# LANDSLIDE DETECTION, MONITORING, PREDICTION, EMERGENCY MEASURES AND TECHNICAL INSTRUCTION IN A BUSY CITY, ATAMI, JAPAN

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**Abstract:** National highway No.135 is a main road that supports the regional economy and sightseeing spots in Izu Peninsula. Atami is a busy city and leading resort with many hotels and resort apartment buildings, attracting more than 8 million visitors every year. In late 2003/early 2004, warning phenomena appeared just before a landslide destroyed a slope along the highway. The road office administrators were concerned that the community would be seriously paralyzed if the landslide intercepted traffic and caused hotels and buildings to collapse.

There had been several small landslides at the bottom of the slope in August and September, causing traffic jams and the successive rupture of water service pipes buried alongside the road. However, the administrators did not realize that the series of phenomena were caused by landslides. Two months later in November, a water service pipe ruptured again, and the road office finally investigated the slope. This time, a landslide scarp and cracks were found on the slope, and the administrators realized that the series of small August/September phenomena had been caused by a landslide 75 m long and 75 m wide.

Monitoring of landslide activity by extensometers was quickly started, by which time the slide velocity had accelerated to more than 5 mm/day. On December 6, the sliding velocity reached 24.8 mm/day, and a landslide was predicted to occur at noon on January 5. In order to grasp the geological situation and the sliding depth, it was necessary to take emergency measures, and so loading earth filling work and drainage boring were carried out. As a result, the slide velocity gradually slowed to 3–5 mm/day by the end of 2003, and the landslide was restrained by anchor work as a permanent measure.

## INTRODUCTION

From late 2003 to early 2004, several signs of landslide movement were observed on a slope beside national highway No.135 in the busy city of Atami. Atami is an eminent resort area in Japan with many hot springs, hotels and resort apartment buildings, attracting more than 8 million visitors every year (Figure 1). Further movement of the landslide would have damaged not only these facilities but also the highway, which could have caused traffic closure and affected the local community and sightseeing industry. This paper describes the emergency countermeasures for the landslide conducted by the national road office administrators with advice from the interim committee organized for this disaster.

## OVERVIEW OF LANDSLIDE

The geology of the area consists of Miocene tuff overlain by Pleistocene andesite lava. National highway No.135 is located by the scarp of the foot of a stratovolcano, which is heavily incised by coastal erosion. Rock fall and surface failure occur frequently on the neighboring slopes, although a large-scale landslide such as reported in this paper has never been observed in historic times (Figure 2).

