Computer Software Development (Galal-M-RP) for Concrete Pavement Analysis and Design

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ABSTRACT -A computer expert system has been developed for structural design of rigid pavements entitled Galal-Muram Rigid Pavement (Galal-M-RP). The developed software program is a design package as well as educational and training tool. The user is assisted to select design inputs by a systematic rule-based expert. These rules are intended to determine AASHTO recommended values. These values are shown on the screen along with a brief explanation during the design process. Screens and various group boxes assist the user in selecting the design inputs. A sensitivity analysis option allows the user to confirm the required precision of the design inputs. The results obtained from this software were evaluated and compared to the manual design case study of Omdurman ring road, as well as with other design examples. They include examples by Huang; AASHO 1993 Guide and Kici, A. and Tigdemir, M. in 2017 applying user friendly software, in addition to lecture notes by Drakos in 2009 at University of Florida. Comparisons were found excellent with differences in pavement thickness ranging between 0.1 and 0.9 cm. Concrete pavement design software Galal-M-RP supersedes conventional design methods regarding errors and difficulties in addition to saving significant time.

Keywords: *Visual Basic; Rigid highway pavement; AASHTO thickness design method; case stud; Comparisons*

المستخلص– تم تطوير نظام برنامج حاسوب للتصميم الإنشائي للأرصفة الصلدة-Galal-Muram Rigid Pavement (Galal-M RP).البرنامج المطور عبارة عن حزمة تصميم وكذلك أداة تعليمية وتدريبية. كما أن البرنامج يساعد المستخدم في تحديد مدخلات التصميم عبر خبير منظم مبني على القواعد. وتهدف هذه القواعد إلى تحديد القيم المثالية من قبل دليل التصميم آشتو. يتم عرضالقيم المثالية على الشاشة مع شرح موجز أثناء عملية التصميم. وتساعد الشاشات ومربعات المجموعات المختلفة المستخدمة في تحديد مدخلات التصميم. كما يُمكن المستخدم من ضمان تأكيد الدقة المطلوبة لمدخلات التصميم. وقد تم تقييم النتائج التي تم الحصول عليها من هذا البرنامج ومقارنتها بدراسة حالة التصميم اليدوي لطريق أم درمان الدائري ، وكذلك مع أمثلة تصميم أخرى من مراجع مختلفة. وهي تشمل أمثلة من هوانغ في سنة 2004، دليل آشتو 1993 للتصميم ، Kici, A. وTigdemir, M. في سنة 2017 يطبقان برنامجًا سهل الاستخدام، بالإضافة الي محاضرة في جامعة فلوريدا من دراكوس في سنة 2009. تم الحصول على مقارنات متميزة مع وجود إختلاف يتراوح بين 0.1 و 0.9 سم. مما يؤكد ان برنامج تصميم الرصف الخرسانيّGalal-M-RP يفوق وسائل التصميم التقليدية فيما يتعلق بالأخطاء والصعوبات بالاضافة الى توفير كثيرمن الوقت.

INTRODUCTION

Rigid pavements are extensively used particularly in developed countries as superstructure slab element for highways, airports, industrial grounds, streets, parking areas etc. If properly designed and constructed, they are capable to serve for several years without major maintenance cost [1]. In terms of cost, initial cost for concrete pavement is higher than asphalt pavement. However, it needs less maintenance throughout its design life [2]. Sound engineering application plays considerably important role. This is because if pavement thickness is designated more than required, its initial construction cost will increase. In contrast, if the thickness of the pavement is thinner than it should be, maintenance cost will increase. Thus, maximum effort should be exercised in designing concrete pavements [3]. Using concrete pavement reduces construction cost by 10 to 35 percent depending on subgrade strength and cumulative equivalent single axle load (CESAL) compared to flexible pavement. The latter is known to be dominating and commonly adopted in Sudan [4].

Design methods used for concrete pavements are generally based on mechanical and experimental sources. Experience is also another source used to design concrete pavements. Thus, because of variations in the sources of concrete pavement design to be taken into account, it is relatively complicated compared to flexible pavement design [5]. AASHTO 1993 method is the pioneer design method continued to be used for years by both designers and researchers [6].

Recently Mechanistic–Empirical Pavement Design Guide (MEPDG) was introduced [7]. It is the outcome of years of work, carried out by AASHTO Joint Task Force on Pavements. The effort was in cooperation with National Cooperative Highway Research Program and FHWA [8]. It was intended to eliminate the limitations of AASHTO (1993) method and provide a pavement design methodology on the basis of engineering mechanistic–empirical procedure.

