MINISTRY OF COMMUNICATIONS
NATIONAL TRANSPORT RESEARCH CENTRE
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USE OF ASPHALTIC MIXES ON ROADS IN PAKISTAN

(A DESK STUDY)

NTRC-192

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OCTOBER, 1996

EXECUTIVE SUMMARY

During last three decades, the pavement design in Pakistan has undergone radical change. The conventional design of granular base, sub-base and triple surface treatment has been replaced by asphaltic concrete on almost all the heavily travelled national and provincial highways. The mix is a costly material. It has been estimated that every year around Rs. 2.0 billion of such materials are used on our roads in the country. Out of this, the major chunk is on the national highways.

2. Unfortunately, the change in most cases has not produced positive results, as most of the road have suffered premature failures i.e. either in rutting or cracking. The failure results in manifold increase in vehicle operating costs as well, resulting in huge loss to the national economy.

3. The salient finding/conclusions of the study are as follows:

a) The design methods are inappropriate as these have been borrowed from other countries without making any attempt to modify them to conform to local conditions particularly extreme environment & loading conditions i.e. axle load.

b) The mixes require very high degree of quality control as compared with other types of surfacing, but the level of quality control is far below the minimum required.

c) The asphaltic mix costs double the conventional aggregate material (to provide equal pavement strength), therefore every effort should be made to evolve other solutions through indigenous research to minimize the thickness of the Asphaltic Concrete layer in the pavement.

d) Research also need to be carried out to make quality control more effective under prevailing local conditions.

CONTENTS

CHAPTER-I

INTRODUCTION

1.1 Use of Road Mode of Transport:

All over the world, the investment on the road mode of transport has increased tremendously over the last few decades. The railway mode of transport which, a few decades ago, was carrying a major chunk of passengers and freight traffic has now slowly loosing its share. The same is the case in Pakistan. The share of road freight traffic over the years has also been continually increasing i.e. from 51% in 1971-72 to 74% in 1982-83 to 85% in 1992-93. The share of road passenger traffic has, however, increased marginally from 78.8% in 1971-72 to 80% in 1982-83 to 85% in 1992-93.

The road mode of transport is presently favoured over rail mainly because of the simple reason that in transport sector, the main criterion "the best service at the least cost" is satisfied much more readily by road transport and than there is the flexibility in operation and almost door to door service.

The railway system normally have fewer access points from where goods can be loaded/reloaded. Thus vast bulk of general goods carried by rail have to be taken to and from railheads by roads. It is also time consuming since the goods which were loaded from the lorry and loaded on to the train at the departure point and reloaded on to another lorry at the rail terminal, prior to the final unloading at the destination. This excessive handling also increase the risk of damage and delay.

In case of roads, the vehicles can travel between two points quickly and cheaply. Indeed in most cases, goods can be taken to within a few feet of their delivery points.

Simply stating, road transport provides the cheapest and most practicable method of delivering goods to the transporters. A good road system enables them to transport their goods as quickly and directly as possible.

1.2. Investment on Road Sector:

The allocations for the road sector has increased tremendously over the last two decades in the country. It can be judged from that fact that during the sixth five year plan, Rs. 13.6 billion were allocated for the road sector which included Rs. 8.0 billion for the federal and Rs. 5.6 billion for the provincial roads against which an expenditure of Rs. 11.00 billion was incurred which included Rs. 6.2 billion for federal and Rs. 4.8 billion for provincial roads. During the 7th five year development programme, Rs. 27.44 billion was allocated for the improvement and widening of the national highways and provincial roads. Against the allocation of Rs. 27.44 billion, the actual expenditure incurred during 7th five year programme stood at Rs. 36.6 billion which included Rs. 20.09 billion for the federal government and Rs. 16.48 billion for the provincial governments.

The 8th five year programme envisages an allocation of Rs. 74.7 billion for the road development projects of the National Highways only. This allocation is 272% more than the expenditure incurred during 7th five year programme on the National highways.

1.3 The Problem:

With the enhancement in the allocation for the road sector, the road construction activity in the country has increased tremendously during the last few decades.

Some of the major projects of national importance currently underway include dualization of National Highway (N-5), construction of Lahore-Islamabad motorway and rehabitation/improvement of Indus Highway (N-55) from Peshawar to Karachi.

Recently, the use of asphaltic concrete layers on our highways have increased tremendously. But in most of the cases, the material has not produced the desired results and most of the road sections have suffered premature failures i.e. either in rutting or cracking within a very short period, much less than the design life, after opening of them to the traffic. The construction of roads cost lot of money and the failure results in loss of investment made. It is especially important for developing countries like Pakistan with limited resources that any investment made should be fully utilized. Moreover, the failure results in manifold increase in vehicle operating costs, resulting in further loss to the national economy.

In Pakistan, currently several pavement design methods are being used to work out the thicknesses of various pavement layers. These methods results in different pavement layer thicknesses of different combination of materials resulting in different costs/Km for the pavement design for the same loading and strength of sub-grade materials. However, the selection of materials and their thicknesses is not given serious thought and it is generally provided according to AASHTO Guide, 86 method which normally results in expensive pavement. Also it recommends a thick layer of asphaltic mix compared to some other methods. As the material normally fails prematurely, the investment made mostly results in wastage. There is a need for giving serious consideration to the selection of pavement design method and selection and thicknesses of pavement layers.

1.4 Objective of the Report:

The objective of the report is to evaluate various options regarding use of asphaltic mixes on our roads keeping in view their costs and performances. The study would also have a critical look on the aspect of using thicker asphalt pavement layers on our main highways in Pakistan vs using thin asphaltic pavements or simply tripple surface treatment as surfacing layer on the water bound macadam base course. Various pavement materials would be studied in the report and the various pavement design methods currently being used in the country would also be discussed.

CHAPTER-II

PAVEMENTS

2.1 Types of Pavements:

Historically, pavements have been divided into two broad categories, flexible and rigid. The essential difference between the two types of the pavements (flexible and rigid) is the manner in which they distribute the load over the sub-grade.

2.1.1 **Flexible Pavements:** The term flexible pavement applies to any construction which does not have inherent flexural strength sufficient to make the pavement act as a beam in bridging irregularities in the foundation. Flexible pavements are assumed to eventually reflect at the surface any distortion or irregularity occuring beneath.

The load carrying capacity of a truly flexible pavement is brought about by the load distributing characteristics of the layered system. Flexible pavement consist of a series of a layers with the highest quality materials at or near the surface. Hence the strength of a flexible pavement is the result of building up thick layers and thereby, distributing the load over the sub-grade, rather than by any bending action.

2.1.2 **Rigid Pavement:** The rigid pavement because of its rigidity and high modules of elasticity tends to distribute the load over a relatively wide area and a major portion of the structural capacity is supplied by the slab itself. This type of pavement is made up of portland cement concrete and may or may not have a sub-base course between the pavement and the sub-grade. The major factor considered in the design of the rigid pavement is the structural strength of the concrete. As presently, we do not have rigid pavements in the country, only flexible pavements have been discussed in the report.

2.2 **Flexible pavements components:**

A flexible pavement may consist of the following layers:

2.2.1 **Sub-Grade:** This is the upper layer of the natural soil which may be undisturbed local material or may be soil excavated elsewhere and placed as fill. In either case it is compacted during construction to give added stability and where weak soils are encountered, the sub-grade may be improved by mixing with imported better soil or a small amount of stabilizing agent.

2.2.2 **Sub-base:** The sub-base is an important load spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the sub-grade, it acts as a working platform for the construction of the upper most layers and it acts as a separation layer between sub-grade and roadbase.

2.2.3 **Base Course:** A base course is the layer immediately under the wearing course. Because the base course lies close under the pavement surface, it is subjected to severe loading. It follows that the materials in a base course must be of extremely high quality and construction must be carefully done.

A wide range of materials can be used as unbound road bases including crushed quarried rock, crushed and screened, mechanically stabilized, or naturally occurring `as dug' gravels. However, the final choice depend on which is the most economical material to provide the structural strength required for base course layer.

The combination of a tightly keyed course aggregate with the bond produced by stone chips and dust creates a base course known as Water Bound Macadam base course and is equally as good as any other untreated bases. Thus, the decision wheather or not to use macadam bases becomes an economic one.

2.2.4 **Surfacing:** This is the upper most layer of the pavement. It will normally consist of a bituminous material namely stone chips on asphalt spray or aggregate pre-mixed.

The surface course of a flexible pavement structure must have the following characterstics and perform the following functions:

a) Provide a smooth, quite surface for traffic.

b) Be resistant to the wear of traffic.

c) Be highly resistant to rutting, showing or other surface deformations.

d) Have a high coefficient of friction to resist skidding and to provide proper traction; and

e) Be of sufficient density to be water proof to retard weathering and pavement damage from freezing and thawing cycles.

CHAPTER-III

PAVEMENT MATERIALS

3.1 General:

In highway construction, various types of materials are used for construction of various layer of pavements. The granular materials, the bitumen materials and combination of these is widely used for the construction of flexible pavements these days. In unbound condition, the granular materials are used for construction of sub grade, sub-base and road bases. In bound form with bitumen, they are used as surface dressings and asphaltic mixes.

The materials used in the construction of a highway are of intense interest to the engineer. In order to construct the highways economically, the efficient usage of locally available material is essential. This requires a thorough understanding of not only the soil and aggregate properties which effect pavement stability and durability, but also the properties of the binding materials.

