The GPS Data Campaign for the Slip Surface Estimation Ciloto Landslide Zone Case Study, West Java, Indonesia

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Key words: GPS campaign, landslide, slip surface

SUMMARY

Landslide is a disaster that often occurs in the rainy season in Indonesia. One in Ciloto West Java has hilly terrain, which continues movement of soil. The effort to carry out disaster prevention is finding a stable material layer by means to find the location of the slip surface, where slip surface is delaminates between sliding material and stable slope material. In the limit equilibrium method, the slip surface is used as surface reference for safety factor computation.

The GPS data campaign provides horizontal and vertical soil movement at each monitoring point in landslide zone. First, the landslide zone is divided into several sections based on the same direction of horizontal movement monitoring points. The similarity direction of horizontal movement at several monitoring points indicates that the monitoring points located at the same slip surface. Second, the intersection point of velocity movement trend lines from each monitoring points, can provide slip surface location as the estimation result. The vertical movement could give estimation of scarp position also. Locations of scarp in vertical section to ensure compatibility with result of geology research at same study area.

Ciloto landslide zone is classified to very slow velocity movement (5 x 10-5 - 5 x 10-7 mm/second). The characteristic of horizontal displacement has diversity directions. Those characteristic gives indications that landslide zone have many slip surfaces. From this research, the landslide type at Ciloto zone has multiple compound (rotational and translational) slip surfaces.

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1. INRODUCTION

Landslide is one of mass movement at slope that people known very well. In Cruden and Varnes definition (1992), landslide is a mass movement of soil down the slope toward slip surface or relative to intensive shear strain (Abramson et.al, 1996). Generally, landslide is local failure which is caused heavy losses in the economy, and even threatens human security. Thus, mitigation efforts should be made to minimize the risk of landslides. In order to minimize the probability of landslides hazard, that is very important to monitor a material stability of the slope. A common monitoring method done by physical method which it calculates the slope stability value or safety factor. The computation is using physical parameters such as slope geometry, resistance of the forming slope material, hydrogeology, soil-rock layers, weather, and geological structure. Physical parameters can give a realistic output to describe the landslide phenomenon, but it also related with kind of materials and field morphology. There needs a sophisticated and expensive tools.

Another alternative to monitor a slope material stability is done by geometric method. There is simpler than physical method. Early indication of landslide is crack on original ground surface which it will become main scarp of landslide zone. Shape of landslide zone scarp will give a clue about shape of slip surface, like as circular and planar. It will effect to mechanism of landslide or landslide type namely rotational, translational and compound slide.

In landslide zone, slip surface is plane that is dividing a stable and unstable material in the slope. If we can estimate slip surface location, furthermore we can determine depth and border of slip surface. That information need to landslide mitigation. This research purpose is estimate to slip surface location by GPS (Global Positioning Satellite) measurement campaign. Landslide phenomenon can be known from the displacement of monitoring point. This method will be implemented to landslide case where the soil movement has a slow velocity. Characteristic of landslide defined from displacement vector which derived from the monitoring point in landslide zone. Type of landslide will defined from a kind of material forming the slope and soil movement mechanism. Slip surface denote a border between unstable or move soil and stable soil, as sliding plane. Location, shape and size of slip surface will be estimated using geometric method, as illustration at figure 1.

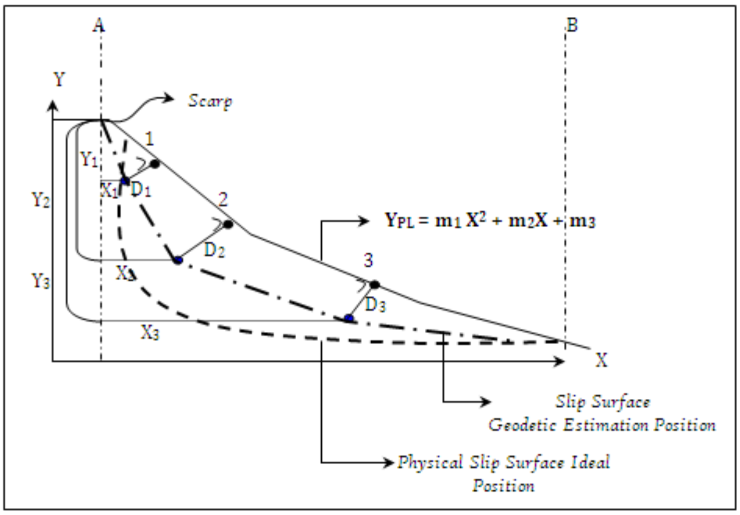

Figure 1. Idea of Estimation of Slip Surface Position (Sadarviana, 2006)

The advantage of information is determine procedure technical engineering for mitigation and very useful for early warning system and evacuation of housing area.

