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ESTIMATION OF FIELD COMPACTION PARAMETERS

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ABSTRACT: This paper describes the current Indian and Australian practices of the estimation of field compaction parameters (maximum dry unit weight and optimum moisture content) based on the laboratory compaction tests, which do not consider large-size particles of the field soil samples. The study indicates that in the absence of realistic estimation procedure, some pavements have failed due to the excessive settlement. A detailed derivation of improved expressions for determining the field compaction parameters is presented. The improved expressions would be useful for the pavements and earthworks and for developing the standards on the compaction tests for the field applications.

INTRODUCTION

In the laboratory, the compaction test is generally performed to obtain the values of compaction test parameters, namely the optimum moisture content and the maximum dry unit weight, which are required for achieving maximum densification of the soil in field with a given compaction energy per unit volume of the soil. In most compaction test procedures, depending on the size of the compaction mould, a fraction of the soil sample having particle size larger than a specific value, say d_0, is discarded. For example, in the standard Proctor compaction test, the soil particles coarser than 19 mm are discarded before compacting soil in the standard laboratory compaction mould [1-4]. If the fraction removed is significant, the laboratory optimum moisture content and the maximum dry unit weight determined for the remaining soil are not directly comparable with the field values. This paper describes the current Indian and Australian practices of the estimation of field compaction parameters based on the laboratory compaction tests. Additionally a detailed derivation of improved expressions for determining the field compaction parameters is presented for the field applications.

CURRENT PRACTICES IN INDIA AND AUSTRALIA

The pavement subbase and base materials consist of natural sand, moorum, gravel, crushed stone, or a combination thereof depending upon the grading required as per the field requirements. Materials like crushed slag, crushed concrete, brick and kankar are also used as subbase and base materials, especially in rural roads. The Ministry of Road Transport and Highways of the Government of India recommends three gradings of subbase materials with soil particle size varying from less than 75 μm to 75 mm [5]. The compaction of subbase/base materials is recommended to be done by rollers; the rolling should be continued till the dry unit weight achieved is at least 98% of the maximum dry unit weight for the material determined as per IS2720 (Part – 8) [2]. It is important to note that IS2720 (Part – 8) [2] does not allow particles larger than 19 mm. It is stated that the removal of small amounts of particles (up to 5%) retained on the 19 mm sieve will affect the density only by amounts comparable with the experimental error involved in measuring the maximum dry unit weight. However, the exclusion of a large proportion of particles coarser than 19 mm may have a major effect on the unit weight and the optimum moisture content obtained compared with that obtainable with field soil as a whole. There is at present no generally accepted method of test calculation for dealing with this difficulty in comparing laboratory compaction test results with those obtained in field. For soils containing larger proportions of particles larger than 19 mm, but up to 37.5 mm, the use of a bigger mould (2250 ml) may avoid major errors.

According the Australian Practice [3-4], the laboratory compaction is conducted over a range of moisture content to establish the maximum mass of dry soil per unit volume achievable for a standard compactive effort (596/2703 kJ/m^3) and its corresponding moisture content. The compaction procedure is applicable to that portion of a soil that passes the 37.5 mm sieve. Soil that passes the 19 mm sieve is compacted in a 105 mm diameter compaction mould. Soil that contains more than 20% of material retained on the 19 mm sieve is compacted in a 152 mm diameter mould. Corrections for oversize material (not more than 20% of material, on a wet basis, retained on the 37.5 mm sieve) are made in accordance with AS1289.5.4.1-2007 [6]. The field maximum dry unit weight and field moisture content are calculated from the following equations [6]:

$$\frac{1}{\gamma_{dF}} = \frac{(1-p)}{\gamma_{dL}} + \frac{p}{G_c \gamma_w} \tag{1}$$

and

$$w_F = (1-p) w_L \tag{2}$$

where, γ_{dF} is the field value of maximum dry unit weight; γ_{dL} is the laboratory value of maximum dry unit weight; p is the percentage of coarser fraction (larger than d_0) discarded from the soil; G_c is the specific gravity of discarded coarser soil particles; γ_w is the unit weight of water; w_F is the field value of optimum moisture content; and w_L is the laboratory value of optimum moisture content.

Eqs. (1) and (2) were presented by Hausmann [7] assuming the coarse fraction (larger than d_0) to be dry and no change in the volume of pore air after removal of the coarse fraction. These assumptions cannot always be appropriate for the field applications of Eqs. (1) and (2). Hausmann has stated that assuming zero moisture in the coarse fraction may lead to overestimating the field dry unit weight, which may not be desirable.

