Do geotechnical engineers need expert systems?

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Expert systems for geotechnical engineers are reviewed and the future role of such systems in engineering practice is discussed.

Introduction

Expert system technology is still new to civil engineers, and there is a perception barrier which needs to be broken down before it will be accepted by practising engineers. This is partly due to the fact that there are, as yet, no useful working systems for civil engineering applications, and partly due to fears that intelligent systems could take over the jobs of experienced engineers in the future. In this paper the role which expert systems should play in geotechnical engineering is discussed and a review is made of systems which have been developed. Some of the criteria for the development of useful systems are also put forward.

Since many engineers will be unfamiliar with the terminology adopted by workers in the artificial intelligence field, some definitions of jargon words may be necessary. Knowledge based systems are computer programs which contain large amounts of varied knowledge which are brought to bear on a given task. Expert systems or intelligent knowledge based systems (IKBS) are computer programs which embody the knowledge and capability which allow them to operate at an expert's level. Since the knowledge is frequently expressed in the form of rules they may be called rule based systems. Heuristics are hunches, rules of thumb, guesses, beliefs. A heuristic rule might be 'if A then maybe B or possibly C' with different weightings applied to each possibility. A fuzzy set is a set which allows for 'graded' membership (i.e., which does not require sharply defined all-or-none membership). Fuzzy logic is a method of reasoning using fuzzy set theory.

The need for expert systems

Some examples where expert systems can have applications are set out by Feigenbaum and McCorduck (1983). They identified five cases:

(i) Capturing, replicating and distributing expertise

'We see a major new business opportunity. We have expertise to exploit it, but not nearly enough. If we use our experts to train others, we will be too late. It takes years of training and expertise to make one of our experts, because the knowledge that makes our experts good is not so well understood and codified that it can be taught directly.'

(ii) Fusing the knowledge of many experts

'There is no one specialist whose expertise spans the whole problem. It can be solved by the interaction of several specialists and the intelligent fusion of their separate expertise.'

(iii) Managing complex problems and amplifying expertise

'Our problem involves so many combinations and possibilities to construct and explore, and therefore our people miss things, or get them wrong. Our experts are good, but not good enough.'

(iv) Managing knowledge

'The problem we face is that excellent performance in our field requires knowing too much. The knowledge we use seems to change so often - it's hard to keep current. And there are so many aspects, exceptions, and subspecialties to be aware of. Solving any one problem is not hard if we only had the requisite knowledge and could use it systematically.'

(v) Gaining a competitive edge

'The techniques we use are well known throughout our industry and used by all. Our market share is small and stable. To bump it up, we need some new idea that will improve performance.'

Many aspects of these five scenarios are present in geotechnical engineering. Understanding ground conditions is more an art than a science, due to the complexity and natural variability of geological materials. This makes the passing on of experience to young engineers a difficult and time-consuming process. Geotechnical engineering is itself a specialty of civil engineering, but even within this field experts develop specialisms within which they operate best. This means that a number of specialists may be required on large or difficult projects.

Major problems in the geotechnical field come from a failure to recognise a critical ground condition, or the lack of appreciation of the significance of a particular feature. A good geotechnical expert is one who has a large knowledge of a range of ground conditions and types of construction. This knowledge will be of greater importance than knowing design rules and formulae. We tend to develop this knowledge by personal experience, since we retain this first-hand material more strongly. This limits our expertise to the areas with which we have had specific dealings. We could operate more widely by making use of other people's expertise, if we had a method of disseminating this knowledge. While published case histories have great value, we are unable to keep track of cases which do not immediately attract our attention, and by the time we wish to tackle a problem where the case history would be relevant we will either have forgotten about it, or will not have the time to find and read it. An expert system could provide the means of distributing this knowledge.

The 'design' in geotechnical design, as it is carried out at present, is based on simple well-established empirical rules, or on simple calculation methods based on simplified theory. However, before these methods can be applied, considerable time and judgment are involved in examining the ground conditions, identifying problem areas and assessing design parameters. The computer has taken a small load off the design engineer by performing the repetitive calculations, but has still left the designer with the full load of assessing the ground conditions. If the computer were able to assist in this area, the engineer would be freed to concentrate on the
problem areas, and think more deeply about the solutions.

