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Materials in Pavement Sub Base in the Highway and Its Properties

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Abstract: Material properties play avital role to determine the structural and functional performance of pavement layers during its service life. Pavement deformation or rutting is one of the key distresses that affect the pavement performance. The strength parameters of subgrade and granular layer are correlated with the permanent deformations characteristics. The individual effect in addition to combined effect of various combinations are considered to estimate rutting using multi linear regression (MLR) and artificial neural network (ANN) techniques. The data was collected in staggered position at every kilometre of a national highway stretch. The characteristic deflection, field dry density, modified liquid limit, California bearing ratio (CBR) were correlated individually with the rutting measurement and sensitivity analysis also performed. The impact of fines and dynamic behavior of soil response are considered in four possible combinations and correlated with rutting. The result shows that characteristic deflection, field dry density, modified liquid limit and modulus of elasticity of subgrade, and granular layer individually consists good relation with rutting except liquid limit. A good correlation was obtained supporting the validity of R2 values of ANN for subgrade and granular layer 0.84 and 0.86 respectively for combinations of parameters. Likewise, results of R^2 values for MLR models obtained are 0.70 and 0.79, for the given layers subsequently comparing the R^2 values of MLR and ANN it is concluded that ANN models are more efficient than MLR.

Keywords: Multi Linear Regression (MLR) and Artificial Neural Network (ANN), California Bearing Ratio (CBR).

I. INTRODUCTION

The global use of concrete is next to water in this era. As the demand for concrete as construction material increases, the demand and scarcity has been raised to a peak. There has been rapid increase in the waste materials and by products production due to exponential growth rate of population from last few decades the basic strategies to decrease solid waste disposal problems have been focused at the reduction of waste production and recovery of usable materials from the waste as raw materials as well as utilization of waste as raw materials whenever possible. The beneficial use of industrial waste or by-products in concrete has been well known for many years and significant research has been published with regard to use of materials such as coal fly ash, pulverized fuel ash, blast furnace slag and silica fume as partial replacement for Portland cement. Such materials i.e., industrial waste utilization in concrete not only enhances durability but gives good strength when compared to Portland cement. The other main advantage of using such materials is to reduce the cost of construction and environmental pollution. In present the demand and scarcity has been raised and hence according to its concern many researches are carried out for alternate material. Granulated blast furnace slag is a by-product material produced from the manufacturing of iron. It is totally inert and its physical and chemical properties are similar to natural sand. Granulated blast furnace slag is a by-product in the manufacture of pig iron. It consists of iron and slag that are obtained in same orders. The slag is a mixture of lime, silica, and alumina in same proportion. The composition of granulated blast furnace slag is determined by that of ores fining stone and impurities in the coke charged in to blast furnace. Similarly M-sand also used as fine aggregates. M-sand is processed from the crushed rock of gravel.

Advantages On Addition of Fly Ash in Concrete:

- Increased compressive strength (late)
- Increased workability
- Reduced heat of hydration (Canada found that 10 ft cubes had a temperature rise of only 35^o Celsius vs. 65^0 using Portland cement).

Scope: Fly ash is becoming a major part of the mix design for the application of concrete. The primary objective of this report is to introduce the general behavior of concrete when a percentage of cement is replaced by fly ash.

Objective: The main objective is to study the effect of utilization of GBF slag in concrete. Along with the use of fly ash. The fine aggregate is replaced by GBF slag in various levels and cement has been replaced by 25% fly ash as constant by weight. The GBF slag replacement is done in weight batching basis.

II. LITERATURE REVIEW

- KeunHyeok Yang, JinKyu Song, Jae-Sam Lee, [14] 2010 studied alkali activated mortars and concrete using light weight aggregates. Test results showed that the compressive strength of alkali activated mortar decreased linearly with the increase of replacement level of light weight fine aggregate regardless of the water Chen Meizhu, Zhou Mingkai, Wu Shaopeng, [9] 2007 worked on mortar made up of ground granulated blast furnace, gypsum, clinker and steel slag sand. The experimental results show the application of steel slag sand may reduce the dosage of cement clinker and increase the content of industrial waste product using steel slag sand.

