AN ELECTRONIC WORKBENCH. FOR GEOTECHNICAL SITE CHARACTERIZATION

by

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Abstract

Compared with many other engineering disciplines, qiwfrftf:fm*cal site characterization (the process of defining the physical and geometric properties of soi Mid rock subgrade) is not highly computerized. This can bft attributed to tfw proctft h^**Q httinf o: trptrMTAfft t*rf itttffttT the pr»ctic« of tMta composing srt«
analysis. Typicafly the process involves Emitort field and laboratory test*ing. extensive inleipfstation of the sparse data samples based on the engineer*s experience, and a formal presentation of results, with infer-motion being communicated between the various participants on a variety of forms and plots (e.g., bore logs, subsurface profSes, fence diagrams, etc).

With the emergence of new computer-based techniques such as engineering workstations and knowledge based expert systems, and with improvements in graphics and database management capabilitiaa, many of the technical impediments to a more comprehensive appication of computers to site characterization have been eliminated.

Specificaiy, four components can aid in several aspects of the process:

- *Detebeses.* Databases serve as the integration mechanism. By having data *online, m* users have immediate access to the most recent information, and communication problems *en* eliminated. Using electronic forms to replace paper, field data is gathered and directly entered into a site database. As the site characterization proceeds* new date is added to the database, budding a complete, o>mprehenaivstnode1ofasitewhi^ is used in all processing.
- *Personet Computers.* PC workstations form the base of the computing environment. They provide direct inexpensive access to the necessary computational resources (includIng graphics)* Using computers in the field and laboratory provides the means to capture drecfly a* data as it is generated. Workstations can also provide immediate feedback, eliminating costSy delays. Such immediate feedback suggests the possibility of using a *dynemic* exoperation strategy*
- *Graphics.* Graphical presentation is one of the prUnary means of communicating results. Direct production of presentation-quality graphics is now a reality.
- Knowledge *Besed Expert Systems*. Tasks such as the interprets-** <* **** lo**and *****todetermine** * f * tHSca *?^n Λ^r * ^structured tasks performed by expert geotechnicai engineers. Since there o no -formal process TOT tros task and many omer stapa-which comprise the ai>» characteriation proceas. their computeriTatton has not been possible in the past; programs have bww. ha yf, owa ^ * ^ l ^ n ? _ h * M r ^ ^ Knowledge based exP6* systems, howe¥er, PITOVIO> tt^mechanisre for dealing with the ait of the site characterization process.

The current reiaarch emphasis is on an independent investigation of the four components described above. The next step is to integrate aU components into an *Electronic Geotechnicsl Engineering Workbench.* T*» workbench concept is <***V*™* to p n ^ a qwiplete etectronic office and UtkuiUky environment eliminating the need for manual *Qrmpantion* of forms and drawings. The workbench does not directly change the basic process of site characterization, but develops an wogrmiiv rwmnKin 01 me fornw, arswinys anu wiioriTicttiun GBVTI*munication. Indirectly, the computer-based process supports a dynamic exploration strategy, saves time, and provides more accurate data.

An initial integration of the database and graphics components of the workbench, using personal computers and -standard- PC software (Auto-CAD, Lotus 1-2-3. and dBASE-III), has been developed. These tools provide rapid prototyping of a complete system, without relying on expensive hardware and time-consuming software development in addttion, since the components are readily available, direct technology transfer and use in both the field and office ars possible.

As expert system technology evolves, and as the power of PCs incresses, it wai be possMe to bufld a more comprehensive cornpuang *mnywrmmetii* that aiternatea arl the rnmnnniinriT <1«M'jih#ri ahove ami transforms much of the site chanKMzation pro<»ss into an elects-based discipline.

1. introduction

The process of site characterization, as opposed to most other engineering processes, is more an *art* than an application of rigorous scientific methods and procedures. On the basis of sampling and laboratory testing of relatively few soil samples combined with their experience, skilled geotechnical engineers will infer the underlying stratigraphy of a site and will make recommendations for the engineering of substructure components. Since there is no formal underlying mathematical process which is directly amenable to computerization, such as in finite element analysis, the use of computers in the site characterization domain has been somewhat limited, and much of the Information flow is through manually prepared forms and drawings. However, the emergence of new computer-based techniques — such as *knowledge based expert systems* and *engineering workstations,* combined with improved capabilities in graphics and database management, and the widespread availability of low-cost, powerful micro-processors — has opened the door to a more comprehensive application of computers to the site characterization process. In this article, these technologies w* be discussed, with the goal of providing a computer-based, electronic environment which enhances the current manual process of site characterization.

1.1. Geotechnical Site Characterization

The objective of the site characterization process is to determine the distribution of engineering properties of the site, inducing:

- Number, location, depth and extent of strata
- Location of groundwater
- Engineering properties of soto, Ie., density, shear strength, etc.

The site characterizstion process is carried out through a series of steps, with data being communicated through a number of forms, graphs and drawings.

- *Reconnaissance* — The first step is a research phase where data from nearby sites and the overall site characteristics are com* bined with an initial site visit to determine site accessNity, topology, geology, drainage, etc This information is used as a basis for further site chiiracttrization and for planning an exploration strategy.

- *Field Explorations* — Reid explorations are used to gather more detafled information on the sits. The exploration strategy selects the number, location and type of borings. Detafled records of the drilling process *an* maintained and *soM* samples are recovered at discrete points along each boring. Log sheets, such as the one shown in Figure 1 are used to record the Md data.

- *Laboratory Testing* — A portion of the recovered soil samples it subjected to laboratory testing. Some tests are performed in the field and their results are added to the field log sheets. At some later date, other tests are conducted on a subset of the so* samples sent to the laboratory. Again, the results are a number of logs ano pfotsoescnoing we so» samples.

- *Interpretation* — After the data has been collected, it is interpreted by experienced geotechnical engineers to infer the *SHB* characteristics. The raw field and laboratory logs are transcribed and combined or grouped into a number of alternative forms and bore logs. The data is then used to form a three-dimensional model of the site, which is presented through a number of two- and three-dimensional profile diagrams, as the one shown in Figure 2.

The result of the site characterization is a formal report describing the site stratigraphy, providing the basis for the engineering of the substructure.

The site characterization process suffers due to the information handling mecr^isnw used in the ain^nt manuaJ process. Transfer of data between field and office is slow, and often, engineers will not make interpretations on fragmentary data. If data were more readily available during the exploration stage, a *dynamic* exploration strategy could be employed (i.e., by considering data obtained, increase or reduce the number of test and borings, etc), resulting in a better site characterization.

2. Development of a Geotechnical Site Characterization Workbench

2.1. Workbench Concept

There are many places in the site characterization process where data can be lost or errors can be introduced through the martual processing of data. In addition, inferring the subsurface model is a complex, »-defined, time-consuming task. Through application of new computer-based technologies, much of the manual process of data handfrtg, forms preparation, drafting and data interpretation can be automatecL

Computers have been applied to many of the detaMed steps in the site characterization process, L*, the determination of drifing location using automated surveying and mapping equipment, automated laboratory data acquisition and signal processing, etc. Current applications are essentially *stand-alone,* the transfer of data between the steps is a manual process, and applications which require expertise, such as log inter pretaiion, are not computerized.

