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AVALANCHE STARTING-ZONE ANALYSIS BY USE OF A KNOWLEDGE-BASED SYSTEM

by

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ABSTRACT

This paper presents the first step in the development of a new kind of computer-based tool which can help a specialist consultant in avalanche path analysis, a *knowledge-based* or *expert system*. In considering an avalanche path, the specialist often needs a simulation of possible avalanches on this path in order to obtain data for probable velocities and pressures. Use of classical numerical tools by an engineer requires a great deal of experience and knowledge. Such knowledge exists, but until the development of knowledge-based systems no computer-based tool was available.

After a short review of such systems, we describe a knowledge-based system currently being developed in CEMAGREF. Its *problem-solving environment* includes methods of analysis developed by a senior consultant, and also numerical and qualitative models. In the first step, which is presented here, it analyses the starting zone of an avalanche path. By means of a digital terrain model and a description of vegetation and main ridges (a model which still needs to be improved) this system can make use of the experience of specialists to produce an avalanche-starting simulation based on specified meteorological conditions. Quite simple rules are employed in order to take into account snow drift. First results are shown on accompanying maps of this *qualitative modelling* and these will need to be tested for validity.

INTRODUCTION

More and more, numerical models are being developed to simulate avalanche flow, yet consultant engineers are partly prevented from using them by the increasing amount of knowledge needed to enable them to choose between these models, and to select their physical parameters, their initial values, and their boundary conditions. However, at the same time their experience will enable them to predict how a starting zone can develop an avalanche in the absence of mathematical methods which can simulate this phenomenon. Numerical models and specialist experience apparently complement each other, although it has not yet been possible to combine them in a single computer system.

The significant development of knowledge-based/expert systems can resolve this problem, because, as Kowalik (1986) stated, such systems enable us to introduce both numerical and symbolic information.

The purpose of this paper is to present an example of a knowlege-based system being developed in CEMAGREF for use in the analysis of avalanche paths. First, we describe the relevance of such a system for field consultation, then we give a definition of knowledge-based systems, and examples of geotechnical domains in which they are already in use. The language employed in our programme is briefly described, and an example of the analysis of a qualitative model of avalanche release in a starting zone is given. Subsequently, our current work is presented, and in conclusion we outline some of the advantages and drawbacks of our system.

WHY A KNOWLEDGE-BASED SYSTEM?

In order to explain the nature of a knowledge-based system we answer the questions which a snow engineer must answer when trying to predict an avalanche path, the range of tools he can use, and the nature of their advantages and drawbacks.

Avalanche-path analysis

Typically, a snow engineer is required to give an opinion about the safety of a place which apparently lies in an avalanche path and, if he thinks the place is dangerous, he must suggest appropriate solutions for the protection of the region. Such a task demands considerable knowledge on the part of this engineer. Where can he find the necessary information? Most of the time he depends upon his own experience, sometimes on other methods, for example numerical methods to calculate avalanche run-out distance. An avalanche expert can predict the manner in which an avalanche is likely to be released at a starting zone, and the volume of snow that can be expected to reach the avalanche track. Such an expert is also able to take into account the possibility of snow drifting on to the avalanche path, and can either use homogeneous values of wind forces or call upon a numerical wind model to obtain a distribution of values of wind forces, in the manner reported by Tesche and Yocke (1976).

Two years ago, CEMAGREF decided to develop a knowledge-based system for avalanche path analysis. The ELSA ("Etude des Limits de Sites Avalancheux" — avalanche-path boundaries study) project is an attempt to build a computer system which could help engineers by integrating a number of mathematical methods with the first-hand experience of experts. We call such a system a *problem-solving environment* (IFIP (International Federation of Information Processing, 1985) workshop) because it gives the specialist a complete working environment and all the tools he needs for his predictions.

Knowledge-based systems

These systems cannot be employed in the same way as numerical programmes. The subroutines which can be used in these programmes are numerous; each expert has his own

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method of analyzing an avalanche path, and as a consequence the system cannot use knowledge in order to reach a definite determination of the required facts. Moreover, the computer system must handle all this knowledge, and we must be able to change an item of knowledge, or to introduce a new one (a new wind model for example), or to suppress an old one, without needing to modify the system completely as we had to do in classical procedural programmes. As a result of this we can no longer write our programme like a procedural routine, and have needed to find a new method.

The architecture of a knowledge-based system is adapted to precisely this kind of problem. Knowledge is not written down with *procedural* programming but with *declarative* programming, and the structure of the system separates snow and avalanche knowledge from data processing in the following manner.

