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RISK ASSESSMENT OF AN UNSTABLE CLIFF ABOVE A HOUSING ESTATE IN VULLY-LES-LACS, SWITZERLAND

MANAGEMENT OF RESIDUAL RISKS FOR THE CANTONAL ROAD RC 502c

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SUMMARY

The studied unstable cliff in Vully-les-Lacs, Switzerland, overhangs a housing estate of some 15 houses built between the fifties and the seventies. Rockfall events, superficial slides and debris flows are common there and have become more and more dangerous since the eighties despite of protection measures. Two important landslides obliged the municipality to withdraw the inhabitants' occupation permits. The estate cannot be saved, but the cantonal road RC 502c, at the toe of the slope, needs some protection.
The purpose of this study is to define the characteristics of all types of phenomena as well as their causes. Hazard maps for each phenomenon were produced with three levels of danger, as well as a vulnerability analysis. Four different hazard scenarios were defined, which might cause damage to the exposed elements. They allowed us to quantify the risk for each element. This risk assessment is useful to identify the most fragile elements and to propose protection works. Finally the impacts (social, economic and environmental) were assessed.

RESUMEN

La pared inestable estudiada, en Vully-les-Lacs, en Suiza, domina un grupo de una quinzena de casas construídas entre los años 1950 y 1970. Caídas de roca, derrumbes y colas de detrito se encuentran frecuentemente allá y han sido más y más peligrosos desde los años 1980, a pesar de medidas de protección. Dos deslizamientos obligaron las autoridades a anular las autorizaciones de ocupación de las casas. El grupo de casas será destruído, pero la carreterra RC 502c, al pie de la pendiente, necesita obras de protección.
El objectivo de este estudio es de definir las características de los fenómenos de inestabilidad

así como sus causas. Mapas de azar para cada fenómeno fueron establecidos con tres niveles de peligro, así como un análisis de vulnerabilidad. Cuatro escenarios de azar fueron definidos, susceptibles de causar daños a los elementos expuestos. Así pudo cuantificarse los riesgos para cada elemento. La evaluación de los riesgos es útil para identificar los elementos más frágiles y para proponer obras de protección. Finalmente los impactos (sociales, económicos y ambientales) fueron considerados.

1. INTRODUCTION

1.1 Location

Vully-les-Lacs is a small group of villages of about 2.300 inhabitants in the Canton of Vaud, located some 75 km north of Lausanne. The unstable cliff extends over 500 m on the west coast of Morat Lake (Fig.1). The altitudes of the cliff vary between 450 and 500 m a.s.l. The natural hazards caused by landslides can be seen on a 3D modelled photograph (Fig.2).

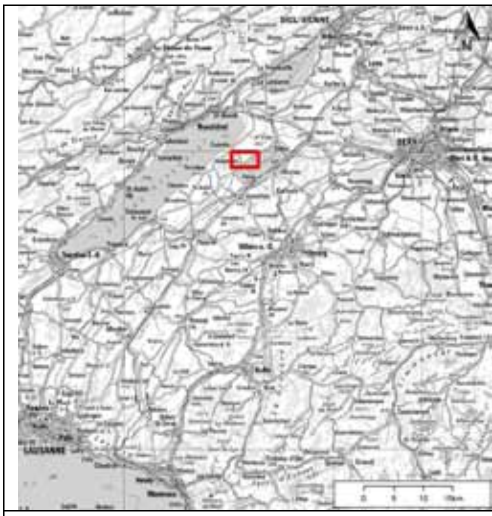

Fig. 1: Location of the study area

Fig. 2: 3D modelled photograph of the study area

The road RC 502c connects two small villages, Vallamand and Mur. About 1.900 vehicles use this road every day. However, in summer, a lot of tourists pass by with bikes or motorcycles. Indeed the Tour of the lake is a very nice activity for people.

1.2 Geological and hydrological setting

The geology of the area is quite simple; it is made of molassic aquitanian rocks composed by sedimentary deposits alternating sandstone and marl. Both types of rock are fairly impervious and these formations have a low cohesion.
Concerning the hydrological setting, there are two small rivulets near the area which have no

influence on the instabilities. An old water tank confirms the presence of several water sources, but their position could not be defined with certainty; nevertheless they have an influence on instability phenomena. sources, but their position could not be defined with certainty; nevertheless they have an influence on instability phenomena.

1.3 Characteristics of the area

Dimensions

The unstable zone is 500 m long and the difference of altitude between the highest point of the cliff and the RC502c is about 55 m. The housing estate is 45 m lower than the highest point of the cliff.

