EVALUATION OF LABORATORY AND FIELD COMPACTION OF DENSE GRADED AGGREGATE BASE

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(138303 A)

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ABSTRACT

The optimum compaction is required to provide an effective path to enter energy into unbound material under its Optimum Moisture Content (OMC). To achieve the optimum energy level, the relationship between OMC, Maximum Dry Density (MDD) and Compaction Effort need to be identified at field conditions. But it is difficult to conduct in field scenario and therefore those condition are simulated at laboratory condition to find above parameters. However understanding of the importance of this relationship is a question in local context.

The information of current compaction practices were gathered by conducting questionnaire survey, while laboratory and field studies were carried out to compare compaction behavior of Dense Graded Aggregate Base (DGAB) at different Moisture Contents (MC) and energy levels. Few number of impact compaction tests and vibratory hammer compaction test were conducted to compare with the field trial test results.

The results of field trial study revealed that the higher compaction effort is needed, when compacting at moisture levels which is deviated from OMC. In addition to that Dry Density (DD) is rapidly increased when lesser number of roller passes are applied at MC which is closed OMC. The comparison of field and laboratory test results shows that the vibratory hammer test is suitable to obtain OMC and MDD for field compaction.

Although compaction effort can be minimized when it compacts at MC close its OMC, common practice is achieving the required density at higher MC by applying an ineffective compaction effort while leading to segregate the DGAB layer. Therefore appropriate compaction effort should be identified prior to compaction for relevant MC in order to achieve an effective compaction.

Key words: Compaction, Energy Optimization, Moisture Content, Dry Density

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LIST OF ABBREVIATIONS

ABC	Aggregate Base Course
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
DGAB	Dense Graded Aggregate Base
DD	Dry Density
DOC	Degree of compaction
ICTAD	Institute for Construction Training and Development
LHS	Left Hand Side
MDD	Maximum Dry Density
MC	Moisture Contents
OMC	Optimum Moisture Content
RDA	Road Development Authority
SSCM	Standard Specification for Construction and Maintenance of Road & Bridges

1 INTRODUCTION

Dense Graded Aggregate Base (DGAB) construction is a most important part of present road construction process. It contributes considerable amount of cost component in road construction projects in terms of financially. Therefore, it has a considerable impacts on the national economy since, it directly influence the quality of road and the design life of the road. DGAB production process effects to the natural environmental in several ways. As a result of that, DGAB production should be minimized. In order to overcome above issues, effectively usage of DGAB is important.

1.1 Back Ground

DGAB compaction process is controlled by three major governing factors; those are moisture content (MC), compaction effort and layer thickness. The relationship between maximum dry density (MDD), optimum moisture content (OMC) and compaction effort should be well stablished for a given layer thickness, prior to commence the field operation. This lead to an effective compaction process by saving the energy, cost as well as the environment

Standard Specification for Construction and Maintenance of Road & Bridges (SSCM) published by the Institute for Construction Training and Development (ICTAD) under the authority of General Manager, Road Development Authority (RDA) of Sri Lanka, is the main guideline for aggregate base course (ABC) compaction in local context. Clause 405.3(b) of SSCM clearly state that "The required amount of water and MC shall be determined by carrying out field trails, but shall normally be within 2% of the predetermined OMC at the time of compaction" (ICTAD, 2009). However, practicing of this norm is a question when examine the ABC construction process at present. The compaction of DGAB is done under higher moisture content than stipulated in SSCM. As a result of that segregation is taken place and fine particles migrate to top surface of the layer. Final outcome of DGAB layer is not functioned due to that improper compaction pattern. As a result of this construction process, DGAB layer does not provide the maximum bearing capacity (Structural layer coefficient) to the pavement.

According to the guideline given by SSCM, maximum dry density and optimum moisture content are determined by Modified Procter Compaction Test (AASHTO T180). However the use of much heavier vibrating rollers in compaction field, densities are reaching to level higher than that of laboratory density (Ping, Guiyan, Micheal , & Zenghai, 2003). Laboratory compaction test methods such as Vibratory Compaction Test and Gyratory Compaction Test have been engaged to overcome this problem in global context. However it is not yet applied to the local construction industries.

1.2 Objective

The objectives of this study are to;

- Identification of laboratory compaction test method to simulate the field condition more appropriately.
- Verification of relationship between MC& Dry Density (DD) at different energy level.
- Evaluate the current practices which are applied in DGAB compaction in Sri Lankan context.
- Evaluation of extent of segregation of DGAB due to the presence of higher MC at compaction.

2 LITERATURE SURVEY

Several studies have been conducted to evaluate the laboratory compaction method for simulating the field compaction. However, most of them have been developed for soil compaction.

The study conducted by Ping, Guiyan, Micheal , & Zenghai (2003) ,Department of Civil & Environmental Engineering of Florida A&M University-Florida State University have revealed that the impact compaction method was not an adequate laboratory procedure to specify the MDD & OMC for the field compaction of crush soil. Further, they showed high field compaction effort leads to increase MDD and decrease the OMC than the modified proctor compaction test. Based on their results they recommend that Gyrator compaction method is more reliable than impact compaction methods, for fine sand compaction. Their findings are illustrated in Fig 2.1. As shown on that, the modified compaction curve does not simulate the field well due to the too much difference between them. The laboratory OMC is much higher than the field OMC and dry unit weight is much lower than the field test.

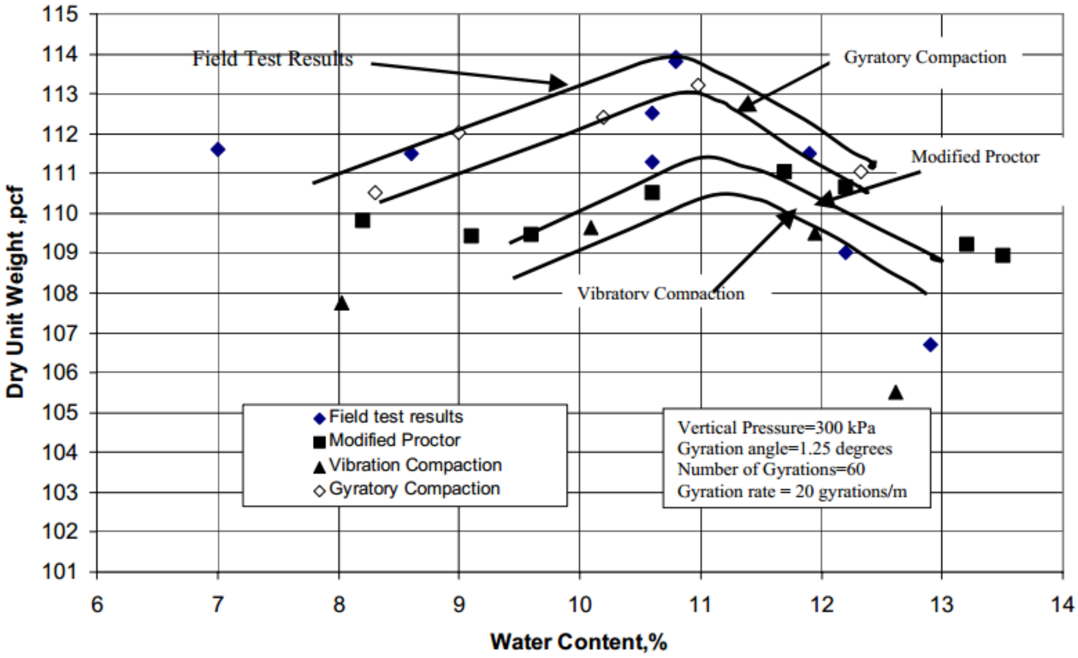


Figure 2-1 Field and Lab compaction curve (Ping, Guiyan, Micheal , & Zenghai, 2003)

According to the NCHRP Synthesis 445, Practices for Unbound Aggregate Pavement Layers published by Transport Research Board, they have revealed that the applicability of the relative compaction values thus determined is dependent on the validity of the following two assumptions: (1) the material tested in the laboratory is identical to the field material in gradation and specific gravity, and (2) similar compactive energies are imparted to the material in the field, as well as in the laboratory. Upon the violation of one or both of these assumptions, the calculated "percent compaction" becomes meaningless. Fig 2.2 shows the compaction curves for Standard Compaction Test and Modified Compaction Test. As shown in the figure, a higher compactive energy leads to an increase in the MDD and decrease in the OMC.

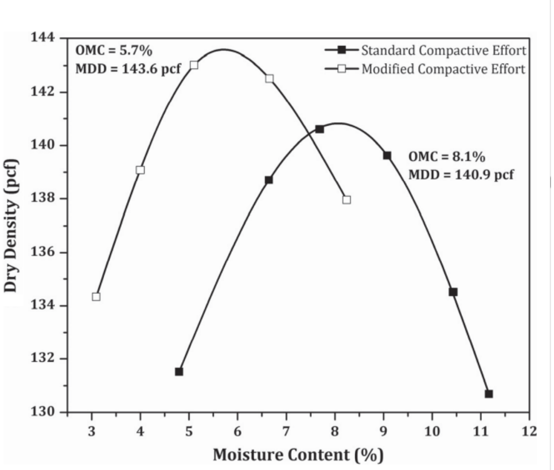


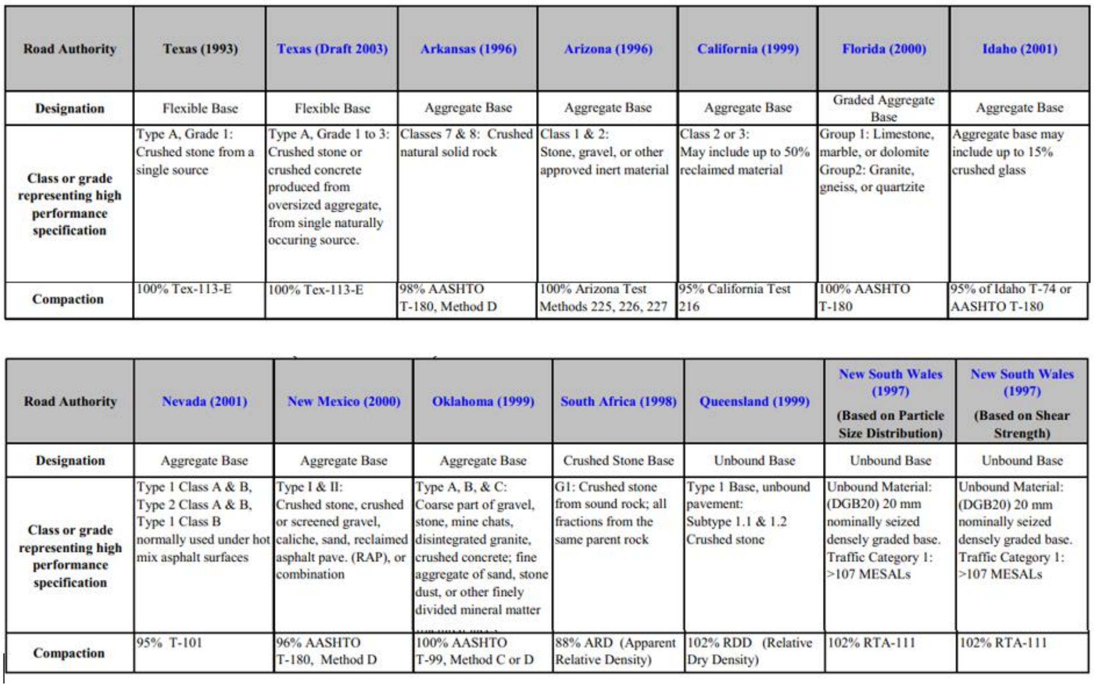
Figure 2-2 Typical compaction curves for a dense-graded crushed limestone material

Further they have found that;

- Compaction characteristics of aggregates established in the laboratory are strongly governed by compaction methods. For example, the maximum dry density values established using AASHTO T 99 are consistently lower than those established using AASHTO T 180 because of the lower compaction energy imparted to the aggregate specimen in the former.
- Drop-hammer–based compaction methods (e.g.,AASHTO T 99 and T 180) may not be adequate for coarse-grained aggregates, particularly with low fines (P200) contents.

- Test procedures similar to ASTM D 7382 that establish the moisture-density curves for unbound aggregates using a vibratory (or a gyratory) compactor may lead to better representation of field conditions in the laboratory.

Based on the research carried out by Arno Hefer and Tom Scullion (2005), Specifications used by the different road agencies have been compared by Fig 2.3



Road Authority	Texas (1993)	Texas (Draft 2003)	Arkansas (1996)	Arizona (1996)	California (1999)	Florida (2000)	Idaho (2001)
Designation	Flexible Base	Flexible Base	Aggregate Base	Aggregate Base	Aggregate Base	Graded Aggregate Base	Aggregate Base
Class or grade representing high performance specification	Type A, Grade 1: Crushed stone from a single source	Type A, Grade 1 to 3: Crushed stone or crushed concrete produced from oversized aggregate, from single naturally occuring source.	Classes 7 & 8: Crushed natural solid rock	Class 1 & 2: Stone, gravel, or other approved inert material	Class 2 or 3: May include up to 50% reclaimed material	Group 1: Limestone, marble, or dolomite Group2: Granite, gneiss, or quartzite	Aggregate base may include up to 15% crushed glass
Compaction	100% Tex-113-E	100% Tex-113-E	98% AASHTO T-180, Method D	100% Arizona Test Methods 225, 226, 227	95% California Test 216	100% AASHTO T-180	95% of Idaho T-74 or AASHTO T-180

Road Authority	Nevada (2001)	New Mexico (2000)	Oklahoma (1999)	South Africa (1998)	Queensland (1999)	New South Wales (1997) (Based on Particle Size Distribution)	New South Wales (1997) (Based on Shear Strength)
Designation	Aggregate Base	Aggregate Base	Aggregate Base	Crushed Stone Base	Unbound Base	Unbound Base	Unbound Base
Class or grade representing high performance specification	Type 1 Class A & B, Type 2 Class A & B, Type 1 Class B normally used under hot mix asphalt surfaces	Type I & II: Crushed stone, crushed or screened gravel, caliche, sand, reclaimed asphalt pave. (RAP), or combination	Type A, B, & C: Coarse part of gravel, stone, mine chats, disintegrated granite, crushed concrete; fine aggregate of sand, stone dust, or other finely divided mineral matter	G1: Crushed stone from sound rock; all fractions from the same parent rock	Type 1 Base, unbound pavement: Subtype 1.1 & 1.2 Crushed stone	Unbound Material: (DGB20) 20 mm nominally seized densely graded base. Traffic Category 1: >107 MESALs	Unbound Material: (DGB20) 20 mm nominally seized densely graded base. Traffic Category 1: >107 MESALs
Compaction	95% T-101	96% AASHTO T-180, Method D	100% AASHTO T-99, Method C or D	88% ARD (Apparent Relative Density)	102% RDD (Relative Dry Density)	102% RTA-111	102% RTA-111

Figure 2-3 Comparison of Specifications for High-Performance Granular Base Courses

The comparisons given by Fig 2.3, further can be scrutinized as follows;

- Maximum dry density (MDD) is used worldwide as reference density.
- Most states in USA use the modified Proctor density (AASHTO T-180; ASTM D 1557-70), or equivalent methods such as Tex-113-E, for establishing a reference density for compaction control.
- Compaction of 95 percent AASHTO T-180 is commonly specified. A limited number of states still use the standard Proctor density (AASHTO T-99; ASTM D 698-70).
- The compactive effort for the T-180 methods includes a 10 lb (4.54 kg) rammer and an 18 in. (457 mm) drop, while the T-99 method includes a 5.5 lb (2.5 kg) rammer and a 12 in. (305 mm) drop.

- The degree of compaction achieved at 100 percent of the density established using the AASHTO T-99 method is therefore substantially less than that achieved using the AASHTO T-180 method.
- New South Wales, Australia, specifies a slightly higher relative compaction of 102 percent RTA111, which is essentially the same as the standard Proctor density.

According the study carried out by Prochska, Drnevich, Kim, & Sommer, (2005) has found that many granular soils do not exhibit compaction that would be conductive to impact compaction tests. Further they disclosed that one point vibration hammer compaction test is not applicable for dense graded aggregates composed of crushed stone or gravel. Moreover they have compared the density against the water content that specimen was prepared and water content that was obtained from the compacted specimen as illustrated by Fig;2:4 . As shown on that compaction curve of standard proctor and vibration hammer shows different pattern to each other.

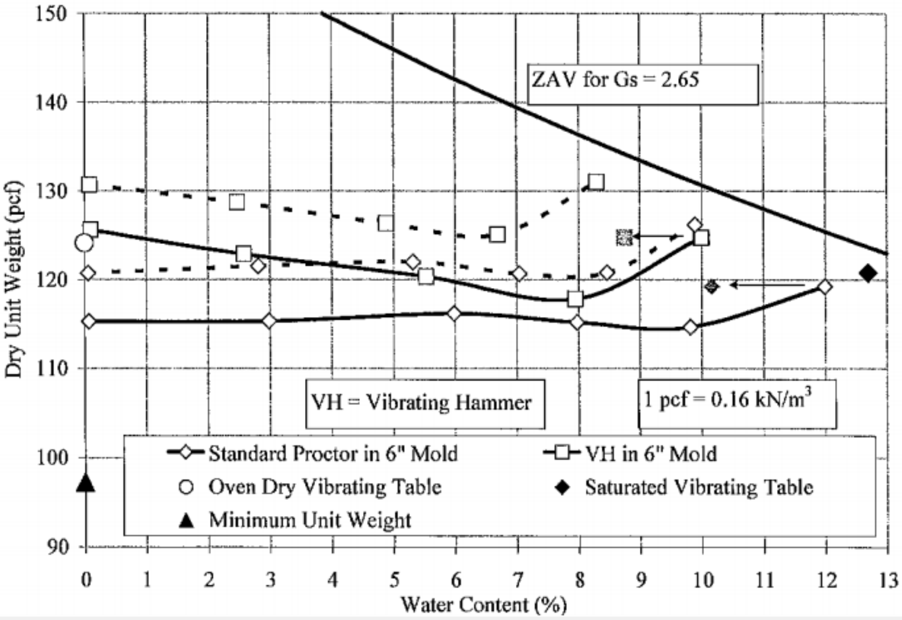


Figure 2-4 Compaction results for Gravel Dense Graded Aggregates (Prochska, Drnevich, Kim, & Sommer, 2005)

According to the research carried by Vincent, Aaron, & Adam (2007), they showed that “Vibratory hammer appears to be a better alternative than the proctor and vibratory table tests for granular soils”

Based on the results of investigation on by Jesmani, Manesh, & Hoseini (2008), they have shown that there is linear relationship between maximum dry unit weight and optimal water content with log (Energy).

