Unzen Volcano : the 1900-1992 eruption

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17. Monitoring Ground Movements of Chijiwa Fault and Mt. Mayuyama Using the Global Positioning System for Surveying

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Introduction

The Institute of Environmental Systems and Shimabara Earthquake and Volcano Observatory have developed a long term, continuous observation system of ground movements using the Global Positioning System (GPS) for surveying. This system was installed to monitor both the activity of the Chijiwa faults in the north of Unzen Volcano and the slope stabilities on Mt. Mayuyama. The outline of this system and the current results are briefly reported.

The GPS is a microwave surveying system using satellites (Leick, 1990; Wells et al., 1986). This system is advantageous allowing highly accurate three dimensional positions. Displacements of measuring points are taken simultaneously. Because of microwave transmission codes, the GPS has the capacity for continuous high-accurary monitoring 24-hours a day in all-weather, over a wide range, over a long distance and over a long term. It is difficult or impossible to achieve this by using conventional surveying methods. The GPS has the potential to revolutionize the practice of surveying; it can be applied to measure various ground movement phenomena, such as land subsidence, landslides, volcanic activity, mountain collapsing, and other kinds of ground movements.

The eruptive activity of the Unzen Volcano in the Shimabara Peninsula, Kyushu, Japan, is closely related to the crustal activities, especially Chijiwa faults in the north of Mt. Fugen. Therefore, monitoring their movements is important in order to evaluate and to estimate the eruptive activities both at present and in the future.

Mt. Mayuyama, one of the Unzen Volcanoes, is situated in the eastern part of the Shimabara Peninsula, located 4.5 km away from Mt. Fugen. It is a lava dome composed of dacite. In 1792, a large scale collapse with a volume of about 3×10^8 m^3 occurred in the Mayuyama lava dome, and the avalanche of fragments of the lava dome rushed eastwards to reach the Shimabara Bay. This catastrophe resulted in many deaths (Ohta, 1969; Katayama, 1974). Considering the current eruptive activity, another large scale mountain collapse might possibly occur in the Mayuyama lava dome. Accordingly it is essential to evaluate the slope stability of Mt. Mayuyama, which could be influenced by external factors such as earthquakes. It is necessary to instantaneously measure its movements with high accuracy, and to take countermeasures before any failures occur.

This study aims to apply the GPS as a long term monitoring system, which measures the movements of active Chijiwa faults in the north of Mt. Fugen, evaluates the stability of Mt. Mayuyama, and stores data in readiness for an emergency.

Outline of global positioning system surveying

The GPS was developed by the Department of Defense of the United States in the 1970s. In the future, there will be 24 GPS satellites in the final orbit in order to eliminate weak areas obseved by

