Relationship Between Number of Passes of Compactor and Compaction Characteristics of Soil

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Abstract - *Compaction of soil though very common, has got limitations over actual field control. Compaction is generally monitored using end product specifications, which are governed by two factors viz. maximum dry density and optimum moisture content. But there is considerable deviation between laboratory compaction and field compaction. So replicating laboratory compaction on field is a difficult task. Hence there is a need for systematic study of relation between compaction characteristics and field compaction procedure. In this study we have made an attempt to establish relationship between compaction characteristic of smooth drum heavy roller with field dry density and moisture content of soil. A regression based equations have been developed where density of soil is shown as a function of field moisture content and number of passes of roller. These equations are developed for three different types of soil which can be further used for predicting number of passes for given optimum moisture content to achieve desired field density.*

Key Words: Compaction, Predictive equations, Number of passes

1.INTRODUCTION

Compaction is a process to increase density of soil by mechanical means, which usually involves rolling, vibrating, tamping or combination of these processes. In this process particles are rearranged by application of external force and air in the voids is expelled out. This external force is applied in the form of rolling, vibrating, tamping or combination of these processes. [5]

Factors influencing compaction

i) Compactive effort

For given type of compaction, the higher the compactive effort, the higher the maximum dry unit weight and lower the optimum moisture content

ii) Water Content

With increase in water content, compacted density increases up to a stage, beyond which compacted density decreases. The maximum density achieved is called maximum dry density (MDD) and the corresponding water content is called Optimum moisture content (OMC).

iii) Method of compaction

Density achieved on the field depends largely upon the method of compaction like kneading, rolling and impact. Rollers like sheepsfoot roller provide kneading effect whereas smooth wheel rollers provide rolling effect. Selection of method of compaction is dependent on the type of soil to be compacted.

iv) Layer thickness

Less compactive effort is required per unit volume of soil if thickness of layer is lesser. Ministry of Road Transport and Highways specify thickness of layer as 200 mm for heavy compaction equipment.

v) Number of roller passes

With every roller pass energy is imparted to the soil and it density goes on increasing. After particular number of passes there is no significant increase in density. Hence there is a need to determine these optimum number of passes.

1.1 Need for Study

Soil compaction is performed to impart the desired engineering properties to a compacted mass. It is not, in general, practical during the construction of compacted soils to directly specify these desired properties. Rather, the engineer must first specify descriptors of the compacted product, the compactive process, or both that are easy to measure and then the engineer must be able to relate these specifications to the desired properties.

Moisture content and dry density of soil are the properties whose relationships should be studied on the field under in situ conditions. But this proves to be uneconomical and time consuming. Hence these relations are established using Proctor test (Proctor 1933) in lab. Energy levels used on the field are very different than that are used in the laboratory, so there is a chance for variability in the results

The quality of compacted material is generally specified in terms of dry unit weight, which is usually expressed as a percentage of the maximum dry density achieved in a specific laboratory compaction test. Construction specifications based on this principle are known as “end-result” specifications. So procedure or algorithm to carry out that compaction is not mentioned in the specifications. In this case, contractor is free to choose any method or equipment to achieve that degree of compaction. But selection of right method and equipment and applying optimum energy to soil to achieve desired density is a major problem to be solved.

2 LITERATURE REVIEW

Kenneth D. Walsh, William N. Houston, and Sandra L Houston[10]. carried out research on field implications of current compaction specification design practices through their research it was found that although the shear strength and volume change characteristics of earth fills are critical factors in controlling performance, compaction control is generally achieved through monitoring the dry density and water content of the fill as it is placed.

In a research report on Laboratory Simulation of Field compaction characteristics [4] a study was done on influence of water content and compactive effort on compaction characteristics of soil in laboratory. Also different laboratory compaction techniques were investigated to determine the best way to replicate field compaction tests.

In a research conducted on "Estimating Optimum Water Content and Maximum Dry Unit Weight for Compacted Clays"[11] a simple empirical method was developed for estimating maximum dry unit weight γdmax and optimum water content (wopt) of clayey soils at compactive effort E using the liquid limit (LL) or the LL and a compaction curve. The method is based on the linear relationships between γdmax and the base 10 logarithm of compaction energy (log E), and the linear relationship between wopt and log E as determined in laboratory testing. Compaction curves and index properties for 22 clayey soils were analysed to develop the method. So it is observed from the research that there is need to establish correlation between compactive effort and index properties of soil.

