FINAL REPORT

For the Florida Department of Transportation

Evaluation of Laboratory Compaction Techniques for Simulating Field Soil Compaction (Phase II)

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METRIC CONVERSIONS

inches = 25.4 millimeters

feet = 0.305 meters

square inches = 645.1 millimeters squared

square feet = 0.093 meters squared

cubic feet = 0.028 meters cubed

pounds = 0.454 kilograms

poundforce = 4.45 newtons

poundforce per square inch = 6.89 kilopascals

pound per cubic inch = 16.02 kilograms per meters cubed

DISCLAIMER

"The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Department of Transportation or the U.S. Department of Transportation. This publication is prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation."

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(Phase II)

PROBLEM STATEMENT

Due to the development of much heavier earth moving and vibratory roller compaction equipment, densities in the field are reaching levels that are not attainable in the laboratory. Higher compaction efforts, routinely seen in the field, not only result in higher unit weights bot also lower optimum moisture contents than those found by the modified Proctor test. The optimum moisture content (OMC) obtained in the laboratory is often higher than that in the field compaction. Consequently, in the field compaction the maximum density compacted using the laboratory OMC will be lower than that obtained using the field OMC. In addition, the impact compaction method does not work well with the pure sandy soil.

A suitable compaction test procedure is evidently needed, which will produce laboratory densities as great or greater than those being obtained under field compaction and traffic in actual pavements and one that will work well for the cohesionless A-3 soil. On the basis of findings from Phase I study, the gyratory compaction is the potential test procedure to achieve these goals.

OBJECTIVES

The primary objective of this project was to further the Phase I study, which was to investigate the potential of using gyratory compaction for field simulation, and try to establish the standard test procedure for compacting silty and sandy soils. The objectives included examination of the effects of the gyratory compaction variables on laboratory-compacted specimens, comparison with other compaction methods such as impact and vibratory compaction, and correlation of these data from the gyratory, impact and vibratory compaction to the results from field tests. Several laboratory compaction procedures were evaluated to determine which would best replicate the field compaction effort.

FINDINGS AND CONCLUSIONS

The findings and conclusions based on the analysis of this experimental study are summarized below.

1. The impact compaction method was not an adequate laboratory test procedure to specify the maximum dry unit weight and optimum water content for the field compaction of cohesionless soils. The study showed that higher field compaction efforts resulted in higher unit weights and lower optimum moisture content than those obtained by the modified Proctor compaction test.
2. Gyratory compaction was more reliable than impact compaction when fine sands were compacted in the laboratory.
3. For the gyratory compaction test, using the vertical stress as a means of increasing the dry unit weight was not effective when the vertical stress was higher than 200 kPa. The 200 kPa stress level was within the range of peak vertical soil stresses measured during the field compaction tests.
4. The gyration angle had some effect on the dry unit weight when the soil had lower percent of fines, and when the number of gyrations was higher. When the soil became more silty (with more than 6% fines), the influence of the gyration angle on the dry unit weight became less significant.
5. When the number of gyrations was increased, there was a continuous increase of dry unit weight, which needed to be adjusted to get the desired dry unit weight.
6. The gyratory test procedure conducted with 200 kPa vertical pressure, 1.25 degree gyration angle, 90 gyrations, and 20 gyrations per minute showed considerable promise for replicating field compaction characteristics.
7. A gyratory compaction test procedure was proposed for determining the maximum dry unit weight and optimum moisture content of the granular soils with a gyratory compactor under conditions that simulated field compaction.

RECOMMENDATIONS

Based on this study, gyratory compaction was the most suitable technique to simulate field compaction for granular soils. The research should be expanded to study the effect of those gyratory variables on clay soils in laboratory as well as to monitor the performance of the clay soils under field compaction.

In Florida, most subgrade soils are classified as A-3 fine sand and A-2-4 silty soil. The gyratory compaction procedure has great potential to be the construction specification for quality control of field compaction. A further research study is recommended for possible implementation of the gyratory compaction method in design and construction.