The details presented here clearly show that there is currently no realistic procedure for calculating the field values of compaction test parameters, especially when the oversize materials consists of a significant part of the soil to be compacted in field. The inaccurate estimation of field compaction parameters has probably been one of the major causes of pavement settlement failures in some roads. Fig. 1 shows a typical failure of a very long section of the newly constructed bituminous pavement of the National Highway (NH) No. 2 in Varanasi during 2007 – 2008.

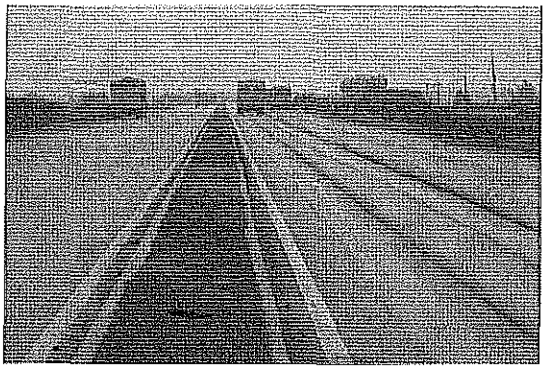

Fig. 1 A typical pavement settlement failure of the NH-2, Varanasi

PROPOSED EXPRESSIONS

Figure 2 shows the phase diagrams for the field and the laboratory compacted soil samples. In Fig. 2, in addition to the weights and volumes of the three phases, unit weights are also shown beneath the phase labels. When the coarser fraction, larger than size d_0 (e.g. 19 mm), is removed, it also takes away some water associated with its water content. In addition, there is also possibility of some change in the air void volume when the soil is compacted without this coarse fraction. All these are reflected in Fig. 2.

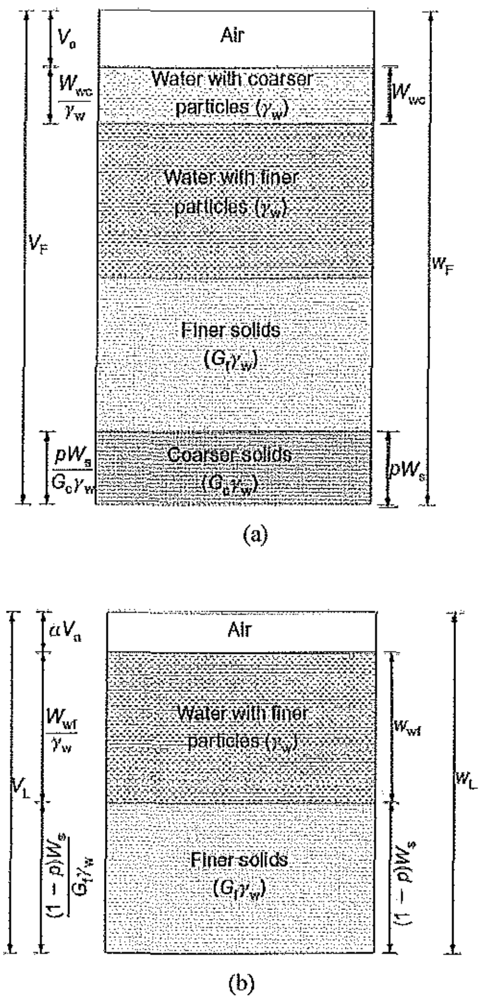

Fig. 2 Phase diagrams: (a) the field compacted sample and (b) the laboratory compacted sample [8]

In the context of Fig. 2, in addition to the notations defined in the previous section, notations are defined as follows: G_f is the specific gravity of the fine soil particles (smaller than d_0) in the field/laboratory soil sample; V_a is the volume of the air in voids of the field soil sample; V_F is the total volume of field soil sample; V_L is the total volume of the laboratory soil sample; w_c is the water content of the coarse soil particles in the field soil sample, W_s is the weight of the soil particles in the field sample; W_{wc} is the weight of the water with coarse soil particles in the field soil sample; W_{wf} is the weight of the water with fine soil particles in the field/laboratory soil sample; α is the ratio of volume of the air in voids of the laboratory sample to that in the field soil sample, $(G_c\gamma_w)$ is the unit weight of the coarser fraction of soil particles in the field soil sample; and $(G_f\gamma_w)$ is the unit weight of the finer fraction of soil particles in the field/laboratory soil sample

