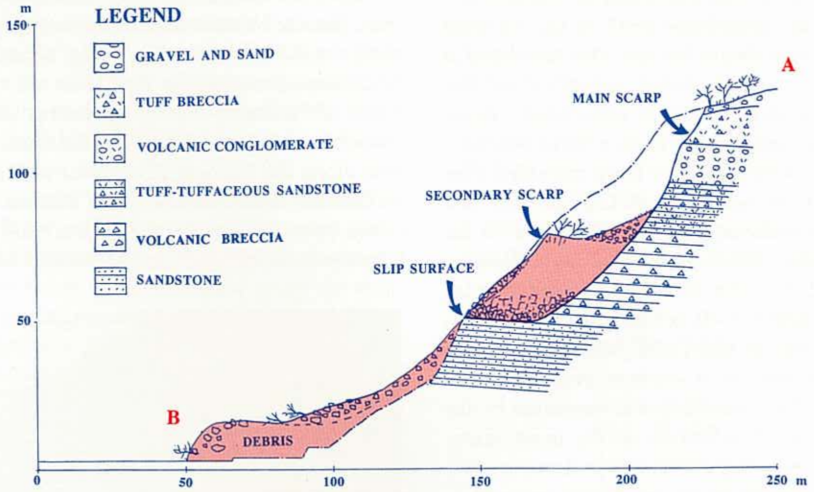

Fig. 4 Profile view of the Okushiri-Port Slide.

Toyohama Shore (To in Fig. 1), rock falls crushed a house and killed two people. Characteristically, the rock falls occurred by spalling of rocks from vertically jointed Miocene volcanic bedrock.

The soil slides occurred on a larger scale on steep planar slopes of upper Miocene to Pliocene semi-consolidated tuffaceous sandstones and/or volcanic breccias. They are typically recognized along the Horonai River (Hor in Fig. 1) and at the northern part of the main scarps of the Kamuiyama Giant collapse (Ka in Fig. 1). The soils, including trees, slid down rapidly, followed by shifting of bare land surface of the topped ridges during strong shaking, to form well-sorted coarse-grained facies. These features are similar to shattered earth described by Nason (1981). High precipitation, as much as 135 mm in a few days during the end of July caused further sliding. In addition, on the island of Hokkaido in areas such as the Sakaehama Shore (Sa in Fig. 1), soil slides occurred from the margins of massive lavas interbedded with clinker, and on steep slopes of soft gravels.

Conclusions

The landslides induced by the Hokkaido Nansei-oki earthquake are identified as rock slides, debris slumps, rock avalanches, rock falls, and soil slides. Most of these landslides occurred from the top of the steep slope of Cenozoic volcanic rocks underlain by tuffaceous or semi-consolidated sandstone.

In particular, the rock slides took place on steep slopes of gentle-dipping semi-consolidated tuffaceous sandstone overlain by coherent massive volcanic rocks. In other words, the latter make up caprocks underlain by soft sandstones. The rock avalanches and rock falls took place from the steep slopes of coherent massive volcanic rocks, and the soil slides and debris avalanches occurred in consolidated or unconsolidated tuffaceous sandstones and/or volcanic breccias.

Acknowledgments

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A System of Monitoring and Warning in a Complex Landslide in Northeastern Italy

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On 17 April 1992, after a snow-melt period and heavy rainfall, a landslide known as the "Tessina landslide" reactivated causing alarm and creating a dangerous situation for some villages in the Province of Belluno, northeastern Italy (Fig. 1).

The landslide, which was first triggered about 30 years ago, is a complex phenomenon with a source area affected by roto-translational slide movement in the upper section; the slide was transformed downhill through a steep channel into a mud flow.

The landslide developed in the Tessina valley between elevations of 1,220 and 625 m, with a total longitudinal extension of nearly 3 km and a maximun width of about 500 m. The source zone is more or less elliptical, with the longest axis oriented N-S for about 600 m, while the shortest axis is about 500 m long.

The mud flow laps the village of Funes and continues down to an elevation of 625 m, where it stops near the town of Lamosano.

The lithology of the area varies considerably. We can identify three main formations: 1) Monte Cavallo Limestone (Cretaceous), which consists of layers of varying thickness from about a centimetre up to approximately a metre with a downslope dip of about 70°. This makes up the main structure of Mt. Teverone. 2) Scaglia Rossa (Upper Cretaceous), which consists of marly limestone with a maximum thickness of about 50 m, outcropping on the southern slope of Mt. Teverone. 3) Flysch (Middle Eocene), which consists of a rhythm marly-argillaceous and calcarenite layers with a thickness of about 1,000 to 1,200 m. This formation makes up the impermeable substratum of the entire sliding area and outcrops at the foot of Mt. Teverone.