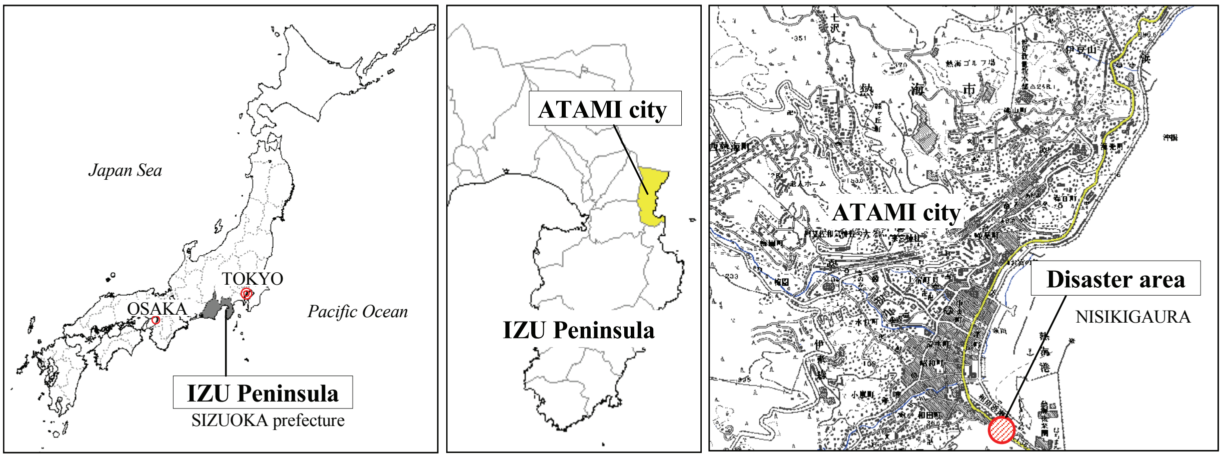


**Figure 1.** Location of disaster

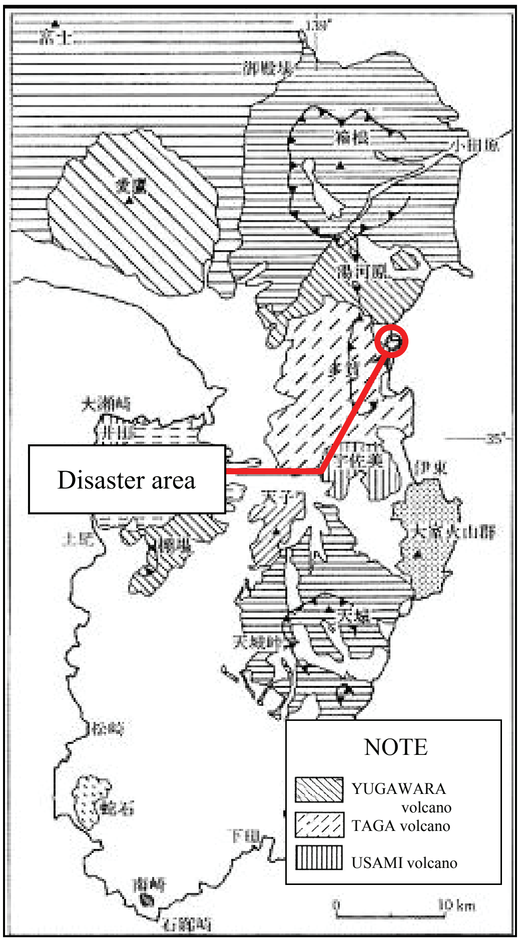


**Figure 2.** Distribution of volcanoes

In the Izu district, continuous rainfall of 59 mm was recorded from August 9 to 11, 2003. Furthermore, rainfall of 401 mm was recorded from August 14 to 19, with daily rainfall of 103 mm on the 15th and 233 mm on the 16th.

Regarding landslide movement, two slope failures in the landslide were observed behind a car repair factory on August 15th. Upheaval of part of the national highway was also reported on the 18th. The back of the car repair factory collapsed again on the 22nd, and the water supply pipe laid underground along the national highway ruptured (Figure 3).

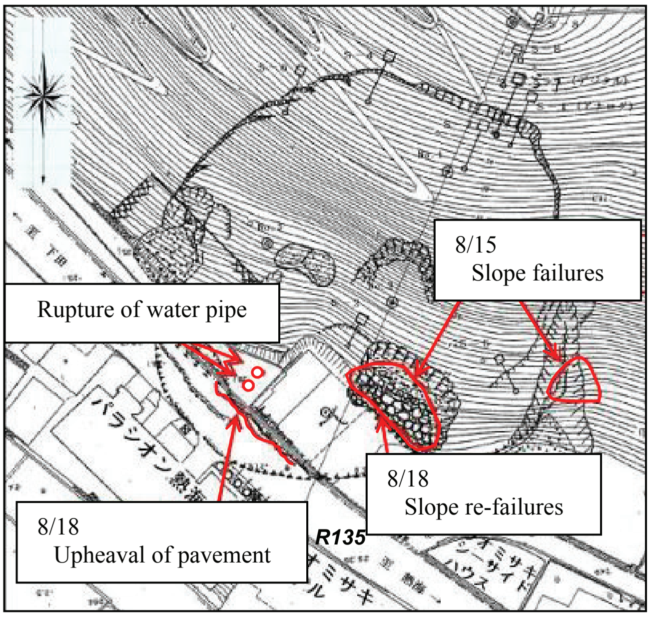

**Figure 3.** Location of phenomena

These phenomena, however, were initially not recognized as triggered by a landslide, and only the car repair factory received a warning letter from the authorities. Eventually, another underground water supply pipe along the national highway ruptured on November 8th after rainfall of 41 mm on the 5th and 6th, and so a further investigation was conducted, which resulted in open cracks being found on the slope on the 17th. The scarp of the major crack located at the altitude of 92 m was 1.0–1.5 m deep. These findings confirmed that a series of phenomena (slope failures, upheaval of pavement, and rupture of water pipe) had been caused by the landslide. Subsequently, an extensometer was set up at the main scarp to monitor the behavior of the landslide, and it initially recorded continuous and slow movement of over 5 mm a day.

