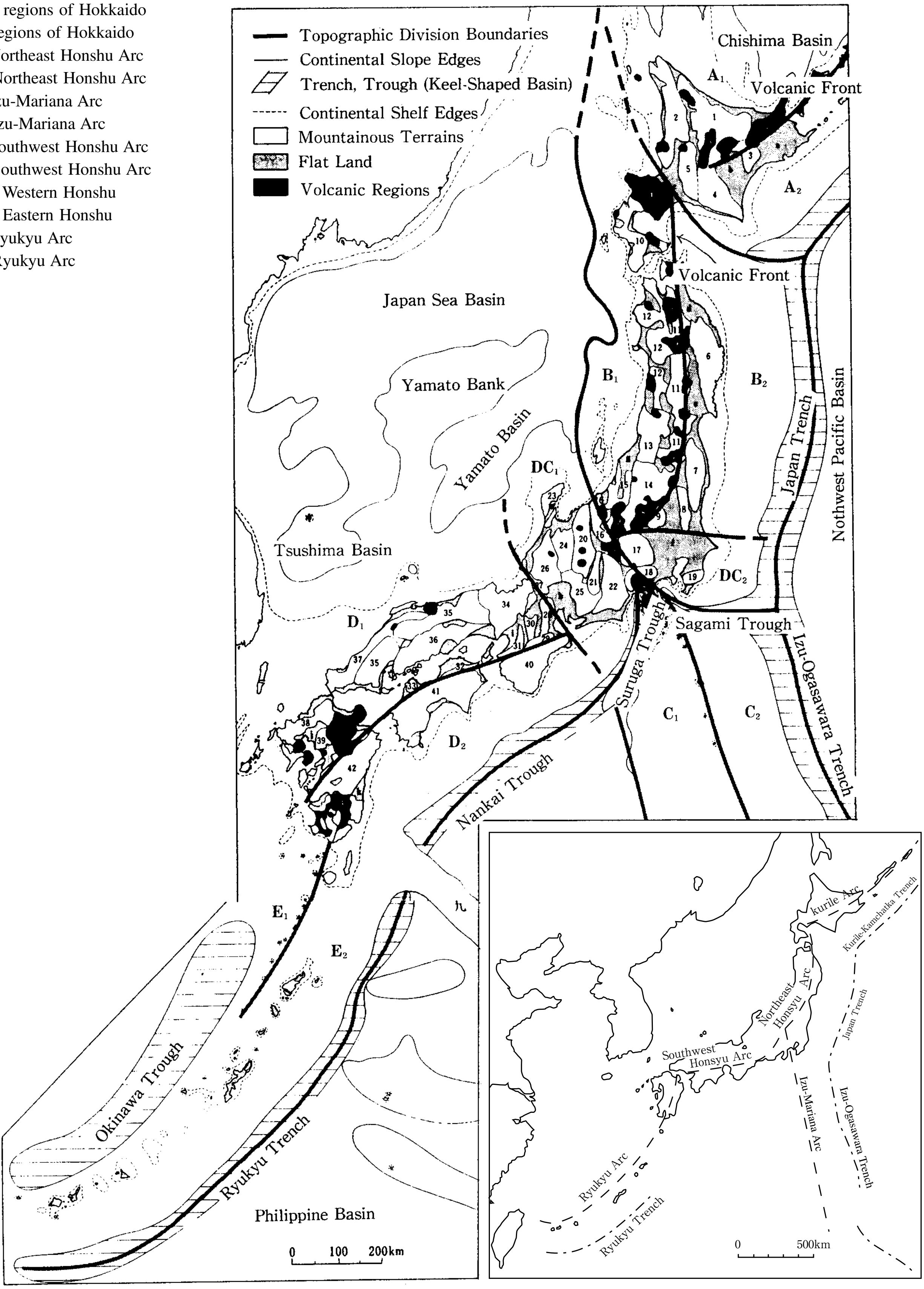

Fig. 1-2 Topographic divisions of Japan (Kaizuka[1])

Fig. 1-1 Trenches and island arcs around the Japanese Archipelago

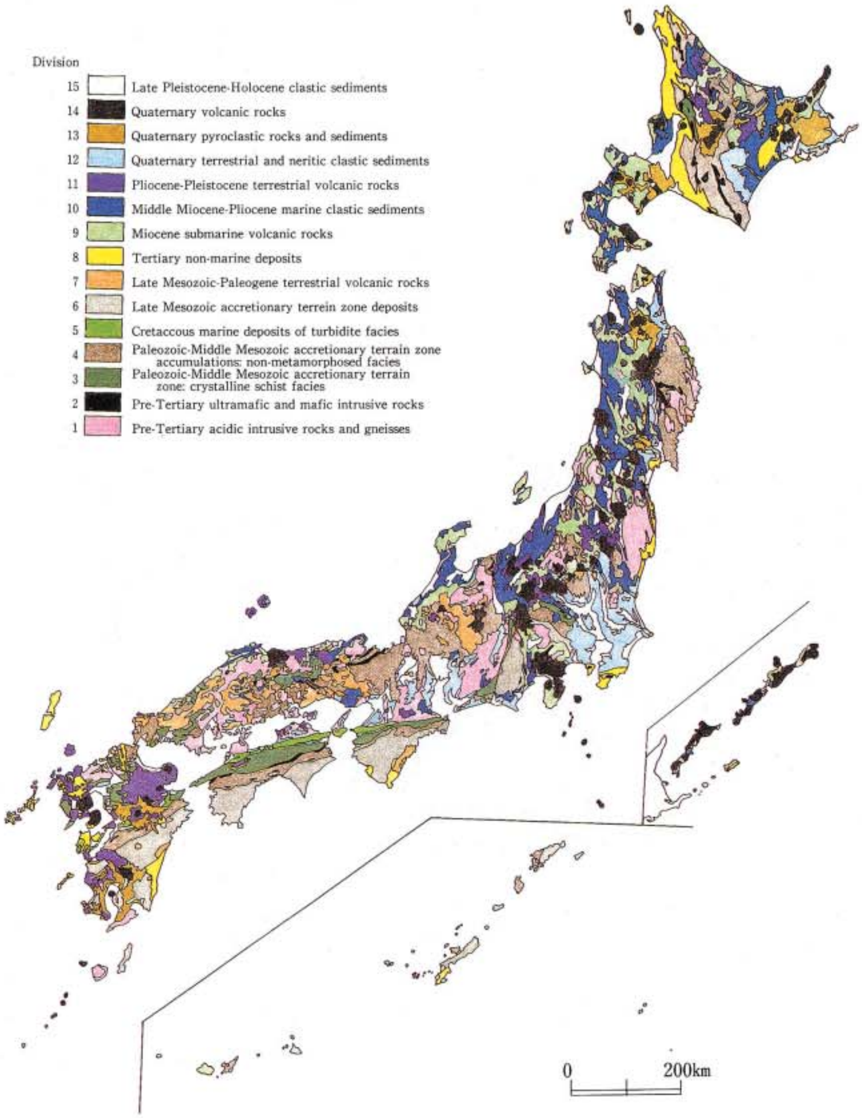

Fig. 1-3 Major engineering geologic divisions of Japan

Fig. 1-4 Distribution of Designated Landslide Prevention Zones

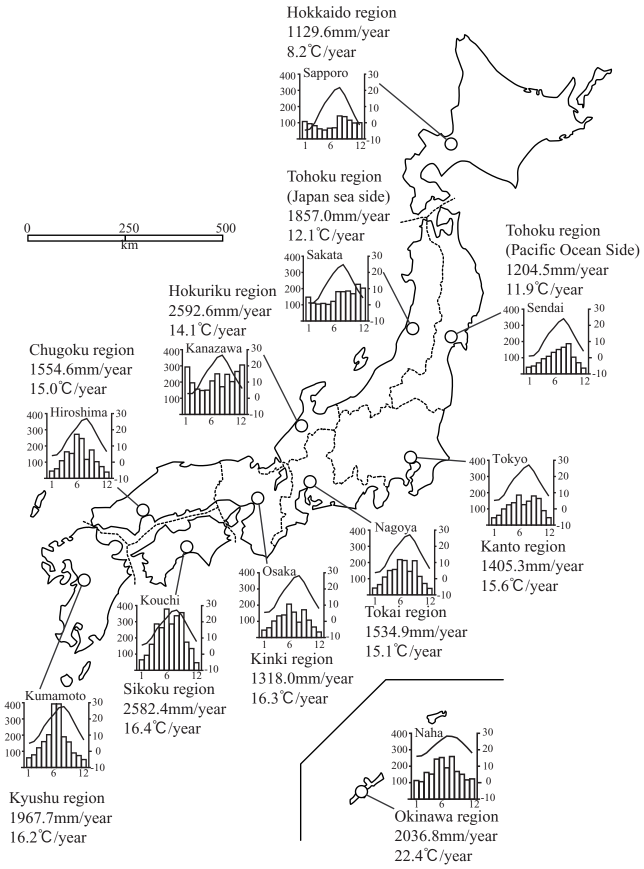

Fig. 1-5 Regional temperature and rainfall records

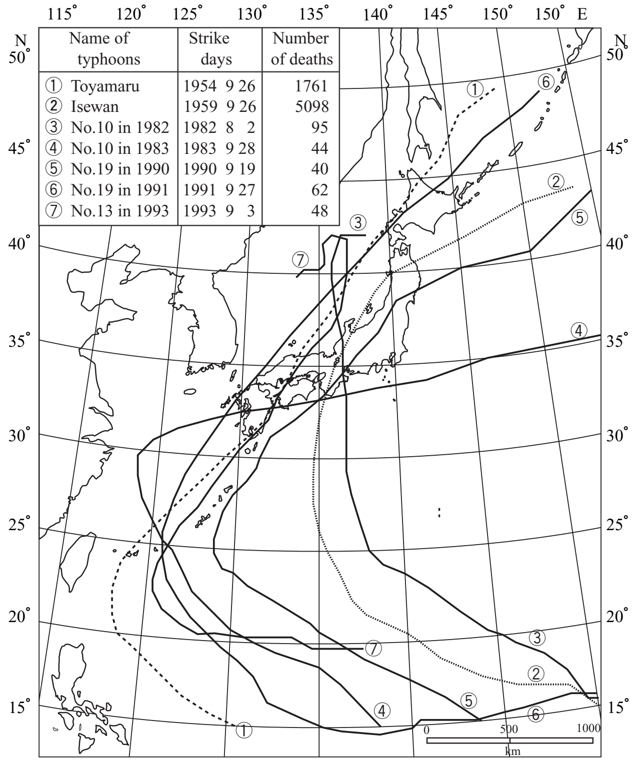

Fig. 1-6 Courses of historic typhoons

tude regions of the Northern Pacific Ocean move northward and circle the western rims of the Northern Pacific air masses, and often land in Japan (Fig. 1-6). 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 4002mm while the Johetsu-shi (Sea of Japan side) records 2880mm (of which one-half is snow).

1.4 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. 1-4). 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, Asou-Machi, Ibaraki Prefecture) of in the Middle to Late Jomon Period (3000-1000 BC). Nihon Shoki (720 literature) recorded numerous landslides and failures associated with the mega-earthquake (along the Nankai Trough) of November 29, 684.

Recent disasters include disasters associated with torrential downpours brought by typhoons at Kagoshima Prefecture in 1993, and resulted 120 deaths ; torrential downpours in Fukushima and Tochigi Prefectures in 1998 resulted in 22 deaths ; and torrential downpours in Hiroshima Prefecture in 1999 resulted in 31 deaths. Notable single disasters with casualties in the last few years include : a rapid slope failure in Okushiri Island, Hokkaido triggered by Southwest Off Hokkaido Earthquake of 1993 (Volume : 1.5 x 10^5m^3, 30 deaths) ; Nikawa landslide, Hyogo Prefecture triggered by Southern Hyogo-Ken Earthquake of 1995 (Volume : 1.0 x 10^5m^3, 34 deaths) ; rock fall at Toyohama Tunnel, Furubira-Cho, Hokkaido in 1996 (Volume : 1.1 x 10^4m^3, 20 deaths) ; debris flow in Gamahara Creek, Nagano Prefecture in 1996 (Volume : 3.9 x 10^4m^3, 14 deaths) ; and a debris flow in Harihara River, Kagoshima Prefecture in 1997 (Volume : 1.6 x 10^5m^3, 21 deaths).

The population density of Japan is 340/km^2 (based on the 2000 census population of 126.9 million). However, the population density of the flat and low lying areas and plateau regions of Japan is 1358/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.

REFERENCE :

1) Kaizuka, S., (1988) : Geographic divisions of Japan, Gekkan Chikyu, Vol. 10, No. 2, pp. 99-101.

2. HISTORY OF LANDSLIDE MITIGATION MEASURES IN JAPAN

2.1 HISTORICAL PERSPECTIVES OF LANDSLIDE MITIGATION MEASURES IN JAPAN

2.1.1 PRE ENACTMENT OF LANDSLIDE PREVENTION LAW

In Japan, full-scale, modern landslide mitigation measures were implemented after World War II, or in the 1950s. In this respect, discussion of the historical perspectives of landslide mitigation measures in Japan is divided into two parts : pre-1950s and post-1950s.

The historical records show that some civil engineering works had been performed as landslide mitigation measures during the Edo Period (1603-1868). According to Takano[1], earth dams and a channel diversion were constructed in Tohkamachi-Shi, Niigata Prefecture as landslide mitigation measures. The measures included the construction of earth dams to stabilize a landslide that consisted of two 6.5m high, 50m long with a 5m crown earth dams ; and one 5 m high, 30m long with a 3m crown earth dam to stabilize a landslide. The channel diversion work included a 358m long tunnel, 1.82m high and 1.52m wide, to divert the flow from the toe of a landslide thereby stabilizing landslide movement. Both works were large-scale projects and the historical records indicate the works were supported by the local administration.

In the Meiji Period (1868-1912), the government undertook flood control works very seriously. In order to obtain advanced European technology, the government invited European engineers. One of the most prominent engineers was Johannes D'Rijeke, a Dutch engineer who lived in Japan from 1873 to 1903. He strongly urged the Meiji Government to consider the importance of sabo works (erosion and sediment control works). In addition, he incorporated torrent works as a part of sabo works, and established the foundation of modern sabo works in Japan.

Furthermore, the Meiji Government enacted the River Law in 1896 and the Forest Law and the Sabo Law (Erosion and Sediment Control Law) in 1897, thereby establishing modern erosion and flood control works in Japan. Thus, the landslide mitigation works were handled as a part of sabo works. During this period, most of the landslide mitigation measures were limited to the works along rivers and channels. Therefore, most of the works consisted of river structures.

In the 1900s, full-scale landslide mitigation measures were implemented on some of the large scale landslides.

Several large landslides were induced along the right shore of an open excavation of the Ohkouzu Diversion Channel during its construction in 1916 and 1919 (Photo 2-1). The work was commissioned to reduce and prevent flooding along the lower reaches of the Shinano River. Furthermore, after the completion of the diversion channel, a post-construction landslide in 1924 delayed the completion date from 1920 to 1927. The predominant control measure for these landslides was the removal of the active landslide masses totaling about 2.88 x $10^7 m^3$. In order to remove such a large volume of earth, a locomotive was utilized, an evolutional approach in those days.

In 1931, a very large landslide occurred along the right shore of the Yamato River at Kamenose District in Kashihara-Shi, Osaka prefecture. This region consists of a narrow valley that connects the Nara Basin and the Osaka Plain. A major National Railroad (Kansai Line) and a Highway (Route 25) run parallel to the Yamato River that signifies the economic importance of the region. The horizontal movement of the landslide reached a distance of 31 meters in 1931, destroying the railroad tunnels. The landslide movement also uplifted a section of the Yamato River by 9 meters, and the subsequent damming inundated upstream area. In order to maintain the river flow and economic pipelines, about 1.87 x $10^6 m^3$ of earth had been removed by 1934.

Photo 2-1 Ohkouzu diversion channel (landslide occurred on the right hand side of the photo) (courtesy of Ministry of Land Infrastructure and Transport)

Photo 2-2 Installation of interceptor underdrain at Chausuyama landslide (courtesy of Nagano Prefecture)

According to Taniguchi [3] along with massive grading works, surface drainage and interceptor underdrains were installed at the Gamou landslide in Tottori Prefecture and the Chausuyama landslide (Photo 2-2) in Nagano Prefecture during that period.

In 1947, about 200ha of gently to moderately sloping terrain located along the foothills of Gongendake Mountain in Noudani-Mura, Niigata Prefecture started to slide. The toe of the landslide reached and deflected the Nou River (Photo 2-3). Damages included 85 homes that are completely destroyed ; 23 partially destroyed homes ; and 50ha of farm land. Furthermore, extensive damage to infrastructures such as roads, bridges and other community facilities were reported. According to Taniguchi[3] the investigation of this landslide was an impetus in establishing the modern landslide investigation and research in Japan.

Following the landslide disasters described above, in 1951 the

Photo 2-3 Maseguchi landslide
(courtesy of Niigata Prefecture)

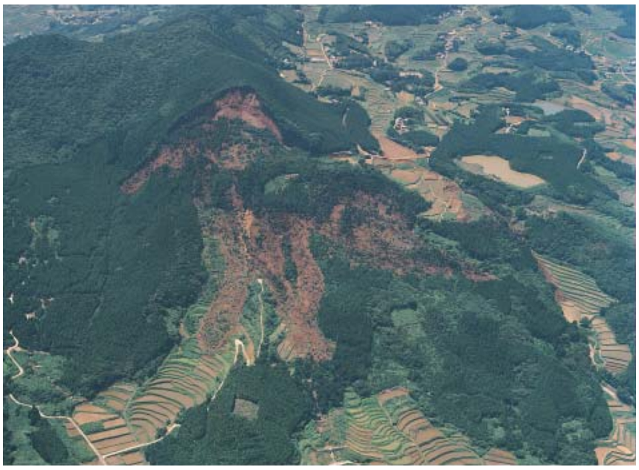

Photo 2-4 Ishikurayama landslide
(courtesy of Nagasaki Prefecture)

Ishikurayama landslide (Photo 2-4) and Ningyoishiyama landslide occurred in Imari-Shi, Saga Prefecture. In 1953, severe damage was caused by disastrous storms in northern Kyushu, and in Hakone Town, Kanagawa Prefecture the Sohunzan landslide occurred. Thus, the reality of frequent landslide disasters leads to the enactment of the "Landslide Prevention Law" of 1958. Following the implementation of the law, landslide mitigation technology, including investigation methods and research, has gradually and systematically advanced in Japan.

2.1.2 POST ENACTMENT OF THE LANDSLIDE PREVENTION LAW

The landslide mitigation measures can be classified into two major categories: (1) "hard measures", involving the construction and implementation of measures and structures; and (2) "soft measures", involving land use restrictions and provisions for a warning and evacuation system. In Japan, the "hard measures" are further classified into two categories: 1) landslide control measures; and 2) landslide restraint measures. The following sections discuss the historical perspectives in the development of the various landslide mitigation measures in Japan.

LANDSLIDE CONTROL MEASURES: Landslide control measures utilizing the river structures for sabo works have been implemented for a long time, as well as surface drainage control and interceptor drain installation. Some of these cases have been described in the previous sections. In recent developments, the representative groundwater control works include: horizontal gravity drains, drainage wells, and drainage tunnels.

Horizontal Gravity Drains: This method involves drilling a series of near horizontal borings directed at the slip surface(s) and water-bearing zones to reduce the pore water pressure along the slip surface(s). Prior to developing this method around 1947, drainage tunnels constructed by tunneling through the landslide mass to remove the groundwater were designed and implemented in the field. However, such drainage tunnels had some disadvantages due to safety and cost. The horizontal gravity drains were developed by chance at one of the mitigation sites in Niigata Prefecture in 1949. Because it is safe and relatively inexpensive, the horizontal gravity drain system replaced the drainage tunnels for groundwater control. Since 1952, the horizontal gravity drains have become one of the most extensively used methods of landslide control.

Drainage Wells: This method involves excavating deep, 3 to 4 meter diameter wells, then drilling numerous radially-positioned horizontal gravity drains at various elevations from the wall of the well. By developing this method, it was possible to reduce the length of the horizontal gravity drains and increase the number of drains, thereby significantly increasing the effectiveness of the dewatering process. The first drainage well was introduced in 1955 at one of the mitigation sites in Niigata Prefecture. The earlier method involved sinking (by gravity) 4 meter, outside diameter steel reinforced concrete cylinders. Since 1960, the liner plates method has been developed such that the efficiency in installation of the well has been increased. In Japan, the drainage well is the most important groundwater control works today.

Drainage Tunnels: Similar to drainage wells, the liner plates method is also utilized in drainage tunnel construction. As a fundamental rule, the drainage tunnels are bored below the slip surface into a stable bedrock formation. Furthermore, NATM Method has been used experimentally to improve its safety. The drainage tunnels have been used with increasing frequency as a landslide control measure in large-scale landslides.

Other landslide control measures include grading works to improve the landslide stability by altering the topographic configuration of the site. There are two types of grading works: buttress fill and earth removal.

Buttress Fill: This method is designed to add weight at the toe portion of a landslide to resist the slide movement. This concept has been used for a long time as evidenced by historical documents. The documents describe the construction of sabo dams (check dams) along the toe portion of a landslide to facilitate sediment deposition thereby increasing landslide stability. This method is currently employed both as a temporary emergency measure and as a permanent solution.

Photo 2-5　Grading work (Earth removal) at Sohunzan landslide (courtesy of Kanagawa Prefecture)

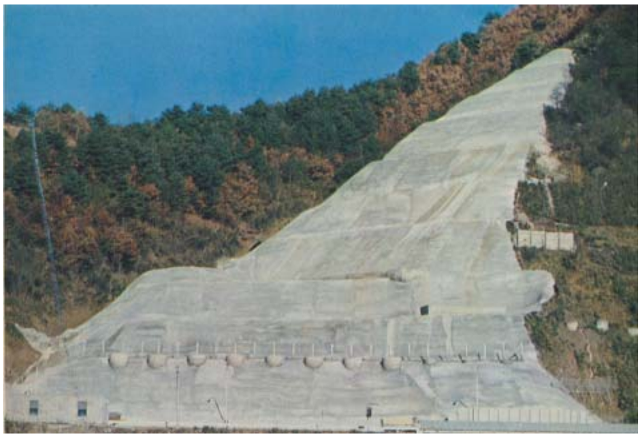

Photo 2-7　Iwadonoyama landslide following the completion of mitigation measures (courtesy of Japan Highway Public Corporation)

Photo 2-6　Yui landslide (courtesy of Forestry Agency)

Photo 2-8　landslide at Ohdo reservoir following the completion of anchor installation (courtesy of Ministry of L. I. and T.)

Earth Removal : In contrast to the buttress fill, earth removal works have not been utilized as long. Earth removal has been an important element of mitigation measures, and in fact very large quantities of landslide debris have been removed from the Ohkouzu Diversion Channel and the Kamenose landslide ; however, they are different from the current concept of "earth removal", which is based on increasing the safety factor of the landslide. It has been suggested that such earth removal works performed on the Ohkouzu Diversion Channel and Kamenose landslide were merely the results of necessity and were implemented without a clear understanding of the significance of the works. According to Taniguchi [3)], the first full-scale earth removal work was performed in 1949 to remove about 1.0 x $10^4 m^3$ from the head portion of a landslide mass in Niigata Prefecture. Then, at Sohunzan landslide (Photo 2-5), about 1.1 x $10^5 m^3$ of earth was removed in 1954. During 1961-1964, a large-scale earth removal works including over 1.3 x $10^6 m^3$ were performed at Yui landslide (Photo 2-6) in Shizuoka Prefecture.

LANDSLIDE RESTRAINT MEASURES : Typical landslide restraint works include : Steel Piles ; Large Diameter Cast-in-Place Shafts ; and Anchors. The construction cost of restraint measures is more than the control measures. However, in large projects such as construction of a dam, a high degree of effectiveness of the groundwater control measures cannot be expected due to the nature of the project - creation of a reservoir [2)].

Pile : The first restraint works, steel piles, were installed in 1962 at a dam constructed by the Ministry of Construction. The steel piles used in this job were 6.9mm thick, had an average length of 12.5m, a diameter of 318.5mm and were designed considering only the shearing force. A bending moment was included in the design of the steel piles and the diameter of the piles were increased to 458mm at a landslide caused by the dam reservoir in Shikoku region. Since then, the design technique has been improved and there is now a clearer understanding of the function of the piles. Today, steel piles are extensively used in Japan as a landslide restraint measure.

Large diameter cast-in-place shafts : As the pressure of rapid urbanization of land increased, the necessity of large-scale landslide mitigation has also increased. With this national movement in the background, the first large-scale, large diameter cast-in-place shafts were installed in 1968 for the National Highway bypass construction in Shizuoka Prefecture. This work included the installation of reinforced concrete structures that were 15m deep with an outside diameter of 300cm, and 50cm thick walls, and completely filled with reinforced concrete. The bottom 6m of the shafts were embedded into the bedrock formation below the slip surface. A landslide that occurred from the construction of the Chuo National Highway at Iwadonoyama (Photo 2-7) temporary closed the highway. The landslide was 80m wide, 80m high and 15 to 20m deep. Twenty five 2 to 3m diameter, cast-in-place shafts were installed as landslide mitigation measure by the Japan Highway Public Corporation. Due to the high cost of installing such massive shafts, this measure is generally utilized only in very large and landslides of high importance where implementation of other measures may not be as effective. In some cases, the shaft diameters exceed 6 meters.

The anchor: The anchor is the most frequently utilized landslide restraint measure. The first application of the anchor as landslide restraint measure in Japan was the mitigation of a landslide induced by the relocation of an access road to a dam constructed by the Ministry of Agriculture and Forestry in 1969. The anchor tendon consisted of twelve, 12.4mm PC steel bars with a design load of 118t per bar. The length of the anchor tendon was 16m with an anchorage length of 6m. A total of 176 anchors were used for this landslide. During the latter part of 1970s, these anchors have been utilized extensively as a landslide mitigation measure for landslides induced by reservoir construction (Photo 2-8). Since tensile force can be added during construction, it will undoubtedly be a popular landslide restraint measure in the future [2].

As demonstrated in the previous discussions, with the advancement of landslide mitigation technologies it is possible to control slide movement of even very large landslides by applying appropriate advanced mitigation measures. However, it is clearly impossible to mitigate and stabilize every landslide. Thus, the necessity of so-called "soft measures", non-structural measures involving warning, avoidance and evacuation, has been increasingly implemented since the 1970s.

Such "soft measures" are based on the development of warning and evacuation systems. Since the late 1980's, heavy efforts have been invested in numerous instrumentations on some of the very active landslides to monitor sudden and unexpected movements. Then plans for the evacuation of residences and traffic control have been developed. The result is highly automated warning systems which are able to relay the results of instrumentation observation in real time in the latter part of 1980's. The system automatically records the quantity of rainfall, amount of ground movement, fluctuations in groundwater level, and other parameters. When any or a combination of the measurements reaches a certain threshold, warning and evacuation signals are issued. A detailed discussion of this warning system is presented in Chapter 4.

This system is indispensable for landslides where around the clock monitoring is required for safety, and for disaster sites that require constant watch for the safety of remaining residents and rescue workers.

2.2 SEDIMENTATIOIN DISASTER PREVENTION LAW

As previously discussed, the necessity of "soft measures" (non-structural measures) as landslide mitigation has been increasing. In particular, urban development has been expanding into hillside regions in recent years. Thus, it is important not only to rely on the instrumentation of the automated landslide monitoring systems, but it is also necessary to impose aggressive land use restrictions in highly populated areas.

A large-scale sedimentation disaster associated with heavy storms occurred in Hiroshima-Shi in June, 1999, claiming 24 deaths. Since many of the victims were residents of recently completed housing developments in hillside areas, attention to the reevaluation of land use policies and enforcement of stricter building codes and building inspection processes for hillside developments was renewed. Thus, a special task force was established by the Ministry of Construction (currently Ministry of Land, Infrastructures and Transport) that was directed towards drafting new legislation. The results of the deliberations were summarized in the report "Comprehensive Legislation for Sedimentation Disaster Prevention", and was consulted to the River Inquiry and Planning Commission. Following reports from the Commission, the Ministry published "A draft Legislation to Promote Sedimentation Disaster Prevention in Affected Regions". As a result, the legislation became law on May 8, 2000.

The following are the significant points of the legislation:

1. The legislation specifically states that it is intended to promote the "soft mitigation measures" such as warning and evacuation systems, and not the conventional construction emphasized landslide mitigation measures.
2. The legislation shall focus on the regions or areas affected by such disasters rather than the causative sites or source areas.
3. The legislation shall be comprehensive and be in conjunction with the land development process and building permit process.
4. The legislation shall be designed to act as a catalyst between the sincere effort of the administration to inform the public and the eagerness of public to know.

The purpose of this legislation is to: (1) define and delineate the areas susceptible to sedimentation disasters; (2) establish warning and evacuation systems for the affected areas; and (3) promote mitigation measures to prevent sedimentation disasters by restricting hillside development and imposing stricter building codes and inspection processes in areas susceptible to serious hazards. Thus, this legislation is intended to promote "soft mitigation measures" to prevent sedimentation disasters. Furthermore, the objective of the legislation is to provide comprehensive sedimentation disaster prevention measures with other existing related legislations such as the Sabo Law, the Landslide Prevention Law and Law for Prevention of Disasters Due to Collapse of Steep Slopes.

A schematic outline of the legislation is presented in Fig. 2-1.

2.3 FRAMEWORK OF LANDSLIDE MITIGATION MEASURES IN JAPAN

The fundamental legislation that governs landslide mitigation measures in Japan is the "Landslide Prevention Law". As previously discussed, this law was enacted in 1958. The law consists of 55 chapters covering such topics as designating Landslide Threatened Area; administrator; Minister in charge; restriction of activities within the district; allocation of cost; and penalties. The landslide mitigation measures will be implemented by the governing legislation. The summary outline is presented in the following paragraphs.

The Minister in charge is either the Minister of Construction (currently Minister of Land, Infrastructures and Transport), and the Minister of Agriculture, Forestry and Fishery. The designated Landslide Threatened Area are administered by either the Sabo Department, River Bureau of Ministry of Land, Infrastructures and Transport, or the Rural Development Bureau, Ministry of Agriculture, Forestry and Fishery or Forestry Agency, Ministry of Agriculture, Forestry and Fishery. The local administrator is appointed to be the Metropolitan and Prefectural Governor; therefore, the governors execute the landslide mitigation measures. However, in cases such as extremely large projects or projects requiring a high level of technology, the Minister in charge may directly execute the works. Thus, the landslide mitigation measures can be executed directly by the Ministry of Land, Infrastructures and Transport; Rural Development Bureau, Ministry of Agriculture, Forestry and Fishery; and Forestry Agency, Ministry of Agriculture, Forestry and Fishery (the three agencies). The mitigation measures can also be executed as subsidized projects by the corresponding department-agency of the Metropolitan and Prefectural governments to which the designated district to belong.