3.2 Granular Materials

In case of flexible pavements the granular materials are commonly used in unbound form for the construction of sub-base or as a road base material. For sub-base construction, the material may be a natural-sand, gravel, crushed-rock, crushed-slag or crushed concrete. The material, however, has to fulfil certain requirements as regards grading of the material and strength requirement such as when used as a sub-base, the material must have a California Bearing Ratio (CBR) of at least 30 percent.

Granular material may be used as a road base in the form of dry-bound macadam, or wet-bound macadam.

3.2.1 **Dry-Bound Macadam:**

Dry-bound macadam is one of the earlier forms of road base construction that replaced hand placed stone or pitching. Crushed rock or crushed slag of either 50 or 40 mm nominal size is used as the coarse aggregate, and fine aggregate is also used that all passes 5 mm sieve. This fine aggregate must be kept dry until required for use. The coarse aggregate is spread first to a thickness within the range 75 mm and 100 mm and rolled; the fine aggregate is next spread on the top to a thickness of approximately 25 mm and vibrated into the voids between the larger particles. In U.K., the Department of Transport limit the use of this material to pavements that will carry not more than 11 million axles during design life.

3.2.2 **Water Bound Macadam:** is a layer composed of broken-stone (or crushed gravel or slag) fragments that are bound together by stone dust and water applied during construction, in connection with consolidation of the layer by a heavy roller or a vibratory compactor. Regarding strength and soundness of aggregates, the AASHTO specifications read as "course aggregate (retained on No 10 sieve) shall consist of hard, durable particles or fragments of stone, gravel or slag. Fine aggregates (passing No 10) shall consist of natural or crushed sand and fine mineral particles passing the No 200 sieve. The coarse aggregate should be subjected to Los Angles Abrasion Test and that loss on the test should not exceed 50% and that the California Bearing Ratio (CBR) shall be at least 80%. This type of macadam road closely resembles those so widely used in the early days of road building, although it is road principally used only in base construction.

Water-bound macadams are constructed in thickness ranging from about 3 to 12 in, depending on the purpose for which they are intended.

3.3 **Bituminous Materials:**

3.3.1 **Bitumen:**

Bitumen is a black sticky complex organic material. Bituminous materials for road purposes is generally defined as substance comprising primarily of bitumen or containing a large percentage of bitumen. This organic material may occur naturally or it may be created artificially during a production process. By defination, bitumen is a material that is soluble in carbondisulfide. Bituminous materials are frequently divided on the basis of their consistency into liquid, semisolid and solid material.

3.3.1.1 **Native bitumens:-** May be defined as the asphalt that occurs in a pure or nearly a pure state in nature.

a) Road asphalts: Native asphalts that are associated with a large proportion of mineral matter is generally termed as "rock asphalt". It is not of practically use where it does not occur.

b) Lake asphalt: Another main naturally occurring material is Trinidad lake asphalt. It is very hard and stiff material. Where blended with the material, the resultant material becomes stiffer and less susceptible to oxidation.

3.3.1.2 **Petroleum bitumens:**

Petroleum or "oil" asphalts are asphalts produced from petroleum oil. A wide variety of refining process may be used to produce petroleum asphalts suitable for use in highway construction. In general, it can be said that petroleum asphalts are obtained by distillation and by blowing air at high temperatures.

Crude petroleums obtained from different parts of the world show great differences in composition and may be generally divided into three categories, that is, asphaltic mixed and paraffin base petroleums. The majority of asphaltic products used for highway purposes are derived from asphaltic base petroleum, although it is possible to derive asphaltic materials from other types of petroleum. Bituminous materials purchased for use in highway construction must, of course, meet certain specifications. Acceptance of the material is based upon the results of certain tests that are performed upon the representative samples.

3.3.2 **Bitumen emulsions:** A bitumen road emulsion is defined as a liquid product in which a substantial amount of bitumen is suspended in a finally divided condition in water by means of one or more suitable emulsifying agents. The emulsifying agents commonly used are soaps, used alone or in combination with other substances. The principal objective of the liquefication of asphaltic materials by this method is to allow their application at normal temperatures without the use of heat.

The emulsion breaks down when sprayed or mixed with mineral aggregate in a field construction process; the water is removed, and the asphalt remain as a film on the surface of the aggregate. The water simply serves as a temporary transporting medium.

3.2.3 **Cut-back asphalts:**

Cut-back bitumens are produced by making the fluxing process further by adding a percentage of kerosine. Cut-backs are described by their viscosity.

3.3.4 **Tar:** Tar may be generally defined as a substance obtained by the condensation of distillates resulting from the destructive distillation of organic material.

Although asphalts and tars are somewhat similar in appearance and general composition, they are produced by generally dissimilar processes and differs sharply in certain properties that are of importance in highway work. Generally speaking, tars are more susceptible to temperature change than asphalts of similar grade, they are toxic in nature, they harden more rapidly when exposed to the air after being incorporated into a wearing surface or pavement.

3.4 **Bituminous surfacings:**

The simplest type of surfacing is a surface dressing containing a thin layer of bitumen into which stone chippings are rolled. This type of surfacing is very flexible and provides a reasonably water proof seal. Depending on traffic and dimatic conditions a single, double or even tripple surface dressing may be used.

The essential requirement of all bituminous surfacings is that they should be waterproof. They should also provide a skid resistant surface. Surfacings do not necessarily have to perform a load spreading function because this can be done by the underlying structural layers.

The surfacing is the most expensive of all the layers and therefore needs to be kept as thin as possible commensurate with the stress that it can withstand.

3.4.1 **Surface treatments**

Tripple surface treatments are widely used for

the surfacing of primary and secondary roads that carry light to moderate amounts of traffic. A surface constructed by this method is frequently quite "open" in character and has excellent nonskid and visibility characteristics. This type of surface is generally so thin that it has little load-supporting value in itself and must depend upon an entirely adequate base and subgrade to function satisfactorily.

Although, it is considered as adequate for light to moderate traffic volumes. However, experience in Pakistan have shown that even on our most heavily trafficked National Highway (N-5), this type of surfacing laid over aggregate base course has worked well. The sub-standard riding quality observed in case of T.S.T in our country is not the fault of the tripple surface treatment but is mainly due to the lack of quality control practices adopted during construction of the road.

3.4.2 **Structural surfacings**

There are many types of surfacings which provide substantial structural strength to a pavement. These consist of precisely defined mixtures of bitumen, course and fine aggregate, sand and fine material called filler. In order to make them properly, it is usually necessary to mix the constituents in specialized plant and hence the materials are generally known as premix or plantmix.

The term hot mix asphalt (HMA) is used generally to include many different types of mixes that are produced at an elevated temperature in an asphalt plant. The category of HMA is divided into three different types of mixes, depending primarily on the gradation of the aggregate used in the mix. The three mix types are a) dense-graded, b) open-graded and c) gap-graded.

3.4.2.1 **Dense-graded mix**

Dense graded mix consist of a uniform or continuous aggregate grading with asphalt cement binder. The mix grading, binder content, and compaction reduce the voids in the mix (vim) to about 3% - 8%.

3.4.2.2 **Open-graded mix**

An open-graded asphalt mixture is one that consists primarily of coarse aggregate, a minimal amount of fine aggregate and asphalt cement binder. The main purpose of this mixture is to provide a very open surface texture that will allow water to drain into the mix and that provides a significant amount of large aggregate for contact with a vehicle travelling over the pavement surface.

3.4.2.3 **Gap-graded asphalt mixes**

A gap-graded asphalt mix is essentially the same as an open-graded mix, however, the amount of fine aggregate incorporated into the mix is usually greater than the amount of fine aggregate used in the open graded mix.

3.5 Some Specific Bitumen Mixes

Some specified asphaltic mixes commonly used these days are:

3.5.1 **Asphaltic Concrete** is continuously graded and almost always over-sanded. Mix properties depend on both fine and coarse aggregate and on the quantity and penetration of the binder.

It is essential to maintain adequate VIM in order to avoid deformation under the heavy traffic. 3%-5% residual VIM after trafficking are the normal target.

Major properties are:

- It is relatively difficult to compact;
- can be impervious;
- can have fairly good resistance to oxidation and cracking, provided the binder content is high enough and VIM are low enough; (SENSITIVE TO MIX PROPORTIONS)

- can have good rut resistance, provided the binder content is low enough and VIM are high enough; (SENSITIVE TO MIX PROPORTIONS)
- gives moderate surface texture.
- Under extreme conditions the requirements for Deformation and Crack resistance are in conflict. When used under such conditions AC is very sensitive to small changes in mix proportions. Avoid this situation unless quality control is exceptionally good.

3.5.2 **Hot Rolled Asphalt (HRA)**

Hot Rolled Asphalt consists of a sand asphalt with asphalt between 30% and 60% of added coarse aggregate. The mix is very dependant upon the properties of the fine aggregate and the binder. It needs angular sand or crushed fines and, usually, 40/50 pen bitumen with a fairly high filler content.

This is a GAP GRADED mix and some of its major properties are:

- It is easily compacted;
- is impervious;
- has good resistance to oxidation and cracking;
- has reasonable rut resistance except at high temperatures;
- results in a smooth finish so that chippings must be rolled in to provide skidding resistance.

3.5.3 **Bitumen Macadams:**

a) Dense Bitumen Macadam is continuously and under-sanded; should always be designed to give adequate retained VIM. Mix properties depend primarily on the aggregate grading, particle shape and texture. Binder penetration also has some effect but less than in HRA and AC.

