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# Soil and Site Improvement Guide: an Educational Tool for Engineered Ground Modification*

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*The proper selection and evaluation of a soil improvement technique for use at a particular site is neither a simple nor a single-outcome proposition. Local conditions and specificity as well as expertise and judgement, are integral parts in the decision-making process. In an applied engineering educational setting, this process lends itself for treatment using a computer-based design and evaluation approach, relying on a comprehensive database of ground modification techniques and an associated decision-aid tool. This paper describes such an approach, which was developed based on the pertinent codes of practice in the field and expert information and guidelines obtained from various sources. The result is a design and teaching tool which guides the user through the decision-making process, while allowing him/her the opportunity to learn, modify and customize. The proposed guide was specifically developed and implemented by students and faculty in the context of a specialized geotechnical engineering soil improvement course at the American University of Beirut.*

## INTRODUCTION

IN THE AGE of faster and easier to use computing facilities, computer-aided learning (CAL) is gaining acceptance and finding greater avenues for application. CAL is attractive to both partners in the learning process, namely the student and the teacher. The increased flexibility and the possibility to combine various information media (text, images, and sound) in great volumes of well-organized and archived data, make CAL a powerful tool, adopted by an increasing number of educational institutions. However, this move towards CAL is slower in most Engineering disciplines, where students use computers to solve problems but rarely use them to learn. In this paper we present work which culminated in the development of a software, which is both a teaching/learning tool, and at the same time a design and problem solving aid. It allows students to acquire knowledge about soil improvement and ground modification in engineering practice, while providing the user with a tool, which aids in solving soil improvement problems.

As a starting point, the program enables the user to establish, given a set of objective criteria (bearing capacity and settlement limits set by the user), whether a particular site requires improvement. It then provides the user with an interactive, flexible and easily modified database of available soil improvement techniques, along with an evaluation of their relative suitability, given the particular conditions at hand. Some of the other interesting advantages of the package presented herein are its ease of upgrade and customization.

## OBJECTIVES AND SCOPE

The main objective of the work described in this paper was to develop and test a Soil Improvement CAL and design tool. Such a tool would enhance the quality of the teaching and learning process as it relates to Soil Improvement and would be applicable in principle, to similar problems in other Engineering disciplines. The end product is a software, which can be used for learning about the various ground modification techniques, their advantages and limitations, their applicability under certain conditions, and the costs associated. The package also provides a platform, which could be used reliably for the selection and design of an appropriate ground improvement technique for any given specific project or site.

The scope of the work included the creation of a comprehensive database, which contains the majority of ground improvement techniques available on the market. The database is processed using a relational scheme allowing for the elimination of various techniques as more and more information about site specifics and project requirements is given by the user. This would lead effectively to the most appropriate technique(s) for the particular soil and site conditions at hand.

The software starts by providing the user with a quick test to determine whether the soil at the site being considered requires improvement, given

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performance criteria set by the user. The program then analyzes the site information provided and identifies the 'weak layers' of interest within the existing subsurface profile. The user can then browse through all the available improvement methods, or filter some of them out, based on suitability criteria (incorporated within the software, and which are accessible and could be modified by the user) and site-specific information.

As new methods and ground modification techniques emerge, and as the user develops more expertise and familiarity with the various methodologies, the software can be easily updated to include new methods and new criteria and/or modify the existing ones, as is discussed below.

*System requirements*

The *Soil and Site Improvement Guide* will run on any PC running Windows 98. The package will require about 13MB of hard-disk space (with its current database). The minimum requirements to run Windows 98 [1]: 486DX, 66 MHz, processor, 16 MB of RAM, about 300 MB Hard Disk, VGA, CD-ROM or DVD-ROM drive, Microsoft Mouse or compatible pointing device.

## GROUND MODIFICATION

Where difficult foundation conditions are anticipated or encountered in a given project, possible alternative solutions are [2, 3]:

1. Relocate the project if possible, in order to avoid the troublesome zones.
2. Design the planned structure to adapt to the anticipated conditions, and select an appropriate foundation scheme.
3. Remove and replace unsuitable soils.
4. Attempt to modify and improve the existing ground.

The work presented in this paper deals with the last option. In situ treatment of soils or ground modification refers to a wide array of approaches and techniques aimed at improving the performance of the soil, saving construction time and costs, and/or reducing known risks. Ground modification applications include [4]:

- groundwater control;
- excavation support;
- foundation rehabilitation;
- site improvement including settlement mitigation and strengthening of marginal soils;
- pollution control.

*Ground modification methods*

Ground modification methods include adhesion/cementation, densification, reinforcement, and physicochemical alteration, among others. In what follows a brief description of some of the techniques is presented [5, 6, 7].

Densification methods:

- dynamic deep compaction
- surcharging
- vibrocompaction
- vibroreplacement
- compaction grouting
- Accelerated consolidation /wick drains.

Adhesion methods:

- cement grouting
- chemical grouting
- slurry grouting
- freezing.

Reinforcement methods:

- minipiles
- soil nailing
- soil and rock anchors.

Physicochemical methods:

- electro-osmosis
- lime treatment
- soil mixing
- vitrification.

