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Expert System in Underground Excavations

Système expert pour travaux souterrains

Expertensystem im Untertagebau

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SUMMARY

The presense of karst is a potential danger in tunneling if not foreseen. An expert system, based on experiences in karstic and in underground engineering has been developped for prediction of karst debacles when a tunnel is excavated through a carbonate rock area. This system has been demonstrated and confirmend by experts.

RÉSUMÉ

Le forage dans les zones karstiques peut entraîner des conséquences désastreuses dans la construction de tunnels. Basé sur la connaissance de la science karstique et des travaux souterrains, une banque de données a été développée, afin de diagnostiquer les dangers karstiques en cours de forage dans la roche calcaire. Ce système expert a pu être testé avec succès et confirmé par des experts.

ZUSAMMENFASSUNG

Unvorhergesehenes Anfahren von Karststrukturen beim Tunnelvortrieb kann katastrophale Auswirkungen haben. Mit dem Wissen chinesischer Experten in Karstkunde und Untertagebau wurde eine Datenbank zur Vorhersage von Karstgefahren beim Vortrieb in Kalkgestein aufgebaut. Das Expertensystem wurde erprobt und von Wissenschaftlern validiert.

1. INTRODUCTION

The problems which we meet very often are karst when tunnels or other underground structures are excavated through a carbonate rock area, such as caves filled with sand and crushed rocks, sinkholes, subterranean rivers etc. In many cases, karst may become a very serious disaster in tunneling if no any prediction. The prediction of karst disasters until now relies, besides lots of data from geological exploration, on a unified analysis of these data and on a proper assessment, both of which involve expertise. AI-expert system which simulates the processes of decision making of an expert by computer has been put into practices in recent year[1] [2] [3]. Therefore, by our point of view,an expert system can be a way to consult about karst disaster for engineers.Under such a consideration we developed an expert system for prediction of karst disasters in tunneling engineering or other underground engineering.

To build an expert system has two ways, one is building by a shell or tools, another is developing proper program according to the characteristics of this problem solving. In this system, the latter way was adopted.

2. KNOWLEDGE BASE

For building this knowledge base, we elicited knowledge from text books, handbooks, research reports, case studies and especially from experts of karst sciences in China by knowledge acquisition [4] .It is known that the development of karst needs a certain environment in which the factors are: soluble and unsolvable rocks (fabric) , water and recent/ancient meteorology, geological structure conditions, topography and conditions of hydrogeology (karst hydrodynamic unit), karst geomorphology,tectonic movements,deep karst and palaeokarst. The general flow chart of this system is showed in Fig.1.

