3.2.2. Result of the observations

If it is given that the observations in March 1991 have a scale error, then it is not possible to detect any significant movement of the points. On the other hand, if it is given that the original observations from March 1991 are correct, it is obvious that all the points have moved ≈0.5 m towards the centre of the triangle they form. It can not be said in this thesis, which is the correct interpretation.

3.3. Visual study of the sites

The result of the test indicated that movements may be found among the external points. The calculated displacement may also originate from scale error, as mentioned in chapter 3.2. To see if any evidences of movement existed, a visual investigation was made. Both the external points and their surrounding areas were controlled.

Picture 3.2. Ceme site.

3.3.1. Description of the Ceme site

The point is situated on a quite steep small hill in a meadow area. The hill is covered with grass and has parts of bare earth. The following observations were made:

- Fractures were found in the ground close to the point as well as further away (see picture 3.3). According to Ing. Tomás Marino, they did not exist in 1991.
- Steep slopes a few meters from the point were badly eroded.
- The whole hill seemed gliding approximately towards the northeast.
- At the closest distance from the point, the fracture has a width of about 25-40 cm. A parallel fracture makes the total width nearly 50 cm.

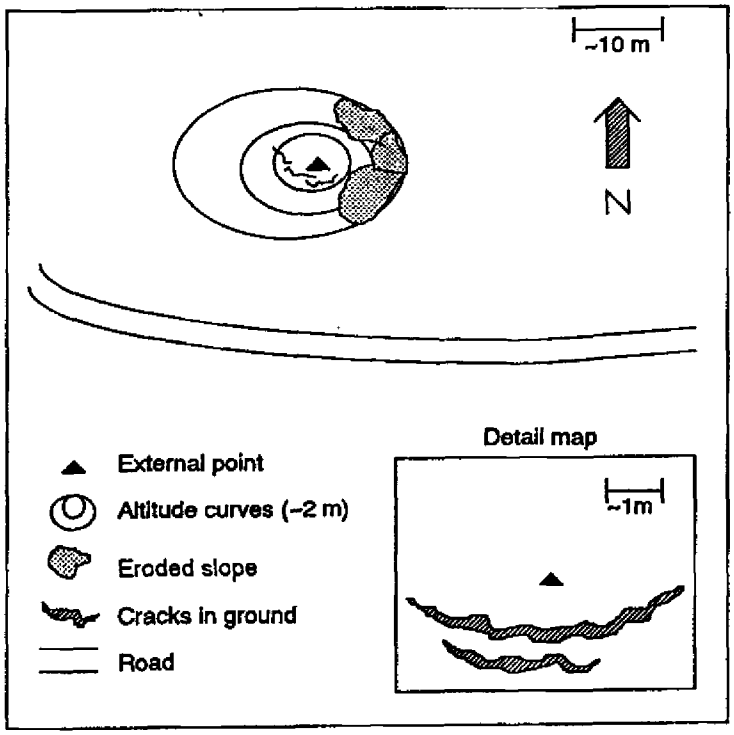
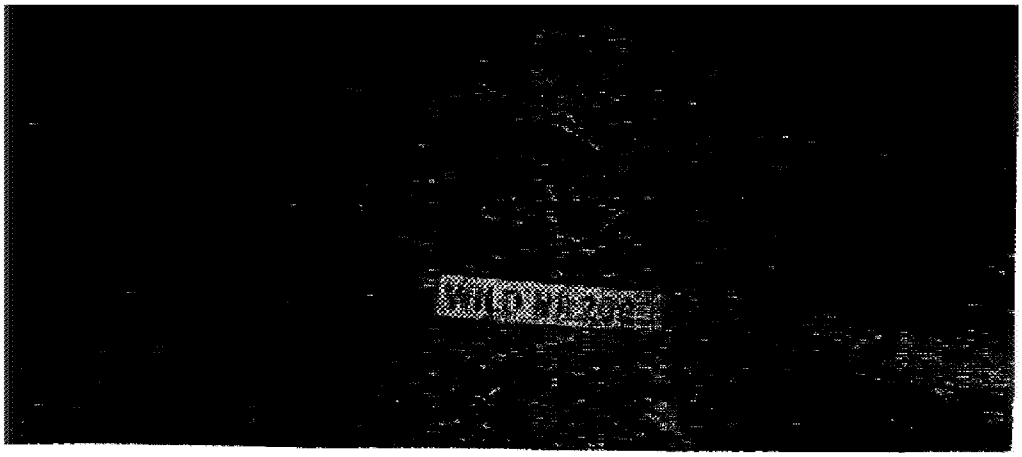


Figure 3.4. Ceme site. Scales and proportions are approximate.