The Quaternary deposits consist of a vast scree slope at the foot of Mt. Teverone and in morainic Würmian deposits from the glacier of the Piave River valley and from other small local glaciers.

The landslide first moved on 30 October 1960, after a particularly heavy rainfall period in which 398 mm of rainfall were recorded in 30 days. This movement involved a total volume of approximately 1 million m^3 of material. The highly fluid material turned into a channeled mud flow moving down the Tessina Valley. It was possible to distinguish an area of feeding in constant expansion, a flat upper accumulation area, a lower accumulation area consisting of the main flow, and a steep narrow discharge channel connecting the two latter areas.

Further landslide events occurred at the site in 1962, 1963, 1973, 1987, 1988, and 1989 after long-term rainfall.

These events caused the filling of the Tessina valley with thicknesses of material ranging from 30 to 50 m, seriously endangering the village of Funés, which is situated on a steep ridge originally quite high above the river bed, but now nearly on a level with the mud flow (Fig. 2).

The history of the landslide during the 33 years since it first occurred has been traced by means of an analysis of maps surveyed in 1948, 1961, 1965, 1970, 1980, and 1985 (Dall'Olio *et al.*, 1985) and by a comparison with maps at a scale of 1:5,000 (1985–1992).

The progressive enlargement of the zone of feeding between 1965 and 1992 is described in the following table:

Year	Source Zone (m^2)	Increment (Annual increment) (m^2)
1965	115,550	32,350 (3,235)
1975	147,900	7,690 (1,538)
1980	155,590	10,560 (2,112)
1985	166,150	140,800 (17,600)
1993	306,950	

In April 1992, a period of quite heavy rainfall (160 mm in 15 days), followed the annual snow-melt period. Under these circumstances, on 17 April 1992 an area of about 40,000 m^2, collapsed on the left-hand slope of the Tessina Stream, involving a volume of approximately 1 million m^3 of material (Figs. 3 and 4). During the months before, signs of intense fracturing (which became worse just a few days before the main event) appeared in this sector.

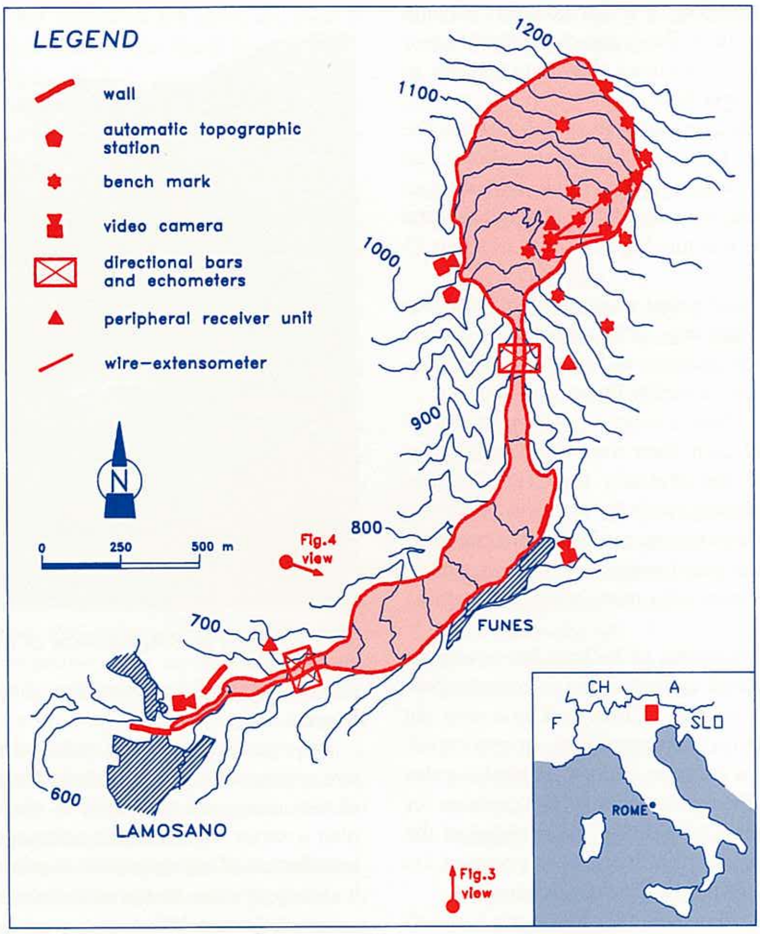

Fig. 1 Index map and location of the instruments within the Tessina Landslide.

