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Landslide monitoring in urban area; reactivating old inclinometers in Roma.

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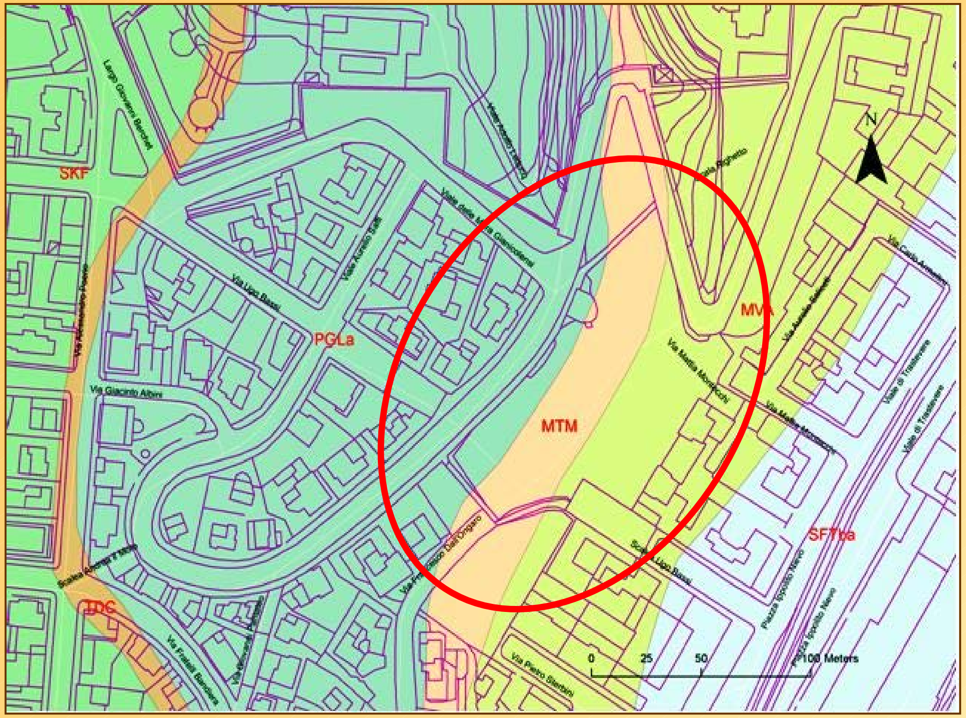
Geological structure

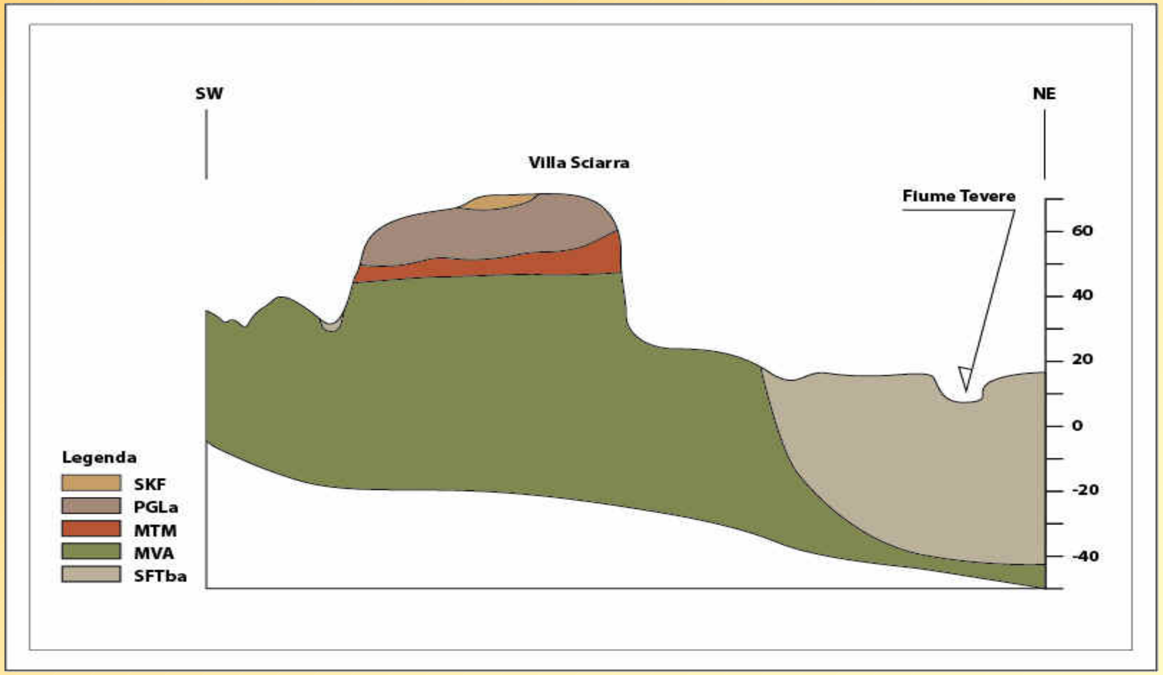


SKF – Tufi stratificati varicolori di Sacrofano - **TUFFS**

PGLa – Formazione di Ponte Galeria - **GRAVEL and SAND**

MTM – Formazione di Monte Mario - **SAND**

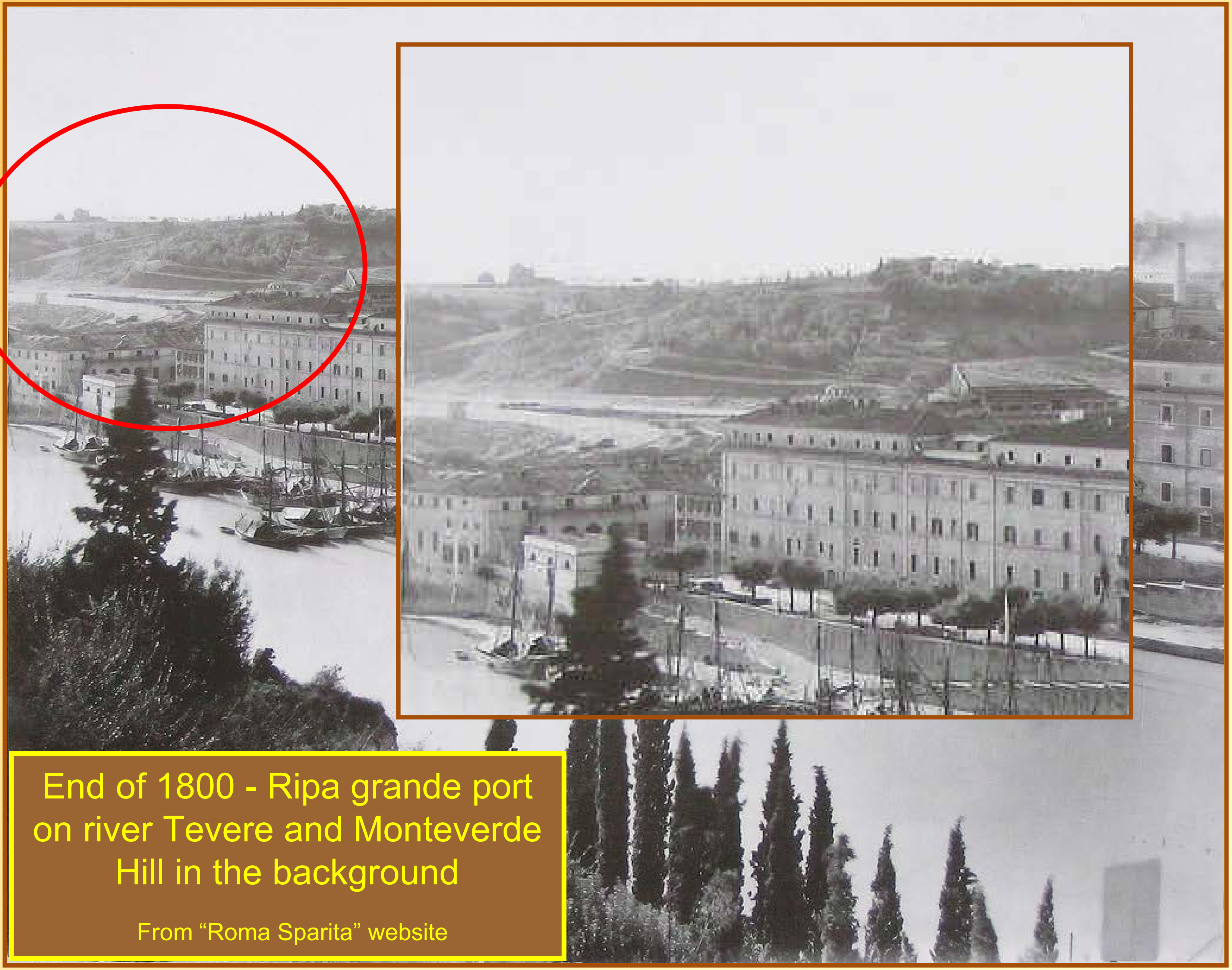
MVA – Formazione di Monte Vaticano - **PLIOCENE CLAYS**



