LANDSLIDES

in research, theory and practice

VOLUME 2

Edited by E. Bromhead, N. Dixon
and M-L. Ibsen

Proceedings of the 8th International Symposium on Landslides
held in Cardiff on 26–30 June 2000

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Effects of Groundwater on the Villerville-Cricqueboeuf Landslides, Sixteen Year Survey (Calvados, France)

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SCIENTIFIC PROBLEM

In Normandy, along the Calvados coast, some parts of the 50km cliffs have been periodically affected by landslides for several centuries. On the eastern side (fig. 1), the 12km long Pays d'Auge section, between Trouville-sur-Mer and Honfleur, has been particulary affected.

The Pays d'Auge plateau is bordered by very high cliffs up to 140 m, the topographic and geologic formation of these cliffs being very varied. The profile changes from one end to the other depending on the thickness of the sedimentary support which is affected by a slight dip toward the east (Maquaire, 1990). The main scarp composed of Cenomanian chalk rests on a glauconitic sand base. Below them a thick series of marls (Kimmeridgian and Oxfordian) are on top of the cornstone limestone of Hennequeville, which between Trouville and the Pointe du Heurt strengthen the cliff toe and constitute a reef flat. At the toe of the scarp, the slope is more gentle and relatively straight. It is an accumulation slope of thick superficial material made of blocks and debris of chalk and flints as well as loess which fill the voids between the chalks blocks. These formations have been placed during the Upper Pleistocene (Flageollet & Helluin, 1987).

In this area, severals spectacular landslides occured at the Cirque des Graves and at Fosses du Macre near Villerville-Cricqueboeuf : the first time, the 10/11 January 1982, a major landslide destroyed totally or partially several houses and damaged the road in several places (Flageollet & Helluin, 1987). Then, the second time, on the night of the 12/13 February 1988, mainly at Cricqueboeuf, a reactivated landslide caused a good deal of damage, an extension upstream and laterally of the mobilised zone and a rise in the strand which dislodged the jetties and the breakwaters (Maquaire, 1990 & 1997). At last, always mainly at Cricqueboeuf, the end of January 1995 or beginning of February 1995 (the precise date of onset is not known), the major displacements occured the recession of the landslide crown (Bourgeois, 1997).

In 1984, for the comprehension of the phenomena and in the perspective of the temporal and spacial risks evaluation, a geomorphological and geotechnical investigation have been undertaken. The survey system has been widened to apprehend the respective weight of the different instability factors in the creation or the maintenance of the activity (Maquaire, 1990). Therefore in this paper, we are only giving the strictly necessary results which are needed to illustrate the topic of this article.

Landslides in research, theory and practice, Thomas Telford, London, 2000.