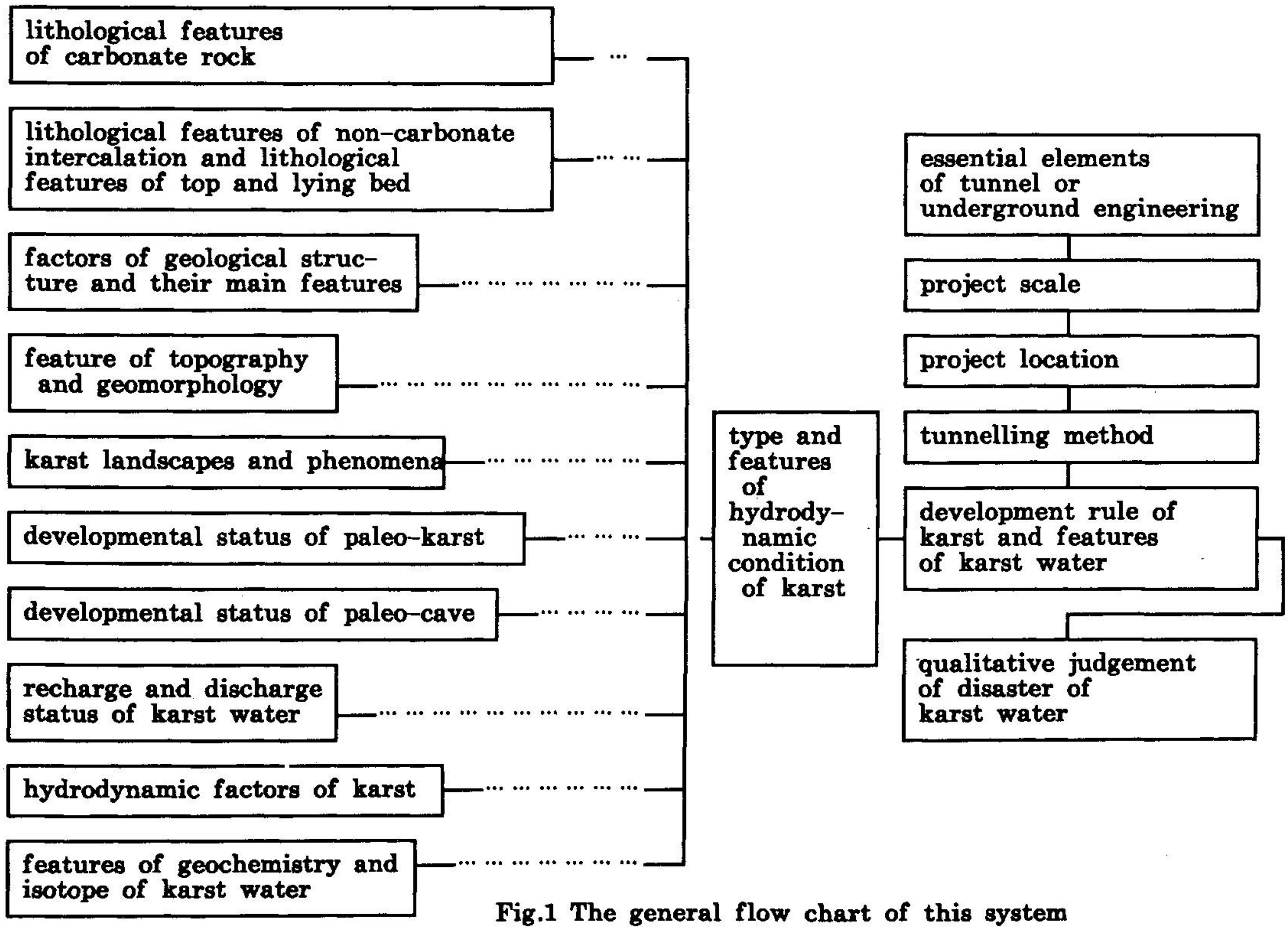


Fig.1 The general flow chart of this system

Of course,it is seen that the development of karst is controlled by ten factors in first order,such as lithological features,which are affected by those factors in second order, and other lower order factors are reasoned by analogy.Obviously,it can be expressed as a reasoning tree. As an example, the factors relationship for the features of paleokarst is showed in Fig.2.

