

“Feasibility of perpetual pavements in developing countries”

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1. Introduction:

In developing construction of flexible pavements with asphalt as wearing course is a concept of few decades old. Rutting & fatigue cracking is being observed due to shear failure in asphaltic concrete due to uncontrolled axle load & high pavement ambient temperature. Despite, the best efforts by the pavement engineers, this could not be solved till to date. The cost of road construction is increasing day by day due to non-availability of suitable aggregates. Hauling distances are continuously increasing, while the ecological destruction that takes place during the mining of aggregates is less and less accepted.

This result in the form of huge investments, loss of material, reconstruction tedium due to which countries economy suffers to a great extent. The need of the present era is to develop such pavement design that could address these problems & pavement must perform the function during its design life. In this paper, actual pavement section has been analyzed using MICHPAVE and CHEVRON and results are compared with stress and strains of different proposed sections including the perpetual pavement. Results in the form of comparison have been presented which clearly shows that perpetual pavement is an economical option.

Key Words; Feasibility, Perpetual pavement, Stress, Strain,

2. Problem Statement:

Non-availability and increasing cost of construction materials along with the heavy axle load & environmental conditions leads to premature failure of roads and force engineers to consider more economical and long life pavement design methods to build roads using indigenous pavement materials. The situation becomes even more critical in underdeveloped countries like Pakistan. In addition, the increasing pressures on the mining, forestry and agricultural industries to minimize production costs necessitate the cost-effective construction of roads with optimum performance and low maintenance costs.

3. Literature review:

3.1 Perpetual Pavement

A Perpetual Pavement is defined as an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and requires only periodic surface renewal in response to distresses confined to the top of the pavement [1]. The concept of Perpetual Pavements, or long-lasting Hot Mix Asphalt pavements, is not new. Full-depth and deep-strength HMA pavement structures have been constructed since 1960s in the developed countries, and those that were well-designed and well-built have been very successful in providing long service lives under heavy traffic [1].

Recent developments in materials selection, mixture design, and performance testing and pavement design are said to offer the potential to construct pavement structures that will last over 50 years with periodic replacement of the pavement surface. A conventional long lasting pavement design includes a relatively thick asphalt section placed over a granular base course [2].

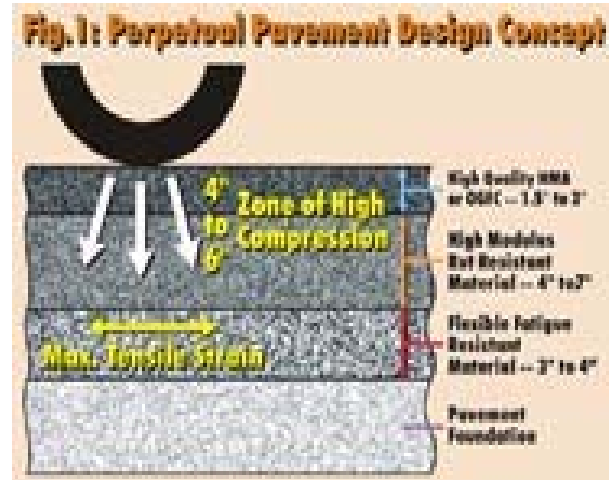


Fig. 1.1

The overall depth of these designs may be as much as 400 mm (16 in)[1]. This thickness of asphalt reduces the strain [deflection due to loading] in the lower level of the pavement under load. If the asphalt is sufficiently thick, this strain reduces to the point where the asphalt's fatigue life (failure caused by cyclic variations in loading) becomes indefinite.

The new idea in perpetual pavements focuses the material designing of each asphalt layer to resist the distresses caused due to a thinner section than adopting conventional design. There are typically three asphalt layers as shown in fig. 1.1 including a rut resistant, impermeable and wear resistant surface layer, a rut resistant and durable intermediate layer and a durable fatigue resistant base layer[2].

Designing a rich-bottomer flexible base layer to resist fatigue cracking has not been widely used. A properly designed pavement structure incorporating a bottom up design and an indefinite fatigue life has a potential life of 50 years or more. When this structure is combined with a renewable pavement surface that is tailored to a specific application and has high rutting resistance, the overall result is durable pavement with a consistently smooth and safe driving surface [1].

