Paper No. 340

Some Aspects of Design of Flexible Pavements in West Pakistan

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1·0. Introduction :

Construction of highways in Pakistan is important for a balanced economy. These provide means to carry agricultural produce, industrial products and other day-today necessities of life. For building an efficient highway system, whether the roads are low cost stabilized or high cost pavements, it is necessary to understand the fundamentals of road design which are a function of the properties of materials used and the stresses to which these are subjected. The selection of the materials, their economic availability, performance under field and laboratory tests lead us to a rational design of road crust which varies with local conditions. Some fundamentals of design and a brief review of the work done in this field in West Pakistan is discussed here.

1. 1. Definition of a Flexible Pavement

Pavements are classified into two categories according to behaviour, *i.e.* rigid or flexible. A flexible pavement is a structure consisting of several layers of selected materials, the primary function of which is to distribute the concentrated loads by internal friction of the seperating layers to the supporting subgrade. The traffic load ultimately transferred to the subgrade does not exceed the bearing capacity of the subgrade. A black-top road is a typical example of the flexsible pavement while a concrete road that of a rigid type.

1. 2. Components of a Flexible Pavement and Their Functions.

A flexible pavement may consist of nothing more than a course of gravel or crushed rock stabilised by natural soil binder as in a gravel road. In improved forms, it may consist of a non-rigid base course sometimes strengthened as well as protected by bitumenous coat or in some cases supplemented by sub-base course. The different components of a road are shown in fig. I and are broadly classified as under :—

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1. Subgrade.
2. Sub-base.
3. Base Course (usually designated as soling and wearing course in present local terms).
4. Surfacing Course.

1. 3. Subgrade

Subgrade is soil surface as is exists at site naturally. It may be classified as clay, silt, sand or a coarse granular soil or a combination of their fractions. Difference in subgrade conditions may require major changes in design of flexible pavement for similar load conditions. If the subgrade is granular, it has a higher bearing capacity and as such, would need lesser pavement thickness to carry the same load as in fig. 2. In cases where the subgrade is poor such as for clay, etc. the required pavement thickness would be comparably more as in figs. 3 and 4.

1. 4. Sub-base

This course is provided in places where the subgrade conditions are poor. It may consist of locally available granular materials which have supporting values higher than the subgrade on which they rest. Sub-base is provided on clay and slag subgrades to increase structural support, provide drainage for the subgrade, minimize the effect of subgrade volume changes, prevent damage from frost heaves, and minimize the effect of plasticity due to excess moisture such as in clayey soils. Keeping these functions of the sub-base in view, the general materials which offer choice as sub-base are : coarse sand, gravel, cinders, crushed quarry waste.

1. 5. Base Course

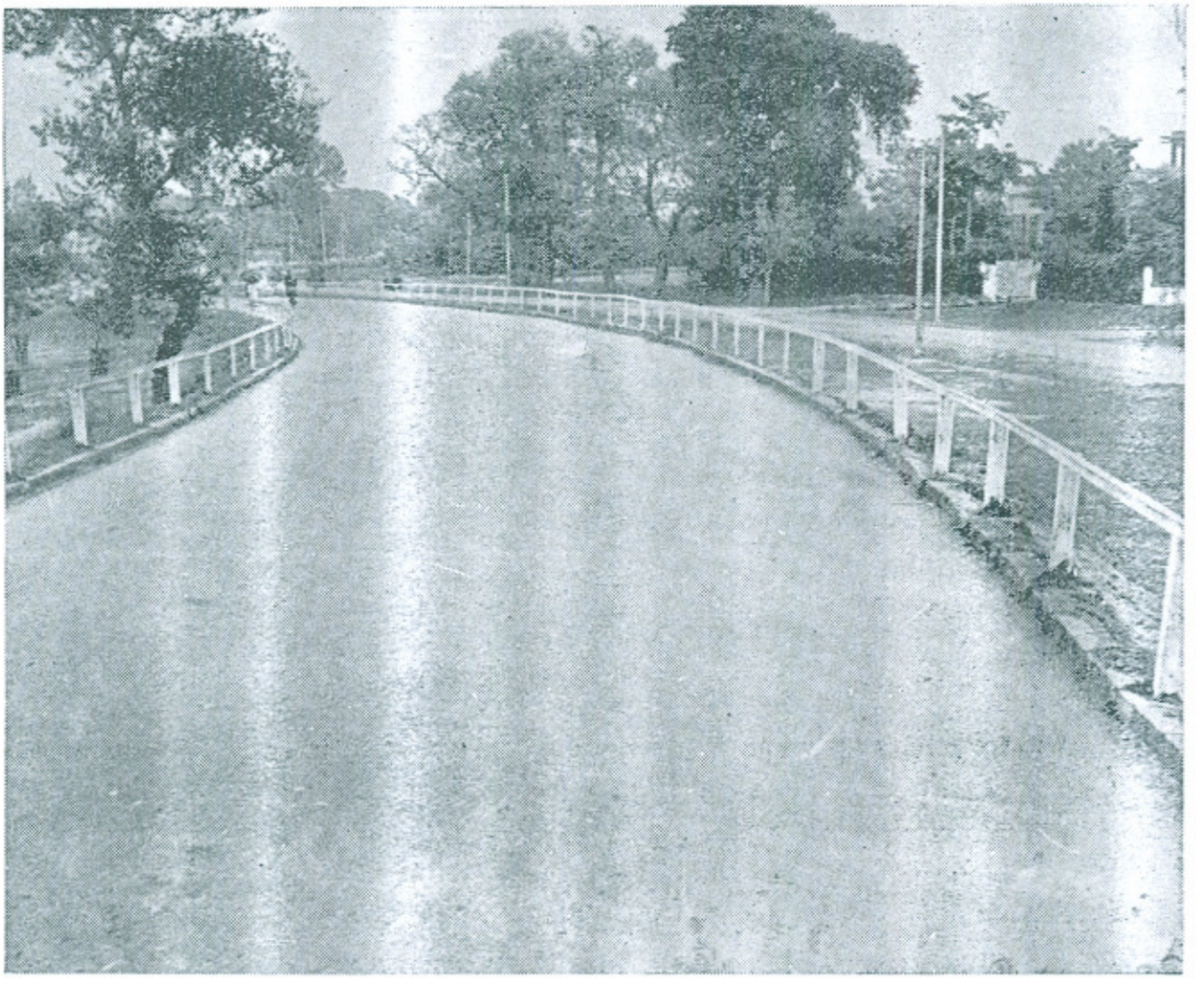
The base course is the body of the pavement and generally consists of a thickness of hard-tough material like stone. According to the practice in this country, the brick or stone soiling plus the stone wearing course constitutes the base course.

1. 6. Surfacing Course

This course is provided at the top of flexible pavement to water-proof the base course against penetration of surface water which might materially lower the load supporting capacity of the base and to protect the base from disintegrating effects of traffic as well as to increase the load supporting value of the entire structure.

2. 0. Desirability of Flexible Pavement

In Pakistan, a majority of pavements is of flexible type, *i.e.*, bitumenous roads. This has been evolved in due course out of the necessity for this type



Photograph No. I
A view of a good flexible pavement.

of construction and economic condition of the country. The first cost has always been an important factor for the choice of flexible pavements in our country in preference to concrete roads, which cost nearly double in their initial cost. Fortunately the bitumen requirements for these roads are being partly met within our country from local sources. On the other hand huge quantities of cement were being imported till recently and as such, concrete road has gained much less popularity for road construction in our country.

2. 1. Necessity of Design.

The construction of pavement has followed the standard practice in vogue since early twenties, that of providing soling, wearing and surface coat to a total thickness of 8″-9″ over an earthen embankment. The depth of the pavement is also fixed irrespective of the type of soil or the intensity of traffic. The standard fixation of road pavement thicknesses on variable conditions of soil and intensity of traffic appears to have led to most of the road failures.

Observations carried out by the Buildings and Roads Research Laboratory, Lahore, have indicated that many roads which were behaving well have started showing deterioration due to heavier loads and greater intensity of traffic. At times a newly constructed road has also shown considerable undulations. One of the main causes of this failure has also been high traffic on a comparatively thin pavement. The public criticism is thus partly genuine, for most of the roads which were standing very well for the last twenty to thirty years are showing deterioration now and some new roads immediately on construction have not stood well. This leads us to the rational conclusion that there should be a proper scientific approach to the design of a pavement keeping in view the subgrade conditions, and the intensity of traffic that a road is expected to carry.

The problem of pavement design is briefly the formulation of methods of calculating the thickness and strength of pavements which has to be placed on a soil foundation to provide a suitable riding surface for specified traffic loads. A correct application of such reliable methods of design can lead to economies by avoiding costly failures and wastages due to over design. A small expenditure on the preliminary soil testing along the proposed road, with an intelligent use of design methods will lead to fewer road failures and lower cost of construction. Some of the methods employed for the design of flexible pavement and a brief review of the investigations carried out have been discussed in this paper, which is hoped will be of interest to the reader.

These factors are now being appreciated by our engineers in general but the financial stringency has not allowed full development of the knowledge of these factors and, therefore, revision of design criteria. The trend of modern traffic and its future development indicates that we have to adopt new methods to determine the strength of pavements and not submit ourselves to makeshift current economies under the false notion of financial savings.

3·0. Methods of Pavement Design

With the development of the science of soil mechanics in the last three decades, it has been possible to classify soils into different groups, and after laboratory tests to predict their behaviour under different loads and set of conditions. This classification and experimentation on soil behaviour has helped in evolving the design of flexible pavements.

At present there are a number of methods for the design of flexible pavement. Some of these methods being empirical, differ in their approach, while in others the approach is entirely mathematical. The problem is, however, complex since it involves the behaviour of soils and other factors which have not been entirely understood upto this time. Inspite of this difficulty, some workable methods have been evolved, after considerable experimental effort, which can give satiifactory results for design. Each set of conditions require a particular treatment and design which may not be applicable in other cases. Some commonsense and experience on the part of engineer is, however, required to utilize the laboratory investigations for field design.