Past events in the area

Date	Ubicazione e descrizione evento	Fonte
End of 1800	Versante orientale di Monteverde, frana estesa che sembra avere raggiunto e superato il Viale del Re, ora Viale Trastevere. Movimenti diffusi sul versante e arretramento della testata del fosso.	Fossa Mancini, 1922. Amanti *et alii*, 2008
1850 - 1907	Versante orientale di Monteverde. La carta del piano regolatore mostra evidenti scoscendimenti e fenomeni di erosione.	PRG, 1908. Leone, 1986.
1915-1918	Via Ugo Bassi. Piccola frana che ha interessato, facendola crollare, parte della scalea Ugo bassi	Fossa Mancini, 1922.
1925-1927	Via dall'Ongaro. Movimento dell'intero versante con demolizione della Casa dei padri missionari Giuseppini, inutili gli interventi di consolidamento. Demolita anche la scala intermedia di via Ugo Bassi e sostituita da scala in legno.	GEOSONDA, 1983. Leone, 1986. Riportato in: Corazza *et alii*, 2002.
1927	Movimento lungo tutto il versante.	Leone, 1986. Sciotti, 1986. Corazza et alii, 2002.
14-ott-28	Questa data, citata da alcuni autori come momento di franamento del versante, si riferisce più precisamente allo sprofondamento della volta di una cavità sotterranea in via Tommaseo, con conseguente crollo di una abitazione.	Corazza et alii, 2002. Funiciello & Testa, 2008. Confronta: Piperno, 1929.
1947	Movimenti analoghi alla successiva frana del 1963. Fluidificazione del piano fondale del muro di sostegno, accompagnata da spinta a tergo.	GEOSONDA, 1983. Sciotti, 1986.
1959	Movimenti lungo tutto il versante. Movimenti successivi a periodo di alta piovosità.	GEOSONDA, 1983. Leone, 1986.
1963, Jan 13th	Evento principale del secolo XX. Zona meridionale del colle del Gianicolo. Movimento franoso che si sviluppa per circa 5 ha tra Villa Sciarra e Piazza Ippolito Nievo, provocando gravissime lesioni ai muri di sostegno, alle sedi stradali ed alla rete fognaria. Movimenti successivi ad un periodo di alta piovosità.	Leone, 1986. Riportato in: Catenacci, 1992. Amanti *et alii*, 1996. Amanti *et alii*, 2008.
Beginning of '70	Il crollo del tratto delle mura Gianicolensi che costeggiano il primo tornante di via Saffi, è stato attribuito da vari autori e dai media ai primi anni '60, in particolare all'evento del 10-1-63 o, in alternativa, in recenti articoli di stampa, al periodo 1980-82. In realtà il crollo sembra essere avvenuto nella prima metà degli anni '70, come riportato da interviste con abitanti del luogo e dalla valutazione di altre fonti . In particolare: in Leone (1986), l'autore dichiara i dissesti delle mura "non dipendenti dal fenomeno in esame". Una scena tratta dal film Brutti, sporchi e cattivi, di Ettore Scola, girato nel 1975-76, mostra il tratto di mura crollato, escludendo quindi l'attribuzione agli anni '80. Infine la relazione GEOSONDA (1983), che descrive dettagliatamente gli eventi succedutisi nell'area e riportati poi dai vari autori, attribuisce il crollo al periodo 1965-1979, escludendo comunque che sia coevo della frana del 1963.	Leone, 1986. GEOSONDA, 1983.
20-feb-87	Via dall'Ongaro. Un movimento franoso provoca il crollo di un muro di contenimento, seppellendo tre auto in sosta.	Catenacci, 1992. Amanti *et alii*, 2008.
from 1990 to today	Vari scivolamenti superficiali del terreno, crolli di piante di alto fusto, apertura di fessure sui muretti di via Saffi e del "Fortino della madonnina".	Amanti *et alii*, 1996. Amanti *et alii*, 2008. Resoconti orali di abitanti dell'area.

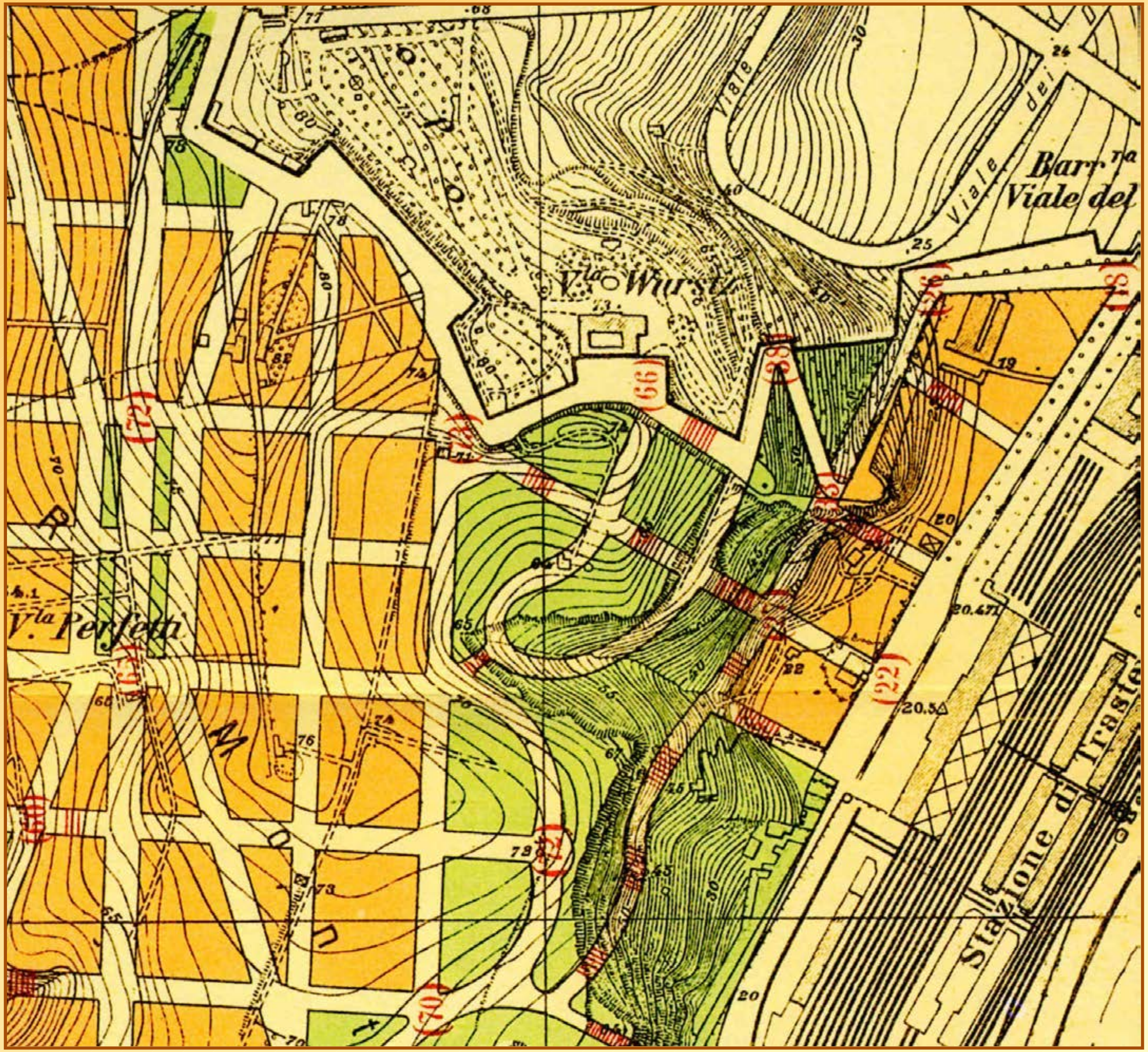
Past events in the area



End of 1800 - Ripa grande port on river Tevere and Monteverde Hill in the background

From "Roma Sparita" website

Past events in the area



City Plan 1908 – By Edmondo Sanjust di Teulada

Past events in the area

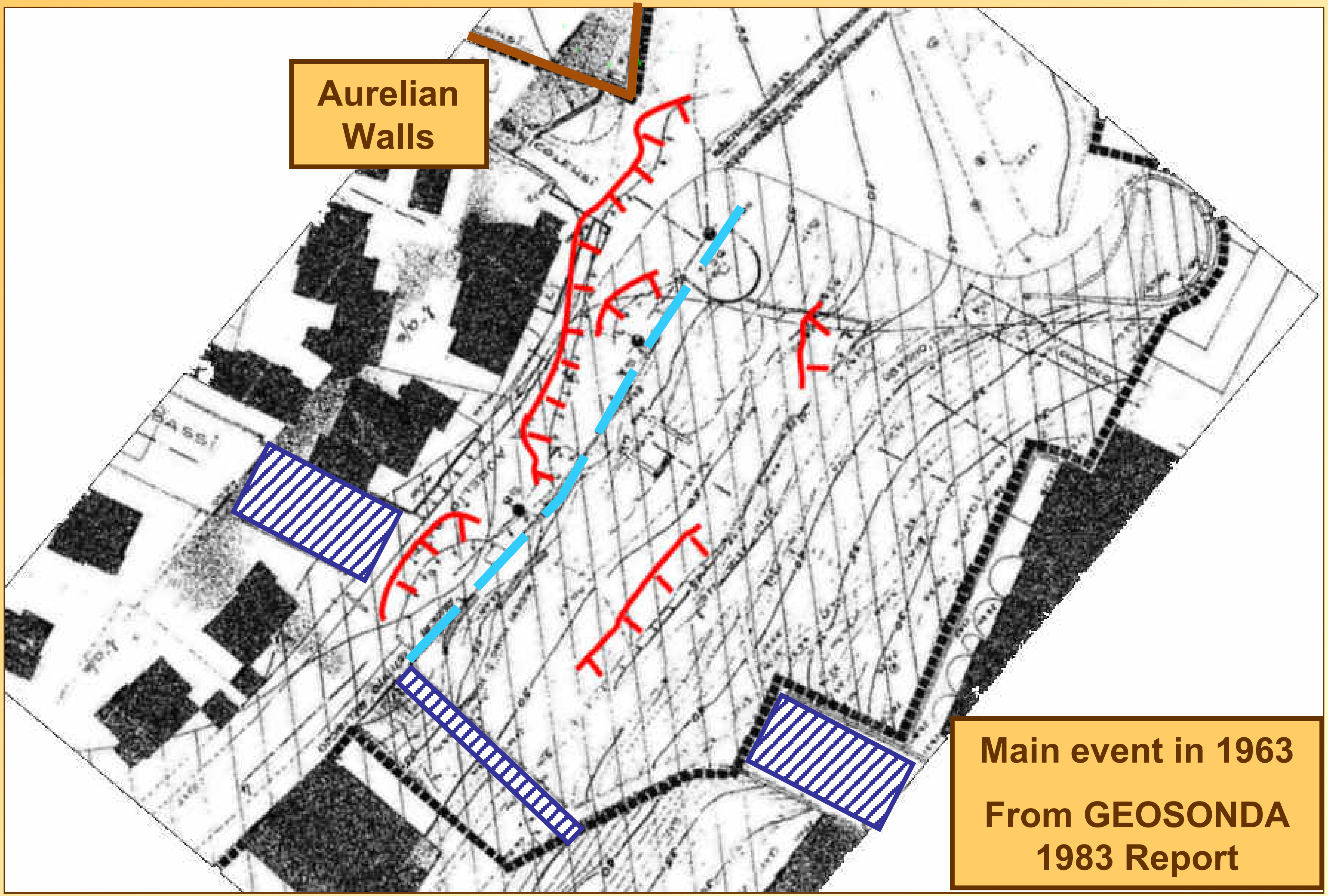

Sbarrata una strada a Monteverde

Un movimento di terra, provocato
minato l'avvallamento del tratto d
I vigili del fuoco, dopo un sopral

1963

1983

Past events in the area



Past events in the area

Until 1927- **brickwork steps**?

