Expert System for Drilled Shaft Construction

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Decisions on how best to install drilled shafts consist of reviewing data gathered in site investigations and estimating how they affect constructability. Decision criteria tend to be predicated on the knowledge of local conditions to which evaluators are accustomed. Neglecting to take into account the effect of any one condition, or combination of conditions, may adversely impact construction operations. A modular, computer-based system that uses several expert system programs is described. The system sorts through relevant data and proposes what methods of constructing drilled shafts can best be implemented. The system also makes suggestions about operations and develops preliminary cost estimates.

Drilled shaft construction methods are not normally forecast by detailed analysis of geotechnical data, and the final selection of construction methods and details are (and should be) left to the experience of the expert drilling contractor (*1*). This premise must be the guiding principle of constructability analyses made during the early planning and design stages of any engineering endeavor (*2*). Foundation designers need to forecast general construction methods to estimate costs and develop appropriate construction specifications. One tool that can help determine a successful, low-cost construction method uses "expert systems" that promote interaction with geotechnical experts and contractors. In an expert system, the experience of one or more experts is captured in a knowledge base that can readily be accessed and referred to in order to assist, not replace, the human decision-making process.

Emphasis has been placed on the development of "shells" or general programs to accommodate the logic in expert systems (*3,4*). In a literature survey, only a few expert systems on driven piling (*5,6*) and only a single discussion of expert system interrelationships for drilled shafts (*7*) can be found.

WHY AN EXPERT SYSTEM?

As the branch of artificial intelligence that has gained widespread acceptance in recent years (*3*), expert systems are particularly well suited for diagnostic problem-solving tasks. Both subjective and factual information are stored and "preserved" in the expert system's knowledge base. Because expert systems are supported by personal computers, they enhance productivity by providing access to information that is consistent, portable, and readily available. In addition, these programs are interactive and user-friendly, serving as an excellent tool for training novices. More specifically, an expert system for drilled shaft construction will anticipate problems by alerting users to geotechnical information that may be overlooked, inconsistent, or incomplete. Output includes constructability recommendations, appropriate inspection procedures, and relevant specifications.

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DECISION SUPPORT MODEL FOR DRILLED SHAFTS

The decision support model contains three steps, each with a specific objective (Figure 1). The systems used in these steps have been collectively named DS^2, for Decision Support for Drilled Shafts. Each DS^2 module can be bridged to external programs, resulting in a combined effort that is not only simple and informative but also powerful. DS^2 was developed using EXSYS Professional, a commercially available, rule-based expert system shell widely used in industry today. From a survey of 37 state-of-the-art expert systems designed for civil engineering end users, EXSYS ranked as the second most popular commercial shell. The rule editor in the shell facilitates the building of heuristic rules in the if-then format. EXSYS permits both forward chaining and backward chaining search strategies to arrive at conclusions. Uncertainty is associated with each rule such that each conclusion is reached with a certain degree of confidence (*8,9*). Knowledge sources for DS^2 included more than 50 hr of interviews with two academicians, one consultant, seven drilled shaft contractors, three design firms, and three equipment manufacturers, among others. In addition, knowledge was obtained from videotaping more than 100 hr of job site operations in the Midwest and Southwest (*8*). DS^2 is available on request for a nominal amount, and information regarding hardware platform requirements may be obtained from the authors.

DS^2 MODULES

Virtually all drilled shaft construction practices in the United States can be placed in three categories: the dry method, the wet method, and the casing method (*2*). The first module, DS^2-GEO, recommends to the end user what construction method is most suited to a given job site. The recommendations are provided with degrees of certainty, using integers from 0 to 10. These represent the confidence with which DS^2-GEO arrives at each conclusion. Degree of certainty values represent the expert's opinion on which method has the great-

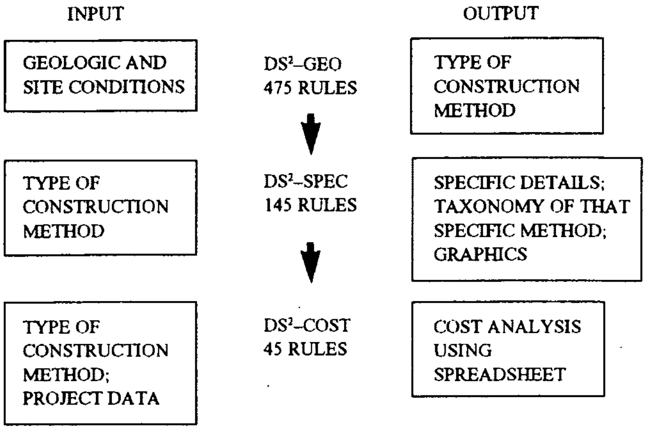

FIGURE 1 DS² decision support model (three separate models).