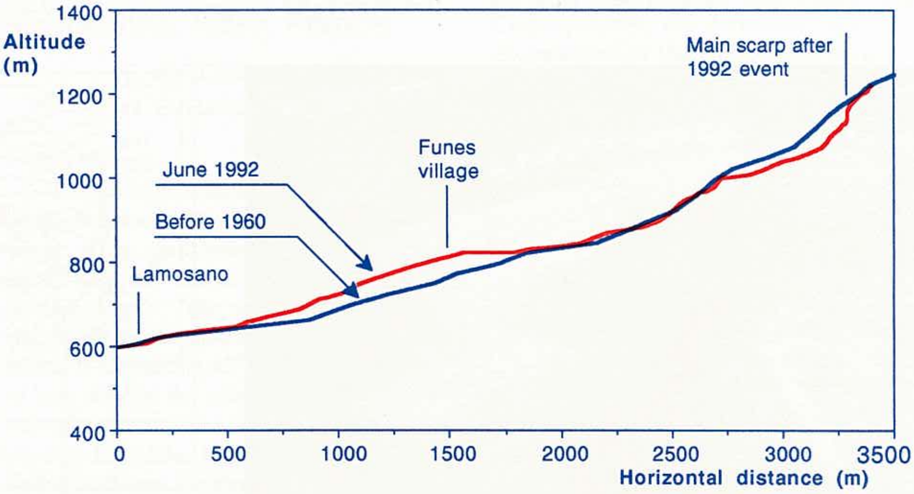

Fig. 2 Surface profiles along the Tessina Stream showing pre- and post-failure.

The main event, a roto-translational slide, with an estimated depth of slip surface ranging from 20 to 30 m, involved even the flysch substratum. It produced a main escarpment approximately 15 m high and moved about 100 m downhill. This caused breakage of the entire unstable mass and disruption of a drainage works built in previous years.

The highly fractured and loosened material from this area ran down into the river bed and, due to constant remoulding and the continuous increase of water content, became more and more fluid, transforming it into a series of earth flows that contributed to increased mud flow.

This flow in just 5 days had reached the village of Funes. This mass, which was about 5 m wide and 1 m thick, moved at an approximate velocity of 10 m/hr, whereas the main slide was moving at a speed of about 15 m/day.

Flow movement continued with varying intensity until July 1992, when it had almost reached the outskirts of Lamosano after having overrun the earlier flows.

After these events, the inhabitants of Funes and Lamosano were evacuated; in the meantime the Ministry for Civil Defense began assigning funds for works to be carried out on a short- and medium-term basis, in order to safeguard residential areas, as well as for installation of a monitoring and warning system.

Civil engineers of Belluno Province built three artificial embankments in order to protect the villages. Close to Lamosano, an experimental structure was constructed, including a concrete bed and several nozzles capable of spraying water at high pressure for the purpose of fluidizing the material of the mud flow and therefore of preventing its accumulation and backwater flooding.

The Italian National Research Council (CNR) Research Institute of Padua was appointed by the Ministry of Civil Protection to install a monitoring and warning system, in cooperation with the CNR Research Institutes of Florence and Perugia and with the Department of Geology for the Veneto Region.

Fig.3 Aerial view of the Mt.Teverone and the Tessina Landslide.

The particular features and evolution pattern of the slide, together with the extension of the area involved, made it necessary to plan a series of innovative solutions for the installation of an automatic monitoring and warning system that would guarantee the safety of the population.

The instruments that were considered the most suitable for monitoring several different types of phenomena (such as the roto-translational slide of the upper section and the mud flow close to the villages) were identified and connected to three peripheral units.

The peripheral units are powered by photovoltaic panels and equipped with backup batteries. These units receive and perform preliminary processing of data coming from the instruments (*i.e.* echometer, directional bars, extensometer) and check that these instruments work properly.

Two multiple-base wire-extensometer units, measuring 280 m and 390 m, were installed in the upper section of the slide in order to obtain a constant check of the movements occurring on the landslide surface. These units consist of a series of 12 measur-

Fig. 4 Aerial view of the mud flow in the proximity of the village of Funes.

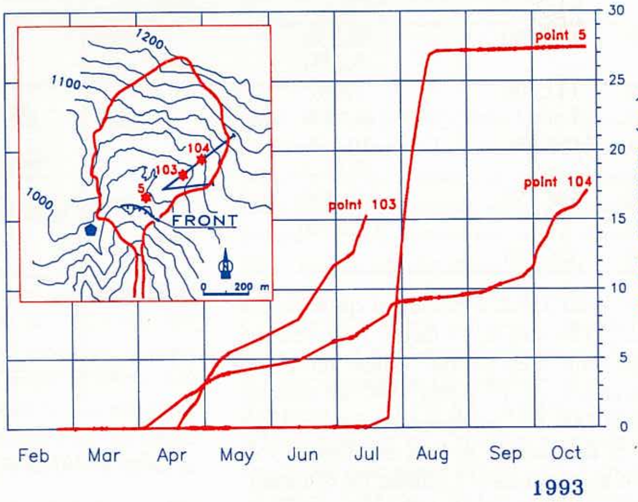

Fig. 5 A monitored landslide event: the continuous movement of the upper part of the landslide (points n° 103 and 104) and the sudden collapse of the front (point n° 5). Point n° 103 has been lost during this event.

ing pulleys fitted with an appropriate scaler system capable of detecting movements as small as a millimetre.