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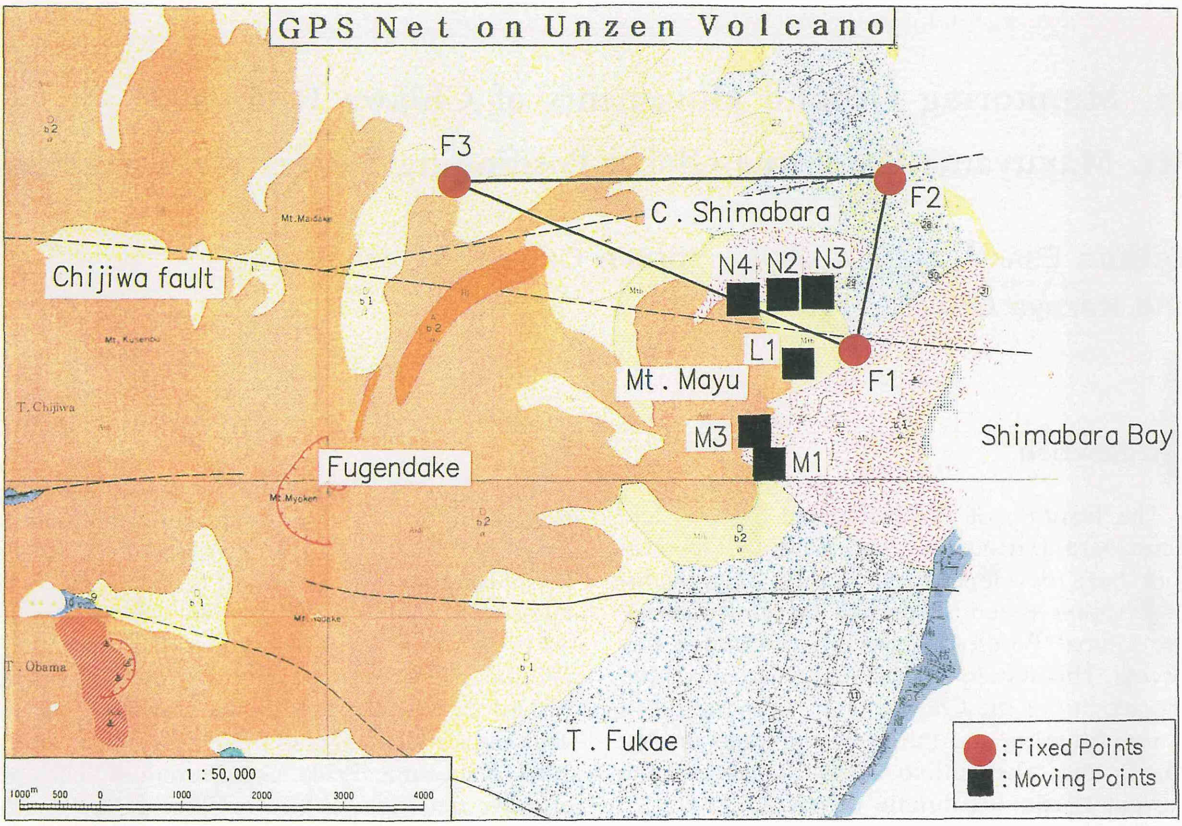

Fig. 17-1. Subsurface geological map, measurement points, and GPS net observation for ground movements on Unzen volcano.

the 18 satellites in orbit at present. This system is being primarily developed to support military navigation. Because the GPS instrumentation and its analyzing software are good enough to be applied for high precision surveying technology, the non-military uses of the GPS for surveying in areas such as earth science, geology, volcanology, geotectonics, seismology are being analysed by many of the finest research teams in Japan.

The GPS surveying techniques can be classified roughly into two types: the static surveying method and the kinematic surveying method. The former has been the standard method for the GPS surveying. The term static has been applied because the receivers occupy stations for a long time, usually an hour or more, while keeping receivers on the same points during the observation. The latter is the most efficient method today for collecting surveying points with the GPS, which is similar to radial surveying with a total station. The base receiver is kept on a control point and a rover receiver is set on a rover point. After a few minutes of gathering common data, the rover moves to another point, and repeats the same process. Though the kinematic surveying method is effective for construction field measurements for example, the static surveying method would be more suitable for monitoring over a long distance, a long time analysis of ground movements or to continuously measure deviation of some fixed points.

The GPS has the following advantages as a surveying method: (1) It is possible to obtain a wide range of precision from a few tenths to a few parts per million (ppm) of the baseline length between the stations for large separation, the station separations being as far as one hundred kilometers. (2) Because of microwave transmission codes, no requirement for line of sight visibility between stations is needed. Also sight adjustment is not needed. Even at night or in bad weather, there is no problem. (3) Three dimensional positions and displacements of many measuring points can be taken simultaneously. (4) Long term, continuous observations can be easily made. (5) Connection between the receivers with communication lines helps to centralize the monitoring system. This would be extremely difficult by using conventional methods.

Monitoring ground movements or measuring ground subsidences on local and regional scales used to depend on conventional methods, which require extremely large efforts and plenty of time. The conventional methods also need disciplines that are only available to those well-trained and well-equipped among us. Grouping the above-mentioned advantages of the GPS surveying together, the GPS is considered to be a more suitable tool for these purposes.

