Studying Landslide Displacements in Megamendung (Indonesia) Using GPS Survey Method

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Abstract. Landslide is one of prominent geohazards that frequently affects Indonesia, especially in the rainy season. It destroys not only environment and property, but usually also causes deaths. Landslide monitoring is therefore very crucial and should be continuously done. One of the methods that can have a contribution in studying landslide phenomena is repeated GPS survey method. This paper presents and discusses the operational performances, constraints and results of GPS surveys conducted in a well known landslide prone area in West Java (Indonesia), namely Megamendung, the hilly region close to Bogor. Three GPS surveys involving 8 GPS points have been conducted, namely on April 2002, May 2003 and May 2004, respectively. The estimated landslide displacements in the area are relatively quite large in the level of a few dm to a few m. Displacements up to about 2-3 m were detected in the April 2002 to May 2003 period, and up to about 3-4 dm in the May 2003 to May 2004 period. In both periods, landslides in general show the northwest direction of displacements. Displacements vary both spatially and temporally. This study also suggested that in order to conclude the existence of real and significant displacements of GPS points, the GPS estimated displacements should be subjected to three types of testing namely: the congruency test on spatial displacements, testing on the agreement between the horizontal distance changes with the predicted direction of landslide displacement, and testing on the consistency of displacement directions on two consecutive periods.

Keywords: *Landslide; Displacement; GPS Surveys; Megamendung.*

1 Introduction

In mountainous terrains and areas of steep slope of Indonesia, landslides are frequent, especially where land cover has been removed. Landslides destroy not only environment and property, but usually also cause deaths. According to *Sugalang et al.* (1999), it is still the greatest geological hazard in Indonesia. During the last second decade, landslide hazards caused 1438 people died and during the last decade, e.g.1987 to 1997, 641 people died and 112 injured, 2116 ha of agriculture field and 5155 houses damaged, 771 public building damaged, 537 m of irrigation channel damaged and 33000 m of road broken off. In the fiscal year 1997/1998 alone, 71 landslides occurred and caused 34 people died and 499 houses damaged.

Considering its disastrous effects, landslide monitoring is therefore very crucial and should be done properly. At the present times, monitoring of landslide in Indonesia is usually done by using terrestrial techniques, using the systems such as extensometer, EDM (Electronic Distance Measurement) and leveling. Recently the Department of Geodetic Engineering, Institute of Technology Bandung (ITB), in cooperation with the Directorate of Volcanology and Geological Hazard Mitigation (DVGHM) has used GPS survey method to study the land displacements at two landslides prone areas in West Java, namely Ciloto and Megamendung (see Figure 1).

Ciloto and Megamendung are located along the main road from Bandung to Jakarta. Ciloto is closed to Cianjur town, while Megamendung is closed to Bogor town. Both sites are located in mountainous region. In this paper, only the results of GPS surveys in Megamendung that will be described and discussed. The results of GPS surveys in Ciloto have been given in *Abidin et al.* (2004).

Landslide phenomena in Mega-mendung have been occurring for several years. The landslide has destroyed not only houses but also environment around the area as shown in Figure 2.

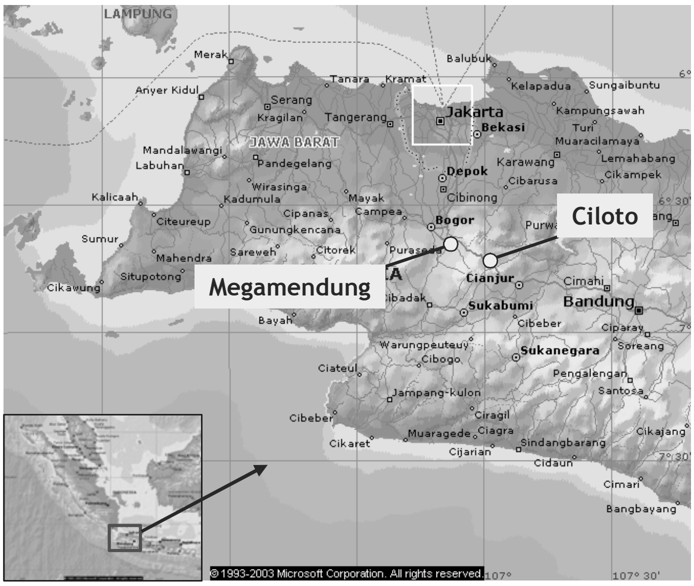

Figure 1 Location of Ciloto and Megamendung.

