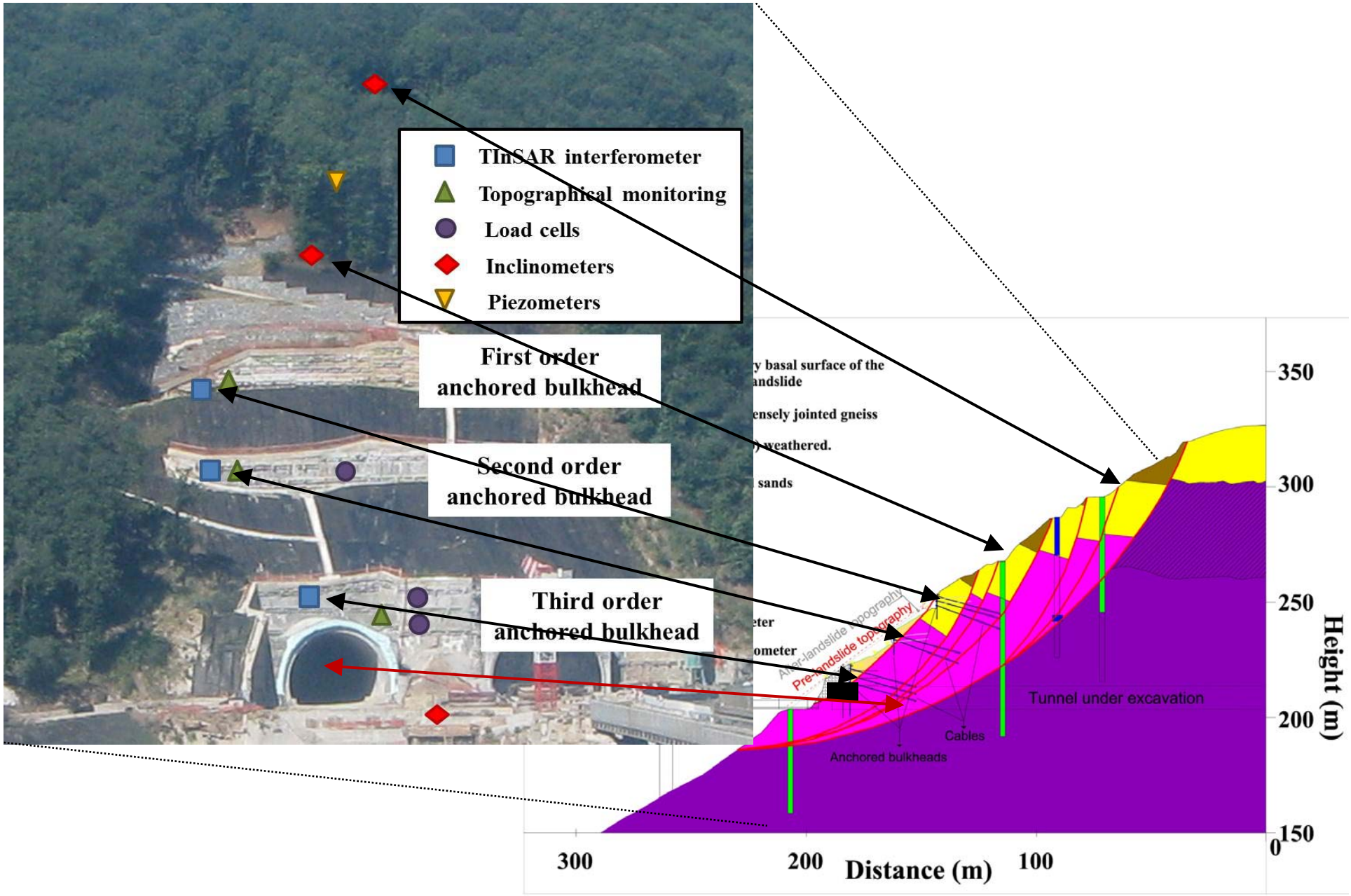
Forecasting methods for landslides interacting with infrastructures

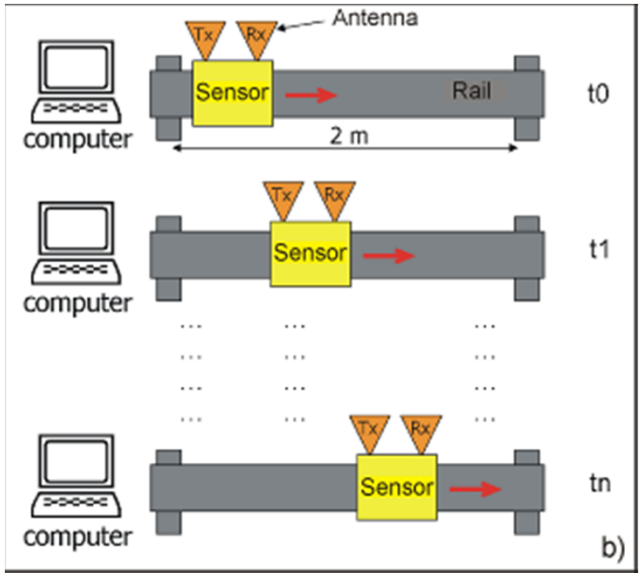
Francesca Bozzano[1,2,3], ***Ivan Cipriani[2],*** Salvatore Martino[1,2], Paolo Mazzanti[1,2,3], Alberto Prestininzi[1,2]