2. CHARACTERISTIC OF CILOTO LANDSLIDE ZONE

Research location has geographic position at 107˚00˙00″-107˚00˙20″E and 06˚42˙40″-06˚43˙00″S at kilometer 88.1 Cianjur-Puncak, Kampung Baru Puncak, Desa Ciloto, Kecamatan Pacet, Kabupaten Cianjur West Java, see figure 2. Ciloto landslide zone has approximately 40 hectares. The base rock of this area is a quarter of a material that has undergone weathering volcanic tuff breccia's 3-7 meters depth. The physical property of the soil is loose and soft rots. However weathering soil resistance to steep slopes when conditions are dry, but when in a state of saturated water then the material is easy to collapse. By geology research, Ciloto landslide zone have soil material category in debris type. Ciloto Peak Region has 5 landscapes units, namely:

1. Unit I that includes Gunung Lemo
2. Unit II that includes Pondok Cikoneng, Gunung Mas, Gunung Gedogan, and Gunung Jongklok
3. Unit III that includes Puncak, Jember and the surrounding areas
4. Unit IV that includes Sindanglaya areas
5. Unit V is the slope of Cempaka hillsides, Tugu and its surrounding areas

Rain water is trapped in the region of Unit I and will accumulate on the Cijember River which then becomes ground water. Cijember local groundwater will flow through the narrow water bearing layers causes increased pressure on local ground water (Purnomo, 1993).

a)

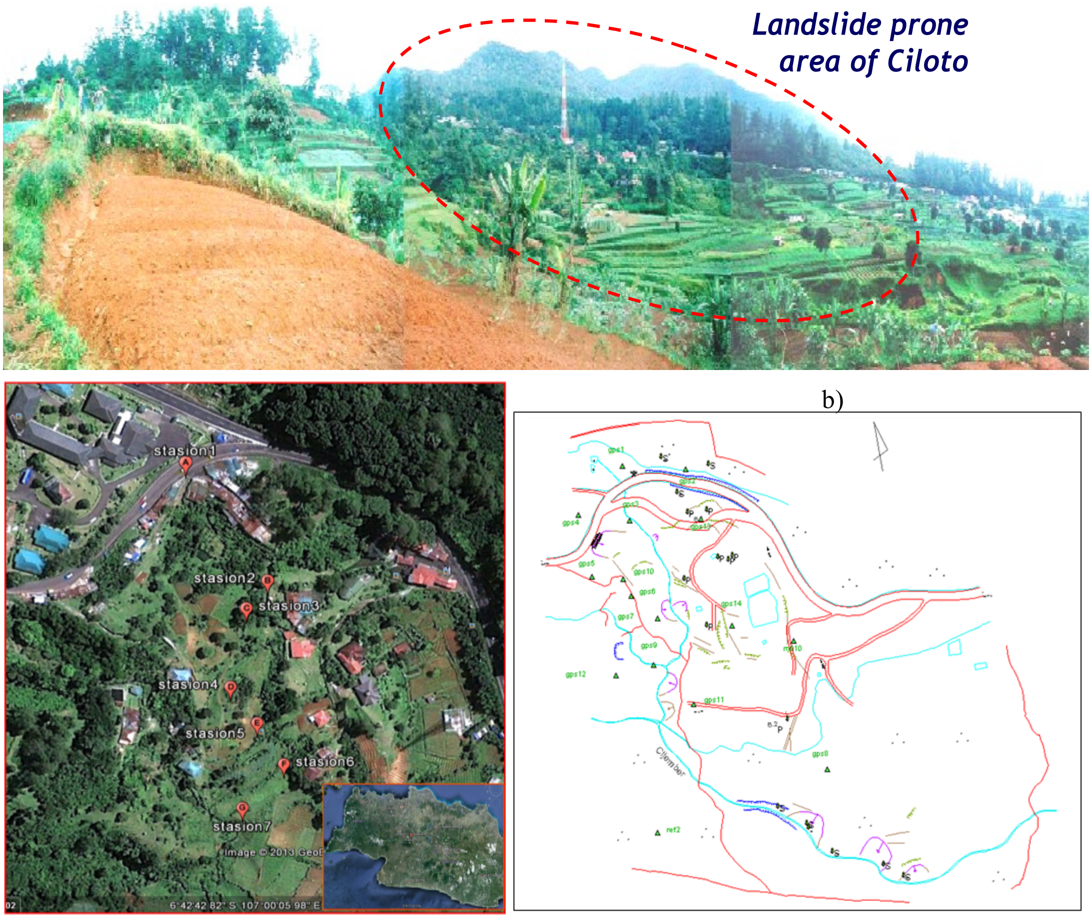

Figure 2. a) and b) Ciloto Landslide Zone (Nugraha, 2013) , b) Monitoring points Distribution (Sadarviana, 2006)

In Ciloto area have population density around 626 man/km^2 (based on population census at 2007). People have main jobs in the agricultural sector about 62.99%. Ciloto landslide zone use vegetation plantation and fish pond. Those kinds of land use make a water pressure to the soil higher than usual.