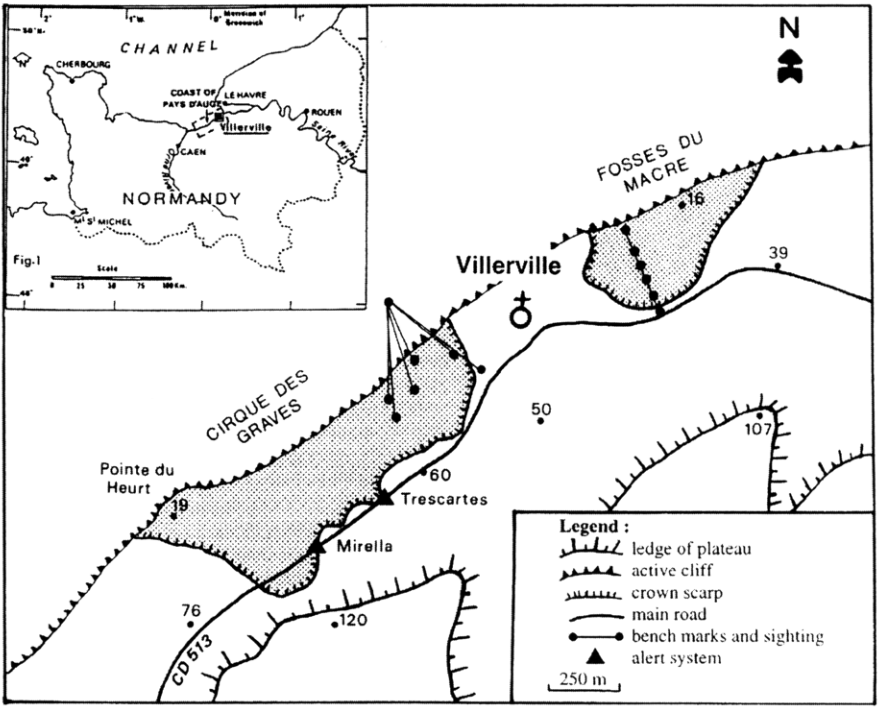

Figure 1. Location of the Villerville-Cricqueboeuf landslides and monitoring networks

MONITORING NETWORKS

A first system of survey had been installed current of the year 1982 : 41 plates for micrometer-screw level and 2 alert systems the long of the road. Since 1984, a monitoring system has been placed. This monitoring system was constituted by 80 cemented bench marks into the ground and the coordinates of them have been regularly measured with a theodolite and an electronic distancemeter (EDM). Also three inclinometers and 21 wells and piezometers have been used to monitor the phreatic water level variations. A regular data collection was performed until 1988. Then, only a irregular survey (approximatively two collections per year -in autumn and at the end of winter-) was realized with the Villerville (Cirque des Graves) device lightened (10 topometric bench marks, 4 piezometers and 2 alert systems) and the Cricqueboeuf network (Fosses du Macre) installed at the end of 1991 (14 topometric bench marks). The water table evolution was also analyzed from wells records (in particular Danestal well) recorded since 1976 implanted on the plateau at 12km to the south-west (Maquaire, 1990). This well has been chosen because the Cenomanian chalk watertable is situated to a depth of 8 to 14m, which corresponds approximatively to the water table depth of Villerville-Cricqueboeuf landslides, in particular for the upstream part.

Climatic values of St Gatien des Bois station have been used. Effective rainfall corresponds to total rainfall, diminished by evapotranspiration (E.T.P.), calculated by the Penmann formula, which is very suitable for the climate of Normandy. The relationship between piezometry and rainfall is established from rainfall or effective rainfall, as has been established in studies carried out elsewhere (Azimi & Desvareux, 1996 ; Gervreau & al., 1992 ; Irgens & Norem, 1996 ; Matichard & Pouget, 1988 ; Noverraz & Parriaux, 1990).

SEASONAL VARIABILITY

Movements vary with the season, and their amplitude relates closely to the climatic conditions : heavy rainfall, melting snows etc. This variation is visible on cumulative movement curves (fig. 2c & d). The latter are obtained from the successive movement values measured between two consecutive topographical surveys, supposing a constant speed between the measurement interval; this is inaccurate, as movements occur in sudden accelerations of unequal magnitude, followed by calm periods.

It is particularly the case for the Cricqueboeuf major movement of January-February 1995 (precise date unknown) whose displacement values have been only measured over a period of a year between 23/04/94 and 29/04/95. We observed similar behaviour in all the points of the slope, with considerable speeds in winter periods which corresponds to high piezometric levels. In summer periods the speeds decreased considerably in relation to the drainage of the flow.

It is difficult to determine a critical level of the ground water table or an effective rainfall quantity corresponding to the beginning of dangerous and suddenly accelerating movements (Van Asch & Buma, 1997 ; Van Esch & al., 1996). The major difficulty arises from the fact that movements are not measured continually. Attempts to establish a relationship between movements and cumulative rainfall or between cumulative movements and cumulative effective rainfall to take account of the pluviometric history (Matichard & Pouget, 1988) have not given the results expected because of the imprecision in the initiation and acceleration of movements. However, we can state that sudden accelerations generally occur during the three winter months of December, up to the end of February.

PLURIANNUAL DEVELOPMENT

At present, we have a series of more or less regular measurements over sixteen years between the end of 1982 and the end of 1998. These measurements enable us to see the various phases in the development of the Villerville-Cricqueboeuf landslide in relation to the piezometric and climatic data.