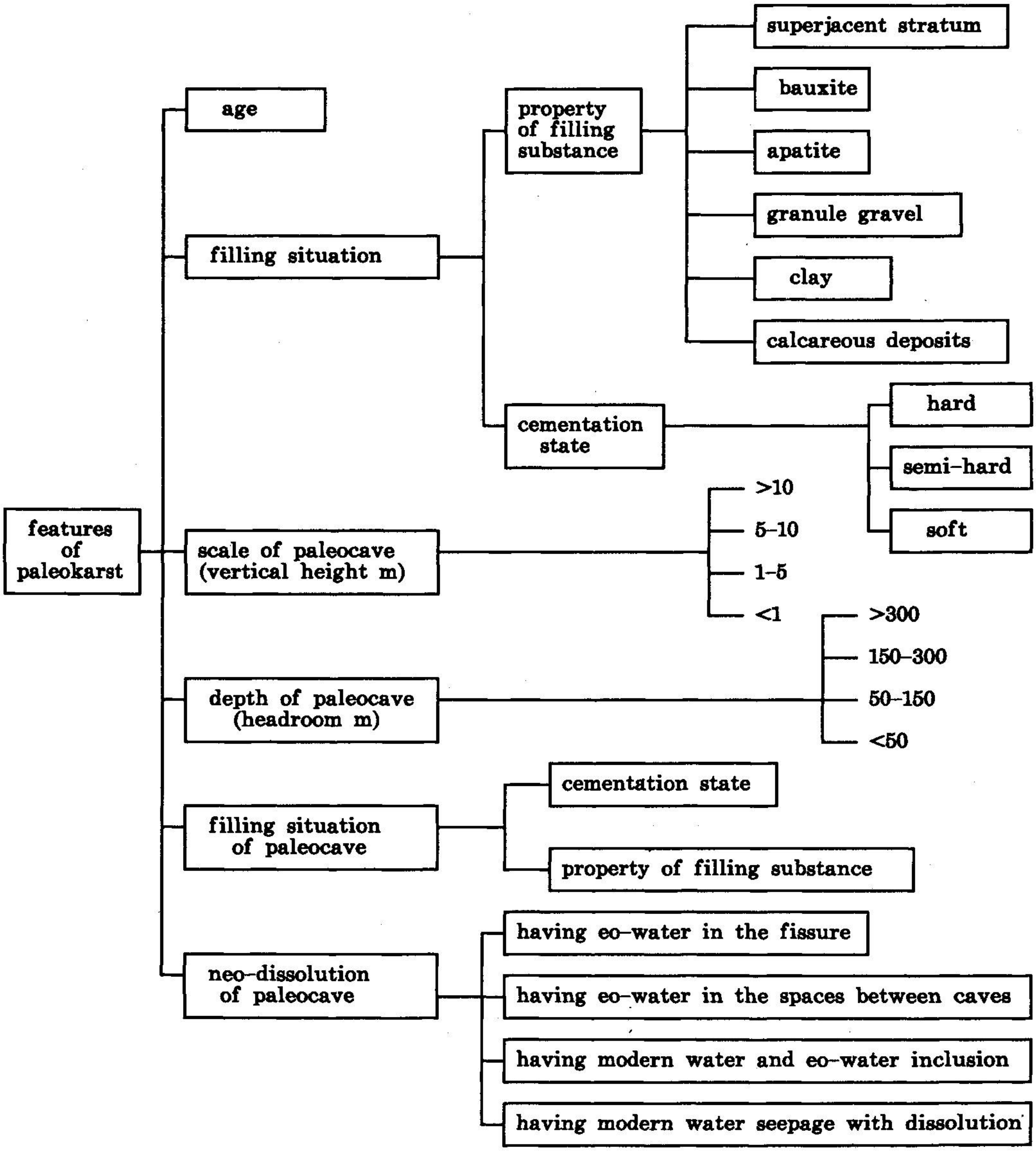


Fig.2 The factors relationship for the features of paleokarst

On this reasoning tree, some of the factors of lowest order are omitted in this paper for simplification. The lowest order factors are the system inputs which should be supplied by user through man-machine communications. Then,the system may infer from the lowest layer, step by step up to the top, to gain the final conclusion.It stands to reason that the above factors should be considered at first from a region of integrated hydrogeological unit including recharge and discharge, and then from a region nearby the underground structure.

3. KNOWLEDGE REPRESENTATIONS

Knowledge representation is a process to symbolize and to formalize these knowledge[5].Both rules and frames are combinably used in this system, that means the knowledge base is composed by parameter file and rule file.