CHAPTER 1

INTRODUCTION

1.1 Background

Fill materials are used in almost all roadway construction projects. When fill materials are used, the engineering properties of the soil need to be improved through compaction. The primary benefit of compacting soil is to increase its strength.

When fill soils are used, testing is required in the laboratory first, in order to determine their maximum dry densities and their optimum moisture contents (OMC). Compacting fill at their optimum moisture content is the most economical technique that a contractor can use to reach the required density of the material. Over the years, several techniques have been developed to compact soils in the laboratory. These include impact, static, kneading, and vibratory compaction. All of these methods are used to determine the density to which soil can be compacted in the field.

Although it has no resemblance to any type of field compaction, impact compaction is by far the most popular laboratory technique; due largely to the fact that impact compaction was the first technique to be standardized. As a result, impact compaction tests have been used for decades and a broad base of data exits for comparison. The tests most commonly used in modern construction are the Standard and Modified Proctor tests. The Standard Proctor test was originally developed in the 1930s to represent the highest degree of compaction achievable in the field at that time. The test was modified in the 1940s but has remained unchanged for decades.

1.2 Problem Statement

Due to the development of much heavier earth moving and vibratory roller compaction equipment, densities in the field are reaching levels that are not attainable in the laboratory. Higher compaction efforts, routinely seen in the field, not only result in higher unit weights but also lower optimum moisture contents than those found by the Modified Proctor test.

The data illustrated in Figure 1.1 show that this result is experienced in the field due to the higher compaction energies produced by modern heavy compaction equipment. Due to this phenomenon, the optimum moisture content (OMC) obtained in the laboratory, is often higher than that in the field compaction. Consequently, in the field compaction the maximum density compacted using the laboratory OMC will be lower than that obtained using the field OMC (point A versus point B in Figure 1.1). In addition, the impact compaction method does not work well with the pure sandy soil.

A suitable compaction test procedure is evidently needed, which will produce laboratory densities as great or greater than those being obtained under field compaction and traffic in actual pavements and one that will work well for the cohensionless A-3 soil. From the Phase I study, the gyratory compaction is the potential test procedure to achieve these goals.

1.3 Scope of the Study

The primary objective of this project is to further the Phase I study, which was to investigate the potential of using gyratory compaction for field simulation, and try to establish the standard test procedure for compacting silty and sandy soils. The first objective of this study is to examine the effects of the gyration compaction variables (vertical pressure, angle of gyration, and number of gyrations) on laboratory-compacted specimens of soil material. Samples of the soil were prepared and compacted in the gyratory machine. During compaction, two of the three variables were held constant while the third was allowed to run through a given range of values. This procedure was repeated for each of the three variables of the machine.

The second objective is to compact these soil samples with other compaction methods such as impact and vibratory compaction, and correlate these data from the gyratory, impact and vibratory compaction to the results from field tests. The field and laboratory results were analyzed to determine the appropriate procedures to simulate the field compaction efforts in the laboratory. Several laboratory compaction procedures were evaluated to determine which would best replicate the field compaction effort.

In addition, the energy from the gyratory compaction was calculated and compared to the energy from the Standard and Modified Proctor methods. Through this study, the gyratory test procedure will be explored to determine if it shows more promise than the impact compaction method.

1.4 Report Organization

This report summarizes the results of the study on field and laboratory compaction characteristics and the analysis of the experimental results.

Chapter 1 presents the background, problem statement and objectives of the field and laboratory programs. A brief literature review of previous research in soil compaction is presented in Chapter 2. A review of the field experimental program and results is summarized in chapter 3. The laboratory experimental program, test material, and laboratory test results are summarized in Chapter 4. The analysis of field and laboratory experimental results, and further correlation of the laboratory test results to the field results are presented in Chapter 5. Finally, conclusions and recommendations of this research study are summarized in Chapter 6. The energy calculation for gyratory compactor is introduced in Appendix A. The proposed test procedure for soil compaction with a gyratory compactor is presented in Appendix B.