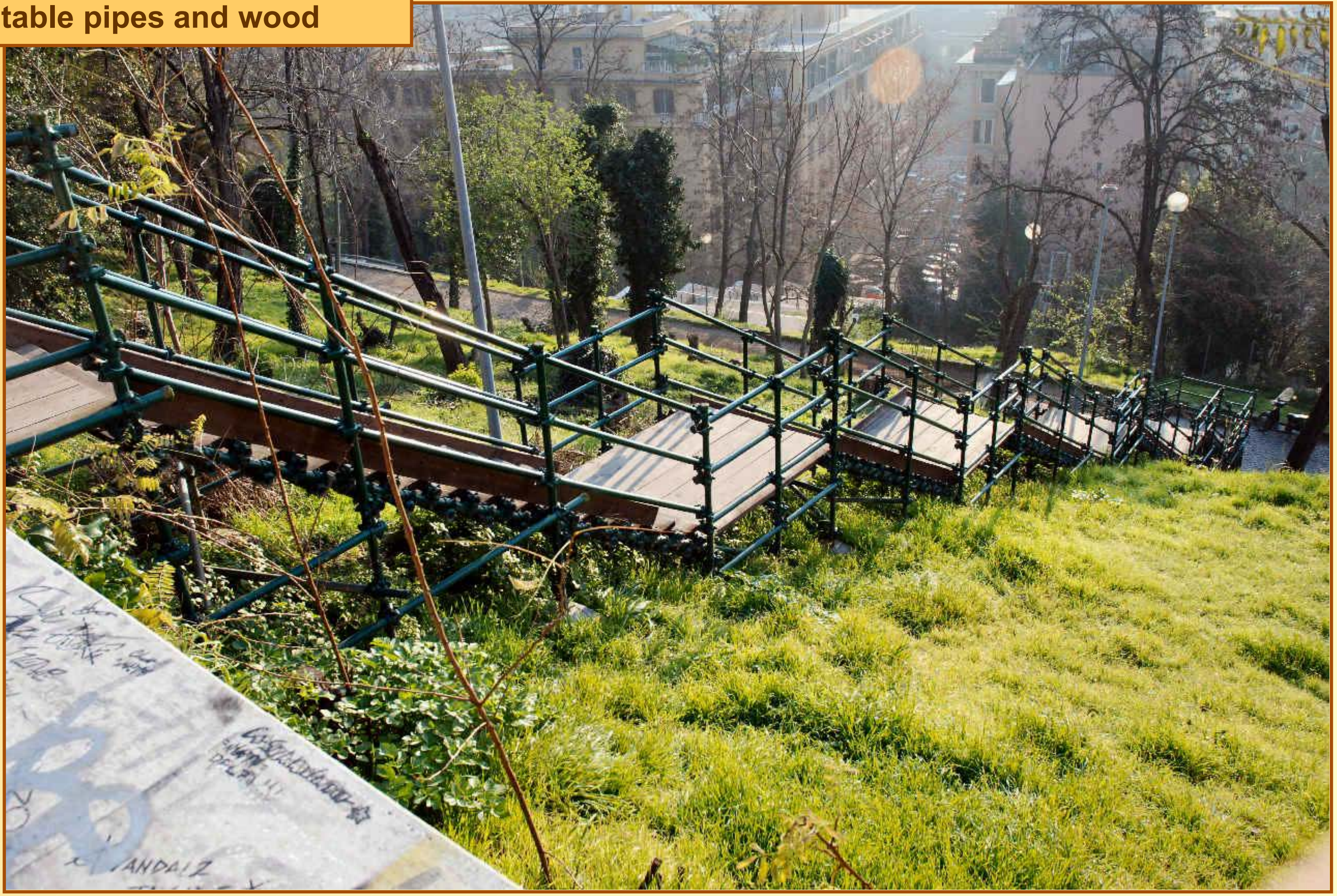
1927 – **woodwork steps**

Beginning of ’60 - **concrete**

Beginning of ‘80 - **concrete**

2000 - **jointable pipes and wood**

Small Steps between the upper and the lower part of via Ugo Bassi



Past events in the area

2000 - today

Cracks in the walls, in the middle of the slope.

Present monitoring plan

At the beginning of **2012** Roma Capitale Municipality asked the **Geological Survey of Italy** to study the area and, if needed, to define a plan to stabilize the slope.

We started a 1 year **characterization and monitoring plan** consisting of:

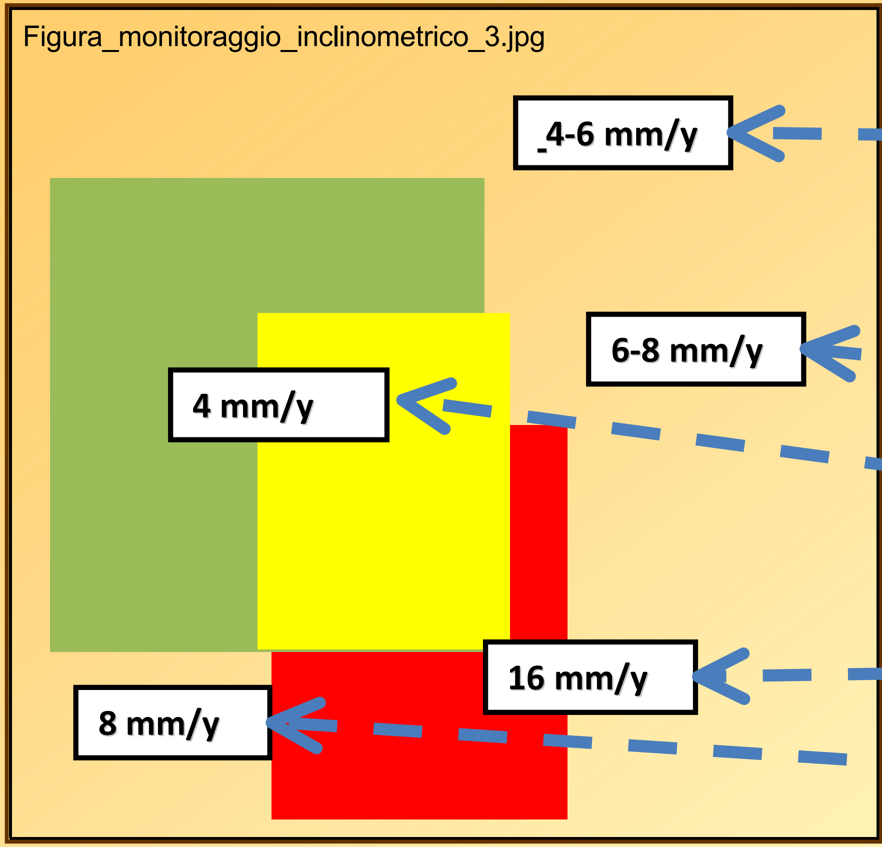
- **Critical revision** of existing studies and data.
- On field detection of **on site instruments**.
- Measurement of existing, reactivated, on site instruments (Piezometers, **inclinometers**, geodetic landmarks).
- **Drilling** of 2 or 3 boreholes, with geotechnical characterization of terrains and installation of new piezometers
- **Geophysical (Seismic and Electric) surveys campaign**, to support the understanding of underground geological model.
- **Stability analysis** using 2d and/or 3d models.

Past monitoring campaigns

Year	Operator	Monitoring	Time	Notes
1985-86	GEOSONDA	Inclinometers	half year	Erratic displacements with a maximum of **2,5 mm** in inclinometers down the bulkhead
1988	GEOSONDA	Inclinometers	half year	Displacements at many depth down the bulkhead and with a **huge displacement of 45mm/49 days** in one inclinometer at SW side of the bulkhead
1990	GEOTER	Inclinometers	1 year	**First preliminary zoning of the area** with different rate of horizontal displacements in the area surrounding the bulkhead
1990-1995	S.A.G.-C.I.M.	Geodetic	5 years	Geodetic **surface measurements** were collected in all the area and the maximum rate of displacement was **1,6 cm/y** along Via dell'Ongaro (downstream the bulkhead): this rate is very similar to the one indicated by GEOTER
1996	9 new inclinometers were installed			
1997	SOGEA	Inclinometers	4 months	Very low rate of displacements in all the instruments monitored (too short period)
2004	4 new inclinometers were installed			
2004-2005	GEOAMBIENTE	Inclinometers	1 year	Measurements during 2004 were linked to the ones of 1997 using the same probe. **Horizontal displacements with vel=1-2mm/y** were detected and attributed to a landslide in act. Consolidation of the entire slope was recommended.
2008-2009	AMANTI-CATALANO	Inclinometers	1,5 year	Measurements were linked to the ones of 2005. Horizontal displacements were detected in all inclinometers and attributed to a landslide that appears to be still in place with the most significant sliding surfaces identified around 10 -12 m from ground level.