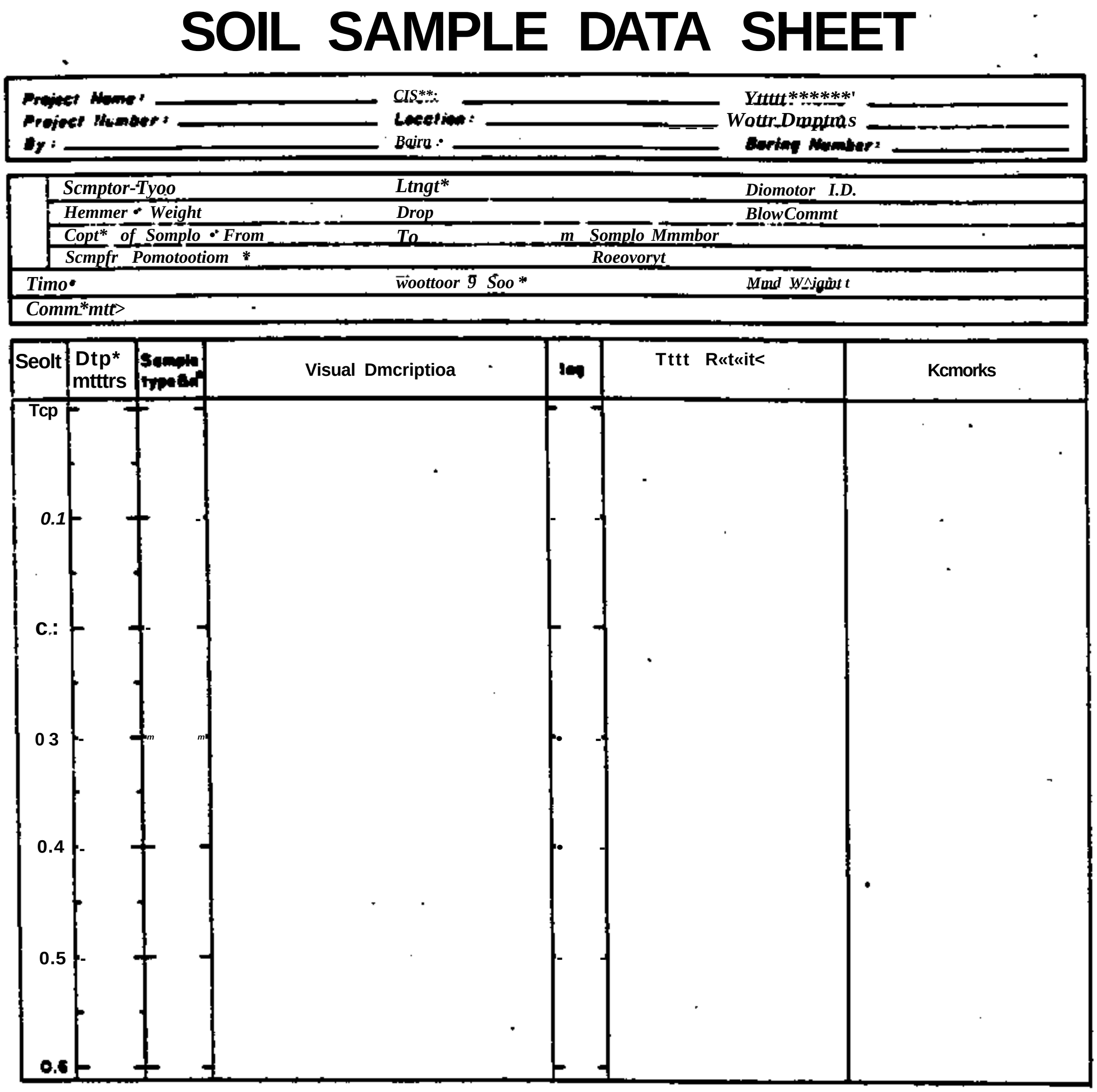
The *workbench* concept is designed to integrate a numb&r of computer-based tools into an electronic environment for computer based problem solving. It is patterned after work at AT&T Bell Laboratories where computer tools have been combined to aid in tasks such as program development [Me 77] and writing and document preparation [MacdonaJd 83]. A similar integrated set of computer-based tools could be used to transform much of the site characterization process from the current manual basis to an electronic-based discipline; providing an electronic office and laboratory facility which eliminates the need for manual preparation of forms and drawings. The workbench does not change the basic process of site characterization (field exploration, laboratory testing, interpretation and document preparation), but develops an electronic realization of the forms, drawings and information communication.

2.2. A Computer-Based Site Characterization Process

Through an exploration of new computer technologies, the concept of a computer-based process for site characterization has been developed. The steps of the process are identical to the manual process outlined in Section 1.1, but computer-based tools are applied to all steps. Potential computer applications and use in the different phases of the process are outlined below (the realization of these applications is presented in the following sections)!

- *Reconnaissance* — Review of nearby sites is one component of initial site reconnaissance. In the manual process, previous site investigation records must be retrieved and examined. In the computer-based process, ail records are stored in a central, *archival* ctatarww, A systematic search of the database is made to find nearby sites, or sites with any similar characteristic (e.g^ same morphology). Computerized searching is less time consuming, permitting the exploration of more alternatives and more detailed background work.

- *Field Exploration and laboratory Testing* — Electronic forms and electronic forms filling (computer based completion of these



SOIL SAMPLE DATA SHEET

Project Name: ______ CIS**: ______ Ytttt******' ______
Project Number: ______ **Location:** ______ Wottr Dmptms ______
By: ______ Bairn: ______ **Boring Number:** ______

Scmptor-Tyoo ______ Ltngt* ______ Diomotor I.D. ______
Hemmer • Weight ______ Drop ______ BlowCommt ______
Copt* of Somplo • From ______ To ______ m Somplo Mmmbor ______
Scmpfr Pomotootiom * ______ Roeovoryt ______
Timo• ______ woottoor 9 Soo * ______ Mud W^igmt ______
Comm*mtt> ______

Seolt	Dtp* mtttrs	Sample type &d	Visual Dmcriptioa	Iog	Tttt R«t«it<	Kcmorks
Tcp						
0.1						
C.:						
0 3						
0.4						
0.5						
0.6						

