Material Planning Approach for Quality Control in Road Construction Works

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Abstract— In the present electronic age, the road development works are going at a very fast speed in developing countries. A well-developed network of roadways is vital for the economic development as well as improvement in the living standard of the people of the country. With the availability of advanced machinery, plants and equipment, the pace of construction of highways has increased manifolds. However the need of time is a comprehensive quality control system to build a durable and well functional roads in a cost effective manner at minimum possible time. We have presented here a strategic real time solutions for material testing, quality limits, selection etc., based upon the critical examination of properties and process in conformation to the specifications and quality objectives. In the existing system, the quality control tests are carried out at the three different levels; before, during and after construction. In the present paper some effective ways to ensure quality control at various stages of the construction planning of pavements are studied.

Keywords: Rigid, Flexible, Surface, Pavements, Quality Control, Base Course, Aggregates

I. Introduction

In roads generally two types of pavement are widely used namely flexible pavements and Rigid Pavement. Flexible pavement in general are the first choice because of their comparatively less capital investment and heavy machinery requirement though these pavements on the whole have low or negligible flexural strength and are rather elastic in their structural action under the loads. The flexible pavement layers transmit the vertical or compressive load to the lower layers by grain to grain transfer through the points of contact in the granular structure therefore all the layers of the pavement from surface to soil subgrade gets simultaneously undulated under impact of heavy load. The flexible pavement behaves like an elastic plate resting on a viscous medium.

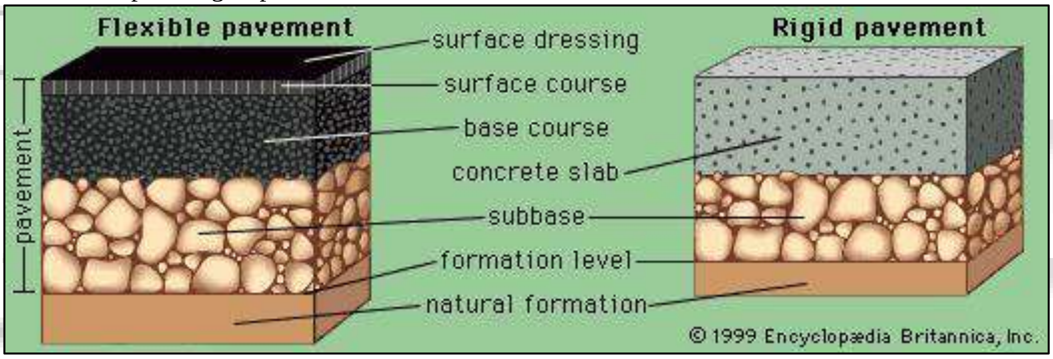

Fig. 1: General Structure of Flexible and Rigid Pavement

Whereas the rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. In rigid pavement, the load transfer is considered to follow slab action where the hard bulk of concrete acts as an elastic plate resting on viscous foundation. Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. 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 cement concrete slab, below which a granular base or sub base course may be provided. Bending of slab due to wheel load and temperature variation produces tensile and flexural stress those can be analysed by finite element analysis. A rigid pavement is considered more strong and durable than flexible pavement but requires 1.5 – 2.0 times more investment for construction. A comparison of various properties of rigid and flexible pavement is summed in the table 1:

SN	Attribute	Flexible pavement	Rigid Pavement
1	Subgrade Deformation	transferred to upper layers	not transferred to other layers
2	Design Assumption	load distributing among the component layers	Design is based on flexural strength or slab action
3	flexural strength	Low	High
4	Load transfer	by grain to grain contact	No grain to grain load transfer
5	Construction Cost	Low	High
6	Serviceable life span	Low (5-15 years)	More (20-30 Years)
7	sub base requirement	needed	Not required,
8	Thermal response	not induced as pavement contract & expand freely	more vulnerable as concrete is poor in contract and expand
9	expansion joints	not needed	needed

10	Sub grade Strength	road strength is highly dependent on the sub grade	Strength of the road is less dependent on subgrade strength
11	Surface Rolling	Needed	not needed
12	Time lag to use road	can be used after 24 hours	Min. 14 days of curing required
13	Friction resistant	is less.	Force of friction is high.
14	Damaged by Oils & Certain Chemicals	Very frequent	Less susceptible
15	Repair & Maintenance	High Cost	Low cost

Table1: Comparison of Flexible and Rigid pavement

II. FAILURES MECHANISM OF PAVEMENT

The main causes for failure in flexible pavement are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Rutting in flexible pavements is a major distress mode, relatively difficult to simulate in computational analyses. The reasons rely on the constitutive relations of the materials (nonlinear and complex) which makes it difficult to characterize under repeated and moving loads. Also, the viscoelastic and visco-plastic (strongly loading time and temperature dependent) nature of the asphalt concrete material which don't linearly function with other unbound materials base, subbase, and subgrade which are only slightly time dependent. The temperature and moisture of the materials vary with every load repetition. Yet we need to be able to predict the expected rut depth, for various materials, structures, traffic, and environmental conditions.

