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ORIGINAL ARTICLE

Horizontal and Vertical Movement Indicate a Slip Surface at Landslide Area Derived by GPS Data Campaign and Visualized by TLS Data

Case Study: Ciloto-Puncak, West Java

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Abstract: Knowledge of movement vectors and slip surface site can prevent landslide and get safety evacuation. The movement vectors give information like as stable and unstable soil or materials, direction and speed of materials movement on the slope. The vectors visualize as a horizontal and vertical materials movement. By kinematic model, the vectors show a slip surface site. So we can use that information to technical step of disaster risk reduction, like wall installation to keep settlement safety from avalanches.

The data visualization and computation can show landslide phenomenon. By visualization, landslide identified from soil crack or scarp, and material displacement or deformation. Scarp is a scar of exposed soil or materials in the landslide area. Terrestrial Laser Scanner (TLS) Image can find a landslide area. By calculation, the kinematic model will give vector of movement, including the direction, speed and acceleration of materials movement with GPS data campaign.

The horizontal movement vector put in motion by measure and direction of slip surfaces which the landslide area has. The Ciloto landslide area has many direction of horizontal movement vector. The vertical movements show a shape of slip surface. The Ciloto slip surface compound between several translational and rotational type. Material speed and acceleration about 5.68 cm/month and 0.80 cm/month2, very slow movement, in Ciloto landslide area. Ciloto area has a creep type of landslide.

Keywords: Landslide, Kinematic Model, Slip Surface

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1. Introduction

Generally, people living in disaster areas have specific characteristics. Most of them inhabit the area because they have no other choice for a place to live. Usually they live with a simple economy and accept the situation as the fate of a given god. One of the efforts to improve the situation is to cut the risk of disaster or prevent a disaster. With increased security of residence and greater life opportunities then they will have want to improve life quality again.

The points monitoring movement can show landslide phenomenon, expressed by horizontal movement (ΔX, ΔY) and vertical movement (Δh). This analysis method suitable for implementation to slow velocity landslide area. The characteristic of landslide defined from pattern of soil or materials movement vector (mechanism) and it have relation to slip surface place. Type of landslide will defined from diversity of materials forming the slope and soil or materials movement mechanism. It is have relation with vertically landslide slope anatomy which is consisting of unstable materials, slip surface site and undisturbed or stable materials. In the anatomy of one area of the slip surface, unstable materials divided into scarp at the crown, materials movement body and toe. Slip surface denote a border between unstable materials and stable materials, as sliding plane. Estimation of slip surface have already done by GPS (Global Positioning System) data campaign and validated by geology result (Sadarviana V., 2006).

Geometrically, the horizontal and vertical movements have correspondent to number and type of slip surfaces. The symptoms will be visualized at the topography surface and recorded by the Terrestrial Laser Scanner (TLS). With information on the movement of slope materials and exist the slip surfaces then we can conduct disaster risk reduction appropriately. The steps analysis can be seen in below figure.

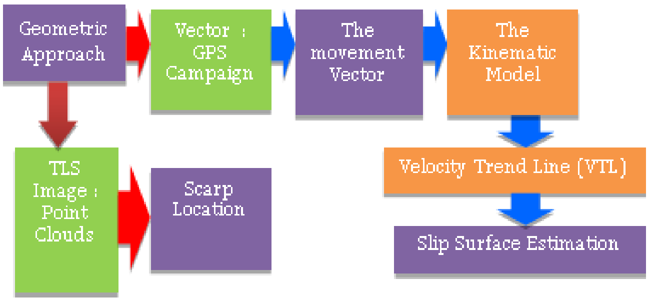

Figure 1. Logic of the Analytical Method

2. Study Area

The site has geography coördinate at 107°00′00″-107°00′20″E and 06°42′40″- 06°43′00″S at kilometer 88.1 Cianjur-Puncak traffic line in Kampung Baru Puncak, Ciloto Village, sub-district of Pacet, district of Cianjur, and West Java. Ciloto landslide zone has about 40 hectares. The base material of this area is a material quarter that has undergone weathering volcanic tuff breccia's 3-7 meters. 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. Ciloto Peak Region has five morphology groups, namely:

