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

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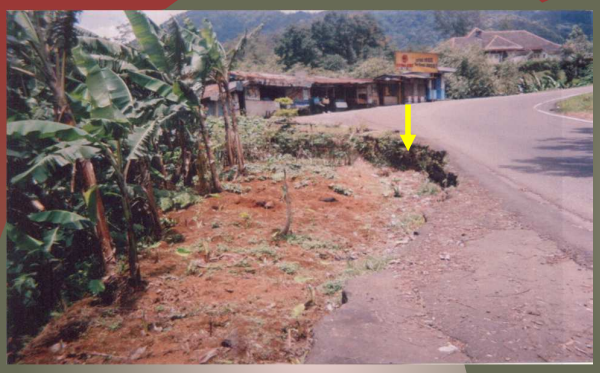
Ciloto zone consist of breccia rock, clay soil, silt soil

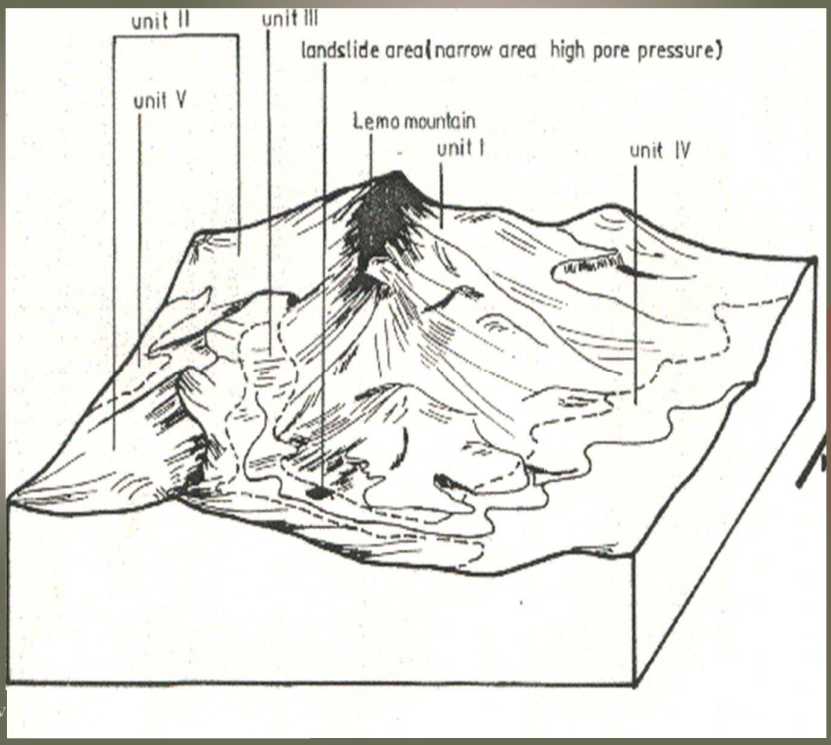
Debris material

Mass Movement Indication in Ciloto Zone



Morphology at Ciloto Area

Unit I : Gunung Lemo Area
Unit II : Pondok Cikoneng Area, Gunung Mas, Gunung Gedogan, and Gunung Joglok
Unit III : Puncak, Jember Area
Unit IV : Sindanglaya Area
Unit V : Cempaka Slope Area, Tugu
(Sugalang, 1989)



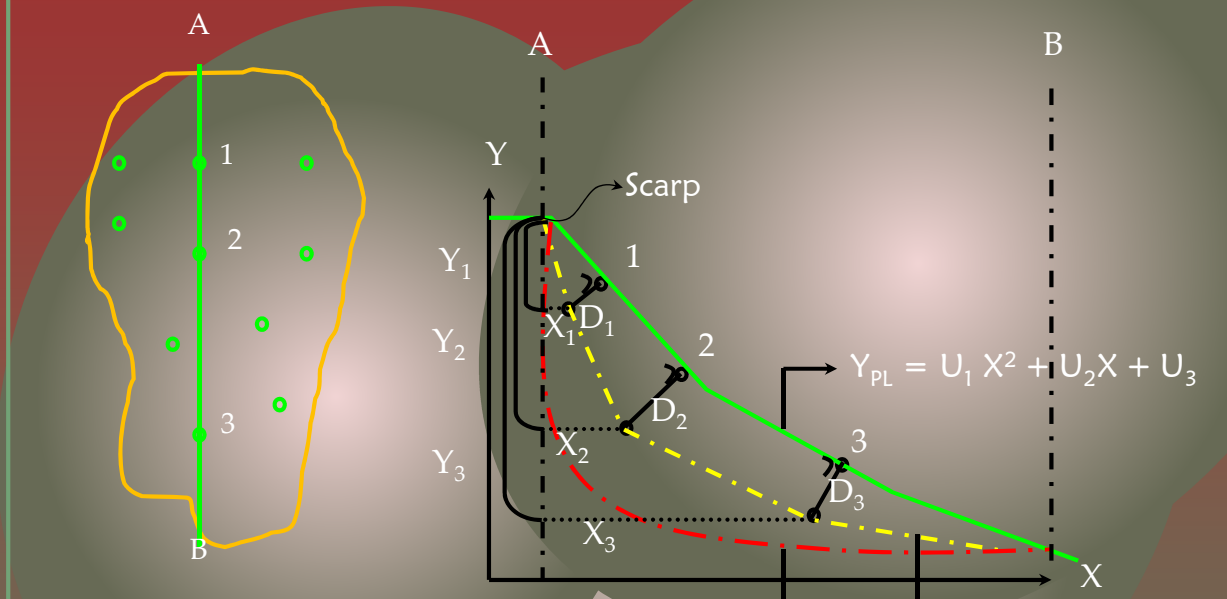
Methodology – Geometric Method

Static model :

- Status vector of horizontal and vertical displacement

Kinematic model :

- Status vector of horizontal and vertical displacement
- Velocity and acceleration of material displacement