Figure 1: Soil Sample Data Sheet

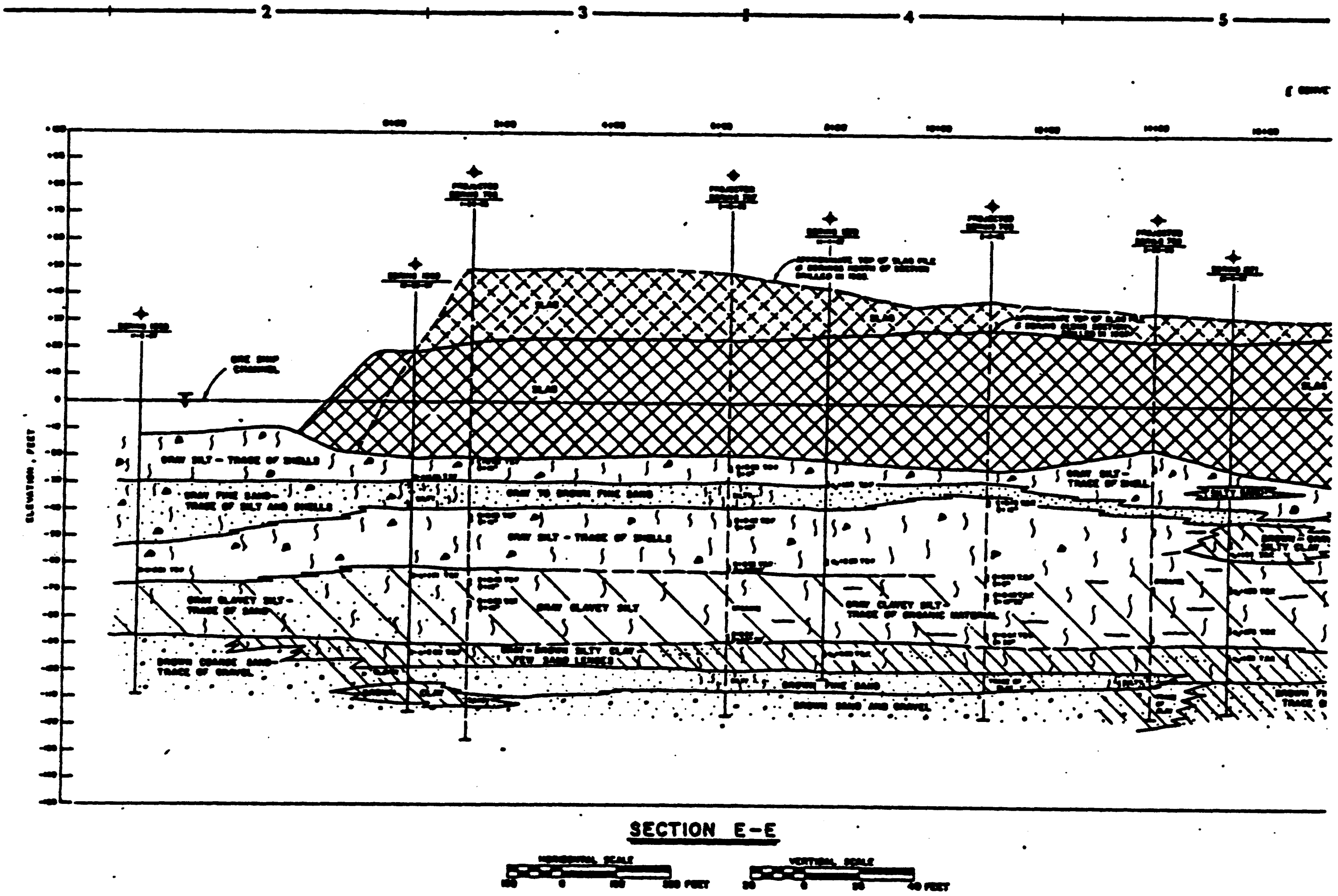


Figure 2: Two-Dimensional Profile Drawing

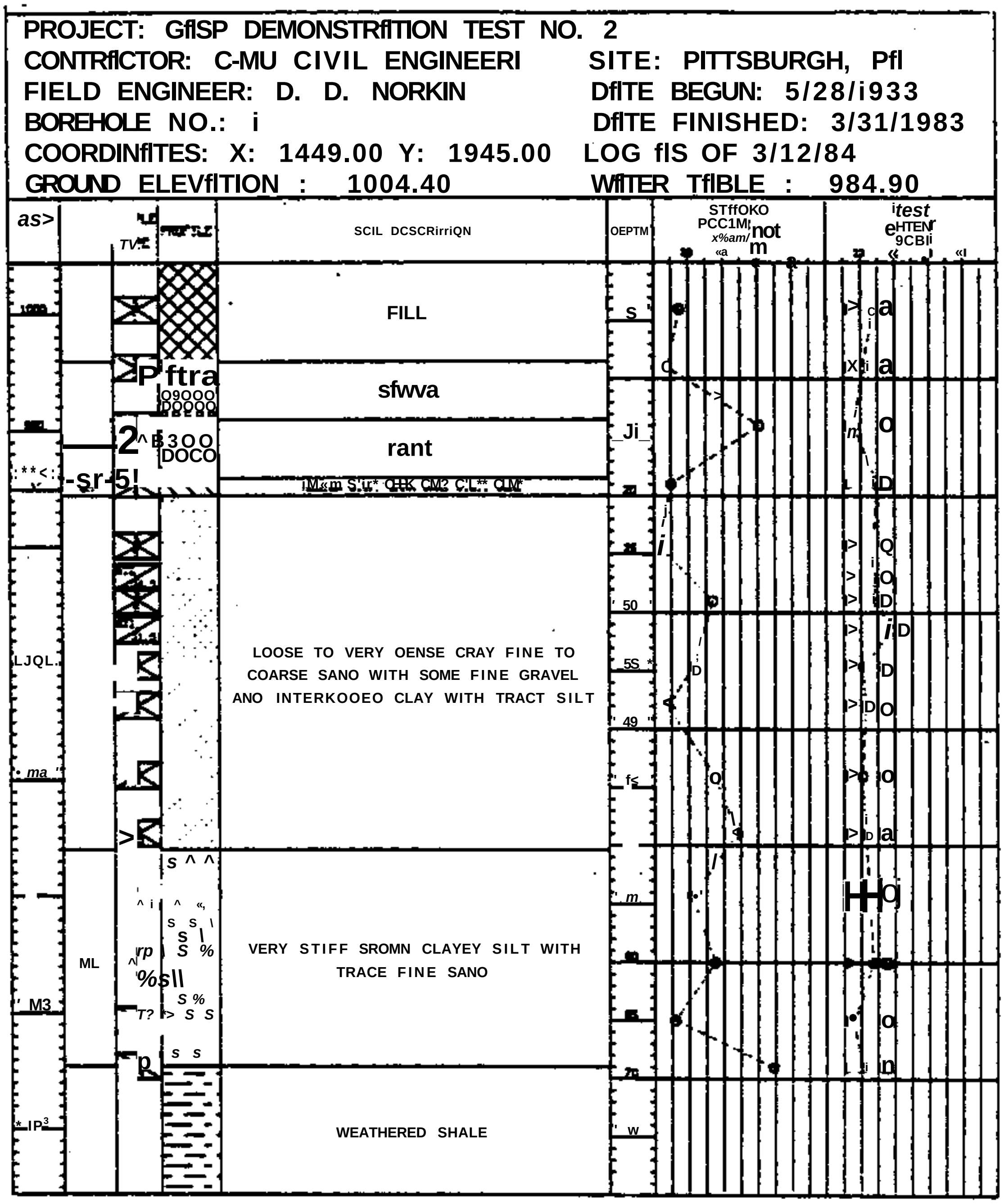
forms) are used to replace the manual process of filling log sheets. All field exploration data is captured as it is obtained and immediately transferred (electronically) to the office, reducing data losses and data handling time. Immediate entry of the data into a *project* database makes it available to office personnel for further analysis and reduces data communication problems. In addition, checks are performed automatically as the data is obtained to ensure its integrity and accuracy (i.e., two related values are in proper proportions, values are within proper ranges, etc.). As with field exploration, the data from laboratory tests is directly captured during testing and entered in the central project database.