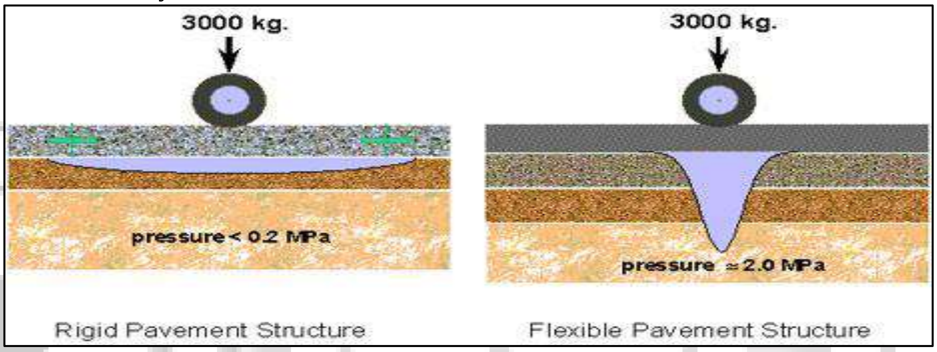

Fig. 2: Load Transfer Mechanism Responsible for Failure of Pavement

Failures of Rigid Pavement is mainly due to traditionally fatigue cracking due to repetitive loading. The allowable number of load repetitions to cause fatigue cracking depends on the stress ratio between flexural tensile stress and concrete modulus of rupture. Of late, pumping is identified as an important failure criterion which is the ejection of soil slurry through the joints and cracks of c.c. pavement, caused during the downward movement of slab under the heavy wheel loads. Other distress in rigid pavements include faulting, spalling, & deterioration.

From the study of failure mechanism it is evidence that material quality and associated workmanship skill are the main reason. Therefore, this paper describes in detail the quality control measures for the material used for both the flexible and rigid pavement. It considers:

- the design of the mix formula;
- the production of the concrete;
- the transportation and placement of the concrete;
- the quality control at the site;
- the testing in the field laboratory; and
- the significance of the test results.

Quality assurance is the planned and systematic actions necessary to provide adequate confidence that the work is satisfying all the quality requirements. Thus, the quality control system includes all those planned actions that are necessary to provide adequate confidence that the products or service will meet the requirements and is essentially a system of planning, organizing, and controlling human skills to assure quality.

III. GENERAL MEASURES AND SITE INVESTIGATION

A. *Preliminary Investigations*

Characteristics of subgrade soils and peculiar features of the site must be known to predict pavement performance. Investigations are required to determine the suitability of the subgrade soils based on soil classification, moisture-density relation, degree of compaction / expansion, characteristics strength, susceptibility to pumping, and detrimental frost action. Other factors such as groundwater, surface infiltration, soil capillarity, topography, rainfall, and drainage conditions may also be studied as they affect mainly to the subgrade in the future by increasing its moisture content and thereby reducing its strength. Past performance of existing pavements over a minimum of 5 years on similar local subgrades should be used to confirm the proposed design criteria. Soil conditions should be investigated by a combination of a general survey of subgrade conditions, preliminary subsurface investigations, and soil borings. Where material is to be borrowed from adjacent areas, subsurface explorations up to 2 to 4 feet below the anticipated depth of borrow should be carried out for above listed properties.

B. Site Preparation

The soil subgrade is a layer of natural soil prepared to receive the layers of pavement materials placed over it. The loads on the pavement are ultimately received by the soil subgrade for dispersion to the earth. It is essential that at no time the soil subgrade is overstressed. It means that the pressure transmitted on the top of the subgrade is within the allowable limit, not to cause excessive stress condition or to deform the same beyond the elastic limit. Therefore it is desirable that atleast top 50cm layer of the subgrade soil is well compacted under controlled conditions of optimum moisture conditions and maximum dry density. It is necessary to evaluate the strength properties of the soil subgrade. This helps the designer to adopt the suitable values of the strength parameter for design purposes and in case this supporting layer doesn't come up to the expectations, the same is treated or stabilized to suit the requirements. Site preparation is the first major activity in constructing pavements. This activity includes removing or stripping off the upper soil layers from the natural ground. All organic materials, topsoil, and stones greater than 3 inches in size should be removed. Removal of surface soils containing organic matter is important not only for settlement, but to care moisture-sensitive, as the soil lose significant strength when wet and get disturbed during construction. Most construction projects also require excavation of in-situ soil to reach a design elevation or grade line. The required limiting number for quality check are for (i) level tolerance - +5mm, (ii) Pavement width -6mm (iii) Position of paving edge – 10 mm.

