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State-of-The-Art Review on Role and Effect of Geotechnical Properties on Pavement Design

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Abstract *This paper describes different geotechnical properties of soil and its effect on pavement design. The type of rock, its mineral constituents and climatic condition of area decides the type of soil [1].Pavement design is very much dependent on the strength of the sub grade soil over which they are going to be laid. Sub grade strength is also depending on the basic properties of the soil [2]. Hence Geotechnical Properties of soil plays an important role for pavement design because it influences the stability of pavement. In this paper various geotechnical properties of soil like Specific gravity, density index, consistency limit, particle size analysis, compaction, consolidation permeability, shear strength, are been discussed.*

***Key Words*: geotechnical properties, Pavement design, Sub grade strength**

1. INTRODUCTION

A pavement section may be generally defined as the structural material placed above a sub-grade layer (Woods and Adcox, 2006). Structure of a specific pavement represents three separate layers of surface, base and sub-base whereas, the characteristics of the soil bed over which the entire pavement system rests on represents pavements geotechnical properties (Mcghee, 2010). , Information about its properties is frequently necessary for proper evaluation of the suitability of that soil as foundation and as construction materials. [3] One of the major causes of road accident is bad road which is usually caused by wrong application of constructional materials (especially laterite as base and sub-base material) by construction companies [4]. In Case of construction and maintenance of rural roads catering to low volumes of traffic, local soil is not only the cheapest but also the highly versatile road material. Information about the surface and sub-surface features is essential for the design of structures and for planning construction techniques [1] The geotechnical issues in pavement design can be organized into two categories: (1) general issues that set the entire tone for the design - e.g., new versus rehabilitation design; and (2) specific technical issues - e.g., subgrade stiffness and strength determination.[6]. The suitability of soil for a particular use should be determined based on its engineering characteristics and not on visual inspection or apparent similarity to other soils. Plasticity index and liquid limit are the important factors that help an engineer to understand the consistency or plasticity of clay. Though shearing strength constants at liquid limits but varies for plastic limits for all clays [9].The shear strength of soils is of special relevance among geotechnical soil properties because it is one of the essential parameters for analyzing and solving stability problems (calculating earth pressure, the bearing capacity of footings and foundations, slope stability or stability of embankments and earth dams)[8]. The loading capability of soil depends upon the type of soil. Generally, fine grained soils have a relative smaller capacity in bearing of load than the coarser grained soils [7]. Considering these, interactions among different geotechnical properties and their influences on have been discussed in this paper

2. GEOTECHNICAL PROPERTIES OF SOIL

2.1. Specific gravity of soil- Specific gravity is the ratio of the mass of soil solids to the mass of an equal volume of water. Based on the study, Roy and Dass [14] found that increase in specific gravity can increase the shear strength parameters (cohesion and angle of shearing resistance)It is relatively important as far as the qualitative behavior of the soil is concerned and useful in soil mineral classification, for example iron minerals have a larger value of specific gravity than silica's [11].Correlations are statistically significant at 1% level of significance indicating influence of specific gravity on CBR. It gives an idea about the suitability of the soil as a construction material; higher value of specific gravity gives more strength for roads and foundations and also observed that increase in specific gravity also increases the California bearing ratio i.e. strength of the subgrade materials used in road construction. Roy [10]

Table -1: Typical values of specific gravity (Bowles, 2012)

Sr.No	Type of soil	Specific gravity
01	Sand	2.65-2.67
02	Silty sand	2.67-2.70

03	Inorganic clay	2.70-2.80
04	Soil with mica or iron	2.75-3.00
05	Organic soil	1.00-2.60

2.2. Density Index - Density index is expressed in percent and is defined as the ratio of the difference between the void ratio of cohesion less soil in the loosest state and any given void ratio to the difference between its void ratios in the loosest and the densest states [12]. The measurement of degree of compaction of fine grained soil is in relation to maximum dry density for a certaincompactive effort, like 90% of light compaction density or proctor density. But a different sort of index is used for compaction in case of coarse grained soils, Depending upon the shape, size, and gradation of soil grains, coarse grained soils can remain in two extreme states of compaction, namely in the loosest and densest states. Any intermediate state of compaction can be compared to these two extreme states using an index called relative density or density index[1]As per Apparao and Rao [13], relative density is an arbitrary character of sandy deposit. In real sense, it expresses the ratio of actual decrease in volume of voids in a sandy soil to the maximum possible decrease in volume of voids i.e. how far the sand under investigation can capable to the further densification beyond its natural state. Its determination is helpful in compaction of coarse grained soils and in evaluating safe bearing capacity of sandy soils

Table 2. Characteristics of soils based on relative density

Relative density (%)	Soil compactness	Angle of shearing resistance (0)
0-15	Very loose	<28
15-35	Loose	28-30
35-65	Medium	30-36
65-85	Dense	36-41
85-100	Very dense	>41

