Available online at www.ejournals.uofk.edu

UofKEJ Vol.4 Issue 2 pp. 25-32 (August-2014)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UofKEJ)

Initial Cost Comparison of Rigid and Flexible Pavements Case Study: Khartoum State

Tarig O. Medani, Abubakr S. Ziedan, Ahmed G. Hussein

Ministry of Infrastructures and Transportation, Khartoum State
Khartoum, Sudan (E-mail: drtarmed@gmail.com)

Abstract: In Sudan, only flexible pavements are used despite some doubts regarding their economic value under different conditions. In this paper, the properties and design of cement concrete rigid pavement and flexible pavement were described. The initial costs of both types of pavements were compared, based on the prices of the Ministry of Infrastructures and Transportation, Khartoum State. While the soil sub-grade and traffic loading govern the pavement design, the material composition is the most relevant factor in the comparison. Although only the initial cost was used for the comparison, it was found that rigid pavements were more economical than flexible pavements regardless of subsoil conditions for traffic volume less than 3,000,000 ESAL. The preference of rigid pavements will definitely be more beneficial when the total life cycle cost is considered. It is advisable for road authorities to develop parametric guidelines regarding the selection of pavement type.

Keywords: *Initial cost comparison; Flexible pavement; Rigid pavement*

1. INTRODUCTION

Historically, pavements have been divided into two broad categories, rigid and flexible. These classical definitions, in some cases, are an over-simplification. However, the terms rigid and flexible provide a good description of how the pavements react to loads and environment.

Flexible pavement consists of various layers of granular materials, topped by a wearing surface of bituminous materials. Rigid pavements are made up of cement concrete and may or may not have a base course between the pavement and subgrade. The essential difference between the two types of pavements, flexible and rigid, lies in the manner in which they distribute the load over the subgrade. Rigid pavement, because of concrete's rigidity and stiffness, tends to distribute the load over a relatively wide area of subgrade. The concrete slab itself supplies a major portion of the rigid pavement's structural capacity. Flexible pavement, inherently built with weaker and less stiff material, does not spread loads as well as concrete. Therefore, flexible pavements usually require more layers and greater thickness for optimally transmitting load to the subgrade.

One further practical distinction between concrete pavement and asphalt pavement is that concrete pavement provides opportunities to reinforce, texture, color and otherwise enhance a pavement, which is not possible with asphalt. These opportunities allow concrete to be made exceedingly strong, long lasting, safe, quiet, and architecturally beautiful. Concrete pavements on average outlast asphalt pavements by 10-15 years before the need of rehabilitation [1]. The comparison between typical properties of flexible and rigid pavements is shown in Table 1.

Regarding the selection of pavement type, in the literature, there is really no consensus about a standard methodology that would best fit a project [2]. Because of the large-scale business in pavement construction, each industry defends the type of pavement of its preference. Newcomb [3] stated that primary factors affecting pavement type selection include traffic, soil characteristics, weather, and construction considerations. Newcomb stated that the pavement type selection process must be a rational process, based not only on financial costs but on facts concerning performance, cost of the pavement structure, speed and timing in construction, safety, and realistic maintenance and rehabilitation schedules. In his opinion, asphalt pavements offer specific advantages when compared to concrete ones.

In 2005, the Asphalt Pavement Alliance (APA) presented a synthesis on pavement life-cycle cost studies using actual cost data. According to the study, hot mixed asphalt (HMA) pavements have lower costs comparer PCC pavements by 10 to 25 percent in both initial construction costs and life-cycle costs [4]. However, there is no mention of user costs in the analysis. On the other hand, The American Concrete Pavement Association (ACPA) states that concrete pavements are a better choice than asphalt pavements, because they have advantages in several areas including

Table 1. Comparison between properties of rigid and flexible pavements

Property	Flexible pavements	Rigid pavements
Deformation in the sub grade is transferred to the upper layers	yes	no
Design is based on	load distributing characteristics of the component layers	flexural strength or slab action (rigid)
Flexural strength	low	high
Load transfer	grain to grain contact	flexural action
Construction cost depends on subgrade strength and traffic loading	yes	yes
Repairing cost	high	low
Life span	shorter	longer
Surfacing can be laid directly on the sub grade	no	yes
Thermal stresses	not critical	critical
Expansion joints needed	no	yes
Vehicles Fuel consumption	more	less

safety, durability, smoothness, versatility, and value. On safety, providing better visibility, reduced wet spray since concrete never ruts, and provides the best traction grip. On durability, concrete hardens over time, and outlasts flexible materials since their average life span is 30 years. On smoothness, concrete stays smoother longer, creating safer, comfortable transportation surfaces and saving fuel. On versatility, concrete pavements can be (1) designed to last from 10 to 50 years, (2) used to rehabilitate old asphalt pavement using white topping, or (3) used to rehabilitate a worn concrete pavement. On value, concrete pavements provide the best long-term value due to their longer life. They are easy to repair, and can be built and opened to traffic in less than 12 hours [5].

