Design and Construction of Rigid and Flexible Pavements

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Abstract— Transportation contributes to the economical, industrial and social development of any country. There are different modes of transportation among which the mode of Transportation by roads has been popular since ages as it is the only mode which gives maximum service to all the classes of people. A Pavement is considered as a durable surface material laid down on an area intended to sustain vehicular or foot traffic. A pavement is said to be good when it is stable and Non-yielding to allow heavy wheel loads of traffic to move with least possible rolling resistance .in order to provide such a stable and even surface for traffic, a Road way is provided with a suitably designed and constructed pavement surface. In this work, an effort has been made in examining the different layers involved in a typical rigid and flexible pavement and have designed the pavement as per the IRC Specifications. The project includes all the required Field and Laboratory tests. The results regarding CBR values, aggregate properties and all other necessary data have been presented in the work.

Key words: CBR values, Flexible Pavements

I. Introduction

Pavement or Road surface is the durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway.

Generally, there are 3 types of pavements which are designed for Transportation:

- Flexible pavements
- Semi rigid pavements
- Rigid pavements

Out of these flexible pavements are the most widely used pavements structures. A pavements structure that maintains intimate contact with and distributes loads to the sub grade and depends on aggregate interlock, particle friction and cohesion for stability is called as a flexible pavement.

Rigid pavements are so named because the pavement structure deflects very little under loading due to the high modulus of elasticity of their surface course. A rigid pavement structure is typically composed of a PCC surface course built on top of either (1) the sub grade or (2) an underlying base course.

A. Flexible Pavements:

Pavements which reflect the deformation of sub grade and the subsequent layers to the surface.

A typical pavement consists of 4 components. They are as follows

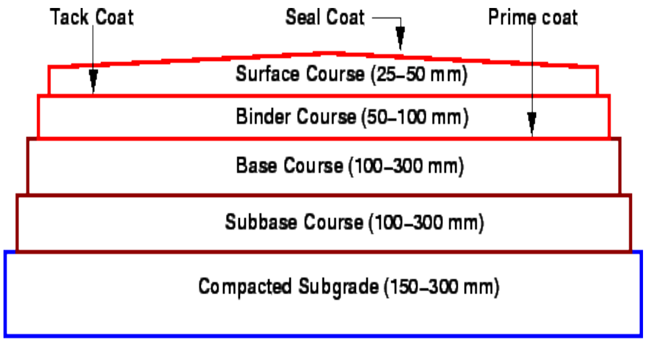


Fig. 1: Natural Subgrade

1) Soil sub-grade
2) Sub base course
3) Base course
4) Surface course

The design of flexible pavement is based on load distributing characteristic of the component layers. The black top pavement including water & gravel bound macadam fall in this category.

B. Rigid Pavement:

Rigid pavements are those which possess note worthy flexural strength or flexural rigidity. These stresses are not transferred from grain to grain to the lower layers as in the case of flexible layers. The rigid pavements are made of Portland cement concrete-either plain, reinforced or prestressed concrete. The plain cement concrete slabs are expected to take up about 40 Kg/sq.cm. The rigid pavements having slab action is capable of transmitting the wheel load stresses to a wider area below.

The cement concrete pavement slab can very well serve as a wearing surface as well an effective base course. Therefore usually the rigid pavement structure consists of a concrete slab, below which a granular base or sub-base course may be provided.

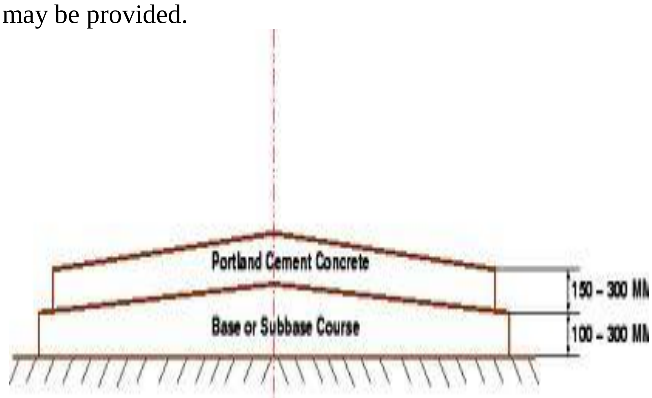


Fig. 1: Typical Cross-section of Rigid Pavement

Though the cement concrete slab can be laid directly over the sub grade soil, this is not preferred particularly when the sub grade consists of fine grained soil. Providing a good base or sub base course layer under the cement concrete slab, increases the pavement life considerably and therefore works out more economical in the long run.