Horpibulsuk, Sudeepng, Chamket, & Chinkulkijniwat (2012) conducted a research to evaluate the compaction behavior of fine grained soils, lateritic soils and crushed rocks. They have found that “the field compaction results at the OMC, shows that initially the dry unit weight increase rapidly with number of roller passes and relationship between dry unit weight and number of roller passes is represented by the logarithm function.

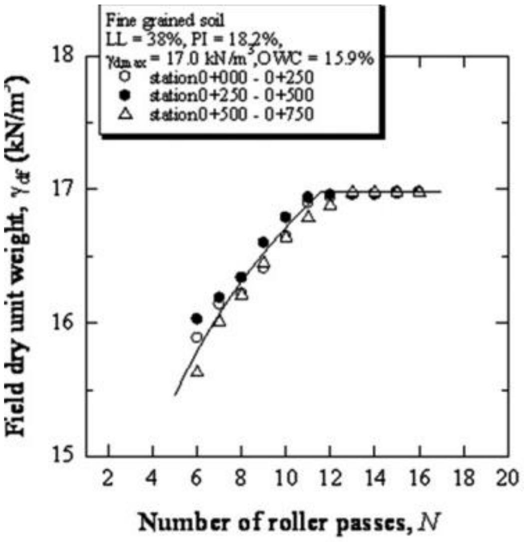


Figure 2-5Feild Compaction Test Results of Fined grained Soils (Horpibulsuk, Sudeepng, Chamket, & Chinkulkijniwat, 2012)

The study on “Segregation Effort of aggregate Base Course during Compaction Process” by Ariyarathne (2015), has reviled that working high moisture content used in the field compaction shows a significant relationship with gradation changing during compaction process.

3 EVALUATION OF DENSE GRADED AGGREGATE BASE COMPACTION METHODS USED IN SRI LANKA

A general guide line for spreading and rolling are given in SSCM. But it can be observed that, this procedure varies from organization to organization, site to site and person to person due to divergence on their experience, knowledge and availability of resources. When compaction methodology is observed, it can be noticed that the required DGAB compaction is achieved under very high MC in most cases. The reason behind this kind of procedure may be the adopting same practice of macadam base construction to DGAB. As the macadam material is open graded "the compaction should be continued until all the voids completely filled and wave of grout flushes in front the roller" (ICTAD, 2009).

Figure 3-1 Compaction of DGAB under high Moisture Condition

3.1 Questionnaire Survey

A questionnaire survey was conducted to gather the information on current practice of DGAB compaction. The questionnaire form is shown in Appendix A-1. This was mainly focused on;

- How to control the MC during compaction process
- What are the methods used for compaction
- How to assure the required compaction level is achieved
- How to assess the required compaction level is achieved

The sample size of the questionnaire was 30 numbers and it was distributed among site supervisors, foreman, technical officers, engineering assistants and civil engineers from various organizations. Figure 3.2 shows the distribution of sample.

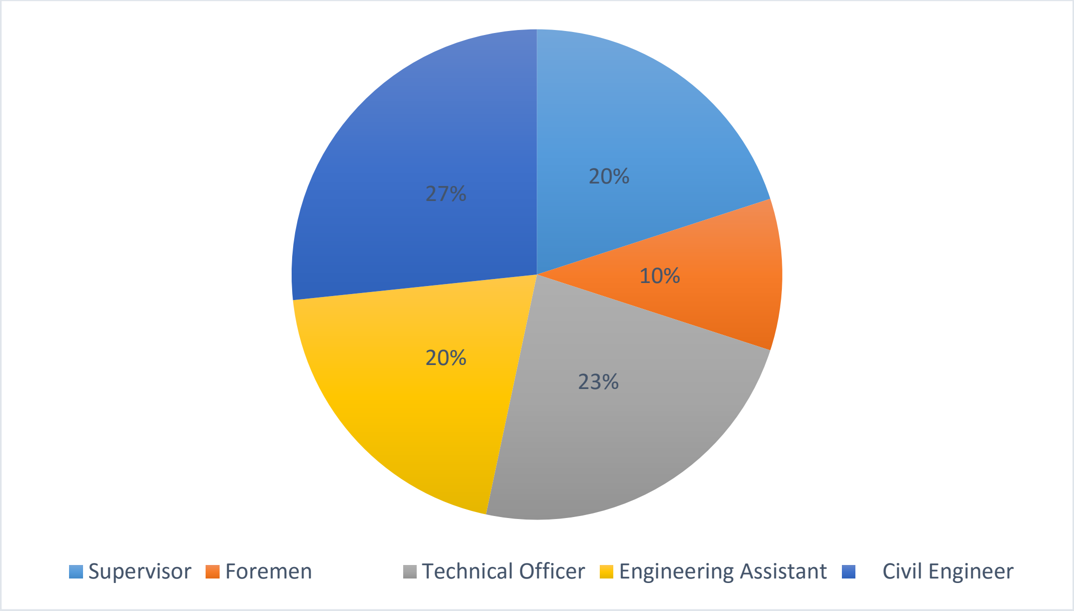


Figure 3-2 Constitution of Questionnaire Survey

It was find that moisture level is mainly controlled at four occasions. Those are;

i. At the stock piles

DGAB is wet at stock pile and thoroughly mixed by means of excavator of any other available machines. Then it is transported to the site. Normally uniform MC can be kept though out the sample. Figure 3.4 shows the mixing of Base material with water in a site.

Figure 3-3 Control the MC of DGAB at stock pile

ii. At the site while spreading

Water is added to laid sample on site and thoroughly mixed by means of mortar grader before compaction is commenced. Uniform MC can be retained throughout the layer in this process. Figure 3.4 shows the laying of DGAB

Figure 3-4 Control the MC of DGAB at Site by Mixing

iii. At the site immediate before compaction

In this occasion watering is done on laid DGAB surface but mixing is not taken place. Therefore only top part of layer is moistured and uniform MC cannot be kept throughout DGAB layer as shown by Figure 3.5

Figure 3-5 Adding water on DGAB & compacting without mixing

iv. At the site while compacting

Here, water is sprayed on DGAB surface while compaction process is gone on. Only top part of layer gets wet in this situation too. Excess water flow through the top surface and fine particle wash away with water balancing segregated surface as illustrated by Figure 3.6

Figure 3-6 Watering on DGAB surface while compacting

3.2 Results of the Questionnaire

Summary of questionnaire survey results is attached in Appendix A-2

According to the results of questionnaire survey, moisture level of DGAB was maintained by following four different approaches, Controlled; 1) at stock pile, 2) at site while laying, 3) at site before compacting, 4) at site while compacting

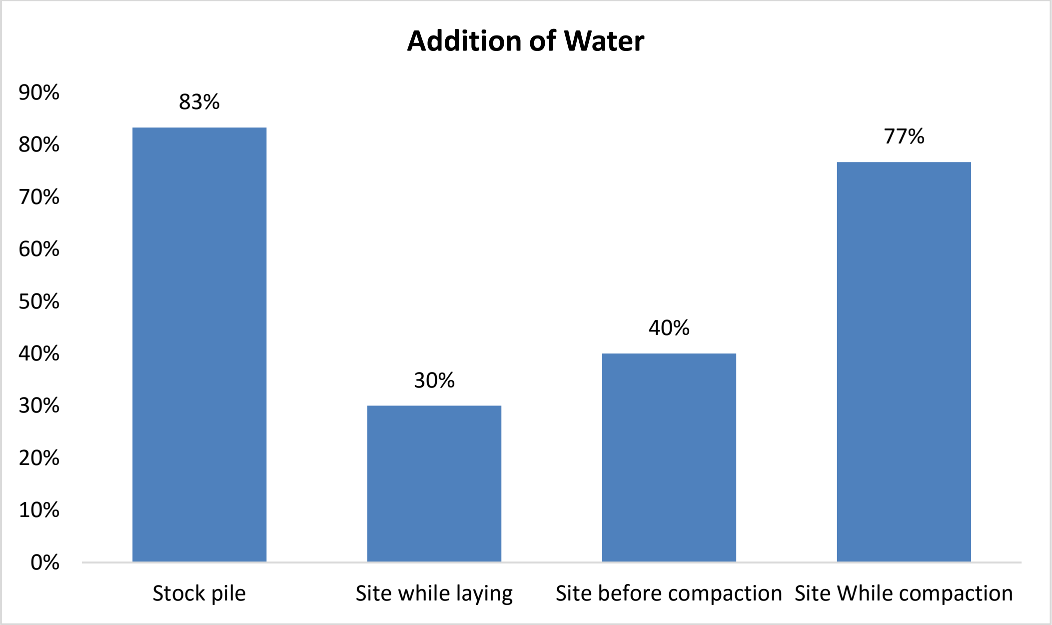


Figure 3-7 Addition of water at different occasion

As demonstrated in the Figure 3.7, 77% of responded maintain moisture level by adding water while compacting.

Further, when questionnaire survey results are scrutinized it is revealed that, the required MC for compaction is assessed basically in two different way and those are

- By visual identification of surface saturation
- By excess water flow underneath the DGAB layer

Spherical representation of above two approaches are shown as Figure 3.8

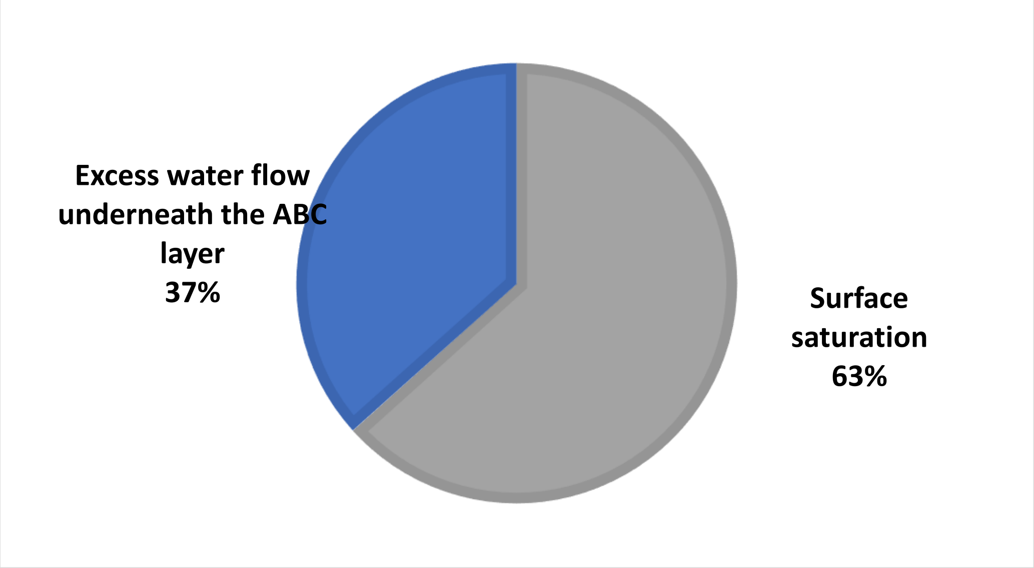


Figure 3-8 Assessing MC for compaction

The achievement of compaction of DGAB in the field, is assessed in several ways based on supervisor's experience before the testing. Those can be categorized as

1) According to the number of roller passes
2) By observation of surface vibration
3) According to the roller operator judgement
4) The occasion when fines particles come out with water to top of DGAB surface
5) By observing the crushing of stone (approximately 37.5mm size) which was kept in between roller and compacted surface.

But majority of site supervisors verify that compactions achieved when fines particles come out with water to top of DGAB surface as shown by Figure 3.9

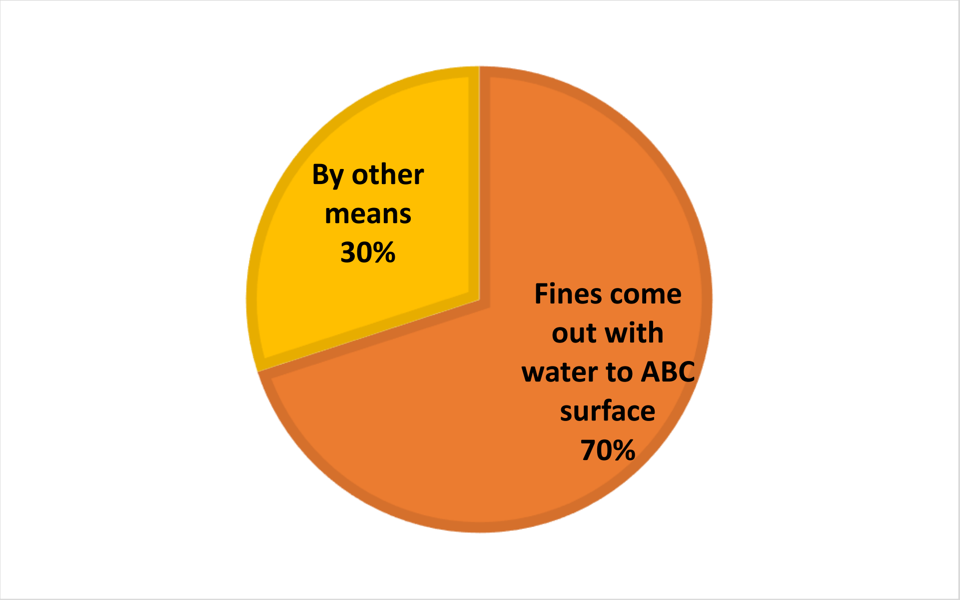


Figure 3-9 assessing the compaction

4 LABORATORY COMPACTION METHODS

4.1 Introduction

“Compaction, In general, is the densification of soil by removal of air, which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. When water is added to the soil during compaction, it acts as a softening agent on the soil particles. The dry unit weight after compaction first increases as the moisture content increases when MC is gradually increased at the initial stage of the compaction with same Compactive effort. Beyond a certain MC, any increase in the MC tends to reduce the DD. This phenomena occurs because the water takes up the spaces that would have been occupied by the solid particles.” (Das, 2007)

The main purpose of compaction process is improving the engineering properties of compacting material. Although the relationship between compacted properties and the variable of compaction process should be duly evaluated in the field, laboratory tests are selected to save time and cost. Therefore, the relationship among the parameters are stablished in the laboratory conditions. However this approach has serious limitation, since actual field condition cannot precisely be simulated in the laboratory. Field compaction is generally achieved by various modes (Dynamic or Static) and various energy level when compared with laboratory.

4.2 Laboratory Compaction Test Types

In order to simulate various field compaction methods different types of laboratory compaction tests have been introduced. Those tests can be categorized as:

- Impact compaction test
- Static compaction test
- Kneading compaction test
- Vibratory compaction test

4.2.1 Impact Compaction Test

The most common two types of impact compaction tests are Standard proctor compaction test and Modified proctor compaction test. These two types of tests are being used as compaction test method, by most of construction specifications. A standard weight is repeatedly dropped on the test specimen for prescribed number of blows. Drop height, drop weight and compaction material volume is adjusted to achieve the appropriate compaction effort.

Standard Proctor Compaction Test (AASHTO T99 / ASTM D698)

The standard proctor compaction test uses a 100mm diameter mold and compacts in three layers. Each layer is compacted by means of 25 number of blows of 2.5kg hammer with falling height of 300mm. This procedure is repeated for a sufficient number of water content to establish a dry density moisture content relationship. This compaction test can be applied for soil which has 30% or less by the weight of particle retained on 19mm sieve. Test apparatus are shown in Figure 4.1

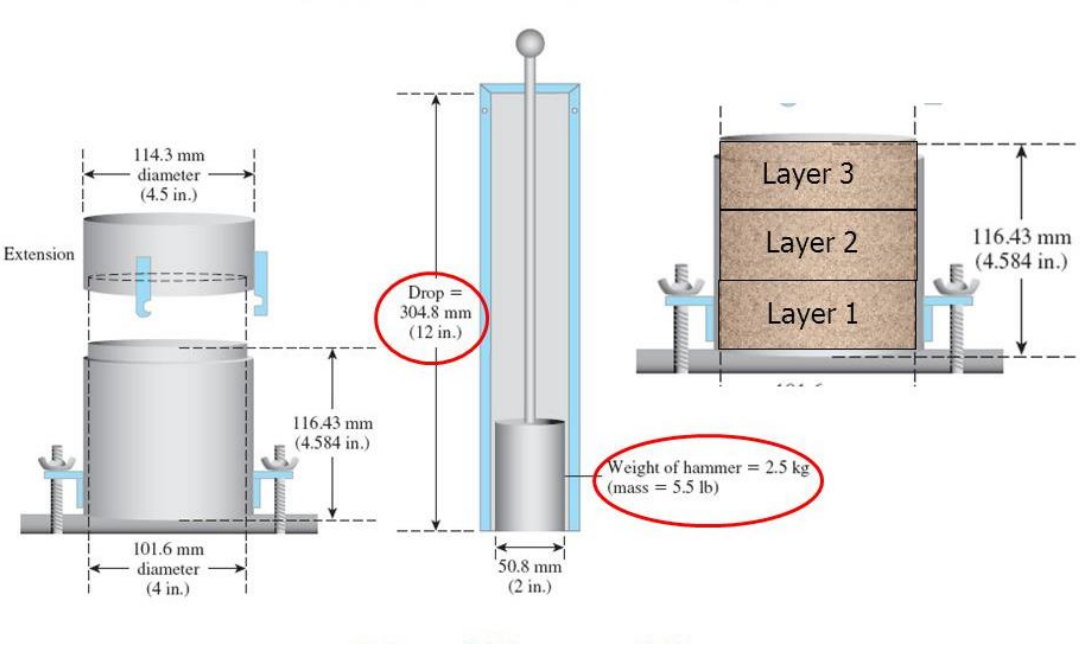


Figure 4-1 Standard Proctor Mold & Hammer

Modified Proctor Compaction Test (AASHTO T180 / ASTM D4235)

This test method uses to determine the relationship between OMC and DD of fine grain and coarse grain soils. AASHTO provides four methods as A, B, C & D. Those test methods are described below;

- Method A & B ; For 40% or less particles retained on 4.75mm sieve
- Method C & D ; For 30% or less particles retained on 19mm sieve

100mm /150mm diameter and 4.54kg drop hammer are used in modified proctor compaction method. The drop height of hammer is 450mm. Five number of layers of testing material are placed on appropriate mold in given MC. Each layer is compacted by 25 number of blows by 4.5kg hammer. This procedure is repeated at least five different MC to establish a relationship between MC& DD. Apparatus used for modified for compaction are shown in Figure 4.2

Figure 4-2 Modified Proctor Mold & Hammer

4.2.2 Vibrator Compaction Test Methods

Impact compaction method does not yield consistent results in some occasions. As a result of that several test procedures have been developed using vibratory compaction. Vibratory compaction provides a better correlation between the field and the laboratory results as it simulates the field conditions up to considerable level.