Specification of monitoring system

Figure 17-1 shows the location of measuring points and their network in the Shimabara region. The network consists of three measuring points (F1, F2 and F3) called "Fixed points" and six measuring points (M1, M3, N2, N3, N4 and L1) called "Moving points", the former being a set for monitoring the activity of Chijiwa Faults, and the latter for measuring the slope movements of Mt. Mayuyama. Static surveying is acceptable for monitoring these points.

Figure 17-2 shows the specifications of the GPS observation system for ground movements. The observations are executed by six sets of GP-R1D surveying instruments. Each of them has an microstrip antenna and a twelve channel receiver. The antenna receives the carrier from the satellites. The receiver measures the phase of the signal from one of up to twelve satellites simultaneously at predetermined times governed by a clock in the receiver. The observed data are stored in the memory of the receiver.

Three GPS receivers constantly occupy the fixed points, which are measured daily, and the other three receivers occupy the moving points, which are measured once or twice per month, simultaneously with the fixed points. The points will be described as follows.

(1) Fixed points

The purpose of measuring fixed points is to monitor the activity of the Chijiwa Faults. Because the receivers, antenna, timers, modems and other observation instruments are located at

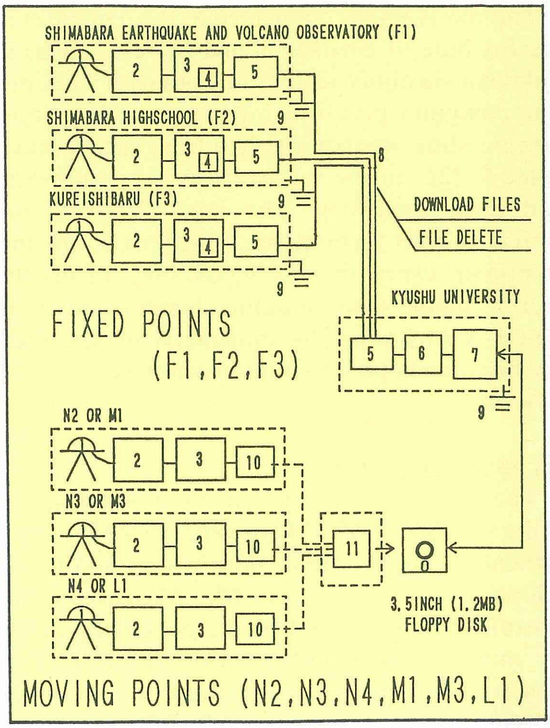

Fig. 17-2 GPS observation system specification for ground movements. 1: microstrip antenna, 2: GPS receiver (TOPCON GP-R1D), 3: timer, 4: power source, 5: modem (OMRON MD96FS5V), 6: computer for downloading (TOSHIBA J3100SX021P), 7: computer for calculating (TOSHIBA J3100ZX171), 8: telephone lines, 9: earth. 10: battery, 11: computer for downloading (= 6).

the measuring points, the observation points need to be located at such places as the instruments can be stored safely and where public power source and public telephone lines are available. Because the radio transmission codes from satellites are used for surveying, the visibility for the satellites needs to be clear. The measuring point F1 was set on the rooftop of Shimabara Earthquake and Volcano Observatory of Kyushu University, F2 on the roof of Shimabara High School, and F3 in the field of Shimabara Communal Training Center for national universities in Kureishibaru. The baselines among F1, F2 and F3 cross the Chijiwa faults estimated as shown in Fig. 17-1. If the faults move, a three dimensional deviation will be noticed in these baseline lengths of the GPS surveying.

The receivers are connected to the computer in the Institute of Environmental Systems (IES) in Fukuoka via public telephone lines with modems. The computer performs four kinds of functions; downloading observation data from each station, deleting files in the receivers, storing daily data and data processing. The data observed and stored in each receiver are transferred into this computer every day at 9,600 bps. From the carrier phase data, baseline lenghts are computed. Concerning the ephemeris of satellites, the broadcast ephemeris information (C/A Code) is used.