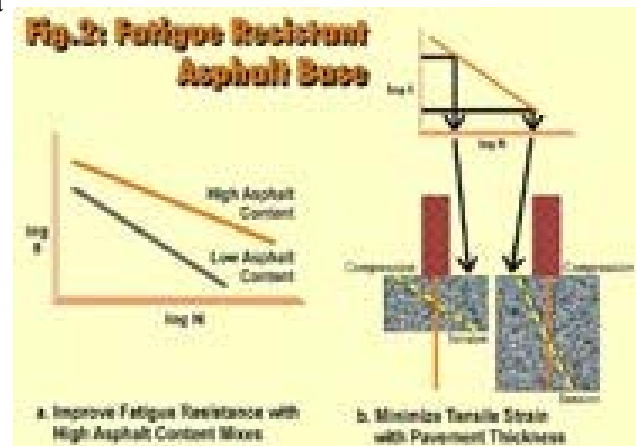


Fig. 1.2

The basic concept is that HMA pavements over a minimum strength are not likely to exhibit structural damage even when subjected to very high traffic flows over long periods of time. Rather, deterioration seems to initiate in the pavement surface as either top-down cracking or rutting. If surface-initiated cracking and rutting can be detected and remedied before they impact the structural integrity of the pavement, the pavement design life could be greatly increased.

HMA base layer. It is the bottom layer designed specifically to resist fatigue cracking. Two approaches are being used to resist this type of failure in the base layer. First, the total pavement thickness can be increased to an extent that the tensile strain at the bottom of the base layer is insignificant. Alternatively, the HMA base layer could be made using an extra-flexible HMA, by increasing the asphalt content. Combinations of both the approaches can be exercised [1].

Wearing surface. This is the top layer designed specifically to resist surface-initiated distresses such as top-down cracking and rutting. Other mode of distresses would depend upon local conditions [1].

Intermediate layer. This is the middle layer designed specifically to carry most of the traffic load. Therefore it must be stable (able to resist rutting) as well as durable. Using stone-on-stone contact in the coarse aggregate and using a binder with the appropriate high-temperature grading can best provide stability.

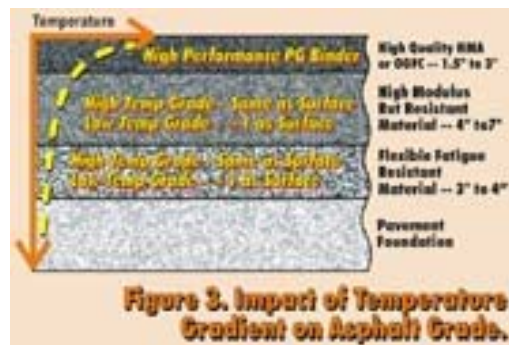


Fig. 1.2

4. Evaluation of Pavement Designs.

Flexible pavement design based on AASHTO-86 of I.J.Principal Road in Islamabad, the capital of Pakistan has been evaluated and feasibility of perpetual pavement as compared with other pavement designs was analyzed. The design variables used in the analysis have been summarized in table 1.1 & 1.2.

Sr. No	Design Variable	Value
1	Analysis Period (Years)	25
2	Design 18000-Ib ESALS (million)	28.71
3	Reliability (Percent)	90
4	Over all standard deviation	0.45
5	Over all design Serviceability loss(DPSI)	1.7
6	Drainage Coefficients (m2, m3)	1
7	Asphalt concrete structural layer coefficient	0.44
8	Base course structural layer coefficient	0.14

9	Sub base structural layer coefficient	0.11
10	Asphalt concrete Elastic modulus (PSI)	4,50,000
11	Base course Resilient modulus (PSI)	30,000
12	Sub base Resilient modulus (PSI)	15,000
13	Road bed soil (sub grade) resilient modules (PSI)	7,800
14	Poisson's ratio for AC	0.40
15	Poisson's ratio for Base course	0.35
16	Poisson's ratio for Sub base course	0.35
17	Poisson's ratio for Road bed soil	0.35

Summary of Design variables Table 1.1

Pavement structure	Thickness	Layer coefficient	Structural Number
Asphalt structure	6" (15cm)	0.44	2.64
Crushed Base Course	10" (25cm)	0.14	1.40
Granular Sub base	16" (40cm)	0.11	1.76
		Total	5.80

Layer thickness design variables Table 1.2

A flexible pavement is a layered structure in which unbound or aggregate layer must be protected from excessive vertical stress to prevent or minimize permanent deformation of the layer. This requires that a minimum thickness of pavement above any specific layer must be provided. In AASHTO flexible pavement design procedure the structural number (SN) is used to protect each of the under laying layers. Following structural numbers were obtained.

