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Technical Note on: The Reliability in Using Standard Pavement Sections Based on Traffic Loading Categories with Wide Ranges

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ABSTRACT

Some regional and international pavement design manuals, mainly based on the empirical approaches, recommend using standard pavement design sections, in which each section represents a range of traffic loading values and a range of subgrade stiffness values. Considering one pavement design section for a range of traffic loadings, means that all of the loading magnitudes within this range have the same effect. All of these Codes/standards or most of them developed those designs using empirical design approaches. The TRL Road Note 31 is the most known one worldwide and has been used in different countries. Some countries have developed their own design catalogues based on the RN 31. This Technical Note, using a mechanistic-empirical approach, is examining and investigating the reliability in using standard pavement design sections for a wide range of traffic loading values in some of these methods, and to assess to which extent this might result in having weak design sections for loading magnitudes at the end point of the loading range, or overdesign for those ones in the beginning of the loading range. The Asphalt Institute M-E Design approach has been used representing the Mechanistic-Empirical design approach. The Road Note 31 Design catalogue and Kenya Pavement Design catalogue have been used representing these standard designs with wide range of loading.

المستخلص

فى هذه المذكرة العلمية تم التحقق من مدى الموثوقية فى استخدام تصاميم الرصف القياسية التى تخدم فئات ذات مدى عريض من الاحمال المرورية والتى بنيت على افتراض أن تأثير كل أحجام المرور الواقعة فى الفئة الواحدة لها نفس التأثير، وكل او معظم هذه التصاميم القياسية بنيت على الطرق التجريبية لتصميم الرصف. تمثل المذكرة البريطانية رقم 31 للبلدان المدارية وشبه المدارية ودليل كينيا للتصميم نموذجين لأدلة التصميم العالمية والاقليمية التى تحوي تصاميم قياسية للرصف تخدم مدى عريض من أحمال المرور والتى استخدمت فيها الطرق التجريبية لتطوير هذه القطاعات التصميمية القياسية، لذا ولغرض المقارنة فى هذه المذكرة العلمية تم اختيار بعض فئات الاحمال المرورية منها. كما تم تطوير عدد كبير من القطاعات التصميمية باستخدام الطرق الرياضية التجريبية ممثلة فى طريقة معهد الاسفلت، لكل الأحمال المرورية الواقعة داخل الفئات المختارة من المذكرة البريطانية رقم 31 للبلدان المدارية وشبه المدارية ودليل كينيا للتصميم ، وذلك لتحديد مدى التغير فى السماكات والرقم الانشائى عند تغيير قيمة الحمل المرورى التصميمى وتثبيت قيمة مقاومة الارض الطبيعية.

Keywords: Mechanistic-Empirical, Empirical, axle loads, Subgrade Strength, pavement design

1 Introduction

Several factors such as traffic, environment, material and design affect the pavement performance overtime. Traffic loads play the key role in pavement deterioration. International roads agencies carried out long term programs to investigate the relationship between truck repetitions and the deterioration rate of fatigue cracking and rutting. Many design approaches obtained from these programs, most of them are empirical, and few of them are mechanistic empirical.

2 Pavement Design Methods

Many methods of designing flexible pavement have been developed by various transportation agencies and evolved throughout the years. These methods range from very simple in concept to highly sophisticated methods. Although different agencies have been using design procedures that satisfy their local conditions, pavement design methods can be grouped into four distinct approaches [1].

2.1 Methods Based on Experience

Many agencies have been adopting standard pavement sections for different ranges of traffic levels and environmental conditions. These standard sections are mostly based on previous experience and are applicable to local materials and budget practice. Although these methods are old, they are still being used by relatively small agencies because of their simplicity, low design cost, and reliability under certain conditions. These methods, however, do not allow for comparison between alternatives. They also do not recognize the varying serviceability with age. These methods also assume average material properties, traffic levels, and environmental conditions. If any of these variables change, this approach loses its validity [1].