- Isa Yuksel, Omer Ozkan, TurhanBilir, [5] 2006 experimented use of non ground granulated blast furnace slag as fine aggregate in concrete. The study concluded that the ratio of GGBs/sand is governing criteria for the effects on the strength and durability characteristics.
- Juan M. Manso, et al.,[6] 2004 carried out work in laboratory to produce concrete with good properties using oxidizing GBF slag as fine and coarse aggregate. The concrete was tested for durability characteristics like soundness, leaching test, accelerated ageing test etc. The durability of the GBF slag concrete was found to be acceptable, especially in the geographical region for which its use was proposed, where the winter temperature hardly ever falls below 32˚F (0˚C). binder ratio.
- R.C. Sharma et.al [2] discussed the classified Indian fly ash basedss on the shape of particles as one of the parameters. According to him group fly ashes contained mainly spherical particles with the size range between 2-25m. The surfaces of glassy spheres in the group are predominantly smooth without any deposit, only some adherence was observed.
- U. Dayal et al [4] have reported the specific gravity of Indian ashes to range between 1.94 and 2.34 with a mean value of 2.16 and standard deviation of 0.21. The specific gravity of flyash decreases as the partial size increase. The specific gravity increases when the fly ash particles were crushed typical value of the surface of Indian fly ashes (3267 to 6842 cm^2/g) were comparable with that of the foreign ashes (2007 to 6073 cm^2/g).
- M.J. Shannag [5] studied the behavior of high strength concrete containing natural pozzolana. He designed for very high strength concrete with a compressive strength in the range of 69-110Mpa with locally available natural pozzolana. (Volcanic tuff from Jai Rimah region of north eastern jordan). He concluded that certain natural pozzolana combination can improve the strength of mortar more than the ordinary cement concrete.
- C Freeda Christy and D Tensing[15] They have investigated about the results of the cement mortar of mix proportion 1:3 , 1:4:5 and 1:6 cement mortar in which cement is partially replaced with class-F fly ash as 0%, 10%, 20%, 25%, and 30% by weight of cement .Richer the mix , higher the compressive strength has been obtained even with partial replacement of fly ash with cement.
- Larralde proposed another model again based on the AASHO road test data relating erosion to the amounts of deformation energy imposed by the application of load; again through a pumping index parameter The deformation energy was computed using finite element modelling and the pumping index is normalized to eliminate the effect of slab length and reinforcement. The model does not consider many important factors related to erosion.
- Van Wijk included factors derived from field data to make improvements to the Larralde model by predicting the volume of eroded material as a function of the deformation energy produced by traffic. The effect of many factors on pumping such as subbase and subgrade type, drainage, load transfer, and climate conditions are considered in this model. Since this model is empirical in nature, its application is limited to the variable ranges included in the database
- The review of existing erosion test methods is summarized in. Key points such as generating erodibility index values, assessment of the strengths and weaknesses of testing approach including its relevance to field conditions are provided.

TABLE I: Summary Of Erosion Test Methods

Test Method	Features	Strengths	Weaknesses
Rotational shear device	Stabilized test samples are eroded by application of hydraulic shear stress. The critical shear stress serves as an index of erosion resistance	Easy to control shear stress	Overestimation of weight loss by coarse aggregates loss
Jetting device	Pressurized water at an angle to the upper surface of unstabilized samples generating weight loss over time	-	Shear stress is not uniform and difficult to evaluate. Overestimation of weight loss by coarse aggregates loss
Brush test device	Rotational brush abrasions generate fines. An erosion index, IE is defined as the ratio of the weight loss to that of a reference material	Easy to setup. Test method considers durability under wet and dry cycles. Relative erodibility of each material is determined using an erosion index, IE	Test times are long and weight losses are overestimated due to displacement of coarse aggregates particles
Rolling wheel erosion test device	Wheel movements occur over a friction pad placed over a sample of the subbase material induces erosion. Average erosion depth is measured after 5,000 wheel load applications	Simulation of field conditions for flexible pavement structures	Voiding of the subbase under concrete slab cannot be considered

