LANDSLIDES IN JAPAN

The Japan Society of Landslide
National Conference of Landslide Control

1972

Organization for the Research and Control of Landslides

The Japan Society of Landslide

(Director: Kenzo SASSA)

This Society was founded in 1964, is located at Ekoda 2-21-2, Nakano-ku, Tokyo, and consists of

1) researchers in the fields of geology, geography, geophysics, civil engineering, forestry, agricultural engineering, etc., working for the universities;
2) reserchers and engineers in charge of control works, of the Ministry of Construction, the Ministry of Agriculture and Forestry, the Japan National Railways and prefectural governments, etc.; and
3) engineers working for private consulting companies, work executing companies and manufacturers of landslide measuring systems.

This Society is striving for exchange and promulgation of research results concerning various landslide phenomena and landslide disaster prevention measures. At present the Society consists of 1,200 members, and is publishing quarterly issues of research journals, and holding research presentation meetings, short training courses, study tours, etc.

National Conference of Landslide Control

(Director: Governor of Nagano Prefecture;
Address: Sabo Section, Construction Division,
Nagano Prefectural Office, Nagano City)

This Council was organized by 44 prefectural governments for the purpose of technical enhancement of member governments as well as development of landslide prevention works by exchange of research information on landslides.

Universities

Landslide Prediction Group – This group is organized by about 40 landslide researchers of various universities. This group is for the cooperative study of physical quantities to forecast landslide occurrences through fundamental researches in motivating causes and mechanisms of landslide occurrences to clarify the relation between these quantities and landslide occurrences. This group is also trying to develop the theory to forecast what kind of change occurs when topography and dynamic equilibrium under the ground is artificiary changed on natural slopes, for the purpose of studying methodology to solve these problems. Its headquarter is placed in Kyoto University Prevention Research Institute (Address: Gokanosho, Uji-city, Kyoto).

Administrative Organizations

Ministry of Agriculture and Forestry
Landslide control for the conservation of farms and forests
Ministry of Construction
Landslide and slope failure control for the conservation of rivers, national highways, dams, residential areas and other public facilities
Japan National Railways Cooperation
Landslide control for the conservation of railroads

Research Institutes

National Research Institute of Agricultural Engineering
Ministry of Agriculture and Forestry
Forestry Research Institute
Geological Survey of Japan
Public Works Research Institute, Ministry of Construction
Geographical Survey Institute, Ministry of Construction
National Research Center for Disaster Prevention
Railway Technical Research Institute, JNR
Technical Research Institute, Electric Power

Related Academic Organizations

Erosion-control Engineering Society – Sabo Gakkai
Japanese Society of Soil Engineers
Japan Society of Civil Engineers
Geological Society of Japan
Geographical Society of Japan
Japan Society of Forestry

Relation between Landslide Disaster and National Life

Numerous records of landslide disasters in the past are reparted, and the major problem has been changing with the vicissitude of times and social structures. Agriculture rice culture being the main part has occupied the major part of national life in Japan and the land has been intensively used. The sliding areas were blessed with rich spring water and natural deep plowing, resulting in conditions favorable for rice cultivation: peasantry naturally gathered to live in or around the sliding areas.

One of the oldest landslide records is that of Sarukuyoji (No. 28) and the inhabitants of the village adopted the primitive control works such as "timber piling" and "tamping" but in vain. A legend has been handed down from old times that a priest on a pilgrimage was buried as a human immolation to check the landslide. Human bones were actually found, and carbon dating indicated 800 years of age to verify the legend.

People in old days used to make good use of the sliding areas for their living, but they could not find any effective measures to prevent landslides praying for protection against the violence of nature. For a long time landslide disasters have afflicated peasantry in the rice fields between mountains, but full-scale landslide control works at last began coupled with the farm policy of agricultural products positively. Thereafter, with the high degree development of economics and the advance of land development, landslides triggered by the reservoir water of dams for water resource development, the construction of highways and the reclamation of building land have become an important social problem as a newly-born disaster.

Budgets related to landslide in the ministries and offices concerned in these twenty years are as the following table which shows a part of magnitude of landslide disasters and of importance of effective measures to prevent them.

Government office concerned	1952	1972
Ministry of Construction	389.0	5,340.0
Ministry of Agriculture and Forestry	222.7	4,972.0

(Monetary unit . . . Million Yen)

Geological Feature and Distribution of Landslide in Japan

General Remarks on the Geological Constitution

The Japanese islands present many interesting problems of landslides because of their geologic and geographic conditions. The islands are situated in the circum-Pacific orogenic zone and represent the summit of a great mountain system of complicated structures. From Paleozoic to Recent Japan has suffered many crustal movements. Among them those in later Mesozoic and Neogene ages have had the most effect on the present geological structure. Igneous activity accompanied the movements, and considerable metamorphism occurred. It is well known that the circum-Pacific volcanic and seismic belts lie within and along the islands. Most of the mountains in the islands have steep slops, and the gradient of the rivers is generally conspicuous. In addition, Japan located in the monsoon-climate and outstanding rainy zones.

The Japanese islands comprise Honshu, Kyushu, Shikoku, Hokkaido and other subordinate islets, which are arranged in an arc shape stretching northeast to southwest. There is a bend in the middle of Honshu, where a geologically ruptured zone called "Fossa Magna" traverses Itoigawa and Shizuoka from the Sea of Japan to the Pacific. This zone divides Japan into two parts, namely Northeast Japan and Southwest Japan, these two show remarkable differences in geology. Southwest Japan is constituted chiefly of Paleozoic and Mesozoic rocks, and has Cenozoic rocks in rather limited area. Northwest Japan is widely covered by Cenozoic rocks in which pre-Tertiary rocks appear in many isolated landmasses. In Hokkaido, the remaining main part belongs to another arc of the folded mountains extended from Saghalien.

Southwest Japan

In Southwest Japan, there is a striking contrast between the geology of the Pacific and the Sea of Japan sides. A tectonic line called the Median Line runs longitudinaly through the island-arc and this line divides Southwest Japan into the Outer Zone and Inner Zone. The characteristic feature of the Outer Zone is the zonal structure elongated parallel to the general trend. In the Inner Zone the extensive distribution of the Paleozoic and the widespread occurence of the acidic intrusives are conspicuous. Relative to some of the intrusion, regional metamorphism are also considerable in areal extent in the Inner Zone, whereas they are scarce in the Outer Zone where the metamorphisms are largely of kinetic origin without intrusion of acidic rocks.

In the Outer Zone of southwest Japan, which is characterized by different rock formations and usually bordered by tectonic lines, are arranged in zones subparallel to the Median Line. They are listed successivley from north to south; (1) Sambagawa terrain : – crystalline schists and phyllistes, and accompanied by Mikabu green rocks, (2) Chichibu terrain : – Paleozoic rocks in which narrow belts of Mesozoic rocks intervene tectonically, including Semi-schist zone and Serpentinite in places, (3) Shimanto North terrain : – "Undifferentiated Mesozoic", mostly Cretaceous in age, (4) Shimanto South terrain : – Undifferentiated formation, mostly Paleogene in age.

Landslides in the Sambagawa metamorphic zone

The geological grouping of metamorphic rocks, character of original rocks and their age, the characteristics of metamorphism and the geological structures in each metamorphic zone have been gradually deciphered. Sambagawa metamorphic zone is representative, which dense landslides of the so-called "Fractured type" or "Schist type" are found. The grade of metamorphism in the complex widely varies from low to relatively high. The zone consists of crystalline schists, phyllites and green metamorphic rocks including basic igneous rocks. The slightly metamorphosed rocks assume phyllitic texture, and they are black phyllite, green phyllite, sandy phyllite, and so forth. Landslides occur in thick talus deposits which are related to weathering of phyllitic rocks. Particularly in landslide area, schistosities, cleavages and minor folding structures are dominant. The talus deposits are formed on the slops of hills and mountains, where landslides occur, accompanying slow movement and occasional collapses.

Landslides in Northwestern Kyushu

In northwestern Kyushu, the well-defined coal-bearing Paleogene and Neogene formations have their full development. Famous landslides of so-called "Hokusho type" are found in the district. Especially, in Sasebo coal field region, landslides occur in places of the Neogene formations covered basalts plateaus, which play the role of "Caprocks". Main sliding layers are formed by the alteration tuff seams into clay which is sandwiched between coal seams. Kita-Matsuura basalts are assigned to Pliocene.

Northeast Japan

Northeast Japan is limited on the west by Fossa Magna, but the isolated landmasses of pre-Tertiary rocks appearing in Northeast Japan bear some relation with Southwest Japan. The disposition of the rocks and structures of the Kanto mountains clearly coincides with that of the Outer Zone of Southwest Japan. The Abukuma and Kitakami highlands lying in the Pacific area can be related to the central axial part of the Inner Zone of Southwest Japan.

The Tertiary rocks are widely distributed in Northeast Japan, excepting areas along the Pacific coast of the Abukuma highland, are Neogene in age and are characterized by the accumulation of abundant submarine volcanic substances chiefly in their lower parts and thick marine sediments in their upper. They have been more or less subjected to tectonic movements, and intensely folded zones are present, particularly in the areas along the Sea of Japan and in the tract of Fossa Magna. The volcanism, the depression and the tectonic movements were carried out quite independently of previous geological evolutions of the Japanese islands. Tertiary rocks of this kind partly extends west beyond Fossa Magna, to such areas as the Toyama, Kanazawa and the Matsue districts along the northern coast of Southwest Japan. During Miocene age the sea invaded extensively and covered the major part of the present Japanese islands. During Pleistocene the sea largely regressed, but the volcanism in Northeast Japan continued until recent time or rather regained the activity and formed the Quaternary volcanic zones.

Landslides in Oil-Tertiary and Green-tuff region

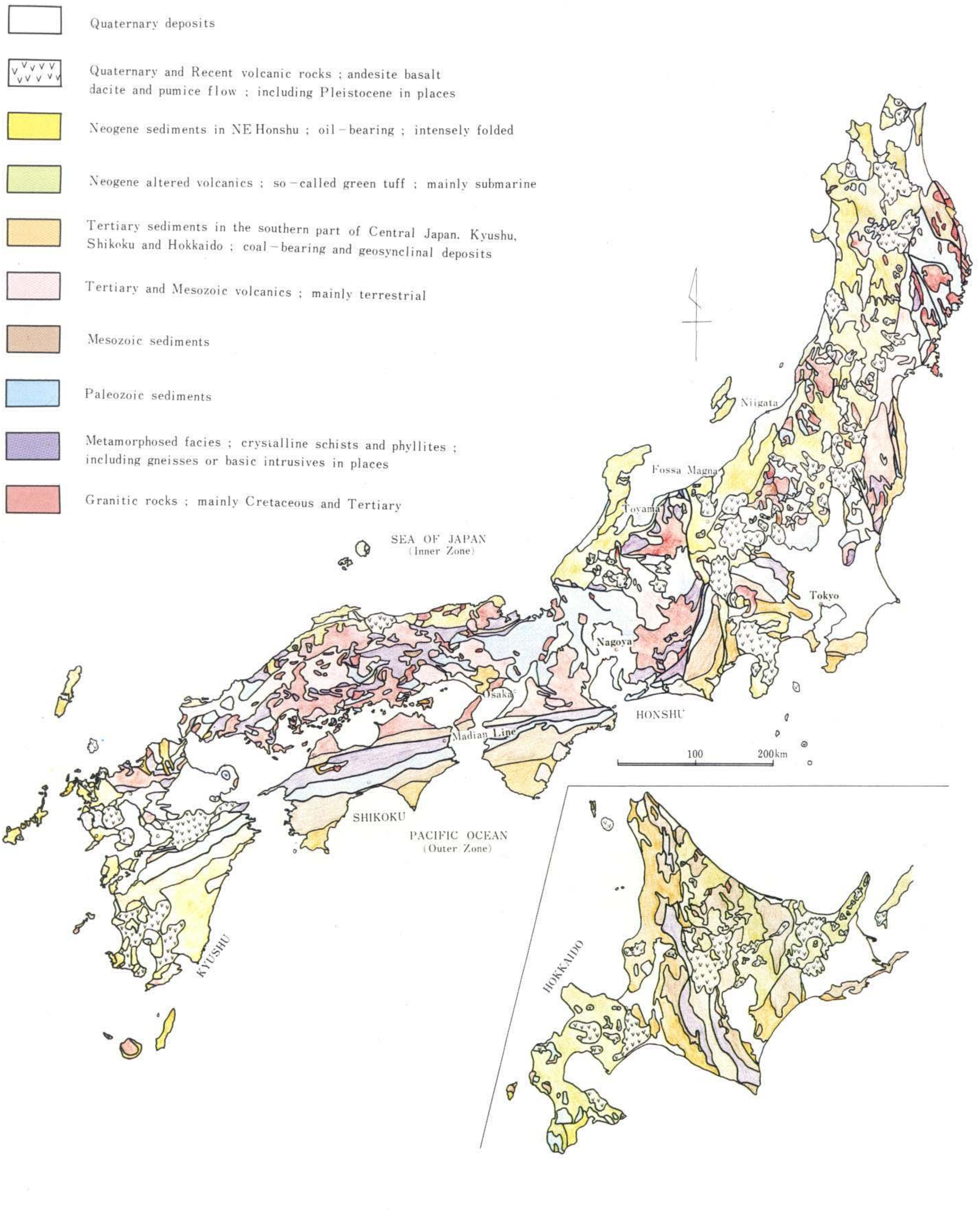
Neogene deposit known as the petroliferous Tertiary formation of Japan are present in the region which extends from the southwest Hokkaido, to the northeastern Honshu, Aomori, Akita (named the Ogashima and Yuri groups), Yamagata, Niigata (named the Kubiki and Chuetsu groups), Nagano (named the Hokushin group) and Toyama (named the Hokuriku group) Prefectures. They have been deposited in several different basins, but more or less interconnected with each other. The lower Miocene is composed chiefly of andesite or rhyolitic tuff-breccia and tuff, or very tuffaceous shale and sandstone, and contains numeous intrusions of basalt and dacite. The middle Miocene is intercalated with pyroclastic beds in many places. These complex of volcanic and pyroclastic rocks are called "green tuff" formation. The upper Miocene is composed chiefly of siliceous shale and dark-gray mudstone and is widely distributed. The Pliocene is composed mainly of argillaceous, arenaceous and pumiceous rocks, lignite seams are sometimes intercalated in it, and gravel beds are found in its upper part.

Many landslides or concentrated occurrence of landslides are distributed in these region, and sliding horizons consist chiefly of mudstone, tuffaceous mudstone, sandy mudstone, characteristic hard shale, tuff, tuffaceous sandstone and alternation of muddy, sandy, and tuffaceous rocks. Most landslides are affected not only by rock facies, but also are closely related to folding axes, beding planes and sheared zones.

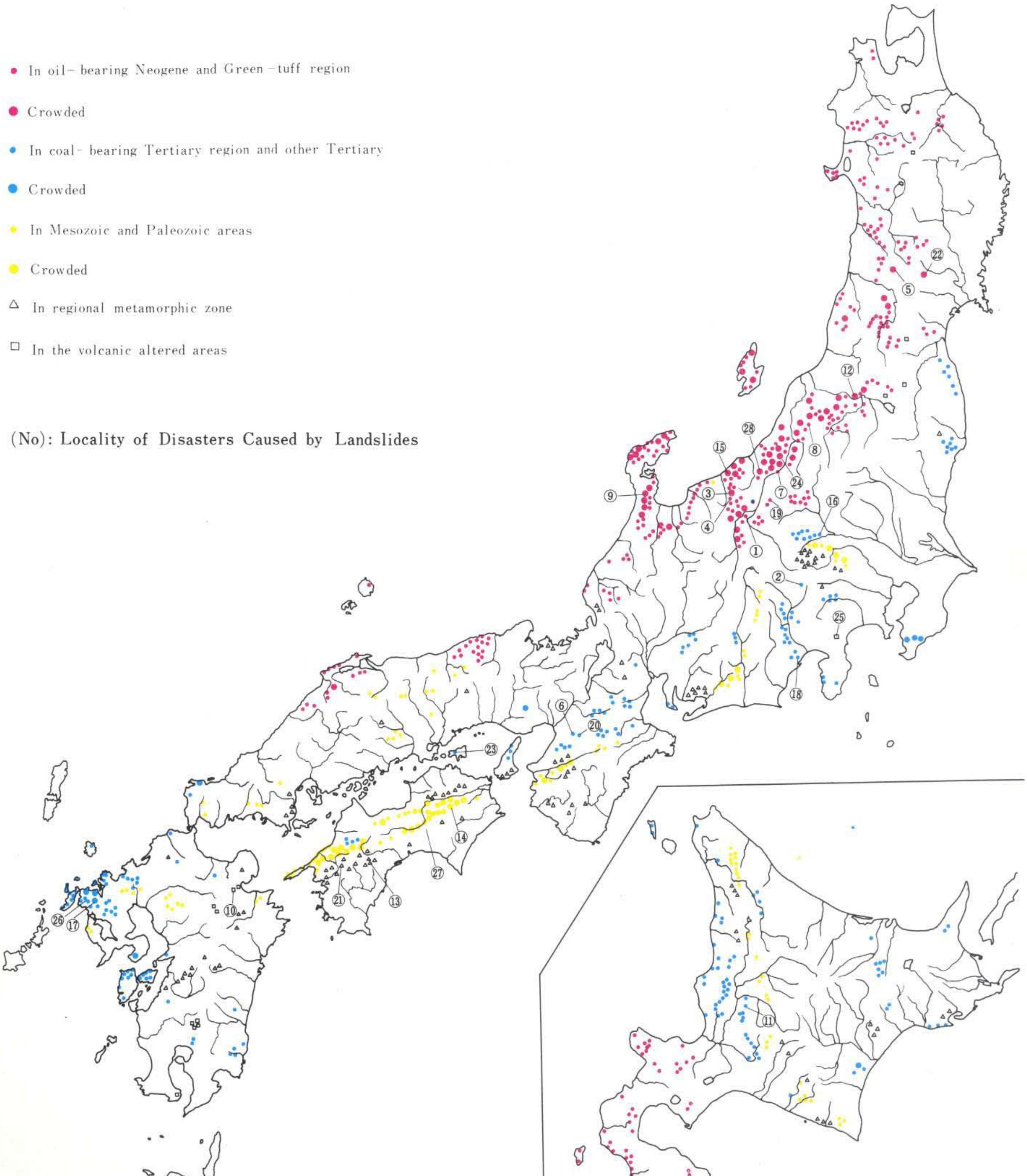
Landslides in volcanic altered areas

Landslides and collapses are frequent in places where volcanics have been subjected to fumarolic or hydrothermal action and altered to argillaceous. The fumarolic zones of Northeast Japan and Kyushu are examples.

Summarized Tectonic Constitution of Japan



Distribution of Landslides in Japan



Recent Investigation Methods of Landslide

The landslide survey is necessary for the elucidation of the mechanism of landslide and planning its prevention works. Depending on the configuration and characteristics of landslide, the landslide survey method and sites of measurements are chosen. The landslide survey is divided into a preliminary survey and a detailed one.

The preliminary survey is made for planning a more detailed survey in case of complicated landslides and large-scale landslides. The detailed survey is carried out to obtain a presumption of the mechanism, ascertain it and plan the concrete landslide control. The subjects of the landslide survey performed up to now are classified as follows:

I Preliminary survey
- (1) Seismic prospecting
  - a Refraction wave method
  - b Shallow layer reflection method
  - c Miscelleneous slight tremor method
- (2) Electric surveying method
  - a Specific resistance logging
  - b Electric survey of layer
- (3) Natural radioactivity survey

II Detailed survey
- (4) Test boring
- (5) Sliding layer survey
  - a Estimation of geological features
  - b Decipher using a borehole
    - i) Decipher by test boring
    - ii) Decipher using a sinker
    - iii) Decipher by measuring
      - A) Sliding layer decipher pipe
      - B) Strain gauge pipe
- (6) Ground-surface movement survey
  - a Method by measuring
    - i) Aerial photography
    - ii) Terrain photogrammetry
    - iii) Moving pile
  - b Tensometer
  - c Tiltmeter
- (7) Groundwater survey
  - a Groundwater pressure
    - i) Void pressure
    - ii) Groundwater level
  - b Distribution of groundwater
    - i) Surface water
    - ii) Groundwater prospection
    - iii) Pumping test
    - iV) Groundwater tracing
    - V) Quality of groundwater
- (8) Soil tests
  - a Physical tests
  - b Mechanical tests
  - c Sounding

Main methods among the above will be explained.

1. Seismic Prospecting

This is a physical investigation using elastic waves and is a method to presume the distributions of layers by measuring the travel time of elastic waves based on the fact that their propagation velocity has close relation to the substances forming the layer. This method is mainly used for prospecting, and is effective in such large-scale landslides that the block of the sliding block is hardly identified. Elastic waves consists of longitudinal waves (P-waves), a transversal waves and surface waves, and among these the longitudinal is generally used.

