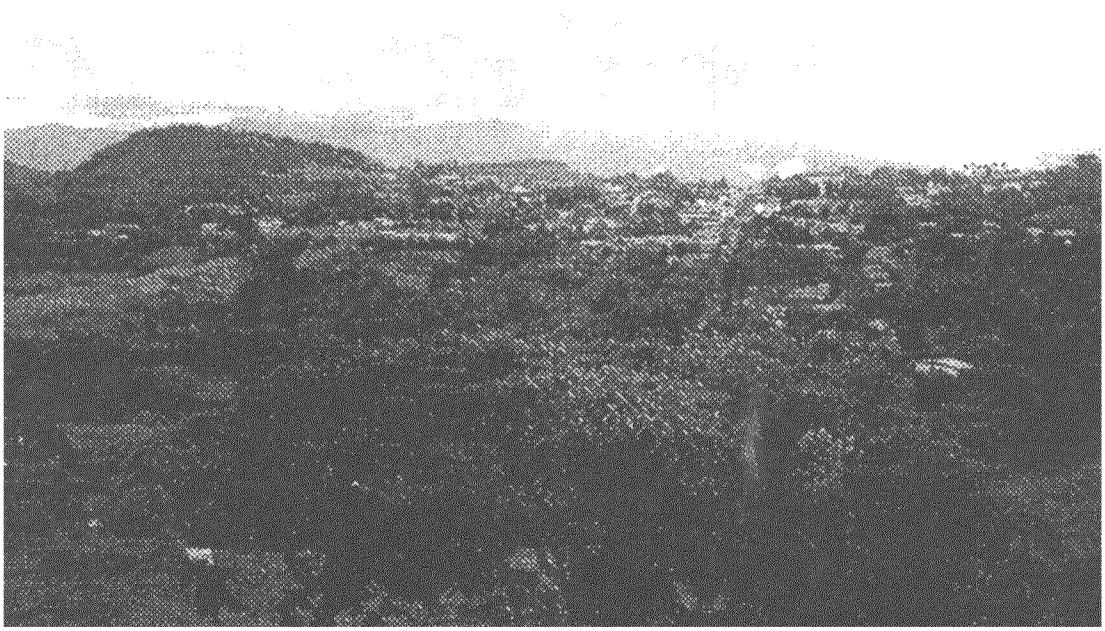
3. Evaluation of external control points

If one has access to points that can be considered fixed and are possible to include in a network, one can calculate absolute deformations. Absolute deformation observations make it possible to determine the size and direction of the movement for the measured area as a whole. It also simplifies the calculations a lot, because of the possibility to use the fixed points for defining the datum of the network. For a relative network, the datum is based upon points without statistically determined movements. This gives the possibility though, that the network as a whole is moving, but with no movements detected (see chapter 6.1).



Picture 3.1. Santiago de Puriscal as seen from the Ceme site.

An attempt to establish fixed points has been done in Santiago by placing points on hills seemingly outside the landslide. Therefore, the first task was to check whether the assumption was true, i.e. if the chosen fixed points are stable or not. The check was done by measuring distances and angles between the three points. This has been done during the previous campaigns as well. It makes it possible to control if the changes of the observations between the epochs are within calculated error limits. If movements can be statistically determined, the chosen points are not fixed.