III. PAVEMENT MATERIALS

Pavements are typically constructed in distinct layers, with each layer serving a purpose in the overall pavement structure. This section discusses these materials and their properties

A. Classification

Pavement materials are classified according to their use and type within a pavement system. Thus, one level of classification is subbase, base, and surface. This classification scheme describes the location of the materials within the pavement system. However, it also provides information about the purpose of the materials. For example, the surface layer is intended to provide a smooth, safe, and durable layer upon which vehicles can travel as well as being a major contributor to the pavement's structural capacity.

B. Aggregate Base

High-quality aggregate bases are constructed with high quality aggregates. The seven classes of aggregates used for base courses are described in Mn/DOT's Specification 3138. Classes 1 through 6 consist of 100 percent virgin aggregate materials. These materials consist of durable particles of gravel and sand, crushed quarry, or mine rock. Class 7 consists of salvaged or recycled aggregate materials that may or may not be blended with virgin aggregate.

C. Treated Base

Treated bases consist of a granular material to which a stabilizing agent has been added. The most commonly used stabilizing materials in Minnesota are asphalt cement used in permeable asphalt stabilized base and asphalt emulsion used in cold mix recycling. The information that follows is intended to serve as a general introduction to the treatment of granular materials.

Bituminous-treated Base: Aggregates may be treated with a bituminous product, resulting in a bituminous-treated base. This treatment can either be done "in-place" with existing materials or at a mix plant. The function of the bituminous treatment is to coat the granular particles with bituminous binder, enhancing the mixture strength and waterproofing characteristics.

- **Cold Mix Recycling:** This process includes the milling of the in-place pavement, the addition of asphalt emulsion, the placement of the new mixture, and a hot-mixed surface overlay. This procedure provides a sound base for a plant-mixed pavement without transporting the millings back to the plant.
- **Permeable:** As with granular bases, bituminous-treated bases may be either permeable or dense graded. When properly constructed, permeable bituminous stabilized bases have characteristics similar to permeable unstabilized bases and they are better able to withstand construction traffic. Permeabilities for drainable bituminous-treated bases are typically 0.35 cps (1,000 fpd) or more.

IV. PAVEMENT SURFACING

The pavement surface must be constructed to a higher standard than other layers in the pavement structure. It is subjected to both direct loadings from the applied traffic and greater wear from environmental factors. The surface layer is designed to provide a smooth riding surface while maintaining adequate friction. Because of its importance to the overall pavement structure, materials used in the construction of the surface are generally of higher quality. The materials most commonly used for pavement surfacing's are aggregates, asphalt mixtures, and Portland cement concrete (PCC).

A. Design Considerations For Base/Subbase

In 1940, the U.S. Army Corps of Engineers were assigned the responsibility for the design and construction of military airfields to support new heavy bomber aircraft such as the B-17 Flying Fortress. Pavement loading from these aircraft was three to five times heavier than any highway or aircraft loading designers had dealt with previously [Ahlvin 1991]. Based on a world-wide review of pavement design procedures, the Westergaard Design Method was chosen based on H.M. Westergaard's work with the Bureau of Public Roads and design method validation from the Arlington Road Tests. In the early days of rigid pavement construction, concrete slabs were placed directly on top of the subgrade without any base/subbase layers. This pivotal work on rigid pavement design by the U.S. Army Corps of Engineers led to a much better understanding of the importance of the use of bases and subbases, their uniformity, and degree of compaction. One of the key findings during the implementation of the new design procedure was the importance of bases for concrete pavements. With an increase in traffic loads, volume, and speed, pumping of the subgrade material was observed through the joints and cracks in the PCC pavement. The loss of support due to pumping resulted in an increase in other distresses such as faulting, roughness, and corner breaks. Initially, a sand filter layer was specified to mitigate pumping of subgrade materials. With continued use, it became apparent that the filter layer also acted as a "subgrade improvement" layer, contributing not only to the reduction in pumping but also to the strength of the pavement and its constructability