In 2002, ACPA published a guide for comparing alternate pavement designs using Life-Cycle Cost Analysis (LCCA). The guide describes the LCCA process factors that influence the results including agency costs (initial cost, maintenance and rehabilitation costs, salvage value), user costs (delay of-use costs, roadway deterioration costs, and accident crash cost), discount rate, selection of rehabilitation activities, use of comparable sections, and length of the analysis period. Present worth (PW) and the equivalent uniform annual cost (EUAC) reported as economic indicators used to express LCCA results. Asphalt Pavement Alliance (APA) recommends EUAC because all costs are expressed in terms of an annual cost over the analysis period. The guide also presents a brief summary of the life-cycle cost and performance studies conducted with historical data in USA. According to these studies, concrete sections lasted between 1.6 and 2.6 times longer than the asphalt sections and were from 14 percent to 250 percent more effective than the asphalt pavements [6].

To this end, as the cost of bitumen, the main ingredient in flexible pavement can change dramatically [7]. However, a clear methodology for selection of pavement type should be identified or developed by local Road Authorities The selection of the type of pavement, flexible or rigid, should not only be based on the initial cost of construction, which mainly depends upon the pavement thickness, governed by the strength of subgrade soil and traffic loading, costs of materials and cost of execution of the work. But, life cycle cost, which includes the discounted maintenance and pavement strengthening costs incurred during the design life of pavement. Other factors which should be considered in the economic analysis for the comparison of the pavement type should cover road user costs and the expected salvage value at the end of the analysis period [8]. It is worth mentioning here that there are models used to estimate user costs, including vehicle operating costs e.g. The Highway Design and Standards Model (HDM) developed by World Bank. Relations for predicting vehicle speed, fuel consumption, and tire wear are based on principles of vehicle mechanics. HDM was formulated for use in developing countries to estimate user costs [9].

In Sudan, flexible pavement is widely used for almost all national and urban road types, despite some doubts regarding their economic feasibility under different conditions. Furthermore, there are no guidelines or protocols for the selection of pavement alternates.

2. MATERIALS AND METHODS

2.1 Pavement Design

The major factor considered in the design of rigid pavements is the structural strength of the concrete. For this reason, minor variations in subgrade strength have little influence upon the structural capacity of the pavement. The main factor considered in the design of flexible pavements is the combined strength of the layers. In this initial cost comparative study of flexible and rigid pavement, the AASHTO 1993 procedure [10] was used for the design of rigid and flexible pavements. For flexible pavement, the design structural number suggested by the AASHTO 1993 procedure was compared to the structural number obtained from the design catalogue suggested by the TRL–Overseas Road Note 31 [11] procedure, which is used in Sudan for the design of flexible pavement.

In the AASHTO 1993 procedure for the design of flexible and rigid pavements, the following parameters are considered: traffic loading, reliability, serviceability and materials properties. The 1993 AASHTO Guide basic design equation for flexible pavements has the following form:

$$log_{10}(W_{18}) = Z_R.S_0 + 9.36.log_{10}(SN+1) - 0.2 + \left\{\log_{10}\left(\frac{\Delta PSI}{(4.2-1.5)}\right)\right\} \Big/ \left\{0.4 + \left(\frac{1904}{(SN+1)^{5.19}}\right)\right\} + 2.32.\log_{10}(M_R) - 8.07 \qquad (1)$$

where: W_{18} = predicted number of 80 kN (18,000 lb.) ESALs

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

SN = Structural Number (an index that is indicative of the total pavement thickness required)

SN = $a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots$
a_i = i_{th} layer coefficient ,
D_i = i_{th} layer thickness (inches)
m_i = i_{th} layer drainage coefficient

PSI = difference between the initial design serviceability index P_i, and the design terminal serviceability index P_t.

M_R = subgrade resilient modulus (in psi).

The 1993 AASHTO Guide basic design equation for rigid pavements has the following form:

$$\log_{10} W_{18} = Z_R\,.S_0 + 7.35.\log_{10}(D+1) - 0.06 + \left\{\log_{10}\left(\frac{\Delta PSI}{(4.2-1.5)}\right)\right\} \Big/ \left\{1 + \left[\left(\frac{1.624\times 10^7}{(D+1)^{8.46}}\right) + (4.22-0.35P_t)*\log_{10}\frac{(S_C)(C_d)(D^{0.75}-1.132)}{(215.63(J)*(D^{0.75}-(\frac{18.42}{\left(\frac{E_c}{K}\right)^{0.25}})}\right]\right\} \qquad (2)$$

where D = slab depth (inches)
P_t = terminal serviceability index
$S`_c$ = modulus of rupture of PCC (flexural strength)
C_d = drainage coefficient
J = load transfer coefficient (value depends upon the load transfer efficiency)
E_c = elastic modulus of PCC
k = modulus of subgrade reaction and other variables are as defined before