In a research conducted on compacting characteristics of light compacting equipment [13] compaction characteristics of rammers, plate compactors, and walk behind rollers were studied. Regression equations developed in this research are useful for field dry density as a function of moisture content, number of roller passes and layer thickness.

In a study conducted on Vibratory Roller Integrated Measurement of Earthwork Compaction by Michael Mooney & Dietmar Adam (2007) it was observed that the ability to continuously monitor soil properties during earthwork compaction is a marked improvement over current spot testing techniques where less than 1% of the compacted material is assessed.

2. IRC GUIDELINES

In IRC SP: 97-2013 [6] "Guidelines on Compaction Equipment for Road Works" it is recommended that as a check or to exercise control over the process on each layer at least one measurement of density for each 1000 square meters of compacted area, for evaluating a day's work is required. The process to determine the density shall be in accordance with IS: 2720 (Part-28) [9]. Test locations shall be chosen randomly. Thereafter a mean value may be obtained from the series of observations which may be indicative of the actual result. Following recommendations have been made by IRC for the choice of rollers according to type of soil

Table -1: Recommendations for Choice of Roller

Sr.No.	Type of Soil	Choice of Roller
1	Granular	i)Static three wheeled roller (8-1 0 Tonne) ii) Vibratory Roller (8-10 Tonne) iii) Pneumatic Tyre Roller (12-15 Tonne)
2	Uniformly Graded Soil	i)Static three wheeled roller (8-10 Tonne) ii) Pneumatic Tyre Roller (12-15 Tonne) iii) Vibratory Roller (8-10 Tonne)
3	Clay and Silt Soil	Sheepsfoot Roller

3. SPECIFICATIONS OF COMPACTION

There are two general types of specifications for earthwork compaction. They are: (1) method or procedure specifications, and (2) end-product or performance specifications [10]. In addition to the compaction control portion of the specification, there is almost always an additional maximum lift thickness (compacted or loose) criterion.

Method Specifications

For a method specification, the type and weight of the compaction equipment, the number of passes, and the maximum lift thickness are specified by the design engineer. This method does not require any QA testing in the field, and therefore the engineer must be certain that the specified compaction process will be adequate to achieve proper compaction. This method requires the engineer have prior experience with the material being compacted. In the event that the engineer does not have experience with the fill material and the compaction equipment being utilized, test sections (test pad areas) must be constructed to determine the necessary number of compactor passes and adequate lift thickness. This process can be time consuming, but it saves cost of over compaction and cost of unsatisfactory compaction.

End-Product Specifications

The end-product specification is much more popular for compaction of highways, building foundations, and embankments. Most commonly, for this method, the design engineer will specify a relative compaction (RC) value that the contractor must achieve. Relative compaction is defined as the ratio between the measured field dry density and a laboratory measured maximum dry density determined using a standardized compaction test, displayed in percentage form. It is important to note that there are other measurements or criteria in addition to RC that can be used in an end-product specification; however, for earthwork compaction specifications the RC measurement is the most common at this time.

The standardized laboratory compaction tests that are most commonly used to determine the maximum dry density are the standard proctor test and the modified proctor test [8]. The resulting data from these tests allows for development of a compaction curve for the tested materials. From the compaction curve, the maximum dry density and the optimum soil moisture content can be determined. Typically, the engineer will specify that the contractor compact the soil to 90% or 95% relative compaction.

In addition to the RC criteria, the engineer will also typically specify a moisture content range which the soil must be compacted within, and a maximum lift thickness. In the case of end-product specifications, the contractor is free to use the compaction equipment of his or her choice, as long as the specified end-product criteria are achieved. For this method, it is imperative that in situ QA compaction verification tests be performed to ensure that the contractor has achieved the desired end-product criteria.

3. MATERIAL AND EQUIPMENT

Material

Soil responds differently to different compactive effort. Selection of type of equipment depends mainly on material to be compacted. In the experimentation program carried out, locally available granular soil was selected. Samples of soils were collected from source of extraction. Approximate 50 kg of sample was taken for carrying out laboratory investigations. Following Table 2 shows results of grain size distribution of soil.