At Villerville, between December 1984 and February 1988, we observe that the high water levels, and to a lesser extent the low water levels, are higher from one year to another. This pluriannual rise of the average flow level arises from the cumulative effect of rainfall from previous years.

This development is observed in wells on the plateau for which there are records over a long period since 1974. The pluriannual rise which began in 1978 continued until March 1982 and April 1983 (fig. 2b). Then there was a period of several years in which the average levels decreased.

This 1978 increase corresponds perfectly with the non-cyclical annual pluviometry fluctuations at the Saint-Gatien station (fig. 2a), which corresponds to a period of effective rainfall considerably higher than the average : +43% in 1978, + 60% in 1980 and +49% in 1981 with an average calculated on this four years (1978-1981) which was 40 % higher than the annual average (1949-1998). The high level of the ground water observed in 1982 is in phase with the onset of the major movement of 10-11 January 1982.

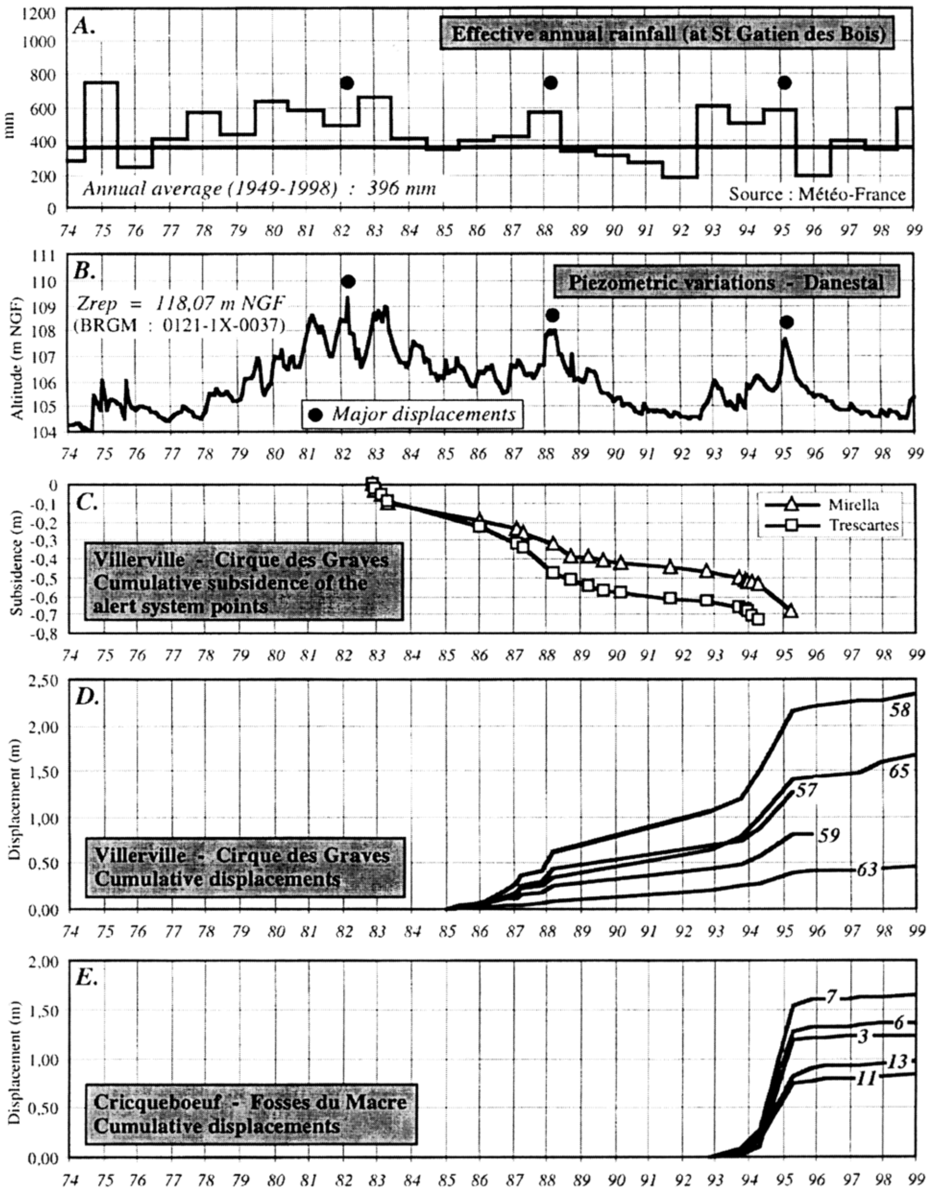

Figure 2. Pluriannual development of the Villerville-Cricqueboeuf landslide in relation to the piezometric and climatic data.

