Int. J. Appl. Engng Ed. Vol. 7, No. 4, pp. 307–315, 1991
Printed in Great Britain.
0742–0269/91 $3.00+0.00

GEOCAD: An Educational Tool for Flexible Pavement Design and Maintenance*

H. DIAB
H. TABBARA
F. MOUKALLED
I. KAYSI
Faculty of Engineering and Architecture, American University of Beirut, 850 Third Avenue, 18th Floor, New York, NY 10022, U.S.A.
L. RAAD
Civil Engineering Department, University of Alaska, Alaska 99775, U.S.A.

Computer aided design (CAD) packages are gaining in importance nowadays due to the powerful computational and graphical capabilities existing in today's computers. This paper describes GEOCAD (GEOtechnical Computer Aided Design), a software package for use as an edutional tool consisting of two functions. The first function of the package is to model and store any geological, geotechnical, or climatic information relating to a specific map. A dynamic database for map storage uses the linked tree representation in order to access the information at a high speed. As such, information can be updated and added dynamically to provide a user-interactive environment. The second function of the package is to aid in flexible pavement design [1–3], performance analysis, and maintenance, while making use of the information stored in the database. The package guides the student in learning the basics of pavement theory through the steps involved in using the AASHTO method for designing flexible highway pavements. Moreover, various significant studies concerning the performance of the designed flexible pavement can be undertaken and graphically presented by the package [4]. For example, the package can analyze and graphically present a plot of the serviceability of any designed flexible pavement over time given various levels of axle-load applications. Finally, the package helps the student evaluate the cost and performance impacts of any number of pavement maintenance strategies.

INTRODUCTION

COMPUTER based models simplify data representation and storage and enable easy manipulation of this data. Once real data is stored, one can manipulate the model and produce results that will be useful in dealing with the real world. An important feature of an educational package in civil engineering is its ability to store different pieces of data available for a given map or region. As such, various applications can refer to the data for study, analysis, and design. This paper presents one such application in the field of flexible pavement design [1].

Valuable enhancements to the educational package presented in this paper includes the dynamic data structure which stores all the required parameters and variables, and the availability of a graphics utility which promotes a user-friendly environment and provides an efficient utility for the analysis of the results.

Flexible pavement parameters, climatic and load-application conditions are entered by the student to simulate a specific design condition. The package suggests possible layer thicknesses for the designed flexible pavement [1, 2, 3]. The *performance analysis* option allows the user to analyse various performance graphs in order to aid in the decision making of the design. Finally, the *maintenance* option provides the user with the ability to evaluate several flexible pavement maintenance strategies which are graphically plotted to show the expected serviceability of the flexible pavement. The use of graphics in this package makes it easier for the student to analyze the results which in turn enhances the learning process [4].

GEOCAD will run on any IBM PC XT/AT or compatible which includes at least 640 Kbytes of main memory and is equipped with an Enhanced Graphics Adaptor (EGA) card and a colour EGA monitor. For applications that involve a large amount of data representing attributes of a high-resolution geo-map area, the data may be stored on a hard disk—instead of a floppy disk—for improving speed of access of information.

1.1 *Objectives*

GEOCAD provides the civil engineering student with a user-friendly environment for the

* Paper accepted June 1, 1991.

design, analysis, and maintenance of flexible pavements. The menu-driven structure of the program together with its *HELP* utility, the graphics facility for the representation of the designed pavement, and the dynamic plotting of the results makes it a powerful CAD tool for the design of flexible pavements. The performance graphs used in analyzing the performance of the designed flexible pavement are based on the AASHTO model [2]. The maintenance part of the package provides the student with different strategies that can be undertaken in order to evaluate the designed flexible pavement for its serviceability and cost effectiveness [5–8]. The package also provides the student with a powerful database that can be used to design and evaluate a specific pavement scheme in different locations on a map where different geotechnical information is stored in auxiliary memory such as a floppy or a hard disk.

1.2 *Basics of flexible pavement design*

GEOCAD, described in this paper, utilizes the AASHTO method [2] as the basis for designing flexible highway pavements. The kernel of the package involves simulating an equation that relates traffic loading conditions, soil support value, terminal serviceability level, as well as the regional factor and obtaining the design structural number. The structural number, *SN*, is an index number which is subsequently converted to thicknesses of the various pavement layers through the use of suitable layer coefficients related to the type of material being used in each layer of the pavement structure. Clearly, many combinations of layer thicknesses and material types may satisfy the design value of *SN*. However, each layer has also to be checked to ensure that an adequate thickness of proper material is provided as cover. As such, it is essential to present the basic inputs, parameters, and steps involved in this design method [1–3].