An application of the refractive wave method and the shallow layer reflection method to the landslide investigation is made; the reflective wave method is for deciding the distribution of layers by measuring the propagation velocity of P-waves which start from the seismic center, propagate layers and arrive at the observing point; the shallow layer reflection mehtod is for presuming the structures of the relatively shallow layers by the measuring waves reflected from layers. A test is also made, which presumes the properties of the ground having amplitude of less than 1 micron (the miscellaneous slight tremor) with a seismometer and by drawing a frequency distribution curve of the cycle as an information showing underground structures.

2. Natural Radioactivity Survey

Rocks forming as the earth is crust generally contain

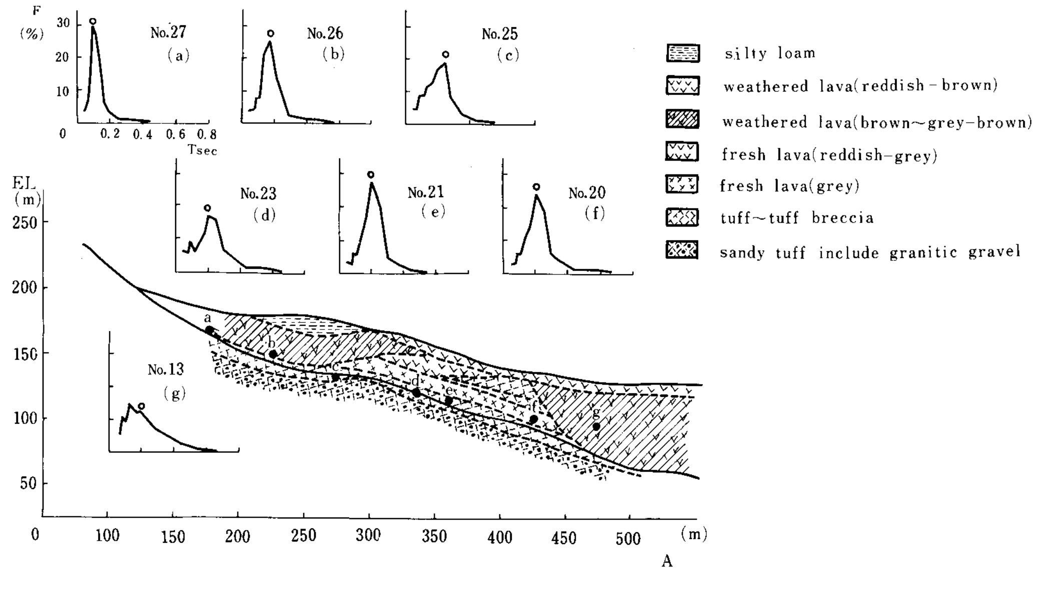


Fig. 1 Relation between sliding surface and excellent recurrence

such natural radioactive element uranium and thrium series, which release radon and thoron gases in their decay processes. These gases are also radioactive and are released from deeply seated to the ground through faults and fissures of rock beds. In the natural radioactivity survey, the gamma-rays emitted by these radon and thoron gases are measured with a scintillation survey meter at each spot of the ground, and the existence of faults and curshed zones is judged from a gamma-ray intensity distribution map of the surveying area. This survey method very effective as a preliminary survey.

3. Specific Resistance Logging

After the drilling survey has been done in the landsliding area, various kinds of investigations are made using boreholes. The specific resistance logging is one of the these investigations and examines deposit conditions of layers and variations in specific resistance. Comparing with the specific resistance logging carried out on the ground, this method gives more accurate correlations of specific resistance values with geological layers and clarifies more accurately underground structures of the landsliding area. Furthermore, this logging is one of the effective methods to draft a drainage plan of groundwater in the landsliding area by locating groundwater aquifers and judging their conditions.

4. Electrical Surveying Method

One of several kinds of electrical surveying methods, the specific resistance method is used for landslide investigation. This method distinguishes constituent soil masses in the ground by the difference in specific resistance and underground structures are presumed comparing with the sequence of layers.

The specific resistance method is divided into the vertical surveying method and the horizontal one. In order to know the properties in the landslide area, the horizontal surveying method is more effective. Since this method gives important fundamental data for drainage works and enables forcasting surveying method as a preliminary survey.

5. Drilling Survey

Boreholes are arranged so that a distance of 30 m is kept as a standard on the main lain of measurement; more than 4 boreholes, at least 3 inside the landsliding block on the line of measurement and 1 on the upper slope, are drilled; and the subsidiary line of measurement keeps a double distance as the main line of measurement. Another consideration is paid again in the case of specially complicated topography.

The bottom of the borehole is more than 5 m into the bed rock; therefore the depth of the borehole becouses the presumed thickness of the landsliding layer plus 5 m.

The borehole diameter is larger than 65 mm and be of all-core boring. The standard penetration test is done along with drilling. The geological logs are drawn based on core samples, referring to geological structures of neighboring places. Bed rocks and weathered zones are clearly distinguished from debris, detritus and volcanic rock fragments.

6. Measurement of Displacement Velocity and Ground Surface Strain with a Tensometer.

This device is mainly used for 1) measurement of displacement velocity and 2) surface strain. In the former case, it is set extending over an immovable place and a moving place, or covering a main rock. Displacement quantities are automatically recorded with a several-fold accuracy.

Correlations between displacement quantities thus obtained and rainfall, groundwater level, etc. are analyzed for the data for studying the mechanism of landslide and for deciding the method as a landslide control.

In the latter case, the strain between to points on the landsliding slope is measured. This strain shows a striking change previous to the collapse of the slope. Since the relation between the constant strain velocity shown by a linear part of the secondary creep and the time of creep failure can be represented as linear relation in a logarithmic graph, this strain measurement is a very effective method for forecasting landslide occurrences. Danger will be automatically warned when the displacement velocity reaches some fixed level.

7. Measurement of Ground Surface Fluctuation with a Tiltmeter

In the landsliding area, a slight change in tilt of the

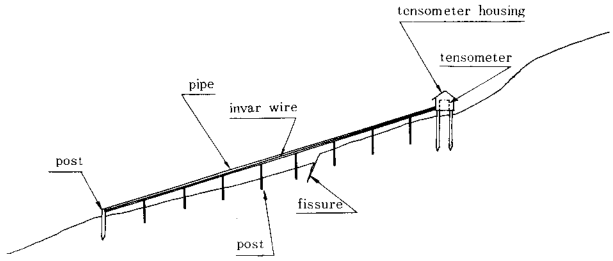


Fig. 2 Setting of tensometer

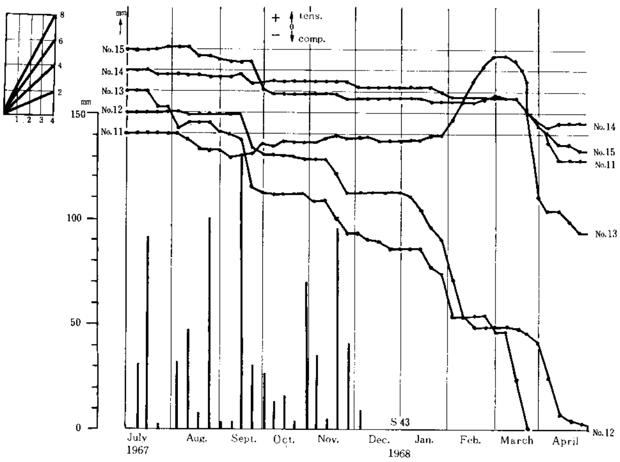
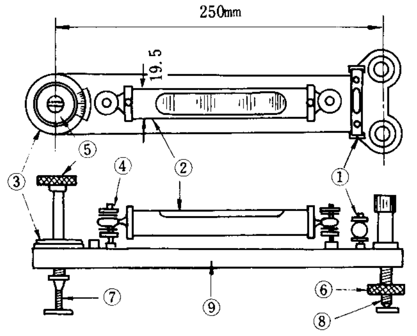


Fig. 3 Daily variation of displacement velocity (No. 12-14 point measurement)



① adjutant bubble - tube
② main bubble - tube
③protractor
④ adjust hinge for bubble - tube
⑤ revolve cramp for main prop
⑥ adjust hinge for sub prop fixed
⑦ main prop
⑧ sub prop
⑨bubble - tube table

Fig. 4 Structure of water type tiltmeter

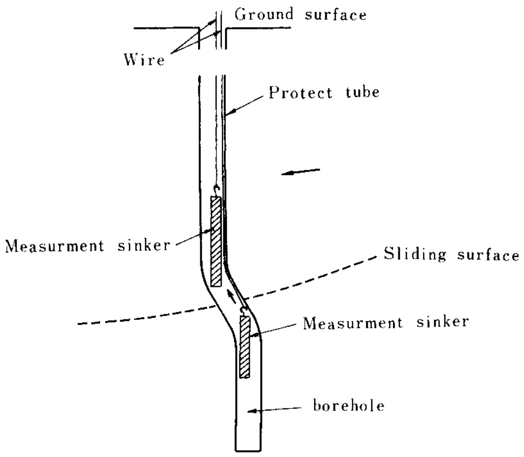


Fig. 6 Measurement of sliding surface

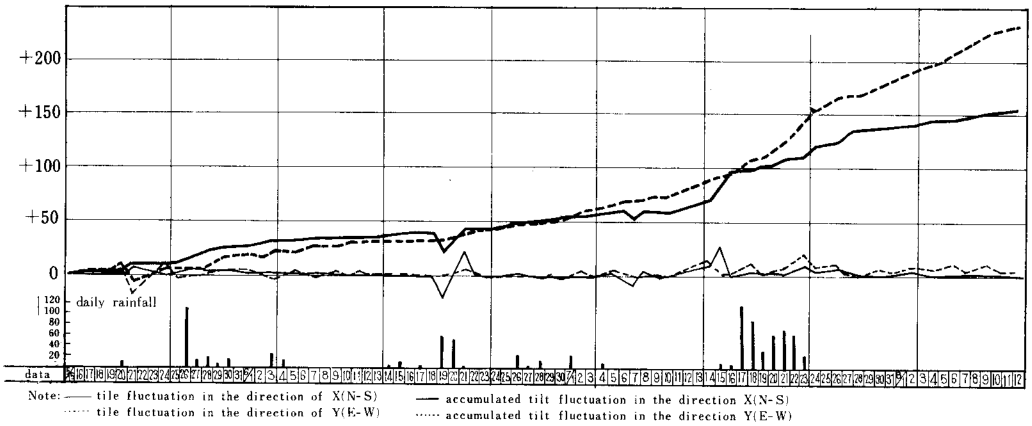


Fig. 5 Example of measurement of tiltmeters

ground is usually generated as a forerunning phenomenon which can not be noticed by human sense. This slight tilt fluctuation can be utilized for forecasting landslide activities.

Two types, an automatic recording type and a manual one, of this tiltmeter are sold in Japan, however, mechanically simple and cheap tiltmeters of water pipe type are generally used. The accuracy of measurement is about 1.2 second. When a tiltmeter of water type is used, two tiltmeters are used as a pair lying in a right angle (usually, east-west and north-south directions). Fig. 5 shows an observational results obtained by a pair of tiltmeters.

8. Decipher a Sinker

A short and heavy pipe is inserted into a borehole, pulled up after a lapse time, and checked. This will give information on bent parts. The method is effective in the activity sliding area, but not more than two sliding layers exist.

9. Aerial Photo Survey

The techniques of aerial photo interpretation have greatly advanced. The measurement of the sliding mass in the active sliding area is made by periodically taking aerial photos and analyzing them.

10. Measurement of Slide Surface with a Pipe Strain Gauge

In order to analyze landslide phenomena and establish a control work plan, it is necessary to know the depth and the shape of slide surface as accurate as possible. An underground strain gauge is one of the effective methods which have been developed for this purpose. This gauge consists of a vinyl chloride pipe on which side a pair of perfect waterproof paper strain gauges are fixed at each measuring depth, and changes in electric resistance of strain gauges by the deformation of a pipe caused by ground displacement are measured with a strain meter.

11. Groundwater Prospecting

In this test the flow conditions of groundwater are investigated using boreholes. Salt solution is injected into the borehole and thoroughly mixed to reduce specific resistance of water in the borehole to about one-tenth of the initial value. The water in the borehole is partially replaced and diluted by groundwater of high specific resistance flowing from layer of high permeability and changes its specific resistance. Changes in specific resistance are measured with this instrument which is made of a combination of measuring systems consisting of a pickup with many electrode pairs, an alternate current, oscillating circuit and a bridge circuit.

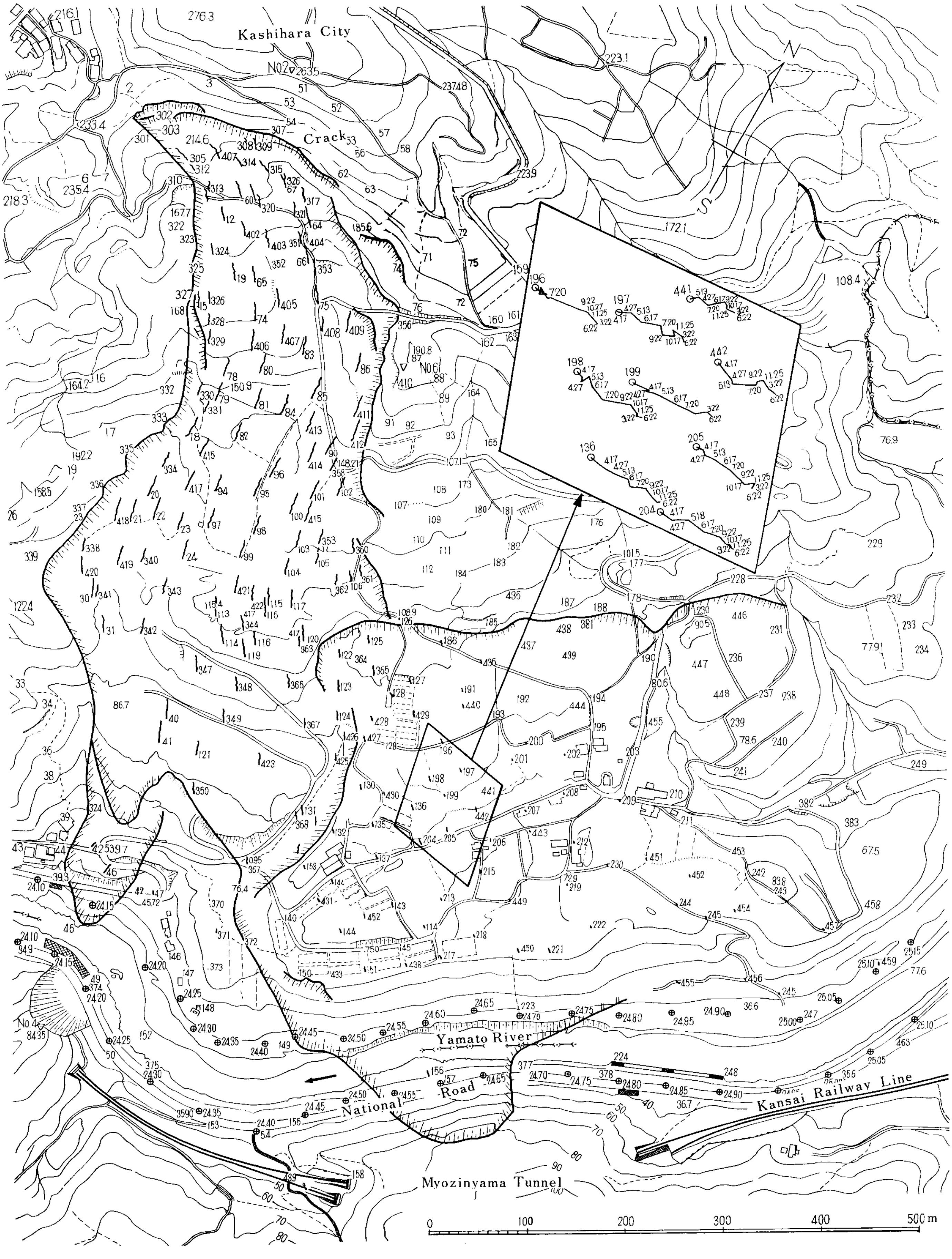


Fig. 7 Analyzed slide by aerial photo survey

12. Groudwater Level Survey

The measurement of groundwater level in boreholes is indispensable for studying the mechanism of landslide and for planning appropriate control works. Various automatic recording apparatuses such as a water-level gauge of float type, of needle touch type, etc. are generally used for measuring groundwater level. In this survey method, correlations are analyzed between groundwater levels and rainfall, ground diplacement, etc.

13. Groundwater Tracing Test

After some flowing routes of groundwater have been presumed in the landsliding area and the neighboring area survey, water level measurement in boreholes, groundwater prospection, tests of groundwater quality, etc., flow velocities and velocity distributions of groundwater flowing of the routes are measured in-situ with this groundwater tracing test.

Groundwater tracers generally used are as follows:

a. Inorganic chemicals : manganese sulfate, sodium dichromate, ammonium chloride, salt, pottassium chloride
b. Fluorescent or coloring reagent : sodium salt of fluorescein, rodamin
c. Radioisotopes : tritium, iodine

14. Quality of Groundwater Survey

In this survey method the flowing routes of groundwater are presumed by classifying characters of the groundwater existing in the landsliding area with quality of groundwater and assuming where they came from. In general, tests are made on water temperature, specific resistance, pH, BCG alkalinity, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, SiO_2, and the results are plotted on a rhombic diagram to classify groundwater characters. Trace elements are also quantitatively analyzed as occasion demands.

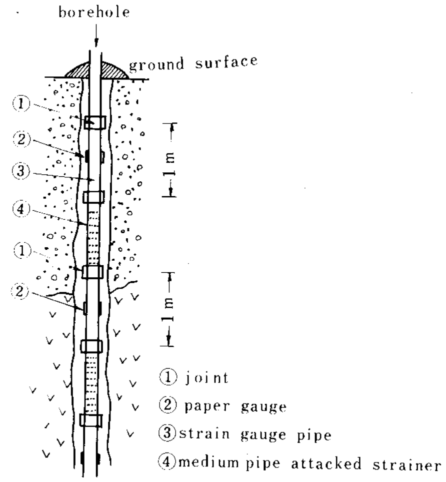


Fig. 8 Setting of pipe strain gauge

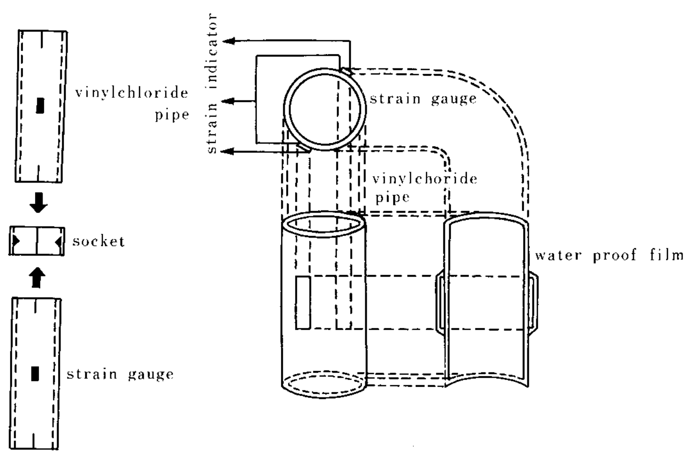


Fig. 9 Structune of strain gauge

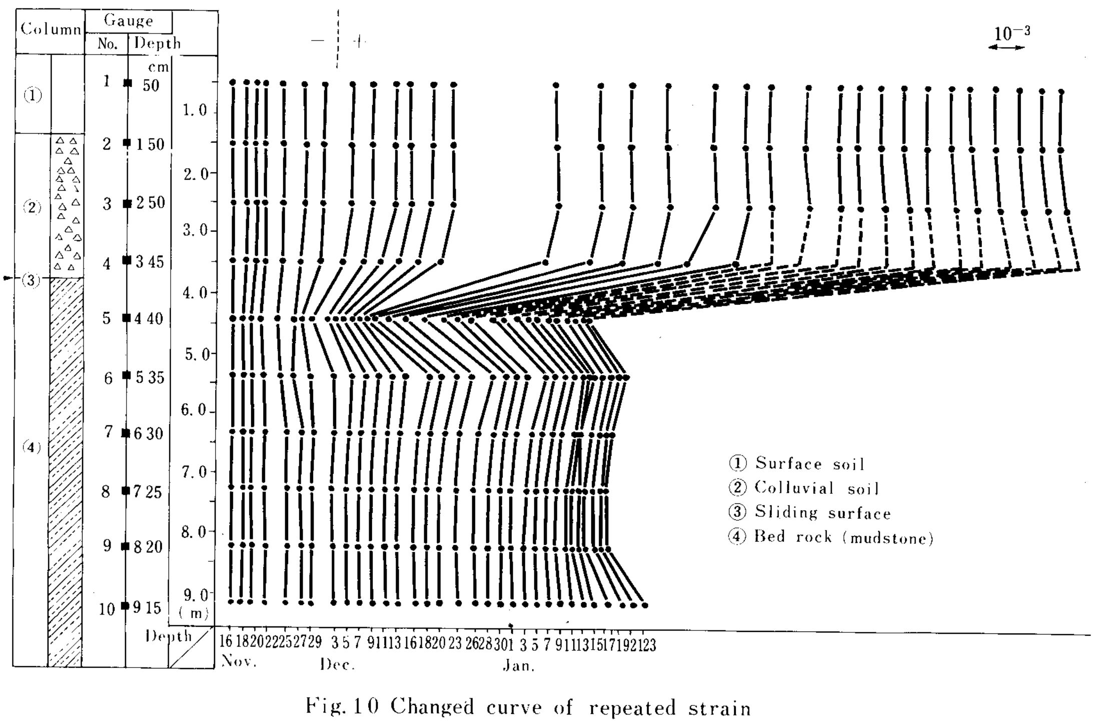


Fig. 10 Changed curve of repeated strain

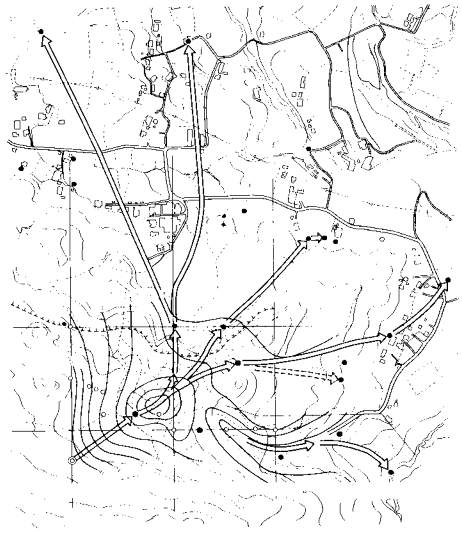


Fig. 11 Results of groundwater tracing test

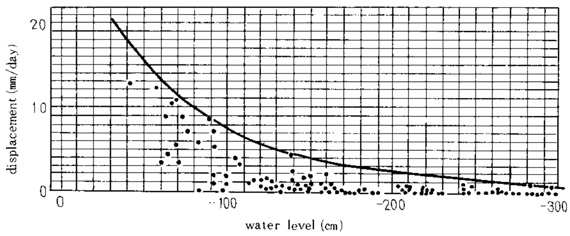
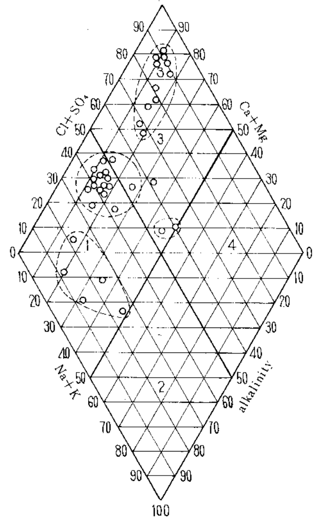