Only few number of vibration compaction test method are available at the moment and those are;

- ASTM D 4253; Standard test method for maximum index density and unit weight of soil using vibratory table
- BS 1377; Part 4 : 1990 (3.7) Vibratory Hammer Method
- Gyratory compaction method
- Based on the results research of Vincent, Aaron, & Adam (2007), a draft ASTM Standard for Standard method of compaction has been written, is well into the balloting process and is to be become an ASTM Standard later.
- USBR -94, Draft: Procedure for Determining the maximum index unit weight of cohesion less soils using a Vibratory Hammer unpublished manuscript.

Vibration Table Method (ASTM D 4253)

This compaction method utilize a vibration tamper to compact the soil sample. ASTM D 4253 test method is applicable to soils that have 15% or lesser particles passing through no.200 (75µm) sieve. Wet or oven dried sample was placed on mold and applying a surcharge of 14 kpa to the surface of soil. Then prepared mold is vertically vibrated by means of a vibration table. The amplitude of vibration is 0.325mm for 8 minute at 60 Hz or 0.475mm for 10 minute at 50 Hz. After completion of vibration dry density is determined. Figure 4.3 shows the apparatus used for Vibration table method.

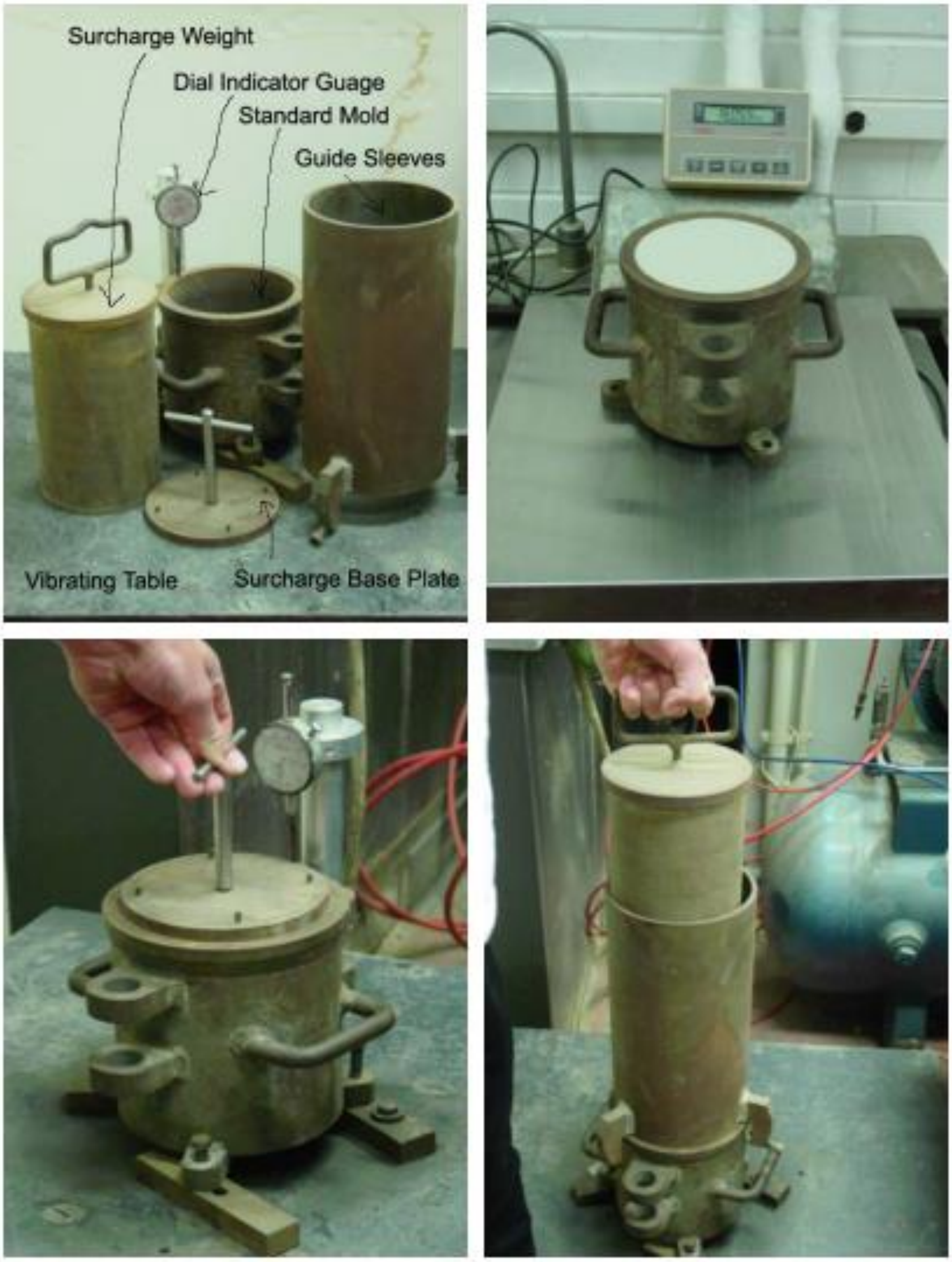


Figure 4-3 Vibration Table

Vibrator Hammer Method (BS 1377)

In this procedure, a vibrator hammer and circular tamping foot are used to compact the soil in a standard cylindrical mold. This method is applicable for soils having less than 30% by weight retained on 19mm sieve and less than 10% retained on 37.5mm sieve. Prior to the compaction, specimen is prepared at selected MC and placed in a 150mm diameter mold in three equal layers.

Figure 4-4 Vibration compaction Test Mold

Each layer is compacted for one minute with vibratory hammer. Always the circular tamping foot should be directly placed on top of the layer. The hammer operate at 25-45 Hz frequency which applied a steady downward force on that. The downward force should be between 300N-400N. After completion of the compaction of three layers, the height of the sample is measured. The same procedure is repeated at different MCs. The weight and MC of compacted samples are used to stablish MC & DD relationship.

Figure 4-5 Vibratory Hammer

4.2.3 Gyratory Compaction

Generally gyrator compactors used in asphalt paving industry. However some Highway Departments referred to this as gyrator soil press. This soil press led to the development of the gyratory compaction machine.

The compaction procedure should simulate the compaction pressure at various depths of by the anticipated wheel load. This test is done at a MC which is assumed, that has immediately after the construction in field. The sample is placed in gyratory compactor for 500 revolution at a one degree gyration angle using the corresponding vertical pressure according to selected depth. Then calculate the DD of sample on the basis of compression ram of the gyratory compactor. To calculate the density, it is necessary to know only the weight of the material and the volume of the test mold for various readings of the ram travel. Then prepare a plot of density versus the number of revolution for each selected depth.

Figure 4-6Gyrator Compactor

4.3 Laboratory Compaction Trial Tests

Several numbers of laboratory compaction test were conducted to evaluate the most suitable compaction test procedure for field compaction. In this chapter two widely used laboratory techniques, impact compaction method and vibratory compaction method were trialed for the comparison. Laboratory testing samples were collected from chainage 43+700 of Bodagama-Hambegamuwa-Kalthota Road which is selected for field trial.

4.3.1 Impact Compaction Methods

The most common impact compaction test are Standard proctor compaction method (AASHTO T190) and Modified proctor compaction method. According to Ping, et al. (2003). Water content and compaction effort are the two main factors that affected for the compaction. In order to study the density-moisture relationship against compaction effort, another two test were carried out in addition to conventional compaction methods.

Totally four no of different tests were carried out at laboratory in order to compare the MC, DD relationship at different energy levels. Those tests are;

1) Standard proctor compaction test (AASHTO T99)
2) Modified proctor compaction test (AASHTO T180, Method D)
3) Standard proctor compaction test method with 56 blows per layer
4) Modified proctor compaction test method with 25 blows per layer

Figure 4.7 shows the conducting of laboratory test at different compaction effort.

(a) (b)

(c) (d)

Figure 4-7 Impact Compact Test Method; (a) Place material, (b) Compaction, (c) Finish of compaction, (d) Weighting of compacted sample

Standard Proctor Compaction Test

Compaction test results are shown in table 4.1 and table 4.2. DD and MC relationship is shown in figure 4.8

Table 4-1 Standard Compaction Test Data

Mold diameter	115mm
Mold height	116mm
Hammer weight	2.5 kg
Drop height	305mm
Number of layers	3
Number of blows per layer	25

Table 4-2 Standard Proctor Compaction Test Results

Moisture Content	Dry Density (kg/m^3)
4.1	2.191
5.9	2.317
7.0	2.330
8.3	2.265
10.2	2.162

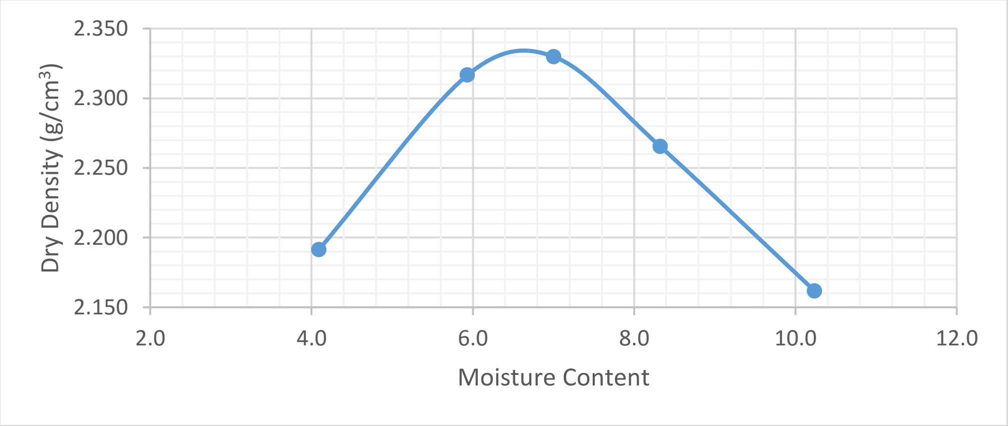


Figure 4-8Standard Proctor Compaction Test DD-MC Curve

MDD (g/cm^3)	OMC
2.342	6.8

OMC and MDD of Standard proctor compaction test are 2.342 and 6.8 respectively.

Modified Proctor Compaction Test

Compaction test results are shown in table 4.3 and table 4.4. DD and MC relationship is shown in figure 4.9

Table 4-3Modified Proctor Compaction Test Data

Mold diameter	153mm
Mold height	116mm
Hammer weight	4.5 kg
Drop height	457mm
Number of layers	5
Number of blows per layer	56

Table 4-4Modified Proctor Compaction Test Results

Moisture Content	Dry Density (kg/m^3)
4.1	2.327
5.5	2.400
6.7	2.416
9.0	2.334
10.4	2.280

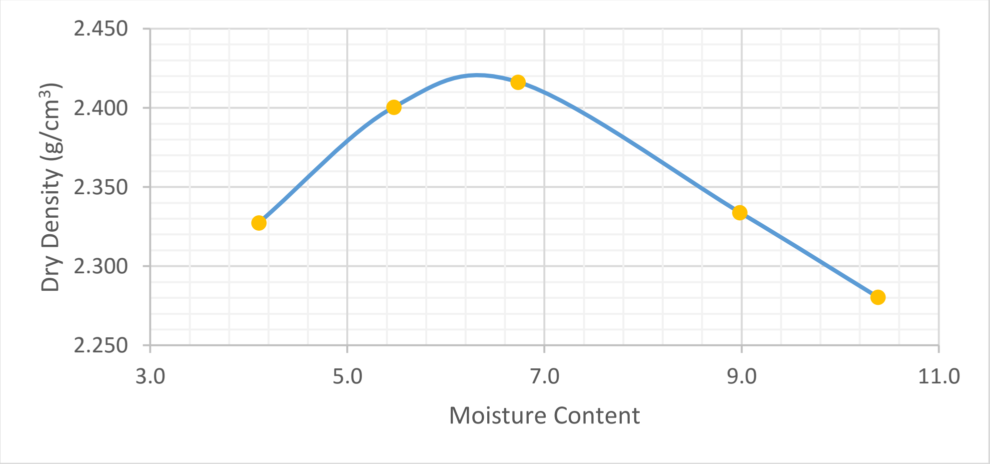


Figure 4-9Modified Proctor Compaction DD-OMC Curve

MDD (g/cm^3)	OMC
2.421	6.4

OMC and MDD of Modified proctor compaction test are 2.421 and 6.4 respectively

Standard Proctor Compaction Test Method with 56 blows per layer

Compaction test results are shown in table 4.5 and table 4.6. DD and MC relationship is shown in figure 4.10

Table 4-5 Standard proctor compaction test method with 56 blows Test Data

Mold diameter	115mm
Mold height	116mm
Hammer weight	2.5 kg
Drop height	305mm
Number of layers	3
Number of blows per layer	56

Table 4-6 Standard proctor compaction test method with 56 blows Test Results

Moisture Content	Dry Density (kg/m^3)
3.1	2.215
5.5	2.365
7.0	2.390
8.6	2.328
10.7	2.232

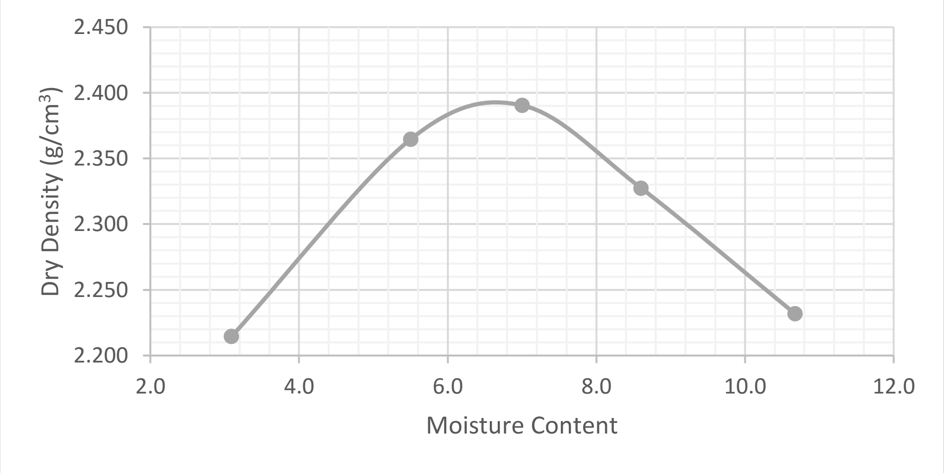


Figure 4-10 Standard proctor compaction test method with 56 blows Test DD-MC Curve

MDD (g/cm^3)	OMC
2.397	6.5

OMC and MDD of compaction test are 2.397 and 6.5 respectively

Modified proctor compaction test method with 25 blows per layer

Compaction test results are shown in table 4.7 and table 4.8. DD and MC relationship is shown in figure 4.11

Table 4-7 Modified proctor compaction test method with 25 blows Test Data

Mold diameter	153mm
Mold height	116mm
Hammer weight	4.5 kg
Drop height	457mm
Number of layers	5
Number of blows per layer	25

Table 4-8 Modified proctor compaction test method with 25 blows Test Results

Moisture Content	Dry Density (kg/m^3)
4.1	2.327
5.5	2.400
6.7	2.416
9.0	2.334
10.4	2.280

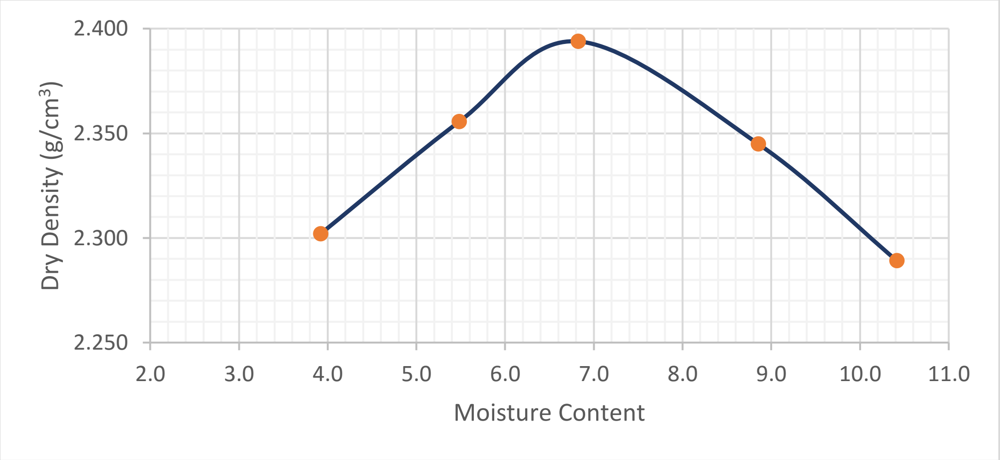


Figure 4-11 Modified proctor compaction test method with 25 blows DD-MC Curve

MDD (g/cm^3)	OMC
2.359	6.9

OMC and MDD of compaction test are 2.359 and 6.9 respectively

4.3.2 Vibratory hammer compaction method

In this study Vibratory hammer compaction method BS 1377: Part 4 were used to develop the compaction curve for the same material as per the specification.