- *Document Preparation* — Documents, forms, graphs, test result reports, etc., are produced directly from the project database without the errors introduced through manual transcription of data. Computer generated documents, such as the bore log shown in Figure 3 are consistent and accurate (i.e., the documents are consistent with the data, data is reproduced without error, the format of all documents is uniform, etc.) while their quality equals or exceeds that of those manually produced.

- *Data Interpretation* — The processes of interpreting soil parameters from cone penetrometer tests, inferring site stratigraphy from bore log data, etc., are assisted by knowledge based expert systems which use the heuristic knowledge of skilled geotechnical engineers. Application of expert system technology extends the range of computer applications in the site characterization domain to tasks which are currently performed by skilled, experienced engineers.

While computer applications to the separate processes outlined above are invaluable in improving the site characterization process, major benefits accrue from integrating the components into one complete system. The objective of the workbench concept is to develop such an integrated system which applies computer aides throughout the process.

The remainder of this paper describes the technologies which can be used in the development of a geotechnical site characterization workbench and discusses current research and the development of some prototype components.



PROJECT: GASP DEMONSTRATION TEST NO. 2
CONTRACTOR: C-MU CIVIL ENGINEERI SITE: PITTSBURGH, PA
FIELD ENGINEER: D. D. NORKIN DATE BEGUN: 5/28/i933
BOREHOLE NO.: i DATE FINISHED: 3/31/1983
COORDINATES: X: 1449.00 Y: 1945.00 LOG AS OF 3/12/84
GROUND ELEVATION : 1004.40 WATER TABLE : 984.90

Figure 3: Bore Log Produced by *GASP*

3. Currently Available Technologies

A number of currently available computer technologies can be used to develop components of a site characterization workbench. Key items are micro-processor based workstations, spreadsheets, database management systems and graphics: A prototype workbench based on these technologies is being developed on machines such as the/BAf PC. To permit rapid prototyping with reduced development costs, off-the-shetf rwcro-processor software is being exploited when posstte.

3.1. Personal Computers: The Hardware Base

Microprocessor personal computer workstations form the base of the computing environment They provide direct, inexpensive access to the computing resources (including graphics) needed to perform the tasks outlined in Section Z2. Usmg computers in both the field and laboratory provides the means to capture directly an data as * is generated, providing immediate feedback and processing, eliminating costly delays. While the current generation of PCs does not provide sufficient secondary storage for archival databases or sufficient processing capabffitfos for large expert systems, advanced function workstations such as *SUNa* and *APOLLOs* provide afl needed resources, and continuing price-performance improvements wffl provide sufficient, low-cost computing resources in the foreseeable future.

3.2. Spreadsheets: Electronic *Form**

Spreadsheets, such as *VJS/CALC* and *Lotus 1-2-3.* provide a powerful non-procedural programming paradigm. The layout of a spreadsheet resembles me paper forms used to capture field and log data, and each of these forms can be recast into a spreadsheet within a few hours.

Using the spreadsheet, the screen becomes an empty form tor the engineer. He may move between fields at win, entering data as it becomes available. To assist the ongvieer, mpui oaxa ?s otspiayeo m a outerent color from the predefined cells which contain labels defining the form. The predefined parts of me form, computational formulae, eta, are protected so they cannot be inadvertently changed

The computational capaWNties of the spreadsheet are used to automatically fill in fields for results, perform units convenpons, etc., eliminating much of the tedious and error prone work. Revisions of results are riandied automatically as data is updated. In addition, extensive checks on data validity are performed as the data is input Once entered on the spreadsheet the data is ~m^{w} the system; it is available for future use and can be made available to others with ease.

A variety of forms of prototype spreadsheets for field and laboratory data acquisition have been developed [Duptencic 84], including soi sample data, water content, density, Atterberg fimits, pocket penetrometar, torvane, sieve anafyso, carbonate content and uncon* fined compressKXi tests. An example of a completed, combined sample data and water content spreadsheet is shown in Figure 4.

Data is acquired from a set of tests performed on soi samples from each boring. The engineer starts with me soi sample data sheet, entermg the sample drittng and soi description information. An entry, such as the depth scale (shown in the left center of Figure 4) is computed automata cafly once the sample depth is input Special *mmcros* are defined so a shigle keystroke wii load any of the other test forms at the bottom of the current sheet and automatically position the input cursor at the first cei to be filled. The engineer may go back to any previous form and change data at wfl. This fiexiWfty permits the engineer to enter data in airy order trie computer does not restrict him to use a fixed input sequence. As data is entered, results, such as the average water content are automatically computed and displayed.

3.3. Databases: The Integration Mechanism

Databases form the basis of the information cornmunication and storage mnpofients of trie workbench. Two types of databases are needed:

- *Archival Databases* provide long term storage of historical project information. In addition to acting as the permanent repository for data from afl protects, historical data is useful in performing reconnaissance and provides me basis for statistical studies of sites and soi parameters [Wood 82].

- *Project Databases* maintain afl information for ongoing site investigations. Once data is obtained or results are computed, they are entered into the project database and are immediately available for use by others. Thus me project database serves as the central integration and information communication mechanism.

Site data is hierarchical in nature. For each site *there* are sets of borings, which in turn are divided *tnto* sets of samples. Associated with each sample are the test results. This hierarchy is depicted in Figure 5. However, data access often crosses hierarchical boundaries (e.g., the query: "What is the average shear strength of ait day samples at depth X for project Y"). Thus the flexibility of data access provided by the *retationdata model* has been selected for data storage [Date 75]. In this form, the basic representation of data is a *relation* which resembles a table, and data access is based on selecting named rows and columns.