A follow-up investigation carried out by Shizuoka prefecture and Atami city, and revealed that the major crack extended continuously straight. While there were longitudinal cracks on the Shimoda side, echelon cracks were observed on the Atami side. The slope at the toe of the landslide also collapsed at several locations. The mountainside of the national highway was uplifted by the movement of the landslide, and the pavement on the seaward side of the national highway was deformed. The office of the car repair factory was leaning, the flat area of the ground was raised, and the rock mass of the scarps collapsed. This sequence of phenomena helped reveal the shape of the landslide, the size of which was 75 m long and 75 m wide (Figure 4).

Following these investigations, a disaster application was submitted to the Ministry of Land, Infrastructure and Transport, because highway No.135 which had been damaged by the landslide was nationally owned. At the same time, an interim committee for countermeasures against the landslide of the Nishikigaura area along national highway No.135, consisting of landslide experts from universities and government organizations, was set up because: 1) the landslide was large and moving fast, 2) the highway is an essential transport route for the local community, and 3) it was considered difficult to avoid the influence on hotels and resort apartment buildings.

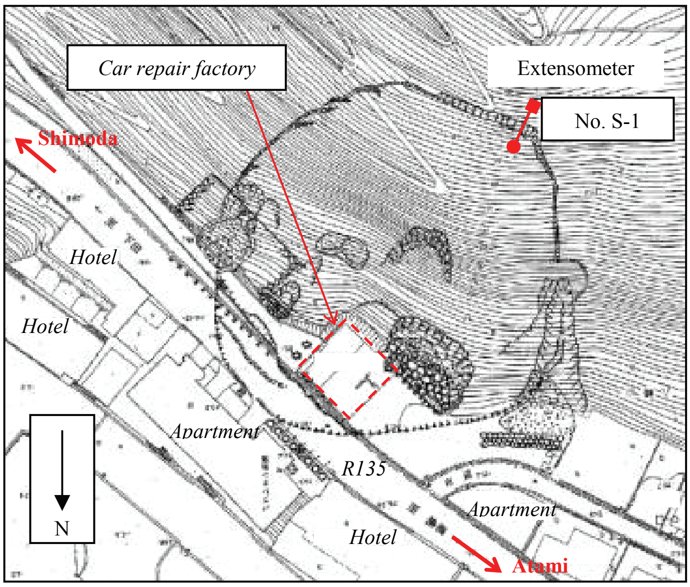


**Figure 4.** Ground plan of investigation

## LANDSLIDE ACTIVITY

The topography of the landslide was identified in the field, suggesting the possibility of further growth. Subsequently, nine extensometers were additionally installed across the main scarp, stretching further up the slope. The movement of the landslide was also monitored on the landslide by an optical theodolite. The longitudinal profile along the national highway was measured to check the deformation induced by the landslide. Data recorded by extensometers showed that the tension displacement was accelerating, 5.2–5.7 mm/day from November 21 to 25, 6.7 mm/day on the 26th and 7.2 mm/day on the 28th (Figure 5). Continuous rainfall of 79 mm from November 29 to December 1 encouraged further displacement, which reached 24.8 mm/day (1 mm/h on average) on December 6. At this stage, further collapse of tertiary creep was predicted using the equation of Saito (1987) to occur at 12:00 on January 5.

The depth of the sliding surface as well as the rock constitution was quickly investigated by boring. The system of monitoring the landslide by extensometers and a theodolite was reinforced by increasing the number of watchmen to look for any change of the surface and toe of the landslide, thus enabling the boring works to be conducted safely (Figure 6).