(a) *Serviceability*. Serviceability is defined as the ability of the pavement to serve the traffic for which it was defined. It is measured on a scale of 0 to 5 with 5 being a *perfect* pavement. The terminal serviceability index P_t is a major input to the AASHTO design method and represents the lowest serviceability level that will be tolerated at the end of the traffic analysis period at which time resurfacing or even reconstruction of the pavement will be necessary.

(b) *Load conditions*. The factor W_{t18} is a proxy for loading conditions prevailing for the pavement to be designed and represents the total number of equivalent 18-kip single-axle load applications during the traffic analysis period.

(c) *Regional factor R*. This factor reflects the difference in climatic environments existing in different locations and is measured on a scale ranging from 0 to 5.

(d) *Soil support*. The subgrade soil support value *S* is established through correlations with standard soil tests such as the CBR or triaxial strength tests [1]. *S* values are measured on an arbitrary scale ranging between 1 and 10.

(e) *Layer coefficients*. The layer coefficients (a_1, a_2, and a_3 for the surface, base, and subbase respectively) express the relative ability of a material to function as a structural component of the pavement. Relations have been developed between layer coefficients and standard strength parameters for surface courses, granular or asphalt-treated or cement-treated bases, and for subbase courses. Typical values of layer coefficients range between 0 and 0.6 for the different layers.

2. SOFTWARE DEVELOPMENT AND IMPLEMENTATION OF GEOCAD

The package was written in Turbo Pascal version 5.0 [9] which includes a powerful debugger and facilitates enhanced graphics options vital for the design of GEOCAD. The software can be divided into three major modules. The first module consists of procedures for handling menus, popup menus, data entry windows, and user *HELP* windows. This module is general in nature and could be used with other packages because of its procedural structure. This module is available to readers upon request from the principal author. The module is relatively easy to build and it is implemented by using the heap area of the Personal Computer (PC) to save general purpose, dialogue or data entry windows [9]. Each window is specified by its diagonal corners' coordinates. Displaying a window requires saving information related to the area on the screen directly under it in the heap memory area of the Disk Operating System (DOS). On the other hand, removing a window involves popping it from the heap. In this way, multiple windows could be displayed simultaneously without affecting each other or destroying displayable data in each overlapped window. The number of popup windows that may be implemented is limited by the maximum allowable memory heap space which is 640 Kbytes. Examples of data entry windows in GEOCAD are shown in Fig. 4 and 7(a), and that of popup menus in Fig. 1.

The second module consists of procedures for handling and manipulating geotechnical data. These procedures handle reading, adding, modifying, and deleting geotechnical data in a user-friendly environment. The heart of this module includes procedures that handle I/O operations such as the retrieval and storage of information on external memory. Finally, the third module is the application module in which flexible pavement design, performance graph, and pavement maintenance routines are implemented [1, 5, 6, 7, 8]. This part implements several numerical analysis methods [10, 11, 12] and interacts with the two other modules to provide a user-friendly data entry

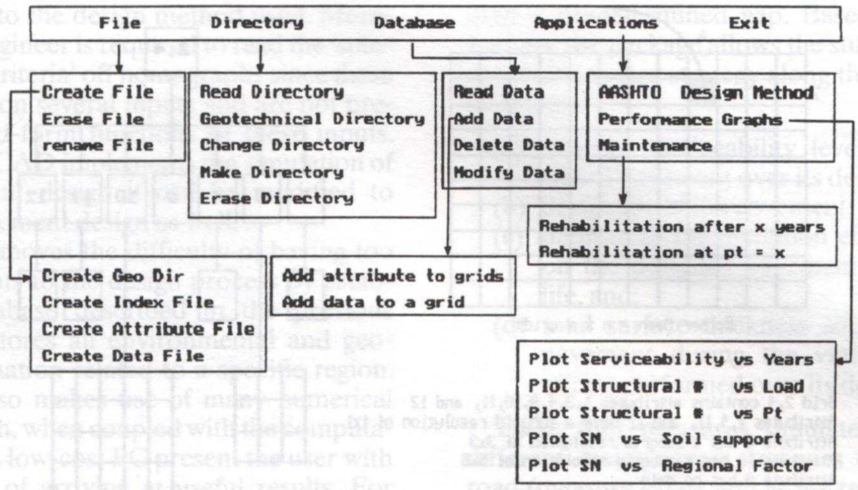

Fig. 1. GEOCAD menu structure.

environment and to retrieve data necessary for design when needed.