3.3.2. Description of the Marin site

The point is situated on a hill near the village boundaries. Coffee and other crops are grown on the slopes, but the hill is mainly covered by forest. The following observations were made:



Picture 3.3. Fractures at Ceme. The ruler is 30 cm. The point is seen at the far right.

- The whole south side is sliding to the SW, towards the village.
- A fracture 15-20 cm wide and 5-10 cm deep was found approximately 2 m to the SW of the point
- A fracture 30-40 cm wide and 20 cm deep was found approximately 1 m further to the SW.

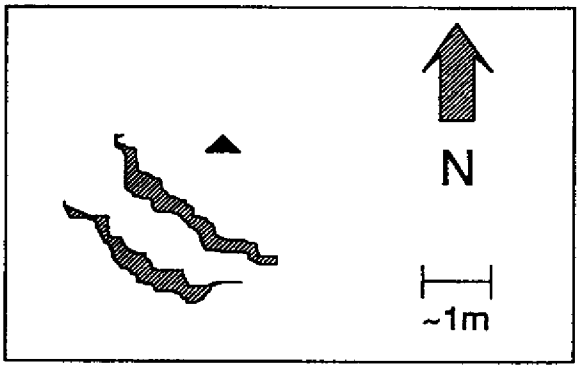


Figure 3.5. Detailed map of the Marin site.

3.3.3. Description of the Tanque site

This point is situated on a ridge-shaped hill with a quite flat top and some trees. No fractures could be seen at this location, probably due to the absence of steep slopes. Observations are difficult here, since the ground is unstable around the point. Even careful walking around the instrument proved to affer the tripod during an observation. The reason for this seemed to be an abundance of shallow roots in the soil.

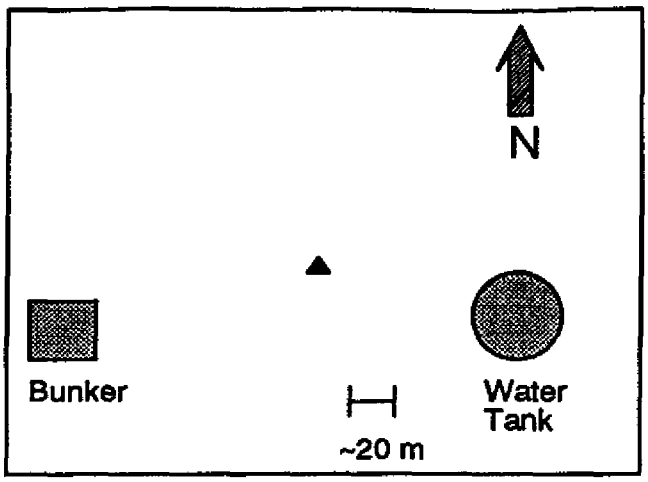


Figure 3.6. Tanque site.

3.4. Possible ways of fixing a moving point

Technically it is possible to fix the external control points and for this three possible solutions will be mentioned in this chapter. Before investigating these methods, it should be considered that all solutions are time and cost consuming. Therefore, it is essential to clearly define the objectives of the deformation analysis in Santiago de Puriscal. If only the internal strains, that induce fractures in town, are of interest, the external control points are abundant (relative network). Whereas if the velocity and acceleration of the town are of interest, the control points should be used (absolute network).

Three ways will be mentioned for obtaining a stable point, which in turn may make absolute deformation observations possible.

