Diagnostic decision support system for bored pile construction

Système de support pour décider du diagnostic et résoudre les problèmes de construction de pieux forés

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ABSTRACT: This paper suggests a formal approach to field diagnostics in the construction of bored pile foundations, considering the construction method and subsurface conditions, with the help of an expert system module, called DS^2-DIAG. This module contains representative heuristics that result in solutions to field problems faced during the construction of bored piles. A knowledge base of the problems and solutions was developed with regard to constructibility and diagnostic analysis, corresponding to three main phases as follows: Pre-construction - before start of construction, During construction - excavation, rebar cage placement, concrete placement, and Post-construction. Solutions are developed through decision trees that ask questions of the user and arrive at recommendations with assigned degrees of confidence based on the feasibility and its apparent cost. DS^2-DIAG is enhanced with scanned still photographs, definitions, and explanations of terms in hypertext. A database of bored pile construction projects is linked to the module.

RESUME: Cette communication offre une approche formelle du diagnostic sur terrain-même des travaux de fondations en pieu foré, au moyen d'un module compétent, appelé DS^2-DIAG, qui examine les méthodes de construction et les conditions souterraines. Ce système performant, offre des caractéristiques heuristiques permettant de résoudre les problèmes se posant au cours des travaux de pieux forés. A cet effet, une base de connaissances de problèmes et de solutions a été créée pour évaluer la faisabilité des travaux et le diagnostic; cette base correspond aux trois phases principales suivantes : précèdant l'execution des travaux - avant démarrage, lors de la construction - excavation, assemblage de la cage en acier, application du ciment et post-construction. DS^2-DIAG est optamisé grâce à des lecteurs immobiles de photographie, et des définitions des termes et commentaires, en hypertexte. La base de données des projets de construction de pieux forés et le module communiquent entre eux.

1 INTRODUCTION

The success of bored pile foundations depends mainly on the subsurface conditions encountered and the selected method of construction. Qualified personnel with the authority to make wise decisions, strict visual inspection, and experience are required to execute a bored pile project successfully. In the case of deep shafts or shafts constructed using the slurry inspection is a partially important issue. Methods of bored pile foundation construction vary significantly with the change in the subsurface conditions. Bored pile construction can be a difficult task if (a) all the geotechnical data are not made available during the planning and design phase, (b) unanticipated subsurface conditions are encountered during excavation, (c) improper drilling/construction techniques are employed, and (d) the geotechnical engineer is not available or does not have adequate experience. Sometimes, improper techniques in the construction leads to unacceptable piles even under favorable subsurface conditions. Bored pile contractors tend to become specialized in dealing with the local subsurface conditions with which they are familiar. When conditions outside the empirical experience of the contractor are encountered expert system technology can be employed. This technology has been being widely used in various fields of civil engineering in recent times. It can be implemented to capture rare human expertise and direct their valuable experience and knowledge to the next generation for future reference. Not only will an expert system for drilled shaft construction assist in minimizing construction delays and claims, but by giving the owner and contractor a common standard of solutions to construction problems it will make the design of bored piles more reliable, since bored pile performance is highly affected by details of construction [O'Neill, & Hassan, 1994].

2 WHAT IS DS^2 ?

DS^2stands for <u>D</u>ecision <u>S</u>upport System for <u>D</u>rilled <u>S</u>haft Construction. It was originated at the University of Houston in 1991[Fisher, O'Neill, & Contreras, 1995]. Initially, five modules were developed to recommend

- Method of construction (DS^2-GEO),
- Specifications for selected method (DS^2-SPEC),
- Solutions to some of the problems faced with the slurry method (DS^2-DIAG),
- Estimated cost of construction from interactive databases with cost information on similar projects (DS^2-COST), and
- An equipment management simulation module (DS^2-SIMPACK)

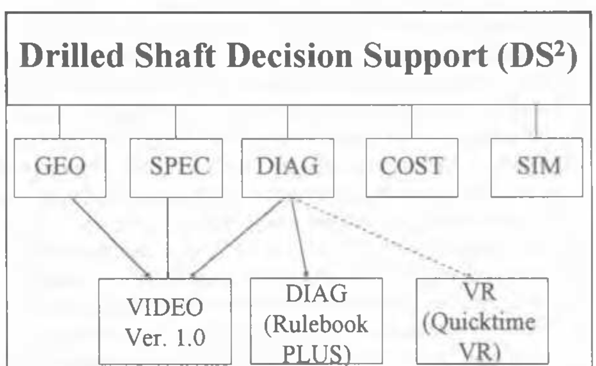

Fig 1. Present Status of the Family of DS^2 Modules

Fig.(1) shows different modules that were developed under DS^2 in the past (white boxes) and the addition of new modules (gray boxes) to existing DS^2 family. It also contains a future module that is currently being developed for virtual reality applications. Two modules were recently added to the family of DS^2:

• A complete diagnostic module that would recommend solutions to problems faced during bored pile construction (DS^2-DIAG) [Tamane, 1996],
• Application of multimedia technology (interface with audio/video files) to existing DS^2 modules (DS^2-VIDEO) [Fisher, O'Neill, Miura, & Tamane, 1995].

3 DEVELOPMENT OF DS^2-DIAG

The active participation of domain experts is an integral part of any expert system development. Domain experts are the best practitioners in their respective fields. Domain experts for DS^2-DIAG were selected from three different fields, a geotechnical engineer/academic (Dr. M. W. O'Neill), an owner, New Mexico State Highway and Transportation Department (NMSHTD), and a bored pile contractor (Albuquerque Caissons, Inc.). The knowledge acquisition process in developing the knowledge base of DS^2-DIAG involved (a) interviewing the domain experts, (b) field visits to bored pile construction site, and lastly, (c) referring to the technical literature on this topic - Association of Drilled Shaft Contractors (ADSC) construction and design guidelines, NMSHTD specifications, text books, articles, and prior publications on bored pile construction. A continuous list of problems and solutions was prepared from the knowledge acquisition sessions with the domain experts. This knowledge base was then converted to IF/THEN rules using EXSYS, Rulebook PLUS.

Problems reported in DS^2-DIAG were structured according to major phases in bored pile construction. These phases include problems during: pre-construction, excavation, rebar cage placement, concrete placement, and post-construction. The problems during the excavation phase were further subdivided into three categories, depending on the construction methods: problems related to the dry method, the wet/slurry method, and the casing method.

Problems can be avoided if proper attention is given by both the owner and the contractor during the pre-construction phase. DS^2-DIAG provides a neutral frame of reference for both parties and therefore a common ground for identifying potential problems and solutions before they occur. But, improper techniques in construction leads to unacceptable shafts even under favorable subsurface conditions. Pre-construction problems included in DS^2-DIAG are inadequate subsurface characterization, vehicular traffic at the site, low overhead clearance, scheduling, site accessibility, coordination, specifications, and adverse weather. Problems during the excavation can be caused either by insufficient subsurface information, unanticipated conditions or wrong drilling practices. Construction problems during the dry method included problems related to unfavorable/unexpected subsurface conditions such as presence of rock boulders, free groundwater, karstic rock, collapse of the underream or the shaft, rise in the elevation of the base, caving soils, base of the shaft that is not clean, movement of adjacent structures, and unexpected moisture variation; problems related to drilling equipment such as unproductive drilling rate, unretractible drilling tools, and failure to maintain the alignment of the borehole; and problems related to the environment such as excavation in contaminated soil/rock, or release of hazardous gases and unexpected utility lines. Many of the problems encountered in dry drilling are routine but nonetheless become the source of claims when inexperienced construction crews or inspectors fail to perceive the problem or overlook a cost-effective solution. When the inflow of ground water occurs, drilling becomes less routine. In the United States, slurry displacement (wet) construction is often employed. Problems with the wet method include problems associated with improper rheological properties of slurry such as sedimentation of slurry, development of thick mudcake, slurry flocculation, slurry contamination, and improperly hydrated slurry. Other problems such as slurry disposal, slurry freezing and inadequate volume of slurry are also observed. Problems with the casing method include problems such as buckled casing due to high external hydrostatic or soil stresses, movement of rebar cage during the removal of temporary casing, and failure to penetrate, remove, or seal the casing. Some of the most serious foundation defects of recent years have been associated with attempts to recover casings during concreting, especially in deep shafts [Peck, Hanson, & Thornburn, 1974]. Problems during the rebar cage placement occur mainly due to poor practices of lifting and placing the rebar cage in the shaft. Problems such as buckling of the rebar cage, failure to lift the cage without permanent distortion, displacement of splices in the cage and storing the cages can be observed during this phase. Problems during concrete placement are caused by improper properties and improper techniques of concrete placement in the shaft. Problems encountered due to improper properties of concrete can be high/low slump of concrete, plugged tremies/pump line, concrete setting too quickly, and failure of concrete to flow near the surface. Problems due to improper concrete placement techniques can be slurry trapped within the shaft, inclusion of soil in the shaft, leaching of concrete, contamination of concrete at the shaft head, collapse of the rebar cage and a broken tremie. Other problems such as enlargement of the excavation, mushrooming of the shaft, and interruption of concreting can also occur during concrete placement. Serious problems can occur if proper attention is not paid to groundwater inflow and caving soils prior to concreting. Post-construction problems are the problems detected after conducting non destructive tests on the completed shaft. These problems include piles exceeding geometrical tolerance and/or trapped slurry or soil inclusion in the shaft. The problem of geometrical tolerance is often observed when piles are drilled through boulder fields which tends to deflect the drilling tools. Solutions to some of these problems are provided in DS^2-DIAG directly without asking any questions, and some of the problems are solved after asking a set of questions.