Table -2: Grain Size Analysis of Soil

% Coarse Gravel (80-20mm)	43.70
% Coarse Gravel (20-4.75mm)	46.50
% Fine Gravel (20-4.75mm)	2.90
% Coarse Sand (4.75- 2mm)	4.80
% Medium Sand (2.0-425μ)	1.10
% Fine Sand (425 μ- 75 μ)	1.00

Same sample of soil was tested for obtaining maximum dry density and optimum moisture content. As per initial observations soil seem to be hard soil, hence experts on field suggested to go for the modified proctor test to determine MDD and OMC. Table 3 shows observations recorded during modified proctor test. And Chart 1 shows moisture density relationships of laboratory compaction.

Table -3: Modified Proctor Test

Determination NO	I	II	III
Mass of Mould	5806	5806	5806
Mass of mould + Compacted soil (gm)	11002	11256	11184
Weight of Container	28.32	34.25	29.85
Weight of Container + Wet Soil	110.75	117.64	101.32
Mass of Container + Dry soil	104.36	109.65	93.24
Wet Density (g/cc)	2.31	2.42	2.39
Moisture Content	8.41	10.60	12.75
Dry Density (g/cc)	2.13	2.19	2.12
Optimum Moisture Content (%)	10.60		
Maximum Dry Density (g/cc)	2.19		

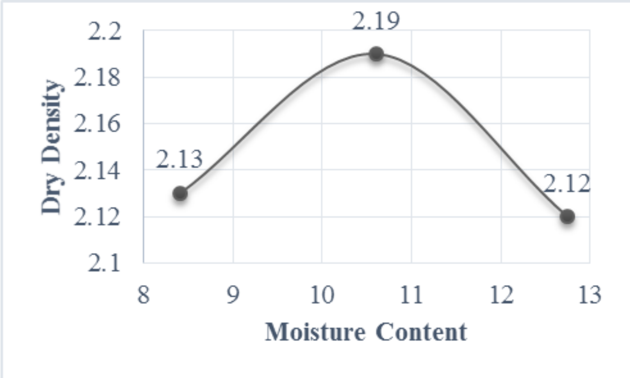

Chart -1: Moisture Density relationship for given soil sample

Equipment

As the site selected for experimentation program was a small scale road construction site advanced soil compactors were not available on site. Also due to constrained area and turning problems it was not feasible to use large compactors. Hence traditional 10 T three wheeled roller was used for testing.

4. FIELD EXPERIMENTATION PROGRAM

Objective of field experimentation program was to develop relation between field dry density, moisture content and number of roller passes at particular thickness of soil layer. For this a stretch of road subgrade 30m long and 4.5m wide was selected. Same dimensions were ideally used by previous researchers [2].

4.2 Construction of Test Stretch

Spreading of Soil

Before dumping soil on the ground existing surface was cleaned, leveled, watered and compacted. Then the soil to be laid was dumped in three heaps at three different locations. Oversized particles were removed manually. Dumped soil was spread in loose thickness of 200 mm approx. Showel of excavator was used for this purpose.

Water Application

As soil was brought from open land subjected to direct sunlight natural moisture content of soil was nil. Hence considerable quantity of water need to be added to achieve desired placement water content which will ensure smooth compaction. Water was sprinkled using flexible hose pipe connected to water tanker. Moisture content was determined using rapid moisture meter. Placement moisture content was found to be 11%.

4.3 Compaction of Layers

Compaction was then carried out using static three wheeled roller. The field densities were measured by sand cone method as per IS 2720 (Part XXVIII). Two tests were conducted at center of rolling path. Locations of testing pit were adjusted slightly to avoid testing at same locations. Following Fig 1 shows test stretch with locations of testing.

