Development of a Computer Program for Rigid Pavement Slab Thickness Design

تطوير برنامج حاسوبي لتصميم سمك البلاطة الخرسانية المستخدمة في إنشاء التبليط الجاسئ

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Abstract:

This paper focused on building a VBasic computer program for Concrete Pavement thickness Design coded as (CONPVD-93). This thickness design utility solves the 1993 AASHTO Guide basic design equation for rigid pavements. It also supplies some basic information on variable descriptions, typical values and equation precautions. CONPVD present both a direct and detailed thickness design process .In detailed mode the step- by-step calculations can be seen in CONPVD desing process.Three options for calculating the predicted ESAL applications namely direct,axle load equivalency facter ALEF-based ,and truck factor TF- based calculations, were presented.To account the composite K- modulus for the presence of rigid footing, a new model has been developed in this study. Seasonal effect was adopted in computing the effective modulus of subgrade reactions. The effect of different values for proposed slab thickness on the final results has been thoroughly studied also. CONPVD has proven very useful as an effective educational tool as well as a powerful design tool.

Keywords: Rigid Pavement, Thickness Design, Subgrade Reaction, AASHTO Design Guide 1993, W18 ESAL and VBasic CONPVD Software

الخلاصة

هذا البحث يتضمن بناء برنامج حاسوبي باستخدام لغة الفيجوال بيسك لتصميم سمك البلاطة المستخدمة في التبليط الجاسئ و سُمي (CONPVD). برنامج السمك التصميمي هذا يقوم بحل المعادلة التصميمية الأساسية (AASHTO) الخاصة للتبليط الجاسئ . كذلك يعرض البرنامج وصف للمتغيرات التصميمية للمعادلة وقيمها النموذجية. يقدم البرنامج كلا اسلوبي التصميم المباشر و التفصيلي . في الاسلوب التفصيلي , جميع حسابات التصميم الوسطية يمكن أن تتابع خطوةً بخطوة . ثلاث خيارات لتخمين الحمل المفرد المحوري المكافئ المسماة : الحساب المباشر , المعتمد على معمل مكافأة الحمل المحوري و المعتمد على معامل الشاحنة. لحساب معامل رد فعل التربة المركب (K) وبوجود طبقة الأساس الجاسئ , تم استحداث معادلة يمكن استخدامها بثقة .التأثير الفصلي تم تضمينه في حسابات معامل رد فعل التربة الفعال . تأثير القيم المختلفة لسمك البلاطة المقترح على النتائج النهائية تم دراسته كاملاً كذلك. ألبرنامج ذات منفعة معتد بها كأداة تعليمية مؤثرة إضافةً إلى كونه أداة تصميمية فعالة.

1. Introduction

Portland cement concrete pavements are commonly referred to as rigid pavements. This classification is based on rigid pavement behavior. Behavior of a pavement is defined as the immediate response of a pavement to a load. Rigid pavements respond to a wheel load as a very stiff material (concrete) over much softer materials (subbase and subgrade). The rigid pavement develops significant bending moments and uses these bending moments to acts as a beam to spread the wheel load over a large area of the subbase and subgrade.

The goal of structural design is to determine the number, material composition and thickness of the different layers within a pavement thickness required to accommodate a given loading regime. For rigid pavement, structural desin is mainly concerned with detemining the appropriate slab thickness based on traffic loads and underlaying material properties, and joint

design. The empirical design approach is one of the principal methods of rigid pavement structural design.
An empirical design procedure is based strictly on the results of experiments or experience and hence the resulted observed performance. Empirical equations are used to relate observed or measurble phenomena with outcomes. One of the widely used empirical design equations are these drawn from the AASHTO Road Test (WSDOT web page).
The aim of this paper is to develop a MS-Windows – based software program to perform an empirical thickness design for these three common rigid pavement types (PJCP, JRCP and CRCP). This Concrete Pavement Design Program (CONPVD-93) is based on 1993 AASHTO Design of Pavement Structure Guide.

2. 1993 AASHTO Rigid Pavement Design

The Association of State Highway and Transportation Officcials (AASHTO) has been a leader in pavement design for nearly 40 years. In the 1950's and early 1960's, AASHTO performed the AASHO Road Test in Ottawa, Illinois. This test collected information, which was incorporated, into the AASHTO design equations for rigid pavements published in a design manual in 1961 (Yoder and Witczak, 1975). With continuing research, AASHTO improved its empirical design procedures, which were shown in the 1972, 1986 and 1993 design manuals. The 1986 and 1993 editions made major steps in moving from an empirical to a more theoretically based design of pavement structures.

For rigid pavements, the initial pavement structure shall be designed and analyzed for a minimum performance period of 30 years. Pavement design methods available must take the advantage of computer applications in solution of empirical or mechanistic design equations.

The 1993 AASHTO design method used serviceability as a user-defined definition of failure. Serviceability is defined as "the ability of a pavement to serve the traffic for which it was designed" . The AASHTO Road Test initially determined serviceability from the mean rating of a selected panel of people who judged each pavement with a zero to five rating (five being excellent pavement). These ratings were given at the time of construction and periodically through the life of the pavement. A statistical analysis was then made to relate these ratings to measurable physical properties of the road.
It is worthwhile mentioning that 1993 AASHTO design procedure is very similar to the 1972 version with the addition of environment, drainage and reliability variables. Methods of evaluating materials and conditions have also been modified. The variables for design are classified into four categories: design variables, performance criteria, material properties and structural characteristics.The 1993 AASHTO guide empirical basic design equation, which adopted in the current created CONPVD program, is listed below (Eq .1) for reader convenience. For more detail, the reader referred to 1993 AASHTO design guide or any related literature.

$$\log(W_{18}) = (Z_R \cdot S_0) + 7.35 \cdot \log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1 + \frac{1.624 \cdot 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 \cdot p_t) \cdot \log\left[\frac{S_c \cdot C_d \cdot (D^{0.75} - 1.132)}{215.63 \cdot J \cdot \left[D^{0.75} - \frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right] \quad \ldots (1)$$

3. CONPVD Software Program

3.1 CONPVD Overview and Embedded Design Process

The wide spread acquisition and use of personal computers that are capable of handling empirical design programs will also provide a much more user- friendly and practical design environment for the pavement designer .

The program evaluates required thickness for initial (new) rigid pavement design using the design models presented in 1993 AASHTO design guide. The AASHTO guide empirical method are valid for specific environmental , material and loading conditions.Hence the user (Trainer / Designer) is assisted in selecting various design input parameters.The researchers reported that CONPVD-93 was designes to be an educational and training tool as well as a thickness design tool. It is programmed and designed using MS-VBasic (ver.6.0) language. Both of Vbasic classical programming statements and the conjugate graphical user interfaces are adopted.

