ICOLD 75th Annual Meeting
Saint Petersburg, Russia, June 24-29, 2007

Symposium: «Dam Safety Management. Role of State, Private Companies and Public in Designing, Constructing and Operating of Large Dams»

GPS APPLICATION ON DEFORMSTION MONITORING AND EVALUATION FOR ACCIDENTAL DISPLACEMENT OF FILL DAMS

Mitsuhiro Oie[1], Fumio Yonezaki[2], Hideki Soda[3], Tomoharu Iwasaki[4]

INTRODUCTION

Measurement performed for safety management of filldams must, in combination with inspection, enable behaviors of the dam body and bedrock to be accurately grasped during its operation. This conventional measurement method about deformation of fill-dam body involves problems in that measurement and organization of results thereof require both time and cost, and that even when there is a need to immediately perform external deformation measurement in an emergency such as after an earthquake, rapid response is not always possible due to time requirements and cost burdens imposed by measurement.

In recent years, efforts have begun to apply GPS (Global Positioning System) for the purpose of displacement measurement of large-scale excavated slopes and landslides. Additionally, the last 10 years have seen improved capability, downsizing, and lower prices in hardware of GPS antennas and receivers. In consideration of these circumstances, we conducted a demonstration test to measure dam body external deformation of a filldam by concomitantly using a conventional method and GPS measurement.

This study evaluates the results of the dam measurement, and at the same time examines a method that utilizes continuous observation performed by GPS measurement in order to detect displacements which accidentally occur during a flood or an earthquake.

DISPLACEMENT MEASUREMENT BY GPS AND SMOOTHING OF MEASUREMENT RESULTS

GPS measurement system

Recently, a measurement method that achieves an accuracy several times higher than conventional methods by performing GPS measurement continuously and using a statistical smoothing method on obtained data has been proposed by Shimizu et al. [1998]. Development of new GPS measurement systems based on this method and specialized for ground measurement are currently underway. Through the recent study, we attempted external deformation measurement of a dam body using a GPS measurement system specialized for ground measurement. A GPS measurement system specialized for ground measurement differs from a surveying GPS in the following points.

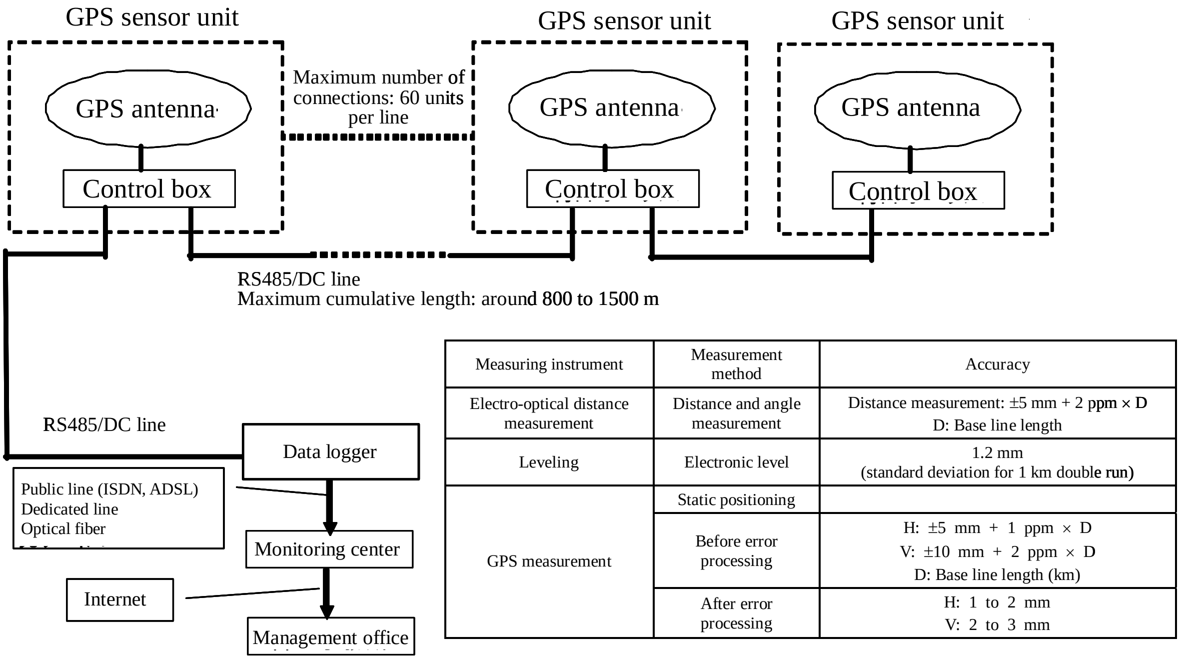
a) Influences of such elements as the ionospheric layer, vapor and satellite radio waves are reduced by shortening base line length (distance between a known point and a measurement point) which greatly affects GPS surveying accuracy.

b) Accuracy is improved by relatively increasing data volume through continuous observation and by factoring dispersion in GPS data into error components and displacement components through statistical processing.

c) Inexpensive measurement compared to surveying GPS is achieved through the use of dedicated GPS sensors with functional restrictions compared to surveying GPS sensors.

With the GPS measurement system used in this study, GPS sensors and data logger aggregator are installed on site. Measurement data received at a GPS sensor is guided by the communication aggregator for transmission to a privately-operated monitoring center via a conventional telephone line (e.g. ISDN). Base line analysis by static positioning is performed at the monitoring center, and after error processing using a trend model, which will be described later, data is organized into such formats as displacement graphs and two-dimensional vector diagrams. These measurement results are distributed hourly via the Internet to the dam inspector. In addition, technical personnel are stationed around the clock at the monitoring center to perform monitoring of GPS equipment and verification of measured values, and when a displacement occurs, make emergency contact with the dam inspector. A GPS measurement system and nominal accuracy of measuring instruments are shown in Fig.1.

This method is advantageous in that processing cost of GPS measurement data at each site may be reduced since analysis processing is centralized at the monitoring center, and that measurement results may be monitored regardless of the time or location as long as Internet access is available.