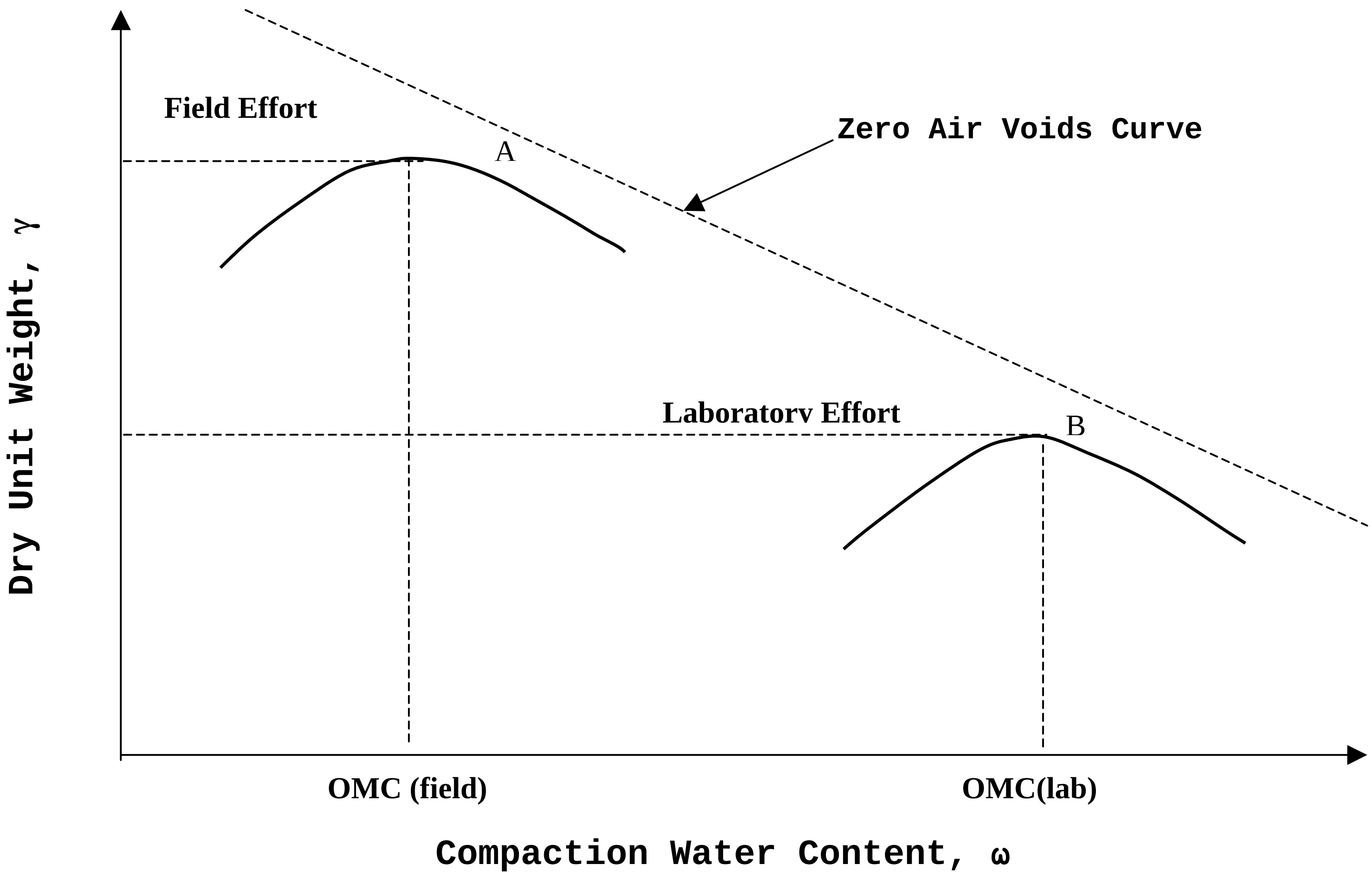


Figure 1.1 Effect of compactive effort on the compaction curve

CHAPTER 2

LITERATURE REVIEW

2.1 Background

Fill materials are used by engineers for a variety of purposes, e.g., to build dams, construct embankments, develop low-lying land, support pavements, and make sites more suitable for support of foundations. With such fills, compacting the soil is almost always necessary to improve the engineering properties. Although the relationships among compacted properties and the variables of the compaction process are most properly studied in the field, this procedure is expensive and time consuming. Accordingly, in the present state of the art, the above relationships are established in the laboratory. But this approach has serious intrinsic limitations, because field compaction is achieved by different modes and at different energy levels than in the laboratory and more variability exists in all variables in the field.