2.2 Methods Based on Soil Formula or Simple Strength Tests

These methods are based on empirical correlations between the required pavement thickness and soil classification or simple strength tests of subgrade materials such as California Bearing Ratio (CBR). This approach is also old and assumes that traffic load is mostly carried by subgrade, whereas pavement layers are mainly used for smoothness and dust control. Similar to the previous approach, these methods are simple, have low design cost, and could be reliable under certain conditions. The disadvantages are, these methods do not recognize the varying serviceability with age. These methods also assume average pavement material properties, traffic levels, and environmental conditions [1].

2.3 Methods Based on Statistical Evaluation of Pavement Performance

These methods are based on extensive field observation of pavement performance under different conditions and developing empirical relations between pavement thickness and material properties, traffic, and environmental conditions. Once these empirical relations are defined, the designer can input various input parameters and determine the required thicknesses of different layer. A typical example of this approach is the 1993

AASHTO (American Association of State Highway and Transportation Officials) design method (AASHTO, 1993), [1].

It was been developed from the results of the Road Test of American Association of State Highway and Transportation Officials (AASHTO) and is suitable for use in the USA. However, it has been widely used in tropical countries. Subgrade strength is defined in terms of the soil support value, while pavement thickness is expressed in terms of the structural number (SN) ranging from 1 to 6. Traffic loading is expressed in terms of cumulative standard axles during the design life of the pavement, or in terms of daily axle applications [2].

The main advantage of this approach over previous approaches is that the method considers the change of serviceability with pavement age. Thus, the designer can design a pavement section to last for a certain designed life with a predetermined serviceability level. This approach also considers in-service conditions and is not based of simple theoretical assumptions. It also allows for economic comparison between design alternatives.

This approach, however, still suffers from the dependency on empirical relations that are limited to the conditions under which they were developed. If changes occur in any input parameters such as increasing axle loads and tyre pressure or if a new pavement material is used such as modified asphalt binders, the method would not be valid [1].

2.4 Methods Based on Structural Analysis of Layered Systems

This approach is more fundamental than all other approaches since it considers basic material responses such a stresses, strains, and deformations. In such cases, the traffic load is applied on a simulated multi-layered-pavement system and the critical material responses are calculated. These critical response parameters are then correlated to performance using transfer functions, typically based on empirical relations. The designer, therefore, has the capability to determine the required layer thicknesses so that the pavement would last for the required designed life without exceeding predetermined distress levels. This approach represents a major improvement over others due to its accuracy and reliability. However, this approach requires extensive testing and computations. Methods based on this approach also incorporate empirical correlations, although the degree of empiricism is small. In addition, theoretical models require extensive calibration and verification since the incorporated assumptions may not exactly match field conditions [1].

Mechanistic-Empirical (M-E) methods represent one step forward from empirical methods. The induced state of stress and strain in a pavement structure due to traffic loading and environmental conditions is predicted using theory of mechanics. Kerkhoven & Dormon (1953) first suggested the use of vertical compressive strain on the top of subgrade as a failure criterion to reduce permanent deformation. Saal & Pell (1960) published the use of horizontal tensile strain at the bottom of asphalt layer to minimize fatigue cracking. Dormon & Metcalf (1965) first used these concepts for pavement design. The M-E design methods of Shell and Asphalt Institute have put the basis for the two strain-based criteria [3].

3 Design methods been considered in this study

3.1 TRL Road No. 31 for Bitumen-Surface Roads

The Road Note 31 (RN31), developed by the Transport & Road Research Laboratories (TRRL) for developing countries, presents a guide to the structural design of bitumen – surfaced roads in tropical and sub – tropical countries. The fourth edition of RN31 considers the traffic loading in terms of the cumulative number of standard axles on the basis of which the type of surfacing, base and sub-base are selected. This edition extended the design of previous editions to cater for traffic up to 30 million equivalent standard axles. It also has accommodated variability in materials properties, traffic forecasts, effect of climate and the axle loads. Also the range of structures has been expanded to provide more detailed advice on specifications and techniques. It provides eight traffic classes ranges from T1 to T8. T1 represents the traffic that less than 0.3 million ESA during the design period, while T8 represents the traffic that between 17 million ESA and 30 million ESA, during the design period. The road note 31 (4th edition), provides six classes of subgrade strength in terms of CBR, that ranges from 2% to 30%. For the prepared designs, the RN31-4th edition provides eight design charts. Each design chart consists of many designs according to the two main factors prescribed above; the traffic and the subgrade strength [4].