Figure 2 Example of landslide impacts in Megamendung.

2 Monitoring Land Displacements

Land displacement monitoring in a certain landslide prone area in principle is the monitoring of changes in distances, height differences, angles and/or relative coordinates of the points (monuments) covering the area being studied. In this case, there are many methods and techniques that have been used for measuring landslide displacements. The examples are given in Table 1, which is adopted and updated, from Gili et al. (2000). The Table shows that each method has its own result, coverage and achievable accuracy level.

In studying landslide displacements in Megamendung, besides GPS survey method, no other geodetic methods have been implemented.

Method/technique	**Result**	**Typical range**	**Typical precision**
Precision tape	distance change	< 30 m	0.5 mm/30 m
Fixed wire extensometer	distance change	< 10-80 m	0.3 mm/30 m
Rod for crack opening	distance change	< 5 m	0.5 mm

Offsets from baseline	coordinate differences (2D)	< 100 m	0.5 - 3 mm
Triangulation	coordinate differences (2D)	< 300 – 1000 m	5 - 10 mm
Traverse/polygon	coordinate differences (2D)	variable, usually < 100 m	5 - 10 mm
Leveling	height change	variable, usually < 100 m	2 - 5 mm/km
Precise leveling	height change	variable, usually < 50 m	0.2 – 1 mm/km
EDM (Electronic Distance Measurement)	distance change	variable, usually 1 – 14 km	1-5 mm + 1-5 ppm
Terrestrial photogrammetry	coordinate differences (3D)	ideally < 100 m	20 mm from 100 m
Aerial photogrammetry	coordinate differences (3D)	H flight < 500 m	10 cm
Clinometer	angle change	$\pm 10^0$	$\pm 0.01\text{-}0.10^0$
Precision theodolite	angle change	variable	± 10”
GPS survey	coordinate differences (3D)	variable	2-5 mm + 1-2 ppm

Table 1 Methods and techniques for measuring landslide displacements, adopted and updated from [*Gili et al.*, 2000].

3 Principle of Landslide Study Using GPS Survey Method

GPS (Global Positioning System) is a passive, all-weather satellite-based navigation and positioning system, which is designed to provide precise three dimensional position and velocity, as well as time information on a continuous worldwide basis [Hofmann-Wellenhof, et al., 1997]. GPS could provide a relatively wide spectrum of positioning accuracy, from a very accurate level (mm level) to an ordinary level (a few m level). For studying landslide phenomena, in order to monitor the land displacement of even very small magnitude, the ideal positioning accuracy to be achieved is in mm level. In order to achieve that level of accuracy then the GPS static survey method based on phase data should be implemented with stringent measurement and data processing strategies [Leick, 1995]. The principle of landslide study using repeated GPS surveys method is depicted in Figure 3. With this method, several monuments, which are placed on the ground covering the landslide prone area, are accurately positioned using GPS survey relative to a certain reference (stable) point. The precise coordinates of the monuments are periodically determined using repeated GPS surveys with certain time interval. By studying the characteristics and rate of changes of these coordinates from survey to survey, the characteristics of land displacements can be derived. These land displacement characteristics in turn can be used to study the geometrical characteristics of landslide phenomena in the area.