In order to simulate the different field compaction methods, a number of techniques have been developed to compact soil in the laboratory – most of the tests fall into four types:

- **Impact** compaction tests in which a standard weight is repeatedly dropped on the soil sample for a prescribed number of blows. The weight is adjusted to achieve the desired compaction effort.
- **Static** compaction tests in which a uniform pressure is applied to the soil and maintained long enough for the soil to compact under the pressure.
- **Kneading** compaction tests in which a small "foot" is loaded, then unloaded, at various locations on the surface of the sample being compacted; the soil is effectively kneaded with this procedure.
- **Vibratory** compaction tests in which the soil is vibrated as it is compacted, which is particularly effective in compacting cohensionless soil such as sand and gravel.

Ideally, the laboratory compaction tests should simulate the characteristics of soil compaction used in field procedures. The direct consequence of soil compaction is densification of the fill. 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 unit weight achieved in a specific laboratory compaction test. Construction specifications based on this principle are known as “end-result” specifications. Many laboratory soil compaction procedures are available. Most of these procedures utilize either impact compaction or vibratory compaction. These include the tests based on the Proctor hammer (AASHTO T 99 and T 180), those using vibratory compaction (ASTM D 4253), and procedures based on the Texas State Highway Department gyratory soils press. Details of these test procedures as well as their applications are presented in the following sections.

2.2 Impact Compaction

The most common impact compaction tests are the standard and modified Proctor tests, AASHTO T 99 and T 180, respectively. Developed in the 1930s and 1940s, these tests were the first to be standardized and as a result a broad base of data exists for comparison. One downfall of the Proctor tests is that impact compaction has proved to be relatively ineffective for the compaction of noncohesive soils because the material displaces under the hammer, and consequently low-density values are obtained. Despite this fact, the majority of states use these test procedures in their construction specifications.

2.2.1 Standard Proctor compaction procedure

This test procedure covers laboratory compaction procedures used to determine the relationship between water content and dry unit weight of soils compacted in a 4 or 6 in. diameter mold with a 5.5 lb. hammer dropped from a height of 12 in. (Figure 2.1) (AASHTO, T99), producing a compactive effort of 12,400 ft-lb/ft^3. A soil at a selected water content is placed in three layers into a mold of the given dimensions, with each layer compacted by 25 blows of the hammer. The resulting dry unit weight is then determined. This procedure is repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content of the soil. This test procedure applies only to soils that have 30% or less by weight of particles retained on the 3/4 in. sieve. Generally a well-defined maximum dry unit weight will be produced for non-free draining soils. If this test method is used on free draining soils the maximum unit weight may not be well defined and can be less than that obtained using the ASTM test procedure D 4253 (vibratory compaction).

2.2.2 Modified Proctor compaction procedure

The Modified Proctor compaction procedure is a test method that covers laboratory compaction procedures used to determine the relationship between water content and dry unit weight of soils compacted in a 4 or 6 in. diameter mold with a 10 lb. hammer dropped from a height of 18 in. producing a compactive effort of 56,000 ft-lb/ft^3. Five layers of soil at a selected water content are placed into a mold of the given dimensions, with each layer compacted by 25 blows of the hammer. The resulting dry unit weight is then determined. This procedure is repeated for a sufficient amount of water contents to establish a relationship between the dry unit weight and the water contents of the soil. This test procedure applies only to soils that have 30% or less by weight of particles retained on the 3/4 in sieve. Generally a well-defined maximum dry unit weight will be produced for non-free draining soils. As with the Standard Proctor test procedure, if this test method is used on free draining soils the maximum unit weight may not be well defined, and can be less than that obtained using the ASTM test procedure D 4253 (vibratory compaction).