IV. MATERIAL INVESTIGATION

It is common practice in pavement design to use locally available or other readily available materials between the subgrade and base course for economy. These layers are designated as select materials or sub bases. Those with design CBR values equal to or less than 20 are designated select materials, and those with CBR values above 20 are designated subbases. Minimum thicknesses of pavement and base have been established to eliminate the need for sub-bases with design CBR values above 50.Where the design CBR value of the subgrade without processing is in the range of 20 to 50, select materials and sub-bases may not be needed. However, the subgrade cannot be assigned design CBR values of 20 or higher unless it meets the gradation and plasticity requirements for sub-bases.

A. Source of Material

The source of all materials to be used on the project must be tested to the satisfaction of and be expressly approved by the Engineer. Any change in aggregate source for bituminous mixes, will require a new mix design, and laying trials, where the mix is based on a job mix design. Stockpiles from different sources approved or otherwise, shall be kept separate, such that there is no contamination between one material and another. Each source submitted for approval shall contain sufficient material for at least 5 days work. Aggregate is produced from materials formed by geologic processes on and within the Earth's crust. Sand and gravel created by the process of erosion may have been deposited thousands of years ago. Sand and gravel deposits are products of erosion of bedrock and the subsequent transport, abrasion, and deposition of the particles. Water and glacial ice are the principle geologic agents that affect the distribution of deposits of sand and gravel. Consequently, gravel is widely distributed and abundant near present and past rivers and streams, in alluvial basins, and in previously glaciated areas .Gravity, commonly with the aid of water, moves soil material down from the mountains or other high areas and it accumulates in stream valleys. Streams pick up the particles and in the process of transporting them, subject the particles to abrasion and rounding. Eventually, stream-transported material is deposited on floodplains. Stream deposits consisting of sand and gravel may be suitable for aggregate, but deposits of silt and clay are not suitable. Bedrock is the source material for crushed stone.

B. Select Materials

Select materials will normally be locally available coarse-grained soils (prefix G or S), although fine-grained soils in the ML and CL groups may be used in certain cases. Limerock, coral, shell, ashes, cinders, caliche, disintegrated granite, and other such materials should be considered when they are economical. A maximum aggregate size of 3 inches is suggested to aid in meeting grading requirements.

C. Sub-base Materials

Sub-base materials may consist of naturally occurring coarse-grained soils or blended and processed soils. Materials such as lime rock, coral, shell, ashes, cinders, caliche, and disintegrated granite may be used as sub-bases when they meet the requirements. The existing subgrade may meet the requirements for a sub-base course or it may be possible to treat the existing subgrade to produce a sub-base. However, admixing native or processed materials is done when the unmixed subgrade reflects the liquid limit and plasticity index as the sub-bases. Material stabilized with commercial additives may be economical as a sub-base. Portland cement, lime, flash, or bitumen and combinations thereof are commonly used.

D. Base Course Materials.

High-quality materials must be used in base courses of flexible pavements. These high-quality materials provide resistance to the high stresses that occur near the pavement surface. Guide specifications for graded crushed aggregate, limerock, and stabilized aggregate may be used without qualification for design of roads, streets, and parking areas. Guide specifications for dry- and water-bound macadam base courses may be used for design of pavements only when the cost of the dry- or water-bound macadam base does not exceed the cost of stabilized-aggregate base course, and the ability of probable bidders to construct pavements with dry- or water-bound macadam base to the required surface smoothness and grade tolerances has been proved by experience in the area.

E. Binder

The binder shall be an appropriate type of bituminous material complying with the relevant Indian Standard (IS), as defined in the appropriate clauses of the specifications. The choice of binder shall be stipulated in the contract or by the Engineer.

F. Fine Aggregates

Fine aggregates shall consist of crushed or naturally occurring material, or a combination of the two, passing 2.36 mm sieve and retained on the 75 micron sieve. They shall be clean, hard, durable, dry & free from dust / friable matter, organic or deleterious matter.

G. Coarse aggregates

The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on the 2.36mm sieve. They shall be clean, hard, durable, of cubical shape, free from dust and soft of friable matter, organic or other deleterious matter. Where crushed gravel is proposed for use as aggregate, not less than 90% by weight of the crushed material retained on the 4.75mm sieve shall have at least two fractured faces.

H. Cement Concrete Slab

It may be of reinforced steel (if heavy loading is likely) which is used for joints. A sound mass of rigid pavement requires cement concrete in which coarse aggregates should not exceed 1/4th slab thickness, gradation ranges from 50 – 4.75 or 40 – 4.75. The required parameter are limited to Aggregate Crushing / Impact / Los Angeles abrasion value: 30% Max and Soundness (for sodium sulphate) value : 12% Max. The finished concrete slab must possess a minimum modulus of rupture of 40Kg/cm^2 on field or to develop minimum compressive strength of 280 Kg/cm^2 at 28 days.