Y_{PL} : Slope Surface Equation

D_i : Distance between monitoring points and estimation point on slip surface

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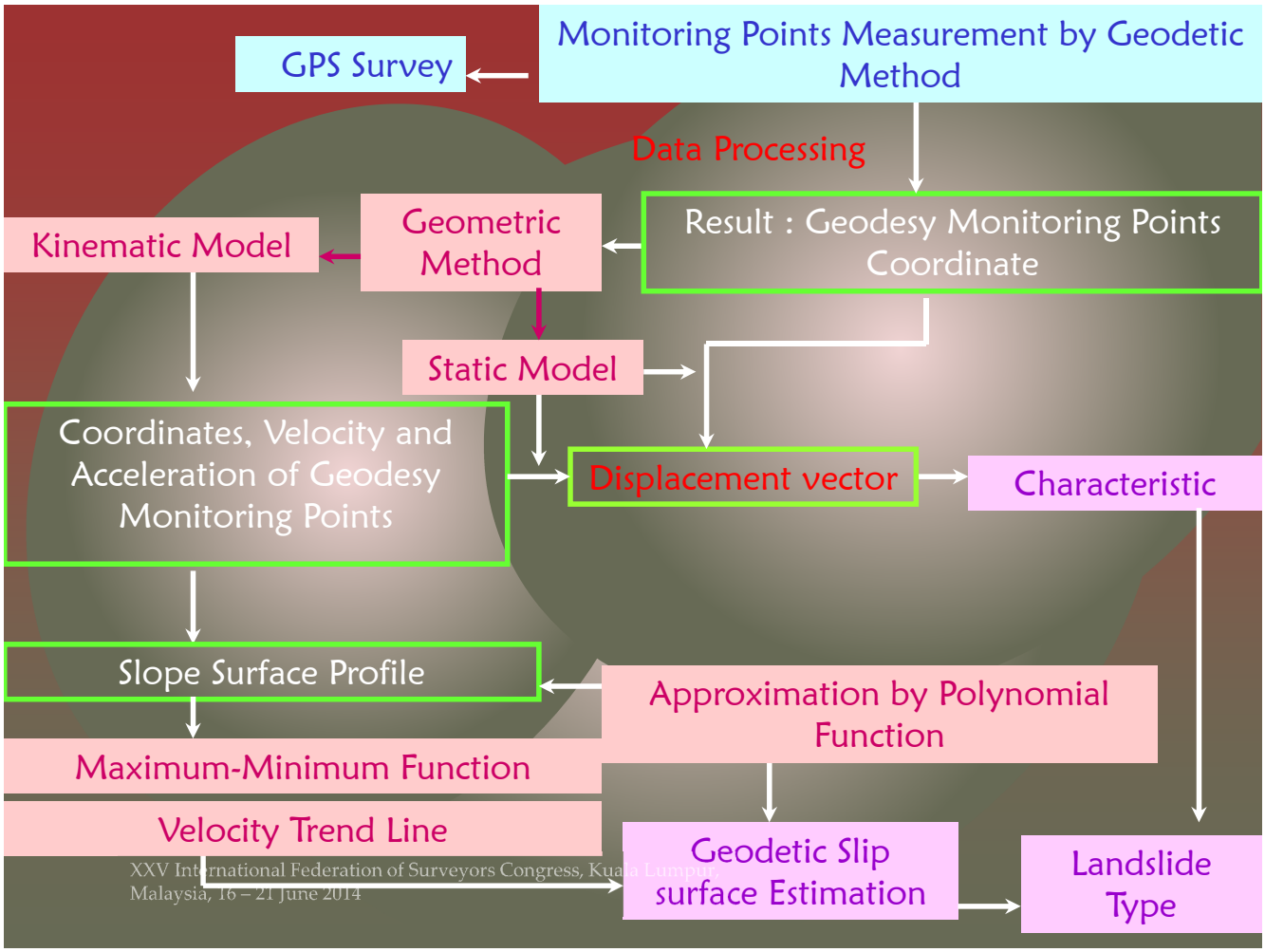
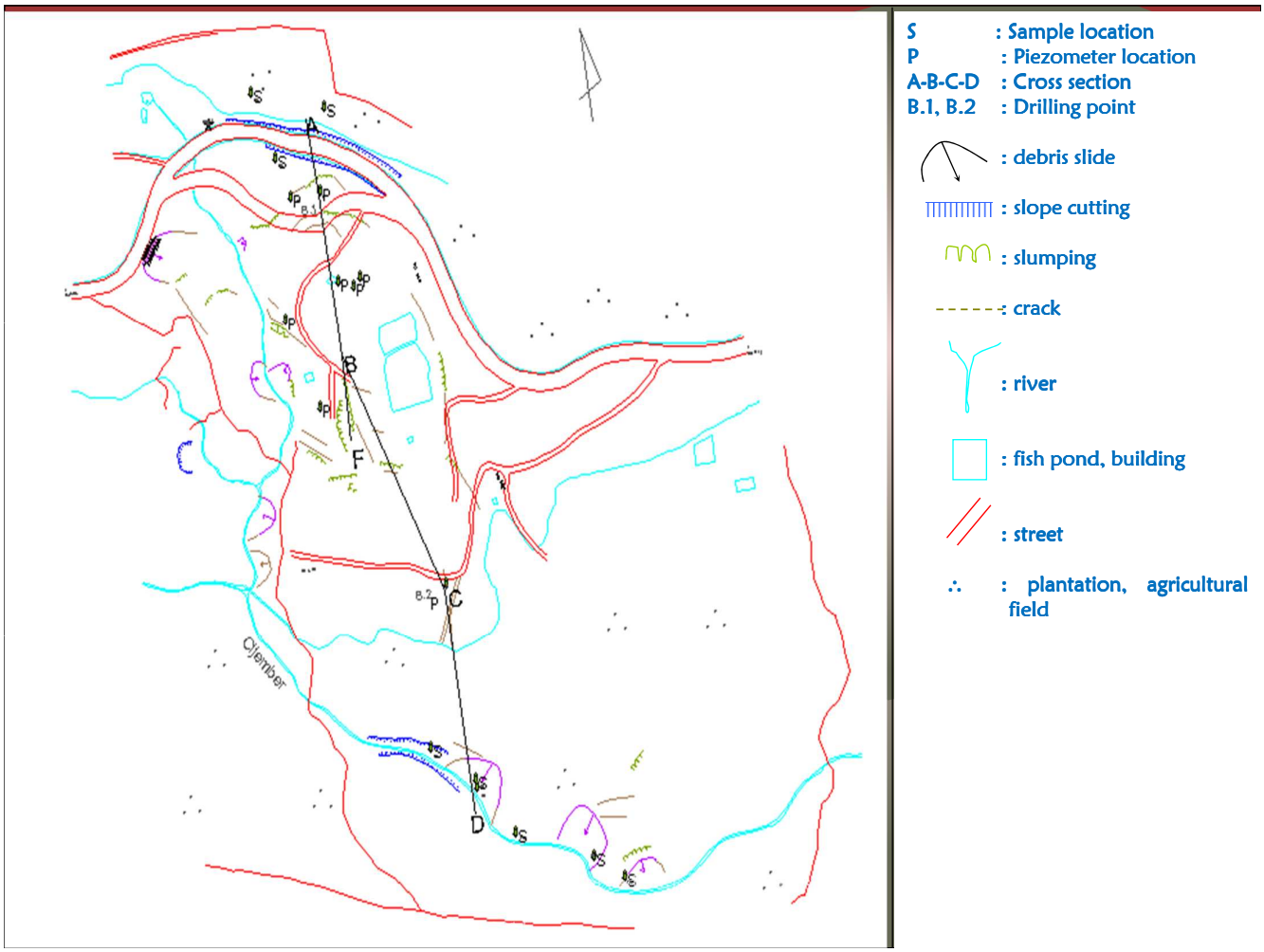
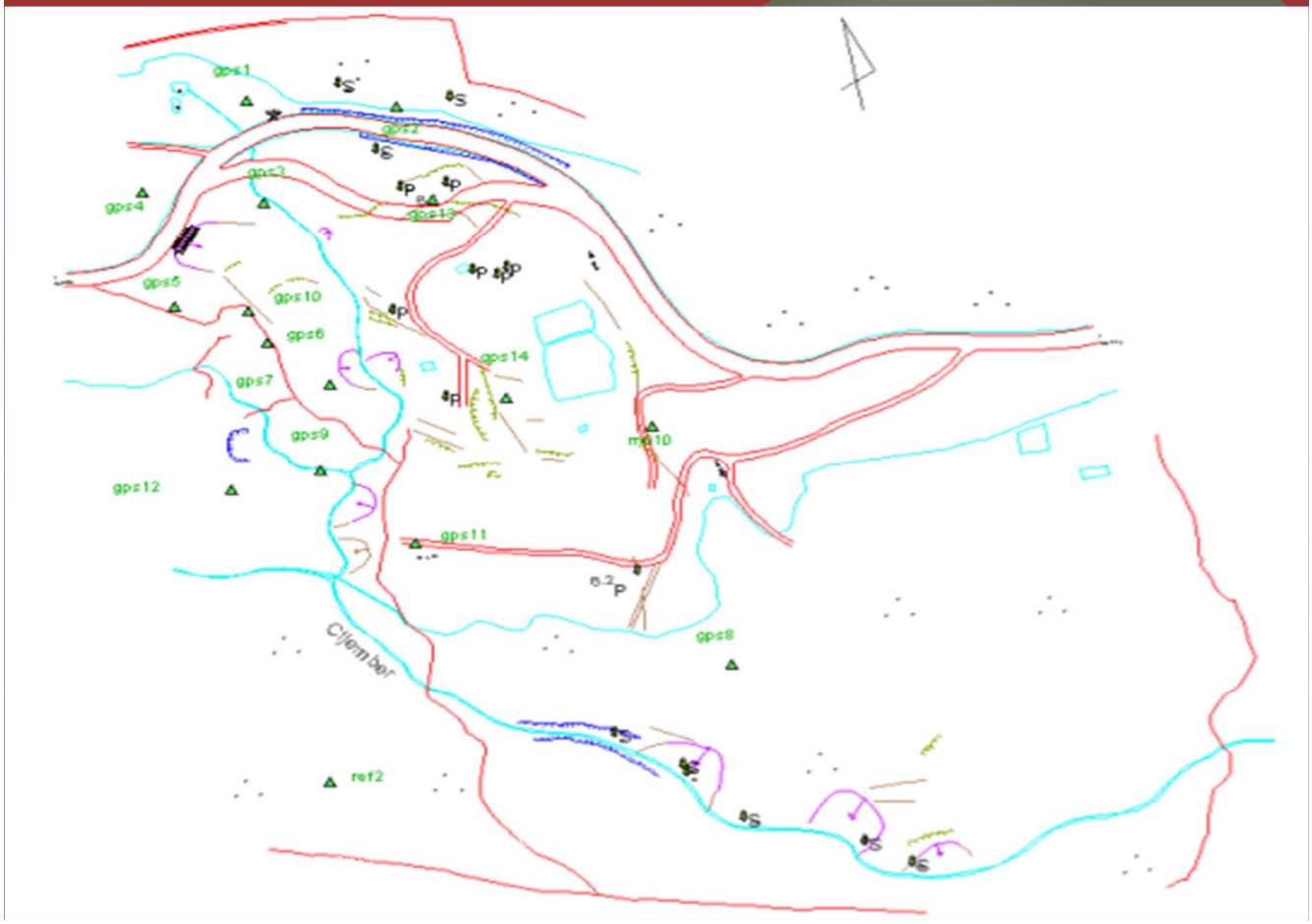