(a) (b)

(c) (d)

Figure 4-12 Vibrator Compaction Test Procedure; (a) sample preparation, (b) Placing of sample for compaction, (c) compaction of the sample, (d) Measure the sample settlement

Compaction test results are shown in table 4.9 and table 4.10. DD and MC relationship is shown in figure 4.11

Table 4-9 Vibrating Hammer Compaction Data

Mold diameter	154mm
Mold height	117mm
Number of layers	3
Compacting Period	60 S
Downward Force	350 N
Operating Frequency	35 Hz

Table 4-10 Vibratory Hammer Compaction Method Test Results

Moisture Content	Dry Density (kg/m^3)
2.35	2.376
3.60	2.390
4.50	2.426
5.80	2.451
7.35	2.395

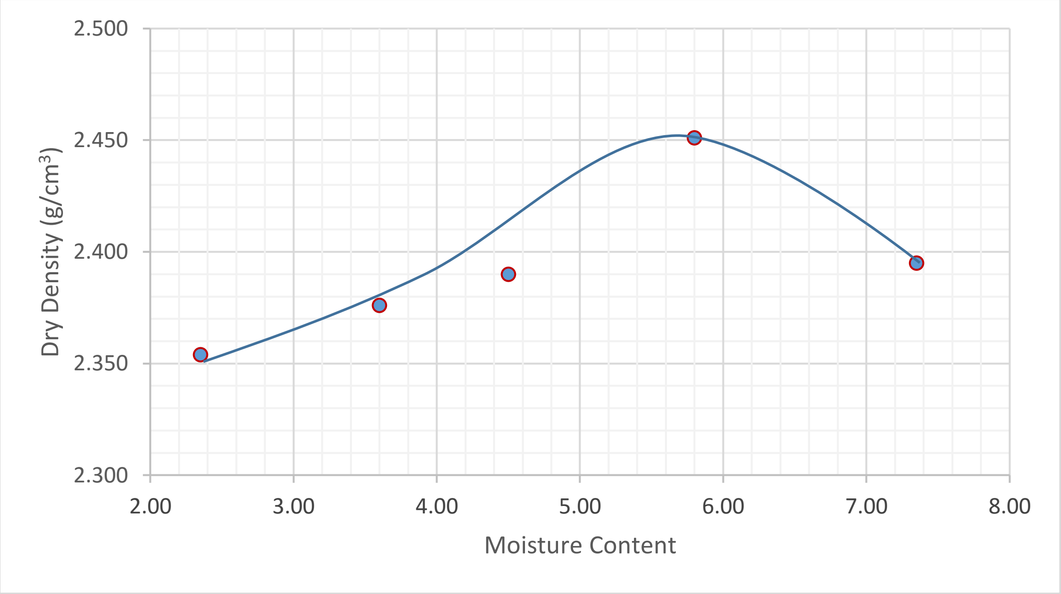


Figure 4-13 Vibratory Hammer Compaction MC-DD Curve

MDD (g/cm^3)	OMC
2.453	5.6

OMC and MDD of Vibratory hammer compaction test are 2.453 and 5.6 respectively

During the Vibratory Hammer Compaction test, it is observed that MC of the test specimen is reduced while it compacting, due to water comes to top of the vibrator hammer plate as shown by figure4.14. This effect is significant when compacting at higher MCs.

Figure 4-14 MC Loss during Vibrator Hammer compaction test

5 FIELD COMPACTION TRIALS

5.1 Introduction

The main objective of this research is evaluate the applicability of laboratory compaction in the field. Therefore the correlation between dry density, moisture content and compaction energy should be identified for field compaction. In order to establish a relationship under field conditions, trials were carried out at different energy levels and moisture levels.

5.2 Case study location

Road section 43+500 km to 43+800 km of Bodagama-Hambegamwa-Kaltota Road (B528) was selected for the case study location for field trials. Figure 5.1 shows the field trial location, near Walawe River. Test section is flat and straight.

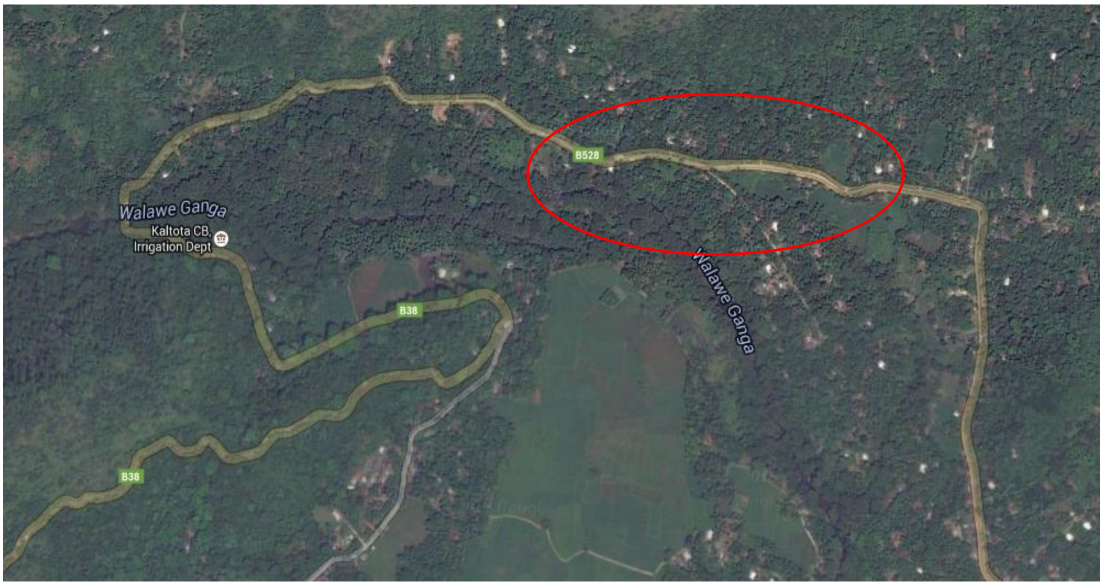


Figure 5-1 Case Study Location

This road was as Rehabilitated in 2015 under local bank fund. The carriageway width and shoulder of the selected section is 6.2m and 1.2m respectively.

Road cross section and pavement design details are shown in figure 5.2

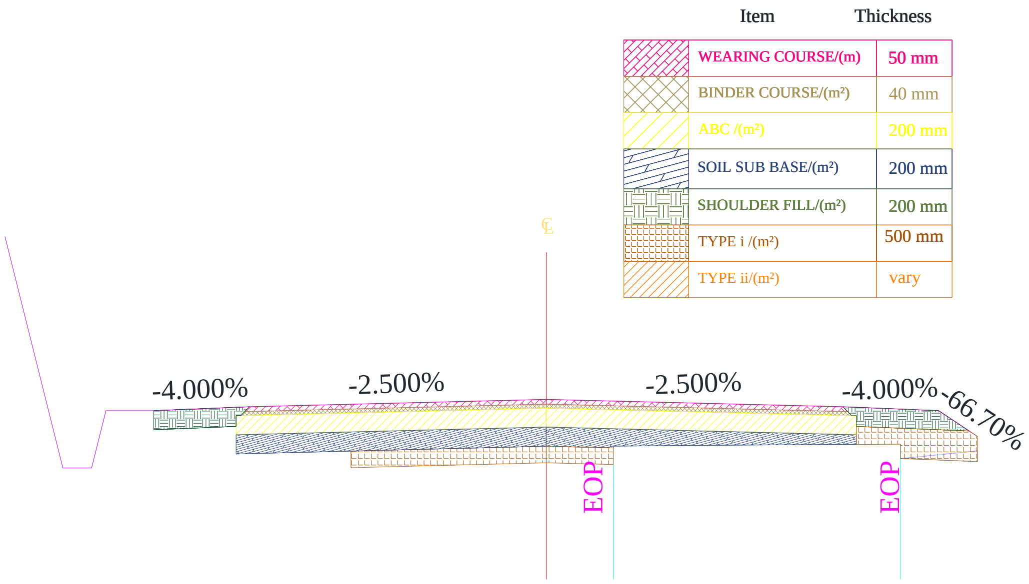


Figure 5-2 Road cross Section of Case Study Location

DGAB thickness of the section is 200mm and it was laid over a Sub Base layer. Six number of field trials were carried out at different strip location for different moisture levels as shown in figure 5.3. The dimensions of strip are approximately 100m in length and 3.1m in width. Thickness of the DGAB layer was 200mm for entire case study. Moisture levels maintained in the test strips are given in table 5.1

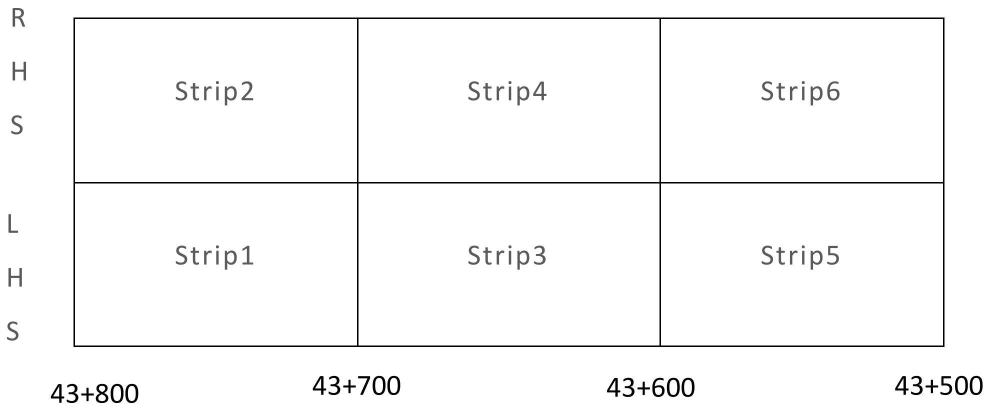


Figure 5-3 Field Trial Strip Plan

Table 5-1 Moisture Levels of Test Strips

Strip No	Moisture Level	Measured moisture content
1	Very low	2.4
2	Low	3.3
3	Medium	4.0
4	Medium	5.5
5	High	6.9
6	Very high	9.3

5.3 Specification of Compacting Roller

Whole field trial compactions process was conducted using “JCB Vibromax Soil Compactor VM 115” type roller. It is single drum vibratory roller and operating weight is 10.85 ton. Drum width is 2100 mm. Roller speed was maintained as 2.5 km/h while constant vibration level (Frequency-31 Hz, Amplitude-1.97mm) was kept for entire compaction process. Manufacture controls relevant to the operation data is given in Appendix A-3

Figure 5-4 Single Drum Vibratory Compacting Roller

5.4 Field Test Procedure

Section 43+700 km to 43+800 km LHS was selected as first trail location. DGAB was watered at stock pile and transported to the site. Then it was uniformly laid over on compacted subbase surface by means of Mortar Grader. The laid DGAB was thoroughly mixed prior to commence the compaction operation

Figure 5-5 Laying of DGAB using a Mortar Grader

Moisture content was maintained at low condition in laid sample and it was recorded as 2.4%. Then compaction process was started. After completion of two number of roller coverages field compaction was tested in accordance with Standard test procedure for density in place by sand cone [Test method T 191-86 (1990)]. One roller coverage can be defined as two roller passes (one forward and one backward motion).

After testing the field compaction another two number of roller coverages were sent through the test strip. Then field compaction was tested after four number of cumulative roller coverages. This procedure was repeated until end twelve number of roller coverages. Field compaction was determined after 2, 4, 6, 8, 10 and 12 roller coverages.

Figure 5-6 Field Compaction Testing Procedure; (a) Field compaction, (b) Sample collection for moisture checking, (c) &(d) Field compaction testing by sand replacement method

After completion of the first test strip, rolling of the second strip was continued. DGAB which pre watered at stock pile, was transported to site. It was laid, following the same procedure as previous case. Then the MC was raised by running a water bowser over the laid DGAB layer. One running of the water bowser over the strip, increased the MC approximately by one percent. Then the laid DGAB was thoroughly mixed and sample was taken to measure the MC and it was recorded as 3.3%. After finding the MC, the compaction process was commenced. Then same test procedure as described in the test strip 1 was followed and density was measured after completion of appropriate roller passes..

(a) (b)

(c) (d)

Figure 5-7 Laying, Compacting & Testing of Second Test Strip

This procedure was repeated for the test strips 3, 4, 5 & 6 while increasing the MC gradually to maintain moisture content at medium, high and very high levels

Preparation of test strip for the next moisture level is shown in figure 5.8. (a) and (b) show the adding water using a bowser and remixing of the base material using mortar grader respectively. Figure (c) and (d) show the compaction and conducting field density test after the first two roller coverages.

This procedure was repeated for next four test strips while increasing the MC gradually. Those were recorded as 4.0, 5.5, 6.9 & 9.3 for test strip 3, 4, 5 & 6 respectively.

5.5 Test Results

The computed DDs at various energy level (Roller Passes) for the test strip are shown in Table 5-1. The test results results for thr test strip 1 to 6 are presented in Figure 5-9, 5-10, 5-11, 5-12 ,5-13 and 5-14 respectively.

Table 5-2 Field Compaction Test Data Summary

Test Strip	MC	Roller Coverages					
		1/2	3/4	5/6	7/8	9/10	11/12
1	2.4	2.234	2.238	2.313	2.351	2.358	2.366
2	3.3	2.249	2.263	2.328	2.368	2.370	2.376
3	4.0	2.254	2.27	2.342	2.367	2.383	2.398
4	5.5	2.226	2.289	2.358	2.395	2.423	2.443
5	6.9	2.265	2.308	2.345	2.379	2.402	2.406
6	9.3	2.282	2.304	2.312	2.334	2.345	2.357

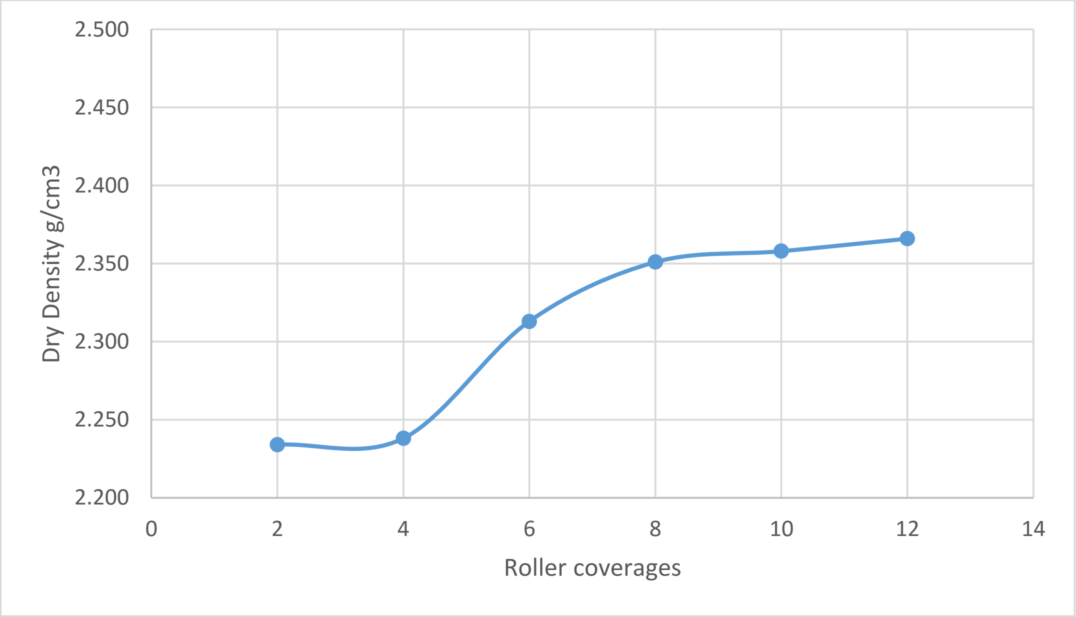


Figure 5-8 DD Vs No of Roller Coverages at Test Strip 1(MC=2.4)

Figure 5.9 shows the density increase according to the roller passes increases and the increment of density is not significant after 8 roller coverages. The increment of density from 8 coverages to 10 coverages about 0.3%.