The methods of design available so far can be broadly classified into four distinct groups.

3·1. Group No. 1.

Empirical Methods Without Using Soil Strength Tests.

The methods under this group are based on the result of the experience from roads built so far and the behaviour of different thickness of pavement required for similar soils and wheel loads. In these methods, the soil is tested for particle size distribution, *liquid and plastic limits and is classified into different soil categories This provides a basis of comparison with the standard classification available and utilising the results of the thickness of the pavement satisfactory for this type. The group index method is a typical example of design under this group.

3·2. Group No. 2.

Empirical Methods Using Soil Strength Tests

In this group, there are numerous methods which use a penetration test of the soil to determine its strength. This test is popular for its convenience in application and the experience obtained with it so far. The results of the penetration test are in turn compared to certain standards and a comparison is obtained about the strength of the soil. The thickness of pavement is evaluated for the type of soil with similar penetration value. The California Bearing Ratio Test is a typical example of this group.

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* Liquid limit is the moisture content at which the material passes from plastic to liquid state, as determined by liquid limit test.

* Plastic limit is the moisture content at which cohesive soils pass from semi-solid to plastic state as determined by plastic limit test.

3·3. Group No. 3.

Methods Based Partly on Theory and Partly on Experience

Under this group the fundamental stress stsain properties of the soil constituting the subgrade and sometimes also of the base material are determined by shear or bearing tests. The results are used in a simplified theory of stress distribution which has been found after some experimental justification.

3·4. Group No. 4.

Wholly Theoretical Methods

In this group, the methods are based on mathematical values of the stress and strain throughout the pavement and subgrade. It is an ideal which has not yet been achieved because of the complex nature of the variables involved. It is, however, at the present stage difficult to use this method in common practice since it defies ease of application.

With experience, it has been observed that methods under Group 1 & 2 are more easy to work with, while the methods under Group 3 & 4 involve difficult mathematical treatment. Therefore details under Group 1 & 2 have only been discussed. A description of methods under these two Groups methods is given below.

4·0. Design Methods of Group No. 1.

Empirical Methods using Soil Classification Test

The strength of the subgrade primarily depends on the structure of the soil,soil particle size and moisture content. The strength of the subgrade in turn determines the thickness of road pavement. The greater the strength of the subgrade the lesser the thickness of the pavement and vice versa.

If the moisture content of the soil and the dry density are adequately controlled by subgrade drainage and compaction, the strength of the subgrade is improved and hence the thickness of pavement is reduced. The composition and structure of the soil or the subgrade is indicated by classification of highway subgrade materials and the thickness of pavement is determinedfrom the past experienee of pavements on similar soils. Briefly the method is as under :—

4·1. Classification of Highway Subgrade Materials

The classification of highway subgrade materials is based on Casagrande (British System) and by Hogentoglar sponsored by the Public Roads Administration in America. The second is the more commonly used method and shall be discussed. According to this method, the subgrade matrials have been divided into 7 groups with sub-groups ranging from A-1 (well graded graval sand) to A—7 clayey soil) which can be determined from sieve analysis tests on 3 sieves (No. 10, 40, 200 sieve), and the liquid limit and plastic limit. The classification chart is given as Table A.

TABLE A
Revised U.S. Public Roads Administration (P.R.) System (1945)

General Classification	Granular Materials (35% or less passing No. 200 sieve*)				
Group classification	A-1		A-3	A-2	
	A-1-a	A-1-b		A-2-4	A-2-5
Sieve analysis, percentage passing :					
No. 10 sieve*	50 max.				
No. 40 sieve*	30 max.	50 max.	51 min.		
No. 200 sieve*	15 max.	25 max.	10 max.	35 max.	35 max.
Characteristics of fraction passing No. 40. sieve*					
Liquid limit (%)			N.P.	40 max.	41 min.
Plasticity index (%)	6 Max.			10 max.	10 max.
Group index [b]	0		0		0
Usual types of significant constituent materials	Stone fragment and sand		Fine sand	Silty or clayey	
General rating as a subgrade	Excellant to good				

Classification Procedure : With required test data available, proceed from left to right on above chart and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

*Plasticity index of A-8-5 sub-group is equal to or less than liquid limit minus 30. Plasticity index of A-7-6 sub-group is greater than liquid limit minus 30.

[b] See group index formula fig. 5 for method of calculation. Group index should be shown in parentheses after group symbol as :—A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc.

*Sieve sizes are American.

Approximate British equivalents as follows:

Classification into Sub - Groups

		Silt. clay materials (more than 35% pasing No. 200 sieve*)			
		A-4	A-5	A-6	A-7 A-7-5 A-7-6
A-2-6	A-2-7				
35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
40 max. 11 min.	41 min. 11 min.	40 max. 10 max.	41 min. 10 min.	40 max. 11 min.	41 min. 11 min.
4 max.		8 max.	12 max.	16 max.	20 max.
Gravel and sand		Silty soils		Clayey soils	
Fair to poor					

United States A.S.T.M.E.11/26	Great Britain.
10 40 200	8 36 200

Under this method, each soil is also given a specific number derived from these values and is known Group Index indicated in the above Table A under each classification. Some empirical values have been prepared for the thickness of the road pavement both for the soil group classification and Group Index. The pavement thickness given in Table B are recommended practice of the Highway Research Board, United States for an 18,000 lbs axle load. This should, however, be used with suitable modifications in our country taking into consideration the axle loads and other conditions for which it is being designed.

Table B

Recommended Thickness of Pavement Courses for 18,000- Lb. Axle Loads

Soil Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7 A-7-5 A-7-6
Depth wearing course inches ...	2	2	2	2	2	2	2	2	2	2	2
Depth base course inches ...	0	5	5	5	6	6	6	8	8	8	8
Depth sub-base course inches ...	0	0-6	0	0-6	0-8	0-10	0-10	2-14	4-14	0-14	0-14

NOTE. (*a*) No sub-base is required over A-1-a and A-2-5 soils where frost action is absent and the water-table is low. In areas subject to severe frost action or where the water-table is near the surface, the maximum thickness should be used.

(*b*) In the case of fine grained A-2-4 and A-3 soils it is often necessary to modify the upper layer by admixture to a depth of several inches with binder soil, stone screenings or bituminous materials to produce a stable surface upon which to place the granular base course.

(*c*) On A-4 and A-5 soils a sub-base course of the minimum thickness specified, consisting of stone screenings or similar material, is desirable to produce a firm support upon which to place the over-lying granular course. The maximum thickness is required only in areas subjected to severe frost action or where the water-table is close to the surface.

(*d*) On A-6 and A-7 soils no sub-base is required where the water-table is permanently below elevation where moisture may reach the base by capilla rity. The maximum thickness is required where the water-table is high and for A-6 soils, where frost conditions are severe.

(*e*) A-4, A-7-5, A-5, A-7-6, A-6 and A-7 soils are highly capillary and rapidly lose supporting power when saturated. When pavements are placed in cuts over such soils, the maximum thickness of sub-base should be employed.

If the soil classification is thus available for the subgrade, after laboratory test the thickness of the pavement can be evaluated from the empirical results given as Table B.

4· 2. Group Index Method

The group index, as already mentioned is an empirical number derived from the tests on the particle size distribution of soil after siveing it through 10, 40, 200 sieve mesh and calculation of liquid and plastic limit. Mathematically it can be put as :—

$$\text{Group Index} = 0{\cdot}2a + 0{\cdot}005\,ac. + 0{\cdot}01bd.$$

where (a) =That portion of percentage of subgrade soil passing No. 200 sieve greater than 35 and not exceeding 75, expressed as a positive whole number (0 to 40).

(b) =That portion of percentage of subgrade soil passing No. 200 sieve greater than 15, and not exceeding 55, expressed as a positive whole number (0 to 40).

(c) =That portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (0 to 20).

(d) =That portion of the numerical plasticity index greater than 10, and not exceeding 30, expressed as a positive whole number (0 to 20).

The value of the Group Index can be calculated easily by consulting chart given as fig. 5. The value of the group index so obtained for soil is in turn used for finding the thickness of pavement and sub-base. For this purpose, empirical curves have been evolved after experience and are available as shown in fig. 6.

There are 5 curves in this figure marked A, B, C, D and E corresponding to different values of group index of the subgrade. Curve A gives the thickness of the sub-base required while curve B, C D & E give the thickness of the surface, base and sub-base for light, medium and heavy traffic respectively as defined in Article 6 later.

The sub-committee recommending these curves has, however, pointed out that these curves are presented as an approximate recommendation and that each user of the method should modify them to his own conditions as experience dictates. This method is being extensively used by the Buildings and Roads Research Laboratory, where the author has experience of designing over 1500 miles of pavement in West Pakistan. Some typical examples have been worked out at the end to show its relative accuracy as compared to other methods. It is, however, not possible at this stage

to suggest any variations for local conditions in the above methed.

5·0. Design Method of Group No. 2. Empirical Methods Using Soil Strength Tests

The methods of this group are used for empirical standards of soil strength in its behaviour under loads. This value of the soil strength has no direct ratio with the bearing strength of the soil. This is so because firstly an analysis of stress strain distribution through pavement and subgrade layers has not been finalised to measure the strength properties of the material for use in such a theory of stress distribution. Methods of pavement design in this group have to by-pass these difficulties by making an entirely empirical approach and the thickness is determined on the basis of experience required for similar strengths in the past.

The strength test which appears suitable for this type of method can be a load test using a plate and having an area equal and similar to the tyre contact area. This would obviously necessitate bulky field equipment to supply added load reaction and involves lengthy procedure. Instead, shortcut is adopted whereby conditions similar to field are bye-passed for expeditious and easy testing. One of these tests and the most important method employing a small scale bearing test is the California Bearing Ratio method generally known as C. B. R. Method.