- SN1 (Protection of the base Course) = 3.388
- SN2 (Protection of the sub base course) = 4.375
- SN3 (Protection of the road bed soil i.e. sub grade) = 5.447

It can be seen that actual thickness design dose not meet the required structural number criteria as shown in table 1.3

Structural Number	Required	Provided	Remarks
SN1	3.388	2.64	Base is not protected
SN2	4.375	4.04	Sub base is not protected
SN3	5.447	5.80	Road bed soil i.e. sub grade is protected

Comparison between Required and Provided Structural Number. Table 1.3

The actual thickness design differs with the values calculated from AASHTO flexible pavement design procedure. The thickness calculated by AASHTO design are presented below,

$$D1 = SN1/a1 = 3.388/0.44 = 7.7 \text{ inch}$$

D1 = the minimum required surface course thickness is found from Layer coefficient.

Since the actual surface course thickness D1* should be equal to or greater than the minimum value of D1, a rounded thickness of 8.0 inch was selected. The actual structural number provided for the surface course;

$$SN1^* = a1 D1 = 0.44 \times 8 = 3.52$$

$$\text{Check} = SN1^* = 3.52 > SN1 = 3.388 \quad (\text{Ok})$$

The base course is protected since the structural number provided by the surface course is greater than the required structural number. The minimum required base course thickness is found from

$$D2 = (SN2 - SN1^*) / a2 m2 = (4.375 - 3.56) / (0.14 \times 1.0) = 5.821 \text{ inches}$$

Since the actual base course thickness D2*, should be equal to or greater than this minimum values, D2, a rounded thickness of 6.0 inches is selected. The actual structural number provided by the base course;

$$SN2^* = a2 D2^* m2 = 0.14 \times 6 \times 1 = 0.84$$

$$\text{Check: } SN1^* + SN2^* = 3.56 + 0.84 = 4.40 > SN2 = 4.375 \quad (\text{Ok.})$$

The sub base course is protected since structural number provided by the surface and base is greater than the required structural number. The minimum required sub base course thickness;

$$D3 = [SN3 - (SN1^* + SN2^*)] / a3 m3 = [5.447 - (3.56 + 0.84)] / (0.11 \times 1) = 9.52 \text{ inches}$$

Since the actual sub base course thickness, D3*, should be equal to or greater than this minimum value, D3, a rounded thickness of 10 inches is selected. The actual structural number provided by the sub base course ;

$$SN3^* = a3 D3^* m3 = 0.11 \times 10 \times 1 = 1.10$$

$$\text{Check: } SN1^* + SN2^* + SN3^* = 3.36 + 0.84 + 1.1 = 5.50 > 5.447 \quad (\text{OK})$$

The roadbed soil (sub grade) is protected since the structural number provided by the surface, base and sub base course is greater than the required structural number.

Hence, the layer thickness of the flexible pavement structure using the AASHTO-86 procedure and actual design variable should be as shown below.

- Asphalt concrete = 8.0 inches
- Crushed stone base course = 6.0 inches
- Granular sub base = 10.0 inches

4.1. Critical Pavement responses and permissible values

When a wheel load is applied to a pavement structure, deflection of pavement layers takes place. This produces stress and strain in each layer of the pavement structure. The stress, strains and deflection are

termed as pavement responses to the applied wheel load. For flexible pavements, various researches have identified the following critical pavement responses.