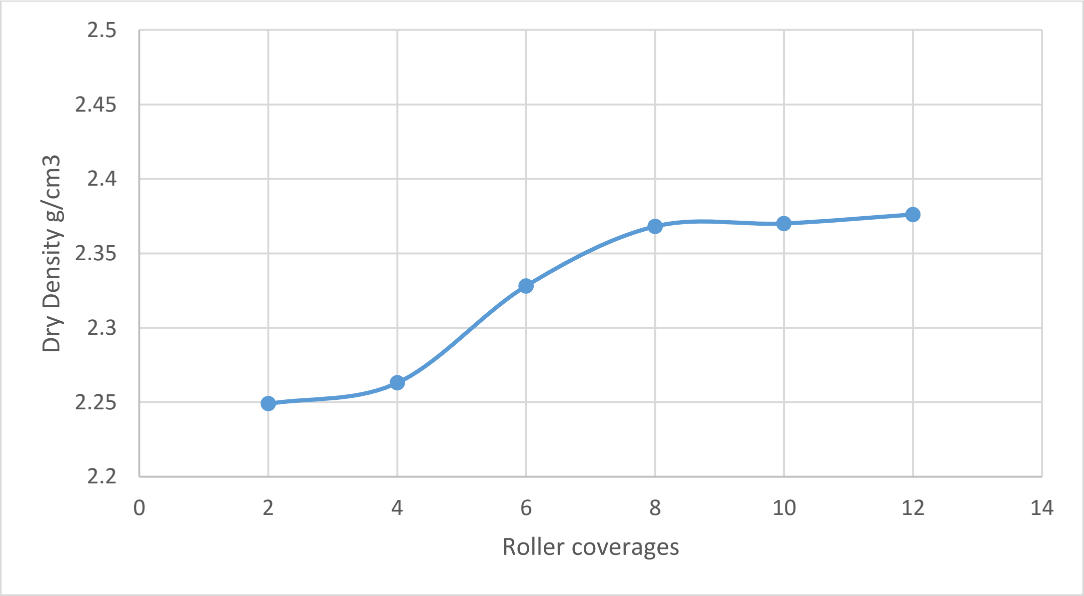


Figure 5-9 DD Vs No of Roller Coverages at Test Strip 2(MC=3.3)

Figure 5.10 shows the density increment of test strip 2 (MC=3.3) against the roller passes. Up to 4 roller coverages density increment is very lower and significant increment can be observed at 4 to 8 roller coverages. Again density increment is almost zero after 8 roller coverages.

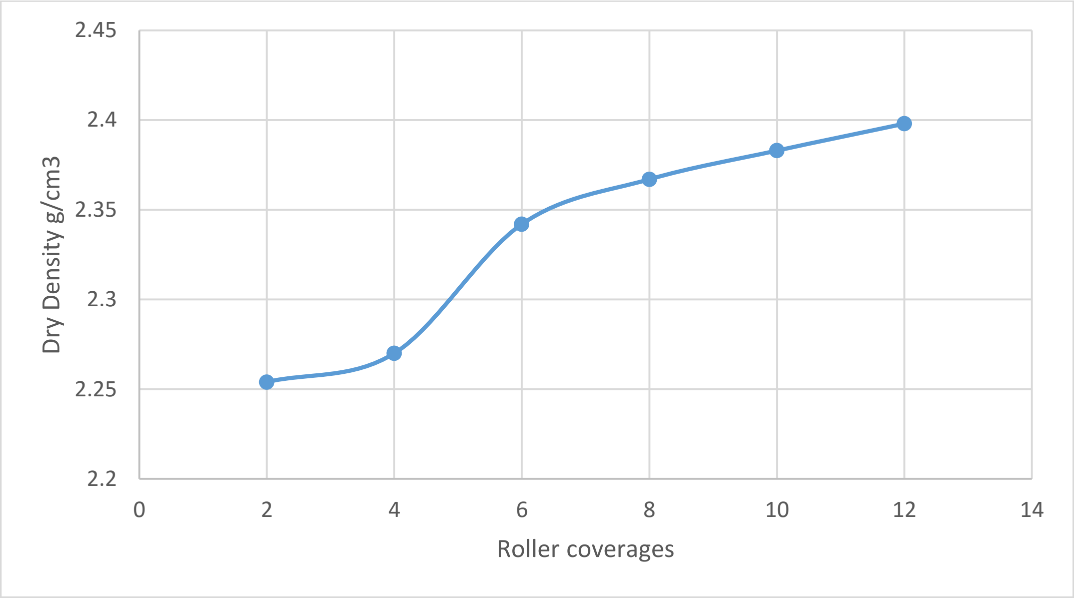


Figure 5-10 DD Vs No of Roller Coverages at Test Strip 3(MC=4.0)

According to the figure 5.11 density increment is comparatively low (1.6%)up to 4 no. of roller coverages. A significant density increment can be observed between 4 to 6 roller coverages, it is 7.2%. After 6 roller coverages again density increment become lesser value.

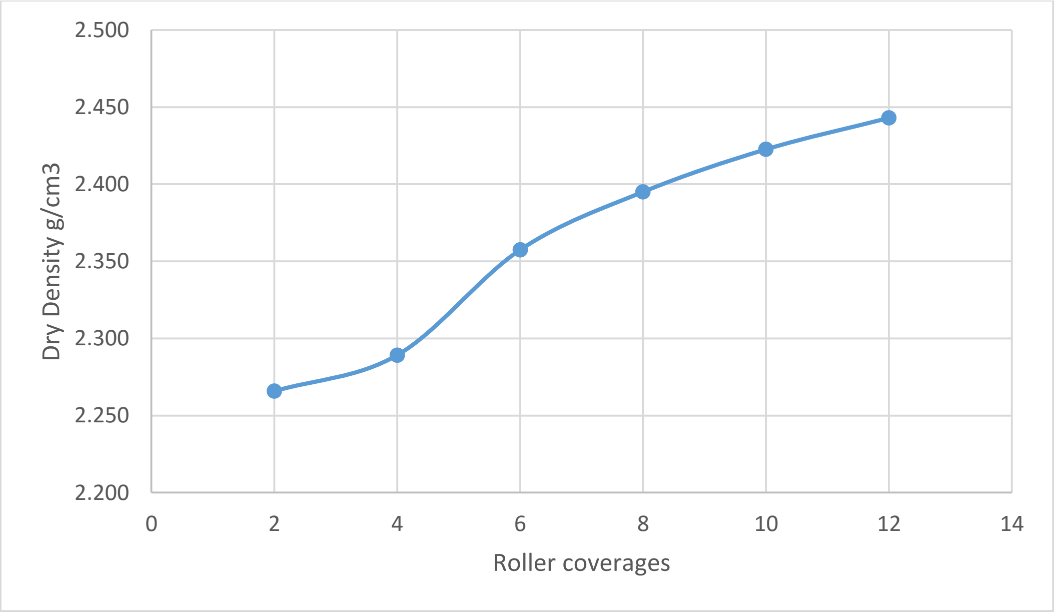


Figure 5-11 DD Vs No of Roller Coverages at Test Strip 4(MC=5.5)

Figure 5.11 describe the density increment at test trip 4, here density increment is similar to previous cases up to 6 roller coverages. But after 6 roller coverage density is further increased gradually.

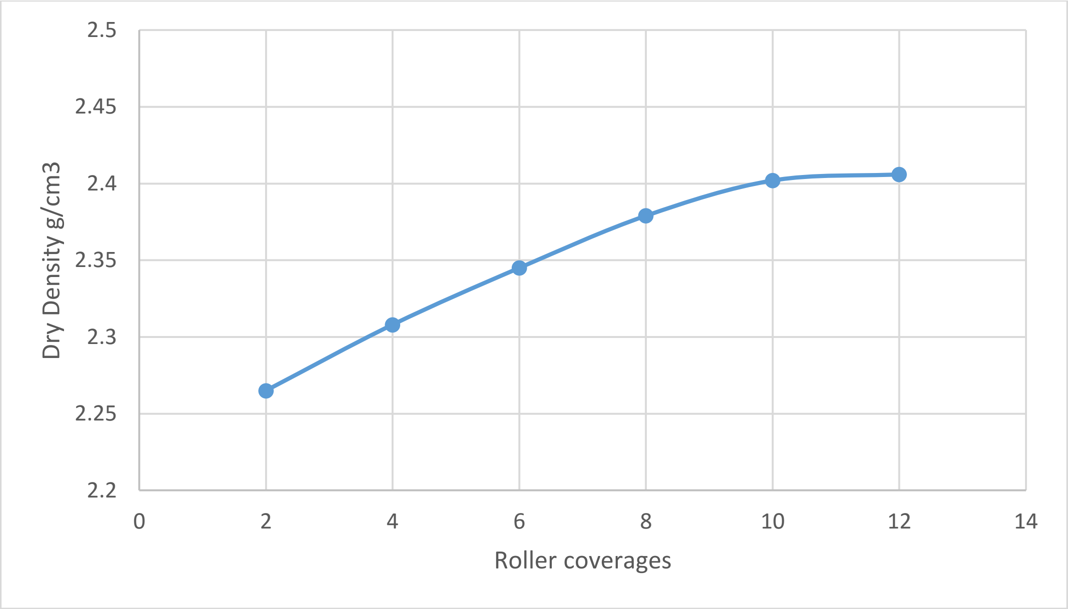


Figure 5-12 DD Vs No of Roller Coverages at Test Strip 5(MC=6.9)

Figure 5.12 shows the increment in density against the roller coverages of test strip 5. Dry density is gradually is gradually increased up to 10 roller coverages (3.4%). After that significant amount of density increment cannot be observed.

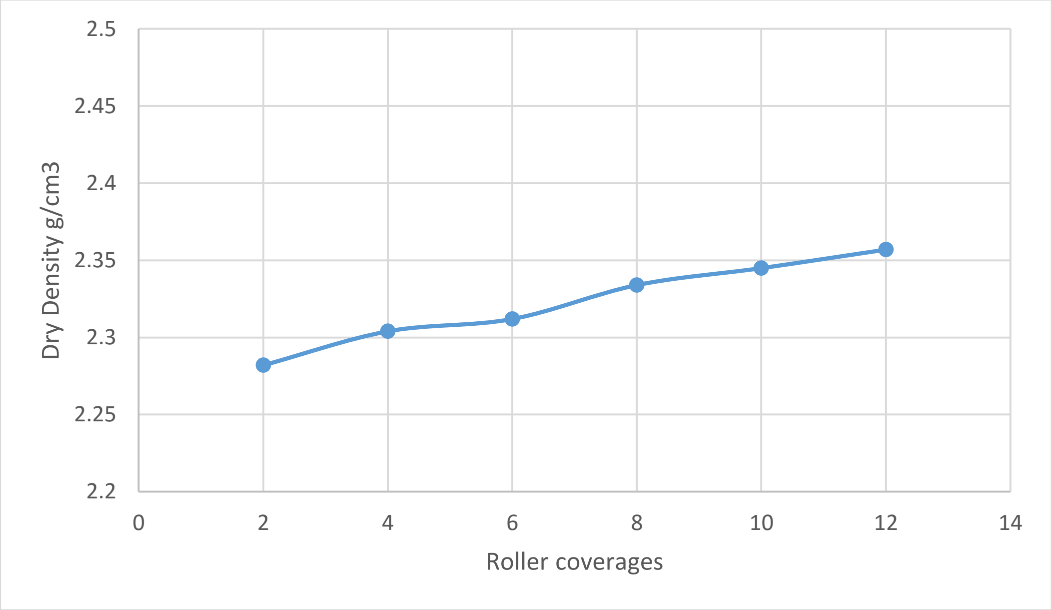


Figure 5-13 DD Vs No of Roller Coverages at Test Strip 6(MC=9.3)

Figure 5.13 describe the density variation with compaction effort at test strip 6. Dry density is gently increased the compaction process until 12 roller coverages. Average density increment is 1.5%.

5.6 Observations

During the field trial testing, it was observed that DGAB can retain maximum water content of about 9%. When water is added beyond that limit excess water drained out without further increasing the moisture level.

Further, there is a drop of MC when DGAB is compacted at higher moisture level. This can be illustrated by the incident happened when trial test strip no five was carried out. Initially MC of the laid sample was 9.2%, but after 12 number of roller coverages it was dropped down to 7.2%. It was noticed that water drained out through the top surface and side edges of DGAB layer while compaction operation was continued. Figure 5.14 shows the loss moisture from surface.

Figure 5-14 Loss of MC with Compaction

6 THE EFFECT OF HIGHER MOISTURE CONTENT ON GRADATION CHANGE OF DGAB

One of the objective of this field trial was to evaluate the segregation of DGAB due to the effects of compaction under higher MC. During the field compaction trials, it was observed that segregation was taken place when compacting under higher moisture level.

Figure 6-1 Segregation of DGAB Layer during the Compaction

A road section close to the trial locations was selected to estimate the extent of segregation of DGAB. Moisture content and the thickness of laid DGAB layer was 9.2% and 200mm respectively. Eight number of samples were collected for sieve analysis test at several location as described in Table 6-1, during compaction process.

Table 6-1 Sieve Analysis Test at sample locations

Sample No	Sample Location
1	From top 100mm of the layer from laid sample
2	From bottom 100mm of the layer of laid sample
3	From top 100mm of the layer after 4 no. of roller coverages
4	From bottom 100mm of the layer after 4 no. of roller coverages
5	From top 100mm of the layer after 8 no. of roller coverages
6	From bottom 100mm of the layer after 8 no. of roller coverages
7	From top 100mm of the layer after 12 no. of roller coverages
8	From bottom 100mm of the layer after 12 no. of roller coverages

6.1 Test Results

All the sieve analysis tests were conducted in accordance with AASHTO: T27-93(ASTM136-84a) standards. Test results of samples collected from 200 mm layer, top 100mm and bottom 100mm layers are shown in Table 6.2. Specification limit also show in the table.

Table 6-2 Sieve Analysis Test Results of Laid Sample

Sieve Size (mm)	Spec limit SSCM Table 1701.5		Initial Sample	Laid Samples	
	min	max		Top 100 mm	Bottom 100 mm
50.0	100	100	100.0	100.0	100.0
37.5	95	100	100.0	100.0	100.0
20.0	60	80	74.0	64.6	75.1
10.0	40	60	53.3	51.3	52.6
5.0	25	40	34.7	32.0	39.6
2.36	15	30	25.2	22.7	33.1
0.425	7	19	15.3	12.1	21.7
0.075	5	12	8.7	4.5	4.5

Figure 6.2 shows the graphical representation of the sieve analysis data of the three sample locations. Spec limits are depicted in the same figure.

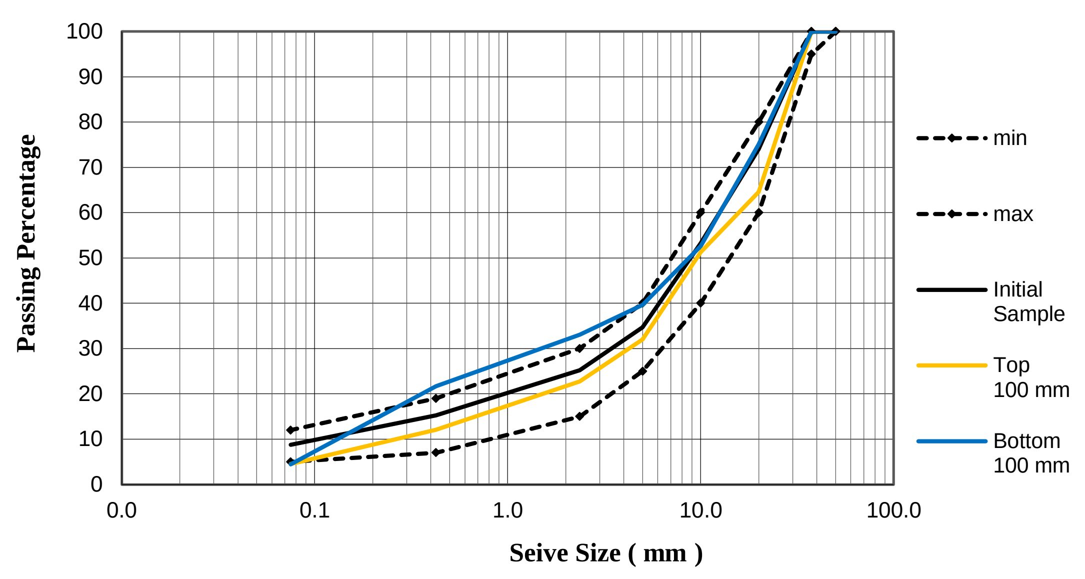


Figure 6-2 Gradation curve of Laid Sample

Results shows the sample collected from top 100mm sample (before compaction) representing the 200mm layer comply with the specification. However sample collected from bottom 100mm is not comply with specification. It shows that fine aggregate content of the sample collected from bottom 100mm is relatively high and outs of the spec limit.

Table 6-3 Sieve Analysis Test Results of Sample after 4 no of Roller Coverages

Sieve Size (mm)	Spec limit SSCM Table 1701.5		Initial Sample	4 Roller coverages	
	min	max		Top 100 mm	Bottom 100 mm
50.0	100	100	100.0	100.0	100.0
37.5	95	100	100.0	100.0	100.0
20.0	60	80	74.0	60.1	65.9
10.0	40	60	53.3	46.3	53.3
5.0	25	40	34.7	33.2	40.8
2.36	15	30	25.2	27.3	34.4
0.425	7	19	15.3	16.3	21.9
0.075	5	12	8.7	4.2	5.4

Table 6.3 shows the test results of the samples collected after 4 roller coverages. 200mm thick DGAB layer was taken as top 100mm and bottom 100mm separately.

Figure 6.3 represents the gradation curves of top 100mm, bottom 100mm and initial sample. The top 100mm layer complies with specification. But bottom 100 mm not comply with spec limits.

Fine aggregate content of the bottom 100mm layer is further increasing and this variation is higher than the previous case (laid sample).