The 1993 AASHTO thickness design process did not depend on pavement type. CONPVD program can calculate the thickness for all those three rigid pavement types (JPCP , RJCP and CRCP) .Basically, the 1993 AASHTO probalistic equation can be solved for any of the variables as long as the others are supplied . Typically, CONPVD outputs are either total accumlated ESALs applications (Allowable & Applied) or the required slab thickness (Ds). In the programmed design process, the rigid pavement equation (Eq.1) is solved simultaneously with the rigid pavement ESAL equation. This numerical solution is an iterative process since both ESALs which a particular pavement can be supported (allowable) and the predicted (applied) 18 kip (80kN) ESAL (if axle load equivalency factor, ALEF, is adopted) are slab depth dependent.

Thereafter, the traditional design process was began by calculating the predicted 18kip-ESALs applications depending on projected slab depth and then comparing this estimated value with one obtained using Eq.(1) depending on the design inputs . The both should be reasonably close, otherwise a new different slab depth assumption should be considered and previous process should be repeated.

Actually, the current study demonstrates that there are no significant justifications for adopting the above iterative procedure. The successive applications of CONPVD with different projected slab depth values, showed just a slight effects on the final design depth. Therefore, just a unique value for projected slab depth is adopted for each program run. DARWin 3.1 program user manual also confirmed this behavior.

3.2 CONPVD Environmental Structure

CONPVD concrete pavement design program has been designed for both analysis (load carrying capacity) and thickness design calculations .This can be easly done by selecting the desired drop- down menu. The program consist of five menus namely File, Pavement Design, Calculate ESALs, Calculate Keff. and Help menu (see Fig.1). Pavement Design menu contains two items namely: Direct Design Mode and Detailed Design Mode. The Calculate ESALs menu contains the Allowable ESALs Mode and Predicted ESALs Mode. The No Seasonal Effect Mode and Seasonal Effect Mode are listed in the Calculate Keff. menu. Activating any mode leads to bring up the accompanying user interface window in which the required input parameters could be entered.Figures (2, 3, 4, 5, and6) show a typical screen shots from CONPVD windows.

CONPVD is directed to be a training and design tool for both highway managers and engineers. Hence, it is composed of amultiple friendly-user interfaces. In addition, the user has been assissted, along with the program, in selecting the suitable inputs based on embedded specified tables and design variable range guiding messages. These tables and pop-up messages data are drawn from AASHTO and related literature.

3.3 CONPVD Design Inputs and Outputs

Concrete pavement design is started by creating a new module within a project.The following are the user-defined parameters should be entered in the specified input box. The user assumed to be familiar with 1993 rigid pavement design method principles.

- **Analysis Period (T) :** CONPVD did not include stage construction procedure . The performance period could be adopted as an analysis period when no maintenance work be planned. The 1993 AASHTO guide recommended analysis period table is incorporayed in the program (see Fig.3).
- **Reliability Level (R): The** reliability value represents a safety factor with higher reliabilities representing pavement structures with less chance of failure. The 1993 AASHTO design guide present R-values in terms of Zr in tabular form. This table was listed in CONPVD (see Fig. 3).
- **Overall Standard Deviation (So):** This parameter represents the variability of the input values have been used. The AASHTO guide recommended range appears to user as a tool tip text. Higher values represent more variability; thus, the pavement thickness increases with higher overall standard deviations.
- **Serviceability Indices (Po and Pt):** For concrete pavement design, the difference between the initial and terminal serviceability (Pi and Pt) is the most important factor (ΔPSI). The recommended AASHTO values are listed in CONPVD as a tool tip text.
- **Load Transfer Coefficient (J):** The load transfer coefficient is used to indicate the effect of dowels , reinforcing steel , tied shoulders and tied curb and gutter on reducing the traffic loading stress.The coefficients table recommended in the AASHTO guide was listed in CONPVD (see Fig. 3).
- **Drainage Coefficient (C_d):** The drainage coefficient characterizes the quality of drainage of the subbase layers under the concrete pavement. The AASHTO Guide tabular values of C_d was listed in the program(see Fig. 3).
- **28-Day Mean PCC Modulus of Rupture (Sc)** : The concrete modulus of rupture is the extreme fiber tensile stress under a breaking load . The required input value is the mean value determined after 28-days using the third-points loading test (AASHTO, T97).
- **28-Day Mean Elastic Modulus of PCC Slab (Ec):** The AASHTO design equation also requires a value for the concrete elastic modulus. It is a measure of the rigidity of the slab.
- **Subbase Layer Thickness (Dsub.):** Th**e** base thickness is an indication of how much support material is available. It is used in the calculation of the composite k-value, which is an intermediate calculation step in the determination of the effective modulus of subgrade reaction (Keff.). 1993 AASHTO guide recommendations were enclosed in the program.
- **Mean Effective Modulus of Subgrade Reaction (k_{eff}.):** The effective modulus of subgrade reaction (Keff.) is a measure of the support provided to the concrete slab by the underlying layers. It should not be confused with the modulus of subgrade reaction for a roadbed soil material (K), which is typically determined through plate load tests. AASHTO (1993) design guide reported that for the case of a slab placed directly on the subgrade (no subbase), the modulus of subgrade reaction (uncorrected for loss of support and rigid foundation) is related to the roadbed soil resilient modulus (Mr) by the following theoretical equation:

$$K\ (psi / in) = Mr\ (psi) / 19.4 \quad \ldots (2)$$

CONPVD provides two methods to input K_{eff} .In the first method, the effective modulus of subgrade reaction (k_{eff}) can be directly input as a single value. While the second , the more rigorouser one , take in the considertion that the effective modulus changes as a function of : (1) the moisture content and temperature of the subgrade, (2) the thickness and elastic modulus of the subbase, (3) the depth from the slab to bedrock, and (4) the loss of support capability of the pavement. If multiple values of the resilient modulus of the subgrade and elastic modulus of the subbase are available, then these can be input and a single value will be output. The seasonal and non-seasonal effects K-windows can be accessed using Detailed Design Process mode (Fig.2) .Non-Seasonal Eff. mode or Seasonal Eff mode which listed in the Calculate Keff pull-down menu (see Fig.4) are also adopted for accessing these two modes directly.

AASHTO developed Eq.(3) for calculating the composite modulus of subgrade reaction (Kcomp) due to the presense of subbase layer, assuming semi-infinite roadbed soil :

$$\text{Log}(K_\infty) = -2.807 + 0.1253\,\text{Log}(D_{SB})^2 + 1.062\log(Mr) + 0.1282\log(D_{SB})\log(E_{SB})\ 0.4114\log(D_{SB}) - 0.0581\log(E_{SB}) - 0.1317\log(D_{SB})\log(Mr) \quad \ldots (3)$$

Where:

K_∞: Composite modulus of subgrade reaction assuming a semi-infinite roadbed soil, (Kcomp.) ,(pci)

D_{SB}: Subbase thickness (in.)