*Ground modification design steps*

The design of a site improvement scheme for any particular situation involves a number of steps including [2]:

- establishing the existing site conditions;
- defining the project objectives and scope of improvement works if needed;
- selecting a suitable approach and methodology that fits current conditions and site specifities and meets the objectives set at the least possible cost.

The tool presented in this paper is concerned with the last two steps.

## INTERFACE DESCRIPTION

The *Soil and Site Improvement Guide* software presents the user with three modules or interfaces. For convenience, they are referred to as the *Wizard*, the *Viewer*, and the *Modifier*:

- The *Wizard* is a module that will present the user with an evaluation as to whether or not the site under consideration requires improvement. The user is asked a series of questions, and prompted to enter site-specific test results (e.g. standard penetration tests, SPT). The *Wizard* then determines if the soil needs improvement.
- The *Viewer* is a module that is automatically launched after the *Wizard*. However, it can be easily accessed at any other point. The *Viewer* enables the user to view the different ground modification methods and filter them based on different criteria.

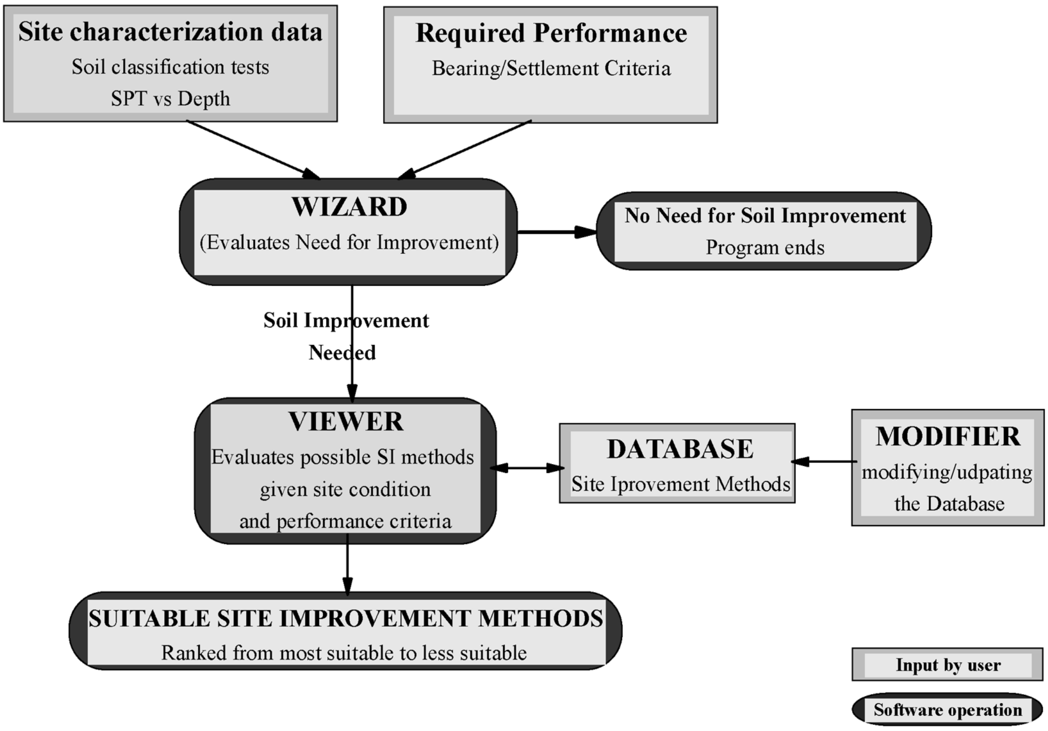


Fig. 1. Flow chart of the software framework.

- The *Modifier* is in effect two modules: A *Customizer*, which enables the user to modify and customize the filtering criteria, and a *Database Modifier*, which allows for the updating of the database.

The various modules and the conceptual framework of the *Soil and Site Improvement Guide* are presented in a flowchart format in Fig. 1.

*The Wizard*

The Wizard (Fig. 2) prompts the user for input regarding minimum loading requirements and maximum tolerable settlement. In addition, in situ test results from the site as is, are required. Typical SPT results below the proposed foundation level are input at various intervals. The program will then calculate the allowable bearing capacity of the soil, based on shear strength and settlement considerations and will point out the weak layers that may need improvement.

*The Viewer*

The viewer (Fig. 3) consists of two windows. The first one can be divided into three parts:

- *Drop-Boxes* for the selection of Soil Type, Improvement type, and Depth of Improvement required. The choice available for these elements, at this stage, can be either a specific type and depth, or just 'Any'. If a specific type is selected, the list of improvement methods, shown in the window to the right, will be modified (Fig. 4). All improvement methods applicable for the type selected will be displayed. Whereas only three criteria are included at this point, the user can include more of them with the *Modifier* up to a maximum of nine *Drop-Boxes*. Each *Drop-Box* can have a maximum of ten choices.
- Ranges. The user can be prompted to enter criteria in the form of numerical ranges as shown in Figs 3 and 4 in reference to the range of soil particle sizes. Ground modification techniques not suitable for these ranges will automatically be filtered out of the list. Other criteria involving ranges of values (e.g. cost/$m^3$ of soil treated, etc.) maybe added using the *Modifier*, up to a maximum of nine *Range* fields.
- List of improvement methods. The third section of the window consists of a listing of ground modification techniques. The list is automatically updated whenever a choice is changed in any *Drop-Box* or *Range*. Highlighting any of the methods in this list by double-clicking with the mouse (or clicking on the View button) will prompt a second window to open.