There is a *knowledge base* which includes experience and methods, and an *inference engine* which is able to use the knowledge base to answer questions posed by the user (Fig. 1). In order to modify knowledge we need simply to change a part of the knowledge base without disturbing the inference engine.

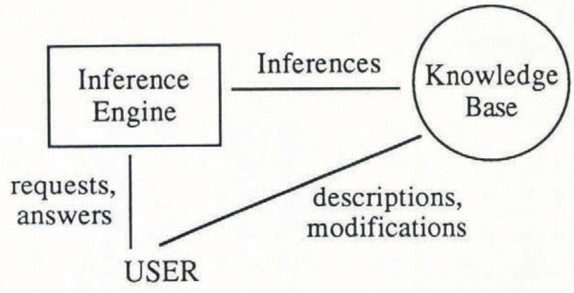

Fig. 1. In a knowledge-based system, all information about application (here snow and avalanches) is coded in a simple way in the knowledge base. The expert describes his experience and the user describes the path he faces and the methods he wants to use. He send requests to the system and the *inference engine* consults the base, uses the methods, and gets the answers.

Mostly *expert* knowledge is written as facts and rules. The language PROLOG (PROgramming in LOGic) enables the programmer to write in the knowledge base logical clauses such as:

"The snow is cold".
"If the wind is strong and the snow cold and light, snow drift is efficient".
"If the snow is heavy it is best to use a dense snow flowing model".

This is very useful to translate knowledge and programming information obtained from a specialist. Computational knowledge can also be written in PROLOG.

In several geotechnical domains, expert systems seem to present new developments such as for example, Prospector described by Duda and others (1979) in geology and Mepra described by Granier and Lefèvre (1984) and Nevai described by Massa-Rolandino (1987) in avalanche forecasting. Problem-solving environments are developed in other domains, by Rousseau (1988) for biology, and for projects in hydrology.

One of the greatest problems we have had to face has been taking into account the terrain features and spatial nature of our problem. Mepra and Nevai deal with time forecasting; they carry out *temporal reasoning*. In avalanche path analysis the system reasons in space, and it is rare for expert systems to have dealt with *spatial reasoning*.

AN EXAMPLE OF THE SYSTEM

Our programme performs an analysis of an avalanche starting zone making a number of assumptions. We assume that snow falls for the first time in the winter, and also that the wind is the same everywhere and has no orographic effects, and that the quality of snow is not modified by drifting. Our biggest assumption is that the expert has exact knowledge of all the phenomena on the starting zone. This is a necessary assumption for building an expert system. We intend to modify some of these assumptions in due course. All the examples in this paper deal with an actual avalanche path, Vallon de Ciagé, in Tende near Nice, France (Fig. 2).

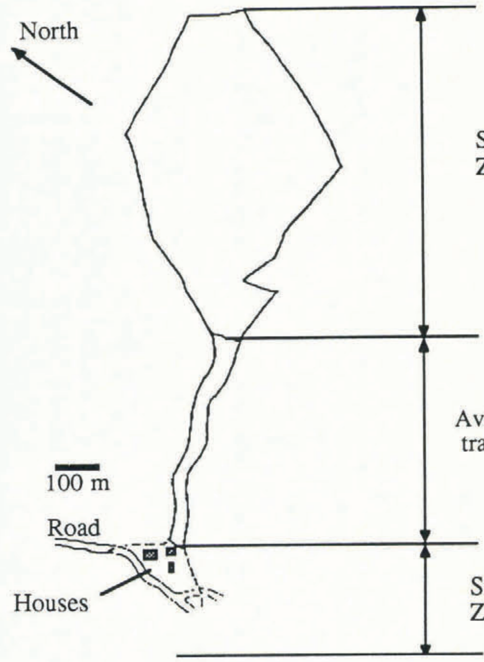

Fig. 2. Ciagé Valley in Tende near Nice. Some of the houses must be protected from an avalanche. This article deals with an analysis of the starting zone with a knowledge-based system. On the avalanche track and the stopping zone, numerical models can be used.

Description of knowledge

The programme needs a description of the terrain. We decided to use an irregular triangulation (Fig. 3) in order to build homogeneous units of terrain, which we call *small panels*, on which slope, exposure, vegetation and distance from main ridges are constant. In reality these factors are *almost* but not precisely constant. A regular grid would have needed too many cells to make possible fit with natural terrain. This triangulation is a kind of *digital terrain model*. The other inputs are triangles and small-panels descriptions (Fig. 4). With small panels, ridges and natural wedges are also given and these can split the flow of an avalanche.