Along with the projects administered by the three agencies (ministries and agencies), landslides induced by the construction of

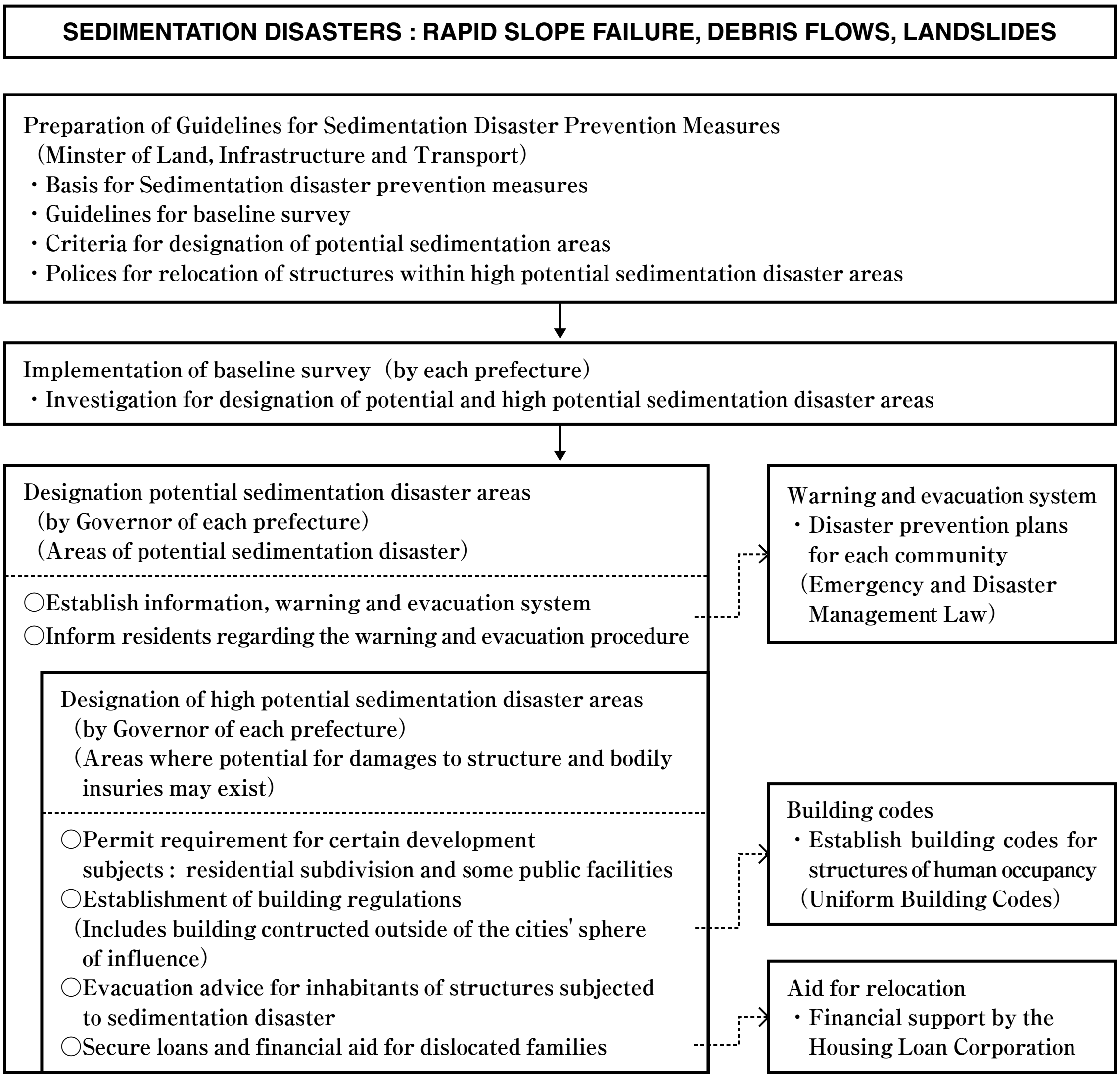

Fig. 2-1 Outline of the Sedimentation Disaster Prevention Law

Table 2-1 Summary of Designated Landslide Threatened Area

	Ministry of Land, Infrastructure and Transport	Ministry of Agriculture, Forestry and Fisheries		Total
		Rural Develope-ment Bureau	Forestry Agency	
Number of area	3,329	1,868	1,725	6,922
Total area (ha)	114,023	107,061	97,927	319,011

highways or dams or during the management of such works, and regardless of the nature of the project (direct or subsidized), the project administrator is responsible for the mitigation works. Furthermore, landslide disasters caused by severe storms, snowmelt or earthquakes which require a high level of urgency, the law requires that the three agencies shall respond to the disaster recovery project. Such emergency works can be administered as either direct or subsidized project.

Table 2-1 summarizes the Landslide Threatened Area administered by the three agencies as discussed above. As in the table shows, about 0.8% of the total area of Japan (378,000 km^2) is designated as a Landslide Threatened Area. The total expenditures of landslide mitigation measures implemented by various agencies during the fiscal year 2000 is shown in Table 2-2.

Table 2-2 Summary of landslide mitigation expenditures in fiscal year 2000

	Ministry of Land, Infrastructure and Transport	Ministry of Agriculture, Forestry and Fisheries	
		Rural Develope-ment Bureau	Forestry Agency
State Subsidy	37,505	14,068	22,273
Direct spending	8,421	5,892	6,471
Total	45,926	19,960	28,744

Unit : 1 Million Yen

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3. CHARACTERISTICS OF LANDSLIDES IN JAPAN

3.1 LANDSLIDE CLASSIFICATION

Landslides are a type of slope movement that can be classified by a combination of material compositions of the sliding mass and the type of movement (Varnes[1]). Cruden and Varnes[2] further classified landslides based on three types of material compositions (rock, debris and earth) and five types of movement (topple, slide, spread, fall and flow) (Table 3-1). However, the type of landslide movement may change from the initial stage of movement to the latter stages. In order to express both types of movement, for example, a landslide that occurred as an "earth slide" and subsequently became an "earth flow" can be expressed as an "earth slide－earth flow"[1].

People have been living in the mountain region of Japan since ancient times. Therefore, damages caused by the landslides have an important influence on quality of life. The magnitude of landslide damages depends on the size of the landslide mass and the rate of movement. The Committee on Glossary of Geology, Japan Landslide Society, has proposed a new landslide classification system incorporating the "damage aspect" of the landslide along with six basic types of movements : fall ; topple ; lateral spread ; slide ; flow ; and creep (Furuya and Kuroda[3]). Creep includes slow continuous deformation of slip-surface clay and colluvium as well as creeping of surficial materials, such as frost creep (solifluction) due to the freeze-thaw cycle of the ground surface.

In Japan, slope movements have been classified into two basic categories for a long time : "jisuberi" and "houkai", and translate into English as "landslide" and "rapid slope failure" or "slope failure", respectively. As shown in Table 3-2, the rate of movement of a landslide is generally slow (less than cm/minute) with a long duration (over 100 hours) and often repeated movement. The rate of movement in rapid slope failures are very fast, and are often faster than 1m/sec. with a duration of movement of less than 1 hour. Further, there are differences in the magnitude of the event, location of origin and slope inclination between the landslides and the rapid slope failures. As described in the schematic diagram (Fig. 3-1), the moving mass in "landslide" often remains at or near the originating zone, while in "rapid slope failure" the moving mass completely vacates from the originating zone and is deposited on the lower slopes. Consequently, economic damages are far greater in disasters caused by "landslides". In contrast, disasters caused by "rapid slope failures" frequently threaten lives. Stabilization of moving masses is the key element in mitigation measures for "landslide", while "rapid slope failure" emphasizes the slope protection of the originating zone and its surrounding areas. This book mainly focuses on "landslide".

3.2 DEVELOPMENTAL PROCESS OF LANDSLIDES AND LANDSLIDE MORPHOLOGY

The movement of a landslide develops various micro topographic features within a moving mass due to compressional and tensile stresses within the slide movement (Fig. 3-1). A bulged slope caused by sagging and accompanied with a series of linear depressions represents the stage prior to development of a slip surface, premonitory topographic expression of an eminent landslide or slope failure. The example in Fig. 3-2 shows several parallel, linear depressions along the upper portions of the slope, and up hill-facing scarps that indicate spreading toward the sides. Based on the landslide distribution maps developed from the interpretation of characteristic features associated with landslides and other slope forming processes on topographic maps and aerial photographs, this indicates that very large portions of mountain regions in Japan are underlain by landslide deposits (Fig. 3-3). Many of the landslide morphologies show evidence of erosion, extensive development of drainage networks on the landslide features, which indicates an "ancient" origin. Currently active landslides are often found within these ancient landslide deposits.

The reasons for such a high frequency of landslide occurrence in Japan include : (1) Increased erosion potential caused by mountain-building process. This is one of the most important factors in landslide evolution, and can be attributed to crustal uplift of up to 1500 m during the Quaternary Period. (2) The geographical location of the Japanese Archipelago produces an abundance of precipitation which accelerates toe slope erosion by rivers and provides plentiful groundwater supplies in the hillsides. (3) Frequent large magnitude earthquakes are also contributing factors. As discussed, since the conditions for developing of unstable slopes exist in the mountain terrains of Japan, the formation of the landslides constitutes the single most important factor in slope forming processes during the Quaternary Period. Thus, these situations represent the importance of landslide prevention in conservation of forest, farm land and settlements within these mountain regions and the construction of roads and dams.

As landslide movement continues, fracturing and accelerated weathering of bedrock, and alterations in groundwater the flow regime advances. Physical properties and strength of materials composing the sliding mass will also change. Therefore, it is possible to interpret the developmental process of a landslide from the landslide morphology as the size and the type of movement of landslides change. Micro topographic features of Yachi landslide located in the Tohoku Region are presented in Fig. 3-4. The landslide area is underlain by hard Miocene mudstone and tuff. The upper slope consists of jagged scarps and large landslide blocks with numerous cracks ; the middle portion of the slide consists of small folds and

Table 3-1 Abbreviated classification of slope movement (Cruden and Varnes[2])

	Type of Material		
		Engineering Soils	
Type of Movement	Bedrock	Predominantly Coarse	Predominantly Fine
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Slide	Rock slide	Debris slide	Earth slide
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	Debris flow	Earth flow

Table 3-2 Difference between landslides and rapid slope failures (Watari[4])

	Landslides	Rapid Slope Failures
Geology	often influenced by geology and geologic structure	little or no influenced by geology and geologic structure
Soils	moves along slip surface(s) that consists of highly plastic clay	usually involves topsoil, residual soil and (highly) weathered bedrock
Topography	occur on gentle to moderate slopes of 5 to 30° the upper slopes often have flat-plateau like topography	usually occurs on slopes steeper than 30°
Nature of movement	continuous, recurrence (repeatitive occurrence) duration of a single episode is generally long	occur suddenly short duration
Rate of movement	generally slow to very slow 0.01 to 10mm/day(most common)	very to extremely rapid 10 m/sec or faster
Nature of moving mass (blocks)	little disturbance within a sliding block often move while retaining the original shape and characteristics	incoherent move as highly disturbed mass
Causes, triggering mechanism	generally influenced by exess groundwater, elevated groundwater table	generally influenced by rainfall intensity
Size	surface area is often large ranges between 1 to 100 ha	surface area is generally small with an average volume of about $440m^3$
Warning signs	often develop cracks, depressions, upheavals, groundwater fluctuation, etc. prior to sliding	hardly any warning signs almost always fail suddenly
Typical original gradient	10 to 25°	35 to 60°

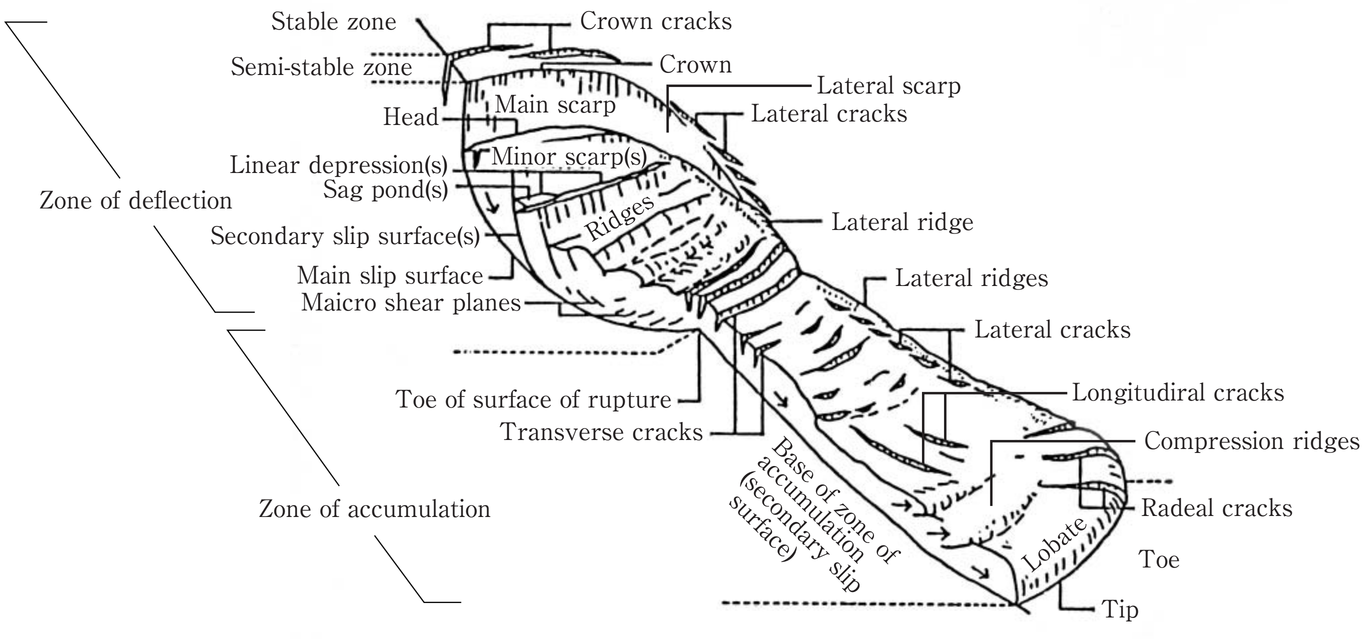


Fig. 3-1 Block diagram of idealized earth slide (Oyagi[5])

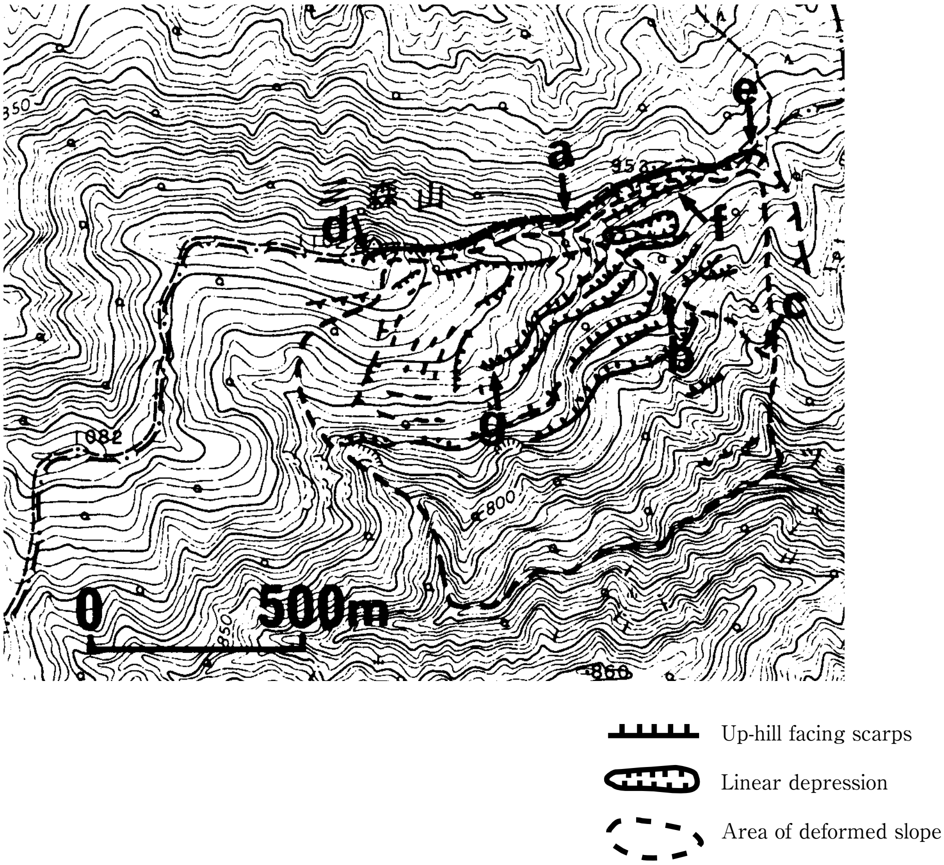


Fig. 3-2 Map showing unstable slope near Sanmoriyama at Iwate-Akita prefecture boundary (Japan Landslide Society, Tohhoku Branch[6])

thrust faults that are oriented perpendicular to the movement direction ; and the lower slope facing the Naruse River is composed of an undulated mass with a small-scale circular scarp. This can be attributed to the morphological transformation process that change landslide configurations, caused by bedrock fracturing from the slide movement, and results in landslide morphology with unique characteristics. In summary, the upper portion of the landslide is formed by a bedrock slide ; the middle portion of the landslide is developed as a secondary landslide from the original bedrock slide. Subsequently, rocks are fractured and weathered yet retain plastic properties that form small scale folds and thrust faults. As down slope movement and fracturing and weathering progresses, the lower portion of the slide consists mostly of clayey materials and develops into a rotational landslide.

Depending on the rock types and geologic conditions, not all landslides follow the development process discussed herein. However, it will be particularly useful, for the prediction of a potential landslide location if an individual landslide topography and landslide phenomena can be understood by incorporating this as one aspect of the landslide morphological evolution process.

3.3 LANDSLIDE TYPE AND CHARACTERISTICS BASED ON THE ENGINEERING GEOLOGIC ZONES

This section describes the engineering geologic zones and particular landslide types often associated with each zone in Japanese archipelago. This presentation is based on the previously discussed landslide classification : type of movement, material composition and rate of movement. Furthermore, the landslide types are classified with the incorporation of particular regional varieties and unique characteristics of bedrock formations in the region.

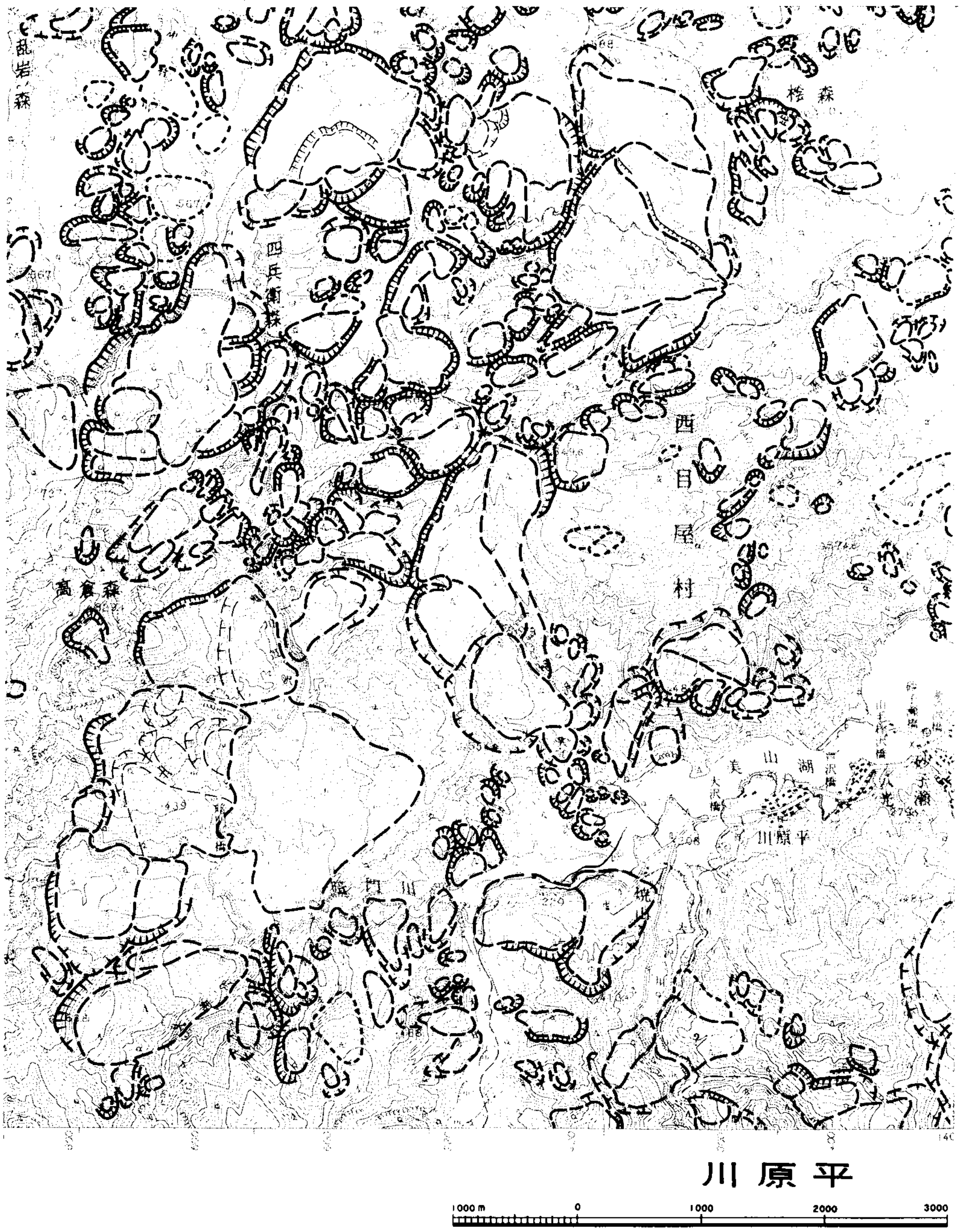
I Pre-Tertiary Accretionary Zone

Rock formations that compose this zone have been accumulated along plate boundaries. The most recent accretion occurred during the Miocene Period, and, piggy backed on top of the basement rock of that period. 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 type of movement that occurs in mountainous areas of high relief (over 300m) where earth debris accumulates along the gentle slopes in front of steep slopes (30 to 40°). Debris creep is most common in this zone. As shown in Fig. 3-5, the gentle slope represents the aggregate of several landslides. Many of the landslides are reactivations of older landslide deposits.

(2) Rapid Debris Slide : This failure is a rapid movement of earth debris caused by heavy rain at the headwater zones of 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 described in (1) above

(3) Rapid Rockslide : This is a rockslide involving more than 10^8 m^3 in volume, and is caused by seismic activity or torrential rains. Most of the rapid rockslides were suspected to have developed on slopes subjected to bedrock deformation. The deformation was attributed to creeping induced by gravitational instability caused by rapid uplift and erosion during the Quaternary Period. Fig. 3-6 shows an example of an overturned structure consisting of interbedded sandstone and slate by creeping followed by a mega cata-



EXPLANATION

Main scarp and Lateral Scarps

Main scarp with fresh and uneroded crown

Main scarp with partially eroded crown

Main scarp with heavily eroded crown

Main scarp with common crown and facing opposite directions

Outline and Boundary of Slide Body

Side body with main scarp having a clearly defined or at least discernible outline.

Main scarp almost completely eroded but part of the landslide mass.

Although it is not completely separated from bedrock, it is assumed to be unstable.

?

Questionable zones

Internal Structure

Minor (or secondary) scarps. Same as "Main Scarp and Lateral Scarps" based on the level of erosion.

Boundaries of secondary slide block(s)

Fig. 3-3 Landslide Map (Landslide Maps, Hirosaki, scale at 1/50,000 “Hirosaki and Fukaura quadrangles”[7] modified a section of Kawaharatai)

EXPLANATION
1. Ridge, small scarps near the ridge, main scarp
2. Bedrock exposed by the slide
3. Minor or secondary scarp(s)
4. Earth flows
5. Areas of micro-folding
6. Drainage and ponds
a. Scarp
b. Upper Block : bedrock sliding blocks
c. Middle Block : zone of compression with folding
d. Lower Block : earth flow zone

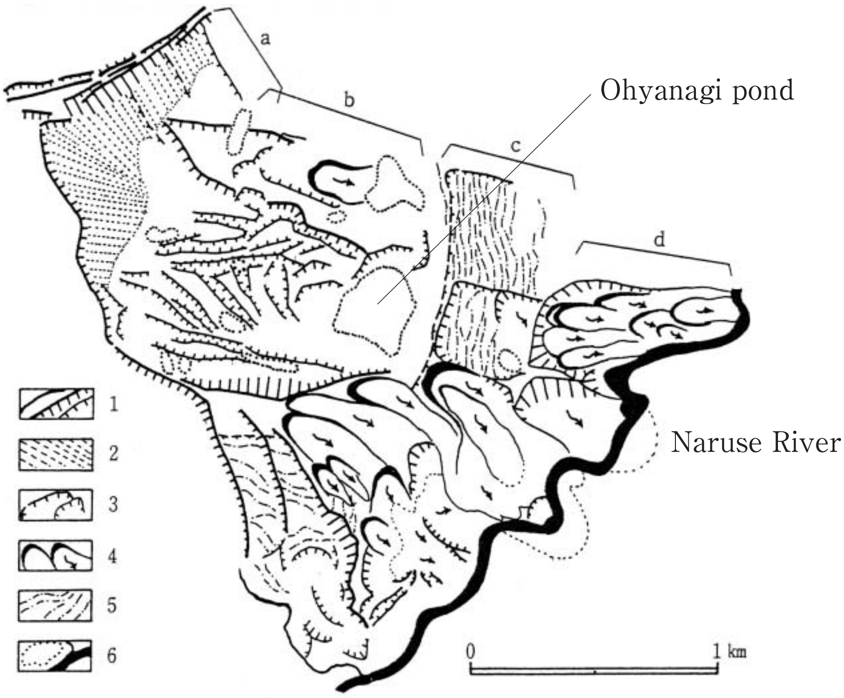


Fig. 3-4 Micro-morphology of Yachi landslide (Miyagi et al.[8])

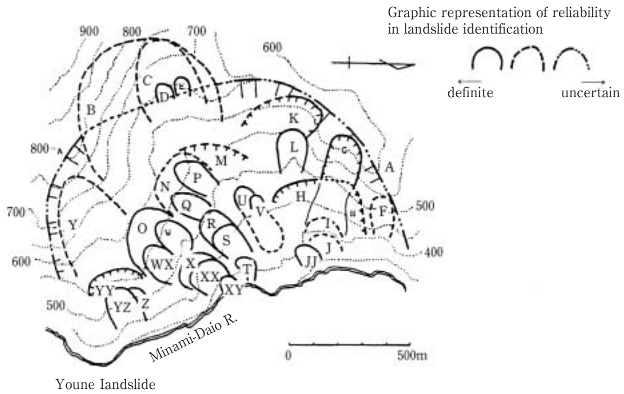


Fig. 3-5 Landslide map from aerial photographic interpretation, Youne landslide

strophic failure.

(4) Slow Rockslide : For crystalline schist, the slip surface is roughly parallel to the plannar schistosity ; for non-metamorphic rocks, the slip surface is sub-parallel to laminar-bedding planes and small low angle faults.

(5) Bedrock Creep : The characteristics of this landform developed in the mountains of high relief from bedrock creep and include scarps that face towards the ridge lines and are accompanied by multiple minor (or secondary) scarps that are roughly parallel to the ridge lines. This type also exhibits linear depressions near the ridge line with bulges toward the lower slopes. For example, the profile of the slope shows convex shape from the ridge to the drainage line. This represents the early stages of deformation of the landform and slope dynamics. However, it is suspected that distinctive slip surface(s) have not yet been formed. There is high possibility that this landform could develop into a rapid slope failure or landslide in future.

II Plutonic Zone

The type of rapid slope failures and landslides are similar within the Plutonic Zone even though the intrusions occurred throughout geologic time.

(1) Rapid Surface Slide : This involves failure of topsoil, residual soil and colluvium triggered by intense rainfall. It is most common in areas underlain by granitic rocks. Failed debris cascades downstream while stripping surficial materials along the way, thereby increasing its volume. Depending on the amount of water available, this type of failure can often develop into debris flows.

(2) Rapid Debris Slide : Earth debris accumulated near the drainage head and knick line during the Pleistocene Epoch subsequently failed by heavy rainfall. It can often develop into debris flows.

(3) Rapid Slide of Weathered Rock or Residual Soil : This type of failure involves deeply and completely weathered bedrock where the failure is generally trigged by intense rainfall. Failure surfaces are generally found within the weathered zone, and other failure surfaces are found along joint surfaces and dikes.

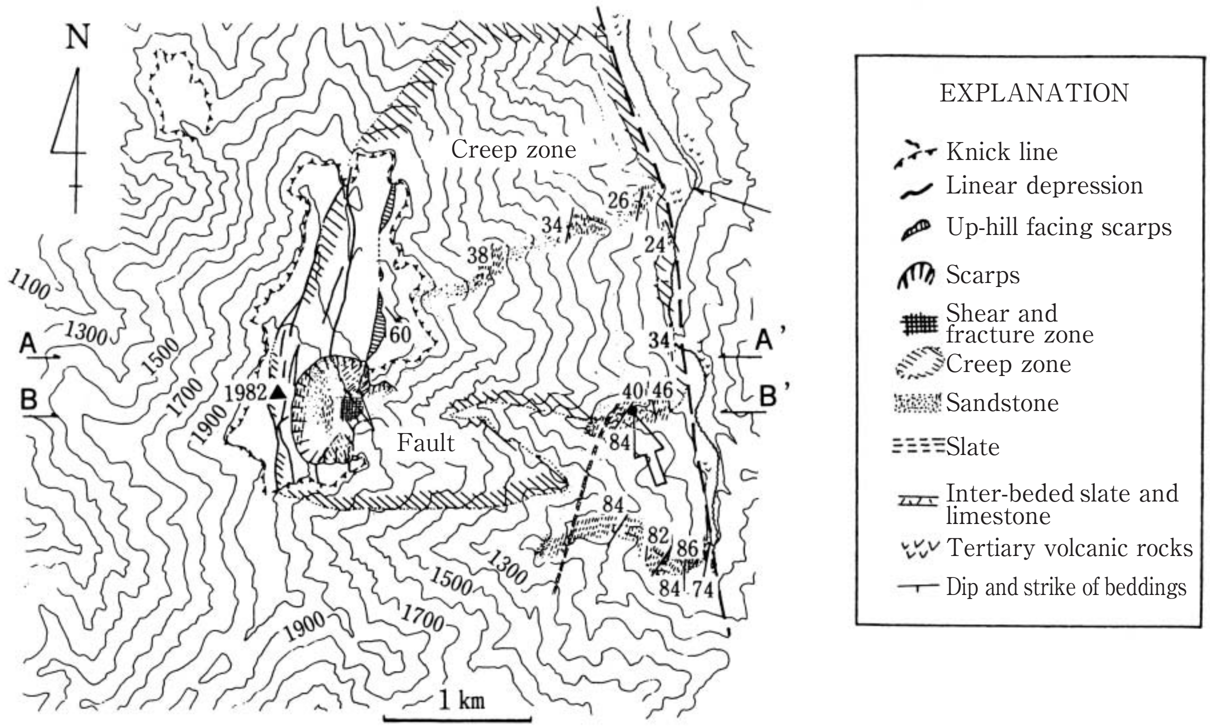
(4) Rapid Rockslide : Although it is rare occurrence, rapid rockslides could develop into a very large scale. This slide often occurs along fault and fracture zones.

III Tertiary Rock Mantle Zone :

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

(1) Clayey Soil Creep / Slow Slide : This type of slide often occurs in areas underlain by mudstone and colluvium along valleys of low relief. Depending on the velocity, the sliding change into a "mud flow". This type of slide is relatively small and ranges in size from 5-100m wide ; 100-500m long ; and 5-20m deep. The cause of initial movement includes increased pore water pressure from snowmelt in spring and intense rainfall.