2.1 *User menu structure*

In order to provide a user-friendly environment, a menu structure was designed to aid the user in selecting the appropriate function required. Figure 1 shows the menu structure of the GEOCAD environment. A dynamic *HELP* window is also provided to lead the user to the next step to be taken. The main menu provides four options: File, Directory, Database, and Application.

File. This option handles files related to GEOCAD applications. Geotechnical files can be created, erased, and renamed. This option was necessary because GEOCAD initializes and handles GEOCAD files in a special way which is transparent to the user such that the structure and format of the files involved in storing the map and the operations necessary for their access from external memory are carried out as a background task. All the user has to do is to specify the map resolution (see Section 2.2), the number of attributes, and file names. The rest of the file and data operations are carried out by the package.

Directory. This option allows the user to manipulate directories (i.e. to read, create, change, or erase directories). Using this option allows the user to store different maps on different directories without exiting from GEOCAD.

Database. In this option, the user can read, add, update, or delete data related to the geo-map database.

Applications. The user has the option to simulate different flexible pavement schemes. Moreover, the user can use either the *peformance graph* option to plot design parameters or the *maintenance* option to evaluate different maintenance strategies [5–8].

Each one of the above options provides a *HELP* window, displayed at the bottom of the screen, in order to lead the user to the next step to be taken. Moreover, the user can, at any time, switch to a dynamic *HELP* mode which describes the functions that may be carried out from that point onwards.

2.2 *Database structure*

A hierarchical data structure was used [13] to store all the geotechnical related information of the package. The use of hierarchy results in speed of access to information and ease of expansion of data storage. To store information concerning a map, a branching structure technique is required. Trees have this structure [13] because first, they can represent a hierarchical system and second, they can follow a branching or forking path. Although the model is represented hierarchically, the categorized nature of the problem definition allows the user to define as many parameters as he/she chooses per category (Fig. 2) of the map. Examples of common parameters used are altitudes, soil types, soil parameters, climate, underground water, etc. Moreover, the resolution of the map and the number of parameters can be increased as required.

The map is stored in auxiliary memory by dividing it into $n*m$ equal squares (Fig. 2) hereafter called grids. Associated with each grid are attributes as described above. Each grid can be subdivided further to provide higher resolution of data in some map regions. In representing the related data, a linked representation tree was used. Linked representations use pointers for each branch of the tree. Figure 3 shows the file related structure used. The root node is the map which is divided into $n*m$ grids. Each grid (i, j) corresponds to a pointer in an index file which points to a record in the attribute file. The attribute file is the file which holds the attributes associated with each grid. For example, grid (1, 2) may contain attributes: altitude, soil, and climate. Corresponding to each attribute is a

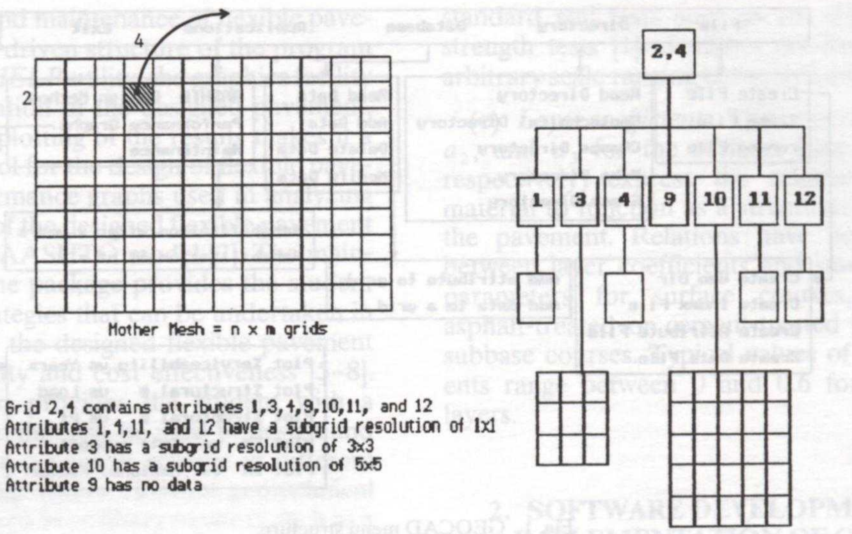

Fig. 2. Hierarchical structure of the attribute definition at the Mother Mesh.

