On the Use of GPS Survey Method for Studying Land Displacements on the Landslide Prone Areas

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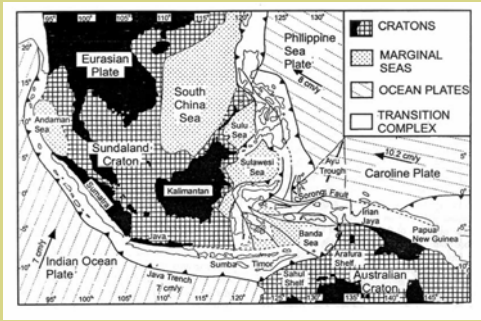
Tectonic Settings of Indonesia

from *Simandjuntak and Barber* (1996)



LANDSLIDE & ITS MONITORING

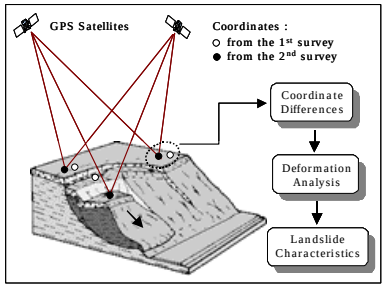
- *Landslide is one of prominent geohazards that continuously affecting Indonesia, especially in the rainy season.*
- *It destroys not only environment and property, but usually also cause deaths.*

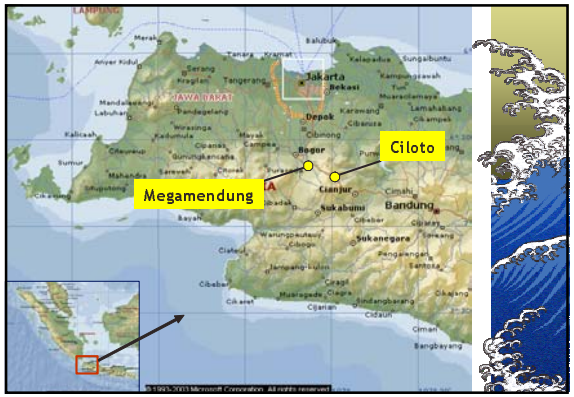
- 641 persons died
- 112 persons injured
- 2,116 ha of agriculture field damaged
- 5,155 houses damaged
- 771 public building damaged
- 537 M of irrigation channel damaged
- 33,000 M of road broken off.

(1987-1997) Figures

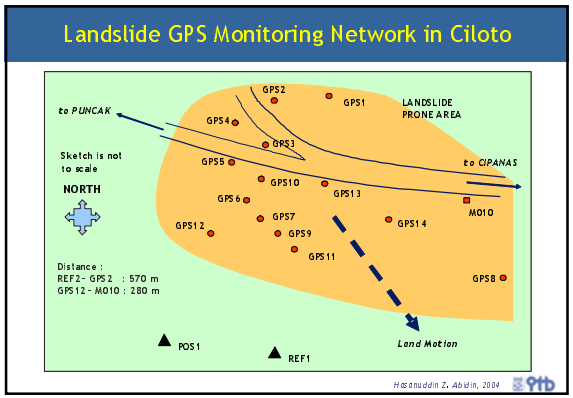
- *Landslide monitoring and mitigation is therefore very crucial and should be done properly.*
- *Monitoring of landslide is usually done by using terrestrial techniques, using the systems such as extensometer, EDM (Electronic Distance Measurement), and leveling.*
- *How about the use of GPS and/or INSAR ?*

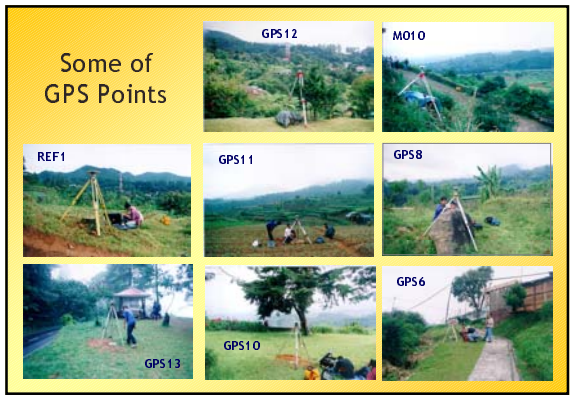
PRINCIPLE OF GPS SURVEY METHOD FOR LANDSLIDE MONITORING





Landslide Study Area (CILOTO)