Measuring instrument	Measurement method	Accuracy
Electro-optical distance measurement	Distance and angle measurement	Distance measurement: ±5 mm + 2 ppm × D D: Base line length
Leveling	Electronic level	1.2 mm (standard deviation for 1 km double run)
GPS measurement	Static positioning	
	Before error processing	H: ±5 mm + 1 ppm × D V: ±10 mm + 2 ppm × D D: Base line length (km)
	After error processing	H: 1 to 2 mm V: 2 to 3 mm

Fig. 1 GPS measurement system and nominal accuracy of measuring instruments

Smoothing method of measurement results

For the present method, a trend model as proposed by Shimizu et al. [1998] was used for GPS measurement error processing. This method estimates true displacement behavior from measurement data containing noise, using a time series analysis model having a probabilistic structure, which is referred to as a trend model. More specifically, the simultaneous model (trend model) presented in Formula 1 was used, where a true displacement u_n of an nth measurement time point to be estimated is a parameter of a system equation referred to as a trend component model, and an actually measured displacement y_n is further associated as an observation equation.

$$y_n = u_n + w_n \qquad \text{(Observation equation)}$$

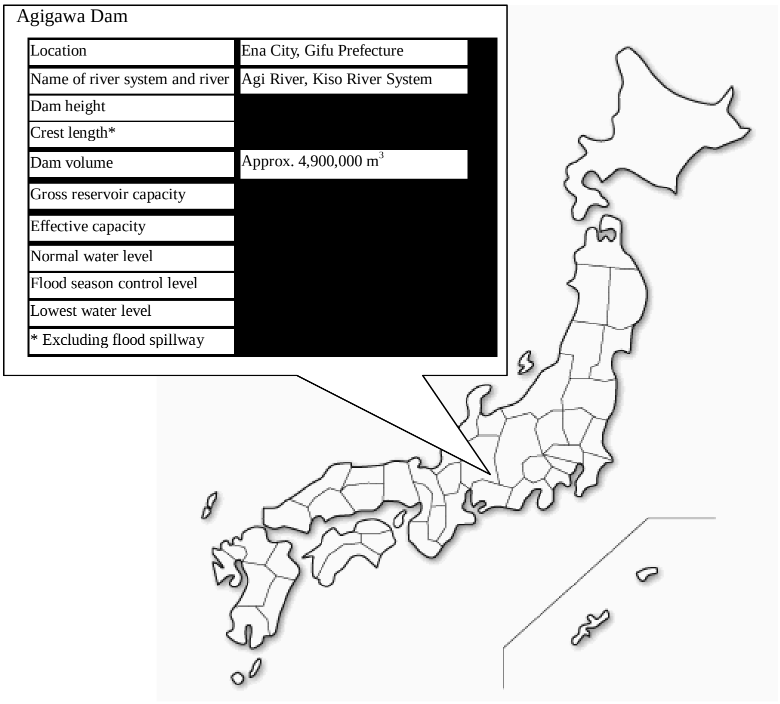
$$\Delta^{\kappa} u_n = v_n \qquad \text{(System equation)}$$

$$\left[\begin{array}{l} y_n : \text{Actual measurement} \\ w_n : \text{Observation noise (normal distribution having a mean of } 0 \text{ and a standard deviation of } \sigma\text{)} \\ v_n : \text{System noise (normal distribution having a mean of } 0 \text{ and a standard deviation of } \tau\text{)} \\ u_n : \text{Net slip (trend)} \\ \Delta^{\kappa} : \text{Temporal difference operator of } \kappa\text{th stage} \end{array}\right] \qquad \text{Formula (1)}$$

ACTUAL GPS MEASUREMENTS AND SMOOTHING RESULTS

Demonstration field

As the demonstration field, we used the Agigawa Dam which is located in the upper reaches of the Agi River in the Kiso River System in central Japan (Fig. 2). The dam has a height of 101.5 m, with a crest elevation of 417.5 m. The ridge elevations of both banks are approximately EL. 700 m. Filling of the reservoir commenced in October 1989. 45 external targets are installed at the Agigawa Dam. The external targets used for this demonstration test were the four points shown in Fig. 3, namely, GD-5, 6, 21 and 25. TD-5 and 6 are placed at the central portion of the dam crest, near the section with the maximum dam height. According to past measurement results, these are the points having maximum displacement. Measurement results from TD-5 following initial impoundment are shown in Fig. 4. In the graph, vertically downward, downstream, and the direction towards the left bank are respectively designated as positive directions.



Agigawa Dam

Location	Ena City, Gifu Prefecture
Name of river system and river	Agi River, Kiso River System
Dam height	[redacted]
Crest length*	[redacted]
Dam volume	Approx. 4,900,000 m^3
Gross reservoir capacity	[redacted]
Effective capacity	[redacted]
Normal water level	[redacted]
Flood season control level	[redacted]
Lowest water level	[redacted]
* Excluding flood spillway	[redacted]