2.3 Vibratory Compaction

For many cohesionless free draining soils, impact compaction does not yield consistent results. As a result, several test procedures have been developed using vibratory compaction. These test procedures produce more consistent results than impact compaction, for the compaction of granular soils. Vibratory compaction also provides a better correlation between the field and the laboratory results, since most field compaction is performed with vibratory compaction equipment.

2.3.1 Vibratory compaction test procedures

The most common laboratory test that utilizes vibratory compaction is the ASTM D 4253, Maximum Index Density and Unit Weight of Soils Using a Vibratory Table, test procedure. Since the development of the ASTM test, several alternative methods have been presented, but none has received wide spread acceptance. One of these alternatives was a vibratory compaction procedure developed by the Concrete and Soil Laboratory of AB Vibro-Verken, Solna, Sweden in the 1960s. This compaction method utilized a vibrating tamper to compact soils. The developers of this procedure claimed that the results obtained during the compaction of cohesionless soils were similar to those obtained by the Modified Proctor impact compaction test. This claim detracted from the validity of this procedure because the Modified Proctor test is not suitable for round noncohesive soils due to the material displacement under the compaction hammer. No other proposed method of vibratory compaction has proved to be as suitable as the ASTM D 4253 test procedure.

2.3.2 ASTM D 4253 vibratory test method

The ASTM D 4253 test method covers the determination of the maximum index density/unit-weight of cohesionless, free-draining soils using a vertically vibrating table. This test method is applicable to soils that may contain up to 15%, by dry mass, of soil particles passing a No. 200 sieve, provided they still have cohesionless free-draining characteristics. Further, this test method is applicable to soils in which 100%, by dry mass, of soil particles pass a 3 in. sieve. The maximum index density/unit weight of a given free draining soil is determined by placing either oven-dried or wet soil in a mold, applying a 2 lb/in. surcharge to the surface of the soil, and then vertically vibrating the mold, soil, and surcharge. The assembly is vibrated using either an electromagnetic, eccentric, or cam-driven vibrating table having a sinusoid-like time-vertical displacement relationship at double amplitude of vertical vibration of about 0.013 in. for 8 min. at 60 Hz or about 0.019 in. for 10 min. at 50 Hz. The maximum index density/unit weight is calculated by dividing the oven-dried mass/weight of the densified soil by its volume. The detail equipment setup is shown in Figure 2.2 (ASTM D4253).

2.4 Gyratory Compaction

In recent years, the use of gyratory compactors in the asphalt paving industry has become very common; primarily due to the advent of the SUPERPAVE asphalt mix design method. Most of the SUPERPAVE gyratory compactors were developed from a manually operated device that was used for many years by the Texas State Highway Department. The Texas Highway Department referred to this device as a gyratory soils press. The soils press was used on both soils and blackbase (asphalt stabilized and emulsion base) materials. This soils press led to the development of the U.S. Army Corps of Engineers Gyratory Testing Machine (GTM)(Figure

2.3)(U.S. Army 1968) and the GTM in turn led to the development of the current gyratory compactors.

2.4.1 Gyratory Testing Machine (GTM)

The U.S. Army Corps of Engineers (1962) conducted an investigation into the use of gyratory compaction for determining density requirements for subgrade and base materials. This research took place at the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, as part of an overall investigation of flexible pavements and soil compaction. The Corps of Engineers found that the AASHTO impact compaction tests proved inadequate in some instances, particularly with cohesionless soils. As a result of these inadequacies, excessive settlement was experienced in the subgrade and/or bases of some flexible pavements. The settlement was due to densification caused by traffic after construction. This indicated that traffic had a greater compacting effect than the compaction achieved during construction. The Corps realized a need for an improved compaction procedure to eliminate these settlement problems.

As stated earlier, the Corps of Engineers had developed their GTM from a device used by the Texas Department of Transportation (formerly Texas State Highway

Department). During the initial development of the Gyratory Testing Machine, the Corps of Engineers undertook a study of the major test variables. During this study, the Corps made several observations. First, the rate of kneading had little or no effect on densification. Additional findings show that increased vertical pressure resulted in a consistent increase in unit weight, that an increased number of revolutions resulted in a consistent increase in unit weight, and that the optimal gyration angle should be between one and two degrees.