1. **CERI, Research Centre on Prevention, Prediction of Control of Geological Risks, "Sapienza" Università di Roma, Piazza U. Pilozzi 9, 00038, Valmontone (RM), Italy**
2. **Department of Earth Sciences, "Sapienza" Università di Roma, P.le Aldo Moro 5, 00185, Rome, Italy**
3. **NHAZCA S.r.l., spin-off "Sapienza" Università di Roma, Via Cori snc, 00177, Rome, Italy**

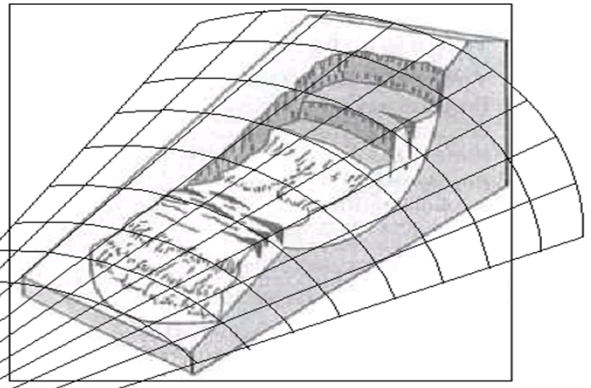
Predicting slope failure...?

Photo of the slope after the landslide of March 2007

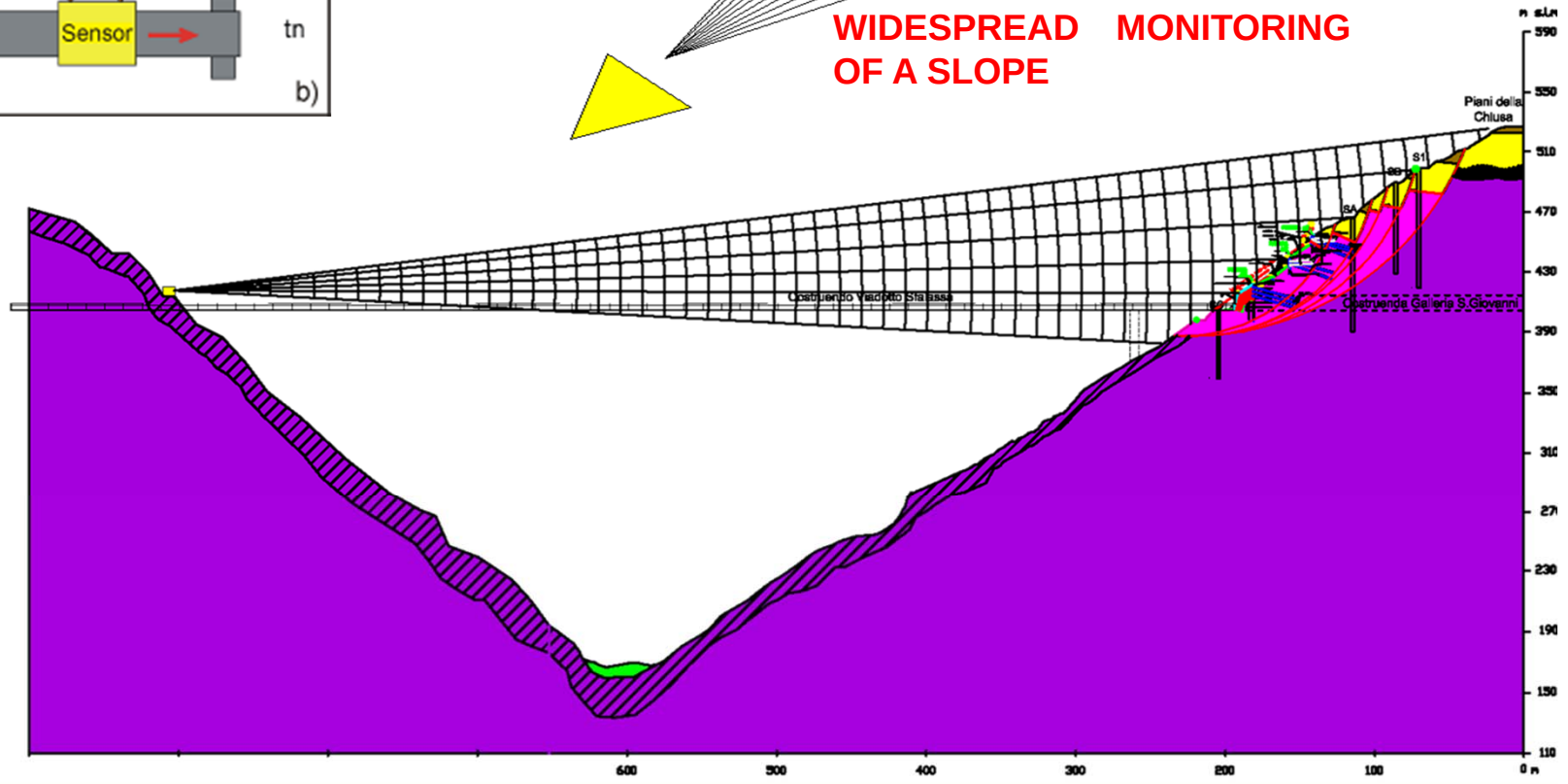

TInSAR interferometer
Topographical monitoring
Load cells
Inclinometers
Piezometers
First order anchored bulkhead
Second order anchored bulkhead
Third order anchored bulkhead
Tunnel under excavation
Cables
Anchored bulkheads
Pre-landslide topography
Distance (m)
Height (m)
300
200
100
0
350
300
250
200
150