The second window (Fig. 5) shows a description of the highlighted method and an illustration. The user is then able to acquaint him/herself with the technique, read about its advantages, disadvantages, and other appropriate information. He/she can then save the description for future reference, print it, go to the next or the previous method on the list, or simply go back to the list of topics. It is important to note here, that whereas the Guide filters the improvement techniques based on the criteria and requirements specified by the user, the user can freely move within the database at any

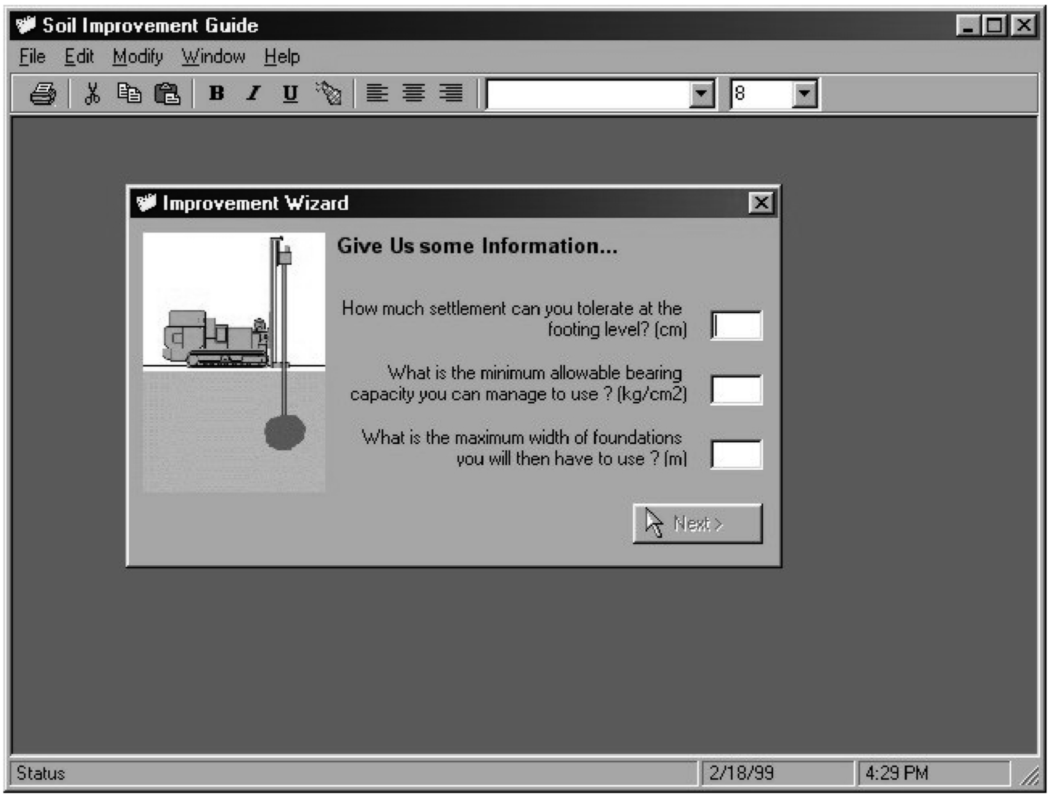


Fig. 2. The first information screen of the wizard.