(2) Rapid Slide of Semi-Consolidated Sediments : This is a



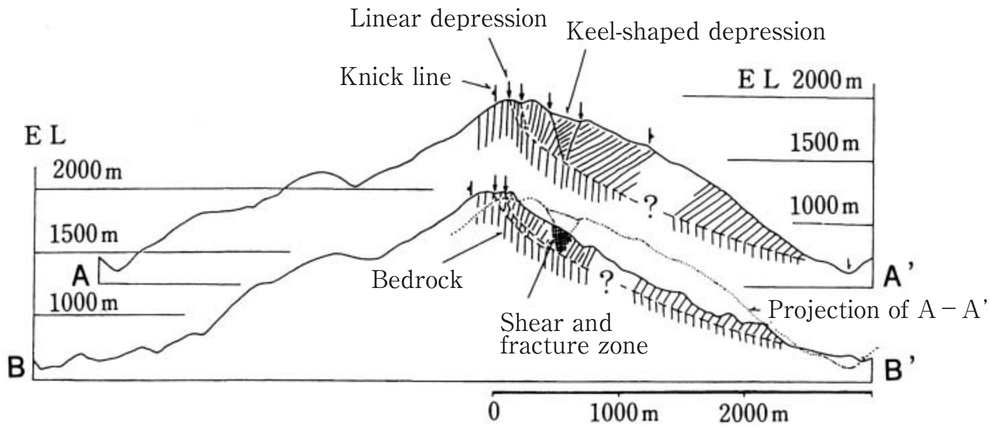


Fig. 3-6 Geologic map and cross sections of the vicinity of Shichimenzan landslide (Chigira[9])

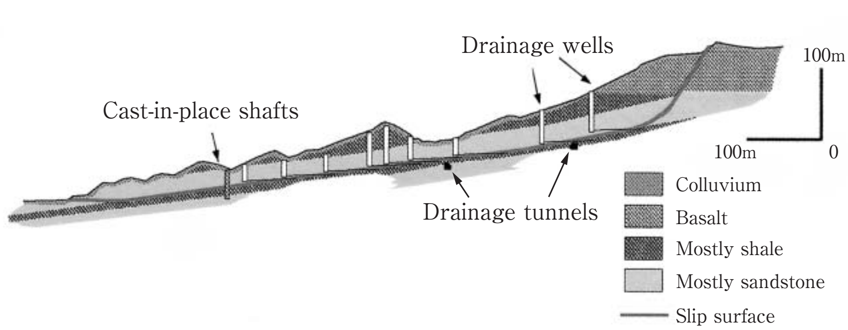


Fig. 3-7 Cap rock structure of Washiodake landslide

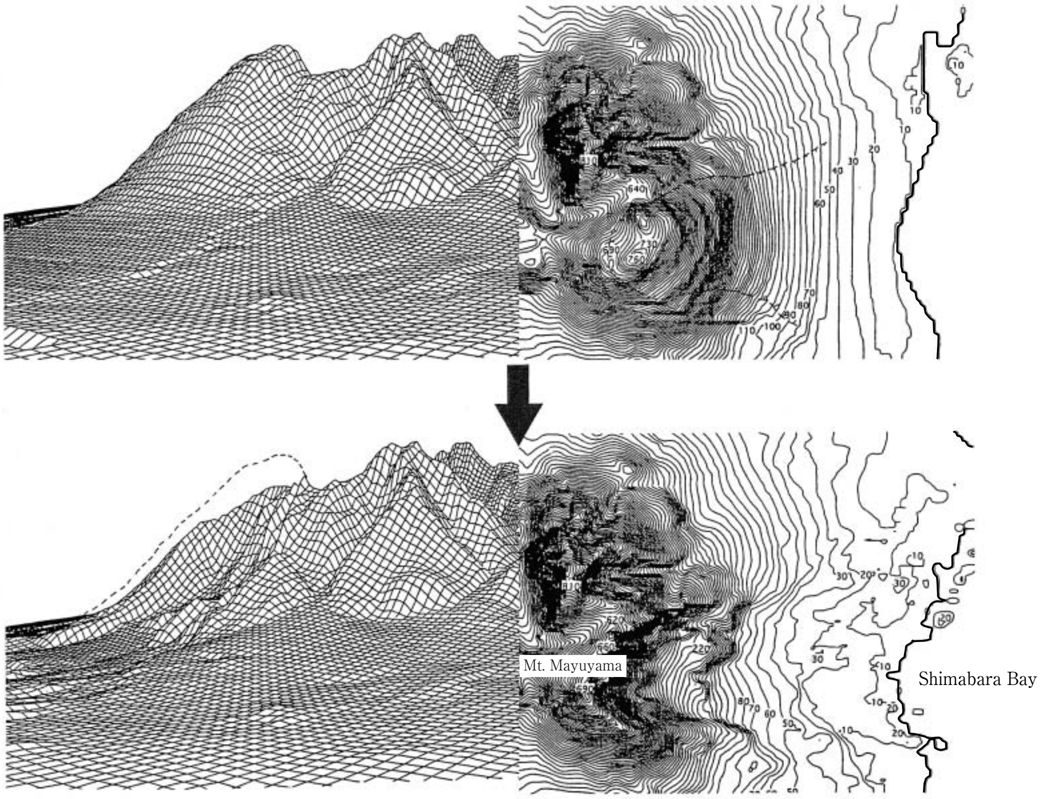


Fig. 3-8 Bird's eye views and the contour maps of Mayuyama before and after the rockslide avalanche in 1792 (Inoue[10])

rapidly moving slide along very steep slopes triggered by excess groundwater or earthquakes. The materials consist of clastic sediments such as gravels (conglomerate), sands (sandstone), and silts (siltstone) deposited during the Pleistocene and Upper Pliocene Epochs. In some cases the rapid slide can become mud flows.

(3) Slow Slide of Consolidated Sediments : The basic composition of the slope-forming materials includes the overlying hard-competent cap rocks with underlying soft-incompetent formations (Fig. 3-7). The competent rocks include massive sandstone, siliceous shale, and massive volcanic rocks, while the incompetent rocks include mudstone and altered tuff. The maximum dimensions of this type of slide could be on the order of : 4km wide ; 5km long ; and 100m deep.

(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 Upper Tertiary-Quaternary Continental Volcanic Deposits Zone

This zone includes continental volcanic deposits of Upper Miocene to Holocene. There are four types of slope movement that have been recognized within this volcanic zone.

(1) Rockslide Avalanche / Debris Avalanche : This type of failure occurs only at 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 groundwater levels could induce a catastrophic failure of the volcano and develop into rockslide avalanche/debris avalanche. This type of failure deposits large, scattered unbroken blocks along foothills and the lower reaches of drainages. The volume of this type of failure is on the order of 10^8 to 10^{10} m^3. Most of the cases involve andesitic volcanoes, but there are cases that involve basaltic volcanoes. Fig. 3-8 shows bird's eye views and topographic maps of hummocky avalanche deposits formed by a rockslide avalanche that was triggered by a large magnitude earthquake in 1792 at Mayuyama, Unzen Volcano, Nagasaki Prefecture. The rockslide avalanche induced a massive Tsunami as the debris fell into Shimabara Bay causing about 15,000 deaths.

(2) Rapid Clay Slide in Hydrothermal Alteration Zone : This type of landslide occurs within zones that receive severe hydrothermal and fumarolic alteration located near the base of craters along the foothills. Examples of this type of failure include Hakone Sohunzan of 1953, and a more recent example is a landslide triggered by a small-scale phreatic eruption at Hachimantai in northern Tohoku Region in 1997.

(3) Slow Slide of Sedimentary Rocks Overlain by Volcanic Cap Rocks : This is a type of landslide formed along the foothills of volcanoes where the terrains are underlain by sedimentary rocks that are in turn overlain by competent cap rocks of lava and pyroclastic rocks. As localized active down-cutting of channels proceeds, the side slopes are over-steepened and became unstable. Thus, large sections of the hillside piggy backing the volcanic rocks slide down slope. The scale of this failure type could be very large, measuring up to 2 km wide and 4 km long. In some cases, lacustrine sediments that were deposited in older calderas beneath the volcanic rocks contribute a triggering mechanism of landslides. Fig. 3-9 shows abundant landslide topography around the foothills of an active volcano, Yakeyama Mountain. The investigation shows lacustrine sediments in an older caldera beneath the active volcano.

(4) Debris Flow : There are two types of debris flows : (1) The first type involves recently deposited volcanic ash fall that is subjected to intense rainfall. The saturated ash could flow downstream, erode the channels and cause numerous debris flows (Sakurajima Mountain, Yakedake Mountain, and others) ; (2) The second type is associated with high temperature pyroclastic flows that melt the existing snow, and flow down slope with the water from the melted snow. The flowing body erodes and consumes materials along the

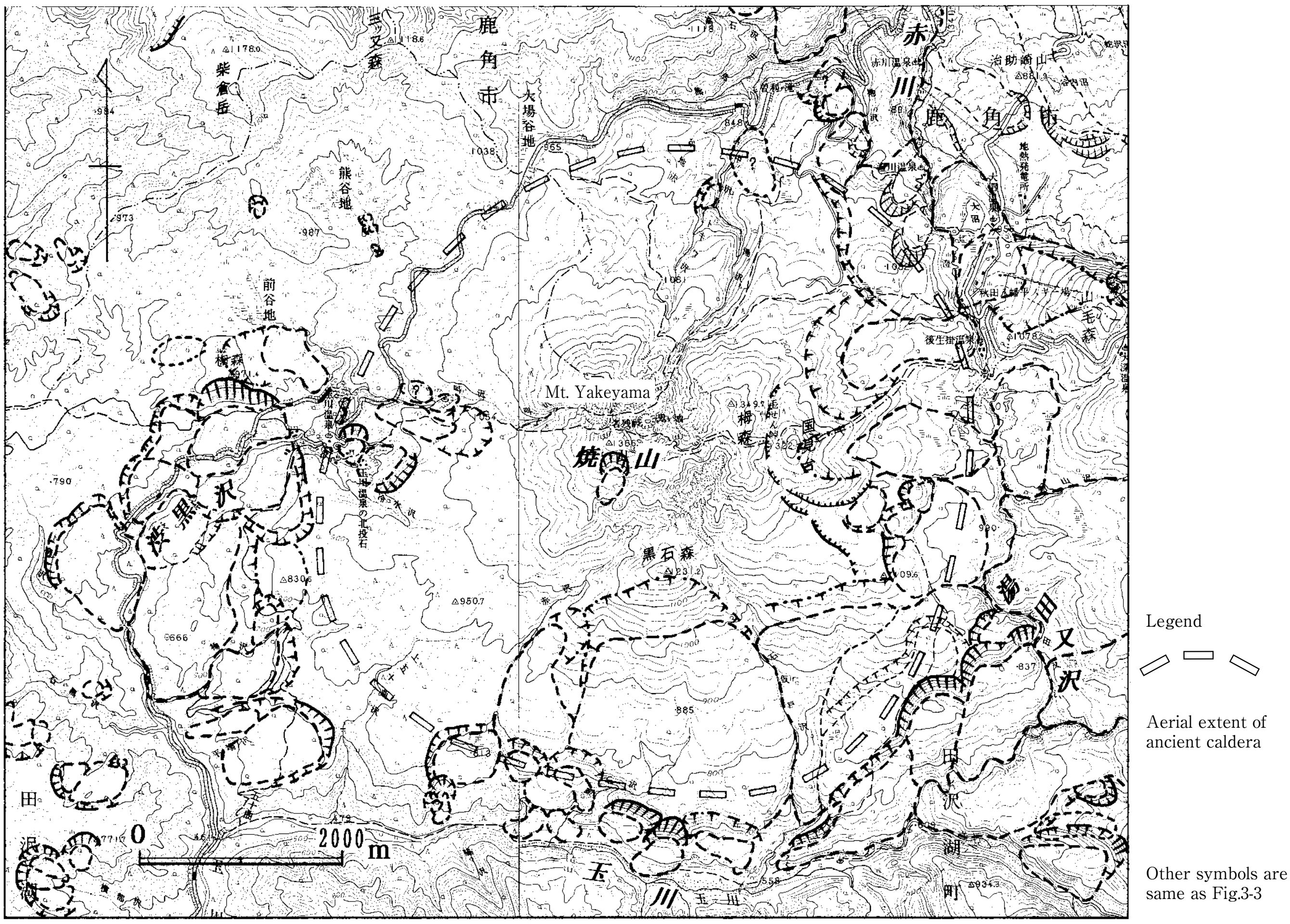


Fig. 3-9 Landslides around the Quaternary volcanic rocks deposited on older caldera (Oyagi[11])

way, becoming a large scale mud flow-debris flow (Tokachidake Mountain).

V Quaternary Regional Pyroclastic Flow Deposits 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 rapid slope failures involve not only pyroclastic flow deposits, but also include plentiful tephra and topsoil that underlies by the pyroclastic flow deposits.

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4. LANDSLIDE INVESTIGATIONS AND PREDICTION

The flow chart shown in Fig. 4-1 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 4-1.

4.1 PRELIMINARY INVESTIGATION

4.1.1 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 signs, groundwater conditions, chronologic topographic change or erosion by rivers, earthquakes, and other factors which may relate with the slope deformation surrounding the investigation site area prior to performing a detailed investigation.

4.1.2 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 aerial photographs of the site and vicinity taken before 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 1/10,000 to 1/40,000. These photographs are used to understand the chronologic and topographic changes over the country. 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 distribution 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 imageries has been particularly useful for analysis utilizing the Thermal Infrared Spectrum which is possible to estimate the distribution of slide areas and groundwater, and live vegetation. Remote sensing can be used for analysis of topographic characteristics and topographic changes in terrain susceptible to landsliding.

4.1.3 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 the 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 should also extend to the surrounding areas where possible future sliding also exists. Additionally, the field investigation should include areas where aerial photographic interpretation is difficult or unclear, and in areas that could aid in the understanding of particular topographic features and characteristics.

4.2 DRAFTING A DETAILED INVESTIGATION PLAN

In order to properly examine the items listed below, a detailed investigation which will satisfy the study objectives should be planned by selecting appropriate investigation methods and instruments described in Table 4-1.

1. aerial extent of the slide, differentiation of moving blocks and identification of the direction of movement
2. location and configuration of slip surface(s)
3. nature of landslide block(s)
4. possibility of further or future movement on slopes beyond the existing slide
5. possibility of continual, future or accelerated sliding
6. distribution of groundwater

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

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

4.3 DETAILED INVESTIGATION

4.3.1 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.

Examples of instrumentation used for the surface deformation investigation include extensometers, ground tiltmeters, movement determination by survey methods including transverse survey, grid survey, laser survey from the opposite bank, movement determination by aerial photographs, and G.P.S. (Fig. 4-2).

(1) Simple Method to Measure Movements

One of the simplest method to determine landslide movement is to drive stakes across a tension crack along the direction of slide movement (Fig. 4-3). Then attach horizontal board to the stakes, and saw through the board. Any movement across the tension crack can be determined by measuring the space between the sawed portion of the board.

(2) 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 cracks and transverse ridges near the toe or front portion of the slide and parallel to the suspected slide direction (Fig. 4-4). Measurements should be accurate to within 0.2 mm, and the magnitude of the movement and daily rainfall data should be recorded to establish the relationship between the measurable movement and the precipitation

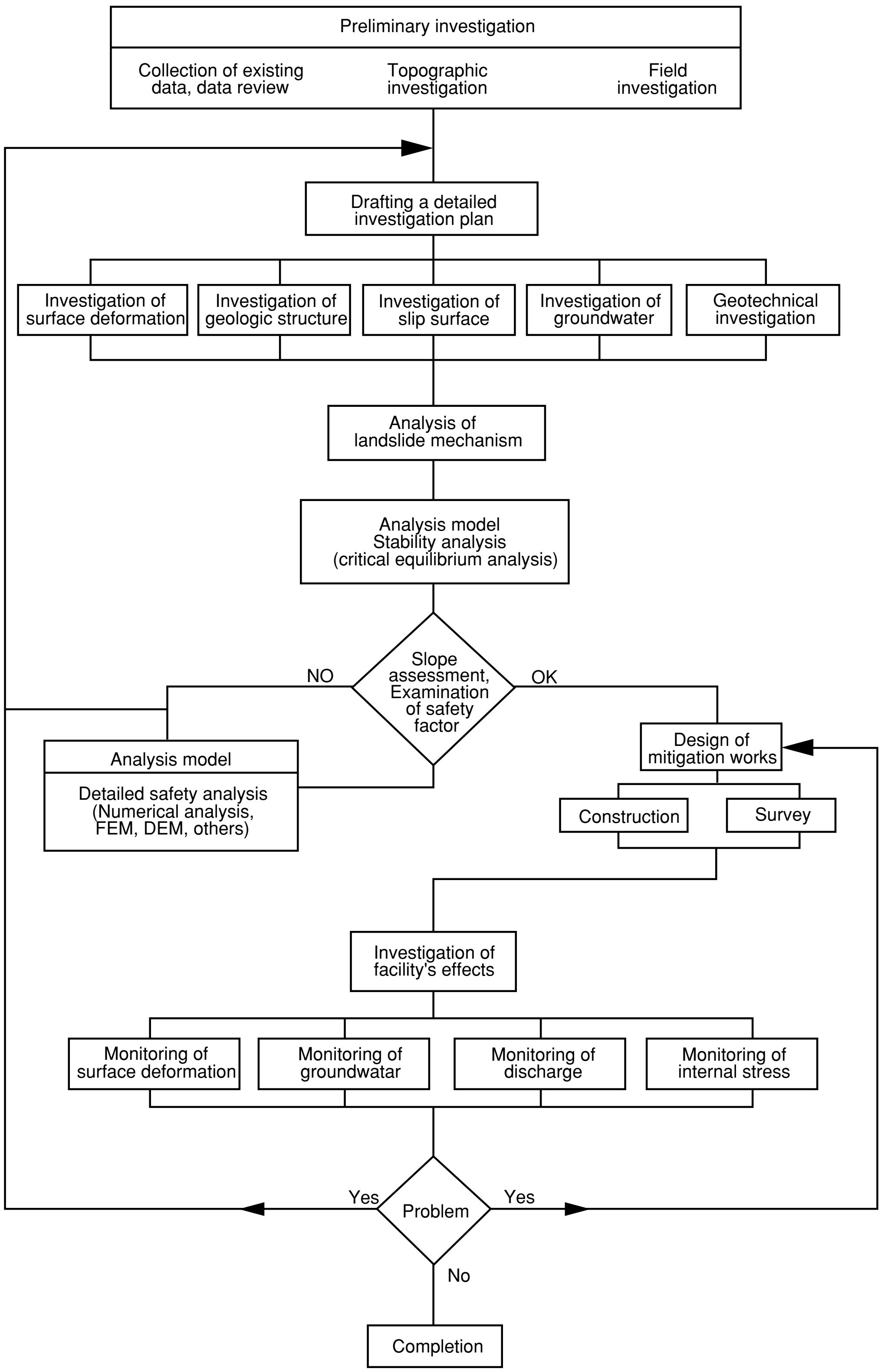

Fig. 4-1 Flow chart for landslide investigation and analysis

Table 4-1 Investigation items and investigation methods

Investigation items \ Invenstigation methods		Interpretation of aeral photographs	Literature research	Topographic survey	Topographic investigation	Surficial geologic investigation	Subsurface exploration by borings	Test adit	Geophysical exploration	Soil tests	Groundwater tests	Investigation of slip surface	Investigation of land deformation	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 structure	rock type and rock quality	△	○			◎	◎	◎	○	△	△			composition of rocks and hardness
	degree of weathering and level of relaxation					△	○	◎	◎		△			
	density of rock formation						△	◎		◎				
	distribution of faults and fracture zones	○	△			◎	◎	◎	○					
	distribution and depths of slip surface	△				○	◎	◎	○			◎		continuity
	inclination of slip surface					○	◎	◎				◎		
	quality of slide mass, composition of slip surface materials					○	◎	◎			○			filling
	mechanical coefficient of slip surface									◎				
	deformation conditions of slip surface											◎		
Deformation condition of ground surface					△								◎	
Conditions of groundwater 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				△									
	deformation of structures				◎									

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

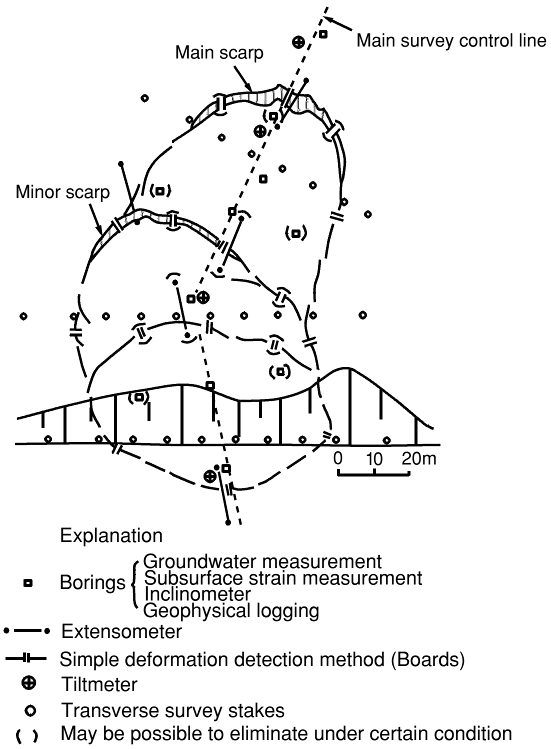

Fig. 4-2 Example of instrumentation

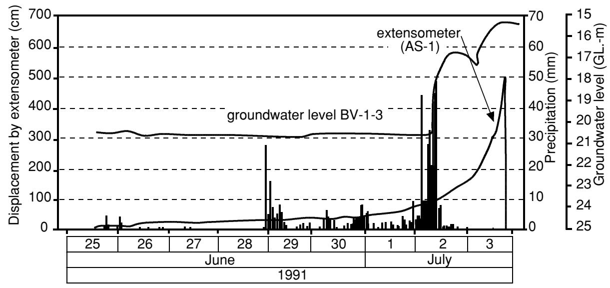

Fig. 4-5 Example of measurement by extensometer

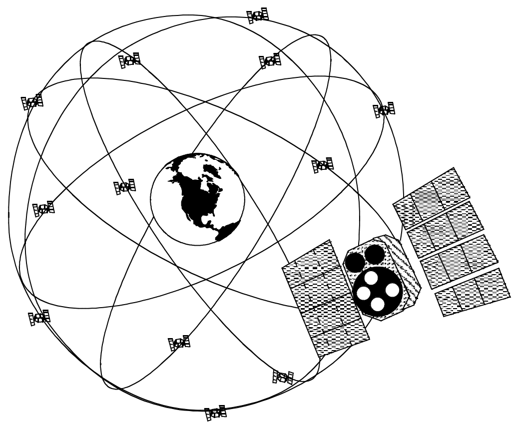

Fig. 4-6 Orbit of G.P.S. satellites

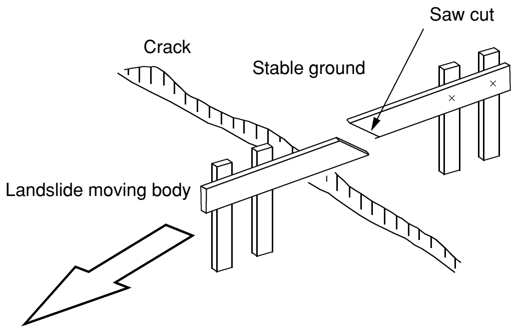

Fig. 4-3 Simple deformation detection method (Board)

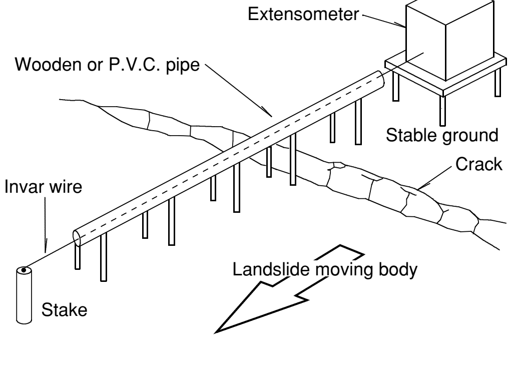

Fig. 4-4 Simplified diagram of extensometer installation

rate (Fig. 4-4 and 5).

(3) Laser Survey

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 is large. Recently, non-prism optical distance meter has been developed which does not require a specific target, and is used for monitoring on very steep slopes.

(4) G.P.S.

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 (Fig. 4-6).

(5) Other Methods

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.

Recently, slope deformation detection systems using fiber optics has been tried. This system adopts the property of reduction in the optic medium within the fiber optics as it bends. It is possible to record the amount of deformation as well as the location of the deformation.

4.3.2 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 radioactive survey) is combined with the boring data.

1) Borings

The majority of the borings drilled are larger than 66 mm in diameter. 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 (Photo 4-1). The boring logs shall include such information as : geologic and soil description ; color ; hardness ; lithologic description ; degree of weathering ; alterations and fractures ; strike and dip of bedding and joints ; boring conditions ; initial and stabilized groundwater levels ; and rate of core recovery.

Geologic assessments 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 slip surface generally have a high moisture content, are highly sticky and plastic and are often associated with abrasion scars and slickensides. During drilling, squeezed earth could occur near slip surface.

Furthermore, using the data from the borings the following information must be assessed or determined.

1. Evaluation of slip surface
2. Groundwater level measurements
3. Groundwater logging
4. Groundwater tracer tests
5. Standard penetration tests, Horizontal loading tests, in-situ tests such as in-situ permeability tests
6. Sampling for soil tests
7. Various geophysical logging.

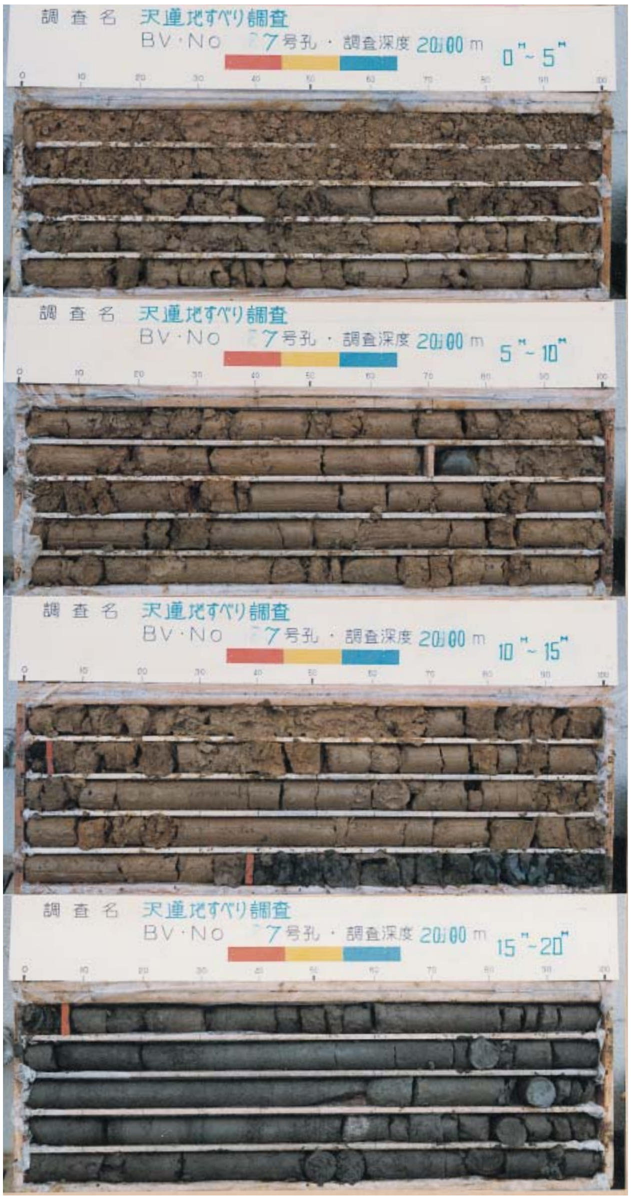

Photo 4-1 Photos of core samples

2) Geophysical Surveys

Geophysical surveys (seismic survey, electric survey and radioactive survey) are conducted to understand the approximate geologic 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 determine the distribution of aquifer(s) and to understand the geologic structure. These surveys include the development of the geotomography method.

4.3.3 EVALUATION OF SLIP SURFACE

Determining the slip surface for actively moving landslides utilize the fact that the rates of movement differ significantly along the slip surface. 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 ; and 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 (Fig. 4-7, 8). 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 1 m 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 slip surface so that data from within the intact formation can be obtained.

(2) Inclinometer

A grooved casing is inserted into the borehole extending into the bedrock formation, and an adequate quality of grout should be placed into the borehole to assure an intimate 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 (Fig. 4-9). 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 the casing will exceed the tilt detection limit of the instrument.

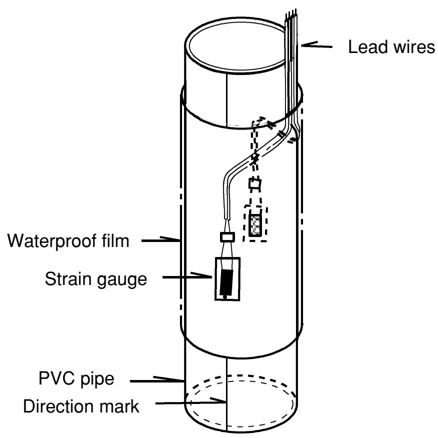

Fig. 4-7 Pipe strain gauge

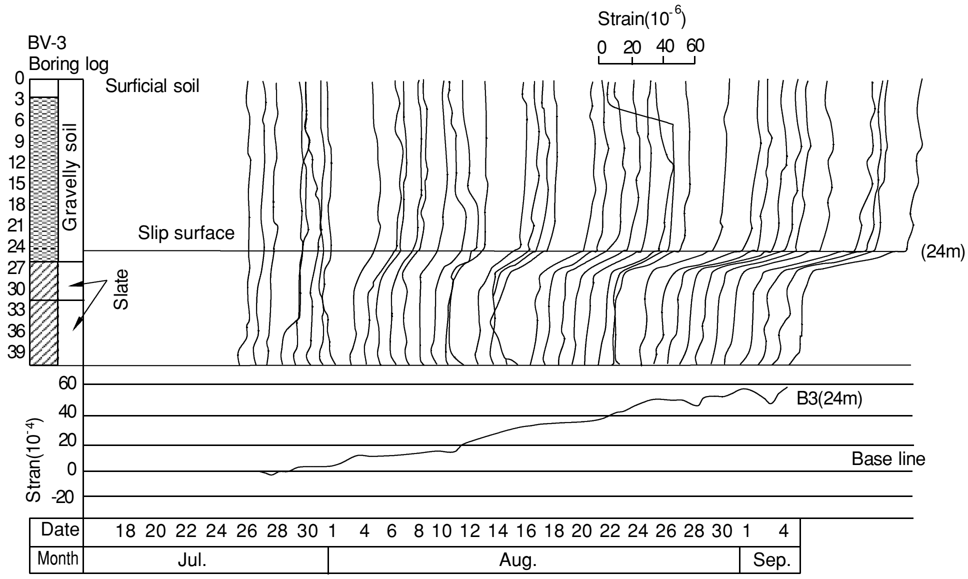

Fig. 4-8 Example of measurement by pipe strain gauge

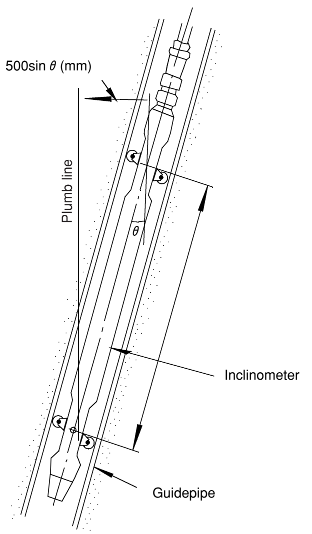

Fig. 4-9 Sensor of insertion type inclinometer

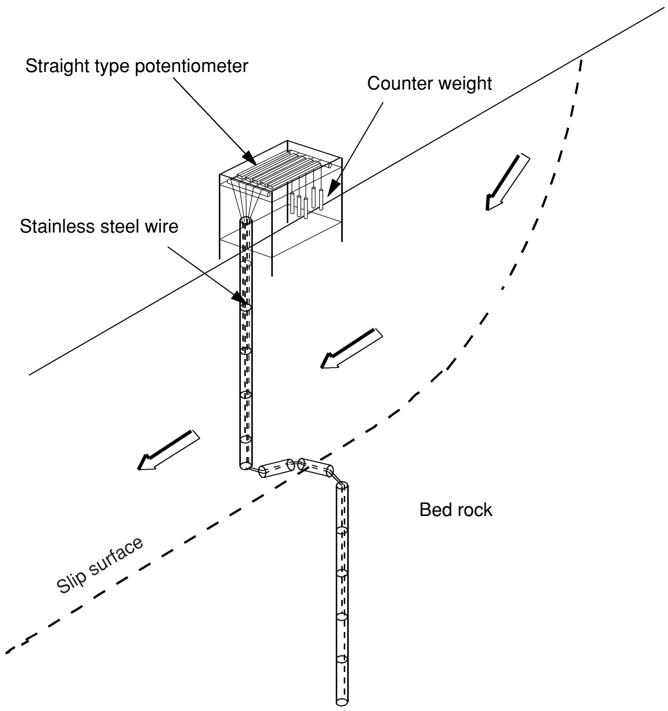

Fig. 4-10 Multi-layer movement meter

(3) Multi-Layer Movement Meter

Several wires are anchored at various depths within a borehole and the attached wires extend up to the ground surface. The magnitude of the displacement of each wire segment can be measured directly using a ruler or potentiometer (Fig. 4-10). 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 borehole.