(2) Moving points

The moving points are set for monitoring the slope stability of Mt. Mayuyama. Since it is very difficult to supply public power lines and public telephone lines as far as Mt. Mayuyama, the instruments are carried to the measuring points by motor vehicle and on foot every time an observation is to be made. Because substantial activities are measured on Mt. Mayuyama, all observation points are located on the checkdam, which are rather insensitive to lacal collapses of the slopes.

Furthermore, the actual observation points are located on top of small concrete blocks (150 mm diameter and 300 mm height) bonded with the crown of the checkdam in order to remove any set-up errors on the antenna installation. It is difficult to remove such errors (usually a few millimeters) when using tripods which are commonly employed for setting a GPS antenna. The antenna is directly, easily and exactly set up over the measuring point with only attaching it to the antenna mount.

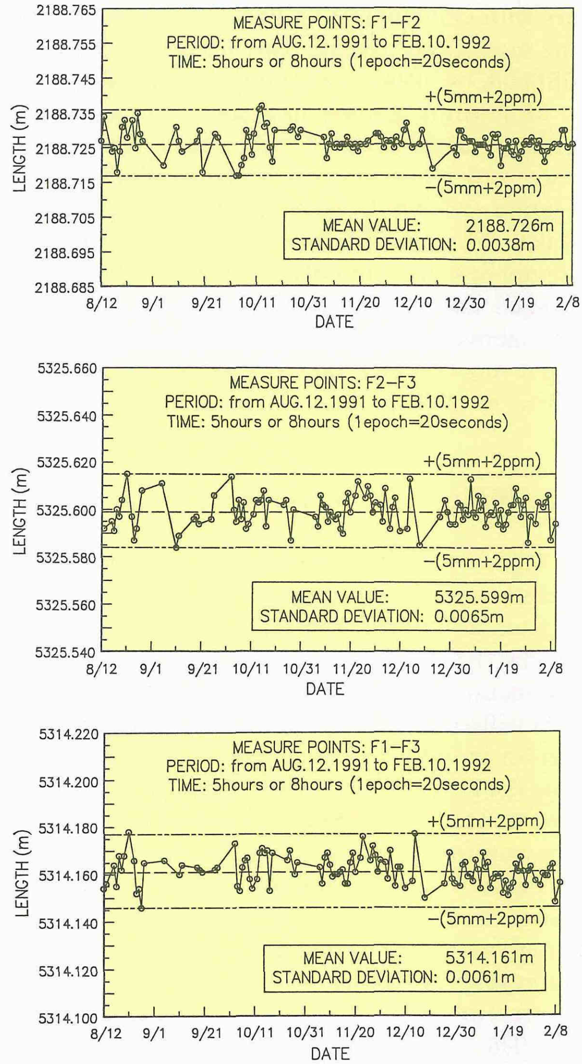

Fig. 17-3 Daily deviation of baseline length by GPS static surveying in the period from August 1991 to February 1992 by GPS static surveying using satellite visibilities of Nos. 2, 6, 11, 14, 15 and 19, with processing L1 phase code and broadcast ephemeris information.

Campaigns works

(1) Observation of the fixed points

As to the fixed points, current observations are conducted for 5 to 8 hours per day when the receivers can catch four or more satellites simultaneously. After the observation the acquired data is sent to the IES with telephone lines and stored in floppy disks. It takes about 10 minutes to collect observation data for each station. Then, the baseline lenghths are accurately computed from the carrier phase data. It takes a few hours to compute the three base line lenghts. The IES students and graduate students handle the data daily.

(2) Observation of the moving points

Before an observation, instruments such as a receiver, an antenna, a timer, a battery, a battery case, cables, a basket and a waterproof sheet are carried to the measuring points. The antenna is attached to the antenna mount on the concrete block above the checkdam, and connected the receiver with the antenna cable. The receiver also is connected to the external battery through the timer with the battery cable. These instruments are entered into a basket, covered with a waterproof sheet to protect them from both rainfall and ash fall and weighted over with a rock for protection against from strong wind.

The obsevation of the moving points is automatically started and stopped simultaneously with the fixed points at predetermined times governed by the timer. After the observation, the stored data in the receiver is downloaded into a laptop type computer.