Area

The hazard area extends over 5.6 ha.

Slope

The particularity of this case study is the slope. It is very significant in some places and can reach 50°. Indeed the steeper the slope, the more dangerous the area. Numerous rockfall events were listed when the slope exceeds 40°. Figure 3 shows the difference of slope in the studied area.

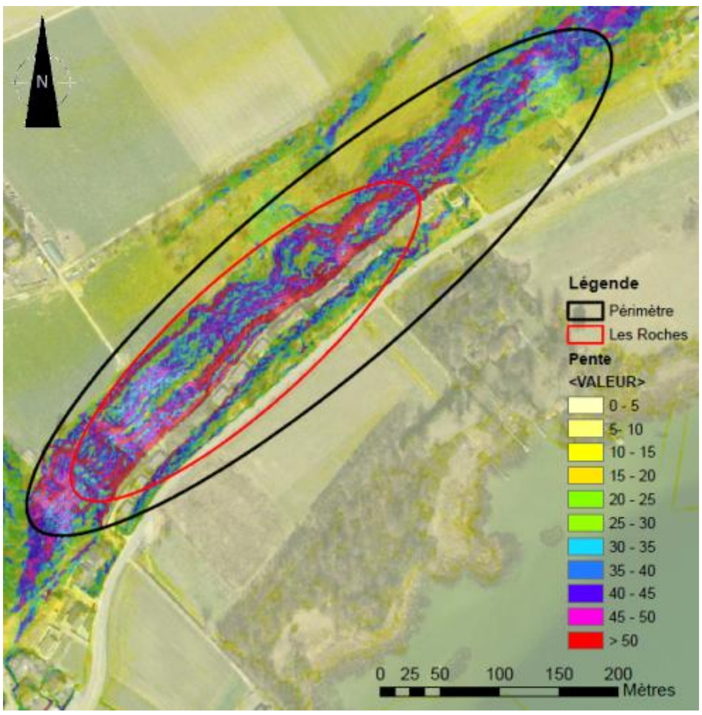

Fig. 3: Slope map (values in °)

1.4 Protection works already carried out

In the past 30 years, several protection measures were undertaken. First of all, an anchored wall was built in order to retain the earth pressure and protect 2 of the 15 houses. A local “debris trap” was also installed. Since 2001 some protection measures were added, such as rockfall nets and anchors.

In 2003 and 2005 local monitoring measures were undertaken. The rainfall data were recorded and regular visual inspections of the cliff are done. Moreover some measuring campaigns including electronic distance measurements were carried out.

2. PRESENTATION OF NATURAL PHENOMENA

2.1 Rockfall

The main danger here is the rockfall. In our case, we have all sizes of rocks, yet they do not exceed 1 m^3. Indeed, the sandstone and the marl rocks are very crumbly and when they touch the floor at the toe of the slope, they disintegrate in smaller pieces. Figure 4 shows some rocks that can be found.

Fig. 4: Example of rocks at the toe of the slope

The intensity classes are determined according to the Swiss federal recommendations (OFAT, OFEE, OFEFP, 1997). This recommendation considers three ranges of energy:

Low intensity: $E < 30$ kJ
Medium intensity: $30 < E < 300$ kJ
High intensity: $E > 300$ kJ

The corresponding hazard matrix is shown in figure 5. The lower limits of the high probability, respectively the lower limit for the low probability class, are stated as a 30 and 300 year return period, with reference to the federal recommendation related to snow avalanche.

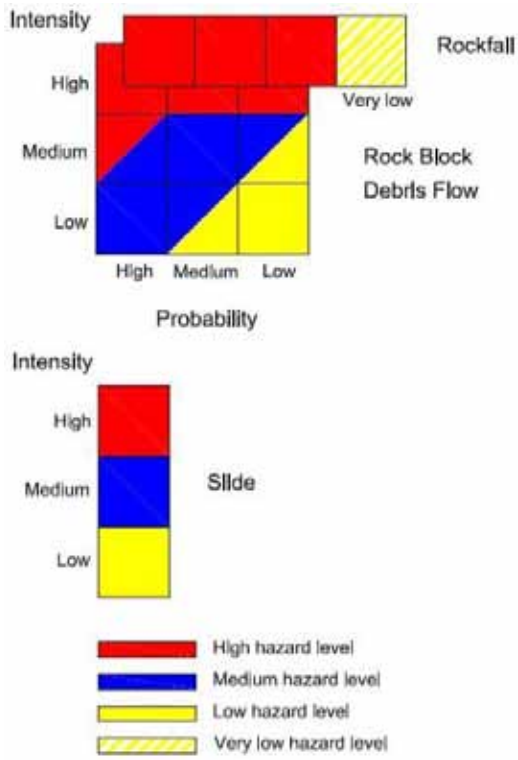

Fig. 5: General matrix representation of the relations between intensity and probability to qualify the hazard level (OAT, OFEE, OFEFP, 1997)

2.1 Superficial slides

Superficial slides are referred to when the sliding surface is less than 2 m deep. Numerous events of this type are reported in the study site. They are mainly due to high precipitation. Figure 6 shows the scars due to superficial slides.

