Design and Construction of Rigid Pavements

B Chandra Sekhar Babu[1], N Avas[2], S Ashok Kumar[3]
[1, 2, 3] Department of Civil Engineering
[1, 2, 3] Kakinada Institute of Technology & Science, Divili

Abstract- *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.*

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.

In this work, an effort has been made in examining the different layers involved in a typical rigid 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.

I. INTRODUCTION

1.1 Introduction

General Transport or transportation is the movement of people, animals and goods from one location to another.

Transportation is a non-separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption.

Types of pavements

- Flexible pavements
- Semi-rigid pavements:

The pavement constructed using the waste materials which are more strong, the traditional aggregates may be treated as semi-rigid pavement.

- Rigid pavements

1.2 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.

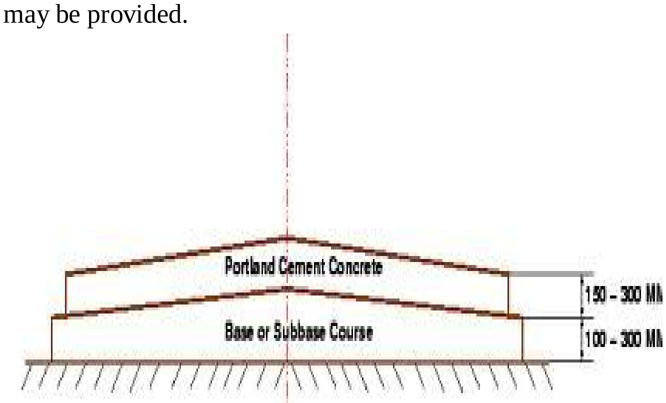


Fig. 1.1 Typical Cross-section of Rigid Pavement

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 functions of various pavement components are.

2.1. 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. 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:

i. California Bearing Ratio test
ii. California Resistance Value test
iii. Triaxial Compression test
iv. Plate Bearing test

2.2. 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.

2.3. 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:

i. Mix design of materials to be used in each pavement component layer.
ii. 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

3.1 Design wheel load

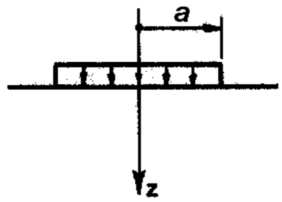
The design of pavement primarily depends on the design wheel load. While considering the design wheel load the various wheel load factors to be considered are:

i. Maximum wheel load
ii. Contact pressure
iii. Dual or multiple wheel loads and equivalent single wheel load
iv. Repetition of loads

3.1.1 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. 3.1 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

3.1.2 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.

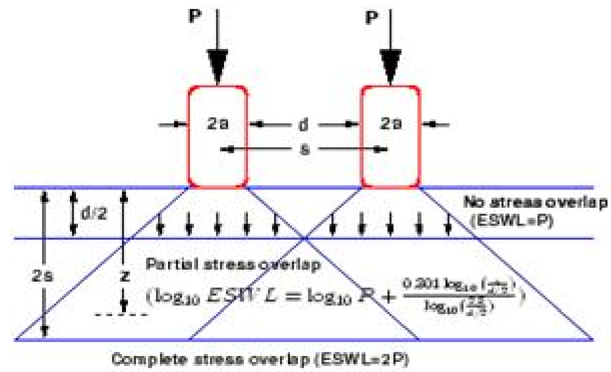
$$\text{Contact pressure} = \frac{\text{Load on wheel}}{\text{Contact area}}$$

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 7 kg/cm^2.

3.1.3 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.



3.2 Stress Overlap due to wheel loads

3.1.4 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.

3.2 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.

3.2.1 Subgrade soil strength

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

i. Soil type
ii. Moisture content
iii. Dry density
iv. Internal structure of soil
v. Type & mode of stress application

3.3 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.

3.4. Climatic factors

The climatic variations cause the following major effects.

i. Variation in moisture condition
ii. Frost action
iii. 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.