2.4.2 GTM test Procedure

Early study information was used to develop test procedures for both bituminous paving mixtures and soils. Most relevant to this report is the proposed Corps of Engineers test procedure (U.S. Army, 1962) for compacting soils with the GTM. This test procedure was proposed as an alternative to the AASHTO impact compaction tests. The procedure suggested the use of compaction pressures based on the theoretical vertical stresses produced at various depths by the anticipated wheel load. The proposed test procedure is listed below:

- Obtain a representative sample of the soil or base course material for the proposed pavement.

- Select a water content for the test specimen that will be representative of the anticipated water content of the material in the field immediately after construction.
- Assuming equivalent circular loading for each tire contact area, calculate theoretical vertical pressure versus depth for the anticipated wheel loading.
- Thoroughly mix the sample of soil or base material at the selected water content and then compact it in the gyratory compactor for 500 revolutions at a one-degree gyration angle using the vertical pressures corresponding to those computed for several depths beneath the wheel load.
- Calculate the dry density of the soil or base material on the basis of vertical movement of the compression ram of 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 revolutions for each selected depth. On these density versus revolutions curves, mark the point where the

next 100 revolutions caused an increase in dry density of only one pound per cubic foot. The density at this point will be considered the required construction density for the proposed material at the selected depth.

2.4.3 Comparison of GTM Test Results

The Corps of Engineers used this procedure to compare field results with those obtained in the laboratory. They used construction and after-traffic density data that was available from two field test sections. The materials used at the test sections included a limestone aggregate base course and a sand-gravel subbase from Columbus Air Force Base, Columbus, Mississippi; and a sand-gravel subbase, and a sand subgrade from the channelized traffic test section No. 2 at the Waterways Experiment Station. The Corps used these data to compare the after-traffic densities from the field sections to those densities determined using the gyratory compactor. The after-traffic and gyratory densities were also compared to the modified AASHTO compaction test results as well as the construction densities. The Corps of Engineer conclusions showed a good correlation between the gyratory computed construction density and the final field density for the four cohesionless subgrade and base materials tested. In addition, they found that the densities obtained using the proposed gyratory test procedure showed a better correlation with the after-traffic densities than those results obtained with the AASHTO compaction test (1962).

The above literature study shows evidence that equilibrium under the tire pressures on the roadway should logically be insured by using not less than the anticipated maximum tire pressure in the compaction of the laboratory specimen. The gyratory testing machine accomplished kneading type compaction under any selected compaction pressure and degree of kneading, thus it provided a rational compaction test for the pavement design engineer. The gyratory testing machine is called a testing machine to distinguish it from a machine used for compaction purposes only, since it is used for other tests including stability or shear tests. This machine can record the shear stress changing with time and height changing with time, so data are easily obtained to calculate energy after each test, without intending to do certain tests to get shear stress.

2.5 Potential Use of Gyratory Compactor for Soil Compaction

In this report, this new compaction technique will be evaluated for compacting soil. The hypothesis is that the new SUPERPAVE gyratory compactors can also be used to compact soils in the laboratory. Several reasons can be given for the beneficial use of gyratory compactors. One reason is that gyratory compaction has a stronger resemblance to field compaction than impact compaction does. This means that the internal structure of specimens created with a gyratory compactor may show a closer resemblance to that resulting from actual field compaction and traffic. A gyratory compactor has the ability to simultaneously apply a vertical load in addition to a self-adjusting kneading action which simulates the moving traffic load experienced by a flexible pavement system (John L. McRae, 1965). In addition to the physical similarities to field compaction, gyratory compactors are generally more precise, effective, and repeatable than impact hammers.

Currently there are no standard test procedures for compacting soil with a SUPERPAVE gyratory compactor. The only previous research available was conducted using the Texas gyratory soils press or the Army Corps of Engineers GTM (1968, 1969). In this study, the gyratory compaction variables will be studied to establish a standard test procedure for soil compaction with a gyratory compactor.