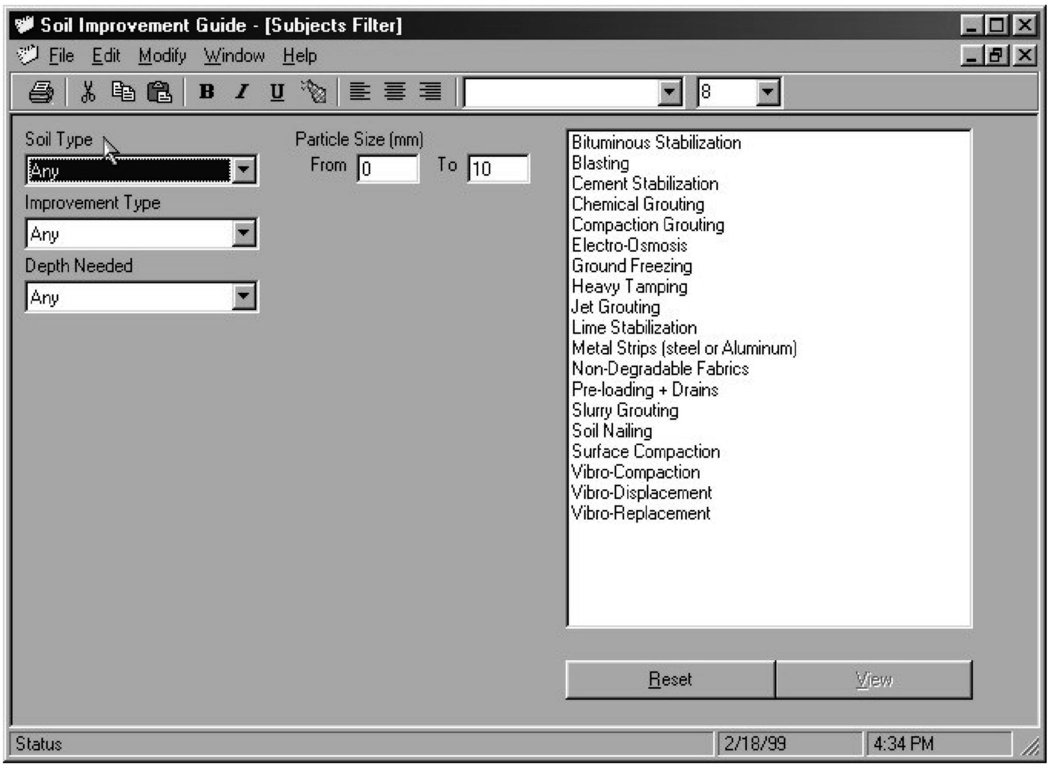


Fig. 3. The filtering screen of the viewer.

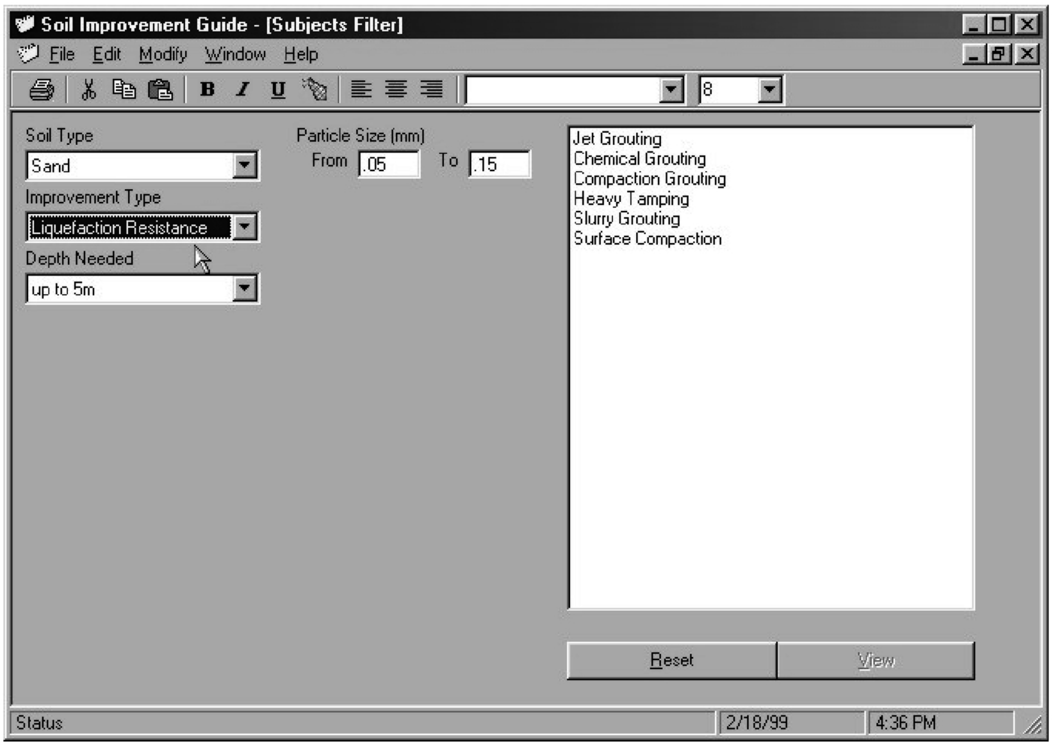


Fig. 4. Based on the selected criteria, methods were filtered out.

