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Development of Knowledge-Based Expert System for Flexible Pavement Design

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Abstract: In this study, the knowledge-based expert system approach was used to design a programmer using shell expert system of KAPPA PC Version 2.4 that is object oriented and displaying higher graphic resolutions. The flexible pavement design based on the accumulation of knowledge from several experts, books and journals results in a modular approach. Normally, the process of flexible pavement design is done by experts. The process was computerized and apply artificial intelligent that is a new technology in providing a system that can design and give the suggestion for user to choices the best and economy of the thickness of pavement layers. The expert system was tested using several design calculation samples. From the test, the success is 100% for pavement design. The expert system has revealed satisfactorily findings in a faster layers design.

Key words: Expert system, flexible pavement, kappa-pc

INTRODUCTION

Expert system according to Firebaugh (1988) is defined as an expert systems are a class of computer programs that can advise, analyze, categorize, communicate, consult, design, diagnose, explain, explore, forecast, form concepts, identify, interpret, justify, learn, manage, monitor, plan, present, retrieve, schedule, test and tutor. They address problems normally though to require human specialists for their solution. Today, with the new advances, an expert system could be defined as: a computer system that simulates the learning, memorization, reasoning, communication and action processes of a human expert in a given area of science, giving, in this way, a consultant that can substitute the human expert systems with reasonable guaranties of success. These characteristics allow expert system to store data and knowledge, draw logical conclusions, make decisions, learn from experience and existing data, communicate with other human experts or expert systems, explain why decision have been made and take actions as a consequence of all the above.

Presently, in the market there are many expert systems software, amongst them are PARADIGM, EXSPAV, PARES, SCEPTRE, ROSE and PRESEVER. PARADIGM (the Pavement Rehabilitation Analysis and Design Mentor). PARADIGM is a microcomputer-based tool to integrate a set of Knowledge-Based Expert Systems (KBES) and algorithmic models for pavement rehabilitation decision-making, particularly at the local level. Because the analysis and design of pavement rehabilitation strategies relies so heavily on experts and many of the tasks involved are both complex and ill-defined. EXSPAV is an expert system program established for use in flexible pavement and overlay design. PARES expert system to assist the New Mexico State Highway and Transportation Department in the evaluation and design of rehabilitation schemes for flexible pavements is described. SCEPTRE (Surface Condition Expert for Pavement Rehabilitation) expert systems that was developed for analysis and selection of pavement design strategies. ROSE expert system was developed to provide advice on proposals for road maintenance activities and PRESERVER was developed to provide advice and assistance to the site engineers and supervisors on the strategies for road maintenance.

In this study the object oriented expert system was developed that is based on KAPPA-PC software package. Mohamed and Mohamad Hussaini (1999) suggested this software package is very attractive with highly graphic display. This package comprised of programmers for analyzing problems of road maintenance that is written in KAL language (Kappa PC Application Language). The output of the package is in the form of display interfacing from the user and the computer. The purpose of developing this software package is to prepare a medium of simple instruction and attractive for person who wants to learn and to know design of flexible pavement. Homely the development of the experts systems software package will safe time and cost in analyzing and design of flexible pavement.

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THE DESIGN OF EXPERT SYSTEM

There are three main components in every expert system as suggested by Adedeji Badiru (1992), namely:

- The knowledge base
- Inference engine
- User interface

In the development of the proposed expert system for flexible pavement design that will be developed, the knowledge base shall contain information about the material, thickness of layers and the basic of totally cost. The knowledge base in the expert system shall be compiled from the observation and experience of the expert in the field as well as those from the published documents.

The success in developing an expert system depend upon the step and strategies that have to be focus upon if it is to be successful. Weiss Sholom and Kulikowski (1984) have suggested the following steps to be taken if success is desired:

- Statement of problem to be solved
- Searching for human expert or the equivalent data or experiences
- Design of the expert system
- Selection of the degree of participation of user
- Selection of the development tool, shell or programming language for development
- Development of prototype
- Prototype checking
- Refinement and generalization
- Maintenance
- Updating

The first step consists of defining the problem to be solved. Utmost emphasis should be placed on this step as it will ultimately save time in the following steps to be taken.

Once, the problem has been completely defined, one must look for a human expert able to solve it successfully or through the data bases on the subject. The third step is design of the expert system which includes the structures for knowledge storage, the inference engine, the explanation subsystem and the user interface and so on. Figure 1 shows the basic flowchart how to develop an expert system.

The last two steps are extremely important if one is looking for product of high quality with potential commercial success. During this step one must pay attention to client complaints and problem, correction of bugs and errors, updating of the product with new advances and so on.