In UK, can be made to Recipe Specifications but is far better designed using Marshal (or other) tests to determine the suitability of aggregate grading and the optimum binder content. For use under heavy traffic it is usually designed to have 6%-9% VIM after rolling with the aim of having 3%-6% after 2 years service.

Properly designed DBM gives excellent resistance to rutting but will usually fail by cracking after 10-15 years unless the surface is sealed (surface dressing or slurry seal) in time (perhaps after 5-8 years).

Major properties are:

- It is fairly easily compacted;
- is not entirely impervious;
- has only moderate resistance to oxidation and cracking;
- has good rut resistance which is less sensitive to high temperatures than most other materials;
- results in a fairly well textured finish.

b) Open Textured Macadam is continuously graded and highly under-sanded to provide very high VIM. This makes it permeable and therefore free draining. It was developed for use on airfield runways, where it prevents aquaplaning. There are specifications for its use on roads where it dramatically reduce spray from vehicle wheels. However, it does not add greatly to the structural strength of a road so it must be treated as an extra layer. This is expensive anwthe material is not used very much.

Trials on trunk roads and motorways showed a reduction in free draining properties with time but were generally very successful.

Major properties are:

- It is very easily compacted;
- is pervious;
- probably has only moderate resistance to oxidation and cracking;
- has adequate rut resistance which is less sensitive to high temperatures than most other materials;
- results in a very well textured finish that combines good skid resistance with a quiet ride.

3.6 Some considerations regarding Asphaltic Mixes

The asphaltic concrete is the most common surfacing material in use on heavily trafficked roads in developing countries. Asphaltic concrete was developed in the USA. Asphaltic concrete is the highest and most expensive and is considered suitable for the most heavily traveled roads. It is mixed and laid at high temperatures and requires a heavy binder. Mineral aggregates are of high quality and are proportioned with tight limits. All sizes of the particles need to be present in precisely the right proportions to ensure a satisfactory mix. A very close control is required to follow the specifications required for mixing, placing, achieving final density and for obtaining the final surface finish i.e. quality control is essential.

The use of this type of material has increased tremendously on our roads during the last two decades. But, unfortunately, in most of the cases, the material did not meet the required expectations and suffered premature failures. Most of the road stretches exhibited plastic deformation within few years after opening of them to traffic.

Asphaltic concrete surfaces are widely used both on rural highways and city streets that are subject to large volumes of traffic and severe service conditions. Properly designed and constructed surfaces of this type of surfaces have proved capable of carrying almost unlimited volumes of truck traffic in developed countries. The asphaltic concrete mixtures are, generally speaking, marked by the use of carefully selected and graded aggregate in conjunction with semisolid Bituminous binders. The composition of the mixture is more rigidly specified and controlled than that for other types of Bituminous surfaces. Similarly, the preparation, placing and finishing of the mixture is performed under more rigid specifications and control. Surfaces of this type are more expensive than other types and less emphasis is placed upon the use of local materials in the preparation of the mix.

Investigations of various failed sections have revealed that many premature rutting problems have resulted from use of mixes with binder contents that are too high, resulting in compaction under traffic to a state where void contents become dangerously low and shear resistance declines sharply. This arises because the compactive effort on site applied to a confined layer of material is more effective than that which occurs in the standard 100 mm dia mould subjected to a Marshall however, many blows may be applied.

Experts of bitumen mixes are of the view that mixes could be improved in terms of their mechanical properties, by simple adjustments to such factors as binder content, binder grade and aggregate gradation.

Studies carried out on some of these rutted sections have revealed that the values of insitu airvoids become very low after initial trafficking and surface shear failure under heavy traffic and high temperatures.

Evidence from sites elsewhere indicate that a minimum airvoids content of 3 percent at refusal density, i.e. after several years of heavy trafficking is required to minimise the risk of deformation in the asphaltic layer. According to TRL experts, who based on monitoring of several years of performance of asphaltic mixes in the tropical countries has concluded that the best way of achieving this is to use a base course mix and to protect the layer with a surface dressing. The base course mixture should be very resistant to deformation and the surface dressing will be very effective in resisting cracking and preventing rapid age hardening of the bitumen in the surface of the base course.

A second method of reducing the susceptibility of a mix made to deformation is to use a bitumen with higher PI values. A mix with bitumen with a PI of + 2 will be twice as resistant to deformation than one made with a bitumen having a PI of - 1/2 - 0.5, also increased softening point normally results in higher marshall stabilities. The loading and thermal conditions on roads in Pakistan are so severe that every possible improvement to mix properties must be employed.

CHAPTER-IV

PAVEMENT DESIGN - LITERATURE REVIEW

4.1 General:

The aim of the pavement design is to select the most economic pavement thicknesses and composition which will provide a satisfactory level of service for the anticipated traffic. Unfortunately, the basic aim of pavement design is not being met.

Methods of pavement design normally being used by the highway engineers can be sub-divided into two main groups.

i) Methods derived from emperical studies of pavement performance.

ii) Methods which either use or are derived from theoretical studies of the mechanical behaviour of the pavement.

4.2 Emperical design methods:

Methods which are based on empirical studies of pavement performance usually include field and laboratory testing of material for identification and classification. Empirically based methods have proved to be satisfactory provided the materials, environment and conditions of loading do not differ significantly from those which applied during the original emperically studies on which the design methods were based. However, traffic volumes and traffic loadings have increased quite dramatically during the last decades and it is unlikely that existing empirical methods can be simply extra-polated to accommodate these changes.

The extension of empirical design methods is a serious problem for industrialist countries but for developing countries like Pakistan, it is particularly difficult. Indeed, many developing countries do not yet have a satisfactory design method of their own based on empirical studies. In such countries pavement design relies on methods borrowed from elsewhere with methods that are often far from satisfactory.

It is not possible for most of the developing countries to devote either the financial resources or the time to the construction and monitoring of sufficient full scale experiments to produce a satisfactory based design method.

Some of the commonly used emperical pavement design methods currently being used in the country are

a) AASHTO 1986 Interim Design Guide.

b) Road Note 31, TRL, UK. (4th Edition, 1995).

c) LR 1132

d) Queensland department of transport method.

4.2.1 AASHTO Guide for Design of Pavement Structure (1986)

The method is probably the most widely used method in tropical countries. This method was developed from the results of the AASHO road test conducted during 1959 and 1960.

A total of 468 test sections, with a minimum of 100 feet were constructed including rigid pavement sections. Each lane was trafficked continuously for two years by specially selected and loaded vehicles with particular axle loads and wheel configurations.

Design Considerations:-

Some of the main design considerations of this method are:

1. Pavement Performance
2. Traffic
3. Roadbed Soil
4. Materials of Construction
5. Environment
6. Drainage
7. Reliability
8. Life - cycle cost, and
9. Shoulder design

The basic design equation used for the flexible pavement design in the guide is

$$\log_{10}(W)_{18} = Z_R x S_O + 9.36\log_{10}(S_N + 1) - 0.20 + \log_{10}\left[\frac{\frac{\Delta PSI}{4.2-1.5}}{0.4 + \frac{1094}{(S_N+1)^{5.19}}}\right] + 2.32\log_{10}(M_R) - 8.07$$

Where W_{18} = Predicted number of 18 - kip equivalent single axle load applications.

Z_R = Standard normal deviate.

S_O = combined standard error of the traffic prediction and performance prediction.

ΔPSI = Difference between the initial design serviceability index P_O, and the design terminal serviceability index, P_t

M_R = Resilient Modules (psi)

S_N = Required structural number indicative of the total pavement thickness required

$$S_N = a_1 d_1 + a_2 d_2 m_2 + a_3 d_3 m_3$$

a_i = ith layer coefficient

d_i = ith layer thickness (inches) and

m_i = ith layer drainage coefficient

The structural number is an abstract number expressing the structural strength of a pavement required for given combinations of soil support (M_R), total traffic expressed in equivalent 18-kip single axle loads, terminal serviceability, and environment.

It is important to recognize that the eq. has been derived from empirical information obtained at the AASHO Road Test. As such equations represents a best fit to the observations at the road test. It is important to use mean values for such factors as soil support, traffic, layer coefficient, drainage coefficients etc.

A few changes has been made in the design equation when compared with the 1972 interim guide. The soil support value has been replaced with M_R (flexible). For the flexible equation, the structural number (S_N) has been modified by the addition of drainage coefficient and the regional factor (R) has been deleted.

(1) **Pavement Performance:**

Concept of pavement performance include some consideration of functional performance, structural performance and safety.

The structural performance of a pavement relates to its physical condition i.e. occurance of cracking, faulting, ravelling or other conditions which would adversely affect the load-carrying capability of the pavement structure or would require maintenance.

The functional performance of a pavement concerns how well the pavement serves the user. In this context, riding comfort or ride quality is the dominant characteristics.

The serviceability of pavement is expressed in terms of present serviceability index (PSI). The PSI is obtained from measurements of roughness and distress eg. cracking, patching and rut depth (flexible), at a particular time during the service life of the pavement. Roughness is the dominant factor in estimating the PSI of the pavement.

The major factors influencing the loss of serviceability of a pavement are traffic, age and the environment.