(4) Pressure-Sensitive Cable

The pressure-sensitive cable consists of an inner wire and outer shield wires that are separated by conductive flexible material and a mesh-like insulator. When the cable is compressed and squeezed by the movement at the slip surface, the inner wire and the outer shield wires short-circuit. The electric pulses sent from the ground surface through the cable is reflected at the short-circuited location. By measuring the arrival time of the reflected pulse, the depth of the slip surface can be determined.

(5) Other Methods

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

4.3.4 GROUNDWATER INVESTIGATION

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

(1) GroundWater Level Observation

As a general rule, groundwater levels should be measured in all the boreholes. In some of the more important boreholes, continuous rainfall data is kept by an automatic recorder to determine the correlation between the slide movement, rainfall and groundwater levels, and collects data on the groundwater distribution and movement regime.

(2) Pore Water Pressure

Groundwater levels in boreholes will often reflect seepage from highly fractured formations or indicate water levels of a predominant aquifer. Therefore, for stability analysis it is best to measure the pore water pressure along the slip surface. Sometimes it is difficult to accurately estimate the depth of the slip surface. In such cases it is desirable to install piezometers in the beds with low seepage or low shear strength. Standard piezometers used in landslide investigations must be durable, and be the open piezometer water level type (Fig. 4-11).

(3) Groundwater Logging

Locations of groundwater flow and flow directions can be determined by measuring the increasing specific resistance of groundwater in flow over time. The measurements will be continued lowering specific resistance of groundwater by injecting a salt solution into the borehole. There should be at least two borings for groundwater 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 groundwater flow and stratigraphic positions, and magnitude and variation of specific resistance of groundwater should be discussed. Furthermore, the results of the analysis should be recorded along with the geologic cross sections in order to understand the overall groundwater flow (Fig. 4-12).

(4) 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 3 m. A time-recovery curve can then be plotted using Jacob's and other formulas, and the coefficient of permeability can be determined.

(5) Geothermal Investigation

This procedure utilizes ground temperature measurements throughout the study area, including ground temperatures near the groundwater veins. By measuring the temperature differences at non-groundwater areas and near groundwater veins, it is possible to isolate the groundwater veins where the temperature difference between the two is largest. 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 groundwater.

(6) Other Methods

Following the injection of tracers such as soluble dye or inorganic chemicals (NaCl) into a borehole, water samples are collected chronologically from other boreholes and water discharging points (springs, ponds, and creeks). From such data, groundwater flow direction(s) and permeability can be estimated. Groundwater tracer

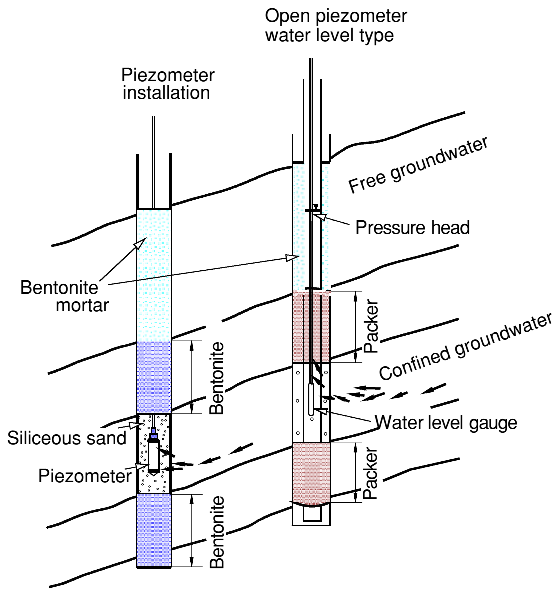

Fig. 4-11 Observation method of pore-water pressure

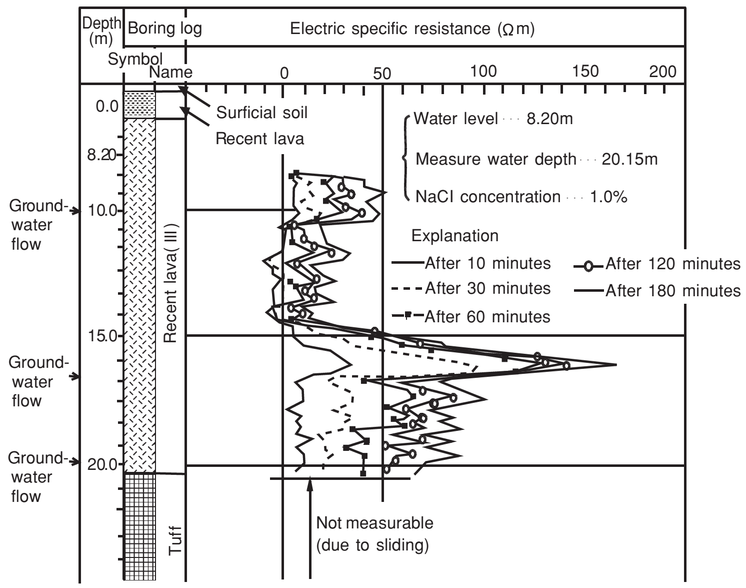

Fig. 4-12 Example of groundwater logging

tests and water quality tests are effective in examining the distribution of the groundwater regime and flow direction(s) where the subject landslide is very large and the groundwater system is expected to be complicated.

4.3.5 GEOTECHNICAL INVESTIGATION (SOIL-ROCK MECHANIC TESTS)

In order to conduct slope stability analyses and to design appropriate control measures for landslides, physical properties such as the strength of slip surface, location and depth of the slip surface 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 slip surface)) (Fig. 4-13). In order to obtain the earth reaction coefficient for the design of the landslide restraint measures, there is a current tendency to

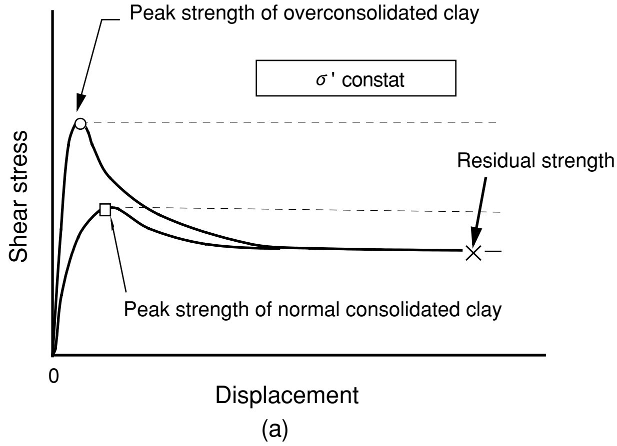

Fig. 4-13 Shear properties of normal and over consolidated clay

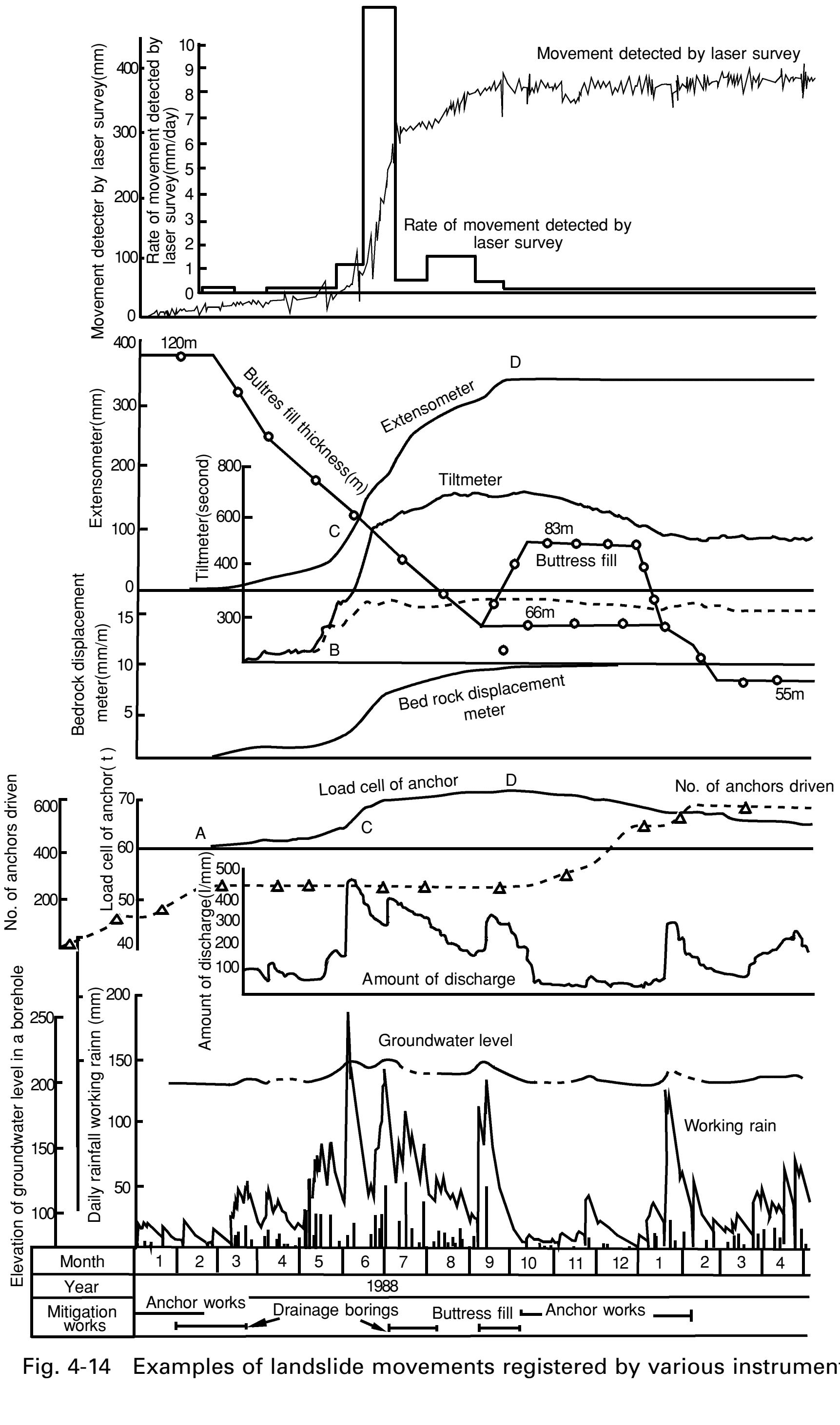

Fig. 4-14 Examples of landslide movements registered by various instruments

conduct more horizontal loading tests and plate loading tests to determine the modules of deformation. Furthermore, the intensity and degree of alteration of the slip surface clays are evaluated by X-ray diffraction methods. The results have also been applied to analyze the origin of the slip surface.

4.3.6 AUTOMATED MONITORING SYSTEM

In the past, measurements of slope deformation have been performed manually. More recently, automatic monitoring systems using data loggers and computers are being used. The instrument set-up in the field has been designed for easy installation, and is weatherproof, durable, maintenance-friendly and economical.

There are three main advantages in using the automated survey system :

1. Surveillance of the conditions of landslide : Issuance and cancellation of landslide watches and warning announcements based on the velocity of the movement, piezometric pressures and variations in the rainfall amounts. Prediction and forecasting of the landslide failure.
2. Understanding of the conditions of the landslide deformation : Chronological measurements of movement velocity. Determination of the slip surface depth. Determination of the relationship between the slope deformation and factors of slide occurrence (pore water pressure against the slip surface, critical pore water pressure related to the time of sliding, rainfall and snowmelt).
3. Effectiveness in determining landslide mitigation measures : Measurement of the amount of earth movement and pore water pressure. Measurement of the earth pressure affected by piles and drainage wells. Determination of the effectiveness of construction.

(1) Semi-Automatic Monitoring System

Semi-automatic systems manually collect data from the data-logger and data-center established at the site on a periodic basis. Data can be retrieved directly from the hard drive of the computer or the computer disc can be replaced.

(2) Full-Automatic Monitoring System

Full-automatic monitoring systems permit remote control in real time and rapid graphic data processing and display. It is possible to store long term data accurately and effectively and would provide early warning signs of slide activity, thereby reducing landslide hazards (Fig. 4-14). Furthermore, recent developments in the informationalized construction systems at construction sites using the real time facilitates safety control during construction. In recent years, landslide monitoring systems utilizing IT technology along with the existing full-automatic monitoring system and GIS has been developed (Fig. 4-15, 16).

4.4 PREDICTION OF LANDSLIDE

4.4.1 LANDSLIDE DISTRIBUTION MAP

Most of the new landslides 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 can be verified through field reconnaissance.

Furthermore, bedrock landslides and weathered bedrock landslides with past movement at the time of sliding is small, and

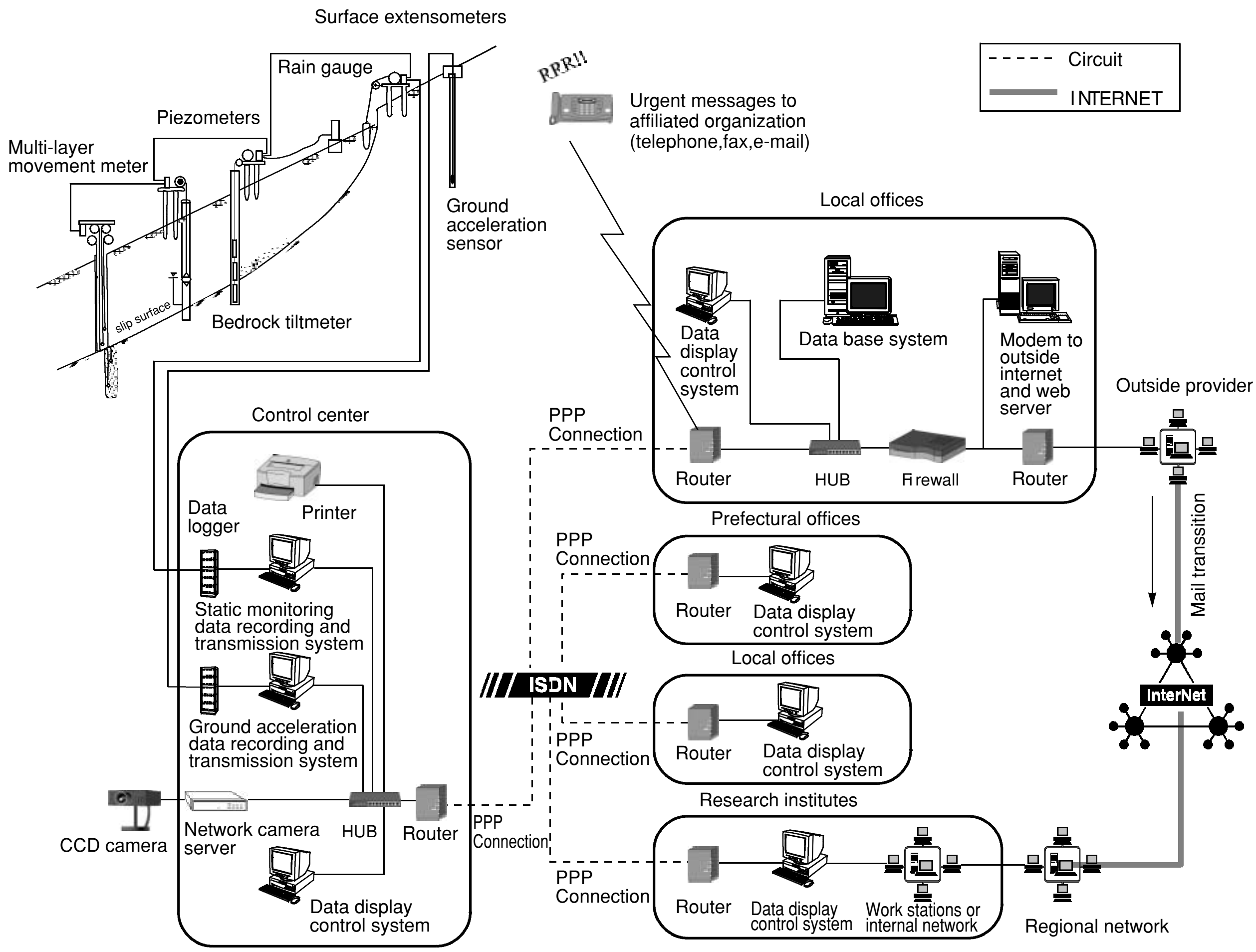

Fig. 4-15 Automated monitoring system using IT Technology

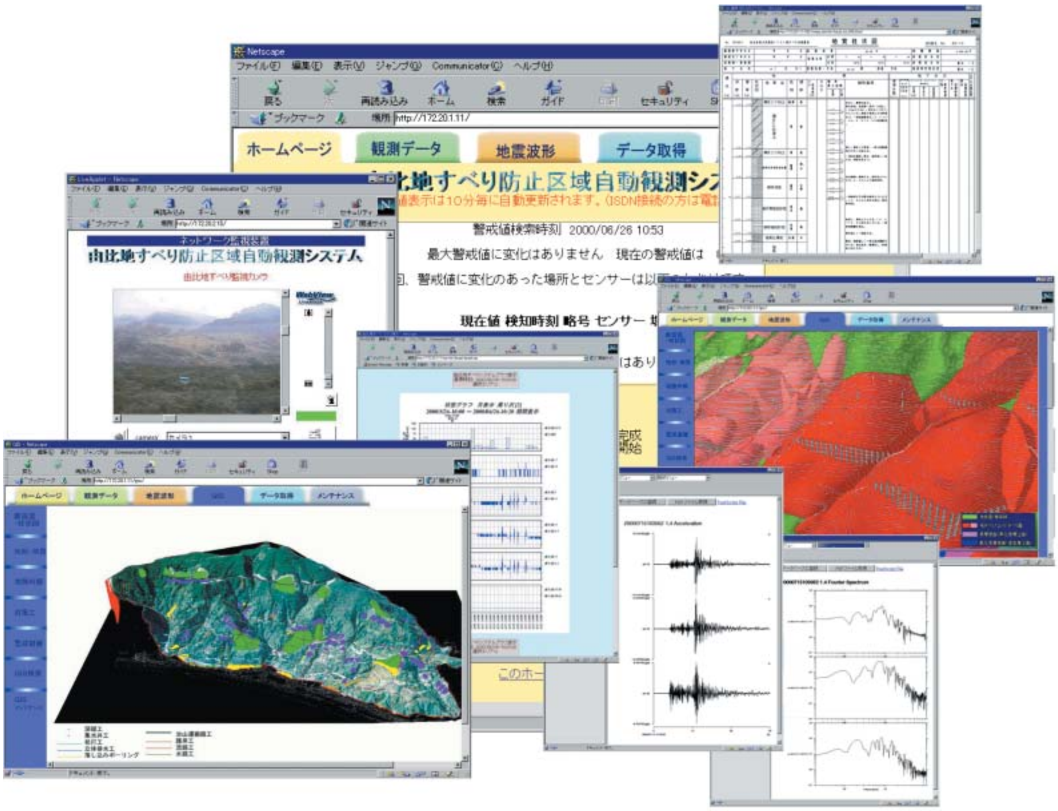

Fig. 4-16 Automated monitoring system combining with IT Technology and GIS System

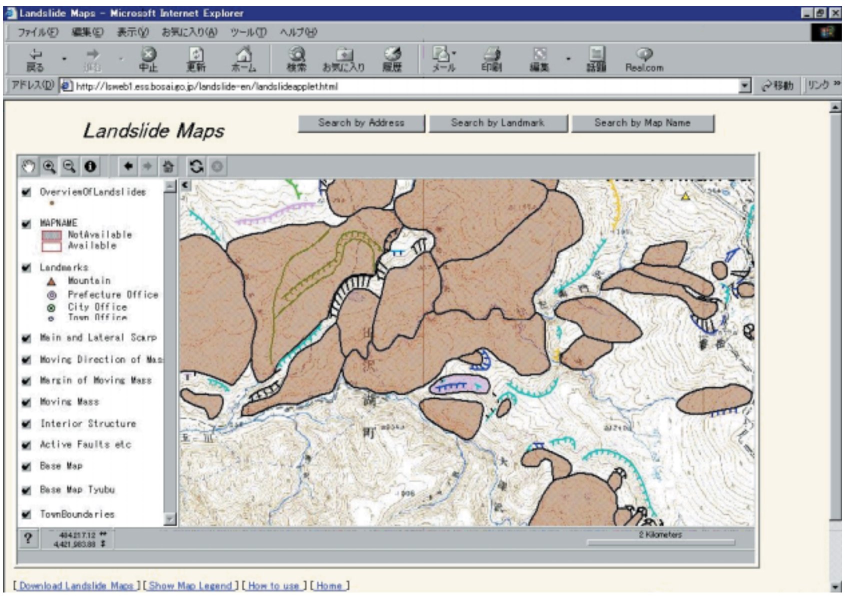

Fig. 4-17 Landslide map database available on website (http: //lsweb1.ess.bosai.go.jp)

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 deep 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. 4-17).

4.4.2 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 selected tension cracks of a slope. Failure predictions rely on extensometers placed across scarps, and affected areas are considered ”off-limits” when the rate of movement exceeds 2 to 4mm/hour. Based on the change in the rate of movement, the following methods are commonly used to predict the timing of landslide failune.

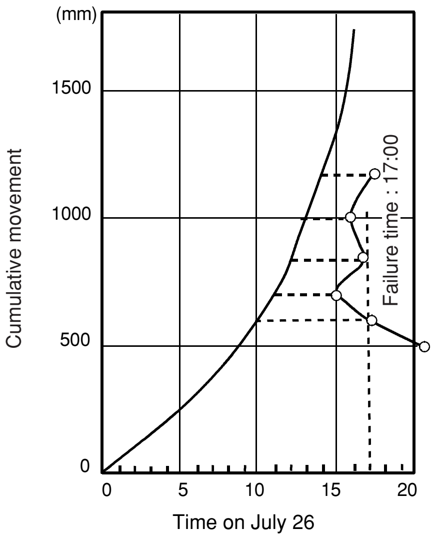

Fig. 4-18 Landslide prediction using Graphic solution of tertiary creep curve (Saito[1])

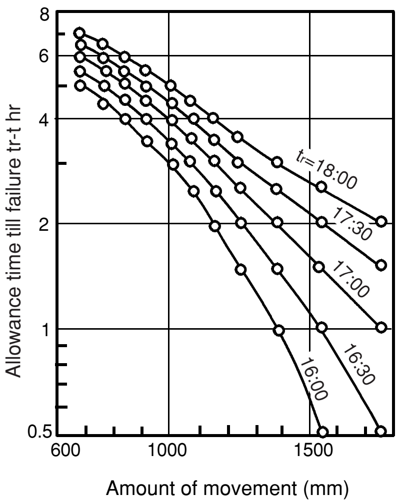

Fig. 4-19 Landslide prediction using Semi-logarithm (Saito[1])

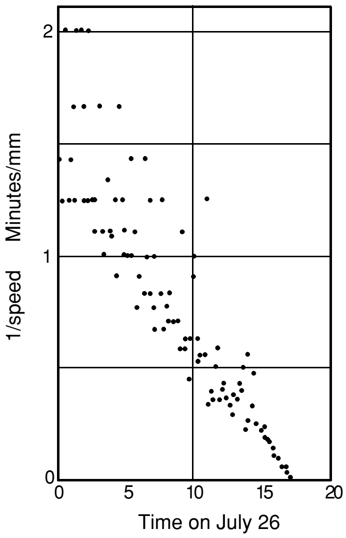

Fig. 4-20 Landslide prediction using inverse number of velocity (Fukuzono[2])

(1) Saito[1] Method

This method focuses on the third-stage creep of the strain velocity during the final stage of landslide failure. Graphic solution (Fig. 4-18) and semi-log solution (Fig. 4-19) have been proposed, and utilizes the inverse relationship between the strain velocity and the residual time of the failure. This method successfully predicted the failure of the Takabayama landslide along the National Railroad in Niigata prefecture. This was the first occurrence in the history of the world that the specific time of a failure was ever predicted.

(2) Fukuzono[2] Method

Based on large scale landslide simulation experiments with artificial rainfall, the surface displacement and the acceleration in failing masses show a straight line on a full logarithmic graph. Using the inverse curve relationship of the velocity, the "inverse prediction method" was proposed (Fig. 4-20). This method can be intuitively understood by not only the landslide specialists, but also the lay persons, and could be applied to predict the time of slope failures.

REFERENCES :

1) Saito, M. (1968) : Prediction of the time of slope failure by third-stage creep, Journal of Japan Landslide Society, Vol. 4, No. 3, pp. 2-8 (in Japanese).

2) Fukuzono, T. (1985) : A method to predict the time of slope failure caused by rainfall using the inverse number of velocity of surface displacement, Journal of Japan Landslide Society, Vol. 22, No. 2, pp. 8-13 (in Japanese with English Abstract and captions).

5. LANDSLIDE MITIGATION MEASURES

Landslide mitigation measures are conducted in order to stop or reduce the landslide movement so that the resulting damages can be minimized. Depending on the situations, the mitigation measures can be divided into two types ; emergency measures and permanent measures. Further, the mitigation measures are classified into two categories ; landslide control measures and landslide restraint measures. Although it is not a direct mitigation measure, a slope monitoring system has been adopted in order to reduce the landslide damages. For an emergency measures, dewatering is accomplished by employing surface drainage improvements, interceptor underdrains, and buttress fill.

The landslide control measures involve modifications of the natural conditions of landslides such as topography, groundwater, and other conditions that indirectly control the landslide movement. The restraint measures, on the other hand, rely on stopping the landslide movement by directly adding a resisting force to the sliding movement.

Specific measures included in the landslide control measures and landslide restraint measures are listed in Fig. 5-1.

Because of the abundance of rainfall, the landslide control measures in Japan are concentrated on groundwater and surface water control as they are the main causes of landslides. For naturally occurring landslides, groundwater is controlled by installing drainage wells and drainage borings ; surface drainage improvement will be implemented for surface drainage control. In particular, the utilization of control measures with emphasis on dewatering landslides whose movement tends to accelerate during the intense rain or snowmelt period, and where abundant groundwater and rainfall are present. The control measures are often employed during the emergency mitigation work. Landslide restraint measures should be utilized on landslides that contain little groundwater or where landslide movement cannot be controlled using dewatering procedures alone, or where construction related measures such as buttress fills and dams are anticipated to be submerge under water. Anchors, piles and large diameter cast-in-place shafts should be utilized as a permanent solution for slope protection and preservation. Retaining walls and slope restoration works can be incorporated with other landslide mitigation measures.

5.1 LANDSLIDE CONTROL MEASURES

5.1.1 SURFACE DRAINAGE CONTROL MEASURES

The surface drainage control measures are implemented to control the movement of landslides accompanied by infiltration of rain water and spring flows. The surface drainage control measures include two major categories : drainage collection and drainage channel works. The drainage collection is designed to collect surface flow by installing corrugated half pipes or lined V-ditches along the slopes, and then connecting them to the drainage channels. The drainage channels are designed to remove the collected water from the landslide zone as quickly as possible, and are constructed from the same materials as the drainage collection works. The surface drainage control measures are often combined with the subsurface control measures (Fig. 5-2, 5-3, Photo 5-1).

5.1.2 GROUNDWATER CONTROL MEASURES

The purpose of the groundwater control measures is to remove the groundwater within the landslide mass and to prevent the inflow of groundwater into the landslide mass from outside sources. The groundwater control measures include shallow and deep groundwater control measures.

(1) Interceptor Underdrains And Interceptor Trench Drains

These systems are most useful to remove shallow groundwater from up to 3 m below the ground surface. The interceptor un-

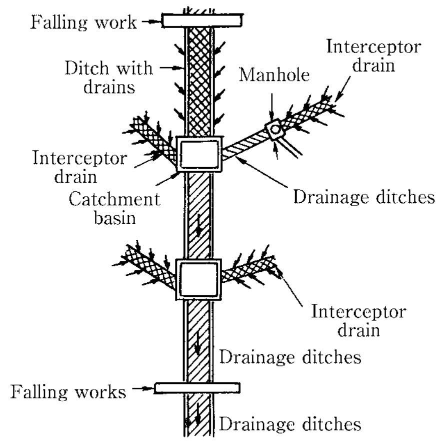

Fig. 5-2 Arrangement of ditches and interceptor drains

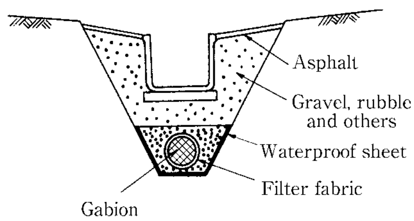

Fig. 5-3 Example of a drainage ditch with interceptor drain

- Landslide Control Measures
  - Surface Drainage Control
  - Groundwater Control
    - Shallow Groundwater Control
      (Interceptor Under Drains, Horizontal Gravity Drains, Interceptor Trench Drains)
    - Deep Groundwater Control
      (Horizontal Gravity Drains, Drainage Wells, Drainage Tunnels)
  - Earth Removal
  - Buttress Fill
  - River Structures
- Landslide Restraint Measures
  - Piles
  - Large Diameter Cast-in-Place Shafts
  - Anchors
  - Retaining Walls

Fig. 5-1 Landslide mitigation measures

Photo 5-1 Surface drainage ditches

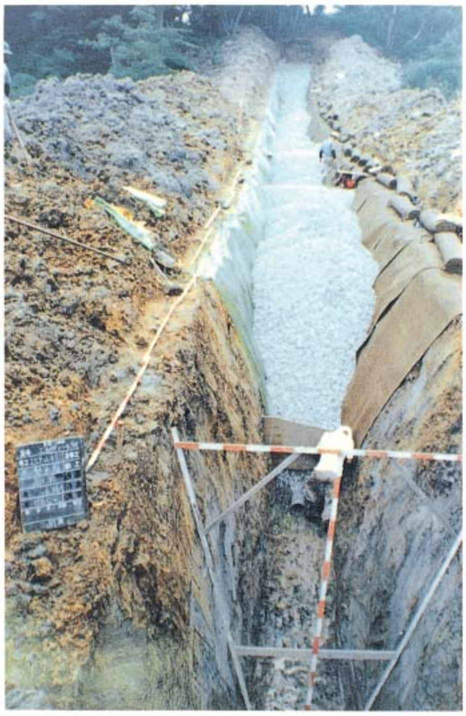

Photo 5-2 Interceptor trench drains

Photo 5-3 Horizontal gravity drains installation

derdrains contain impervious sheets at the bottom of the trench, and gravels are wrapped with filter fabric and the drains are connected at ground sils or catch basins (Photo 5-2)

Structurally, the interceptor trench drain is a combination of the interceptor underdrain and surface drainage control, and are commonly used (Fig. 5-3).

(2) Horizontal Gravity Drains

In order to remove groundwater, 30 to 50 m-long horizontal gravity drains are installed. The pipes could be either perforated P.V.C. (polyvinyl chloride) or steel construction, and are typically drilled at an angle of 5 to 10° from the horizontal line (Photo 5-3, 5-4).