Measuring results about fault activity

Three baseline lenghts between the measuring points F1, F2 and F3 were observed daily by the GPS static surveying, with observation set continuously for 5 to 8 hours where the receivers could catch four or more satellites simultaneously, with 20-second epoch intervals (sampling intervals).

Figure 17-3 shows the daily deviations of baseline lengths in the period from August 1991 to February 1992, by post-processing only the L1 transmission wave using C/A code. As can be seen, each baseline length does not remain constant and is within ±15 mm deviations.

The dotted line means an allowable error level of 5 mm ±2 ppm. The daily deviation is within this error range and conspicuous changes of the baseline lenghts among F1, F2 and F3 were not noticed for this period.

Figure 17-4 shows histograms with respect to the deviation of baseline lengths and their normal distribution approximations. Table 17-1 shows the results from Chi square test of goodness of fit with respect to the distribution functions. This table shows that all distributions of the observed errors are considered to follow normal distributions within a 5 % significance level. The deviations can be considered to result from the observation errors such as weather conditions, observation conditions and estimated errors of the satellites' orbit.

As we mentioned above, the daily deviations of baseline lenghts are within the allowable error levels and follow the normal distribution around the average values, and conspicuous changes were not noticed for this period. These confirm that large movements have not occurred in the

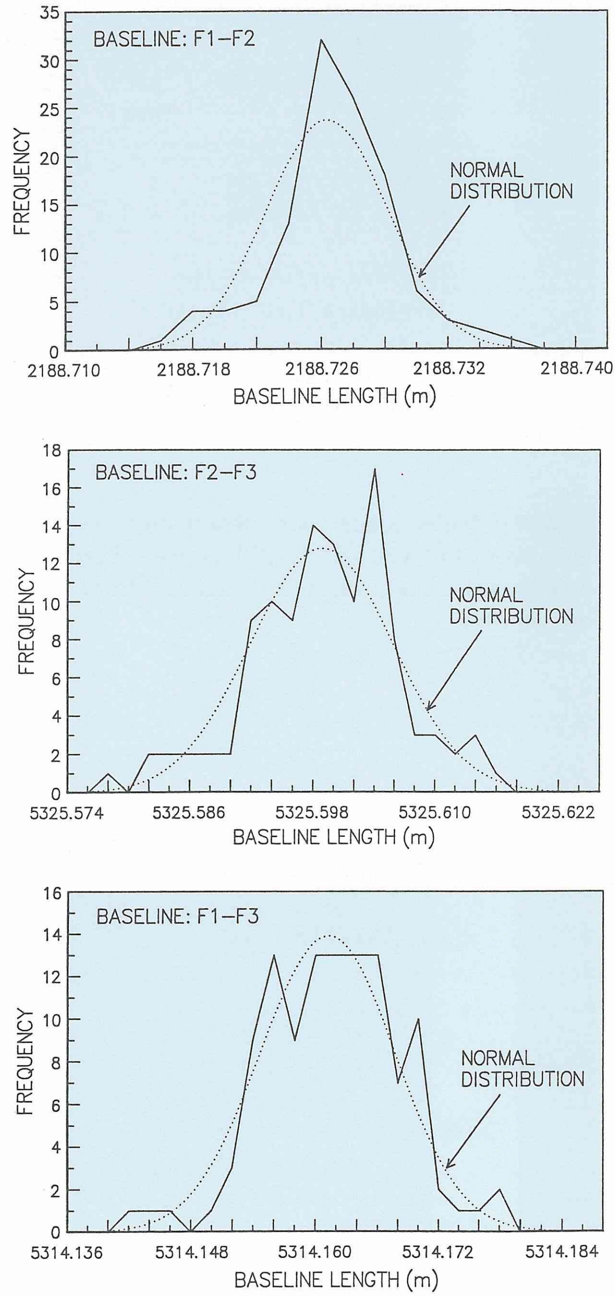

Fig. 17-4 The histograms with respect to the deviation of baseline lengths and their normal distribution approximations.