Fig. 12 Relationship between displacement velocity and groundwater level at landslide



1. Carbonate Hardness
   Waters containing calcium and magnesium bicarbonates as main constituent
2. Carbonate Alkali
   Waters containing potassium and sodium bicarbonates as main constituent
3. Non Carbonate Hardness
   Waters containing earths chloride and sulfate as main constituent
4. Non Carbonate Alkali
   Waters containing alkali chloride and sulfate as main constituent such as waters mixed with as water and fossil brine

Fig. 13 Rhomic diagram to classify groundwater characters

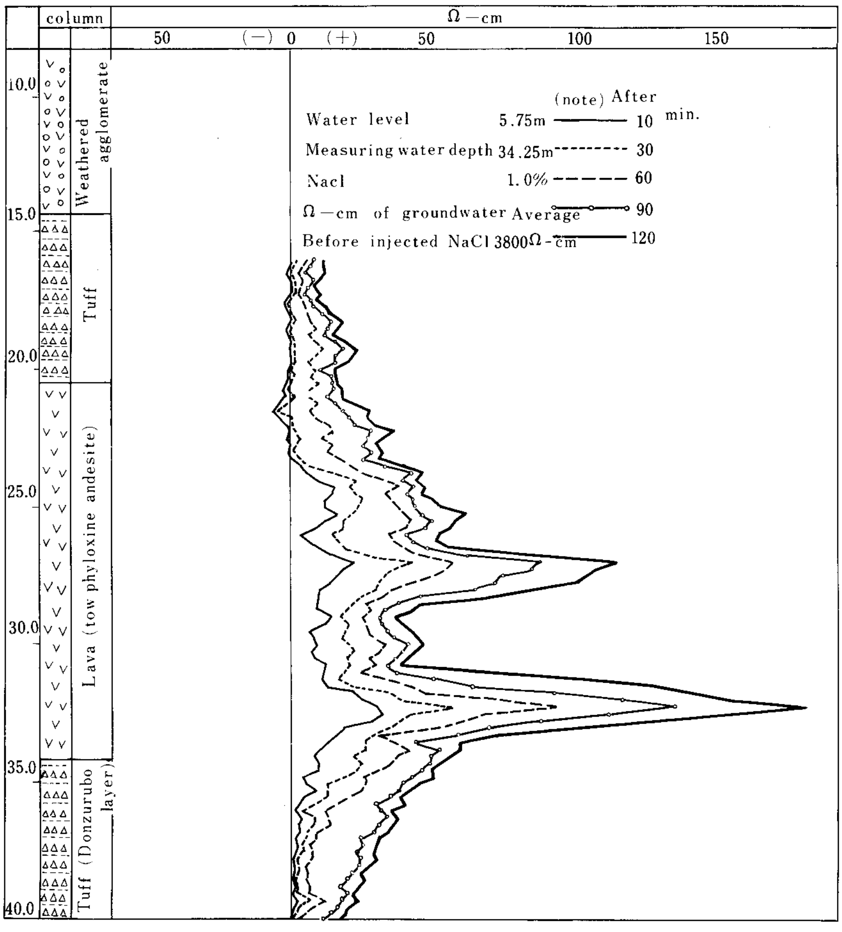


Fig. 14 Groundwater prospecting at Kamenose landslide (No. 4217borehole)

Landslide Control Work

The landslide control work is divided into a precaution control and a prevention control. The precaution control includes the method to transfer the inhabitants and houses to other safe areas, and to change the route of roads or rivers by foreknowing dangerous areas and considering the expenses for prevention works and to avoid landslide by digging a tunnel into the stable rock. When public works are obliged to be done in the dangerous area, the prevention works are previously performed to increase stability.

The prevention control work of landslide is divided into a suppresion work and restraint work. The purpose of the suppression work is to stop or moderate the landslide movement by changing the topography, soil and groundwater or natural condition. The restraint work means a method to protect the public institutions and houses in the landslide-threatened area from accidents by stopping the landslide movement partially or completely with restraint structures. The engineering methods included in the suppression work and the restraint work and the restraint work are as follows:

1. Soil Removal

This is one of the most effective engineering methods, generally being used in the middle or small landslide area. The purpose of this method is to obtain required safety by removing the landslide mass partially or completely. Fig. 1 shows a plan of soil removal performed in the Yui landslide area.

2. Surface Drainage

As landslide is liable to be caused or activated by the permeation of precipitation and the re-permeation of spring water or pond water, this method is generally adopted in most landslide areas. This drainage is divided into permeation work of precipitation and water channel work by which surface water is rapidly collected and removed to other areas. Fig. 2 shows a plan of surface water drainage works.

3. Underground Drainage

Groundwater is one of the effective causes leading to and promoting landslide occurrences and its removal is one of the most important problems in the landslide controlling. The groundwater drainage work is divided into two : collection and drainage of groundwater existing around the sliding layer, and collection and drainage of groundwater before flowing from other areas. The drainage can be classified into shallow groundwater drainage and deep groundwater drainage.

A) Shallow groundwater drainage
  1) Underdrainage
  2) Open channels
    This method is performed to collect and drain groundwater within a depth of 3 m from the surface and to flow the same channel as a surface water drainage. Underdrainage is effective where jointly used with open channels.
  3) Horizontal boring
    When the shallow groundwater drainage cannot be applied on account of topography and depth conditions, the horizontal boring is done. The horizontal boreholes generally have a length between 30 and 50 meters, being digged with a slightly upward direction between 5 and 10 degrees, and perforated tubes of hard vinyl chloride tubes with a diameter of about 2 and 2.5 inches are inserted.

B) Deep groundwater drainage
  1) Long horozontal boring
    This type is adopted for discharging groundwater in specified layers and digged to an upward or downward direction. The downward digging is useful for the drainage of pressure groundwater.
  2) Drainage well
    This is useful for draining groundwater above or around the base rock. Generally, a well with a diameter of 3.5 m is digged and from its inside horizontal boreholes are drilled to collect groundwater. Collected groundwater is drained through a long drainage borehole or by pumping. Ferroconcrete or linerplate is used in reinforcing the well wall.
  3) Drainage tunnel
    This is an effective and reliable method useful for the drainage of much groundwater within or around the base rock. The tunnel with a diameter 1.8 or 2.5 m is digged searching for groundwater veins, corrugate tubes and linerplates are used in reinforcement. It is also performed to raise the efficiency of collecting groundwater by drilling boreholes within the tunnel.

4. Interception of Groundwater

This is used when much groundwater flows into the landslide area from other area and when the water channel and the water-bearing layers are clearly identified. This is a method to lead groundwater to the surface through horizontal boring by intercepting groundwater by building a interception wall outside the sliding area. The interception wall method is divided into : the inject ion of chemicals into the ground, and installing a wall by excavation. In case of deep water-bearing layers, the injection method is used.

5. River Structures

The methods to prevent landslide occurrence by protecting the tip of the sliding area from river erosion are as follows:

a) Sabo dam work
b) Consolidation work
c) Revetment
d) Spur dikes

6. Piling Work

In order to prevent landslide, the driving of piles into the sliding soil mass has been used. Timber sticks were formaly used, and ferroconcrete piles, steel tubes and H-type steels are often used. Steel tubes are most generally used at present. The tubes are driven into the large vertical borehole drilled by the boring machine which penetrates the sliding layer to reach the base rock. The prepacked concrete is usually filled in and the H-type steels are often inserted for reinforcement. Steel tubes, the heads of which

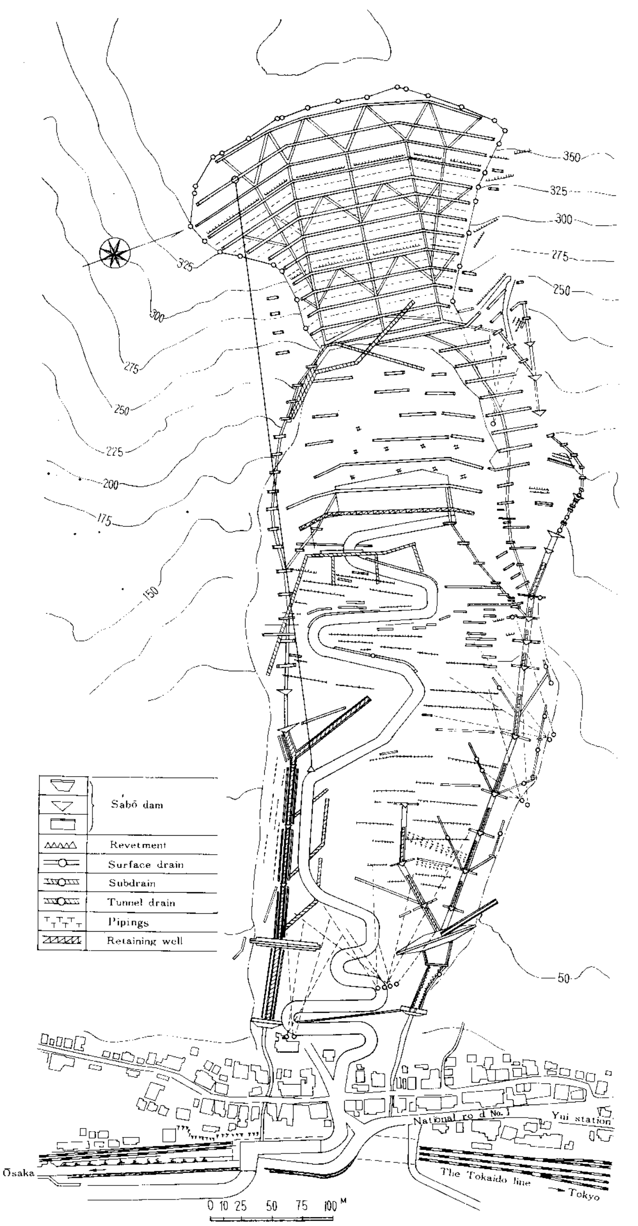


Fig. 1 (General control works of Yui slide area

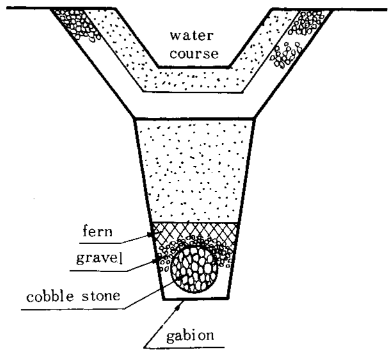


Fig. 2(a) Surface water drainage channel and subdrain

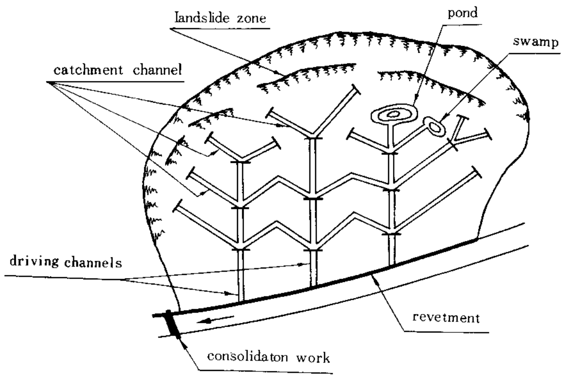


Fig. 2(b) Preventive work by water drainage net

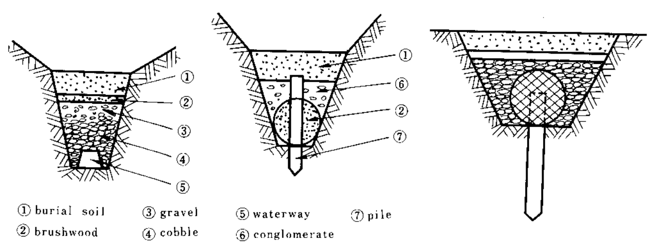


Fig. 3 Underdrain

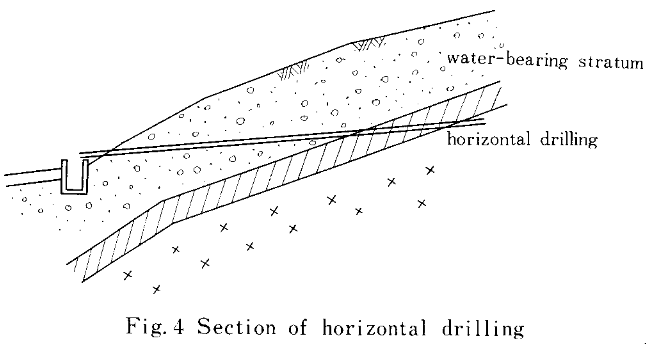


Fig. 4 Section of horizontal drilling

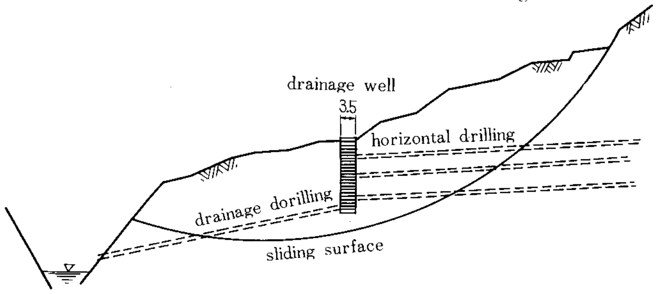


Fig. 5 Section of drainage well

are tied with each other, are used for raising resistance against bending by taking anchor ties from the heads to the oblique downward direction. The diameter of the tubes ranges from 318.5 to 459.2 mm.

7. Retaining Walls and Cribwork

These are used in order to prevent the sliding at the tip of the slide area. Since the surface deformation of the ground is large and much groundwater is encountered with the cribwork is often used. Timber, ferroconcrete suquares and tubes are generally used as materials.

8. Other Prevention Works

In volcanic landslide areas, the pressure of volcanic gas in pores sometimes causes landslide. In such a case, landslide is stabilized by removing the gas from high pressure zone through boreholes drilled obliquely downward.