The comparative study (Comparison between the Empirical and Mechanistic-Empirical Pavement Design Methods), [5], showed that the TRL Road Note 31 produces pavement sections with less structural number compared to those produced using AASHTO 1993 Pavement Design Method, under the same traffic loads and subgrade strengths, however they are both empirical methods.

The traffic loading categories in this design method is as follows.

Table 1: Traffic Classes of RN 31

Traffic Class	Loading (Millions of ESA)
T1	< 0.3
T2	0.3 – 0.7
T3	0.7 – 1.5
T4	1.5 – 3.0
T5	3.0 – 6.0
T6	6.0 – 10
T7	10 - 17
T8	17 - 30

3.2 Pavement Design Manual of Kenya

Pavement design in Kenya has undergone considerable development since rule- of- thumb design in the 1940s and 1950s. During the 1960s most major roads were designed on the basis of the earlier editions of RN 29 and RN 31. Then, a road design manual adopted in 1970 required the designer to determine traffic loading on the basis of the number of heavy vehicles expected per 24- hour day five years after the road was opened to traffic. The latest design procedure, adopted in 1981, requires the designer to determine the subgrade quality, in terms of the CBR and traffic loading, during the design life of the pavement, in terms of cumulative standard axles as determined by RN29. The pavement structure is then selected from a catalogue of structures depending on the materials available for construction. It will be noted that the Kenyan design procedure, simulates the French method of using a catalogue of pavement structures, and dissimilar to RN 29, that uses charts. The Pavement design manual of Kenya contains 15 standard pavement structures covering wide range of subgrade materials, volumes and types of traffic and it gives the choices in selecting the construction material [6].

The traffic loading categories in this design method is as follows:

Table 2: Traffic Classes in Kenya

Traffic Class	Loading (Millions of ESA)
T1	25 million – 60 million
T2	10 million – 25 million
T3	3 million – 10 million
T4	1 million – 3 million
T5	0.25 million – 1 million

3.3 The Asphalt Institute Method for Structural Thickness Design for Pavements

The Asphalt Institute method for structural thickness design for pavements allows various combinations of asphalt concrete, emulsified asphalt and granular layers. It offers guidelines for defining subgrade properties, material properties and traffic values required for the selection of appropriate thickness of the pavement layers. In this design procedure the pavement is regarded as a multi-layered elastic system. The materials in each layer are characterized by a modulus of elasticity (E) and Poisson, s ratio (μ). Traffic is expressed in terms of repetitions of an equivalent 80 KN (18000 Ib) single-axle load applied to the pavement on two sets of dual tires. For pavements composed of full-depth asphalt layers the pavement is regarded as a three-layer system. The pavement with the untreated aggregate is considered a four-layer system. The subgrade, the lowest layer, is assumed infinite in the vertically downward and horizontal directions. The other layers, of finite thickness, are assumed infinite in the extent in the horizontal directions [7].

3.3.1 The Design Software of the Asphalt Institute SW-1

Various computer programs based on Burmister's layered theory have been developed. The earliest and the best known is the CHEV program developed by the Chevron Research Company (Warren and Dieckmann, 1963). The program can be applied only to linear elastic materials but was modified by the Asphalt Institute in the DAMA program to account for nonlinear elastic granular materials (Hwang and Witczak, 1979), [8].