Fig. 2 Location of Agigawa Dam

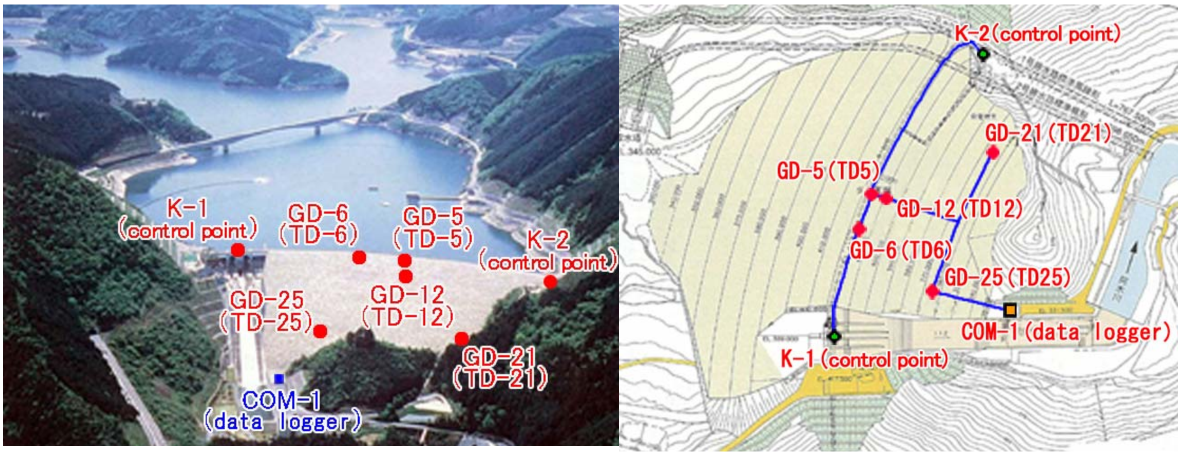


Fig. 3 Positions of object points

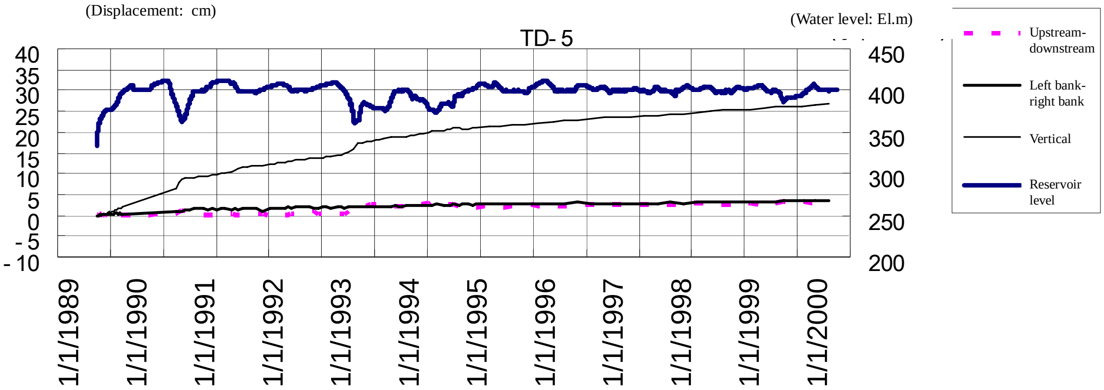


Fig. 4 Long-term behavior of an object external target (TD-5)

Outline of measurement

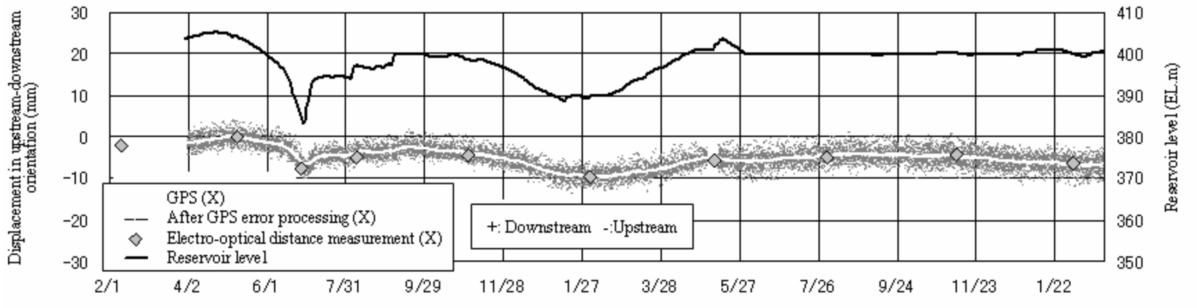
In order to evaluate the presence and/or influences of error factors occurring on an annual cycle as well as influences of meteorological conditions such as typhoons and lightning with respect to measurement accuracy and long-term stability of the present GPS automatic measurement system, we considered that a measurement period of approximately 2 years was necessary. This paper presents measurement results of water levels and dam body behavior over that period, and discusses qualitative consistency between electro-optical distance measurement and GPS measurement. Incidentally, GPS measurement and electro-optical distance measurement have been organized on the assumption that the two were consistent as of the time of manual measurement performed on May 9, 2005.

Measurement results

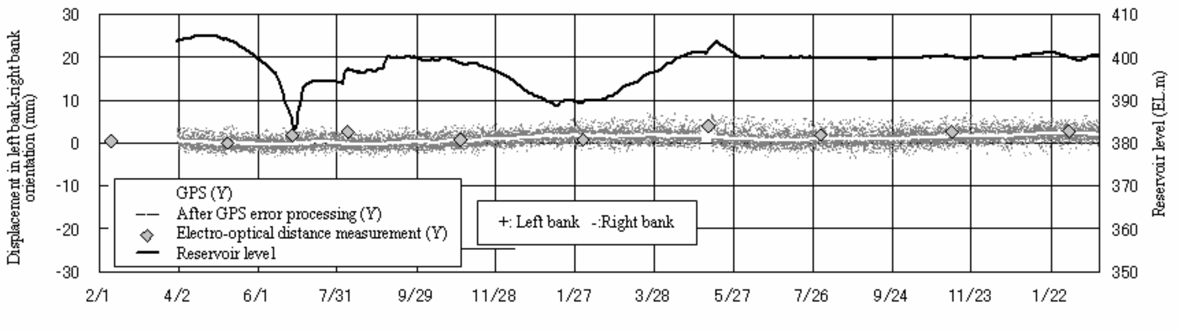
Fig. 5 shows the reservoir water level, GPS measurement results (GD-5), and manual measurement results. From the upper to the lower direction, the charts respectively represent displacements in an upstream-downstream orientation, a left bank-right bank orientation, and a vertical orientation. The charts were obtained through analysis using an hour's worth of data received every 30 seconds at the GPS sensor, plotting the results obtained as GPS measurements for a single point, and performing error processing by trend model.

The GPS measurement results are distributed within a horizontal range of ±3 mm and a vertical range of ±10 mm. The dispersion in the measurements are errors attributable to influences of elements such as the ionosphere or the troposphere, orbit errors of the artificial satellite, and noises at the GPS receiver which are not removable by GPS base line analysis. On the other hand, while fluctuations of 1 mm or less occur in the trend model error processing results, fluctuation range is around 1/3–1/10 of those prior to error processing, which suggests that error processing was performed in a satisfactory manner. This is consistent with the results of Iwasaki et al. [2004] and Yamaguchi et al. [2005].