- The first method uses a new location, where one can be sure that no local movements exist, i.e. were the ground is stable. This involves a location which is evidently outside the landslide area. A drawback is that it can be difficult to obtain sight to other points (including the network) from a new location.

- The second method deals with fixing the existing point by installing local control points on stable ground nearby them. With this method, it is possible to keep a location with clear sight to other points while at the same time getting around the local movement problem.
  From the control points, it is then possible to measure the new location of the moved point. The determined new location then has to be controlled if it coincides with the position determined from the other fixed points. This means that observations from the control points and the other external

determine the same new location for the moved external point. If this is not the fact, the control point area as a whole may also be moving. If three local control points are set out, one has the possibility of controlling the internal configuration of the three, and thereby be able to detect any internal movements of the new control points. If such a movement can be proved statistically, the method is useless, and a new strategy has to be invented.
A drawback with the method is that more observations are added, which is cost and time consuming. The calculations are also more difficult, since the moved external point can not be considered the same from one epoch to another.

- The third method involves GPS measurements. The external control points are unnecessary in this case, since GPS measurements can be done on several selected points in the town network. They should be measured relative to a fixed point, that does not have to be within visible reach from the town. Thereby, the risk of placing a fixed point inside landslide boundaries can be avoided. Introduction of GPS to the study would have great advantages. However, time and cost aspects as well as instrument and software availability could be problematic at present.

3.4.1. Fixing the Ceme site

For this point, it is difficult to find a location which is clearly outside the landslide area while having clear sight to the other control points. Therefore, the alternative of using local control points was investigated.

When checking the surroundings, it was found that a road nearby was situated on a ridge. Although the road might be inside the landslide boundaries, the road itself is a stabilising factor, because its stable structure may prevent it from gliding.

Three control points can be established near the roadside. The whole hypothesis is very uncertain though, so it must be declared that this solution is recommended only if a fixed point is necessary and no other possibilities exist.

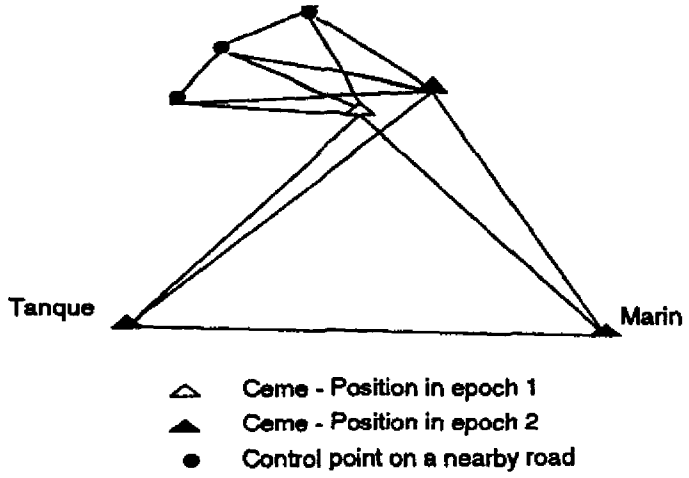


Figure 3.7. Proposal to structure for fixing the Ceme point.

3.4.2. Fixing the Marin site

Since no stable areas can be found nearby, this point is very difficult to stabilise. Difficult sight due to vegetation is also a problem.

3.4.3. Fixing the Tanque site

This point seems to be the most stable of the three when investigating the site. A reason for this may be that the hill where it is situated has a flatter top than the other external points. The point can be controlled by using a bunker and the top or the sides of the nearby water tank (see figure 3.6).

3.5. Conclusions

If it is concluded that the observations from March 1991 have a scale error, then it is not possible to detect any significant movement of the points. On the other hand if the original observations from March 1991 are correct it is obvious that all the points have moved ≈ 0.5m towards the centre of the triangle they form. It can not be said which is the correct interpretation. But considering other indications, like fractures around the points, the experience of the OVSICORI personnel, no indications of errors in the DI3000 (the same in all three epochs), it is more likely that the displacements have occurred. It would have been valuable if the DI3000 had been calibrated for scale error and not only addition error.

For the reasons mentioned above the external control points are excluded from further studies in this thesis.