2.3. Consistency limit-Water content of soil greatly influences consistency of fine-grained soil. A gradual increase in water content causes soil to pass from solid state to semi solid state, from semi solid state to plastic state and finally to liquid state. The water contents that correspond to these changes of state are called as Atterberg limits. The water content corresponding to transition from one state to next are known as liquid limit, the plastic limit and the shrinkage limit [19]. Large numbers of studies were done by the previous researchers to find out different physical and engineering behavior of different soils. Nath and Dalal (2004) has assessed physical and engineering properties of different soil and reported that due to increase of liquid limit, plasticity index of soil increases and frictional angle decreases [3]

The Liquid limit of a soil is the water content expressed as percentage of weight of oven dried soil, at the boundary between liquid and plastic states of consistency of soil [22].The soil has negligibly small shear strength. The water content having Percentage of the weight of oven dried soil, at the boundary between semi solid states and plastic states of consistency of soil is called as plastic limit. At plastic limit water content earth roads are easily useable and also excavation work can be easily carried out. When the water content is between liquid limit and plastic limit the soil is said to be in plastic range. The soil were classified by Atterberg, shows the correlation between plasticity index, soil type, degree of plasticity and degree of cohesiveness (table3)[16]

Table 3. Types of soils based on plasticity index

Plasticity Index (%)	Soil type	Degree of plasticity	Degree of cohesiveness
0	Sand	Non-plastic	Non-cohesive
< 7	Silt	Low plastic	Partly cohesive
7-17	Silt clay	Medium plastic	Cohesive
>17	Clay	High plastic	cohesive

The shrinkage limit is the maximum water content expressed as a percentage of oven-dried weight at which any further reduction in water content will not cause a decrease in volume of the soil mass, the soil mass being prepared initially from remolded soil [15].Greater amount of shrinkage is observed in finer particles of the soil. More shrinkage is observed in soil containing montmorillonite clay mineral.

Consistency is an important and is a useful measure for the processing of very fine clayey soils. Plasticity and cohesion reflect the soil consistency and workability of the soils. These properties of the soils play an essential role in many engineering projects, such as the construction of the clay core in an earth fill dam, the construction of a layer of low permeability covering a deposit of polluted material, the design of foundations, retaining walls and slab bridges, and determining the stability of the soil on a slope.

2.4. Particle size analysis-The percentage of different sizes of soil particles coarser than 75 μ is determined by sieve analysis whereas finer than 75 μ are determined by hydrometer analysis. Particle size distribution curves are plotted based on the particle size analysis. The idea regarding the gradation of the soil is obtained i.e. it is possible to identify whether a soil is well graded or poorly graded.

As per Dafalla [17], shearing strength of soil will get affected by the sand shape whether rounded, surrounded, or angular. More interlock and increased shear resistance is provided by angular grains. The gradation and size of the sand affect the shear resistance. Well-graded materials provide more grain to grain area contact than poorly graded materials. Porosity and spaces available for clay within the sand is an important while considering the mixtures of clays and sands.

Apparao and Rao [13] said that the grain size analysis is widely used in classification of soils. The grain size distribution curves data is used in the design of filters for earth dams and to determine suitability of soil for road construction, air fields. Bowles [11] determined that particle-size is one of the suitability criteria of soils for roads, airfield, levee, dam, and other embankment construction. Soil particles which are very fine are easily carried in suspension by percolating soil water, and under drainage systems are rapidly filled with sediments unless they are properly surrounded by a filter made of appropriately graded granular materials. The particle-size analysis predicts the proper gradation of this filter material. Particle-size of the filter materials must be larger than the soil being protected so that the filter pores could permit passage of water but collect the smaller soil particles from suspension.

2.5. Compaction- Soil compaction is the ground improvement techniques. In this by expending compactive energy on soil, the soil grains are more closely rearranged. Compaction triggers the shear strength of soil and reduces its compressibility and permeability [19, 21]. The densification of soil with mechanical equipment thereby rearranging the soil particles which makes them more closely packed resulting in an increase of the ratio horizontal effective size to the vertical effective stress. The degree of compaction is measured in term of its dry weight and it increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and curb undesirable settlement of structures [18]. Prakash and Jain [16], explained that compaction of soils increases the density, shear strength, bearing capacity but reduces their void ratio, porosity, permeability and settlements. The results obtained are useful in the stability of field problems like earthen dams, embankments, roads and airfields. The moisture content at which the soils are compacted in the field is controlled by the value of optimum moisture content determined by the laboratory proctor compaction test. The compaction energy applied in the field is also controlled by the maximum dry density determined in the laboratory.