GPS Survey
Monitoring Points Measurement by Geodetic Method
Data Processing
Result : Geodesy Monitoring Points Coordinate
Geometric Method
Kinematic Model
Static Model
Coordinates, Velocity and Acceleration of Geodesy Monitoring Points
Displacement vector
Characteristic
Slope Surface Profile
Approximation by Polynomial Function
Maximum-Minimum Function
Velocity Trend Line
Geodetic Slip surface Estimation
Landslide Type
XXV International Federation of Surveyors Congress, Kuala Lumpur
Malaysia, 16 – 21 June 2014


S : Sample location
P : Piezometer location
A-B-C-D : Cross section
B.1, B.2 : Drilling point
: debris slide
: slope cutting
: slumping
: crack
: river
: fish pond, building
: street
: plantation, agricultural field
A
B
C
D
F
Ojember

GPS SURVEY (2002-2005)



GPS Survey Strategy

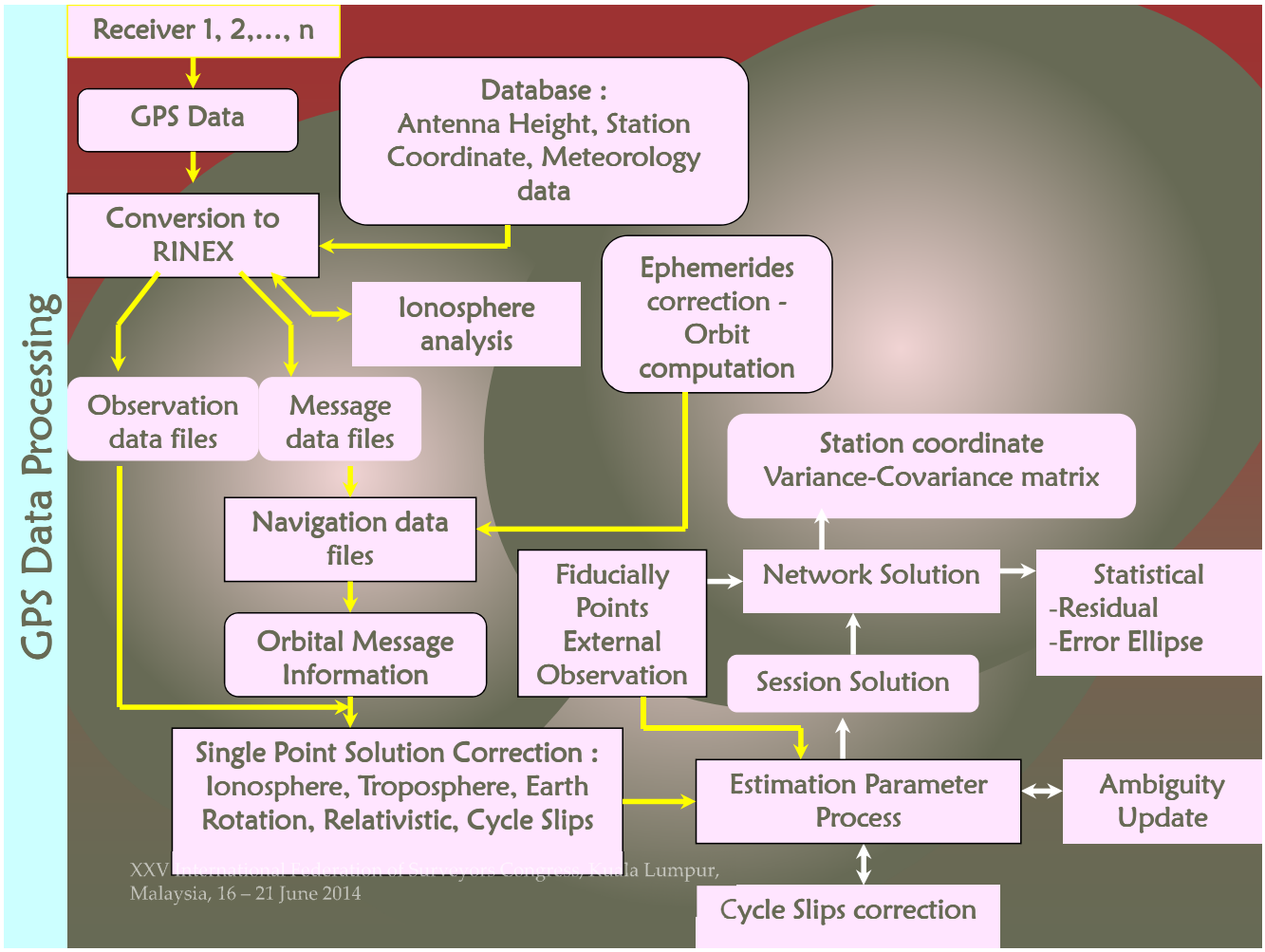
Measurement Method	Differential Static
Equipment Type	Dual Frequency , Geodetic type
Data Type	P and C/A code Carrier phase
Duration	4 - 6 hour
Epoch Interval	30 "
Elevation Mask	15 ^{0}

GPS Measurement Campaign

- Epoch 1 : 21-22 January 2002
- Epoch 2 : 04-05 April 2002
- Epoch 3 : 10 Mei 2003
- Epoch 4 : 14-15 Mei 2004
- Epoch 5 : 03-04 July 2005

GPS Receiver type

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



Kinematic Model

Equations (Yalcinkaya dan Bayrak, 2004) :

$$E_j^{(i)} = E_j^{(i-1)} + (t_i - t_{i-1})V_{Ej} + \frac{1}{2}(t_i - t_{i-1})^2 a_{Ej}$$

$$N_j^{(i)} = N_j^{(i-1)} + (t_i - t_{i-1})V_{Nj} + \frac{1}{2}(t_i - t_{i-1})^2 a_{Nj}$$

$$h_j^{(i)} = h_j^{(i-1)} + (t_i - t_{i-1})V_{hj} + \frac{1}{2}(t_i - t_{i-1})^2 a_{hj}$$

Calculation of vector status prediction (scalar, velocity and acceleration) by Kalman Filtering Method

Kalman Filtering

$$\bar{Y}_{i,1} = \begin{bmatrix} E \\ N \\ h \\ V_E \\ V_N \\ V_h \\ a_E \\ a_N \\ a_h \end{bmatrix}_{i,1} = \begin{bmatrix} I_{3,3} & I_{3,3}(t_i - t_{i-1}) & I_{3,3}\dfrac{(t_i - t_{i-1})^2}{2} \\ 0_{3,3} & I_{3,3} & I_{3,3}(t_i - t_{i-1}) \\ 0_{3,3} & 0_{3,3} & I_{3,3} \end{bmatrix} \begin{bmatrix} E \\ N \\ h \\ V_E \\ V_N \\ V_h \\ a_E \\ a_N \\ a_h \end{bmatrix}_{(i-1),1}$$