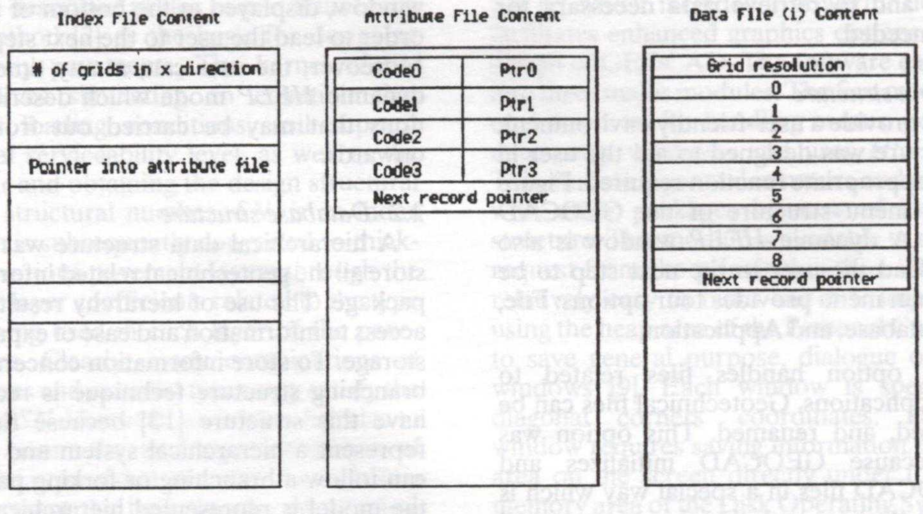

Fig. 3. File structure used to store map related information.

pointer to a data file which holds the data of the grid's attribute. Thus,to read all stored information for a given region on the map, we access the index file which will point to the record in the attribute file storing the attributes of the grid in question. Reading the record provides us with pointers pointing to data files which hold the data of each attribute. In order to dynamically increase the number of attributes per grid, the linked list representation was used in the attribute file. Each record can hold a number of attributes per grid. When this number is exceeded, a new record is created and pointed to by the previous full record. Each grid can be selectively divided into $K*K$ subgrids which allows the implementation of different resolutions for different grids. This data representation allows speed of access to information concerning a given grid. However, it requires a lot of data space to store the pointers involved.

A limitation of the database structure is the fact that as the resolution of the geo-map increases (i.e. n and m), the number of attributes and pointers to data files increase. As a result of this increase in information: (1) the access time for fetching the value of an attribute for a particular subgrid increases, and (2) the maximum size allowable for the database—limited by the size of the hard disk available—may be exceeded.

2.3 *Flexible pavement design application*

One of the functions of GEOCAD is to aid in the design of flexible highway pavements. In pavement design, local environmental conditions as well as the geotechnical characteristics of the area are significant inputs to the design process. Moreover, the materials available for construction of pavements have a major influence on the design. Consequently, it has been traditionally essential in the design process to have access to large amount of data representing characteristics of a flexible pavement and subgrade materials, and their relation to the parameters—as described in Section

1.2—according to the design method used. Moreover, the civil engineer is required to read the 'solution' or 'design criteria' off nomographs since these criteria depend on several inputs and are not presented as closed-form functions of these inputs. Although GEOCAD implements the simulation of flexible pavement design it can be modified to handle rigid pavement design as well.

GEOCAD removes the difficulty of having too many basic inputs to the design process by establishing the database described in the previous section which stores all environmental and geotechnical information related to a specific region. The package also makes use of many numerical techniques which, when coupled with the computational speed of a low-cost PC present the user with efficient means of arriving at useful results. For instance, the cubic splines method was used to interpolate tabulated values such as soil support scales and structural layer coefficient. Moreover, the secant method was used in order to solve the equation which computes the structural number (*SN*) [10, 11, 12]. This procedure replaces the use of the traditional nomograph in coming up with the *SN* value. Moreover, this educational package presents a new utility in flexible pavement design by providing access to *performance graphs*. Here the user has the option of plotting any of the following graphs.

(a) Serviceability vs years
(b) Structural no. vs traffic
(c) Structural no. vs final serviceability level
(d) Structural no. vs soil support
(e) Structural no. vs regional factor.

Moreover, the user can vary one additional parameter in these graphs thereby producing multiple plots per figure (see Fig. 6). The optional parameters which could be the basis for such multiple plots are:

(a) Traffic load
(b) Regional factor
(c) Soil support
(d) Serviceability.