The total change in PSI at any time can be obtained by summing the damaging effects of traffic, swelling clay, and/or frost heave.

$$\Delta PSI = PSI_{Traffic} + PSI_{Swell\ /\ Frost\ heave}$$

$\Delta PSI =$ Total loss of serviceability

$PSI_{Traffic}$ = Serviceability loss due to traffic (ESAL's) and

$PSI_{Swell\ /\ Frost\ heave}$ = Serviceability loss due to swell/frost heave swelling and / or frost heave of road bed soil

(2) **Traffic**

The procedure used in this guide is to convert mixed traffic stream of different axle loads and axle configurations into a design traffic number by converting each expected axle load into an equivalent number of 18-kip single axle loads and to sum these over the design period.

The available load equivalent factors are considered the best available at the present time, representing information derived from the AASHO Road Test. The emperical observation on the road test covered a range of axle load from 2 to 30 kips on single axle and 24 to 48 kips on tandem axles. It should be noted that load equivalency factors are, to a minor degree, function of pavement type rigid or flexible, thickness, and terminal serviceability (P_t) used for the design.

(3) **Road Bed Soil:**

The definite material property used to characterize road bed soil for pavement design in this guide is the resilience mudulus (M_R). The resilience modules is a measure of the elastic property of soil recognizing certain nonlinear characteristics. It is recognized that many agencies do not have equipment for performing the resilient modules test. Therefore, suitable factors are reported which can be used to estimate M_R from standard CBR, R-value and soil index test results or values.

Heukelom and klomp have reported correlations between the corps of Engineers CBR value using dynamic compaction, and the in situ modules of soil. The correlation is given by

$$M_R(\text{Psi}) = 1500 \times \text{CBR}$$

Similarly relationship have also been developed by the Asphalt Institute which relates R values to MR as

$$M_R\ (\text{Psi}) = A + B \times (\text{R-value})$$

Where $A = 772$ to 1155
$B = 369$ to 555

the guide recommends the following value

$$M_R = 1000 + 555 \times (\text{R-value}).$$

Resilience modules (M_R) values for pavement structure design should roundly be based on the properties of the compacted layer of the road bed soil. It is important to note that the design of the pavement structure by this guide is based on the average M_R value.

(4) **Drainage Layer:**

A number of agencies are now considering or constructing pavements with a drainage course or layer. The location of the longitudinal drain with respect to travelled way can vary depending upon the designer preference and local experience. It is important for the designer to give some consideration to the performed construction sequence when specifying a drainage system in execution and installation after the travel lane paving has been completed.

(5) **Surface Course:**

It consists of a mixture of mineral aggregates and bituminous materials placed as the upper course and usually constructed as on a base course. In addition to its major function as a structural portion of the pavement, it must be designed to resist the abrasive forces of traffic, to reduce the amount of surface water penetrating the pavement and to provide a skid-resistance surface.

(6) **Drainage:**

Drainage of water from pavements is the most important consideration in road design. However, the methods of design have often resulted in base courses that do not drain well. This excess water combined with increased traffic volumes and loads often leads to easily pavement distress in the pavement structures. Water enters the pavement structure in many ways resulting in reduced strength of unbounded granular materials, reduced strength of roadbed soils and pumping of fines in aggregate base under flexible pavements.

7. **Reliability:**

The procedure for design of both rigid and flexible pavements provide a common method for incorporating a reliability factor into the design based on a shift in the design traffic.

The final summary description of the reliability concept as given in the guide is that the reliability of a pavement design performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period.

Comments on method:

The method suffers from several important deficiencies as far as its relevance to the tropical countries is concerned.

i) The road test on which the method is based was located in the northern mid-west of the United States near Chicago in an area where winter temperature cause upto 1.5 meters of frost penetration for the three months of the year. Almost all the pavement deterioration took place during spring thaw when the pavements were saturated with water. The condition in our country are totally different from these in Chicago.

ii) The road test was built on one type sub-grade of very low strength. Estimating the performance of roads built on other sub-grade from the results of the road test is different.

iii) The road test was an accelerated test. The environment plays an important role in the deterioration of flexible pavements and a much longer test would have been necessary to allow this to become manifest. For example the hardening of bitumen is very important in hot countries and affects the fatigue life of bituminous materials quite dramatically.

iv) The design of vehicles have changed and the present day vehicles are different from those used in the test. The types of tyres have also changed.

v) The wheel load and contact presume experienced by each test section was always the same. It is expected that if mixed trafficking had been used the conclusions would be somewhat different especially as regards the relative damaging effect of each wheel load.

vi) The axle loads plying on our roads are much higher than those used in the AASHO road test. The tyre pressures of our commercial vehicles are much higher than those vehicles used in the road test.

vii) The range of base and surfacing thickness was such that the road test did not include sufficient test sections covering the thicknesses encountered in developing countries.

4.2.2 **TRL 1132 Method:** The last edition of the Road Note 29 was published in 1970. However, since than damaging power of the commercial vehicles have increased tremendously in U.K. As a result, the most heavily trafficked roads are now designed for cumulative traffic up to 10 times that envisaged when the first motorways were opened.

The TRL 1132 method is just not a replacement of Road Note 29. But it is based on the research carried out during the last thirty five years. The design guidance is based on the measured performance of the full scale road experiments. These have now yielded a much greater quantity of data than at the last review in late sixties, when several major experiments had only recently been built.

The structural design standards for bituminous roads provided in RN 29 were based on the observation of the performance of a number of experimental roads built into the public road network. The design curves developed from observation on pavements that had carried less than 10 msa; the design have proved generally satisfactory up to cumulative traffic of 40 msa. However, to accommodate the recent rapid growth in the number and the damaging power of the heavy goods vehicles, the busiest motorways in U.K. now need to be designed to carry 150 msa over 20 years. The empirical method of design used in RN 29 does not provide a satisfactory basis upon which to produce designs for traffic levels that are so far in excess of those observed on the experimental roads.

Main features of this method of design are;

a) **Design Criteria:** The design criteria recommended in this method is that to give satisfactory service, a pavement must satisfy a number of structural criteria; important of which are:

i) The sub-grade must be able to sustain traffic loading without excessive deformation; this is controlled by vertical stress or strain at formation level.

ii) Bituminous materials and cement bound materials used in road base design for long life must not crack under the influence of traffic; this is controlled by the horizontal tensile stress or strain at the bottom of the road base.

iii) In pavements containing a considerable thickness of bituminous materials, the internal deformation of these materials must be limited; their deformation is a function of their creep characteristics.

iv) The load spreading ability of granular sub-bases and capping layers must be adequate to provide a satisfactory construction platform.

b) **Design Life:** Road Note 29 recommended a design life of 20 years for bituminous roads, because their life may be extended by strengthening overlays. In Road Note 29, the end of the design life was associated with a surface rut of 20 mm or more severe cracking and crazing and the pavement was considered to be in a failed state and in need of a major strengthening overlay or partial reconstruction.

The conditions associated in this method at the end of design life are 10 mm rut depth and initial cracking. According to TRRL 1132 method, it is preferable to carry out pre-emptive overlay at the onset of the critical conditions, because it makes best use of the strength of the existing pavement, it results in pavement of more uniform strength, and it is more readily anticipated by the in-situ deflection measurement and it can be more readily planned. Beyond the critical condition the nature and rate of deterioration becomes much less predictable.

The design life recommended in the LR 1132 is also 20 years. According to work done by Abell (1983) pavements with a bituminous road base, the optimum design life that minimizes the total transportation costs discounted over 40 years is closed to 20 years, with 85 percent probability that roads will survive that period without requiring a strengthening overlay to extend their lives. It should be noted that this design will give a sufficient longer lite than a road Note 29 design for 20 years because it is based on structural deterioration with a 10 mm rut in the wheel path rather than 20 mm rut.

CONDITIONS ASSOCIATED WITH END OF LIFE

	LR 1132 "New Design Limit" Critical	RN 29 "Severe Cracking" Failed
Rutting	10 mm	20 mm
Cracking	initial cracking	Severe cracking

c) **The Subgrade:** The road pavement must reduce the stresses on the subgrade due to traffic loads to a level that ensures that there is only very limited deformation at the end of the design life.

The California Bearing Ratio (CBR) test is a generally accepted and practical measure in this method that can be used to give an estimate of both stiffness and strength of the sub-grade soil.

For the design of new roads, it can be applied to laboratory samples compacted at the appropriate field moisture content. It can also be used to test material in-situ at depth likely to be un-affected by seasonal variations of moisture when this strength condition is considered appropriate for design.

d) **Sub-Base:** The Sub-Base material in the guide has been defined as a structurally significant layer, generally of a granular material, that provides a working platform on which material can be transported, laid and compacted; it also acts as a level regulating course and insulates the sub-grade against the action of weather. The various sub-grade material described in the guide are granular sub-base and cemented bound sub-base. The cemented-bound sub-bases may be preferred, particularly for construction in wet weather.

Road Bases: The thickness of the road base material indicated in the guide are based on the performance of the 144 sections of the experimented roads. The different types of the road bases indicated in the guide are:

a) **Bituminous Road Base:** There are two main modes of deterioration associated with this type of road base, a gradual build up of deformation observable at the surface in the wheel paths and development of cracks in the bituminous material.