The extreme nature of the rain previous this landslide is also fully demonstrated by the return period; the annual effective rainfall (hydrological year), which is higher than ten years. For the two or four previous years this return period corresponds to the maximum of the 50 years of pluviometric observation (1949-1998). In the same manner, but to a lesser degree, the reactivation of February 1988 occurs after two hydrologic years higher than the average, but especially after very rainy previous months responsible of an abrupt and important water table elevation. For the Cricqueboeuf major movement of January-February 1995, a water table elevation is favored by two very excess previous years (+54% in 1993 and +28% in 1994) and by three very rainy previous months.

Thus, since the end of 1982 the subsidence measurements of the two points of the warning system along the CD 513 (fig. 2c) and the displacement of the Villerville and Cricqueboeuf bench marks (fig. 2d & e) in relation to the piezometric and pluviometric variations show:
- a movement deceleration phase following the major movement of January 1982 ;
- a movement acceleration phase since the beginning of 1985 which is demonstrated by a more or less sloping curve with the general appearance of an exponential curve on the cumulative movement curves ;
- a sudden onset of movements in February 1988 ;
- a deceleration phase for movements not wholly stable over approximately five years until the autumn of 1992 when a increasing of displacements was recorded during 1993 in relation to the rise in the flow (fig. 2d & e) ;
- a second movement acceleration phase with the exponential cumulative movement curves ;
- a sudden onset of movements in January-February 1995, mainly in Cricqueboeuf (fig. 2e) ;
- a second deceleration phase for movements not wholly stable until the end of 1998. We observe only a small acceleration at Villerville for the bench marks n°65 and n°58 and at Cricqueboeuf for the bench mark n°13 which are localized at the foot of the slope.

Thus these movement measurements fully confirm the major role of water in the onset and reactivation of movements. The slope stability analysis shows that an water table elevation of a meter diminishes the safety global factor of approximately 6 %. But we should not forget the role of the sea, which prevents the installation of a balance slope, such as can be found inland in the Auge, because of its erosive action at the foot of the slope : a recession of approximately ten width meters fall the safety global factor of only 2 % (Maquaire, 1990).

CONCLUSIONS

At Villerville-Cricqueboeuf landslides, during sixteen years, the monitoring networks enabled us to take precise and more or less regular measurements of movements, both on the surface and in depth, of the fluctuation of the phreatic flow in relation to rainfall.

It emerges very clearly that the mechanisms are governed by rainfall. They play a decisive part in the temporal variability of movements. They have been studied on different time scales, as their role in triggering movements occurs in the rise of ground water which itself follows an annual or pluriannual cycle, spread through the season in relation to rainfall. Nevertheless we still face many difficulties in linking the three parameters, because of the lack of data over long periods and variations in the flow and displacements were not recorded continually.

Therefore attempts to establish correlations between the water level increases and absolute rainfalls have been made for different time steps in the various analyses. It cleary appears that most of the frequent events happened during the "humid" periods. The very high water table recorded in 1982, is in phase with the beginning of the major movement observed the 10th and 11th of January 1982. To a lesser degree, the high piezometric level recorded during the

1988 winter and the 1995 winter, corresponds to the start of the February 1988 and January-February disturbances at Cricqueboeuf.

This study indicates that these areas are subjected to a **quasi permanent activity** which permits the classification of these slidings as **active movements**. As that is often demonstrated in others regions, the rain and the groundwater play a major role in the onset or the reactivation of these landslides.

AKNOWLEDGMENTS

Thanks to Franck Levoy of team "Morphodynamique Continentale et Côtière" (University of Caen) for his help on the field and Jean-Philippe Malet (University Louis Pasteur of Strasbourg) for drawing the figure n°2.

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