SW-1 was designed for pavement design professionals who may need to design pavements for a wide variety of uses including airports, roadways, and parking lots. SW-1 provides a computerized methodology for thickness design of asphalt pavements for a wide variety of pavement uses. SW-1 is based on the respected design procedures of the Asphalt Institute as detailed in several Asphalt Institute manual series (MS), information series (IS), and research report (RR) documents. These methods are based on mechanistic-empirical principles and have been developed and refined over a period of 30 years by the Asphalt Institute. SW-1 is a new Microsoft Windows-based computerized method for pavement thickness design that builds upon four familiar Asphalt Institute DOS computer programs for pavement design. The four DOS-based programs were DAMA (CP-1), HWLOAD (CP-2), AIRPORT (CP-3), and HWY (CP-4) (49). The developers of SW-1 embedded the original computational algorithms from DAMA, HWLOAD, AIRPORT, and HWY into SW-1 and developed a new Windows user-interface to collect input data, report output, and manage data files. SW-1 uses the resilient modulus to characterize subgrade stiffness, but can correlate from CBR or R-values are the user has this type of information. The user is asked to select the type of strength measure, input the stiffness values, and select design subgrade value in order to calculate the Design Subgrade Resilient Modulus. CBR and R-value correlations of the Asphalt Institute are considered applicable to fine-grained soils classified as CL, CH, ML, SC, SM, and SP (Unified Soil Classification) or for materials that are estimated to have a resilient modulus of 30,000 psi, or less. These correlations are not applicable to granular materials, such as base aggregate, which may require direct laboratory testing to obtain resilient modulus values or using other correlations [8].

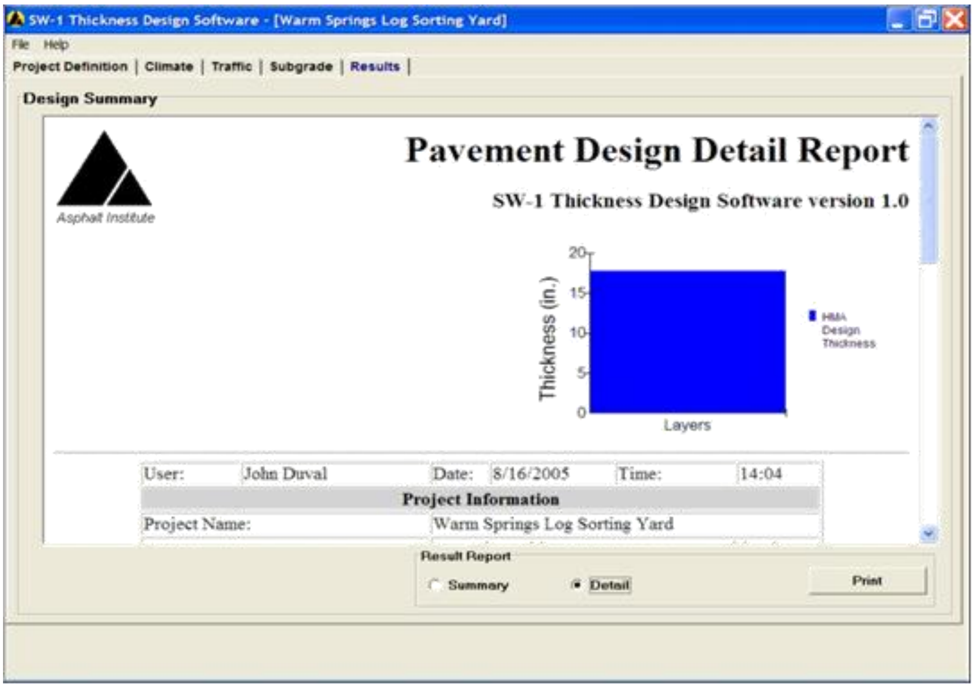

Figure 1: The Design Software of the Asphalt Institute SW-1

4 The Study Methodology

Two traffic categories have been considered for this study, (17 - 30 Million ESA) from the TRL RN31 and (10 – 25 Million ESA) from the Kenya Road Manual. The two categories are wide ranges in terms of traffic loading, and it is more likely that the predicted loading scenarios for new roads with heavy traffic, to fall within these ranges.