For highly traffic roads a minimum thickness of bituminous layers of 100 mm is recommended. This thickness is close to the minimum that can be laid and is sufficient to avoid excessive sub-grade stress under the occasional very heavy wheel load on hot days, a rapid failure could otherwise occur. As the design thickness increases, deformation within the bituminous layers becomes increasingly important for design lives in excess of, say 80 msa, a method of analysis based on laboratory creep test can be used to check that the layers have adequate resistance to deformation.

b) **Wet-Mix Granular Road Base:** The design thickness of wet mix granular road bases are based on the performance of the pavement sections with wet mix road base and rolled asphalt surfacing. The performance in terms of deflection and rut depth of 42 sections of experimental road that included a range of crushed rock aggregate and graded slag was used to develop the standard design. Minimum layer thickness at low traffic levels are dictated by practical considerations.

4.2.3 Road Note 31 method, TRL, (UK)

Road Note 31 is based on the research undertaken by the Overseas Unit of TRL in tropical countries during the last 20 years. It is a design guide which underlines those aspects of the pavement design which are universally important whilst recognizing the large differences in conditions between countries. This note gives recommendations for the structural design of bituminous surfaced roads in tropical and sub tropical climates. It is aimed at highway engineers responsible for the design and construction of new road pavements and is appropriate for roads which are required to carry up to 30 million cumulative standard axles in one direction.

The purpose of the structural design is to limit the stresses in- duced in the sub-grade by traffic to a safe level at which sub-grade deformation is in-significant whilst at the same time ensuring that the road pavement layers themselves do not deteriorate to any serious extent within a specified period of time.

Design process:

The three main steps to be followed in designing a new road pavement are

i) Estimating the amount of traffic and the cumulative number of equivalent standard axles that will use the road over the selected design life.

ii) Assessment of the strength of the sub-grade soil over which the road is to be built.

iii) Selecting the most economical combination of pavement materials and layer thickness that will provide satisfactory service over the design life of the pavement.

The note considers each of these steps in turn and puts special emphasis on five aspects of design that are of major significance in designing roads in most tropical countries.

- The influence of tropical climates on moisture conditions in road sub-grade.
- The severe conditions imposed on exposed bituminous surfacing materials by tropical countries and the implications of this for the design of such surfacings.
- The high axle loads and tyre pressures which are common in most countries.
- The inter relationship between design and maintenance. If an appropriate level of maintenance can not be assured, it is not possible to produce designs that will carry the anticipated traffic loading without high costs to vehicle operators through increased road deterioration.

- The influence of tropical climates on the nature of the soils and rocks used in road building.

Basis for the Design Catalogue

The Note provides a design catalogue which covers design loading upto 30 million standard axles and sub-grade strength from 2 to 30+. The catalogue is primarily based on

a) The results of the full-scale experiments where all factors affecting performance have been accurately measured and their variability quantified.

b) Studies of the performance of as-built existing road networks.

Where direct empirical evidence is lacking, designs have been interpolated or extrapolated from empirical studies using road performance models.

In view of the statistical nature of the pavement design caused by the large uncertainties in traffic forecasting and the variability in material properties, climate and road behaviour, the design charts have been presented as a catalogue of structures, each structure being applicable over a small range of traffic and sub-grade strength.

4.2.4 Queensland Department of Transport Method Pavement Design Manual:

The manual provides procedure for the design of pavements for the Queensland Department of Transport (Australia). The manual is intended to provide a uniformity of approach to pavement design throughout the department of Transport. These procedures are similar also to those used by the AUST ROADS (previously NAASRA) document "Pavement Design - A Guide to the Structural Design of Road Pavements". The manual contains detailed discussion of sub-grade evaluation, pavement materials evaluation, analysis of traffic loading and structural design.

a) **Basis of Design Method:-**

The procedures in the manual are intended for the design of pavements where primary distress mode is load associated.

The method used is based on the elastic theory of pavement response to traffic stresses and the results of field and laboratory investigations in which material properties and behaviour have been characterized. It assumes that loss of pavement serviceability and structural integrity can occur due to either or both of the following:-

- Fatigue of bitumen-bound or cemented layers due to repetitions of tensile strains at the bottom of such layers.

- Permanent deformation of the sub-grade due to the repeated vertical compressive strains induced in the sub-grade.

The design curves have been developed in a manner ensuring that specified limiting strains at these locations are not exceeded. The design curves have been drawn in terms of number of repetitions of Equivalent Standard Axles (ESA's) which are predicted for the design life of the pavements and the design sub-grade CBR.

The manual provides procedures for design which incorporate the following materials;

Unbound granular materials

Cemented materials

Bituminous materials

b) **Determination of Optimum Solution:-**

The manual provides design curves for a range of alternative pavement types. The optimum pavement design solution is that which satisfied the design requirements for the specified input at minimum cost, for the whole life of the pavement and allows for the following considerations:-

Design considerations. The need of the road users. Future maintenance. Availability of plant and materials.

- Although asphalt surfaces are more costly than sprayed surface treatments, they are provided on heavy trafficked roads because of the costs, traffic disruption and dangers to traffic and workmen associated with maintaining a sprayed seal.

- Where the pavement is likely to be exposed for extended periods to soaked conditions, cement or bituminous bound material will be required to protect the structural integrity of the pavement despite possible additional costs.

- When comparing the cost of structurally equivalent alternatives, consideration must also be given to non-productive costs associated with establishments, overheads, provision for traffic and wet weather, which may be different for each alternative.

c) **Thin Asphalt Surfacings:**

In any of the design charts which show granular or cemented material as the top layer, the sprayed bitumen seal which would normally be applied to these pavements may be supplemented by a 35 mm asphalt surfacing, without any modification to the design.

This type of surfacing may be appropriate in urban areas or other situations in which a smooth surfacing is required.

The sprayed seal should not be omitted because it provides more positive water proofing than the thin asphalt layer.

The asphalt must be kept as thin as is practical so that it functions only as a surfacing and not a structural layer. If more than 35 mm of asphalt is used, the asphalt can be expected to show premature fatigue cracking. If thicker asphalt layers are to be used, the design should be based on the charts which show asphalt as the top layer.

4.3 **Analytical road design method**

The analytical procedure may be described as one where the layered pavement system is subjected to surface loading and the resulting stresses and strains at critical locations are calculated and then compared with the maximum allowable values for the materials in use.

The elastic properties of the various materials need to be known for the purpose of analysis and failure conditions have to be specified in terms of stress or strain.

The main problem involved in applying this approach to pavement lies in the complex engineering behaviour of the individual materials and the fact that failure of pavements tends to be a repeated load effect in the sense that it depends on number of load applications as well as their magnitude.

4.3.1 Some well known analytical design methods

(1) Shell method

In Shell design method pavement is regarded as linear elastic multi layers system: the sub-grade, the base layer and a top layer which represents all bitumen-bound layers. The layer materials are characterized by Young's modules of elasticity (E) and poison ratio and thickness. Layers are assumed to have horizontally infinite dimension.

In 1985, the method was updated in an addendum based on experience over the previous ten years. Though resulting from computer calculations of stresses and strains in the pavement structures, the manual is in the form of graphs, charts and tables, so that it can be used by engineer's with no access to sophisticated computer aids.

In 1963 shell published a set of charts for the thickness design of flexible pavements, which represented a partly analytical and partly empirical method. In 1978, this system was extended significantly with analytical components and published as the Shell Pavement Design Manual (SPDM). The SPDM enabled the designer to introduce the effects of temperature, traffic density etc on the pavement, the asphalt mixes being characterized with respect to the stiffness and fatigue behaviour and bitumen type. The SPDM represents the finest practical, analytically based design method for the asphalt (road) pavements.

In the basic design procedure the pavement is regarded as a three layered system. The lowest layer taken as infinite in vertical direction represent the sub-grade. The top layer represent an asphalt or bitumen bound layers. All layers are considered to have complete friction between them.

Failure parameters in shell design method

- The horizontal tensile strain in the bottom of the asphalt layer, if this is excessive cracking of the layer will occure.
- The compressive strain in the surface of the sub-grade if this is excessive permanent deformation will occure at the top of the sub-grade.
- Permissible tensile stresses or strains in any un-bound base layers.
- Integrated permanent deformation at the pavement surface due to deformation in the individual layers.

Depending upon material used and prevailing condition either the sub-grade or asphalt strain may be the deciding criterion.

Design input data for shell method

- Total no of standard axles in design life - N
- The temperature environment (W-MAAT)
- Determination of modules of the sub-grade (E3) and granular material (E2)
- Characterization of the behaviour of the bitumen layer by assigning a mix code e.g. S - F - pen

  stiffness - fatigue - penetration grade.

Although the method takes into account the effect of temperature, but the problem with this method is that it takes into account only the mean annual air temperature whereas the deformation and rutting in bituminous mixes mainly occurs due to the extremely high temperatures at day time during the summer months.

4.3.2 Role of Digital computers in analytical road design methods

In the analytical pavement design methods the analysis to be carried out by a computer program will ideally have the following characteristics.

1. Program should simulate the pavement with highest possible accuracy.
2. The program should be able to model the behaviour of multi layer structure.
3. It should take into account the loading characteristics of any non destructive testing device.
4. It should be sensitive to the nature of the materials.
5. It should have ability to calculate deflection strain, and stresses at critical location.
6. It should have short run time and user friendly.

Some computer programmes:

Several computer simulation model have been developed and used with different theoretical approach and sophistication. Majority of programs are based upon simple elastic solution of layered systems. While there are few models, which have used principles of plasticity, vis co elasticity and even of fracture mechanics.

Generally these approaches are less used and consequently it was felt that elastic solutions may provide optional computational basis within the knowledge based system.

Problems with the existing computer programme

- The non uniqueness of the layer moduli
- The error due to variation in thickness of pavement layers.