With this input data the system can compute new information with classical computation (surfaces, slopes), vectorial (hydrographic network) or topological reasoning (juxtaposition of small panels). For example hydrographic network can be built and represents the small panels joined with a fall line.

Because meteorological conditions such as quality of falling snow, direction and force of wind are also input data, the system can take into account the action of wind on a ridge. Schematically, the wind sweeps snow on one side of the ridge and creates accumulation of snow on the other side. This action depends on the distance to the ridge and on the angle of incidence of the wind at the ridge. With the digital terrain model, the system evaluates this action, but here it does *qualitative modelling*, because there is no mathematical model but only imitation of specialist reasoning with expert rules. For this reason the programme can compute a family of distributions of snow cover according to the natures of wind and ridges, select the small panel which is likely to be the trigger, and predict the magnitude of the critical precipitation. In order to

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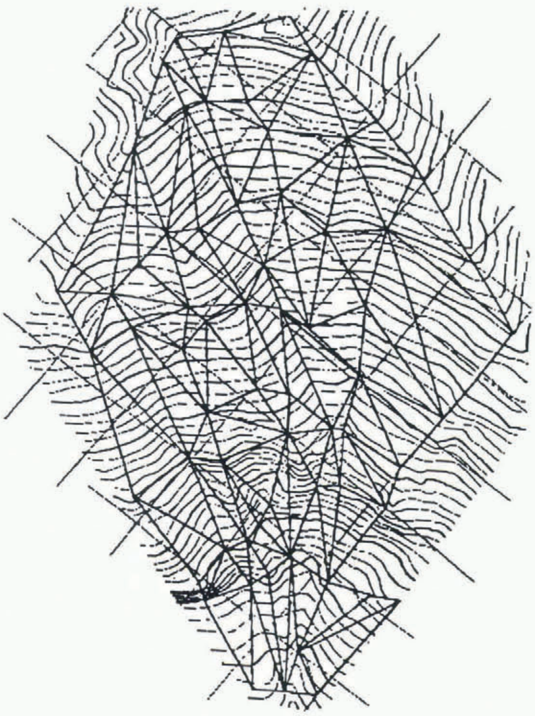

Fig. 3. The figure shows the topography of starting zone in Ciagé Valley and the triangular irregular grid used as digital terrain model.

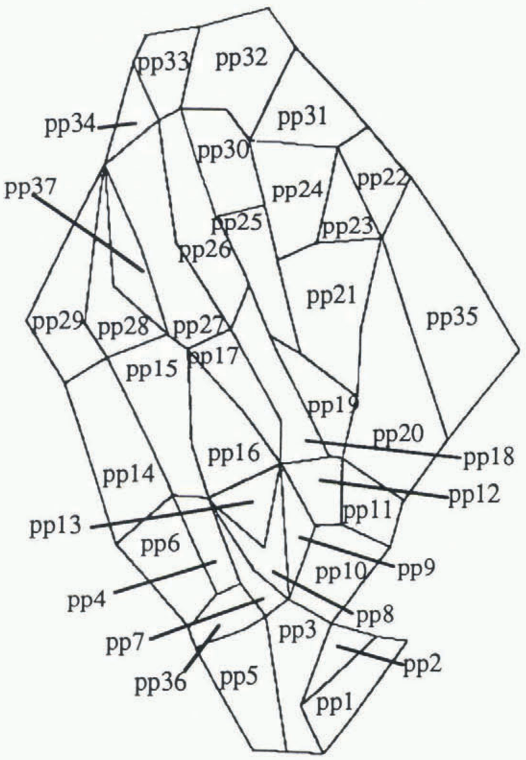

Fig. 4. This figure shows the partition of starting zone in small panels. Each small panel is almost homogeneous from the point of view of slope, vegetation, exposure and distance to ridges. Ridges are not represented here.

achieve this quality of snow, vegetation and slope are used by the system. For this precipitation the programme produces the distribution of snow over the whole starting zone, and shows the stability of each small panel.

The propagation of break through the snow cover is then inferred with a special algorithm in a qualitative manner. The main parameters are relative position, stabilities of snow, masses, and boundary lengths. A number of different rules have been written; for example, we used the following rules to decide whether a small panel, p2, is able to release a small panel, p1.

"If small panel p1 is very unsteady
and if small panel p2 starts
and if p1 and p2 are juxtaposed
then small panel p1 starts".

"If small panel p2 is above panel p1
and if small panel p2 starts
and if snow mass of p2 is much greater than snow mass of p1
then small panel p1 starts to move".