- Complex I : Gunung Lemo
- Complex II : Pondok Cikoneng, Gunung Mas, Gunung Gedogan, and Gunung Jongklok
- Complex III : Puncak, Jember and the surrounding areas
- Complex IV : Sindanglaya areas
- Complex V : the slope of Cempaka hillsides, Tugu

Puncak

A rock-forming region domination consist of pyroclastic deposits, which originated from the mountain Megamendung. Pyroclastic deposits consist of alternating between tuffaceous sandstone, limestone, breccia and agglomerate. While the sandy loam soil and silt loam there weathering form generally brown-black, medium-high plasticity, and firm consistency.

The Gunung Lemo, complex Pondok Cikoneng, Gunung Mas, Gunung Gedogan and Gunung Jongklok regions become trap. That will accumulate on the Cijember River which then becomes ground water. Cijember local groundwater from this will flow through the narrow water-bearing layers causes increased pressure on local ground water (Purnomo, 1993). Sub Watershed (DAS) Cijember describe the slope condition is quite active and we see as presence of cracks and irregular assistance ladder (Panggabean, 1998). While significant surface water on the landslide area is water from the rivers that have Cijember 1 meter wide and 0.5 to 0.75 m depth width valley with a depth of 20 meters and 7-10 meters. Ground water influence landslides in this area appear at the bottom with a discharge that is big enough that some a small channel through in. Several springs also emerged in the slope-buckling curve, among them large enough to have a debit ± 20 liters per minute, which is located on the eastern slope of landslide area. Local hydrological conditions are not influenced by season; this is proven by the amount of water that flows continue throughout the year. Several springs flowing into the Cijember River. Based on rainfall data from the Balai Pertanian Cigunung, Kabupaten Cianjur showed that the area of Kampung Baru, Ciloto have averaged the highest annual rainfall in 1993. The monthly rainfall, in October to March has the highest level.

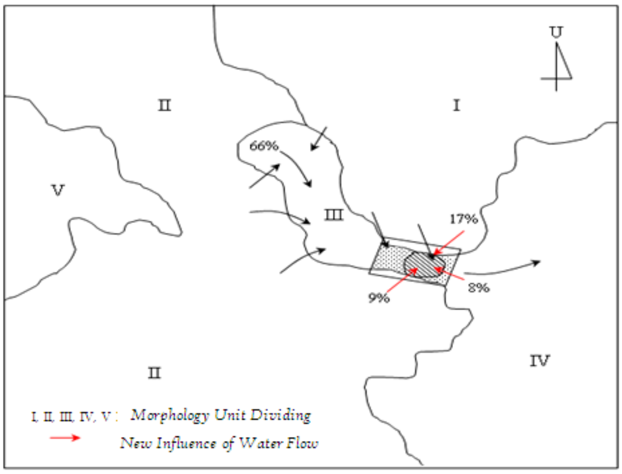

Figure 2. Morphology Units of Ciloto Area (Sugalang, 1989 and Sadarviana, 2006)

Figure 3. Ciloto Landslide Area, The red points are Equipment Stationing (Nugraha, 2013)

In Ciloto area have population density around 626 man/km2 (based on population census at 2007). People have main jobs in the agricultural

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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. Methodology

The equipment is Leica Scanstation C10 which have capabilities to acquisition data as height density and correct points cloud in practice ways. At beginning, we have two campaign TLS acquisition data at April and October 2012. Further, we observed 2 campaign TLS acquisition data at April and September 2013. We get 4 series 3D surface and intensity map. The observation at 2013 we measured 10 stationing points with GPS.

The TLS's image show land cover from the variously of intensity reflecting wave. The next process is filter all of object over the surface and we get a terrain surface or 3D surface. By combining of 3D surface, we have a relative movement 3D surface. For the estimation of slip surface site, we need relative movement of several sample point in order that we can get speed of material movement for each sample monitoring point. There for we should define a coördinate of sample point and there's movement. But we difficult to get sample point and define it's coordinate because so many point clouds and we cannot give code for monitoring.