- The error involved in assuming a semi-infinite sub-grade.
- The error due to the non linearity of pavement materials.
- The error due to in accuracies in determining the input values.
- The time involved in the iteration process.

Some of the commonly used computer programmes are DEF PAV, PAFEC, CHEVRON, BISTRO, BISAR.

DEFPAV: This programme, in addition to computing elastic stresses and deflection can be used to predict the permanent deformation profile of pavement.

This program was produced in 1975 by Snaith and Kirwan, the present version is "the option version". Defpav is a powerful tool. However, it is felt that the program should be modified by increasing the nos of element.

PAFEC: This program is a multi task finite element structural analysis package produced by (Brooker et-al-1987). This programme provides facilities for automatic plotting of stress contours and displacements.

The program used to be powerful but unsuitable for routine analysis of pavement structure due to

i. Long familiarization time with the package.

ii. The considerable computation time.

iii. The lack of out put read ability.

Computer programs used by shell method

BISTRO - (Bitumen Structure in Roads)

In the late sixties Shell research limited developed the BISTRO program which calculates stresses, strains and displacements at any position in a multi layer system. This program has been changed and renamed BISAR i.e. (BITUMEN STRESS ANALYSIS IN ROADS), as personal computer is power full enough to solve problems. Shell have developed BISAR-PC to calculate maximum tensile and compressive stress and strain in the selected positions.

The main frame version of BISAR has the facility for handling a greater number of pavement layers and points where the stresses and strains can be calculated.

Analytical design methods require a considerable amount of materials testing and computational effort before they can be properly used. It is therefore unlikely that in the immediate future the full technique will be used for the design of the individual roads in developing countries. However, the analytical method is capable of allowing a good design to foresee and guard against many types of potential failure.

CHAPTER-V

PAVEMENT ECONOMICS

5.1 COST OF VARIOUS PAVEMENT LAYERS

A pavement can be designed for a particular loading condition and sub-grade strength using various combinations of different materials. Not only that different methods would provide different pavement thicknesses, but even using the same design method, there could be different alternative pavement designs fulfilling the same strength requirement. Under these circumstances, it becomes essential for the design engineer to recommend a design that is not only safe but is also economical.

As per famous AASHTO road test, the structural number for the asphaltic concrete base course is 0.40 while that aggregate base course is 0.14. It would mean that 1" thick asphaltic concrete is equivalent in strength to 0.4 / 0.14 = 2.8 inch thick layer of aggregate base course. Hence it is important to know the cost ratio between these two types of materials to have comparative idea about various pavement options in terms of cost effectiveness.

In this regard, several approved PC-I's of different projects as detailed below were studied to get the cost of different items of materials.

Serial No.	Project (PC-I)	Cost (Rs/CM)			
		Aggregate		Asphaltic	
		Sub-Base course	Base course	Base course	Wearing course
1	Lahore Bypass Project (Oct, 1994)	901	1212	4582	5145
2	Sukkur Bypass Project (March, 1995)	350	500	4125	4250
3	Mansehra-Nara Section (May, 1993)	442	700	2349	2599
4	Bridge Over Chenab River	370	427		2376
5	Overhead Bridge at Wazirabad Railway Carriage & Wazirabad Sialkot Road (1991)	450	550		2280
6	Construction of Peshawar-Torkham (N-5) (March, 1996)	205	212	2507	2850
7	Strengthening and Improvement Programme on N-5				
	Hyderabad	460	558	2489	2798
	Nowshera	278	341	2430	2732
	Rawalpindi	396	414	2519	2824
	Sahiwal	608	657	2649	2938
8	Upgradation & Improvement of National Highway (N-25) Kararo-Wad Section	600	860	2877	2991
9	Bridge over River Indus near Larkana (Sept, 1995)	550	650	4000	4250
10	Construction of additional carrigeway (N-5) Cheblat-Nowshera Section (Oct, 1994)	200	300	2588	2771
	Average	447	568	3010	3139

From the above table, it can be seen that the asphaltic concrete base is roughly (3010/568) 5.3 times the cost of the aggregate base course. From the structural number (S_N) concept of the various pavement layers as provided by the AASHTO Interim Guide, structurally one inch of asphaltic concrete base is equal to the 2.8" of aggregate base. As such to get same structural strength, the asphaltic concrete base material costs double the cost of the aggregate base material. It would imply that the less is the thickness of the asphaltic layer in the pavement, the more cost effective will be the pavement in our country.

5.2 Selection of Pavement Materials:

The selection of pavement material is probably the most important aspect of pavement design where the biggest financial savings can be made in developing countries. Unfortunately, this aspect is never given serious thought in our country. Such as, the cost of asphaltic materials in our country is roughly two times the cost of the equivalent strength of crushed stone base course material. As such, by reducing the AC layer thickness and providing equivalent strength crush stone base course layer in our design can result in enormous savings in construction costs.

Moreover, it is not only the financial aspect, past performance in our country has revealed that the biggest disadvantage of using asphaltic mixes in our country is that the pavements using thick asphaltic concrete layers are more prone to failure in rutting. In contrast to this properly laid tripple surface treatment over crush stone base course have performed well even on heavily trafficked main national highways without failure. Under these circumstances, surface dressing in our country is perhaps the best option for long term durability and resistance of the asphalt to deformation. In this case, the required pavement strength can be provided by laying thick crushed stone aggregate base course. The riding quality can be improved by improving quality control practices in construction.

5.3 Pavement design methods-economic aspect

Different pavement design methods can provide different combination of materials for the same loading condition and same sub-grade strength. The most cost-effective design for a given set of materials is one which maximizes the thickness of the material that provide the most structural contribution for each Rs spent (in our case, crushed stone) and minimizes the thickness of the least structurally cost-effective material (in our case, the asphalt concrete).

In comparing various alternative pavement types and configurations, cost is a prime consideration. To determine the most economical pavement, a cost comparison must be made.

Alternative projects/designs should be evaluated primarily according to the criterion of minimum total cost, giving consideration also to the safety and service of road users.

A simple example can illustrate the above facts. A pavement is designed for a 10 years design life loading of 20 million ESA and sub-grade strength of 7 CBR value. The pavement design methods used are AASHTO, 86, Road Note 31 (UK, 1993) and Pavement Design Manual of Queensland Transport Department (Australia), 1990. The three design methods give the following combination/thickness of various material layers (different combination of materials for the same design method are also possible) as given below.

Thickness of pavement layers (20 million ESA, CBR=7)

Sl No	Material	AASHTO, 86	Road Note, 31 (UK), 1993	Pavement Design Manual Queensland, 1990 (Australia)
1.	Asphaltic concrete wearing course	8 1/2 inch (215 mm)	6 inch (150 mm)	-
2.	Surface treatment	-	-	Surface treatment
3.	Aggregate Base-course	7 inch (175 mm)	10 inch (250 mm)	6 inch (150 mm)
4.	Granular Sub-base	5 inch (125 mm)	11 inch (275 mm)	19 inch (475 mm)

Design charts are appended (Appendix-1).

To get comparative idea about the various designs, rates of various materials were taken from an approved PC-I proforma (construction of Additional Carriageway (N-5), Chablat Nowshera Section.

These rates have been used to work out the pavement cost/km by each of the three methods. The cost estimates are given below.

TABLE - 1

PAVEMENT COST COMPARISON (RS/KM)

Pavement Design for Loading (ESA) = 20 x 10^6 , Sub-grade CBR=7.0

				AASHTO 1986		ROAD (UK) NOTE 31		Queen's Land Australia	
Sl No	Item Descpt.	Unit	Rate (Rs)	Qty.	Amount	Qty.	Amount	Qty.	Amount
1	Asphaltic Concrete Plantmix (BC+WC)	C.M	2750	1570	4317,500	1095	3011,250	-	-
2	Surface Treatment	S.M	50	-	-	-	-	7300	365,000
3	Aggregate Base-Course	C.M	300	1314	394,200	1825	547,500	1095	328,500
4	Granular Sub-base	C.M	200	913	182,600	1278	255,600	3358	671,600
					4894,300		3814,350		1365100

* Rates taken from the PC-I Proforma (October, 1994) of "Construction of additional carriageway N-5, Chablat - Nowshera Section", by A.A. Associates.

The table shows that pavement design by AASHTO would cost Rs. 4.9 million/km while that by RN 31 is Rs 3.8 million/km and by Queensland Manual, is Rs. 1.37 million/km. The simple example demonstrates how much difference using different pavement design method and different combination of materials can cause to the cost. Thus, in order to determine the most economical and safe pavement, a cost comparison among various pavement alternatives should be made.

CHAPTER -VI

DISCUSSION & CONCLUSIONS

1. The use of asphaltic mixes has increased tremendously on our road network. The mixes are being used as a part of base course and as wearing course layers of the pavement. Almost on all the major roads (National as well as provincial), the material is being recommended for use by the design engineer's/consultants. The material is considered as ideal for roads carrying heavy traffic. Unfortunately, the material has not produced the desired results in most cases in Pakistan and met with premature failures. Most of the road stretches have exhibited plastic deformation within asphaltic concrete layer sooner or later within first few years after their laying and opening to traffic.

2. The asphaltic concrete mix is a costly material. It has been estimated that every year around Rs. 2.0 billion of such materials are used on our roads in the country and its failure causes a loss to the national exchequer. Moreover, the failed/deteriorated state of road causes the vehicle operating costs plying on these roads to increase many folds, thus causing further loss to the national economy. As such it is very essential that these mixes must not continue failing on our highways.