est likelihood of being used, rather than probability of successful implementation. A high confidence value indicates a high likelihood that the expert believes one particular method will be required, because of the unlikely success of a less expensive method. The primary bases for these recommendations are geologic and site-specific conditions, such as sand content, water table elevation, soil permeability and strength, rock joint characteristics, and job site restrictions. DS²-GEO can analyze uniform layers and geomaterial profiles with two separate primary layers (Figure 2). Graphic support is also provided to improve communication between the end user and DS²-GEO. The knowledge base can be easily modified or expanded to include additional rules developed later that will take into account more complex profiles. There are now 475 heuristic rules, each representing a possible combination of soil and site factors, that enable DS²-GEO to make recommendations. One of hundreds of possible paths in DS²-GEO is illustrated in Figure 3, in which recommendations are developed for the general construction method for a drilled shaft in a clay profile. As can be observed, the questions are posed in such a way that requires the user to either consult with a geotechnical engineer or have at hand a geotechnical report with thorough documentation of site conditions.

After using DS²-GEO, the end user can proceed to DS²-CON, which provides details and specifications that are automatically linked to the construction method in DS²-GEO. DS²-CON's knowledge base consists of information on the three operations in drilled shaft construction: excavation, setting of steel reinforcement, and concrete placement. When investigating excavation procedures, DS²-CON provides the end user with information such as specifications and tolerances for shaft dimensions, inspection procedures, type of concrete and drilling fluids that may be used, safety precautions, and maintenance of borehole quality, among others. DS²-CON also provides relevant information on the installation of steel reinforcing (i.e., precautions for using a partial- or full-length cage, auxiliary devices to support handling and installation) and concreting (i.e., mix requirements, tremie/pump operations). By providing pertinent information at each phase of the construction procedure, simple and clear guidelines can be developed for each field operation to ensure the safety of all personnel on site. There are 145 rules in DS²-CON, all of which can be easily updated or modified.

The third module, DS²-COST, estimates the total cost of the particular construction method chosen in DS²-GEO by itemizing expenditures that are associated with a specific