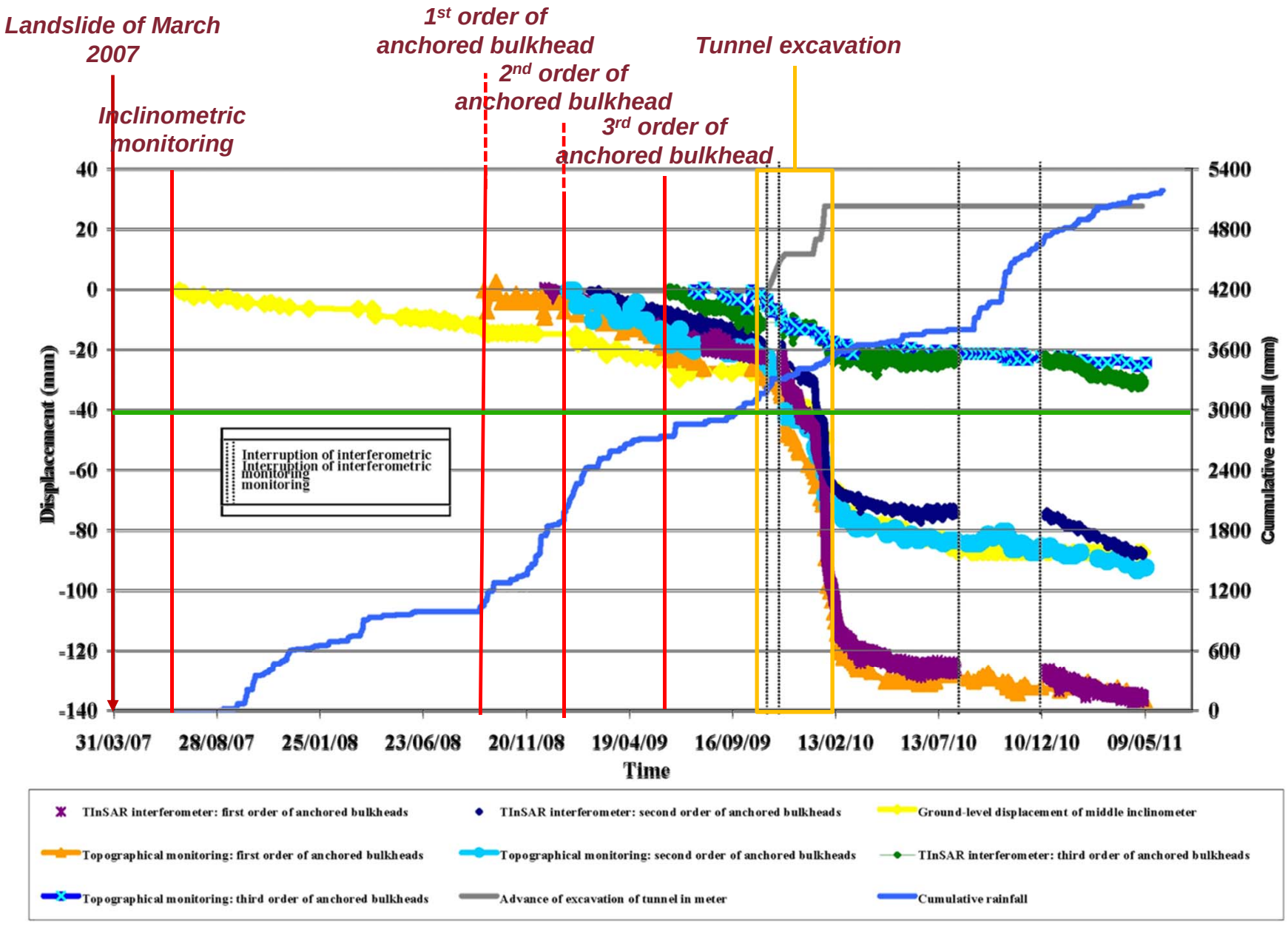


MONITORING UNDER ANY WEATHER AND LIGHTENING CONDITIONS



WIDESPREAD MONITORING OF A SLOPE



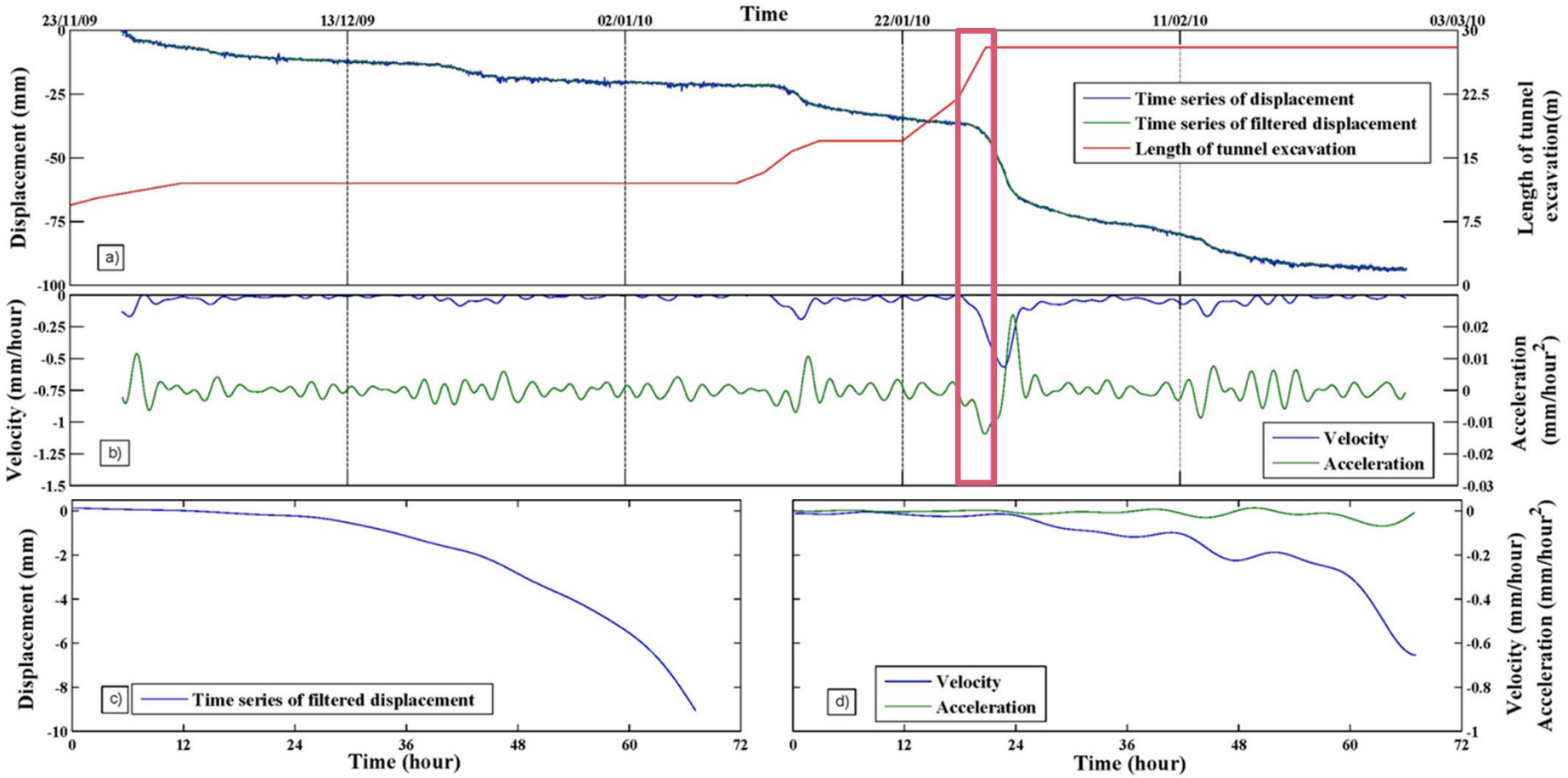

Landslide of March 2007
Inclinometric monitoring
1st order of anchored bulkhead
2nd order of anchored bulkhead
3rd order of anchored bulkhead
Tunnel excavation
Displacement (mm)
Cumulative rainfall (mm)
Time
31/03/07
28/08/07
25/01/08
23/06/08
20/11/08
19/04/09
16/09/09
13/02/10
13/07/10
10/12/10
09/05/11
Interruption of interferometric monitoring
TInSAR interferometer: first order of anchored bulkheads
TInSAR interferometer: second order of anchored bulkheads
Ground-level displacement of middle inclinometer
Topographical monitoring: first order of anchored bulkheads
Topographical monitoring: second order of anchored bulkheads
TInSAR interferometer: third order of anchored bulkheads
Topographical monitoring: third order of anchored bulkheads
Advance of excavation of tunnel in meter
Cumulative rainfall