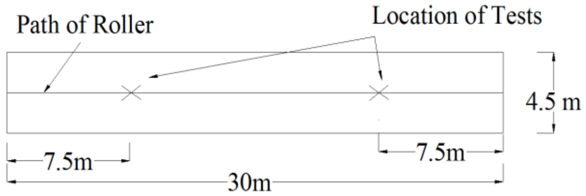

Fig -1: Test Stretch and Location of Field Tests

5. FIELD EXPERIMENTATION PROGRAM

Field dry density was calculated after every number of pass till 95% of the maximum dry density is achieved. Table 4 shows sample observations for pass no 7

TABLE- 4 : Observation Table for Sand Cone Method

	Pass 7	
Description	T1	T2
Weight of Mix in pit (W) gm	2020	2200
Weight of Sand Before Pouring (W1) gm	6800	6800
Weight of sand after pouring (W2) gm	4883	4747
Weight of Sand in Cone (W3) gm	377	377
Weight of Sand in pit (W4)= W1-W2-W3 gm	1540	1676
Bulk density of Standard sand gm/cum (Yb)	1.44	1.44
Volume of Pit V= W4 / Yb	1069.44	1163.89
Wet Density of Soil = (W/V) gm/cum	1.89	1.89
% Moisture	9.5	9
Dry density of soil	1.72	1.73
% of MDD	78.8	79.23

Moisture content was simultaneously recorded using rapid moisture meter. Table V shows summary of test results. Total 12 number of passes were required to achieve 95 % of MDD required.

6. Data Analysis

Influence of number of passes on field dry density can be calculated for every number of pass is as shown in Chart 2

Development of predictive equations

The predictive equation for field dry density as a function of moisture content and number of roller passes for a particular lift thickness were developed. Multiple regression analysis was used to develop this equation. Data mentioned in the Table V was used for Equation (1)

TABLE- 5 : Summary of Test Results

Pass No	Moisture Content	FDD (g/cc)	Pass No	Moisture Content	FDD (g/cc)
1	10.5	1.17	7	9.5	1.72
1	11	1.20	7	9	1.73
2	11	1.21	8	8	1.83
2	12.5	1.28	8	9	1.79
3	12	1.21	9	8	1.84
3	11.5	1.28	9	8	1.87
4	10	1.44	10	8	1.92
4	10	1.47	10	7.5	1.90
5	10	1.59	11	8.5	1.96
5	10.5	1.65	11	7	2.04
6	10	1.59	12	8.5	2.07
6	10.5	1.65	12	7	2.09

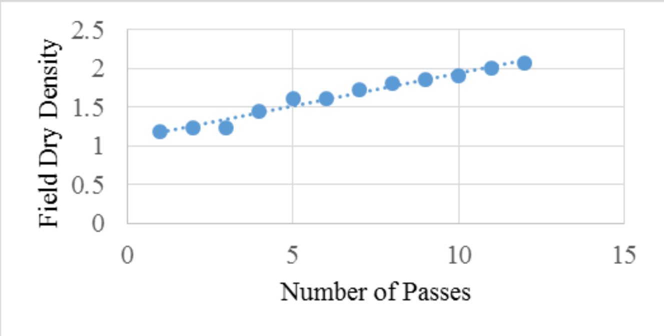

Chart -2: Influence of number of passes on Field dry density

$$FDD= 1.065 + 0.033\ (M/C) + 0.084\ (N) \quad (1)$$

Where

FDD= Field Dry Density (g/cc)

M/C= Moisture Content (%)

N= No of passes of roller.

These equation can be used to predict number of passes required to achieve required field dry density for particular compactive effort.

7. Discussions and Conclusions

Compaction of soil is most commonly used method of soil stabilization. Hence quality control and quality assurance of this process is an important area of research. While specifying criterion for compaction, end product specifications are generally used which neglects method of compaction to be used. This leads to use of uneconomical process of compaction.

Laboratory tests use impact compaction to determine maximum dry density that can be achieved for given type of soil at particular moisture content. However static compaction is used on field, hence to evaluate maximum achievable field dry density at particular moisture content field compaction trials should be carried out.

Field compaction trials are very useful for large scaled projects where compaction of soil is a major item of construction. These trials can be carried out as specified in the experimentation program above with different moisture content and different rollers. The appropriate type of roller for particular type of soil, optimum depth of layer to be compacted, placement water content can be determined using these compaction trials. Cost of compaction trials can be justified by savings in cost of over compaction and non-uniform compaction.

Roller optimum moisture content varies with type of soil and type of compacting equipment. Moisture content at which 95% of maximum dry density is achieved is lower than that of laboratory OMC.

Predictive equations used in the research can be used to predict number of passes required to achieve desired dry density when similar type of soil is used for the construction. For large scale projects it is important to develop similar kind of equations to achieve effective quality control and to optimize the process of compaction.

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