3. ACQUISITION DATA

Data obtained from five campaigns by GPS measurement 2002-2005 to15 monitoring points and 2 reference points. In bellow table, we can see about measurement strategy and data availability.

Table 1. Measurement Strategy

Measurement Method	Differential Static
Equipment Type	Dual frequency geodetic type
Data Type	P and C/A code, Carrier L1 and L2
Duration	4 - 6 hour
Campaign Interval	30”
Elevation Mask	15 ^{0}

Table 2. Equipment Type

Receiver	unit
Ashtech Z-XII3	3
Trimble 4000SSi	7
Leica SR9500	2
Leica SR520	2

Table 3. GPS Data Availability

Point Name	Campaign 1	Campaign 2	Campaign 3	Campaign 4	Campaign 5
POS G	✓	✓	✓	✓	✓
REF 2	✓	✓	✓	✓	✓
GPS 1	✓	✓	✓	✓	✓
GPS 2	✓	✓	✓	✓	✓
GPS 3	✓	✓	✓	✓	✓
GPS 4	✓	✓	✓	✓	✓
GPS 5	✓	✓	✓	✓	✓
GPS 6	✓	✓	✓	✓	✓
GPS 7	✓	✓	✓	✓	✓
GPS 8	✓	✓	✓	✓	✓
GPS 9	✓	✓	✓	✓	✓
GPS 10	✓	✓	✓	✓	✓
GPS 11	✓	✓	✓	✓	✓
GPS 12	✓	✓	-	-	-
GPS 13	✓	✓	-	-	-
GPS 14	✓	✓	-	-	-
M010	✓	✓	✓	✓	✓

4. MATHEMATIC MODEL

This research has a GPS processing in scheme like in figure 3 and slip surface estimation scheme in figure 4 . As we seen the distribution of the monitoring points in Figure 2. By processing GPS data, we obtained position of monitoring points at each campaign in UTM coordinates (E, N, h). Status of monitoring points displacement are obtained by geometric method, which is divided in two kinds of mathematic model namely static and kinematic model.

Table 4. Model Mathematic of Geometric Method for Displacement

Model	Input	Output
Static	Coordinates of the monitoring points $(E, N, h)_{i-1}$ and $(E, N, h)_i$, i=1,2,3,4,5 (i : survey period)	Vector of displacement the monitoring points (scalar and direction)
Kinematic	Coordinates of the monitoring points $(E, N, h)_{i-1}$ and $(E, N, h)_i$, i=1,2,3,4,5 (i : survey period)	Prediction result : displacement position, velocity and acceleration to time

Equation of static model:

$$d_j = x_j^{(i)} - x_j^{(i-1)} \qquad \text{(1)}$$

Equation of kinematic model:

$$X_j^{(i)} = X_j^{(i-1)} + (t_i - t_{i-1})V_{Xj} + \frac{1}{2}(t_i - t_{i-1})^2 a_{Xj} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