With the stationing points as a sampling and interpolation reference, we hope that we can define a coördinate of point clouds and use it to the slip surface site estimation. The principle, we need to monitored a movement of the same point or object. In TLS point clouds, we difficult to identification of the same point or object. A framework of TLS and GPS data acquisition can be seen at figure 4

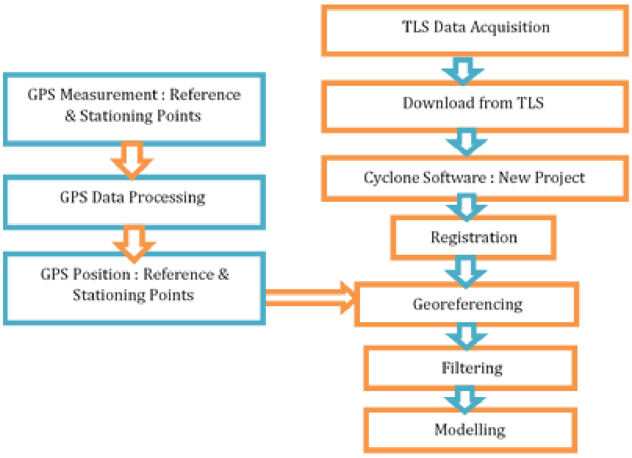


Figure 4. Framework of Data Acquisition and Processing

Mathematic model process the GPS Data campaign in table 2 and Kalman Filtering. Five GPS data campaign are computed by kinematic model and gave the output a velocities and materials acceleration.

Data obtained from five campaigns by GPS measurement 2002-2005 to 15 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. Model Mathematic of Geometric Method for Monitoring Points Vector

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 directio
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 positio velocity and acceleration to time

In Yalcinkaya M. and T. Bayrak (2004) has the equation of static model:

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

In Yalcinkaya M. and T. Bayrak (2004) has the equation of kinematic model:

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

Where dj is movement of the monitoring point, $X_j^{(i)}$ is coordinates prediction of the monitoring point i, $X_j^{(i-1)}$ is observation coordinates of the monitoring point j at period (i-1), V_{xj} is the movement velocity monitoring point from data survey, a_{xj} is the movement acceleration monitoring point from survey data, t_i and $t_{(i-1)}$ is time of survey campaign i and (i-1).

Horizontal direction classification is use for estimation of slip surface by direction similarity. We set up of slip surface site, shape and size by Velocity Trend Line (VTL) for each monitoring point. The intersection point of two VTL, we can estimate points coördinates as one point of slip surface curve or line. The further, there are shape a slip surface and we can get their site (how depth they are).

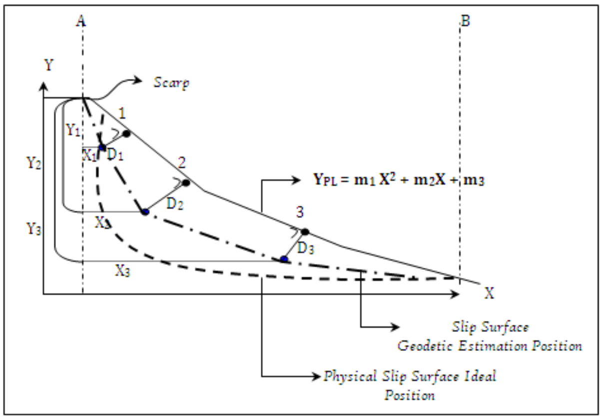


Figure 5. Idea of Estimation of Slip Surface Position (Sadarviana, 2006)

