BLOCK ADJUSTMENT AND DIGITAL MODEL OF PHOTOGRAMMETRIC DATA IN A CONTROL PROBLEM FOR THE "ANCONA '82" LANDSLIDE

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1. Introduction: the problem.

In December 1982, a large scale landslide (220 ha) has interested the district of Ancona (Italy), touching also some residential quarters of the city. A working group consisting of geologists, geophysicists, geotechnicians and geodesists has been set up in order to analyze the causes, to control the ground settling and to determine the consequent destination of the area.
Inside this working group, geodesists have performed the control surveying by topographic and photogrammetric instrumentation. The former is a still going operation intended to control the settlement of the terrain after the landslide, the latter is mainly the study of the deformation of the landscape derived from photogrammetric material taken before and after the landslide occurrence. Figure 1 shows the landslide area with the graph of the photogrammetric block. The importance of such a survey consists in supplying quantitative data, useful for the geological analysis of the causes of the landslide itself.

2. Block adjustment.

The photogrammetric work consists in a simultaneous block adjustment of photograms taken at two different times (Summer 1980 and December 1982, the day after the sliding) and at two different heights. The higher strip (scale ∿1:11 000) is the old one (4 models) and the three lower strips (scale ∿1:6 000) are the new ones (19 models).
This means to consider, in the aerotriangulation adjustment, as "separated" the identical points "in landslide", whose displacements are to be known, and as "coincident" the identical points "out of landslide", which are supposed to be fixed.
The reason of such a procedure is because of the impossibility of determining during the ground settling, by topographic operations, control points "contemporary with the flight". Note that, for the knowledge of the movements, the relative position between the two blocks is more important than their absolute position.
For the higher strip only, the horizontal control points at ground are 12 and the vertical ones are 69. Other 24 height ground control points are taken from the shore-line, tide effect being corrected. Many tie points are made as pricked points, the others are mainly on buildings.
The measurements are done on an analytical plotter Zeiss Planicomp C 100. The relative orientations, made with 12 points, give 4.8 μm as average m.s.e. and 6 μm as highest m.s.e.
The adjustment is made with the program of the Stuttgart University in a way to check the real accuracy of measurements and estimates. The inner instrumental precision, checked with grid plate is less than 2 μm.

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Fig 1 - Landslide boundary and photogrammetric block