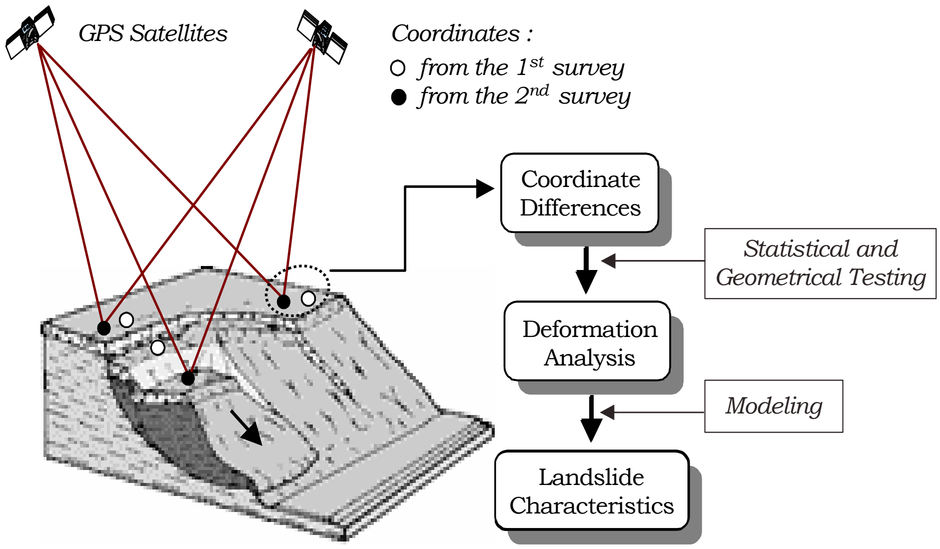

Figure 3 Principle of GPS Survey Method for Landslide Study.

In order to obtain the coordinate differences with precision at several mm level, GPS survey should be conducted using dual-frequency geodetic type GPS receivers. Observation length at each monitoring point is adjusted according to its baseline length, and for baseline length less than 5 km, the observation period of about 3 hours is usually enough to achieve the precision level of several mm. GPS survey method has been widely used for studying landslide phenomena [*Gili et al.,* 2000; *Moss,* 2000; *Malet et al.,* 2002; *Rizzo,* 2002; *Mora et al.,* 2003]. In order to obtain comprehensive information about the landslide characteristics, the GPS derived information should be integrated and correlated with the hydro-geological characteristics of the area.

4 GPS Surveys in Megamendung

GPS surveys to study landslide displacement in Megamendung, a relatively well-known landslide prone area, have been done three times, namely on 19 April 2002, 11 May 2003 and 13 May 2004. All GPS surveys were conducted during dry season with the period of about a year between the two consecutive surveys. Location and configuration of GPS network involving 8 points is shown in Figure 4. REFM is a stable point located outside the sliding area and it is connected to the Indonesia IGS station in BAKOSURTANAL, Cibinong, Bogor, located about 100 km away.

These GPS points as shown in Figure 4 were selected to enable a reliable detection of landslide displacement signal in the area. At the same time these points should satisfy the criteria for good GPS point, e.g. it is a relatively stable location, has a good sky view and is relatively less affected by multipath [*Abidin,* 2000]. The distances between REFM with other monitored GPS points are less than 1 km. The GPS surveys at all points were all carried out using dual-frequency geodetic-type GPS receivers. REFM was used as the reference (stable) point with known coordinates. Since the baselines are relatively short, namely less than one km, GPS observations were conducted with the session lengths of about 3 to 4 hours. The data were collected with a 30 second interval, and elevation mask was set at 15^0 for all points.