Twenty One Design sections have been developed using one subgrade strength value resilient modulus of 51.1 MPa equivalent to (CBR=5), against twenty One loading scenarios. As the Design Software (SW-1) gives many choices of design sections, the (hot mix asphalt, granular base & granular subbase) have been used. The depth of granular layers has been kept constant to observe the change on the hot mix asphalt layer thickness, to ease the comparison and to show the change on a simple way instead of using the structural numbers for each design section

5 The Developed Pavement Design Sections

Here under the pavement design sections been developed using loading scenarios between 10 million ESA and 31 million ESA:

5.1 Design Sections on the Range (17 - 30 Million ESA)

Table (3) shows 14 pavement design sections been developed using the design software sw-1, for the loads ranging from 17 Million ESA to 30 Million ESA representing the loads class under study. The CBR value has been kept as constant to observe the change in the design thickness when changing the load.

Also, Figure (2) shows the total pavement section thickness been obtained plotted against the Axle loads, representing the 14 different design sections obtained by using 14 different axle loads.

Table 3: Developed Pavement Sections for Traffic Loads between 17 & 30 Million ESA

No.	CBR	M_r	ESAL (million)	Design Section (m.m)		Total Thickness of Pavement (cm)
				HMA	Aggregate Base & Subbase	
1	5	51.5	17	337	450	78.7
2	5	51.5	18	340	450	79
3	5	51.5	19	343	450	79.3
4	5	51.5	20	346	450	79.6
5	5	51.5	21	349	450	79.9
6	5	51.5	22	352	450	80.2
7	5	51.5	23	354	450	80.4
8	5	51.5	24	358	450	80.8
9	5	51.5	25	361	450	81.1
10	5	51.5	26	364	450	81.4
11	5	51.5	27	367	450	81.7
12	5	51.5	28	371	450	82.1
13	5	51.5	29	374	450	82.4
14	5	51.5	30	377	450	82.7

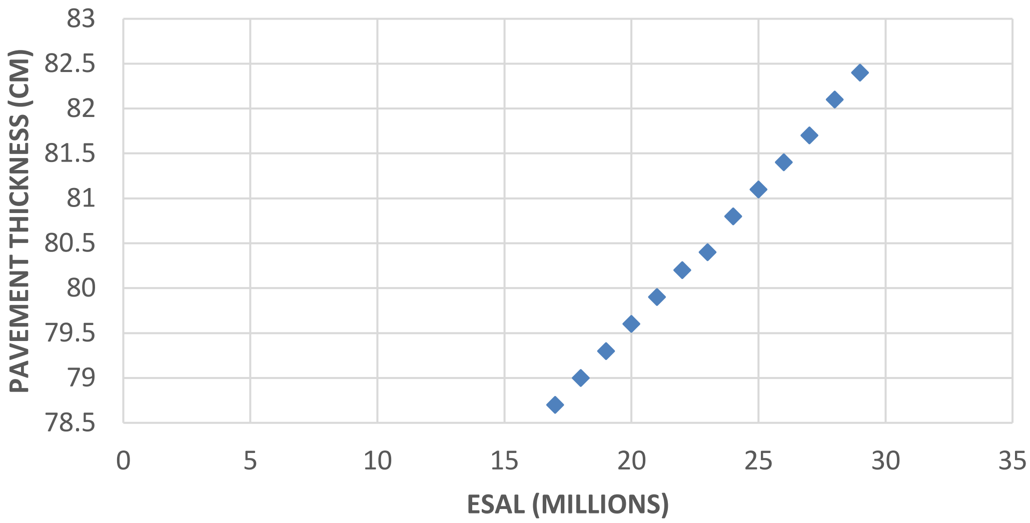

Figure 2: Traffic Loads (17 & 30 Million ESA) against the Obtained Pavements Thicknesses

5.2 Design Sections on the Range (10 – 25 Million ESA)

16 pavement design sections been developed using the design software SW-1 for the loads ranging from 10 Million ESA to 25 Million ESA representing the loads class under study, Table 4. The CBR value has been kept as constant to observe the change in the design thickness when changing the load. Figure (3) shows the total pavement section thickness been obtained plotted against the Axle loads, representing the 16 different design sections obtained by using 16 different axle loads.