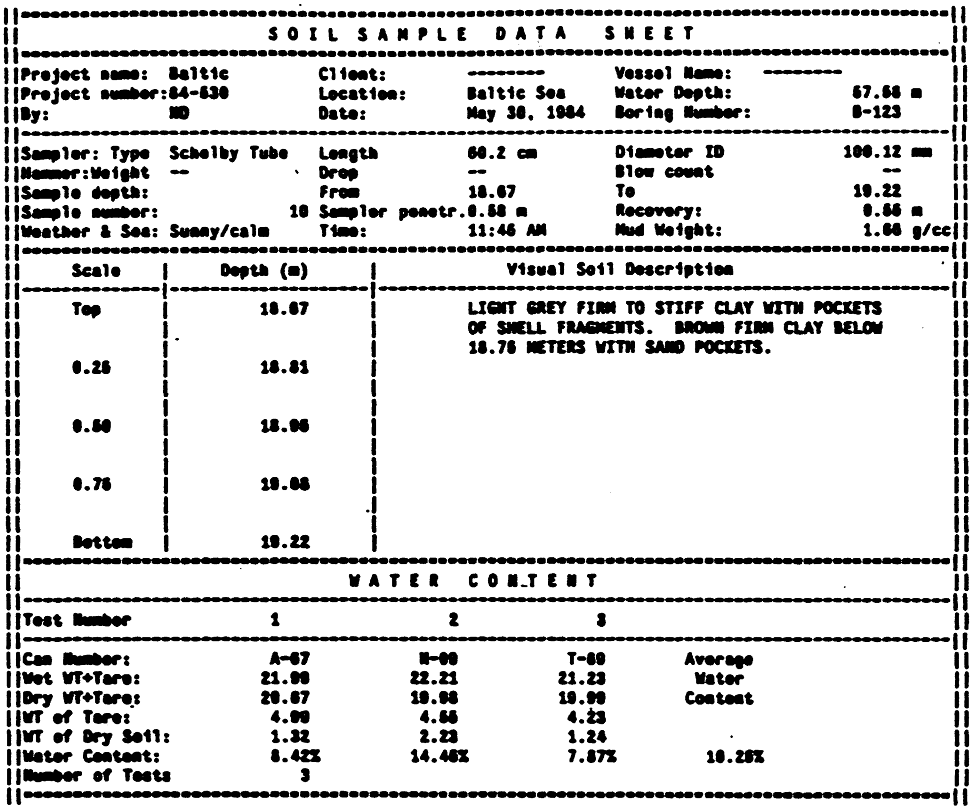
The project database must contain a number of relations to store afl me data from att spreadsheets for the entire project Due to the large quantity of data, only summary information is used for much of the later stages of analysis. An example of a summary data relation is shown in Figure 6. Each *tup** (row) in the relation contains the values of afl test results *(attributes)* for one sample. The first three attributes *{Protect, Boring* and *Sample Number)* form the *key* which identifies a unique row in the table. P?1 is acrffwri by specifying which attributes (columns) are needed for some range of samples (rows). Thus access is independent of actual data organization, but is based on database content As stated above, mis flexibitty of data access provided by the relational model is me basis of its selection for afl database components of me workbench.

3.4. Graphics: Production-Quality Presentation of Results

Afl of the spreadsheets and database quantities can be output to a high quafity printer for inclusion m project reports. Due to the large quantity of data, and the need to make interpretations over the entire site, graphical presentation of summary results is preferred to volumes of tabular output.

The bore tog produced by*6ASP [Caniang 82], shown in Figure 3, is an example of the type of output which can be produced automaticafly. The summary information contained in the relation illustrated in Figure 6 is sufficient to produce such a drawing.

Flewbflity in production of drawings is also needed. The exact set of results to be doplayed, and their organization in the drawing may vary between projects, or different forms may be required for different uses. A drafting system is being used to produce such drawing. The basic bore log output sheet is divided into a header and several vertical data regions. Each data region contains me results of one test arid is defined as a subdrawmg (i.e., depth scale, soil description, water content blow count etc). The drafting system provides the capabilities to piace these subdrawings side-by-side, providing the *engineer* the freedom to readdy form any number of alternative layouts. External data interfaces provide the mechanism to transfer information from the spreadsheets and project database to the drawings. An example of a bore log produced by the drafting system is shown in Figure 7.



```
||========================================================================||
||                     S O I L  S A M P L E  D A T A   S H E E T          ||
||========================================================================||
||Project name:  Baltic          Client:           --------   Vessel Name:  --------   ||
||Project number:84-530          Location:         Baltic Sea Water Depth:        57.58 m  ||
||By:            MD              Date:             May 30, 1984 Boring Number:    B-123    ||
||------------------------------------------------------------------------||
||Sampler: Type  Schelby Tube    Length            60.2 cm    Diameter ID        100.12 mm ||
||Hammer:Weight  --              Drop              --         Blow count            --     ||
||Sample depth:                  From              18.67      To                 19.22     ||
||Sample number:              10 Sampler penetr.0.58 m        Recovery:           0.56 m   ||
||Weather & Sea: Sunny/calm      Time:             11:45 AM   Mud Weight:         1.00 g/cc||
||========================================================================||
||    Scale     |     Depth (m)     |          Visual Soil Description    ||
||--------------|-------------------|-------------------------------------||
||    Top       |       18.67       |    LIGHT GREY FIRM TO STIFF CLAY WITH POCKETS ||
||              |                   |    OF SHELL FRAGMENTS.  BROWN FIRM CLAY BELOW ||
||              |                   |    18.76 METERS WITH SAND POCKETS.            ||
||    0.25      |       18.81       |                                     ||
||              |                   |                                     ||
||    0.50      |       18.96       |                                     ||
||              |                   |                                     ||
||    0.75      |       19.08       |                                     ||
||              |                   |                                     ||
||    Bottom    |       19.22       |                                     ||
||========================================================================||
||                          W A T E R   C O N T E N T                     ||
||------------------------------------------------------------------------||
||Test Number             1             2             3                   ||
||------------------------------------------------------------------------||
||Can Number:           A-07          N-00          T-09      Average     ||
||Wet WT+Tare:          21.99         22.21         21.23     Water       ||
||Dry WT+Tare:          20.87         19.98         19.99     Content     ||
||WT of Tare:            4.99          4.56          4.23                 ||
||WT of Dry Soil:        1.32          2.23          1.24                 ||
||Water Content:         8.42%        14.46%         7.87%      10.25%    ||
||Number of Tests          3                                              ||
||========================================================================||
```

Figure 4: Soil Sample Data and Water Content Spreadsheet

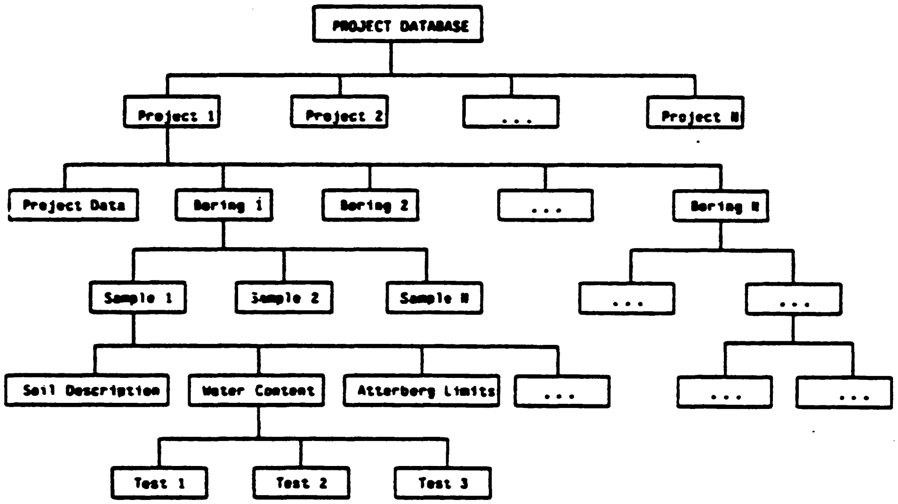
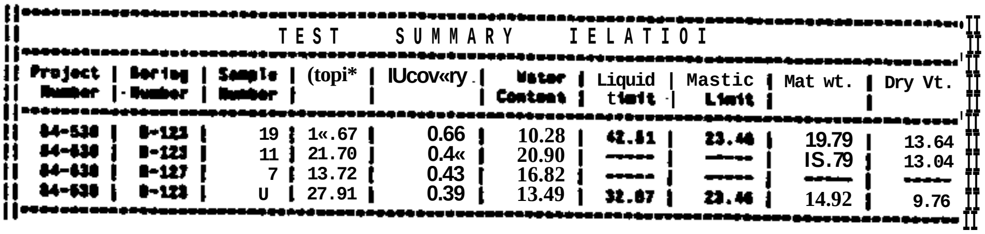