Local experience regarding computerized pavement design was conducted by Ali and Muram entitled GalalM-RP. This software was intended to design highway rigid pavements based on Portland cement Association method PCA.
Although programs were developed for rigid pavement design guide, the designer might find it difficult to comply with the required instructions. Additionally, rigid pavement designer finds it confusing to identify different scenarios in order to determine the right slab thickness. Furthermore, considering application of these scenarios, determination of concrete slab thickness cannot be always easily achieved.

This is due to several detailed and complicated computations using formulas associated with design methods. Another aspect leading to difficulty is misreading numerous tables, charts and various nomographs in order to determine design thickness. Designers who carry out these computations manually may face difficulties or make mistakes during the design process [9].In many cases this might ultimately lead to road failure. Thus, there is need to develop a user-friendly software for design of concrete pavements. Various types of software were developed by AASHTO are expensive and rarely used. Hence, the current research was conducted to address this problem by developing software using Visual Basic net Microsoft language. This would enable programming, designing, computing, saving, and making installable format of the program besides other features.

Visual basic is the most widely used computer language. Rapid Application Development (RAD) is the process of rapidly creating an application. Visual Basic provides powerful features such as graphical user interface, events handling access to Win 32 API, object-oriented features, error handling, structured programming and much more.

Development of software computer program was worth studying and applying as it proved to provide reliable solutions.

Methodology

Rigid Pavement Design Methods

Various methodologies have been developed for the design of rigid pavements, the majority of which are semi-empirical and mainly based on results from experimental pavements.

All pavement design methodologies assume that rigid pavement failure due to load related distresses occurs at the end of the design period [10]. The first trial for rigid pavement thickness design based on fatigue process was by Portland cement Association [11]. The method relied on Older's empirical equations (1924) for computation of induced stresses at the corner of a concrete slab subjected to a wheel load [12].

Portland cement Association revised the original method in 1951 based on the results of several research projects conducted in several USA states. In this revision, Pickett's equations were taken into consideration for stress calculation at concrete slab corner [13]. Consequently, the effects of slab thickness, wheel load, tire contact area and modulus of subgrade reaction were taken into account in PCA method. While fatigue failure modes were also considered earlier, new data on fatigue curve, showed static loads affect concrete pavement stress more than moving loads. Pickett-

Ray influence charts were subsequently taken into account in PCA method, published in 1966.

In 1972 AASHTO published pavement design guide based on evaluation of results from road tests conducted by state highway agencies [14]. The concept of equivalent single axle load (ESAL) was introduced to simplify the design Procedure in AASHTO method.

Results of Packard and Tayabji (1985) on concrete highway and street pavements design were then taken into account and for the first time the concept of erosion was considered in concrete pavement damage evaluation [15].

AASHTO 1993Rigid Pavement Design Method

AASHTO 1993 pavement design method is based primarily on empirical models developed from field performance data from AASHTO Road Test (ART). ART included a series of experiments designed to determine how traffic loading contributed to pavement deterioration and loss of serviceability. The last major experiments carried out between 1958 and 1960 in Ottawa, Illinois, set the basis for AASHTO Interim Design Guide published in 1972 [14].

A subsequent version entitled AASHTO Guide for Design of Pavement Structures was published in 1986 including a number of notable additions to the method. The major additions included improved materials characterization. AASHTO 1993 Guide further improved and upgraded the method by including rehabilitation design considering drainage and environmental conditions. The basic procedure of AASHTO 1993 rigid pavement design is similar to flexible pavement design with a number of required design input parameters. AASHTO 1993 method applies Equation (1) for design of rigid pavements [6].

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

Where:

w_{18}	the number of 18-kip (80-kN) single-axle load applications
Z_R	Normal deviate for a given reliability R
S_O	Overall Standard Deviation
D	Slab Thickness in Inches
ΔPSI	present serviceability index
P_t	the serviceability at time t
S_c	Modulus of Rupture of Concrete
C_d	Drainage coefficient
J	Load Transfer Coefficient
E_c	Elastic Modulus
k	Modulus of subgrade Reaction

Figure 1 is a Nomograph for solving design Equation (1).