5.1. California Bearing Ratio Method

This method was originally devised by California State Highway Department, U. S. A. and has since been modified by U. S. Corps of Engineers during the war. The test gives a relative strength of the subgrade and consists of causing a cylinderical plunger 3 sq. inch in end cross section to penetrate a sample of soil in a test mould 6″ diameter and 5″ deep at a constant rate. The load required to cause a penetration of ·1″ and ·2″ at the rate of 1/20″ per minute is measured by attached micrometers. This load is measured on either undisturbed sample in the field or laboratory or a remoulded specimen of the soil if the first two alternatives are not possible.

To compare the laboratory test with worst field conditions under moisture which may exist subsequent to construction (water-table near the surface), the procedure requires a specimen to be soaked for 4 days before testing. The test is thus repeated for the soaked sample which has been completely immersed in water for 4 days so as to allow free access of water from bottom through a perforated disc and checking the swell of the sample for the top. In this way, CBR is obtained for soaked soil condition.

The test procedure includes many other details which are not considered essential in the present context, In brief, however, the lower C. B. R. value for soaked and unsoaked sample is taken and minimum value adopted for design purposes.

Having found out a correct value of C. B. R. for the subgrade, charts are available for thickness of the pavement against different values of C. B. R. as shown in fig. 7.

The use of chart is simple. For example, consider a C. B. R. value of say 3. Let the design be against curve 5 (denoting 5,000 lbs wheel load). the thickness of the pavement is 15″ which may be split up as under :—

(*a*) Sub-base of 8″ granular material with soil C. B. R. value 15%.

(*b*) 5″ selected material surfacing consisting of stone ballast or well graded gravel C. B. R. value 50%.

(*c*) 2″ surfacing on top, or less.

The above split up is done after experience, although guidance is available from tables etc. Values of design shall, however, vary for each wheel load, but the one may be selected which is expected to ply on the road in the next 20 years.

6. 0. Traffic Loads in Relation to Road Design

After subgrade material, the traffic load is the most important factor governing the pavement design. There are different ways of evaluating traffic loads of which two are generally used ; one in which the maximum load is considered and the second in which the number of vehicles passing in excess of 4,500 lbs wheel load.

Unless the wheels are sufficiently close, so that wheel loads overlap, the maximum single wheel load is considered for pavement design and not the gross weight of the vehicle. Assuming that 2/3rd of the vehicle load is taken by the rear axles and 1/3rd by the front ones; a 6 ton carrier with 4 wheels has 2-ton maximum wheel load which determines pavement design with reference to C. B. R. Method. Repeated application of load results in cumulative deformation, although a single application of the same load would not cause much deformity. Some of the design methods make an allowance of such a repetition and increase the wheel loads before substituting it in formula.

In second case the traffic is classified as light, medium and heavy according to the number of vehicles passing over the road with over 4,500 lbs wheel load, which is generally accepted for design and designated according to the number of vehicles as under :—

Light traffic.	< 50 commercial vehicles per day.
Medium traffic.	50-300 commercial vehicles per day.
Heavy traffic.	> 300 commercial vehicles per day.

In evaluating the class of traffic, the figure is obtained by a one way traffic count of commercial vehicles with wheel loads in excess of 4500 lbs.

Since the traffic is, liable to change, this figure is increased by a percentage of development expected during 20 years and the average of these two values is taken for design purposes. Unfortunately reliable traffic census are not available for our roads but the present figures roughly indicate over 200% increase in traffic on most of our roads. Besides, heavier military vehicles move every day and industrial progress brings increased traffic in its wake. Some foresight and balance must, therefore, be execised for forecasting correct traffic figure for design of our future roads.

7. 0. Application of Design Methods

The Buildings & Roads Research Laboratory is working on the design of flexible pavement in West Pakistan which are either new roads, yet to be constructed or existing metalled roads showing deterioration. A few typical examples are listed below :-

7. 1. Design of Hab-Chauki Lasbella Road

The Hab-Chauki-Lasbella Road forms a part of Karachi Kalat Road.

The soil samples from the road were tested for the particle size distribution, plasticity index, sieve analysis and C.B.R. The results obtained from these tests have been attached as Appendix 'B' at the end. Referring to this appendix, consult 1st reading for Bawani miles 5. The soil is non-plastic, percentage passing 10 mesh is 100, passing No. 40 is 99·5 and passing No. 200 is 27·5. Now consult Table A for classification of subgrade material. It would be seen that after eliminating A—1 and A—3 the classification is A-2-4 and group index value is given in the same chart against A-2-4 as 0. Hence soil has been denoted as A-2-4(0) in the next column of Appendix B. Other values can be similarly worked out from these charts.

A perusal of these results shows that most of the samples taken from Bawani to Wingoi Dhera (from 5-52) consist of fine sand with excess of material pass 200 mesh with exception of one for Khul Khera (R.D. 199,700). The soil is non-plastic and the group index value is zero and falls under soil classification A-2-4. Starting from Wingoi Dhera to Uthal village (from mile 52-65) all the samples are clayey with a plasticity index ranging along 16 and fall into one of the groups under A-4 to A-6 with a group index of 8-10. The C.B.R., value of the sandy sample has an average value of 10 whereas the clayey one gives a value of 4 only.

Design of the Pavement

For design of flexible pavement, since the soil characteristics vary from fine sand, clay, gravel, it is essential that different thicknesses of the pavement should be used for each length where the soil is uniform. For this purpose the road is divided into different lengths with uniform soil characteristics, the traffic, rainfall, drainage etc., being uniform. Regarding the traffic conditions, it is difficuit to predict with accuracy the traffic on the road in the next 20 years. Keeping in view the under developed nature of the country-side the traffic shall remain pretty low except for the military traffic which is very heavy but moves for short durations. As such, the road has been designed for medium traffic of 50-300 commercial

vehicles per day and a corresponding wheel load of 7,000 lbs for C. B. R. method.

1. From Bawani to Wingol Dhera (except R. D. 199, 700 Khur Khera).

(a) By Group Index Method

Soil : fine sand, group index = 0 (please refer App: B at the end)

Medium traffic = 50-300 commercial vehicles per day. (Assumed).

Consulting chart given as fig. 6, to total thickness of surface, base and sub-base = 9″

This may be split up as under :—

5″ thickness of pit run gravel and

3″ of crushed stone or graded aggregate with

1″ thick 3 coat of surfacing.

(b) By C. B. R. Method

C.B.R. Value = 10 (Average)

Wheel load = 17,000 lbs.

∴ depth of construction required = 9 inches.

From (a) & (b) above it may be noted that practically both methods will have the same results. Therefore, an average value of 9″ may be adopted in this case.

The possibility of providing brick soling for this road in base course, as per general practice seems to be remote. The soil was tested and found to be sandy with a high percentage of lime content. Even if some clay is mixed with the sand for brick moulding, excess of lime will make the brick suscceptible to an early disintegration. The area is dry and sub-mountaneous There are a few nalahs, which have coarse aggregates in them. As such, the use of aggregate in base would be in confirmity with the optimum use of local material. The soil at R.D. 199,700 (Khur Khera) was tested and found to be clayey and plastic but the lime content and total soluble salts exceed the maximum limits and as such is also not useful for brick moulding. The thickness of the pavement for the balance portion of the road was similarly designed and has been tabulated in the Appendix B and shown diagramatically as fig. 8.

It would be observed from Fig. 8 that the thickness of the pavement is different along a 110-mile length of this road and varies with the type of soil in the locality. The thickness of pavement is initially 9″ upto 52 mile except for small length. The portion of the road where the road is clayey, the thickness is 17″ for the same load. In portion from mile 68 to mile 95, the soil is gravel, and hence the thickness of pavement is only 4½″. Any thickness is excess of 4½″ in this length wonld tantamount to a waste of material. Considering the overall cost of the project, it would be

nearly just as much or less as a road of standard specifications, which would have failed along certain reaches, while it would have wastefully consumed more material at other places. This road is under construction, according to the design recommended by the labratory.

7. 2. Design of Jhang Sahiwal Road.

This portion of the Sargodha Jhang Road which falls under the Provincial Division, Sargodha has been badly affected by waterlogging. The River Jhelum flows at a few miles from the road. The flexible pavement of the road has been constructed on a formation of 2 to 4 ft. in general and the sub-soil water-table is encountered at or beyond 5 ft. below the ground level. It, however, fluctuates with the seasonal changes. Although the pavement is from 7 ft. above the water-table, yet the multi-form disintegration is in progress. The riding quality of the road is generelly bad and very poor at places. The payment has developed cracks, pot-holes, partial settlements and is bumpy. It requires a constant and watchful maintenance which is proving very expensive. A research party was delegated to carry out the soil survey and sampling of the road. These samples were tested in the B & R Research Laboratory Lahore with details as below.

Testing of the Soil Samples and their results.

The soil samples were tested for their Atterberg limits, group index, particle size distribution and C.B.R. value. Tests were also conducted at site to determine the dry density of the subgrade. The results are given as Appendix C and D at the end. It may be seen from the results that the liquid limit of the soil samples varies from 25 to 40 with a plasticity index of 8 to 18. The material passing through 200 mesh is at least 77 percent with a maximum of 99 per cent. The soil falls under the classification groups of A-4 and A-5 with a group index of 8 to 11. It consists of silt aud clay and rates as fair to poor as subgrade material.

The C.B.R. value of the soil varies from 2·6 to 6·6, but the general value approaches to 4 with an inclination towards 3 rather than to higher values. The dry density of the subgrade in situ varies from 91 to 98 lbs. p.c.f., and the maximum dry density varies from 106 to 119 lbs. p.c.f., thus showing a proctor compaction of the subgrade from 72 to 87 per cent, with a rare exception of 95 per cent. The degree of compaction must have been even less at the time of construction.