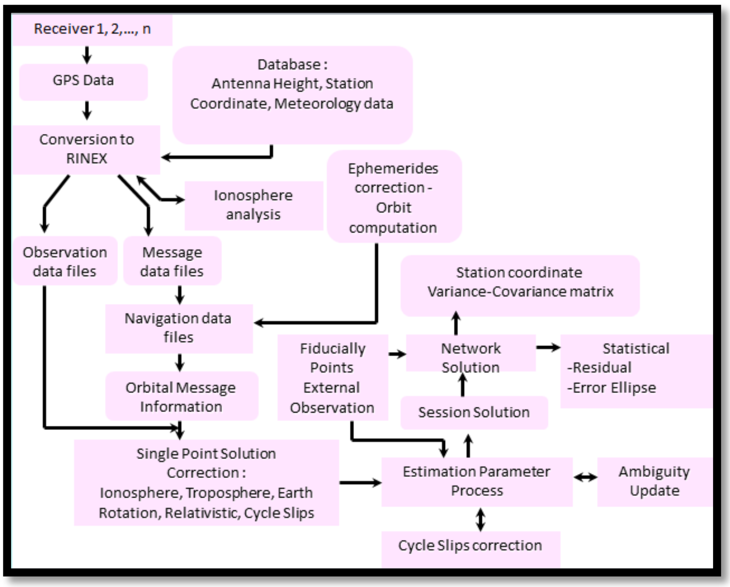

Figure 3. GPS Processing Scheme

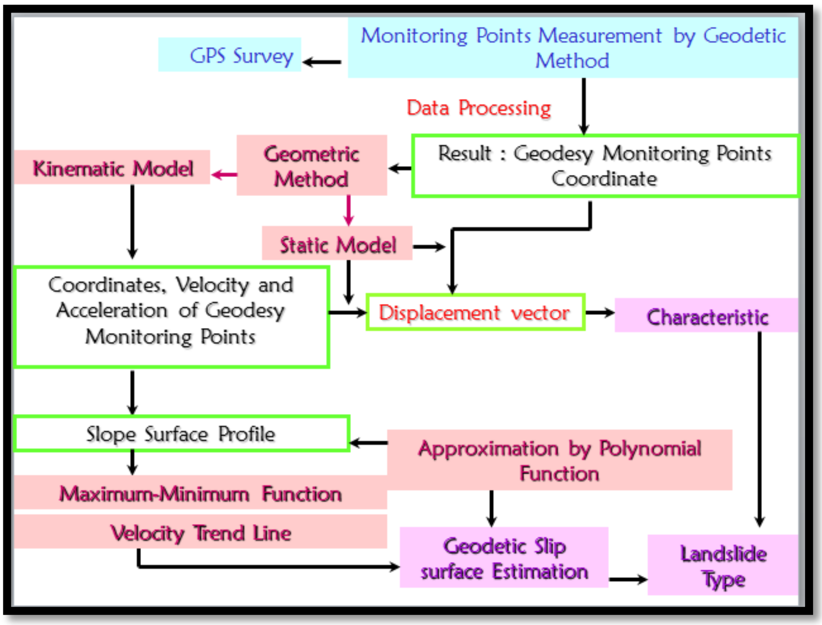

Figure 4. Idea Scheme of Slip Surface Estimation (Sadarviana, 2006)

Notation : d_j is displacement the monitoring point, $X_{j(i)}$ is coordinates prediction of the monitoring point j at campaign i, $X_{j(i-1)}$ is observation coordinates of the monitoring point j at campaign (i-1), V_{xj} is displacement velocity of monitoring point j, a_{xj} is displacement acceleration of monitoring point, t_i, t_{i-1} is measurement campaign at i and (i-1). Further, the next computation step can see bellow.

$$\overline{Y}_{i,1} = T_{i,(i-1)} \hat{Y}_{(i-1),1} \text{ ....(3)}$$
$$Q_{Yi,Yi} = T_{i,(i-1)} Q_{Y(i-1),Y(i-1)} T^T_{i,(i-1)} \text{ ....(4)}$$
$$\hat{L}_{i,1} = L_{i,1} + v_{Li,1} = A_{i,i} \hat{Y}_{i,1}$$
$$v_{Li,1} = A_{i,i} \hat{Y}_{i,1} - L_{i,1} \text{ ....(5)}$$

Notation : $\hat{Y}_{(i-1),1}$ is vector status matrix (position, velocity and acceleration) in campaign or epoch (i-1), $T_{i,(i-1)}$ is prediction matrix, $\overline{Y}_{i,1}$ is vector status prediction matrix in campaign i, $Q_{Y(i-1),Y(i-1)}$ is prediction vector status cofactor matrix in campaign (i-1), $Q_{Yi,Yi}$ is prediction vector status cofactor matrix in campaign i, $\hat{L}_{i,1}$ is GPS true (corrected) data matrix, which it is function of prediction vector status in campaign i as parameter.

Prediction vector status matrix in campaign i is doing by Kalman Filtering Method, with the step like a bellow illustration (Cross, 1983) :

- Value estimation $\hat{Y}_{i,1}$:
  $$\hat{Y}_{i,1} = (A^T_{i,i} P_{i,i} A_{i,i})^{-1} A^T_{i,i} P_{i,i} L_{i,1} \text{ ....(6)}$$
  $P_{i,i}$: weight matrix
- Cofactor matrix $\hat{Y}_{i,1}$:
  $$Q_{\hat{Y}i,\hat{Y}i} = (A^T_{i,i} P_{i,i} A_{i,i})^{-1} \text{ ....(7)}$$
- First vector status matrix :
  $\overline{Y}_{i,1} = T_{i,(i-1)} \hat{Y}_{(i-1),1}$ is equation number (3)
- Kalman gain matrix $K_{i,i}$
  $$K_{i,i} = Q_{\hat{Y}i\hat{Y}i} A^T_{i,i} (P_{i,i}^{-1} + A_{i,i} Q_{\hat{Y}i\hat{Y}i} A^T_{i,i})^{-1} \text{ ....(8)}$$
- Prediction vector status $\overline{Y}'_{i,1}$ estimation value $\hat{Y}_{i,1}$:
  $$\overline{Y}'_{i,1} = \hat{Y}_{i,1} + K_{i,i}(L_{i,1} - A_{i,i} \hat{Y}_{i,1}) \text{ ....(9)}$$
  Cofactor matrix $\overline{Y}'_{i,1}$ is :
  $$Q_{\overline{Y}'_i,\overline{Y}'_i} = (I_{i,i} - K_{i,i} A_{i,i}) Q_{\hat{Y}i\hat{Y}i}$$
- For Iteration, assuming that (i=i+1) dan $\hat{Y}_{i,1} = \overline{Y}'_{i,1}$, so prediction vector status $\overline{Y}_{i,1}$:
  $$\overline{Y}_{i,1} = T_{i,(i-1)} \hat{Y}_{(i-1),1} + N_{i,1} \text{ ....(10)}$$
  $N_{i,1}$: *noise*