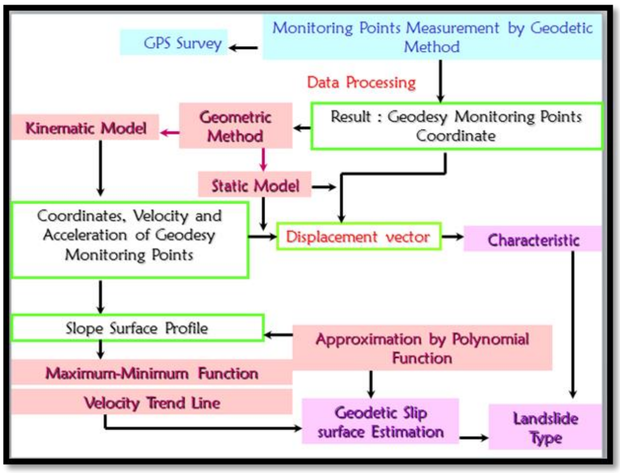


Figure 6. Scheme of Slip Surface Estimation (Sadarviana, 2006)

Status of movement vector will be analyzed from two perspective, namely horizontal (two dimensional coordinates function: easting-northing) and vertical perspective.

Further, the next computation step can see bellow.

$$\bar{Y}_{i,1} = T_{i,(i-1)} \hat{Y}_{(i-1),1} \tag{3}$$

$$Q_{Yi,Yi} = T_{i,(i-1)} Q_{Y(i-1),Y(i-1)} T_{i,(i-1)}^T \tag{4}$$

$$\hat{L}_{i,1} = L_{i,1} + v_{Li,1} = A_{i,i} \hat{Y}_{i,1}$$

$$v_{Li,1} = A_{i,i} \hat{Y}_{i,1} - L_{i,1} \tag{5}$$

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, $\bar{Y}_{i,1}$ 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 $\hat{Y}_{i,1}$:

$$\hat{Y}_{i,1} = (A_{i,i}^T P_{i,i} A_{i,i})^{-1} A_{i,i}^T P_{i,i} L_{i,1} \quad (6)$$

$P_{i,i}$: weight matrix

Cofactor matrix $\hat{Y}_{i,1}$:

$$Q_{\hat{Y}i,\hat{Y}i} = (A_{i,i}^T P_{i,i} A_{i,i})^{-1} \quad (7)$$

- First vector status matrix :

$\bar{Y}_{i,1} = T_{i,(i-1)} \hat{Y}_{(i-1),1}$ is equation number (3)

- Kalman gain matrix $K_{i,i}$

$$K_{i,i} = Q_{\hat{Y}i\hat{Y}i} A_{i,i}^T (P_{i,i}^{-1} + A_{i,i} Q_{\hat{Y}i\hat{Y}i} A_{i,i}^T)^{-1} \quad (8)$$

- Prediction vector status $\bar{Y}'_{i,1}$ estimation value $\hat{Y}_{i,1}$:

$$\bar{Y}'_{i,1} = \hat{Y}_{i,1} + K_{i,i}(L_{i,1} - A_{i,i}\hat{Y}_{i,1}) \quad (9)$$

Cofactor matrix $\bar{Y}'_{i,1}$ is :

$$Q_{\bar{Y}'_i,\bar{Y}'_i} = (I_{i,i} - K_{i,i} A_{i,i}) Q_{\hat{Y}i\hat{Y}i}$$

- For Iteration, assuming that (i=i+1) dan $\hat{Y}_{i,1} = \bar{Y}'_{i,1}$, so prediction vector status $\bar{Y}_{i,1}$:

$$\bar{Y}_{i,1} = T_{i,(i-1)} \hat{Y}_{(i-1),1} + N_{i,1} \quad (10)$$

$N_{i,1}$: *noise*

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

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

For the smoothing, we used :