The moisture content of the soil at the brick soling level was found to vary from 9 to 25 per cent while most of the values are above 10 percent and very close to plastic limit for each type of soil. This observation was taken before the rainy season set in and, therefore, the values during and after the rains must be higher than these ones given here.

Design of the Flexible Pavement.

The design of the pavement has been made on two methods as given below :—

(A) Group Index Method

Type of soil = silt and clay.

Classification Group (S) = A-4 and A-6

Group Index = 8 to 11 (selected value 10)

Traffic conditions = medium, 50 to 300 commercial vehicles per day.

From this data, we arrive at the following results :—

Total thickness of surface, base and sub-base required (fig. 6)	=17 inches.
Thickness of sub-base required	= 9 inches.
Therefore, thickness of surface and base	= 8 inches.

The material for the sub-base is not specified but in all cases it should be better than the subgrade. It may be any granular material like coarse sand or its equivalent, Working out in terms of the current design, we get—

Sand (or equivalent) sub-base	= 9 inches.
Brick soling	= 4½ Inches.
Wearing course	= 3½ Inches.

It has been assumed that the compaction of the fill should not be less than 95 percent of the maximum dry density and the compaction of the base and sub-base not less 100 percent. It requires the subgrade to be sufficiently above the water-table to permit the proper compaction of the subgrade prior to placing the base or sub-base and soil drainage or sufficient embankment height to be provided where necessary to keep the water-table at least 4 or 5 ft. below the surface. Without those precautions, the base and the sub-base are going to have further deterioration and the designed crust shall not stand unless the actual conditions at site are controlled according to limitations laid down for the group index method.

(B) C. B. R. Method

Wheel load	= 9,000 lbs, medium traffic.
Clayey subgrade, C.B.R.	= 4% (average value).

Designing the pavement on this data by referring to fig. 7, we obtain :

Total thickness of surface, base and sub-base	= 17 inches.
Thickness of surface and base	= 9 inches.
∴ thickness of sand sub-base	= 17-9″ = 8′

Analysing the above results for the current design :—

Thickness of sand sub-base	= 8 inches.
Brick soling	= 4½ inches.
Wearing course	= 4 inches.
Surfacing course	= ½ ,, (shown as Fig.9)

Probable Causes of Road Failure

The present road failure can be attributed to the following causes :—

(*I*) *Under-design.*

The pavement has been under-designed. As worked out in the above two methods, it should have a total thickness of 17 inches for the medium traffic. The existing pavement has a thickness of 6 to 7 inches (4½″ brick soling, 1½″ to 2½″ stone wearing) in all. So it is deficient by 10 to 11 inches. The prevision of granular sub-base is indispenssble, especially since the road is affected by water-logging. It is an integral part of the pavement. Following the empirical way of construction, it should have a wearing course of 3½ to 4½ inches on a brick soling of 4½ inches (or preferably of crushed stone if economics allows its use at that site) resting on a sand 'granular sub-base of 8 to 9½ inches. Method of laying sub-base and choice of material is referred later.

(*2*) *Water-logging*

The road failure can also be attributed general waterlogged conditions of the soil. The sub-soil water-table keeps on fluctuating in different seasons. Although the water-table is at present 5 ft. below the subgrade, it rises in the rainy season.

(*3*) *Under-compaction*

The embankment has not been compacted properly. The density of soil, in place, is not more than 87 per cent now that the road has been open to traffic for a long time. The density of soil, therefore, at the time of construction must have been even lower than this value. It shows that the consolidation was not done properly. Thc parcentage proctor compaction should not be less than 95 per cent of the maximum dry density of the soil and may be preferably 105 per cent, if conditions allow.

(*4*) *Embankment*

The formation of the fill or the embankment out of the native soil or subgrade is itself a source of failure. The soil is silty and clayey with a high plasticity. It is subject to volume and shrinkage changes. Increasing the height of fill out of the subgrade does not improve the conditions. The engineering properties of the subgrade remain the same as those of the soil and the rise of capillary water upto the base of soling is only a matter of time even though the embankment is raised appreciably above ground level. The road could be in a much better condition if this fill was made out of an imported material, *i.e.*, some granular, material, which had better bearing capacity in the presence of water and less volume changes.

In a flexible pavement, it is actually the subgrade sub-base and base that bears the brunt of the traffic and not the bitumenous top. If the under-

strucrure of thc black top is weak and insufficient, the pavement is bound to deteriorate even if the surface has got the best structure. It is irrational to improve upon the super-structure on weak foundations. For a successful design, the base and sub-base must be sound and reasonably worked out. This is all the more important in waterlogged areas where the clayey subgrabe has very low bearing capacity and gets worst under moist conditions.

(5) *Use of clay as a Binder*

Clay has been used as a binder in the brick soling and within the wearing course. This material serves as a lubricant and expedites the failure of the pavement when moisture gets into the body of pavement. Sand could be profitably used for this purpose or any soft stone, which has some cementation properties.

Alternative Design

An alternative design of the pavement can be done scientifically by a better distribution of sand. It is admitted that wellgraded mixtures have high bearing capacity than the composite materials. Therefore, a well balanced mixture of sand, silt and gravel (or Kankar) can prove more useful than the pure sand. Following this principle, an alternative to the above design is produced in the form of a sketch below :—

1″ Bitumen top
$3\frac{1}{2}$″ crushed stone
3″ 50%gravel + 25% sand + 25% subgrade
4″ 50% sand+25% gravel + 25% subgrade
6″ 50% sand + subgrade
9″ 30% sand + subgrade.

The existing payment may be removed in this case. Keeping the grade of the road intact, a portion of the embankment from the top may be pulled down to replace it with the given specifications. The same quantity of sand will be required here but the mixing charges may be extra. In this design, $4\frac{1}{2}$″ brick soling and $3\frac{1}{2}$″—$4\frac{1}{2}$″ wearing course has been replaced with $3\frac{1}{2}$ inches of crushed stone and 2″ inch of bitumenous top, although gravel is used in base course.

This design is not final and absolute. It can be modified in details if it is followed in principale. The successive layers have got higher C. B. R. values proceeding from the subgrade to the surface. And greater stress has been laid on the strength of the sub-base and base course.

8·0. Miscellaneous Design Considerations and Selection of Suitable Material

The object of design of a pavement is the production of a structure which is stable under all conditions. For this to be mechanically stable, the materials constituting pavement, the subgrade material, the moisture movement and volume changes of subgrade have an important role to play. Proper understanding of problems affecting the stability of the pavement, selection of material at site should be kept in view at the time of construction, otherwise equally expensive failures can occur. These are the conditions and materials relating to Subgrade, sub-base, base and surfacing coat.

8.1. Subgrade Design & Choice of Material

For a subgrade to be stable, it is essential that under varied conditions of loading, rainfall and capillary moisture movement, there is no appreciable volume change, or shrinkage effects, and it be capable of transmitting the loads without any detrimental deformation, within a reasonable moisture range. The problem is one of efficient internal and external drainage, substitution of suitable material if soil is susceptible to waterlogging.

Conditions at site in most of our waterlogged areas are, however, not favourable, drainage being difficult and embankment height above a reasonable limit being an economically non-feasible proposition. This necessitates the working out of correct volume changes, Sometimes the sub-base of porous material A-1 or A-2 is provided in a layer over subgrades as a cut off.

One of the important considerations for subgrade is control of volume change since it effects the C.B.R. value and leads to distortion or even failure of the road surface. For this purpose soils should be tested in relation to the pavement and the amount of volume changes or swell should be noted down. The maximum value as indicated from tests shows that the percentage volume swell of such soils should be kept below 2% with the moisture content of the soil within a suitable range.

The compaction of the subgrade material is important in many respects. Generally speaking, for cohesive soils the higher the maximum density, the greater will the C.B.R. and lesser the the possibility of absorbing moisture in excess of the optimum. Hence if the compactive effect is more and relative compaction obtained in the field is thus higher at a lower optimum moisture, the saturated C.B.R. value would be greater and more economic structures can result.

For illustration purposes, some work was carried out by the Buildings and Roads Research Laboratory to indicate in a precise manner the effect of poor compaction on the values of C.B.R. which have indicated the following results, for a sandy silt soil ;—

Proctor's Percentage Compaction	C.B.R.
105%	18
95%	14
92%	4
90%	2·4

This would indicate that above type of soil compacted at 105 proctor compaction would give a 7″ thickness of pavement against a C.B.R. value of 1 8, while the same pavement if compacted upto 90% would give a thickness af 20 inches, against the same load relative to a C.B.R. of 2·4. The economy of proper compaction thus cannot be over stressed. Results mathus be summarized as ,

(*i*) Precautions should be taken to use soils which have little volume change.

(*ii*) Compaction of the embankment material should be done to as high a compaction as is economically feasible. Values over 100% proctor Compaction may be economical for low swelling material.

(*iii*) The local material with sodium or magensium sulphate which causes fluffing of the material and hence loss of density should be replaced by the better quality material.

(*iv*) The subgrade be placed at a minimum of 5 ft. above the water table or extra provision be made in the sub-base for lesser heights as suggested in Table B.

8.2. Sub-base Materials and Selection

Where the embankment material is poor and liable to volume change as met with generally in the alluvial soils of West Pakistan, it is useful to have a sub-base with the characteristic of low volume changes and a relatively high compaction density. This layer in fact serves many purpose and may be required for other than the above reasons in order to serve as an economic substitute for the lower layers of a base course beyond 8 inches thickness to prevent frost heave, to act as a drainage course and a capillary drainage cut course or to limit the possibilities of soft subgrade material penetrating into the base course.

For this purpose the sub base material may be formed among soil classified under A-1, A-2 and A-3 groups, which are gravels, cinders, quarry waste or fine sand having other admixtures like over burnt brick bats. Sometimes a stabilised soil with cement or lime is used as a sub-base and its C. B. R. value is specified (15 or over). The materials falling in A-1, or A-2 group being cohesive, sometimes require incorporation of material in the top 3″ sub-base layer, so as to give a firm surface on

which the base course may be laid. Similarly the use of such material over a soft subgrade may require a substitute of sand content or sandy soil between the sub-base and the subgrade to prevent soft clay working into the sub-base.

