LANDSLIDE RISK MANAGEMENT AT SÉCHILIENNE (FRANCE)

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ABSTRACT

The National Road RN 91 has been threatened for about twenty years by a huge rockslide, located 25 km south-east of the town of Grenoble. If several million cubic meter of rock fell down, the debris will dam the valley. Then the failure of the dam by overtopping and rapid erosion would result in a catastrophic flood and dramatic consequences for human life, environment and economy throughout the valley. The paper presents the hazard estimation based on geological and hydrological surveys, and the risk evaluation and risk assessment that have been performed and the main prevention actions taken. A short range diversion of the RN 91 was constructed in the 90's. The daily risk management relies upon extensive monitoring of the unstable slope. Various solutions for a diversion of the river and for a new safe route of RN 91 are under study.

1. THE DISCOVERY OF THE PROBLEM AND THE EMERGENCY MEASURES (1980 - 1985)

In 1980, rockfalls occurred on the National Road RN 91, in the valley of the Romanche river, approximately twenty kilometers south-east of Grenoble town (figure 1). The starting point of the blocks, called “Les Ruines de Séchilienne”, is situated 300 m above the valley bottom, one kilometer downstream from Séchilienne village in the French Alps. And the RN 91 lies exactly at the foot of the slope...

Rockfalls are frequent in mountainous areas and nobody paid special attention to the event of 1980. But in 1985, new rockfalls occurred and the road had to be closed during several days. An emergency monitoring was decided, on a visual mode during the day, on an auditive one during the night. Soon afterwards a barrier of concrete blocks was set up; the blocks were surmounted by detecting wire connected to red lights located at the ends of the danger zone, one hundred metres long.

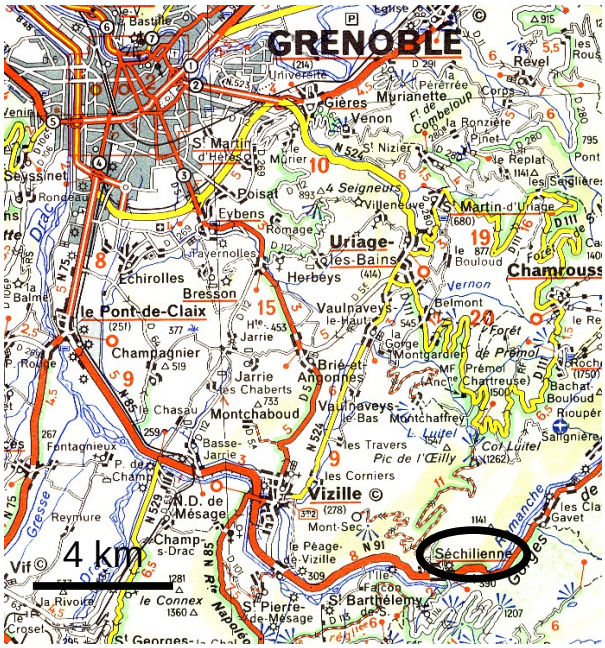

Figure 1 - Location map (from the Michelin map)

The first geological surveys showed that the unstable area, not very accessible and wooded, is not just a matter of one cliff generating the rockfalls, but includes a volume of a few million cubic metres. The study of a diversion road was then decided.

2. THE MONITORING AND THE DIVERSION OF THE ROAD (1985 - 1990)

From the moment the landslide hazard was identified, the risk management was based on a monitoring system associated with an emergency plan. This system, made initially of geodetic and extensometric manual measurements (cables stretched through fractures), was gradually developed and improved [1].

In 1985-1986, a diversion of the RN 91 has been carried out in the valley bottom, at the foot of the slope opposite to Les Ruines, with temporary bridges at each side of the exposed area. The heavy loads had to keep using the old road. To avoid the wanderings of the river dammed by debris in case of a rockslide, a diversion channel has been dug; it is protected by an earth barrier, supposed to be able to retain 4 hm3 of debris.

The final bridges were built a few years later (figure 2).