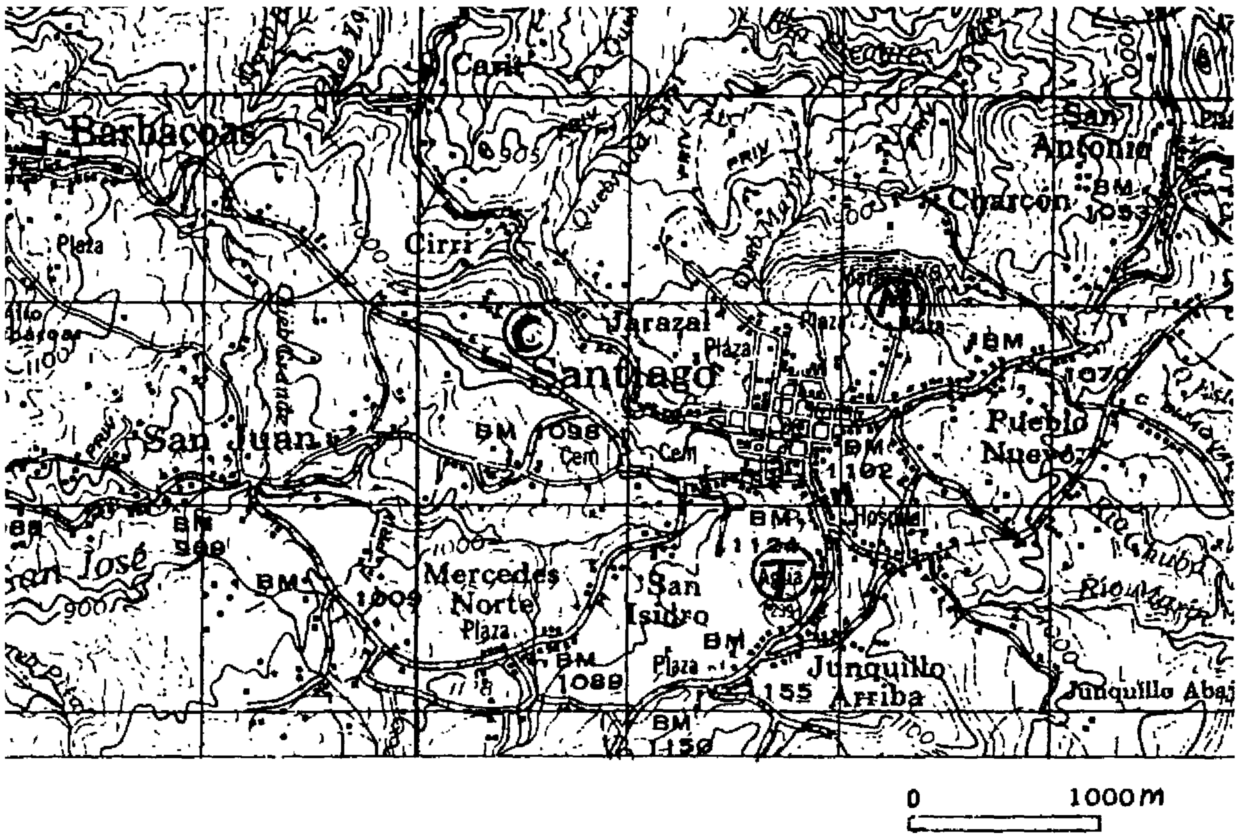


Figure 3.1. The area surrounding Santiago de Puriscal. M,C and T denote the Marin, Ceme and Tanque point locations (map from Instituto Geográfico Nacional, C.R.).

The proposed method for this project was first to determine that no movements had occurred for the external points. If the assumption was true, observations would have been done as seen in figure 3.2 to connect the fixed points with the network. These observations include distance and angles to and from the fixed points.

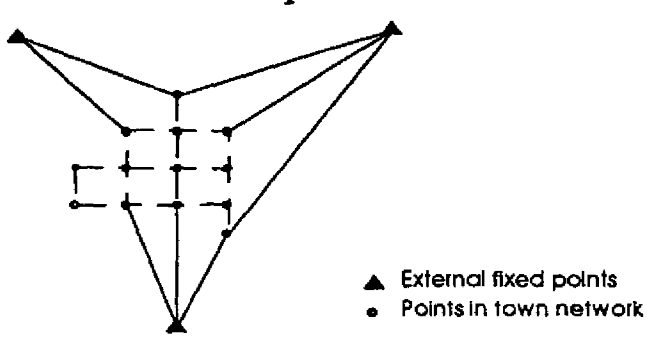


Figure 3.2. Example of fixed points included in a network.

If the points can not be considered fixed, they can be used as a separate relative network to determine the extension of the landslide. To determine a confident datum for such a network, several points need to be included. Points that have moved may then be inside the landslide. However, the external points involved in this project are too few to make such a determination.

3.1. Observations of the external points

In March 1991 and in July 1992 observations were done on the three sites. In August 1992 some observations were done in order to see whether the displacements found between previous two epochs could be correct.