On the upper section of the slide, a topographic system with an automatic benchmark detector for measuring surface movements was installed. It consists of a high-precision theodolite provided with a servomotor run by means of a personal computer, which controls the system activity and insures data reading and recording of 13 points every 30 minutes. Each group of recorded data (angles and distances) of immediately compared with the previous readings to obtain displacement trends. An example is plotted in Fig. 5 in which it was possible to detect a collapse in the front of the source area (point no. 5); after that, earth flow movements occurred in the upper portion of the landslide (points no. 103 and 104).

On the mud flow, two control units, one consisting of three tiltmeter bars and an ultrasonic echometer, the other of two tiltmeter bars and an echometer, were installed some 100 m uphill from the villages.

The working principle of the tiltmeter bars (which are steel bars 2 m long, suspended on a cable stretched across the flow) is based upon the tractional and rising effect of the moving mass on the bars. If these remain tilted more than 20° from their vertical position for more than 20 seconds, an alarm is set off by the closure of a mercury switch. The echometers, which constantly measure the height of the surface of the flow, are used to confirm and backup the alarm from the tiltmeter bars.

Three videocameras were also installed to record and watch over the slide movements in the most critical areas.

A central monitoring station, located inside the building of the local government of Lamosano, receives data coming from the peripheral stations to which the sensors are connected. It also defines possible situations of danger and sends data and signals, via modem, to a warning station situated at the Fire Brigade Station of Belluno. Basically the central monitoring station consists of an MS-DOS computer running dedicated software which handles and processes data with the aim of highlighting situations of possible danger.

In the event of a critical development of the situation, various warning levels can be determined, Pre-warning, Normal Warning, Serious Warning, with an indication of the peripheral units and sensors directly involved.

It is at any rate possible to access data in real-time mode by connecting to each peripheral device and checking on the instrumentation, as well as providing access to recorded data coming from each sensor.

In conclusion we feel that the monitoring system installed in the Tessina landslide is providing the necessary data for carrying out a Civil Defense programme, including the evacuation of the population from the residential areas in the event of a catastrophic reactivation of landslide activity.

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A Huge Slope Movement at Séchilienne, Isère, France

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A huge slope movement is underway not far from Grenoble, in the south-eastern part of France (Fig. 1), which endangers a small housing estate and a highway of major economic importance that provides access to several famous winter sport resorts. During winter and spring holidays, many people move to these resorts, and the traffic frequently exceeds 25,000 vehicles per day. This slope movement is of great concern for the authorities in charge of public safety. Detailed studies have been carried out since 1985 to understand the phenomenon, design protection works, and support the administration in formulating a plan for public safety in case of an emergency.

Sketch of Morphological and Geological Settings

1) Morphology

The landslide is located on the right bank of the Romanche River about 2.5 km downstream of the small township of Séchilienne. At the site, the valley is narrow, with steep, uniform slopes. The unstable slope on the right bank has an elevation difference of 800 m and is inclined at 45° (Fig. 2). At the top of both sides of the valley the morphology is that of a plateau dissected by glacial erosion. Ancient landslides had already been identified in different locations and especially at Mont-Sec. The latter is part of the movement described in this paper.

2) Lithology and Structure

From a geological point of view, the rock masses that build up the slopes in the vicinity of Séchilienne are part of an element of the crystalline basement of the outmost facies belt of the French western Alps. Consequently, the different rock types encountered at the site consist mainly of metamorphic rocks, such as micaschists, leptynites, and some amphibolites.

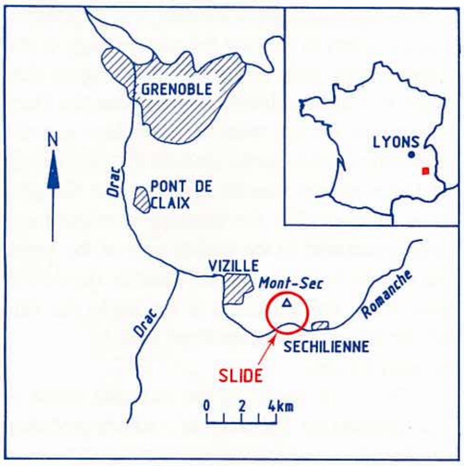

Fig. 1 Location map showing the site of the slide and the main localities downstream..

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