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

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

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

Result-1

- Status vector of horizontal and vertical displacement
  - Quantification of material displacement
  - Comparation of displacement characteristic of landslide zone common with single sliding→ head, depletion zone (in middle), accumulation zone (foot-toe) to find movement mechanism →single/succesive/multiple/retrogressive sliding
  - Comparation between horizontal and vertical (negative-positive) displacement of monitored point→terain profile to find minor scarp position, subsidence & bulging → translational/rotational slide

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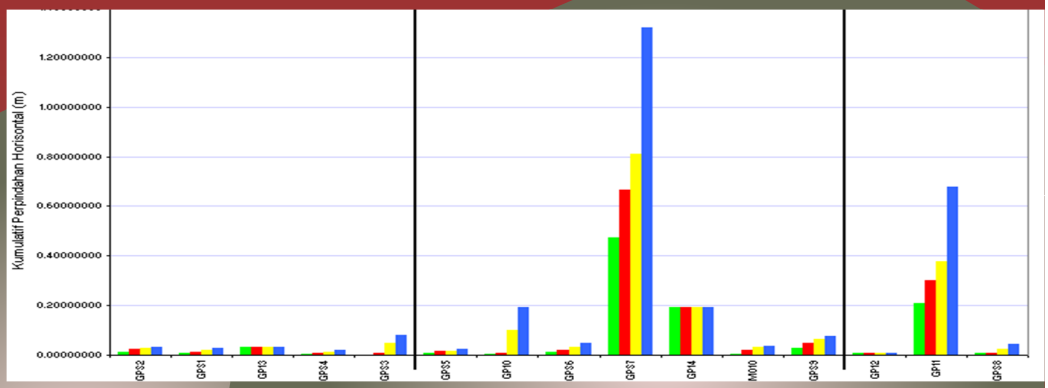
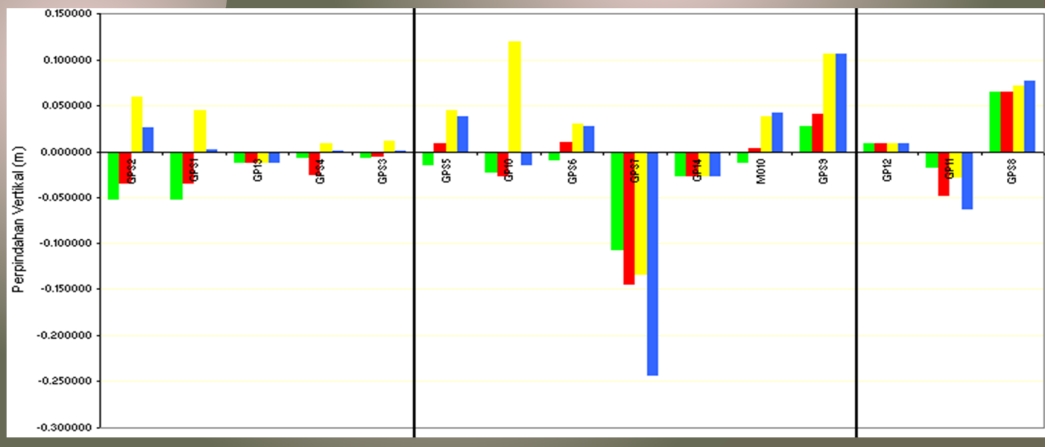
Kinematic M. : Cumulative Horizontal Displacement



Kinematic M. : Cumulative Vertical Displacement



- Epoch 1-2
- Epoch 2-3
- Epoch 3-4
- Epoch 4-5

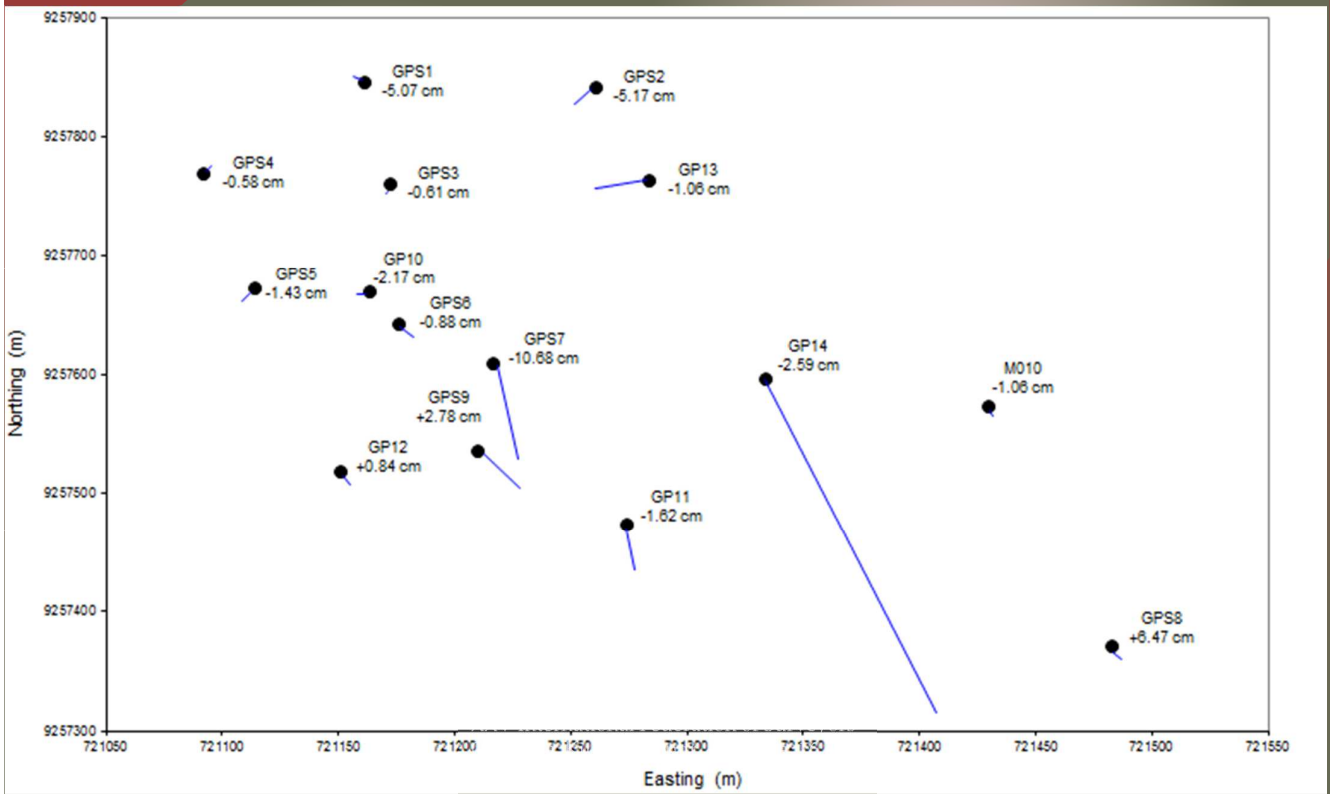
Top of Landslide zone | Middle of Landslide zone | Toe of Landslide zone