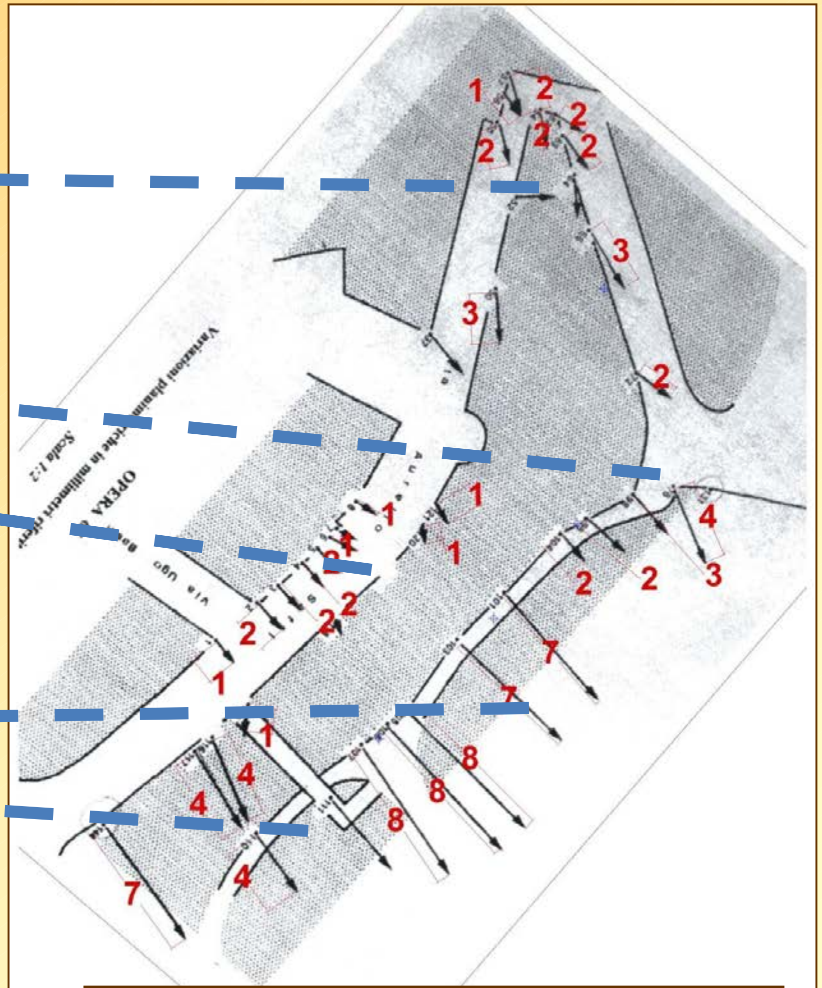
Past monitoring campaigns

Superimposing superficial displacements information with horizontal in depth displacement suggested by GEOTER (1990) gives a more complete information about old displacement rate along the slope.



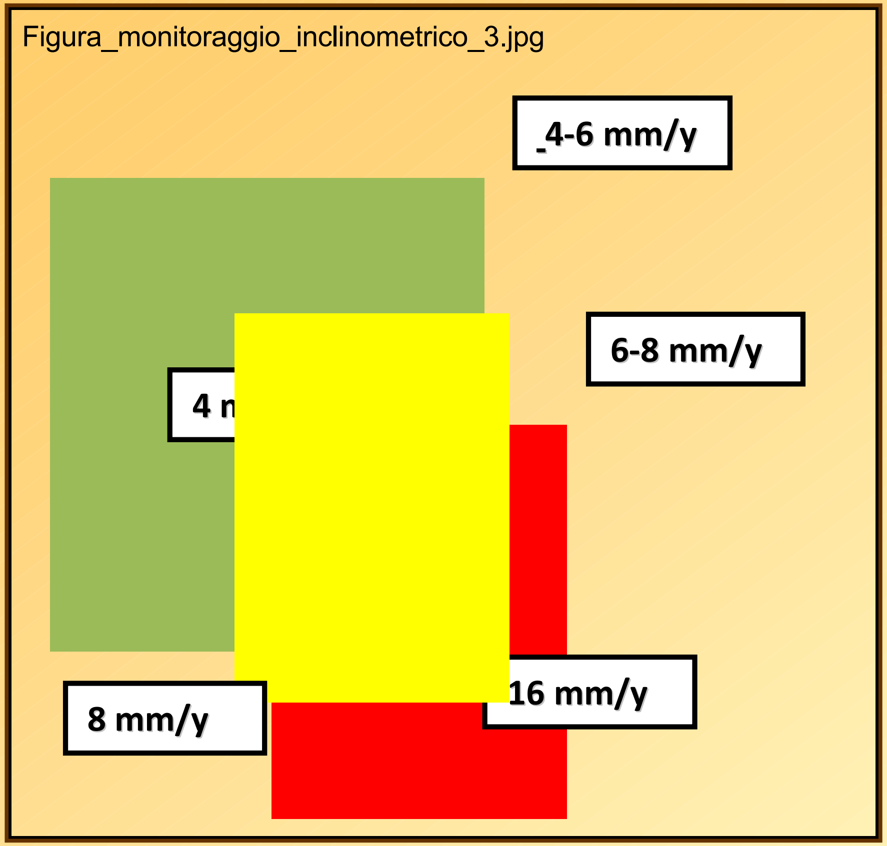
Preliminary zoning deriving from GEOTER inclinometer monitoring (1990 – 1year)

- 5 mm/y
- 5-10 mm/y
- 10-22 mm/y



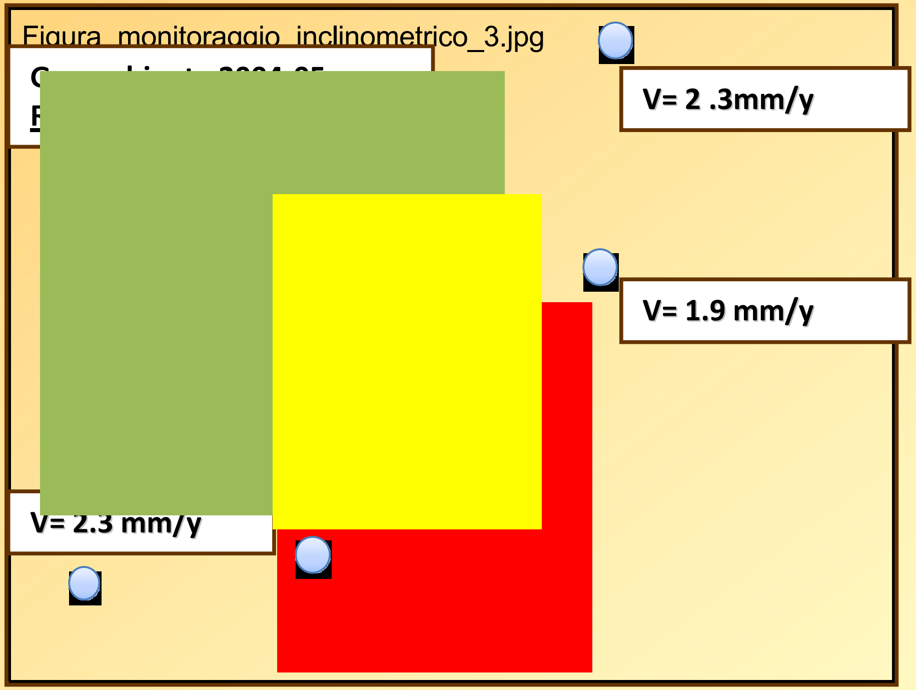
S.A.G.-C.I.M. 1990 - 1995
Total superficial displacements from geodetic measurements (in cm)

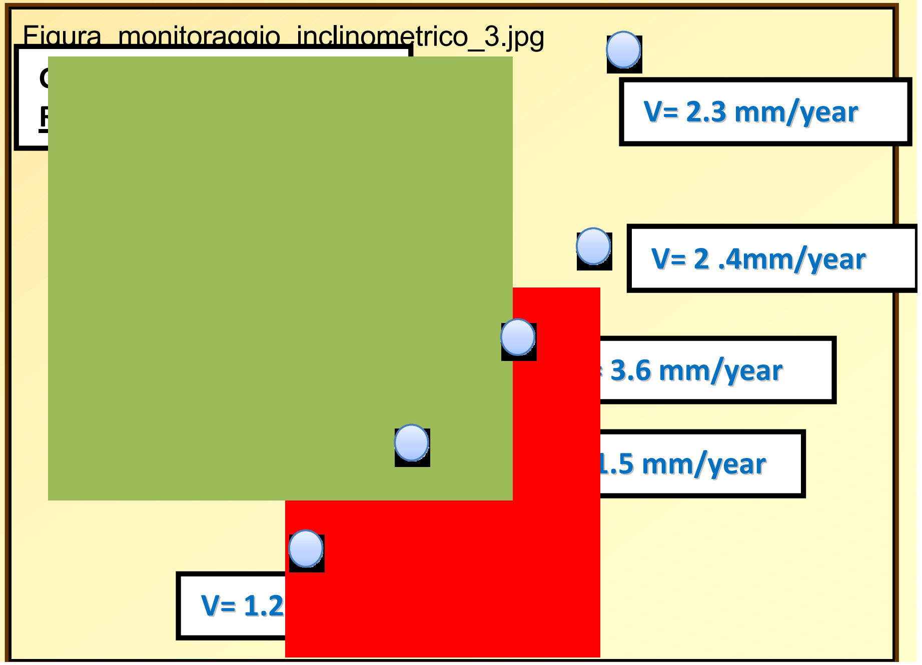
Past monitoring campaigns



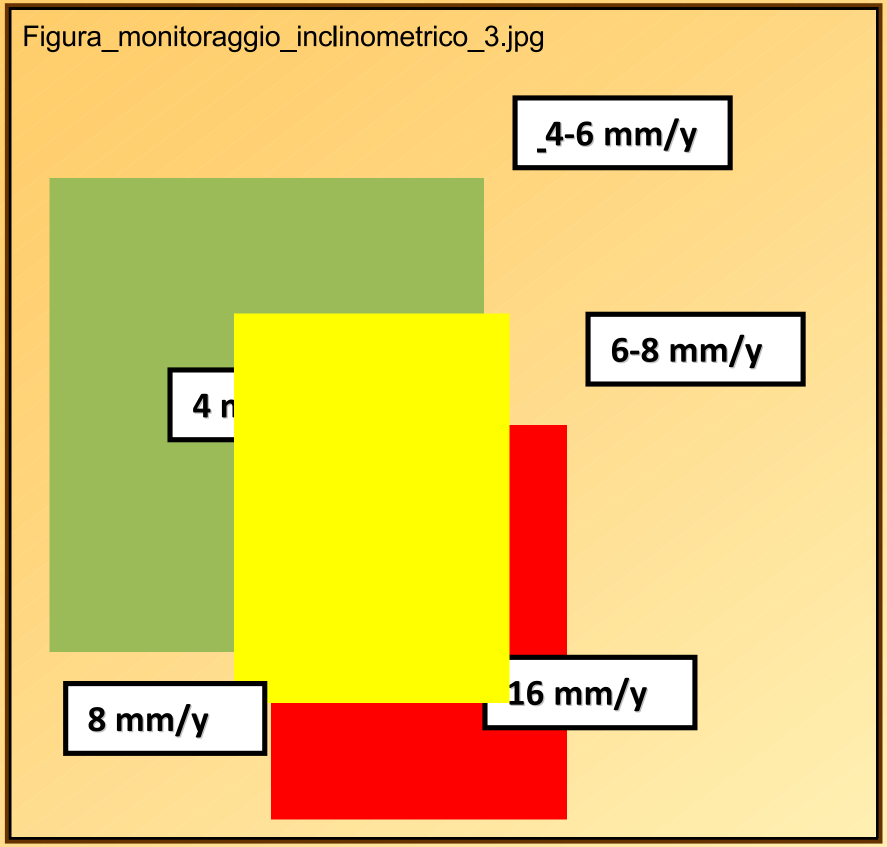
Preliminary zoning GEOTER inclinometer monitoring and S.A.G.-C.I.M surface geodetic (1990 – 1995)