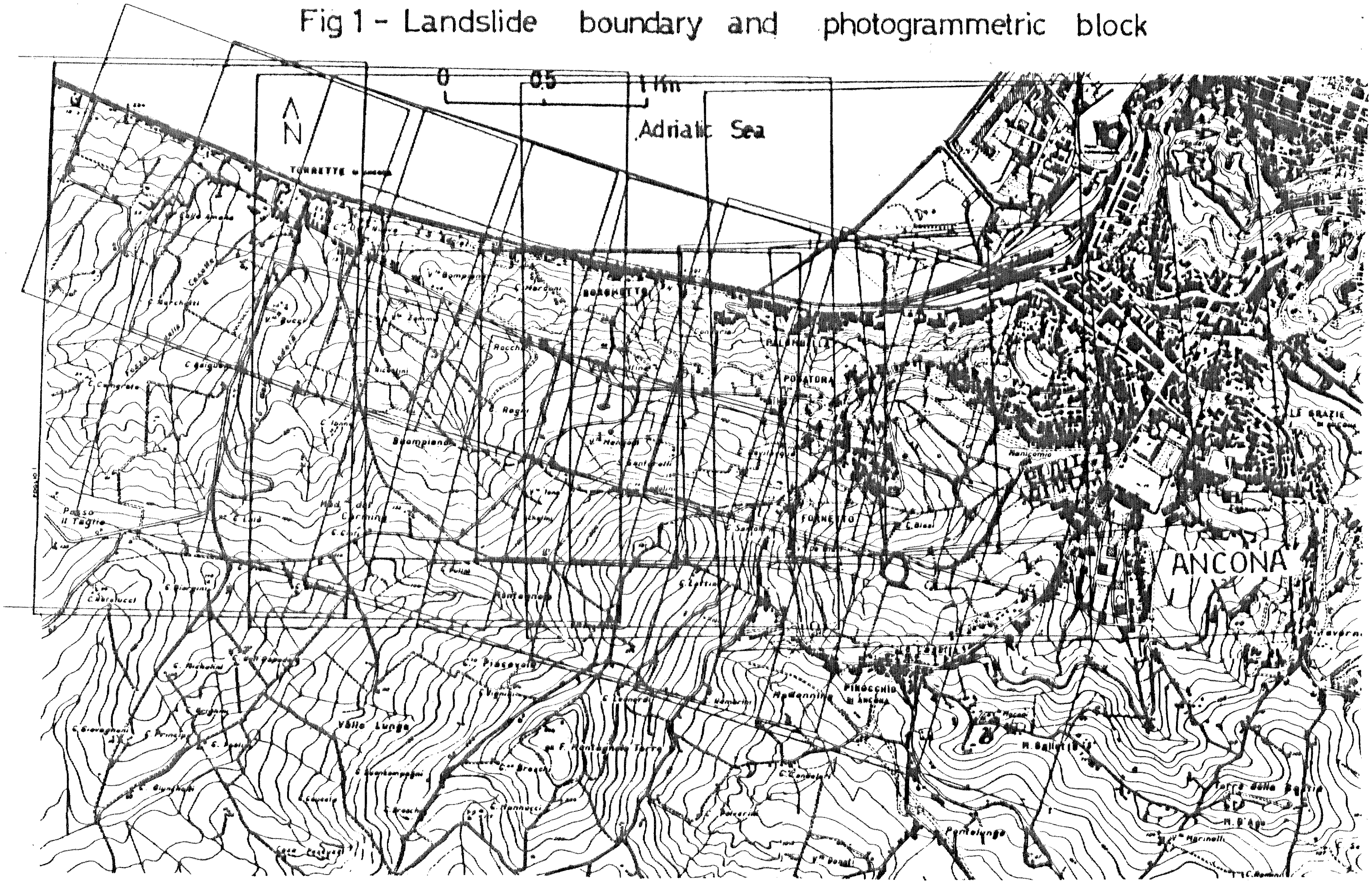


Table 1 lists the type of measured points and the final accuracy of adjustment, according to the running program.

TAB. 1	Model Points	Control Points in the models	Redundancy - Sigma naught
Ho. Points N.	1046	20	1220
RMS X (m)	0.230	0.385	0.312
RMS Y (m)	0.246	0.358	
Ve. Points N.	1130	104	728
RMS Z (m)	0.162	0.339	0.207

The differences of the coordinates among points "separated in landslide" furnish the movement occurred at the moment of the slide (see fig. 2).
In order to evidence the real precision of point positions and displacements, the RMS of the "out of landslide" points transformed coordinates are computed, as shown in Tab. 2.

TAB. 2	Points on buildings	Pricked Points
Points Number	147	82
RMS X (m)	0.309	0.190
RMS Y (m)	0.312	0.157
RMS Z (m)	0.161	0.144

As regards the first type of points, generally located at ground level close to the buildings foot, note that the horizontal position precision is rather low, due to their very hard identification process.
This means that the real precision of the estimated movements is about .5 m for horizontal displacements, while it is nearly .3 m for the vertical ones.
As first statistical analysis of movements, some regression curves have been calculated, for two central zones, pairing the following variables: ΔY displacements and Y positions, ΔZ and Y, ΔY and X, ΔZ and X, where Y is the direction of the landslide, X the transversal one, and Z the altitude. The first two regression curves are cubic functions, the last two straight lines, as shows fig. 3. These curves give preliminary information about the landslide shape, but this result is not sufficient to explain the whole movements.

3. Digital model.

By means of the least squares collocation method, a digital model allowing to study in detail the surface deformation, is constructed on the set of the displacements values. In such a way one gain the knowledge, on a regular and dense grid, of both plano-altimetric and only altimetric movements; the former starting from the displacement determination on well identifiable points, the latter, deriving from singling out the altitude changes (in the same planimetric positions). At the moment, the first analysis only is carried out.
In fig. 4 are shown the correlograms of the displacements.