4 HARDWARE AND SOFTWARE

The hardware used to develop DS^2-DIAG included an IBM compatible PC, with 16 Mb RAM, 1.2 Gb HD, VGA monitor, and Windows-95 environment. The software used to develop DS^2-DIAG included a commercially available expert system shell from EXSYS, Inc., Rulebook PLUS version 1.1.2-W to develop the system, Epson Scan! version 1.00 was used to scan the still photographs into PCX images, and Adobe Photoshop version 3.0 was used to make minor changes to the scanned PCX images. Overall hard disk requirements to run DS^2-DIAG without graphics are 361 KB. An additional 3.33 MB are required to display 16 graphics files interfaced throughout the system and the database file. An IBM compatible PC with a minimum of 8 Meg RAM, 3.7 MB HD, VGA monitor, and Windows with a runtime program of EXSYS, Rulebook PLUS are required to run DS^2-DIAG. The runtime program of Rulebook PLUS (RBPL_RUN.EXE) can be distributed with the finished product to any number of end-users.

5 INTERFACES TO DS^2-DIAG

DS^2-DIAG was interfaced with scanned still photographs, explanatory text, and a database. Still photographs were scanned and converted into PCX files. Explanatory text was created using Windows TEXT editor. PCX files and explanatory text were later programmed using an *.SCR file (custom screen file) into DS^2-DIAG in the hypertext format. Scanned photographs and explanatory text are used to explain some of the terms used in bored pile construction. A database of 9 bored pile projects was interfaced to DS^2-DIAG. The database was created using the Windows TEXT editor as an ASCII file. This ASCII file is then viewed using a display command in Exsys, Rulebook PLUS.

6 VALIDATION

Domain experts' knowledge can be incomplete or imprecise or unstructured which makes it difficult to identify whether or not the expert system is providing correct information [Lee, & O'Keefe, 1990]. DS^2-DIAG was validated in the following manner: (a) Comparing the output of DS^2-DIAG with projects enumerated in the database. (b) Asking one of the domain experts, Mr. Thomas Brown, Albuquerque Caissons Inc., Albuquerque, NM to run the system and lastly, (c) Using the built-in expert in EXSYS, Rulebook PLUS.

The improvements to DS^2-DIAG, after validation, included a change in the perspective of looking at problems, the addition of new problems and solutions, and a change in the certainty factors of the solutions. Validation resulted in the addition of 11 new problems, and 20 solutions to the knowledge base. DS^2-DIAG, was also randomly validated using the built-in expert of EXSYS, Rulebook PLUS due to the size of the system.

7 CONCLUSIONS

Bored pile foundations can be constructed successfully provided proper steps are taken during the planning, design and construction phases. DS^2 points to a requirement to conduct a subsurface investigation adequate for the project at hand, that identifies the presence of boulders, cobbles, cohesionless layers, ground water and soil/rock properties. It suggests the construction of trial construction shafts when warranted, reminds the owner of critical issues in the construction specifications and the need to employ qualified contractors.

DS^2-DIAG, the diagnostic module, has been developed in a multimedia format to make it easy and enjoyable to use and is particularly useful in an instructional environment both for owners and contractors. A total of 64 problems and 321 solutions are included in DS^2-DIAG. A database of bored pile foundation projects completed in the state of New Mexico is included.

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