E_{SB}: Subbase elastic modulus (psi)

Mr: Roadbed soil elastic (resilient) modulus (psi).

Abo Shaeer (1996) and Al-Obaidee (2000) reported that Eq.(3) was apparently wrong as it can lead to unrealistic results completely different from those of Figure (3.3) of AASHTO Guide-1993.Therefore, Al-Obaidee presented the following equation :

$$\text{Log}(K_\infty) = -1.638 + 0.8878\,[0.1253\,(\text{Log}D_{SB})^2 + 1.062\log(Mr) + 0.1282\log(D_{SB})\log(E_{SB}) + 0.4114\log(D_{SB}) + 0.0581\log(E_{SB}) - 0.1317\log(D_{SB})\log(Mr)\,] \quad \ldots (4)$$

After verification, the researchers adopted the above equation in this work. Thereafter, to account the effect of rigid foundation near the surface if a bed – rock lies within 10 ft (3.28 m) of the surface has a significant length along the project, AASHTO guide developed the following equation:

$$\text{Log}(K_{rf}) = 5.303 - 0.071\log(D_{SG})\log(Mr) - 1.366\log(K_\infty) - 0.9187\log(D_{SG}) - 0.6837\log(Mr) \quad \ldots (5)$$

Where:

K_{rf}: Composite K-value (pci) considering the effect of rigid foundation near the surface, and

Kcomp: Composite K-value obtained from Eq. (2 or 4)

Abo-Shaeer (1996) again reported that the first constant in (Eq.5) is apparently wrong comparing with Fig. (3.5) listed in 1993 AASHTO design guide. She suggests this relation:

$$\text{Log}(K_{rf}) = 2.92 - 0.071\log(D_{SG})\log(Mr) - 1.366\log(K_\infty) - 0.9187\log(D_{SG}) - 0.6837\log(Mr) \quad \ldots (6)$$

Al-Obaidee (2000) used Eq.(6) directly in his work without any verification. The researchers in this work verified Abo-Shaeer's equation and found an unrealistic results completely different from those obtaining using Fig.(3.5) in 1993 AASHTO guide .Hence, they developed their own statistical model (Eq.7) using STATISTICA program (ver.5.5) based on multiple regression techniques. This model is a strong relationship with (R2 = 99.67 %). Figure (3.5) listed in the AASHTO guide was the source of the three inputted dependent variables, Mr, Drf and Kcomp (1359 input value for each one).

$$K_{rf} = 0.7025\exp(3.718 + 0.0834\log(D_{SG})\log(Mr) + 1.3267\log(Kcomp) - 1.0137\log(D_{SG}) - 0.5184\log(Mr)) \qquad R^2 = 99.67\% \quad \ldots (7)$$

Both Table (1) and Fig.(7) show the input and output come from the application of Eqs. (6 & 7) and AASHTO Figure. It is evident that there is a considerable convergence between this work developed model (Eq.7) and 1993 AASHTO Krf figure .Next equation (Eq.8) can be used to estimate relative damage Uri due to moisture for each season of the year:

$$U_{ri} = \left[D^{0.75} - \frac{18.42}{(Ec/Ki)^{0.25}} \right]^{b} \quad \dots (8)$$

Where:
D = Pavement slab thickness (in.)
Ki = Modulus of subgrade reaction (pci)
Ec = Concrete elastic modulus (psi)
b = 4.22 – 0.32 pt
Pt = Terminal serviceability index
The average relative damage is given in Eq.(9) , which is a function of seasonal relative damage and the number of seasons :

$$\overline{Ur} = \frac{\sum_{1}^{n} Uri}{n} \quad \dots (9)$$

Then, the effective modulus of subgrade reaction, Keff can simply be computed by replacing the (Uri) in Eq. (8) by the one obtained using Eq. (9).
Finally, loss of support factor (LS) essentially defines the size of the area of pavement slab, which experiences a complete loss of support due to erosion. AASHTO Guide-1993 represented a graphical correction for modulus of subgrade reaction for loss of support .Abo-Shaeer 1996, reported the below statistical models based on AASHTO graphical correlation.These models are adopted in this work after verified it.

$K= 0.89\ K_{eff}^{0.832}$ for LS = 1
$K= 0.804\ K_{eff}^{0.646}$ for LS = 2 , and … (10)
$K= 0.879\ K_{eff}^{0.492}$ for LS = 3

AASHTO Guide 1993, listed a table to estimate the loss of support value depending on types of material beneath the slab .This table is listed in CONPVD for pavement designer convenience.

- **18 kip (80kN) ESAL Over Initial Performance Period**

The design 18kip ESALs application are the accumulative number of different types of vehicles ,such as cars , buses , single –unit trucks and multiple –unit trucks,in terms of 18-kip ESAL expected to use the highway during its initial performance period.
CONPVD program consider the accumulative ESAL as a design input when Pavement Design Module menu is activated (Fig.2 &3). The program presents two options for calculating the cumulative predictied ESAL from traffic data. Predicted ESAL Mode item in the Calculate ESAL Module menu was created for direct access (see Fig.5). In the both option the program will ask the user to input some of the specific traffic data. Thereafter, the program will calculate the total predicted ESALs depending on the following equations reported by Garber (1997) based on AASHTO design guide principles:

$$ESAL_i = AADT_i * 365 * Gf * F_d * F_{Ei} * N_i \quad \dots (11)$$

$$ESAL_i = AADT_i * 365 * Gf * F_d * TF_i \quad \dots (12)$$

$$ESAL = \sum_{i=1}^{n} ESAL_i \quad \dots (13)$$

Where:
$ESAL_i$: Equivalent accumulated 18 Kip single axle load for the axle category i
$AADT_i$: First year annual average daily traffic for axle category i
Ni : Number of axles on each vehicle in category i
F_{Ei} : Axle load equivalency factor for axle category I (ALEF)
F_d : Design lane factor
G :Growth factor for a given growth rate (r) and design period ,and
TF_i : Truck factor for vehicles in truck category i

It is important to state that the accumulated ESAL for all categories of axle loads or truck is calculated using Eq.(13) .The AASHTO Axle load equivalency factor (ALEF) is defined as the damage per pass that caused to a specific pavement system by an axle relative to the damage per pass for a standard axle weighing 18 Kip (single axle load with a duel tire on each end). It also represents the number of 18 Kip single axle repetitions that will have the same effect on the pavement performance as that caused by one repetition of the given axle load. Equation (11) is devoted for this case. AASHTO statistical equations for computing ALEF were mensioned by Huang (Huang,1993) and had been implicitly listed in CONPVD program.

In contrast, if the axle load is unknown, then Eq. (12) shuld be adopted .At which the equivalent 18 Kip ESAL can be determined from the vehicle types by using a truck factor for these vehicle types from results of classification counts. The truck factor is defined as the number of 18 Kip single load applications caused by a single passage of a vehicle. Asphalt Institute (Asphalt Institute,1991), depending on statistical traffic data, suggest a table for distribution of truck factors (TF) for different classes of highways and vehicles in United States. This table was listed in CONPVD for designer use when local data is missed.