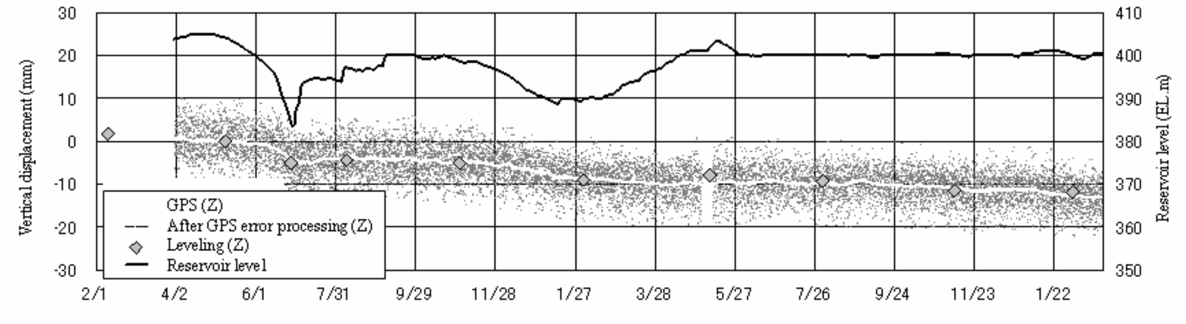
The behavior of a central core-type rockfill dam typically involves deformation of the dam body towards the downstream-side due to water pressure from rising water levels, and a reverse deformation towards the upstream-side when the water level drops. In addition, a decrease in buoyancy during low water levels is known to cause settlement due to dead load. These properties will be confirmed for consistency with dam body behavior. At GD-5, displacement in the upstream-downstream orientation occurred towards the downstream-side when water level is high and towards the upstream-side when water level is low. In addition, as for displacement in the vertical orientation, it was shown that settlement progresses when water level is low. No fluctuations in longitudinal displacement were found, implying that dam-axial displacement having a high degree of restriction was insignificant. In addition, the measurements indicated a state where the dam body deforms towards the downstream-side when water level rises during floods.



(a) Displacement in transverse direction of the dam



(b) Displacement in longitudinal direction of the dam



(c) Displacement in vertical direction

Fig. 5 Results of GPS measurement (GD-5)

DETECTION OF SUDDEN DISPLACEMENTS

Overview

Here, the applicability of the methods of GPS data and a trend model processing is studied for a discontinuous displacement which occurred accidentally daring floods or earthquakes.

Fig. 6 shows behavior of GPS data from GD-6 before and after a sudden displacement was forcibly applied with an occurrence of an earthquake in consideration. The charts show the results of error processing by trend model after a 10 mm displacement was applied after 0:00 on October 1 on data from preliminary measurement performed prior to March 2005. As shown, U-D components follow the displacement more slowly than the N-S and E-W components. This is due to the fact that the U-D component is the most significant component contained in GPS measurement error, and causes the trend model to calculate a portion of the displacement as error.

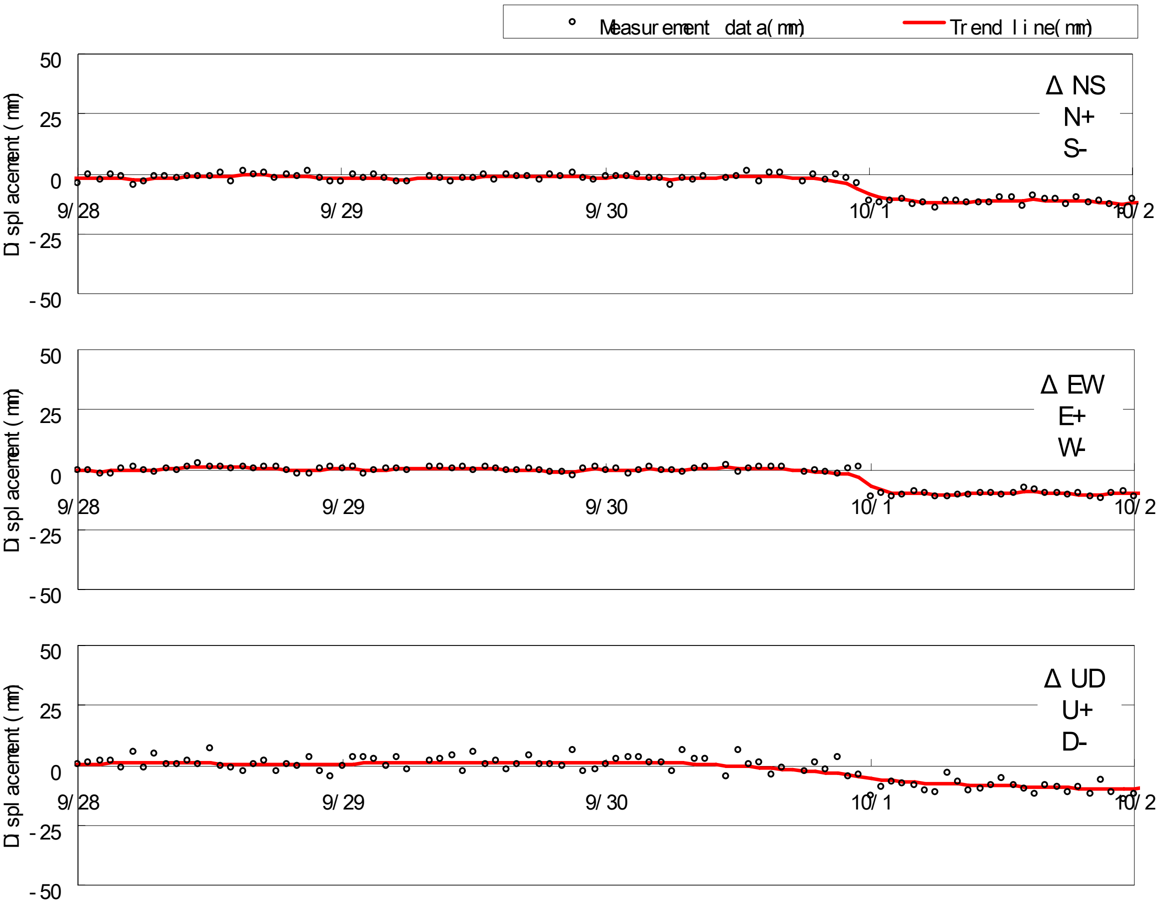


Fig. 6 Measurement in a case where a forced displacement was applied (GD-6)

Examination of sudden displacement by numerical calculation

Examination of displacement error range and accuracy by trend model in GPS measurement with respect to elapsed time was performed for a case where rapid displacements occur during an event such as an earthquake.