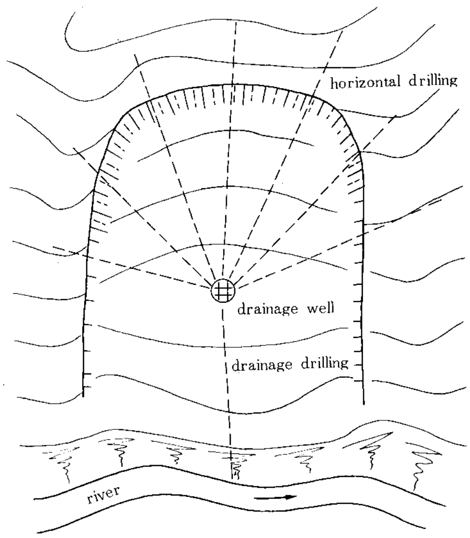


Fig. 6 Plan of drainage well

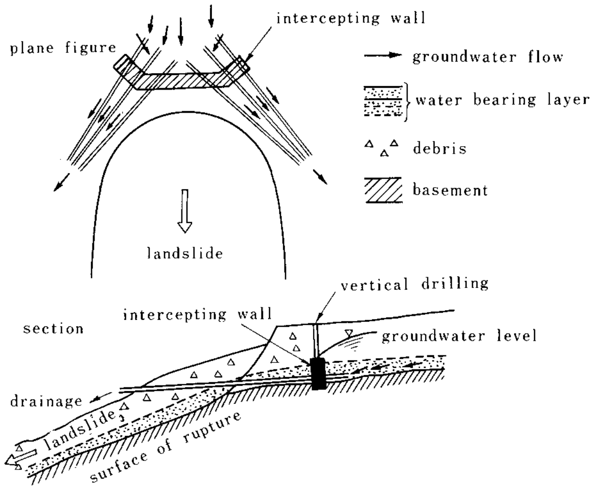


Fig. 8 Plan of groundwater interception

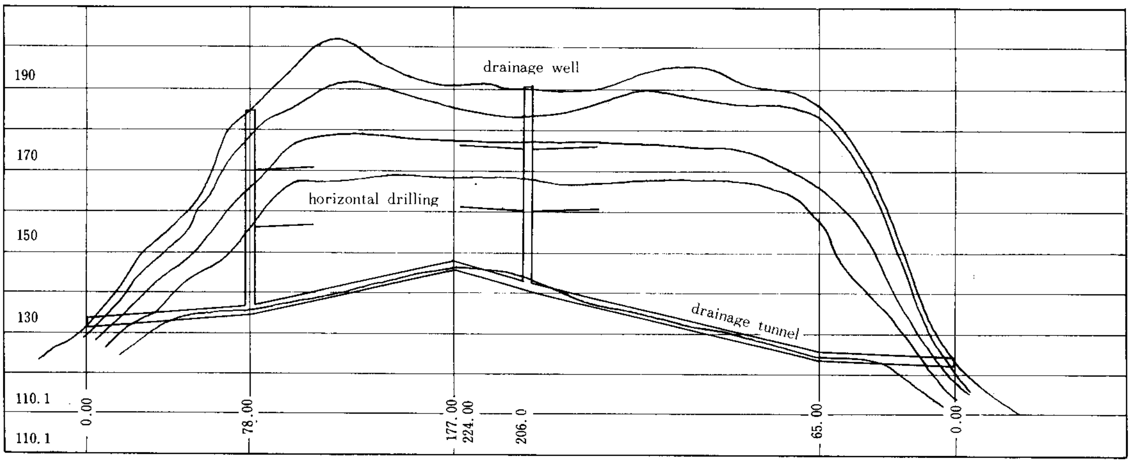


Fig. 7 Section of drainage tunnel and drainage well

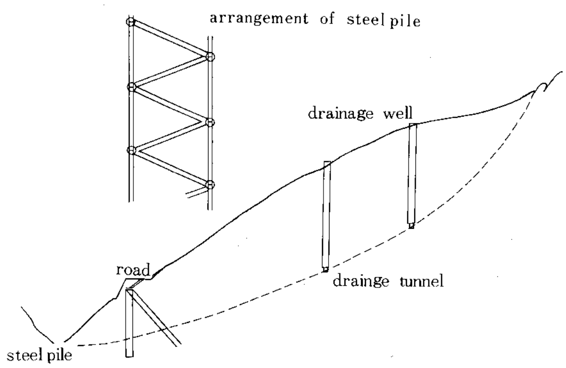


Fig. 10 Section of steel piling

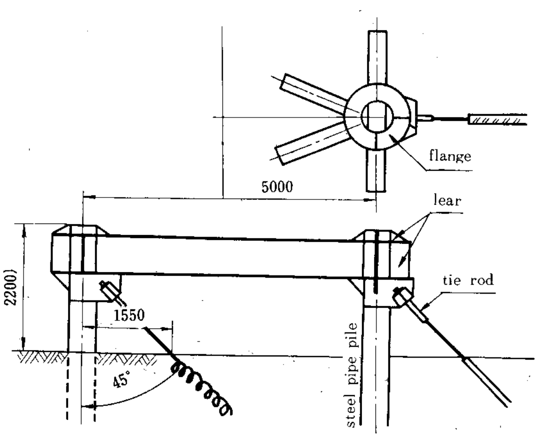


Fig. 9 Connection of top of pile

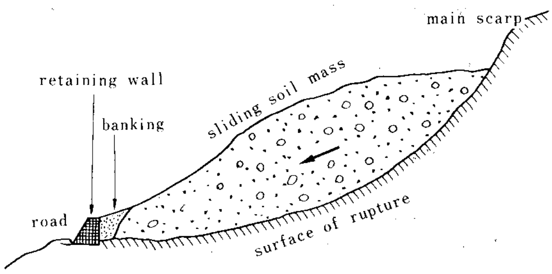


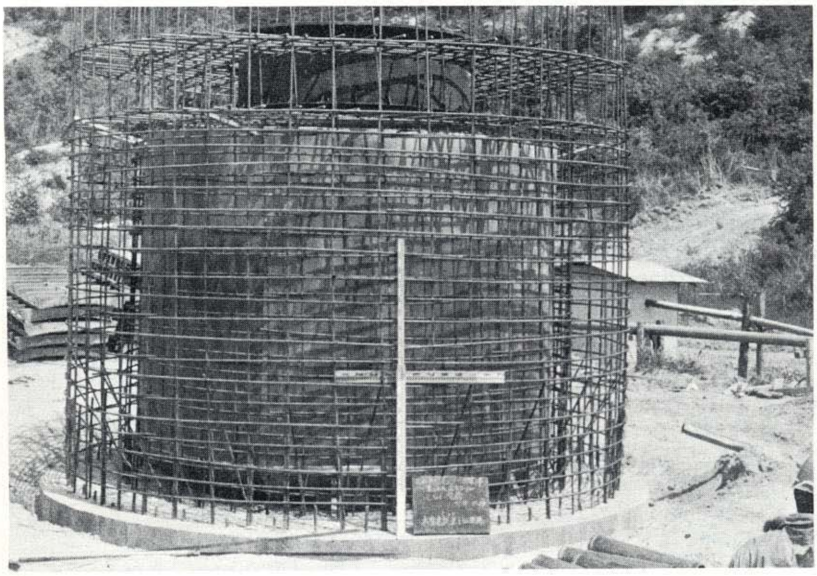
Fig. 11 Retaining wall

Disasters Caused by Landslides

Chausuyama Landslide in Nagano-Shi, Nagano Prefecture (1)

The direct motive of this landslide is regarded as the Zenkoji earthquake which occurred in 1847. Foretokens of landslide appeared in 1884, the whole outline of the activity being nearly clarified in 1898 and the activity lasting up to now. At present this landlisde is 2,000 m long, and has an area of 46 ha, and a soil mass of $9.0 \times 10^6 m^3$ has been pushed out. This is divided into the area of origin (800 m long) in the upper part and the secondary area (1,200 m long) in the lower part. Geology: the Miocene series, sandstone, mudstone and tuff, holding lignite seams. In the upper area many depression ponds were found and a large amount of ground water including sulphates springing out. Detailed investigations of the mechanism, movement and the ground-water has been carried out. During the first period of activity extending from 1930 to 1940, at the tip of the sliding area, the rate of moving velocity was measured as 25.4 cm/day (average between March 1935 and Nov. 1937). Between 1940 and 1945, the sliding movement was inactive. In 1945 the second period of the activity began, lasting for 15 years since. In 1960 the activity began to be inactive again, but from 1965 an active sliding movement was caused by the Matsushiro earthquake swarm. Control works: deep wells, drainage wells, water channels and steel tube piles were installed and in the movement has nearly come to be inactive.

General view of the upper part of Chausuyama landslide
1 Main scarp, 2 Slump zone 3 Flowing zone 4 Immovable land 5 Village



Férroconcrete drainage well constructing and reinforcing steel construction (Chausuyama landslide)

Iwadonoyama Landslide along the Highway, Otsuki-Shi, Yamanashi Prefecture (2)

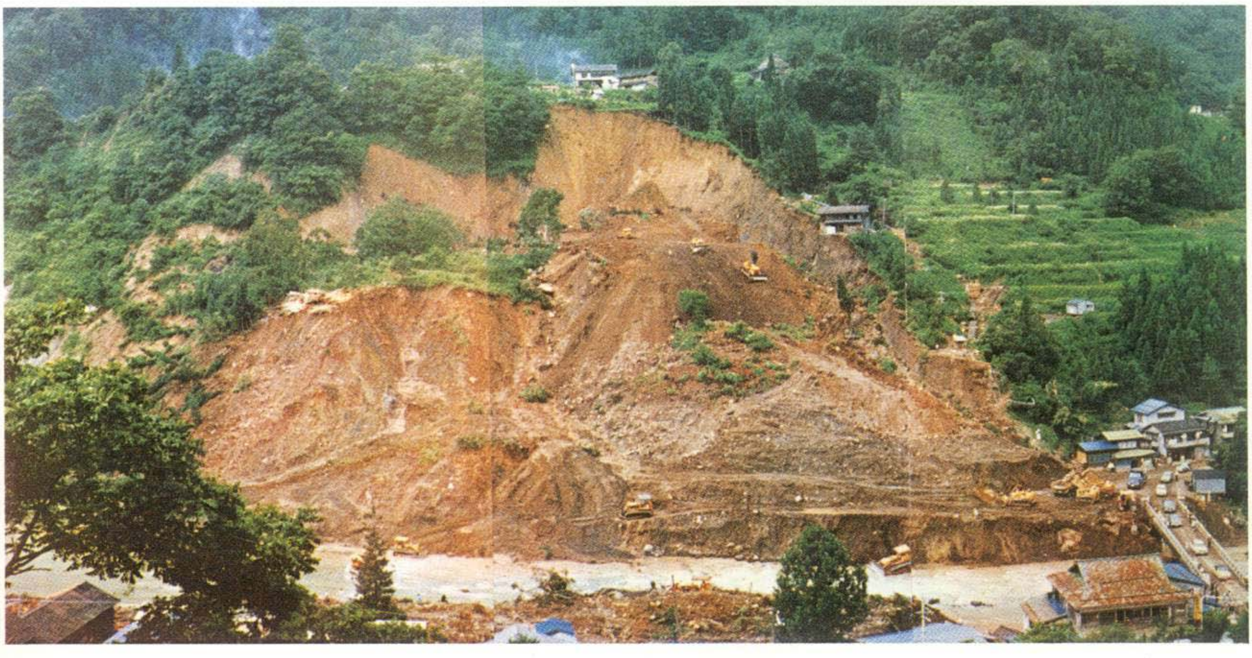
This is a landslide which occurred on the southern sloping land of Mt. Iwadono in March 1972. Mt. Iwadono is located between Otsuki and Lake Sagami, along the Chuo Highway constructed through a cut in the sloping land and of the mountainside adjacent to the Katsura river. The gradient of the slope is measured as 34° on average, and the slide occurred at a height of about 100 m above the highway, a width of the tip being 80 m. Geology: the host rock is mainly composed of the metamorphosed basalts, bearing metamorphosed andesites, tuff breccia and mudstone seams. No changes were found along the highway, but large cracks broke out in the cut open mountainside and the crib which was constructed there. On 21 March, a moving velocity of 3 mm/hour was measured, but on 29 March, the velocity rose to 13 mm/hour being affected by heavy rain fall. For three years since opening to traffic service, the Highway was shorting the Metoropolitan sphere with the Ko-Shinetsu district, and the closing of the highway for control works had a socially great effect upon the transportation of goods to the Metropolitan area.

Shimizuyama Landslide in Otari-Mura, Nagano Prefecture (3)

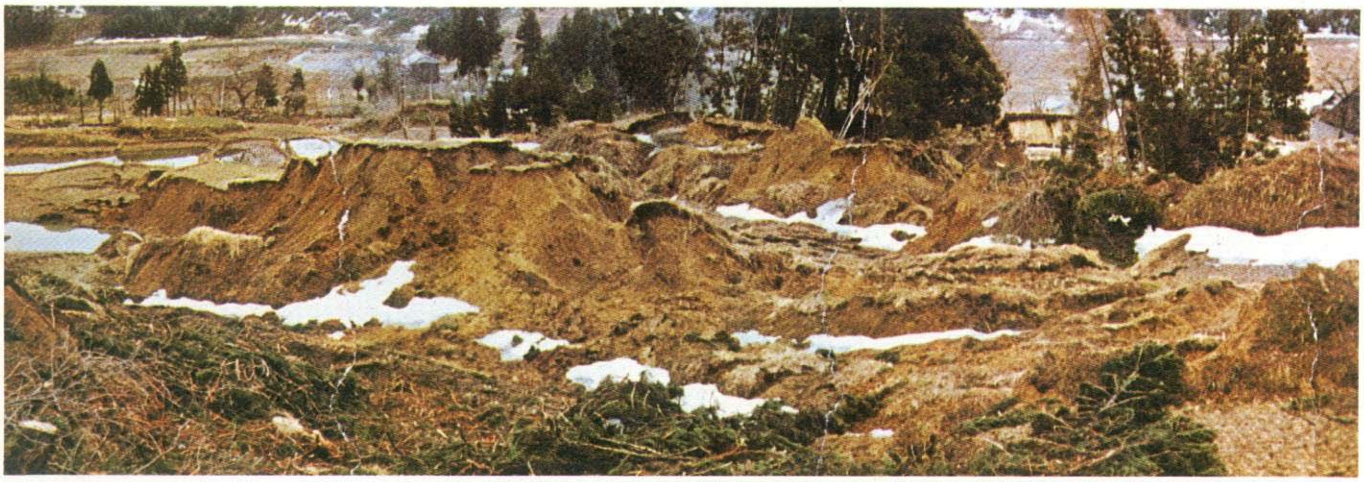
This is one of the landslides distributing in the Otari district along the Hime river basin, macroscopically belonging to the "Fossa Magna" zone. This landslide in the form of the long and narrow belt is about 2,000 m long and about 500 m wide, having an area of 116 ha. Geology: are complicated and composed of the mixture of the Miocene mudstone and sandstone with the rhyolite dike intruded into the Miocene series. Changes of mudstone into clay and of rhyolite into bentonite are conspicuous. This is a topography of repeated landslide occurrences. A crack occurred in an area of 10 ha near the village in March 1960; subsequently a soil mass continued sliding for two days. Then, a moving velocity of 10 cm/sec. was measured. Between February and March 1961, the sliding area spread toward the upper part, and in April, soil mass in the area of 15 ha flowed out at a maximum velocity of 30 m/min. And then, a soil mass of about $10 \times 10^5 m^3$ was pushed out to bury the Nakaya river in the lower part.

Ozuchiyama Landslide in Otari-Mura, Nagano Prefecture (4)

At 14:10 on 16 July 1971, this landslide brake out all of sudden. This area belongs to a part of a frequently repeated landslide area with an length of 170 m and a width of 150 m along the Hime river. In this landslide, a soil mass of about $2 \times 10^5 m^3$ was collapsed and the debris filled up the Hime river, and the running water of the Hime river ran over the banks to flood many houses. Geology : Neogene, in which sandstone and tuff prevail, and fault structures are conspicuous, belonging to the so-called "Fossa Magna" (Itoigawa-Shizuoka tectonic line) zone. This is noted as the collapse landslide closely related to faults.



Nishikawa Landslide in Mamurogawa-Machi, Yamagata Prefecture (5)



Nishikawa Landslide along the Mamuro river

This landslide broke out in December 1968. On previous days, foretokens such as the occurrence and spread of depression, rumbling of the earth and cracks were noted. This is a heavy snowfall area, but the direct motive of the landslide is regarded as the rainfall of 112 mm fallen in four days. Geology: Miocene, mainly tuffaceous sandstone. Fault structures are developed at the west side of the damaged area. Since rainfall on August 1955, along faults structures, a few stripes of cracks already occurred and the landslide broke out at the dangerous meandering belt of a river.

Kamenose Landslide in Kashihara-Shi, Osaka Prefecture (6)

General view of Kamenose landslide

1 Yamato river 2 National road 3 Kansai Railway line
4 Scarp at the head 5 Soil removal work

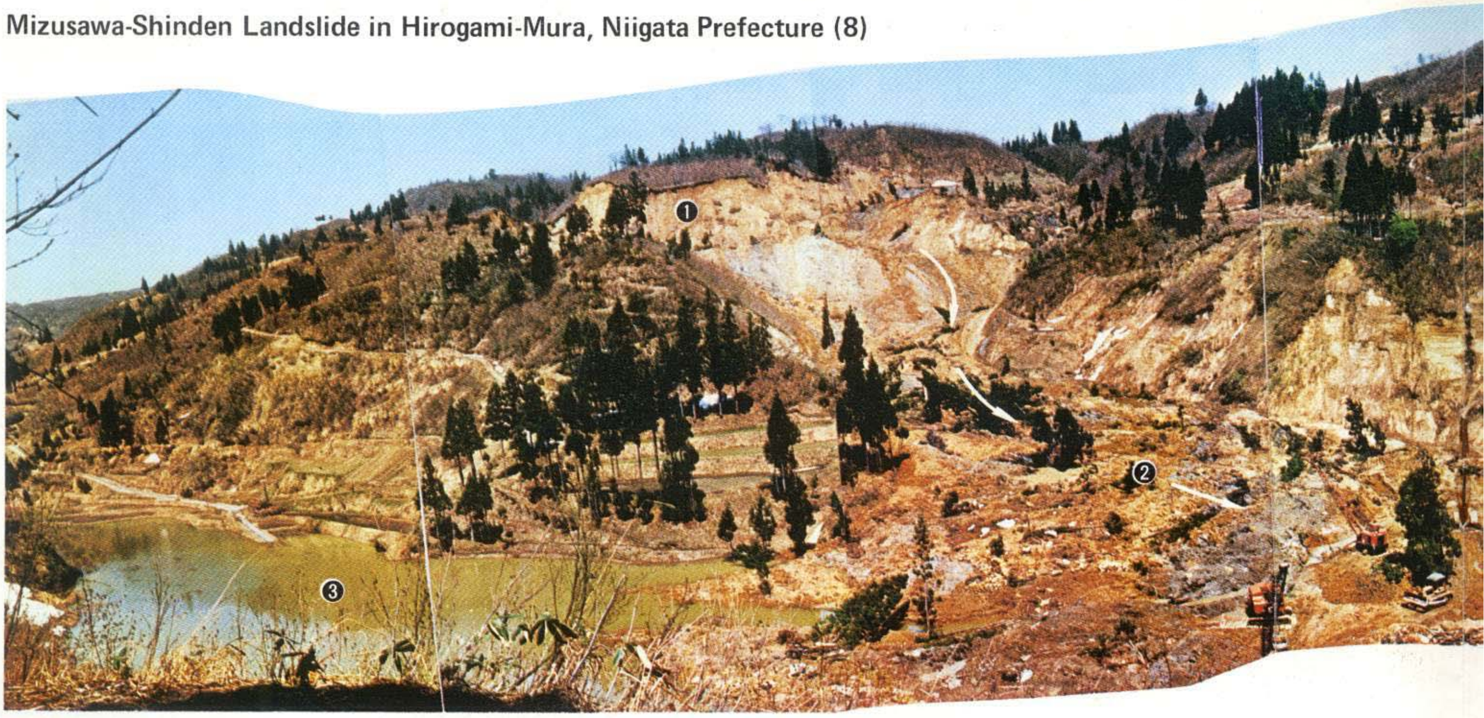
Kamenose is located at a place of traffic importance. This landslide damaged the Kansai railway line, national roads and the Yamato river. Between 1931 and 1932, and between 1951 and 1968, a mass as large as 53 ha slid. Geology: Miocene, consisting of andesite lava and tuff breccia, holding thin layers of tuff, sandstone and conglomerate. This slide was caused by the debris of weathered lava and pyroclastic rocks in the brecciated state. Control works: surface drainage, well drainage, tunnel drainage, soil removal and steel tube piling were performed.

Collapse of Takabayama Tunnel by Landlise along the Iiyama Railway Line, Niigata Prefecture (7)

General view of slide
1 Collapse of Takabayama tunnel 2 Iiyama Railway line 3 National Road 4 Shinano river

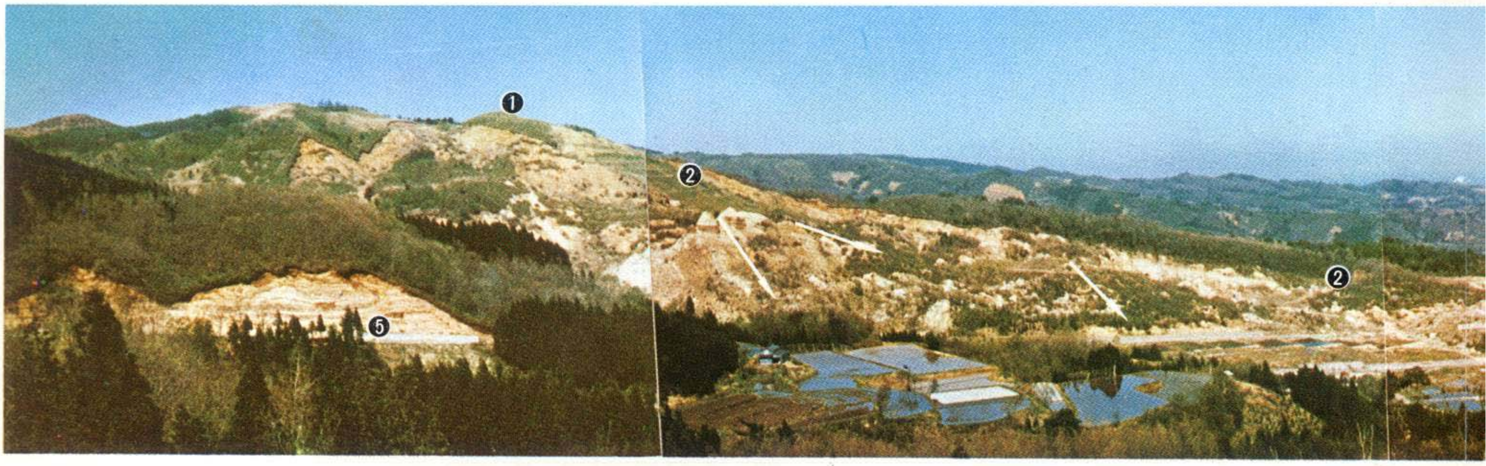
At 1:24 a.m. on 22 January 1970, about one half of the Takabayama Railway Tunnel (187 m long) was collapsed by landslide. Geology: Neogene, consisting of an alternation of mudstone and sandstone. This tunnal, built in about 1925, runs through the foot of Takabayama hill jutting into the Shinano River. Deformation caused by landslide had been noticed from old times, and landslide investigations and control works had been carried out. It is noted that the time of collapse was exactly forecast by using data obtained with the landslide gauges and the relation between the distortion velocity and the time of creep destruction (tr). Before the foretokens of landslide were found on the surface of the earth, landslide displacements in the tunnel were being noticed for a long time. At the time of collapse, a soil mass which slid from the upper sliding area of the hill pushed out a lower soil mass. In Japan, many landslides are threatening the railways, and 93 areas (50 in Tertiary system, 25 in crystalline schists or serpentinites and 18 in Palaeozoic or Mesozoic or volcanic rocks) are representative.