CONPVD adpot individual values for ALEF,TF and growth rate for each vehicle class .Hence , the resultant calculations is more precise projection of ESALs than these of some similar programs which adopt a single overall value for such factors.In addition, the program provide a separate ESAL calculations for each vehicle class (Eq.11 or 12) ,then finally totaled (Eq.13) . This procedure easly enable the users to identify those vehicle classes that make both significant and insignificant contributions to the overall ESAL's applications.

- **Allowable 18-kip ESALs**

The allowable 18-kip ESAL can be calculated as an output if the slab depth and other parameters are entered as a design inputs. This calculation can be accessed using Allowable ESALs Mode in the Caculate ESAL pull-down menu (see Fig.6).

- **Projected Slab Thickness (Dpro.)**

The projected slab thickness is an input in the calculation of thickness design (Detailed Design mode), predicted accumulated ESALs (ALEF mode), and the Keff. (Seasonal Effect mode). Inclusions of this input follows the procedure described in 1993 AASHTO guide. However, as stated previously, by substituting several different values for this variable, it can be seen that the effect of this input on the outputs is negligible. Holding other design variables as constants , Figs. (8,9 and 10) present a diagrammatic illustration for this conclusion.

- **Calculated Design Thickness**

The output of the convential design process is the thickness of the portland cement concrete slab. In a rigid pavement, this is the layer that is expected to carry most of the load. This process can be easly activated by clicking the Thickness Design Modes in the Pavement Design Module pull-down menu .Both the direct and detailed design modes are shown in figures (2&3) respectively.

4. CONPVD Program Verification

For checking CONPVD adequacy and proofing its accuracy, a comparative five design examples have been adopted. These examples were solved using 1993 AASHTO guide design charts and other three comuter-based solutions. The three programs were : RPDPBA software (Al-Obaidee , 2000) , AASHTO Pavement Design Spreadsheets (Smith ,1998) and 1993 AASHTO Empirical equation Solver (Washington DOT Training web-Page, 2005) .Table (2) and Fig.(11)showed obviously that the developed program have a quite realistic results .

5. Conlusions

1. CONPVD has proven very useful as an enhanced computerized version of the 1993 AASHTO thickness design method for rigid pavements.CONPVD is an effective educational tool as well as a powerful design tool.
2. By substituting several values for proposed slab thickness,Dpro , it can be observed that the effect of this input on the outputs is negligible. Holding other design variables constant, figures (8,9 and 10) present a diagrammatic illustration for this conclusion.
3. The step- by- step calculations can be seen in CONPVD desing process, so each intermediate step can be investigated rather just a final "black bos" answer.
4. The computerized design process calculations are more precise projection of ESALs, since individual ALEF, TF, and Gf were separatly applied for each vehicle class.
5. The user (genior trainer / pavement designer) can easly identify the vehicle classes that make both significant and insignificant contributions to the overall ESALs.
6. To account the composite K modulus for the presence of rigid footing within 10', equation (7) can be safly used.
7. The presence of the seasonal effect option in K_{eff} calculations give the flexibility to the user for simulating the real life environmental condition and hence more realistic results.

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Fig. (1): Screen prints for Admin (Maim Menus) window.

Fig. (2): Screen prints for Direct Design Process Mode window.

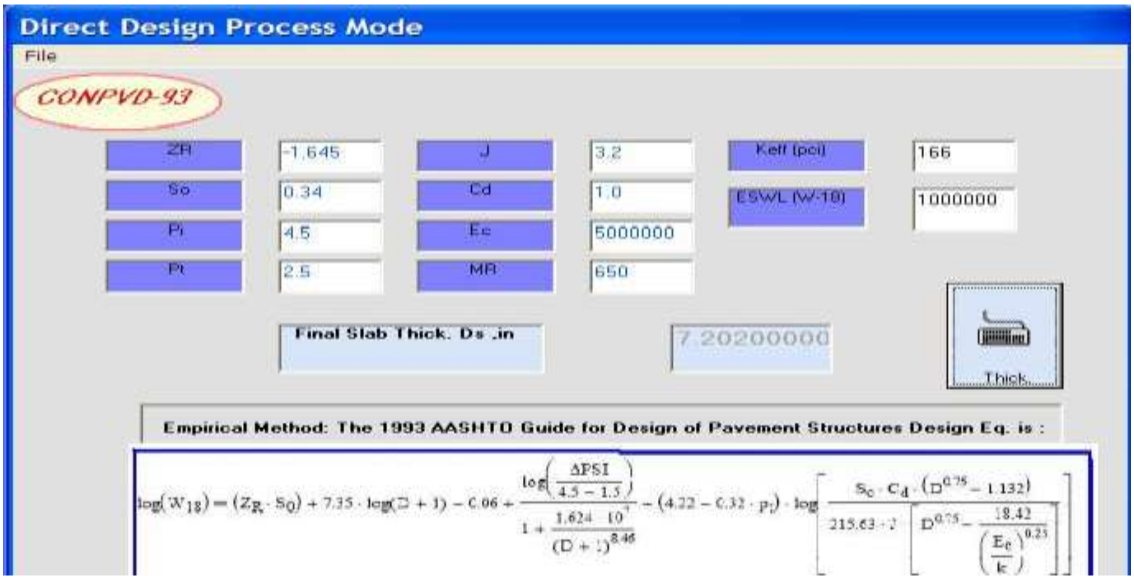


Fig. (3): Screen prints for Detailed Design Process Mode windows repectively.