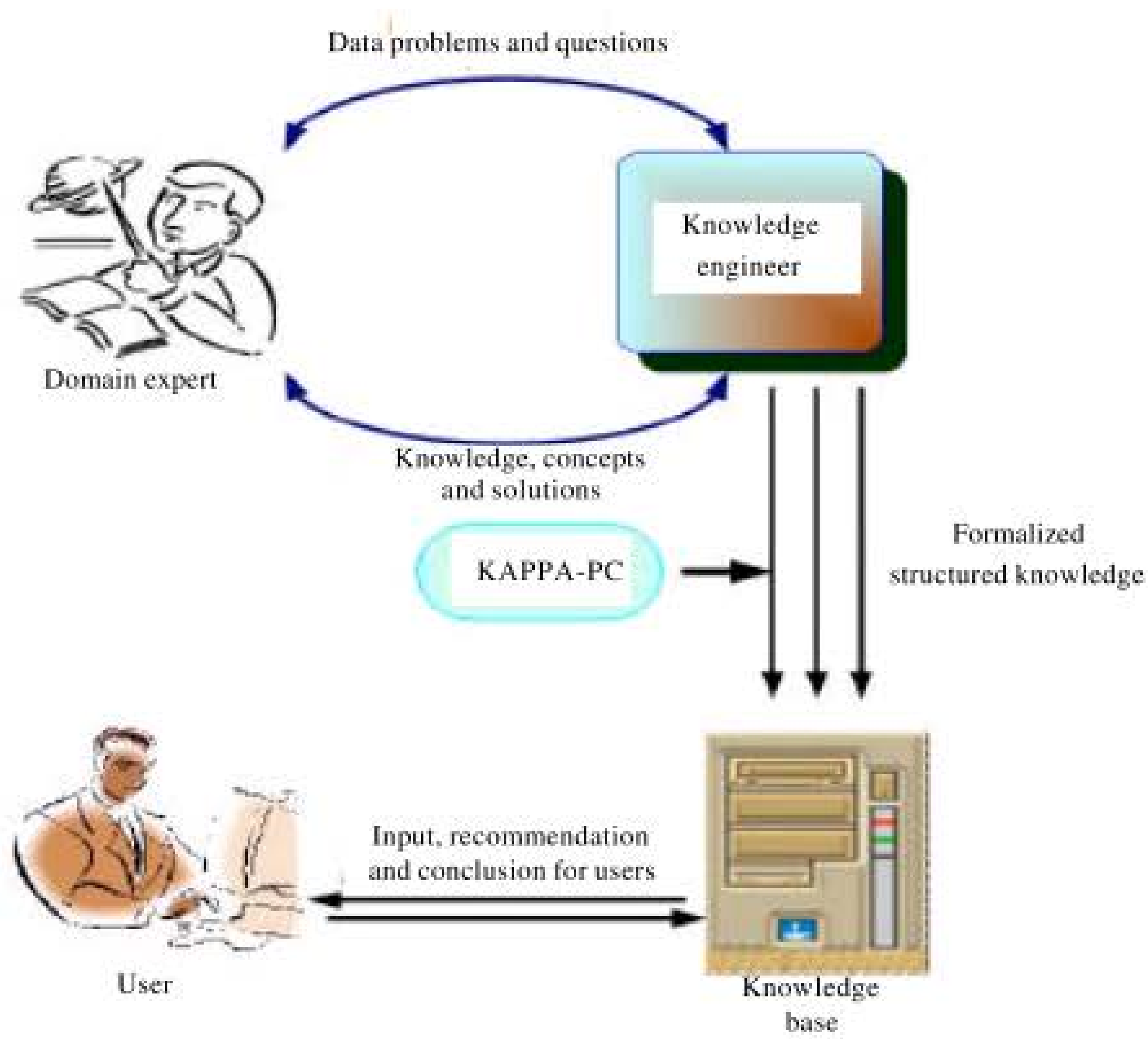

Fig. 1: The expert system procedure

In this study an expert system was development for a flexible pavement design and called ES-DMFP.

THE MODULE OF DESIGNING FLEXIBLE PAVEMENT

The main module is basic of flexible pavement design to ES-DMFP. The objective of the ES-DMFP is to collect and provide the input data of design variable in order to further process in flexible pavement design. Then output will be received for user automatically and the system will be recommendation to user about the materials with optimum thickness for each layer and low cost.

The variables involved in flexible pavement design are, California Bearing Ratio (CBR), materials, soil strength, modulus of rupture (flexural strength), vehicle wheel load or axle load, configuration of traffic vehicle wheels or tracks, volume of traffic during the design life of pavement, drainage.

The American Association of State Highway and Transportation Officials guide also uses the resilient modulus (M_r) of the soil to define it is property. However, the method allows for the conversion of the CBR value of the soil to an equivalent M_r value using the following conversion factors, in the partial of Fig. 2 shows resilient modulus interface for this system.

$$M_r\ (\text{lb in}^{-2}) = 1500\ \text{CBR (for fine grain soil with soaked CBR of 10 or less)} \quad (1)$$

The materials used for construction can be classified under three general groups is sub-base, base and surface. The partial of Fig. 3 show the list of materials used in each layers.

The quality of the material sub-base used is determined in term of the layers coefficient, a_3, which is used to convert the actual thickness of the sub-base to an equivalent SN. Look the partial of Fig. 3 show the materials of sub-base. The materials of base selected should satisfy the general requirements for base course materials by the American Association of State Highway and Transportation Officials. Structural layers coefficients, a_2, for the material used should also be determined. The partial of Fig. 3 show the materials of base.

The material of surface most commonly used material is a hot plant mix of asphalt cement and dense-graded aggregates with a maximum size of 1 in. The structural layer coefficient (a_1) for the surface course can be extracted, which relates the structural layer coefficient of a dense-grade asphalt concrete surface course with it is resilient modulus at 68°F. The materials of surface shown in partial of Fig. 3.