Figure 5: Site Data Hierarchy



TEST SUMMARY IELATIOI									
Project Number	Boring Number	Sample Number	(topi*	IUcov«ry	Water Content	Liquid Limit	Mastic Limit	Mat wt.	Dry Vt.
84-530	B-121	19	1«.67	0.66	10.28	42.51	23.46	19.79	13.64
84-530	B-123	11	21.70	0.4«	20.90	-----	-----	IS.79	13.04
84-530	B-127	7	13.72	0.43	16.82	-----	-----	-----	-----
84-530	B-123	U	27.91	0.39	13.49	32.07	23.46	14.92	9.76

Figured: Test Summary Relation

3.5. PC Workbench: A Prototype Integration

A prototype workbench for data acquisition, maintaining a project database, and drawing bore logs has been developed on a 77 *Professional PC* [Oupiancic 84]. The spreadsheet presented in Figure 4 is one example of those which have been developed using *Lotus 1-2-3.* Data storage is provided by a relational database using *dBASE-III.* Graphics, such as shown in Figure 7, are produced through the *Auto-CAD* drafting system. Components of the prototype workbench have been directly ported to an *IBM PC, and* alternative software components (e^, *Knowiedgeman* for database management) have been investigated. Interfaces between these programs are small, custom written data translators.

The overall organization and dataflow in the workbench are depicted in Figure 8. Data is captured using the spreadsheets and is printed as needed. As data is entered, summary Quantities are automalicaBy com* puted and transferred to a database summary aprsad6haet which resembles the relation shown in Figure 6. All test and summary data is transferred from the spreadsheets to the project database. A translator reformats a subset of the summary data for the drafting system to produce the bore log drawings. Since the file interchange functions of each of the standard software components are not fully compatible (e.g., *Auto-CAD's* exchange file format does not correspond with *dBASE-HI's* exchange file format), complete integration requires the interface/transtatcrs. the overs* system model includes a translator on each data path, however, for some pairs of components **(e.g.,** *Lotus 1-2-3XudBASE-UI)* it may not be required.

4. Knowledge Based Expert Systems: An Emerging Technology for Dealing with the *Art* of the Process

Qeotechnical engineering might be unique with respect to other engineering disciplines in that most of the process is based on ex**perience.** Tasks such as site characterization are often called an *art.* Since the rigorous mathematical procedures usually associated with computer-based problem solving do net exist such tasks have not been successtuny compuienzeo. nowever, me concept or a miowieoge naseo expen system is an emerging technology which permits such heuristic, intelligent, expert problem solving to be performed by a computer.

4.1. Definition of Expert Systems

Artificial Intelligence (A!) is the branch of computer science **which** oeais with the design of computer programs which have the characteristics of an intelligent human being. A program is considered intelligent if it can give correct answers ana can expiaw its reasoning process, A knowledge based expert system is an AI program that performs intelligent tasks cwirentty peHcMir>ed by hi^»y skived people. A number of sucn expen systems nave oeen oeveiopeo in recent years, nctuotng programs which are capable of problem solving at the human expert level of performance in fields such as medicine, science and engineering. An extensive-survey of such programs appears in Nau [Nau 83].

In essence, an expert system is Mist another type of computer program. A conventional (algorithmic) program can be divided into program (code) and data. The programmer completely specifies the problem solving behavior which is embodied in the program by writing a sequence of statements *{rules)* which are executed in the order predefined by the programmer. An explicit, a priori statement of all the rules, in the proper order, for afi cases, is imposstote for any realistic domain. This is especially true of domains such as design, interpretation or understanding which are considered *m-defined or Unstructured [Simon* 81] and where no explicit problem solving process exists. An expert system addresses this problem by-breaking the program part into a set of rules which specify the problem solving process *(knowledge* which is stored in a *knowledge base) ami* a *knowledge processor* (or *inference mechanism)* which manipulates and applies the appropriate rules in the appropriate circumstances. Thus an expert system is free to use knowledge in the most appropriate manner and is not limited by a fixed, predefined problem solving approach. In addition, through the explanation subsystem, the user can ask the expert system *why* and *how* it is solving a problem.

An essential feature of a knowledge based expert system is that it embodies the knowledge of human experts acquired through their experience with particular types of problems or situations. Hence, its problem solving behavior is no better than that of the experts whose knowledge is encoded in the knowledge base. An expert system does not learn and is not innovative.

Expertise is gathered from *domain experts. Knowledge engineers* convert the expertise into the format required by the expert system. Through testing, the system's knowledge is refined and expanded to improve its problem solving behavior.