Numerical calculations were performed after applying forced displacements of 10 mm, 20 mm, 30 mm, 50 mm, 100 mm and 200 mm to hourly measurements in the measured GPS data to duplicate a state where sudden displacements occur and acute fluctuations are imposed. Temporal changes in the measurements subsequent to the acute fluctuations were calculated. The number of GPS data elements necessary for accurately verifying acute fluctuation values from obtained calculated values was confirmed. In addition, errors that occur after acute fluctuation until the calculated values become true values were also confirmed.

An exemplary result is shown in Fig. 7. The left side of Fig. 7 represents a displacement of 10 mm, while the right represents a 200 mm-displacement. Fig. 8 shows relationships between displacements after the forced displacements were applied and GPS measurements for different elapsed times, based on the above results. Since displacements of 1 mm or less are indistinguishable from dispersions after processing by trend model, only measurements proving fluctuations of several mm or more may be recognized as actual displacement. For the horizontal orientations of N-S and E-W which have relatively high measurement accuracy, displacement may be detected within 3–6 hours with errors of 1 mm or less, regardless of the size of displacement. On the other hand, for the U-D vertical orientation having a lower accuracy, for displacements of 30 mm or more, displacement may be detected within 6 hours with errors of 1 mm or less in the same manner as the N-S and E-W orientations. However, around 12 hours are required in cases of vertical displacements of 10 mm and 20 mm.

Both of the results show that measurements converge to true values after about 12 hours. The greater the applied displacement, the shorter the time until convergence of measurement. The time required for convergence of measurement is longer in the vertical orientation than in the horizontal orientations. Additionally, for displacements of 30 mm or less, there are hardly any changes in measurements an hour after occurrence of displacement, suggesting that values processed by the trend model are not too responsive to displacement. Even so, for the horizontal orientations, displacements are substantially detected 6 hours later regardless of the magnitude of displacement. However, for the vertical orientation, adherence of measurements to displacement is somewhat delayed when the displacement is 20 mm or less.

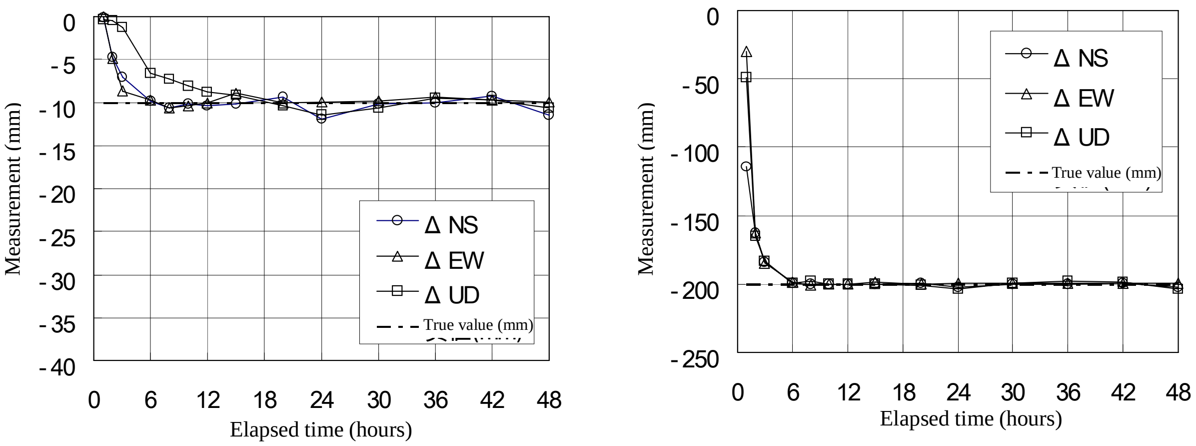


Fig. 7 Behavior subsequent to forced displacement
(Left: 10 mm displacement, right: 200 mm displacement)

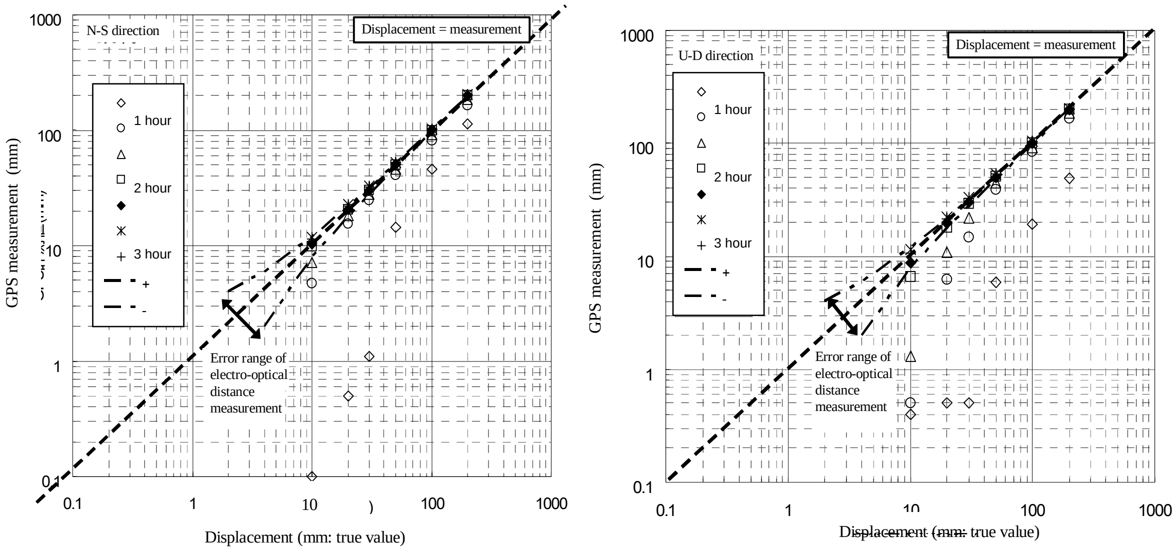


Fig. 8 Relationship between displacements after forced displacement is applied and GPS measurements for different elapsed times

Examination of sudden displacement by on-site experiment

To verify whether the method described in the previous section is effective or not, a forced displacement experiment was carried out on site by moving the actual GPS sensors by several cm. The measurement results were used to examine applicability of the trend model and were compared with the numerical experiment. Forced displacements of 50 mm and 80 mm were respectively applied in a horizontal direction (upstream-downstream orientation or N-S direction) and the vertical direction (U-D orientation). After a 3-week steady state of the measurement, forced displacements were applied twice, 4 days apart.