Finally, once the student has decided upon a certain design for the flexible pavement structure and analyzed its performance, GEOCAD allows the student to evaluate any number of maintenance strategies for the designed flexible pavement [5, 6, 7, 8]. The student has the option of triggering maintenance efforts either every *x* number of years until serviceability reaches a pre-specified minimum, at which time the designed pavement is considered to have reached its design life. Beyond this point it is considered that minor resurfacing efforts would not be sufficient and reconstruction of the pavement structure would be warranted. Alternatively, the student may choose a maintenance strategy which involves resurfacing efforts whenever serviceability reaches a pre-specified level *x*. The design life of the pavement is defined by the point when resurfacing is needed at time intervals shorter than a predetermined gap. Based on these two options, the package allows the student to evaluate any maintenance strategy along the four following measures:

(a) average serviceability level for the maintained pavement over its design life;
(b) design life of the pavement;
(c) number of rehabilitation efforts performed on the designed pavement over its design life, and;
(d) total surface thickness added to designed pavement during the various resurfacing efforts performed over its design life.

These four measures simulate the impact of different maintenance strategies on users of the road (measure (a) as well as the required resource costs and the agencies maintaining the road (measures (b), (c), and (d)).

3. RESULTS

GEOCAD was used to aid in designing a flexible pavement structure given certain input parameters some of which are shown in Fig. 4. As shown, the user has the option to specify the *surface layer marshall stability*, the *surface structural coefficient* or the *surface modulus of elasticity*. Figure 4 shows that the *surface modulus of elasticity* was chosen to be 430,000 psi. Then a set of inputs are required by GEOCAD which are the total equivalent 18-kip single-axle load applications, design period, percentage traffic growth rate, terminal serviceability, regional factor, base CBR, subbase CBR, and subgrade CBR. The user has the option of selecting one of three different base type specifications for the base layer as shown in Fig. 4. The crushed stone base was chosen with CBR equal to 80. Figure 5 shows the results of the designed pavement with respective thicknesses of each of the surface, base and subbase layers. Moreover, the structural

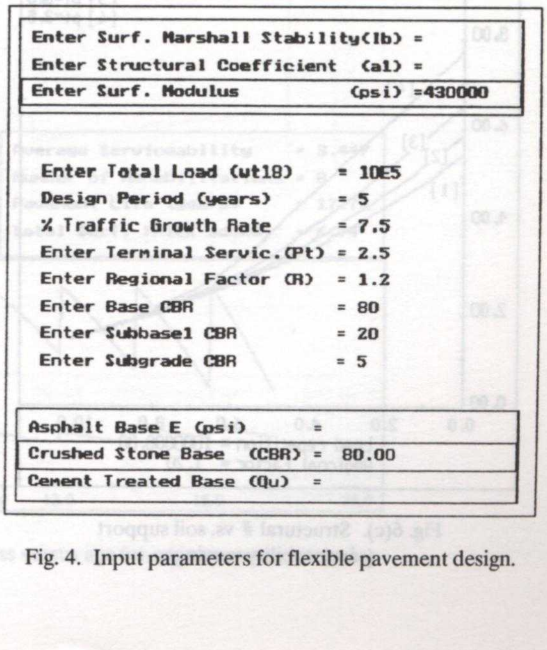

Fig. 4. Input parameters for flexible pavement design.

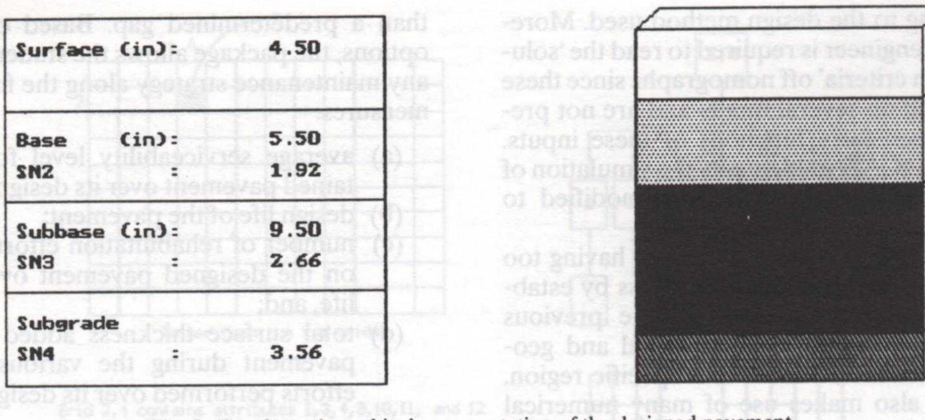

Fig. 5. Results and graphical representation of the designed pavement.