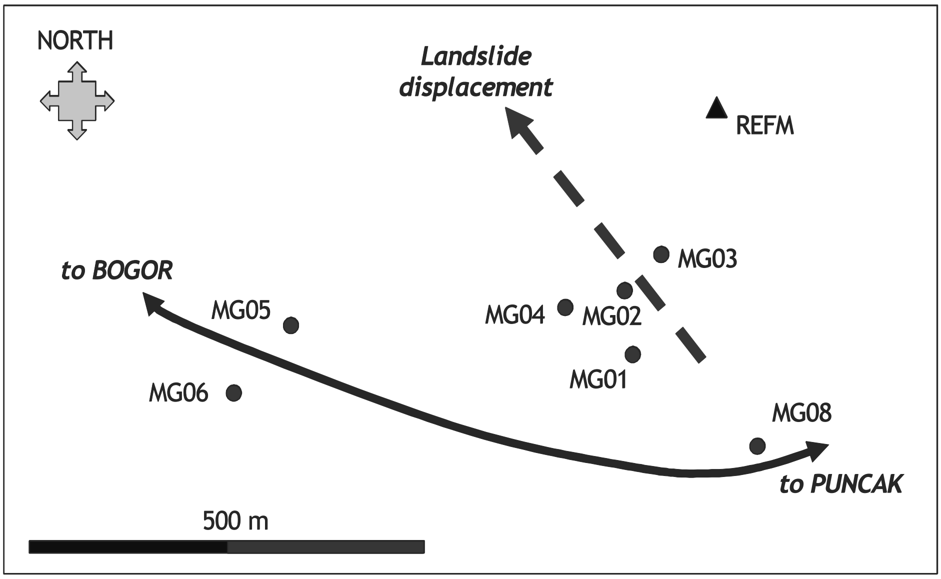

Figure 4 Landslide GPS monitoring network in Megamendung (West Java, Indonesia).

5 Data Processing, Results and Analysis

The coordinates of REFM were computed by using BERNESSE 4.2 scientific software [*Beutler et al.,* 2001] from an Indonesia IGS station in BAKOSURTANAL, Cibinong, Bogor, located about 100 km away. The coordinates of the monitored points, e.g. MG01, MG02 up to MG08, were then computed radially from REFM by using the commercial software SKIPro [*Leica*, 2004]. Considering the relatively short baselines, only broadcast ephemerides were used for data processing, and the residual ionospheric and tropospheric biases are considered negligible after data differencing.

The obtained standard deviations of the computed coordinates were typically in the order of several mm for Easting (E), Northing (N) and Ellipsoidal Height (h) components, respectively, as shown in Figure 5. This Figure shows that in general standard deviations of the horizontal components are better than 3 mm, and those of vertical component are better than 5 mm, except for one point from the first survey and one point from the third survey. These results indicate that GPS data processing has been properly performed.

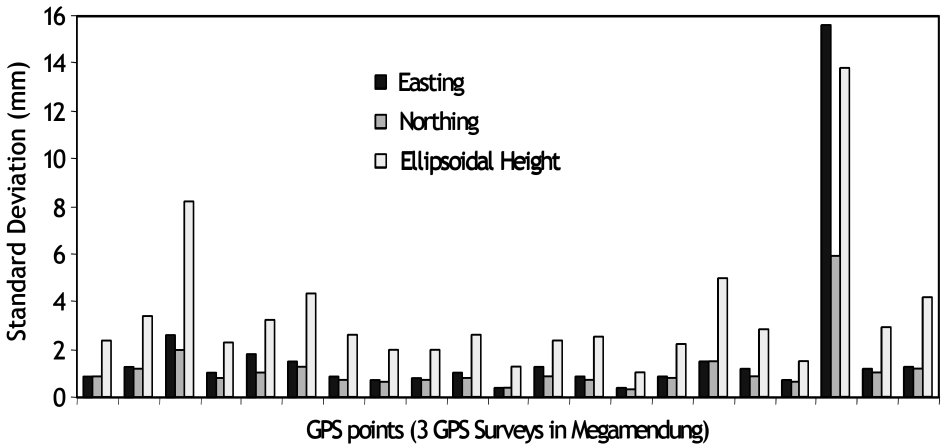

Figure 5 Typical standard deviations of the estimated GPS coordinates obtained from three GPS surveys.

In this study, landslide displacements are obtained by differencing the coordinates of GPS points obtained from two consecutive surveys. In this case, the obtained coordinate differences (dE,dN,dh) along with their standard deviations are shown in Table 2.

The GPS derived horizontal displacements are shown in Figures 6 and 7. Their corresponding error ellipses are not drawn, since their sizes are too small. It can be seen from these Figures and Table 2 that four points, i.e. MG01, MG02, MG03 and MG04, show relatively large displacements in the amount of 2-3 m in the period of April 2002 to May 2003, and 3-4 dm in the period of May 2003 to May 2004. The other points show relatively much smaller displacements. Inspection on the field in general supported these amounts of land displacements detected by GPS surveys.