Mizusawa-Shinden Landslide in Hirogami-Mura, Niigata Prefecture (8)



Not a few landslides in Niigata district occur in the Miocene series, but this landslide broke out in the hill belt composed of the Pliocene series. The gradient of layers are generally gentle and they are composed of the alternation of sandstone, siltstone and relatively loosely combined conglomerate. The landslide broke out as a collapse landslide 7:00 on 26 April 1969 and soil mass of about $8.4 \times 10^5 m^3$ moved and flowed for a distance of about 600 m, destroying ten houses, causing a loss of eight human lives and damaging fields. The sliding area can be divided into the main part in the upper (150 m long and 250 m wide) and the secondary part composed of mudflow zone in the lower (450 m long and 80 m wide). In the upper part a slide

Kurumi Landslide in Himi region, Toyama Prefecture (9)



Himi region is an active sliding area where slides have been repeated from old times. Geology: mainly Miocene, in which the alternation of mudstone, tuff and tuffaceous sandstone prevails. The slide occurred on 16 July 1964, destroyed 88 houses at Kurumi Village (61 houses were razed, 6 houses partially destroyed and 20 houses pulled down), and damaged rice fields, farms, forests, rivers and roads. The sliding area is about 500 m from east to west, and about 150 m from south to north and has an area of about 70 ha. This area slid for about three hours from noon of the day. A loss of human lives was avoided by foreknowing the slide through the crack occurrence, the change of spring water and the landslide alarm. The repair works of rivers, roads and farms and the landslide control works were performed later. This slide is regarded as a complicated combination of a structural landslide in the weathered bed rock and a secondary revolving landslide in the colluvial soils.

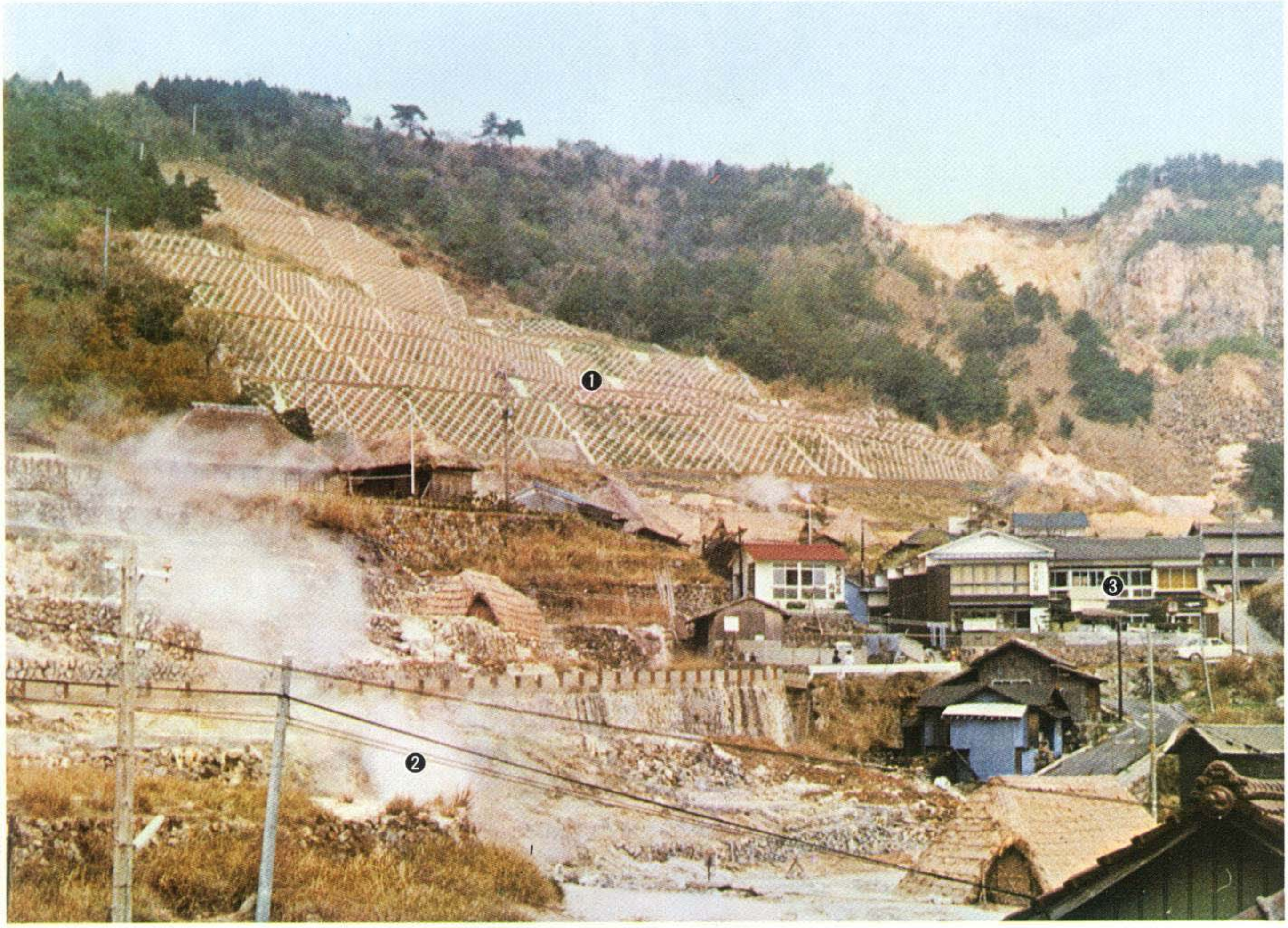
General view of Mizusawa-Shinden landslide
1 Main scarp, about 40 m in height; the part of in front was depressed. 2 Earthflow which caused damages 3 River partly dammed up

cliff with a height of 40 m and a depression occurred, and a part of collapsed soil turned into a streaming mudflow. The decrease in intensity of strata and the thawing snow permeated them are regarded as the direct motive. It is noted that the landslide turned into the earthflow type one caused great disasters.

General view of Kurumi landslide
1 Head 2 Main scarp–connected N~S 3 Toe
1 ~ 2 about 1500 m 4 Kurumi village 5 Road

Depth	Pattern	Geology	Remarks
m 10		Colluvial A	Mainly soils
20		Colluvial B	Mainly rock fragments.
		Clay changed from tuft	Surface of rupture remarkable clay.
30		Black mudstone	Weathered in the upper part, intimate rock in the lower part.
40		Fine tuff	Whitish gray, include small pumice, conspicuously weathered
50 60		Black mudstone	Blackish gray, massive 62~64m tuffaceous clay.
70 80		Pumiceous tuff	Blueish gray, include many green spot. Partially soft and clayey.
90		Black mudstone	Massive. Adjacent 90m clayey.
100 110		Coarse tuff	Blueish gray, include purmice and green spot. Partially hold fine mudy seams.

Geological column in the Kurumi landslide
(Drilling No. 7, about central point)

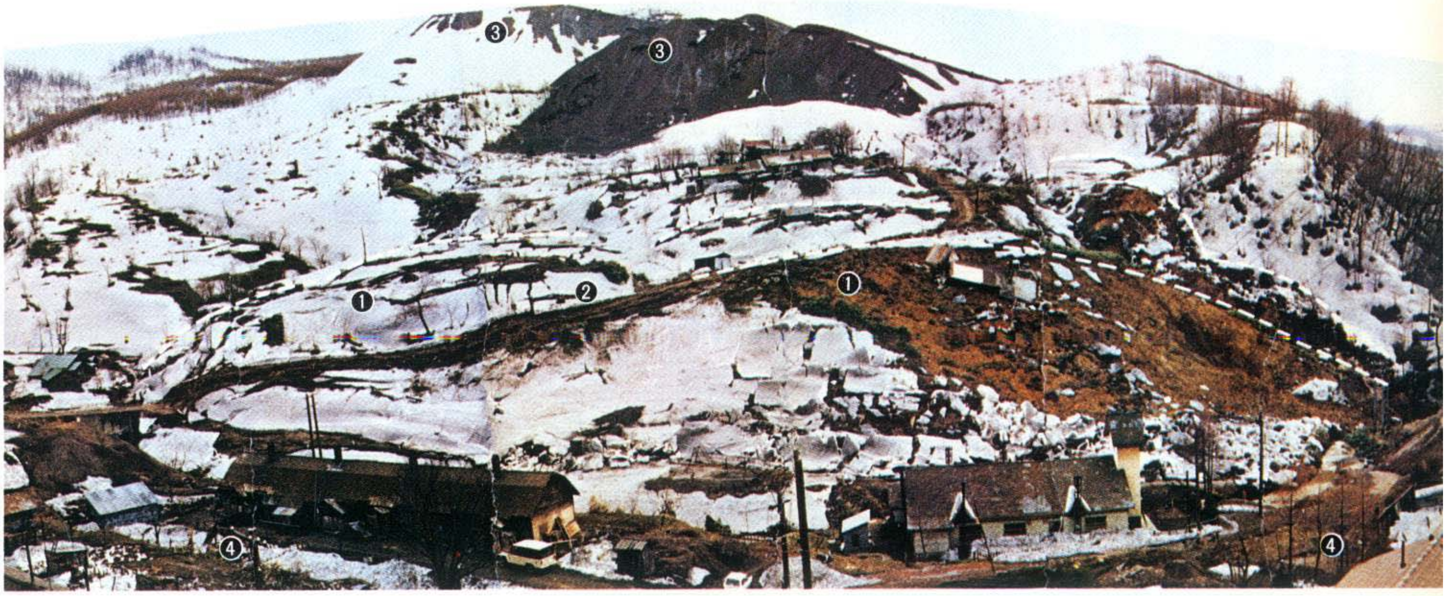


General view of Myoban landslide 1 Slide area 2 Fumarolic 3 A part of hotspring hotel

The word "Myoban" literally means "alum". Myoban Hot Spring belongs to Beppu Hot Spring group and is famous for being good for diseases and wounds. The landslide broke out before dawn on 25 Sept. 1966 soon after the passing of a typhoon. This area consists of andesite altered by volcanic fume and altered clay and accumulated debris. Landslides in such a volcanically altered zone are under the complicated influence primary causes and motives and it is difficult to find reasonable control works for such a landslide. The landslide had a length of 80 m and a width of 120 m, but the area began to slide with a rumbling of the earth and the tip of the sliding part approached closely the back of hot-spring hotels. The sliding plane is about 15 m deep at the deepest point and the soil mass collapsed is about $3 \times 10^4 m^3$. Together with various sorts of investigations, the large amount of soil removal and buttresses are performed.

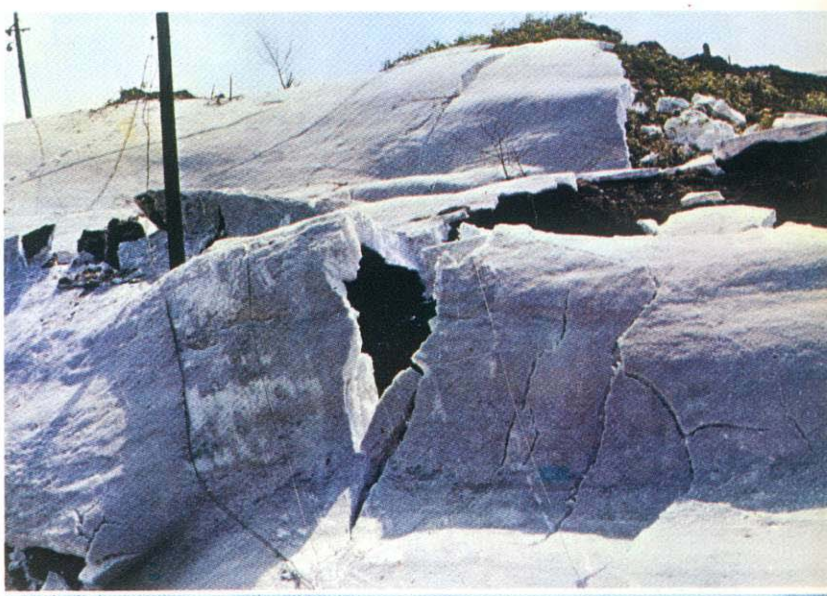
Slide area after controlling

Tokiwadai Landslide in Bibai coal field, Hokkaido (11)

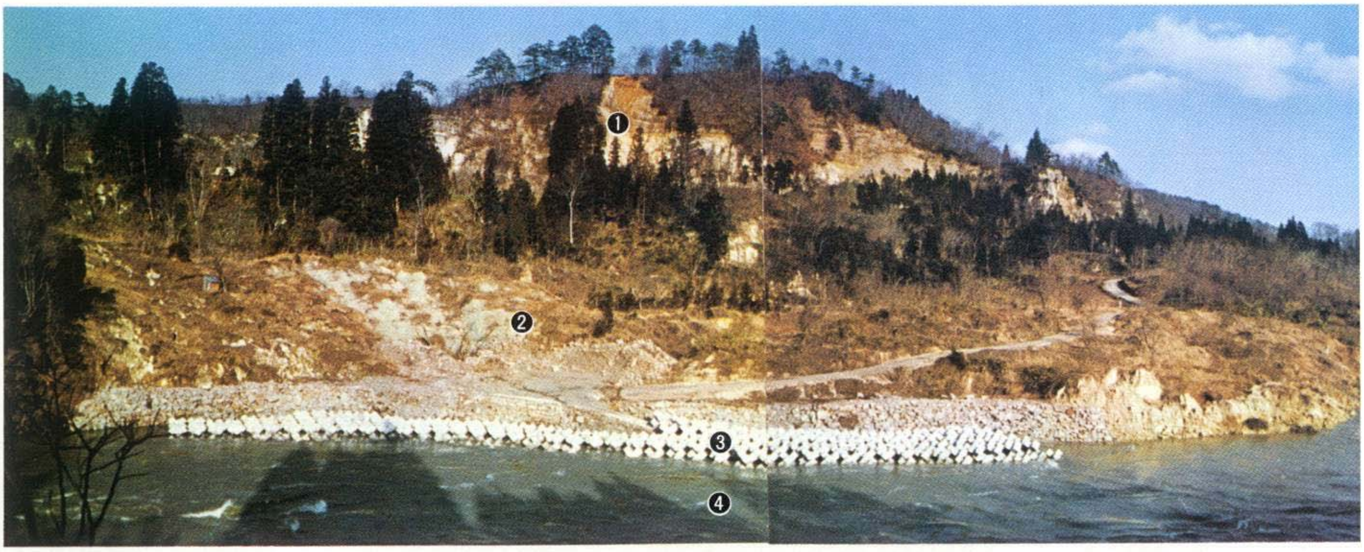


General view of landslide at North-Ichinosawa, Tokiwadai area
1 Main slide place 2 Road 3 Coal mine industrial waste
4 Same part of Tokiwadai town

The total sliding area is about 80 ha. Geology: belong to the Paleogene Tertiary, consisting of the alternation of sandstone and mudstone and holding coal seams. The upper part of the mountainside has an old scarp and from this scarp the gentle slope characteristic of the sliding area spreads to the tip of the sliding area. The sloping land is generally composed of thick weathered layers and talus which cause the repeated landslides. This sliding area can be divided into a few blocks and in April 1964 Kita-Ichinosawa block was activated. The landslide pushed out soil of 6 $\times$ $10^5 m^3$, destroying houses and concrete retaining walls along roads. For four days 14 to 17 April, foretokens and behavior of landslide were observed in full detail. Underground structures, groundwater and sliding planes were investigated thereafter. This landslide is regarded as the complex of structural landslide in the weathered rocks and the revolving landslide in the debris. Control works: tunnel drainage, steel tube piling and valley barrier were performed.



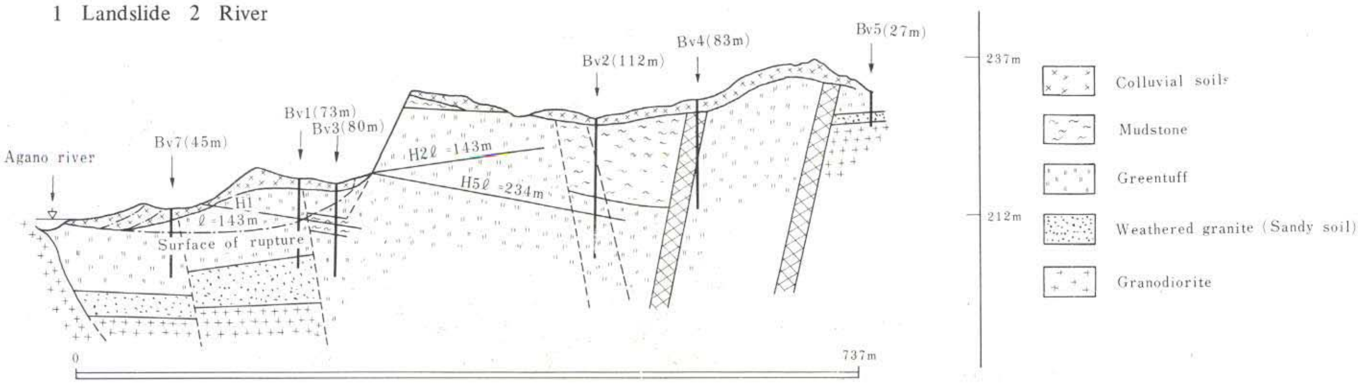
Above: Sliding state
This landslide occurred at snow melting time, April 1969
Below: Damage of houses a caused by landslide



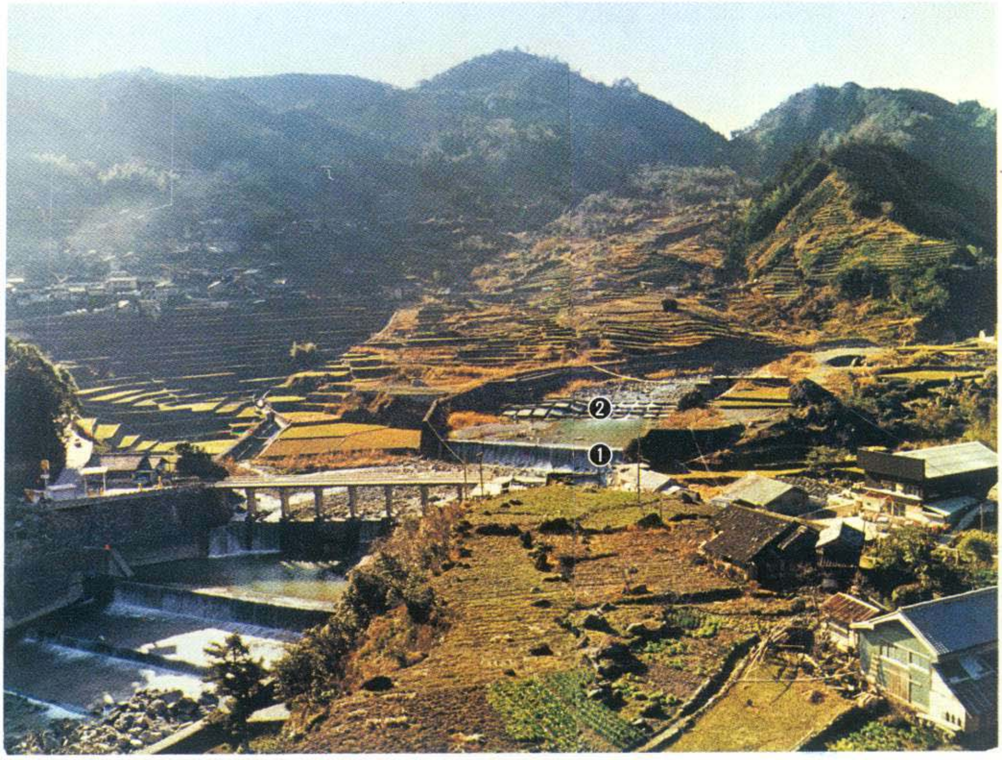
General view of Tokiwa area
1 Main scarp consisting of green tuff 2 Thrust up zone by slump
3 Erosion control 4 Agano river

This landslide has an area of 147 ha, being divided into a few blocks in which landslides are repeated. Geology: are composed of granodiorite and the Neogene system overlying it, the latter is mainly composed of green tuff (pumiceous tuff and tuff breccia). The geological features are very complicated, slide cliffs and depression ponds formed by landslide being developed. The landslide occurred in 1888 in the Matsusaka area damaged fields, and at the slide which occurred in 1905, Tokiwa area slided into the Agano river to destroy many houses. In 1949, a landslide occurred in the Matsusaka area, causing cracks, depressions and upheavals in the upper part and mudflow in the lower. Various investigations were carried out. Control works: water channel, drainage well and drainage boring were performed.