The problem has been that the assessment exercise cannot be achieved simply by number crunching or by applying statistical laws to a set of data. It involves considerable judgment and uses both qualitative and quantitative information. It involves cross-checking different measurements, with knowledge of which measurement techniques are more reliable; comparing results against what would be expected for a particular material; knowing when results have to be 'adjusted' to be compatible with a particular design technique; knowing when particular geological processes have introduced additional factors which will not be represented in the measurements, and so on. The judgment does not end with the selection of design parameters, but continues after design calculations have been performed. The results obtained using different design methods will be examined and compared and also compared with what would be expected from past experience. For a computer to assist in this area requires an expert system, which 'understands' geological engineering as a result of being programmed with expert knowledge.

The role of an expert system

The first decision about the role of an expert system must be the intended user. Do we wish to develop systems which will be operated by non-experts in order for them to act as experts? There are clearly grave dangers in adopting this strategy. Systems are not infallible, and their use by those who do not have the engineering judgment to spot inconsistencies would be worrying.

A major role for expert systems could be in training would-be experts; those who have had a basic grounding in geological engineering, but have not had the experience of practical engineering. By interacting with an expert system, as they would currently interact with a senior engineer, they could learn from the expert knowledge programmed into the system.

Possibly the best use of expert systems will be as an assistant to an experienced engineer. This may seem an anachronism but, as has already been discussed, expert systems do have their role to play in this area. Systems can be developed which can interact with the engineer in considering different situations, which can help in the task of assessing large amounts of data, which can provide checks (even experts are fallible), which can provide knowledge relating to aspects which may not be in the main specialism of the engineer and which can provide access to case histories with which the engineer has not been personally involved. It is this type of system to which we should be looking for the future.

The simplest system would be a computerised checklist, or a computerised code of practice. The user would simply be asked a series of questions such as 'Have you thought of ...?' or 'What about ...?' The system would require relatively little problem specific data, and the input by the user would be simple, possibly only requiring yes/no answers. This type of system is relatively simple to implement, but it is only of real use to a non-expert. The experienced engineer would soon find it tedious to use, as the majority of questions would already have been answered in his own mind.

A sophisticated system would be able to go through the same process as the engineer, and the checking would then come from a comparison of the decision making process followed by the engineer, with that followed by the computer. If a discrepancy occurred the engineer would be able to track back the route followed by the computer until the reason for the discrepancy became apparent.

A more practical approach would be to adopt an intelligent interactive system. For this, the system would need to be 'intelligent' enough and would require sufficient detailed input to be able to interact with the engineer at his level. Rather than following the decision making process to completion, the system would query the engineer about which route to adopt, and would rely on the engineer's own experience to guide the process. However the system would point out where oversights appeared to have been made, would identify problem areas which appeared not to have been addressed in sufficient detail and would make suggestions about the best procedure to follow, if required.

The question still remains - if systems are able to assist engineers, will they be able to replace engineers? Blockley and Robertson (1983) have attempted to set out the characteristics of a good civil engineer. A system would need to have all these characteristics before it could be seen as a threat to engineers. They identify three major characteristics:

- Is technically sound;
- Has all the qualities of a well-educated professional;
- Has good personal qualities.

While expert systems may be able to satisfy the criteria of technical soundness, they are far from satisfying the other criteria. Engineers have the ability to take responsibility; to appreciate what they are doing in the context of society; to organise; to judge character; to be creative; to motivate and so on. All expert systems will do is take away the drudgery of repetitive data processing and information searching, in the way that standard computing has been used for repetitive calculation.

Existing Systems

Expert systems have been extensively developed to assist in the task of mineral and petroleum exploration. The best known is the classic expert system Prospector (Duda et al, 1979), which is a consultation system to assist geologists working on hard rock mineral exploration. It has knowledge of the most important types of ore deposits and matches this with user data on the major rock types, minerals and alteration products. It relies primarily on surface geological observations, and does not use a structural visualisation of the geology. A similar system muPetrol (Miller 1987) was developed to assist with location of petroleum resources. This system does embody geological concepts of tectonics, depositional and lithological sequences.