Landslide GPS Monitoring Network in Ciloto
to PUNCAK
GPS2
GPS1
LANDSLIDE PRONE AREA
GPS4
GPS3
Sketch is not to scale
GPS5
to CIPANAS
NORTH
GPS10
GPS13
GPS6
MO10
GPS12
GPS7
GPS14
GPS9
GPS11
Distance :
REF2 - GPS2 : 570 m
GPS12 - MO10 : 280 m
GPS8
POS1
REF1
Land Motion
Hasanuddin Z. Abidin, 2004

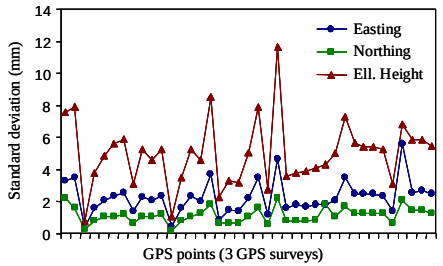

Some of GPS Points
GPS12
MO10
REF1
GPS11
GPS8
GPS13
GPS10
GPS6

GPS Surveys in Ciloto

SURVEY	OBSERVATION PERIOD	OBSERVED GPS STATIONS
1	21-22 Jan. 2002	POS, REF1, GPS1, GPS2, GPS3, GPS4, GPS5, GPS6, GPS7, GPS8, GPS9, M010, GPS10, GPS11, GPS12, GPS13, GPS14
2	4-5 April 2002	
3	10 May 2003	POS, REF1, GPS1, GPS2, GPS3, GPS4, GPS5, GPS6, GPS7, GPS8, GPS9, M010, GPS10, GPS11

- GPS receivers are of the geodetic dual-frequency type.
- Baseline lengths are less than 1 km.
- Observation session lengths are about 3 to 6.5 hours.
- Data rate is 30 seconds.
- Mask angle is 15° for all stations.

Typical standard deviations of the estimated GPS coordinates



Testing - 1 : Congruency (statistical) test

The test statistics for this test is:

$T = \delta d_{ij} / (\sigma \text{ of } \delta d_{ij})$

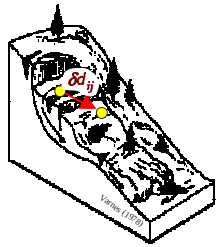
$\delta d_{ij} = (dE_{ij}^2 + dN_{ij}^2 + dh_{ij}^2)^{1/2}$

The hyphothesis :

$H_o: \delta d_{ij} = 0$, $H_a: \delta d_{ij} \neq 0$

The region where H_o is rejected :

$|T| > t_{df, \alpha/2}$



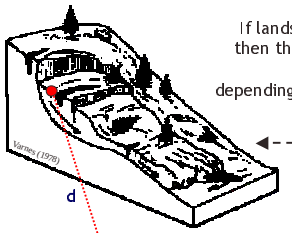
Summary on congruency test of GPS derived displacements (12)

Station	δd_{12} (cm)	$\sigma\delta d_{12}$ (cm)	T	Significant displacement ?
GPS1	2.5	0.8	3.0	YES
GPS2	2.0	1.1	1.9	NO
GPS3	0.9	0.2	4.6	YES
GPS4	3.2	0.5	6.6	YES
GPS5	0.8	0.4	1.8	NO
GPS6	1.4	0.3	4.4	NO
GPS7	65.3	0.3	223.1	YES
GPS8	15.2	0.4	36.6	YES
GPS9	1.6	1.2	1.3	NO
M010	2.3	0.6	4.0	YES
GPS10	0.6	0.3	2.1	NO
GPS11	27.2	0.2	177.6	YES
GPS12	5.6	0.5	10.5	YES
GPS13	5.2	4.1	1.2	NO
GPS14	26.2	0.2	110.5	YES