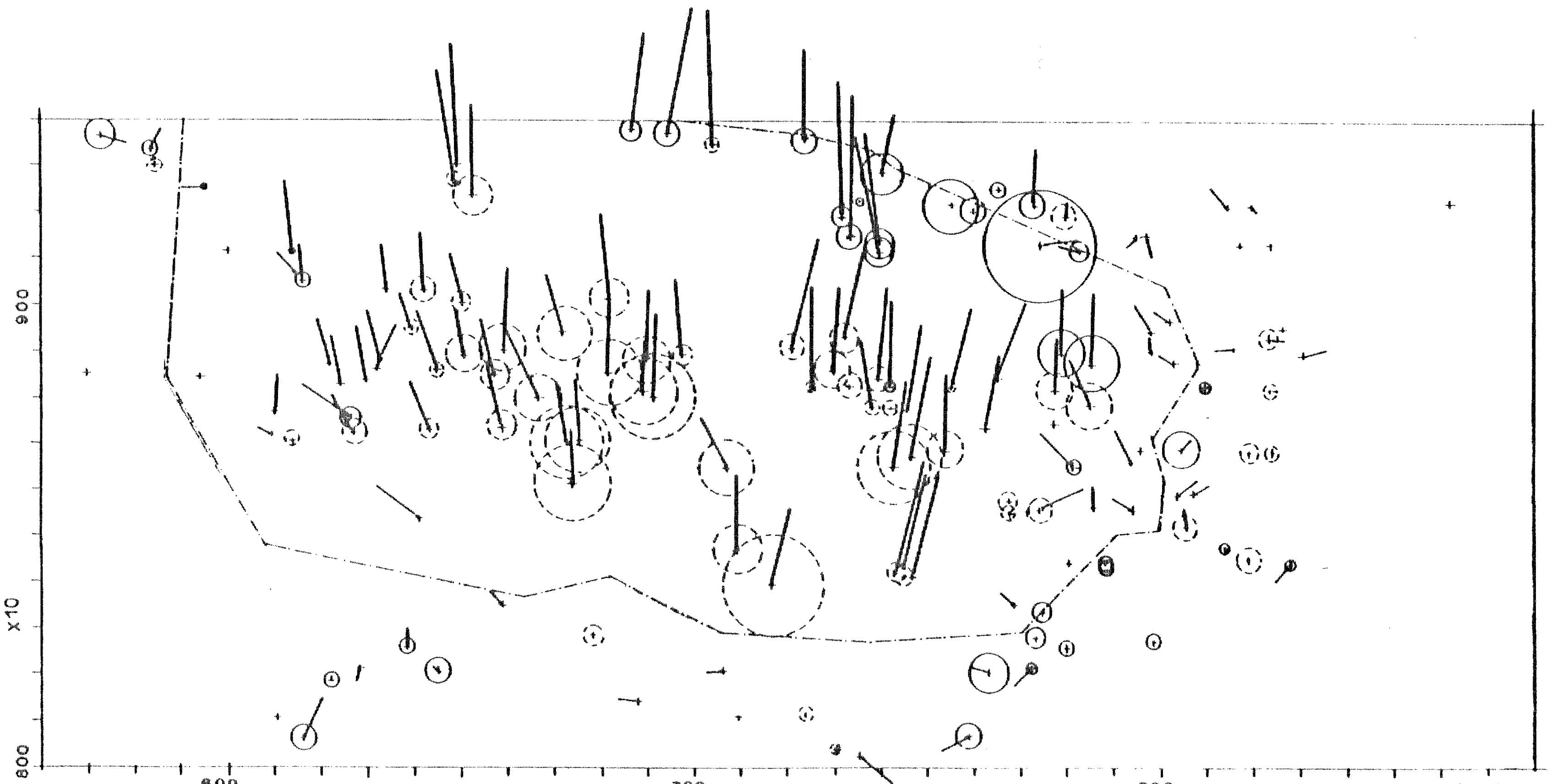
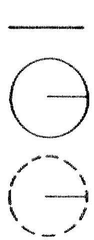