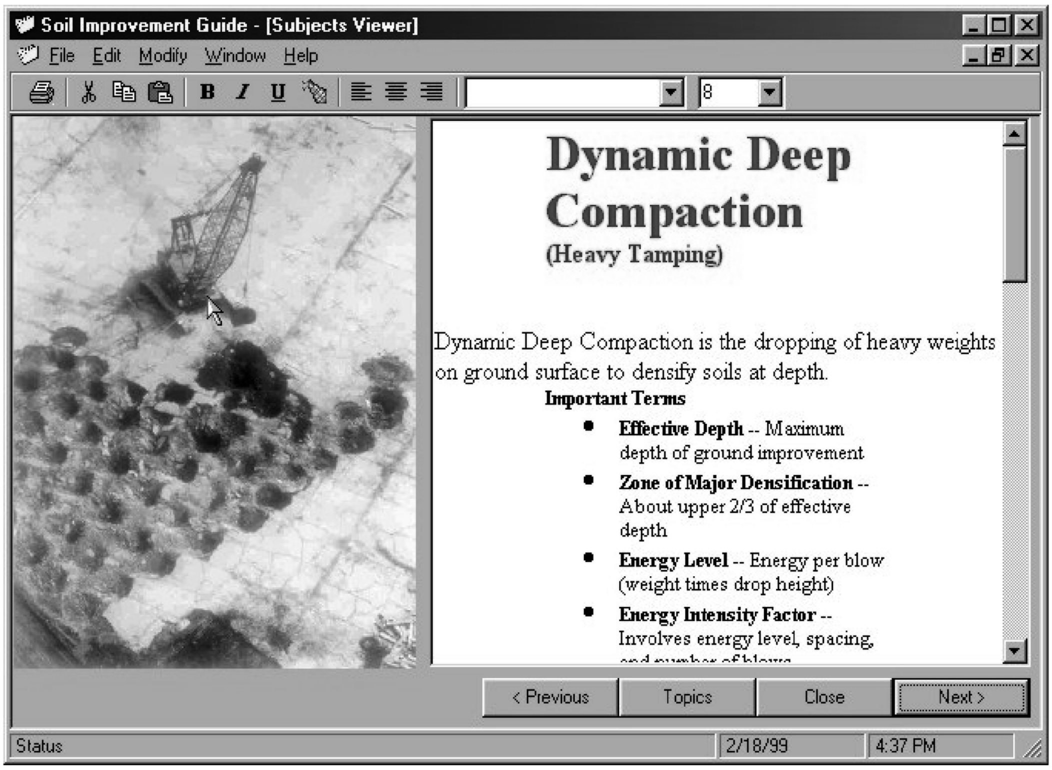


Fig. 5. Viewing the methods descriptions.

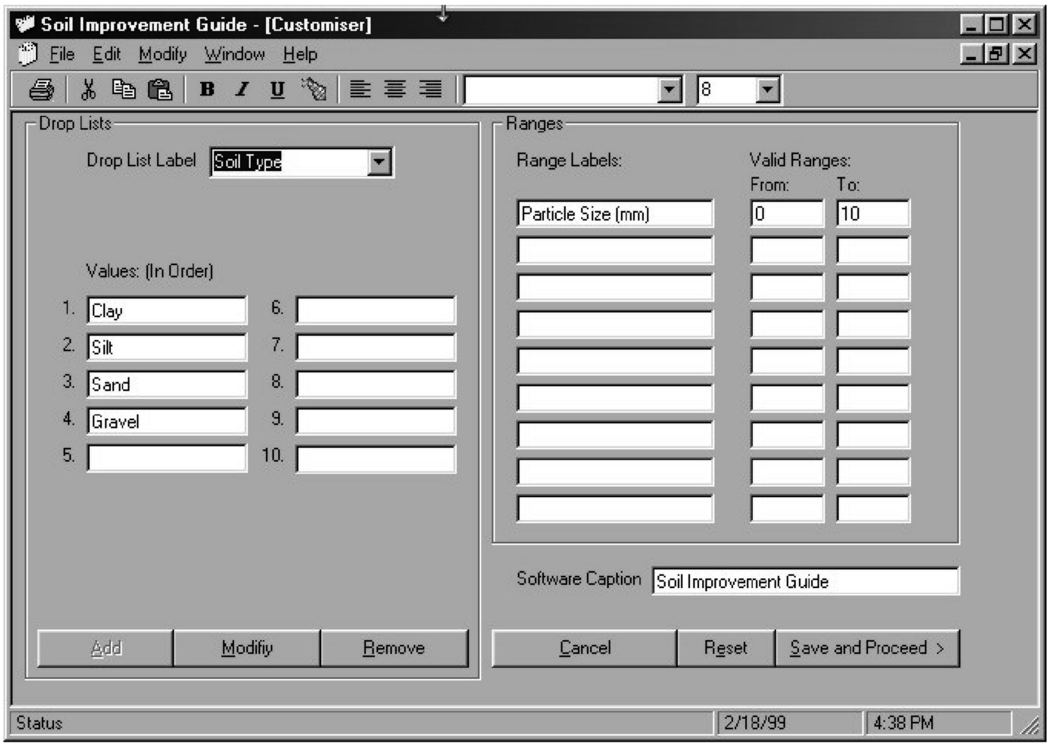


Fig. 6. The customizer.

time to get more information about any of the techniques available. The process is driven in large part by the needs and interests of the student.

*The Modifier*

The *Modifier* itself contains two separate modules:

- The *Customizer* module, in which the user can add or modify *Drop-Boxes* and *Ranges*.
- The *Database Modifier* where the user can modify the ground improvement methods and/or add new ones.

*The Customizer*

The *Customizer*, shown in Fig. 6, enables the user to add choices to an existing *Drop-Box* in the *Viewer* module or to add a new Box. Adding choices is very easy: the user just has to enter a caption for a choice after the last entered choice (in Box 5 of Fig. 6 for example). He/she will then have to press on the modify button.

Adding a *Drop-Box* is similar, clicking on the 'drop-list label' box and entering a new name, then adding choices and pressing 'Add' will do the job (ref. Fig. 6)

Using the same simple concepts, the user can also add or modify *Ranges* and even change the software captions.

*The database modifier*

The database modifier enables the user to add, modify or delete ground improvement methods and all their related data (Fig. 7).

The user can choose an existing name to edit or type in a new name to create. He/she has the possibility to specify a picture name and use the full-featured text editor to enter a description for the method. The user must also enter suitability coefficients for each of the choices. If, for example, slurry grouting was originally designed for use with sand, then the suitability value assigned for sand for this method will be 100. Since it is not applicable for silts, then the value assigned should be 0. These values are used to filter methods out in the *Viewer*. A value of zero will remove the method from the list of improvement methods in the *Viewer*, if that particular choice is made in the *Drop Box*. A value of 100 will put it at the top of the list, a value of 20, for example, will place it towards the end.