The boring cores consisted of fractured clay and hollows underneath relatively fresh andesite lava that can also be observed at outcrops, indicating that weaker rock types existed in the deeper layers. The deformation of the landslide mass was also observed by an inclinometer using these bore holes 2 to 3 days after the guide pipe of the inclinometer was installed. According to this measurement and observation, the maximum depth of the slide surface was 24 m deep (Figure 7).

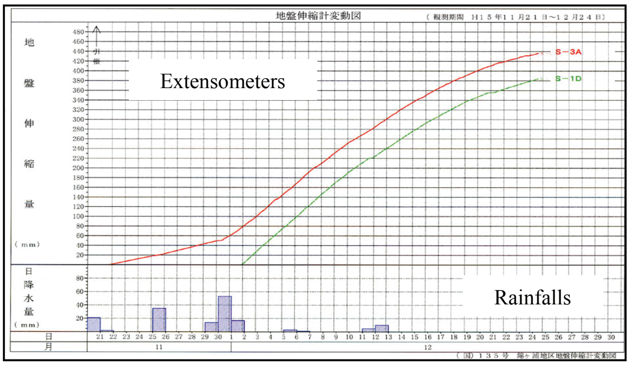

**Figure 5.** Displacement of extensometers

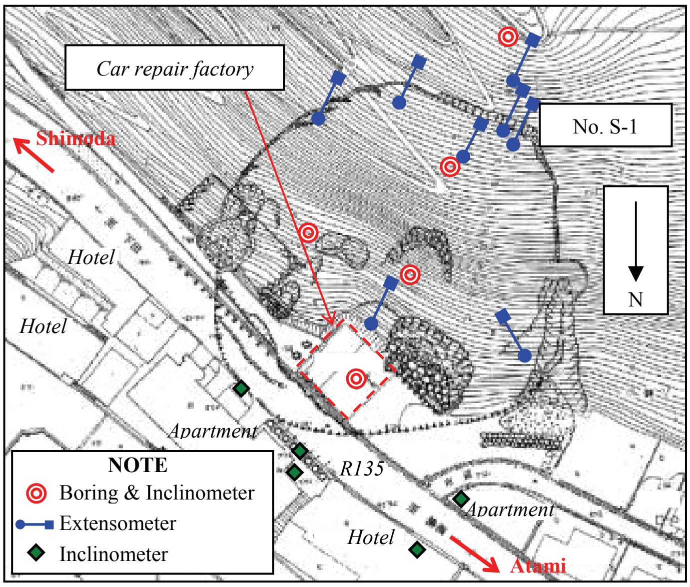

**Figure 6.** Locations of installations

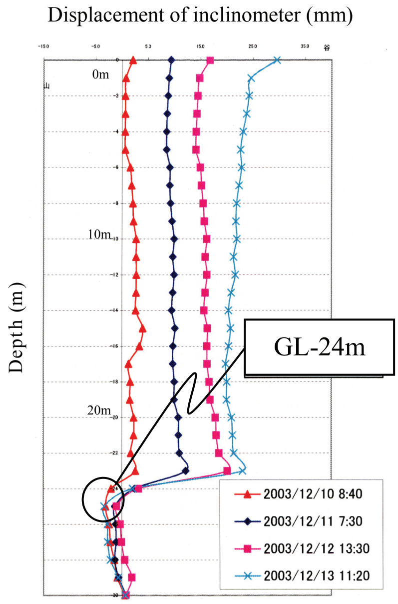

**Figure 7.** Depth of slide surface

## EMERGENCY COUNTERMEASURES

Emergency countermeasures conducted to slow the landslide movement included drainage of underground water and counterweight filling at the toe.

Horizontal drilling was carried out to drain underground water flowing into the landslide. The work required special care to prevent water from entering the drilling holes and to minimize vibration so as not to activate the landslide Therefore, rotary drilling, rather than rotary percussion drilling, was adopted due to its light weight, which enabled the instrument to be carried by a monorail and shortened the time required for completing the work. The counterweight filling work at the toe of the landslide was carried out in cooperation with Atami city, which officially ordered the removal of the car repair factory.