Result-2

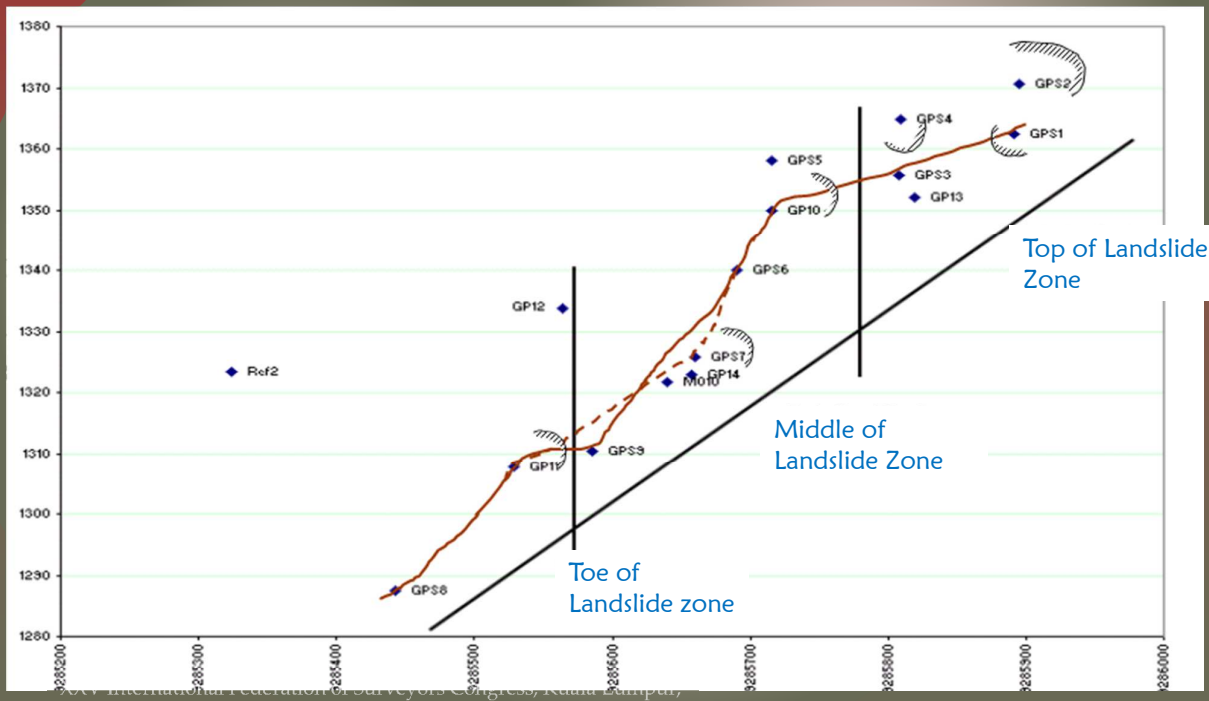
Kinematic Model

- Velocity and acceleration of material displacement
  - High horizontal velocity in depletion zone
  - High vertical velocity in head (vertical -) and accumulation zone (positive +)

Illustration of Horizontal Displacement

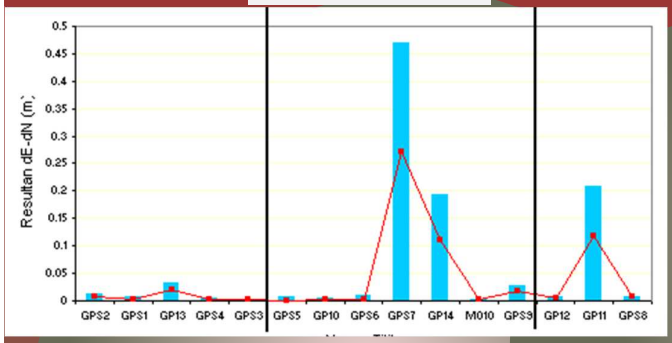


Vertical profile

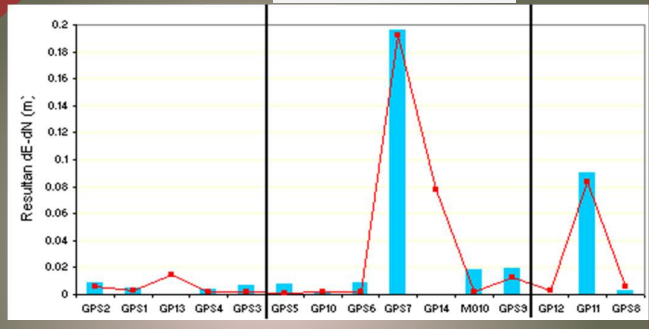


Velocity – Displacement (Horizontal)

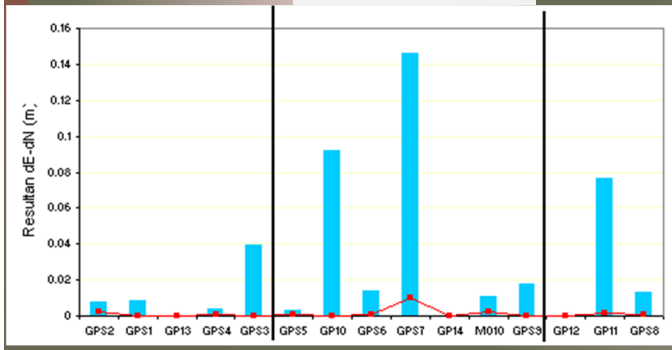
Epoch 1-2



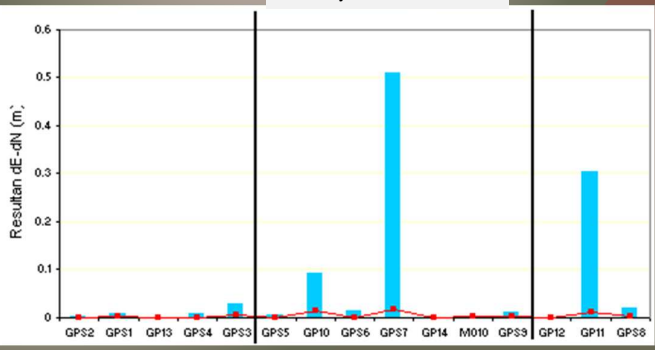
Epoch 2-3



Epoch 3-4



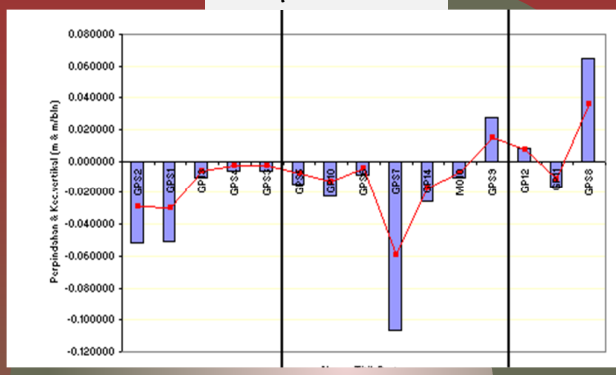
Epoch 4-5



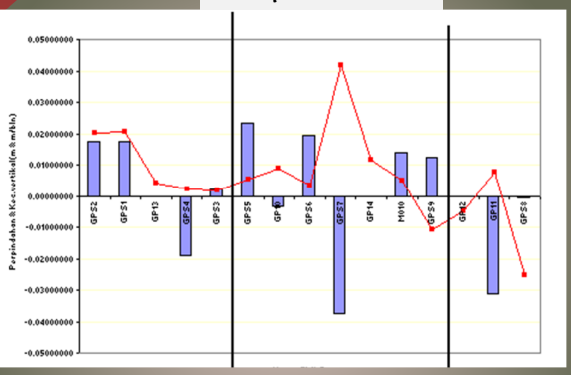
Horizontal Displacement — Horizontal Velocity

Velocity – Displacement (Vertical)