In the TRL Overseas Road Note 31, the design catalogue for flexible pavement is based on the traffic loading expressed in terms of million equivalent standard axle loads (ESAL) and the strength of the subgrade soil represented by California Bearing Ratio (CBR). The K-value and resilient modulus were calculated using Subgrade Resilient Modulus Calculator and k-value Calculator developed by American Pavement Concrete Association (APCA) [12]. For the purpose of this study, the following geometrical properties of road were assumed (Fig. 1).
Length of road: 1000 m.
Width of driving lanes: 7 m (2 lanes),
The following design parameters were used for reinforcing the rigid slab:
Dowel Bars [12]: diameter 25 mm, 500 mm length and spaced every 300 mm
Tie Bars [12]**:** diameter 12 mm, 800 mm length and spaced every 850 mm

The following parameters are chosen for flexible and rigid pavement:

1. Reliability
   a. Reliability level in percent (R) %85.
   b. Combined standard error (S_o) 0.4.
2. Serviceability
   a. Initial serviceability index (p_i) 4.5
   b. Terminal serviceability index (p_t) 1.5
3. Elastic Modulus for concrete Ec=4000000 psi
4. Modulus of Rupture for concrete S'c=700 psi

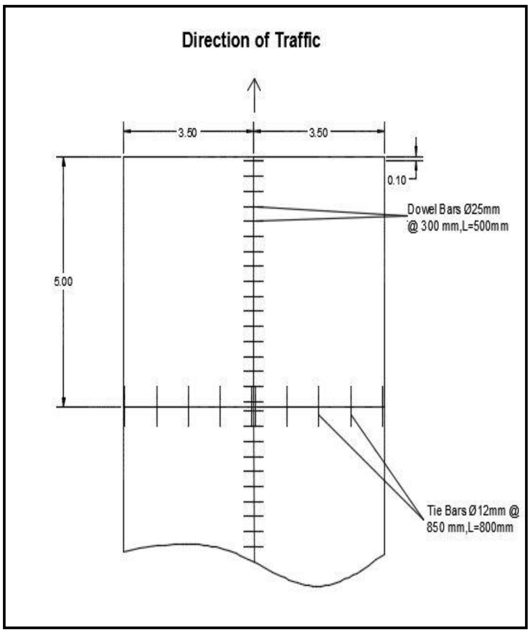
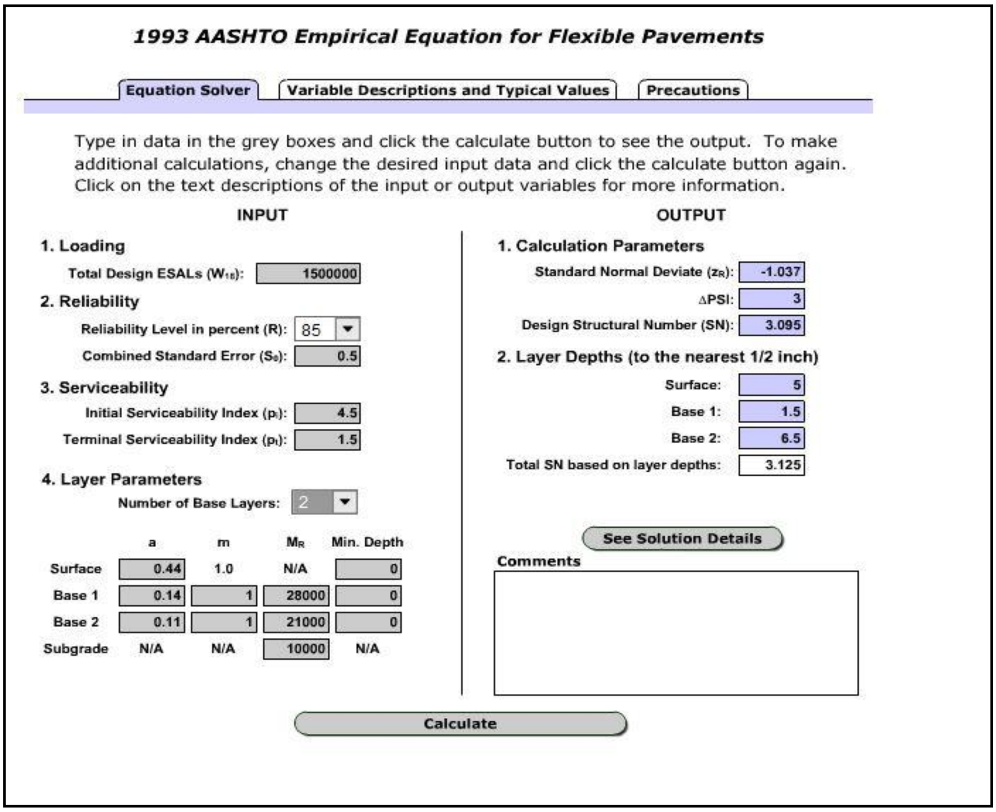
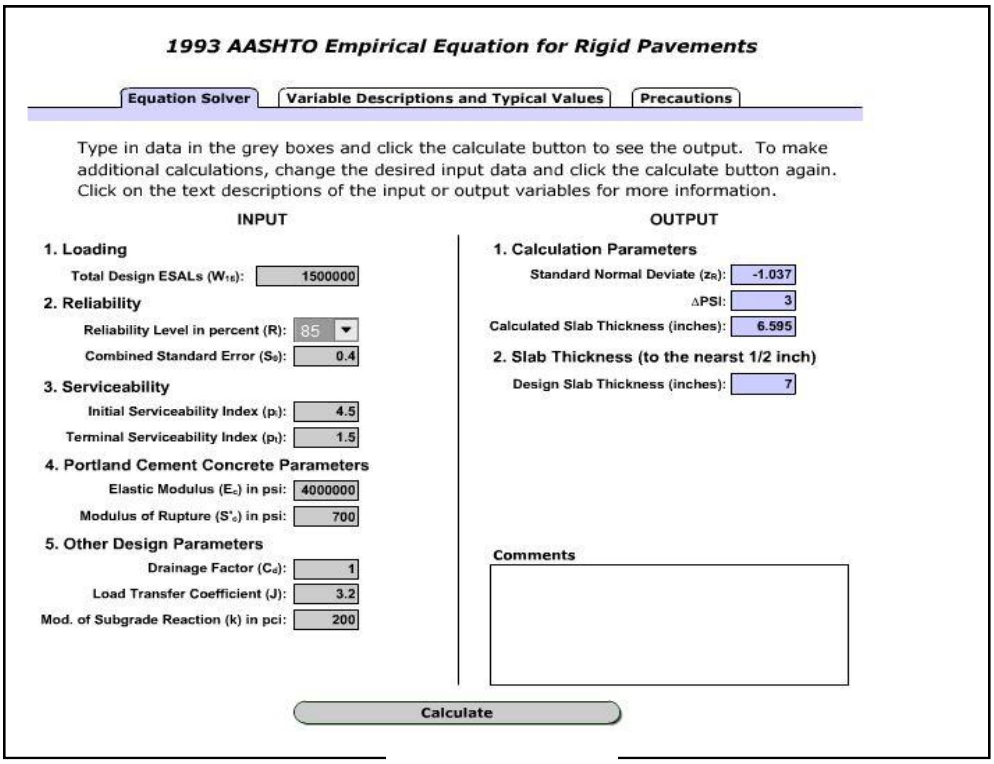