fig. 2 - Landslide: Ancona '82



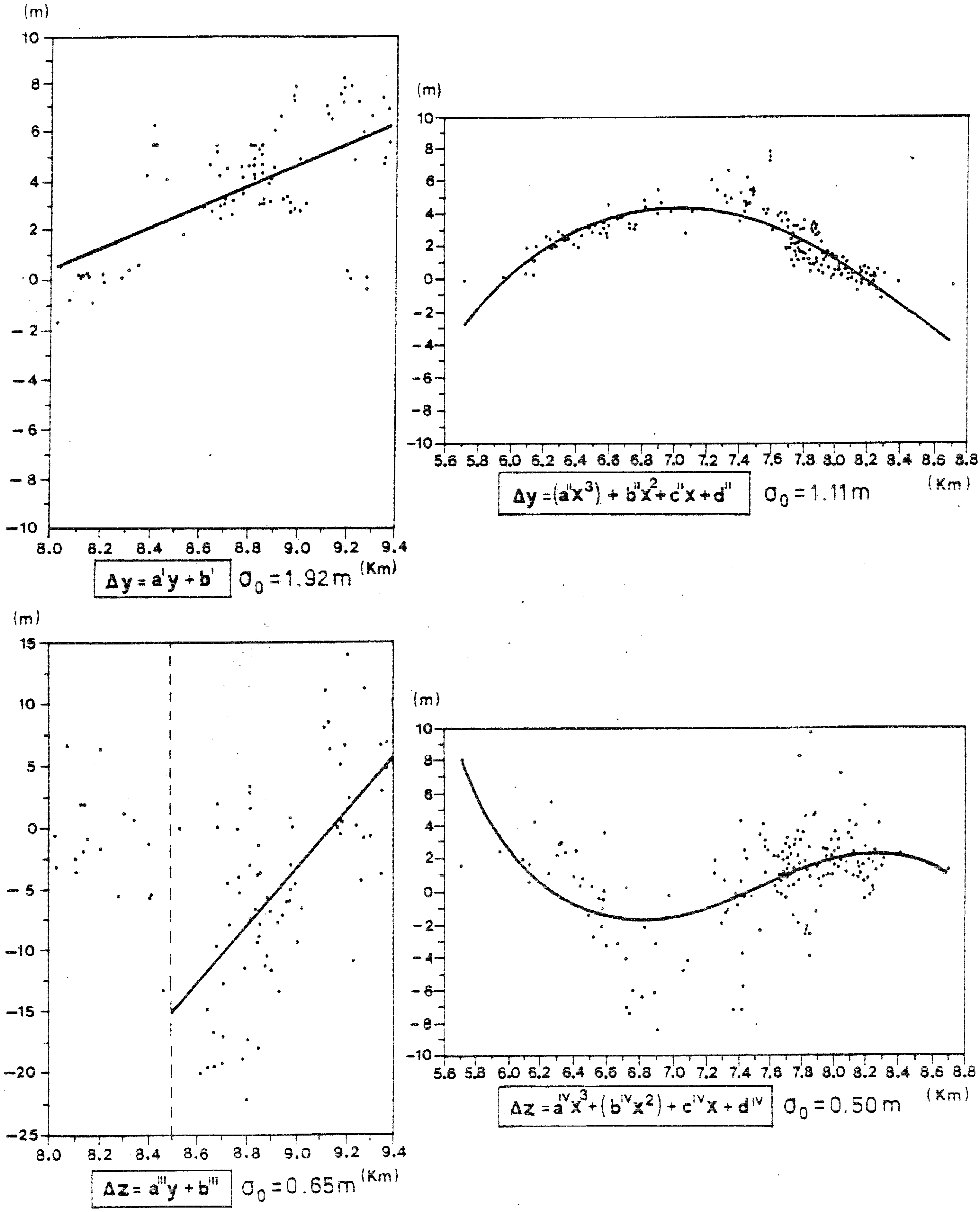


fig. 3 –Regression curves of displacements

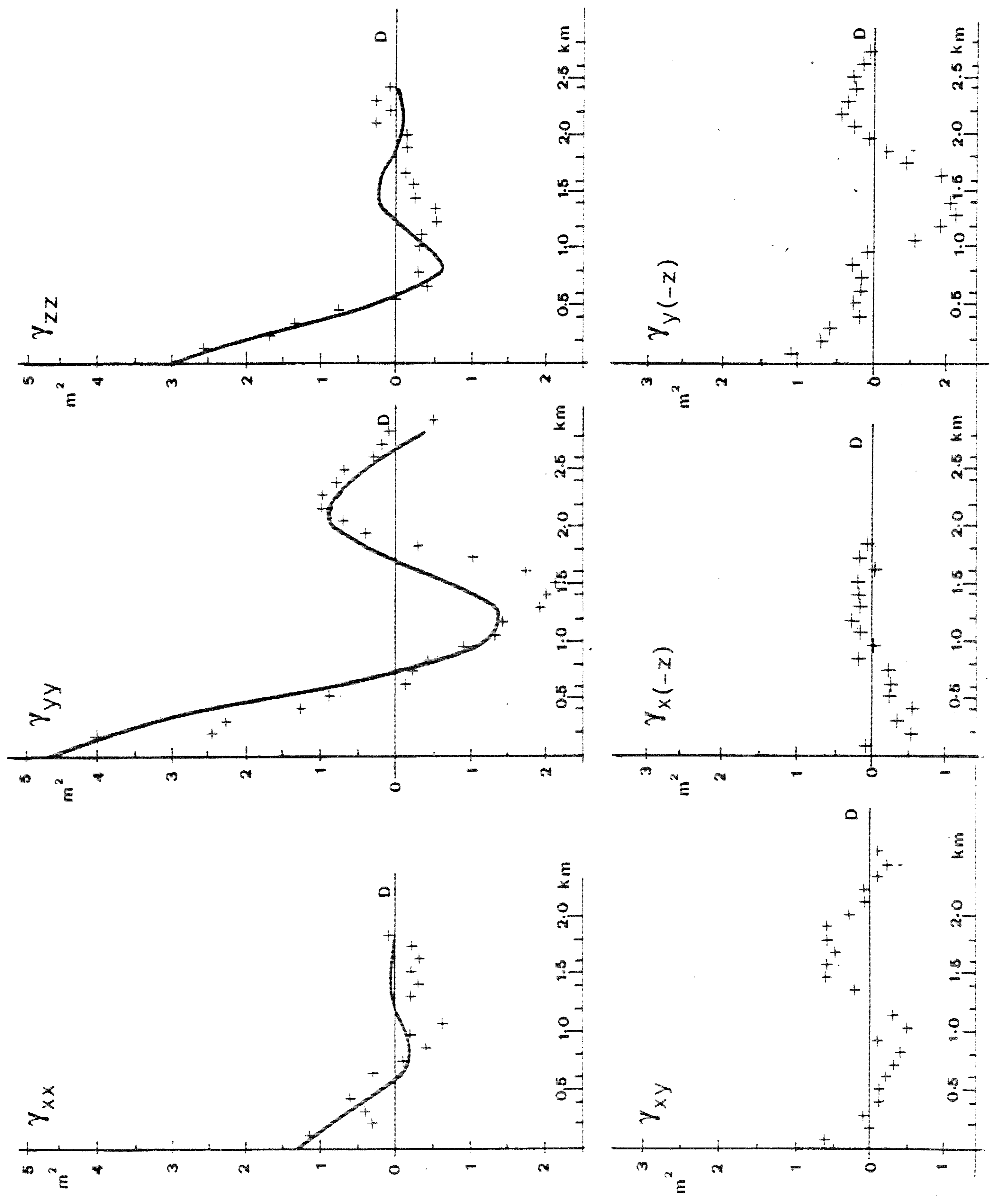


fig. 4 - Estimate covariance functions of displacements
+ empirical values
—— best fit function of empirical values

Since the distribution of the points is sparse but irregular, the optimum lag for the correlograms, which needs to be estimated, is found where $\sigma^2 - \gamma(1)$ comes to a minimum (see Tab. 3).

TAB. 3	50	100	105	110	115	120...	150...	500m
$Tr \mid C(0)-C(1) \mid_{Ho}$	0.98	0.70	0.58	0.57	<u>0.56</u>	0.58	0.64	1.71
$\sigma_z^2 - \gamma(1)_z$	0.25	0.22	0.19	<u>0.19</u>	0.20	0.20	0.21	0.31

$$Tr|C(0)-C(1)|_{Ho} = \sigma_x^2 - \gamma(1)_x + \sigma_y^2 - \gamma(1)_y$$

Table 4 lists the coefficients of the best fitting covariance functions: $\gamma = a\, e^{-bD} J_o(CD)$, where J_o is the Bessel function of zero order.

TAB. 4	σ^2 (m^2)	$a = \sigma_s^2 (m^2)$	$b (Km^{-1})$	$c (Km^{-1})$	σ_n^2 (m^2)
γ_{xx}	0.65	0.16	1.28	4.19	0.49
γ_{yy}	4.91	4.39	0.19	3.14	0.52
γ_{zz}	0.39	0.21	0.86	4.82	0.18

$\gamma(0)_{xy} = \sigma_{n_{xy}} = 0.30\ m^2$

$\gamma(0)_{x(-z)} = -0.02\ m^2$ $\qquad \gamma(0)_{y(-z)} = 0.36\ m^2$

Note that the difficulty to model suitably the cross-covariance functions has suggested to separate planimetry from heights and to regard γ_{xy} only as noise. Therefore filtering and prediction are performed independently for the planimetry components and for the heights.
Table 5 lists the quantity and the precision of the filtering.