Fig. 9 shows a GPS sensor, and numerical calculations and on-site experiment results for the U-D direction. Results of numerical calculations are indicated by a solid line, while on-site experiment results are plotted by dots. Measurements of the on-site experiment in the case of the 50 mm-displacement were: 0 mm after 1 hour; 43 mm after 2 hours; 47 mm after 3 hours; and 50 mm after 6 hours. Measurements in the case of the 80 mm-displacement were: 32 mm after 1 hour; 66 mm after 2 hours; 75 mm after 3 hours; and 80 mm after 6 hours. Unlike the numerical calculations, although no displacements could be detected in the case of the 50 mm-displacement after an hour, similarities between the numerical calculation results and the results of the forced displacement experiment are sufficient to determine that the numerical calculation results accurately duplicate on-site displacement measurement.

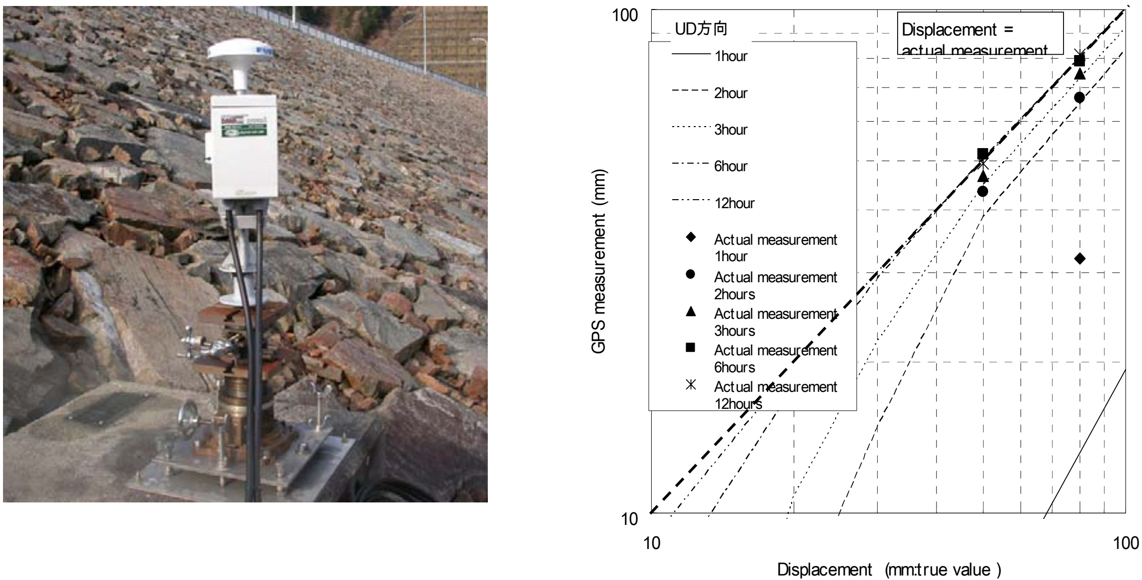


Fig. 9 GPS sensor, and comparison between numerical calculations and on-site experiment results

Examination of sudden displacement detection

In this section, for the purpose of enhancing detection accuracy of sudden displacements, a sudden displacement detection method using GPS measurements containing error was examined. During examination, of noteworthy significance were the changes to measurements immediately after occurrence of sudden displacement. As shown in Fig. 6, while GPS measurements display changes from immediately after the occurrence of sudden displacement, in the statistical method using a trend model, underestimation occurs immediately after the sudden displacement due to influences of measurements prior to the sudden displacement. On the other hand, if it is possible to have the GPS automatic measurement system acknowledge a trigger notifying "a possible occurrence of a sudden displacement at a given time" from earthquake information released by the Meteorological Agency or from information obtained from a seismograph placed in the dam, weighting may be performed on measurements subsequent to the displacement occurrence and sudden displacements may be evaluated.

Arrangement and analysis of measurements

With a method that evaluates the measurements without modification immediately after the occurrence of sudden displacement, it is difficult to perform appropriate displacement evaluation since errors contained in the measurements are entirely unconsidered. Accordingly, arrangement and analysis of measurements were performed. GPS measurements were confirmed to be normally-distributed, and a standard deviation σ was estimated. By confirming that the measurement shows the deviation of $n\sigma$ or more, it may be evaluated that the displacement has occurred at a certain probability.

Detection method of sudden displacements

(1)Evaluation by standard deviation σ

Using a standard deviation σ prior to sudden displacement, displacement was evaluated while allowing a deviation corresponding to $n\sigma$ to the measurements immediately after the occurrence of sudden displacement. In this case, as evaluation conditions, we assumed that 1) data immediately after sudden displacement changes over time and 2) data after sudden displacement exhibits a normal distribution, and that measurement evaluation of true displacement may be performed using a statistically significant method by allowing a deviation of σ multiplied by n to measurements immediately after occurrence of sudden displacement.

(2)Evaluation by t-estimation

t-estimation refers to a method for estimating an average of a population of normal distribution using t-distribution. This method involves calculating a true displacement after sudden displacement from displacement immediately after sudden displacement and standard deviation. Assuming now that, in addition to conditions 1) and 2) presented above, 3) both a true displacement (m) after sudden displacement and a standard deviation (u2) are unknown, the true displacement (m) can be estimated by the following formula.

$$m = x \pm t(n-1, \alpha/2)\frac{u_1}{\sqrt{n}}$$ (α: Confidence probability) Formula (2)

	Displacement	Standard deviation	Number of data elements
Immediately after earthquake	Variance (x)	Variance (u1)	Variance (n)
After earthquake	Unknown (m)	Unknown (u2)	100 or more

(3)Evaluation by Z-estimation

Similar to t-estimation, Z-estimation is a method for estimating an average of a population of normal distribution, and may be used when the standard deviation of the population is known. This method involves calculating a true displacement after sudden displacement from displacement immediately after sudden displacement and standard deviation prior to sudden displacement. Assuming now that, in addition to conditions 1) and 2) presented above, 4) a true displacement (m) after sudden displacement is unknown and 5) standard deviation remains unchanged before and after sudden displacement (u2 after earthquake = σ before earthquake), the displacement (m) after the earthquake can be estimated by the following formula.