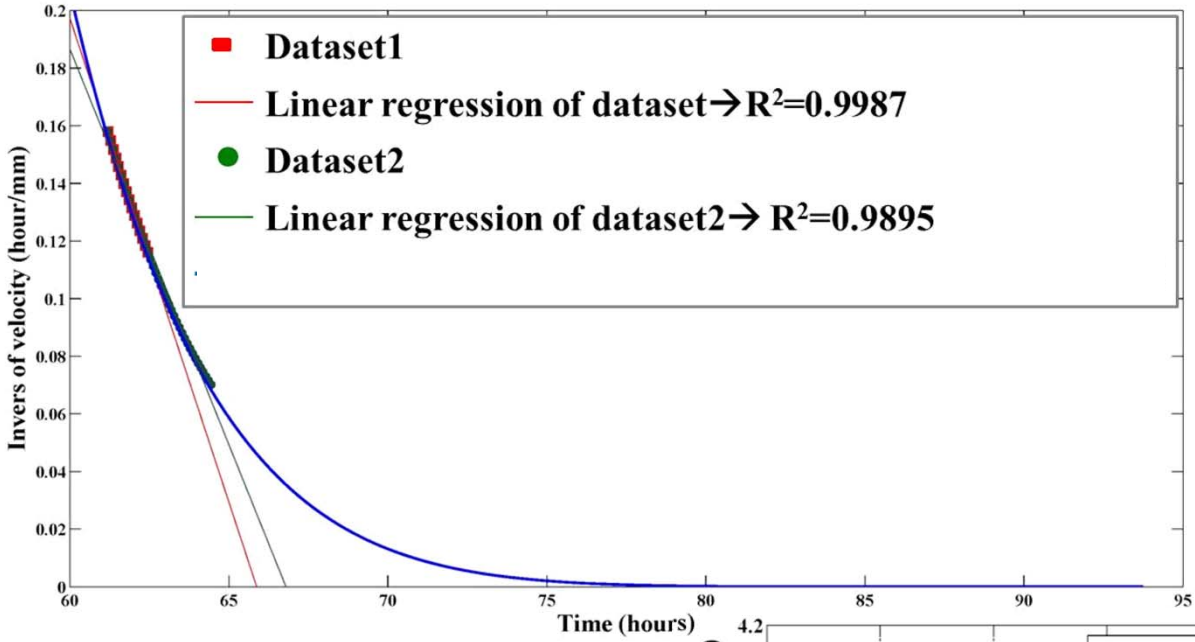
METHODS FOR PREDICTION OF THE SLOPE EVOLUTION

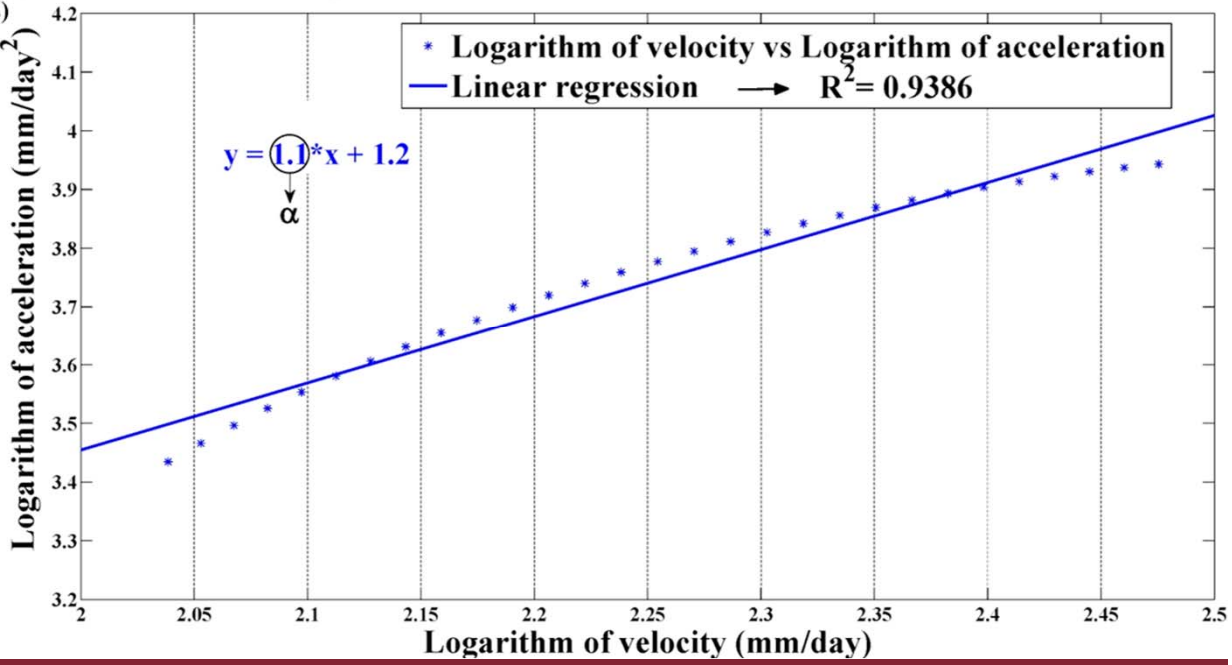
- Semi-empirical forecasting method based on the tertiary creep theory (Fukuzono 1985, Voight 1989, Crosta & Agliardi 2003)