- Cofactor Matrix $\overline{Y}_{i,1}$:

$$Q_{\overline{Y}i,\overline{Y}i} = T_{i,(i-1)} Q_{Y(i-1),Y(i-1)} T^{T}_{(i-1),i} + Q_{NNi,i} \quad \ldots\ldots(11)$$

For the smoothing, we used :

$$\overline{Y}_{(i-1),1} = \hat{Y}_{(i-1),1} - (A^{T}_{(i-1),(i-1)} P_{(i-1),(i-1)} A_{(i-1),(i-1)})^{-1} T^{T}_{i-1,i} A^{T}_{i,i} G_{i,1} \quad \ldots\ldots(12)$$

$$G_{i,1} = -(P^{-1}_{i,i} + A_{i,i}(A^{T}_{i,i} P_{i,i} A_{i,i})^{-1})(L_{i,1} - A_{i,i}\hat{Y}_{i,1})$$

5. SLIP SURFACE ESTIMATION

The landslide zone have three characteristic of movement or displacement mechanism, namely the top, middle and toe of landslide zone. The top of landslide zone have indication that material displacement has tendency to subsidence (negative vertical displacement higher than horizontal displacement) or sinking or a crack. The middle of landslide zone, the material has tendency to sliding with horizontal displacement higher than negative vertical displacement. The toe of landslide zone, the soil in the lowest of the slope (toe) has tendency to accumulation and become a bulging because positive vertical displacement higher than horizontal displacement.

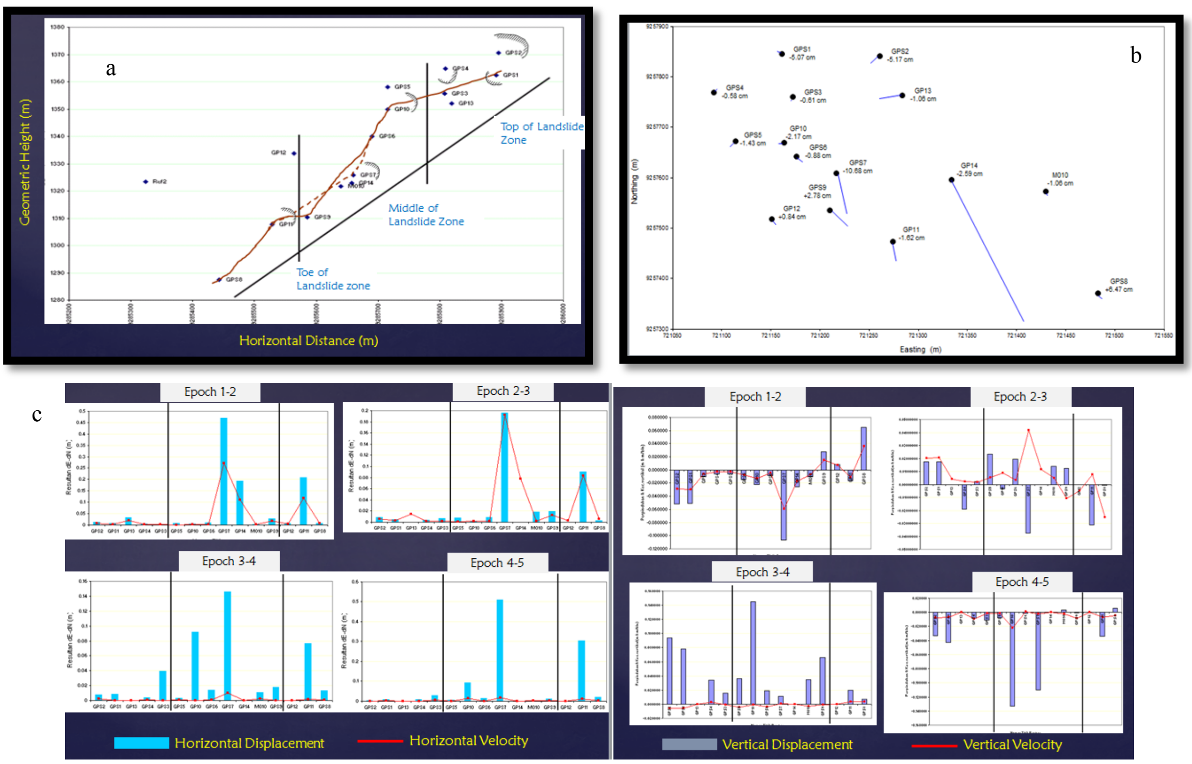

Figure 5. a. Landslide Zone Dividing b. Horizontal Displacement Vector c. Vector Status of The Kinematic Model (Sadarviana, 2006)

The Ciloto landslide zone is major-zone of landslide hazard. There is have several minor-zone in a major-zone. Each of zone has a same indication of characteristic. A crack usually indicate a the top of landslide zone, major either minor zone, define as minor scarp. If we interpretate the vertical displacement of the each monitoring point so we will find several minor scarp location, can be seen in Figure 6. The field check is needed to get the truth of that interpretation. The facts give a clue that number of a scarp same as number of slip surface. That conclusion support with another assumption that one slip surface effect to similar direction of the monitoring point displacement. As the Ciloto landslide zone have various of displacement direction so the Ciloto zone have more than one slip surface.