## SOFTWARE DEVELOPMENT AND IMPLEMENTATION

The program was developed using Microsoft Visual Basic© 6.0, which facilitates the development of Windows-based packages. Visual Basic© was adopted for its ease of use, particularly when working with databases.

The programming effort consisted of eight parts:

- Designing the interface.
- Writing a function/algorithm to calculate if improvement is needed and to point out the weak layers.
- Designing the layout of the database tables.

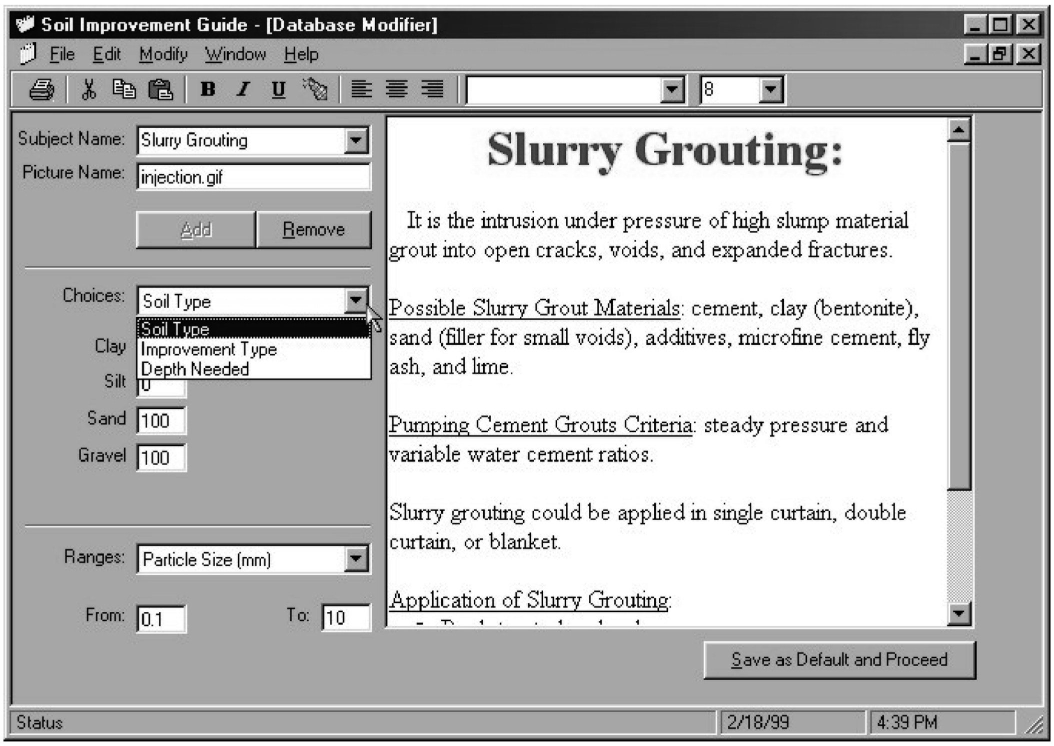


Fig. 7. The Database Modifier.

- Writing filtering functions to filter and sort the ground improvement methods in the list.
- Writing code to modify the database.
- Writing miscellaneous code.
- Writing all the checks needed on the input of the users.
- Refining the interface and adding or modifying code as necessary.

In the following sections some of the more interesting programming elements and stages are discussed in detail.

*Finding if improvement is needed*

The approach used to evaluate the allowable bearing stress on a given sandy soil based on settlement considerations is based on the work by Meyerhof (1965) as modified and presented by Bowles and Das [8. 9].:

$$q_{net(all)}(kN/m^2) = 19.16NF_d\left(\frac{S}{25.4}\right)$$

for $B \leq 1.22$m, and

$$q_{net(all)} = 11.98NF_d\left(\frac{S}{25.4}\right)\left(\frac{3.28B+1}{3.28B}\right)^2$$

for $B > 1.22$ m
where: $F_d = 1 + 0.33(D_f/B) \leq 1.33$
$S$ = tolerable settlement in mm
$B$ = width of footing
$D_f$ = embeddement depth

The determination of the need for ground improvement is then made based on the tolerable settlement as specified by the user, and the actual net pressure as applied by the proposed foundation system for the envisaged structure. Effectively, this is a simple and rough test for the need for ground modification, other criteria may be applied and included in the Guide, at a later stage.

*Designing the database*

The database was designed using Microsoft Access©. All the data related to the software is stored on one Access file. The data was placed in three separate tables. The first table only contains few entries: The software name and other internal data. The second table contains information relating to the *Drop-Boxes*, the *Ranges*, and their respective choices and values. Note that the limits placed on the number of drop-boxes and ranges are purely due to the limited display space on the screen: in a $640 \times 480$ display we can only fit nine Boxes with 10 choices in each. The third table contains the ground improvement methods and all their related data: Pictures names, the suitability coefficients, descriptions (stored in rich text format) and the names assigned to the methods.

When the program starts, it will access the database and show the appropriate drop-boxes and ranges, it will also load the names of the methods and their suitability coefficients into memory and display them.