Point	Coordinate differences and their standard deviations obtained from the 1st and 2nd GPS surveys.					
	dE(m)	σdE (m)	dN(m)	σdN (m)	dh (m)	σdh(m)
MG01	-1.511	0.001	1.922	0.001	-0.347	0.002
MG02	-1.615	0.001	1.920	0.001	-0.198	0.003
MG03	-0.939	0.002	1.563	0.001	-0.612	0.004
MG04	-1.373	0.003	2.324	0.002	-0.106	0.008
MG05	-0.056	0.002	0.100	0.001	-0.109	0.003
MG06	-0.019	0.002	-0.001	0.001	-0.069	0.004
MG08	-0.001	0.002	0.003	0.001	-0.051	0.004
Point	**Coordinate differences and their standard deviations obtained from the 2nd and 3rd GPS surveys.**					
	dE(m)	**σdE (m)**	**dN(m)**	**σdN (m)**	**dh (m)**	**σdh(m)**
MG01	-0.339	0.001	0.397	0.001	0.002	0.003
MG02	-0.332	0.002	0.421	0.002	0.117	0.005
MG03	-0.227	0.002	0.372	0.001	-0.039	0.004
MG04	-0.299	0.001	0.494	0.001	0.047	0.002
MG05	0.160	0.016	-0.014	0.006	0.086	0.014
MG06	0.003	0.002	0.001	0.001	0.126	0.004
MG08	0.003	0.001	0.014	0.001	0.099	0.004

Table 2 Coordinate differences of GPS points and their standard deviations.

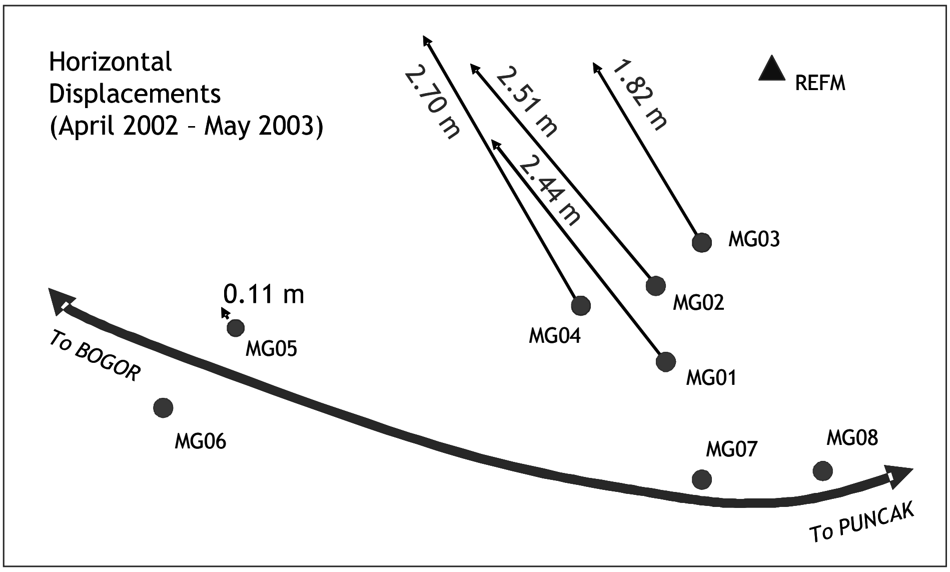

Figure 6 Horizontal displacements of GPS between April 2002 and May 2003.