The Highway Research Board U. S. A., has divided sub-base material into two categories, (i) which serves as a drainage layer and gaurds off effects of frost over silty subgrade. It uses nonplastic material with not more than 8% passing 200 sieve, (ii) the sub-base on soils of low support which are susceptible to volume changes. For this purpose materials mentioned above are suitable alongwith those which have more than 65% retained on 200 sieve together with a maximum liquid limit of 35 and a maximum plasticity index of 15. For sub-base to act as drainage courses, materials for A-1 & A-3 should be selected, the interstices of material should be large enough to allow free drainage but when laid over an inferior subgrade should be small enough to prevent the soil penetrating into the drainage course.

7·8. Base materials, their selection and behaviour

The base course in a flexible pavement generally relies for its stability by interlocking of material and distribution of load through lateral displacement. The materials constituting this layer should thus have angular faces for interlocking, be water resistant to prevent softening of the stone and posibility of volume change, be hard enough to prevent shear under traffic and otherwise should not be so hard that interlocking becomes difficult during the process of compaction.

The general practice followed in our country consists in use of brick soling plus a layer of crsuhed stone as base material where in the stone is deficient in fine grade and a single size is used. At times, the screenings are replaced by a road side soil, although it basically conflicts with the theory of flexible pavement. If at all, any filler has to be used, it should not be clay but crushed rock with some cementing power, since clay tends to lubricate the stone in presence of water and dispersion of load cannot occur.

It is most importent that base course should consist of a material that has a constant volume. Assuming the aggregate to be water resistant chemically non-reactive, it remains to ensure that the moisture which the pores can absorb should not produce swelling there by reducing stability of the layer. Such volume changes occuring during shrinkage may also produce cracking or voids in the base course which would in turn lead to cracks in bitumenous surfacing, and further deterioration of pavement by water perculation from top.

With the progress of soil mechanics, it is now possible to use stabilised bases in place of hard crushed material. This has been extensively used with success abroad. The more important type out of these is the soil



Photograph No. 2

An example of road failure. Note the hump in the centre and depressions along the wheel line. Also note the errodded surface in foreground. Failure in this road is primarily due to under design and bad compaction. The berms have opposite slope and drain in, which further deteriorates the pavement.

cement stabilisation in which nearly 3-5% of cement is mixed in dry state and compacted at optimum moisture. Similar stabilizations are available with lime (3-5%), bitumen (3-4%) and chemical stabilization with sodium chloride or calcium chloride. These stabilized soil base courses have been used for light to medium loads with upto 1000 vehicles per day. The

Surface coat and bitumenous material

The surface coat is the bitumenous surface, *i.e.*, surfacing which ranges between $\frac{1}{2}''$ to over $2''$ thickness for low, medium or heavy traffic. The general practice in our country consists of surfacing in three layers. The surface coat acts primarily to keep off the moisture from getting into the body of the road and to provide smooth, hard and resistant surface for the traffic. It also prevents loss of stability or displacements due to dynamic loads. The design of the surface coat depends primarily on the aggregate used and the bitumenous material available. However, it is also affected by the volume and nature of traffic, temperature, climatic conditions and rainfall. A uniform application of 3 coats of surfacing making an overall thickness of $\frac{1}{2}''$ as at present being followed, should not have a universal application. Roads where the traffic is very high, or rainfall is heavy, warrant a thicker surface coat and may be used upto 2 inches.

9·0. General-Recommendations

In view of the foregoing discussions on the design of flexible pavement and the work already carried out in West Pakistan, it would be observed that the following general recommendations may be applied with advantage :—

1. Whenever a new road is to be constructed, the soil conditions, traffic census, rainfall and water-table data should be properly collected. Investigation be carried out by different methods, and one adopted which is most suitable for local conditions. The nature of soil for embankment construction should also be investigated and, if necessary, changes may be made in local soil material to avoid volume changes.

2. Cases in which the existing roads are showing deterioration should be investigated, The exact cause of trouble should be located, *i.e.*, whether the failure is due to under-design, bad compaction of the embankment or water-logging, etc. Where existing thickness of the pavement is short of the design thickness, no amount of repair or patch work can maintain the road surface and it is essential that suitable modifications should be made in the road crust to increase thickness of the pavement.

3. The height of the embankment should be nearly 5 ft. above the highest water table and the embankment material should

be suitably modified not to have a liquid limit greater than 40 and the volume change greaters than 2%. Lesser height of the embankment necessitates increased subbase thicknesses as given in table B.

4. The compaction of the embankment specially at the subgrade level cannot be over-emphasised. A bad compaction is conducive to failure due to low penetration resistance (low C.B.R.) and in turn requires higher thickness of the pavement. Some experiments conducted indicate, that over compacted subgrade upto 105% (Proctor compaction) can be used as a part of the pavement. The compaction be carried under laboratory control.

5. Sub-base material should be coarse and granular as for as possible. Sand is locally available practically everywhere below NSL, in canals or river beds and should be extensively used. Places where the subgrade material is so soft as to penetrate into the sub-base, some admixture of subgrade material should be done with the coarse material to give a compacted base. Similar procedure is useful for the top of the sub-base to provide a hard and tough surface for laying base course.

6. Base material is to be hard, tough and non-porous with proper grading. Use of the pit-run gravel, stabilished bases and crushed stone should be encouraged to replace brick soiling with due regard to economy. However, stabilsied bases should not be encouraged at places where high traffic is encountered.

7. Surfacing material should be hard. tough and may be crushed and graded without fines. In place traffic is very high or rainfall is excessive, it is suggested that 1″-2″ carpet should be laid to seal the pavement from ingress of water percolation.

10·0. Conclusion

It is hoped that this paper would introduce the subject of road pavement design to the engineers working on construction of roads in Pakistan. The author considers that the approach to the subject presented here may be lacking in many ways. He has relied for his views on the data published abroad and work already carried out in the Buildings and Roads Research Laboratory, Lahore for the last over 2 years. Some of the inferences and conclusions are possibly open to objection and may be subject to critcisim, but he feels that if this paper can awaken some healthy discussion on the subject and brings proper realisation of the importance of road design, the effort and the criticism will be all worth while.

Acknowledgements.

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APPENDIX A

U. S. Public Roads Administration Classification (1945) Granular Materials.

Group A-1.

The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand and a non-plastic or feebly plastic soil binder. Howeves, this group includes also stone fragments, gravel, coarse sand, volcanic cinders, etc.

Sub-group A-1-a.

Includes materials consisting predominantly of stone fragments or gravel, either with or without a well graded binder of fine material.

Sub-Group A-1/b.

Includes those materials consisting predominantly of coarse sand, either with or without a well-graded soil binder.

Group A-3.

The typical material of this group is fine beach sand or fine desert blown sand, wlthout silty or clay fines or with a very small amount of non-plastic silt. The group includes also stream-deposited mixtures of poorly graded fine sand and limited amounts of coarse sand and gravel.

Group A-2.

This group includes a wide variety of granular materials which are border-line cases between the materials falling in Groups A-1 and A-3 and the silt-clay materials of Groups A-4, A-5, A-6 and A-7. It includes all materials containiug 35 per cent or less passing a No. 200 sieve which cannot be classified as A-1 or A-3, owing to finer content or plasticity or both in excess of the limitations for those groups.

Sub-Groups A-2-4 and A-2-5.

Include various granular materials containing 35 per cent or less passing a No. 200 sieve and with the portion passing a No. 40 sieve having the characteristics of the A-4 and A-5 groups. They include such materials as gravel and worse sand with silt content or *plasticity index in excess of the limitation of Group A-1. and fine sand with non-plastic silt content in excess of the limitations of group A-3.

Sub-Groups A-2-6 and A-2-7

Include materials similar to those described under sub-groups A-2-4 and A-2-5 except that the fine portion contains plastic clay having the charac-

*Plasticitv Index represents amount of moisture necessary to destroy the cohesion represented by the plastic limit and is defined as difference between the liquid limit and plastic limit.

teristics of the A-6 or A-7 group. The approximate combined effects of plasticity indices in excess of 10 per cent and percentages passing a No. 200 sieve in excess of 15 are reflected by the group index values ranging from 0 to 4.

Silt-clay Materials

Group A-4

The typical material of this group is a non-plastic or moderately plastic silty soil usually having 75 per cent or more passing a No. 200 sieve. The group includes also mixtures of fine silty soil and upto 64 per cent of sand and gravel retained on a No. 200 sieve. The group index values range from 1 to 8 with increasing percentages of coarse materials being reflected decreasing group index values.

Group A-5

The typical material of this group is similar to that described under group A-4 except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit. The group index values range from 1 to 12, with increasing values indicating the combined effect of increasing liquid limits and decreasing percentages of coarse material.

Group A-6

The typical material of this group is a plastic clay soil usually having 75 percent or more passing a No. 200 sieve. The group includes also mixture of fine clay soil and upto 64 percent of sand and gravel retained on a No. 200 sieve. Materials of this group usually have a high volume change between wet and dry states. The group index values range from 1 to 16 with increasing values indicating the combined effect of increasing plasticity indices and decreasing percentages of coarse material.

Group A-7

The typical material of this group is similar to that described under group A-6 except that it has the high liquid limits characteristics of the A-5 group and may be elastic as well as subject to high volume change. The range of group index values is from 1 to 20 with increasing values reflecting the combined effect of increasing liquid limits and plasticity indices and decreasing percentage of coarse material.

Sub-Group A-7-5

Includes those materials with moderate plasticity indices in reaction to liquid limit, which may be highly elastic as well as subject to considerable volume change.

Sub-Croup A-7-6.