*Filtering and sorting*

Whenever the user selects a specific criterion from any *Drop-Box*, all the suitability coefficients for each of the selected criteria from each *Drop-Box* are multiplied by each other, and sorted in

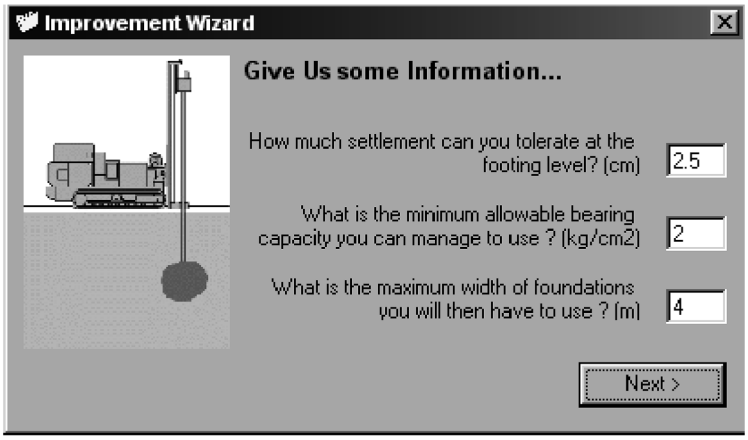


Fig. 8a. Wizard questions.

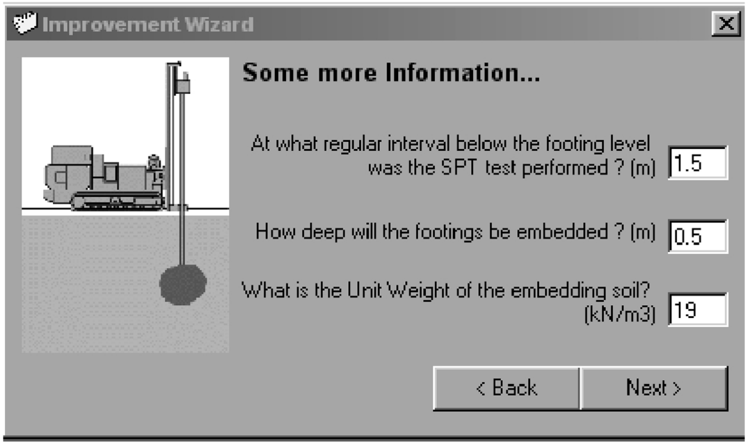


Fig. 8b. Wizard additional questions.

descending order, all zero values are eliminated, and the remaining methods are displayed, as sorted, in the list. The top of the list will therefore consist of the most suitable methods while the bottom, of the least suitable.

*Modifying the database*

Modifying the database is done using Visual Basic©'s Data Access Objects. In order to avoid database corruption or loss due in case of power failure or computer crash or lock-up, a new database file is created every time the *Modifier* module is launched. The existing data is imported from the original database file. The modifications are made on the new file, which is then backed up at the end of the operation. Finally the old data file is backed-up and the new modified file renamed, effectively replacing the original file. Note also, that a third copy is installed which includes all the default data, so that the user can always restore the database as it is provided in the start-up *Soil Improvement Guide*.

## ILLUSTRATED EXAMPLE

In order to highlight some of the features of the proposed Guide and to clarify issues relevant to implementation a simple example is included herein. The case is that of a proposed construction on a loose sand deposit. The envisaged structure will load the soil through a basic foundation system consisting of isolated footings. The maximum design column load is approximately 3000 kN. The design criteria require that the limit on total settlement for any footing is 2.5 cms. Standard penetration tests were conducted on site at depth intervals of 1.5 m.

When the *Soil Improvement Guide* is launched, the *Wizard* asks a set of questions presented, along with the answers given in this example, in Figs 8a and 8b. The field test results are then entered as seen in Fig. 8c. After the completion of this step the software then moves automatically through the *Wizard* module and establishes whether the site conditions as described necessitate improvement given the performance criterion set (a maximum settlement of 2.5 cms, in this case). The result of this analysis is presented by the *Wizard* in Fig. 8d. Note that the specific layers which require improvement are identified, along with a minimum improvement level, expressed as a target Standard Penetration Number.

The Guide then triggers the next module, the Viewer, which queries the existing database of

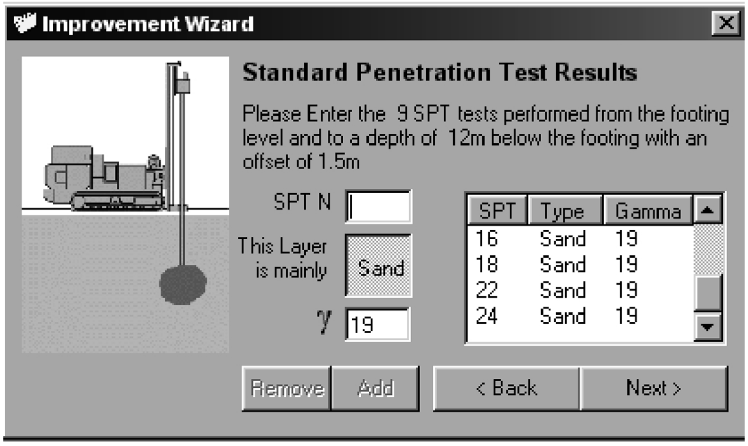


Fig. 8c. Field test results (input by user).