- Surface deflection
- Vertical compressive stress/strain at the top of
 - 1 AC surface
 - 2 Granular base and
 - 3 Road bed soil (Sub grade)
 - 4 Radial tensile strain at the bottom of the
 - a. AC surface
 - b. Stabilized base

The first two responses result in pavement deformation of the materials and was related with cutting where as the third response was related with fatigue cracking. The principal objective in designing AC pavement structure is to keep the level of the above-mentioned critical responses with in some allowable limits.

The allowable limits, among other factors, vary with material and environmental conditions. For Pakistan no relationship has yet been developed which relates the strain level with fatigue cracking and rutting AC pavements.

In the absence of local fatigue and rut models, the models mentioned in table 1.4 and 1.5 have been used to estimate the permissible radial tensile strain at the bottom of AC layer and permissible vertical compressive strain at the top of unbound layers or sub grade

The out put of NAASRA, Australia model for fatigue criteria (allowable tensile strain at bottom of asphalt layer) indicates that for the traffic condition of I J P road, the radial tensile strain at the bottom of AC layer should be less than **117 micro strain** and the sub grade strain criteria of university of Notingham (mean rut 13 mm) model indicates allow able vertical strain at the top of unbound layers sub grade is **177 micro strain** for **28 x10⁶ ESAL**:

Allowable tensile strain at bottom of asphalt layer

Basic equation: $\text{Strain (allowable)} = A \cdot (N/10-6) \cdot B \cdot (E/3000)^c$

Where, A, B, C are coefficients, E is the modulus of asphalt (Mpa), and N is he number of load repetition

Model	A	B	C	E
Asphalt Institute USA	0.00024	0.302	0.85	3,103
Shell 1977	0.000054	0.25	0.00	3,103
NAASRA, Austria	0.000227	0.2	0.00	3,103
Illinois, Class 1 cracking	0.000059	0.333	0.00	3,103
University of Nottingham, DBM pen-200	0.000094	0.347	0.00	3,103
University of Nottingham, DBM pen-100	0.000133	0.285	0.00	3,103
University of Nottingham, HRA	0.000209	0.204	0.00	3,103
Thin continuously graded mixes, South Africa	0.000279	0.183	0.00	3,103
Thin gap- graded mixes, South Africa	0.000331	0.137	0.00	3,103
Verstraeten, CRR, Belgium	0.000088	0.21	0.00	3,103
Nardo Italia, 1983	0.000165	0.243	0.00	3,103
Giannini & Camomilla Italia	0.000142	0.234	0.00	3,103

Fatigue Criteria Table 1.4

Allowable Vertical strain at Top of sub grade

Basic Equation: Strain (allowable)-A* (N/10*6) *B

Where A and B are coefficients, and N is the number of load repetitions

Model	A	B	Allowable Strain
Shell 1978, 50% probability	0.000885	0.250	318
Shell 1978, 84 % probability	0.000696	0.250	250
Shell 1978, 95% probability	0.000569	0.200	251
Chevron, mean rut 10mm	0.000482	0.223	193
University of Nottingham, mean rut 13mm	0.000451	0.280	143
South Africa, Terminal PSI=1.5	0.001005	0.100	667
South Africa, Terminal PSI= 2.0	0.000728	0.100	483
South Africa, Terminal PSI=2.5	0.000495	0.088	345
NAASRA, Australia	0.001212	0.141	680
Verstraeten, rut less	0.000459	0.230	179

than 15 mm			
Kenya	0.001318	0.245	483
Giannini & Camomilla Italia	0.000675	0.202	295

Subgrade Strain Criteria Table 1.5

The analytical evaluation of consultant was carried out using CHEVRON and MICHPAVE computer programs. Tables 1.6 summarize the road and material data used in the analysis table 1.7 summarizes the analysis results.

Single wheel load	= 9000 lbs	
Tire pressure	= 130 Psi	(NTRC axle load study1995)
AC elastic modulus Layer coefficient=0.44	= 450000 Psi	Poisson's ratio = 0.40
Base course resilient modulus Layer coefficient = 0.14	= 30000 Psi	Poisson's ratio = 0.35
Sub base resilient modulus Layer coefficient = 0.11	= 15000 Psi	Poisson's ratio 0.35
Road bed soil elastic modulus MR= 1500X CBR	= 7800 Psi	Poisson's ratio = 0.45

Load and Material Data Table 1.6

The analytical evaluation shows that the actual design has the potential for developing very large radial tensile strains as well as very large vertical compressive strains at the critical locations. The development of the large critical strains will lead to accelerated deterioration of the flexible pavement structure. This conclusion was confirmed using MICHPAVE, shows a fatigue life of only 8.35×10^6 EASL and a rut depth of .36 inch.