TAB. 5	N.val.	RMS (Δ)	RMS $(\hat{n})$	RMS $(\hat{n}_-)$	$\sqrt{M}$ (σ_e^2)
ΔX, ΔY (m)	530	1.67	0.67	0.51 (-33 val.)	0.26
ΔZ (m)	265	0.63	0.37	0.29 (-11 val.)	0.17

$\hat{n}_-$ = noise sample cut off at level of significance $\alpha = 5\%$ (two-side test)
σ_e = standard error of estimated signals

Note that the RMS after tailing are comparable with the formerly estimated precision of the movements.
Fig. 5, 6, 7 show signal at measured points, noises and signal at grid points respectively.

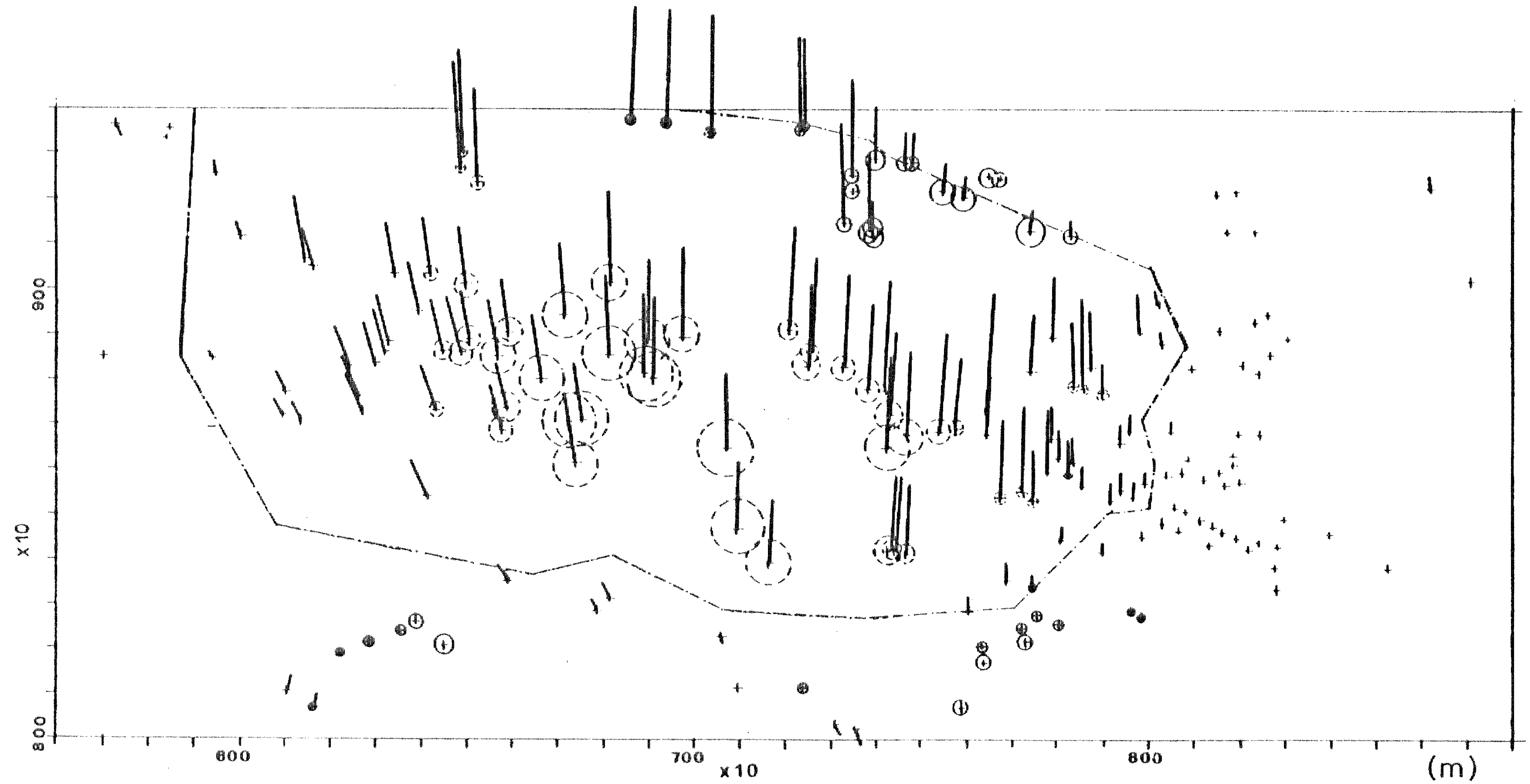


fig. 5 – Landslide: Ancona '82 (signal at the measure points)

