THE USE OF NUMERICAL IMAGERY AND PHOTOGRAMMETRIC METHODS FOR THE MONITORING OF UNSTABLE SLOPES

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Abstract

The comparison and combination of high-resolution Digital Elevation Models and ortho-images generated from multi-date stereo-photogrammetric aerial views, provides a powerful tool for the study of large ground movements, e.g. landslides and creep. Several sites have been studied in France; for each, a digitised image of the deformation field of a continuous ground surface has been computed. The extraction of qualitative and quantitative data, such as displacement and the volume of superficial deformation, provides the necessary data for characterising and understanding the evolution of such sites

1. Basis of the method and traditional methods

The monitoring of unstable slopes is based on the identification and definition of many different elements, such as slope morphology, the morphology and size of affected areas, the apparent complexity of the movement, geology of the site, the hydrological and climatic settings, and the historical context. It is thus very important, when studying ground movements, to define several parameters correctly, including the geometry of the disturbed area, displacement velocity (if possible), and the geometry of the rupture surface. The last point can be very difficult to ascertain, as generally it is visible over only a few metres in the upper part of the slide area Various disciplines help in this type of work, in particular photo interpretation, topometry and photogrammetry, not counting the obvious need for site investigation.

Topometry, which is based on the measuring of angles and distances, is used for determining the direction and amplitude of the displacement of fixed markers on the site, and requires surveying skill. The aim of *photogrammetry* is to determine the x, y, z coordinates of easily identifiable points on aerial photographs. Although less precise, and longer and more expensive in its application than topometry, it provides a very large number of measurements. However, both methods. with the occasional exception of photogrammetry, generally only provide discontinuous data in space, and thus cannot provide a complete image of the superficial deformation field of an unstable site

Photointerpretation, thanks to the scale and spatial definition of airphotos, partly fills this gap. It is especially useful for the comparison of the morphology of a slope before and after an event However, the obtained results largely depend on the visual acuity of the photointerpreter, his perception of depth or relief, and it is always necessary to observe two photos at the same time in order to obtain a maximum of information. In addition, the examination of a stereo couple, unfortunately, remains mostly qualitative, and quantitative data are very difficult to obtain except in some cases by using intermediate photogrammetry.

2. Numerical tools for a new approach

Using interpolation software, it is possible to transform a fairly dense network of points defined by their coordinates x, y and z, obtained from photogrammetry, into a file of elevation data according to a regular grid, called a digital elevation model (DEM). To each mesh of this DEM, an elevation 'z' value is attributed that depends on the z values of the points that lie within a predetermined distance from the centre of the mesh. It now has become possible to obtain DEMs and ortho-images with very fine grids of less than 4 x 4 m, the latter based on digitised aerial photographs, after an automatic search through auto-correlation for homologous points on a stereo pair of airphotos. This method does, however, require very good quality airphotos and considerable computing power.

Based on these tools, a new approach has become possible, comparing DEMs and orth0-images, and describing the successive morphology and surface conditions observed for a slope over a certain period The vertical component of surface deformation is easily calculated from the variations in elevation of corresponding pixels between successive DEMs. The image of differences in the DEMs provides valuable qualitative and quantitative information that helps in defining the deformation and, if warranted, the (geological) structures that control it. In addition to a large number of topographical profiles. it is also possible to extract displacement vectors from these data, which provide information on the movement dynamics.

3. The example of La Clapière

La Clapière is a slope in the Alpes Maritimes (S. France), which is over 1000 m long at its base and is affected by creep over a height of more than 650 m that covers an area of about 85 ha. This is not the place to review its history or structural specifics (see Folacci, 1988), suffice it to say that an extremely dense network of photogrammetric data has been used to calculate DEMs of the slope for 1970 and 1986, using a 5 x 5 m grid. Comparison of these DEMs gave a map of surface deformation, which shows the surface expression of deep movements and, to a certain extent, of deformation dynamics. The map shows in particular the role played by fracturing. With the help of a specific geological map at scale 1:10,000, it was then possible to analyse the deformation in each of the lithological units found on the slope.