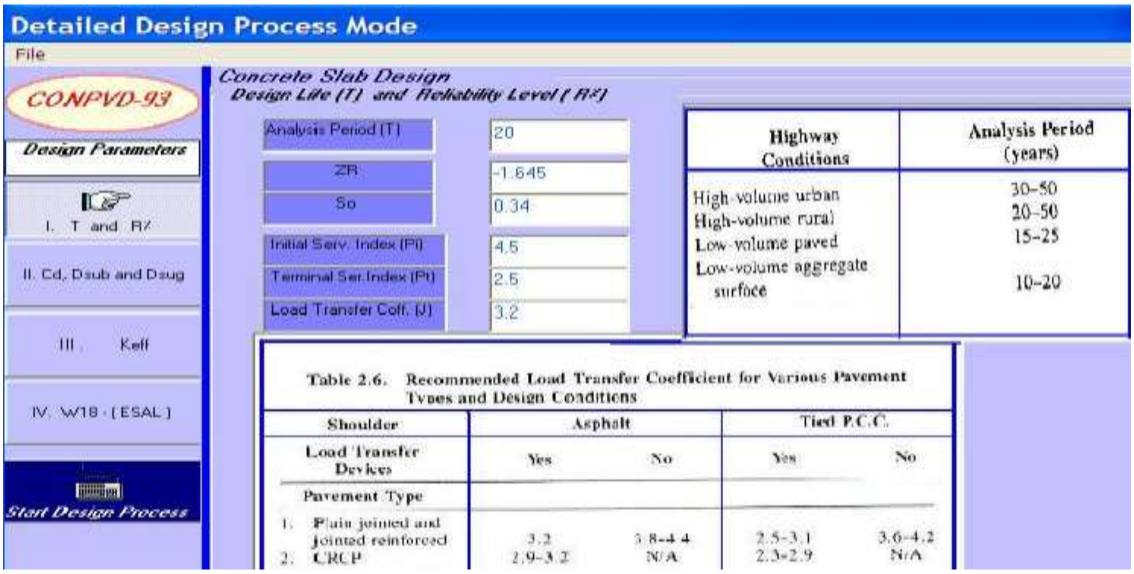
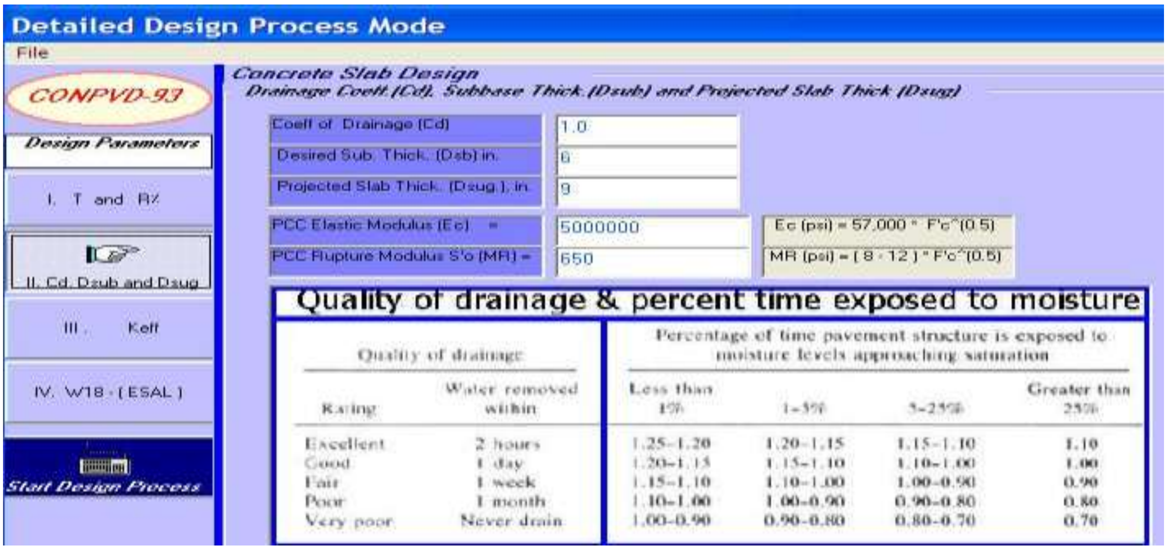


Fig. (3): continued



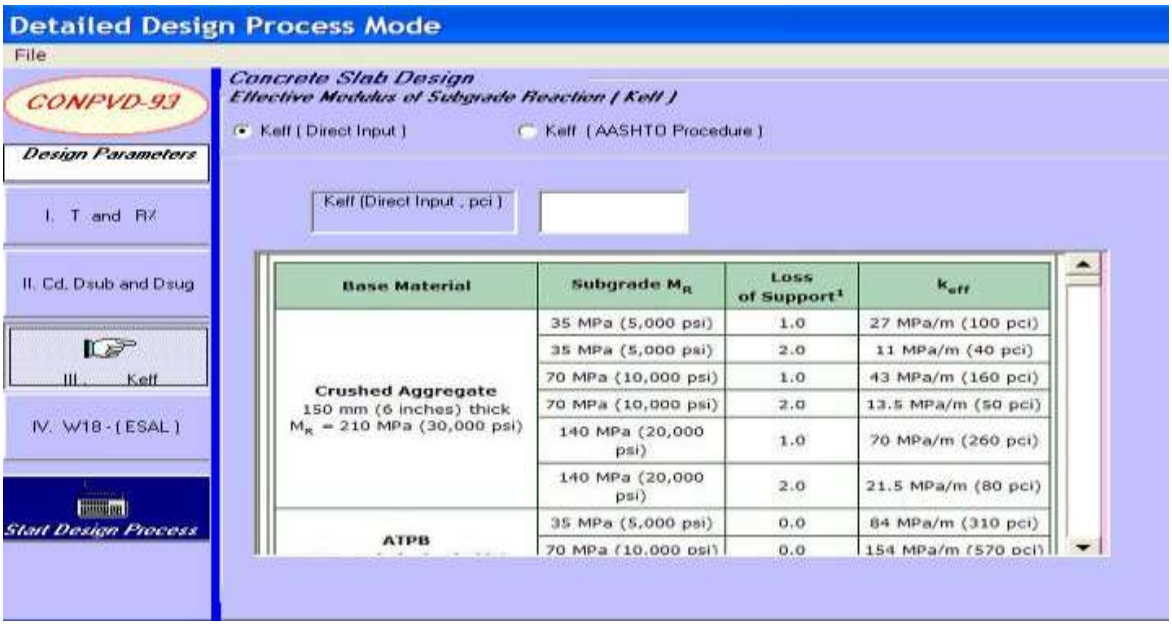


Fig.(3): continued

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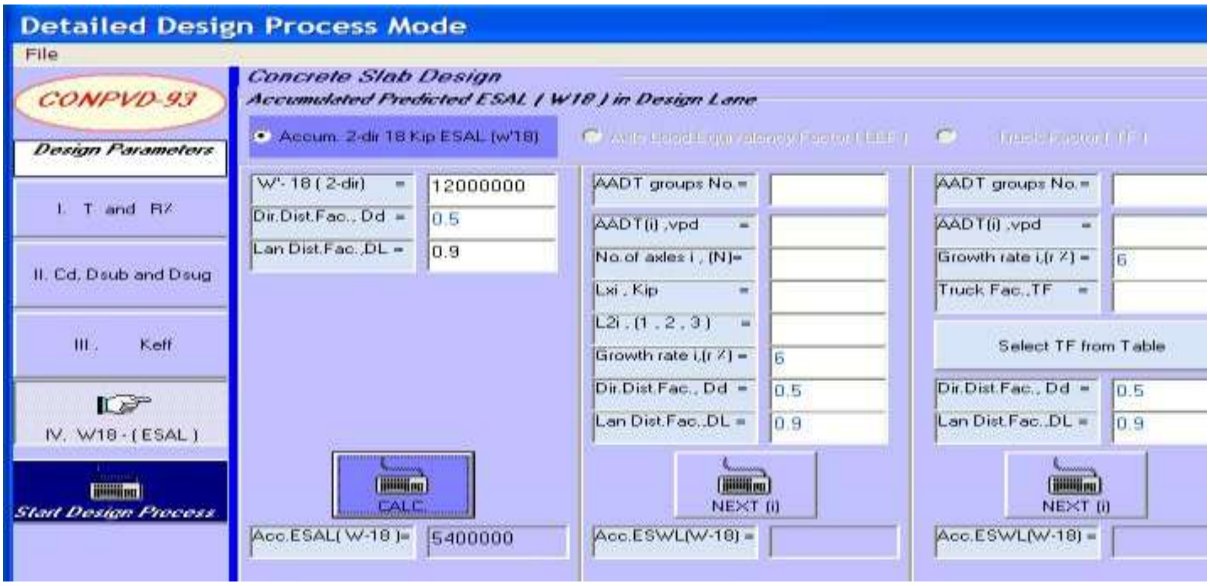