(same symbols as fig. 2)

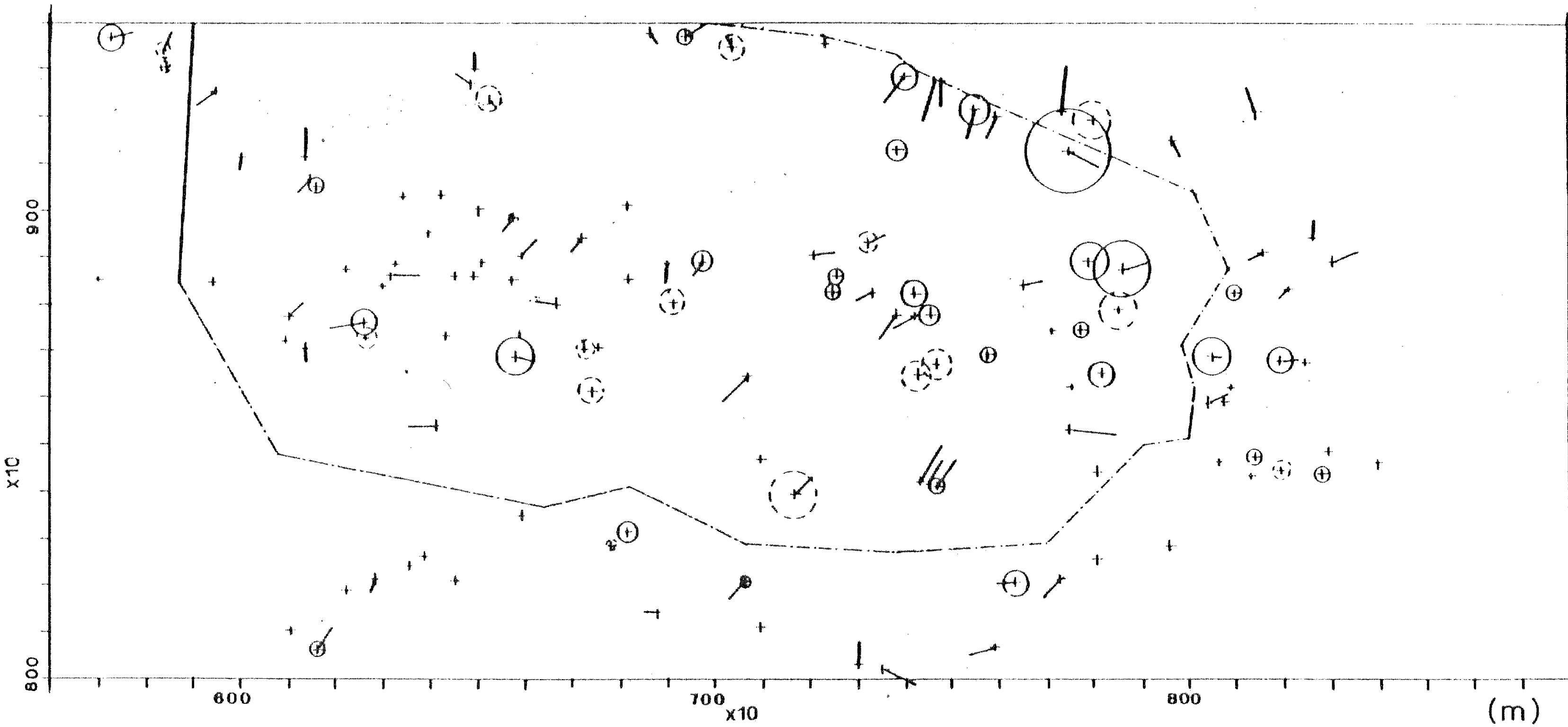


fig. 6 – Landslide: Ancona '82 (noises)

(same symbols as fig. 2)