4.2. Example of Rule-Based Knowledge Applied to Site Characterization

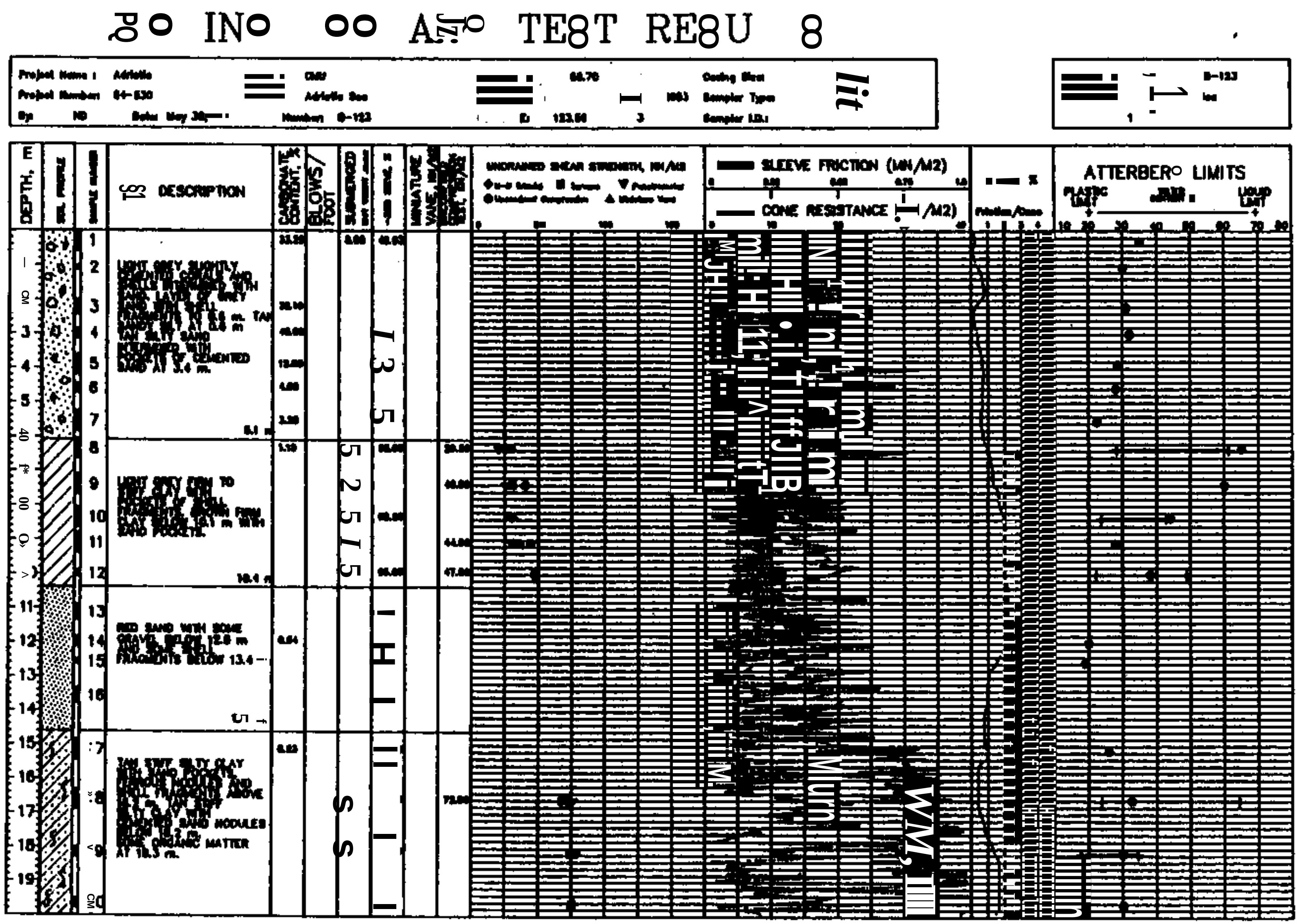
4.2.1. Micro-Level Knowledge

As an example of rule-based knowledge that may be used for the purpose of site characterization, consider the problem of matching the geometric trends of soil layers based on discrete samples from borings.

At a particular depth, 2, day is sampled in Borings *A and* C, and day also is observed near elevation *2* in Boring *B.* One may ask: "Does the day observed in the three borings form a continuous stratum and, if so, how thick is the stratum at various points?"

Alternatively, suppose day is not sampled in Boring *B.* Then one may ask: "Does day exist in Boring 3 *near* elevation *z* and. if so, does the day form a continuous layer among the three borings? (Also, how thick is the day at each sampling point?)"

The answer will, of course, depend greatly on the site geology and on the vertical and horizontal spacing of the sampling points. The degree of proximity in elevation implied by the term *near* also must be defined.



[illegible]e 7: Bore Log Produced by – -CAD

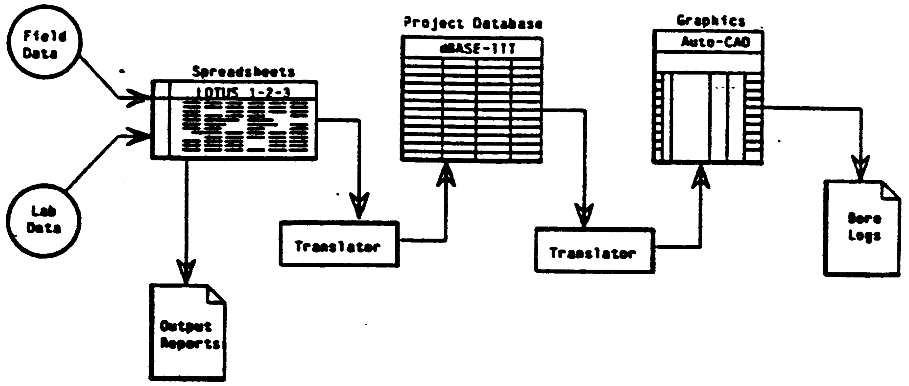


Figure 8: PC-Based Geotechnical Site Characterization Workbench Software Configuration

Suppose, however, that these factors have been accounted for by a human expert in reviewing the data (or alternatively through an additional set of rules in an expert system). He may wish to invoke rules such as the following:

GEOMETRIC TREND RECOGNITION RULE-SET

RULE GTR-01:
```
IF          the same type clay exists near the same depth in three
            adjacent borings
THEN        the soil in each boring belongs to the same deposit
            (certainty 96%)
```

RULE GTR-02:
```
IF          the same soil deposit exists in three adjacent borings
THEN        the deposit forms a continuous layer of varying thickness
            (certainty 86%)
```

RULE GTR-03:
```
IF          the same type clay exists near the same depth in two
            borings
      AND
            the same type clay is missing in an intermediate boring
THEN        the soil type exists in the intermediate boring near the
            elevation in question and has a layer thickness equal to
            the average thickness of the layer in the two borings
            where it appears (certainty 60%)
```

RULE GTR-04:
```
IF          the same type clay exists near the same depth in two
            borings
      AND
            the same type clay is missing from an intermediate boring
      AND
            the same type clay exists in a nearby boring
THEN        the soil type exists in the intermediate boring near the
            elevation in question and has a layer thickness equal to
            the average thickness of the layer in the two borings
            where it appears (certainty 70%)
```

RULE GTR-05:
```
IF          the same type clay exists near the same depth in two
            borings
      AND
            the same type clay is missing in an intermediate boring
THEN        the soil type does not exist in the intermediate boring
            (certainty 40%)
```

RULE GTR-06:
```
IF          the same type clay exists near the same depth in two
            borings
      AND
            the same type clay is missing in an intermediate boring
      AND
            the same type clay exists in a nearby boring
THEN        the soil type does not exist in the intermediate boring
            (certainty 20%)
```

Consider an example instantiation of the above rules: the soil type in question is the clay deposit near elevation *z*; the three adjacent borings are *A*, *B* and *C* (*B* is the intermediate boring); and *D* is the *nearby* boring.

In the example, rules *GTR-03* and *GTR-05* have the same premise but have opposite conclusions. In a similar fashion, rules *GTR-03* and *GTR-04* infer the same result (with different certainties) based on different conditions. Thus, the expert system can deal with conflicting opinions (such as rules *GTR-03* and *GTR-05*) and can represent different ways to reach the same conclusion (such as rules *GTR-03* and *GTR-04*). In a traditional algorithmic program, such cases may not exist, and the program must always yield one unique conclusion.