Distant view of Takisaka area
1 Landslide 2 River



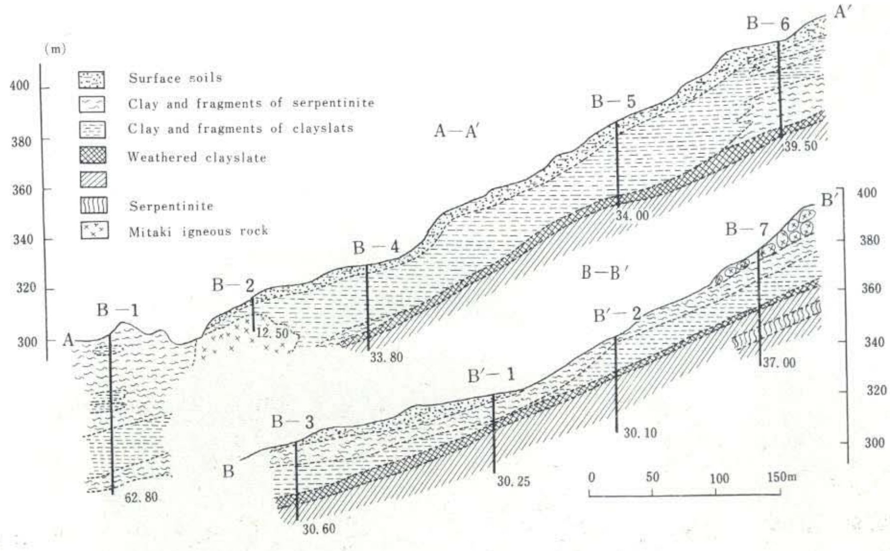
Choja Landslide in Niyodo-Mura, Kochi Prefecture (13)



1 Choja river 2 Upheaval of the toe

1 Choja river 2 Upheaval of the toe

The landslide has a length of about 900 m, a width of about 200 m and an area of about 68.4 ha. Geology: this is one of the landslides distributing in the Chichibu terrain and composed of the Paleozoic clayslate and the serpentine intruding it. Old records of landslides exist, and the tip of the sliding area was largely collapsed by the typhoon No. 9 on August 1963 (835 mm of rainfall). Thereafter, a slow sliding movement has been continue. The central part of this sliding area is composed of the colluvial layer made up debris of clayslates and serpentinite, having unstable sloping land with a gradient of about 20° and sliding toward the Choja river. In order to prevent the erosion, many retaining walls and training walls to protect the tips of the sliding area were built. Control works: drainage well and horizontal boring drainage were performed.

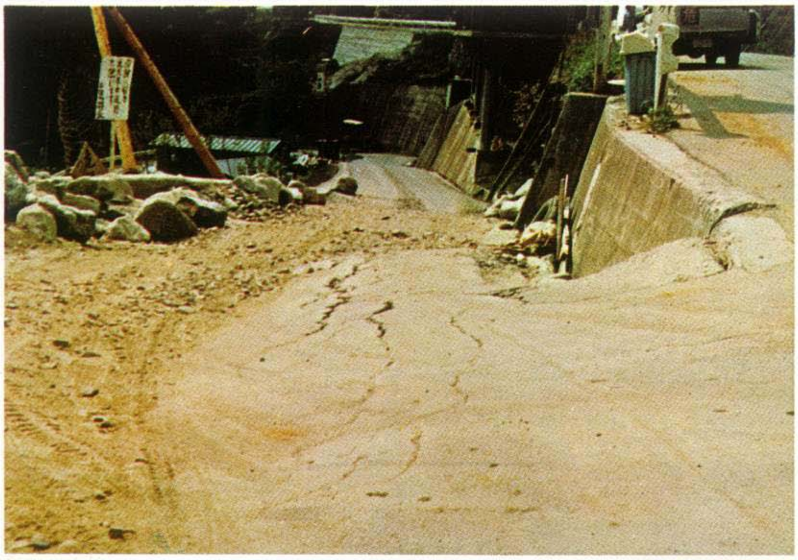


Main cross-section of the Choja landslide

Zentoku Landslide in Iya region, Tokushima Prefecture (14)

General view of Zentoku landslide
1 Iya river

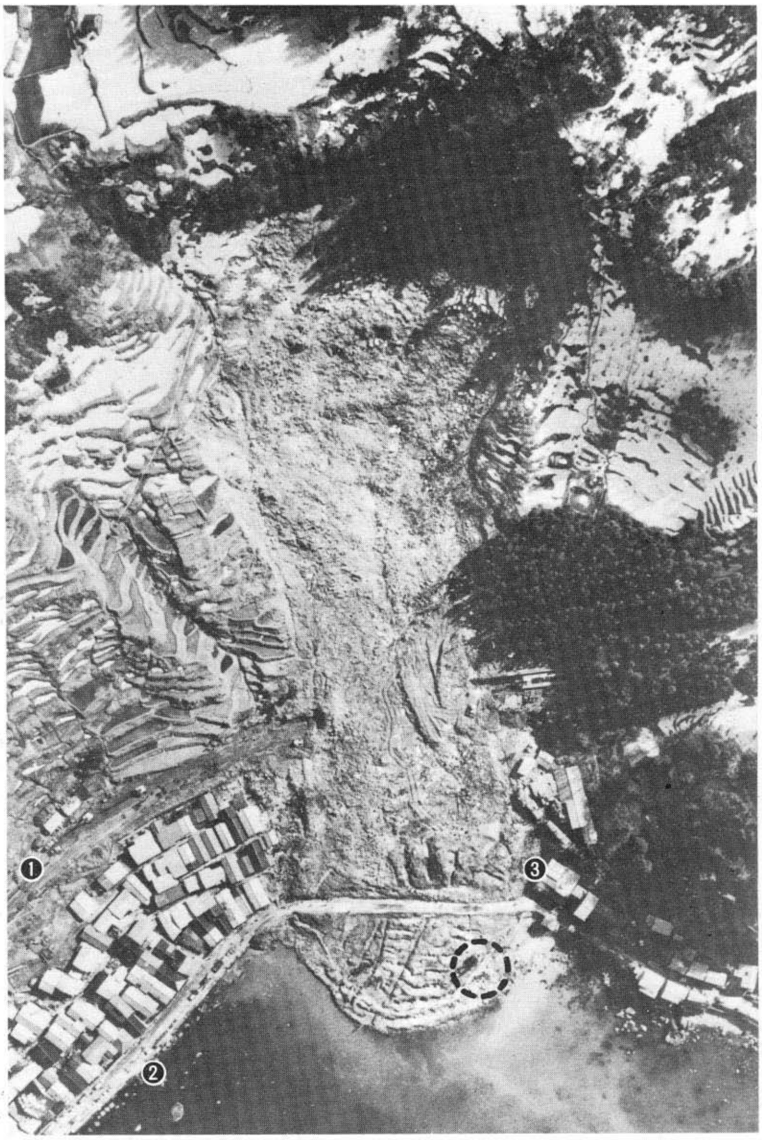
This is one of the schist type landslides distributing in the Iya region. The slide area distributes between 350 m and 830 m above the sea level and has an average gradient of 26°, a length of 900 m, a width of 2,000 m and an area of 108 ha. Geology: Kawaguchi formation of the Yoshinogawa group, mainly consisting of pelitic schist and holding schistose sandstone, basic schist and siliseous schist. According to the survey by drilling and seismic prospecting, the thickness of talus debris constituting the sloping land is mostly between 20 m and 30 m and about 50 m at the thickest part. In 1945, 1949 and 1954, heavy rains collapsed and interrupted only a prefectural road to the interior. A considerable sinking of the road, inclination of houses and cracks is retaining walls have come to be noted.



Above: Mudflow on the road by heavy rain
Below: Damages of retaining wall along the road

Kodomari Landslide along the Hokuriku Railway Line in Nou-Machi, Niigata Prefecture (15)

The region extending from Itoigawa to Naoetsu along the Hokuriku railway line is a well-known landslide zone. Geology: mostly Miocene, the main material being mudstone and an alternation of sandstone, mudstone and tuff. The landslide broke out on 16 March 1963 and had a total length of about 370 m, a width between 100 m and 170 m and an area of 4.5 ha. The slid mud mass was about $15 \times 10^4 m^3$. This slide attacked a running railway train: its locomotive was pushed away for about 170 m into the mud mass and the railway and a road were interrupted fore a long time. The mud mass flowed across the streets of Kodomari into the Japan sea, to destroy 28 houses completely or partially, to cause many casualities and to display terrors. Possible disasters to be caused by succeeding landslide were prevented by building a new tunnel in the section between Itoigawa and Naoetsu of the Hokuriku Line which is about 40 km long.



Photograph shows after landslide
1 Railway 2 National road 3 A part of Kodomari street
4 Locomotive engine carried away by slide

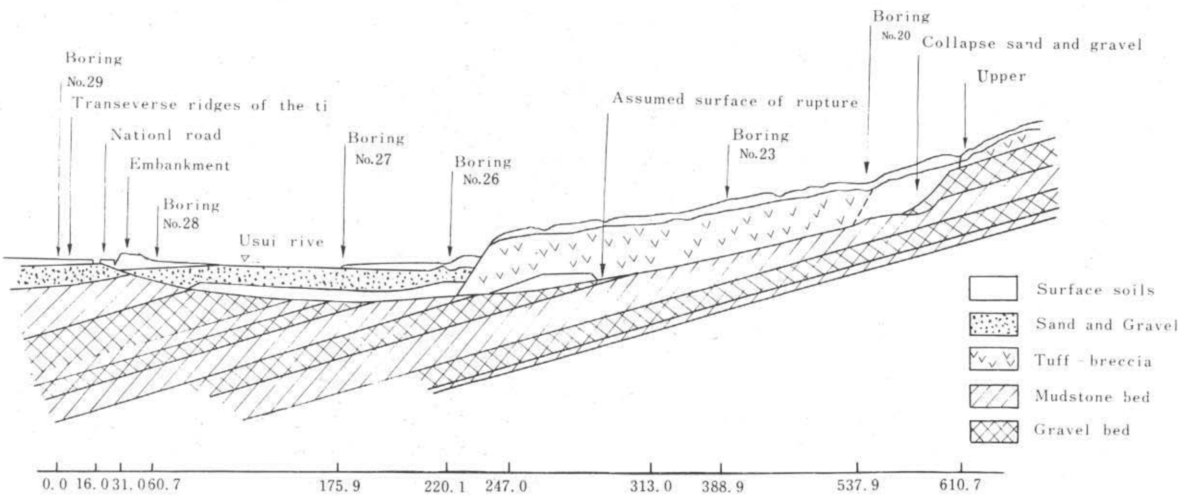
Main scarp at the top of landslide
The scarp are about 30 m heigh, and seepage water can be seen near the middle and lower parts of the scarp

Railway buried by landslide
The slide mass mainly consists of muddly substance

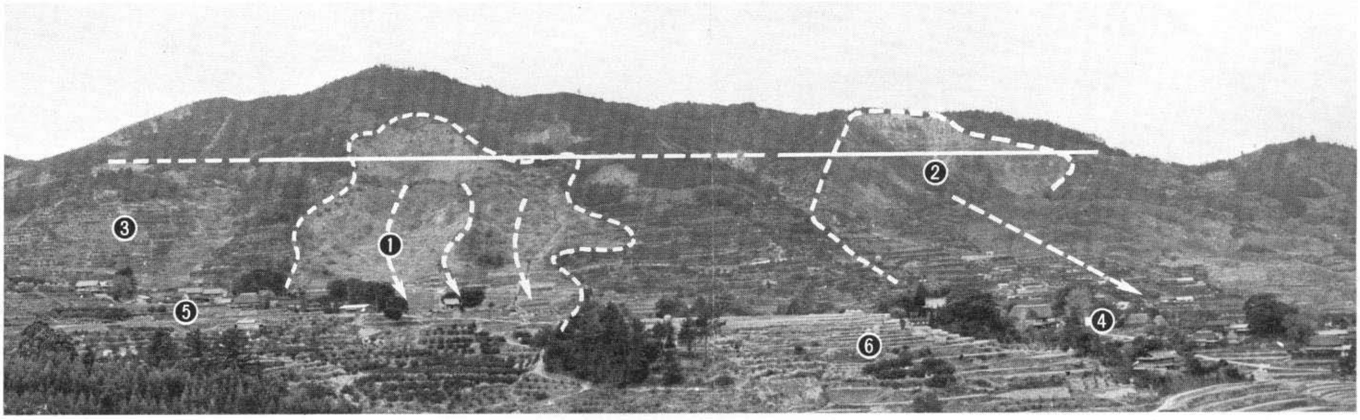
Upheaval of the toe

Damage of the Terasawa bridge

This area is where landslide has been repeated from old times and disasters of the Usui river and houses are recorded. Now, the area appointed to the dangerous slidable zone reaches about 85 ha. Geology: are the mixture of the Neogene system composed of the alternation of sandstone, mudstone and conglomerate with the Quaternary tuffs and tuff breccias. The strata are of a monoclinal structure with a gradient between 18° and 20° from north to east. In recent, an area of about 36 ha spreading from Terasawa to Fujizuka, from Sept. 1958 to June 1961 slided activity. Such phenomena as crack occurrence, partial sliding, depression and upheaval were noted. The upheaval of the tip of landslide in Fujizuka crossing the Usui river was specially noted, damaging the national road No. 18 and the leftside bank of about 300 m. The rate of upheaval of the national road was measured a maximum rate of about 45 cm/day and the total upheaval reached about 3.5 m in total. Control works: horizontal boring drainage, tunnel drainage and steel tube piling were performed.



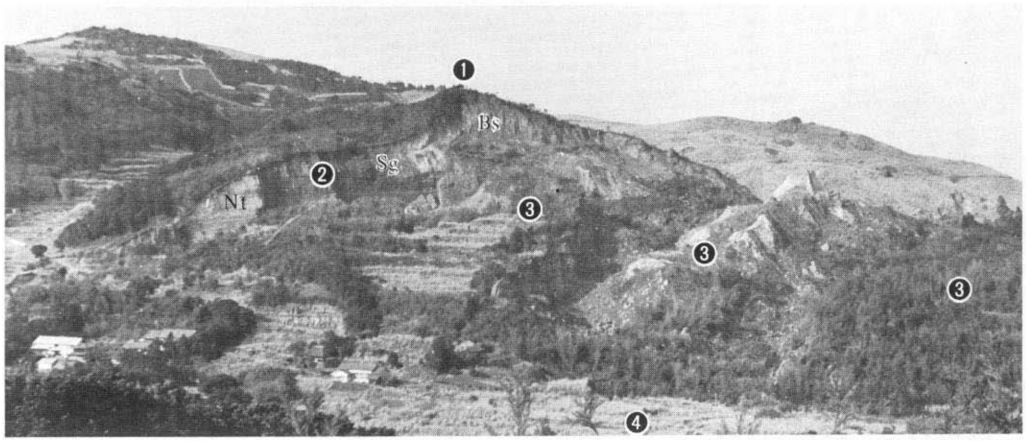
Main cross-section of the Shorinzan landslide



Same part of severed cliff, mudstone and sandstone alternation Distant view of Mt. Ningyoishi landslide area

1 Ningyoishiyama landslide (occurred in July 1957) 2 Yamashiro landslide (occurred in Feb. 1951) 3 Nishiokubo landslide 4 Hirakoba village 5 Nishiokubo village 6 Steps rice field at Tateiwa landslide

These landslides caused grate loss of life, and damaged houses and farms



Distant view of the Hirayama landslide

1 Mt. Atago 2 Grate cliff by landslide 3 Slide mass 4 Devastated rice field

Bs...Basalt lava Sg...Sandstone and gravel bed Nt...Neogene Tertiary

Geology: coal-bearing Neogene underlying the plateau basalts. The Neogene consist of an alternation of snadstone, sandy mudstone and mudstone, holding coal seams in the mudstone. The basalts consisting of the alternation of lava beds, pyroclastic rocks and gravel beds plays the role of the so-called "cap rock". Large-scale landslides often occur around the basalt plateau, and slides occurring at Hirayama, Tarukochi, Nagatashiro, Motofure, Washiodake, Ningyoishiyama, Yamashiro and Ishikuradake are representative.

In Hirayama landslide area, such foretokens as the change of spring water, ground upheaval and cracks occurred from January 1960. Subsequently, cracks crossed the summit of Atagoyama Mt. and the two-thirds of the mountain or an area of 64 ha began to slide. From October 1963 to February 1964, cracks gradually developed in the ground, and the depth from the summit to the sliding plane reached about 180 m. The part of the Neogene system was almost vertically cut to make a depression zone in front of the cut cliff. The main sliding surface is a coal seam called Nanaheda, and a tuff seam having a thickness of 20 cm turned into bentonite. The gradient of the sliding surface is about 4° to NNE.

In the area called Tarugawachi, which is adjacent to Hirayama, a landslide having an area of about 40 ha occurred from February 1959 to May 1960, and a very active sliding lasted for about three months. Ningyoishiyama and Yamashiro landslides, which were of the sudden type, destroyed many human lives. Soil and debris pushed out by Ishikurayama landslide severely damaged the Matsuura railway line and the national roads.

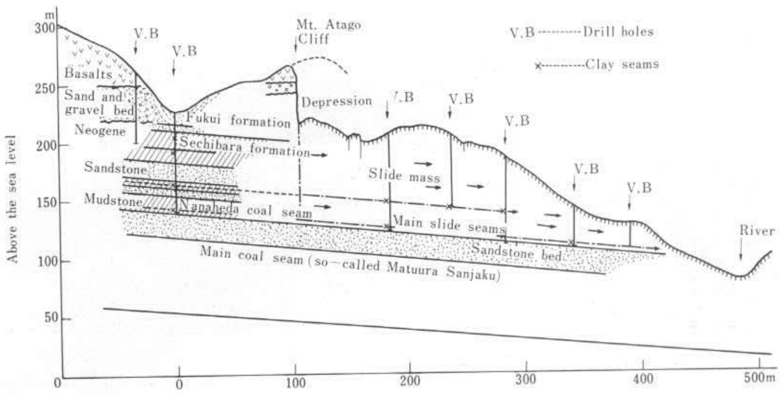
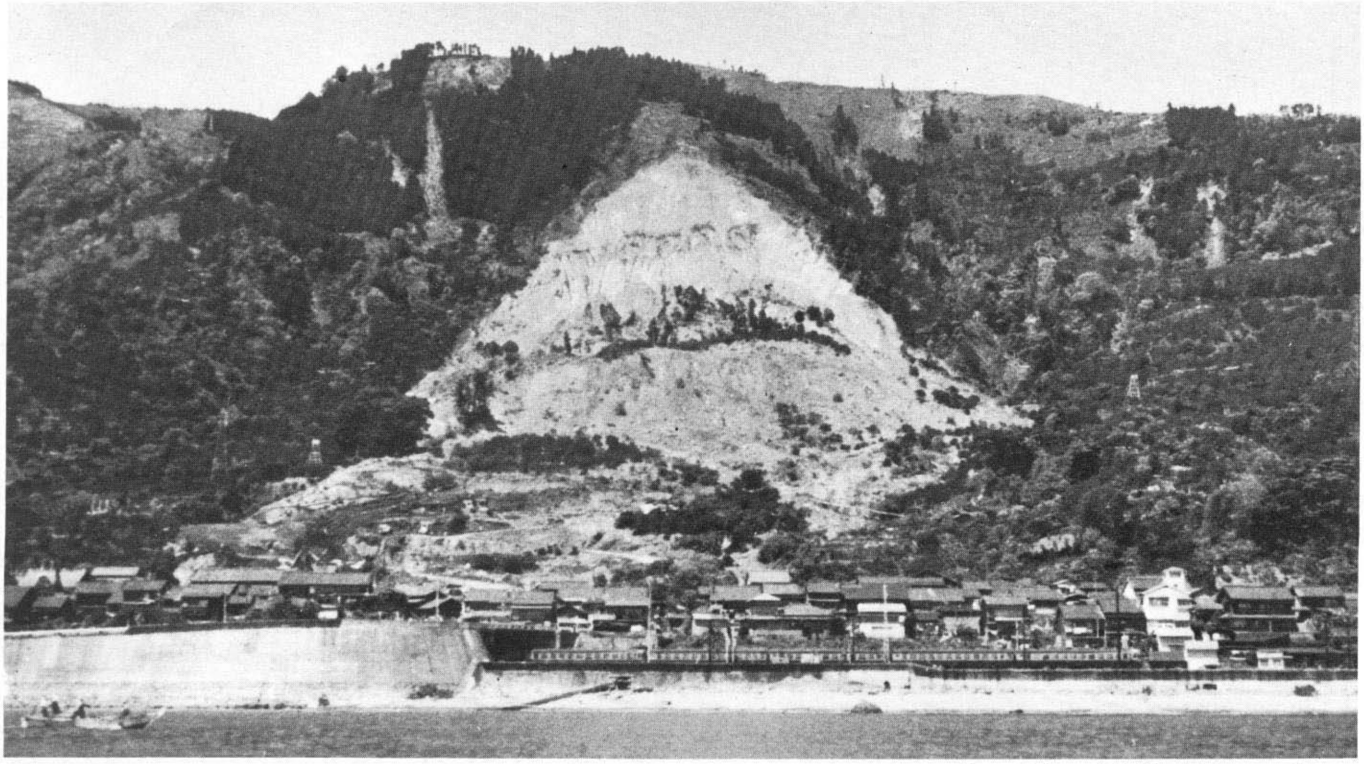
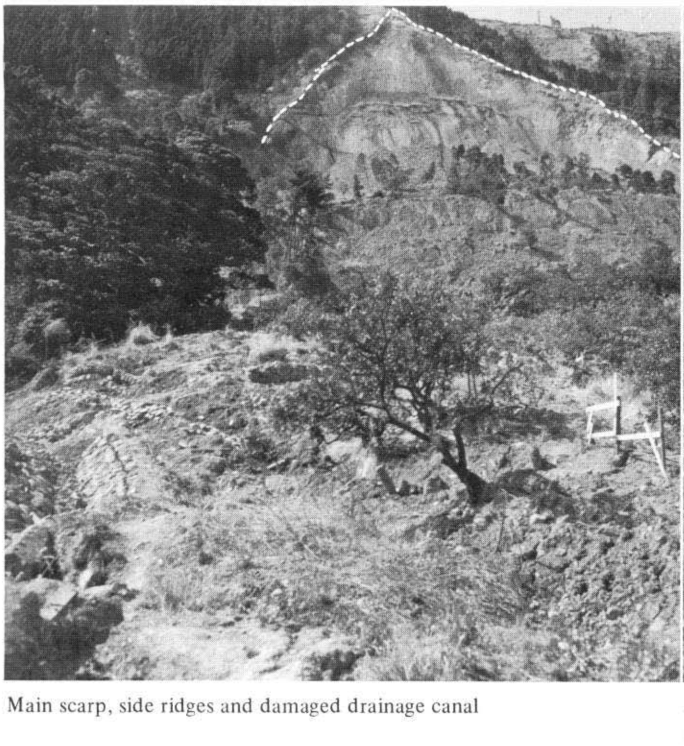


Diagram of underground profile in the central part at Hirayama landslide



General view of Yui landslide from the sea.