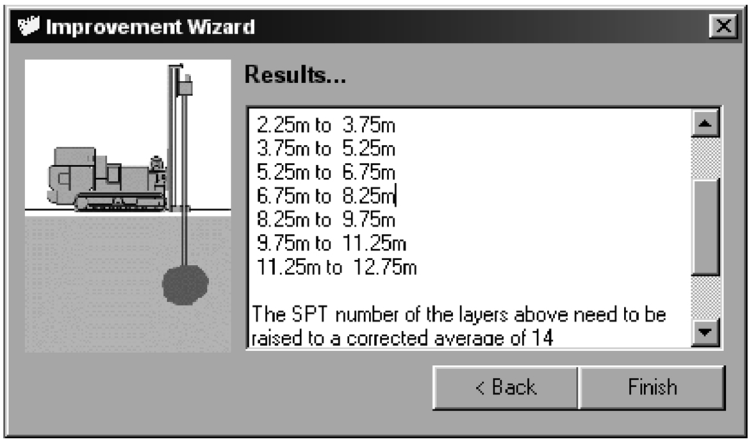


Fig. 8d. Wizard results. The layers listed need improvement.

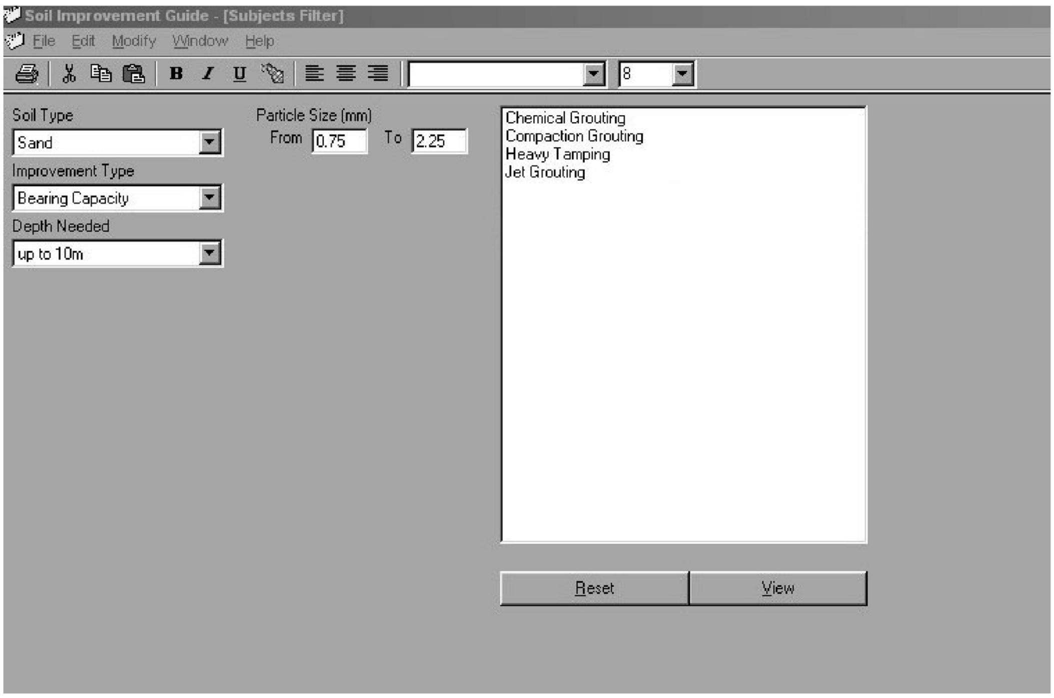


Fig. 8e. Methods of treatment as suggested by the *Soil Improvement Guide*.

various site improvements methods and techniques, based on the site-specific data and the level of improvement required (ref. to Fig. 1). The *Viewer* then presents the user with a list of suitable methods, which would achieve the required goal and are suitable given the site specifics, as shown in Fig. 8e. The user can then, by simply highlighting any of the methods presented, move to learn more about the technique itself and associated advantages and disadvantages, and links to sites on the World Wide Web that may contain specific information, contractors, and some case studies. The user may repeat this process for all the listed methodologies. In the end, any decision the user makes is a better-guided and more informed decision.

## CONCLUSIONS

The *Soil and Site Improvement Guide* presented in this paper has proven to be a valuable teaching and learning tool, based on the feedback from faculty and students who have used it. Despite the limited scope of the testing and use of the software to date, the fact remains that similar approaches based on CAL can, and should be used as a part of the teaching and learning process in Engineering. The alternative methods of providing the information that is made available in the guide, are at best tedious and dry. The guide makes the information accessible, given that it is presented in the form of a menu-driven design tool. The student can readily compare and contrast different alternative solutions and ground modification techniques in a simple and interactive environment. Further, the experience of involving the students themselves in the development of the guide was a very rewarding and inspiring exercise for all concerned. The guide and the associated database and suitability criteria can be modified, customized and updated. It can be envisaged that the students who end up working in the area of site improvement and ground modification may rely on this tool and shape it to suite their experience, the markets they work in, and the level of expertise and judgement acquired. Future improvements will include the addition of typical case studies for each of the techniques. Finally, it is important to note that the package developed can easily be modified to address similar decision making exercises in the Engineering field by building the necessary database, criteria and associated suitability and desirability coefficients.

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