5 mm/y
5-10 mm/y
10-22 mm/y





Past monitoring campaigns



Preliminary zoning GEOTER inclinometer monitoring and S.A.G.-C.I.M surface geodetic (1990 – 1995)

5 mm/y
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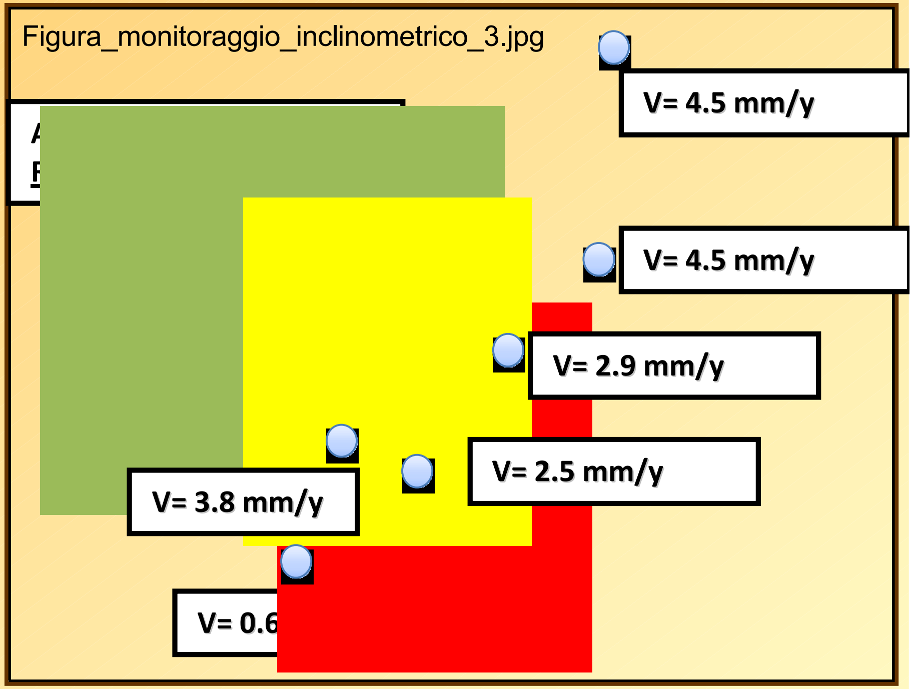
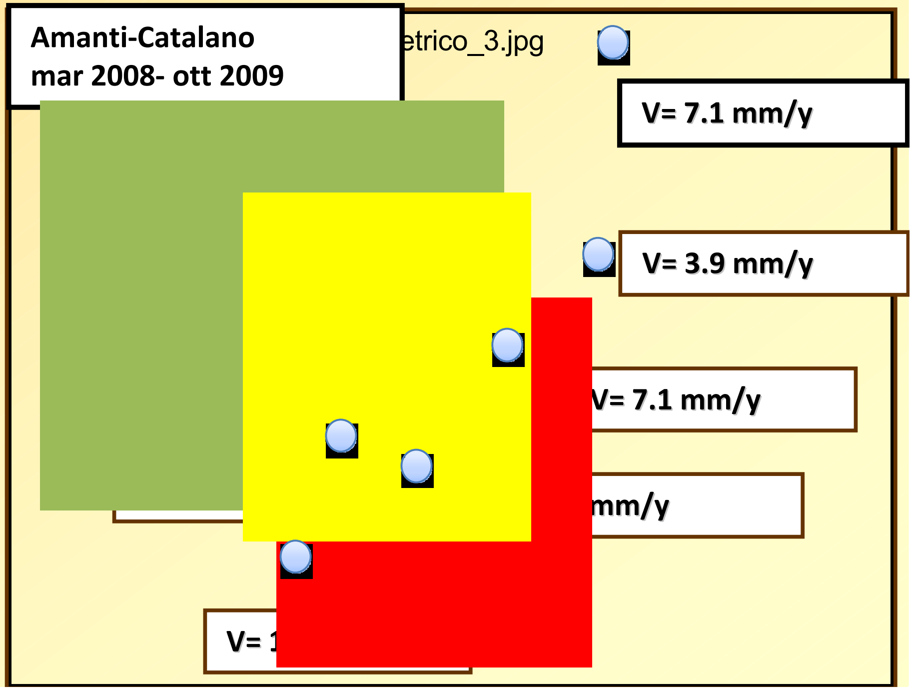
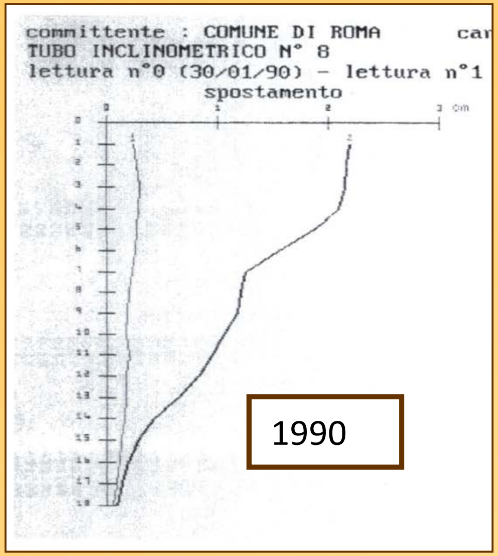
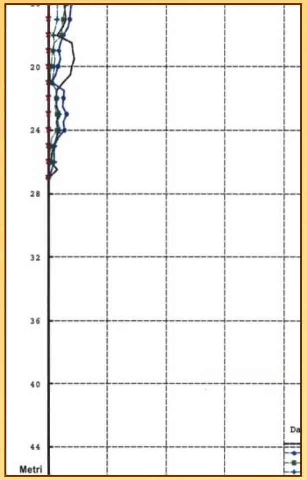
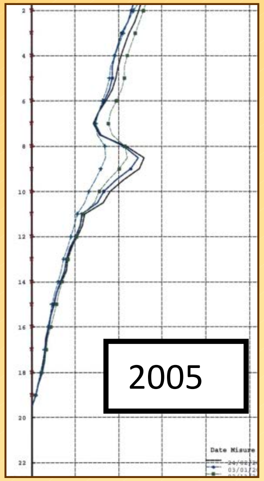




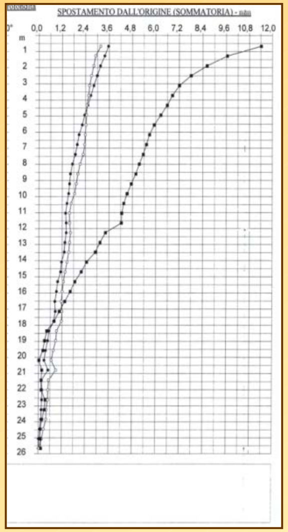
Past monitoring campaigns

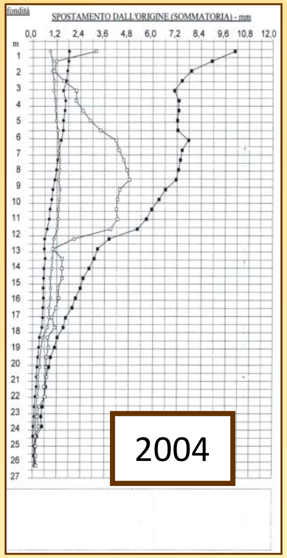


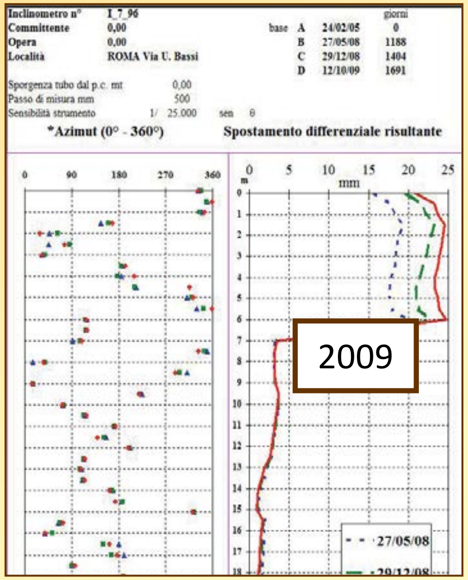




Are this measurements representative?
How the “real” value of displacement could be recognized?







Monitoring movements **before** a possible acceleration requests a **high value of accuracy** because the displacements are very small in magnitude and the variation in time could be on par to the **level of accuracy** of the instrument, moreover all **sistematic errors** that could affect measurements should be eliminated (or at least recognized …..)

In such condition, given the **low rate of horizontal displacement**, and the need to monitor the landslide movements during a possible acceleration phase (resulting maybe from rainfall events), inclinometer measures could be processed only using a **statistical approach**.