3.1 Parameter file

Parameter file is composed by frames. Any concepts or events,which are called parameters here, appeared in rules should be defined with frames. A frame is a collection of semantic net nodes and slots that together describe a stereotyped object, act, or event. The components of a frame are showed as the following:

Prmti (i=1,2,...n)
- name :
- type :
- ask :
- show :
- range :
- score :

In this system the classification of parameters may be divided into: yes/no, single value, multi-value and fuzzy. such as:

Prmt2
- name : lithologic character and texture of carbonate rock
- type : m-value
- ask : "lithologic character and texture of carbonate rock"
- range: crystalline texture, fragmental texture, skeleton texture, pel-micrite structure

Prmt3
- name : single layer thickness
- type : fuzzy
- ask : "single layer thickness of carbonate rock"
- range: >2, 2–0.5, 0.5–0.1, 0.1–0.05, <0.05
- score: $\tau 0$ $\tau 1$ $\tau 2$ $\tau 3$ $\tau 4$

where the content in the slot of "ask" is the words appeared on the screen, which need to answer by the user as the input, and "score" expresses the degree of confidence(d. c. see the next section, "Approximate Reasoning" in detail).

3.2 Rule file

Rule file is composed with rules. A rule consist of an "if" part and a "then" part. To work forward with such rules, moving from condition-specifying "if" part to action- specifying "then" part,which are called condition-action rules or production rules. Its formal type may be defined as:

```
rulei (i=1,2,...n)
    if   antecedent1 (d.c.1)
         antecedent2 (d.c.2)
              :
    then  consequent  (d.c.i)
```

where the (d.c.i) is the degree of confidence of this antecedent and this rule.

for example:

```
rule70
    if   time is D or C or P or T                          (1)
    and  texture is crystalline or skeleton                (1)
    and  single layer thickness is (2-0.5m)                (1)
    and  lithological features is pure carbonate rock      (1)
    then a-conclude is fit for strong karst development    (1)
```

4. APPROXIMATE REASONING

Domain experts very often do some reasoning based on their own knowledge according to personal experiences, more or less subjective judgement, more or less precise and/or certain evaluation and appreciation. Consequently the inference is faced to lots of uncertainties. Approximate reasoning is a way to deal with this kind of problems, and is a very active research topic in artificial intelligence.There are many approaches in this area, some are based on Probability, some on Fuzzy Set Theory, or are called non-numerical method [6]. In this system fuzzy set theory approach was used by two steps, first the d. c. of antecedent was determined and then the d.c. of conclusion was concluded.

4.1 The Degree of Confidence of Antecedent

The d.c. of antecedent is defined by frame score slot in which for single values d.c. is 1; d.c. with the preferred are 1 or are distributed through weight in m-value, and the fuzzy one is dealt with by the following way.

for example:

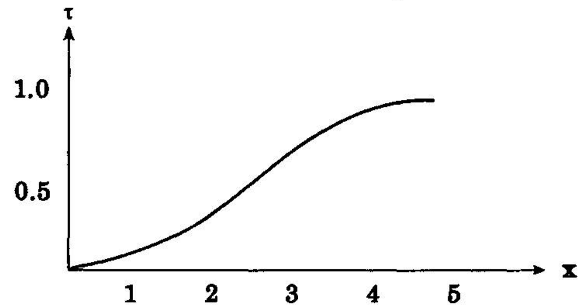
```
prmt3
    name  : single layer thickness
    type  : s-fuzzy
    ask   : "single layer thickness of carbonate rock(m)".
    range : >20, 20-5, 5-1, 1-0.5, <0.5
    score : 1.00, 0.64, 0.00, 0.00, 0.00
```

If the user's answer to the "ask" about the layer thickness is >20m.This input is a precise value but an approximate one, which means somewhere may be equal to 20m or somewhere are less than 20m. To reflect this situation and to fulfil the requirement of fuzzy reasoning later, the following means was used.