The example also illustrates how inferences are related and how they combine to produce the complete problem solving process. When the condition of rule *GTR-01* is found to be *true*, the corresponding action is deduced. The condition of rule *GTR-02* is identical to the action of rule *GTR-01*. Thus, the inference from rule *GTR-01* triggers rule *GTR-02*, generating additional facts and triggering other rules (this process is denoted *forward chaining*). Alternatively the system could work backwards (*backward chaining*), proving the outcome of *GTR-02* requires its premise be *true* which requires *GTR-01* (or some other rule which produces this outcome) be evaluated.

In a complete system, numerous additional rules are needed. Such rules infer items such as when three bore holes are adjacent, which is the intermediate boring, which borings are classified as *nearby*, etc. Finally, note that the rules and certainty factors usually will be influenced significantly by the site geology and the disparate classification of contiguous soils. If, for example, the soil were classified as a silty sand (rather than clay) surrounded by clean sand, one's certainty that the two soils are in fact distinct layers might differ from those denoted in the example.

4.2.2. Macro-level Knowledge

Macro-level inferences are used to determine overall trends and characteristics of the entire site. While the micro-level rules given above take site data and make direct inferences, macro-level rules develop hypotheses on site geomorphology, lithology, fault locations, marker beds, etc., that must be verified to classify the site. The following are a few of an expert's rules for determining site geomorphology:

GEOMORPHOLOGY RULE-SET

RULE GM-01:

```
IF         silt layers are scattered through confined areas near the
           same elevation
    AND
           the site has alluvial origins
THEN       there is an indication of point bar deposits
    AND POSE HYPOTHESIS
           there are isolated organic oxbow deposits near the
           elevation
    AND POSE HYPOTHESIS
           there is possible terrace veneer stratification of other
           similar point bar deposits along the migration path of
           the river
```

RULE GM-02:

```
IF         soft organic layers are found near the same elevation in
           some isolated borings in a confined area
    AND
           deposits are along the path of migration of the river
THEN       there is an indication of some old oxbow lakes
```

RULE GM-03:

```
IF         soft organic layers are found near the same elevation in
           some isolated borings in a confined area
THEN       then the channel once cut through the area and it was
           refilled with organics
```

RULE GM-04:

```
IF         there is an indication of channel cutting
THEN POSE HYPOTHESIS
           there are traces of the channel in point bar sands and
           organics
```

4.3. Site Characterization Expert System Prototype

An expert system prototype for geotechnical site characterization, based on a blackboard model framework, has been designed [Norkin 84]. The expert system is designed to aid an engineer in inferring the subsurface stratigraphy from available bore log data, field and laboratory test data (blow counts, water content, etc.) and overall site characteristics. Due to time limitations, an engineer can explore only a small number of potential inferences. The expert system aids in developing alternatives and provides the engineer with the opportunity to pursue more alternatives.

The rule sets illustrated in Section 4.2 are examples of types of knowledge required in the expert system. Each set forms the basis of a *knowledge module* (essentially, the knowledge base of a mini expert system) which provides the expertise for one problem solving task. Cooperation of several types of problem solving, such as determining morphology, determining lithology, geometric trend recognition, matching soil descriptions, determining proximity, etc., is required to complete the characterization and infer the subsurface stratigraphy. The blackboard model framework is designed to support such cooperating expert problem solvers [Erman 80], and is a natural selection as the basis for a site characterization expert system.

A blackboard model expert system consists of a set of knowledge modules, each of which performs a particular problem solving task. All the cooperating problem solvers which comprise the expert system communicate through a global data structure, denoted the *blackboard*, which contains the descriptions of the site characterization hypotheses under consideration and the inferred model of the site. The inference mechanism of the expert system controls the selection and execution of the knowledge modules which perform the various problem solving tasks. The site characterization prototype system is design to simultaneously operate at two levels of problem solving:

- At the *strategic* level the overall process of characterizing the site is performed. The strategic problem solvers pose hypotheses on the overall site stratigraphy, i.e., faults are present, marker beds are present, depositional patterns result from oxbow lakes, etc., and several different alternatives are pursued in parallel. Lower level *tactical* problem solvers are used to carry out the selected characterization strategy. Strategic processors also monitor the progress of the problem solving process and redirect the system to focus its attention on those alternatives and hypotheses which are most promising.

- At the *tactical* level a set of problem solvers attempt to prove hypotheses and fill in the details of the characterization (i.e., find a marker bed, match two samples, etc.). Tactical processors perform tasks for, and under the direction of, the strategic level processors. Again, many tasks are processed in parallel.

The results of the characterization are then presented to the engineer through a set of two- and three-dimensional subsurface diagrams.

A more detailed description of the site characterization expert system prototype is beyond the scope of this discussion and is premature due to the current state of the research.

5. Discussion

The evolution of computer technologies has resulted in the tools and capabilities to extend computer applications into more engineering domains. The work described above is an example of how advanced technologies can aid the engineer in the geotechnical site characterization process.

The workbench concept described above has evolved over the last three years. *GASP* [Canilang 82] was the first attempt at building such a system. Based on a mainframe computing environment, it provided bulk data input and a file mechanism for project data storage, and produced, either on a graphics terminal or by plotter, bore logs and site maps. It required approximately one man-year of development.

The PC-based prototype discussed in Section 3 provides improved capabilities and additional features. Data input is interactive, and the data processing sequence is selected by the user. The spreadsheet program can be used to produce final reports. The database management system provides capabilities to query and search the database, an improvement over to the data file storage and transfer mechanisms used in *GASP*. The drafting system provides the capability to produce a variety of alternative layouts of the bore logs. Development required approximately three man-months, with initial spreadsheets and graphics developed in only a few days. In addition, since it is based on off-the-shelf technologies, it can be transferred immediately to practice.

An uncompleted aspect of *GASP* was the production of two- and three-dimensional subsurface diagrams. The difficulty is not in the drafting, but in inferring the subsurface stratigraphy from the bore log data. The expert system work discussed in Section 4.3 provides the mechanism to incorporate such processing in the workbench. It is anticipated that the next version of the workbench will incorporate such processing. In addition, more powerful micro-processors (32 bit, virtual address space machines) with capabilities to display multiple windows (e.g., simultaneous display of multiple two- and three-dimensional subsurface diagrams along with display of hypotheses and expert system problem solving status) and run multiple processes (i.e., concurrent execution of spreadsheet, database management, graphics and expert system software) of will be used.

The workbench software can be used in a manner similar to manual processing; data is entered interactively and hardcopy results are produced immediately. Alternatively, complete interactive use is possible. All forms and drawings are created and manipulated on the screen, and hardcopy is produced only for final reports. It is anticipated that future work will be directed towards a system which provides a tighter integration of components of the four components described above, yielding a workbench which provides an electronic office and laboratory environment for the geotechnical engineer. Once in-place, it is anticipated the workbench and its component technologies can be used to improve the overall process of geotechnical site characterization.

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