<u>Pavement Response</u>	<u>Value</u>
1. Surface deflection (inch) 0 .02	
2. Vertical compressive stress (psi)	
. At the top of Ac surface	130
.At the top of granular base	26.93
.At the top of road bed soil	4.2
3. Vertical compressive strain ($\times 10^{-6}$)	
. At the top of AC surface	173
. At the top of granular base	359
. At the top of Road bed soil	143
4. Radial tensile strain ($\times 10^{-6}$)	
. At the bottom of AC surface	235

Results of Analytical Evaluation (I .J .P. Road) Table 1.7

<u>Pavement Response</u>	<u>Value</u>
1. Surface deflection (inch)	0.018
2. Vertical compressive stress (psi)	
. At the top of Ac surface	130
. At the top of granular base	14.62
. At the top of road bed soil	3.88
3. Vertical compressive strain ($\times 10^{-6}$)	
. At the top of AC surface	87.8
. At the top of granular Sub base	49.6
. At the top of Road bed soil	159.4
4. Radial tensile strain ($\times 10^{-6}$)	
. At the bottom of AC surface	165.7
. Fatigue life	18.99 $\times 10^6$ ESALS
. Rut depth (inches)	0.11

Analytical results of AASHTO based design Table 1.8

4.2. Queens Land Pavement Design

Queens land department of transportation pavement design manual provides design for a range of alternate pavement types. The manual provides procedure for design, which incorporates the following pavement type's combinations.

1. Full depth granular pavement.
2. Full depth Asphaltic pavement.
3. Full depth cemented material pavement.
4. Granular material over cemented material.
5. Asphaltic Concrete over granular material.
6. Asphaltic concrete over cemented material.
7. Cemented granular & Asphalt.

In any of the design charts which shows granular or cemented material as the top layer the sprayed bitumen seal which would normally be applied to these pavement may be supplemented by a 35mm asphalt surfacing with out any modification to the design.

4.3. Option of rigid pavement:

Another option to avoid the premature failure of pavement and to enhance the pavement life is to provide rigid pavement. Using the following parameters, rigid pavement design based on AASHTO design manual has been worked out:

Design variables	values
Design ESALS(millions)	28
Effective modulus of sub grade reaction (psi/in)	50
Concrete elastic modulus ($\times 10^6$ psi)	3.3
Mean concrete modulus of rupture(psi)	600
Load transfer coefficient	3.2

Drainage coefficient	1
Initial serviceability index	4.5
Terminal serviceability index	2.5
Reliability(%)	90
Overall standard deviation	0.35
Loss of support	2
Sub base (crushed stone , E=30,000 psi)	6"

Summary of recommended design variables Table 1.9

Type of construction	JRCP
Slab dimensions	24' long x 12' wide
Slab thickness (in)	13
Sub base thickness (in)	6
Dowels	1.5" dia , 24" long @12" c/c (Grade 60)
Note1 : If the mesh is not available then use 2/8" dia at 6" c/c for longitudinal reinforcement and 2/8" dia bars at 12"cc for transverse reinforcement.	
Note 2: The reinforcement to be provided at the top only (3 " below the slab surface)	
Tie bars: 4/8" (no. 4 bars) on 1'-9" centers (24" long)	

Summary of Design Details Table 1.10

4.4. Perpetual Pavement Design

Perpetual pavement design recommends the following structural design for I.J.Principal Road under same parameters;

AC Surface (a=0.44) = 12 inch
 Granular sub base (a= 0.11) = 10 inch (optional, just to protect weak subgrade soils)

<u>Pavement Response</u>	<u>Value</u>
1. Surface deflection (inch)	0.016
2. Vertical compressive stress (psi)	
. At the top of Ac surface	130
. At the top of granular sub-base	6.4
. At the top of road bed soil	3.47
3. Vertical compressive strain (x10 ⁻⁶)	
. At the top of AC surface	16.33
. At the top of granular Sub base	150.6
. At the top of Road bed soil	126.6