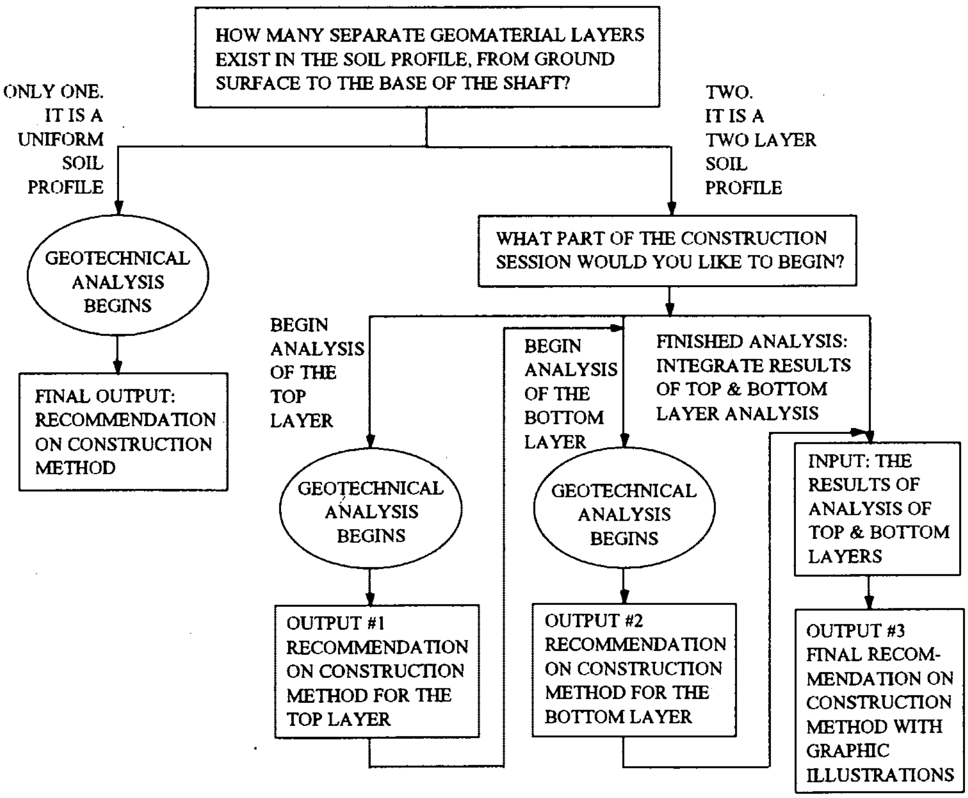

FIGURE 2 DS²-GEO module: analysis of uniform and two-layer profiles.

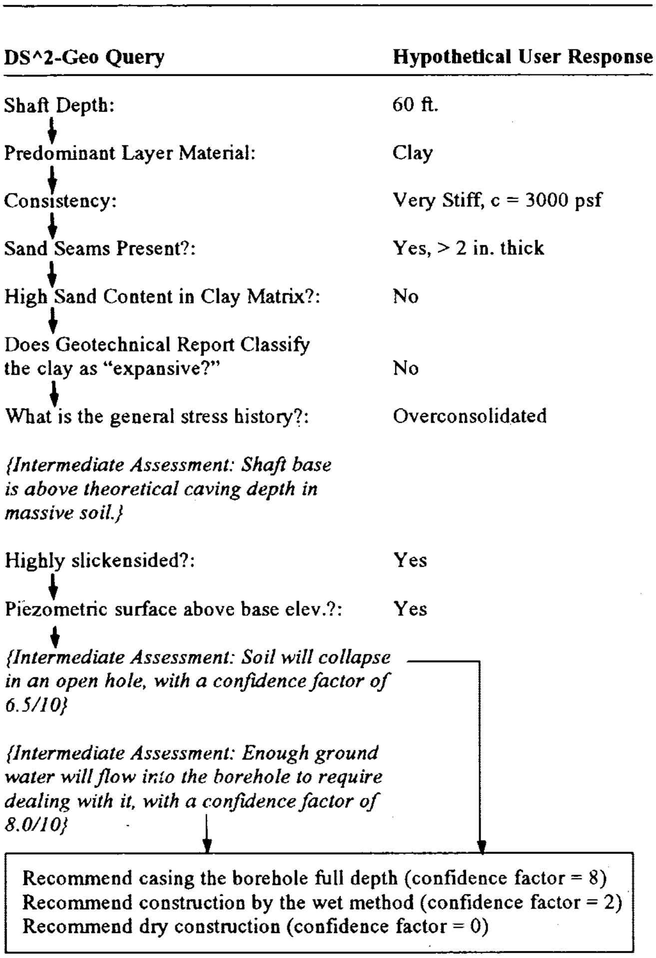

FIGURE 3 Example path for arriving at recommendations for construction method in DS²-GEO for a simple, single-soil profile.

method. Cost items are categorized into excavation costs, concreting costs, and steel placement costs. Each is further subdivided into labor wages, equipment, and miscellaneous costs. DS²-COST can interface with a spreadsheet data base containing union labor wage rates for 20 U.S. cities (*10*, p. 108) should the end user decide not to use his or her own wage rates. Unit costs for concrete and steel can be derived in the same manner. Historical cost data bases may also be accessed from this module, with comparison capabilities from presolicited criteria, such as shaft diameter, number of holes, and total linear feet. Thirty-two cases are stored in this data base.

VALIDATION AND CONCLUSIONS

An 85 percent similarity agreement was obtained for DS²-GEO recommendations and 13 published construction case studies. Further validation of 23 random cases analyzed by DS²-GEO, against recommendations provided by three consultants and four contractors resulted in a 70 percent similarity rating. Although much of the knowledge used to develop DS² was obtained in Texas and neighboring Southwestern states, the geographic locations of the 13 case studies and the areas of expertise of the three consultants represent regions throughout the United States. The various DS² modules are revolutionary not only because of the knowledge they can store and the interactive manner in which this knowledge can be retrieved, but because they provide an automated medium through which general technical consensus can be acknowledged and differences examined and reviewed. In effect, this ensures improved communication among designers, contractors, and geotechnical and field personnel.

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