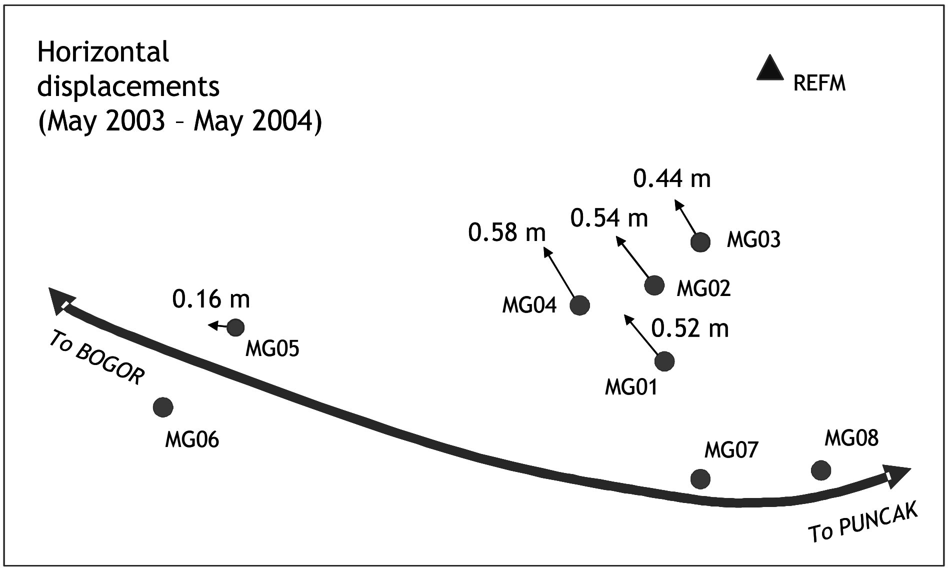

Figure 7 Horizontal displacements of GPS between May 2003 and May 2004.

Figures 6 and 7 also show that the GPS derived direction of landslide displacement in the study area of Megamendung is in general consistent with the previously assumed direction that is based on field observation. The Figures show that the landslide displacement is in a northwest direction.

However, in order to statistically check the significance of the displacements derived by GPS surveys, the congruency test [*Caspary*, 1987] was performed on the following variable

$$\delta dij = (dEij^2 + dNij^2 + dhij^2)^{1/2} . \qquad (1)$$

where δdij is the displacement of a point from epoch i to j. The null hypothesis of the test is that there is no displacement between the epochs. Therefore:

null hypothesis $\quad H_o : \delta dij = 0$, (2)

alternative hypothesis $\quad H_a : \delta dij \neq 0$. (3)

The test statistics for this test is:

$$T = \delta dij / (\sigma \text{ of } \delta dij) , \qquad (4)$$

this has a Student's t-distribution if Ho is true. The region where the null hypothesis is rejected is [*Wolf and Gilani,* 1997] :

$$|T| > t_{df,\alpha/2} , \qquad (5)$$

where df is the degrees of freedom and α is the significance level used for the test. In our case, for GPS baselines derived using 3 to 4 hours of GPS data with 30 seconds data interval, then df → ∞ (infinity). Please note that a t-distribution with infinite degree of freedom is identical to a normal distribution. If a confidence level of 99% (i.e. α=1%) is used, then the critical value $t_{\infty,0.005}$ is equal to 2.576 [*Wolf and Gilani,* 1997]. If the values are adopted for the congruency test, then the testing results are summarized in Table 3.

Point	**δd_{12} (cm)**	**σ of δd_{12} (cm)**	**T**	**Significant displacement ?**
MG01	246.9	0.1	3562.0	YES
MG02	251.7	0.1	2116.4	YES
MG03	192.4	0.2	977.9	YES
MG04	270.1	0.2	1211.3	YES
MG05	15.8	0.2	63.6	YES
MG06	7.2	0.4	18.2	YES
MG08	5.1	0.4	11.7	YES
Point	**δd_{23} (cm)**	**σ of δd_{23} (cm)**	**T**	**Significant displacement ?**
MG01	52.2	0.1	491.5	YES
MG02	54.8	0.2	274.7	YES
MG03	43.8	0.1	324.4	YES
MG04	58.0	0.1	763.3	YES
MG05	18.2	1.5	12.0	YES
MG06	12.6	0.4	33.0	YES
MG08	10.0	0.4	23.4	YES

Table 3 Summary on congruency test of GPS derived displacements.