3.5. Special factors

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

i. Height of embankment and its foundation details
ii. Depth of sub surface water table
iii. 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. DESIGN OF RIGID PAVEMENTS

4.1 General Design Considerations

Cement concrete pavements represent the group of rigid pavements. Here the load carrying capacity is mainly due to the rigidity and high modulus of elasticity of the slab itself i.e., slabs action. H. M. Westergaard is considered the pioneer in providing the rational treatment to the problem of rigid pavement analysis.

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil Subgrade, which is assumed as a dense liquid. Here it is assumed that the upward reaction is proportional to the deflection, i.e., p=K , where the constant K is defined as the modulus of Subgrade reaction. The unit of K is kg/cm^2 per cm deflection i.e., kg/cm^3.

4.1.1. Westergaard's Modulus of Subgrade Reaction

The modulus of Subgrade reaction , K is proportional to the displacement. The displacement level Δ is taken as 0.125cm in calculating K. If p is the pressure sustained in kg/cm^2 by the rigid plate of diameter 75cm at a deflection Δ= 0.125cm, the modulus of subgrade reaction K is given by:

$$K = p / \Delta = p / 0.125 \text{ kg/cm}^3$$

4.1.2. Relative Stiffness of Slab to Subgrade

A certain degree of resistance to slab deflection is offered by the subgrade. This is dependent upon the stiffness or pressure-deformation properties of the subgrade material. The tendency of the slab to deflect is dependent upon its properties of flexural strength.

The resultant deflection of the slab which is also the deformation of the subgrade is a direct measure of the magnitude of the subgrade pressure.

The pressure deformation characteristic of the rigid pavements is thus a function of relative stiffness of slab to that of subgrade.

Westergaard defined this term as the *Radius of relative stiffness.*

$$L = [Eh^3 / 12K (1-\mu^2)]^{0.25}$$

Here

l = radius of relative stiffness, cm
E = modulus of elasticity of cement concrete kg/cm^2
μ = Poisson's ratio for concrete = 0.15
h = slab thickness, cm
K = subgrade modulus or modulus of subgrade reaction, kg/cm^3

4.1.3. Critical Load position

Since the pavement slab has finite length and width , either the character or intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface.

4.1.4. Equivalent Radius of Resisting Section

Considering the case of interior loading, the maximum bending moment occurs at the loaded area and acts radially in all directions. With the load concentrated on a small area of the pavement, the question arises as to what sectional area of the pavement is effective in resisting the bending moment.

4.2. Wheel Load Stresses

A.T. Goldbeck indicated that many concrete slabs failed at the corners. He derived a corner formula due to a point load at the corner of the slab. Goldbeck's formula for stress due to corner load is given by:

$S_c = 3P / h^2$

Here, S_c = Stress due to corner load, kg/cm^2

P = corner load assumed as a concentrated point load, kg

h = thickness of slab, cm

4.2.1. Westergaard's stress equation for wheel loads

The cement concrete slab is assumed to be a homogenous, thin elastic plate with subgrade being vertical and proportional to the deflection.

The commonly used equations for theoretical computation of wheel load stresses have been given by Westergaard. He considered three typical regions of the cement concrete pavement slab for the analysis of stresses, as the interior, edge and the corner regions. The critical stresses S_i, S_e and S_c at the typical locations i.e., interior, edge and corner are given in the below equations:

Interior Loading $$S_i = \frac{0.316P[4\log_{10}(l/b) + 1.069]}{h^2}$$

Edge Loading $$S_e = \frac{0.572P[4\log_{10}(l/b) + 0.359]}{h^2}$$

Corner Loading $$S_c = \frac{3P[1- (a\sqrt{2}/l)]}{h^2}$$

Here,

S_i, S_e, S_c = maximum stress at interior, edge and corner loading, respectively, kg/cm^2

h = slab thickness, cm

P = wheel load, kg

a = radius of wheel load distribution, cm

l = radius of relative stiffness, cm

b = radius of resisting section, cm

V. CONSTRUCTION OF RIGID PAVEMENT

The cement concrete pavement maintains a very high recognition due to its excellent riding surface and pleasing appearance. The cement concrete pavements are constructed with or without the sub-base course. This decision is made depending upon the soil type, design load and economic consideration. The various purposes of the sub-base course beneath the cement concrete pavements are:

i. To provide a strong supporting layer.
ii. To reduce thickness requirements of cement concrete slab and lower the cost of construction.