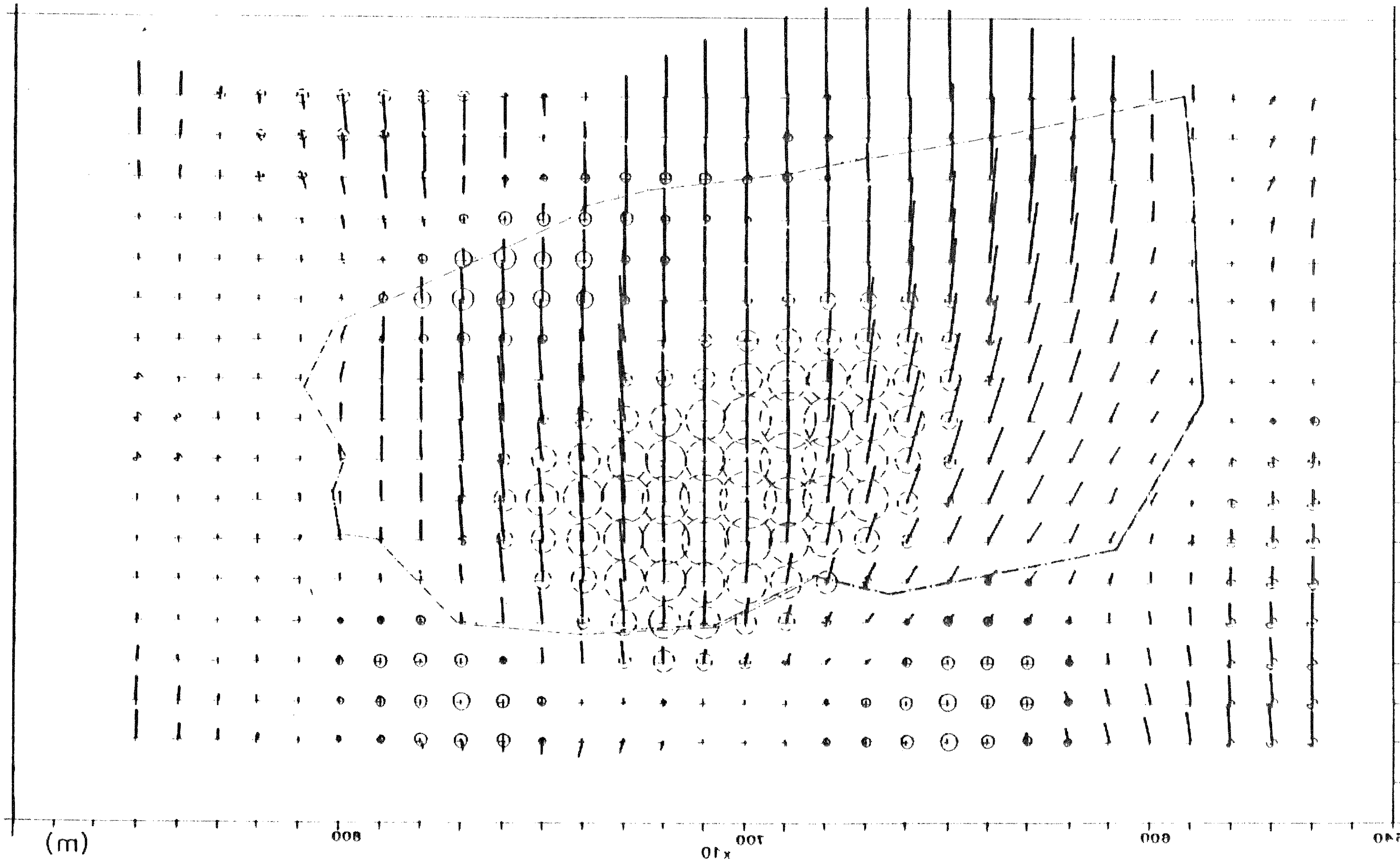


fig. 7 – Landslide: Ancona '82 (signal at the grid points)

(same symbols as fig. 2)

Conclusions: further developments.

The photogrammetric models are now under observation in order to achieve a regular grid of points on the ground, before and after the sliding. It will be possible:

- to make a comparison between the same vertical cross-sections of the slope;
- to point out the landslide boundary;
- to compute the earth settlements and the volumes involved;
- to analyse the shape and the pattern of the fissures and the graping cracks;
- to observe building tilts and rotations.

Note that singling out the altitude changes in the same planimetric positions does not call for targeted points. If the results will be acceptable, it follows that the slide monitoring is easy also in a non-urban area, as it is needed in many hilly zones in Italy.

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