But, to appreciate the full contribution of this method, it should be known that the Clapière site was fitted with a topometric monitoring system that, even though quite sophisticated, only comprises about 30 targets. This means that only one measurement for approximately each 3 ha is available and that it is not certain that all points are really representative for the areas where they are located.

The method as proposed here enables the study of the behaviour of 34.000 unit surfaces, i.e. 850,000 $m^2/25\ m^2$, and provides an image of deformation that is continuous in space. Processing of these data has shown that subsidence affects a surface area that is 1.9 times larger, and a volume that is 3.1 times greater, than the uplift of the topographic surface. The volume of this superficial deformation is as much as 8.2 million m^3, for a movement whose overall mass is estimated to be about 40 million m^3.

4. The Friolin site

This site is located in Savoie (France) and was the first application of a study based on DEMs and commercially available ortho-images. The latter were calculated according to a 4 x 4 m grid from digitised airphotos, of which two pairs were obtained, taken in 1970 and 1986 at a scale of 1:30,000 by the IGN, the National Geographical Institute of France, as part of its systematic repeat coverage of the country.

Since the early 1980s, the east face of the Pointe de Friolin has been affected by creep of an exceptional magnitude. Only the careful study of several photographs taken over a long period by B. Goguel has enabled the recognition of this feature. Comparison of DEMs has helped in the mapping of the entire area affected by this ground movement, and in defining its boundaries and those areas that are subsiding or being uplifted. Roughly speaking, about 38 ha are affected and the volume of superficial deformation is around 5.6 million m^3. The differential image from the two DEMs perfectly corroborates Goguel's observations. Extraction of several comparative profiles and numerous displacement vectors has led to further definition of the phenomenon, and will be the subject of a future publication.

In this manner, the ground movement at Friolin was completely defined. The most remarkable feature of this work is that it was based on standard archive pictures and that no specific study was carried out over the site This implies that it will be possible to use the photographs available in the national photo-library, searching for similar events that can be evaluated before any site work is necessary.

5. Conclusions

The method as proposed is based on an old principle, but one that has always been difficult to implement, i.e. the comparison with time of the successive morphology as presented by an unstable slope. Recent technological advance now has made this method practicable.

The results obtained are valuable for more than one reason. Drawing of a map that shows morphological evolution and identification of displacement vectors reveal the movement dynamics. They also help in the optimisation of the traditional monitoring methods, whether on site or remote, because of the better understanding of the phenomenon they provide.

Without wishing to substitute for the traditional methods, which have other objectives and levels of precision, this new method complements them, and leads to the much more rapid evaluation of a monitored site and of the phenomenology of its change, as is shown in Table 1.

However, this method should not be seen as a surveillance tool. Not only is the time needed for its implementation too long (about 1 month after the airphotos have become available), but the level of accuracy of about 0.5 m is insufficient as well.

Finally, this method at present is only suitable for the study of ground movements of great magnitude, but work is presently ongoing to make it applicable to small movements as well.

Table 1. Scenario for the study of a large ground movement.

PERIOD	PROPOSED OPTION	STANDARD METHOD
T1 (T0 + few days)	Selecting existing photographs	Preliminary reconnaissance: risk evaluation; emergency measures, possible aerial survey
T2 (T0 + few weeks)		Detailed reconnaissance (poll, mapping, geological and hydrogeological analysis, search for probable causes, search for existing photographs, IGN site survey) duration: several weeks
T3 (T0 + 1 month)	Photogrammetric analysis of two pairs of aerial photographs	Specific aerial survey mission. Possible photogrammetric analysis for drawing up a contour map
T4 (T0 + 2 month)	Numerical mapping of the affected area. Detailed analysis of changes Optimization of monitoring work	Study for the installation of a monitoring network, or for any drilling to be carried out
T5 (T0 + 3 to 4 months)	Pilot installation of a monitoring system; reconnaissance through optimized instrumentation	Monitoring or reconnaissance by periodically read instrumentation
T6 (T0 + 6 months)		First analyses of the disorder dynamics available

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