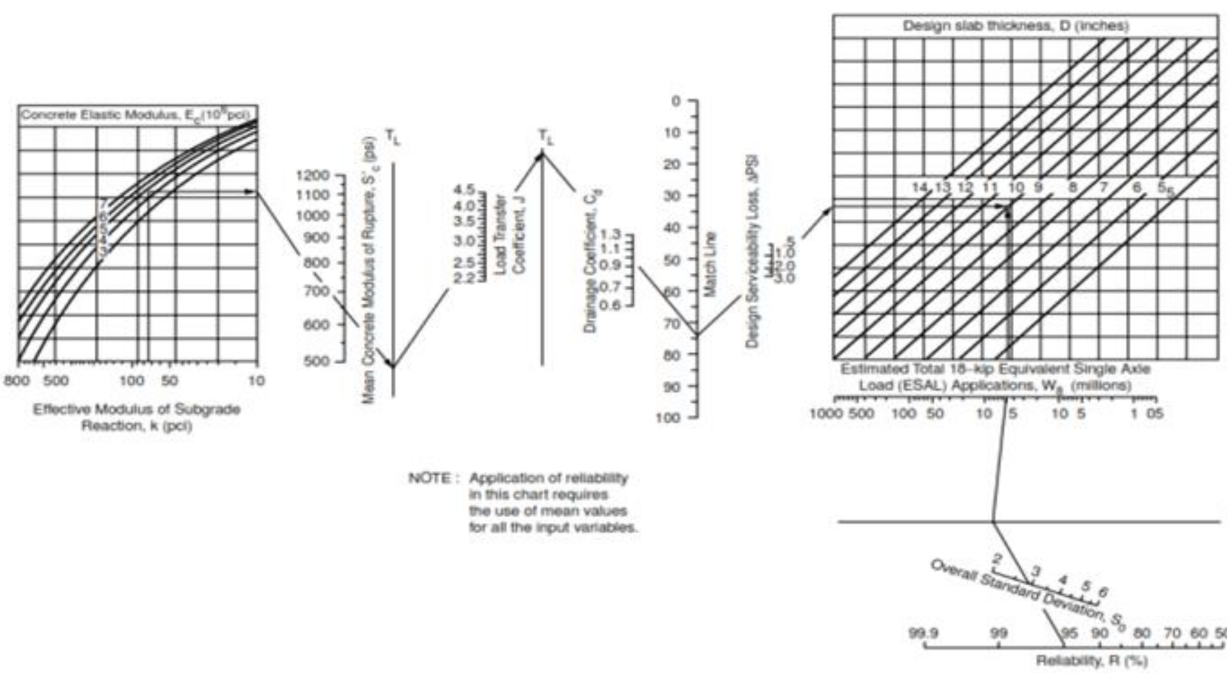

Figure 1: Design chart for rigid pavements based on mean values (1 in. = 25.4 mm, 1 psi = 6.9 kPa, 1 pci = 271.3

kN/m³). (From the AASHTO Guide for Design of Pavement Structures. Copyright 1993. American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)[6]