B. Design Of Base/Subbase For Rigid Pavements

The pavement support, consisting of base, subbase and subgrade, is typically quantified by the modulus of subgrade reaction (also known as the k-value). One of the key assumptions in the design of concrete pavements is that the deflection of the support at any point under a concrete pavement is directly proportional to the vertical stress applied at that point. Conceptually, the concrete slabs are considered to be supported on a spring-like or dense liquid foundation. The k-value is determined by means of a plate load test in accordance with AASHTO T 122 and ASTM D 1996: Nonrepetitive Static Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements. The k-value is expressed in units of pounds per square inch per inch (psi/in) and is often stated as pounds per cubic inch (pci).

Base/Subbase Material Characteristics:

- Less than 10 percent passing No. 200 sieve.
- Plasticity index of 6 or less and liquid limit of 25 or less.
- Maximum particle size not exceeding one third of layer thickness.
- Los Angeles (L.A.) abrasion resistance (AASHTO T 96) of 50 percent or less.
- Permeability of approximately 150 ft/day and not exceeding 350 ft/day.

V. COST CONSIDERATIONS

The base type should be selected while considering the purpose of the base, locally available materials, and their cost-effectiveness. Evaluating the cost-effectiveness is most appropriately carried out using life cycle cost analysis. Two of the crucial inputs needed for the analysis include the cost of materials and construction as well as the performance expected from various design features including the base types [Cole and Hall 1996]. The performance expectations should be based on an agency's past experience and data from previous projects, if available. However, the expected performance of a particular design feature, such as the base type, is often difficult to characterize, as the performance also depends on other design features [Hoerner et al. 2004, FHWA 1992, and Hall et al. 2007]. Table summarizes the cost comparisons of various base types relative to a cost of 100 assigned to a reference of dense-graded unstabilized base, which may be used as a general guide. As an alternative, considering the estimated construction cost may reveal insight into the cost-effectiveness of the various base types. The cost estimate should include all of the costs that are common to most projects as well as the additional costs and savings that may be achieved by using recycled materials and any incidental costs.

TABLE II: Relative Cost For Different Types Of Base

Base Type	Relative Cost
No base/subbase	84
Dense-graded unstabilized base	100
Open-graded unstabilized base	114
Lean concrete base	122
Open-graded asphalt-treated base	123
Open-graded cement-treated base	124
Lean concrete base	122
Dense-graded asphalt base	135

Early roads had fairly thick bases and subbases. In the early 1900s, with the use of asphalt- and cement bound surface layers, base and subbase thicknesses were decreased as shown in Fig.1.

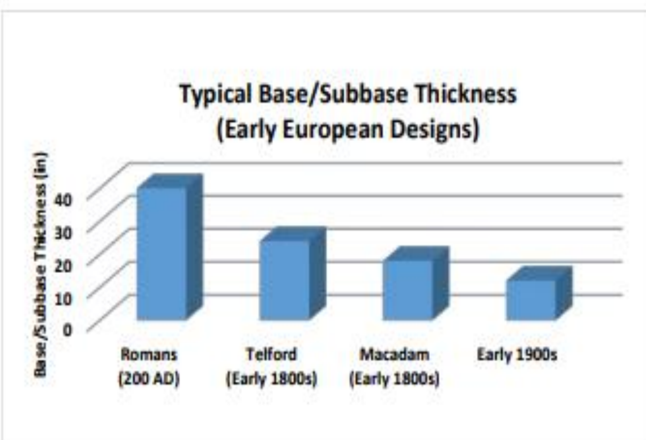

Fig.1.Base And Subbase Thickness For Early Roads.

Portland cement concrete (PCC) was originally used as a base and was surfaced with wooden blocks, bricks, and cobblestones. The primary benefit of using PCC was its ability to spread load over a larger area than granular or bituminous bound materials, thereby allowing road builders to use less aggregate material. Issues for PCC included non-uniform and low compressive strength, inadequate mixture design, mixing, consolidation and curing, and jointing issues (orientation and spacing). PCC was first used as a wearing surface in North America beginning in 1891, in Bellefontaine, OH as shown in Fig.2.