4. Radial tensile strain ($\times 10^{-6}$)	
. At the bottom of AC surface	58.60
. At the bottom of AC surface	103.0
. Fatigue life	140×10^6 ESALS
. Rut depth (inches)	0.12

Analytical results of perpetual pavement design Table 1.11

Sr. No.	Pavement Response	Actual Design	AASHTO Design	Perpetual Pavement Design
1	Structure	AC= 6 inch	AC= 8"	AC= 12"
		Agg. Base = 10 inch	Agg. Base = 6"	
		Agg. Sub-base= 16 inch	Agg. Sub-base= 12"	Agg. Sub-base= 10"
2	Surface deflection (inch)	0.02	0.018	0.016
3	Vertical Compressive stress (psi) at top of AC surface	130	130	130
4	Vertical Compressive stress (psi) at top of granular surface	26.93	14.62	6.4
5	Vertical Compressive stress (psi) at top of roadbed soil	4.2	3.88	3.47
6	Vertical compressive strain at top of AC surface	173	87.8	16.33
7	Vertical compressive strain at top of granular surface	359	49.6	150
8	Vertical compressive strain at top of road bed soil	143	159.6	126.6
9	Radial tensile strain at bottom of AC	235	165.7	58.6
10	Radial tensile strain at bottom of AC	-	-	103
11	Design Life (millions ESAL'S)	8.35	18.99	140
12	Cost Per Kilometer for a period of 50 years (approximately)	42.00 millions	38.00 millions	30.5 millions

Comparison of Pavement response at critical locations Table 1.12

5. Major findings

From the above exercise it has been cleared that thick layer of Asphalt concrete is required to control the stress/ strain in critical locations for longer periods as we see the use of Asphaltic concrete layers on our high ways has not produce the desired results and most of the road sections has suffered premature failure ie. Either rutting or cracking with in a very short period, much less than the design life, after opening of

them to traffic. Similarly, cost per kilometer for a period of about 50 years, perpetual pavements proves to be economical. A precise estimate of the cost of rigid pavement was also carried out for the same period, which is about 36.5 millions per kilometer i.e 20 % more than perpetual pavements.

Perpetual Pavement combines the well-documented smoothness and safety advantages of asphalt with an advanced, multi-layer paving design process that with routine maintenance extends the useful life of a roadway to half a century or more. This type of construction is quite popular in areas where local materials are not available. It is more convenient to purchase only one material i.e HMA, rather than several materials from different sources, thus minimizing the administration and equipment costs.

Full depth asphalt pavements have little need of permeable granular layers to entrap water and impair performance. Time required for construction is reduced. On widening projects, where adjacent traffic flow must usually be maintained, full depth asphalt can be especially advantageous. When placed in a thick lift of 4 inch or more, construction seasons may be extended. They provide and retained uniformity in the pavement structure. They are less affected by moisture or frost. According to limited studies, moisture contents do not build up in subgrades under full-depth asphalt pavement structures as they do under pavements with granular bases. Thus, there is little or no reduction in subgrade strength.

Perpetual Pavements use multiple layers of durable asphalt to produce a safe, smooth, long-lasting road. The Hot Mix Asphalt (HMA) design begins with a strong, yet flexible bottom layer that resists tensile strain caused by traffic, and thus stops cracks from forming in the bottom of the pavement. A strong intermediate layer completes the permanent structural portion, and a final layer of rut-resistant HMA yields a surface that lasts many years before scheduled restoration. A Perpetual Pavement provides a durable, safe, smooth, long-lasting roadway without expensive, time-consuming and traffic-disrupting reconstruction or major repair.

When scheduled surface restoration is performed, Perpetual Pavements can be maintained easily and cost-effectively without removing the road structure for reconstruction, saving time and money while keeping motorists happy. Asphalt is recyclable, providing further cost savings and environmental benefits. Asphalt has a proven safety record as a driving surface, offering stronger visual contrast with center stripes and other markings. Among other advantages can include reduced noise, reduced splash and spray, and greater skid resistance

6. Refernces:

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