Fig. 6: Scars due to superficial slides

3. HAZARD MAPPING

The final hazard map is the result of three different maps, carried out for each type of phenomenon. These maps were prepared on the basis of the history of the region and of what has been observed on the site during different visits. The different levels (low, medium and high) were applied considering the matrix given in figure 5. When two levels of hazard are superimposed, the highest one is chosen and applied on the map (Swiss federal recommendation). Zones in red are principally due to rockfall phenomena. They are the most significant hazards observed. In blue or yellow are represented areas where either superficial slides or debris flow are observed (see Figure 7).

Fig. 5: Hazard map considering rockfall, superficial slide and debris flow; the red dots indicate the houses still in use.

4. VULNERABILITY

Vulnerability is expressed by a level of potential loss due to a given phenomenon with a defined intensity. The vulnerability assessment results from the knowledge of the interaction between phenomena and exposed elements (Bonnard et al., 2004). Therefore it is first necessary to define which elements are exposed and to which phenomena. Indeed not all elements are exposed to the same natural phenomenon here because they are not located at the same place. In this study the main exposed elements are:

- Users of the cantonal road RC 502c
- The road RC 502c itself
- 15 houses of the abandoned estate

- 4 houses that are still occupied (see red dots in figure 7)
- Inhabitants of these 4 houses
- Wildlife and flora on and around the cliff

The second step in vulnerability assessment is to determine the relevant hazard levels. In this case, four different hazard levels are determined, related to the respective return period:

- ≤ 5 years
- 30 years
- 100 years
- 300 years (extreme scenario)

A matrix based on a well-known method was carried out (Leone et al., 1996). It includes each exposed element assessed within each scenario. The result consists in a level of damage for each exposed element (in function of the intensity of each phenomenon).

The main exposed elements are of course the abandoned houses (Les Roches estate) that are still owned by their owners, although a global arrangement has been settled to compensate their loss; but everything is not yet finalized.

5. RISK ASSESSMENT

5.1 Theoretical approach

There is no legal method in Switzerland to evaluate the risk. However, several parameters are important to state it. First of all, the probability of occurrence of the natural phenomenon (P_0) is one of the most important parameters. Then, the intensity and the location of each phenomenon must also be considered. Finally the potential damage to each element is considered. When all of these parameters are known, a first approximation of the risk can be given (Prina et al., 2004). Nevertheless some other probability values must be assessed to determine the equation of the risk and thus give an appropriate risk level. These other probability values are:

- Pa : probability that the phenomenon reaches the exposed element
- Pp: probability that the exposed element is there when the phenomenon occurs (it is equal to 1 for fixed elements, like houses).

Considering these parameters the notion of specific risk can be given. The specific risk is the risk incurred by each exposed element.

$$Rs = fct(Po, Pa, Pp) \times D$$

Equation 1: Specific risk (D stands for damage)

The global risk is defined as expressed in the next equation.

$$Rg = \sum Rsi \times V_i$$

Equation 2: Global risk

With:

- Vi: actual value of the exposed element or of a set of exposed elements with the same level of damage

5.2 Practical approach

The Pa probability was defined based on the history of the site and also with respect to the sensitivity of the authors, especially for the extreme scenarios, which is not strictly objective. Indeed, each person has a different sensitivity when facing extreme hazards and then the result may be quite different.

In this study each probability was defined for each scenario. For example Pp for the exposed element "RC 502c" is expressed according to the length of the exposed section of the road, the daily average traffic density on the road (TJM) and the velocity authorized on the road. Then the equation is:

$$RC\ attendance = \frac{L}{v} * \frac{TJM}{24}$$

Equation 3: Vehicle attendance per hour on the RC 502c

These parameters change for each danger because the length of the exposed section of the road is not the same for each phenomenon. This little example shows the complexity of the study and how much a rigorous analysis is required. When each probability is found for each scenario with each type of phenomenon, the risk level can then be found. A map of the area with the risk levels can finally be designed. In this study a map was prepared for each scenario (5 years, 30 years, 100 years and 300 years).Table 1 shows the five chosen risk levels.