From Fig. 1(b), the laboratory dry unit weight and the water content can be obtained as

$$\gamma_{dL} = \frac{(1-p)W_s}{V_L} \tag{3}$$

and

$$w_L = \frac{W_{wf}}{(1-p)W_s} \tag{4}$$

The corresponding maximum field dry unit weight can be obtained as

$$\gamma_{dF} = \frac{W_s}{V_F} \tag{5}$$

where

$$V_F = V_L + (1-\alpha)V_a + \frac{W_{wc}}{\gamma_w} + \frac{pW_s}{G_c\gamma_w} \tag{6}$$

with

$$V_L = \frac{(1-p)W_s}{\gamma_{dL}} \tag{7}$$

By substituting Eq. (6) with Eq. (7) into Eq. (5), the maximum field dry unit weight is obtained as

$$\gamma_{dF} = \frac{1}{\dfrac{1-p}{\gamma_{dL}} + \dfrac{(1-\alpha)V_a}{W_s} + \dfrac{pw_c}{\gamma_w} + \dfrac{p}{G_c\gamma_w}} \tag{8}$$

where

$$w_c = \frac{W_{wc}}{pW_s} \tag{9}$$

From Fig. 1(b), we get

$$\frac{\alpha V_a}{W_s} = \frac{V_L}{W_s} - \frac{W_{wf}}{\gamma_w W_s} - \frac{1-p}{G_f\gamma_w} \tag{10}$$

Substitution of values from Eqs. (3) and (4) into Eq. (10) provides

$$\frac{V_a}{W_s} = \frac{1}{\alpha}\left[\frac{1-p}{\gamma_{dL}} - \frac{(1-p)w_L}{\gamma_w} - \frac{1-p}{G_f\gamma_w}\right] \tag{11}$$

Substitution of Eq. (11) into Eq. (8) gives

$$\frac{1}{\gamma_{dF}} = \frac{1-p}{\alpha\gamma_{dL}} + \frac{p}{G_c\gamma_w} + \frac{pw_c - \left(\frac{1-\alpha}{\alpha}\right)(1-p)w_L}{\gamma_w} - \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{1-p}{G_f\gamma_w}\right) \tag{12}$$

Assuming $\dfrac{1-\alpha}{\alpha} = \beta$, Eq. (12) can be expressed as

$$\frac{1}{\gamma_{dF}} = \frac{(1-p)(1+\beta)}{\gamma_{dL}} + \frac{p}{G_c\gamma_w} + \frac{pw_c - (1-p)\beta w_L}{\gamma_w} - \frac{(1-p)\beta}{G_f\gamma_w} \tag{13}$$

From Fig. 1(a), the field optimum moisture content, w_F, can be expressed as

$$w_F = \frac{W_{wf} + W_{wc}}{W_s} = \frac{W_{wf}}{W_s} + \frac{W_{wc}}{W_s} \tag{14}$$

Using Eq. (4) and (9), Eq. (14) can be expressed as

$$w_F = (1-p)w_L + pw_c \tag{15}$$

Eqs. (13) and (15) provide improved expressions for calculating the maximum dry unit weight and the optimum moisture content, respectively, of the field sample based on the test values obtained from the laboratory compaction test on the laboratory sample which does not contain soil particles larger than the maximum size limit of the compaction mould.

If the removal of the coarse fraction from the field sample does not alter the volume of the air present in voids of the remaining soil for the laboratory test, then $\alpha = 1$. For this case, Eq. (13) reduces to

$$\frac{1}{\gamma_{dF}} = \frac{(1-p)}{\gamma_{dL}} + \frac{p}{G_c\gamma_w} + \frac{pw_c}{\gamma_w} \tag{16}$$

and Eq (15) remains unaltered.

If the removal of the coarse fraction from the field sample does not alter the volume of the air present in voids and the removed coarse particles are dry, then $\alpha = 1$ and $w_c = 0$. For this case, Eq. (13) and (15) reduce to Eqs. (1) and (2), respectively, as presented by Hausmann (1990).

CONCLUSIONS

There is currently no realistic procedure to estimate the field compaction test parameters based on the laboratory compaction tests which have limitations of the particle size. This causes inaccurate estimation of the maximum dry unit weight and the optimum moisture content of the field soils, especially for soils used in subbase and base materials. In the authors' experience, this has probably been one of the major causes of the excessive pavement settlement failure of roads. The expressions [Eqs. (13) and (15)] proposed by Shukla et al. [8] for the field values of maximum dry unit weight and the optimum moisture content as presented here in detail are quite suitable for field applications. The proposed expressions require the values of the parameters α and w_c in addition to the laboratory values of compaction parameters (γ_{dL} and w_L) for calculating the field values of the maximum dry unit weight (γ_{dF}) and the maximum moisture content (w_F). The water content (w_c) of the coarse fraction, removed from the field soil sample for the laboratory test, can be determined in the laboratory as a routine test, but the appropriate value of α should be considered with caution.

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