This landslide broke out on March 1961 in the sloping land of hilly district lying near the Tokaido railway line and the national road No. 1. Since this is a place of traffic importance which ties the east Japan with the west Japan, the landslide has given a great threaten to the railway, the road and human houses, drawing economical and social attentions. The landslide had a length of 520 m, a width of 200 m and an area of 10 ha, and such phenomena preceding landslide occurrence as slide scarps, depression, upheaval, cracks, tilting and mudflow were observed. The site belongs to a part of Yui landslides zone. The bed rock is composed of the Neogene Tertiary system. The lower district of the sloping land is the Miocene series mainly composed of tuffaceous mudstone and the upper hilly district is the Pleistcene series consisting of the alternation of tuffaceous sandstone and tuff breccia. Surveys and investigations of the mechanism and control works were carried out by the researchers of national research institutes. The controlling plans and works taken on the basis of the research results have greatly contributed to the development of landslide researches and control works in Japan.



Main scarp, side ridges and damaged drainage canal

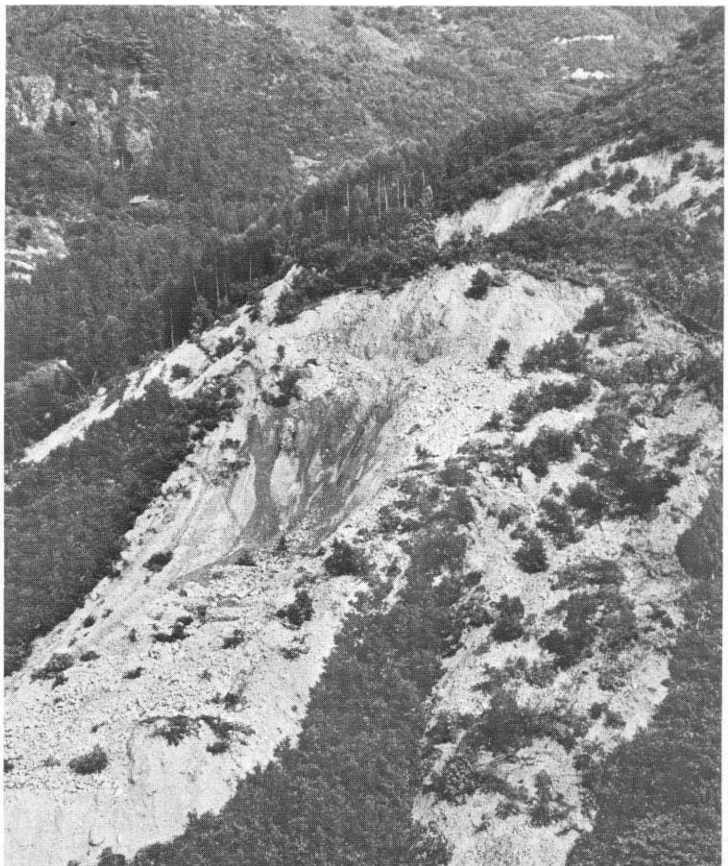
Accumulation or colluvial soils. Part of soils flowed out along the swamp.

Landslide in the epicentral area of the Matsushiro Earthquake swarm, Nagano Prefecture (19)

General view of Makiuchi landslide, caused by spring of much artesian water during earthquakes.

On 3 August 1965 Matsushiro earthquake swarm broke out. In September 1966, during the third period of its activity, many cracks developed around Minakami Mt. and from these cracks a large amount of pressure ground water sprang out. On 17 Sept. 1966, Makiuchi landslide broke out and on 9 Oct. 1966 Nishidairayama landslide occurred. These were caused by the large amount of ground water which sprung out from cracks made by the earthquake swarm.

Makiuchi landslide occurred in the sloping land near the mountain, being 250 m long and 160 m wide and soil mass of about $2.0 \times 10^5 m^3$ being pushed out. The material of landslide is composed of the Quaternary fan deposits which are a mixture of conglomerate and clay. In the upper part a rotational slamp was generated, a part of debris turning into earthflow. From right under the slide cliff a large amount of spring water issued like a rivulet.

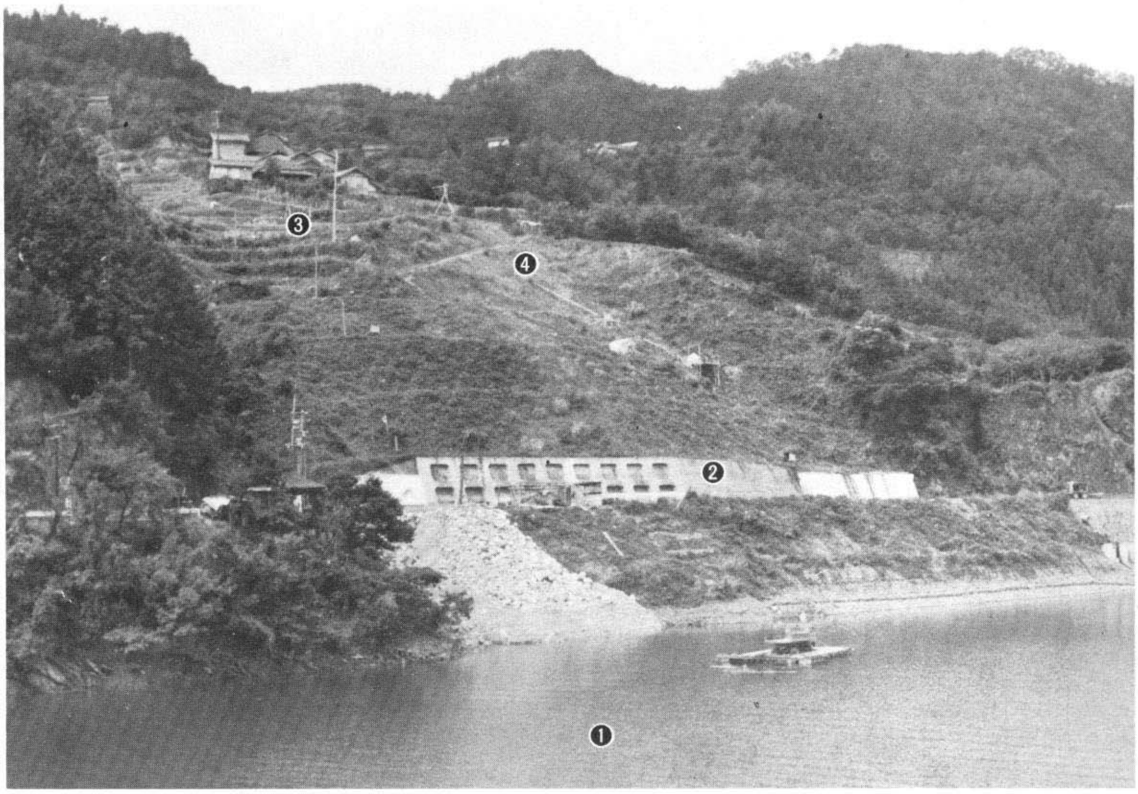


Rockfall at Nishidairayama, caused by earthquakes.

Tanabe Landslide along the Highway, Osaka Prefecture (20)

The view of Kashiwabara interchange and the neighborhood after landslide.
1 Kashiwabara Interchange, 2 Hospital, 3 National Road, 4 Kinki Nippon Railway, 5 Nishi Meihan Highway

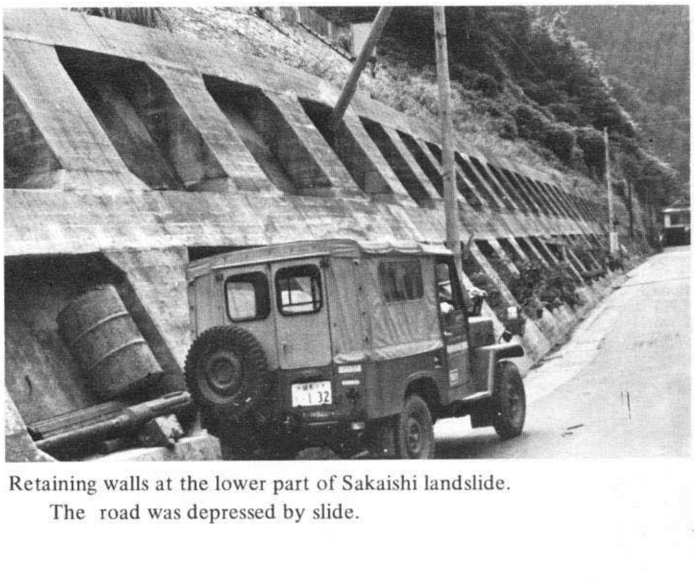
This landslide occurred on April 1968 in the Kashiwabara interchange of the Nishi-Meihan Highway. The railway and a national road upheaved at the rate of 1 cm day, and cracks developed on the pavement and the retaining wall of the highway. A hospital located at the upper side of the highway suffered damages due to cracks. The long horizontal drilling drainage was found very effective to stabilize the movement.



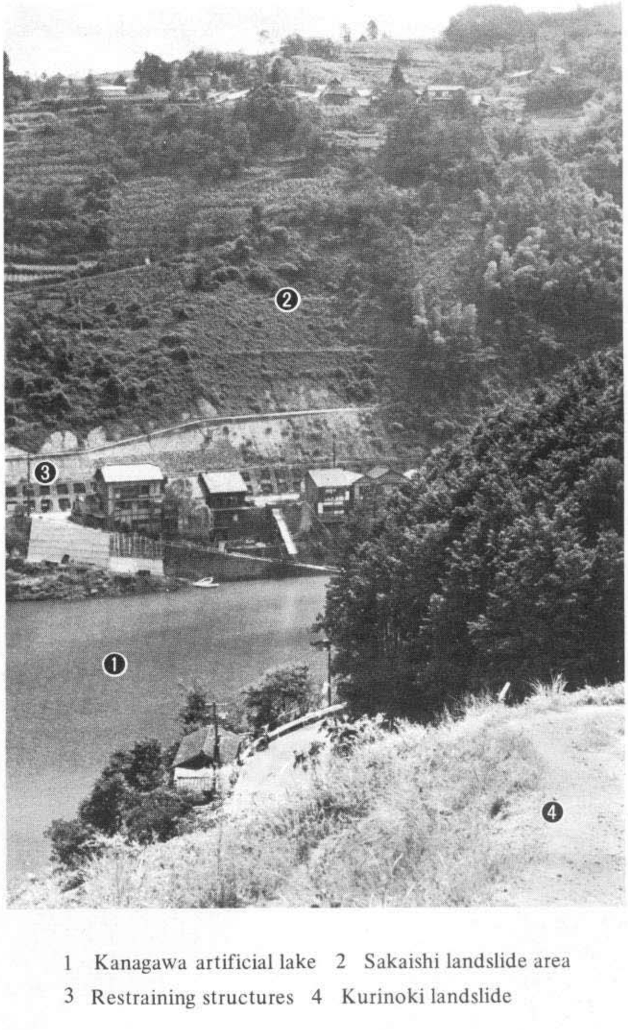
Distant view of Kurinoki landslide

1 Kanogawa artificial lake 2 Restraining structure 3 Drainage well and ditches 4 Tensometer

Kanogawa dam is a multipurpose dam for flood control and water utilization, and was built at the middle reaches of the Hiji river in 1958. The dam is of concrete gravity type with a height of about 60 m and a length of about 190 m and a pondage of about 4,820 x $10^7 m^3$. The landslide was caused by the water of the artificial lake. Geology: the site belongs to the Chichibu Paleozoic Terrain and consists of the alternation of clayslate and sandstone, and conspicuously developed fractured structures are partially found. Oji, Sakaishi and Kurinoki landslides which occurred along the shore of the lake are large-scale slides with slow movement. After the building of the dam, the water level rose about 36 m and thereafter landslides became more active. Control works: tunnel drainage, drainage well, steel tube piling, soil removal work, retaining wall work and buttreses are performed.

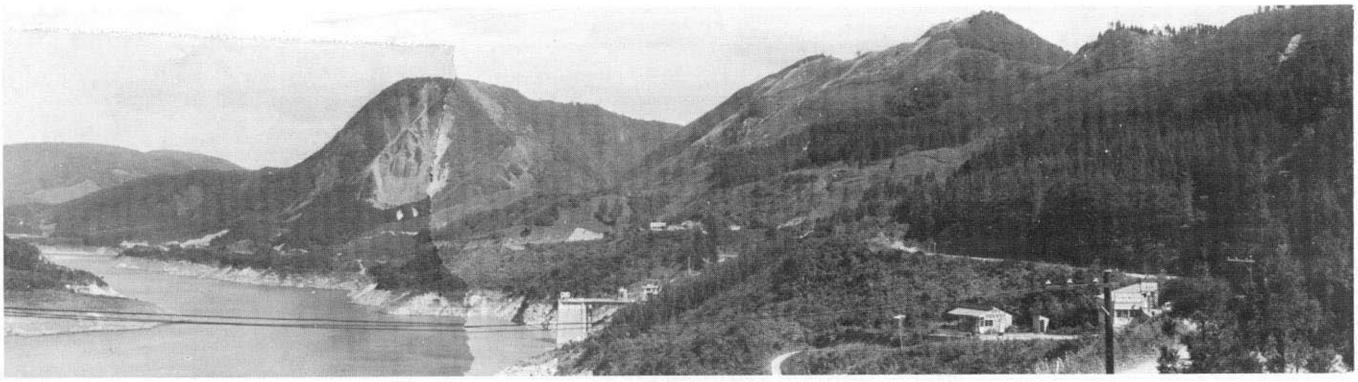


Retaining walls at the lower part of Sakaishi landslide.
The road was depressed by slide.

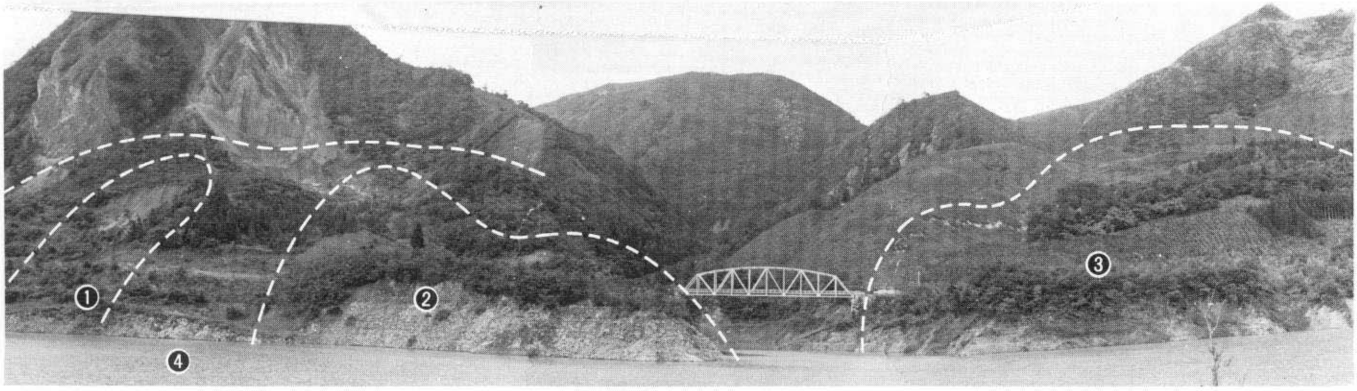


1 Kanagawa artificial lake 2 Sakaishi landslide area
3 Restraining structures 4 Kurinoki landslide

Landslides on the shore of Narugo Reservoir, Miyagi Prefecture (22)



General view of landslides on the shore of Narugo Reservoir



Distant view of No. II No. III and No. IV landslides

1 No. II landslide (about 2.5 ha are active) 2 No. III landslide (about 2.3 ha are active) 3 No. IV landslide (about 15.0 ha are active) 4 Narugo Reservoir

Narugo arch dam, which has a height of 94.5 m and total pondage of about $5 \times 10^7 m^3$, was built in April 1957. After the storage of water cracks in the ground and cliffs caused by landslide occurred in places on the shore of the reservoir and for this reason the relation between the storage of water and the occurrence of landslide began to be investigated. Six landslide occurrences have been found in the reach of about 2.5 Km along the left-hand shore of the reservoir and the toes of the sliding parts sank under the water. After summer the landslide is generally apt to be stabilised and is liable to be activated in the rainy season and the early spring when the snow begins to melt. Geology: bed rocks are mainly the alternation of the Miocene green tuffs and shale, and in part, granites. Faults, fracture zones and decomposition due to hydrothermal process are found in places and talus debris is developed in the slope. Synthetic investigations and control works are being carried out.

Hitoyama Landslide at Shodo Island in Seto Inland Sea (23)

On 10th Sept. 1965, a landslide occurred at a small island in Seto Inland Sea after a typhoon with 200 mm precipitation. The local sinking velocity was 5 cm an hour at maximum. At the tongue area a debris flow occurred and damaged a house, a road and farms. This slide frightened many inhabitants and houses at the foot of the slope.

Aerial photo of landslide area.

General view of landslide area.

The hill belt is composed of Neogene in which tuff, mudstone and sandstone, and an anticlinal structure called "Matsunoyama Dome" is developed. Centering around the Daimatsu Mt. (738 m) which consists of tuff, large-scale landslides such as Matsunoyama and Mizunashi were radially developed. Matsunoyama landslide has an length of about 3,600 m, a width of about 2,400 m and an area of about 850 ha. An active slide was observed from the middle of spring to that of autumn in 1962. This area is divided into several blocks, according to the activity of slide. The depth of sliding surface ranges from 4 m to 30 m, and the greatest movement velocity on the ground surface is measured as about 12 cm/day. The land mass moved for 20 m in total, damaging rice fields, farms, houses and public buildings, such as a school and the village office. Control works: drainage have been performed.

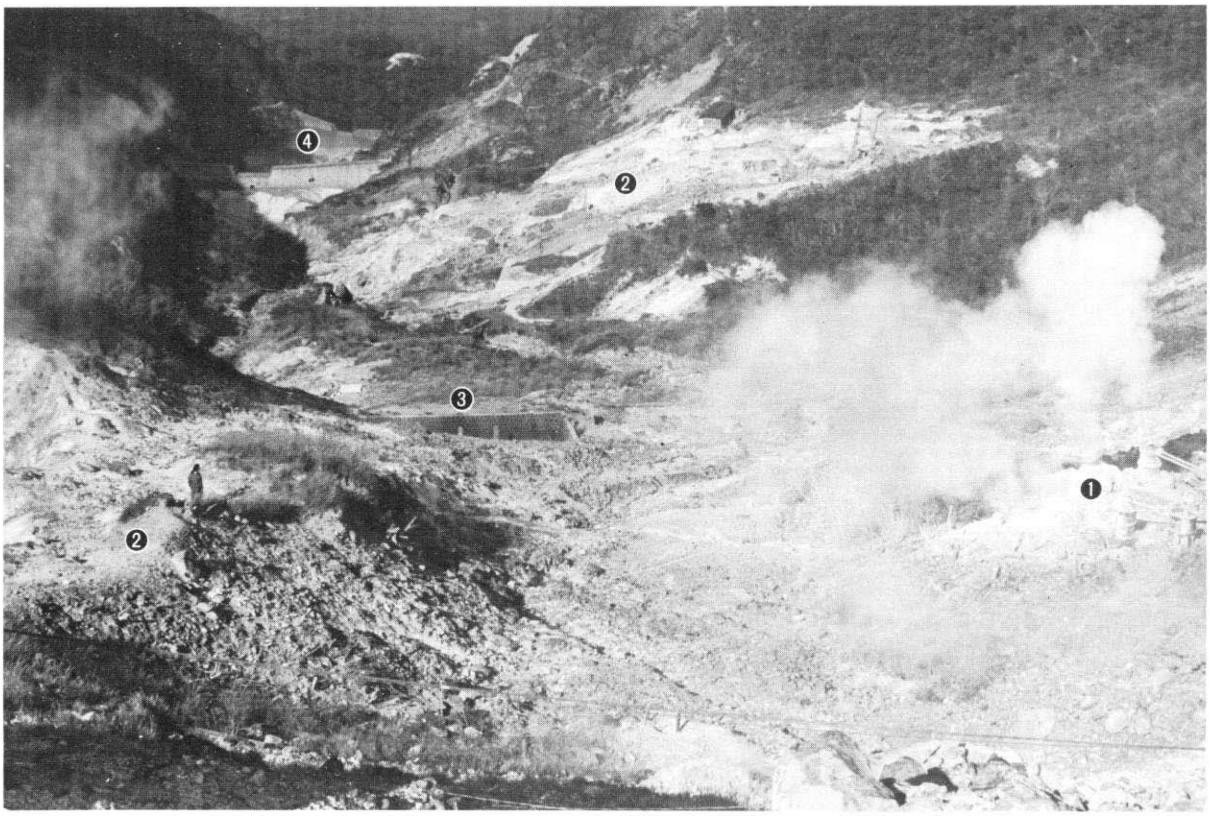
Comparison of road shape before and after slide.