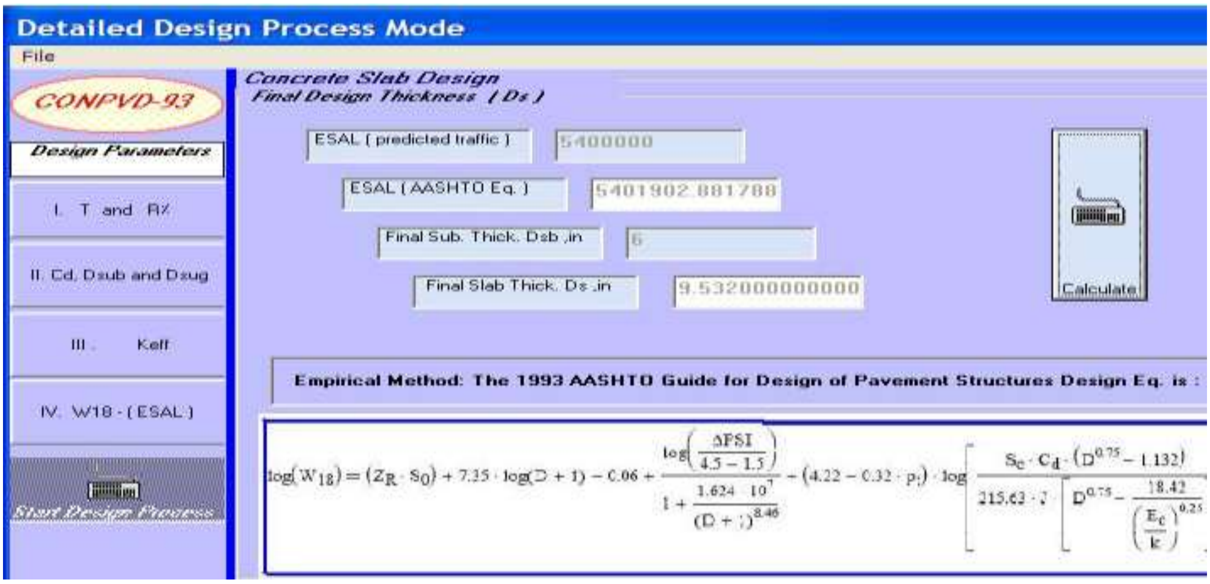


Fig. (4): Screen prints for K_{eff} Seasonal Mode window.

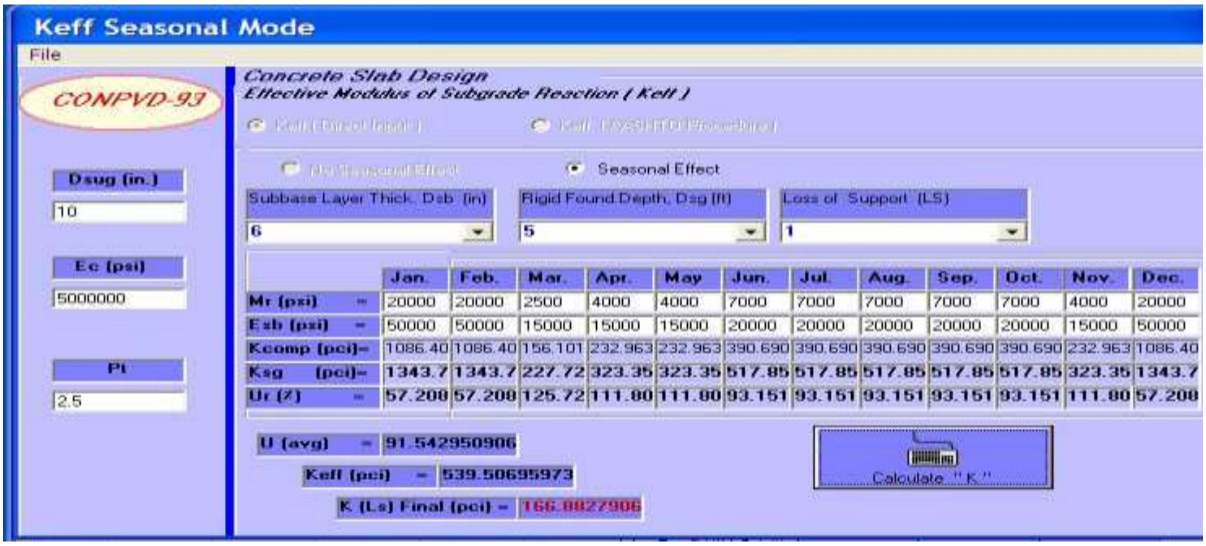
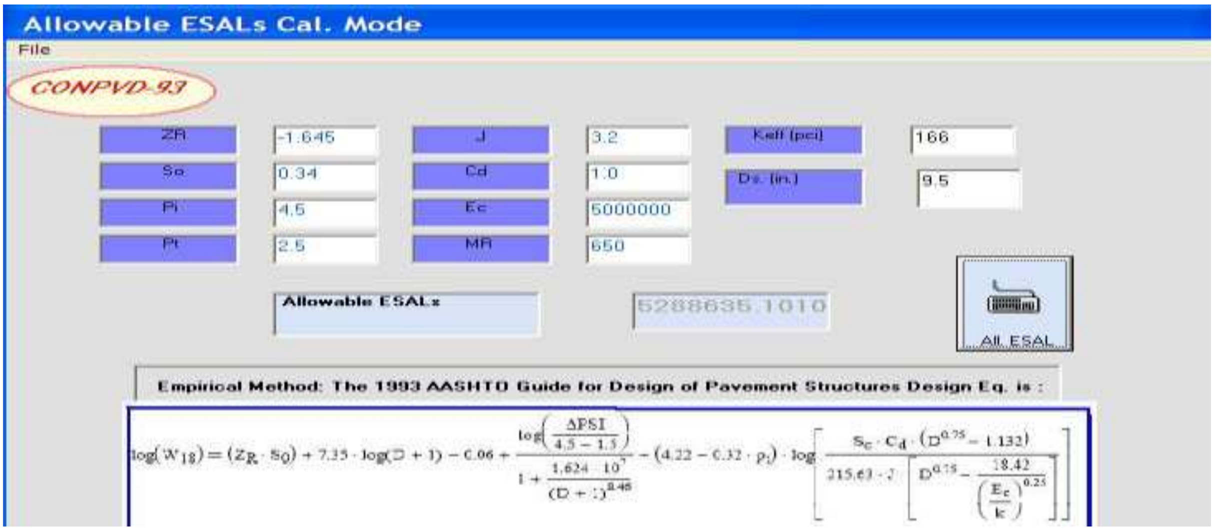
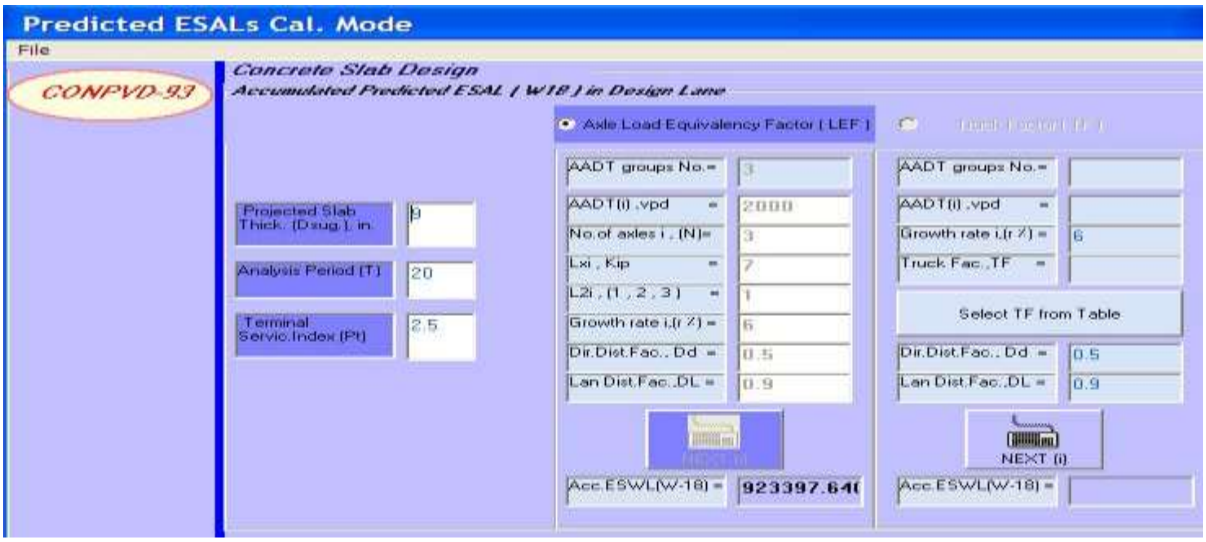