(3) Drainage Wells

Drainage wells with a diameter of 3.5 to 4.0 m are excavated within areas of concentrated groundwater. A series of radially-positioned horizontal gravity drains are drilled at various elevations and collect the groundwater into the drainage wells. They are constructed of either steel or reinforced concrete segments, and concrete is used at the well bottoms and the upper portion of the well (Fig. 5-4, Photo 5-5, 5-6).

(4) Drainage Tunnels

The primary purpose of the drainage tunnels (which are constructed below the slip surface within a stable bedrock formation) is to remove collected water from within the landslide mass by interconnecting the drainage wells. 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 measure where numerous groundwater veins exist within the landslide mass. Furthermore, this work is most effective in maintaining the existing facilities.

Generally, the diameter of the tunnel is between 1.8 and 2.5 m, and the drainage channel is constructed along the invert (Fig. 5-5, Photo 5-7).

Photo 5-4 Outlet of horizontal gravity drain pipes

Photo 5-5 Drainage well using steel segments

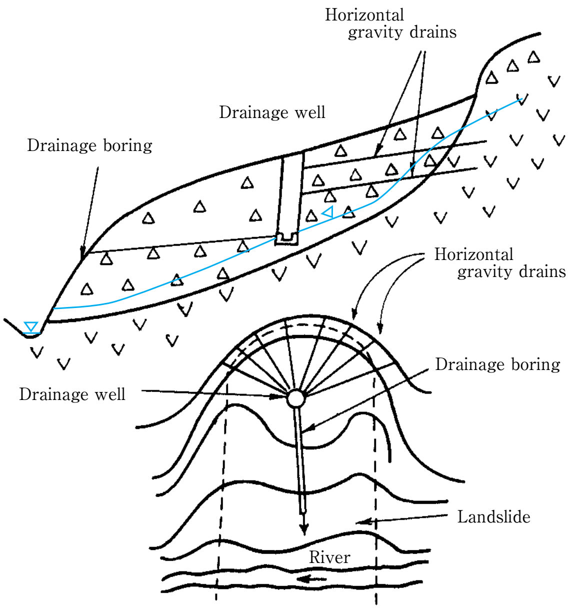

Fig. 5-4 Drainage well, horizontal gravity drains, drainage boring

Photo 5-6 Drainage well using reinforced concrete segments

5.1.3 EARTH REMOVAL

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 earth removal is focused on the head portion of the slide (Photo 5-8).

5.1.4 BUTTRESS FILL

The buttress fill is placed at the lower portions of the landslide in order to counterweigh the landslide mass. This method is often employed as an emergency measure. It is most effective if the soils generated by the soil removal works are used (Photo 5-9).

5.1.5 RIVER STRUCTURES

Degradation and channel bank erosion reduces earth stability and often tends to induce slide activity. In such cases, sabo dams, ground sils, revetments and other river structures can be constructed to prevent further erosion (Photo 5-10).

Photo 5-7 Inside of a drainage tunnel

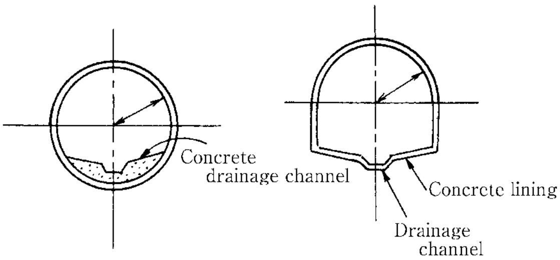

Fig. 5-5 Cross section of a drainage tunnel

Photo 5-9 Buttress fill

Photo 5-8 Earth removal

Photo 5-10 Sabo dam (check dam)

5.2 LANDSLIDE RESTRAINT MEASURES

5.2.1 PILES

Piles are driven into the pre-drilled shafts in order to tie the moving landslide blocks and the stable ground together. The piles are designed to resist shearing and bending stress, and generally consist of thick walled steel construction. The interior of the piles are filled with concrete (Photo 5-11).

5.2.2 LARGE DIAMETER CAST-IN-PLACE SHAFTS

The large diameter, cast-in-place shafts function similar to those of the piles and are also designed to tie the moving landslide and the stable ground together. However, this measure involves much larger diameters. Construction is similar to that of drainage wells, and generally consists of shafts with diameters of 1.5 to 6.5 m, and are then filled with reinforced concrete. Compared to the piles, the large diameter cast-in-place type are much more resistant to bending stresses (Photo 5-12).

5.2.3 ANCHORS

The anchors utilize the tensile force of anchor bodies embedded through the slide mass and into stable bedrock, and are connected to thrust blocks located on the ground 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 (Photo 5-13).

5.2.4 RETAINING WALLS

Retaining walls are constructed to prevent smaller sized and secondary landslides that often occur along the toe portion of the larger landslides. Because of the large-scale earth movement and numerous springs that are expected in landslide terrain, more flexible crib walls are common instead of conventional reinforced concrete retaining walls (Photo 5-14).

Photo 5-11　Pile driving

Photo 5-12　Installation of large diameter cast-in-place shafts

Photo 5-14　Crib walls

Photo 5-13　Completed anchor installation

6. RECENT REPRESENTATIVE LANDSLIDES AND SLOPE FAILURES IN JAPAN

This chapter introduces 27 representative landslide and slope failure cases that occurred recently in Japan. Most of the cases are "landslide or jisuberi", and "slide" as defined by the committee on glossary of geomorphology and geology, the Japan Landslide Society. The latitudes and longitudes described in this chapter are Japanese designations, and not the international designation.

6.1 JOZANKEI USUBETSU-GAWA LANDSLIDE

(1) Location : Jozankei, Minami-Ku, Sapporo-shi, Hokkaido ; Ishikari office of Okujozankei National Forest (42° 54' N, 141° 07' E)

(2) Size : Length : 700 ± m ; Width : 100 ± m (Max width 270 m) ; Area : 7ha ; Thickness : 10 - 30m ; Volume : 2.0 x 10^5 m^3.

This landslide is divided into three blocks : the Upper ; Middle ; and Lower Blocks. The width of the Upper Block is about 250m wide, and the Middle Block is about 100m wide. The Lower Block is a fan-shaped depositional zone.

(3) History and Damages : This landslide occurred on May 15, 2000. The Middle Block of the landslide, consisting of about 2.0 x 10^5 m^3, became a mudflow and the sediments dammed the Usubetsu -Gawa River. The flow continued for about 300m downstream.

(4) Geology, Mode of Movement : The geology of this landslide includes Miocene tuff breccia and tuff which are strongly altered by hydrothermal alteration and silicification. The ridge area is underlain by Pliocene andesite and pyroclastic rocks that are loose. There was an abundant snow accumulation in the year 2000 ; furthermore, prolonged and heavy rain during the snowmelt period caused excess surface water infiltration into the hydrothermally altered, weak, clay rich tuff breccia and tuff. This resulted in the failure of the lower portion of the Upper Block and the movement continued to the lower portion of the Middle Block. The continuous heavy rain critically increased the water content of the landslide mass and triggered the mud flow.

(5) Mitigation Measures : Mitigation measures were performed as a direct project by the Forestry Agency. Since the triggering mechanism was the increased groundwater level in the Upper and Middle Blocks, and some of the landslide mass remained. The mitigation measures included groundwater control and pile installation. For the Lower Block, which is a depositional zone of the sliding mass, soil retaining structures and piles were installed. Sediments deposited by the mud flow were removed, and river structures such as sabo dams and revetments were constructed along the Usubetsu River.

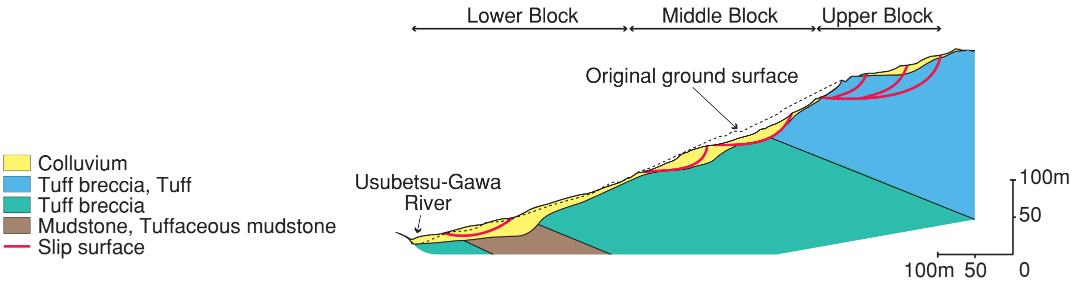

Fig. 6-1 Cross section of Jozankei Usubetsu-gawa landslide

Photo 6-1 Jozankei Usubetsu-gawa landslide (courtesy of F. Agency)

6.2 ROCK FALL AT DAINI SHIRAITO TUNNEL

(1) Location : Shimamaki-Mura, Shimamaki-Gun, Hokkaido ; National Highway, Daini Shiraito Tunnel south portal (42° 39' N, 139° 52' E)

(2) Size : Initial Fall : Max. Height : 130 ± m ; Max. Width : 70 ± m ; Max. Thickness : 20 ± m ; Volume : 4.2 x $10^4 m^3$;
Second Fall : Max. Height : 80 ± m ; Max. Width : 30 ± m ; Max. Thickness : 20 ± m ; Volume : 1.4 x $10^4 m^3$.

(3) History and Damages : On August 25, 1997 at about 14 : 30, the wall at the south portal of the Daini Shiraito Tunnel located along the National Highway failed. The fall damaged about 114m of spread-out and 12m of retaining wall, and covered a section of the highway about 120m wide. The debris reached the ocean which is located about 80m down slope. No one was injured and no other damages occurred other than that to the highway structures. The second fall took place three days after the initial failure.

(4) Geology, Mode of Movement : A 200 to 300m high cliff covers the site area which is composed of Pliocene inter-bedded tuff and water-cooled cataclastic rocks. Based on observations of the failed faces and debris, it is suspected that the initial fall took place after separation and dropped almost vertically, making striation marks on the parting faces and then landing at the gently sloping base of the cliff. The block then toppled and slid further down the slope. It is further suspected that multiple factors were involved over a long period in the formation and deterioration of the parting faces, including : (1) weathering of the bedrock by groundwater ; (2) its weight (gravity) ; (3) freezing and thawing ; and (4) earthquakes. Heavy rainfall immediately proceeding the failure could have affected the cause of the fall.

(5) Mitigation Measures : As part of the investigation for the recovery works of the damaged highway, a slope stability analysis was performed on the rock face, including the failed face, for a distance of about 1.7km. The results of the investigation revealed that there are numerous locations, including the subject site, that show a high possibility of further rock falls. In order to avoid future failures, a new tunnel has been constructed. The construction of the 1806m tunnel began in November 1997 and was completed on April 8, 1999.

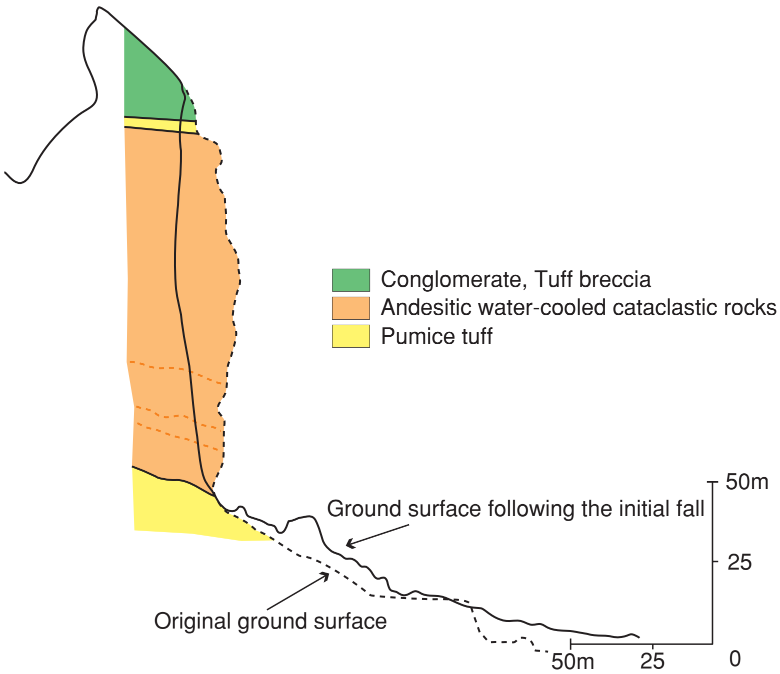

Fig. 6-2 Cross section of rock fall at Daini Shiraito Tunnel

Photo 6-2 Initial fall of rock fall at Daini Shiraito tunnel (courtesy of Ministry of L. I. and T)

Photo 6-3 Second fall of rock fall at Daini Shiraito tunnel (courtesy of Ministry of L. I. and T)

6.3 OIRASE LANDSLIDE

(1) Location : Shiribe-Yama National Forest, Towadako-Cho, Kamikita-Gun, Aomori (40° 31' N, 140° 58' E)
(2) Size : Length : 160m ; Width : 150m ; Area : 2.4ha ; Thickness : 20m ; Volume : 2.0 x 10^5m^3
(3) History and Damages : The landslide occurred on March 10, 1999. Earth materials mixed with large blocks of rock formation of about 2.0 x 10^5m^3 slid down slope and closed the National Highway. The debris also buried and closed the scenic Oirase River.
(4) Geology, Mode of movement : The geology of the site area consists of, from youngest to oldest : volcanic ash and pumice falls of the Towada Volcano ; tuff and welded tuff ; and Lower Quaternary, moderately hard siltstone, sandstone, and conglomerate. The slip surface is located at the contact between sandy siltstone and conglomerate (some within the mudstone which immediately overlies the siltstone). The welded tuff, although closed, shows well developed vertical columnar joints facilitating rain water and groundwater infiltration, and is suspected to be the cause of the slide. Further, an anticline axis near the main scarp contained a series of parallel joints that developed due to the tensile stress, providing conditions for easy groundwater infiltration. The lower sedimentary formation is comprised of siltstone with well developed lamina plane, and acts as an aquiclude. Due to the presence of anticline, the site area is in a dip-slope condition, which is a structural factor that also contributed to the sliding. Furthermore, it was determined that the immediate cause was accelerated snowmelt due to increasing temperatures in early March of that year resulting in groundwater infiltration into the bedding planes.
(5) Mitigation Measures : The mitigation measures include three levels of anchors, three drainage wells, earth embankments utilizing on-site materials to prevent future failures from the near vertical main scarp, and various surface drainage improvements.

Since the landslide is located within the Towada Hachimantai National Park, all of the anchor blocks have been buried for aesthetic reasons. Circulation mad from borings had been treated prior to discharge into the scenic Oirase River. Following field studies regarding the effect of noise caused by the construction works to birds and other wild life, construction was not performed during breeding periods.

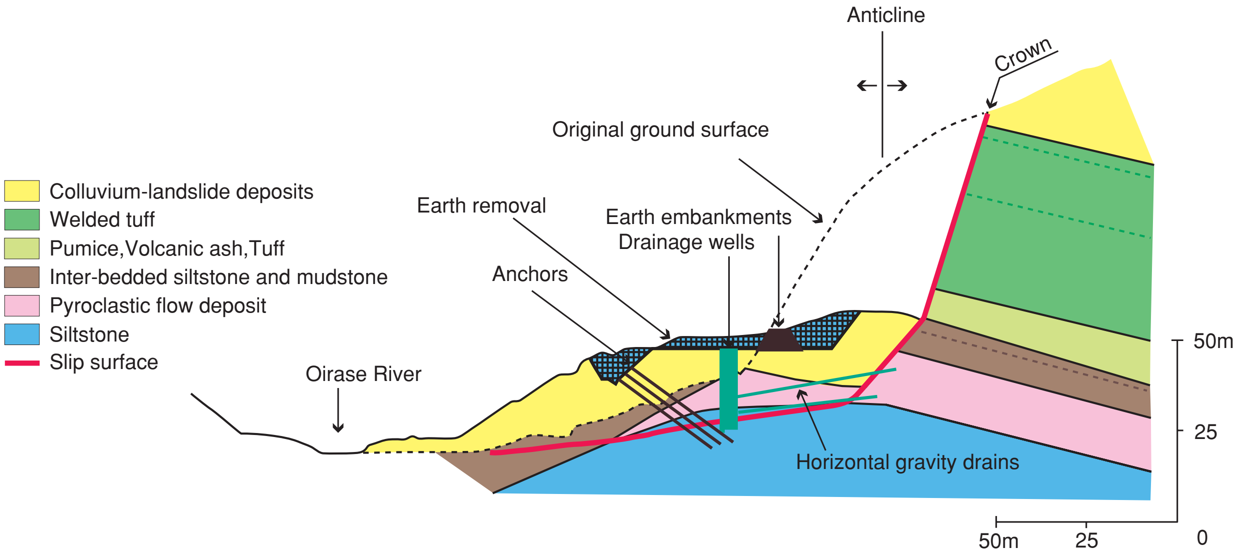

Fig. 6-3 Cross section of Oirase landslide

Photo 6-4 Oirase landslide (courtesy of F. Agency)

6.4 YAMADATE LANDSLIDE

(1) Location : Yamadate, Tawara, Esashi-Shi, Iwate (39° 11' N, 141° 14' E)

(2) Size : Length : 235m ; Width : 100m ; Area : 2.35ha ; Thickness : 15m ; Volume : 3.5 x $10^5 m^3$

This landslide is divided into two blocks : Upper Block and Lower Block. It appears that each block influences the other.

(3) History and Damages : There are no historical records for this landslide. The first landslide occurred suddenly on September 13, 1998, the second slide occurred on September 28, 1998, and the third landslide occurred on January 7, 1999. The first landslide buried and closed the main Prefectural Highway for a distance of 120 m and buried about two-third of the Ide River. The second landslide involved the head-ward enlargement of the first for 25m. The third landslide continued to enlarge head-ward for an additional 60m and completely blocked the Ide River. In all of the other landslides, the movement finished within several minutes.

(4) Geology, Mode of Movement : The site geology includes Upper Tertiary volcanic rocks consisting of tuff breccia dipping 15 to 20° toward the Ide River forming a dip-slope condition. The tuff breccia includes small cobbles of several centimeters to large boulders of several meters in diameter with thin tuff beds void of large particles. Advanced weathering in the tuff beds is evident, and tuff often turns into clay. The slip surface was found in one of the tuff beds.

It is suspected that the triggering mechanism of the first landslide is attributed to : (1) heavy rainfall between August 27 to 31 with total precipitation of 250mm ; and (2) Magnitude 6.1, Iwate Mountain Southwest Earthquake of September 3, 1998. It is also suspected that the third landslide occurred due to rapid snowmelt by off season heavy rain. In all cases, it is evident that the triggering mechanism was an unusual and rapid groundwater increase along the geological zones of weakness.

(5) Mitigation Measures : The mitigation measures were implemented as highway damages recovery works and erosion and sediment control works, including : (1) earth removal at the head area ; (2) dewatering by drainage wells ; (3) piles ; and (4) surface water drainage improvement.

The emergency recovery works conducted to maintain the flow in the river immediately following the third landslide were performed by unmanned equipment operated remotely and under close watch aided by monitoring of extensometers and pipe strain gauges.

Photo 6-5 Yamadate landslide area prior to sliding (courtesy of Iwate Prefecture)

Photo 6-6 Yamadate landslide following the first landslide (Sep. 13, 1998) (courtesy of Iwate Prefecture)

Photo 6-7 Yamadate landslide following the second landslide (Jan. 7, 1999) (courtesy of Iwate Prefecture)

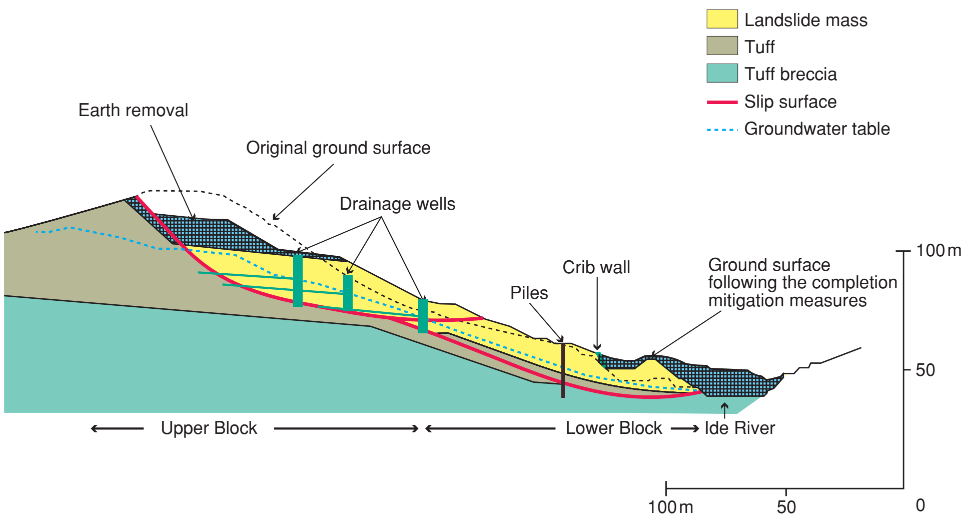

Fig. 6-4 Cross section of Yamadate landslide

6.5 SUMIKAWA LANDSLIDE

(1) Location : Kumazawa National Forest, Hachimantai, Kazuno-shi, Akita (39° 59' N, 140° 48' E)

(2) Size : Length : 800m ; Width : 400m ; Area : 19ha ; Thickness : 60m ; Volume : 6.0 x $10^6 m^3$

Based on the landslide morphology and distribution of major scarps, the landslide is divided into at least three blocks.

(3) History and Damages : Signs of landslide movement such as cloudy drinking water supplies and cracks on the road, appeared during the snowmelt period, around May 4, 1997. Following rainfall in excess of 100mm between May 7 and 9, major landslide movement occurred on May 10 around the 2 : 30 hour, destroying a bath house at a Sumikawa hot spring resort which is located within the slide blocks. On the following day, May 11, around 8 : 00 further movement completely destroyed nine residence halls. By then the landslide debris had turned into a debris flow and completely destroyed seven structures at another hot spring resort (Akagawa hot spring resort) located 1.2km down stream. The debris flow continued and buried a bridge of the National Highway. Fortunately, the 51 guests and employees of the resort were warned in advance and evacuated prior to the arrival of the debris flow.

(4) Geology, Mode of Movement : The geology of the site area consists of, from the youngest to the oldest : Quaternary andesitic lava ; Lower Quaternary altered clayey tuff ; Lower Quaternary-Upper Tertiary altered and hard white tuff. The slip surface developed within the altered clayey tuff, and boring samples at the slip surface and the exposed slip surface at the toe area exhibited slickensides. The slip-surface clay at the upper portion of the landslide exhibits a greenish color, while the lower portion exhibits a whitish color. Geothermal exploration near the Sumikawa Hot Spring indicates the existence of montmorillonite and chlorite at shallow depths. Therefore, it is suspected that the slip surface materials may contain the minerals above.

(5) Mitigation Measures : Since the landslide occurred within the National Forest, the Tohoku Regional Forestry Office was responsible for the majority of the mitigation works. Emergency mitigation measures were executed in a timely manner immediately following the landslide, and included construction of temporary drainage improvements to divert the flow, temporary surface drainage works and installation of drainage borings. As the site is situated within a geothermal region and the potential for toxic gases typically associated with volcanic activity exists, construction of drainage wells and drainage tunnels, which requires prolonged activities underground, were determined to be unfeasible for safety reasons. Thus, permanent measures for this landslide have emphasized the installation of piles, earth removal and placement of buttress fill. Furthermore, in order to prevent further discharge of accumulated landslide debris, construction of check dams and channel improvements were performed for the rivers affected by the debris flow.

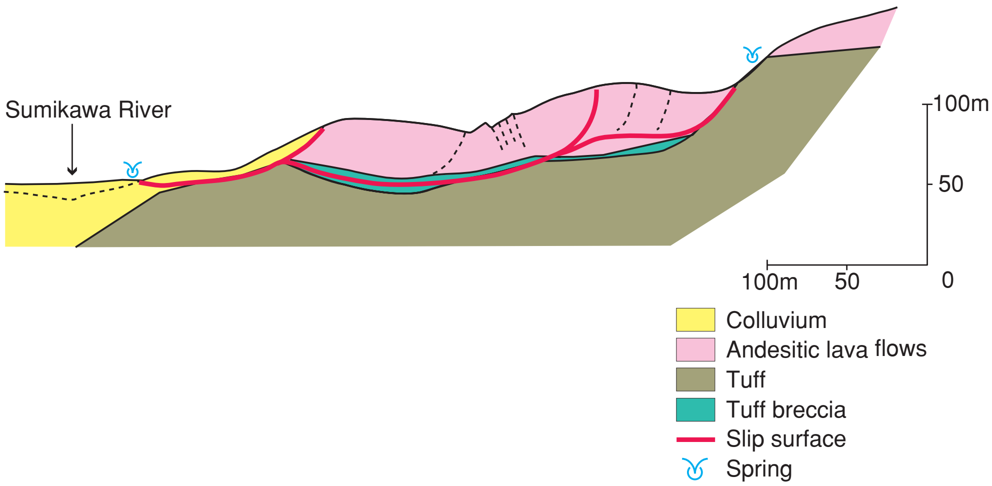

Fig. 6-5 Cross section of Sumikawa landlside

Photo 6-8 Sumikawa landslide (courtesy of F. Agency)

Photo 6-9 Deposition of debris and sediments by debris flow caused by Sumikawa landslide (courtesy of F. Agency)

6.6 HIRANE LANDSLIDE

(1) Location : Hirane, Tsunokawa, Tozawa-Mura, Mogami-Gun, Yamagata (38° 39' N, 140° 10' E)

(2) Size : Length : 200 - 1000m ; width : 350 - 800m ; Area : 301.9ha ; Thickness : 15 - 45m ; Volume : 1.55 x 10^7m^3

This landslide is divided into four blocks : the North ; the Central ; the Southeast ; and the South Blocks.

(3) History and Damages : Since the initial movement in 1899, movements repeated over a dozen times, and the movement was almost always during the snowmelt period. Most of the damages occurred on farm land and roadways ; however, landslides that occurred within the North Block in 1944 and 1974 involved damages to some residential structures. The head portion of the Southeast Block clearly indicates evidence of old scarps and displays hummocky topography.

(4) Geology, Mode of Movement : The site geology consists of Pliocene sandstone, mudstone and conglomerate which is unconformably overlain by Quaternary pyroclastic flow deposits of about 10,000 years old. This region receives heavy snowfall, and the average maximum snow accumulation between 1982 and 1998 was 338 cm. It is suspected that the triggering mechanism of the movement was increased pore water pressure along the slip surface within the weathered Pliocene sedimentary rocks as snowmelt water percolated through the unwelded pyroclastic flow deposits in April and May.

(5) Mitigation Measures : This landslide was designated as a Landslide Threatened Area in 1962, and mitigation works were administered by the Yamagata Prefectural Government. Since 1972, the National Government took over as a direct project. The typical mitigation measures include : drainage wells ; drainage tunnels ; horizontal gravity drains ; and surface drainage improvements. Drainage tunnels were constructed to remove groundwater at the Southeast Block, the largest of the four blocks which has a clear graben topography. The effect of the drainage tunnels is very evident as the groundwater table near the drainage tunnels has dropped 5 to 10m. At the North Block, a number of experimental underdrains were installed between 1999 to 2001 and show promising results.

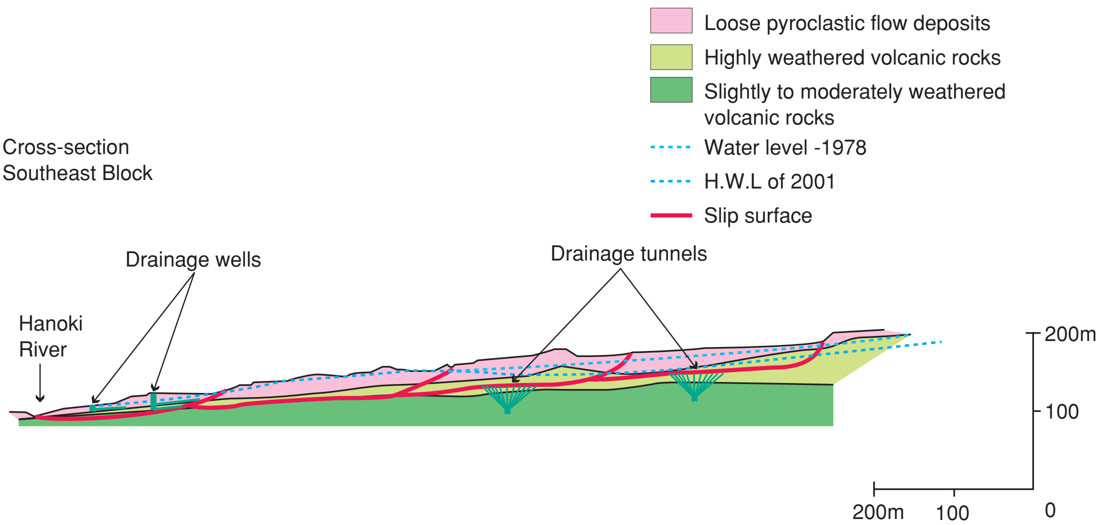

Fig. 6-6 Cross section of Hirane landslide

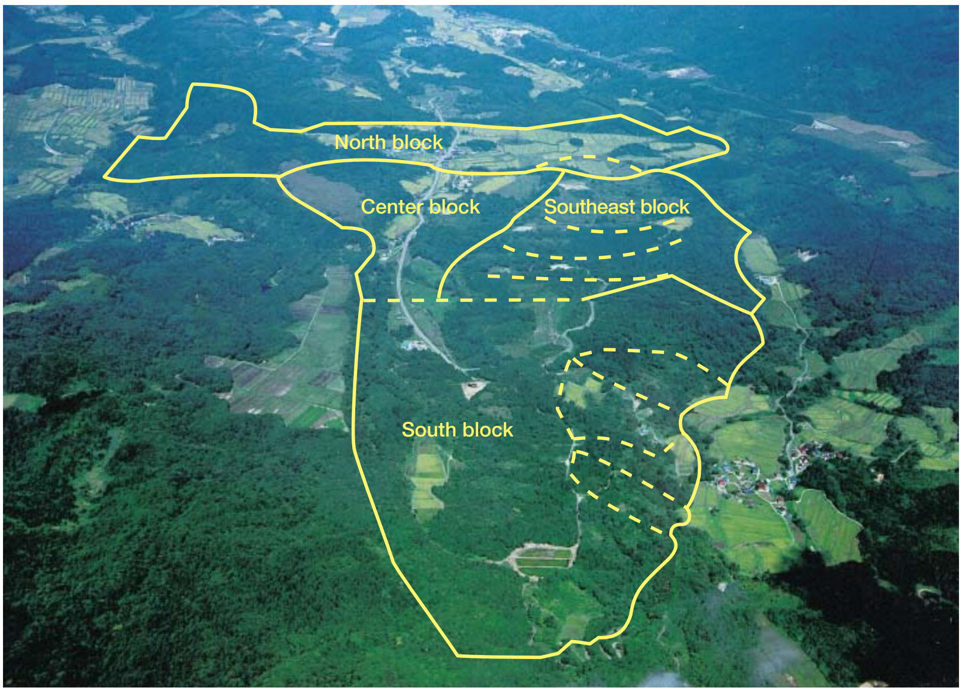

Photo 6-10 Hirane landslide (courtesy of Minstry of L. I. and T.)