The rigid pavements are usually designed and the stresses are analyzed using the elastic theory, assuming the pavement as an elastic plate resting over elastic or a viscous foundation.

The main point of difference in the structural behavior of rigid pavement as compared to the flexible pavement is that the critical condition of stress in the rigid pavement is the maximum flexural stress occurring in the slab due to wheel load and the temperature changes where as in the flexible pavement it is the distribution of compressive stresses.

As the rigid pavement slab has tensile strength, tensile stresses are developed due to the bending of the slab under wheel load and temperature variations. Thus the types of stresses developed and their distribution within the cement concrete slab are quite different. The rigid pavement does not get deformed to the shape of the lower surface as it can bridge the minor variations of lower layer.

II. Functions of Pavement Components

The cross section of pavement consists of surface course or cement concrete slab followed by base course or wearing course and the lowest layer consists of the soil sub-grade which has lowest stability in case of rigid pavement .And wearing surface at the top, below which is the base course followed by the sub-base and the lowest layer consists of the soil sub-grade which has lowest stability among the four typical pavement components in case of flexible pavements The functions of various pavement components are described in this chapter.

A. *Soil sub grade:*

The soil Sub grade is a layer of natural soil prepared to receive the layers of the pavement materials placed over it. The load on the Pavement is ultimately received by the soil Sub grade for the dispersion to the Earth mass. It is essential that at no time, the soil Sub grade is Over-stressed.

It is desirable that at least top 50cm layer of the Sub grade soil is well compacted under controlled conditions of Optimum Moisture Content and Maximum Dry Density. It is necessary to evaluate the strength properties of soil Sub grade. This helps the designer to adopt the suitable values of Strength parameter for design purposes. In case the supporting layer doesn't come up to the expectation the same is treated a stabilized to suit the requirements.

Many tests are known for measuring the strength properties of Sub grades. Mostly the tests are empirical and are useful for their correlation in the design. Some of the tests have been standardized for the use. The common strength tests for the evaluation are:

– California Bearing Ratio test
– California Resistance Value test
– Triaxial Compression test
– Plate Bearing test

B. *Sub-base and Base course:*

These layers are made of broken stone, bound or unbound aggregate. Sometimes in sub-base course a layer of stabilized soil or selected granular soil are also used. In the sub-base course, it is desirable to use smaller size graded aggregate or soil aggregate mixes or soft aggregates instead of large boulder stone soling courses of brick on edge soling course, as these have no proper interlocking and therefore have Lesser resistance to sinking into the weak sub-grade soil when wet.

When the sub-grade consists of fine grained soil and when the pavement carries heavy wheel loads, there is a tendency for these boulder stones to penetrate into wet soil, resulting in formation of undulations and uneven pavement surface.

The functions of base course vary according to type of pavement. Base course and sub-base courses are used under Flexible Pavement primarily to improve the load supporting capacity by distributing the load through a finite thickness. Thus the fundamental purpose of a base course and sub-base course is to provide a stress transmitting medium to spread the surface wheel load in such a manner as to prevent shear and consolidation deformations.

C. *Wearing course:*

The purpose of Wearing course is to give a smooth riding surface that is dense. It resists pressure exerted by tyres and takes up wear and tear due to the traffic. Wearing course also offers a water tight layer against the surface water infiltration. In rigid Pavement, the cement concrete acts like a base course as well as a wearing course.

III. Desgin Factors for Pavement

Pavement design consists of two parts:
1) Mix design of materials to be used in each pavement component layer.
2) Thickness of design of the pavement and the component layers.

The following are the different factors that are to be considered for the design of pavements:
1) Design Wheel Load
2) Sub grade soil
3) Climatic factors
4) Pavement component materials
5) Environmental factors
6) Special factors

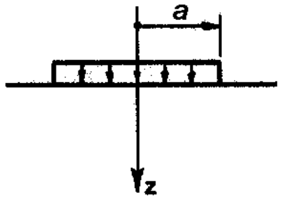
A. *Design wheel load:*

The design of pavement primarily depends on the design wheel load. While considering the design wheel load the various wheel load factors to be considered are:
1) Maximum wheel load
2) Contact pressure
3) Dual or multiple wheel loads and equivalent single wheel load
4) Repetition of loads

1) Maximum wheel load:

The wheel load configurations are important to know the way in which the loads of a given vehicle are applied on the pavement surface. For highways, the maximum legal axle load as specified by Indian Road Congress is 8170kg with a maximum equivalent single wheel load of 4085kg.