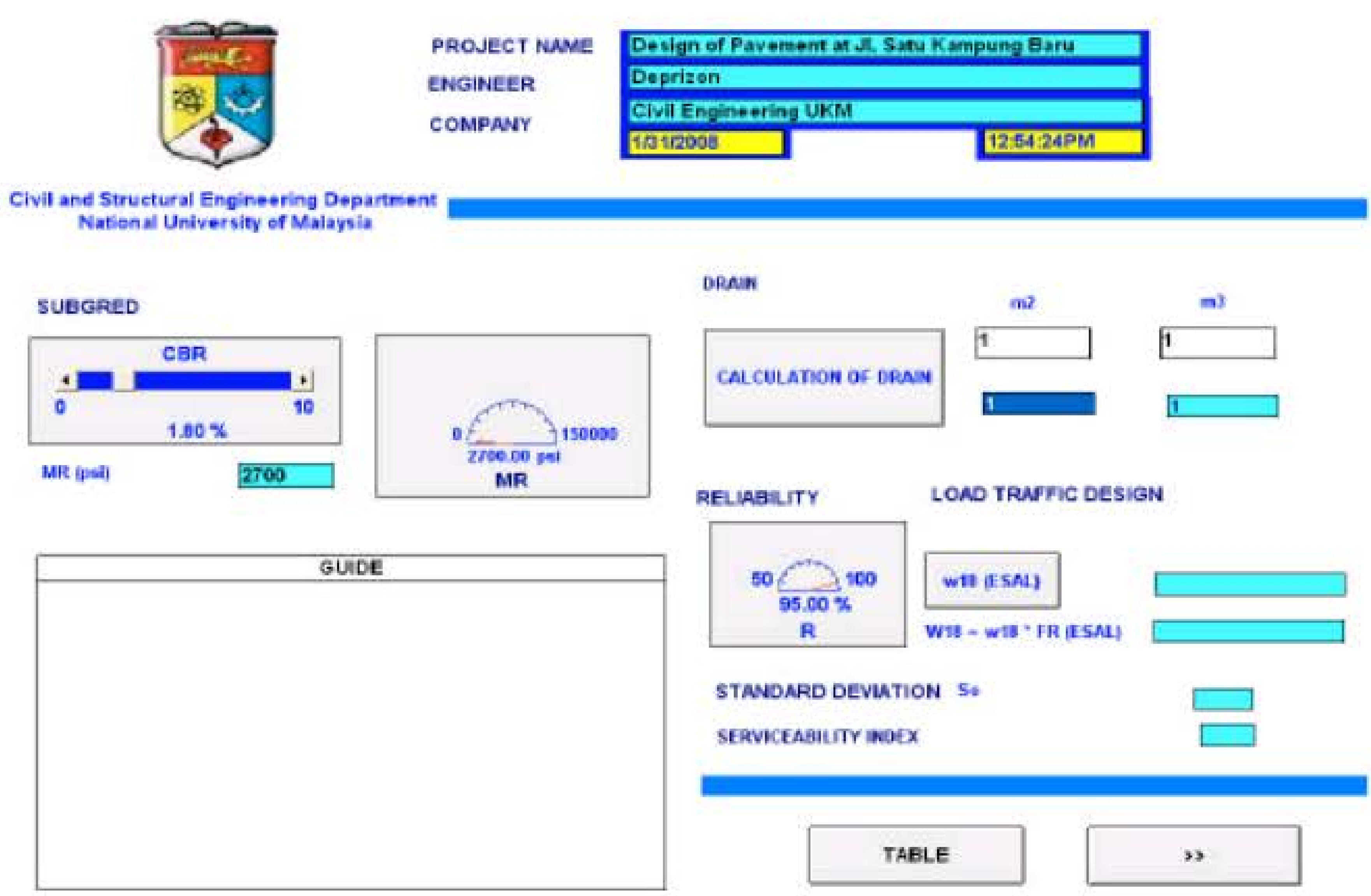

Fig. 2: Resilient modulus (M_r) interface

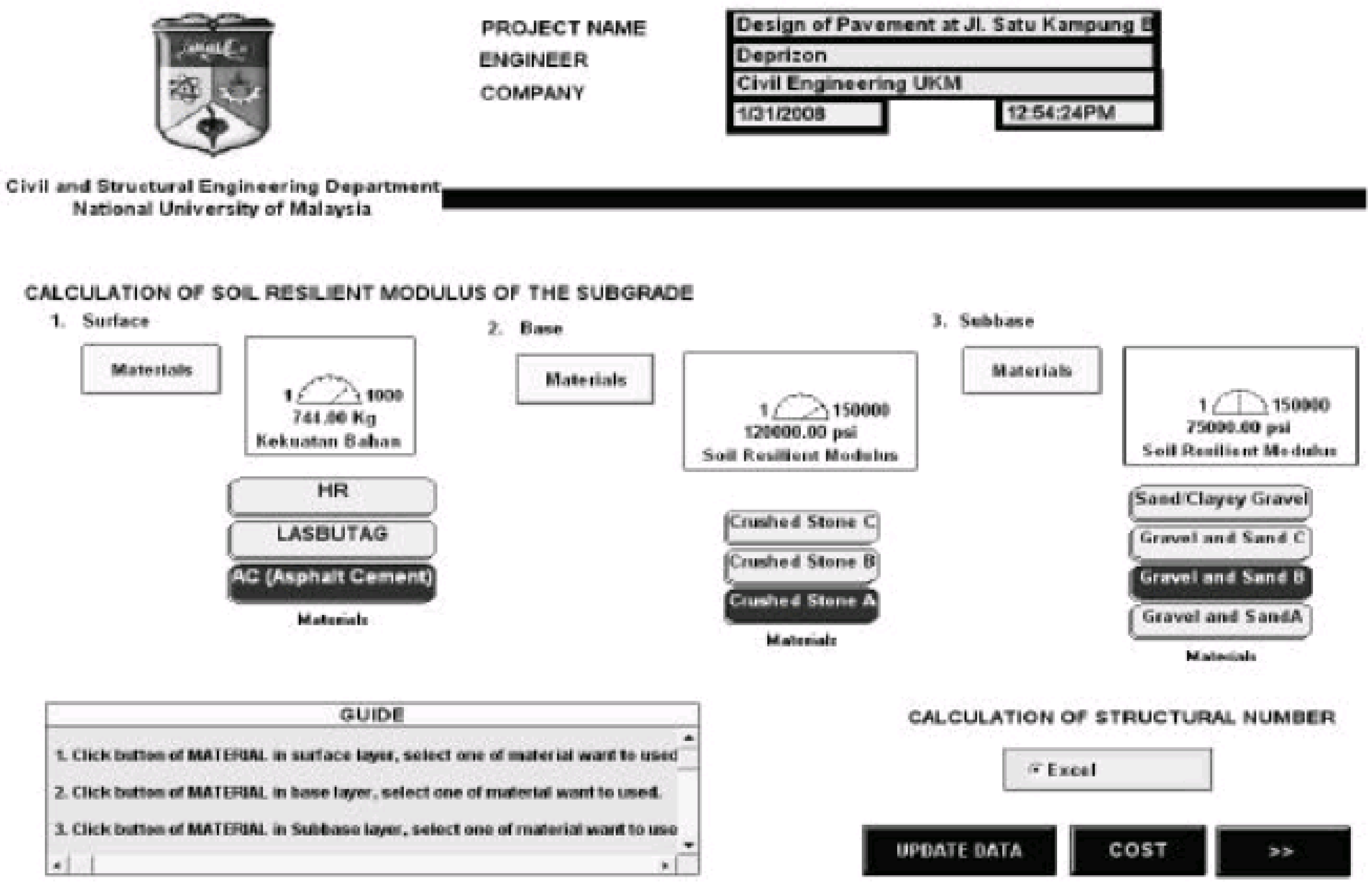

Fig. 3: The list of materials each layers interface

The effect of drainage on the performance of flexible pavements is considered in the American Association of State Highway and Transportation Officials guide with respect to the effect water has on the strength of the base material and roadbed soil. The approach used is to provide for the rapid drainage of the water from pavement structure by providing a suitable drainage layer and by modifying the structural layer coefficient. The modification is carried out by incorporating a factor m_i for the base and sub-base layer coefficients (a_2 and a_3). The m_i factors are based both on the percentage of time during which the pavement structure will be nearly saturated an on the quality of drainage, which dependent on the time it takes to drain the base layer to 50% of saturation. As shown in Fig. 4 part of calculation to gives recommended m_i values for different levels of drainage quality.

The variables above for calculation of design module and traffic load module. With the module user will know detail how to get a value of vehicle in years as shown in the Fig. 5.

Traffic load will be consideration by single-axle loads (ESALs) an 18-kip during age of design and performance period. Actually in American Association of State Highway and Transportation Officials the value showed to effect damage of road from the single-axle loads are 18-kip (80 kN) ESALs. Examples axle loads is 54 kN, then road will be damaged with the value is 0.23 from the axle loads of 80 kN. The procedure presented earlier is used to determine the design ESAL. The equivalence factors used in the case, however, are based on the terminal serviceability index to be used in the design and the Structural No. (SN). A general equation for accumulated ESAL for each category of axle load obtained as:

$$ESAL_i = f_d \times G_{jt} \times AADT_i \times 365 \times N_i \times F_{Ei} \qquad (2)$$

Where:

- $ESAL_i$ = Equivalent accumulated 18,000 lb (80 kN) single axle load for the axle category I
- f_d = Design lane factor
- G_{jt} = Growth factor for a given growth rate j and design period t
- $AADT_i$ = First year annual average daily traffic for axle category i
- N_i = No. of axles on each vehicle in category i
- F_{ei} = Load equivalency factor for axle category i
- N = No. of truck categories
- ESAL = Equivalent accumulated 18.00 lb axle load for truck category I