Epoch	Measured by	Points included	Instruments used and their a priori error	Remarks
March 1991	Tomás Marino	All	WILD T2000 (1.5cc) WILD DI3000(3mm+1ppm)	
July 1992	Tomás Marino Magnús Agnarssson Thomas Dubois	All	WILD T2000 (1.5cc) WILD DI3000(3mm+1ppm)	One distance measured in only one direction
August 1992	Tomás Marino Magnús Agnarssson Thomas Dubois	Stations only at Tanque and Ceme	WILD T2000 (1.5cc) WILD DI3000(3mm+1ppm)	Not a complete network

Table 3.1. Observation epochs of the external points.

During the observations all directions were measured in 3 rounds, with a maximum difference of 1.0-1.5 mgon between rounds. Distances were measured 10 times.

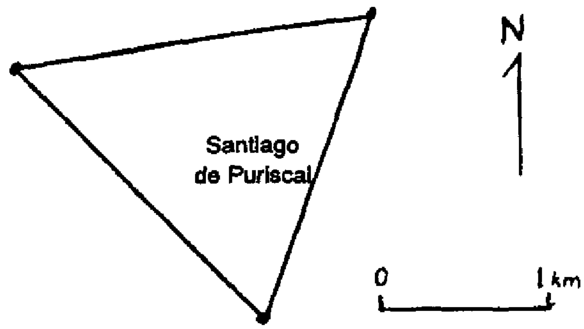


Figure 3.3. Approximate configuration of the external points.

3.2. Interpretation of the observations

The interpretation of the observations was done by comparing the observation data of the epochs. This is not a strict mathematical analysis but more of an approximate analysis of the movements and their characteristics. The reason for not using the adjustment programs is that they can only indicate the displacement of one point as the other two are needed for datum definition.

First, the observations from March 1991 and July 1992 are compared to see whether any significant movement can be distinguished.

Stations	Distances March 1991 (m)*	Distances July 1992 (m)*	Difference (m)	$(\frac{d_{March1991}}{d_{August1992}}-1)$
Marin-Tanque	1417.0855	1416.1502	-0.9353	660.5 ppm
Tanque-Ceme	1362.0187	1361.0790	-0.9397	690.4 ppm
Ceme-Marin	1647.0337	1645.8742	-1.1595	704.5 ppm

Table 3.2. Measured distances corrected for atmospheric influence and transferred to Tanque's level.

This difference of distances is very big and is without any doubt significant, at least when comparing to an a priori error of approximately 5 mm for each distance. The proportional change, as shown in the last column, does indicate that the displacement is somehow systematic. According to geologists at OVSICORI a movement of 1m is very possible for areas with this condition.

back-station-forward	Angles March 1991 (gon)	Angles July 1992 (gon)	Difference (mgon)
Tanque-Marin-Ceme	57.91811	57.91824	-0.13
Ceme-Tanque-Marin	80.73362	80.73278	0.84
Marin-Ceme-Tanque	61.34880	61.34895	-0.15
Σ	200.00053	199.99997	

Table 3.3. Angle observations from March 1991 and July 1992.

The difference of measured angles is very small, in two cases not even significant compared to the a priori error of 0.15 gon. This indicates that no changes have occurred in the angles during this period, except maybe in the second one. The difference in the second angle can mean a maximum of 20 mm displacement.

Considering data from both distance- and angle observations the conclusion must be that the triangle sides have become shorter but that it keeps its form. This fact must be considered as a very unlikely coincidence. To see what effect those seemingly similar scale changes have, it was tested if the scalar difference is the cause of the displacements, i.e. to test if the displacement is non-significant. Thus it is assumed that there is some kind of scale change in the observations between the epochs. The average scale difference between the two epochs is calculated to 685.1 ppm. Then it is subtracted from the distances measured in March 1991 and the following results are obtained.

Stations	Distances March 1991 d (-685.1 ppm)	Distances July 1992 (m)	Difference (mm)
Marin-Tanque	1416.1147	1416.1502	-35
Tanque-Ceme	1361.0856	1361.0790	+7
Ceme-Marin	1645.9053	1645.8742	+32

Table 3.4. Distances corrected for scalar change.