6.7 DOZANGAWA LANDSLIDE

(1) Location : Minamiyama, Okura-Mura, Mogami-Gun, Yamagata (38° 38' N, 140° 12' E)
(2) Size : Length : 1200m ; Width : 1100m ; Area : 130ha ; Thickness : 110m ; Volume : 1.3 x $10^8 m^3$
(3) History and Damages : In recent years, landslide movements were observed in June 1966 and April 1981. The most recent large-scale movement occurred in May 1996. The affected area involves 130ha, and a portion of the National highway which traverses near the head of the landslide was destroyed. Numerous cracks and grabens have developed within the forest and farm land, disrupting the life of the residents and the local economy. Further, the 1996 landslide destroyed previously installed anchors and drainage wells. As the toe of the landslide mass reached and fell into the Dozan River, dangers of debris flow were seriously considered for the residents located in down stream areas. Fortunately, the movement slowed down in July and reduced the possibility of the debris flow.
(4) Geology, Mode of Movement : The topography of the site area includes volcanic, hilly terrain underlain by thick layers of pyroclastic flow deposits. Along the Dozan and Furumizu rivers, there is advanced erosion and dissection forming very steep cliffs. The site area is underlain by Upper Tertiary black mudstone and tuffaceous sandstone that is overlain by thick pyroclastic flow deposits which tend to lose cementation with increases in moisture content and then develops into loose rock mantle. Subsurface explorations including borings revealed that the upper beds of the Upper Tertiary sediments are incoherently mixed and highly sheared. From this information, it is clear that a slip surface exists within these beds, and as the slide movement continues, the moving masses are repeatedly deformed and sheared to the extent of turning the slide masses completely over. It is suspected that groundwater infiltrated into the slide mass through relatively porous pyroclastic flow deposits, promoting the weathering process and adding to its load thereby reducing the strength of the rock. With the presence of groundwater, shearing was initiated along the bedding planes and the landslide began. A landslide moving toward a lower elevation as the Dohzan River removed its support caused the development of a graben at the head portion the landslide. This condition produced instability to the main scarp and contributed to the development of retrogressive landslide.
(5) Mitigation Measures : The Yamagata Prefectural government administered the landslide mitigation works in the early stage of the work ; however, because of the magnitude of the mitigation measures involved, the Tohoku Regional Forestry Office of the Forestry Agency took over as a direct project since 1992. Immediately following the 1996 landslide, numerous pieces of monitoring equipment were installed to prevent the disasters associated with debris flows. Because of the enormous thickness of the landslide mass, the main thrust of the mitigation measures were centered on the groundwater control including drainage tunnels, drainage wells, drainage borings. In order to enhance the effectiveness, the above measures were combined and inter-connected 3-dimensionally. Due to the extra time required to complete the 3-dimenssional drainage networks, temporary emergency pumping has been employed to supplement the dewatering process until the proposed permanent works are completed.

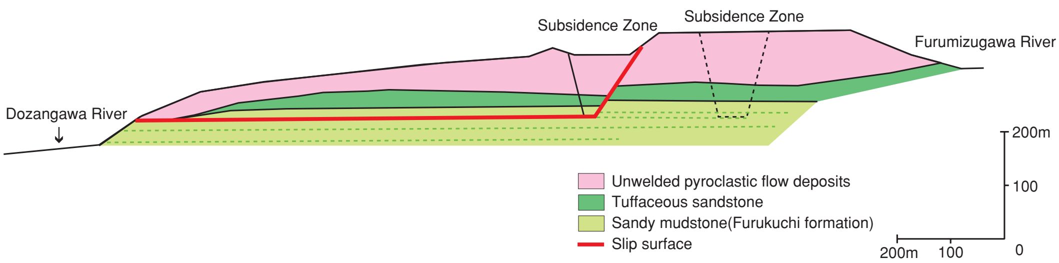

Fig. 6-7 Cross section of Dozangawa landslide

Photo 6-11 Dozangawa landslide (courtesy of F. Agency)

6.8 YUZURIHARA LANDSLIDE

(1) Location : Yuzurihara, Onishi-Cho, Tano-Gun, Gunma (36° 08' N, 139° 02' E)

(2) Size : Length : 600m ; Width : 1700m ; Area : 100ha ; Thickness : 40 - 50m ; Volume : 2.0 x 10^7m^3

This landslide is divided into three blocks : Kayakabu Upper ; Kayakabu Lower ; and Shimokubo Blocks.

(3) History and Damages : Record show that there were some movements prior to 1940. The records also indicate that residences were evacuated. In recent years, following the concentrated heavy rain brought by a typhoon in October, 1991, and in August, 1992, the landslide was reactivated and developed numerous cracks and scarps causing wide spread damages in residential structures, highways and other infrastructures.

(4) Geology, Mode of Movement : The site area is underlain by Mesozoic Era crystalline schist belonging to the Sambagawa Metamorphic Belt. The crystalline schist has well developed planar shistocity and joint faces. These structural surfaces form a dip-slope condition. Furthermore, numerous faults and shear zones exist throughout the belt. Such structural conditions with abundant rainfall promote deep weathering that facilitates the development of slip surface.

(5) Mitigation Measures : The Gunma Prefectural Government administered the mitigation works as a subsidy project until 1995. Since then, the National Government took over as a direct landslide mitigation project. The mitigation measures performed in the kayakabu Upper and Kayakabu Lower Blocks include : drainage tunnels, horizontal gravity drains, drainage wells and surface drainage control. In the future, it is planned to implement control works in the Shimokubo Block.

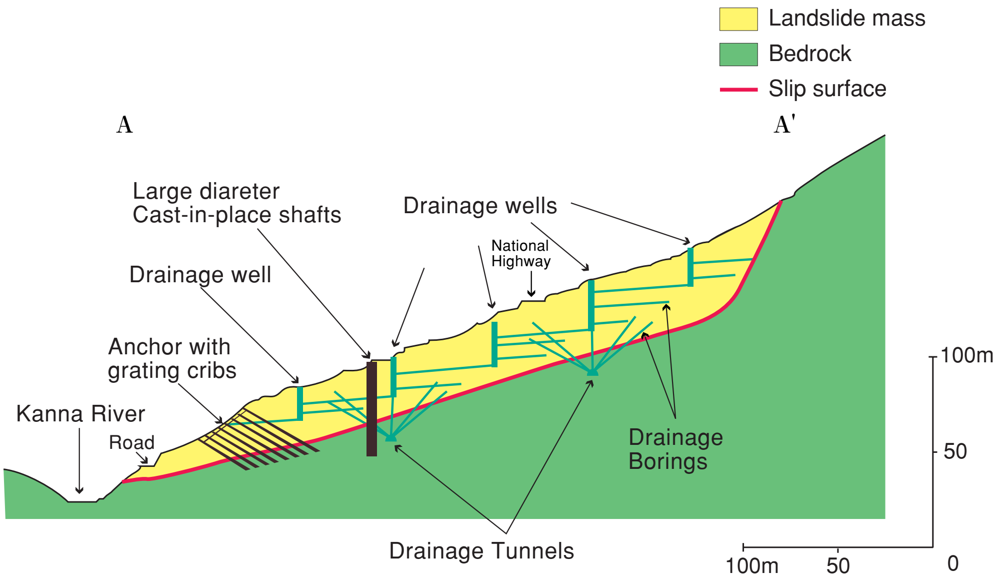

Fig. 6-8 Cross section of Yuzurihara landslide

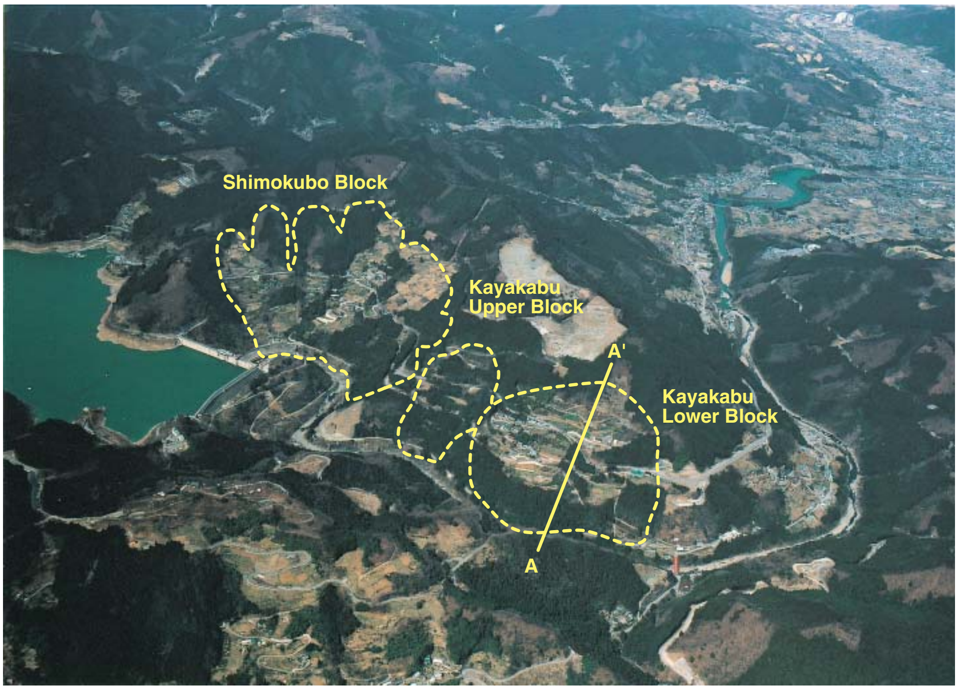

Photo 6-12 Yuzurihara landslide (courtesy of Ministry of L. I. and T.)

6.9 IYOGATAKE LANDSLIDE

(1) Location : Arakawa-Higurinaka, Tomiyama-Cho, Awa-Gun, Chiba (35° 06' N, 139° 55' E)

(2) Size : Length : 300m ; Width : 100m ; Area : 3.5ha ; Thickness : 34.5m ; Volume : 1.5 x $10^5 m^3$

Based on the morphology, this landslide is divided into four blocks : Upper ; Middle ; Lower ; and Channel Blocks.

(3) History and Damages : The landslide was induced by intense rain in excess of 330mm/day during Typhoon No. 17 in September 22, 1996. The failed landslide mass turned into a debris flow. The flow dissected forest roads, scouring the channel banks and beds for 80m. Although no injuries or damages were sustained from this flow, the possibility of damages by subsequent debris flows to the down stream areas was very high.

(4) Geology, Mode of Movement : The geology of the site area consists of Upper Tertiary inter-bedded sandstone and mudstone. The fracturing and shearing from a complicated geologic structure promoted accelerated alteration and weathering in the Upper Tertiary sedimentary rocks. It is speculated that the accelerated geologic process probably promoted the conditions susceptible to the landsliding.

The lower section of the Upper Block which had been subjected to past movement failed, and this failure may be the immediate cause of the landslide. The Middle Block had been stable due to the previous mitigation measures ; however, the intense rain by the typhoon caused an increase in the pore water pressure. Furthermore, sliding of landslide masses from the Upper Block on to this block added weight, thereby reducing the stability of the Middle Block. The combined factors contributed to the movement of the Middle Block.

(5) Mitigation Measures : Considering the landslide morphology, a design safety factor of 1.10 was established. Combined mitigation measures of control measures and restraint measures have been adopted.

The improvement of the safety factor was attempted by earth removal from the head portion of the Upper Block and supplemented by dewatering. For the Middle Block, an increase in the safety factor was accomplished by installing four drainage wells supplemented by three rows of steel piles. Mitigation measures in the Lower Block included earth retaining structures, sabo dams, and ground sils to prevent further movement of earth materials.

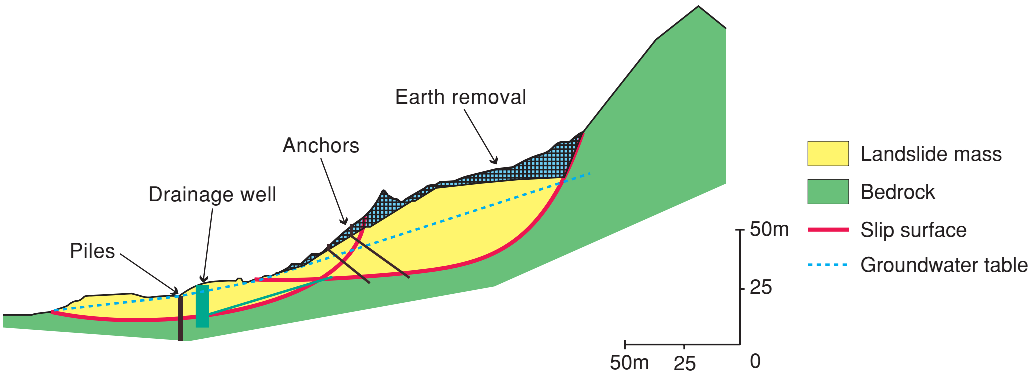

Fig. 6-9 Cross section of Iyogatake landslide

Photo 6-13 Iyogatake landslide (courtesy of Chiba Prefecture)

Photo 6-14 Iyogatake landslide following the completion of mitigation measures (courtesy of Chiba Prefecture)

6.10 OHRISAWA LANDSLIDE

(1) Location : Sawajiri, Kouzushima-Mura, Tokyo (34° 12' N, 139° 08' E)

(2) Size : Length : 70m ; Width : 40m ; Area : 0.3ha (Landslide Threatened Area : 22.92ha) ; Volume : 2.8 x $10^4 m^3$

(3) History and Damages : An earthquake of Magnitude 6.4 occurred on July 1, 2000, and total rainfall of 291mm was recorded between the 7 and 8 of July with a maximum rainfall intensity of 52mm/hour. Furthermore, on July 9, another earthquake of Magnitude 6.0 with a series of after shocks induced failure at the toe portion of the landslide with cracks and scarps along the head area. Part of the debris derived from the failure caused serious damage to the resort hotels.

(4) Geology, Mode of Movement : The region is a large Landslide Threatened Area with relief of 10 to 278m from the beach to the ridge line. The terrain is divided into two zones : (1) the upper steep terrain with an average slope of 35° along the highway ; and (2) lower gentle slopes with average gradients of 10° to 20°. The landslide blocks which make up the upper slopes show a little disturbance by the slide movement. The results of the subsurface exploration with borings indicate the materials consist mainly of weathered volcanic ash and volcanic cobbles with an N-value of up to 30. The lower slopes below the highway are far more disturbed than the blocks of upper slopes. The boring logs indicate that the materials mostly consist of colluvium-landslide deposits with an N-value of up to 10. The borings also reveal that the site area is underlain by multiple layers of paleosols inter-bedded with colluvium-landslide deposits.

(5) Mitigation Measures : Since the site required immediate stabilization of the affected area, landslide control measures have been used. Landslide control and restraint measures have been utilized for selected economically and socially important landslide blocks. Considering the prevention of the failures in front of the affected blocks, restraint measures, including combined anchor-grating crib, were implemented.

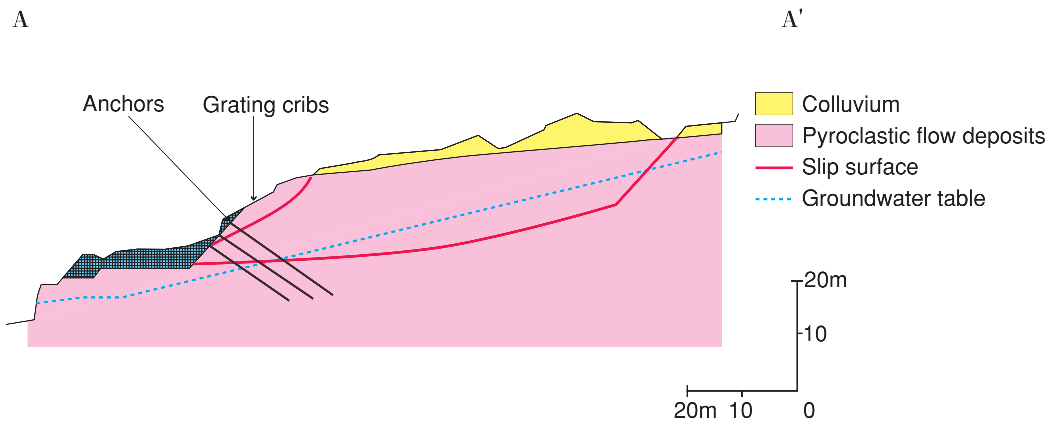

Fig. 6-10 Cross section of Ohrisawa landslide

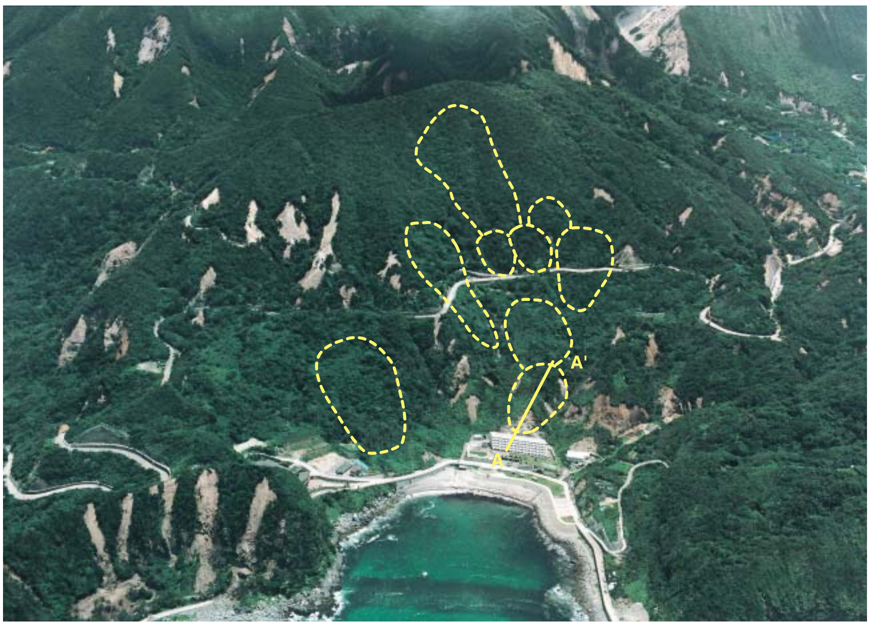

Photo 6-15 Ohrisawa landslide (courtesy of Tokyo Metropolitan Government)

6.11 SORAKUMASHINDEN LANDSLIDE

(1) Location : Sennoh, Noh-Machi, Nishikubiki-Gun, Niigata (37° 06' N, 138° 02' E)
(2) Size : Length : 260m ; Width : 280m ; Area : 7.28ha ; Volume : $2.9 \times 10^6 \pm m^3$
(3) History and Damages : The landslide occurred on March 17, 1997. Damages include 430m of roadway, 430m of water main, 0.3 ha of farm land, and 680m of channels.
(4) Geology, Mode of Movement : The site area is underlain by Pliocene gray mudstone inter-bedded with thin, occasional, fine- to medium-grained sandstone beds. The upper portion of the formation consists mainly of inter-bedded mudstone and medium-grained sandstone. The overall structure of the mudstone includes advanced fragmentation and softening, and often exhibits onion-skin weathering. Such weathered mudstone is soft and friable.

The geologic structure in the region is controlled by a syncline located east of the landslide, and at the site the mudstone beds are dipping about 20° to the east. Reflecting such geologic structure, the site area represents cuesta topography, and more landslides occur on the left side of the river due to the dip-slope structure.

This region is underlain by numerous old landslides, and the subject landslide is a reactivation of a much larger, older landslide. It is suspected that heavy rainfall followed by rapid snowmelt in late November to early December of 1996 supplied an enormous amount of groundwater, thereby reactivating a part of an old landslide block.

Based on the height of the main scarp and size of the graben in the mid portion of the landslide, it is estimated that the vertical displacement is on the order of 10 to 15m. The horizontal displacement is estimated to be a maximum of 30m where sediments were produced by the movement of toe. This indicates that this landslide has an unusually large vertical displacement compared with other landslides that occurred on these Tertiary sedimentary rocks.
(5) Mitigation Measures : The mitigation measures focused on dewatering as the excess water within the landslide mass was the immediate triggering mechanism of this landslide. The mitigation measures included : a drainage well, horizontal gravity drains, surface drainage improvements and erosion prevention in order to enhance the overall stability of the landslide.

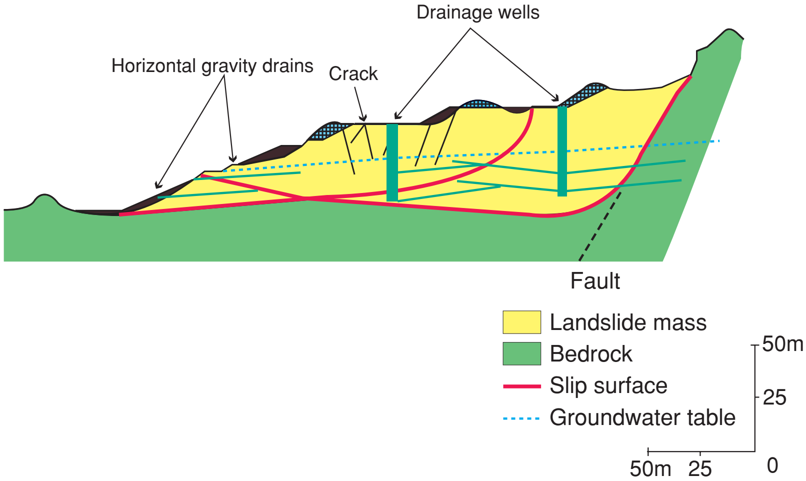

Fig. 6-11 Cross section of Sorakumasinden landslide

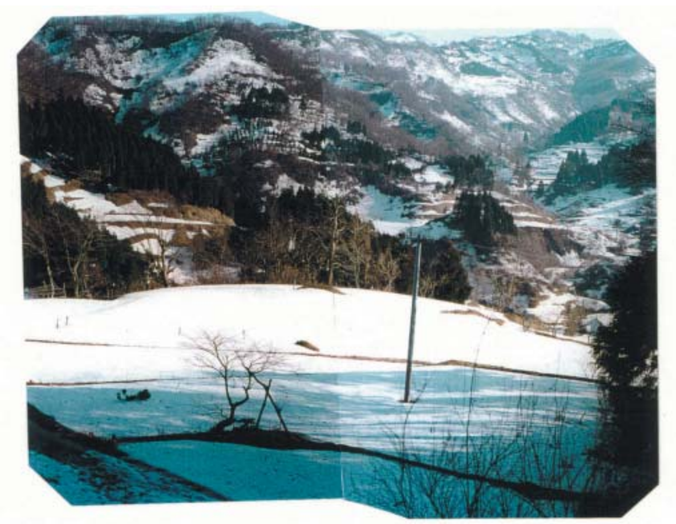

Photo 6-16 Sorakumashinden landslide prior to the sliding (Mar. 13, 1997) (courtesy of Niigata Prefecture)

Photo 6-17 Sorakumashinden landslide following the sliding (Mar. 17, 1997) (courtesy of Niigata Prefecture)

6.12 KINYUBA LANDSLIDE

(1) Location : Kamifunakura, Yasuzuka-Cho, Higashikubiki-Gun, Niigata (37° 05' N, 138° 30" E)

(2) Size : May 6, 1996 landslide : Length : 350m ; Width : 150 m ; Area : 5.3ha ; Thickness : 17m ; Volume : 9.0 x $10^5 m^3$

August 12, 1996 landslide : Length : 250m ; Width : 130m ; Area : 3.3ha ; Thickness : 17m ; Volume : 5.5 x $10^5 m^3$

(3) History and Damages : The May 6, 1996 landslide damaged a 150m section of the roadway. The landslide mass had very high water content and was very fluid. The fluid landslide mass traveled down 900m along the Funakura River, filling the river with debris, and buried three sabo dams and destroyed one bridge. The August 12, 1996 landslide moved 80m in response to the instability created by the May 6 landslide. An additional 200m section of the roadway was also destroyed.

(4) Geology, Mode of Movement : The site area is underlain by Upper Tertiary black mudstone that is overlain by 10 to 20m of thick clayey colluvium with mudstone fragments. The contact between the bedrock and colluvium is clear at the upper and the central portions of the landslide, however, the contact is not well defined at the lower portion. It is suspected that the slip surface exists near the contact between the bedrock and the colluvium. The groundwater table is located between the bedrock and the slip surface. The groundwater in the lower half of the landslide mass is confined. The structural geology of the site area is monocline dipping to the northwest at 20 to 30°, forming a dip-slope structure.

The triggering mechanism of the May 6 landslide is attributed to be the increase in pore water pressure due to excess water infiltration into the landslide mass from snowmelt water. As discussed, the water content of the landslide mass was extremely high and very fluid due to the abundant and continuous supply of water from the snow pack. On the other hand, the August 12 landslide was triggered by the 20 to 30m scarp formed by the May 6 landslide. This created a very unstable condition for the up slope area which finally failed.

(5) Mitigation Measures : Mitigation measures for the May 6 landslide include ground sils and earth retaining structures to prevent further flow of the colluvium ; surface drainage improvements to prevent surface water from entering into the landslide blocks ; and cast-in-place grating cribs to prevent weathering of the exposed bedrock. Drainage wells, horizontal gravity drains and piles were installed for the unstable area above the main scarp. Mitigation measures for the August 12 landslide are focused on dewatering around the slip surface with horizontal gravity drains and surface drainage improvements. The large quantity of sediments-debris flow into the river was removed as a "Disaster Related Emergency Erosion and Sediment Control Project" and a series of ground sils were constructed.

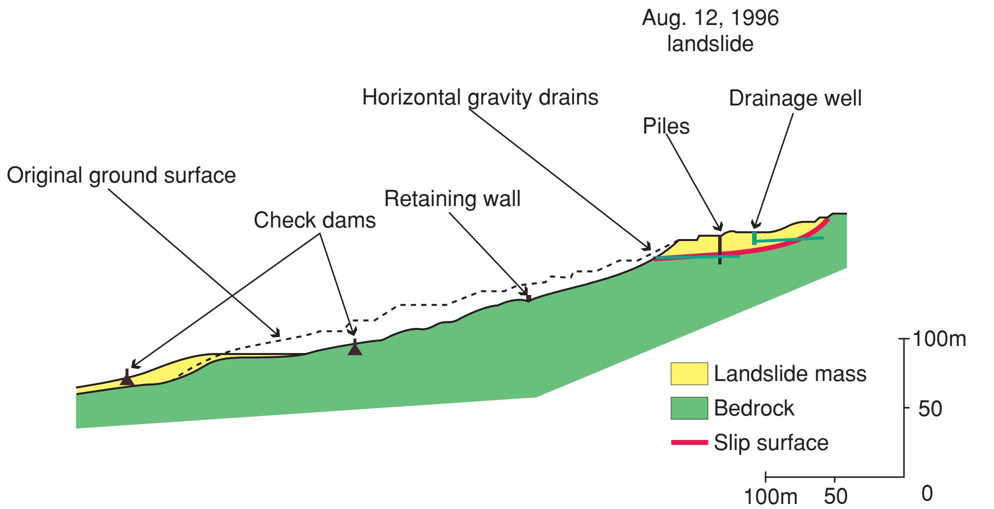

Fig. 6-12 Cross section of Kinyuba landslide

Photo 6-18 Kinyuba landslide (May 6, 1996) (courtesy of Niigata Prefecture)

Photo 6-19 Kinyuba landslide following the second landslide (Aug. 12, 1996) (courtesy of Niigata Prefecture)

6.13 KUWANOKIDAIRA LANDSLIDE

(1) Location : Ohmogidaira, Yasuzuka-Cho, Higashikubiki-Gun, Niigata
(37° 02' N, 138° 29' E)

(2) Size : Length : 430m ; Width : 80m ; Area : 3.42ha ; Thickness : 10m ; Volume : $1.3 \times 10^5 m^3$

This slide is divided into two blocks : Upper Block and Lower Block.

(3) History and Damages : This is a partial reactivation of an existing very large older landslide. Previous mitigation measures for the older landslide include pile driving in 1986 at the lower portion of the landslide following the completion of a major forest road. On April 29, 1999, due to a rapid snowmelt caused by warm temperature and rainfall reactivated a portion of a large landslide. The slide movement damaged sections of the forest road and previously installed piles. The slide debris dammed the Oguro River, destroying the existing dam and flooding upstream areas.

(4) Geology, Mode of Movement : The site area is underlain by Upper Tertiary sandy mudstone including inter-bedded black mudstone and sandstone, ryolitic tuff, blocky black mudstone and blocky siltstone. Because of the age, the sandy mudstone is not well lithified and easily weathers and becomes clay. The geologic structure of the site area is complicated as an east-northeast to west-southwest trending Takaba fault runs near the site. Factors contributing to the partial reactivation of the older landslide include : (1) The site is underlain by soft clayey soil ; (2) This is one of the most famous regions for snow and up to 5m of snow fall ; (3) Higher mountains continue upslope providing topographic conditions for concentrated groundwater accumulation ; and (4) Recently, unused rice paddy fields have increased in the region. The neglected clay liner of the paddy fields permits the infiltration of surface water into the existing landslide mass, developing cracks and small scarps. As discussed, this failure represents the reactivation of larger and older landslide (Length : 400m ; Width : 250m).

(5) Mitigation Measures : The mitigation measures for the Upper Block include : two drainage wells ; 60 piles ; and horizontal gravity drains at six locations. The mitigation measures for the Lower Block include : revetments, check dams, seven earth retaining structures, earth removal, interceptor underdrains, and channel improvements. The exposed slopes are protected and stabilized by log grating cribs and terracing with logs and re-vegetated with the aide of straw mats.

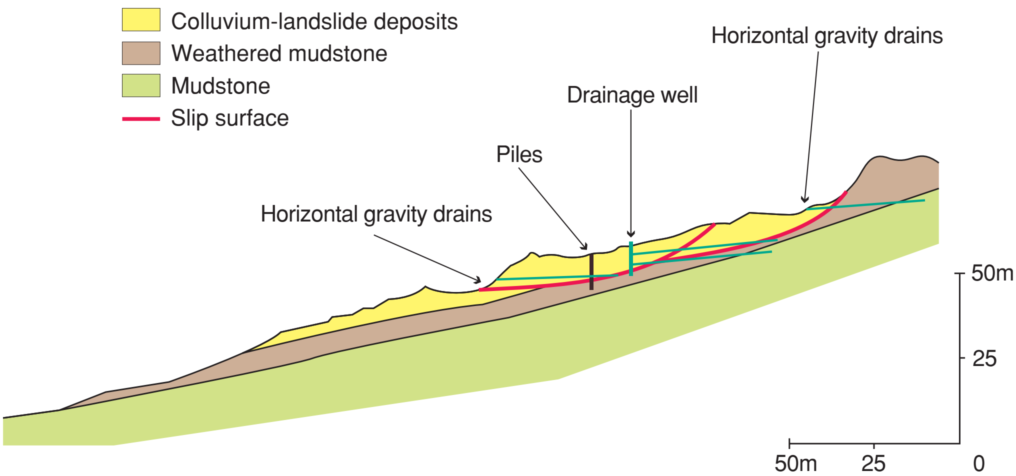

Fig. 6-13 Cross section of Kuwanokidaira landslide

Photo 6-20 Kuwanokidaira landslide (courtesy of F. Agency)

Photo 6-21 Kuwanokidaira landslide following the completion of mitigation measures (courtesy of F. Agency)

6.14 KURASHITA LANDSLIDE

(1) Location : Hakuba-Mura, Kitaazumi-Gun, Nagano (36° 43' N, 137° 51' E)

(2) Size : Length : 800m ; Width : 800m ; Landslide Threatened Area : 78.64ha ; Thickness : 60m ; Volume : 3.2 x $10^7 m^3$ This landslide is divided into five blocks : Block A through Block E.

(3) History and Damages : Some deformation including cracks were observed on revetments along the Matsukawa River in 1995. Further examination of up slope areas revealed landslide related deformation on roads and retaining walls.

(4) Geology, Mode of Movement : The site is located adjacent to the Fossa Magna (Itoigawa-Shizuoka Tectonic Line), a major tectonic boundary in Japan. Therefore, the region has been subjected to repeated episodes of tectonic activity since the Permian Period, and exhibits a very complicated geologic structure. The landslide area is underlain by Jurassic shallow marine deposits, and quartz andesite co-exists with the Lower Tertiary welded tuff. Marine deposits composed of Permian to Triassic shale, sandstone, and conglomerate deposited on top of the basement rock of serpentine melange. Following deposition, continuous tectonic activities, including faulting, mixed the sedimentary rocks and the serpentine melange together. The Lower Tertiary welded tuff unconformablly overlies the older rocks. Block A, the most active part of the landslide, is underlain entirely by the welded tuff with a maximum thickness of 60m. Block D, which includes Block A and Block B, does not appear to be active at this time. However, based on the geologic investigation it is suspected that the slip surface is located within the Jurassic marine sedimentary rocks.