Historically, part of the highway near the landslide had collapsed when resort apartment buildings were constructed in 1973. Although steel piles with two rows of anchors were subsequently installed in the shoulder of the road, a part of the upper row was not functioning in 2003.

Judging from the results of boring and the history of landslide disasters in the area, it was estimated that the counterweight filling work could be effective only in the area of weak geological soils, including the highway area, because the filling could actually trigger further movement of the landslide, possibly damaging hotels and resort apartment buildings. Therefore, inclinometers were set up over the landslide, and crack-gauges were installed on the highway, such as on the concrete block retaining wall, in order to detect the landslide movement (Figure 8). The counterweight filling work was continued step by step with careful monitoring.

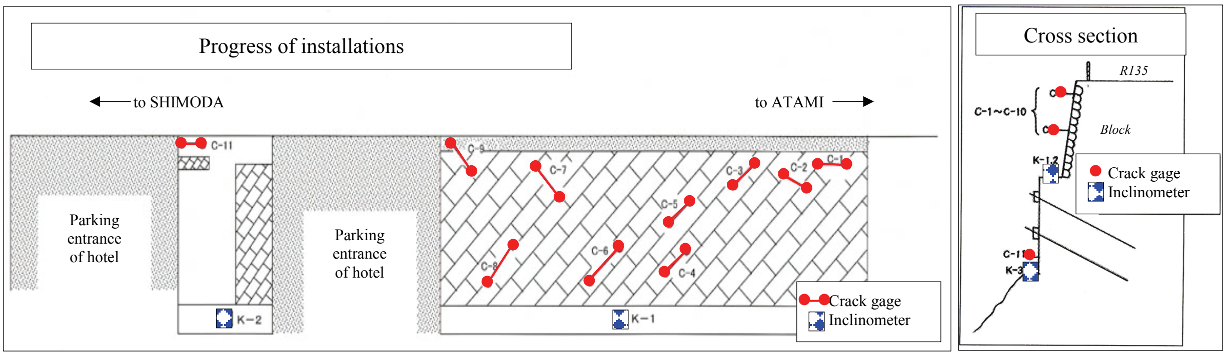


**Figure 8.** Location of installations for structure (concrete block wall, etc.)

The safety factor of the slope was initially estimated to be Fs = 0.95, and counterweight filling work was expected to increase the factor to 1.00. The factor, however, could not be measured directly, and had to be estimated based on observation while the counterweight filling and boring works were under way. Furthermore, the depth of the slide surface had to be determined by observation and monitoring using several installations. Fortunately, the counterweight filling work required only a short period by utilizing a stock of concrete wave-dissipating blocks (1 m cube) to establish the foundation of the fill (Figure 9).

While the counterweight filling work was carried out under careful observation and monitoring by watchmen and installations, water flow from a concrete block retaining wall on the side of the national highway started increasing. Although the water seepage was located 10 m lower than the slide surface, it was assumed that the water was related to the landslide movement. Subsequently, work for draining the underground water was planned and conducted in order to make the counterweight filling effective and reduce the water pressure against the concrete block retaining wall. Judging from the circumstances of neighboring structures, three deep wells, each of 25 cm in diameter, were set up from December 29 to 31 (Figure 10). The wells pumped up and drained water to mitigate the landslide movement. The depth of water in each well was around 11 m and a large volume of underground water was effectively drained.

The landslide movement was initially 20–30 mm/day when it was discovered, but this was slowed to 3–5 mm/day from late December to early January following the progress of emergency measures (counterweight filling work, horizontal drilling, and deep well).