It can be seen in this table that considering the difference as a scale error and compensating for it the displacements are almost eliminated. This may indicate that the changes in the triangle are only of scalar nature. However, the difference is still too big to be considered as non-significant compared to the a priori error of the instrument. But when comparing to the estimation of errors of the observations, the displacement is non-significant (see chapter 3.2.1).

The result of these two epochs shows either movement or a very severe scale error of the measuring device. The authors find it very difficult to believe that a movement of approximately 1m does not alter the angles of the triangle. Therefore this observed movement was believed to be due to instrumental failure or some other error. For this reason observations were done in August 1992 to control whether the displacements could be verified.

In the following table the results of the angle observations can be seen and the differences between the prior epochs.

back-station-forward	Angles August 1991 (gon)	Difference March 1991-August 1992 (mgon)	Difference July 1992 - August 1992 (mgon)	Difference March 1991 - July 1992 (mgon)
Ceme-Tanque-Marin	80.73023	-3.39	-2.55	-0.13
Marin-Ceme-Tanque	61.35089	-2.09	-1.94	0.84

Table 3.5. Angle observations from August 1992 and changes compared to other epochs.

It can be seen that a big change has occurred between July 1992 and August 1992, but that the change is less between March 1991 and July 1992. Though it should be noted that the change of -3.39 mgon means a 88 mm displacement, which is a significant displacement.

Stations	Distances August 1992 (m)	Difference March 1991 and August 1992 (m) no scale correction	Difference March 1991 and August 1992 (m) with scale correction	Difference July 1992 and August 1992 (m)
Marin-Tanque	1416.1419	-0.9436	0.0273	0.0083
Tanque-Ceme	1361.0727	-0.9460	-0.0129	-0.0018
Ceme-Marin	1645.8832	-1.1505	-0.0221	-0.0090

Table 3.6. Distance observations from August 1992 and changes compared to other epochs.

It can be seen from the table above that the displacements between March 1991 and August 1992 are very small when the scale error is corrected for, or very big if the scale error is not considered.

3.2.1. Error estimation of the observations

To estimate the error in the observations of a triangle various methods exist. The prerequisite for error estimation is knowledge of what should be the correct result. In the method the authors have chosen, the triangle is seen as a traverse. Then one point is seen as the origo and co-ordinates calculated from the observations. When the traverse returns to origo the co-ordinates should be the same as the ones in the beginning, the difference is then the closure error. For both epochs Tanque was chosen as origo and the bearing 0 gon towards Ceme.

For the March 1991 epoch this method gives a closure error of 7.6 mm in x-co-ordinates and 7.2 mm in y-co-ordinates, thus the radial error will be

$\varepsilon_r = \sqrt{\varepsilon_x^2+\varepsilon_y^2}$, or 10.4 mm. The misclosure in the sum of angles in the triangle is -0.53 mgon (the sum should be 200 gon but was measured to 200.00053 gon). This indicates that the radial error is mostly due to the distance observations.

For the July 1992 epoch this method gives a ε_x = 5.3 mm and ε_y = -48.2 mm, and the radial error 48.3 mm. The misclosure in the sum of angles in the triangle is 0.03 mgon (measured to 199.99997 gon).

For the August 1992 epoch this kind of calculation is not possible and only the a priori error data for the instruments can serve as an aid for the estimation of errors. Only one distance was measured in both directions with a difference of 30 mm, which is high above the 5 mm a priori error of the instrument. Thus the estimated error of each distance observation should be at least 15-30 mm. For angles only 0.15 mgon can serve as a guideline.

The estimated error of the displacement should be the root sum square ($m_d = \sqrt{\varepsilon_1^2 + \varepsilon_2^2}$) of the sum of the estimated errors of respective epoch. Then the minimal detectable displacement is estimated equal to two times the error of the displacement. This assumption is of course not statistically correct, but the error estimation should be sufficient for this application. Here the problem is to decide whether the movement is 1m or none.

- For the period March 1991 and July 1992 the displacement error is estimated to 49 mm.
- For the period March 1991 and August 1992 the displacement error is estimated to ≈32 mm.
- For the period July 1992 and August 1992 the displacement error is estimated to ≈57 mm.

It should be noted that the displacement error is not a standard error.