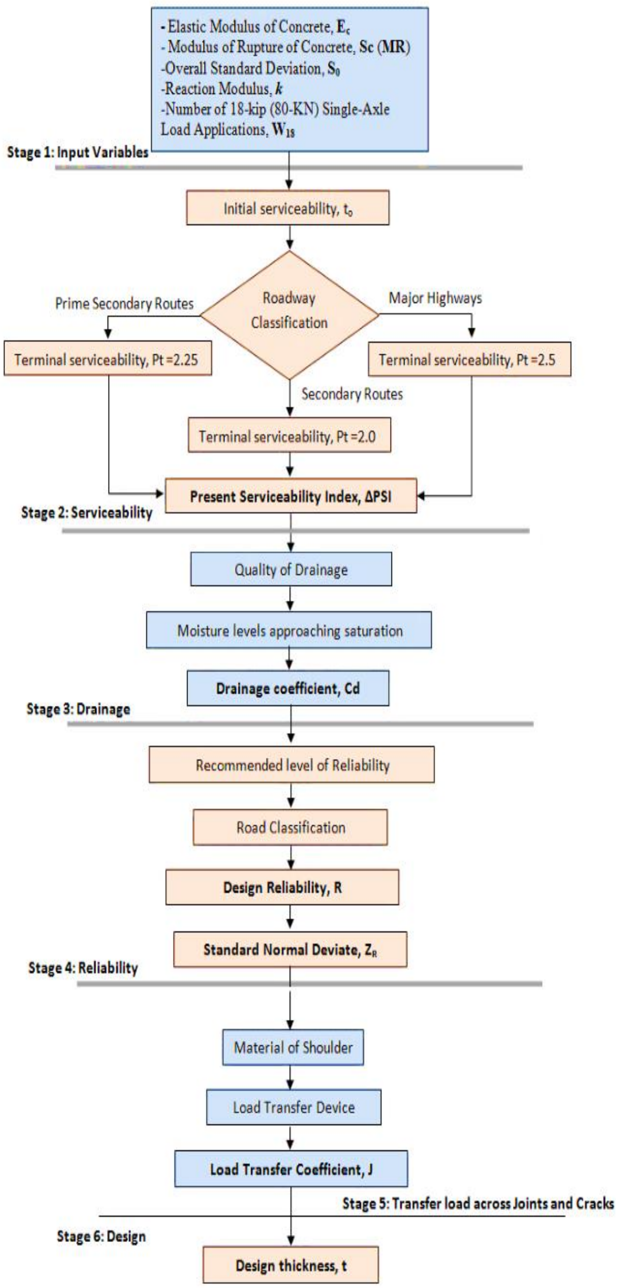

Figure 2: Conceptual Flow Diagram of the Main

Development of Computer Software Program

Background

Galal-M-RP computer program was written in Visual Basic and can be run on computers with visual studio 2008 Windows 95 or higher. Galal-M-RP has been developed for design thickness by American Association of State Highway and Transportation Officials (AASHTO) and applies only to highway rigid pavements.

Program for AASHTO 1993 Design Method

To facilitate entering and editing data, some tables and charts can be used. The program uses menus and data entry tabs to create and edit the data file. Although the large number of input parameters appears overwhelming, default values are provided to many of them, so that only a limited number of inputs will be required.

AASHTO design concrete pavement computer screen is divided into six group boxes as follows:

- Group box one: Input Variables
- Group box two: Serviceability
- Group box three: Drainage
- Group box four: Reliability
- Group box five: Transfer load Across Joints and Cracks
- Group box six: Design

The program described in this paper was applied to several examples to test its accuracy and suitability for the proposed applications. A case study was selected to include all software applications in the area of pavement design.

Main Screen

Galal-M-RP was designed with screens and windows of the program operated by clicks and mouse light movement (Figure 3).

To open a new file click;