3. The failure of the asphaltic mixes could be attributed to many causes.

a) Hot climates are severe on bituminous binders causing them to deteriorate much faster in the developing countries. The temperature range in developing countries is likely to be much higher and the load-spreading properties of the bituminous materials considerably reduced. Then there is the problem of greater variability of construction.

b) The quality control practices required for these mixes are of much higher standards than other types of surfacings. Mineral aggregates required are of high quality and are proportioned with very tight limits. All aggregate sizes of the right proportions are to provided to ensure a satisfactory mix. A very close control is required to follow the specifications required for mixing, placing, achieving final density and for obtaining the final surface finish. This type of close control is generally not found in Pakistan.

c) The most important aspect is the greater increase in the volume and weight of the road traffic. This has resulted in high axle loads. Moreover, to carry the maximum possible loads, the owners inflate the tyres to the maximum possible extent. Whereas the maximum axle load limit plying on developed countries is 10 tons, the axle load plying on our roads are far in excess of these limits. Recent Axle Load Survey (1994) indicates that about 43% of rear axles of commercial vehicles on our roads exceed even 12 ton limit.

d) Mix design methods currently being used (i.e. marshall mix design etc) in the country does not seem capable of coping with the extreme environmental and loading conditions prevailing in the country and there is a need for using some other techniques. There is a need for developing design mixes that are capable of performing well under local conditions. Evidence from failed/rutted sites have indicated that a minimum airvoids of 3 percent after several years of heavy trafficking (at refusal density) is required to minimise the risk of deformation in the asphaltic layer. According to research carried out by the Transport Research Laboratory (TRL) U.K. who after monitoring of several years of performance of asphaltic mixes in the tropical countries has concluded that the best way of minimizing risk of deformation is to use a base course mix and to protect the layer with a surface dressing. The base course mixture should be very resistant to deformation and the surface dressing will be very effective in resulting cracking and preventing rapid age hardening of the bitumen in the surface of the base course.

e) In our country, we do not have our own structural design method based on empirical studies and relies on methods borrowed from elsewhere that are often far from satisfactory. Normally, these emperically based methods prove to be satisfactory provided the materials, environment and conditions of loading do not differ significantly from those which were applied during the original empirical studies on which the design methods were based. Traffic loading have increased quite dramatically during the last decades and is much higher than those in the developed countries and it is unlikely that existing empirical methods of the developed country can be simply extra-polated to accommodate these changes. The extension of these empirical design methods for our country is perhaps a serious flaw in our design procedure. The design manuals prepared in the developed countries should not be followed blindly which are not suited to our local conditions.

4. The asphaltic mixes in our country's cost more than five times the cost of the aggregate base course of equal thickness. From the structure strength coefficient concept of AASHTO, one inch of asphaltic base mix is roughly equal to 2.8 inches of aggregate base. This would mean that asphaltic mix is about double the cost of the aggregate base material for achieving the same strength. Thus, any reduction in thickness of asphaltic mix and replacement by equal strength aggregate material results in considerable savings. The selection of pavement material is probably the most important aspect of pavement design where the biggest financial saving can be made in developing countries. Unfortunately this aspect is not given serious thought in our country.

5. There are several opinions among engineers regarding the use of asphaltic mix materials in our country. Certain quarters of engineers in the country are of the view that utilization of this type of material is must for our highways to have smooth nice roads in the country. However, another quarter of engineers feel that as the material is costly and since it is not providing the desired results, its use may be limited so that even if it fails, the loss is limited. However, another opinion exists

that why not to discontinue its use on our highways till the time that we are able to develop a mix which is capable of functioning on our local conditions without failure and surface treatment be used as surfacing layer for the time being. As far as the riding quality of the roads using surface treatment as surfacing layer is concerned, it could be improved by using better quality control practices. Perhaps this is presently the most suitable option. The option of using minimum of asphaltic mix material may be a course of action to be followed on our highways. Simultaneously, we should continue efforts to develop some type of mix which could be capable of functioning satisfactorily on our highways. In this way, we might be able to save not only billion of rupees but also would be able to have our roads free from untimely failures we witness every day.

6. Moreover, due to insufficient fundings, normally it is not a good solution to construct even the major roads for longer period design standards and some form of stage construction be used. For flexible pavements, the commonest form of the first stage construction is the well compacted graded stone laid directly on an improved sub-grade or a granular sub-base. Again, modern structural design procedures should be used to ensure that the stone layer is thick enough to limit the shear stress in the sub-base and sub-grade to a level at which deformation will not occur. On this binding surface, a heavy duty surface dressing preferably of hot bitumen, should be applied to bond the surface and keep out water. A bituminous overlay should be used as the second construction stage once unacceptable deformation has occurred.

7. Probably, the option i.e. stage construction with tripple surface dressing is reply to our problem today. In this way we might be able to avoid the problem of premature failures of pavements we are facing and save huge sum of money. Meantime, the executing agencies may carry on laying experimental sections using different asphaltic mixes on our heavily trafficked roads and come up with a mix capable of coping with the severe local environmental conditions and heavy axle loads plying on

our roads. Moreover, the quality control practices required for the material are very strigent and we must have to improve our practices to a level required for this type of material. Else, we may continue with the dilemma of premature road failures in our country.

In view of above, it is concluded that:

i) Use of asphaltic mixes on our main rural highways may be limited as far as possible for the time being. Simultaneously, we may continue with the construction of experimental sections using asphaltic mixes on our heavily trafficked highways to get a mix capable of performing well on our highways.

ii) The asphaltic mix in our country costs double the conventional aggregate material (to provide equal pavement strength), therefore every effort should be made to evolve other solutions through indigenous research to minimise the thickness of the asphaltic concrete layer in the pavement.

iii) We may not depend only the AASHTO method for pavement design purpose, as it generally provide thicker asphaltic concrete layer in the pavement compared to many other pavement design methods. Other design methods should also be explored and the one which gives the minimum asphaltic thickness may be adopted as it would provide in least cost pavement structure.

iv) The concept of using stage construction may also be explored initially constructing granular layer with surface dressing. Till the time that overlay is required, we might be able in designing a mix capable of performing well under our local environmental and loading conditions.

v) Research also need to be carried out to make quality control more effective under prevailing local conditions.

APPENDIX 1-A

UIDE, 1986

$ESA = 20.0 \times 10^6$

$CBR = 7.0$

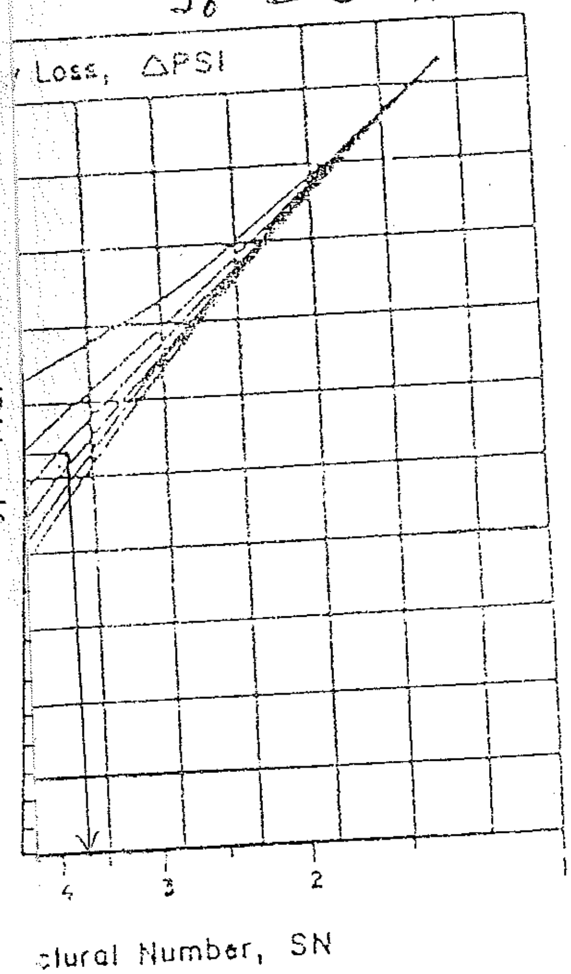
$M_R = 10,500$ psi

$\Delta Psi = 1.7$

M_R Base = 30,000 psi

M_R S/Base = 15,000 psi

$S_0 = 0.45$



6-73

$AC = \frac{3.7}{0.4}$ $SN_1 = 3.7$

$SN_2 = 4.7$

$GB = \frac{4.7-}{0}$ Total $SN = 5.2$

$GSB = \frac{5.2 - ...}{0.11}$

Figure 6-2.11

APPENDIX 1-B
OVERSEAS
ROAD NOTE 31
TRL, UK, 1993

KEY TO STRUCTURAL CATALOGUE

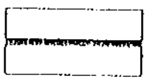
Traffic classes (10^6 esa)

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

Subgrade strength classes (CBR%)

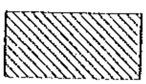
S1 = 2
S2 = 3, 4
S3 = 5 - 7
S4 = 8 - 14
S5 = 15 - 29
S6 = 30+

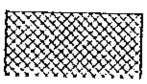
Material Definitions


Double surface dressing


Flexible bituminous surface

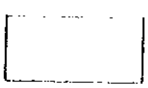

Bituminous surface
(Usually a wearing course, WC, and a basecourse, BC)