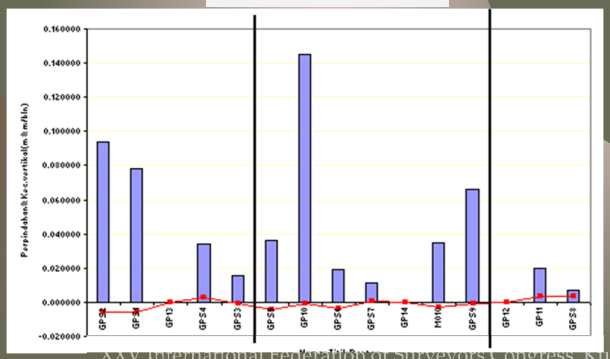
Epoch 1-2



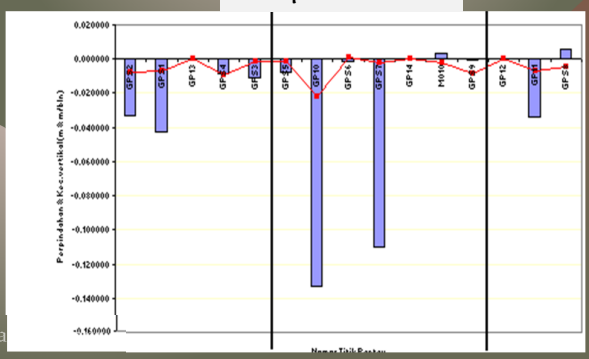
Epoch 2-3



Epoch 3-4

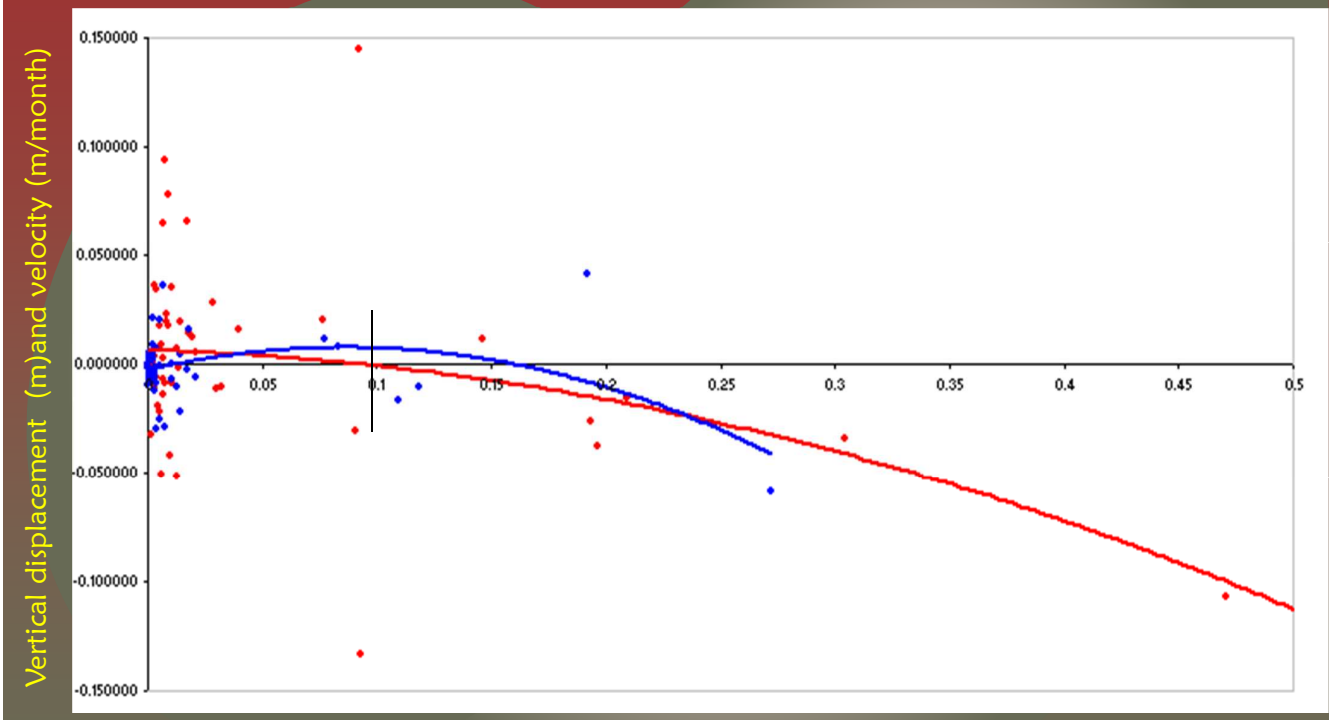


Epoch 4-5



Vertical Displacement — Vertical Velocity

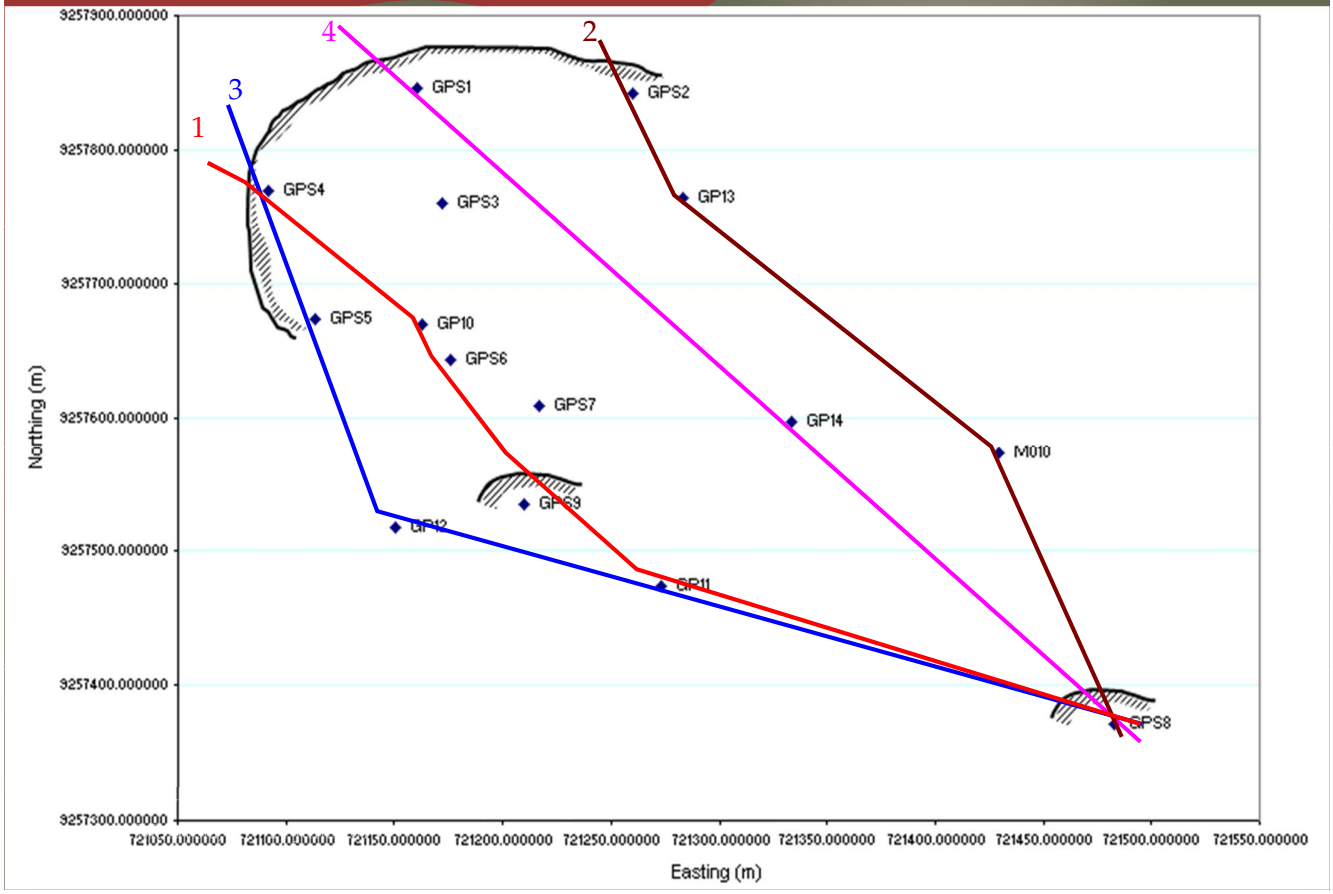
Relation of Displacement and Velocity



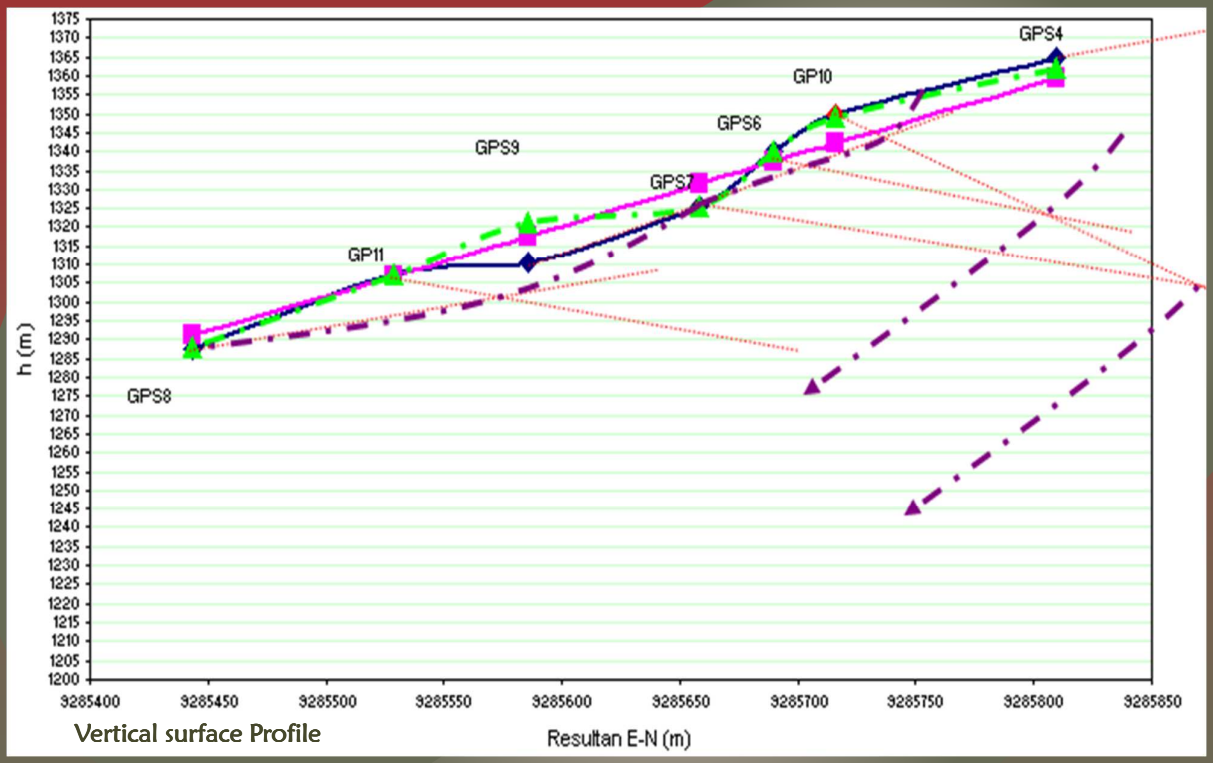
Discussion

- **Vector Status of Position and Velocity**
  - Evacuation area
  - Position of instability point (subsidence and bulging)
  - Position of stability point (breakline)
- **New Minor Scarp**
  - Retrogressive indication
  - New scarp caused new external factor