Other systems have been developed to interpret oil well logs (eg Ganasia 1986, Wu and Nyland 1987). These identify strata boundaries from each log, and then use pattern matching techniques to generate a geological column from a number of logs. Another expert system for the petroleum industry is a drilling expert system, Cases (Perrot et al, 1986).

Seismic hazard is an area where a number of systems are available (Watada and Yao 1984, Miyasato et al 1986). These systems use heuristics or fuzzy sets to deal with the judgment and uncertainty present in
assessing the level of risk to a structure due to earthquakes. A specifically geotechnical expert system which shows some promise is described by Alim and Munro (1987). This allows input of crude soil descriptions, including grading and consistency, and SPT values. On this basic level it is able to make recommendations on the type of foundation, can identify possible problems or recommend drilling and sampling techniques suitable to the soil type. However the system embodies only very low level, textbook expertise, and would only be of value to a user who had no knowledge of geotechnics. It is also implemented in Prolog with little attempt to develop a user-friendly dialogue.

A geotechnical system limited to a specific aspect of ground investigation is Cone (Mullarkey and Fenves 1986). This is an interpretative system for field cone penetrometer (CPT) data, to provide stratigraphic and soil characterisation information. It can deal with the quantitative and the qualitative information within a fuzzy logic framework. Another system, Pile (Santamarina and Chameau 1987), can assist in selecting the appropriate type of piled foundation. It includes a soil data base, and has knowledge specific to pile design and construction.

The way forward

It has been argued that expert systems can provide a useful role in assisting geotechnical engineers, and systems addressing some aspects have been developed. It seems worthwhile, therefore, to examine what features geotechnical expert systems need, to make them useful and acceptable to practising engineers.

It is suggested that developing simple checklist type systems will have only a limited usefulness. What is needed are more intelligent systems which can interact with experienced personnel at their own level. In order to achieve this a system needs to have access to the same data as the engineer. It must be able to deal with both qualitative (descriptive) data as well as the quantitative (numerical) data which computers deal with at present. It needs to deal with the uncertainties and imprecision present in all geotechnical data. It must also be able to create a visualisation of the ground conditions, by inferring relationships between the conditions observed at specific borehole positions, and be able to examine trends and changes across a site. Systems will also need very user-friendly ways of communicating with engineers before they find acceptance. Simplified natural language communications are possibly the best way this can be achieved. Rigid data structures with strict rules for data input must be avoided.

Some of these features have already been incorporated into existing systems or investigated in other contexts. Database structures for site investigation data have been developed (eg Cripps 1978, Day et al 1983), although freer structures which allow more qualitative data are needed. The use of expert systems may help in the standardisation and use of such databases. The use of probability theory or fuzzy sets (eg Blockley 1979, Atwell 1987) has provided methods of dealing with uncertainty, and Mullarkey and Fenves (1986) have shown that similar concepts can be used with qualitative data. Visualisation of the ground conditions is an extension of the methods used in oil well interpretation (Ganascia 1986, Wu and Nyland 1987), although the techniques need combining with a knowledge base of geological processes such as that used by Miller (1987). Interpolation systems have also been used for site investigation information (eg Day et al 1987), but these use no expert knowledge to help in the process. Knowledge based systems will be much more powerful in this respect.

The techniques are therefore established, and such systems are feasible. That does not mean that they will be easy to develop. Alim and Munro (1987) suggest that two to five man years are needed to develop a system, and for that they were considering a very simple system. Development of useful systems will involve considerably more input.

Conclusion

It is argued that expert systems do have a major role to play in geotechnical engineering. This will largely be as a tool to assist experienced engineers. However they will also be useful as a means of training junior engineers. The techniques needed to develop geotechnical expert systems are available, and simple systems have been developed. A considerably greater effort will be needed to develop systems which will really be useful in practice. It is suggested that the requirements of a system which will be useful, and will find acceptance among practising engineers, are:

- Intelligent enough to interact with an experienced engineer;
- Can deal with both qualitative and quantitative data;
- Can deal with uncertainty and imprecision;
- Can construct a visualisation of the ground conditions;
- Has a user-friendly natural language type dialogue.

References

Feigenbaum EA and McCorduck P (1985) The fifth generation, Addison-Wesley, US.