Includes materials which have high plastic city indices in relation to their liquid limits and which are subject to extremely high volume changes.

APPENDIX B

Showing the Results of Soil Testing for Hab-Chauki Lasbela Road

Serial No.	Description	Liquid Limit	Plasticity Index	Sieve Numbers		
				10 pass	40 pass	200 pass
1.	Boowani Mile 5		Non-Plastic	100	99·5	27·5
2.	Bangar Nallah Mile 16		Non-Plastic	100	99·5	26·0
3.	Luk Beelhoke Mile 20		Non-Plastic	100	99·0	23·0
4.	Nacca-Kharari Mile 25		Non-Plastic	100	99·0	9·0
5.	Mile No. 30		Non-Plastic	100	98·0	23·0
6.	Kathore Bajee, R.D. 162200 Mile No. 35		Non-Plastic	100	99·5	17·0
7.	Khur Khera/ R.D. 199700	31·4 Plastic	17·1 Limit=14·3	100	99·8	95·0
8.	Wingoi Hotel, Mile 46		Non-Plastic	100	95·5	33·0
9.	Siranda Lake, Mile 97	18·6	Non-Plastic	100	95·5	39·0
10.	Wingoi Dhora, Mile 52.		Non-Plastic	100	95·5	19·9
11.	Opposite Ulthal Kantya (Mile 63)	24·2 Plastic	8·1 Limit=16·1	100	99·8	91·0
12.	Ulthal village, Mile 65	29·8 Plastic	13·2 Limit=16·6	100	100	98·0
13.	From Mile 68 to Mile 95.	Gravel				
14.	Near Lasbela, Mile No. 100	24·0 Plastic	8·9 Limit=15·1	100	99·5	88·0

Soil classification and Group Index	C.B.R. Value	Total thickness of flexible payment for medium load.	Pavement split up		Water-table and Rainfall	
			Sub-base	Base and Surface		
A-2-4(0)	10	9″	...	$4\frac{1}{2}''+4''+\frac{1}{2}''$	Deep	Low
A-2-4(0)	10	9″	...	Do	,,	,,
A-2-4(0)	10	9″	...	Do	,,	,,
A-2-4(0)	10	—	...	Do	,,	,,
A-2-4(0)	10	9″	...	Do	,,	Arid Zone
A-2-4(0)	I0	9″	...	Do	,,	,,
A-6 (10·8)	4	17″	9″	$3\frac{1}{2}+4''+\frac{1}{2}''$	,,	,,
A-2-4(0)	10	9″	...	$4\frac{1}{2}''+4''+\frac{1}{2}''$	,,	,,
A-4(8)	4	17″	9″	$3\frac{1}{2}''+4''+\frac{1}{2}''$		Low
A-2-4(0)	10	9″	...	$4\frac{1}{3}''+4''+\frac{1}{2}''$	,,	,,
A-4 (8)	4	17″	9″	$3\frac{1}{2}''+4''+\frac{1}{2}''$	,,	,,
A-6 (9)	4	17″	9″	$3\frac{1}{2}''+4''+\frac{1}{2}''$	,,	Arid Zone
A-1 (0)	—	$4\frac{1}{2}''$	...	$4''+\frac{1}{2}''$	,,	,,
A-4 (8)	4	17″	9″	$3\frac{1}{2}''+4''+\frac{1}{2}''$	,,	,,

APPENDIX C

Results of the Soil Testing for Sahiwal-Jhang Road

Serial No.	Description	Atterberg Limits			Particle Size Distn			Group Index Classification
		Liquid Limit	Plastic Limit	Plasti-city index	10 sieve	40 sieve	200 sieve	
1.	Mile No. 37/0	24·5	14·6	9·9	100	99·91	76·55	A-4 (8)
2.	,, ,, 37/2	39·3	21·7	17·6	100	99·96	89·00	A-6 (11)
3.	,, ,, 37/4	40·1	22·7	17·4	100	99·96	98·80	A-6 (11)
4.	,, ,, 37/6	27·6	17·9	10·0	100	99·91	76·67	A-4-6 (8)
5.	,, ,, 38/0	25·2	16·4	8·8	100	99·93	84·25	A-4 (8)
6.	,, ,, 38/4	33·4	18·5	14·9	100	99·73	93·28	A-6 (10)
7.	,, ,, 39/4	24·4	16·8	7·6	100	99·96	79·79	A-4 (8)
8.	,, ,, 40/4	31·2	16·9	14·3	100	99·96	93·05	A-6 (10)
9.	,, ,, 41/4	32·8	22·7	10·1	100	99·70	93·79	A-4-6 (8)
10.	,, ,, 42/4	29·0	18·0	11·0	100	99·91	97·85	A-4-6 (8)
11.	,, ,, 43/4	30·2	18·0	12·2	100	99·85	87·01	A-6 (11)
12.	,, ,, 44/4	27·5	17·8	9·7	100	99·96	87·31	A-4 (8)
13.	,, ,, 45/4	38·9	22·8	16·1	100	99·94	96·65	A-6 (10)
14.	,, ,, 46/4	36·2	19·3	16·9	100	99·93	93·91	A-6 (10)
15.	,, ,, 47/4	34·0	I9·8	14·2	100	99·94	87·05	A-6 (10)
15.	,, ,, 48/4	34·6	23·9	10·7	100	99·73	87·22	A-4-6 (8)
17.	,, ,, 49/4	37.7	21·0	16·7	100	99·75	95·36	A-6 (10)
18.	,, ,, 50/4	25·1	16·6	8·5	100	99·85	82·18	A-4 (8)

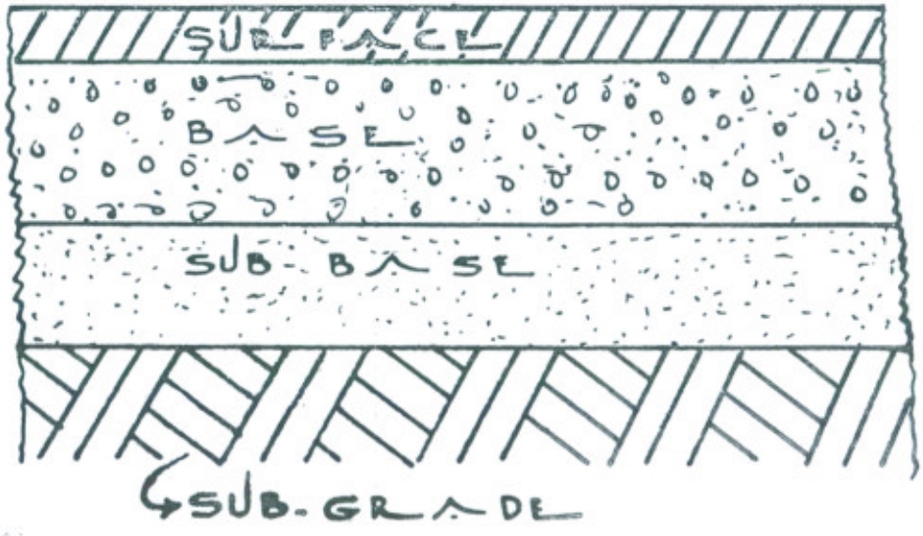
APPENDIX D

Sahiwal-Jhang Road

Serial No.	Mile No.	Subgrade condition at site			Optimum Moist-content %	Maximum Dry Density Lbs./cft.	C.B.R. Values		Degree of Compaction %
		Moisture content %	Wet Density Lbs./cft.	Dry Density Lbs./cft.			At O.M. Content.	After Soaking	
1.	37/0	14·2	110·14	96·4	15·1	116·7	3·3	3·3	82·60
2.	37/2	16·7	105·86	90·7	16·2	104·3	3·3	3·3	82·59
3.	37/4	25·19	103·42	82·6	17·3	109·2	6·6	2·6	75·64
4.	37/6	16·70	104·94	89·9	14·7	119·3	2·3	4·0	75·37
5.	38/0	10·70	105·50	95·3	—	...	...	...	...
6.	38/4	8·90	95·48	95·9	15·4	114·5	8·6	6·3	75·01
7.	39/4	11·6	109·00	97·6	14·2	114·9	3 3	4·0	84·92
8.	40/4	12·99	105·30	93·2	16·7	112·8	3·6	3·8	82·62
9.	41/4	14·30	106·50	93·1	14·6	113·0	8·6	6·6	82·37
10.	42/4	16·70	108·60	93·0	16·3	111·6	5·0	2·8	83·35
11.	43/4	10·90	106·50	96·0	14·7	116·1	7·3	4·5	82·21
12.	44/4	16·30	107·70	92·6	14·4	117·5	7·6	5·3	78·82
13.	45/4	15·5	99·15	85·8	15·9	119·2	7·3	4·0	71·95
14.	46/4	12·6	105·50	93·7	16·0	113·4	7·0	4·5	82·8
15.	47/4	16·4	126·10	108·3	14·3	114·4	4·3	3·6	94·86
16.	48/4	8·5	95·79	88·3	14·0	112·8	4·6	3·0	87·3
17.	49/4	9 2	108·60	93·0	18·3	106·4	4·0	4·3	87 31