V. ASSESSMENT OF ENGINEERING PROPERTIES

Engineering properties of material placed in any layer including Subgrade to top surface, binding material and reinforcement should be checked for quality control.

A. Gradation

In coarse and fine aggregates well defined gradation is required to provide interlocking and a compact mass provided the material should be free of any deleterious mixing at source. Gradation of material at subgrade, sub base, wearing coarse and for concrete must be checked for desired specification based upon the source and workmanship requirements.

B. Strength

The subgrade must be able to support loads transmitted from the pavement structure. This load-bearing capacity is often affected by degree of compaction, moisture content, and soil type. Subgrade materials are typically characterized by their strength and stiffness. Three basic subgrade stiffness/strength characterizations commonly used are: California Bearing Ratio, modulus of subgrade reaction (k), & elastic resilience modulus.

C. California Bearing Ratio (CBR)

The CBR test is a simple strength test that compares the bearing capacity of a material with that of a high quality well-graded crushed stone (considering a CBR of 100%). The CBR is a comparative measure of the shearing resistance of soil. A subgrade having a CBR of 10 or more is considered essential to support heavy loads and resist repetitious loading without excessive deformation. The CBR value for a soil will depend upon its density, moulding, and moisture content. Relative ratings of supporting strengths as a function of CBR values are given in Table 1.

CBR	>80	50-80	30-50	20-30	10-20	5-10	<5
Material	Sub base			Subgrade			
Rating	7	6	5	4	3	2	1
7=Excellent, 1- Very Poor							

Table 1: Relative CBR values for sub-base and subgrade soils

The higher the CBR value of a particular soil, the more strength it has to support the pavement. The guiding CBR values for base material are for clays < 6, Silty and sandy soils 6 to 8, and the sands and gravels > 10. Details of strength requirement for various earthy material are given in table 2 for a quality check.

Subgrade soils for design	Unified soil classification	Load support & drainage characteristics	Mod. of Sub gradeReaction (k) psi/in	Resilient Modulus (MR),psi	CBR Range
Crushed Stone	GW,GP and GU	Excellent support and drainage characteristics with no frost potential	220 to 250	> 5700	30 to 80
Gravel	GW,GP and GU	Excellent support and drainage characteristics with slight frost potential	200 to 220	4500 to 5700	30 to 80
Silty gravel	GW-GM, GP-GM, and GM	Good support & fair drainage chara. with moderate frost potential	150 to 200	4000 to 5700	20 to 60
Sand	SW, SP, GP-GM, and GM	Good support & excellent drainage characteristics with slight frost Potential	150 to 200	4000 to 5700	10 to 40
Silty sand	SM, NP & > 35% silt	Poor support and poor drainage with very high frost potential	100 to 150	2700 to 4000	5 to 30
Silty sand	SM, PI <10, and <35 % silt	Poor support and fair to poor drainage with moderate to high frost potential	100 to 150	2700 to 4000	5 to 20
Silt	ML>50% silt LL <40, PI <10	Poor support and impervious drainage with very high frost value	50 to 100	1000 to 2700	1 to 15

Clay	CL, LL >40 & PI >10	Very poor support & impervious drainage with high frost potential	50 to 100	1000 to 2700	1 to 15

Table 2: Material Suitability in reference to Engineering Properties
Plasticity Index (PI), non-plastic (NP),
Source: Design manual of SUDAS (Statewide Urban Design and Specifications)

D. Moisture content

Moisture tends to affect a number of subgrade properties, including load-bearing capacity, shrinkage, and swelling. Moisture content can be influenced by a number of factors, such as drainage, groundwater table elevation, infiltration, or pavement porosity (which can be affected by cracks in the pavement). Generally, excessively wet subgrades will deform under load.

E. Shrinkage and/or Swelling

Some soils shrink or swell, depending upon their moisture content. Additionally, soils with excessive fines content may be susceptible to frost heave in northern climates. Shrinkage, swelling, and frost heave will tend to deform and crack any pavement type constructed over them. Pavement performance also depends on subgrade uniformity. However, a perfect subgrade is difficult to achieve due to the inherent variability of the soil and influence of water, temperature, and construction activities. Emphasis should be placed on developing a subgrade CBR of at least 10, else the sub-base material may deflect under traffic loadings similar to the subgrade. Such deflection are common in both pavements.

VI. CONCLUSIONS

1) Ensure that road interventions are carried out safely, more efficiently and to high quality standards while causing as little inconvenience as possible.
2) To avoid risk involved in a project such as completion of work on time and any inefficiency that could result in poor quality of products.
3) Contribute to an increase in product quality, improvements in workmanship and efficiency, a decrease in wastage.
4) To avoid the failures in roads such as ruttings, ditches, potholes, corrugations etc. and to prevent accidents and loss of life.

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