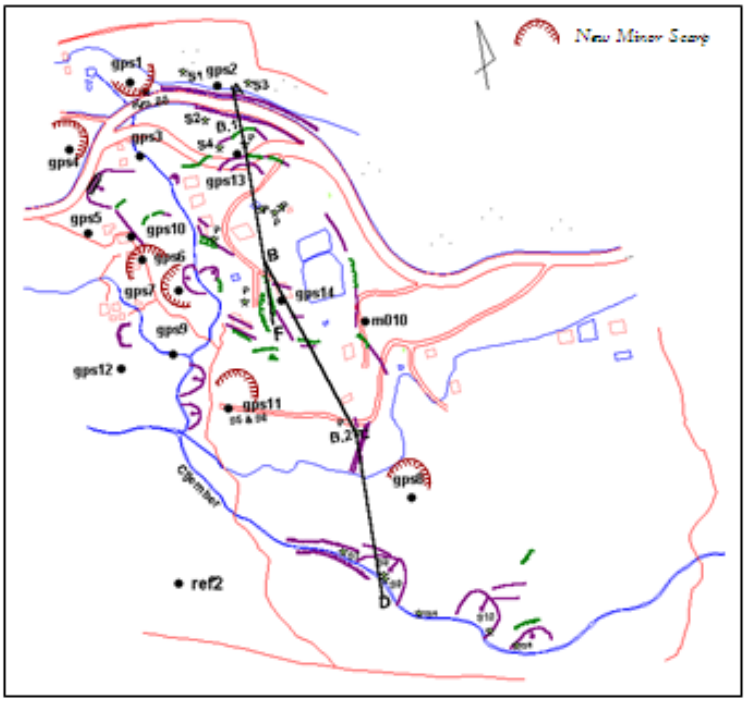

Figure 6. Interpretation of Minor Scarp Location (Sadarviana, 2006)

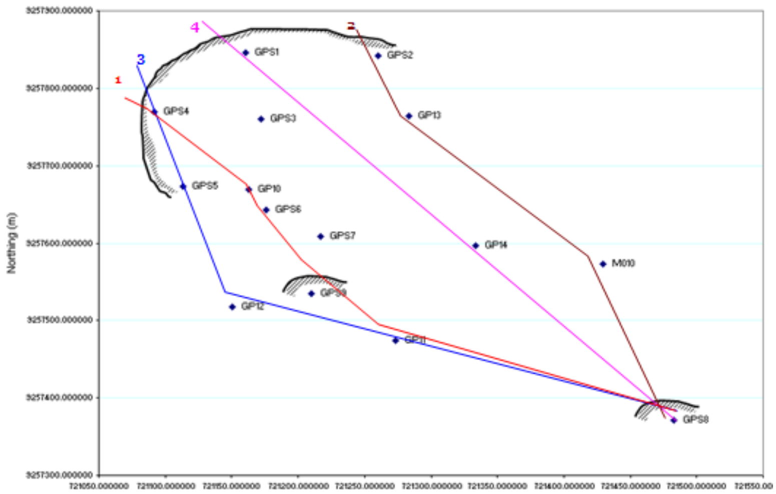

Figure 7. Cross Section Line Based on The Same Direction of Horizontal Displacement (Sadarviana, 2006)

In figure 7, line of cross section made by the similarity direction identification of horizontal displacement. We got four cross section lines.

By the result of kinematic model, we can make displacement Velocity Trend Line (VTL) for each monitoring point of a cross section line. We use assumption that all material have same velocity on the same plane of slip surface. So we need an intersection of VTL. The illustration of slip surface formation can be seen at bellow figure.