Fig.2. Early Concrete Pavement Construction In Québec.

As shown in Figure, loads applied to a PCCsurfaced rigid pavement are spread over a large area of subgrade, compared to loads applied to an asphalt concrete-surfaced flexible pavement. This permits the use of thinner bases for rigid pavements than for flexible pavements as shown in Fig.3.

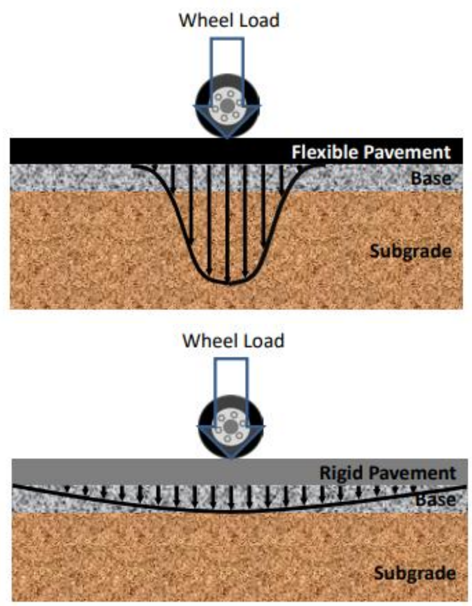

Fig.3.Illustrations. How Rigid Pavements And Flexible Pavements Transfer Applied Loads To The Layers Beneath.

A. Rigid Pavement Layer Configuration

Rigid pavements are typically constructed using a portland cement bound surface layer over one or more support layers over a prepared natural earth subgrade (Figure). The base layer is typically provided to support construction traffic and to provide uniformity of support to the PCC surface. The base layer may consist of unbound aggregate, bitumen-, or cement-bound aggregate. The bound layers may be conventional dense-graded asphalt, lean concrete, or cement-treated; or open-graded asphalt or concrete designed to promote lateral drainage within the pavement structure as shown in Fig.4. The subbase layer is typically used to protect the pavement from the effects of frost heave and/or used to improve the constructability of the pavement layers above the subbase.

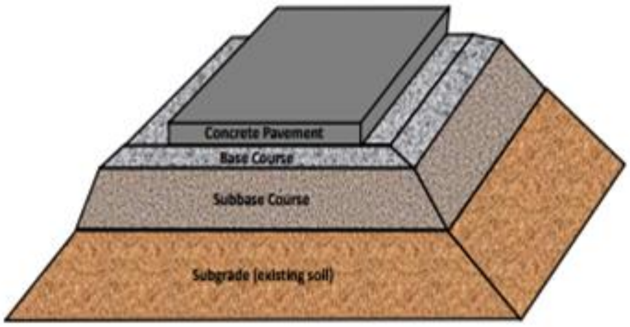

Fig.4. Illustration. Definitions of Base And Subbase Layers.

B. European Practices – A Brief Summary

This section describes some of the current European practices that are relevant to base and subbase layers in rigid pavement systems. There is not a single practice representative of all of Europe, and the relevant practices vary from one country to another. As such, the summary provided herein is only for informational purposes and is by no means a comprehensive overview of the entire European practice.

C. European Rigid Pavement Design Methodologies

European countries use various methodologies for rigid pavement design, ranging from empirical approaches (e.g., United Kingdom) to mechanistic empirical design methodologies (e.g., Netherlands and France) [FHWA 1992, Hall et al. 2007]. In addition, an empirical design method known as the "Catalogue Design" is used in countries such as Germany, Austria, and Belgium [Houben 2009, Rens 2016]. Unlike the U.S. rigid pavement design practice, in which the primary purpose of a base or a subbase layer is to prevent pumping, European designs generally emphasize the frost protection of subgrade and subsurface drainage, irrespective of the design methodology.