Figure 2 - View from the upstream: the bridge of the new road on the Romanche river and the Couloir des Ruines

3. THE GEOLOGICAL SURVEYS AND THE RISK EVALUATION (1990 - 2000)

The studies of the unstable slope have multiplied since the Nineties: aerial photo-interpretation, field geological surveys, survey gallery 240 m long (1994-1995), geophysical investigations (electrical and seismic methods), numerical modelling of the slope deformation and of the run-out of the debris.

The phenomenon appears to be very complex. It is not a true landslide in the usual meaning (i.e. with a pseudo-circular failure surface), but a large deep slope deformation (the far end of the survey gallery did not reach the stable rock mass). It may be described as a toppling of old gneisses and mica-schists which are cut across by many discontinuities dating from hercynian and alpine orogenies. The most active sectors of the slope are traversed by fissures which open gradually and local sinkholes have appeared. Rockfalls occur several times per year.

The process of deformation probably started ten thousands of years ago, after the withdrawal of the glacier which filled the Romanche valley. It has been accelerating for a few decades, perhaps in consequence of the development of deep weathering or in relation to earthquakes.

The recordings of the sensors show seasonal variations which correlate to the rainfall and snow melting (figure 3), but the process of the hydraulic control is not well understood. The long term trend is a very progressive increase of the velocities.

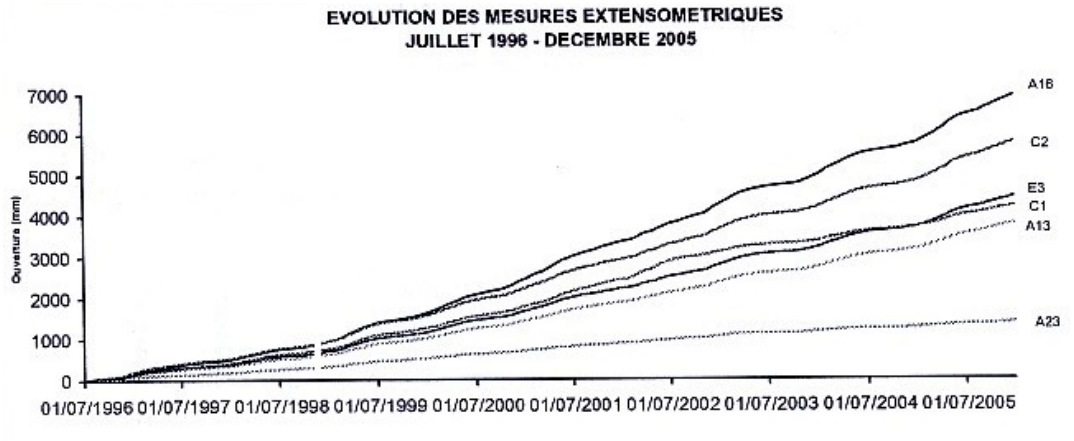

Figure 3 - Extensometric data in the frontal zone. The opening of the most active fractures exceeds 7 m in 10 years.

It is interesting to evoke the scenarios of rupture proposed at the various times.

- In 1988, four scenarios of rockslides, going from 2 to 10 hm3, were defined. In the maximum scenario, the valley is dammed by the debris, which reach the houses of L'Ile-Falcon located immediately downstream. The RN 91 is entirely covered by rock debris. A lake will form upstream and it will drown part of the village of Séchilienne; the hypothesis of sudden rupture of the natural dam, by overflow and erosion, has been considered; it would generate a devastating flood downstream. The efficiency of the earth barrier is revalued downwards (capacity: only 2 to 3 hm3 of debris).
- In 1992, a group of experts is requested and confirms the probable rupture of the rock mass (3 hm3) within 3 years. It recommends the boring of a gallery of diversion for the Romanche river.
- In 1995, some people mentioned the figure of 100 hm3 of moving rock mass… Two scenarios are considered in the medium term: 7 hm3 and 20 hm3; one expects a windblast effect at the time of the impact of debris on the valley bottom (thinking of the example of the Valtelline, Italy, rockslide, which occurred in 1987); these assumptions would lead to the formation of a high dam through the valley and to a major risk in case of dam failure.
- In 1997, to prevent the consequences of a 25 hm3 rockslide, the principle of the evacuation of the inhabitants of L'Ile-Falcon, possibly reached by the debris and especially by the flood after rupture of the dam, was decided (approximately 300 people).