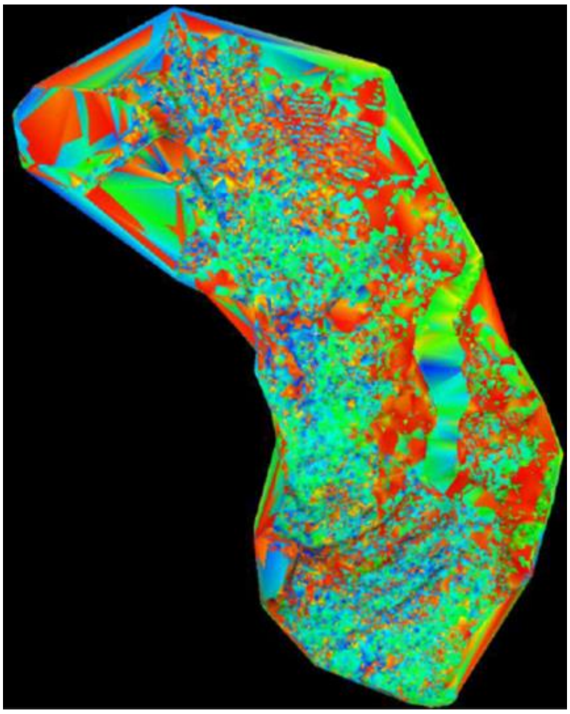
$$\bar{Y}_{(i-1),1} = \hat{Y}_{(i-1),1} - (A_{(i-1),(i-1)}^T P_{(i-1),(i-1)} A_{(i-1),(i-1)})^{-1} T_{i-1,i}^T A_{i,i}^T G_{i,1} \quad (12)$$

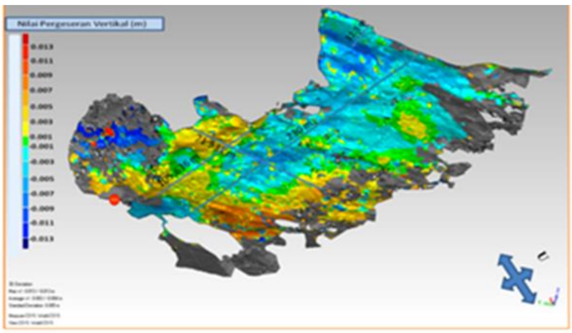
$$G_{i,1} = -(P_{i,i}^{-1} + A_{i,i}(A_{i,i}^T P_{i,i} A_{i,i})^{-1})(L_{i,1} - A_{i,i}\hat{Y}_{i,1}) \quad (13)$$

We can know a minor scarp by two indications, namely horizontal displacement smaller than vertical displacement and negative vertical displacement surrounded by positive vertical displacement. Scarp is place of intersection point between slip surface and slope surface so scarp location used as a starting point of slip surface. An ending point of slip surface is on point that has positive vertical displacement (uplift or bulging)..

4. Result and Discussion

Two kinds landslide analyses are visualization and calculation. TLS measurement visualization is 3D surface and intensity map of Ciloto land cover. TLS data gave relative movement of landslide material from 2 periods by color classification. Intensity map give information of land cover variation. From TLS image, landslide can be identified from soil crack or scarp. Scarp is a scar of exposed soil on the landslide. A crack or minor scarp is identified by high negative vertical movement or sinking or subsidence of the surface. Shape of scarp gives a clue for shape of slip surface. Intensity map give information of land cover variation. In some landslide cases, land cover is major influence to the material movement which contribute to water infiltration. In Intensity Map, Red is high density vegetation, Blue/Green is low density vegetation (Figure 7.)





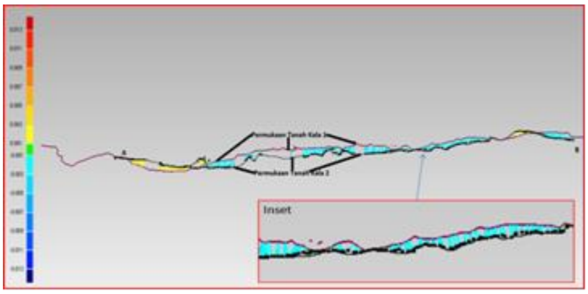


Figure 7. Relative Vertical movement 2 periods in 6 months duration April-October 2012