- Stress-strain numerical analysis based on the finite difference code FLAC2D

SEMI-EMPIRICAL FORECASTING METHOD BASED ON THE TERTIARY CREEP THEORY



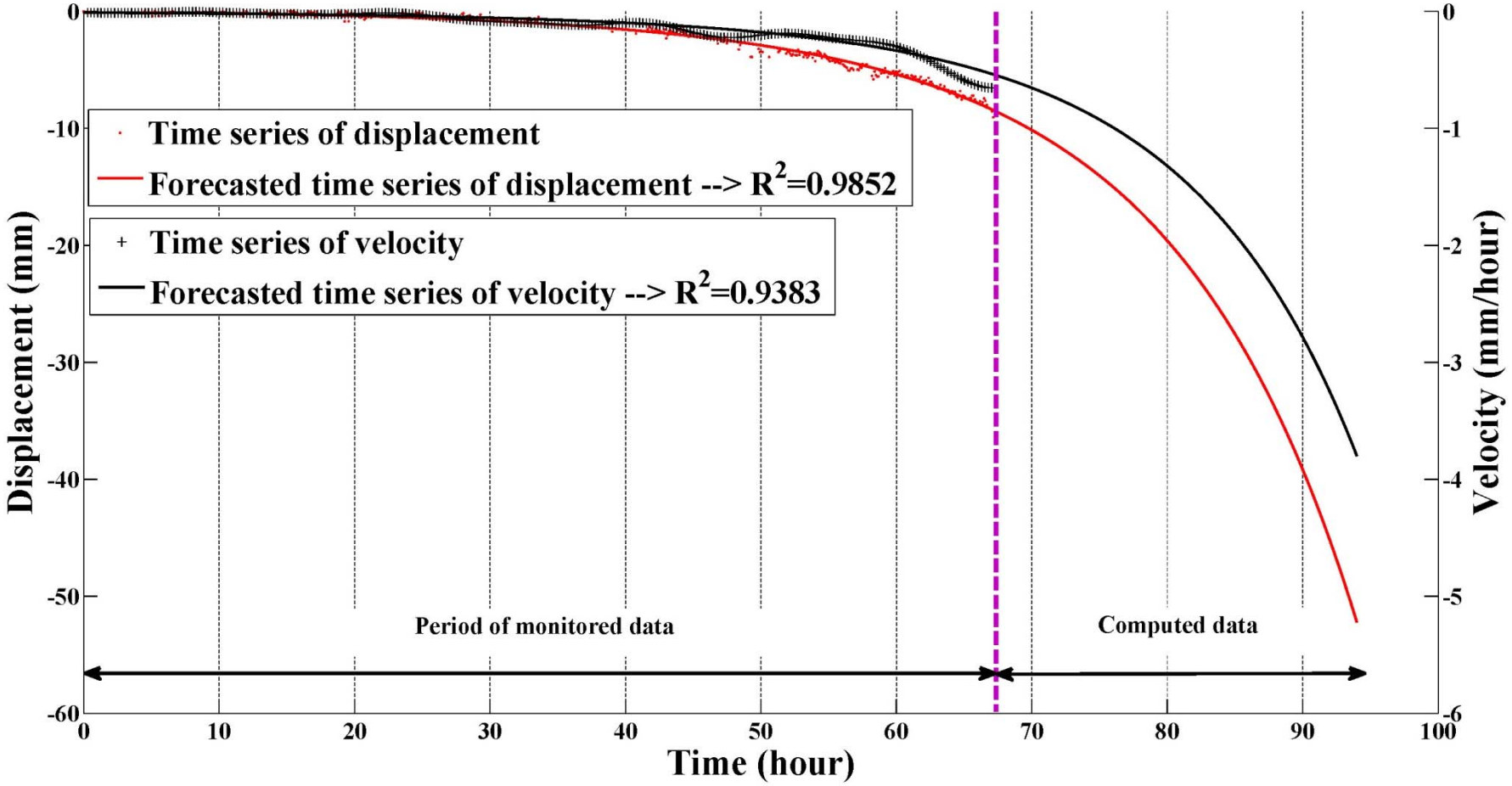




Fukuzono (1985)