Fig. 1. Road plan

The 1993 AASHTO Web applets for design of flexible and rigid pavements are shown in Figs 2a and 2b



(2a)



(2b)

Fig. 2. The 1993 AASHTO Web applet for design of flexible and rigid pavements

3. RESULTS AND DISCUSSION

3.1 Slab Thickness V. Subgrade CBR

Using the above design parameters and assuming a thickness of 200 mm granular sub base, the relationship between slab thickness and subgrade CBR for different traffic classes, as defined in TRL Road Note 31 are shown in Table 2 and depicted as shown in Fig. 3.

As expected, the slab thickness decreases slightly with the increase of subgrade strength for all traffic loading conditions. When the traffic class is T3 the slab thickness ranges between 160 - 110 mm. The range of slab thickness increases slightly with the traffic class T4 to 180–130 mm. This trend continues for traffic classes T5 and T6 with slab thickness 205– 171 mm for T5 and from 223–191 mm for T6, respectively. In general, the difference between the maximum and minimum slab thickness values is approximately 50 mm for all traffic load conditions.

3.2 Proposed Subgrade Classes for Rigid Pavements

To reduce the initial cost of the rigid pavement, it was proposed to divide the subgrade soil class S5 as defined by TRL Road Note 31 into two subclasses namely, S5-1 and S5-2, for CBR range 15-23 % and 24-29 %, respectively.

3.3 Recommended slab thicknesses for rigid pavements

The recommended slab thickness for different values of subgrade CBR and different traffic classes are shown in Fig. 4.

A catalogue for the design of rigid pavements for the different values of subgrade CBR and different traffic classes is shown in Fig. 5.

3.4 Cost Comparison between Flexible and Rigid Pavement

It is essential in economic evaluation that all cost accruing during all the life of the facility should be included. When making economic comparisons this has not always been carefully practiced or understood by pavement designers. This is because comparisons are often made over a fixed equal design period. Thus, designers assumed that first-cost comparisons are adequate for economic studies. This is not true, and, in order to emphasize the need for a complete cost analysis, the term "life-cycle cost" was coined about 1970 for use with pavements.