Summary on congruency test of GPS derived displacements (23)

Station	δd_{23} (cm)	$\sigma\delta d_{23}$ (cm)	T	Significant displacement ?
GPS1	2.7	0.5	5.5	YES
GPS2	1.5	2.9	0.5	NO
GPS3	1.2	0.3	4.6	YES
GPS4	3.3	0.6	5.4	YES
GPS5	6.7	0.6	10.9	YES
GPS6	2.0	0.4	4.7	YES
GPS7	8.5	1.3	6.7	YES
GPS8	11.5	0.4	27.7	YES
GPS9	5.8	0.8	7.1	YES
M010	6.2	0.6	9.7	YES
GPS10	3.4	0.7	5.0	YES
GPS11	3.8	0.5	7.8	YES

Testing - 2 : The observed-predicted agreement of the distance changes



If landslide displacement is real, then the distances will be usually shorter or longer by times depending on the relative geometry

In this illustration :

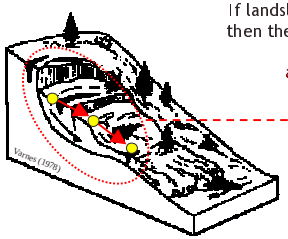
d → will be shorter

Summary on the 2nd Testing Results

Baseline	hdc(12)	Concurring ?	hdc(23)	Concurring ?
REF1 - GPS1	-0.8	YES	1.2	NO
REF1 - GPS3	-0.5	YES	0.1	NO
REF1 - GPS4	-0.8	YES	0.2	NO
REF1 - GPS5	-	-	-1.5	YES
REF1 - GPS6	-	-	-1.7	YES
REF1 - GPS7	-63.5	YES	-3.6	YES
REF1 - GPS8	1.6	YES	1.2	YES
REF1 - GPS9	-	-	0.0	NO
REF1 - M010	0.3	YES	-2.4	YES
REF1 - GPS10	-	-	-0.7	YES
REF1 - GPS11	-22.3	YES	-2.4	YES
REF1 - GPS12	0.5	NO	-	-
REF1 - GPS14	-16.5	YES	-	-

Note : hdc(ij) = horizontal distance change from survey-i to survey-j

Testing - 3 : The temporal consistency of displacement directions



If landslide displacement is real, then the displacement directions should be consistent across observation times.

In this illustration :

the directions are consistent

Summary on the 3rd Testing Results

Baseline	hdc(12)	Concurring ?	hdc(23)	Concurring ?	Real ?
REF1 - GPS1	-0.8	YES	1.2	NO	✗
REF1 - GPS3	-0.5	YES	0.1	NO	✗
REF1 - GPS4	-0.8	YES	0.2	NO	✗
REF1 - GPS5	-	-	-1.5	YES	?
REF1 - GPS6	-	-	-1.7	YES	?
REF1 - GPS7	63.5	YES	-3.6	YES	✓
REF1 - GPS8	1.6	YES	1.2	YES	✓
REF1 - GPS9	-	-	0.0	NO	✗
REF1 - M010	0.3	YES	-2.4	YES	✓
REF1 - GPS10	-	-	-0.7	YES	?
REF1 - GPS11	22.3	YES	-2.4	YES	✓
REF1 - GPS12	0.5	NO	-	-	✗
REF1 - GPS14	-16.5	YES	-	-	?

Note : hdc(ij) = horizontal distance change from survey-i to survey-j

Closing Remarks

- *GPS survey method is a reliable method for studying and monitoring landslide displacement.*
- *PROBLEMS :*
  - *Signal obstruction (canopies and topography)*
  - *Multipath*
- *ANALYSIS OF THE OBSERVED DISPLACEMENTS :*
  - *the congruency (statistical) test,*
  - *the observed-predicted agreement test*
  - *the temporal consistency test.*
- ***RESULT INTERPRETATION :***
  - *Correlation with the hydro-geological and geotechnical characteristics of the studied area and its surrounding.*
  - *Integration with the results obtained by other geodetic monitoring techniques such as leveling and EDM measurements.*