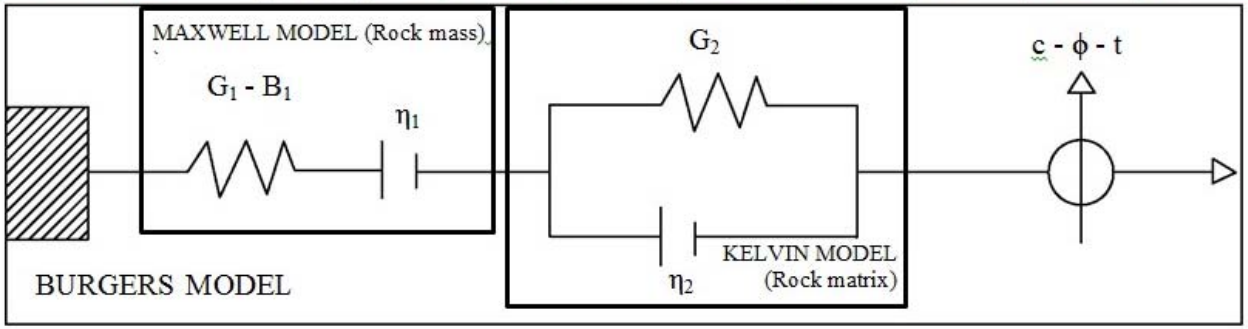
$$\Omega = \frac{1}{A(\alpha-2)}\left\{\left[A(\propto -1)t_f + \dot{\Omega}_f{}^{1-\propto}\right]^{(2-\propto)/(1-\propto)} - \left[A(\propto -1)(t_f - t) + \dot{\Omega}_f{}^{1-\propto}\right]^{(2-\propto)/(1-\propto)}\right\}$$

α=1.08 t_f=94.10 hours A=0.070 $\dot{\Omega}_f$=3.82 mm/h



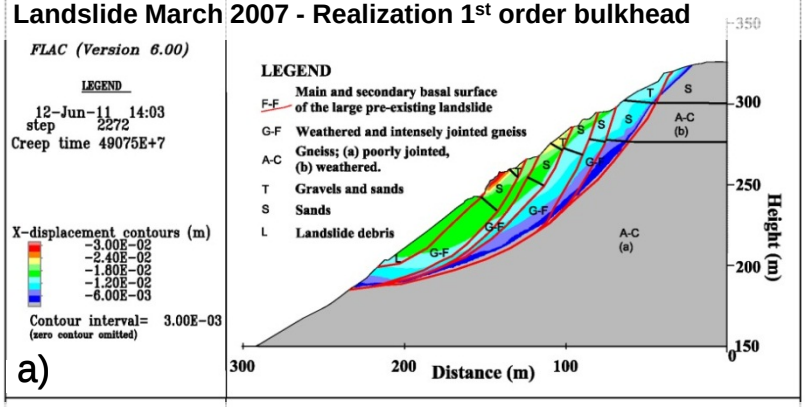
NUMERICAL ANALYSIS METHOD OF FORECASTING

Material	c (Pa)	ϕ (°)	den (kg/m3)	t (Pa)	B1 (Pa)	G1 (Pa)	η1 (Pa*s)	G2 (Pa)	η2 (Pa*s)
Gneiss hard (A-C a)	9.97E+05	63.6	2.69E+03	1.35E+05	2.92E+10	1.75E+10	9.00E+21	1.96E+10	9.00E+22
Gneiss weathered (A-C b)	9.97E+05	63.6	2.69E+03	1.35E+05	2.92E+10	1.75E+10	9.00E+20	1.96E+10	9.00E+21
Weathered and intensely jointed gneiss (G-F)	4.70E+05	47.7	2.69E+03	6.00E+03	2.49E+10	1.48E+10	2.00E+16	1.96E+10	2.00E+17
Surface of the landslides (F-F)	3.21E+05	42.5	2.69E+03	5.00E+03	2.38E+10	1.42E+10	1.50E+15	1.96E+10	1.50E+16
Marine gravels and sands (T)	5.00E+03	38	1.80E+03	6.00E+03	1.98E+08	9.12E+7	M-C	M-C	M-C
Marine sands (S)	5.00E+03	36	1.80E+03	6.00E+03	1.98E+08	9.12E+7	M-C	M-C	M-C