Table 2. TRL Road Note 31 Traffic and subgrade classes

CBR Class		Proposed	
Class	CBR range	Traffic class	Range (10^6 esa)
S1	2	T1	<0.3
S2	3-4	T2	0.3-0.7
S3	5-7	T3	0.7-1.5
S4	8-14	T4	1.5-3.0
S5	15-29	T5	3.0-6.0
S6	>29	T6	6.0-10.0

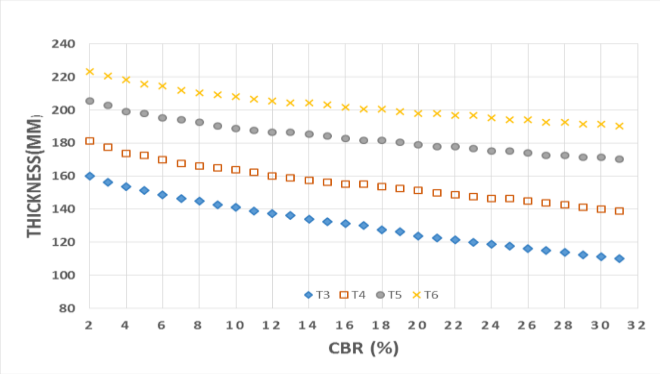


Fig. 3. Relationship between slab thickness and subgrade CBR

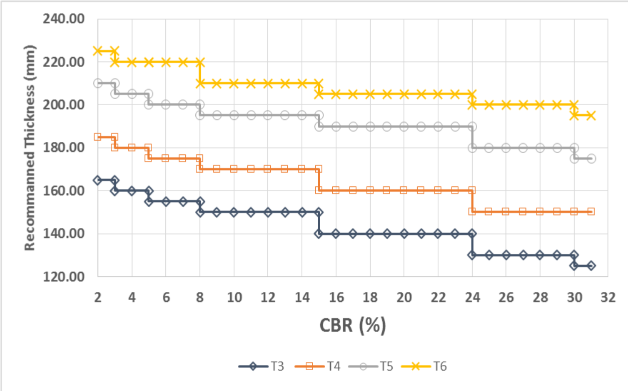


Fig. 4. Recommended slab thickness for different values of subgrade CBR and different traffic classes

Life-cycle cost analysis procedure is desired when developing alternates. Cost comparison should consider the life cycle cost that refers to all of the costs involved in provision of a pavement during its entire life cycle. This includes construction cost, maintenance costs, rehabilitation costs, etc.

The major initial and recurring costs that should be considered in the economic evaluation of alterative pavement include the following:

Agency costs: initial construction costs, future construction or rehabilitation costs(overlays, seal coats, reconstruction …etc), maintenance costs, recurring throughout the design period, savage return or residual value at the end of the design period and traffic control costs.

User costs: Travel time, vehicle operation, accidents, discomfort, time delay and extra vehicle operating costs during resurface or major maintenance [10].

Due to lack of data that enables a comprehensive study of the life cycle cost of flexible and rigid pavements in Sudan, an initial construction cost of the two pavements types was performed, based on the price list of the Ministry of Infrastructures and Transportation–Khartoum State in 2014 shown in Table 3[14]