File ⟶ New Design ⟶ New Design Highway ⟶ AASHTO

Figure 3: Main Screen

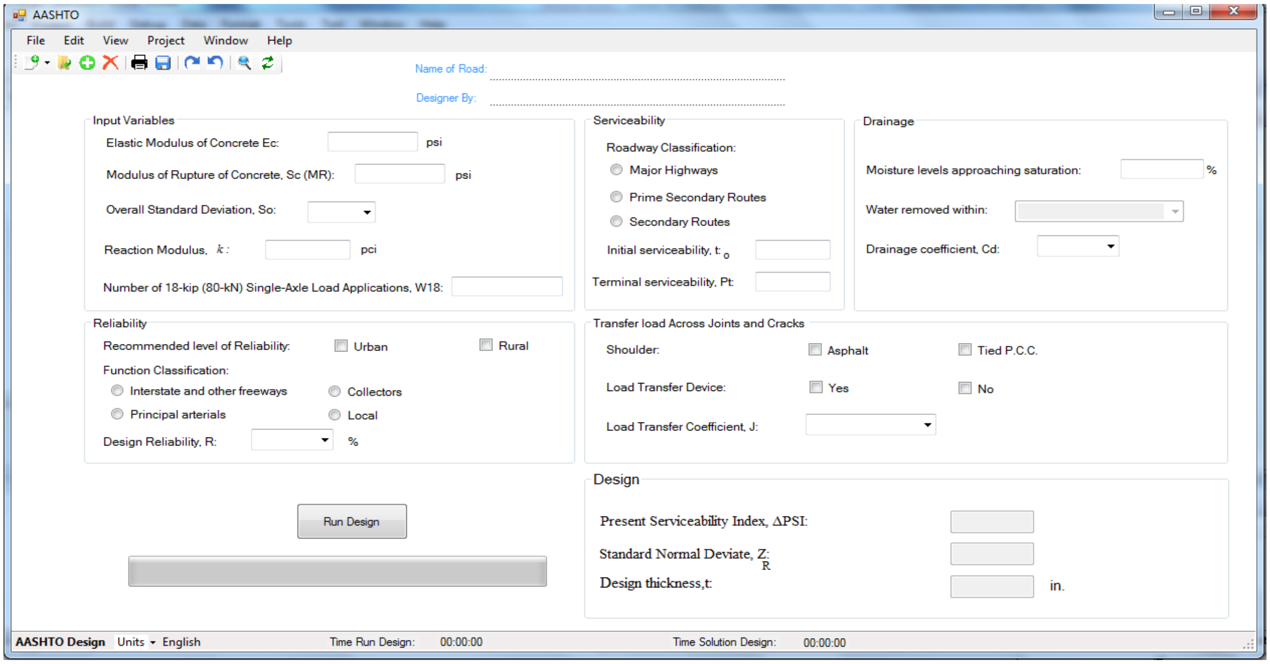

Figure 4: AASHTO Screen

AASHTO Screen

Galal-M-RP window of main screens appears immediately after screen one. This window allows the user to enter all inputs regarding materials, serviceability, reliability and drainage. It also transfers load across joints and cracks. When the user presses a button run design, the program carries out the following computations (Figure 4):

- Design present serviceability index, ΔPSI.
- Standard Normal Deviate, ZR.
- Design thickness, t.

Results and Discussion

Once the software was developed the input data were collected to test the software for accuracy and authenticity.

The compiled data were put in the software and the results were obtained. The same data used in the design through manual and AASHTO method. The results were compared with those obtained from the software. In case of any error or mistakes, necessary measures were taken and changes made to remove errors. Both results were taken and compared to find satisfactorily accurate results.

Comparison of thickness design between Galal-M-RP and reference design thickness for AASHTO design method is provided in (Table 1) and (Figure 5).

TABLE 1: COMPARISON OF THICKNESS DESIGN BETWEEN GALALM-RP AND REFERENCE DESIGN THICKNESS

Reference Example	**(Huang, Y. H., 2004)**	**Case Study: Omdurman Ring Road**	**(AASHTO, 1993)**	**SDU.Pave. R Software**	**(Drakos, C.,2009)**
input					
E_c (GPa)	34.5	34.5	34.5	41.4	34.5
S_c (MPa)	4.5	4.1	4.5	4.5	4.5
S_o	0.29	0.30	0.29	0.30	0.30
k (MN/m^3)	19.5	81.4	86.8	19.8	19
W_{18}	5 .10 x 10^6	7.72 ×10^6	4.60 x 10^6	6.00 x 10^6	5.00 x 10^6
t_o	4.2	4.5	4.5	4.2	4.5
P_t	2.5	2.5	2.5	2.6	2.8
C_d	1	1	1	1	1
J	3.2	3.2	3.2	3.2	3.3
R (%)	95	92	95	95	95
output					
ΔPSI	1.7	2	2	1.6	1.7
Z_R	-1.645	-1.405	-1.645	-1.645	-1.645
Galal-M-RP Software Design thickness, t (cm)	24.3	24.7	22.0	25.4	25.2
Reference Design thickness, t (cm)	24.7	24.6	22.9	25.7	25.1
Difference (cm)	±0.4	±0.1	±0.9	±0.3	±0.1

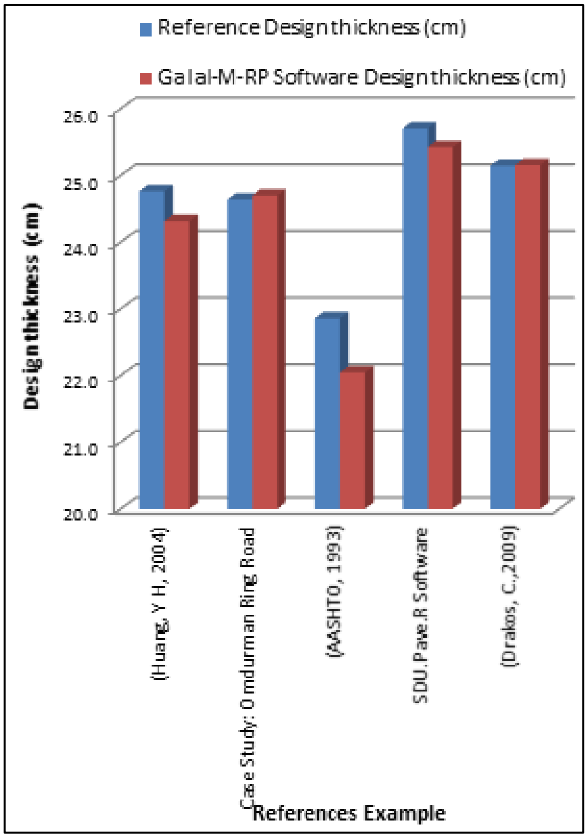

Figure5: Comparison between Reference Solution and Galal-M-RP Software Design Thicknesses