5.1. Specifications of Material for Cement Concrete Pavement Slabs

The materials required for plain cement concrete slabs are cement, coarse aggregates, fine aggregates and water.

5.1.1. Cement

Ordinary Portland cement is generally used. In case of urgency, rapid hardening cement may also be used to reduce time curing.

5.1.2. Coarse Aggregates

The maximum size of coarse aggregates should not exceed one fourth the slab thickness.

5.1.3. Fine Aggregate

Natural sands should be preferred as fine aggregate, though crushed stones may also be used.

5.1.4. Water

The water used for mixing the pavement materials should be clean and free from corrosive metals.

5.2. Construction Steps for cement concrete pavement slab

The following points explicate the construction procedure of a cement concrete pavement:

5.2.1. Preparation of Subgrade and Sub-base

The subgrade or sub-base for laying of the concrete slabs should comply with the following requirement:

i. That no soft spots are present in the subgrade or sub-base,
ii. That the uniformly compacted subgrade or sub-base extends atleast 30cm on either side of the width to be concreted,
iii. That the subgrade is properly drained,
iv. That he minimum modulus of the subgrade reaction obtained with a plate bearing test is 5.54kg/cm^2.

Fig. 5.1 Preparation of Subgrade Soil & Sub-base

5.2.2. Placing of Forms

The steel or wooden forms are used for this purpose.

Fig. 5.2 Placing of Forms

5.2.3. Batching of Material and Mixing

After determining the proportion of ingredients for the field mix, the fine aggregates and coarse aggregates are proportioned by weight in a weight-batching plant and placed into the hopper along with the necessary quantity of cement. Cement is measured by the bag.

Fig. 5.7 Concrete Mixer

5.2.4. Transportation and placing of concrete

The cement concrete is mixed in quantities required for immediate use and is deposited on the soil subgrade or sub-base to the required depth and width of the pavement section within the form work in continuous operation. Care is taken to see that no segregation of materials results while the concrete is being transported from the mixer to its placement. The spreading is done uniformly. A certain amount of re-distribution is done with shovels. Needle vibrator is employed in splicing of concrete.

Fig. 5.8 Spreading of Concrete & Screed

5.2.5. Compaction and Finishing

The surface of pavement is compacted either by means of a power-driven finishing machine or by a vibrating hand screed.

5.2.6. Curing of Cement Concrete

The entire pavement surface of the newly laid cement concrete is cured in accordance with the following methods:

Initial Curing: the surface of the pavement is entirely covered with burlap, cotton or jute mats. Prior or being placed, the mats are thoroughly saturated with water and are placed with wet side down to remain in intimate contact with the surface.

VI. LABORATORY TEST RESULTS

6.1 CBR Test

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

1. CBR% at 2.5mm penetration = $\frac{\text{Load at 2.5mm penetration x100}}{1370}$

= 8.96%

2. CBR% at 5.0mm penetration = $\frac{\text{Load at 2.5mm penetration x100}}{2055}$

= 8.66%

Table 4-1: CBR Readings in case of rigid pavement

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

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

6.2 Abrasion Value:

Thus, the abrasion value of aggregates was found to be 28%. As per IRC specifications, the abrasion value of aggregates to be used in Cement Concrete mix is maximum of 35% and as per ISI is a maximum of 30%. Hence the aggregates can be used in preparing the concrete mix.

6.3 Impact Value:

Thus, the impact value of aggregates was found to be 26%. As per IRC specifications, the impact value of aggregates to be used in Cement Concrete mix is maximum of 30%. Hence the aggregates can be used in preparing the concrete mix.

6.4 Crushing Value:

Thus, the impact value of aggregates was found to be 29%. As per IRC specifications, the crushing value of aggregates to be used in Cement Concrete mix is maximum of 30%. Hence the aggregates can be used in preparing the concrete mix.

VII. 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.

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