Table 17-1. The results from Chi square test of goodness of fit with respect to the distribution functions of the observed errors and their normal distribution approximations.

baselines		F1-F2	F1-F3	F2-F3
number of samples		118	114	112
mean value	(m)	2188.726	5314.161	5325.599
standard deviation	(mm)	3.76	6.11	6.47
accuracy	(ppm)	1.72	1.15	1.22
number of classes	k	10	10	10
degree of freedom	k-2-1	7	7	7
observed value of the chi-square test static χ^2		9.327	6.326	6.538
critical value at the 5% significance level $\chi^2_7(0.05)$		14.067	14.067	14.067

Chijiwa faults since our observation began. However, the volcano is still active, therefore continuous monitoring is still needed from now on as well.

Stability of Mt. Mayuyama

As examples of the results about the movement of Mt. Mayuyama, Fig. 17-5 shows the horizontal deviations on the locations of Moving points L1 and N4 in the period from July 1991 to February 1992, by processing only the L1 phase code using the broadcast ephemeris information.

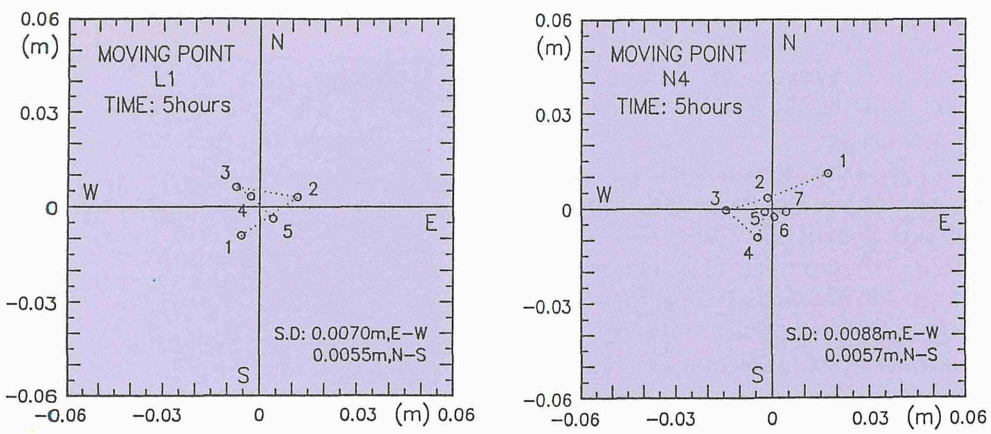

Fig. 17-5 The horizontal deviations on the locations of the observation points L1 and N4 of Mt. Mayuyama in the period from July 1991 to February 1992 by GPS static surveying using satellite visibilities of Nos. 2, 6, 11, 14, 15, and 19, with processing L1 phase code and broadcast ephemeris information.

In this figure, the x-axis indicates the eastward direction and the y-axis indicates the northward direction. The origin points indicate the average values of coordinates obtained form obsevations and the number next to each points indicates the sequence of observation dates. As can be seen, the co-ordinates of the moving points do not remain constant, but has about ±10 mm deviations around the mean values. However, no conscious changes in the coordinates were noticed during this period. These deviations are considered to result not from the slope movements of Mt. Mayuyama but from observation errors. As mentioned above, the slopes of Mt. Mayuyama have kept their stability until present.

Conclusions

From a practical point of view on ground observation, the potential of the GPS is investigated and the advantages of the GPS are discussed. The GPS is applied as a long term monitoring system which measures the movements of active faults in the north of Mt. Fugen and evaluates the stability of Mt. Mayuyama. Continuous monitoring of crustal movements and slope movements by the GPS is effective especially in this region, where crustal activities or volcanic activities are high and short-period changes of fault motions are anticipated.

The results of this continuous observation confirm that the GPS is an effective tool for dealing with long term environmental monitoring. Since our observation began, we have noticed no conspicuous movements of the Chijiwa faults and the slopes of Mt. Mayuyama have kept their stability up to the present. Considering that the volcano is still active and the avalanches of Mayuyama in 200 years ago, continuous monitoring is still needed to study the crustal and volcanic activities around the Unzen Volcano carefully.