4. APPROACH BY THE SCENARIOS (2000 -?)

In 2000, an international group of experts, chaired by Marc Panet, the president of the International Society of Rock Mechanics, was charged to carry a diagnosis on the situation and its evolution. Their report makes a clear distinction between:

- short-term risk, about ten years: falling of the frontal zone (figure 4), the most active one (approximately 3 hm3),
- risk in the medium or long term (twenty years or more), mobilizing 10 to 20 hm3.

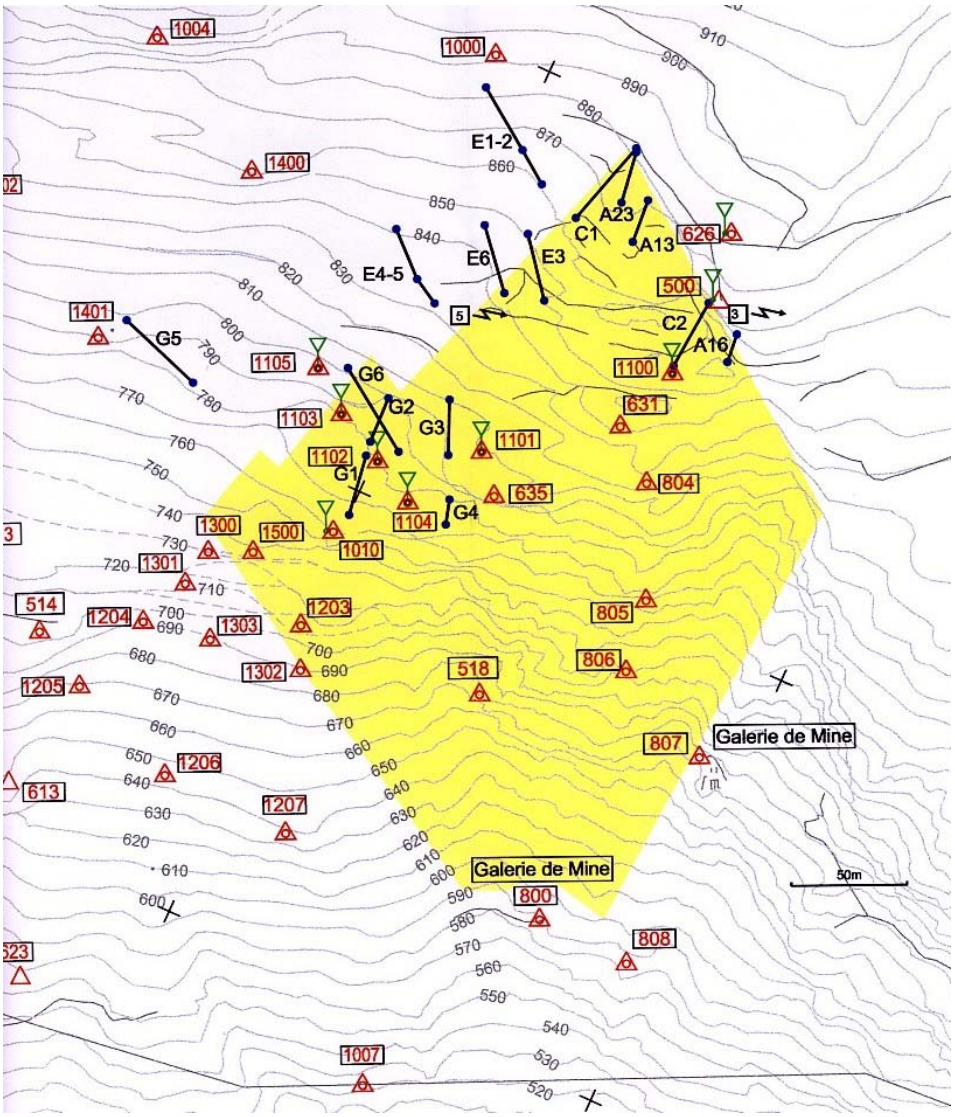

Figure 4 - Frontal area. Monitoring equipment: geodetic points and extensometers

The most probable scenario in the short run is a failure of the frontal zone occurring in several episodes, each one with a volume from a few thousands to a few hundreds of thousands of cubic meters. Under these conditions, the earth barrier may be overtopped by some debris, the emergency channel for the river may be partly blocked and the RN 1 may be reached by a few blocks or by the wandering flow of the Romanche river which will follow the slide.