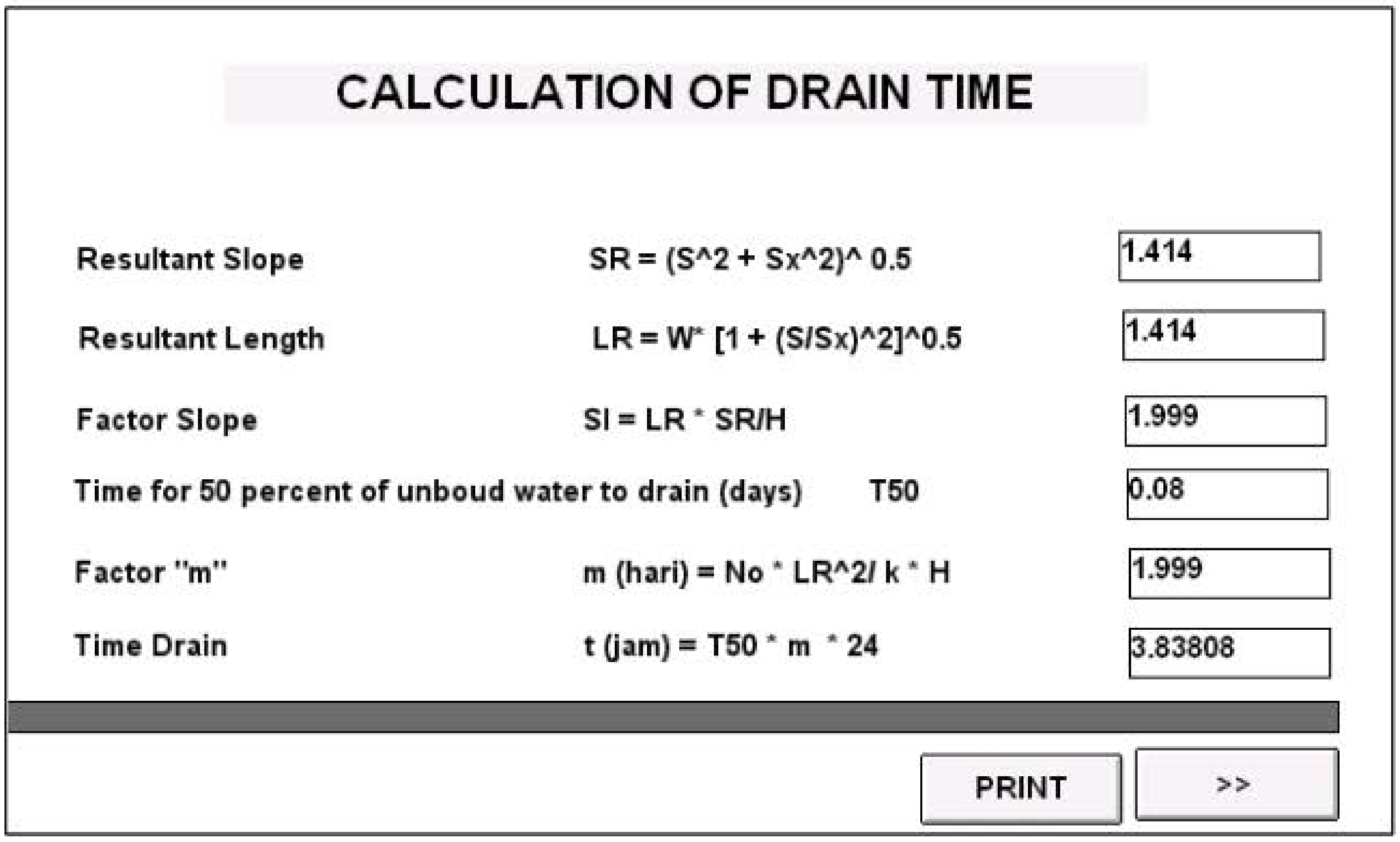

Fig. 4: Calculation of drainage coefficient interface

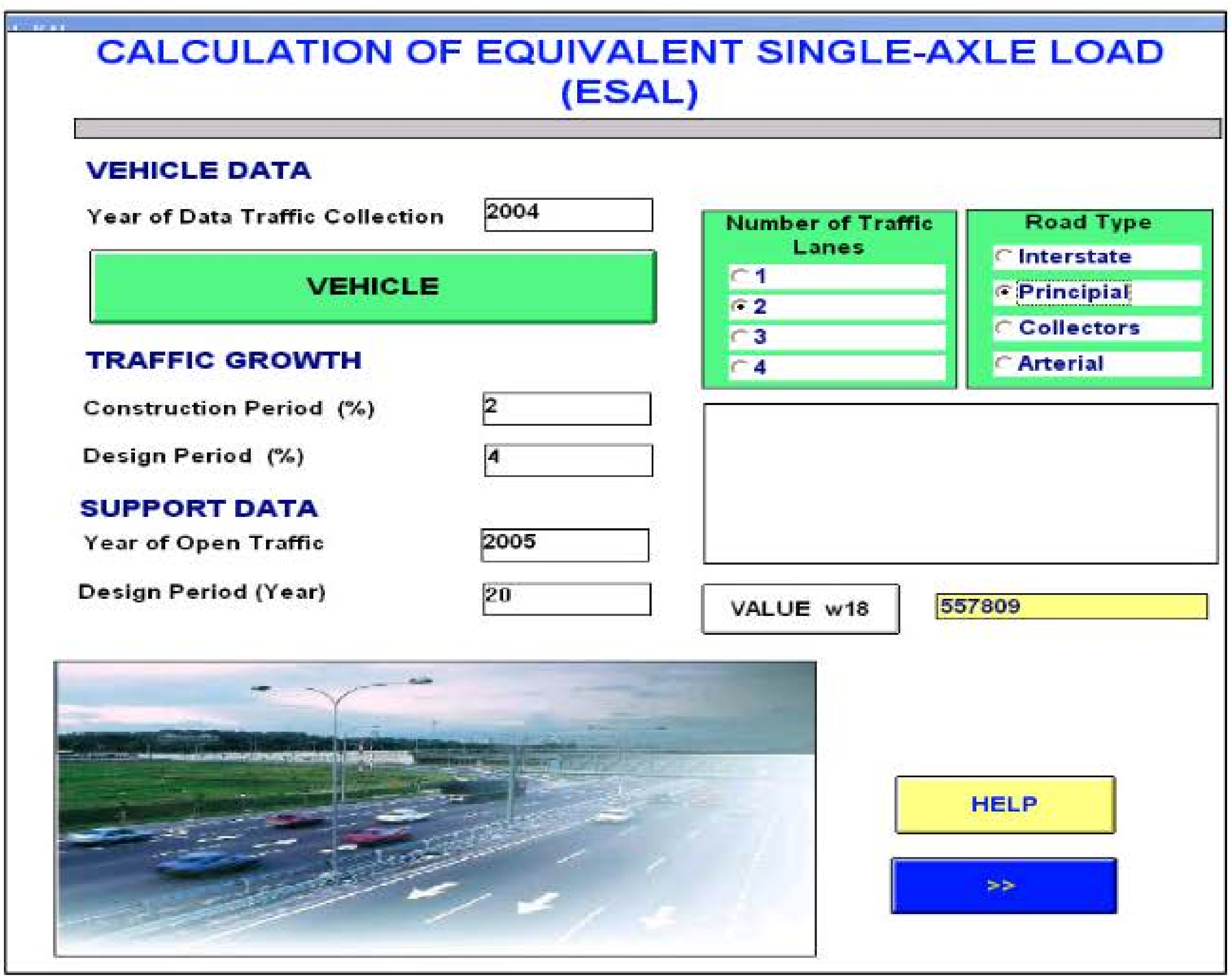

Fig. 5: ESAL calculation interface

When truck factor are used, the ESAL for each category of truck is given as:

$$ESAL_i = f_d \times G_{jt} \times AADT_i \times 365 \quad (3)$$

$$ESAL = \sum_{i=1}^{n} [ESAL_i] \quad (4)$$

In Fig. 6, the expert system ES-DMFP will give the final of the structural number value.

The objective of the design using the AASHTO method is to determine a flexible pavement SN adequate to carry the projected design ESAL. It is left to the designer to select the type of surface used, which can be either asphalt concrete, a single surface treatment, or a double surface treatment. The American Association of State Highway and Transportation Officials (AASHTO, 1993) guide gives the expression for SN as:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \quad (5)$$

Where:

- m_i = Drainage coefficient for layer i
- a_1, a_2, a_3 = Layer coefficient representative of surface, base and subbase course
- D_1, D_2, D_3 = Actual thickness in cm of surface, base and subbase courses

The basic design equation given in the AASHTO guide is:

$$\log_{10} W_{18} = Z_R S_o + 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}[\Delta PSI/(4.2-1.5)]}{0.40 + [1094/(SN+1)^{5.19}]} + 2.32 \log_{10} M_r - 8.07 \quad (6)$$

Where:

- W_{18} = Predicted number of 18,000 lb (80 kN) single axle loads applications
- Z_R = Standard normal deviation for a given reliability
- S_o = Overall standard deviation
- SN = Structural number indicative of the total pavement thickness
- ΔPSI = p_i - p_t
- p_i = Initial serviceability index
- p_t = Terminal serviceability index
- M_r = Resilient modulus in lb/in^2

The SN parameter in Eq. 6 can be automatically solved using ES-DMFP. User can get the SN value easily after input all required data. This expert system of ES-DMFP is not time consuming compared to the manual calculation. Interface of thickness of each layer is shown in Fig. 7.