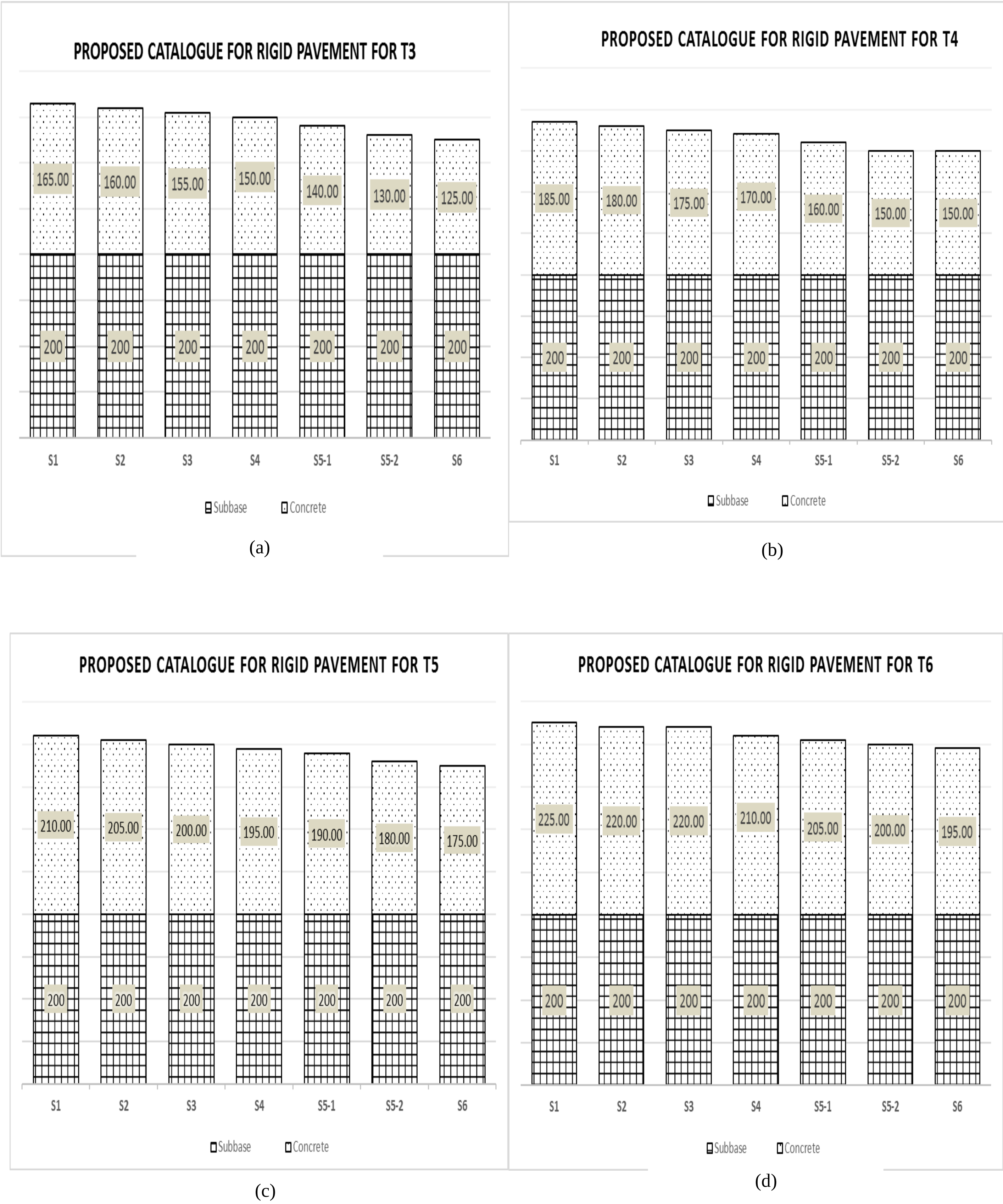


Fig. 5. Proposed catalogue for design of rigid pavement

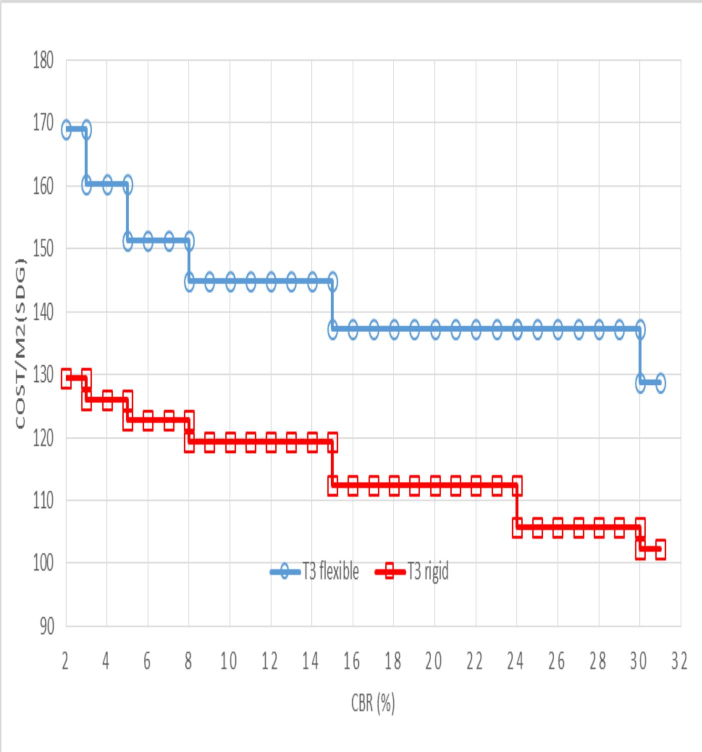


Fig. 6. Comparison between rigid and flexible pavement initial cost for T3

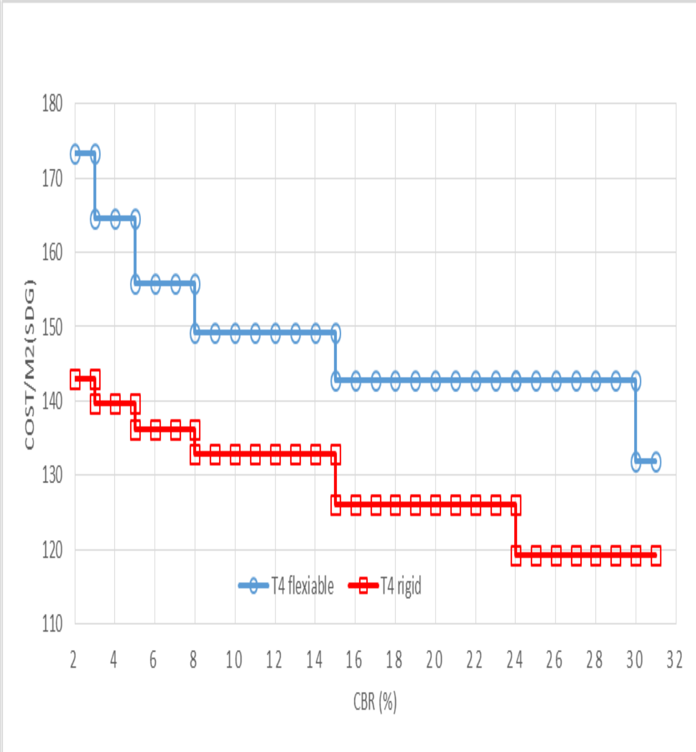


Fig. 7. Comparison between rigid and flexible pavement initial cost for T4

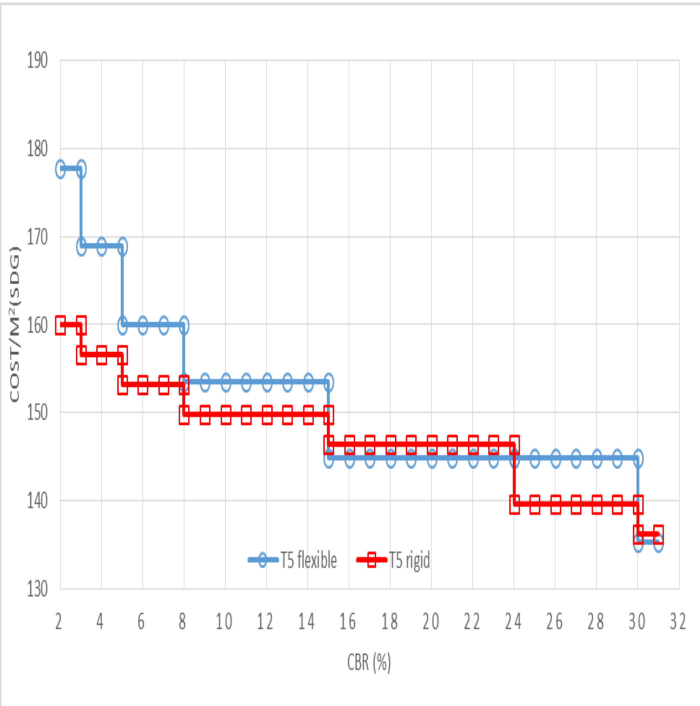


Fig. 8. Comparison between rigid and flexible pavement initial cost for T5