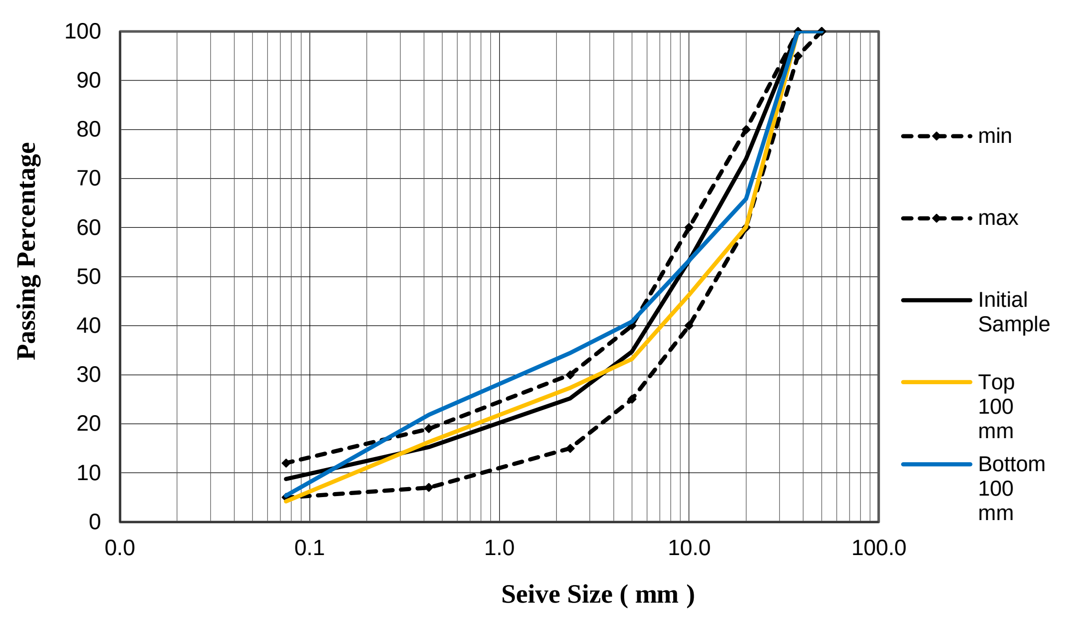


Figure 6-3 Gradation curve of Sample after 4 no of Roller coverages

Table 6-4 Sieve Analysis Test Results of Sample after 8 no of Roller Coverages

Sieve Size (mm)	Spec limit SSCM Table 1701.5		Initial Sample	8 Roller coverages	
	min	max		Top 100 mm	Bottom 100 mm
50.0	100	100	100.0	100.0	100.0
37.5	95	100	100.0	100.0	100.0
20.0	60	80	74.0	62.8	68.3
10.0	40	60	53.3	47.1	51.0
5.0	25	40	34.7	37.3	40.3
2.36	15	30	25.2	29.1	28.0
0.425	7	19	15.3	17.8	12.8
0.075	5	12	8.7	4.9	5.0

Table 6.4 shows the sieve analysis test results of top 100mm and bottom 100mm of 200mm DGAB layer. Those samples were collected at the end of 8 roller coverages.

Figure 6.4 shows the graphical representation of table 6.4 test results. Fine aggregate content of top 100mm layer moves to higher value and bottom 100mm layer fine content become relatively lower value. However both top and bottom layers gradation are within the spec limits even though it differs from its initial gradation.

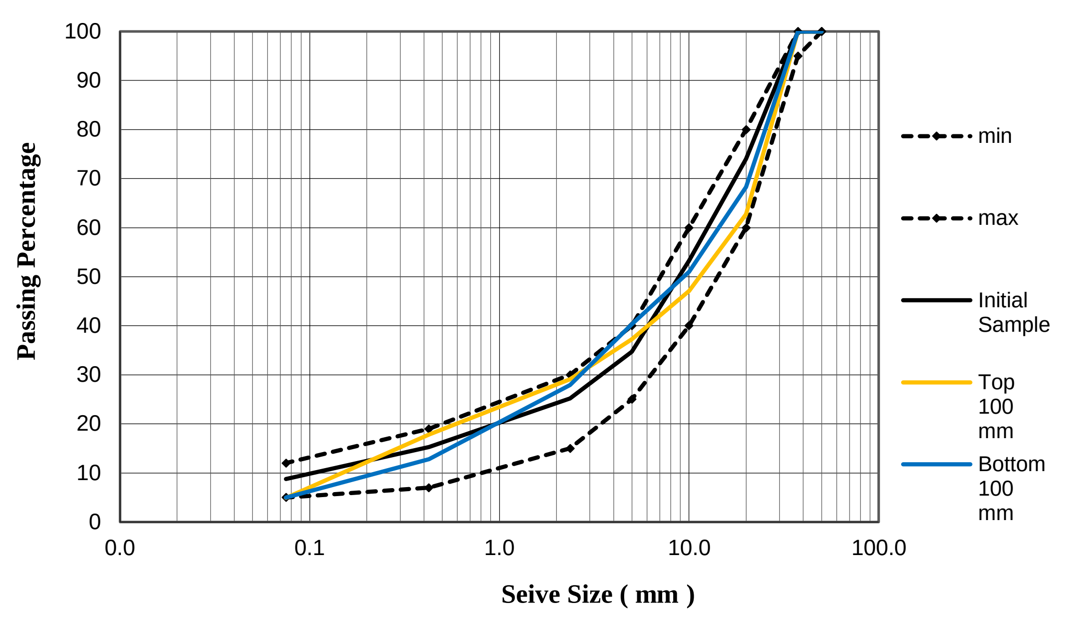


Figure 6-4 Gradation curve of Sample after 8 no of Roller coverages

Table 6-5 Sieve Analysis Test Results of Sample after 12 no of Roller Coverages

Sieve Size (mm)	Spec limit SSCM Table 1701.5		Initial Sample	12 Roller coverages	
	min	max		Top 100 mm	Bottom 100 mm
50.0	100	100	100.0	100.0	100.0
37.5	95	100	100.0	100.0	100.0
20.0	60	80	74.0	67.1	67.9
10.0	40	60	53.3	48.9	50.8
5.0	25	40	34.7	38.5	40.3
2.36	15	30	25.2	33.3	30.2
0.425	7	19	15.3	21.1	13.1
0.075	5	12	8.7	4.8	5.6

Table 6.5 shows the sieve analysis test results of top 100mm and bottom 100mm samples, which were collected after completion of 12 roller coverages.

Figure 6.5 gives the graphical representation of table 6.5 test results. It shows fine aggregate content of the top 100mm layer is reached to highest value, when compared with previous results and it is out of specification limits. The particles passing from 5.0mm and 2.35 mm sieve sizes are high in bottom 100mm layer and it reaches the upper margin of spec limits.

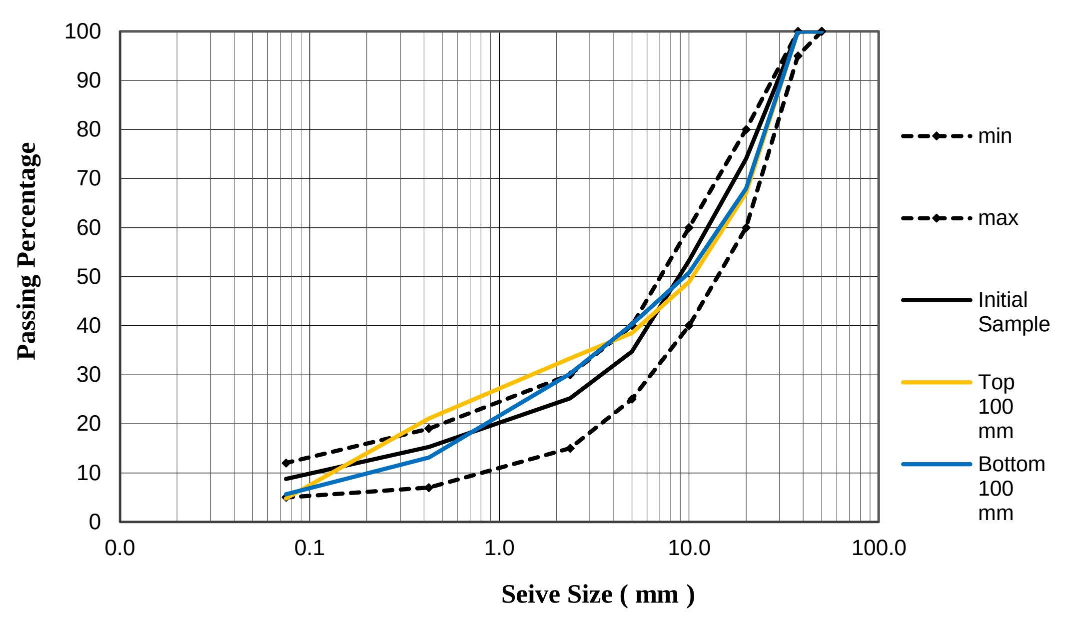


Figure 6-5 Gradation curve of Sample after 12 no of Roller coverages

7 SUMMARY AND ANALSIS OF EXPERIMENTAL RESULTS

7.1 Specification Requirements

ICTAD is the organization which implements the requirement and standards for the road construction work in Sri Lanka. According to their SSCM which is pertained for the construction work of roads and bridges in the country, certain limitations & standards have been stabilized to control the quality of construction works.

According to clause 405.3 of this specification (ICTAD, 2009), “The aggregate base shall be compacted to not less than 98% the maximum dry density of material as determined by BS1377, test 13 (Heavy) or AASHTO T 180 (Modified)

Grading requirement of DGAB is specified by (ICTAD, 2009) under clause 405.2 and table 1701.5 of sub section 1701.3(b). The gradation for nominal of 37.5mm is shown in table 7.1

Table 7-1 Gradation Limits of DGAB (SSCM Table 1701.5)

Sieve Size	Percentage by weight passing sieve ((Nominal Size 37.5mm)	
(mm)	min	max
50.0	100	100
37.5	95	100
20.0	60	80
10.0	40	60
5.0	25	40
2.36	15	30
0.425	7	19
0.075	5	12

7.2 Data Analysis of Laboratory Compaction Trail Tests

MDD, OMC, Degree of compaction (DOC) and Compaction Energy of all five laboratory tests are shown in Table 7-2. According to clause 405.3 of SSCM (ICTAD, 2009), required compaction level is 98% of MDD obtained from Modified Compaction Test (T 180). Therefore, density requirement in the field for 98% compaction is 2.373 g/cm^3 (2.421x0.98)

Table 7-2 MDDs, OMCs, Degree of compaction (DOC) & Compaction Energy of Laboratory Tests (Prochaska & Drnevich, 2005)

	Test Method	MDD (g/cm^3)	OMC	Degree of compaction At OMC *	Compaction Energy (MJ/m3)
1	Standard proctor compaction test	2.342	6.8	96.7%	790
2	Modified proctor compaction test	2.421	6.4	100.0%	6030
3	Standard proctor compaction test method with 56 blows per layer	2.397	6.5	99.0%	1783
4	Modified proctor compaction test method with 25 blows per layer	2.359	6.9	97.4%	2692
5	Vibratory hammer compaction test	2.453	5.6	101.3%	10958

*With respect to modified proctor

Range of moisture content which provide the required compaction level under various laboratory conditions are shown in Table 7.3

Table 7-3 MC Range for Lab tests to provide required compaction

	Test Method	Range of moisture for 98% DOC	OMC	Tolerance
1	Standard proctor compaction test	6.8	6.8	-
2	Modified proctor compaction test	5.0-8.0	6.4	-1.4 to +1.6
3	Standard proctor compaction test method with 56 blows per layer	5.7-7.7	6.5	-0.8 to +1.2
4	Modified proctor compaction test method with 25 blows per layer	6.7-8.0	6.9	-0.2 to +1.2
5	Vibratory hammer compaction test	2.3-7.5	5.6	-3.3 to +1.9

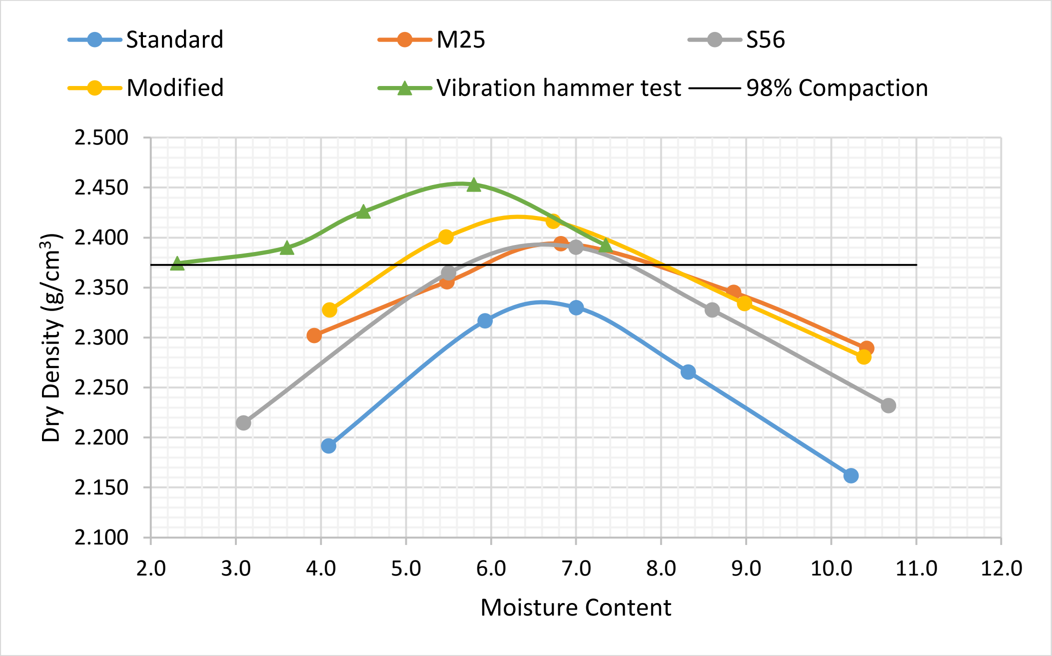


Figure 7-1 MDDs& OMCs of Laboratory Tests

Figure 7-1 Illustrates that MDD increases while OMC drops with the compaction effort increases in the laboratory conditions. Modified proctor compaction test gives highest MDD and lowest OMC from impact compaction test results. Standard proctor compaction test gives minimum MDD out of all four impact compaction tests. Further its MDD is lower than the required density, specified in SSCM.

Vibratory compaction hammer test the gives highest density at the lowest OMC compared with the impact compaction tests.

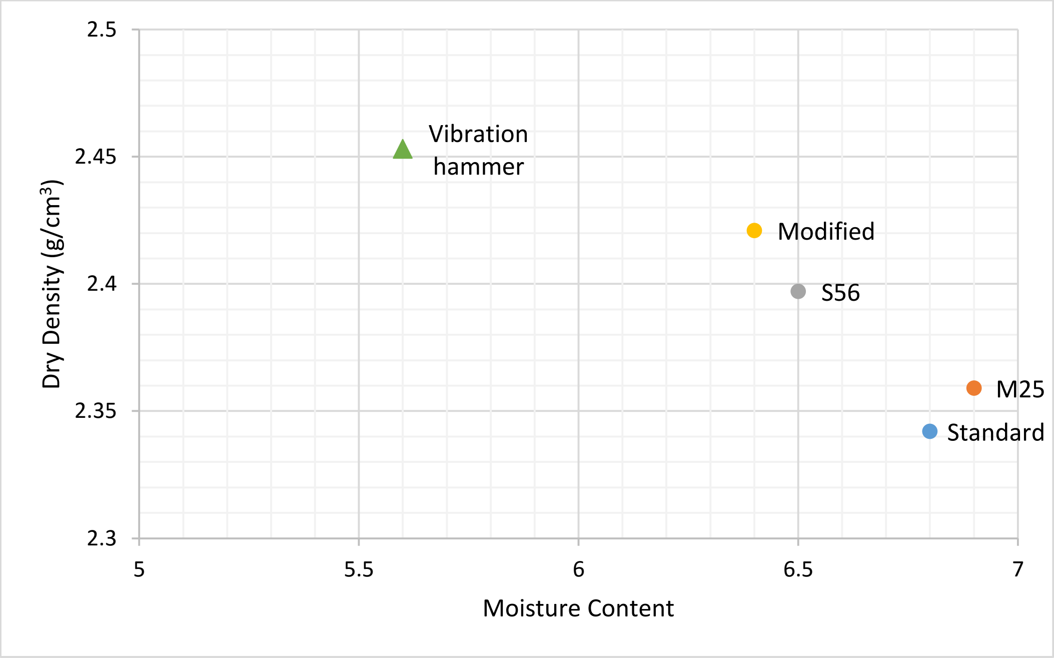


Figure 7-2 Variation of MDD & OMC at laboratory Compaction Tests

The major conventional tests that used for this study are Standard compaction test, Modified compaction test and Vibration hammer compaction test. The variation pattern of MDD and OMC can be compared by Figure 7-2. When Standard and Modified tests are compared 0.079 g/cm^3 difference between MDDs and 0.4% difference between OMCs can be observed. Further when Modified compaction test and Vibration hammer test results are compared about 0.032 g/cm^3 MDD and 0.8% OMC difference can be noted.

7.3 Data Analysis of Field Compaction Trail Tests

Field compaction test results for all five stripes are shown in Figure 7-3

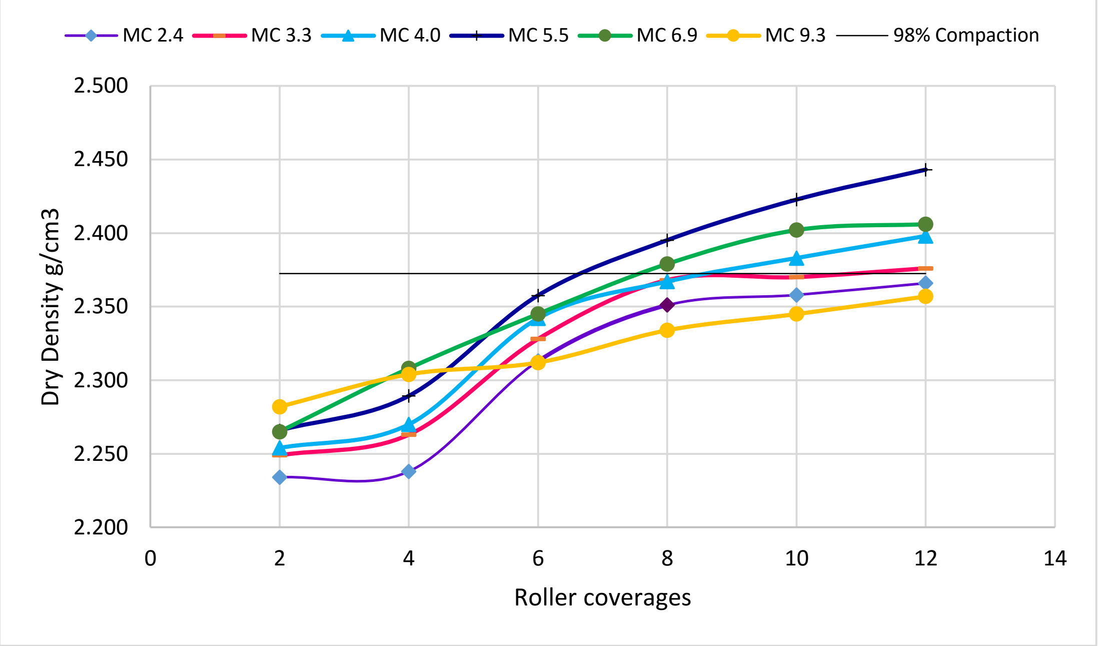


Figure 7-3 Roller Passes Vs Dry Density

As presented on figure, 98% compaction could only be achieved at 3.3, 4.0, 5.5 and 6.9 moisture levels. In all other MC, required compaction level were not achieved until end of twelve number of roller coverages. It shows that moisture content above 6.9 and below 4.0 gives unsatisfied results in the field compaction.