(5) Mitigation Measures : Since the maintenance of the Matsukawa River is a direct erosion and sediment control project of the National Government, buttress fill was added onto the existing revetment in 1997 by the National Government. Drainage tunnels, drainage wells and horizontal gravity drains were added upslope as landslide mitigation measures. The 455m drainage tunnel was constructed by NATM method, and with a system of drainage wells discharging several hundred liter per minute.

Hakuba-Mura (meaning village of white horses) on which the landslide is located was the site of the 1998 Nagano Winter Olympic Games. This area offers various winter sport events such as the ski jump and alpine skiing, and is visited by many skiers and tourists year around. The landslide area is located opposite the Happou-one Ski Resort that was the site of downhill competitions during the Olympics. This region is commonly called "Donguri-Mura or Acorn Village" with numerous hotels and condominiums.

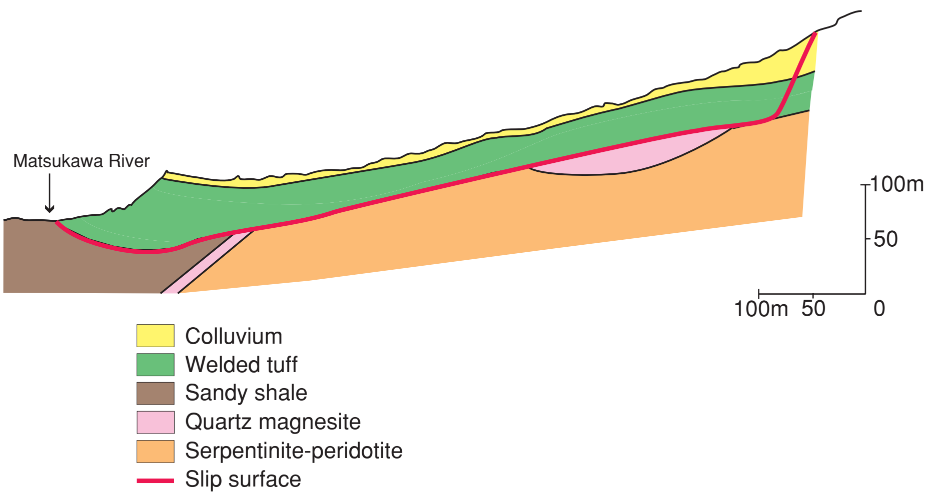

Fig. 6-14 Cross section of Kurashita landslide

Photo 6-22 Kurashita landslide (courtesy of Nagano Prefecture)

6.15 SHIOMOTO LANDSLIDE

(1) Location : Takefusa, Shinshu Shin-Machi, Kamiminochi-Gun, Nagano (36° 33' N, 138° 01' E)
(2) Size : Length : 360m ; Width : 250m ; Area ; 6.05ha ; Thickness : 43m ; Volume : 2.0 x $10^6 m^3$

This is a partial reactivation of a larger and older landslide. There are shallower secondary landslide blocks within the reactivated landslide.

(3) History and Damages : The historical records indicate there was a large-scale movement during the Edo Period (1603 - 1867). The records also show that there was wide spread damage to structures and the landslide mass extended to the river. In recent years, as the landslide moves continuously, damage occurs to roads, farmland (mostly on rice paddy fields) and structures by cracking and other deformations associated with the landslide movement.

(4) Geology, Mode of Movement : The site area is situated at the northern Fossa Magna region, and the geology consists mostly of Tertiary sedimentary rocks and volcanic rocks. In general, the sedimentary rocks are soft and weak, and in some areas it had been deformed and fractured by localized tectonic activity such as faulting and folding. Such geologic conditions contributed to the reactivation of the landslide.

This region is located in the central portion of Honshu and has been subjected to very rapid up-lifting (about 0.5mm/year), resulting in accelerated erosion. This is one of the factors contributing to the formation of numerous landslides in this region.

As discussed, the landslide area is underlain mainly by Pliocene sandstone and mudstone that is overlain by Holocene colluvium. The upper portion of the landslide is underlain by volcanic rocks such as andesite and tuff breccia. These volcanic rocks can hold an enormous amount of groundwater, which can be released later to various landslide blocks, thereby contributing to landslide formation.

(5) Mitigation Measures : The mitigation measures had been implemented by the Nagano Prefectural Government. However, due to the magnitude of the mitigation works and the consorted effort and high level of technology required, the National Government took the project over as a direct project in 1992. Since the affected areas are in agricultural and is farming communities, the Ministry of Agriculture, Forestry and Fishery administers the mitigation works. The mitigation measures are focused on lowering the pore water pressure in large areas by installation of drainage tunnels, drainage wells, and horizontal gravity drains. Furthermore, in order to stabilize the shallower secondary landslide blocks, drainage wells, horizontal gravity drains, drainage channels, and earth retaining structures have been constructed.

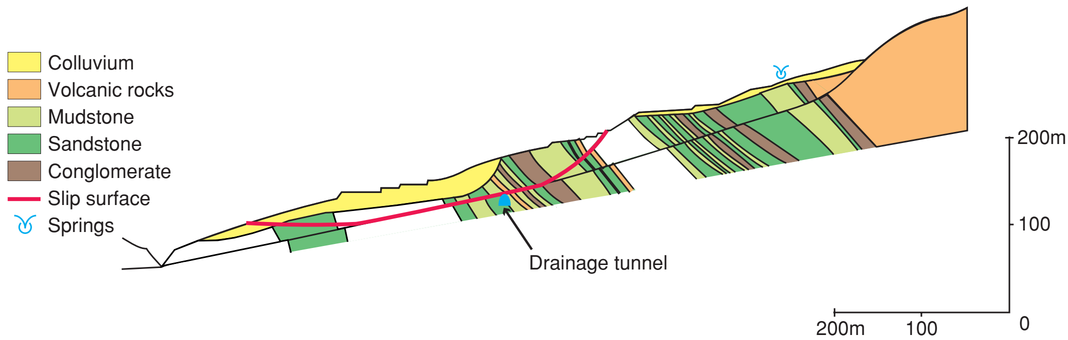

Fig. 6-15 Cross section of Shiomoto landslide

Photo 6-23 Shiomoto landslide (courtesy of Ministry of A. F. and F.)

6.16 KOSHIO LANDSLIDE

(1) Location : Kashio, Ohoshika-Mura, Shimoina-Gun, Nagano (35° 37' N, 138° 05' E)

(2) Size : Length : 800m ; Width : 250m (Max. Width : 350m) ; Landslide Threatened Area : 149.12ha ; Thickness : 20 - 75m ; Volume : over 6.0 x $10^7 m^3$

(3) History and Damages : Historical records indicate there had been small-scale landslide movements in the past. However, activity has increased in recent years. The accelerated movement occurred following heavy rains in June 1992. The immediate damages included destruction of one check dam and deformation of 8 other check dams, and numerous tension cracks that developed along the slope. Further movement of the slide mass damaged residential structures and National Highways, and buried a section of the Kashio River which created the potential for a large scale debris flow on the central area of Ohoshika Village located down stream of the slide area.

(4) Geology, Mode of Movement : The Median Tectonic Line traverses along the west side of the landslide. A fragmented (discontinuous) syncline axis extends on the upper slopes where the bedding planes dip into the slope. The site area is underlain by high-pressure metamorphic rock while the lower hillside are underlain by pelitic schist, basic schist, and siliceous schist of the Sanbagawa Metamorphic Belt with intrusive bodies of serpentine. The upper slopes are underlain by greenstone, peridotite and serpentine of the Mikabu Metamorphic Belt. As a whole, the schistose rocks are severely fractured and create favorable conditions for argillization. The currently active landslides consist of multiple slide blocks, with a maximum depth of 75m. The maximum depth of the Upper Block and the Lower Block are 30m and 50m, respectively.

(5) Mitigation Measures : As a dewatering procedure, a total of 45 drainage wells, two drainage tunnels and horizontal gravity drains at six locations had been constructed by 2001. The movement of the Lower Block gradually slowed down. The shallow blocks on the upper slopes, even though the rate of movement was reduced compared to the earlier stages, still show uneven cumulative movements. Thus, mitigation measures focused on groundwater control such as drainage wells and drainage tunnels have been implemented.

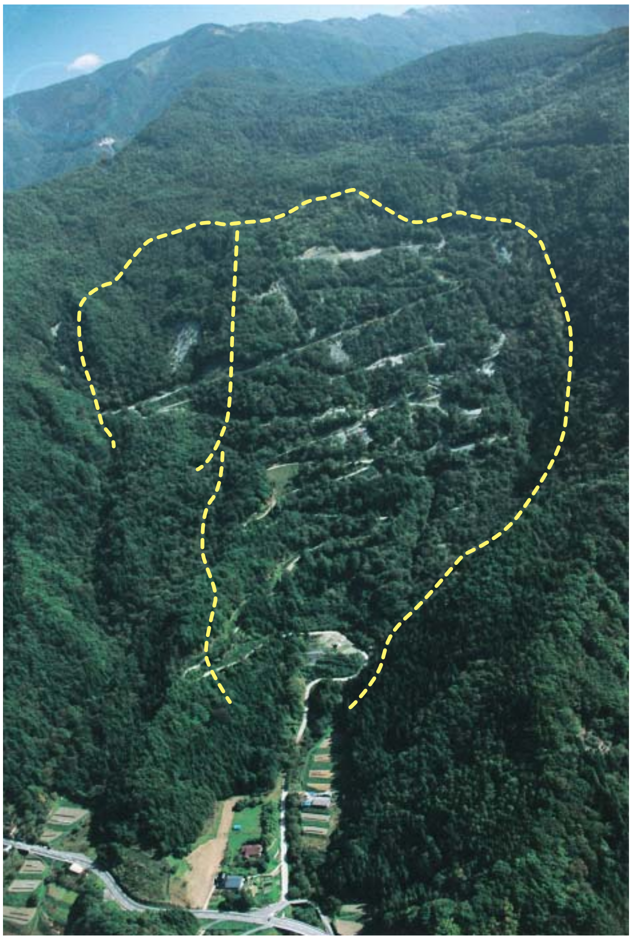

Photo 6-24 Koshio landslide (courtesy of F. Agency)

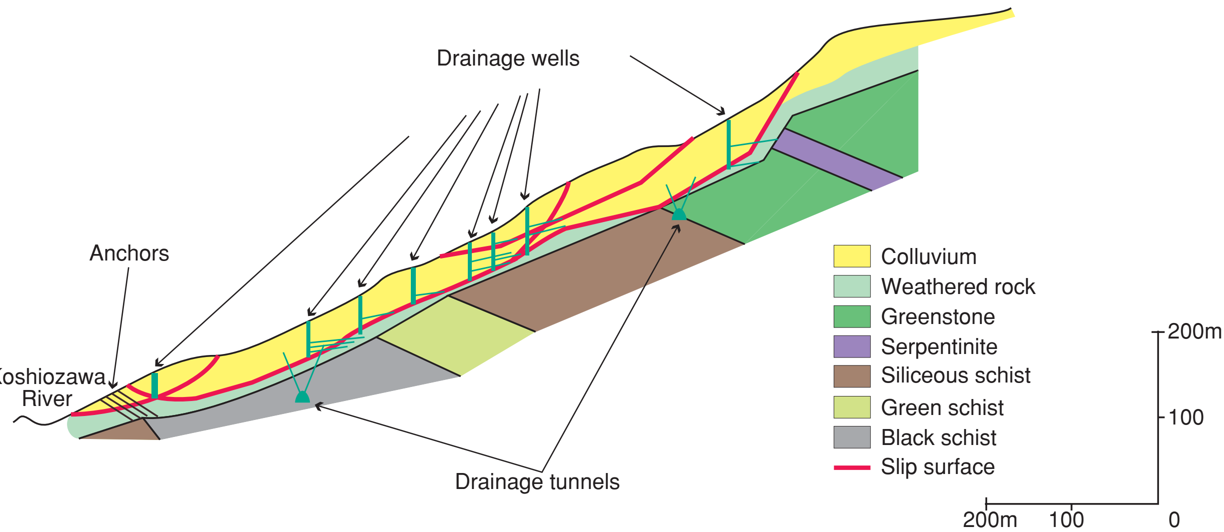

Fig. 6-16 Cross section of Koshio landslide

6.17 NYUYA LANDSLIDE

(1) Location: Nyuya, Ohshika-Mura, Shimoina-Gun, Nagano (35° 34' N, 138° 04' E)

(2)Size: Length : 1000m (Max.) ; Width : 1200±m (Max.) ; Area : 138±ha ; Thickness : 30 - 40m

(3) History and Damages: The sliding history includes movements in 1961, 1982, 1983, and 1992. Heavy rains caused by typhoons in 1982 and 1983 produced damages such as tilting and cracking in residential structures, roadways, and retaining walls. The movement in the toe of the landslide was prominent during the snowmelt period in 1992.

(4) Geology, Mode of Movement: As the site area is situated next to the Median Tectonic Line, the underlying rocks have been intensely sheared, fractured, and highly metamorphosed. Such conditions promote deep weathering and accelerated the argillization process. Thus, this region represents a highly concentrated cluster of fracture zone- related landslides and rapid slope failures. The structure of the landslide includes about 30m of greenstone and related rocks that form the sliding mass underlain by the intact bedrock formation composed of inter-bedded black and green schist. A slip surface consisting of serpentine or talc schist exists near the contact zone.

(5) Mitigation Measures: The early stage of the mitigation works were conducted by the Nagano Prefectural Government. Comprehensive mitigation measures have been conducted by the National Government since 1988. The mitigation measures include drainage wells, horizontal gravity drains, and installation of anchors and piles.

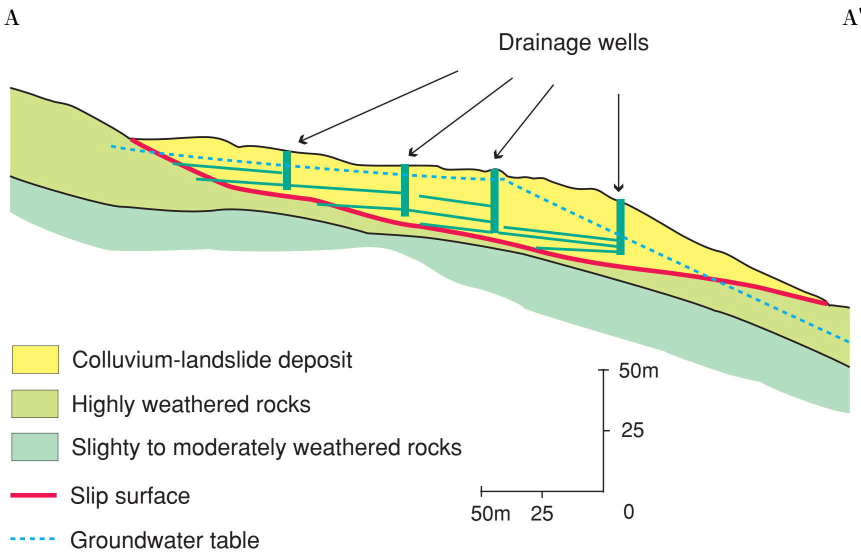

Fig. 6-17 Cross section of Nyuya landslide

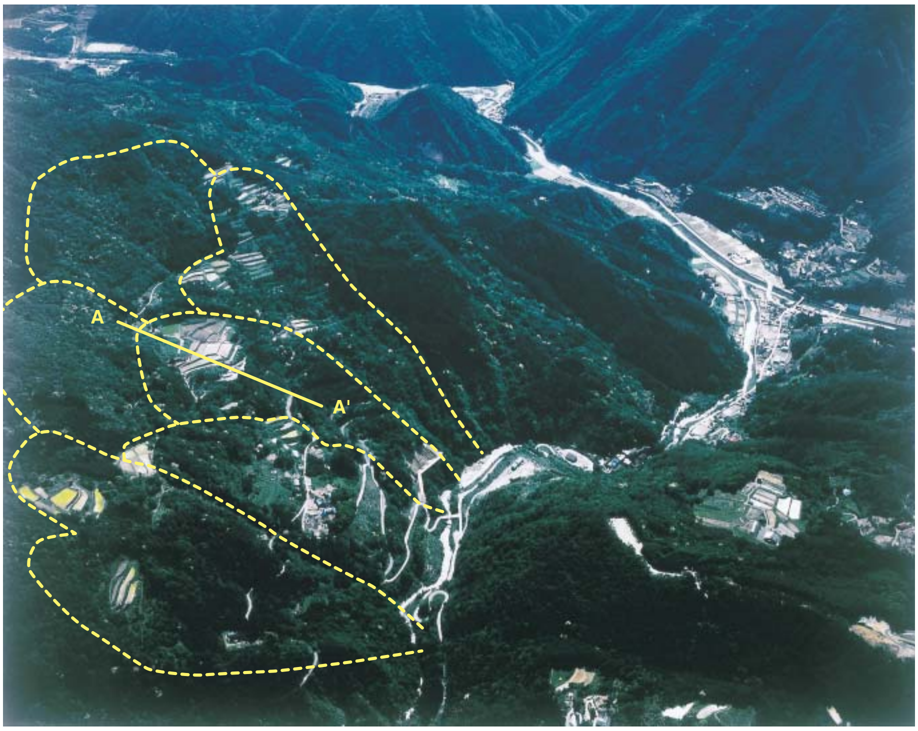

Photo 6-25 Nyuya landslide (courtesy of Ministry of L. I. and T.)

6.18 JINNOSUKEDANI LANDSLIDE

(1) Location : Shiramine, Shiramine-Mura, Ishikawa-Gun, Ishikawa (36° 07' N, 136° 45' E)

(2) Size : Length : 1500m ; Width : 1050m ; Landslide Threatened Area : 502.5ha ; Thickness : 50 - 100m ; Volume : 7.0×10^7 m^3

This landslide is located along the foothills of the Hakusan Mountain between 1600 and 2200m in elevation. The slide is divided into three major blocks and several minor blocks.

(3) History and Damages : It is not clear when the initial movement took place ; however, it is speculated that the movement was triggered by a large magnitude earthquake in the past. Damages to the existing drainage tunnel and sabo dams were reported in the 1960s. The landslide is actively moving as evidenced by the cracks on sabo dams and their wings.

(4) Geology, Mode of Movement : The site area is underlain by Mesozoic Era shale and sandstone, and these sedimentary rocks are irregularly overlain by Tertiary volcanic eruptive rocks consisting of lava, volcanic ashes, and pyroclastic flow deposits. The contact between the lava rocks and the sedimentary rocks forms the main scarp and developed into several large-scale landslide blocks. The slip-surface is suspected to be a clay layer originated within the sandstone formation that had been fractured and sheared by the continuous movement of the landslide blocks.

(5) Mitigation Measures : Signs of movement detected on a sabo dam in the 1950s were the impetus for the mitigation works. This landslide has been assigned as a direct project of the National Government and mitigation has been concentrated on dewatering works. Based on the assumption that the stabilization of the smaller lower landslide blocks could eventually lead to the stabilization of the upper major landslide blocks, effort has been devoted to the mitigation measures on the small landslide blocks. With installation of drainage tunnels, horizontal gravity drains and drainage borings. the movement stopped by 1972 ; however, the movement renewed around 1975. The work resumed in 1981, and many drainage wells have been installed since 1995.

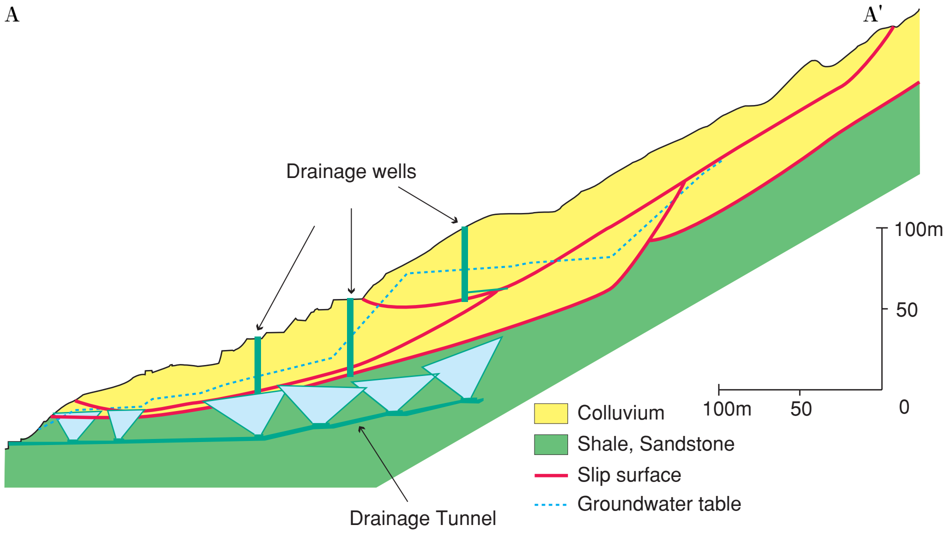

Fig. 6-18 Cross section of Jinnosukedani landslide

Photo 6-26 Jinnosukedani landslide (courtesy of Ministry of L. I. and T.)

6.19 HANSAI LANDSLIDE

(1) Location : Hansai, Kikukawa-Cho, Ogasa-Gun, Shizuoka (34° 45' N, 138° 05' E)

(2) Size : Length : 170 ± m ; Width : 100 ± m ; Thickness : 20 ± m ; Volume : 2.2 x $10^5 m^3$

(3) History and Damages : Repeated visits of typhoons between September 15 and 22, 1998 resulted in record breaking rainfall. Further, another heavy rain on September 24 triggered an early morning landslide. One home was destroyed without any injury. However, with the possibility of further movement, in particular, failure at the toe area, it was feared that homes located at the lower slopes would be destroyed. Affected residences were ordered to evacuate, and residents remained at the emergency shelter for nine and a half months.

(4) Geology, Mode of Movement : This region is underlain by Pliocene inter-bedded sandstone and siltstone, and the beds dip 5 to 8° to the northwest. A joint set almost perpendicular to the bedding creates potentially weak zones within the bedrock. Furthermore, the bedrock is not well lithified and the expansive nature of the formation promotes stress release and weathering. By comparing detailed topographic maps of the site, before and after the event, it is determined that the subject landslide moved about 20m along the dip, in approximately the same direction. The main scarp and the north-eastern lateral scarp formed near vertical walls. The sliding blocks are intact without breaking and slid along the bedding plane. This is classified as a translational or block slide.

(5) Mitigation Measures : Comprehensive mitigation measures were necessary for this landslide because : (1) it was induced by heavy rains ; (2) it is relatively large ; and (3) it was a potential danger to residential structures and river. The selected landslide control measures to increase the safety factor include : earth removal at the head area ; buttress fill at the toe area ; drainage wells ; and horizontal gravity drains. Further, in order to maintain the design safety factor, steel piles were driven at selected locations. At the scarp area, the inclination of the slopes were reduced by cutting, followed by hydromulching for erosion control, and the graded faces were supported by anchors.

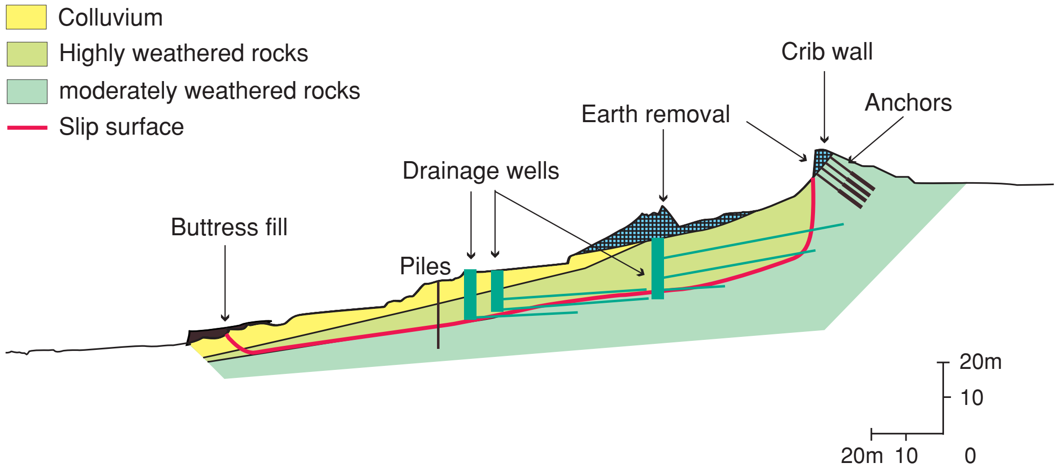

Fig. 6-19 Cross section of Hansai landslide

Photo 6-27 Hansai landslide (courtesy of Shizuoka Prefecture)

Photo 6-28 Hansai landslide following the completion of mitigation measures (courtesy of Shizuoka Prefecture)

6.20 SUGI LANDSLIDE

(1) Location : Sugi 1-Chome, Hirakata-Shi, Osaka (34° 48' N, 135° 43' E)
(2) Size : Length : 70m ; Width : 130m ; Area : 0.9 ± ha ; Thickness : 10m ; Volume : 1.2 x $10^4 m^3$
(3) History and Damages : This landslide occurred on October 19, 1996. This region is located within a northeast to southwest trending ridge, and the landslide is situated along the northwest-facing slope that forms a scarp and grabens. Damages include the destruction of a couple of residential structures and relocation of 11 families of 55 people.
(4) Geology and Mode of Movement : The basement rock of the site area consists of granitic rocks of the Paleozoic Era that is overlain by the Plio-Pleistocene inter-bedded clays, sands, and gravels. The geologic structure includes a gentle dip-slope condition. The landslide debris consists entirely of the Plio-Pleistocene deposits. The sliding was initiated by weakened upper clayey beds with a groundwater table that rose due to rainfall.
(5) Mitigation Measures : The Osaka prefectural Government administered the mitigation measures as emergency work following authorization by the Ministry of Land, Infrastructure and Transport. The landslide mitigation measures included : piles, horizontal gravity drains, and earth removal.

Following the completion of the mitigation measures, the city of Hirakata converted the site into a regional park that is in harmony with the surrounding environment.

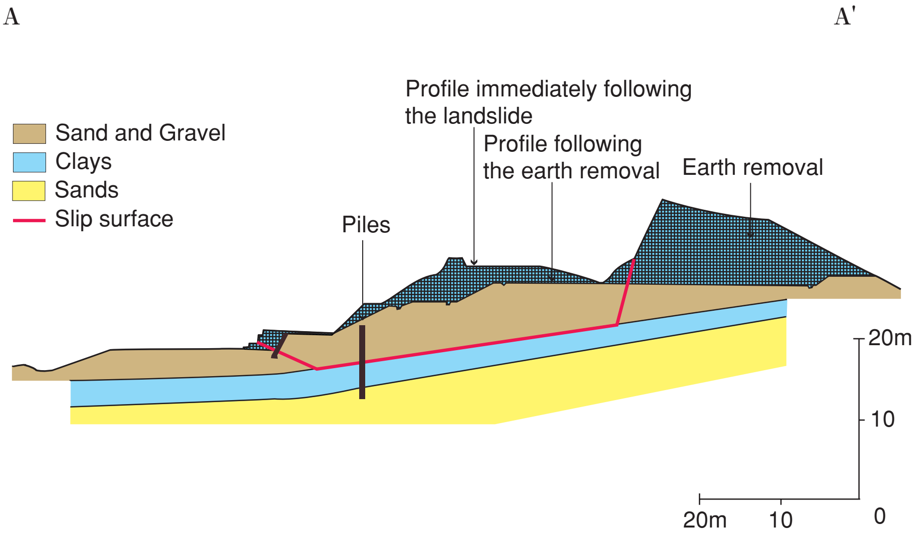

Fig. 6-20 Cross section of Sugi landslide

Photo 6-29 Sugi landslide (courtesy of Osaka Prefecture)

6.21 KAMENOSE LANDSLIDE

(1) Location : Karindoubata, Kashihara-Shi, Osaka (34° 35' N, 135° 39' E)

(2) Size : Length : 1100±m (Max.) ; Width : 900±m (Max.) ; Thickness : Max. over 80m, Average 30 - 40m ; Landslide Threatened Area : 94.29ha ; Volume : 1.76 x 10^7m^3

The landslide is composed of two large blocks ; Touge Block and Shimizudani Block, with each block influencing and interfering each other as they move.

(3) History and Damages : 1931-1932 : Two parallel northeast to southwest trending cracks of 1.5cm wide were discovered in a farm field at the northeast corner of Touge Block. Cracks and deformation were observed at the west portal of the Kamenose Tunnel, one of the main lines (Kansai Line) of the National Railroad. A reservoir for rice paddy developed leakage and eventually dried up. The western half of Touge Block moved first, which induced movement in the eastern half of the block, affecting a total area of about 32ha. The total horizontal movement during that period was recorded to be 31 to 33m. The maximum horizontal movement was recorded to be about 51cm/day, and is a direct response from heavy rains. Eventually, the slide movement destroyed the Kamenose Tunnel, and the railroad trucks and the tunnel had to be relocated onto the left bank of the Yamato River. The slide movement uplifted the National Highway (Route 25) for about 16m and the Yamato River bed for over 9m, causing the areas of upstream to flood. Other damages included the destruction of 25 homes in Touge Block.

1967 : A crack running through the middle of the eastern section of Shimizudani Block was discovered. Later, the movement extended into the previously moving Touge Block, with a total affected area of about 50ha. The horizontal movement was recorded to be about 26m with the maximum enlargement of the crack about 25cm/day. The National Highway was uplifted about 1.3m.

(4) Geology, Mode of Movement : The site geology consists of, from the oldest to the youngest : granitic basement rocks ; Miocene volcanic and sedimentary rocks ; and Plio-Pleistocene clays, sands and gravels. The slip surface within Touge Block was found in a thin tuffaceous conglomerate that is sandwiched between andesitic lava flows. In Shimizudani Block, the slip surface was found in a highly argillizated bed between two members of Miocene rocks.

(5) Mitigation Measures : In the earlier stages of the mitigation work, the Osaka Metropolitan Government administered the works. According to the Landslide Prevention Law of 1959, the Kamenose landslide was designated as a Landslide Threatened Area. Because the landslide is extremely large and mitigation measures required advanced technology, the works became a direct project for the National Government. Earth removal work was performed as one of several permanent measures for Shimizudani Block. Following the 1967 movement, as an emergency dewatering measure, groundwater drainage works were implemented along with the installation of steel pilings at selected locations. Since 1970, a series of large diameter cast-in-place shafts were installed at both blocks. The main mitigation measure in Touge Block since 1986 consists of the installation of Large diameter cast-in-place shafts measuring 6.5m in diameter with depths ranging from 80 to 100m.