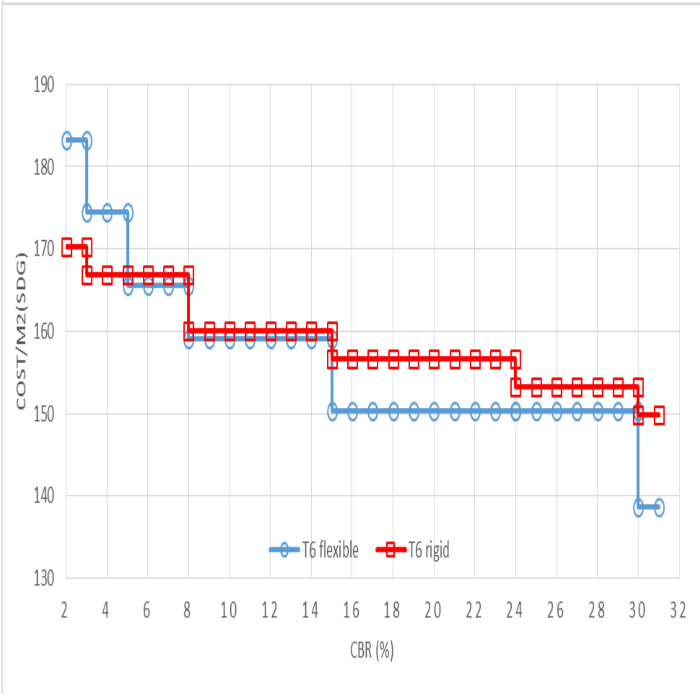


Fig. 9. Comparison between rigid and flexible pavement initial cost for T6

Table 2: Materials prices in Khartoum State

Material	Cost/m^3(SDG)
Capping Materials	65
Granular Sub base	85
Granular Base	130
Asphalt Concrete	2180
Plain Concrete	680

Comparison Between Rigid and Flexible Pavement Initial cost in Khartoum state for different traffic load classes and subgrade CBR is shown in Figs 6,7,8 and 9.