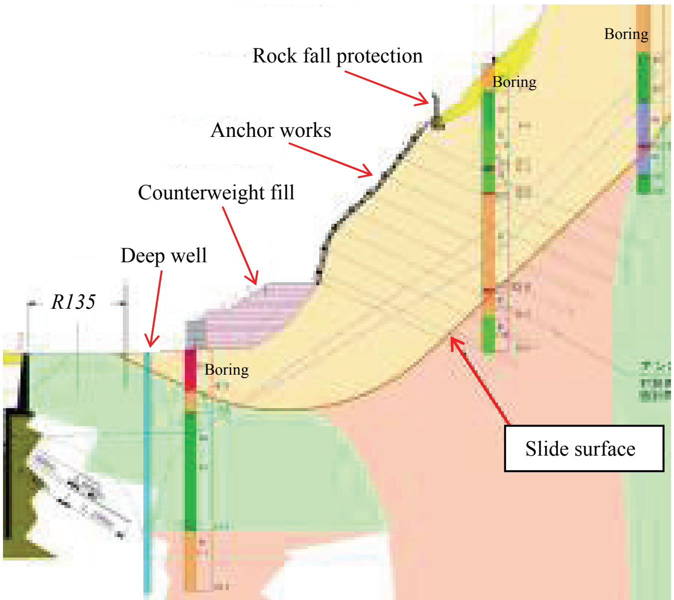


**Figure 9.** Section of emergency measures

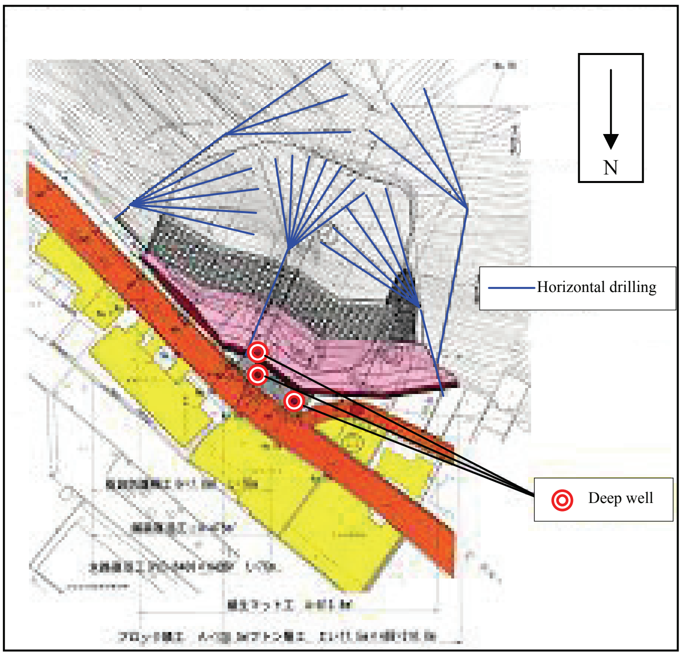


**Figure 10.** Location of deep well

## EVACUATION ADVISORY AND TRAFFIC CONTROL

Because of the heavy traffic along the highway (15,000 cars/12 hours) as well as many hotels and resort apartment buildings in this area, a landslide would have caused huge damage to the local community. Therefore, an evacuation area was set up (Figure 11), and meetings to explain the circumstances to the residents were held to make them aware of the landslide and the evacuation system in advance (Figure 12).

The committee for countermeasures against the landslide of the Nishikigaura area presented the data of extensometers and rainfall, and announced control evacuation standards and traffic closures in response to the landslide. The landslide control standards were as follows.

1) In case of displacement of 2 mm/hour and continuous slope failures of small areas, an evacuation advisory and traffic closure would be implemented, and information about the landslide movement would be reported to the police.
2) In case of displacement of 2 mm/hour for 2 hours continuously, total rainfall of >60 mm and hourly rainfall of >15 mm, an evacuation advisory would be announced and the road would be closed. Fire alarm devices would be used to inform tourists staying at hotels and resort apartment buildings.