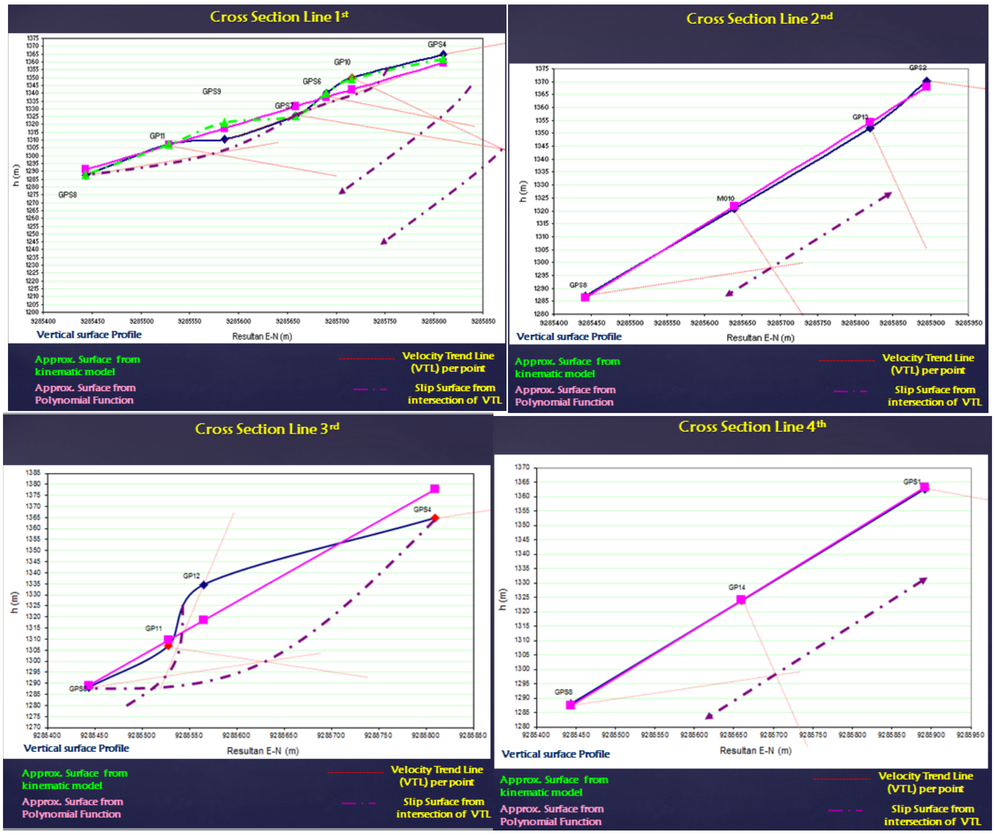

Figure 8. The illustration of Slip Surface Formation by VTL Intersection

By the graphic, the depth of slip surface around 5 metres until 60 metres. If we integrated of slip surface estimation from 4 cross section lines, we will get the geodetic estimation of slip surface. For the validation, geodetic method to geometric estimation of slip surface will be compared to slip surface from geology method to physical approach in ciloto landslide zone. The illustration can be seen in figure 9.

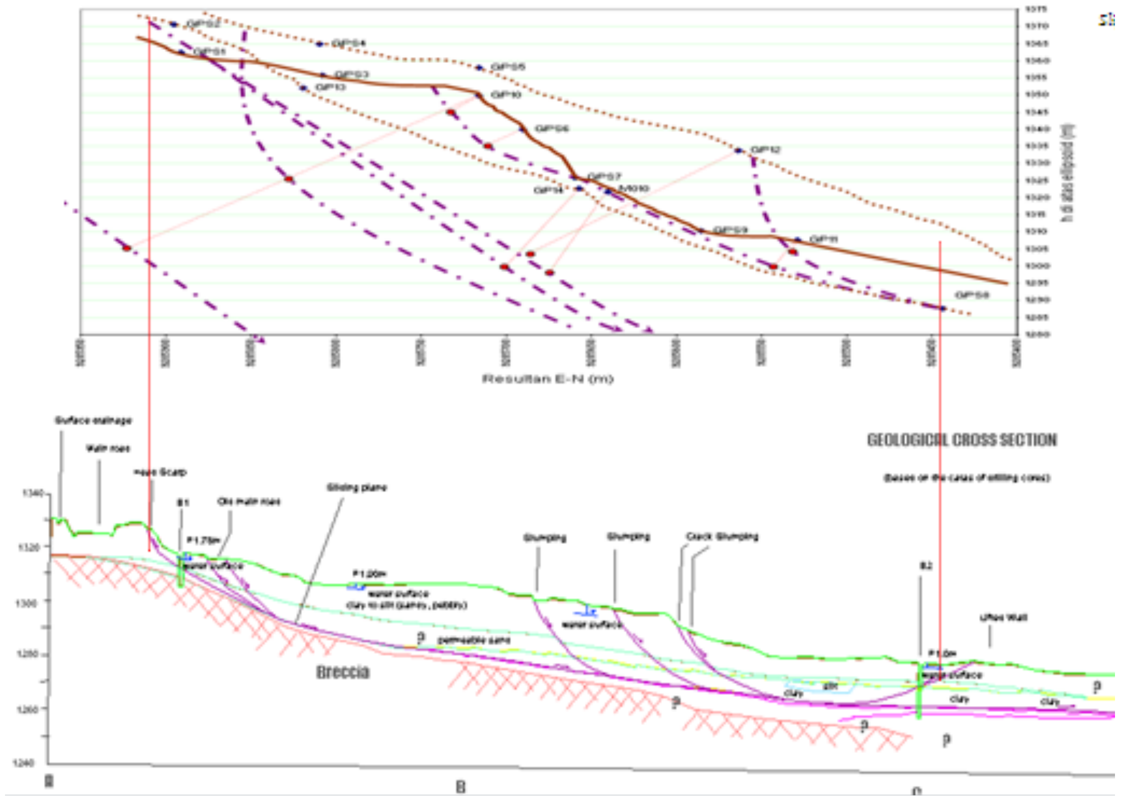

Figure 9. Comparison of Slip Surface from Geology and Geodetic Method (Sadarviana, 2006 and Sugalang, 1989)