Drainage arrangements and works, a circular structure in the center shows a ferroconcrete well (Chausuyama landslide)

Rinerplate drainage well, vertical stiffener for reinforce are bend by landslide (Zentoku landslide)

Drainage tunnel, the amount of drainage is about 300 l/min. (Washiodake landslide)

Landslide at Hakone volcano, Kanagawa Prefecture (25)

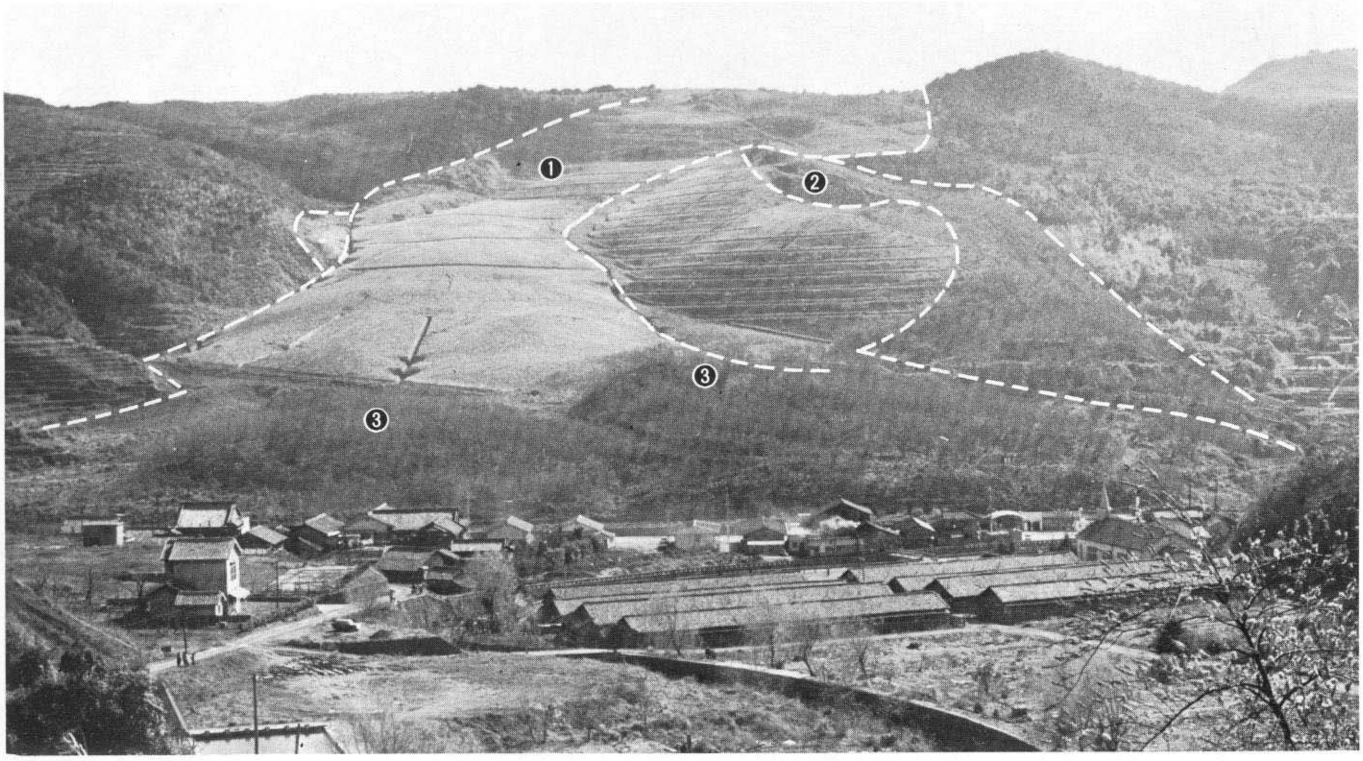


Above: Altered zone at Owakudani
1 Fumarolic 2 White part consists of altered clay 3 Erosion-control revetment 4 Consolidation dams

Right: Scarp at the top of landslide
1 Fumarolic 2 Altered white clay

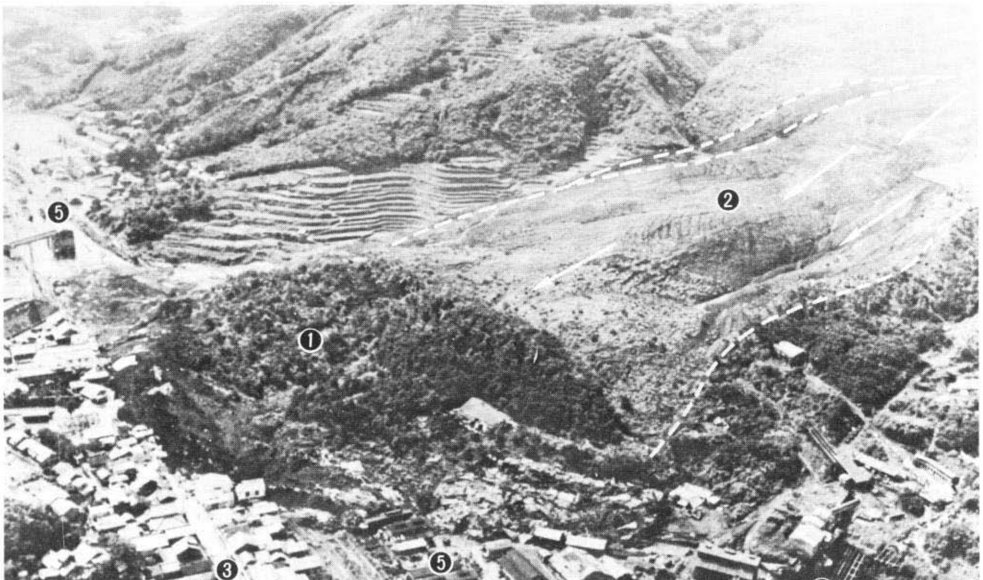
This landslide broke out in an area altered by fumarolic and hydrothermal activities of the volcano. The altered area is divided into several blocks, and among them Owakudani and Sounzan are located in the north side of Kamiyama mountain (1438 m) and are surrounded by very steep slopes, and large landslide disasters in the past were recorded. Since they are adjacent to the upper part of Gora Hot Spring street, attentions are always drawn. Souzan landslide occurred on August 1953 pushed out debris of about $8 \times 10^5 m^3$ from within the fumarolic depression. A mudstream flowed down for about 2 km with the velocity of about 7 m/sec. to destroy a temple and to lose 9 human lives. The mudflore mostly consisted of a milkwhite hydrothermal clay including fragments of andesite. At Owakudani, large collapses occurred in 1910, 1935, 1948 and 1950. Heavy rains, volcanic earthquake swarm and volcanic gas pressure are regarded as their direct motives. Control works: large-scale debris barriers, stair-like valley barriers, gas removal works and works on mountainside were performed.

Landslide of coal mine waste at Senryu, Sasebo coal field, Nagasaki Prefecture (26)



Present condition after control
1 Coal mine wastes are accumulated on this slope about 20 × 10^5 m^3 2 Remaining waste 3 Same part of waste which slided down

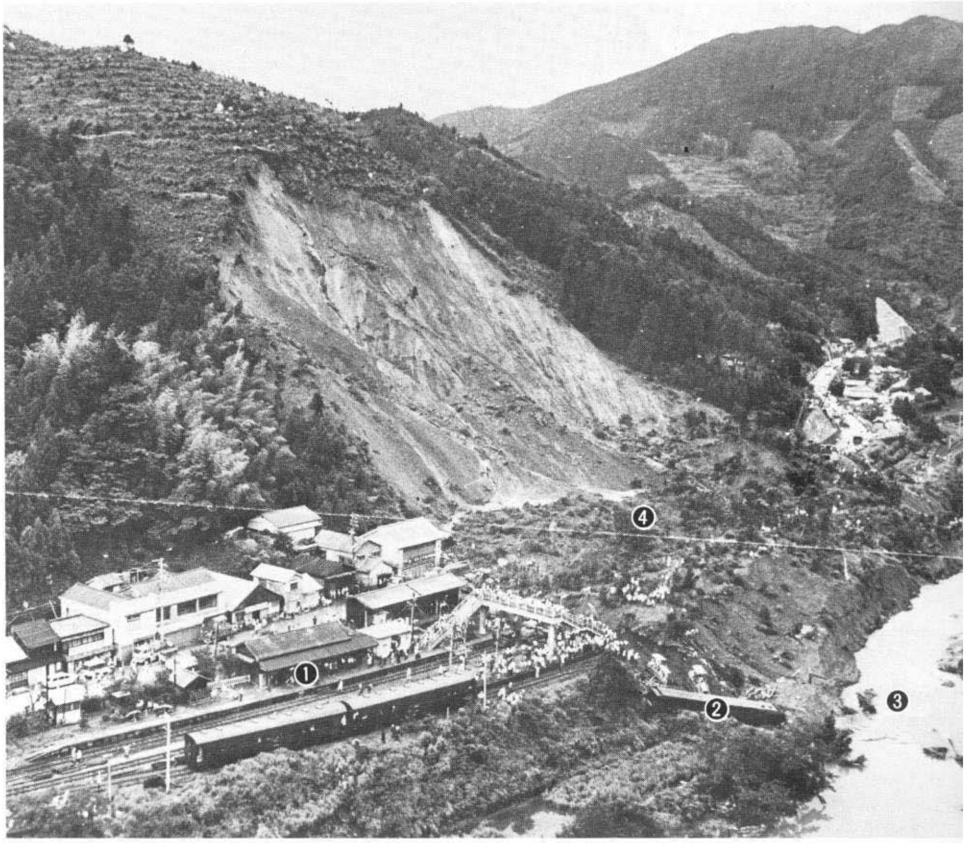
This landslide broke out at Senryu coal mine on July 1962, destoroed 217 houses at Senryu town, damaged a railway line about 400 m long and national road about 350 m long. The sliding area had a length of 700 m, a width of 250 m and moving mass of about 2 × 10^6 m^3. The landslide lasted from at 4:30 on 8 to 15:00 on 9 July. This is noted as a large landslide triggered of coal mine waste (called Bota-yama) on the slope.



Senryu street and Railway line be attacted by landslide of coal mine waste
1 Slide mass 2 Surface of rupture 3 Street 4 Kita-matsuura Railway Line 5 Same part of industrial coal mine

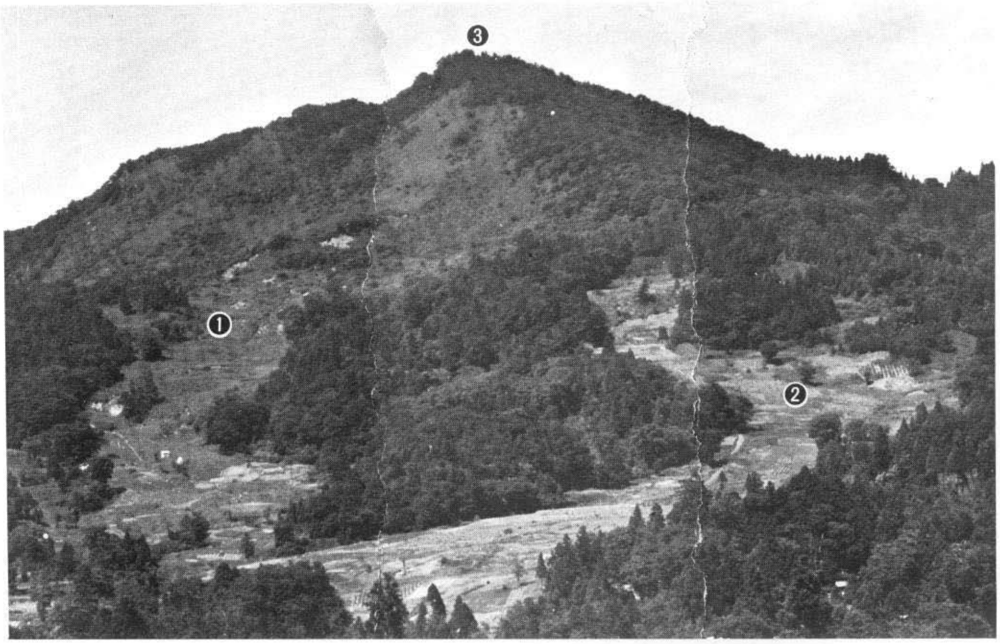
Shigeto Landslide along the Railway and Road, Kochi Prefecture (27)

At 11:00 on 5 July 1972, a large soilfall broke out near Shigeto Station of the Dosan line. Soils slumped from a hill with a height of 80 m. The slide had a width of 170 m and the fallen soil mass was about $10^5 m^3$. Fifty-nine persons were killed, and 11 houses destroyed. A locomotive and two railway carriages halting at the station were pushed out into the Ananai River. Geology: the slided area is identical with that of the northern belt of Chichibu terrain, which lithological by consists of clay slate, bearing sandstone and chert. In addition to this, this district is a famed heavy rain zone in Japan (average rainfall between 1931 and 1961 is reported as 3,389 mm/year), and the concentric heavy rainfall which triggered the slide reached 742 mm/day, which had never been experienced in the area.



Shigeto Landslide
1 Shigeto station 2 Railway carriage pushed out by slide 3 Ananai river 4 Slide mass

Sarukuyoji Landslide in Arai region, Niigata Prefecture (28)



General view of Sarukuyoji landslide 1 and 2 Sliding areas 3 Mt. Jogayama

Geology: the area is where the Miocene series consisting of the black mudstone is widely exposed and landslides frequently break out. Sarukuyoji landslide is one of the slides developed around the andesite dyke called Jogayama. The main sliding zone has an area of 24 ha. Records of landslides which occurred about 800 years ago are remenbered. The bed rock consists of the black mudstone and the debris with a thickness of about 5 m moves slowly on this bed rock holding a sliding clay with a thickness of a few centimenters. The gradient of sliding plane is estimated as between 10° and 15°. This landslide area is an experimental field of the Public Works Research Institute Ministry of Construction. The mechanism of movement was analysed and of control works of landslide were tested through ground survey and observations of movement. Control works: drinage wells and water intercepting walls were executed.

General Trend of Landslide Researches and Controls

With the rapid social progress, the aspects and scales of disasters caused by landslide have become larger. Landslide localities are estimated as more than 7,000 in total number. "Law on the landslide prevention" in Japan was put in effect in 1958. In the Law, 3,300 districts (March 1970) are designated as landslide-threatened ones. Landslide reseaches and controls have come to be more and more important from the viewpoint of regional development, land conservation and disaster prevention.

The Journals of the Japan Society of Landslide (No. 1–No. 28, 1964–1972) contain more than 180 papers, and the Journal published by the National Conference of Landslide Control, more than 80 papers : this shows a great progress in landslide investigations and controls. Landslide investigations comprise geology, geophysics, civil engineering, agricultural engineering, forestry, soil engineering and hydrography which are interconnected synthetically. Landslide is investigated by a number of researchers in various fields, and many papers on landslide are published deepening the mutual understanding between different fields of study. It is, in essential, difficult to divide landslide investigations into a few classes, but their tentative classification will be as follow:

1. Mechanisms of landslide phenomenon,
2. Ground structures causing landslide,
3. Prediction of landslide,
4. Flowing behaviour and tracing of groundwater,
5. Properties of soil causing landslide,
6. Methods of investigation, and
7. Engineering works for landslide protection.

The application of obtained results is of great importance. From this viewpoint, the following two subjects are regarded as particularly important:

1. Elucidation of the mechanisms and the reliable prediction of landslide, and
2. Engineering works effective for landslide prevention.

From these points, the following will be mentioned concerning the trend of landslide researches and controls:

(A) Numbers of observations and investigations are indispensable for the elucidation of observations and investigations are indispensable for the elucidation of mechanisms and the prediction or the forecasting of landslide occurrences. Physical quantities characteristic of the sloping land are to be measured using various observation gauges, and it is to be studied how to link the results of such observations to the mechanism and prediction of landslide. Investigations of the predominant causes of landslide judged from geological and topographical viewpoints and rough deciphers of the dangerous sloping land are also to be made. Let us draw attention to the remarkable results obtained from recent investigations. Soil mechanical investigations reveal the relationship between the change of properties of soil and the prediction of landslide occurrences. Geophysical investigations furnish a basic method for investigating the mechanism of landslide and the electric resistivity survey for giving effective information to a presumption of sliding layers. The tensomater gives the daily variation of soil strain which has some similarity and some relations to the behaviours of landslide. The tiltmeter also gives some similarity of motion relationship to the moving behaviours of landslide and sliding movements. The slight tremor measuring method gives a presumption of grade of weathering in the sliding area and of depth of sliding plane. These methods seem to presume some possibility of prediction of landslide occurrence. The underground deformation survey using the pipe strain gauge has made a remarkable progress in measurement and gives effective information to the indentification of the sliding plane and the decision of movement mechanism.

Geological investigation such as structure analyses of phases, joints, faults and foldings relating to the mechanism of landslide, gives detailed characteristics of sliding layers in slide areas. In general, geological researches reveal the history of sedimentation and surroundings, geological constituents and the characteristics of properties of rocks causing landslide. The mineralogical identification gives data related to the decipher of the sliding topography using aerial photos and the history of development of the topography.

Investigations of soil mechanics present the relation between the temperature variations and characteristics of creep of the sliding clay and that between the stress of yielding and the mechanism of movement and the rheological characteristics of soil in the viscous state. Properties of the sliding soil have been compared between the Tertiary areas and the metamorphic zones, and great difference between them are found, but an excellent agreement is observed in the rheological characteristics of the sliding clay and those of moving behaviours of landslide. Creep characteristics and resistance of the unsaturate clay both in Tertiary zones and the metamorphic areas were also investigated under the condition of triaxial compression, to compare the theoretical values with the experimental results. The theoretical researches of sliding breakdown of the fragile clay are made, and in consequence, experimental results obtained up to now are theoretically explicated.

Various observations have been carried out to obtain a number of useful observation results : the main problem is to find a reliable method of prediction of landslide occurrence using observational and experimental results obtained, and the establishment of a reliable method of landslide prediction will be one of the most important subjects for landslide researches in future.

(B) The social meaning of the landslide control has come to be more and more important. Basic investigations concerning at the Japan Society of Landslide. On the other hand, basic researches of landslide control are carried out centering at the National Conference of Landslide Control. At the anual meeting of the landslide control conference, reports and discussions of engineering works and landslide researches are made. As engineering works for landslide control, surface drainage, underdraining, horizontal drainage drilling and oblique drainage drilling have been put into practice. Groundwater tracing has become possible by injecting chemicals, and the measurement of the goundwater discharge by pumping up. The understanding of the flowing behaviours of groundwater in the sliding areas leads to the introduction of drainage well using linerplates and of drainage tunnels. When the urgent stopping of landslides occurring at rivers, dams, roads and special buildings is required, steel tube piling into the ground is often carried out. The removal of soil mass causing landslide is one of the excellent methods of the prevention of landslide, but the high expenses and the problems of land required have prevented it from performing.

The progress of machinery used for engineering works have made construction works easy, and the soil removal is adopted where the reliability and immediate effect of stopping landslide are required. The progress of landslide prevention works. The works require a colossal sum of expenses, but the prevention is necessarily connected with the improvement for the reliable technical method of landslide prevention therefore, are required.