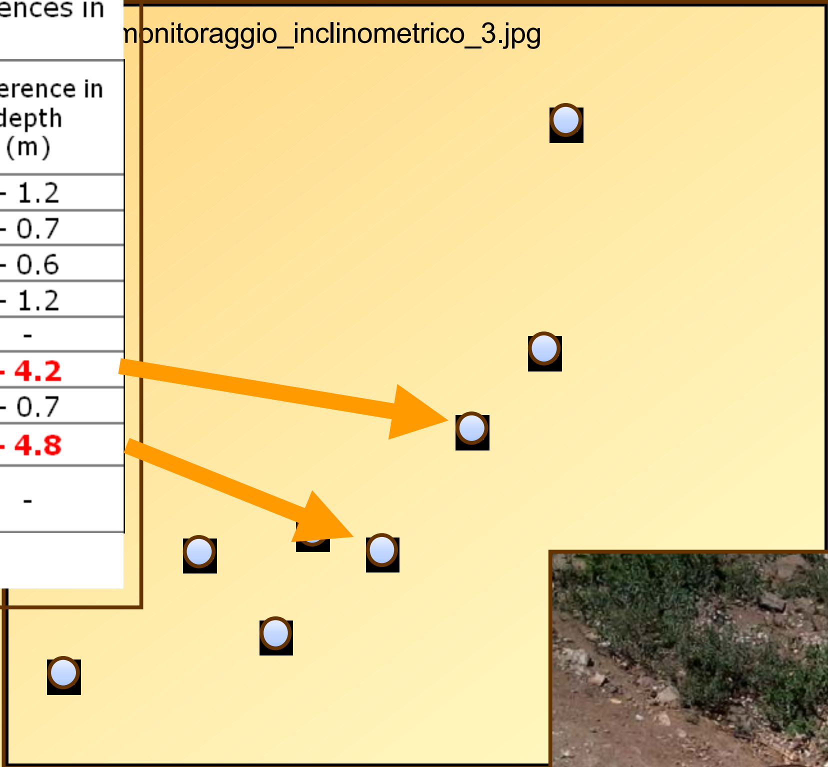
Present monitoring plan

As a first step it was necessary to check all the existing instruments, to evaluate their functionality before starting measurement. Some of them were installed more than 20 years ago, many inclinometers were restored in 2004.

Existing inclinometers with relative differences in depth from 1988 to 2011

	Code	Original depth (m) (*)	Depth in 2011 (m)	Difference in depth (m)
Via U. Bassi	I_2_96	30	28.8	- 1.2
	I_3_96	31	30.3	- 0.7
	I_9_96	30	29.4	- 0.6
Via Dall'Ongaro	I_5_96	28	26.8	- 1.2
	I_4_04	24.5	24.5	-
	I_7_96	25	20.8	**- 4.2**
	I_4_88	12	11.3	- 0.7
	I_3_04	26	21.2	**- 4.8**
Scala Righetto	I_1_88	19	19	-

(*) from Geoambiente 2004-2005



Our instrument consisting in a digital inclinometer system from RST Instruments with a data resolution of 0.005 mm / 500mm.

SPECIFICATIONS

INCLINOMETER	METRIC SYSTEM	IMPERIAL SYSTEM
Wheelbase	0.5 m	24 in
Probe diameter	25.4 mm	1.00 in
Probe length (including connector)	710 mm	28.0 in
Probe weight	1.4 kg	3.0 lbs
Probe material	Stainless steel	Stainless steel
Full-scale range (other ranges available)	30 degrees	30 degrees
Data resolution	0.005 mm per 500 mm	0.00002 ft per 2 ft
Memory	>1,000,000 readings	>1,000,000 readings
Repeatability	±0.002°	±0.002°
System Accuracy	±2 mm per 25 m	±0.1 in. per 100 ft
Axis alignment	Digitally nulled	Digitally nulled
Temperature rating	-40 to +70°C	-40 to +158°F
Sensor Type	MEMS Accelerometer, Biaxial	

AMANTI, CHIESSI & PUZZILLI - Landslide monitoring in urban area; reactivating old inclinometers in Roma.

STATISTICAL APPROACH FOR INCLINOMETER MEASUREMENTS

Standard readings taken in the opposite directions along plane A (A0, A180) and plane B (B0,B180) are espressed as:

$$A_0 = A + \varepsilon^s_{A0} + \varepsilon^r_{A0}$$
$$B_0 = B + \varepsilon^s_{B0} + \varepsilon^r_{B0}$$
$$A_{180} = -A + \varepsilon^s_{A180} + \varepsilon^r_{A180}$$
$$B_{180} = -B + \varepsilon^s_{B180} + \varepsilon^r_{B180}$$

where εs and εr are sistematic errors and random errors respectively. Supposing that sistematic errors are due only to instruments bias and that:

$$\varepsilon s_{A0} = \varepsilon s_{A180}$$
$$\varepsilon s_{B0} = \varepsilon s_{B180}$$

The differences represent the measure at each depth for each plane (plus gross error)

$$\overline{A} = \frac{A_0 - A_{180}}{2} = A + \frac{\varepsilon^r_{A0} - \varepsilon^r_{A180}}{2} = A + \varepsilon^r_A$$
$$\overline{B} = \frac{B_0 - B_{180}}{2} = B + \frac{\varepsilon^r_{B0} - \varepsilon^r_{B180}}{2} = B + \varepsilon^r_B$$

while the checksum represent a control parameter because it's value is costant with depth except for measures containing gross error:

$$S_A = \frac{A_0 + A_{180}}{2} = \varepsilon^S_A + \varepsilon^r_A$$
$$S_B = \frac{B_0 + B_{180}}{2} = \varepsilon^S_B + \varepsilon^r_B$$

Given the normal distribution of checksum S, differences and checksum have the same variances on each plane.

$$\overline{A} = A + \varepsilon_A^{r(-)} \approx N(\hat{A}, \sigma_A^2)$$
$$\overline{B} = B + \varepsilon_B^{r(-)} \approx N(\hat{B}, \sigma_B^2)$$
$$S_A = \varepsilon_A^s + \varepsilon_A^{r(+)} \approx N(\hat{S}_A, \sigma_A^2)$$
$$S_B = \varepsilon_B^s + \varepsilon_B^{r(+)} \approx N(\hat{S}_B, \sigma_B^2)$$

We can manage measures suspected to be affected by gross error applying Chauvenet criteria.

In a series of N experimental data, if some values □□exhibit a deviation from the mean value that is likely to occur less than 1/2N then those values □□should be discarded.

Outliers are identified calculating the mean and std dev of checksum (for ex.) along axis A ($S_{\hat{A}n}$ e σ_n).

and for the suspected measure

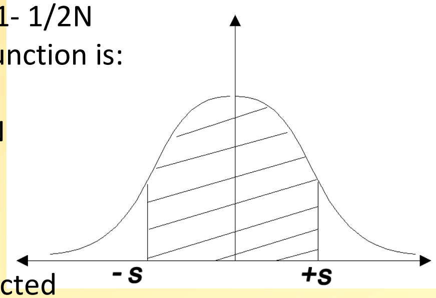
$$t_{sosp} = (A_{sosp} - \hat{A}_n) / \sigma_{n0}$$

(i.e. number of variances exceeding the mean value)

Given the probability p = 1- 1/2N the value for probability function is:

F(s)=1-1/4N

and if $|t_{sosp}| > s$



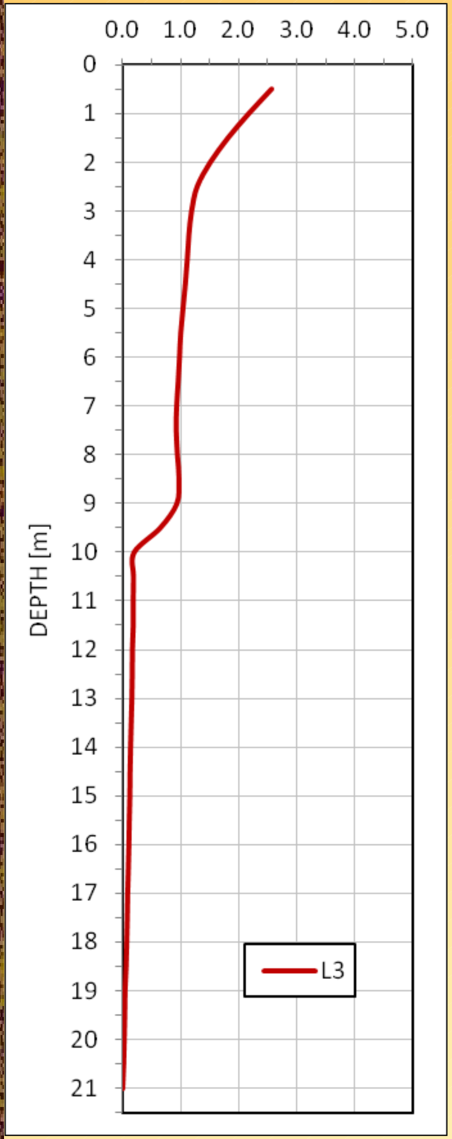
the measure could be rejected The recalculated values of mean and variance by rejecting t_{sosp} could be used as a **measurement of accuracy of readings and moreover to estimate accuracy of displacements**.

Simple bibliography:

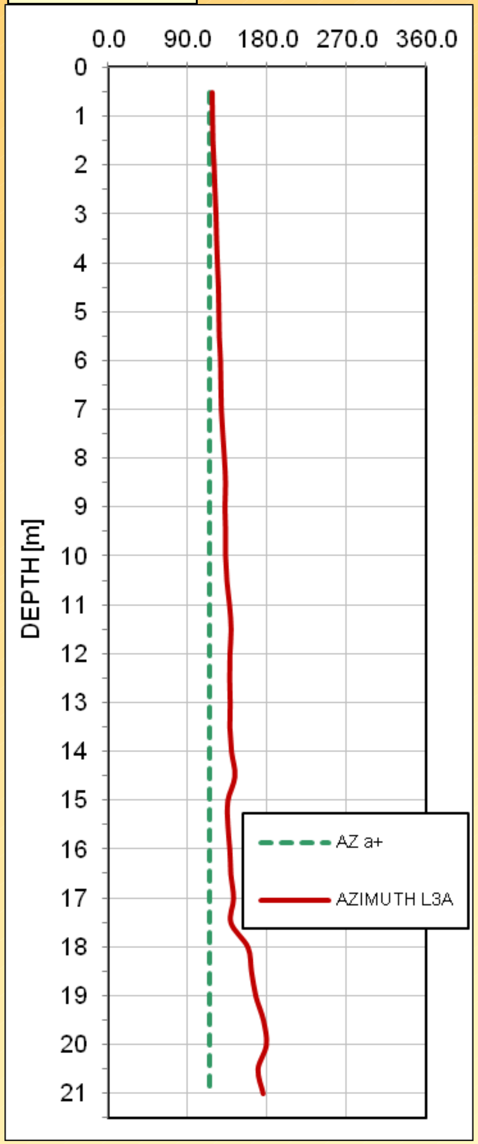
MIkkelsen, 2003. Simeoni, 2006. Simeoni & Mongiovì, 2007.