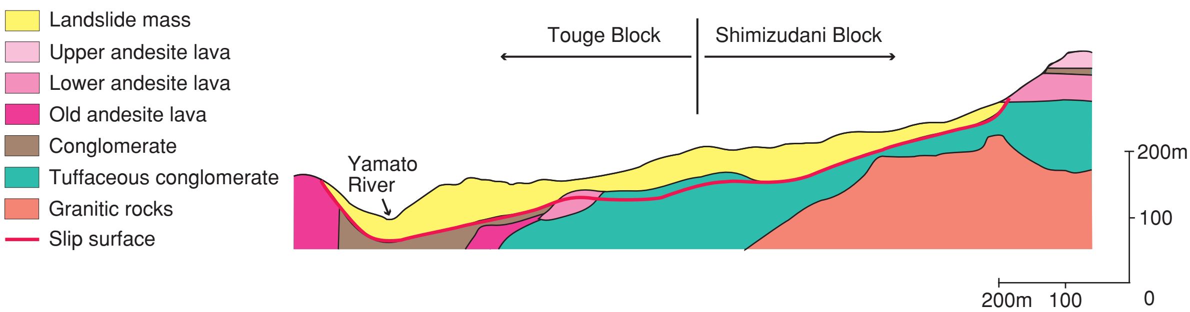

Fig. 6-21 Cross section of Kamenose landslide

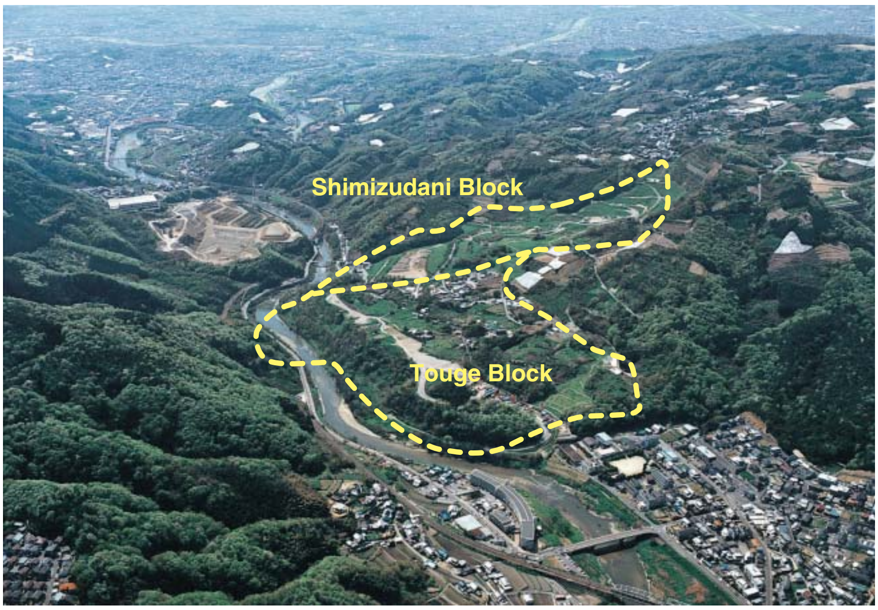

Photo 6-30 Kamenose landslide (courtesy of Ministry of L. I. and T.)

6.22 LANDSLIDES IN KITAKOBE REGION

(1) Location : Kobe-Shi ; Miki-Shi ; Yokawa-Cho, Minou-Gun, Hyogo (34° 50' N, 135° 10' E)

(2) Size : This region includes 38 Designated Landslide Threatened Area with numerous landslides of varying size. Larger landslides measure up to : Length : 600m ; Width : 300m ; Depth : 45m.

(3) History and Damages : Historical records show a large-scale landslide movement in 1897. A landslide occurring in September 1942 destroyed eight homes. Since then, numerous slide movements have destroyed residential structures, roadways, and farmland.

(4) Geology, Mode of Movement : The site area is located along the north side of Rokko Mountain at an elevation of between 100 and 250m. The site is underlain by Upper Tertiary sedimentary rocks. Active tectonism in the region uplifted Rokko-San resulting in the majority of the beds dipping towards the west. The site area has been subjected to other severe forms of deformation including folding, faulting and flexing, 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 slip surfaces developed due to infiltration of rain water and groundwater.

(5) Mitigation Measures : In order to remove the groundwater (the primary cause of the sliding), drainage wells, and horizontal gravity drains were installed. Surface drainage improvements and piles works have also been implemented. Further, in conjunction with the farmland restoration projects, large scale buttress fills have been placed to improve stability in some of the landslides.

Photo 6-31 Landslides in Kitakobe Region (courtesy of Ministry of A. F. and F.)

6.23 ZENTOKU LANDSLIDES

(1) Location : Zentoku, Nishiiyayama-Son, Miyoshi-Gun, Tokushima (33° 52' N, 133° 50' E)
(2) Size : Length : Max. 2000m ; Width : Max. 900m ; Landslide Threatened Area : 221 ± ha

This landslide is divided into seven large blocks, Z1 Block through Z6 Block and Imakubo Block.

(3) History and Damages : The landslide movement occurred at the eastern section (Z6 Block) in the early Meiji Period (1860s). Further movements in 1945, 1949, and 1954 caused serious damages to roadways. In 1965, movement caused damages to residential structures and roadways. A lower portion of Z6 Block failed (110m long ; 50m wide ; and 15m thick) in 1984. Z2 Block started to move in 1987, causing further damages to the roadways. Z1 Block displayed numerous cracks in 1992.

(4) Geology, Mode of Movement : The site area is comprised of the Sanbagawa crystalline schist belt and is sandwiched between the Median Tectonic Line and the Mikabu Tectonic Line, and consists predominantly of argillaceous schist. These crystalline rocks exhibit well developed structural zones of discontinuity such as planar schistocity, joint surfaces, and fault planes promoting accelerated weathering and softening of the rocks. The entire Zentoku landslide is in a dip-slope condition.

The Zentoku landslide was formed due to unfavorable geologic conditions and complicated geologic structures which are typical of landslides in fracture zones. Furthermore, heavy rainfalls increased the groundwater table that induced the movements. This landslide is unique because there are two types of movements within one landslide. There are relatively shallow landslides with the slip surfaces located in colluvium, and deep landslides where the slip surfaces are located in the weathered bedrock formation. These landslides are inter-mingling with each other, developing very complicated movement patterns.

(5) Mitigation Measures : It is speculated that the Ansei Earthquake of 1854 may have triggered the Zentoku landslide, since active movement continued. The landslide was named as a Desinated Landslide Threatened Area in 1959. Since 1952, the Tokushima Prefectural Government has implemented mitigation measures such as horizontal gravity drains, drainage wells, and surface drainage improvements. However, in 1982 the Ministry of Construction took it over as a direct project. Comprehensive mitigation measures started in 1992, including groundwater control measures and installations of large diameter cast-in-place shafts and anchors for Z1 Block. Recently, mitigation measures have been implemented for Z6 Block and Imakubo Block.

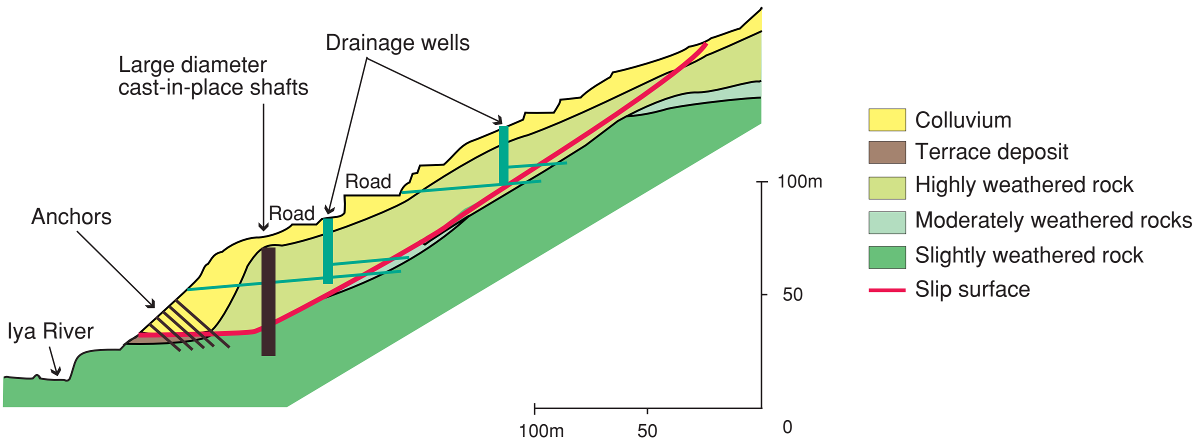

Fig. 6-22 Cross section of Z1 Block of Zentoku landslide

Photo 6-32 Zentoku landslides (courtesy of Ministry of L. I. and T.)

Photo 6-33 Zentoku landslides, Z1 Block following the completion of mitigation measures (courtesy of Ministry of L. I. and T.)

6.24 KASHIO LANDSLIDE

(1) Location : Kashio, Higashiiyayama-Son, Miyoshi-Gun, Tokushima (33° 50' N, 133° 53' E)
(2) Size : Length : 1100m ; Area : 50ha ; Thickness : 20 - 50m ; Volume : 1.5 x $10^7 m^3$

The landslide is divided into three blocks : B and C Blocks (upper blocks) and A Block (lower block) displaying a continuous landslide morphology.

(3) History and Damages : There is no historical record of the landslide ; however, the slide is thought to have originated in prehistoric time. The movement is almost imperceptible and chronic, about 5cm/year, showing some deformation on residential structures and settlement in roadways. In 1993 and 1994, increased movement of up to 30cm/year caused partial destruction of a house, roadway settlements, pushed out revetments, and pressure cracking on embankments.

(4) Geology, Mode of Movement : The site is located within the Sanbagawa crystalline schist belt that is sandwiched between the Median Tectonic Line and the Mikabu Tectonic Line. The rocks in the Sanbagawa belt in this area include pelitic schist, basic schist and siliceous schist. Due to large scale tectonic activity, the rocks are highly fractured and weathered. The slip surface is recognized within highly weathered pelitic schist which is stratigraphically over the basic schist. With response to heavy rainfall (150mm/day) and an increase in water table by 2 to 3 m, the slide movement is recorded to be 2 to 3cm/year (prior to the implementation of the control measures).

(5) Mitigation Measures : Since 1995 integrated groundwater control measure involving four drainage tunnels and 36 drainage wells have been constructed. At the same time, surface drainage improvements were implemented. Future mitigation measures included installation of large diameter cast-in-place shafts and anchors as restraint measures.

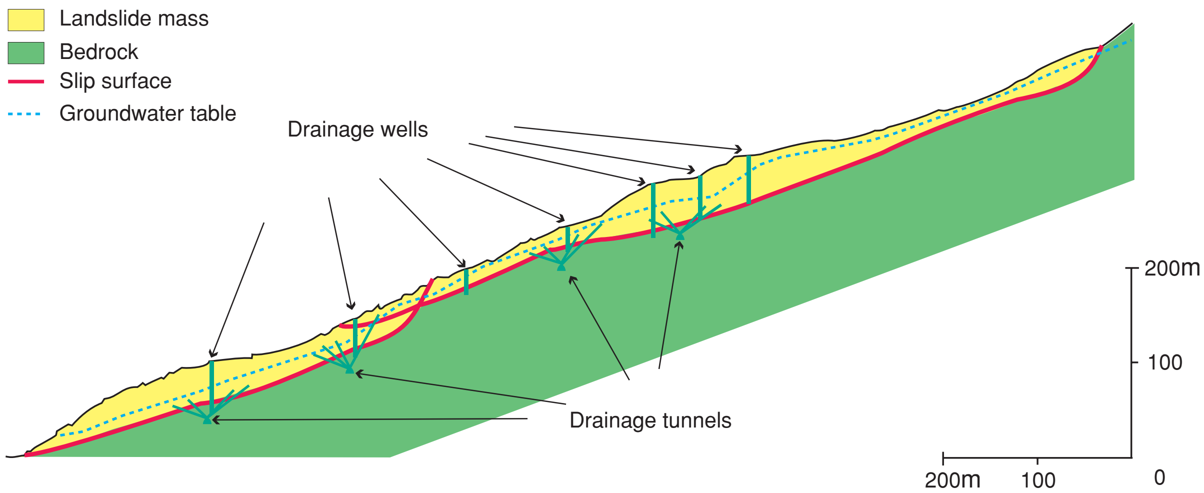

Fig. 6-23 Cross section of Kashio landslide

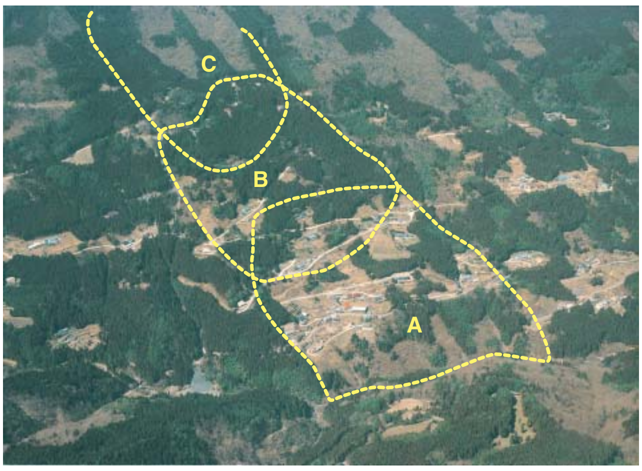

Photo 6-34 Kashio landslide (courtesy of F. Agency)

Photo 6-35 Surface deformation of Kashio landslide (courtesy of F. Agency)

6.25 MARUYAMA DISTRICT LANDSLIDE

(1) Location : Iyomishima-Shi, Ehime
(33° 58' N, 133° 33' E)
(2) Size : Length : 250m ; Width : 160m ; Thickness : 30m
(3) History and Damages : This landslide developed during grading operations for the proposed freeway construction. The cut involved a 220m long, maximum height of 40m and the proposed removal of about 2.0 x $10^5 m^3$ of earth. Because of local geologic conditions and the magnitude of the proposed grading, Landslide had been anticipated and the works proceeded with close monitoring for any signs of slide. According to the design, piles had been installed as mitigation measures for the anticipated landslide in 1981. As grading work progressed, cracks were discovered in the upper cut slope, and the monitoring equipment also revealed signs of movement. It was determined that the size of the landslide was much larger than previously anticipated. Consequently, the grading work was suspended. Following a supplemental investigation, additional mitigation measures were implemented. The grading work and the mitigation measures were completed by March of 1984.

(4) Geology, Mode of Movement : The site area lies within a narrow belt sandwiched between the Median Tectonic Line to the south and the Ikeda fault to the north. The northern side of the Median Tectonic Line is underlain by Cretaceous sandstone and granite, while the southern side is underlain by metamorphic rocks of the Sanbagawa Belt. The landslide is located within a hilly terrain about 130m in elevation, with the region displaying large-scale landslide morphology.

Reddish topsoil is developed over highly weathered and fractured pelitic schist. Furthermore, clay beds, with the appearance of an ancient slip surfaces which may have developed from large bedrock landslides, were observed in several locations.
(5) Mitigation Measures : As a mitigation measure for the anticipated landslide, a total of 66, 50.8cm diameter piles were driven into the cut face. Following the realization of the actual size of the slide, a 245m long drainage tunnel was installed in order to lower the groundwater level. Furthermore, as a landslide restraint measure, a total of 190 anchors were installed and an additional 122, 50.8cm diameter piles were driven into the cut faces.

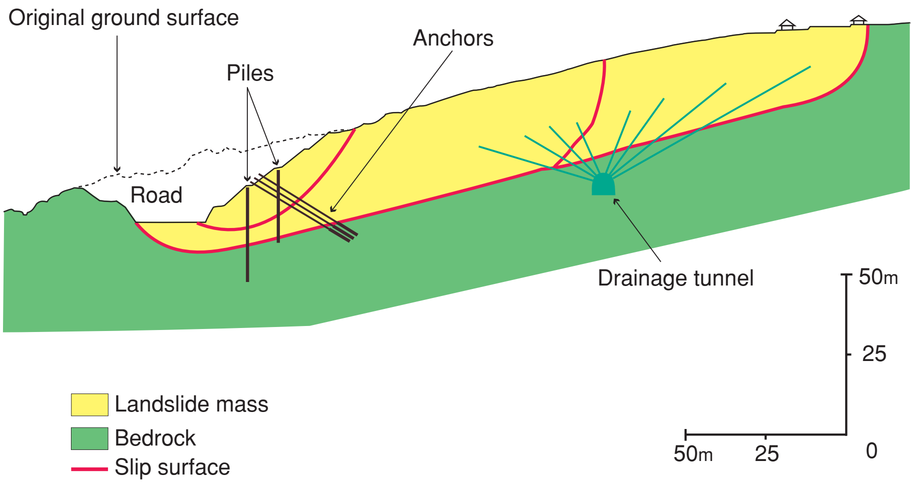

Fig. 6-24 Cross section of Maruyama district landslide

Photo 6-36 Maruyama district landslide (courtesy of Japan Highway Public Corporation)

6.26 HARABUN LANDSLIDE

(1) Location : Harabun-Cho, Sasebo-Shi, Nagasaki (32° 13 N, 129° 43' E)
(2) Size : Length : 70m ; Width : 50m ; Area : 0.3ha ; Thickness : 7m (max 10m) ; Volume : 1.7 x $10^3 m^3$
(3) History and Damages : This landslide occurred on July 7, 1997 at the 14 : 00 hour and was triggered by intense rainfall generated by a stationary rain front which develops annually in the early summer in Japan. Continuous rain further enlarged the landslide head-ward, contributing to further damages. The reported damages include : complete destruction of three homes ; partial destruction of three homes ; damaged roadways ; and disruption to the lifelines. Since the landslide occurred within a heavily populated area, 51 families totaling 146 residents living down slope of the landslide were evacuated and had to stay in emergency shelters for two months.
(4) Geology, Mode of Movement : The site area is underlain by Upper Tertiary mudstone and sandstone and is overlain by recent basaltic caprock. The site area is also underlain by many ancient landslide deposits. The landslide is located at the base of a steep slope along an alluvial plain. The moving mass consists of clayey colluvium derived from volcanic rocks, and the slip surface is located near the boundary between the sedimentary bedrock formation and the colluvium. As discussed, the slide was triggered by the intense rain associated with the early summer stationary rain front with total rainfall of 410mm. The maximum movement was recorded to be 174mm per hour between July 10 and 13, 1997. Movement of over 10mm per hour continued for about one month. Movement in the head area reached a maximum of 5m in two months.
(5) Mitigation Measures : Emergency Measures : As the landslide occurred within a heavily populated area, secondary failures and further down slope movement of the slide debris was an eminent concern for the officials. For the emergency landslide mitigation measures, horizontal gravity drains and temporary earth retaining structures to capture future debris movement were constructed at the base of the slope.

Permanent Measures : As landslide control measures, horizontal gravity drains and surface drainage improvements were implemented. As landslide restraint measures, piles and anchors were also installed.

A number of structures were partially destroyed within the landslide block, which created potential danger. As the typhoon of July 25 approached, in order to prevent further damage by the disintegration of the damaged homes, they were removed. This landslide occurred as the result of the pressure for urban development onto the steep slope. If the plateau area had left undeveloped, the damages to the structures constructed on the plateau would not have occurred. In this respect, this landslide could be classified as an urbanization induced disaster.

Photo 6-37 Harabun landslide immediately following the sliding (courtesy of Nagasaki Prefecture)

Photo 6-38 Harabun landslide causing damages to residential structures (courtesy of Nagasaki Prefecture)

Photo 6-39 Harabun landslide following the completion of mitigation measures (courtesy of Nagasaki Prefecture)

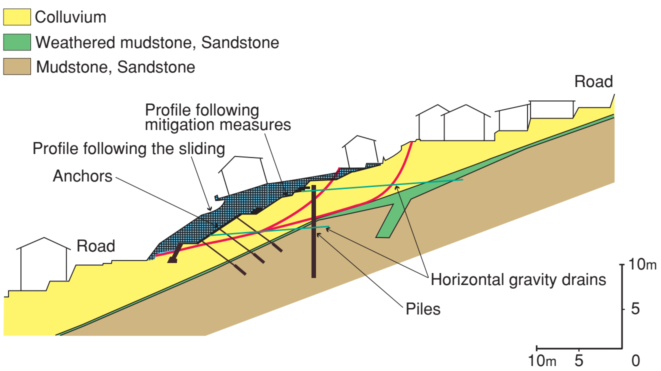

Fig. 6-25 Cross section of Harabun landslide

6.27 CHUJUN LANDSLIDE

(1) Location : Chujun, Kitanakagusuku-son, Nakagami-Gun, Okinawa (26° 18' N, 127° 47' E)
(2) Size : Length : 150m ; Width : 120m ; Thickness : 18m ; Volume : 2.2 x $10^5 m^3$ (for the main block)

This landslide is divided into four blocks : the largest Main Block ; a Small Block located below the Main Block ; Side Block-I and Side Block-II located upslope of the Main Block.

(3) History and Damages : A total of 220mm of rain fell between October 4 and 5, 1998. The slide movement increased on October 5 and reached a total cumulative distance of 10m. The damages caused by the movement included ; destruction of one home, partial destruction of two homes and 90m of roadway, and near complete destruction of a park facility. The toe of the slide reached the community center and partially damaged the building. Fortunately, no one was injured.

(4) Geology, Mode of Movement : The site area is underlain by Upper Tertiary mudstone and sandstone. This mudstone is highly susceptible to weathering and easily turns into clay. Okinawa regions underlain by this mudstone are prone to landsliding. It is determined that the landslide was triggered by a rapid increase in pore water pressure from the heavy rain and infiltrated into this highly weathered and weak mudstone formation. The morphology of the landslide is an amphitheatre-shaped crown and tangue-shaped toe with a keel-shaped slip surface.

(5) Mitigation Measures : The mitigation measures have been implemented as an emergency work. Since the increased groundwater table was the cause of sliding, groundwater control measures are the focus of the mitigation measures in conjunction with landslide restraint measures for each block. For the Main Block, 50.8cm diameter steel piles were driven ; for the Small Block, 50cm diameter steel piles with anchors were installed ; for Side Blocks-I and II, anchors were installed. Groundwater control measures included numerous horizontal gravity drains positioned in such a way as to maximize the efficiency of surface drainage.

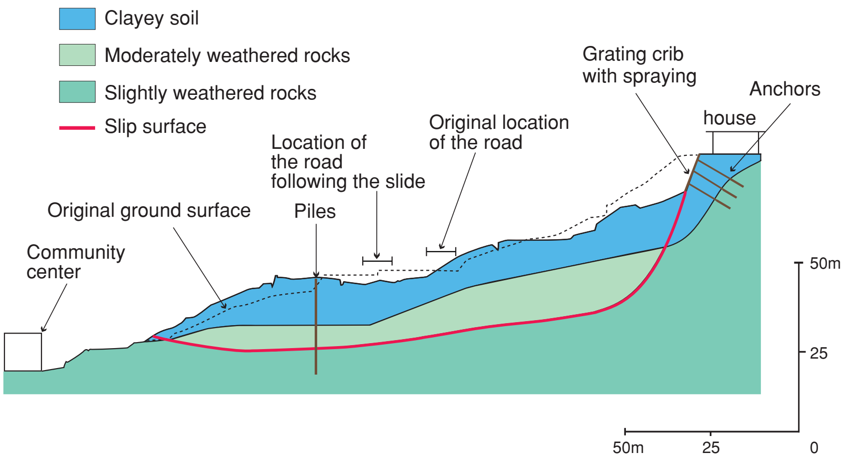

Fig. 6-26 Cross section of Chujun landslide

Photo 6-40 Chujun landslide (courtesy of Okinawa Prefecture)

7. PROFESSIONAL ORGANIZATIONS ENGAGING IN LANDSLIDE STUDY AND MITIGATION

7.1 JAPAN LANDSLIDE SOCIETY

This academic Society was established in 1964, with a current membership of about 2,500 composed mostly of scientists and engineers working in the fields of geology, geomorphology, geophysics, civil engineering, sabo engineering (erosion control engineering), forestry, agricultural engineering, and other fields concerning landslides and related phenomena. Many of the members are affiliated with universities, research institutes, public agencies, consulting firms and other private sectors.

The journal "JISUBERI" (Landslide) is published quarterly with over 147 published issues by the end of 2001. The journal contains predominantly research papers printed mostly in Japanese with English subtitles, abstracts and captions.

Annual meetings attract about 1,200 participants and over 100 papers are presented. In addition, the Society and its sections sponsor symposia and workshops in various cities annually throughout Japan.

As for international activities, the International Division was established and has organized and sponsored numerous international events. The society organized the first International Symposium on Landslide (ISSMGE-TC11 ISL) in 1972 in Kyoto. The symposium is held every four years. The 2nd International symposium was organized in Tokyo in 1977, with the 3rd symposium held in New Delhi in 1980. The last symposium was held in UK in 2000. The Society also joined and organized the "Landslide Field Conference" with American colleagues in 1979 and 1983 (in U.S.A.), and in 1980 and 1985 (in Japan) to exchange experiences, and the conference developed into an organization of International Conference and Field Workshop on Landslides (ICFL) that is supported by the United Nations, the U. S. National Research Council and other organizations. Over 200 professionals participated in the 4th International Conference held in 1985 in Tokyo following the field workshops throughout Japan, and 31 papers were published in proceedings. This success resulted in the 5th ICFL in Australia and New Zealand, 1987; the 6th ICFL in Switzerland, Austria and Italy, 1990; and the 7th ICFL in Czech and Slovak Republics, 1993; the 8th ICFL in Spain, 1996; and 9th ICFL in England, 1999. The Society has jointly organized many International meetings on landslides with Asian countries.

The annual International Newsletter "Landslide News" has been published in English by the Japan Landslide Society to promote the exchange and opinions on landslides on a worldwide basis since 1987. The latest issue (No. 13) was published in June 2000. Each issue is about 40 pages and contains "Recent Landslides/Research", "IGCP-425: Landslide Hazard Assessment and Cultural Heritage", "Landslide Research Organization", and "News/Reports of Meetings, Information." International editorial board review and select papers for publication. About 2,000 copies of "Landslide News" are distributed free of charge to overseas landslide researchers, government officials, and consulting firms. The "Landslide News" and its Japanese translation are also distributed to the members of Japan Landslide Society. The first ten issues of "Landslide News" were consolidated into a single volume titled "Landslides of the World" and published at Kyoto University Press in 2000. All issues of the "Landslide News" can be reviewed at the Homepage of the 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:

Japan Landslide Society
President: Hiroyuki Nakamura
Address: Kaga Bldg., 5-30-7, Shinbashi, Minato-ku, Tokyo 105-0004 Japan
Phone: 81-3-3432-1878
Fax: 81-3-5408-5250
E-mail: office@landslide-soc.org
Home Page: http://japan.landslide-soc.org/index-e.html

7.2 NATIONAL CONFERENCE OF LANDSLIDE CONTROL

The Conference is composed of the governors of the 47 Prefectures of Japan. The purpose of this conference is to contribute the technical improvement of landslide mitigation measures for engineers working for the local governments through annual workshops and presentations on investigation and research.

Chairman: Governor of Niigata Prefecture
Address: c/o Sabo Section, Department of Public Works, Niigata Prefectural Government
4-1, Shinko-cho, Niigata 950-8570 Japan
Phone: 81-25-285-5511

7.3 FOREST CONSERVATION ENGINEERING RESEARCH ASSOCIATION

The association was established in 1956, and its members include forest conservation engineers, academics, public and private organizations and industries engaging in forest conservation and related disciplines. The purpose of the association is to advance the forest conservation technology and to develop and increase business activities through research and development in forest conservation technology and exchange of technical information.

The chairman of the association is the Director of Forest Conservation Department of the Forestry Agency, and consists of eight chapters with 7500 members. The association publishes the monthly journal "CHISAN" (forest Conservation) and holds annual meetings for the presentation of research papers. In addition, each chapter sponsors various activities.

President: Director, Conservation Division, Private Forest Department, Forestry Agency
Address: 1-2-1 Kasumigaseki, Chiyoda-Ku, Tokyo, 100-8952 Japan
Phone: 81-3-3502-8111

7.4 JAPAN ASSOCIATION OF LANDSLIDE CONTROL TECHNIQUES

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", sponsors lecture meetings, and is increasing their efforts of mitigating landslide techniques in order to study new control methods and develop new instruments.

President : Shigenobu Sakano
Address : Kaga Bldg., 5-30-7, Shinbashi, Minato-Ku, Tokyo 105-0004 Japan
Phone : 81-3-3438-0493
Fax : 81-3-3438-0803
Home Page : http : //www.jisuberi-kyokai.or.jp/

7.5 UNIVERSITIES AND COLLEGES

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

7.6 PUBLIC AGENCIES

1) Ministry of Agriculture, Forestry and Fisheries ;
Forestry Agency, Ministry of A. F. and F :
Home Page : http : //www.maff.go.jp/eindex.html
conducts investigations and implements the landslide mitigation measures related to the conservation of farm and forest land.
2) Ministry of Land, Infrastructure and Transport :
Home Page : http : //www.mlit.go.jp/english/index.html
The Ministry overseas the National Institute for Land and Infrastructure Management, Geographic Survey Institute and Public works research Institute, and conducts investigations and implements landslide mitigation measures on slope failures and landslides especially along rivers, highways, dams and residential areas.
3) Japanese Highway Public Corporation :
Home Page : http : //www.jhnet.go.jp/english_new/index.html
conducts investigations and implements landslide mitigation measures along freeways.
4) Water Resources Development Public Corporation :
Home Page: http://www.water.go.jp/html/index.html (in Japanese)
conducts investigations and implements landslide mitigation measures on landslides caused by construction of dams.
5) Local Governments :
conducts investigations and implements landslide mitigation measures on landslides under the jurisdiction of their respective local governments.

7.7 RESEARCH INSTITUTES

1) National Institute for Land and Infrastructure Management
Home Page : http : //www.nilim.go.jp/english/eindex.htm
2) Geographical Survey Institute
Home Page : http : //www.gsi.go.jp/ENGLISH/
3) National Research Institute for Earth Science and Disaster Prevention
Home Page : http : //www.bosai.go.jp/index.html
http : //lsweb1.ess.bosai.go.jp/ (landslide maps)
4) National Institute of Rural Engineering
Home Page : http : //www.nkk.affrc.go.jp/index-e.htm
5) Forestry and Forest Products Research Institute
Home Page : http : //www.ffpri.affrc.go.jp/
6) Public Works Research Institute
Home Page : http : //www.pwri.go.jp/english/eindex.htm
7) Civil Engineering Research Institute of Hokkaido
Home Page : http : //www.ceri.go.jp/index_e.html
8) Geological Survey of Hokkaido
Home Page : http : //www.gsh.pref.hokkaido.jp/e_index.html
9) Railway Technical Research Institute
Home Page : http : //www.rtri.or.jp/index.html
10) Sabo Technical Center (STC)
Home Page : http : //www.stc.or.jp/ (in Japanese)
11) Fukuda Geological Institute
Home Page : http : //www.fgi.or.jp/index-e.html
12) Central Research Institute of Electric Power Industry
Home Page : http : //criepi.denken.or.jp/eng/

7.8 OTHER PROFESSIONAL ORGANIZATIONS

1) Japan Society of Erosion Control Engineering
Home Page : http : //www.jsece.or.jp/indexe.html
2) Japanese Geotechnical Society
Home Page : http : //www.jiban.or.jp/
3) Japan Society of Civil Engineers
Home Page : http : //www.jsce.or.jp/e/index.html
4) Geological Society of Japan
Home Page : http : //wwwsoc.nii.ac.jp/gsj/index-e.html
5) Japan Society of Engineering Geology
Home Page : http : //wwwsoc.nii.ac.jp/jseg/ (in Japanese)
6) Japanese Forestry Society
Home Page: http://wwwsoc.nii.ac.jp/jfs/index.html (in Japanese)
http : //wwwsoc.nii.ac.jp/jfs/jfr.html (Journal of Forest Research)
7) Association of Japanese Geographers
Home Page : http : //wwwsoc.nii.ac.jp/ajg/english/xindexe.html
8) Japanese Society of Irrigation, Drainage and Reclamation Engineering
Home Page :
http : //www.jsidre.or.jp/english/brochure/eibunpanf.htm
9) Japanese Geomorphological Union
Home Page : http : //wwwsoc.nii.ac.jp/jgu/homee.html
10) Landslide Research Council of Japan
Home Page :
http : //landslide.dpri.kyoto-u.ac.jp/j-LRCJ.htm (in Japanese)
11) International Consortium on Landslide
Home Page :
http : //landslide.dpri.kyoto-u.ac.jp/ICL-e.htm

INDEX MAP OF RECENT LANDSLIDES AND SLOPE FAILURES ILLUSTRATED IN THIS BOOK