The results of statistical testing shown in Table 3 indicate that all GPS points have statistically significant displacements. In order to further confirm the reliability of GPS derived displacements, after the above statistical testing, other two testing were imposed on the GPS derived displacement of each GPS point. These other two testing are:

- testing on the agreement between the horizontal distance changes with the predicted direction of landslide displacement, and
- testing on the consistency of displacement directions on two consecutive periods.

The above two testing can be illustratively explained by the following Figures 8 and 9.

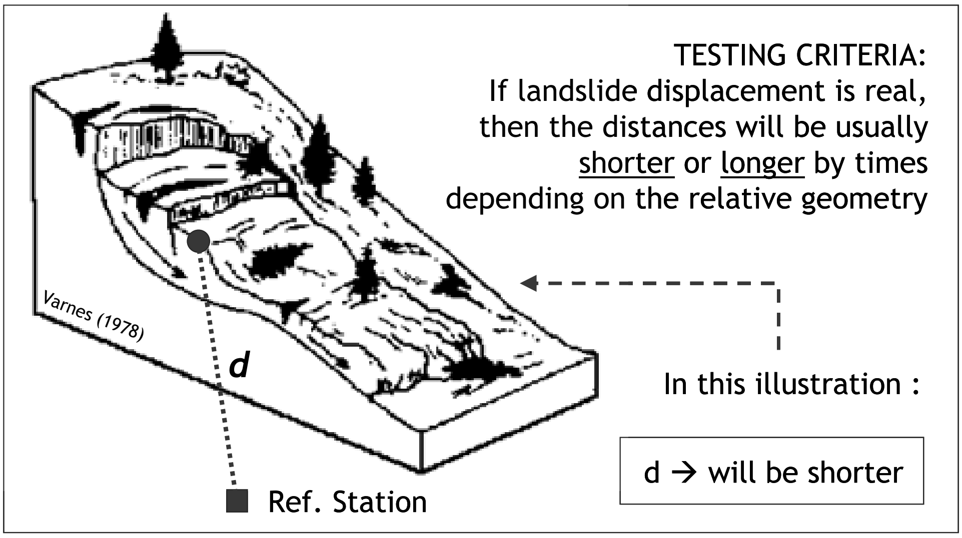

Figure 8 Illustration of the testing on the agreement between the horizontal distance changes with the predicted direction of landslide displacement.

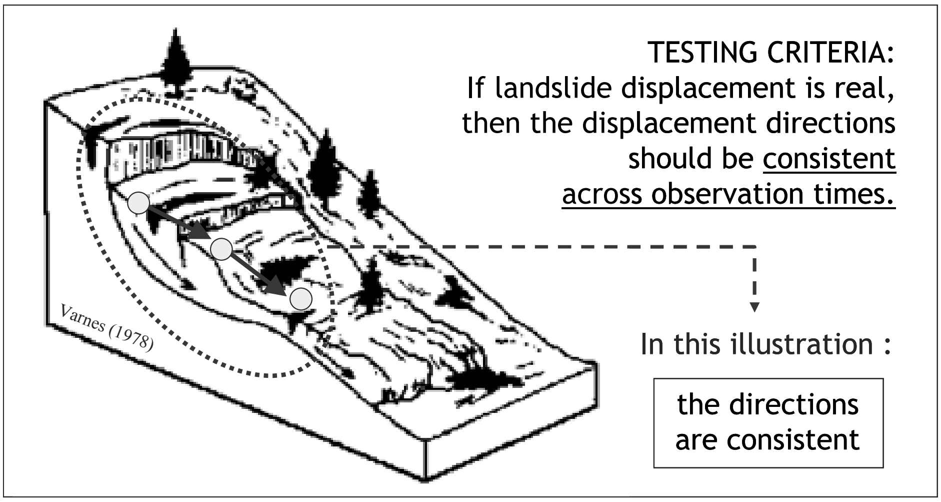

Figure 9 Illustration of testing on the consistency of displacement directions on two consecutive periods.