The monitoring point movement divided into 3 parts so landslide characteristic can be analysed. Part 1, material in the upper slope has tendency to subsidence (negative vertical movement more higher than horizontal movement). Part 2, material in the middle slope has tendency to sliding with horizontal movement more higher than negative vertical movement. Part 3, soil in the lower slope (toe) has tendency an material accumulation and become bulging because positive vertical movement higher than horizontal movement. A high negative vertical movement or sinking or subsidence of the surface show a crack or minor scarp. If we analyse vertical movement and find that mentioned criteria thus we call minor scarp interpretation. In TLS 3D surface, we can see scarp location by identification curve shape like as in figure 6. The shape of scarp is curve, that's clue for the slip surface shape is rotational. There is new scarps show that Ciloto have retrogressive landslide.

From 3D surface, we can got profile of cross-section, like as figure 5. Stationing Points has 2 result from a TLS processing and GPS processing The difference's between GPS and TLS processing is around 3 mm - 30 cm. In stationing, we know movement vector, consist of scalar and direction of movement. The variously of that direction give a clue about number of active slip surface. The analysis give about 5 active slip surfaces when observation was doing. For a slip surface site calculation, we need a point clouds coördinates (TLS). We couldn't know that the coordinate because the coordinates fail to be retrieved from equipment's database. We can see a scarp location which it's head of slip surface (Figure 8.)

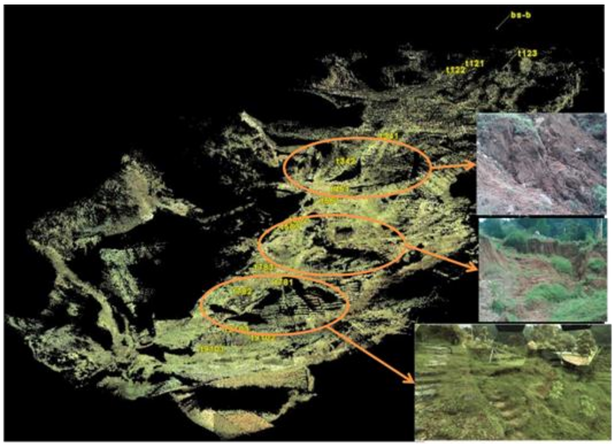


Figure 8. Ciloto 3D Surface and New Scarp Identification

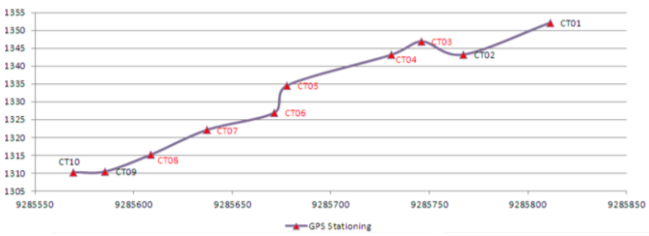
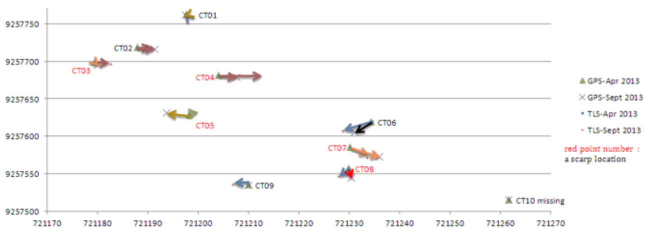


Figure 9. Cross Section Of Equipment Stationing

Variation of the direction horizontal movement are write down some slip surface, include several scarp. The vertical movement of monitoring points can find as the scarp.



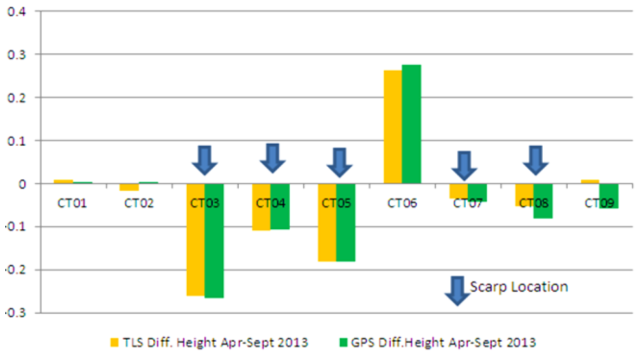


Figure 10. The Analysis of Scarp Number and Position

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 speed on the same plane of slip surface. So we need an intersection of VTL. The slip surface formation can be seen at bellow figure.