6. DISCUSSION

Ciloto landslide zone have two kind of slip surface, namely circular and planar. The mechanism of soil movement is rotational and translation or compound type. Each of monitoring point could had a different direction of displacement in every campaign. It mean that one monitoring point can be on more than one slip surface. In left side of zone, there is scarp which it's shape is curve and topography profile is hilly. It is indication of rotational slip surface. In right side of zone, we did not found a scarp and topography profile is smooth slope. That is indication of translational slip surface.

From geology investigation, we know a material of slope is debris type. Accordingly, Ciloto landslide zone map and minor scarp location in Sugalang's research report at 1989, we were plotting minor scarp interpretation on the same map. The all scarp plotting almost have same location and there are new scarp developing (retrogressive landslide). See illustration in Figure 6. Soil movement velocity is 5 x 10-5 to 5 x 10-7 mm/second (very slow). Validation is done by comparison geodetic slip surface (result of geodetic method estimation) and slip surface use geology research which is done by Sugalang (1989) in same location.

7. CONCLUSION

By geodetic data, soil movement can be quantified and identified new phenomenon in landslide zone like as new scarp or crack and known displacement vector and velocity of soil.

Characteristic of Ciloto landslide zone include in very slow category 5 x 10-5 – 5 x 10-7 mm/second and various direction of movement.

Geometric method can be used to a location and shape of slip surface estimation by intersection of Velocity Trend Line (VTL) of each monitoring point. Slip surface by Geodetic and physic method give a good conformity. Type of landslide zone is multiple compound (rotational and translational) debris slides.

REFERENCES

Abidin H.Z., I.Gumilar, V. Sadarviana, M. Sulaiman, I.H. Hasibuan, E. Kriswati, (2012): 3D Modeling of Manmade Structure and Natural Object use TLS Case Study : Ciloto Landslide Zone, ITB East Auditorium and Pasupati Fly-over, Research Report, Geodesy and Geomatic Department, FITB, Institute of Technology Bandung.

Abidin H.Z., Andreas H., Gamal M., Kusuma M.A., Darmawan D., Surono, Hendrasto M., and Suganda O.K., (2005): Studying Landslide Displacements in Ciloto Area (Indonesia) Using GPS Survey Method, Journal, Spatial Science,

Abramson L.W., Thomas S. L., Sharma S., and Boyce G.M., (1996) : Slope Stability and Stabilization Methods, Edition I, 629 Page, Canada, John Wiley & Sons Inc.

Anghel S., R. Paulica, B. Nicolae, and L.Irina, (2001): New Concept in Slope stability analysis, Journal, URL http://www.ins.itu.edu.tr/2001/abstract%5c2317.htm, date 06/04/2002, Technical University Gh.Asachi, Romania.

Dikau R., Brunsden D., Schrott L., and Ibsen M.L., (1996) : Landslide Recognition-Identification, Movement and Causes, Report No.1 of the European Commission Environment Programme, John Wiley and Sons, Chichester-England.

Hasibuan Ilman, Hasanuddin Z.A. , Irwan Gumilar, Vera Sadarviana (2012): Using of Laser Scanner Technology for Data Availability of Landslide Monitoring, Minithesis, Geodesy and Geomatic Department, FITB, Institute of Technology Bandung

Japan Landslide Society (JLS), (1995): Landslide in Japan, Journal, http://www.tuat.ac.jp/~sabo/lj/image/ ljhome.gif, date 26/03/2002, National conference of landslide control.

Nugraha Agung, Hasanuddin Z.A. , Irwan Gumilar, Vera Sadarviana (2013): Landslide Monitoring use Terrestrial Laser Scanner Technology at Ciloto Area (Cianjur), Minithesis, Geodesy and Geomatic Department, FITB, Institute of Technology Bandung

Purnomo H., (1993) : Land Movement Monitoring at Ciloto Area, Kabupaten DATI II Cianjur West Java, Field Report, Bandung, Division of Environment Geology,

Dirjen of Geology and Mineral Resources, Department of Mining and Energy.
Sugalang, (1989) : Landslide in Ciloto Area West Java Indonesia, Thesis, 72 Page, Sweden, Department of Soil Mechanics, Luleå University of Technology.
Yalcinkaya M. and T. Bayrak, (2004) : Comparison of Static, Kinematic and Dynamic Geodetic Deformation Models for KutlugÜn Landslide in Northeastern Turkey, Journal, Natural Hazard 34, Page 91-95.
Zâruba Q. and Vojtêch Mencl., (1969) : Landslides and their Control, 193 Page, Prague, Czechoslovak Academy of Sciences.

BIOGRAPHICAL NOTES

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