PAPER NO 340

FIG. 1



PAPER NO 340

FIG 2



FIG. 3

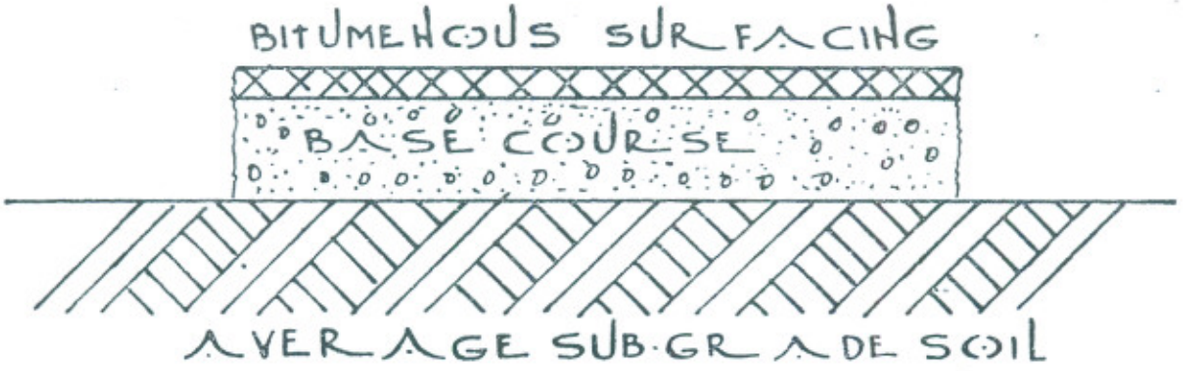
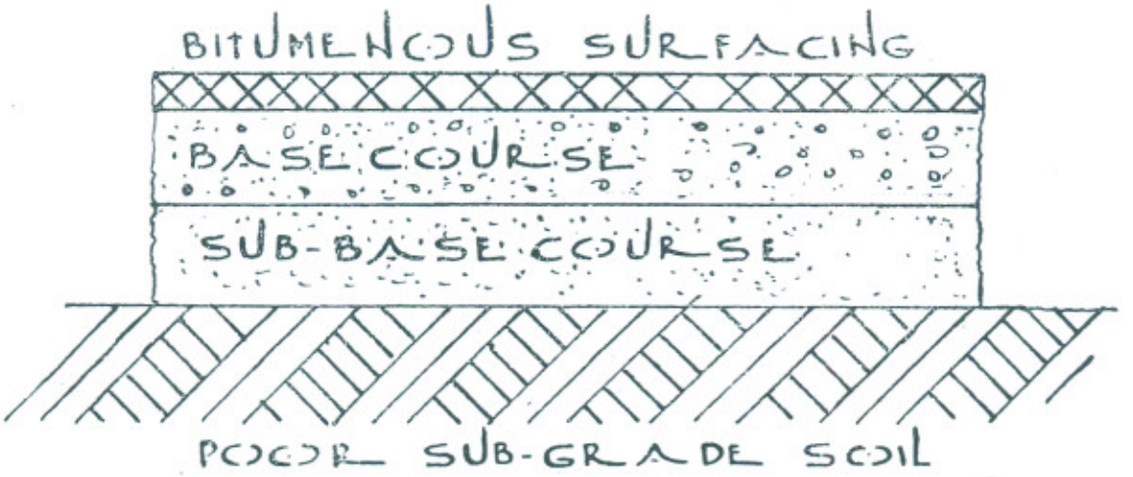


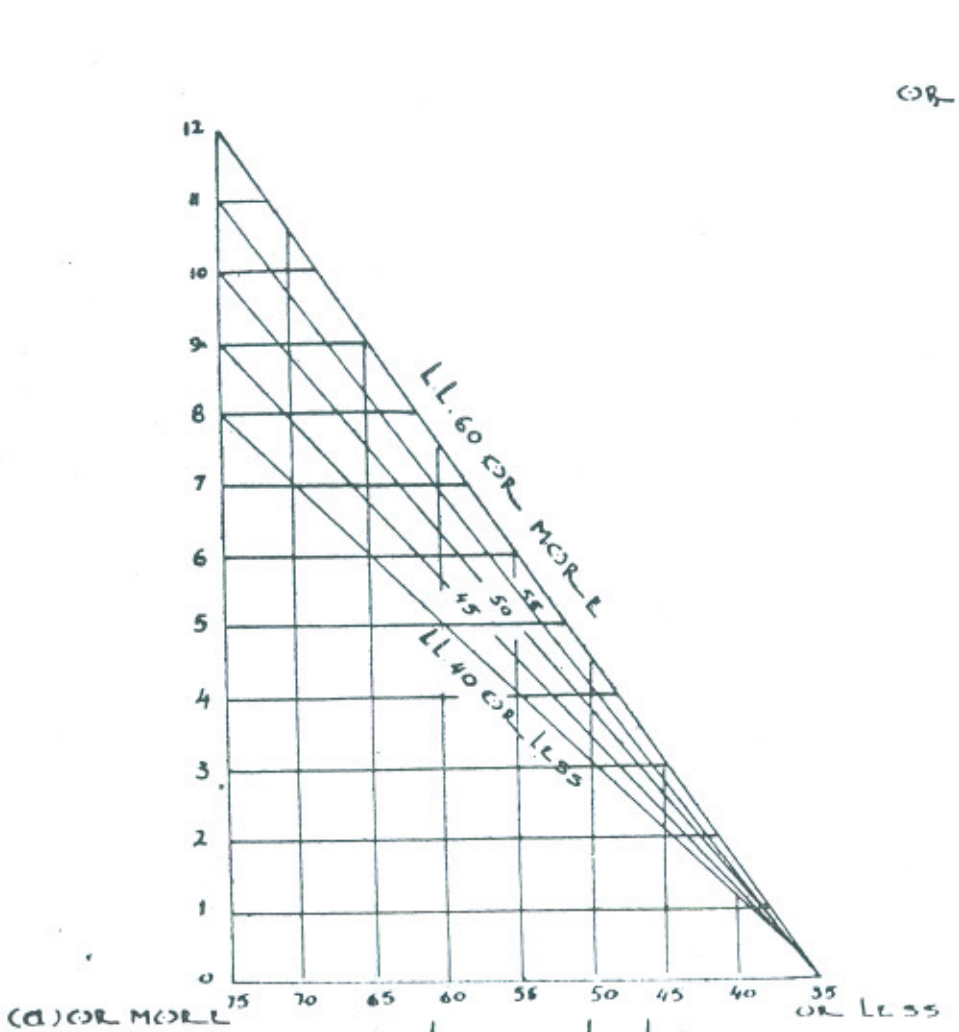
FIG. 4

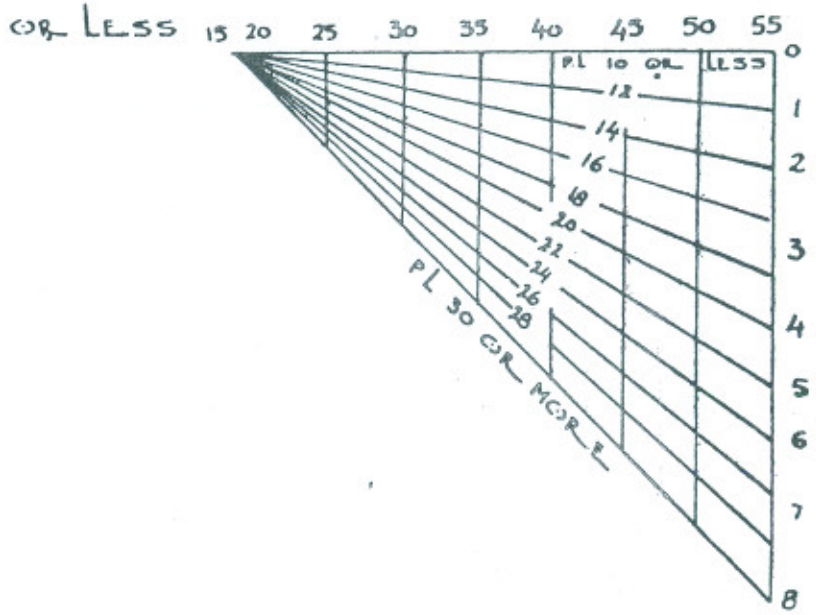


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FIG. 5

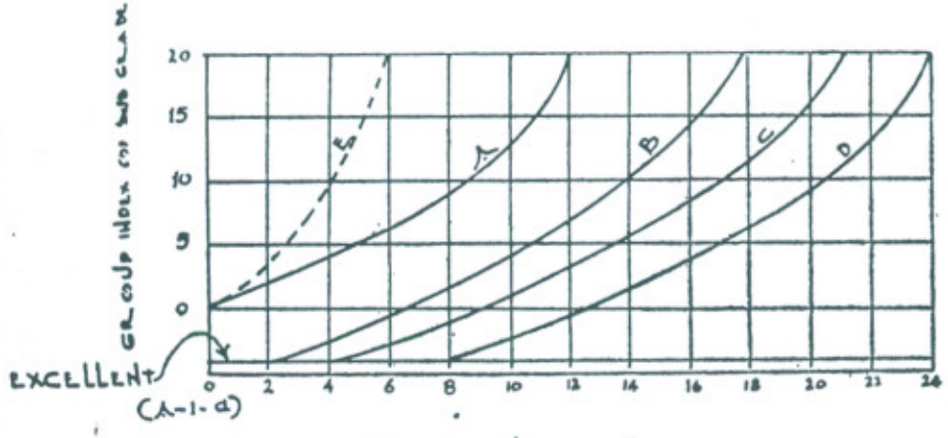
GRAPHS FOR DETERMINATION OF GROUP INDEX.





GROUP INDEX = SUM OF READINGS ON VERTICAL SCALE OF CHARTS

TENTATIVE DESIGN CURVES U.S. HIGHWAY ENGINEERS GROUP INDEX METHOD.



THICKNESS - INCHES

CURVE A THICKNESS OF SUB-BASE REQUIRED

" B TOTAL THICKNESS OF SURFACE BASE & SUB-BASE. LIGHT TRAFFIC

" C TOTAL THICKNESS OF SURFACE BASE & SUB BASE. MEDIUM TRAFFIC

" D TOTAL THICKNESS OF SURFACE BASE & SUB-BASE. HEAVY TRAFFIC

" E THICKNESS OF ADDITIONAL BASE WITCH MAY BE SUBSTITUTED FOR SUB-BASE OF CURVE (A)

LIGHT TRAFFIC. < 50 COMMERCIAL VEHICLES/DAY.