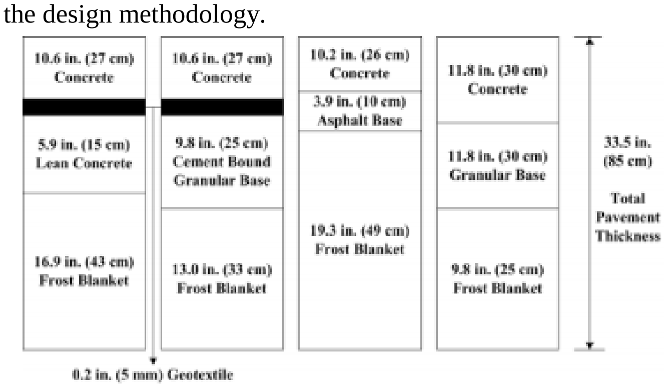

Fig.5.rigid pavement structures for motorways in german design catalogue rsto 12 [germany 2012].

As a result, the European designs typically use base and subbase layers that are substantially thicker than those in the U.S. Furthermore, some countries specify the total thickness of the pavement as the thickness of all layers that are not frost-susceptible. As an example, Figure 4.10 shows the rigid pavement structures specified in the German catalogue for Class SV motorways, which have cumulative traffic of more than 32 million equivalent single axle loads (ESALs) during their design life. The total pavement thickness required for this roadway class is 33.5 inches, regardless of the base type as shown in Fig.5. Once the type of base material is determined, the thicknesses of PCC, base, and subbase layers are read from the catalogue [Germany 2012].

D. Materials for European Base and Subbase

Similar to the materials used in the U.S., typical materials allowed for use in the design of European base include asphalt and cement-treated bases, lean concrete base, granular materials (mostly crushed stone), or a combination of these materials. The base is typically constructed on top of a thick subbase layer composed of dense graded granular materials or lime-stabilized soil. Table 3 summarizes the base/subbase types and their thicknesses frequently used in the Europe.

TABLE III: Summary Of European Base/Subbase Materials

Base (Typical Thickness)	Subbase	Country
Asphalt-treated (2.5 in. to 4.0 in.)	Granular	All
Asphalt-treated (2.0 in.) + cement-treated or lean concrete (8.0 in.)	Granular	All
Asphalt-treated (2.0 in.) + cement-treated or lean concrete (8.0 in.)	Stabilized	Several
Geotextile (0.2 in.)* + lean concrete (8.0 in.)	Granular	Germany
Unstabilized (12.0 in.)	Granular	Germany

Many European countries use treated materials such as lean concrete or cement-treated base for the base on top of an aggregate subbase. In addition, to prevent the erosion problem frequently encountered in the base, a recent trend in countries such as France, Belgium, and Netherlands is to place an asphalt interlayer, 2.0 to 3.5 inches thick, between the PCC and the base layer consisting of lean concrete base or cement-treated base [Summer 2008].

VI. CONCLUSION

Because of the high strength, stiffness, and load distribution characteristics provided by the concrete surface, rigid pavements do not necessarily require a strong foundation. It is more important that the foundation provides uniform support to the concrete slabs. Although the primary purpose of base/subbase layers in a rigid pavement system is to prevent pumping, these layers provide additional advantages, such as more uniform support to the concrete slabs compared to the subgrade, a more stable working platform for construction equipment, and improved control of soil expansion and differential frost heave. However, a rigid pavement system does not always require a base or a subbase layer; the engineer should study the available data and site conditions to decide whether a base layer is warranted. Furthermore, if a base layer is to be used, the engineer should consider the different base types while considering the available materials and their cost. Irrespective of the type of base used, the best results are obtained by:

- Selecting a base (or a combination of base and subbase) material that is not prone to pumping. • Selecting materials that will remain stable over time.
- Selecting a base type that does not exhibit excessive deflections under traffic loading.
- Treating the surface of the cementitious base to prevent bonding and reduce friction at the interface of the PCC and base.
- Specifying a gradation or other material controls that will ensure a consistent base along the length of the project.
- Specifying and constructing the base with grade controls that allow for consistent thickness and smoothness of concrete.

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