Conclusions

By comparing the various results of each reference design with Galal-M-RP results, the following conclusions are warranted:

A computer program (Galal-M-RP) in Visual Basic was developed which was not easy consuming considerable effort and time. Galal-M-RP program proved to possess simplicity with comprehensiveness in treating and translating design AASHTO procedure to computer application.

Comparison of the program results with the references -computational designs were very favorable, varying with differences ranging between 0.1 and 0.9 cm.

According to the references design thicknesses and Galal-M-RP Software design thickness used in the study and the favorably comparative results, it is justifiable to conclude Galal-M-RP program can be confidently used to design highway concrete pavements.

In the expert system, rules are shown to the user as they “fire”. This helps each user to understand the reason why certain values are chosen. Step-by-step computations are visualized such that each intermediate step can be recognized prior to final result.

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REFERENCES

[1] Delatte, N. J., (2014). “*Concrete Pavement Design, Construction, and Performance*”, CRC Press.

[2] Milind V. and Kadam K.N., (2016). A Comparative Study on Rigid and Flexible Pavement: A Review, IOSR Journal of Mechanical and Civil Engineering, Volume 13, Issue 3 Ver. VII (May-Jun. 2016), PP 84-88.

[3] Kici, A and Tigdemir, M., (2017). A User-Friendly Software for Rigid Pavement Design, International Journal of Engineering & Applied Sciences (IJEAS), Vol.9, Issue 4, 1-16.

[4] Ali, G. A. and Akasha, N., (2016). Investigation of Using Concrete Pavements in Developing Countries: A Case Study for Conditions of Khartoum State in Sudan, SUST Journal of Engineering and Computer Science, Vol. 17, No. 1.

[5] AASHTO, (1986). *Guide for Design of Pavement Structures*, Washington DC, American Association of State Highway and Transportation Official.

[6] AASHTO, (1993). AASHTO Guide for Design of Pavement Structures, Washington, DC: American Association of State Highway and Transportation Officials.

[7] AASHTO, (2008). Mechanistic-Empirical Pavement Design Guide (MEPDG). Washington, DC: American Association of State Highway and Transportation Officials.

[8] NCHRP, (2004). Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, 1-37A. National Cooperative Highway Research Program, Transportation Research Board, Washington DC: National Research Council.

[9] Ali, G. A. and Mohammed, M., (2017). Development and Application of a Computer Program for Structural Design of Rigid Highway Pavements applying PCA method, 8th International Conference on Structural Engineering and Construction Management, Kandy, Sri Lanka.

[10] Nikolaides A., (2015). “*Highway Engineering Pavements Materials and Control of Quality”,* CRC Press.

[11] Portland Cement Association, (1966). "*Thickness Design for Concrete Pavements"*, Skokie, IL: Portland Cement Association.
[12] Yousefi, M., (2007). "*Response of Concrete Pavements Under Moving Vehicular Loads and Environmental Effects*", PhD. Dissertation, Centre of Built Environment and Engineering Research, Queensland University of Technology, Australia, Supervisor David P. and Nataatmadja, Andreas.
[13] Pickett, G., and Ray G. K., (1951). Influence Charts for Concrete Pavements, Transactions, *ASCE*, Vol. 116.
[14] AASHTO, (1972). AASHTO Interim Guide for Design of Pavement Structures, Washington, DC: American Association of State Highway and Transportation Officials.
[15] Packard R. G. and Tayabji S. D., (1985). New PCA thickness Design Procedure for Concrete Highway and Street Pavements, Concrete Pavement & Rehabilitation Conference, Purdue, USA.
[16] Drakos, C, (2009). Lecture Notes, University of Florida, published.
[17] Huang, Y. H., (2004). *Pavement Analysis and Design*, 2nd Ed, Pearson Prentice-Hall, USA.