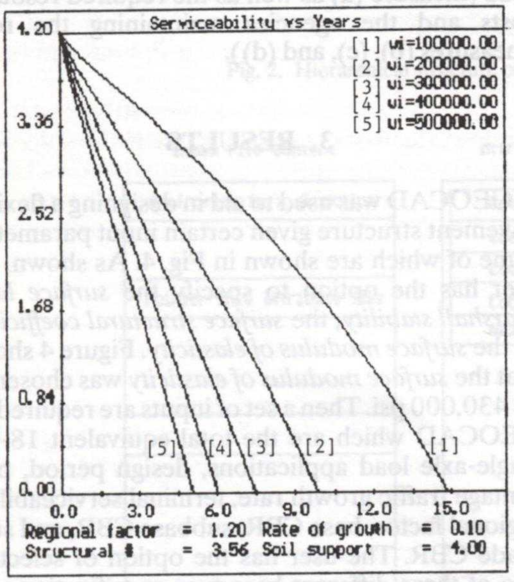

Fig. 6(a). Time variation in serviceability (initial load varying).

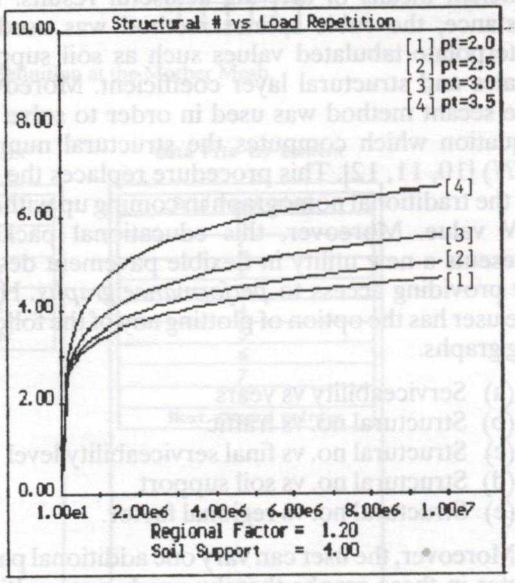

Fig. 6(b). Structural # vs. load repetitions (serviceability varying).

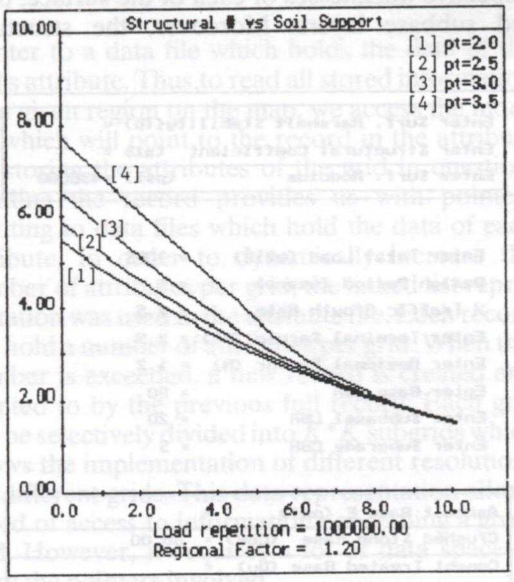

Fig. 6(c). Structural # vs. soil support (serviceability varying).

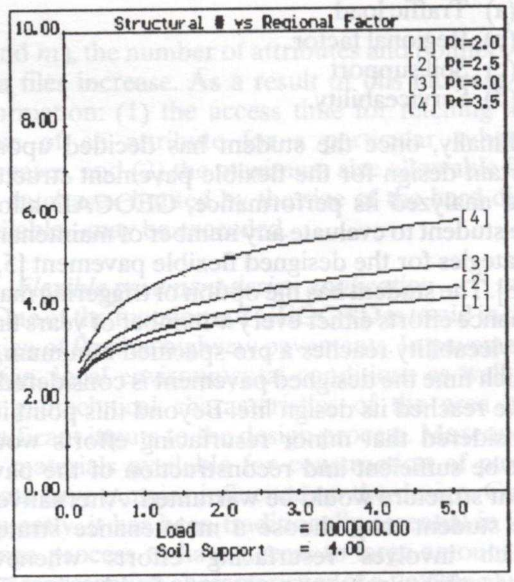

Fig. 6(d). Structural # vs. regional factor (serviceability varying).

numbers evaluated for the base, subbase and subgrade were 1.92, 2.66 and 3.56 respectively. The right portion of Fig. 5 shows an up-to-scale graphical representation of the designed pavement for the parameters shown in Fig. 4, which allows the student to visualize the relative thicknesses of the layers.