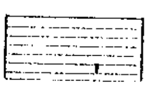

Bituminous roadbase, RB


Granular roadbase, GB1 - GB3


Granular sub-base, GS


Granular capping layer or selected subgrade fill, GC


Cement or lime-stabilised roadbase 1, CB1


Cement or lime-stabilised roadbase 2, CB2

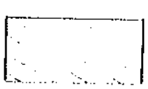
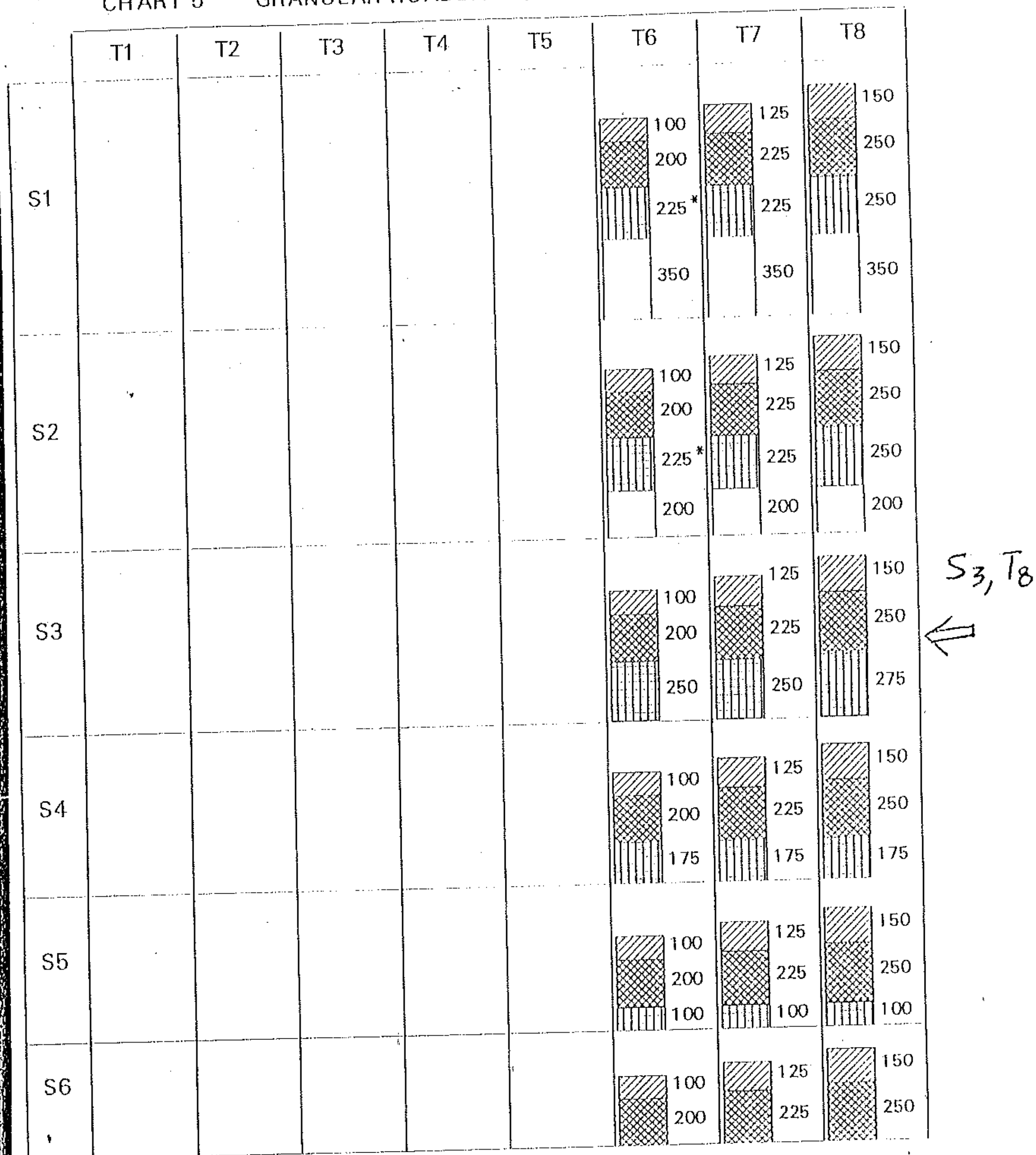

Cement or lime-stabilised sub-base, CS

CHART 5 GRANULAR ROADBASE / STRUCTURAL SURFACE



Note: 1 * Up to 100mm of sub-base may be substituted with selected fill provided the sub-base is not reduced to less than the roadbase thickness or 200mm whichever is the greater. The substitution ratio of sub-base to selected fill is 25mm : 32mm.

2 A cement or lime-stabilised sub-base may also be used.

FULL DEPTH GRANULAR - Normal Design Standard
Standard Specification Base

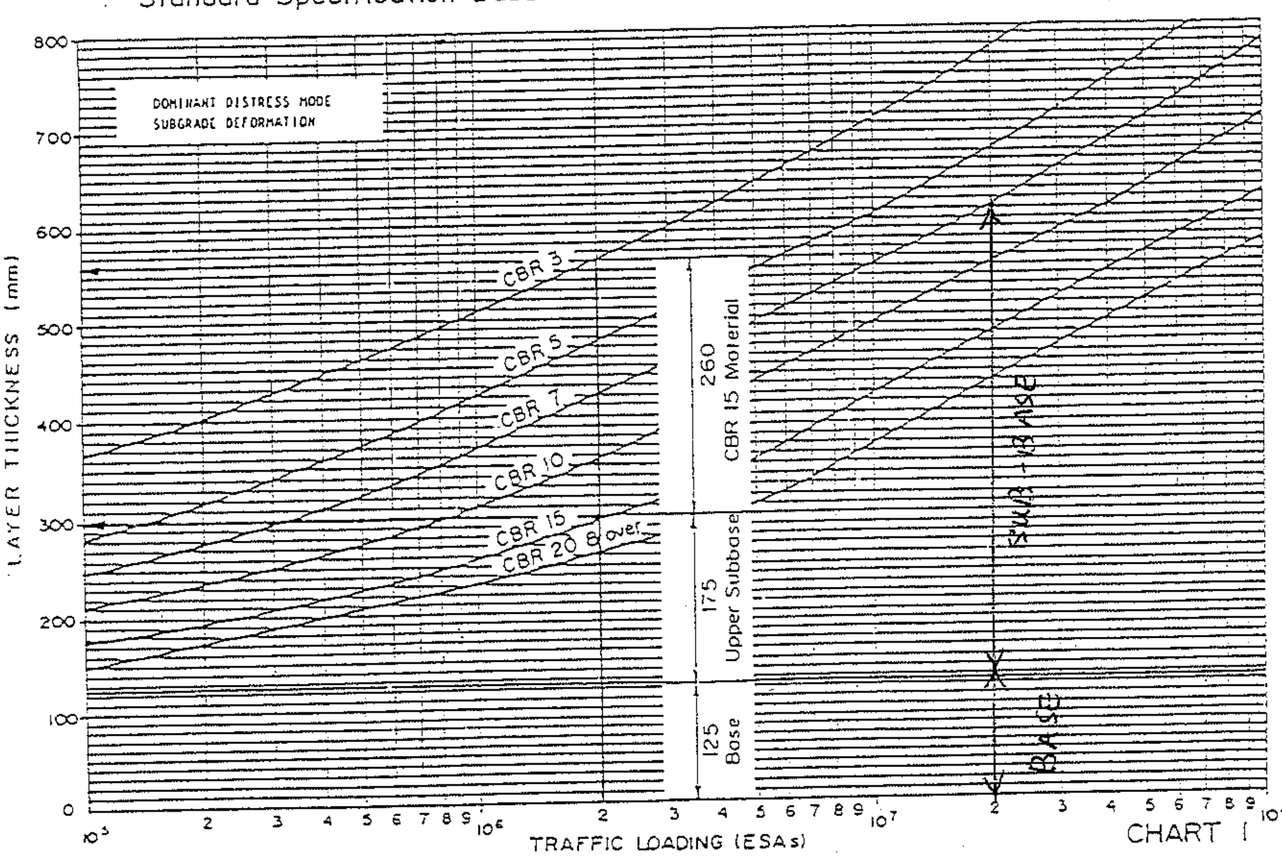


CHART 1

(NOTE: Any other break up of base and sub-base with at least 125 mm in each course would be acceptable)

OUR EXAMPLE

CBR = 7
ESA = 20×10^6

SUBBASE = 475 mm
BASE = 150 mm

EXAMPLE

DESIGN SUBGRADE C.B.R. - 3
DESIGN TRAFFIC - 2×10^6 ESAs
NORMAL DESIGN STANDARD

AVAILABLE MATERIALS

C.B.R. 15 MEASURED AT DESIGN MOISTURE CONDITIONS

STANDARD SPECIFICATION BASE + SUB-BASE

SOLUTION

MATERIAL C.B.R.	REQUIRED DEPTH OF COVER
3	560
15	300

TOTAL PAVEMENT THICKNESS = 560 mm

THICKNESS OF C.B.R. 15 MATERIAL = 560 - 300 = 260 mm

THICKNESS OF SUB-BASE MATERIAL = 300 - 125 = 175 mm

THICKNESS OF BASE MATERIAL = 125 mm (minimum)

USE OF DESIGN CHARTS FOR FULL DEPTH GRANULAR PAVEMENTS (CHARTS 1-8)

FIGURE 8·3