The equation for vertical stress computations under a uniformly distributed circular load is given by Boussinesq's theory:



$$\sigma_z = q\left[1 - \left\{\frac{1}{1 + (a/z)^2}\right\}^{3/2}\right]$$

Fig. 2: Boussinesq's Stress Distribution

Where,

q = surface pressure
z = depth at which vertical stress is calculated
a = radius of loaded area

Here, the equation gives the vertical stress at depth z

2) Contact pressure:

The influence of tyre pressure is predominating in the upper layers. At a greater depth the effect of tyre pressure diminishes and the total load exhibits a considerable influence on the vertical stress magnitudes. Tyre pressure of high magnitudes therefore demand high quality of materials in upper layers of pavement. The total depth of pavement is however not influenced by the tyre pressure. With constant tyre pressure, the total load governs the stress on the top of sub grade within allowable limits.

Generally the wheel load is assumed to be distributed over a circular area. Three terms in use with reference to tyre pressure are:

1) Tyre pressure
2) Inflation pressure
3) Contact pressure

Theoretically, all these terms should mean the same. Tyre pressure and Inflation pressure mean exactly the same. The contact pressure is found to be more than tyre pressure when the tyre pressure is less than 7 kg/cm^2 and it is vice versa when the tyre pressure exceeds this value. Contact pressure is given by the relation:

$$\text{Contact pressure} = \frac{\text{Load on wheel}}{\text{Contact area}}$$

The ratio of contact pressure to tyre pressure is defined as *Rigidity factor*. Thus value of rigidity factor is 1.0 for an average tyre pressure of $7kg/cm^2$.

Rigidity factor is higher than unity for lower tyre pressures and less than unity for tyre pressures higher than $7kg/cm^2$.

3) Equivalent single wheel load (ESWL):

To maintain the maximum wheel load within the specified limit and to carry greater load, it is necessary to provide dual wheel assembly to the rear axles of the road vehicles. In doing so the effect on the pavement through a dual wheel assembly is obviously not equal to two times the load on any one wheel. In other words, the pressure at a certain depth below the pavement surface cannot be obtained numerically adding the pressure caused by one wheel load. The effect is in between the single load and two times the load on any one wheel. The following figure shows the stress distribution in pavement.

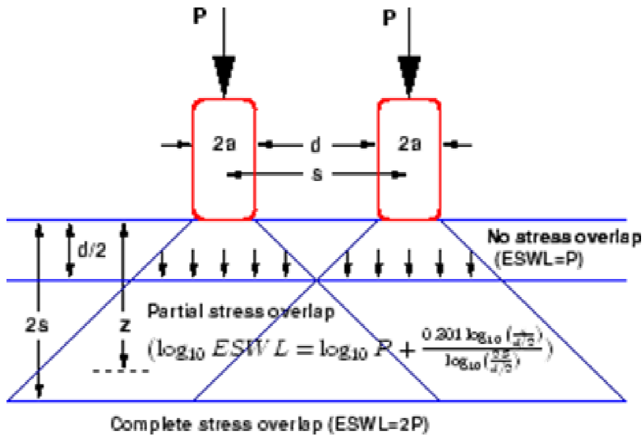


Fig. 3: Stress Overlap due to wheel loads

4) Repetition of loads:

The deformation of pavement or sub grade due to single wheel application of wheel load may be small. But due to repeated application of the load there would be increased magnitude of plastic and elastic deformations and the permanent deformations may even result in pavement failure.

B. Subgrade soil:

Subgrade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The subgrade soil and its properties are important in the design of pavement structure. The main function of subgrade is to give adequate support to the pavement and for this the subgrade should possess sufficient stability under adverse climatic and loading conditions.