The final model is the division of the starting zone into *large panels*, which are the necessary entities for the starting of an avalanche. Two small panels are in the same large panel if they both either start (or do not start) and if they will not be separated by a stem before they leave the starting zone. While small panels are static units of terrain, large panels are dynamics units; with such a division we will be able to provide numerical models with initial values.

An analysis

The operator gives a direction and an efficiency for the wind. The results (Fig. 5) are rather realistic simulations

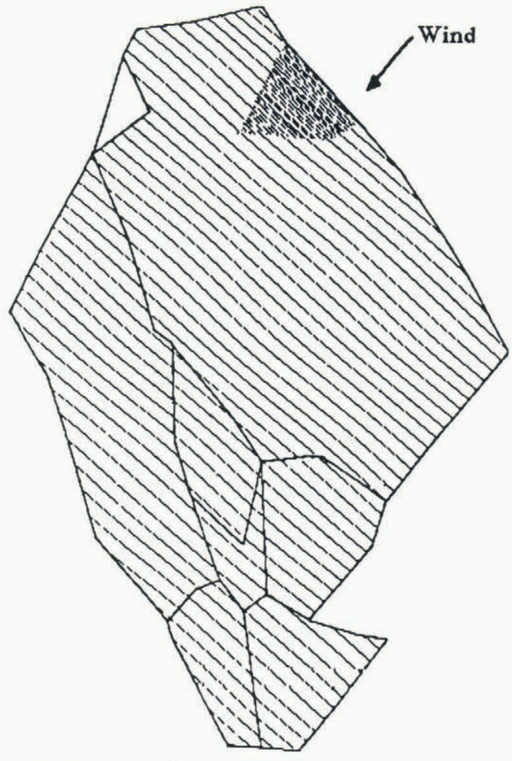

Fig. 5. An example of analysis. The very shaded surface is the small panel that acts as the trigger. The shaded surface is the part of starting zone which is released, the white surfaces are the part which is not released. Lines are boundaries of large panels. The trigger is just beside the upper ridge because the east wind creates a large accumulation of snow there.

of real phenomena. The specialists in CEMAGREF agree in general terms with these analyses. Influence of wind seems to be well analyzed by the system, although problems of validity testing still remains.

DEVELOPING A PROBLEM-SOLVING ENVIRONMENT

A new knowledge representation

Because we wanted graphic interface, quick answers, and assumptions-management in our system, we are developing a prototype on a powerful working station (SUN 3-110) in a language well adapted to symbolic computing: LISP (LISt Processing). We are also developing a graphic interface which would allow an engineer to use the

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system without being a computer specialist. Moreover, a graphic representation of terrain by maps and also of snow covers, meteorological events and hydrograms will be of general interest. This new prototype is very much faster in operation than the first programme we devised.

Testing validity of qualitative modelling

To perform a validity test we need to describe the terrain of the avalanche starting zone, its vegetation, the previous meteorological conditions, and the actual releasing phenomenon (heavy snowfall, temperature rise, blast, ...). The comparison between observation in the field and results from the system in relation to snow-cover, released part of starting zone, and volume of snow must be used to improve the knowledge base.

The programme we have already implemented cannot be considered as proven. We have too few observations on the Ciagé valley, and the assumptions about quality of snow and about meteorological conditions are either too numerous or too simple. However, despite these disadvantages, this programme shows that a system reasoning in space at a starting zone can be developed.

Last winter we had two sites in Alpe d'Huez winter sports resort which were regularly visited and monitored by a member of the ski patrol. Meteorological conditions such as temperature, wind and snow cover analysis were recorded. Unfortunately, this year there was not enough snow and therefore very little avalanche activity on the paths in this area. Next year we plan to work on more avalanche starting zones in different parts of the French Alps.

CONCLUSION

The numerous methods developed to simulate avalanche flowing require a lot of knowledge from the engineers concerned. They must choose physical parameters, initial values, and boundary conditions according to their own experience. Knowledge-based systems, and especially problem-solving environments, are able to handle such knowledge and by their use it seems possible to perform qualitative modelling of the starting zone of an avalanche path. Such systems are being implemented in CEMAGREF. Their main drawbacks are slow speed and the large number of assumptions which need to be made. The aim now is to build a problem-solving environment which would contain all the methods useful in avalanche path analysis. A prototype of such a system is currently being developed, and validity tests of qualitative modelling on starting zones will be performed next winter. We think that the speed problem will be solved by use of a new computer language. One of the biggest problems we might have to face is the increase in the number of methods that will need to be handled as the system becomes able to deal with more general situations. When a restrictive assumption is withdrawn, new and more general methods must be introduced into the system.

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