STATISTICAL APPROACH FOR INCLINOMETER MEASUREMENTS

Cumulative displacement (mm)

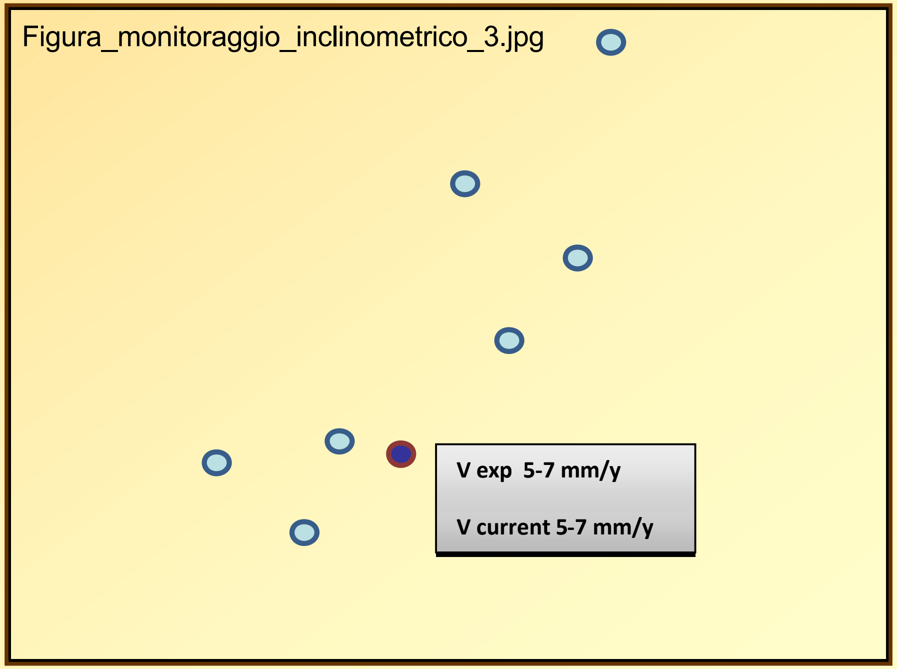


Direction (°N)

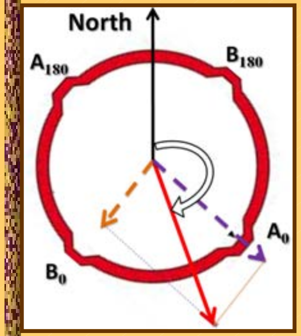


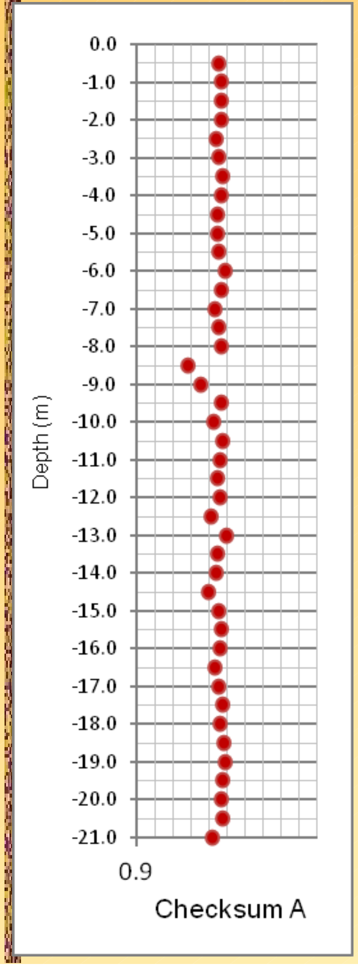
After about six months the integrated cumulative displacement for this inclinometer is about 2.6 mm that represents half of the expected value for 1 year.

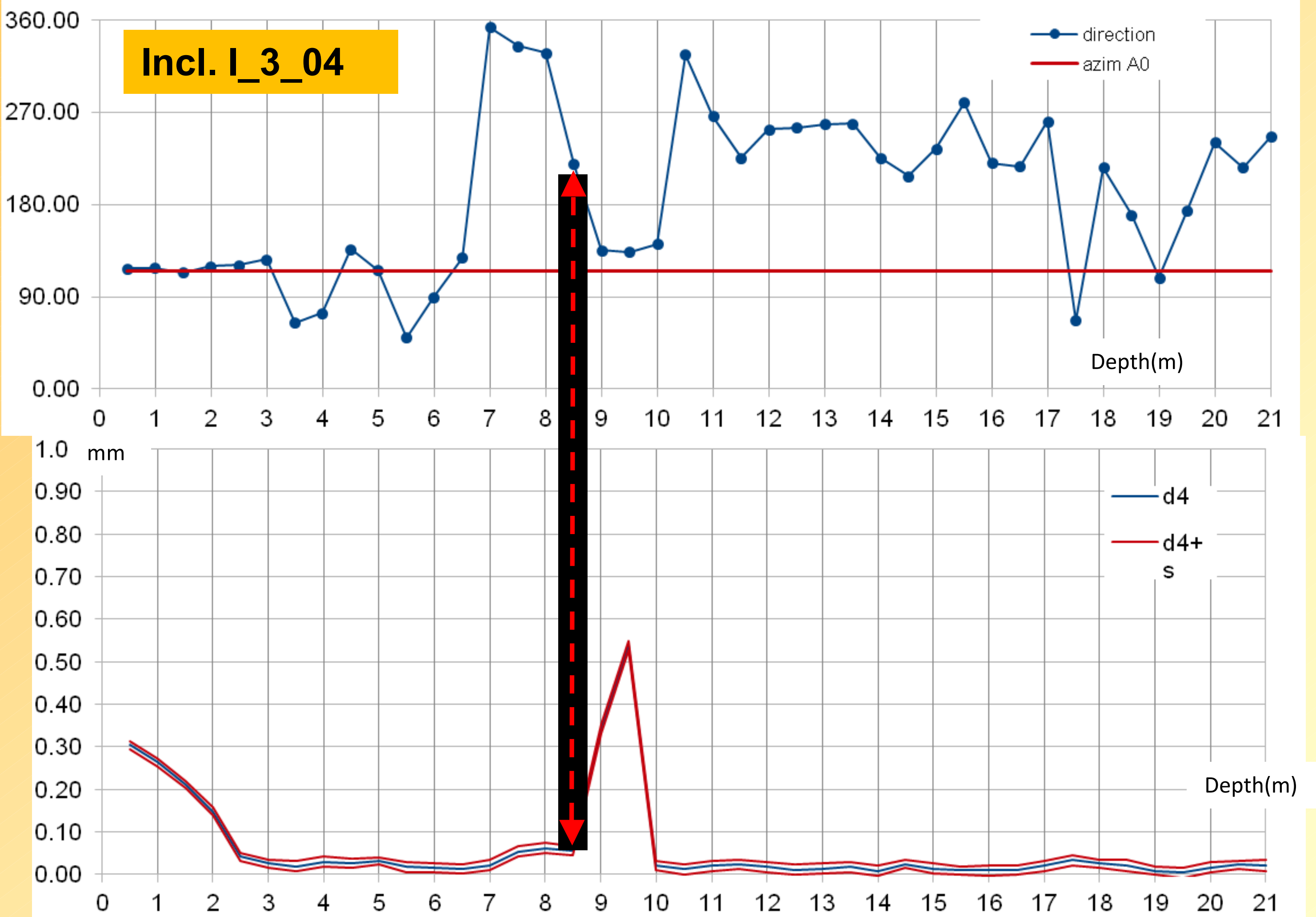
The curve is clearly affected by a very **small sistematic error** but it's necessary to investigate the reliability of the displacement in the depth range **9-10 mt** and in the depth range **0.5-5 m**