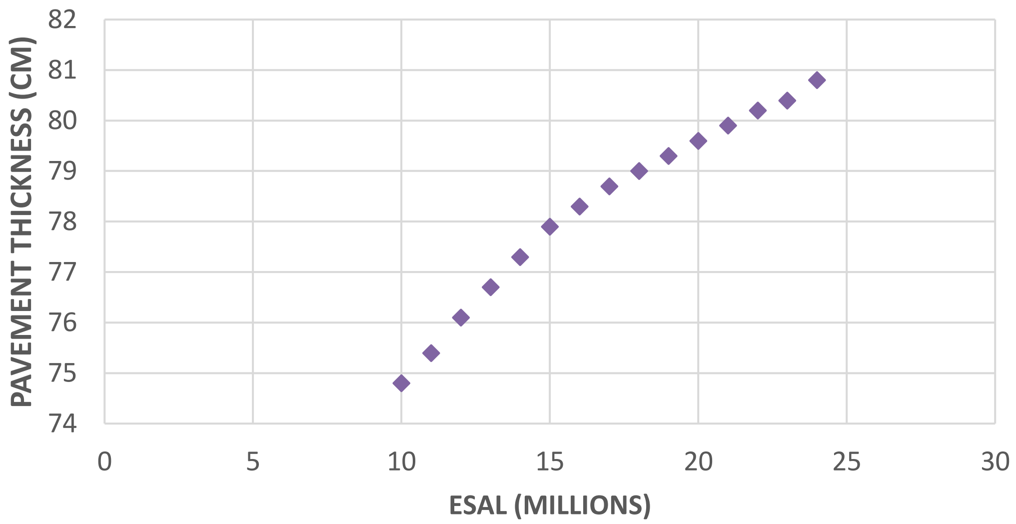

Figure 3: Traffic Loads (10 & 25 Million ESA) against the Obtained Pavements Thicknesses

Table 4: Developed Pavement Sections for Traffic Loads between 10 & 25 Million ESA

No.	CBR	M_r	ESAL (million)	Design Section (m.m)		Total Thickness of Pavement (cm)
				HMA	Aggregate Base & Subbase	
1	5	51.5	10	298	450	74.8
2	5	51.5	11	304	450	75.4
3	5	51.5	12	311	450	76.1
4	5	51.5	13	317	450	76.7
5	5	51.5	14	323	450	77.3
6	5	51.5	15	329	450	77.9
7	5	51.5	16	333	450	78.3
8	5	51.5	17	337	450	78.7
9	5	51.5	18	340	450	79
10	5	51.5	19	343	450	79.3
11	5	51.5	20	346	450	79.6
12	5	51.5	21	349	450	79.9
13	5	51.5	22	352	450	80.2
14	5	51.5	23	354	450	80.4
15	5	51.5	24	358	450	80.8
16	5	51.5	25	361	450	81.1

6 Conclusions

This Technical Note has concluded the following:

- For the TRL Road Note No.31 traffic loading category (17 - 30 Million ESA), the pavement design sections been developed showed 40 mm difference in thickness between the loading value of 17 Million Equivalent Single Axle Load and the the loading value 30 Million Equivalent Single Axle Load, on the hot mix asphalt layer. This difference in terms of Structural Number is equivalent to 1.76, [1], which is not a small value and totally changing the total structural number of the pavement and its capacity of sustaining loads which indicating low reliability in using these design sections for all loads within the specified range.

- For the Pavement Design Manual of Kenya and its traffic loading category (10 - 25 Million ESA), the pavement design sections been developed showed 63 mm difference in thickness between the loading value of 10 Million Equivalent Single Axle Load and the loading value 25 Million Equivalent Single Axle Load, on the hot mix asphalt layer. This difference in terms of Structural Number is equivalent to 2.77, [1], which is a big value and totally changing the total structural number of the pavement and its capacity of sustaining loads which indicating low reliability in using these design sections for all loads within the specified range.
- A standard pavement design section with wide range of traffic loading, may produce weak section if it is subject to the maximum loads within the same category of loads, and may produce uneconomical section if based on the maximum loading value within the same loading category. Even when based on the average loading value, the difference on the structural number remains high.
- With the high cost of roads construction and maintenance it is necessary to make sure that the obtained pavement design section is the optimum and economical one that can carry out its function safely during the design period.

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