MEDIUM TRAFFIC. 50-300 COMMERCIAL VEHICLES/DAY

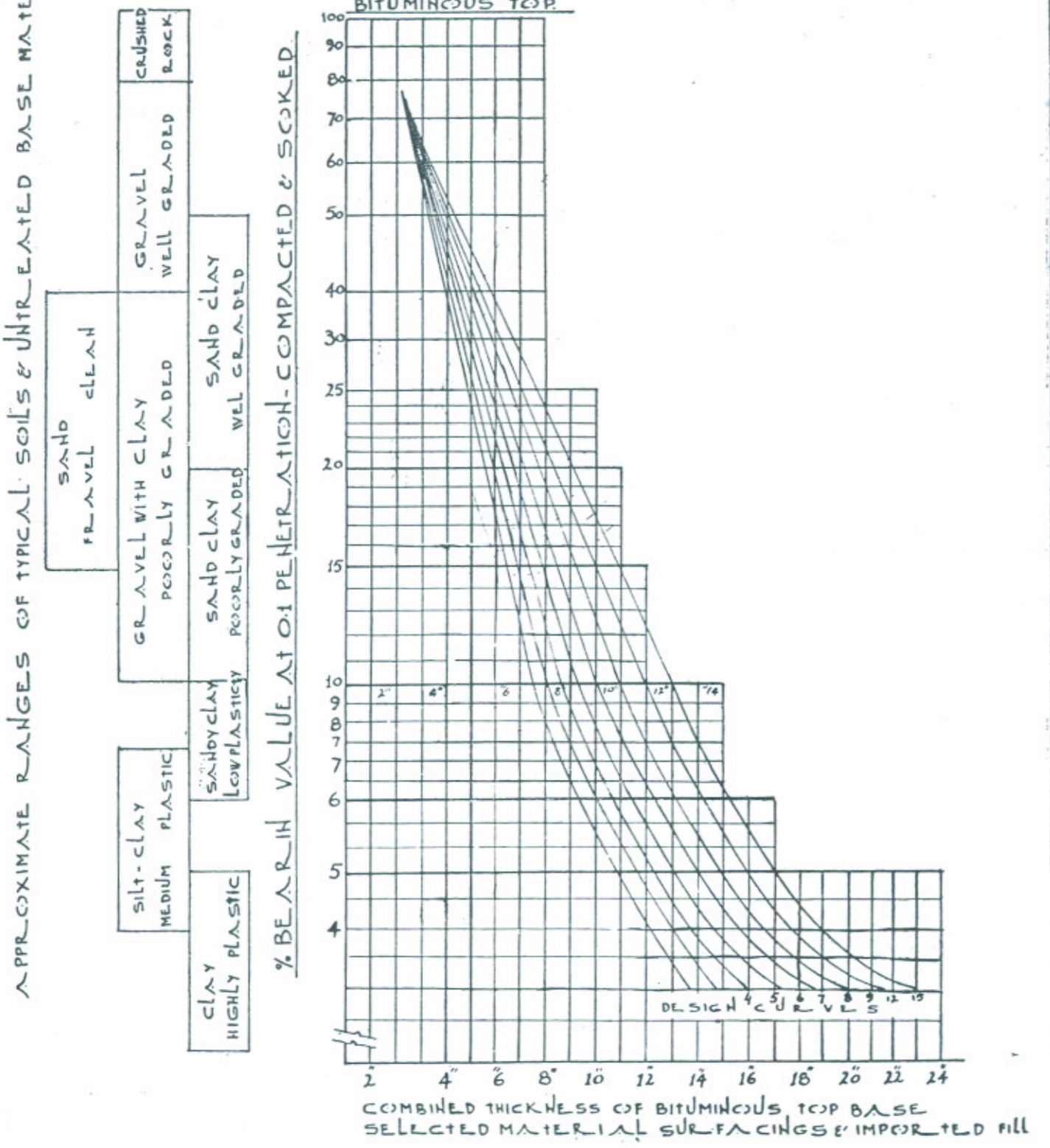
HEAVY TRAFFIC. > 300 COMMERCIAL VEHICLES/DAY.

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WYOMING HIGHWAY DEPARTMENT

FIG 7

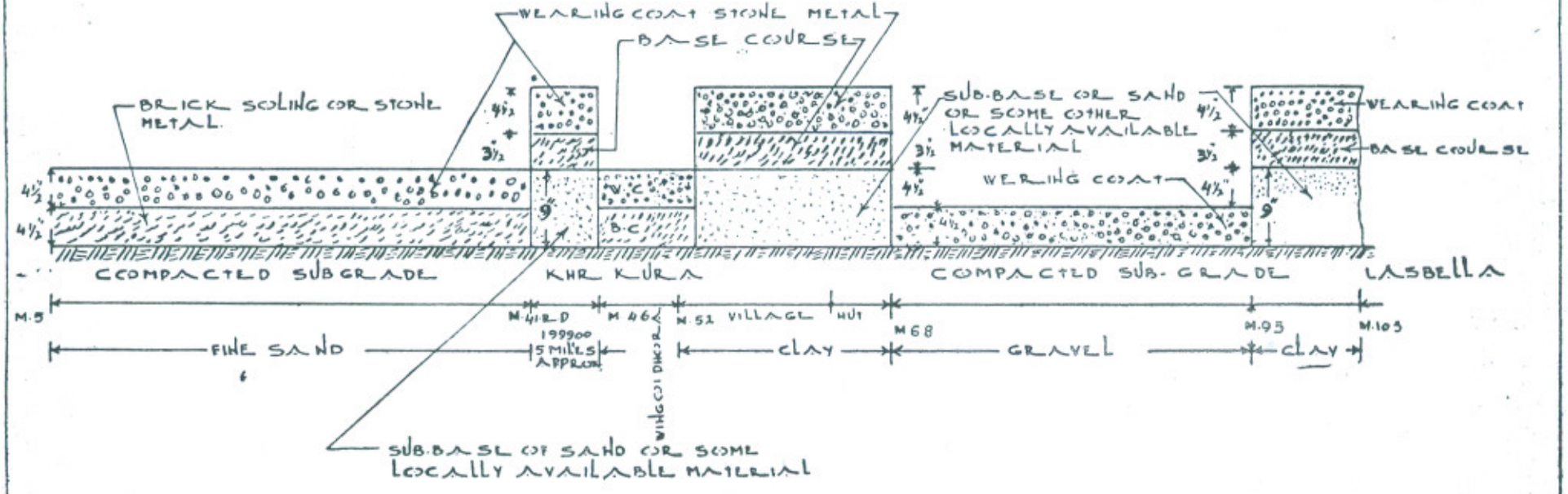
DESIGN DATA FOR EMBANKMENT · SELECTED MATERIAL SURFACING · SUB-BASE & BITUMINOUS TOP



PAPER NO 340

FIG. 6

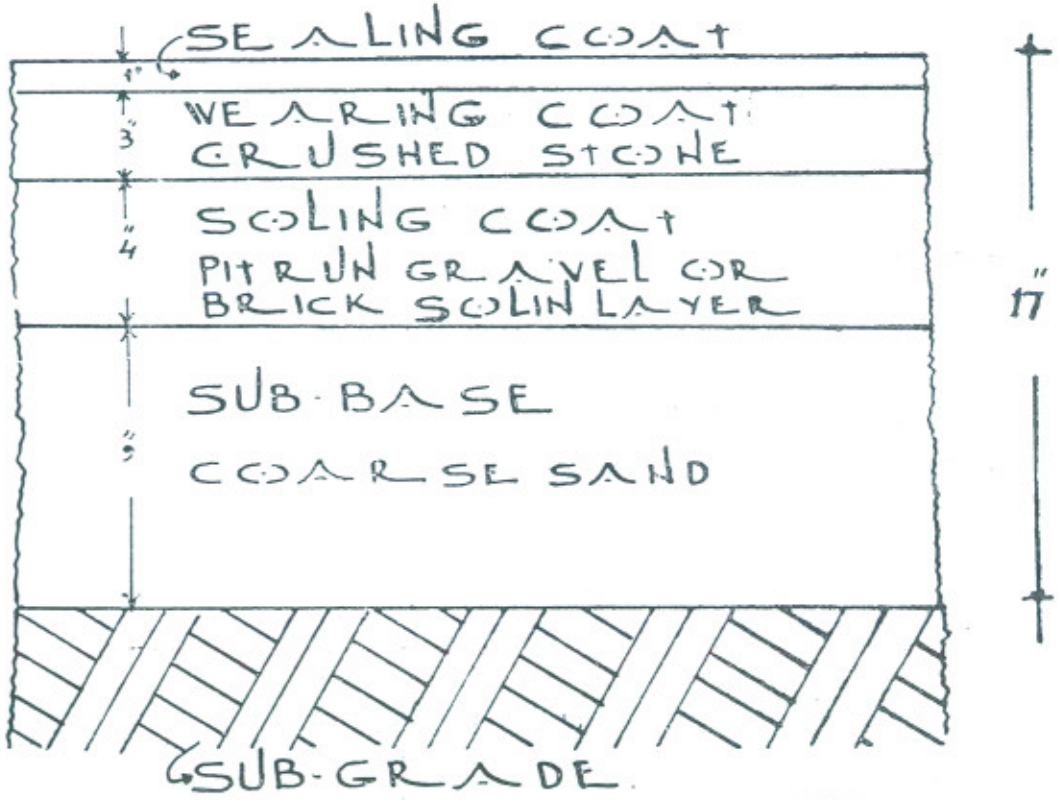
DESIGN OF FLEXIBLE PAVEMENT FOR HAB-CHOWKI LASBELLA ROAD.



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FIG. 9

DESIGN OF JHAN-SAHJWAL ROAD



Errata : Substitute values of:—

Sub-base as 8″ instead of 9″ Wearing coat as 4″ instead of 3″

Soling coat as 4½″ instead of 4″ Sealing coat as ½″ instead of 1″