7.3.1 Density Increment with Number of Roller Coverages

The increment of DD against the roller passes at five moisture levels are presented by Figure 7-4, 7-5, 7-6, 7-7 & 7-8.

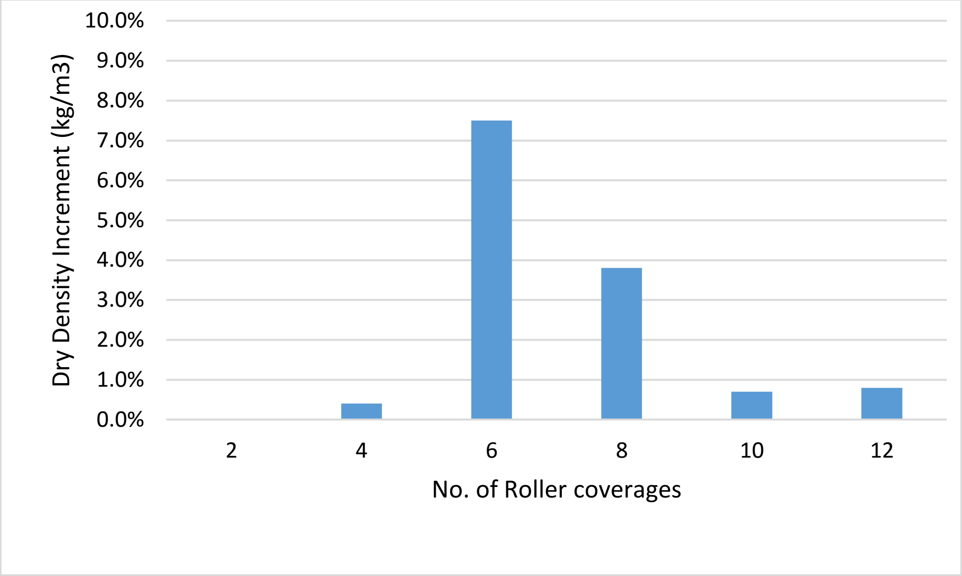


Figure 7-4 Dry Density Increment (kg/m3) at MC= 2.4

When MC is 2.4, considerable amount of DD is increased at the end of six and eight roller coverages. But after eight number of roller coverages no significant density improvement can be observed.

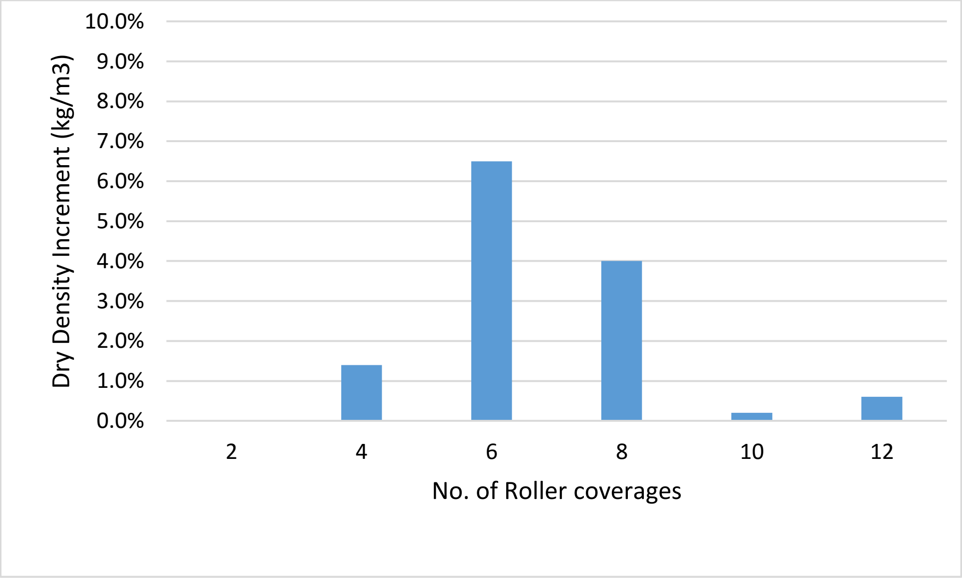


Figure 7-5Dry Density Increment (kg/m3) at MC= 3.3

When MC is equal to 3.3, increment of DD is almost same as previous case (MC=2.4). After eight number of roller coverages, there is no considerable density improvement

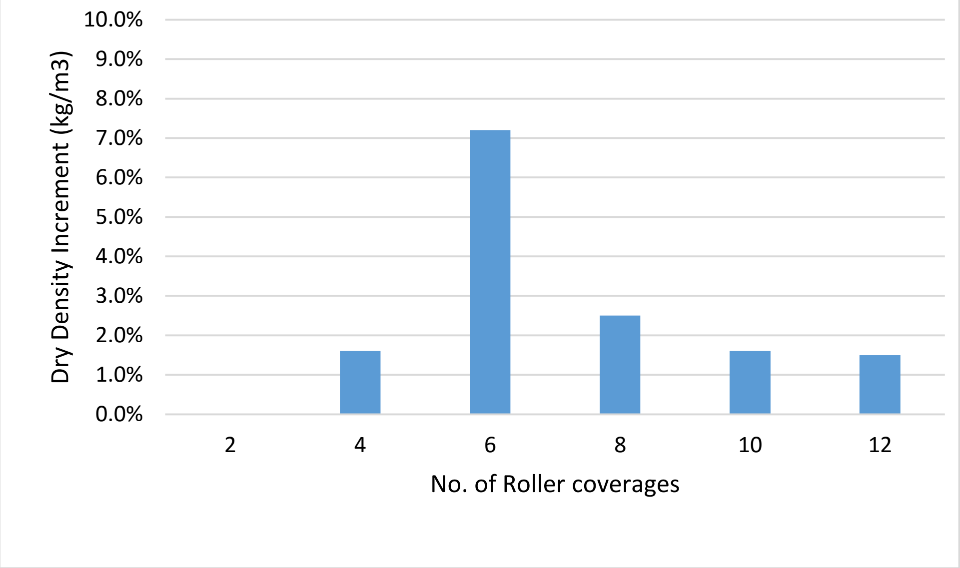


Figure 7-6 Dry Density Increment (kg/m3) at MC= 4.0

Noticeable density increment can be observed after 4 and 6 number of roller coverages at 4.0 moisture level compared with previous case (MC=3.3). After that density is uniformly increased with roller coverages.

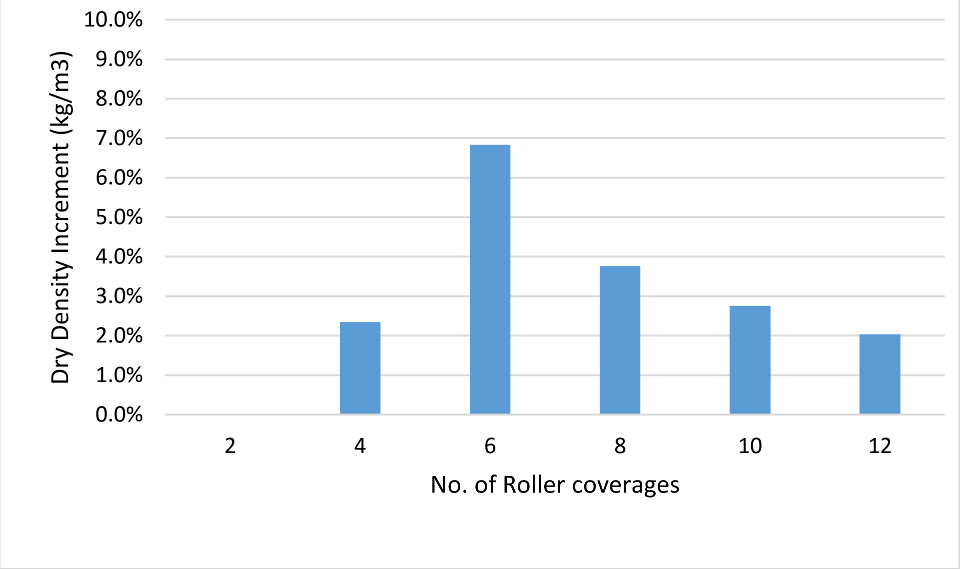


Table 7-4 Dry Density Increment (kg/m3) at MC= 5.5

Figure 7.4 shows that significant increment in DD after 6 roller coverages. But intensity of density increment is gradually reduced after that.

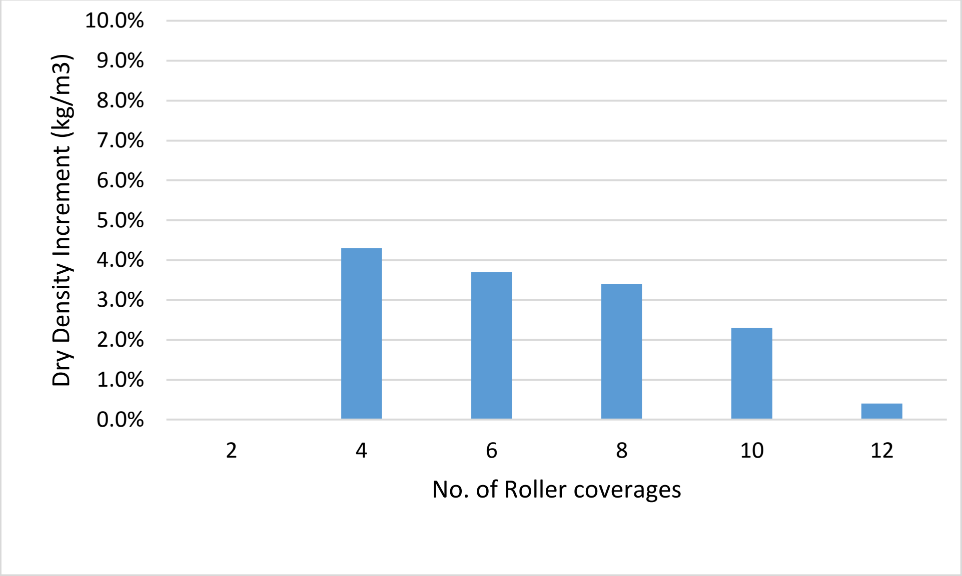


Figure 7-7 Dry Density Increment (kg/m3) at MC= 6.9

When MC equals to 6.9 increment of after 4 coverages is significantly high and achieved around 50% of the required compaction.

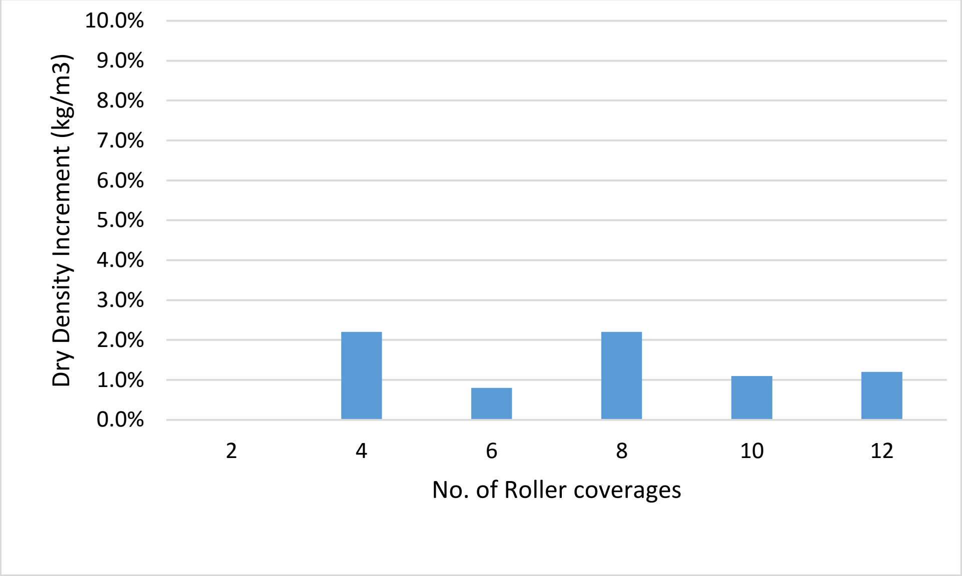


Figure 7-8 Dry Density Increment (kg/m3) at MC= 9.3

Increment of dry density is lower at each roller passes.

7.3.2 Log (No. of Roller Coverages) Vs dry Density

A linear relationship can be noticed between logarithm value of roller coverages and DD. This can be illustrated by Figure 7-9. When MC is 2.4, 3.3 and 4.0 that linear relationship can be observed only at between 4 to 8 roller coverages. At 5.5 moisture level, linearity between DD & logarithm value of roller coverages can be observed after 4 roller coverages. When MC is 6.6 up to 10 roller coverages linear relationship can be seen.

MC 9.3 curve shows the well linear relationship between dry density and logarithm value of roller coverages when compared with other conditions

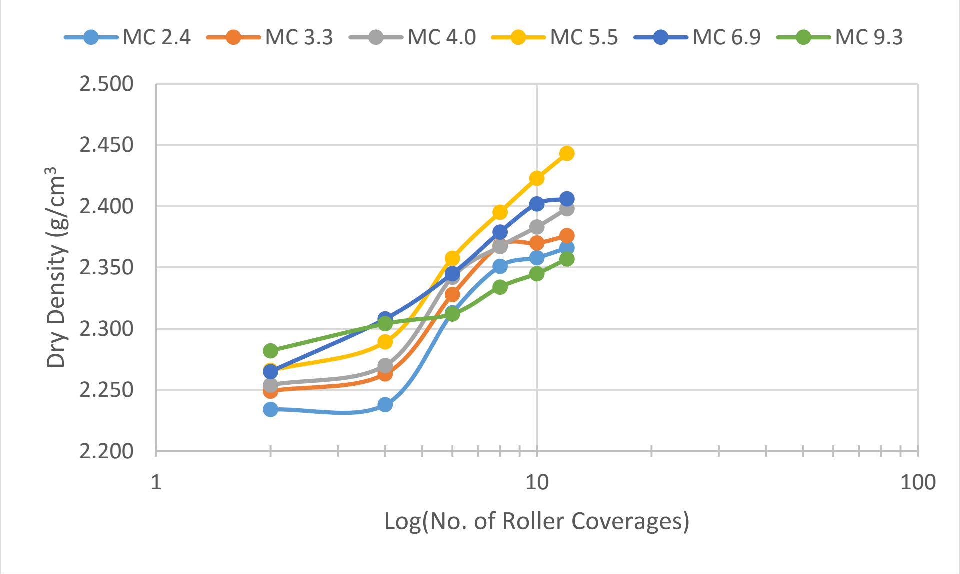


Figure 7-9 Log (No. of Roller Coverages) Vs dry Density

7.3.3 Dry density- Moisture Content curve for field Compaction

The relationship between DD and MC of the field trials are shown in Figure 7-14

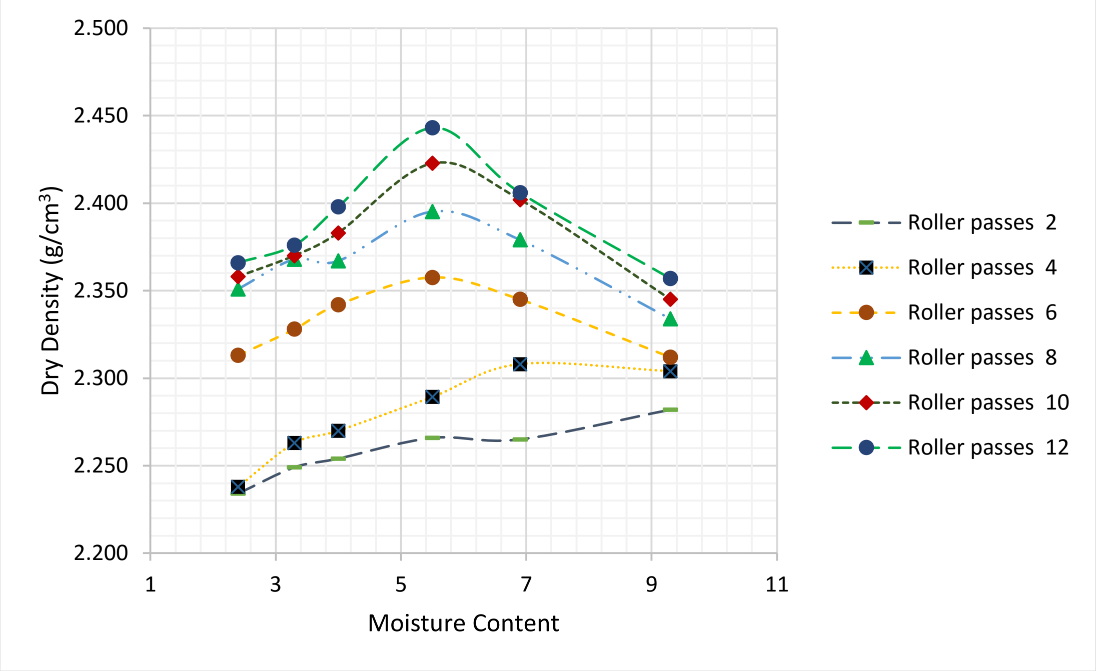


Figure 7-10 DD - MC relationship of the field trials

Table 7-5 MDD & OMC Data of Field Compaction

Number of Roller Coverages	MDD	OMC
2	2.282	9.2
4	2.310	7.8
6	2.352	6.4
8	2.384	5.9
10	2.404	5.5
12	2.410	5.2