At the end, it is possible to determine the risk for each exposed element and take a decision to this respect. Is the risk acceptable? If not, what can be done to reduce it? For each scenario these two questions were asked and some protection works were proposed, in order to reduce the risk level, when it appears to be necessary.

Table 1: description of risk classes

Risk level	Color	Qualification or risk
0	Grey	No or little risk
1	Yellow	Residual risk: either the risk is very low or the hazard level is high but the zone is either protected by specific works that are well designed and maintained, either by natural or man-made protection (vegetation, houses of les Roches estate).
2	Geeen	Public awareness zone: information must be given (sign posts). Wildlife shelter are in danger
3	Blue	Prescription zone: as people are exposed outside of buildings, namely even in their cars, traffic may be tolerated, but requires control measures (monitoring, maintenance works, study of possible protection works in case of increase of risk level). Animals and vegetation are strongly threatened, their shelter may be partially destroyed or strongly damaged.
4	Red	Prohibition zone: the high level of risk requires immediate realization of protection works and an eventual stop of traffic in case of serious danger, as there is a severe risk for human life. People are threatened inside buildings. Animals and vegetation are in death danger. Their shelter are destroyed

5.3 Protection works

In most scenarios, the risk level was too high. In order to reduce it, several measures should be taken. In this study the goal stated is to protect the area from phenomena having a return period equal to 100 years (T=100 years). This goal is based on the history of the site and also for obvious economical reasons.

The houses that are now empty will be destroyed (during these works specific measures will need to be taken to protect workers). A reinforced dike will be built instead of the house, as planned by the authorities. Several reinforced walls will also be built behind the houses which are still occupied. Additionally, several upstream drainage systems may be carried out.

To complete these construction measures, some preventive actions might be taken. For example, two photogrammetric flights per year should be done. They will help to see the evolution of the area. Figure 8 shows the photogrammetric system called R-Pod. It is really small, but fast and low cost.

Fig. 6: R-Pod

Source. www.r-pod.ch

Another measure would be to install a GPS system along the cliff. This measure will help to see possible movements of the cliff and order the evacuation of the area if necessary (especially during the deconstruction works).

5.4 Risk analysis with protection works

All the risk analysis was also done considering protection works. The same parameters as before were used in order to have representative results. The final analysis shows that an acceptable risk level is reached for phenomena having a return period equal to 100 years. All exposed elements are not directly threatened. The next picture shows the final risk map for an event with a return time of a hundred years, after the construction of the dike.

Fig. 7: Final risk map (T=100 years); the road only incurs residual risks

5.5 Impacts

We may consider three types of impact:

- Economical
- Social
- Environmenal

In the economical perspective, impacts are small. Indeed all costs due to the rehabilitation of the zone (town and country planning, protection works, monitoring with GPS, etc.) are divided among the Swiss Confederation, the Canton de Vaud and the Commune of Vully-les-Lacs.

The final impacts of the project will be positive in a social perspective. The zone will be secured and all the inhabitants of the estate Les Roches, once they have settled in their new homes, will not be threatened and worried anymore. However it is necessary to recall that they have lived in stress conditions for more than 20 years and that they have not yet obtained some land to rebuild a house with the insurance compensation received

Environment impacts will be minimal, except in the case of a road accident, due to a natural phenomenon. In that case fuel could contaminate the area (soil and water). This case is unlikely but some urgent measures should be taken; for example, a dam could be built in the rivulet in order to stop the contamination. Indeed both rivulets are directly connected to the lake. So the pollution must be stopped before it reaches the lake.

6. CONCLUSIONS

The present paper only develops a condensed part of the study of the unstable cliff in Vully-les-Lacs, focussing more on the risk analysis and less on the landslide mechanisms and their causes. With a sufficient background of what happened during the last 23 years, it is possible to find reasons for the instability phenomena and to suggest protection works consistent with the case study and its circumstances.

The vulnerability assessment shows damage to houses that in turn may cause hazardous situations. The risk analysis confirmed the necessity of building protection works. Moreover, the notion of protection objective is useful to determine which protection works are realistic and feasible. The final risk analysis is very important to insure that the designed protection works are the appropriate ones, because they are efficient and cost effective.

Finally the impact assessment shows that the costs are reasonable and the zone should be secured, in order to guarantee enough safety on the road in the long term.

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