$$m = x \pm Z(\alpha/2)\frac{u_2}{\sqrt{n}} = x \pm Z(\alpha/2)\frac{\sigma}{\sqrt{n}}$$ (α: Confidence probability) Formula (3)

	Displacement	Standard deviation	Number of data elements
Before earthquake	Known (p)	Known (σ)	100 or more
Immediately after earthquake	Variance (x)	Variance (u)	Variance (n)
After earthquake	Unknown (m)	Known (u2 = σ)	100 or more

Optimum method for sudden displacement evaluation

In the previous section, displacement evaluation methods respectively using nσ, t-estimation and Z-estimation were presented. Fig. 10 shows each evaluation method applied to a simulated occurrence of a sudden displacement of 30 mm. In the charts, the solid lines represent GPS measurements after error processing by trend model, and show that a displacement has occurred at an elapsed time of 0 hours.

As for evaluation using standard deviation σ, high/low lines of ±3σ (appearance ratio of 99.7 %) with respect to the GPS measurements are drawn as bar graphs. The standard deviation σ is 1.3 mm in the NS-direction and 2.8 mm in the UD-direction, and was calculated from measurements taken during the 4 days prior to displacement occurrence. With this method, displacement detection accuracy will not improve even as time advances after the occurrence of displacement, and remains stable at ±3.9 mm in the NS-direction and ±8.4 mm in the UD-direction.

For evaluation using t-estimation, a standard deviation U1 applied to Formula (2) was calculated from measurements obtained after displacement occurrence. The chart shows a t-estimation range of 99% confidence probability. Although this method enables improvement of displacement estimation accuracy over time, clear detection of the sudden displacement 2 hours is hard.

For evaluation using Z-estimation, it is assumed that the standard deviation U2 used for the estimation is the same as the standard deviation σ calculated from measurements prior to displacement occurrence. The chart shows a Z-estimation range of 99% confidence probability. This method enables improvement of displacement estimation accuracy over time. In addition, displacement detection accuracy in the N-S orientation in 2 hours after displacement occurrence is better than that using the trend model.

In conclusion, estimation using Z-estimation may be considered to be the model most suitable for sudden displacement detection. For a case of an occurrence of a displacement of 30 mm, it is conceivable that a sudden displacement occurrence may be released within 2 to 3 hours and reliable numerical information may be detected within 24 hours by performing displacement estimation using Z-estimation for the first 3 hours after occurrence of an earthquake in the N-S orientation and for the first 5 hours in the U-D orientation, and by subsequently using values after error processing using a trend model.

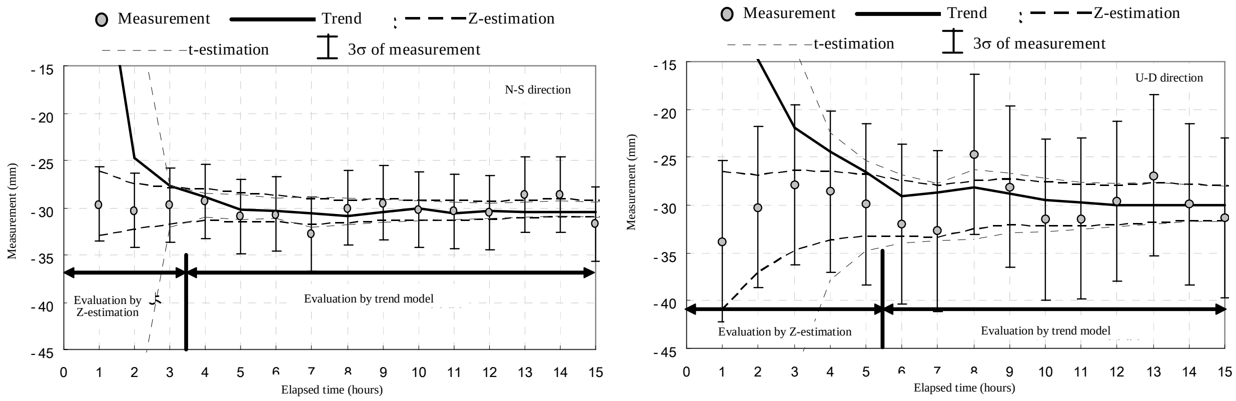


Fig. 10 Diagram showing result of examination upon occurrence of sudden displacement of 30 mm (GD-6)

Sudden evaluation methods capable of responding to aftershocks

When an occurrence of an earthquake would be informed by the meteorological agency or a dam inspector, the inspector may acquire highly accurate quick bulletins on displacements from 1 hour after the earthquake by shifting from normal analysis processing (trend model) to sudden displacement analysis processing (Z-estimation and trend) within the GPS automatic measurement system.

However, according to the examination leading to the previous section, information of the earthquake occurrence is provided only once, and examinations with respect to aftershocks which occur several times after the main shock have not been performed. In the case of the 2004 Chuetsu Earthquake, several aftershocks at levels similar to the main shock occurred within 6 hours of the main shock. With respect thereto, according to results of examination providing earthquake information even during aftershock, it was found that displacements subsequent to aftershock obtained by Z-estimation may be evaluated with similar accuracy to displacements obtained from the main shock (Fig. 11). Therefore, when using the sudden displacement evaluation method by Z-estimation, it is essential that aftershock information are applied in addition to the main shock information.