Once this design stage is complete, the user may wish to study the behavior of the designed flexible pavement under various conditions [1–3], as shown in Fig. 6, by using the *performance graphs* option. Figure 6(a) shows the variation of serviceability with time for several initial load settings and specific parameter values. As the five curves in Fig. 6(a) indicate, the serviceability factor decreases with time. This decrease becomes more rapid with higher initial loads. Figure 6(b) presents the variation in the required structural number (*SN*) based on the variations in traffic load for a regional factor of 1.2 and soil support factor equal to 4. As shown, *SN* increases as the traffic load increases. When increasing the serviceability level, *SN* increases for specific traffic load factors as depicted by the four plots in Fig. 6(b). Figure 6(c) shows the variation of *SN* due to variation of the soil support factor. As shown, *SN* decreases as the soil support increases. The initial value of *SN* increases as the terminal serviceability value increases as indicated by the four plots in Fig. 6(c). Finally, Fig. 6(d) shows plots of *SN* versus the regional factor for different serviceability values for a total load of 10^6 and soil support equal to 4. As shown *SN* increases as the regional factor increases. When increasing the serviceability level, *SN* increases for specific regional factor values as depicted in the four plots in Fig 6(d). The performance graphs present a very useful utility which helps civil engineering students in understanding the mechanics and interactions of the pavement design process.

The pavement maintenance option allows the user to simulate different strategies for pavement maintenance. Figure 7(a) shows the input parameters of a maintenance strategy that implements

Rehabilitation after x years	
Rehabilitation at pt = x	
Regional Factor	= 1.20
Final Serviceability	= 2.50
Surface Structural Coefficient	= 0.42
Design Surface Thickness (in)	= 4.00
Base CBR	= 80.00
Subgrade SN	= 3.18
Subgrade Soil Support	= 4.00
Load repetition in first year	= 81898.74
% Deterioration in surface/year	= 10
Traffic % growth rate	= 10
Rehabilitation each (year)	= 2
Minimum serviceability	= 2_

Fig. 7(a). Input parameters for strategy I for pavement maintenance.

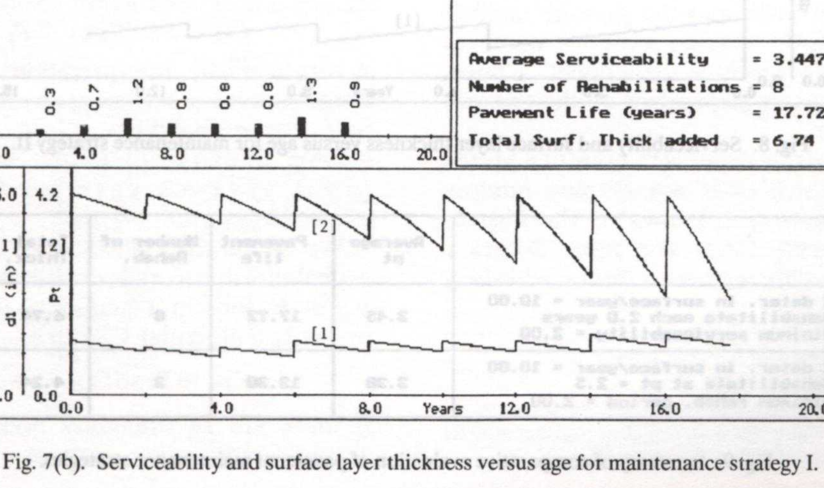

Fig. 7(b). Serviceability and surface layer thickness versus age for maintenance strategy I.

rehabilitation after *x* years. Some of these user-defined parameters include the percentage deterioration in surface layer per year, the traffic percentage growth rate, the rehabilitation period, and the minimum terminal serviceability tolerable when resurfacing would not be sufficient and reconstruction of the pavement would be warranted. The corresponding results for this strategy of serviceability and surface layer thickness versus age is shown in Fig. 7(b). The top left window of Fig. 7(b) shows a bar graph of the added surface layer in inches every two years (i.e. the value specified for the rehabilitation period). As shown in the second plot of Fig. 7(b), every two years after resurfacing the pavement the serviceability value is initialized to 4.2 then decreases with time at a rate dependent on the age of the pavement. The maintenance terminates when the minimum serviceability specified is reached (in this example it is 2). The upper right window in Fig. 7(b) shows the results of this strategy including the average serviceability (3.447) during the maintenance period, the number of rehabilitations (8) or resurfacing, the flexible pavement life (17.72 years), and the total thickness of surface material added (6.74 inches) which in turn reflects the cost involved in maintaining the pavement under this strategy. Similarly, the results of another strategy that implements resurfacing when the pavement serviceability reaches a user-defined value (in this example 2.5) are shown in Fig. 8.

GEOCAD can also display a summary table of the results of up to six different maintenance strategies for comparative evaluation by the user. Figure 9 shows a summary of the results of the two diferent maintenance strategies described above. In conclusion, the maintenance utility of the package presents the student with the opportunity to explore different maintenance scenarios in the future and to compare the performance and effectiveness of these scenarios.