This analysis by scenarios spread out in time and of increasing importance makes it possible to distinguish between the measures to be taken in the short-term and in the long-term. It resulted in refining the studies corresponding to the short-term hazards: geological and hydraulic surveys, and detailed modeling of the debris run-out (figure 5) and of the flooding due to the dam failure (figure 6).

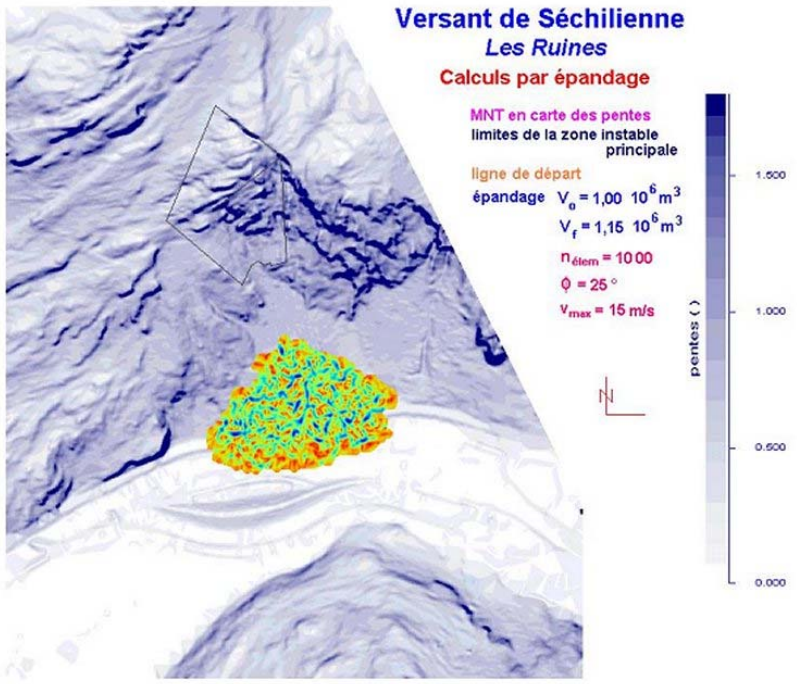

Figure 5 - Modeling of the scree cone for a rock volume of 1 million cubic meter (according to [2]). The debris cover the river but do not reach the earth barrier nor the RN 91.