When the thickness input is >20m, then the d.c. of >20m is 1, but other indexes thickness also have their d.c., τ i(range/d.c.) as:

>20m/1.00, 20–5m/0.64, 5–1m/0.16 1–0.5m/0.00 <0.5m/0.00

This calculation was adopted out of consideration for that the membership function was normal distribution and could be enumerated by the formula in Fig.3. Where kj and tj are the parameters of membership function, kj=n(the general number of factors) , tj may be determined according to Zadeh's method, that is τ =0.5 at its crossover point[7].



$$\tau_i=\exp[-(\frac{k_j-x_j}{t_j})^2]$$

Fig.3 Membership function

4.2 The Degree of Confidence of the Conclusion

4.2.1 If the rule has only one antecedent, such as:

if A(τ 1) then B(τ 2)

where A is antecedent with d.c.= τ which may be determined by the frame or by the lower inference, and B is conclusion with rule's d.c.= τ which is provided by domain expert. Then the d.c. of conclusion B is

$$\tau = \tau 1 * \tau 2$$

4.2.2 If the rule has multiple antecedents, such as:

if A1(τ)&A2(τ)&.....An(τ) then B(R)

where R is the d.c. of this rule, τ is the d.c. of antecedent.Two cases may be occurred: if A1, A2, ... An play the same role ,that is to say these antecedents are equal weight, otherwise their weights W1, W2, ...Wn should be defined by domain expert respectively. Then the d.c. of conclusion from this rule is:

$$\tau = \{ \sum_{i=1}^{n} (\tau i * Wi) \} R$$

for example:

rule 32

if the height of groundwater divide is >300m (τ 1)
and groundwater hydraulic gradient is 0.27 (τ 2)
and speed of karst water is >10 (τ 3)
and hydraulic—relation among carbonate rock is very weak (τ 4)
and leakage relation is very weak (τ 5)
then the characteristic of hydrodynamic is weak karst water(R32) τ =0.7

That means the d.c. of the conclusion inferred from this rule is 0.7

5. FUZZY PATTERN CLASSIFICATION

The conclusions of prediction disasters are divided into four categories:

(1) The disaster with serious active karst water

From one or multiple vasculars of active karst water will flow in suddenly with large specific yield also in company with debrises and sands. If the flow will continue in a long period more vasculars will be induced and collapese on ground surface will be occurred.

(2) The disaster with action karst water

From one or more than one vasculars active karst water flows in with not large specific yield which will be increased after certain time ,and then more vasculars will be induced. Karst water is in company with debrises and sands. If the flow keeps in a long period, collapese on the surface also can be found.

(3) The disaster with close-active karst water

From only one vasculars of active karst water flows in. But there are karst water inclusions dispersed permeation from which the karst water may also be sent out with lots of debrises and sands.If the closed karst water flows in, the volume of them will be decreased with time, but the active water volume will be increased. The collapese will be occurred on surface partly if long period karst water flows in.

(4) The disaster with karst water inclusion

Only the closed karst water will flow in with debrises and sands.During this karst water is diminished, attention must be pay to other induced karst water.

It is not possible that the conditions of hydro- geology and engineering geology of a concrete position of a structure are fulfilled the antecedent's requirements for karst development of one of the above categories. For example, maybe some antecedents coincide with the second category, but some of them coincide with the third one. For this reason a technique called nearest neighborhood was adopted[8].The patterns recognized are supposed to be fuzzy subsets A1, A2, ... An of the universe of discourse U. A certain pattern B also is a fuzzy subset in U. The principle of nearest neighborhood is:

$$(B, Ai) = \max_{1<i<n} (B, Ai)$$

where Ai is the d.c. inferred from the real engineering set, which means that the degrees satisfied those antecedents of the four categories respectively. B is one that implies a fulfillment one of antecedents of the four categories.

6. OPERATION of THIS SYSTEM

This system runs on IBM-PC and its program was programmed with C. The operation is proceeded through man-machine communication. Once the conclusion is reached then the reasoning line could be given from the explanation facilities of this system. The validity of this system has been demonstrated and affirmed by domain experts.

7. CONCLUSION

Until now some of the technologies in engineering sciences are dealt with by expertise of domain experts, prediction of karst hazards is one example of them. The expert system appeared in recent years has provided us a means to handle this kind of problems. In this system lots of experiences in karst development were collected from Chinese experts in karst sciences. It is believed that this kind of accumulations is very beneficial to engineers. This system can be used in tunneling engineering or other underground engineering with great potential for cost saving.

8. ACKNOWLEDGEMENT

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