1) Subgrade soil strength:

Since subgrade plays an important role in designing the pavement. The factors on which the strength of soil depend are:

1) Soil type
2) Moisture content
3) Dry density
4) Internal structure of soil
5) Type & mode of stress application

C. Pavement Materials:

For design purposes it is required that the various pavement materials are assigned strength parameters suitable to the design method employed for the purpose. The general strength values are

1) CBR value: The test has been explained in 6.1. The strength values so obtained for the materials tested are of relative significance and do not provide as absolute measure. There are design methods which employ the CBR strength values of materials used in different pavement layers.
2) Elastic modulii: Depending upon the design methods, the elastic modulii of different pavement materials are evaluated .mainly, plate bearing test is employed for this purpose.

D. Climatic factors:

The climatic variations cause the following major effects.

1) Variation in moisture condition
2) Frost action
3) Variation in temperature

The pavement performance is very much affected by the variation in moisture and the frost. Variation in temperature generally affects the pavement materials like bitumen and concrete.

E. Special factors:

The special factors include environmental and as well the miscellaneous ones also. The following are the environmental factors affecting the pavement:

1) Height of embankment and its foundation details
2) Depth of sub surface water table
3) Depth of cutting

The choice of bituminous binder and the performance of bitumen should also be taken in to due consideration.

The formation of shrinkage cracks, fatigue behavior should also be studied before arriving at the design.

IV. LABORATORY TEST RESULTS

A. CBR Test:

Diameter of mould = 150mm
Height of the mould = 125mm
Volume of mould = 22089c.c
Proving ring constant = 6.14

1. $\text{CBR\% at 2.5mm penetration} = \frac{\text{Load at 2.5mm penetration}}{1370} \times 100 = 8.96\%$

2. $\text{CBR\% at 5.0mm penetration} = \frac{\text{Load at 2.5mm penetration}}{2055} \times 100 = 8.66\%$

Dial gauge reading	Penetration depth (mm)	Proving ring reading, P	Load = P x 6.14 (kg)
50	0.5	3	18042
100	1.0	6	36.84
150	1.5	10	61.4
200	2.0	16	98.24
250	2.5	20	122.8
300	3.0	23	141.22
350	3.5	25	153.5
400	4.0	28	171.92
450	4.5	29	178.06
500	5.0	29	178.06
550	5.5	32	196.48
600	6.0	35	214.9
700	7.0	38	233.32
800	8.0	40	245.6
900	9.0	43	264.02
1000	10.0	48	294.72
1100	11.0	52	319.28
1200	12.0	54	331.56

Table 1: CBR Readings in case of rigid pavement

Hence by using the California Bearing Ratio test (CBR), the CBR value of subgrade soil (gravel) is found to be 9% for rigid pavement.

Dial gauge reading	Penetration depth (mm)	Proving ring reading, P	Load = P x 6.14 (kg)
50	0.5	2	12.28
100	1.0	8	49.12
150	1.5	12	73.68
200	2.0	18	110.52
250	2.5	22	135.08
300	3.0	24	147.36
350	3.5	25	153.50
400	4.0	27	165.78
450	4.5	28	171.92
500	5.0	29	178.06
550	5.5	33	202.62
600	6.0	37	227.18
700	7.0	40	245.60
800	8.0	43	264.02
900	9.0	44	270.16
1000	10.0	47	288.58
1100	11.0	53	325.42
1200	12.0	55	337.70

Table 2: CBR Readings for flexible pavement

Hence by using the California Bearing Ratio test (CBR), the CBR value of sub-grade soil is found to be 10%.

V. CONCLUSIONS

In case of *rigid pavement* the following conclusions were drawn:

The design and construction of Rigid Pavement have been successfully presented in this project. The pavement has been designed as per the Design Considerations and the wheel load stresses. Various tests have been conducted on the soil samples. All the respective studies and the laboratory tests are also included in this work.

In case of flexible pavement the following conclusions were drawn:

- The flexible pavements have been designed as per IRC: 37-2001 to meet the safety and serviceability requirements.
- The pavements consists of 4 layers namely sub-grade, sub-base course, base course and wearing course.
- To determine the strength of sub-grade soil, CBR tests were conducted in the laboratory. The CBR value of existing sub-grade was found to be 10%.
- Wet Mix Macadam (WMM) was laid down as a base course. It has a capacity to carry traffic more efficiently when compared with Water Bound Macadam (WBM).
- Relevant tests namely Los Angeles Abrasion test, Aggregate Impact test and Aggregate Crushing test were carried out on the aggregates that are used in WMM.
- As per design charts of IRC: 37-2001, for the obtained CBR value, the thickness of pavement was found to be 630mm.

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