Fig.(5): Screen prints for Allowable ESWL Calculation Mode window.



$$\log(W_{18}) = (Z_R \cdot S_0) + 7.35\cdot\log(D+1) - 0.06 + \frac{\log\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624\cdot 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32\cdot p_t)\cdot\log\left[\frac{S_c\cdot C_d\cdot(D^{0.75}-1.132)}{215.63\cdot J\left[D^{0.75}-\frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right]}\right]$$

Fig. (6): Screen prints for Predicted ESWLsCalculation Mode window.



* AADT=12000 composed from : 50% Pc (1000 Ib / axle) , 33% 2axle Truck (5000 Ib / axle) and 17% 3axle Truck (7000 Ib / axle).

Table 1: Results of Krf-values obtained from AASHTO,Al-obaidy and developed models (AASHTO Example, PP. II-43)

Season no.	Mr (psi)	Kcomp (pci)	D_{rf} (in.)	AboShaeer Eq.(6)	AASHTO Figue(II,3.3)	Developed Model Eq.(7)
1	20000	1100	5	9.316	1350	1366
2	20000	1100	5	9.316	1350	1366
3	2500	160	5	5.959	230	235
4	4000	230	5	2.571	300	318
5	4000	230	5	2.571	300	318
6	7000	410	5	7.746	540	552
7	7000	410	5	7.746	540	552
8	7000	410	5	7.746	540	552
9	7000	410	5	7.746	540	552
10	7000	410	5	7.746	540	552
11	4000	230	5	2.571	300	318
12	20000	1100	5	9.316	1350	1366

Fig.(7): Results of Krf-values obtained from AASHTO, Al-obaidy, and the developed models (AASHTO Example, PP. II-43)

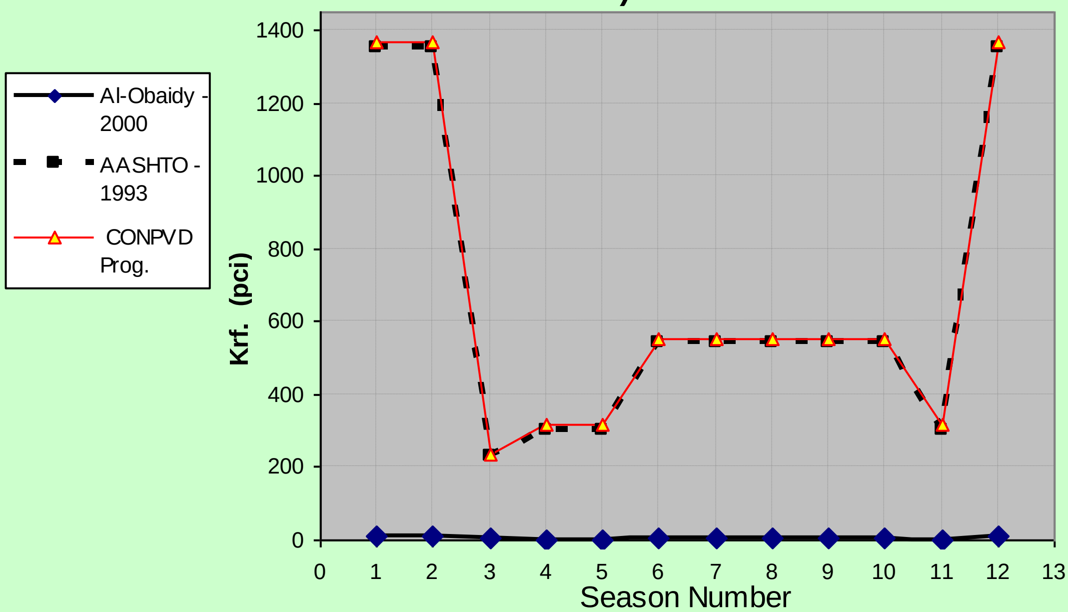


Fig.(8):The ESALs for different values of Dpro.