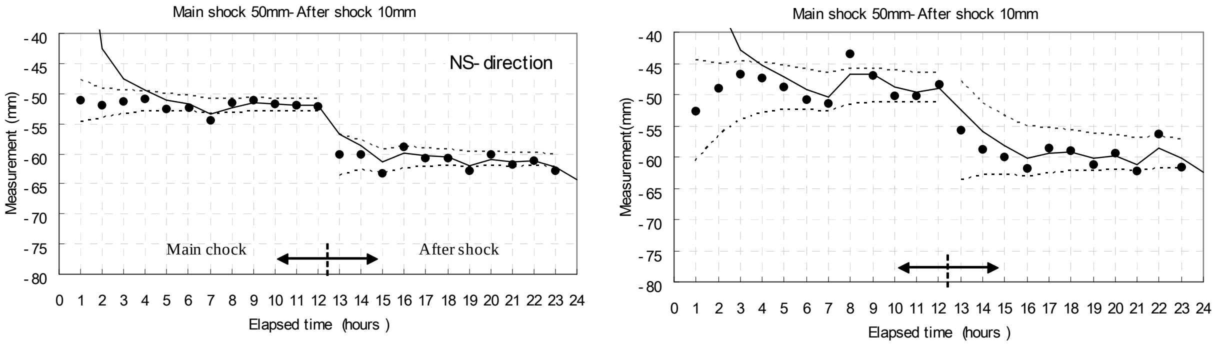


Fig. 11 Post-aftershock relationship between trend model and Z-estimation (GD-6)

CONCLUTION

With respect to external deformation of filldams, the applicability of GPS measurement on the dam body deformation not only in an usual condition but also in an emergency condition such as during earthquakes was verified through a demonstration test in respect to time and cost, which is amount to much in conventional electro-optical distance measurement and leveling.

Since the present method performs prompt measurement at higher frequencies compared to conventional electro-optical distance measurement and leveling, it is believed that the method may promote enhancement in safety management of the fill dams. Enhancement in safety management using GPS measurement may be expected during, for instance, initial impoundment which produces maximum deformation and has a high observation frequency. In addition, measurement accuracy using GPS measurement was confirmed for a case of occurrence of sudden deformation, and the possibilities of detection within a few hours of displacement occurrence have been clarified.

In consideration thereof, it is believed that methods involving primary use of GPS measurement and secondary use of measurement using conventional electro-optical distance measurement and leveling, crosschecking respective measurement results, and reviewing arrangement of targets and frequencies of both GPS and conventional measurement, are worthwhile subjects of future investigation. Furthermore, since detection of a sudden displacement is notified immediately after occurrence of the displacement and may be acquired by means such as a mobile phone, the method offers another advantage in that it serves as a reminder towards inspection without increasing the burden placed on the management structure, thereby contributing to further promotion of safety management.

REFERENCES

Japan Institute of Construction Engineering, "Revised: Commentary – Cabinet Order concerning Structural Standards for River Management Facilities, etc.," Sankaido, Jan. 2000: 95–97.

Japan Commission on Large Dams, "Revised: Dam Structure Management Standards," Japan Commission on Large Dams, May 1986.

River Environment Division, River Bureau, Ministry of Land, Infrastructure and Transport, ed., "Rules on Dam Management – 2003 Edition," Water Resources Environment Technology Center, Oct. 2003: 232–258.

Institute for Dam Management, "Dam Management Practices," Water Resources Environment Technology Center, March 2000: 215–243.

Shimizu, N., Hiroshi, A. and Shuji, K., "Application of a Smoothing Method to Measured Displacements of Large Slopes by Using the GPS Monitoring System," Minerals and Materials, vol. 114, June 1998: 397–402.

Matsuda, H., Hiroshi, A., Yoshie, N. and Norikazu, S., "Applicability of the Trend Model for Smoothing Measured Displacements by Using Global Positioning System and Methods for Predicting Displacement Behavior," Collected Papers of the Japan Society of Civil Engineers, no. 715/III-60, Sept. 2002: 333–343.

Iwasaki, T., Kunika, T., Akira, T. and Norikazu, S., "Development of a Measurement Evaluation System for Maintenance and Management of Road Slopes," Tsuchi to Kiso, vol. 50, no. 6, no. 533, June 2002: 25-27.

Otera, M., Yukinobu, Y., Junji, U., Kuniaki, O. and Tomoharu, I., "Examination of Practical Application of Dynamic Observation Using GPS," Collection of Lectures Delivered at the 2002 Meeting for Presenting Technical Research Held by the Shikoku Branch of The Japanese Geotechnical Society," Nov. 2002: 47-48.

Iwasaki, T., Norio, O. and Norikazu, S., "New GPS Monitoring Systems for Slope Measurement (2) – Improvement of Measurement Accuracy using the Trend Model," Collection of Lectures Delivered at the 41st Meeting for Presenting Technical Research Held by The Japan Landslide Society, Aug. 2002: 193–196.

Iwasaki, T., Kohei, O., Hiroyuki, O., Makoto, O., Naoki, Y. and Norikazu, S., "Filldam Dam Body Measurement by a GPS Automatic Measurement/Observation System using the Internet," Collection of Lectures Delivered at the 59th Annual Academic Lectures Held by the Japan Society of Civil Engineers, Sept. 2004.

Yamaguchi, Y., Toshihide, K., Genji, Y., Makoto, O. and Tomoharu, I., "A Consideration on Filldam External Deformation Measurement using GPS," Dam Engineering, vol. 15, no. 2, Aug. 2005: 137–148.

Sato, N., "Study on Dynamical Behavior of a Rockfill Dam Body Based on Actual Measurements," doctoral thesis, Yamaguchi University, Sept. 2004: 80–91.

Iwasaki, T., Ayumu, S., Koichiro, I. and Hideki, S., "Study on Detection of Filldam Dam Body Displacement during an Earthquake using GPS Automatic Measurement," Collection of

Lectures Delivered at the 61st Annual Academic Lectures Held by the Japan Society of Civil Engineers, Sept. 2006.

---

1. Water Resources Engineering Department, Japan Water Agency
936 Jinde, Sakura-ku, Saitama-shi, Saitama-ken 338-0812,Japan
Telephone: 048-853-1785 Fax: 048-855-8099 E-Mail: mitsuhiro_oie @water.go.jp
2. Water Resources Engineering Department, Japan Water Agency
936 Jinde, Sakura-ku, Saitama-shi, Saitama-ken 338-0812, Japan
Telephone: 048-853-1785 Fax: 048-855-8099 E-Mail: fumio_yonezaki @water.go.jp
3. Research and Design Division, Tokuyama Dam Construction Office, Japan Water Agency.
448 Kaida, Ibigawa-machi, Ibi-gun, Gif-ken
Phone: 0585-52-2910; Fax: 0585-52-2325; E-mail:hideki_soda@water.go.jp
4. Shamen-net Division, Kokusai Kogyo Co., Ltd.
2-23-1 Harumi-cho, Fuchu-shi, Tokyo-to
Phone: 042-307-7210; Fax: 042-330-1047; E-mail:tomoharu_iwasaki@kkc.co.jp