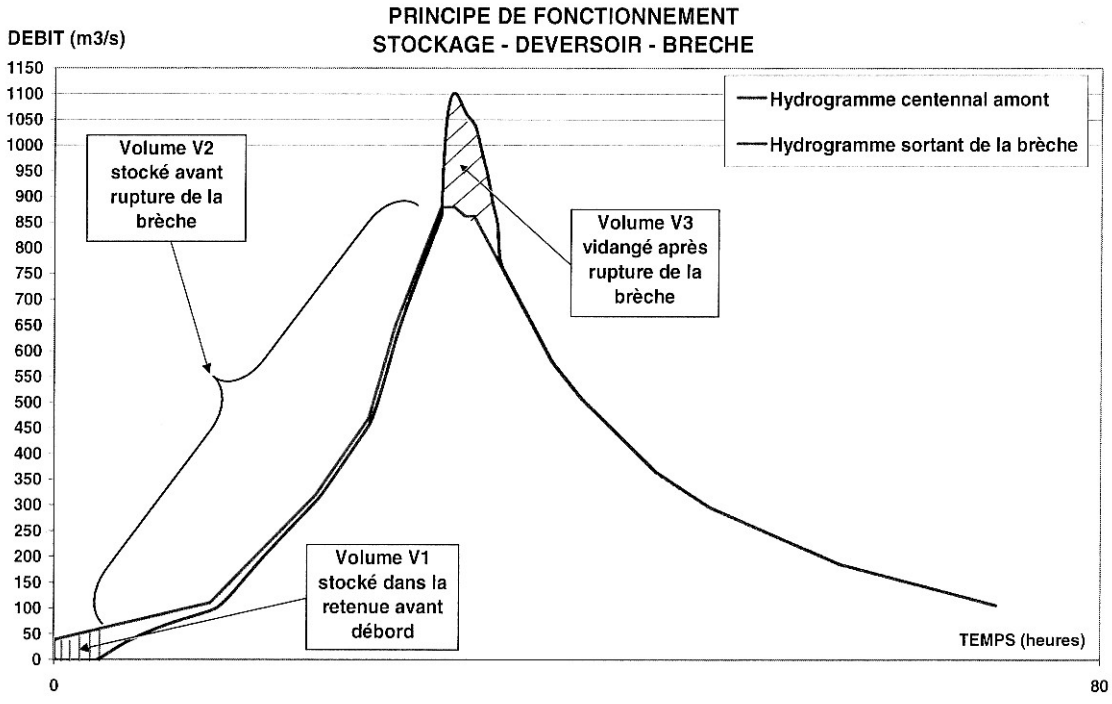

Figure 6 – Discharge hydrograph of the Romanche river : 100-year flood, without and with failure of the dam (source: Sogreah). Discharge in m3/s, time in hours.

5. ROAD RISK AND HYDRAULIC RISK

The RN 91 constitutes the natural way to the high valley of the Romanche river (11 000 inhabitants) and to tourism resorts in the mountain (more than 80 000 beds). There is on the one hand a daily traffic between the high valley and the low valley (Vizille and Grenoble), and on the other hand the seasonal flow of the winter tourists (mainly ski resorts of L'Alpe-d'Huez and Les Deux-Alpes) and, to a less extent, of the summer tourists. The average traffic is 9000 veh/day, but one notes peaks with more than 20 000 veh/day. In case of closing of the road at Séchilienne, the solutions of replacement are definitely insufficient:

- one very narrow road, on the southern slope of the valley, inaccessible to the heavy lorries and buses,
- a mountainous road, with many turns, representing a lengthening of 46 km,
- the route through the Lautaret pass, more than 2000 m above sea level, closed in winter, with strong avalanche hazard, and representing an extension of more than 200 km.

A closure of the RN 91 would lead to costs which were evaluated as follows:

- lengthening of route: 100 000 to 150 000 € per day,
- loss of earnings in the tourist activity (in season): 400 000 € per day.

The damming of the valley following the rockslide would generate the formation of a lake up to a level which is a function of the height of the lowest point of the dam. According to the volume of water retained, the bridge upstream and the crossroads could be submerged by water of the lake. In case of failure of the dam, by overflow and erosion, a brutal flood, the importance of which is a function of the volume of water behind the dam and of the speed of the wash-out of the dam, would propagate downstream. The RN 91 would be damaged in several places, part of the town of Vizille would be flooded, as well as chemical industries located downstream; certain districts of the town of Grenoble could be reached by the flood. It is clear that the maximalist scenario would involve considerable consequences fore human lives and in the economical and environmental fields.

6. POSSIBLE COUNTERMEASURES

Taking into account the extent of the slope movement and its complexity, solutions of *in situ* stabilization of the slope are not possible. Controlled rock blasting, on a purely preventive basis, would involve several million cubic metres of rock, and this technique, although suggested by some local authorities, would be too expensive, too long, and very delicate.

The protection of a road located in the valley bottom is technically possible only with respect to rockfalls of limited volume. The most recent studies show that the existing earth barrier, even prolonged or raised, can hardly retain a volume larger than 2-3 hm3, and that the channel arranged for Romanche river is not sufficient in period of flood. Consequently, even for events probable in the short run, the RN 91 will be exposed to rockfalls and to the wandering of the river, and thus will undergo a lasting closure.

A more complete protection of the RN 91 at the foot of the Ruines de Séchilienne can be assured either by a tunnel 800 m long at least (the portals must be located beyond the run-out distance of the debris!), or by a road driving up sufficiently on the southern slope (figure 7).