Cross Section Line



Cross Section Line 1st



Vertical surface Profile

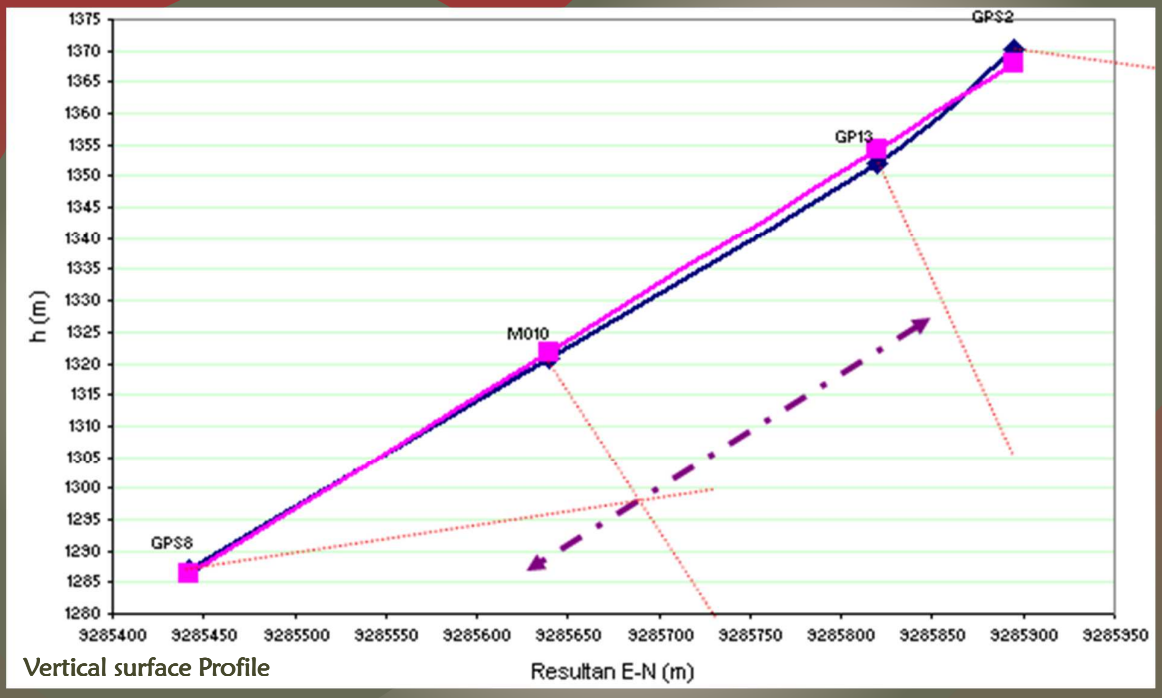
Approx. Surface from kinematic model

Approx. Surface from Polynomial Function

Velocity Trend Line (VTL) per point

Slip Surface from intersection of VTL

Cross Section Line 2nd



Vertical surface Profile

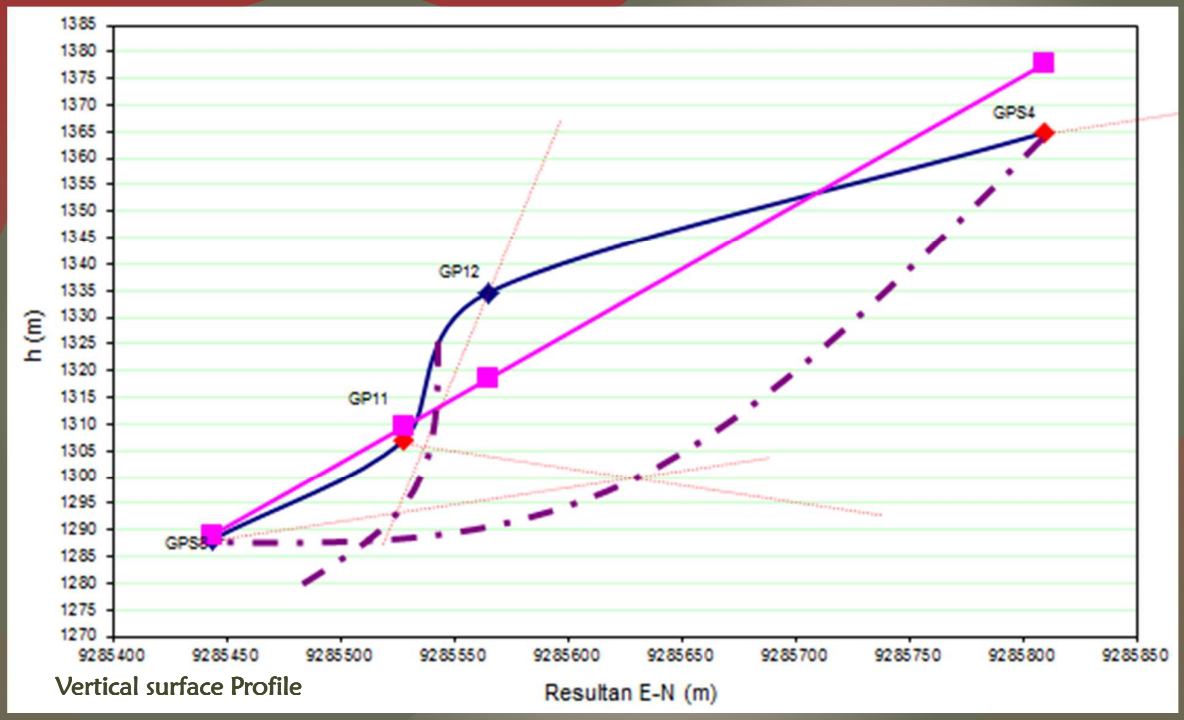
Approx. Surface from kinematic model

Approx. Surface from Polynomial Function

Velocity Trend Line (VTL) per point

Slip Surface from intersection of VTL

Cross Section Line 3rd



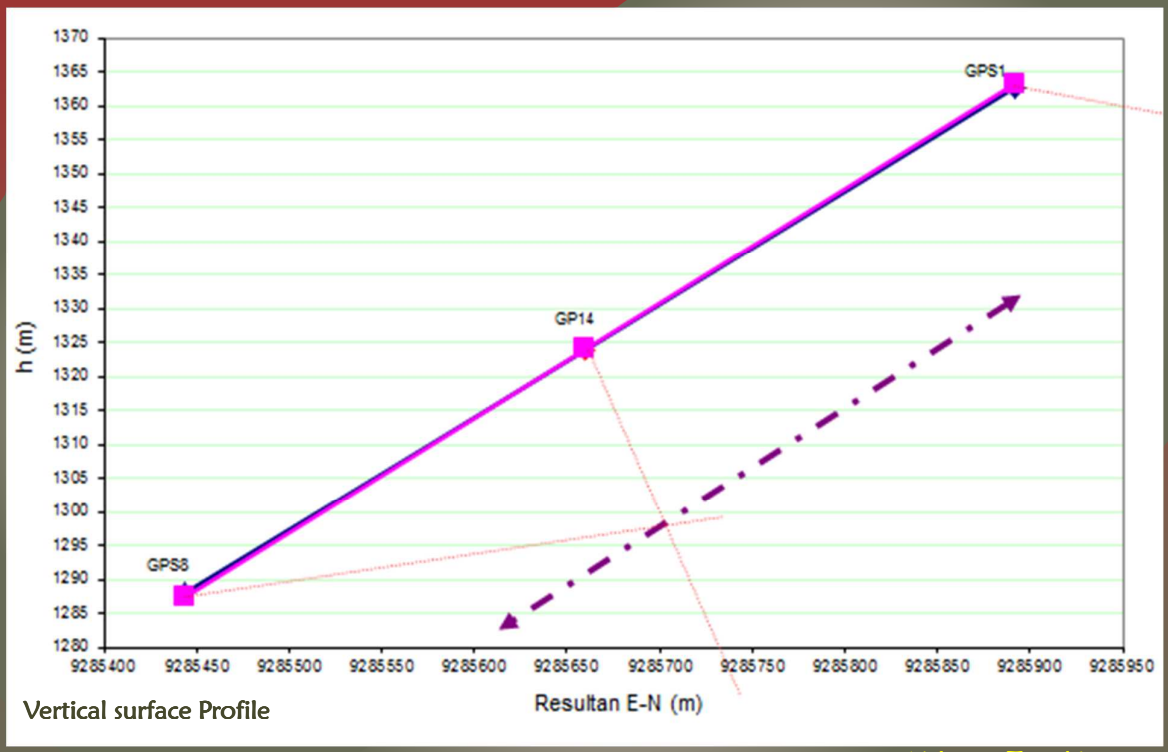
Approx. Surface from kinematic model

Approx. Surface from Polynomial Function

Velocity Trend Line (VTL) per point

Slip Surface from intersection of VTL

Cross Section Line 4th

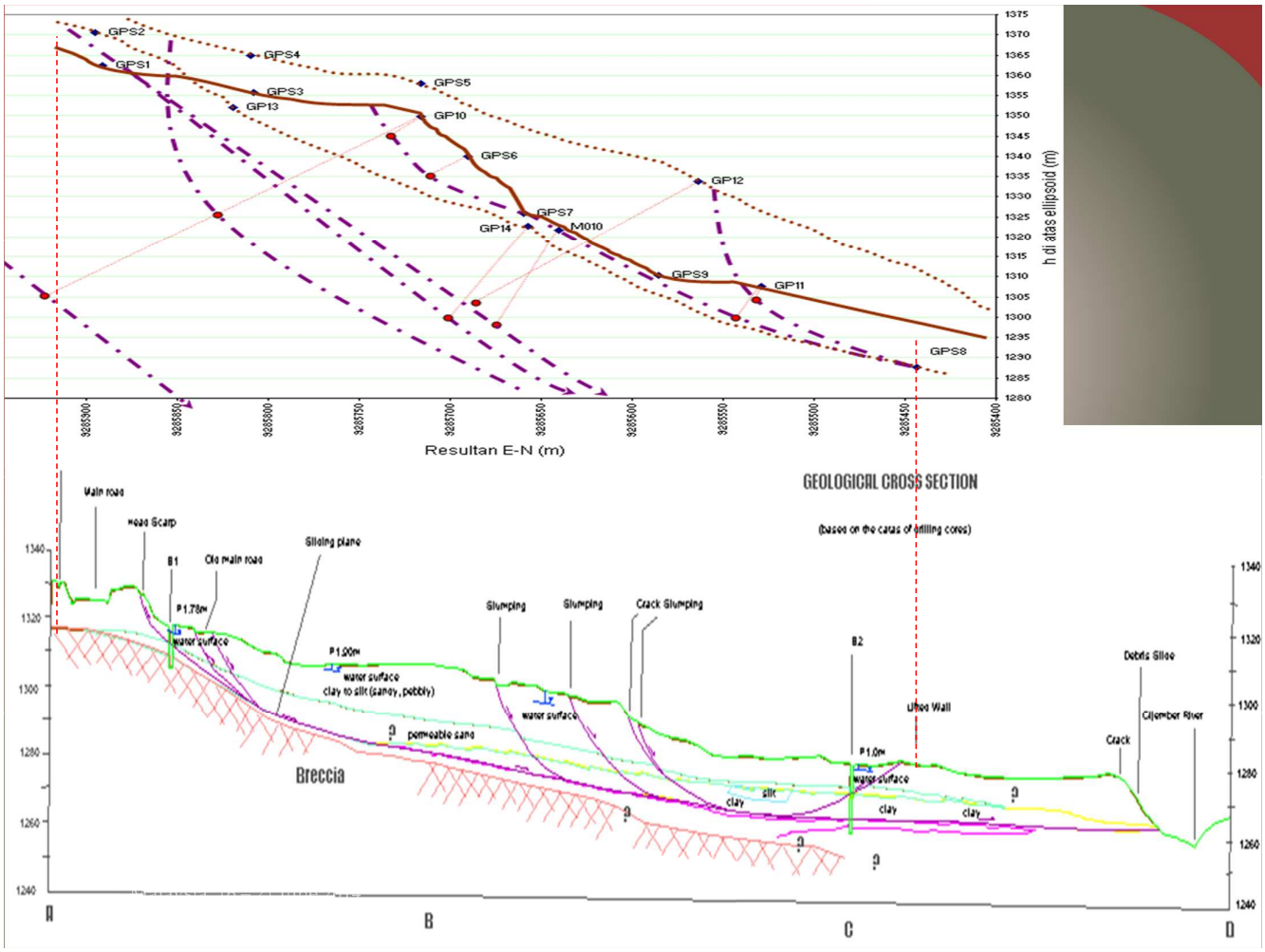


Approx. Surface from kinematic model

Approx. Surface from Polynomial Function

Velocity Trend Line (VTL) per point

Slip Surface from intersection of VTL



Conclusion

- **Characteristic**
  - Displacement Velocity is very slow $5 \times 10^{-5} - 5 \times 10^{-7}$ mm/second
  - Environment effect (rainfall→water infiltration→stress→strain : subsidence/bulging) to material displacement can defined magnitude and direction
  - New minor scarp give information of instability area of landslide zone
- **Landslide Type**
  - Multiple compound (rotational and translational) debris slide

Landslide Hazard Mitigation

Technical Engineering can applied with information :

- Priority location to minimize water infiltration
- Location of vulnerable area
- Direction and magnitude of velocity of material displacement
- External factor which influence to landslide zone can be defined well, like as river, spring, busy road, farm land