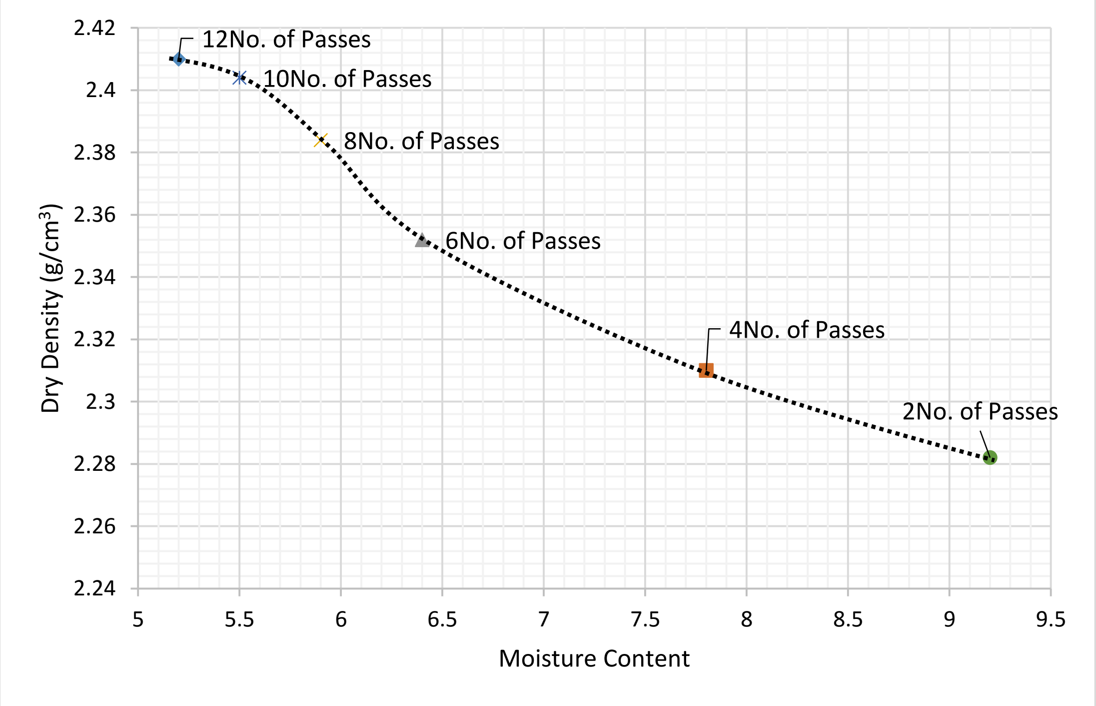


Figure 7-11 MDD & OMC Variation against No of Roller Coverages

These results showed that the variation of MDD & OMC against the number of roller coverages at field condition. A considerable increment of the density can be observed with roller passes. The increment of the density is considerably low after 10 no of coverages. Density of the base is almost same at 10 and 12 passes of roller and it can be observed that highest MDD achieves with lowest MC at 12 roller passes.

7.4 Comparison of Laboratory and Field Compactions

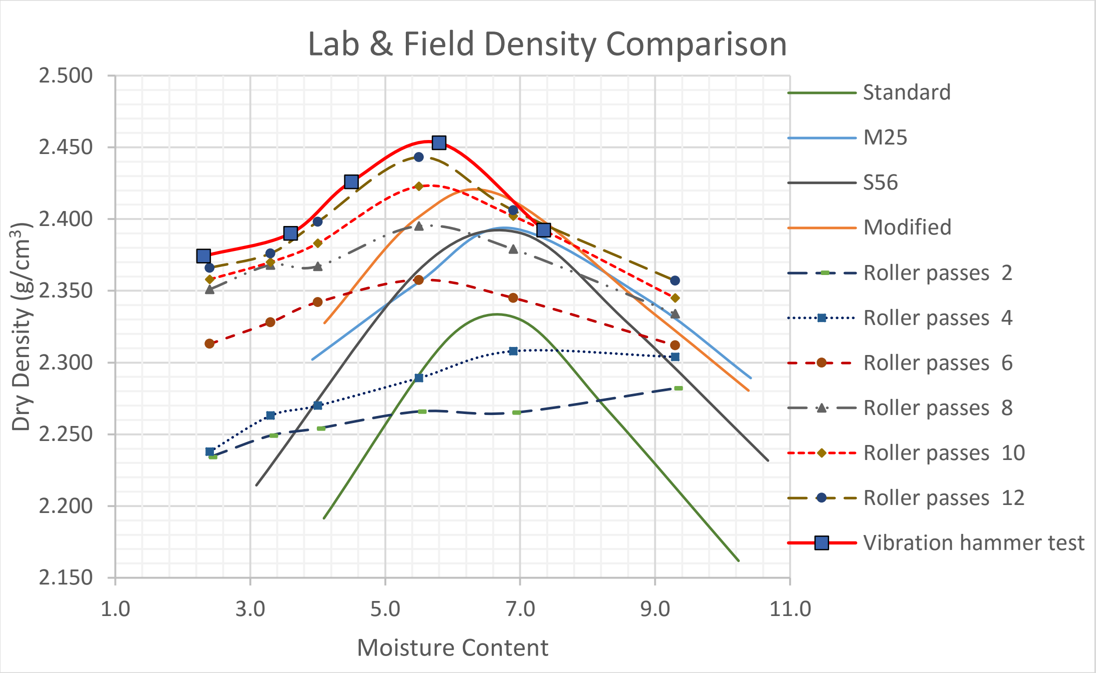


Figure 7-12 Comparison of Lab & Field Compaction Curves

The laboratory compaction curves are compared with field compaction curves in Figure 7-16. From this figure laboratory impact compaction curves show a deviation from the field compaction curves. Vibratory hammer compaction curve shape is more similar to field compaction curves when compared with impact compaction curves.

When MDD's of field and laboratory tests are compared, modified compaction test gives the closer results to the field compaction tests, while vibratory hammer test MDD is much higher than the field results.

Vibrator hammer test's OMC is closer to the field compaction test results than modified test results. OMC of impact compaction test are deviated from that of the field test. OMC is one of important parameter to maintain in the construction. Results of the Vibratory hammer method is very close to the field compaction.

7.5 Data Analysis of Sieve Analysis Tests

7.5.1 Top 100mm Layer

Gradation curves of top 100mm of the DGAB layer

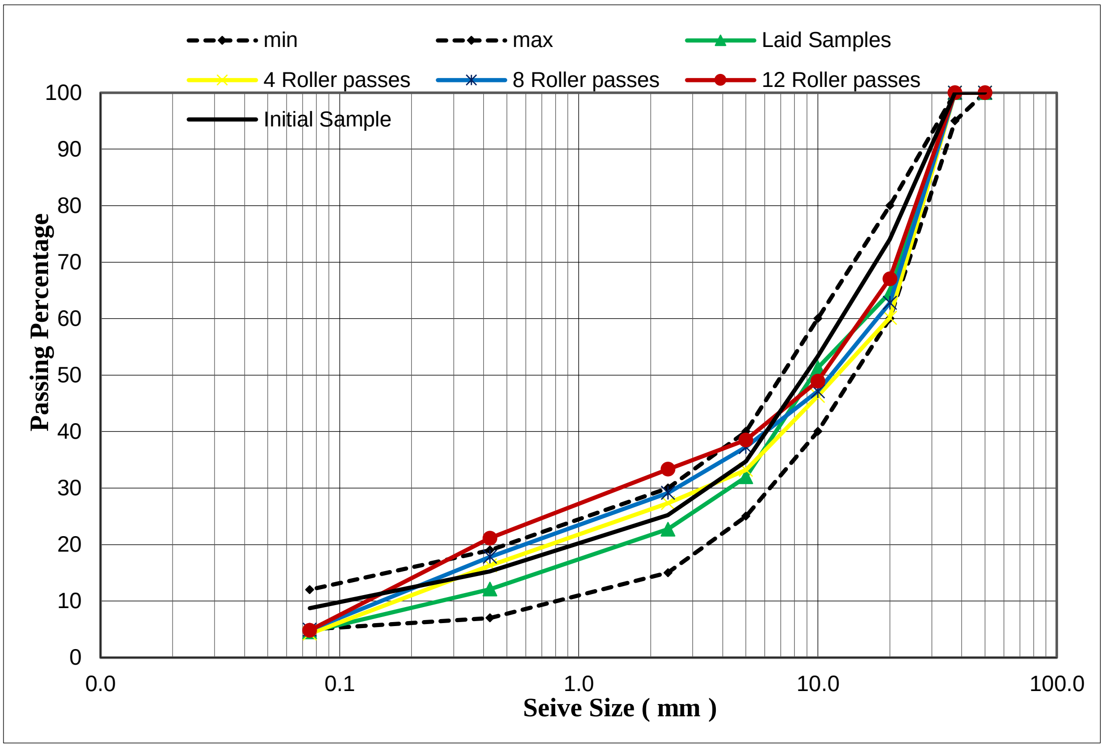


Figure 7-13 Gradation curves of Top 100mm of the DGAB layer at higher moisture content with roller passes are shown in figure 7.17.

Based on the gradation curves of DGAB samples collected from top 100mm, fine content of the layer has gradually increased with roller passes.

Initial sample shows a well graded curve and it is within the specified margins. Gradation curves of laid sample which was watered to increase the MC up to 9.2%, passing percentages of all range of sieve sizes decreased. This effect is significant for fine particles. However gradation still remains within the specified boundaries.

At the end four number of roller coverages percentage passing of fine particles has increased, while coarse particle percentage has decreased and it is within the limits.

After completion of eight number of roller coverages gradation curve shape is same as previous case, but deviation from initial sample is much greater.

The passing percentage of fine particles exceeded the maximum specific limits at the completion of twelve number of roller coverages. Corse particles passing percentage is lower than the initial sample and it is within the specified region.

7.5.2 Bottom 100mm Layer

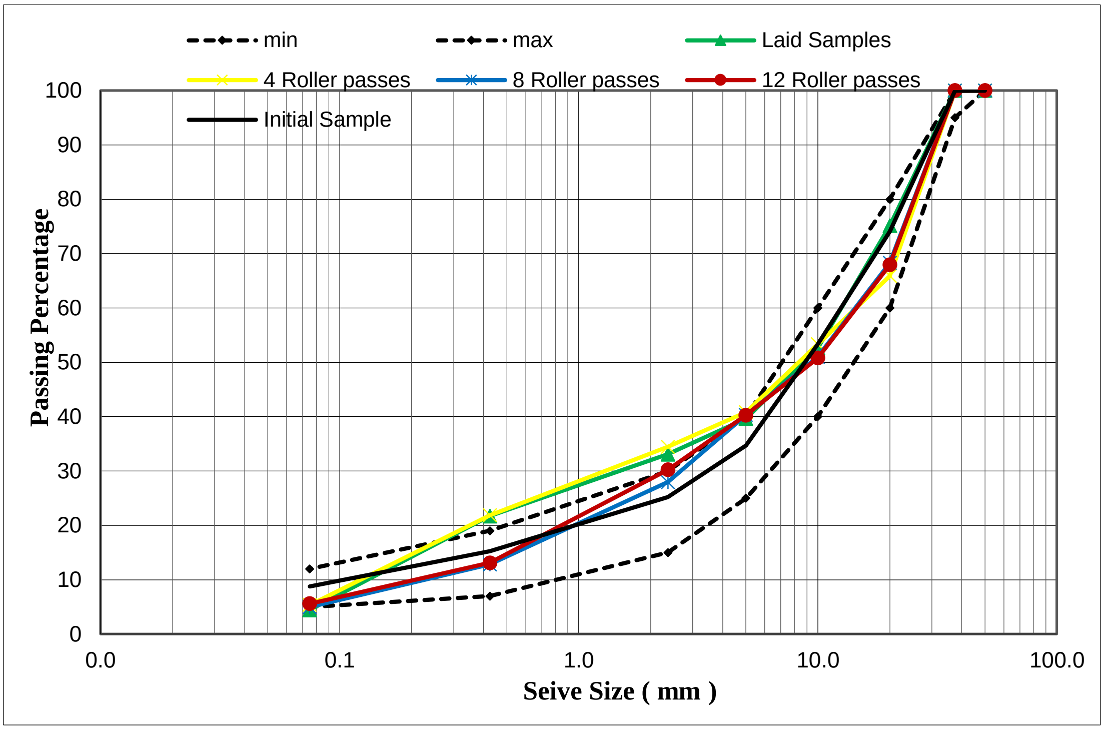


Figure 7-14 Gradation curves of Bottom 100mm Layer

As shown in figure 7.18, the passing percentages of fine particles of laid sample exceeded the maximum specified limits, while coarse particles curve kept same as initial sample.

Gradation curve is almost same as laid sample after four number of roller coverages.

At the end of eight number of roller passes passing percentage of 20mm. 0.425mm, and 0.075mm sieves are lower than the initial sample while 2.63mm and 5mm sieve sizes are higher than the initial sample.

After completion of twelve number of roller coverages gradation curve is similar to previous one and passing percentage of 2.36mm and 5mm sieves are marginally exceed the specified upper limits.

7.5.3 Combine Effect of Gradation

When top and bottom layers are compared following observation can be made.

By adding of too much of water to DGAB layer, fine particles moves from top to bottom. With the starting of compaction, fines particle further moves downwards. With the increase of roller passes, fines start to move upward again. This upward movement further increase with compaction, after twelve number of roller passes, most of fine particles of DGAB layer are deposited on top surface.

8 CONCLUSIONS AND RECOMENDATIONS

8.1 Conclusions

According to the questionnaire survey analysis, it can be concluded that DGAB is compacted under higher moisture content in most of the cases in local context. Sieve analysis test reveals that compacts at very higher MC leads to segregate the DGAB layer

Based on the analysis of field and laboratory experimental results, the following conclusion can be made.

Vibration hammer compaction test gave higher MDD and lower OMC compare to impact compaction test.

The field study showed that higher compaction efforts resulted in lower OMC than those obtained by the modified compaction test. However MDD of the modified compaction was close to the field compaction.

When field compaction curves and Vibratory hammer test results were compared, Vibratory hammer test gave higher DD than field test results and MDD was close to the each other.

The required 98% of compaction could be achieved in the field by applying less than eight number of roller passes when MC is maintained around its OMC. If the MC s deviated from OMC, compaction effort has to be increased proportionately.

8.2 Recommendations

Field compaction under high MC should not be allowed as it misspends the compaction energy and lead to segregate the DGAB layer.

Based on the result of this study, vibratory compaction hammer test is the most suitable laboratory compaction method to simulate the field compaction of DGAB, because compaction curves are much closer to the each other.

Following recommendations can be made for vibratory compaction hammer test when they are used as predetermined test for field compaction.

Vibratory Compaction Hammer Test

Required density for 98% compaction of MDD using modified hammer in study is about 2.373 g/cm^3.

So the recommended compaction level is 97% of MDD of modified compaction test (2.373/2.453x100%)

Recommended MC for compaction is OMC +/- 2 %

However this study was only focused on a 200mmthick DGAB layer and 11 ton vibratory roller as compactor. The research should be expanded to study the effect of different layer thicknesses and compaction efforts to find the correlation between field and laboratory compaction curves.

REFFERENCE LIST

AASHTO. (1982). *ASSHTO Materials, Part ii.* Washington: Ammerican Assoociation of State Highway and Transportation Officials.

Ariyarathne, K. V. (2015). *Segregation Effort of aggregate Base Course during Compaction Process20.* University of Moratuwa.

ASTM. (2007). *Annual Books of ASTM Standards Vol 04.08.* Conshohoen: American Society for Testing and Materials.

BSI. (1990). *Methods of Test for Soil for Civil Engineering Purpose , BS 1377-4.* London: British Standard Institute.

Das, B. M. (2007). *Priciple of Geotechnical Engineering.* Stamford: Cengage Lernining.

Horpibulsuk, S., Sudeepng, A., Chamket, P., & Chinkulkijniwat, A. (2012). *Compaction Behaviour of Fine Grained Soils, Lateric Soils and Crushed Rocks.* Japanies Geotechnical Society.

ICTAD. (2009). *Standard Specification for Construction and Maintains of Highway and Bridges.* Institute forConstructiion Training and Development.

Jesmani, M., Manesh, A. N., & Hoseini, S. (2008). *Optimum Water Content and Maximum Dry Unit Weight of Clayey Gravels at Different Compactive Efforts.* Electronic Journal of Geotechnical Engineering.

Ping, W. P., Guiyan, X., Micheal , L., & Zenghai, Y. (2003). *Evaluation of Laboratory Compacton Techniques for Simulating Feld Soil Compaction.* Tallahassee: Florida Department of Transportation.

Prochska, A. B., Drnevich, V. P., Kim, D., & Sommer, K. E. (2005). *Availability Hammer Compaction Test for Granular Soils and Dense Graded Aggregate.* Wshington: TRB.

Vincent, D., Aaron, E., & Adam, P. (2007). *A Study of Effective Soil Compaction Control of Granular Soils.* Indianapolis: Indiana Department of Transportation .

APPENDIX A: QUESTIONNAIRE FORMAT

APPENDIX B: ROLLER OPERATING DATA