Based on the configuration of GPS network shown in Figure 3 and the expected direction of landslide, then if the displacements do occur, the horizontal distances from REFM point to all other GPS monitored points will be theoretically shortened. Based on this hypothesis, testing on the agreement between the horizontal distance changes with the predicted direction of landslide displacement is applied, and the testing results are shown in Table 4. The testing is only applied to those GPS points that are considered having significant displacement by the previous statistical testing. The results on Table 4 show that after the statistical and horizontal distance changes agreement testing, all points can be considered to have significant displacements in the two observation periods, except for point MG06 in the first period.

Baseline	Theoretical hdc sign	Observed hdc(12), cm	In Agreement?	Observed hdc(23), cm	In Agreement?
REFM-MG01	negative	- 140.4	YES	- 28.0	YES
REFM-MG02	negative	- 112.6	YES	- 25.3	YES
REFM-MG03	negative	- 119.9	YES	- 28.3	YES
REFM-MG04	negative	- 119.9	YES	- 24.9	YES
REFM-MG05	negative	- 0.5	YES	- 12.9	YES
REFM-MG06	negative	1.6	NO	- 0.3	YES
REFM-MG08	negative	- 0.3	YES	- 1.4	YES
note : hdc(ij) = horizontal distance change from survey-i to survey-j					

Table 4 Testing results on the agreement between the horizontal distance changes with the predicted direction of landslide displacement.

Finally in order to decide the points that have significant and real displacements, the testing on the consistency of displacement directions on the consecutive survey periods is applied. This testing is based on the idea that for a point experiencing landslide displacement on a certain slope, the direction of its real displacement will be generally consistent from one survey period to the next period. In the context of the previous testing, this consistency testing is actually similar to the previous agreement testing that is imposed to be consistent for consecutive survey periods. If this testing is applied to the points that have passed the two previous testing, then the points that show consistent direction of displacements on two consecutive periods are all points, except MG06. Therefore in this study area, only those six points, i.e. MG01, MG02, MG03, MG04, MG05, and MG08, that are considered to experience real and significant landslide displacements during the survey period between April 2002 to May 2004. The amounts of displacements have been given in Table 2. If we see the configuration of GPS network shown in Figure 3, those all six points are located in northern part of the highway on a descending slope of the hill. The largest observed displacements are associated with a cluster of MG01, MG02, MG03 and MG04 points.

6 Closing Remarks

Based on the results obtained from three GPS surveys that have been conducted in the landslide prone area of Megamendung, it can be concluded that the landslide displacements in the area are relatively quite large in the level of a few dm to a few m. The displacements up to about 2-3 m were detected in the April 2002 to May 2003 period, and up to about 3-4 dm in the May 2003 to May 2004 period. In both periods, the landslides in general show the northwest direction of displacements. The displacements vary both spatially and temporally. These land displacements in Megamendung are significantly larger than those measured in Ciloto area [*Abidin et al*, 2004], which is just in the order of a few cm to a few dm.

Based on the studies that have been conducted in Ciloto and Megamendung, it can be concluded that GPS survey method is a reliable method for studying and monitoring landslide displacements. Precision level of mm to cm can typically be achieved, although achieving this level of precision is not an easy task to do. In this case the use of dual frequency geodetic type receivers is compulsory along with good survey planning, stringent observation strategy, and stringent data processing strategy. Considering its relatively high accuracy, all-times weather-independent operational capability, wide spatial coverage, and its user friendliness, the use of repeated GPS surveys for landslide displacement monitoring can be expected to gain more recognition.

From the GPS based landslide monitoring studies in Ciloto and Megamendung, it can also be suggested that in order to assure the existence of real and significant displacements of GPS points, the GPS derived computed displacements should be subjected to three testing; namely: the congruency test on spatial displacements, testing on the agreement between the horizontal distance changes with the predicted direction of landslide displacement, and testing on the consistency of displacement directions on two consecutive periods.

Moreover, in order to provide physical meaning to GPS derived displacements, the results should be correlated with the hydro-geological and geotechnical characteristics of the study area. Finally it should be emphasized that further research is still needed to clarify the real mechanism and pattern of landslide displacements in the Megamendung area.

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