3.5 Discussion

- For roads with traffic volumes less than 3,000,000 ESAL (Traffic classes T3 and T4), Jointed Reinforced Concrete Pavement (JRCP) is more economical than flexible pavement regardless of the subsoil condition.
- When the traffic volumes between is 3,000,000 and 6,000,000 ESAL (Traffic class T5), JRCP is more economical than flexible pavement (the subgrade CBR <15%).
- For roads with traffic volumes more than 6,000,000 ESAL (Traffic class T6 or higher), JRCP is more economical than flexible pavement only for weak soils (subgrade CBR<4 %).
- By consideration of the initial cost only, the choice of rigid pavement over flexible pavement for several traffic loading and subgrade strength is beneficial. However, when the total life cycle cost is considered, rigid pavements will become even more favorable. This was suggested in previous studies [10]. The study showed rigid pavement design procedure implies no major maintenance or rehabilitation on rigid pavements for 30 years. However, flexible pavement design procedure recommends that the initial pavement structure perform for at least eight years before an overlay is needed. This suggests that flexible pavements require substantial rehabilitation cost to achieve the same design life. These factors must be accounted for in the total cost calculation.

4. CONCLUSIONS

The study came to the following conclusions:

- A design catalogue for Jointed Reinforced Concrete Pavement for various traffic loading and subgrade strength conditions is proposed.
- In roads with traffic volumes less than 3,000,000 ESAL, Jointed Reinforced Concrete Pavement is more economical than flexible pavement regardless of subsoil condition.
- The main ingredient in flexible pavement is bitumen and in rigid pavement is cement. While, the international price of bitumen is fluctuating, the price of cement is rather stable. In Sudan, due to the availability of cement, and the scarcity of foreign currency, it is advisable to use rigid pavements, whenever their life cycle cost is favorable.
- Due to the apparent benefits of rigid pavement such as longer life span and less life cycle cost, road authorities in Sudan are strongly encouraged to develop parametric guidelines for the selection of pavement type.

REFERENCES

[1] Taunk, G.S "Rigid Pavement VS flexible Pavement", *Indian National Congress*, Vol 26, No. 2, ISSN: 0376-7256, New Delhi, India, (1998).

[2] Andrew J. Wimsatt, Carlos M. Chang-Albitres, Paul E. Krugler, Tom Scullion, Tom J. Freeman, and Maria B.Valdovinos ,"*Considerations for Rigid VS. Flexible pavement designs when allowed as alternate bids: Technical report*", Texas Department of Transportation Research and Technology Implementation Office, FHWA/TX-09/0-6085-1, Texas, USA, (2009).

[3] Newcomb, *D.* "*Decisions, Decisions... The Pavement Type Selection Process Can Help you make them*", HMAT: Hot Mix Asphalt Technology- National Asphalt Pavement Association, Vol 9, No 2, Maryland, USA, (2004).

[4] Villacres, J.N.,"*Pavement Life-Cycle Cost Studies Using Actual Cost Data*", Asphalt Pavement Alliance Report, Maryland, USA (2005).

[5] Asphalt Institute, *www.asphaltinstitute.org /store_product.asp?inveid=238*. Accessed on (January 30, 2008).

[6] American Concrete Pavement Association, "*Life-Cycle Cost Analysis: A Guide for Comparing Alternate Pavement Designs*", Report No. EB220P, Illinois, USA, (2002).

[7] T. Akakin, Y. Engin, S. Ucar, "*Initial cost comparison of rigid and flexible pavements: under different traffic and soil conditions*", Proceedings of the Joint International Ready Mix Concrete Congress, Seville, Spain, (2010).

[8] Mitchell. M and Walker. R, "*The Economic of Pavement Type Selection*". Department of Transportation, Pretoria, South Africa, (1985).

[9] HDM 4 Version 2, "*www.hdmglobal.com/ hdm4version2.asp*".Accessed on (January 30, 2008).

[10] American Association of State Highway and Transportation Officials, Washington, D.C, AASHTO 1993, "*AASHTO Guide for Design of Pavement Structures*", ISBN 1-56051-055-2, Washington D.C., USA, (1993).

[11] TRL Road Note 31: "*A guide to the structural design of bitumen surfaced roads in Tropical and Semi-Tropical countries*", Overseas Centre, TRL, 1993 ISSN 0951-8797, Berkshire, UK, (1993).

[12] T. F. FWA, "*The handbook of highway engineering",* ISBN 0-8493-1986-2, Florida, USA, (2006).

[13] American Pavement Concrete Association (APCA), "*www.apps.acpa.org*", Accessed on (May 20, 2014).

[14] Ministry of Infrastructures and Transportation-Khartoum State, "*Price list for pavement materials in Khartoum State-2014*", (2014).