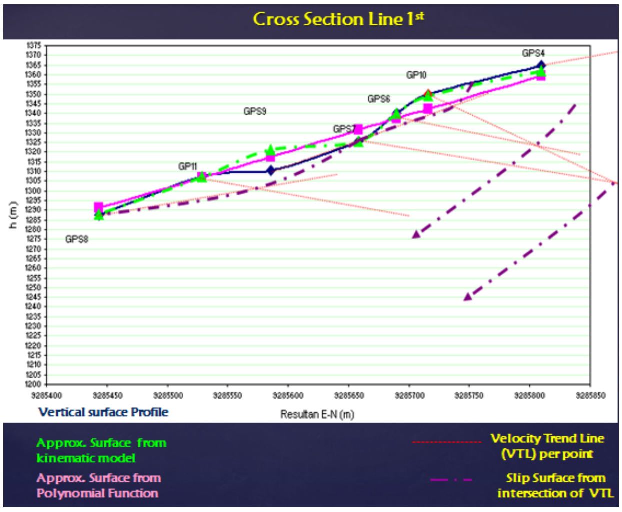


Figure 11. The illustration of Slip Surface Derivation by VTL Intersection

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, we will compare a geodetic method as a slip surface geometric estimation to slip surface from geology method to physical approach in ciloto landslide zone.

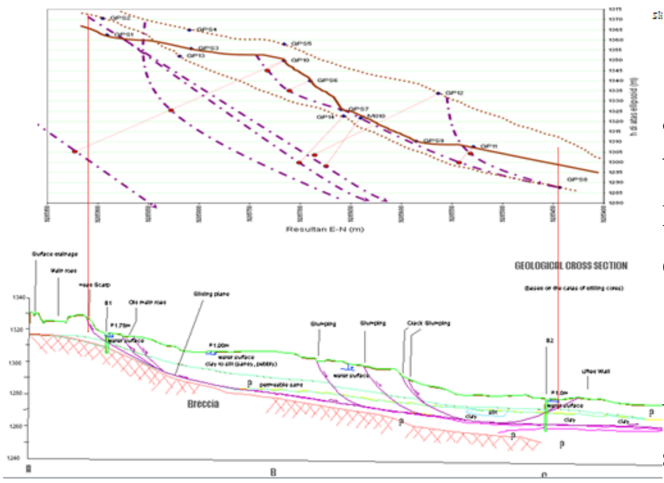


Figure 12. Comparison of Slip Surface from Geology and Geodetic Method (Sadarviana, 2006 and Sugalang, 1989)

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 different direction of displacement in every campaign. It mean that one monitoring point have on more than one slip surface. In left side of zone, there is scarp which its shape is curve and topography profile is hilly. It is sign of rotational slip surface. In right side of zone, we did not find a scarp and topography profile is a smooth slope. That is sign of translational slip surface.

5. Conclusion

By TLS, we get information about intensity map, characteristic of material movement and new scarp location (retrogressive). We can identification of land cover changing from intensity map. Ciloto landslide zone have several of movement direction thus the landslide zone have more than one an active slip surfaces. Ciloto landslide zone have complicated phenomenon because that zone have influence from many direction of ground water level pressure. The pressure is cause generating several slip surface in Ciloto zone. The scarp is curve show that Ciloto have rotational slip surface.

By kinematic model, we can get speed and acceleration of material movement in landslide area. Velocity and acceleration of material in Ciloto landslide area about 5.68 cm/month and 0.80 cm/month2, very slow movement.

By that information we can build a wall or piles with the depth same as the depth of the slip surface site. So we hope that the resident will be safer than before

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