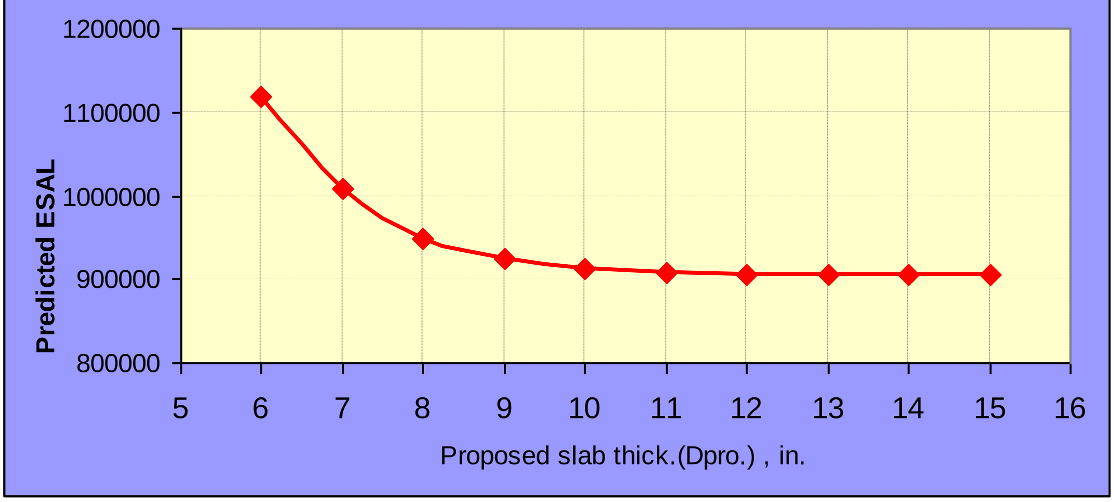


Fig. (9): Keff for different vaues of Dpro

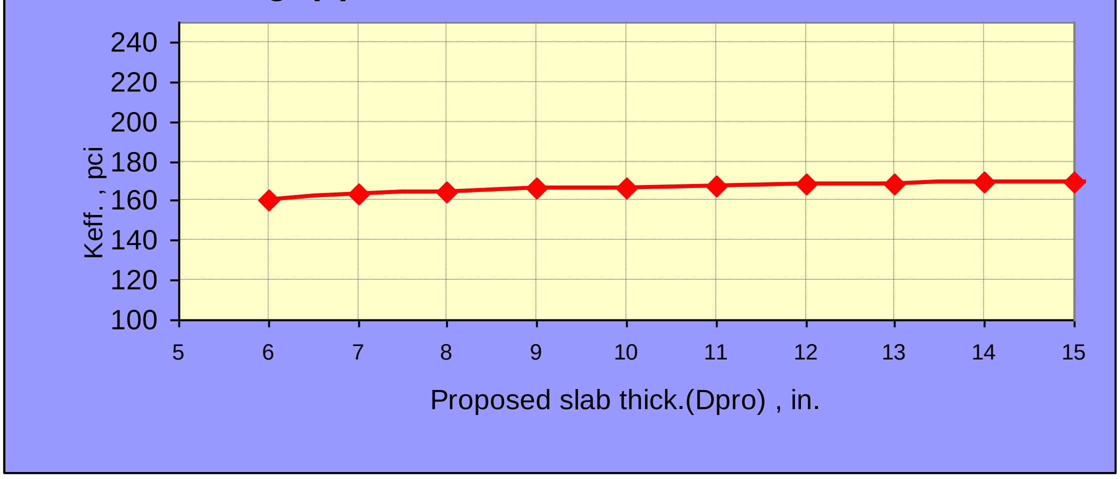


Fig.(10): The final effect of Dpro. on Dfin

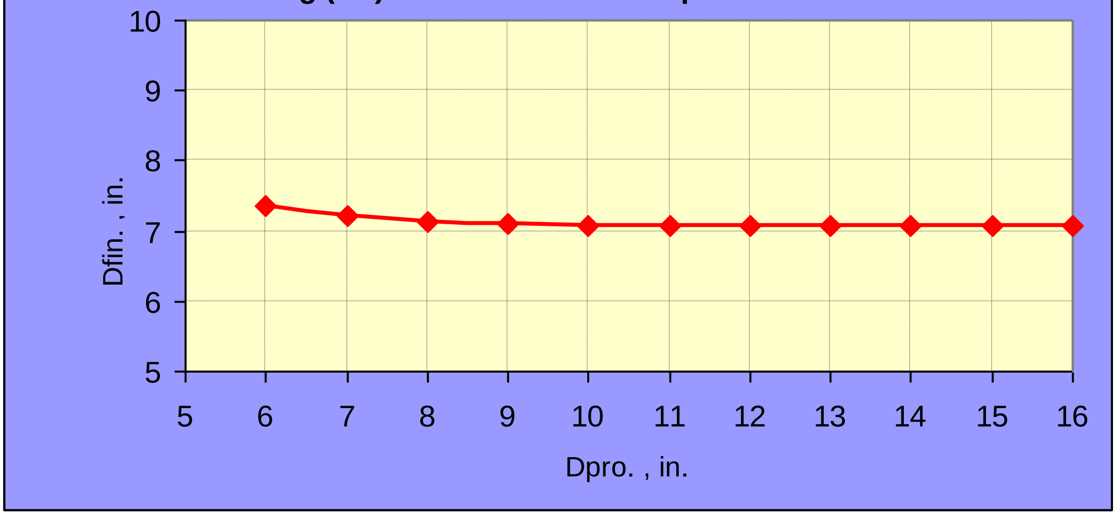


Table 2: Shows the Comparative results of the inputs and outputs five adopted design examples solving by different appraoches.

Deign Inputs and outputs	Design Problem No.				
	1	2	3	4	5
W18(ESAL)	5.1 E06	5.1 E07	5.0 E06	5.0 E06	3.0 E06
Keff(pci)	71	11.8	197	24.5	150
Cd	1	1	0.7	0.7	1
J	3.2	3.2	3	3.2	3.2
R(%)	90	90	90	90	90
So	0.29	0.37	0.37	0.37	0.37
Po	4.2	4.5	4.5	4.5	4.5
Pt	2.5	2.5	2	2	2
S'c(psi)	650	725	638	725	650
Ec(psi)	5.0 E06	5.0 E06	5.0 E06	5.0 E06	5.0 E06
T(mm) AASHTO Design Chart	238	320	263	278	200
T(mm) Al-Obaidee(2000)	248	333	264	265	189
T(mm) AASHTO Pavement Design Spreadsheets (1998)	235	334	261	270	205
T(mm) WSDOT Web-Page Training (199)	240	322	263	275	212
T(mm) CONPVD Program	238	332	265	274	205