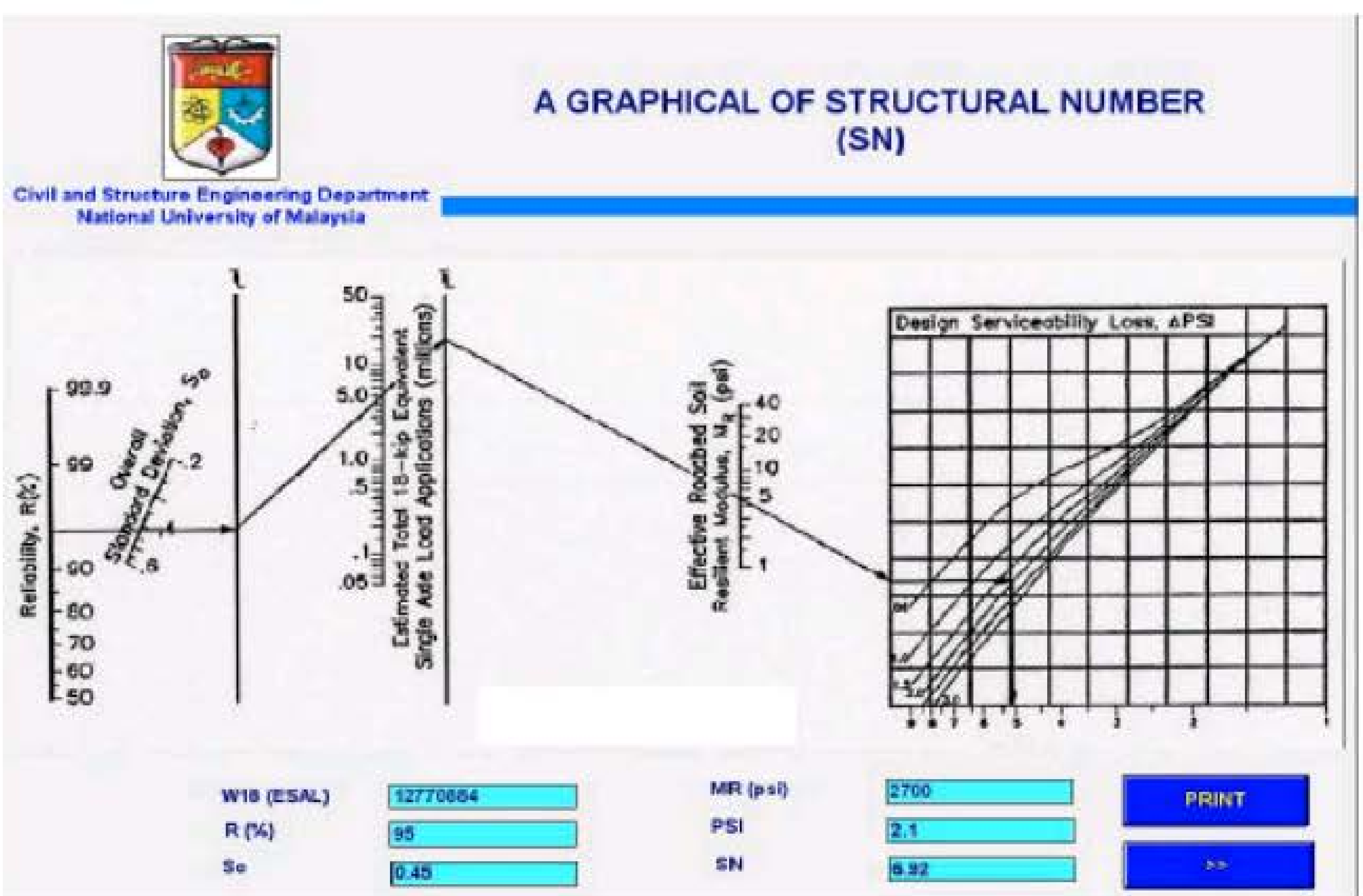

Fig. 6: Structural number interface

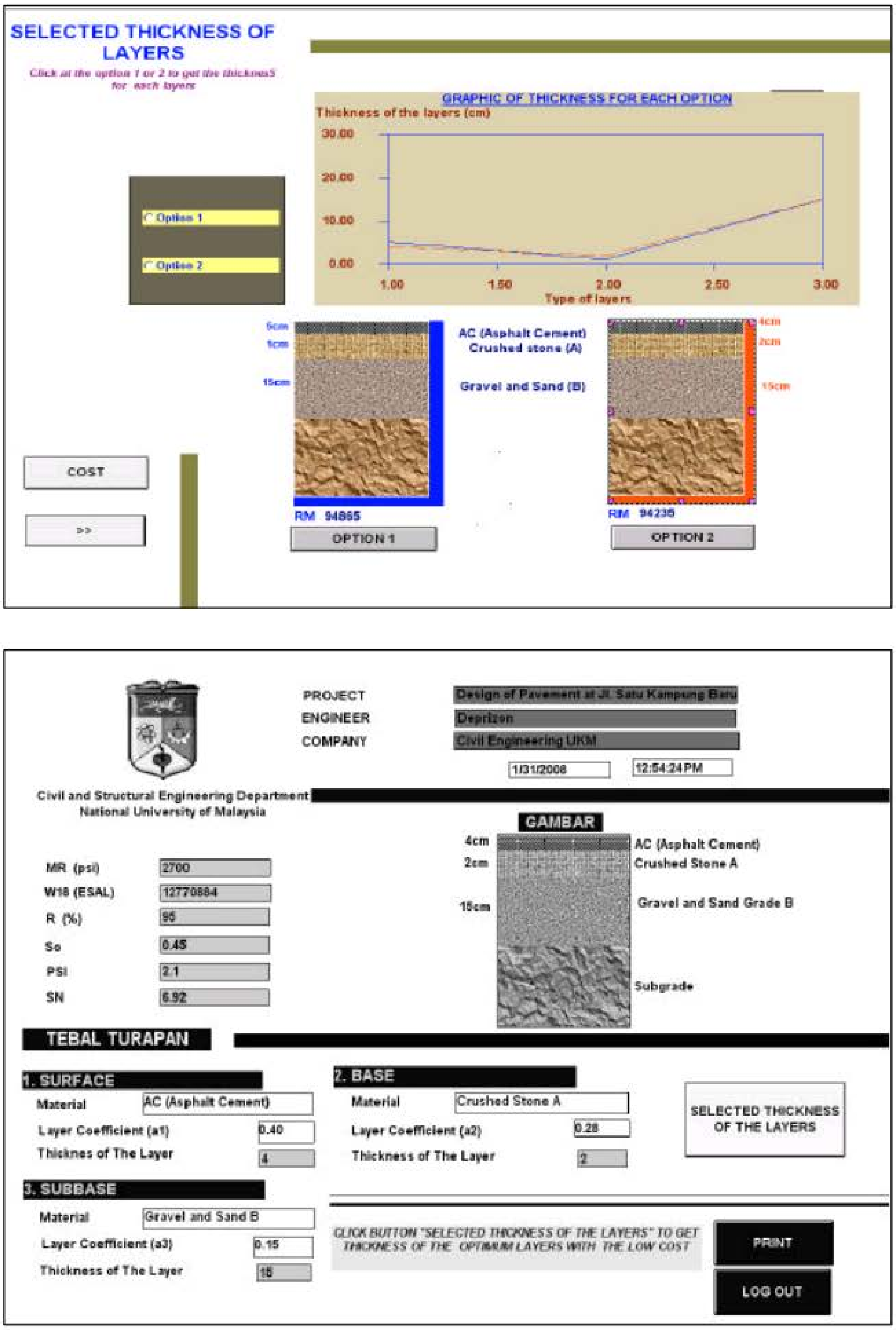

Fig. 7: Interface of thickness each layers

Table 1: The input data for local sample

	Input data		
Samples	1	2	3
No. of line	1	2	3
Type road	Local	Primary road	Highway
Annual growth rates	90,000	100,000	50,000
Grow up of traffic load	0	0	2
Type of axel load	Single	Tandem	Triple
Axel load (kips)	30	36	42
Terminal serviceability index	2.5	2.5	2.5
Design period	20	25	30
CBR (%)	4.5	5	5.5
Materials of surface	HR	Asphalt cement	Asphalt cement
Materials of base	Crushed stone B	Crushed stone A	Crushed stone A
Materials of subbase	Sand B	Sand A	Sand A

Table 2: The result manual and ES-DMFP calculation

	Manual calculation			System ES-DMFP calculation		
Samples	1	2	3	1	2	3
MR (psi)	6750	7500	8250.00	6750	7500	8250.00
$SN_{temporary}$	5	5	6	5	5	5
p_t	2.5	2.5	2.5	2.5	2.5	2.5
Axle load equivalency factors	2.18	1.38	0.567	2.18	1.38	0.567
Growth factors	20	25	40.57	20	25	40.57
D_D	0.5	0.5	0.5	0.5	0.5	0.5
D_L	1	0.90	0.7	1	0.90	0.7
R	0.80	0.95	0.95	0.80	0.95	0.95
Z_R	0.841	-1.645	-1.645	-0.841	-1.645	-1.645
S_o	0.45	0.45	0.45	0.45	0.45	0.45
ΔPSI	1.70	2.00	2.10	1.70	2.00	2.10
W_{18} (ESAL)	4689743	8536535	22134826	4689743	8536535	22134826
SN	4.1	5.0	5.1	4.2	4.80	5.3
a_1	0.35	0.40	0.40	0.35	0.40	0.40
a_2	0.28	0.28	0.28	0.28	0.28	0.28
a_3	0.12	0.14	0.14	0.12	0.13	0.14
D_1 (cm)	2.287	2.75	4.25	2.57	3.50	4.75
D_2 (cm)	7.50	7.50	7.50	7.50	7.50	7.50
D_3 (cm)	10	10	10	10	10	10

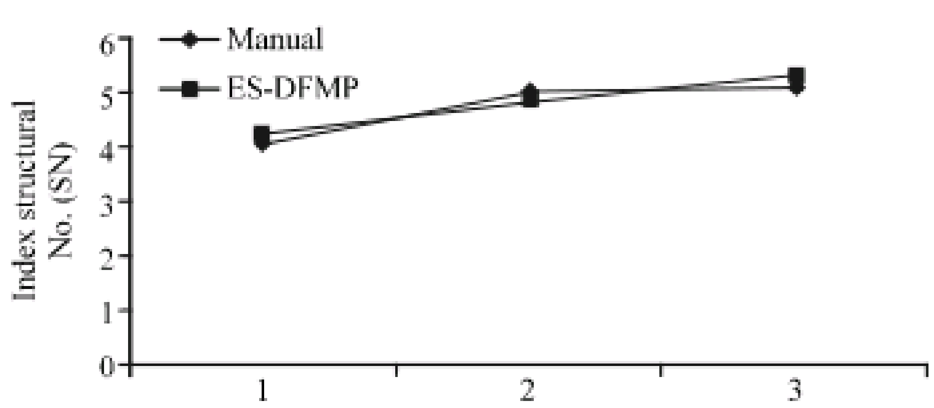

Fig. 8: Graphs of manual and ES-DFMP structural number

ES-DMFP analysis result was analyzed by local sample shown in Table 1 for design flexible pavement to see the finally result of system. The finally result of system with local sample design showing similarity. The results of manual calculations with expert system ES-DMFP shown in Table 2.

Final of result from the manual calculation with expert system ES-DMFP don't have to much different, only index of structural number (Fig. 8). It is because the manual calculation to get structural number using monographs, but in the expert system ES-DMFP to get index of structural number by modification formula.

CONCLUSION

This study described about the study on the provision of design output based on the accumulation of knowledge from several experts by applying the modular approach. Normally, the process of pavement layer design and distress diagnose are done by experts. The process was computerized and apply artificial intelligent that is a new technology in providing a system that can design efficiently. The expert system uses the American Association of State Highway and Transportation Officials (AASHTO) design standard to calculate the minimum layers thickness and can be give the suggest for design of the thickness of pavement layer design. The expert system was tested using several design calculation samples. From the test, the success is 100% for pavement design. The expert system has revealed satisfactorily findings in a faster layers design.

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