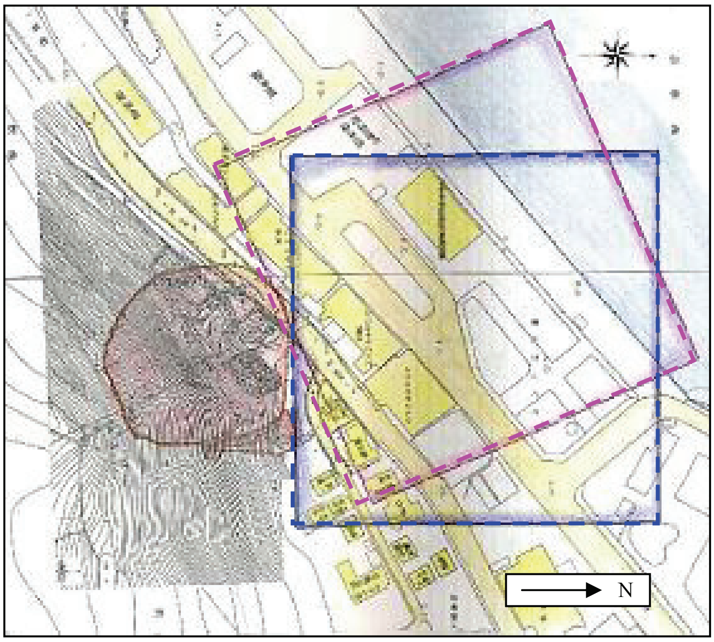


**Figure 11.** Region of evacuation advisory landslide

## CONCLUSION

The landslide in the Nishikigaura area in Atami city, Shizuoka prefecture was noticed as a result of uplifting of the pavement of national highway No.135 on November 29, 2003. Further investigation of the landslide followed. The authorities were concerned about the toe of the landslide in particular, which reached the highway that is the lifeline of the economy and industry in Izu Peninsula. It was even considered at one stage that evacuation and traffic closure were inevitable, since movement of the landslide had reached up to 30 mm/day. However, the situation, which could have greatly damaged the tourist industry during the busy new-year holiday season and threatened human lives as well as the local economy due to prolonged traffic closures in Izu Peninsula, was avoided through desperate efforts to stop the landslide movement.

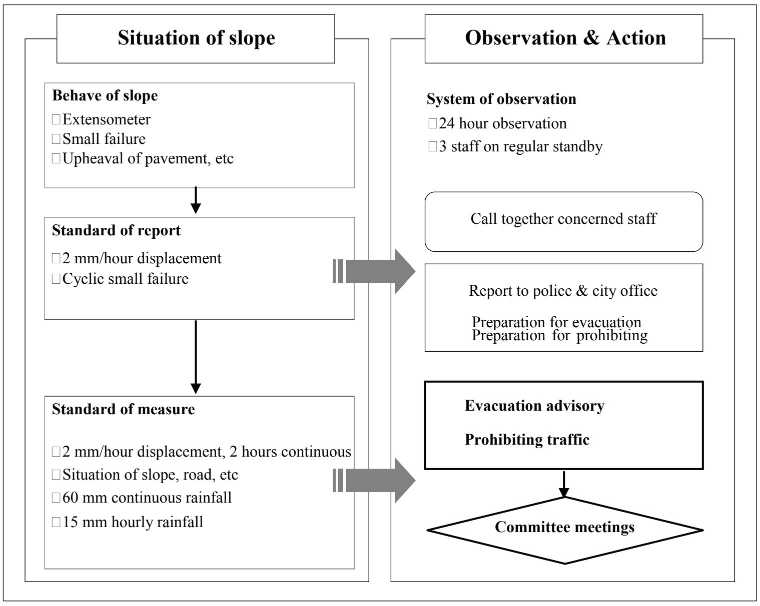


**Figure 12.** Observation system

Shizuoka prefecture reinforced the system for monitoring the landslide, conducted field surveys and introduced emergency measures (counterweight filling work, horizontal drilling, and deep wells). As a result, the landslide slowed down after 1 month, and the area was no longer in danger. This series of experiences highlighted the importance of early detection of landslides and suitable countermeasures.

Long-term countermeasures for the landslide in the area have now been completed. Shizuoka prefecture, Atami city, the fire authorities, and local residents together helped contain the damage caused by the landslide. The case reported here is an excellent example of emergency landslide measures swiftly conducted in a populated urban area.

## REFERENCES

HARADA, T., FUJISAWA, K. & TAKEDA, H. 2004. Countermeasures for landslide in an urban area – Example of Atami city, Shizuoka Pref. –. *43rd Colloquium of Japan Landslide Society,* 61-64.

FUJISAWA, K., HARADA, T. & TAKEDA, H. 2004. Observation of and emergency measures for a landslide in an urban area. *The Foundation Engineering & Equipments, Vol32, No.9,* 19-23.