2.6. Consolidation- According to Prakash and Jain [16], the main target of a consolidation test is to obtain soil data which are used in predicting the rate and amount of settlement of structure founded on clay primarily due to volume change of the clay. Following settlements may occur (i) total settlement of foundation under any given load, (ii) time required for total settlement due to primary consolidation, (iii) settlement for any given time and load, (iv) time required for any percentage of total settlement or consolidation, and (v) pressure due to which soil already has been consolidated/compressed. soil layer undergo compression when it is subjected to compressive stress due to construction activities. The rearrangement of particles, seepage of water, crushing of particles, and elastic distortions causes compression. Settlement of a structure is analyzed for three reasons: appearance of structure, utility of the structure, and damage to the structure. The aesthetic view of a structure can be damage due to the presence of cracks or tilt of the structure caused by settlement. Settlement caused to a structure can damage some of the utilities like cranes, drains, pumps, electrical lines etc. Further settlement can cause a structure to fail structurally and collapse. Settlement is the combination of time-independent (e.g. immediate compression) and time-dependent compression (called consolidation) [14]

2.7. Permeability- The engineer should know the principles of fluid flow, as groundwater conditions are frequently encountered on construction projects. Water pressure is always measured relative to atmospheric pressure, and water table is the level at which the pressure is atmospheric. Shear strength of soils also depends indirectly on its permeability, because dissipation of pore pressure is controlled by its permeability. According to U.S.Bureau of Reclamation, soils are classified as (i) Impervious (coefficient of permeability) less than 10-6 cm/sec, (ii)Semi pervious: k between 10-6 to 10-4 cm/sec (iii) Pervious: k greater than 10-4 cm/sec The amount, distribution, and movement of water in soil have an important role on the properties and behavior of soil. Soil mass is divided into two zones with respect to the water table: (i) below the water table (a saturated zone with 100% degree of saturation) and (ii) just above the water table (called the capillary zone with degree of saturation ≤ 100%) [20]. The permeability of soils has a decisive effect on the stability of foundations, seepage loss through embankments of reservoirs, drainage of subgrades, excavation of open cuts in water bearing sand, and rate of flow of water into wells [9]. Prakash and Jain [16] explained that water flowing through soil exerts considerable seepage forces, which have direct effect on the safety of hydraulic structures. The rate of settlement of compressible clay layer under load depends on its permeability

2.8. Shear Strength- The characteristic of the road or runways depends to a large extent on the strength and shear parameter of subgrade material. The evaluation of subgrade strength is an important for the road pavement during design, construction and service stages [23]. The shear strength of a soil is of prime importance for foundation design, earth and rockfill dam design, highway and airfield design, stability of slopes and cuts, and lateral earth pressure problems The shear strength of soils is of special relevance among geotechnical soil properties because it is one of the essential parameters for analyzing and solving stability problems (calculating earth pressure, the bearing capacity of footings and foundations, slope stability or stability of embankments and earth dams)[8]. Different researchers explained that the capability of a soil to support a loading from a structure, or to support its overburden, or to sustain a slope in equilibrium is governed by its shear strength Akayuli et al. [35] found that the friction angle is high for a sandy soil than its cohesion and vice versa for clayey soil.[21] For short term stability of foundations, dams and slopes, shear strength parameters for unconsolidated undrained or consolidated undrained conditions are used, while for long term stability shear parameters corresponding to consolidated drained conditions give more reliable results.

Concluding Remark- Researchers observed that all geotechnical properties of soil plays important role from civil engineering construction point of view. Roads are the important transport facility because it affects directly and tremendously to the country's economy so due importance should be given to it .About specific gravity it gives an idea about the suitability of the soil as a construction material; higher value of specific gravity gives more strength for roads and foundations. Also increase in specific gravity increases the California bearing ratio i.e. strength of the subgrade materials used in road construction as well as increase in shear strength parameters is observed. Density index determination is helpful in compaction of coarse grained soils and in evaluating safe bearing capacity, especially of sandy soils. Consistency Limit- properties of the soils play an essential role in many engineering projects such as the construction of the clay core in an earth fill dam, the construction of a layer of low permeability covering a deposit of polluted material, the design of foundations, retaining walls and slab bridges, and determining the stability of the soil on a slope. The grain size analysis is widely used in classification of soils. The grain size distribution curves data is used in the design of filters for earth dams and to determine suitability of soil for road construction, air fields. Particle-size is considered to be one of the suitability criteria of soils for roads, airfield, levee, dam, and other embankment construction. Compaction of soils increases the density, shear strength, bearing capacity but reduces their void ratio, porosity, permeability and settlements. The results obtained are useful in the stability of field problems like earthen dams, embankments, roads and airfields. The main target of a consolidation test is to obtain soil data which are used in predicting the rate and amount of settlement of structure founded on clay primarily due to volume change of the clay. In case of permeability water flowing through soil exerts considerable seepage forces, which have direct effect on the safety of structures. Hence road should have minimum permeability. The characteristic of the road or runways depends to a large extent on the strength and shear parameter of subgrade material. The evaluation of subgrade strength is an important for the road pavement during design, construction and service stages

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