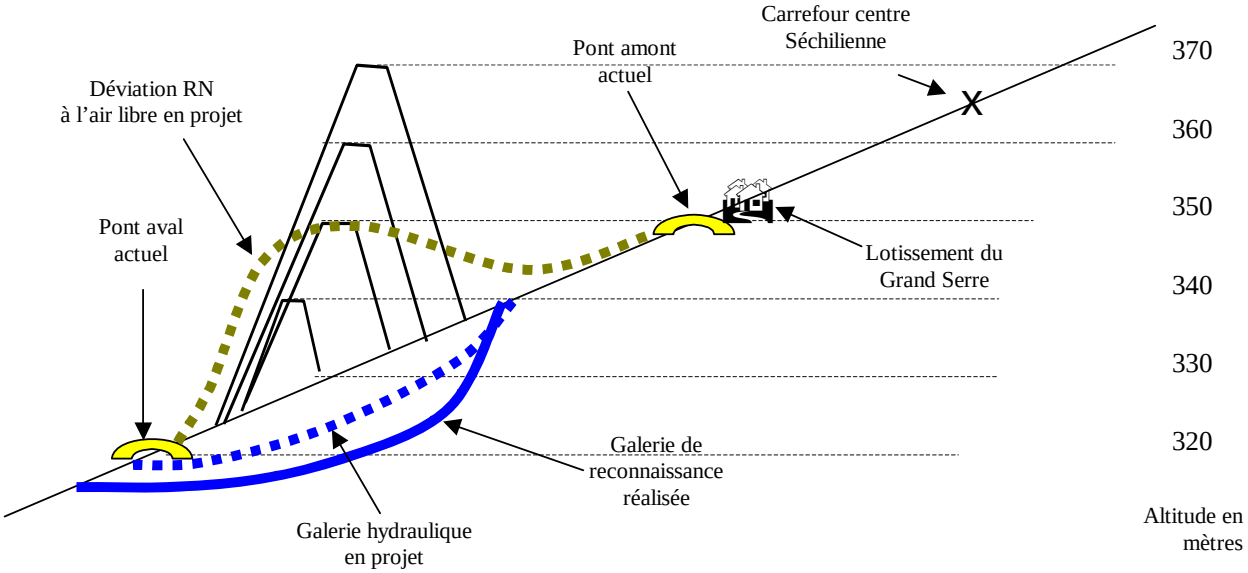

Figure 7 - The main countermeasures in relation to different dam heights. The bed of the Romanche river is drawn with a constant slope.

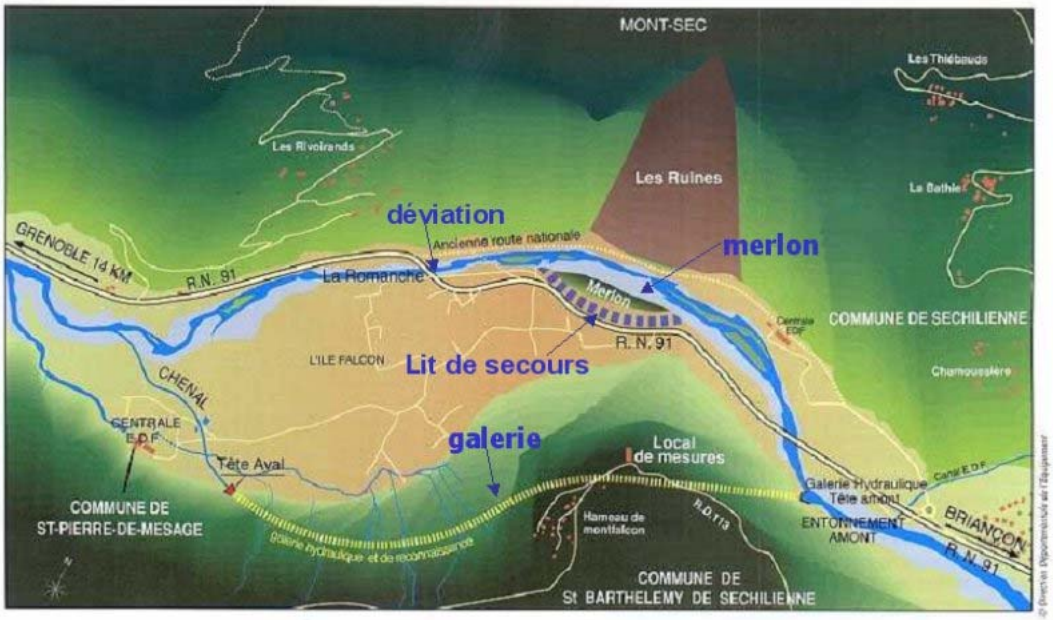

Figure 8 - Works already implemented: earth barrier, emergency riverbed, road diversion, reconnaissance gallery.