STATISTICAL APPROACH FOR INCLINOMETER MEASUREMENTS



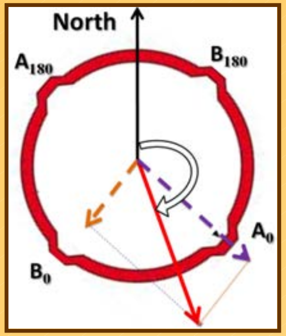


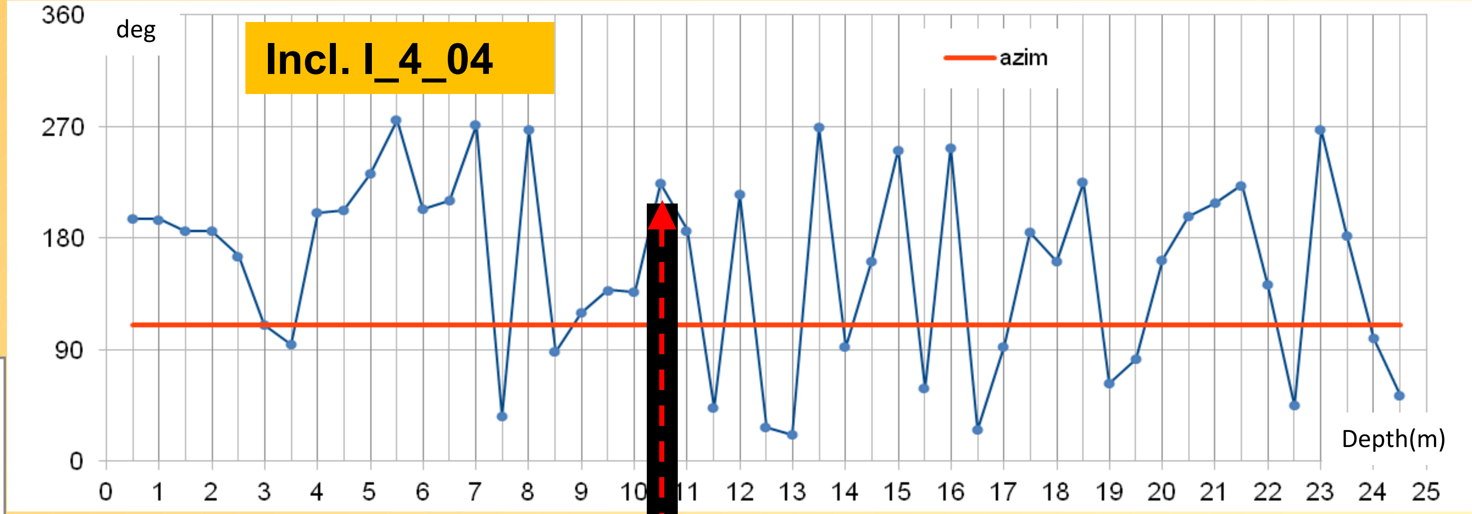


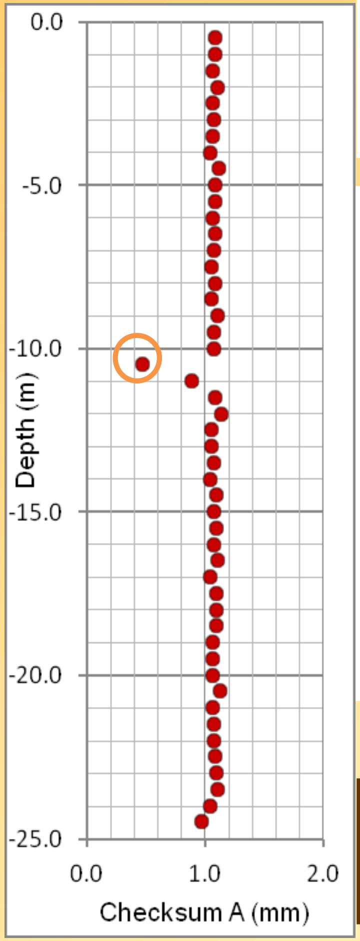
Integrated displacement and direction at each depth (after 165 days)

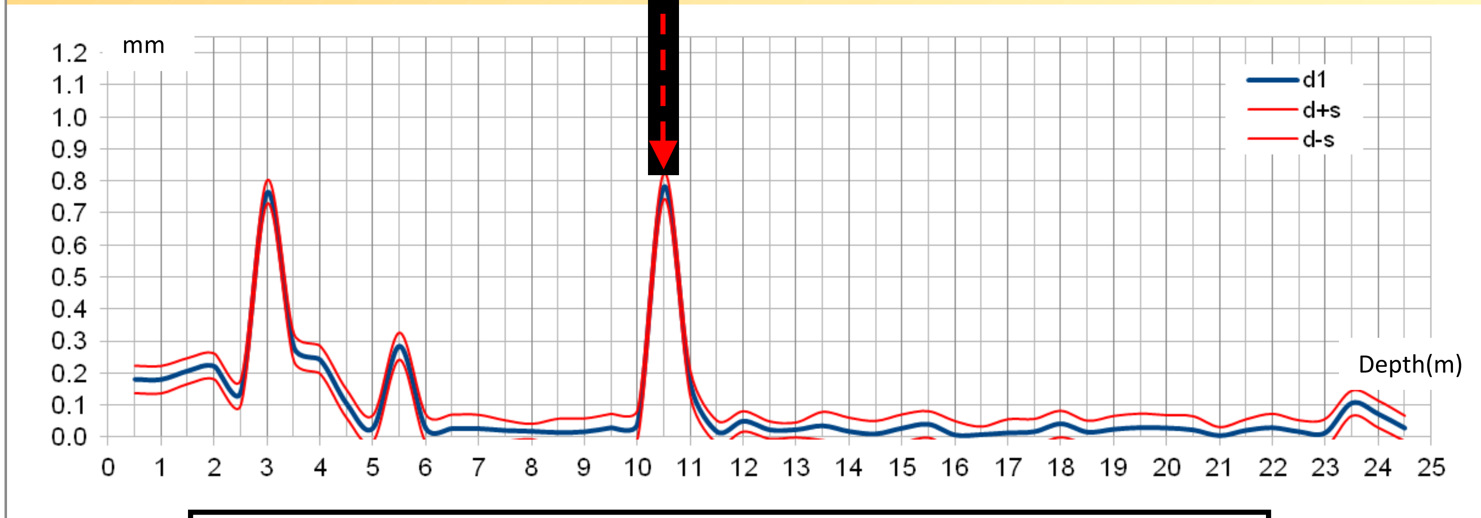
Checksum value at depth of **8.5** is suspected to contain **a gross error**, value was rejected applying a statistical analysis (chauvenet criteria).
The direction of integrated displacement in the **depth range 9-10 m** is not so far from A0.
The depth range of interest for this inclinometer is now from 10 mt up to surface.

STATISTICAL APPROACH FOR INCLINOMETER MEASUREMENTS





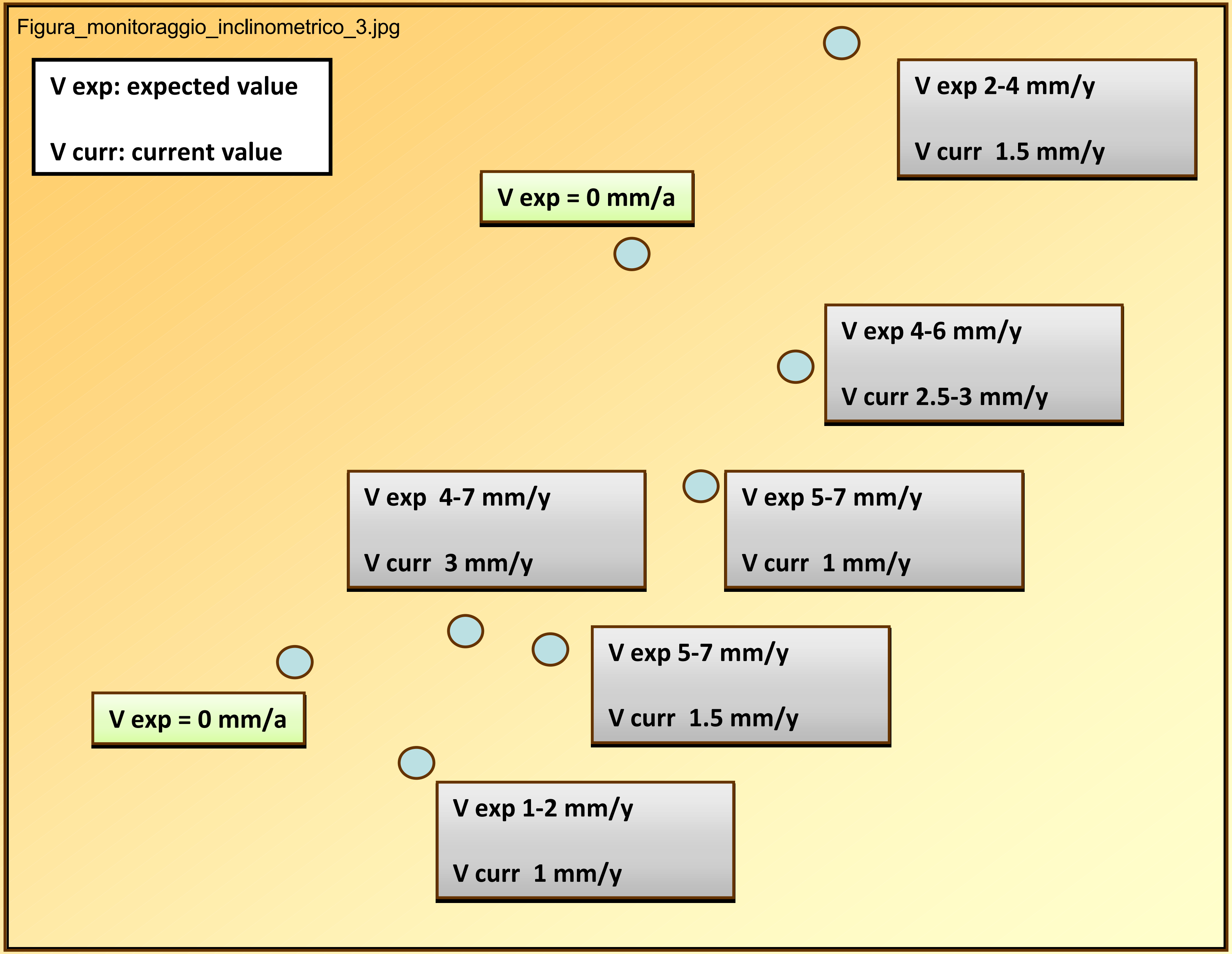




Integrated displacement and direction at each depth (after 30 days)

Checksum value at depth of 10,5 m is suspected to contain a gross error, value was infact rejected applying a statistical analysis (chauvenet criteria).
The direction of integrated displacement for depth of 10,5 m is far from the direction A0 (in red).

RATE OF HORIZONTAL DISPLACEMENT AT JUNE 2012 (6 months)



Next steps

Continue monitoring measures in inclinometers for almost a year

Use statistical approach to obtain clean data

Compare inclinometers (in depth) data with surface data coming from geodetic measures

Integrate inclinometers network with stratigraphic, piezometric and geophisical data

Quel lettore che intendesse fare o comprare o prendere in affitto una casa proprio a Monteverde, e volesse sapere come mi regolerei io al suo posto, non sarà dunque sorpreso se gli dichiaro che nei suoi panni,comincerei col rivolgermi ad un geologo.

Enrico Fossa-Mancini, 1922

A reader of this book who wants to build or buy or rent a house in Monteverde, and who asks me what I would do in that case, well, that reader will not be surprised if I say that my first action would be to ask a geologist.

Enrico Fossa-Mancini, 1922

Thanks for your attention

Eastern side of Monteverde hill in Roma.