4. CONCLUSION

This menu-driven package along with its *HELP* utility and enhanced graphical capabilities allows the civil engineering student to practice flexible pavement design, performance analysis, and maintenance strategy evaluation in a user-friendly environment. It also provides the user with an efficient educational CAD tool on a low-cost workstation. Moreover, the hierarchical structure of the database map information bank is a powerful utility that provides high speed of access of the geotechnical data. Although the package allows only the design and maintenance of flexible pavements, such a package is clearly an effective educational tool which makes the learning of flexible pavement design basics visual, more effective and enjoyable.

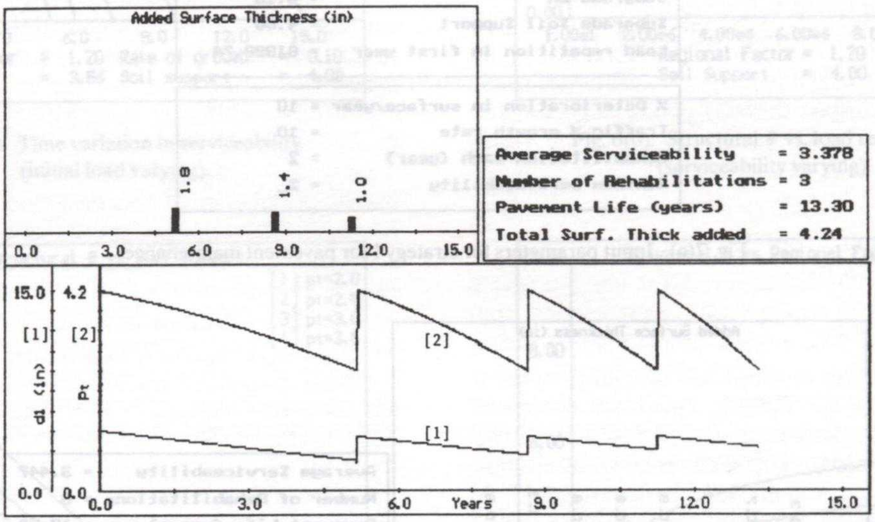

Fig. 8. Serviceability and surface layer thickness versus age for maintenance strategy II.

	Average pt	Pavement life	Number of Rehab.	Total Thick.
% deter. in surface/year = 10.00 Rehabilitate each 2.0 years Minimum serviceability = 2.00	3.45	17.72	8	6.74
% deter. in surface/year = 10.00 Rehabilitate at pt = 2.5 Minimum rehab. period = 2.00	3.38	13.30	3	4.24

Fig. 9. Summary of comparative evaluation of pavement maintenance strategies.

REFERENCES

1. E. J. Yoder and M. W. Witczak, *Principles of Pavement Design*, pp. 504–519, John Wiley, New York (1975).
2. AASHTO, *A Policy on Geometric Design of Highways and Streets*, Washington, DC. (1984).
3. AASHTO, *Interim Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington (1981).
4. J. D. Foley and A. VanDam, *Fundamentals of Interactive Computer Graphics*, Addison-Wesley, California (1982).
5. C. V. Carnahan, Optimal Maintenance Decisions for Pavement Management, *J. Transp. Engng*, ESCE, **113**, 542–554 (1987).
6. K. Ksaibati and K. C. Sinta, Development of a Routine Pavement Maintenance Data Base System, *Transp. Res. Rec.*, **1109**, 36–42 (1987).
7. A. Stein. A Microcomputer-Based Pavement Rehabilitation and Maintenance Management, *Proc. Second North Amer. Conf. on Managing Pavements*, 2, Toronto, 2.373–2.386 (1987).
8. P. E. Theberge, Development of Mathematical Models to Assess Highway Maintenance Needs and Establish Rehabilitation Threshold Levels, *Transp. Res. Rec.* **1109**, 27–35 (1987).
9. *Turbo Pascal Owner's Handbook*, BORLAND International, Scotts Valley, California (1989).
10. W. Cheney and D. Kincaidk, *Numerical Mathematics and Computing*, Brooks/Cole, California (1985).
11. G. Dahlquist and A. Bjorck, *Numerical Methods*, Prentice-Hall, Englewood Cliffs, N.J. (1974).
12. J. Nievergelt, J. G. Farrar and E. M. Reingold, *Computer Approaches to Mathematical Problems*, Prentice-Hall, N.J. (1974).
13. A. M. Tenenbaum, *Data Structures*, Prentice-Hall, Englewood Cliffs, N.J. (1986).