The comparison of the costs lead to choose a cut and fill solution (approximately 17

million euros, versus 55 for the tunnel) on the southern slope of the valley, at a level which will put the road safe from a landslide of 3 to 4 million cubic metres. Another advantage of the aerial solution is the least duration of construction: 2 years, against 4-5 years for a tunnel. The tunnel solution would be to consider only in one score of years, if the evolution of the site requires it; however, as a precaution, the preliminary studies should be carried out now.

Several countermeasures may be considered with respect to the hydraulic risk: diversion gallery for the Romanche river; levees and basins in the area of L'Ile-Falcon, aimed at decreasing the flood power; reinforcement and raising of the existing levees along the river downstream, in Vizille for instance.

The design of a diversion gallery for the Romanche river is a very complex task, since it is necessary:

- to locate the portals beyond the debris run-out,
- not to plan the inlet at a too high level, because this level will determine the residual volume of water in case of damming,
- to ensure a maximum discharge capacity of the gallery, taking account of its slope and of the design of the inlet,
- to choose the reference flood: the probability that a major landslide occurs at the time of a flood is not negligible, both being more probable after an important rainy episode; a 100-year flood should be at least taken into account, which leads to a gallery of large diameter, approximately 11 m.

A reconnaissance gallery was driven in 1997-2000, without particular difficulty. The studies of optimization of the project of gallery ∅ 11m are in progress. The option to drive only one gallery, used both by the RN 91 in usual time and by the Romanche river in case of catastrophic landslide, was considered; it was pushed back because of its cost and of constraints for the road operation.

The objective of the levees and hydraulic racks in L'Ile-Flacon is to reduce the flood downstream generated by the rupture of the dam:

- in case of a small dam, in the present situation, i.e without hydraulic gallery;
- in case of a dam of average height, once the gallery has been driven: the most critical situation corresponds to landslide and thus to heights of dam that are intermediate, important enough to generate a detrimental flood discharge after the dam failure, but unable to load the gallery completely and thus to give him its full effectiveness.

The risk of brutal overflow and sudden rupture of the dam also forces to protect the future road downstream, in particular the embankment crossing L'Ile-Falcon, which makes it to reach the level wished in the face of Les Ruines. The works of crossing of the Romanche river and the connexions with the current road off the area at risk have also to be protected.

7. SHORT-TERM RISK MANAGEMENT

The current risk management is based on a monitoring of the slope, carried out uninterrupted by Centre d'Etudes Techniques de l'Equipement (CETE) of Lyon, on

behalf of the local authorities. Those also profit from the support of a college of seven experts, who are regularly informed of the evolutions of the site; they meet twice a year and are mobilizable in case of crisis.

The sensors on the slope take measurements of displacement automatically every two hours; these measurements are immediately transmitted by telephone link to the CETE of Lyon; the system automatically calls the engineer-geologists responsible for the site (a permanence 24h/24h is organized) in case of measured values beyond the thresholds fixed in advance. It is necessary to add that the field inspection of the site is an essential complement of a monitoring relying only on computers…

The system included, as already said, the extensometric measurements through active fractures and distance measurements per infra-red ray from the opposite slope. Two problems were raised a few years ago:

- to ensure a monitoring in all weathers: infra-red distance measurements are inoperative when by foggy or rainy day, whereas it is probable that a major landslide will start by bad weather conditions;
- after a first large rockfall, the conditions of access to the site could be dangerous; the monitoring in real time will be very useful if works have to be done in the valley bottom, for example to repair the road, whereas residual rockfalls are probable.

To answer these two requirements, a new system of distance measurement with a ultra-large-band radar (ULB) has been developed [3]. The accuracy of measurements is remarkable when one places metal reflectors one the site (the current situation, figure 8); it will not be so good, but sufficient if the reflectors disappear during a first slide, measurements being then carried out directly on the naked ground.

