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Resilient modulus of black cotton soil

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Abstract

Resilient modulus (M_R) values of pavement layers are the basic input parameters for the design of pavements with multiple layers in the current mechanistic empirical pavement design guidelines. As the laboratory determination of resilient modulus is costly, time consuming and cumbersome, several empirical models are developed for the prediction of resilient modulus for different regions of the world based on the database of resilient modulus values of local soils. For use of these relationships there is a need to verify the suitability of these models for local conditions. Expansive clay called black cotton soil (BC soil) is found in several parts of India and is characterized by low strength and high compressibility. This soil shows swell – shrink behaviour upon wetting and drying and are problematic. The BC soil shows collapse behaviour on soaking and therefore the strength of the soil needs to be improved. Additive stabilization is found to be very effective in stabilizing black cotton soils and generally lime is used to improve the strength and durability of the black cotton soil. In this paper, the results of repeated load tests on black cotton soil samples for the determination of M_R under soaked and unsoaked conditions at a relative compaction levels of 100% and 95% of both standard and modified proctor conditions are reported. The results indicate that the black cotton soil fails to meet the density requirement of the subgrade soil and shows collapse behaviour under soaked condition. To overcome this, lime is added as an additive to improve the strength of black cotton soil and repeated load tests were performed as per AASHTO T 307 - 99 for M_R determination. The results have shown that the samples are stable under modified proctor condition with M_R values ranging from 36 MPa to 388 MPa for a lime content of 2.5% and curing period ranging from 7 to 28 days. Also, it is observed that, the CBR based resilient modulus is not in agreement with the laboratory based M_R value and therefore it is necessary to use the laboratory determined M_R or M_R predicted from an appropriate prediction equation for pavement design. An attempt is also made to develop an empirical model for the prediction of M_R of lime stabilized black cotton soil. There is a good agreement between the predicted and laboratory M_R values with an error of 12%.
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Keywords: Resilient Modulus; Lime Stabilization; Strength; Prediction Model

1. Introduction

Flexible pavement design is based on dimensioning multi-layered system where layer thicknesses vary depending on the subgrade load carrying capacity. An excessive plastic and repeated elastic deformation in a pavement leads to cracking of the structure. The resilient properties of the pavement components influence the short term deformations of the pavement structure. Resilient modulus is a measure of the elastic modulus of the material at a given stress state. Therefore, resilient modulus of subgrade soil is one of the key material property that is required for the mechanistic-empirical (M-E) design/analysis of multi-layered flexible pavement system. The use of the resilient modulus for pavement design is recommended by the AASHTO [1–3] to replace bearing capacity parameters such as CBR and SSV.

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The 1993 AASHTO Guide for Design of Pavement Structures [2] describes four different approaches i.e., laboratory testing, back calculation using non-destructive testing, estimation of M_R from correlations with other properties and estimation of M_R from original design and construction data for the determination of design resilient modulus value.

The factors that influence the resilient modulus of subgrade soils include physical condition of the soil (i.e., moisture content and unit weight), stress level and soil type. Many studies have been conducted to investigate these effects on the resilient modulus. The resilient modulus of soils is not a constant stiffness property but depends on stress state, which includes the deviator and confining stress, soil type and its structure [4], soil gradation, compaction method, specimen size and testing procedure [5]. The effect of some of these factors on the resilient modulus of subgrade soils is significant. Research studies showed that the resilient modulus of subgrade soil decreases with an increase in the moisture content or the degree of saturation [6–10]. Unsaturated cohesive soils showed that the resilient modulus decreases with the increase in moisture content and pore pressure build-up [9]. The resilient modulus increases with an increase in the dry unit weight of the soil [8,11–13]. However, this effect is small compared to the effect of moisture content and stress level on resilient modulus [14]. In general, the increase in the deviator stress results in decrease of the resilient modulus of cohesive soils due to the softening effect [14]. Several models [15–32] have been proposed for the prediction of resilient modulus of soils based on soil physical characteristics and stress state. But, these models are region specific and there is need to verify these models for prediction of M_R of local soils. There are limited studies on the prediction of M_R values of stabilized soils [33,34]. These studies have reported the prediction model for resilient modulus in terms of unconfined compressive strength (q_u) [33] and back calculated falling weight Deflectometer (FWD) modulus in terms of q_u [34]. The correlation developed by Thompson [33] is recommended to determine the design resilient modulus for lime stabilized subgrade [3,35]. But, it is reported that the M_R values predicted from the correlations developed by Thompson [33] and Little et al. [34] demonstrated the lack of clear relationship between M_R and q_u [36] and these relations have a severe limitation as they do not take into account the stress state. The literature demonstrates that the clayey soils can be effectively altered with lime stabilization. Lime stabilization reduces plasticity, swell potential and improves strength and stiffness of the soil [37–45]. Cation exchange and flocculation/agglomeration reactions takes place relatively rapidly and produces quick changes in plasticity, workability and engineering properties [39]. The cementation is mostly by pozzolonic reaction and can significantly improve the long term performance of the lime stabilized soils [46,47].

Black cotton soils are formed by the weathering of Deccan lava in the major parts of India. The black cotton soils are inorganic clays characterized by high plasticity, higher fraction of fines, low strength, high compressibility and are expansive in nature. These soils show very high swell – shrink behaviour due to moisture variations which makes them unsuitable for foundations, subgrades etc. There are many failures of road bases, foundations, canal slopes founded on such expansive soils. BC soils are formed over large geographical areas and replacement of such soils locally will not be cost effective. Therefore, such soils have to be stabilized and M_R values are to be determined to develop empirical correlations for the prediction of M_R values for the pavement design.

This paper reports the results of resilient modulus of black cotton soil at relative compaction levels of 95% and 100% under both standard and modified proctor conditions. An attempt is made to explore the effectiveness of lime stabilization for improving the resilient modulus of expansive black cotton soil subgrade, verify the suitability of existing models for prediction of M_R and development of a new model for the prediction of M_R of lime stabilized BC soil.

2. Materials and methods

2.1. Materials

Black cotton soil which is widely available in several parts of Karnataka state, India is considered for the present investigation. Black cotton soil was collected from Bagalkot, Karnataka, India and tested for its engineering properties. All the tests were carried out as per relevant Indian standard guidelines and Table 1 shows the engineering properties of the selected soil.

The soil consists of 10% sand, 36% silt and 54% clay and Fig. 1 shows the grain size distribution curve. The soil is classified as A-7-C as per HRB classification system and A-7-6 AASHTO classification system [48] and highly compressible clay with the group symbol CH as per IS classification system and unified soil classification system [49]. The liquid limit and plasticity index of the soil are 71% and 48% respectively. The BC soil has a free swell of 34% and the soil is classified as low swelling clayey soil [50]. The soaked CBR is less than 2% under modified proctor conditions. The unconfined compressive strength is 89kPa under unsoaked condition and the soil showed collapse behaviour when it is subjected to soaking. As per MoRT&H [51] guidelines the soil having liquid limit greater than 71% and plasticity index greater than 45% respectively is unsuitable for subgrade. In addition, the MoRT&H [51] guidelines specifies minimum dry unit weight of 18 kN/m^3 for compacted subgrade. IRC:SP:72-2007 [52] specifies the use of unit weight corresponding to standard proctor condition for low volume roads. The selected soil fails to meet the MoRT&H criteria (i.e., liquid limit, plasticity index and unit weight requirements) to be used as subgrade for low volume roads (village roads). The selected soil shows reasonably good strength under

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