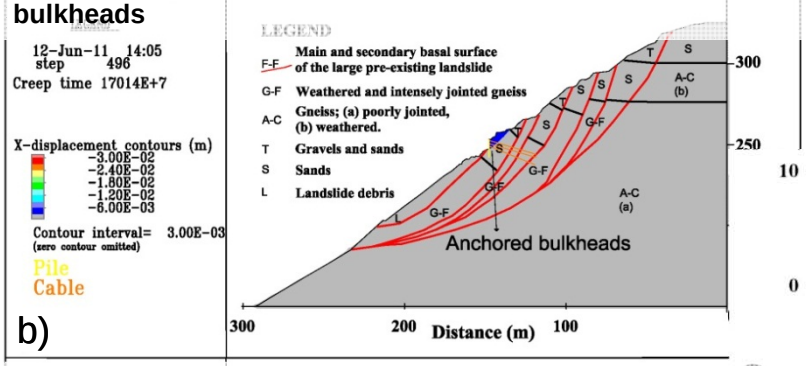


Tertiary creep

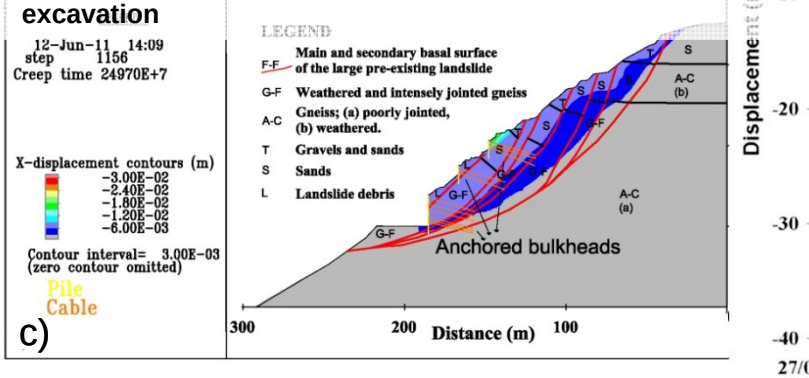
Landslide March 2007 - Realization 1st order bulkhead

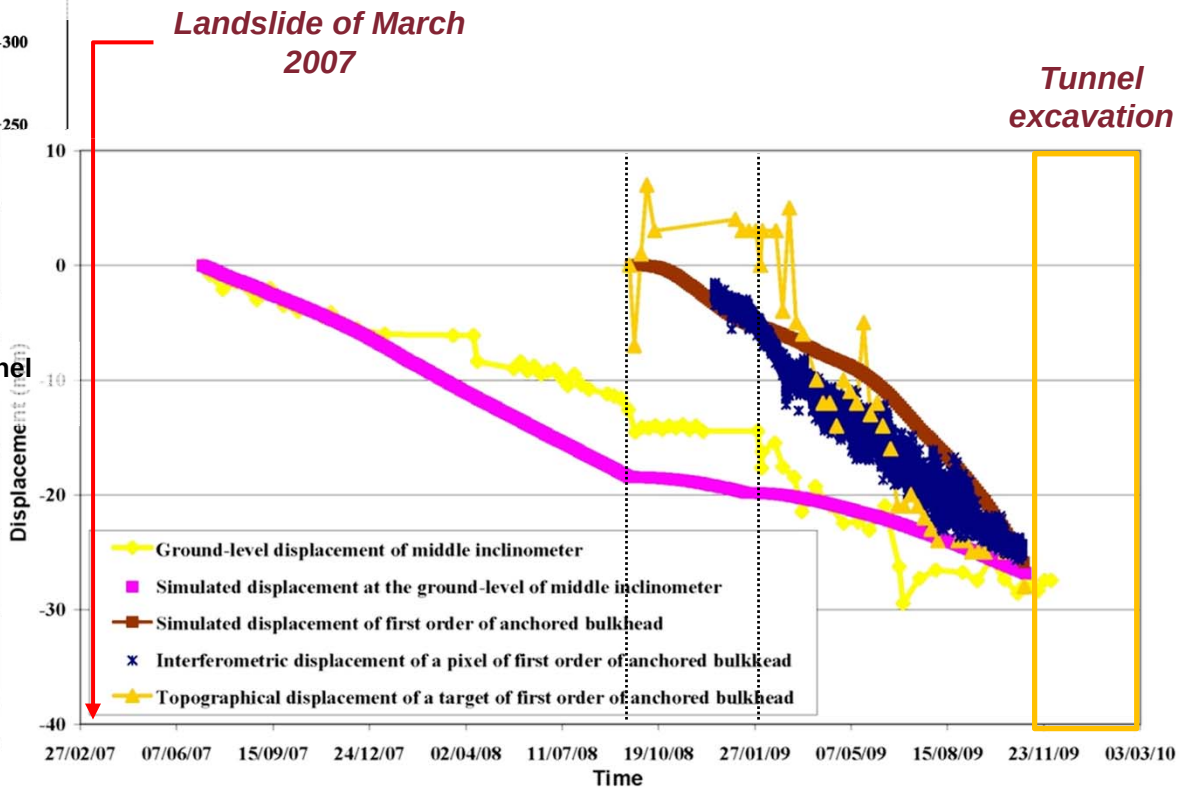


Realization 1st order bulkhead – Realization 2nd and 3rd order bulkheads



Realization 2nd and 3rd order bulkheads – Starting of tunnel excavation





CONCLUSION

- Thresholds of velocity and displacement of bulkheads deformation by the modified semi-empirical approach of Crosta e Agliardi (2003)

- Calibration and validation of the numerical model in the secondary creep by Burger's model

OUTLOOKS

- Calibration and validation of the numerical model in the tertiary creep

- A cross-check of the numerical model data with the data of the semi-empirical analysis