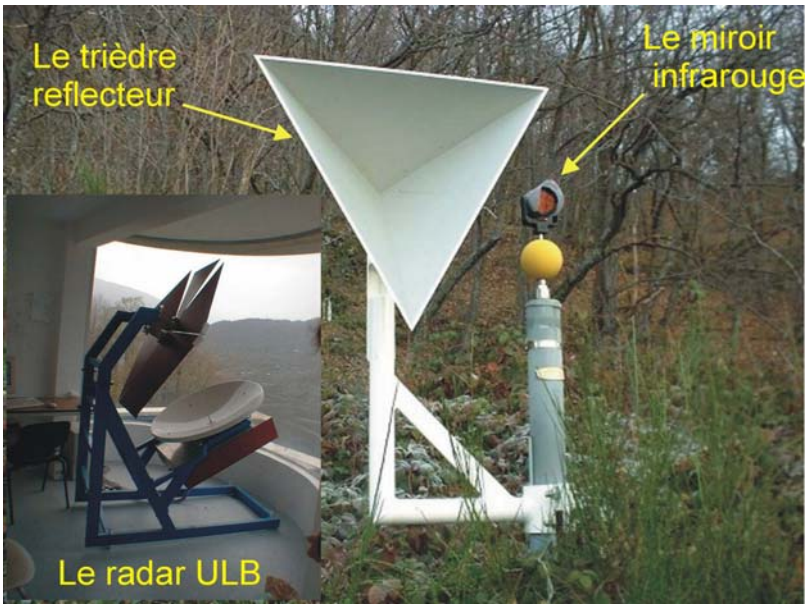

Figure 9 - Distance measurements by radar: on the left, the radar sheltered in a cabin located on the southern slope; a trihedron reflector for the radar measurements, beside a mirror for the infra-red measurements.

Four increasing alarm levels were defined: pre-alarm, reinforced vigilance, serious concern, imminent danger. “Pre-alarm” and “reinforced vigilance” are decided mainly on moving rate or weather criteria. From the “serious concern”, the college of experts will be involved, an emergency response team shall be set up and various safety measures are taken. An emergency plan has been elaborated for several years; at first the road will be closed to traffic, with installation of the diversion routes, then the people downstream will be informed, etc.

The project of road diversion is now completed. Once realised (time: 2 or 3 years), this new road will make the short-term risk (landslide of volume up to 3-4 hm3) under control: the traffic will not be stopped (or only for one a very short time), the debris will form a small dam that will not produce significant hydraulic disturbances.

The question of any protection with respect to the long-term hazard has not yet been answered.

8. CONCLUSIONS

Facing a danger with low probability and major consequences, the decision maker is always embarrassed. The users of the RN 91 and the inhabitants of the valley are wondering why one did not already drive both a tunnel road diversion and a hydraulic gallery able to make forward the 1000-year return period discharge of the river. To that the ministry for transport could answer that:

- a wise management consists of making large expenses only when they become essential; a scenario where the slope would stabilise gradually, after failure of the frontal area, is not completely to exclude, and in this case the galleries carried out in advance would never be used; the main difficulty arises from the fact that the possible decision to drive a tunnel diversion road should not be taken too late;
- a 1000-year discharge flood would produce catastrophic damage in the whole valley, and the event “Séchilienne” would increase only marginally the extent of damage.

The works of the (aerial) diversion road should start very soon. On the economical viewpoint, this investment is completely advantageous if one takes into account the rather strong probability that the current route will be cut off in a few years and the cost of closing of traffic during at least one or two months.

In November 2006, a rockfall of approximately 30 000 m3, coming from the frontal zone, covered the old route of RN 91 and a few blocks reached the Romanche river, but no rocks reached the earth barrier. This rupture did not start the alarm, because the monitoring system is conceived to detect the premises of a major rockslide (a few hundreds of thousands of cubic metres), likely to endanger the road users, and not to deal with the case of small rockfalls. However the abnormal activity of the site during the previous month drew the attention of the experts of the CETE de Lyon, so that the rockfall could be filmed. The forecast of a large failure in a near future remains topical…

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