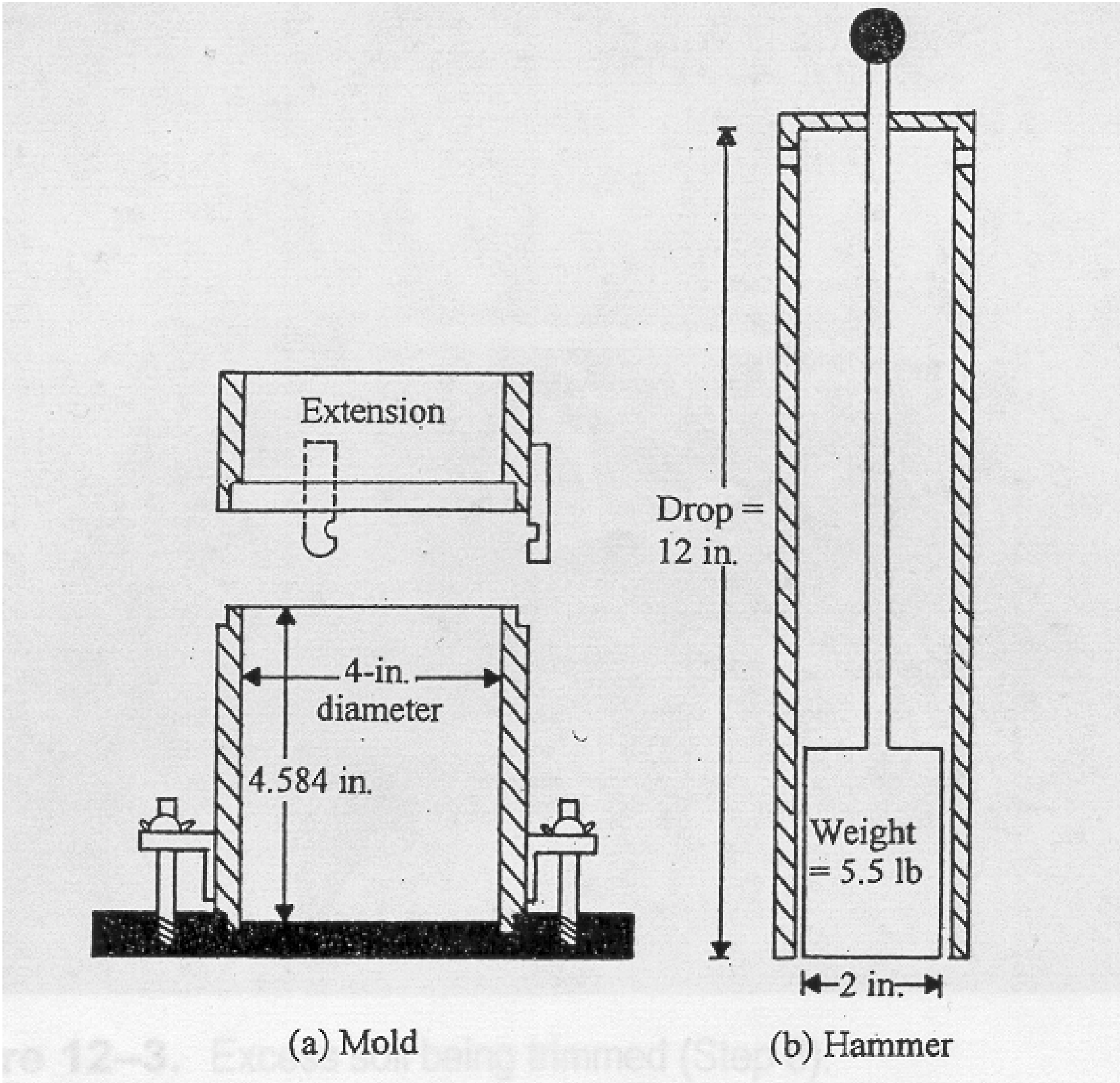


Figure 2.1 Standard Proctor mold and hammer

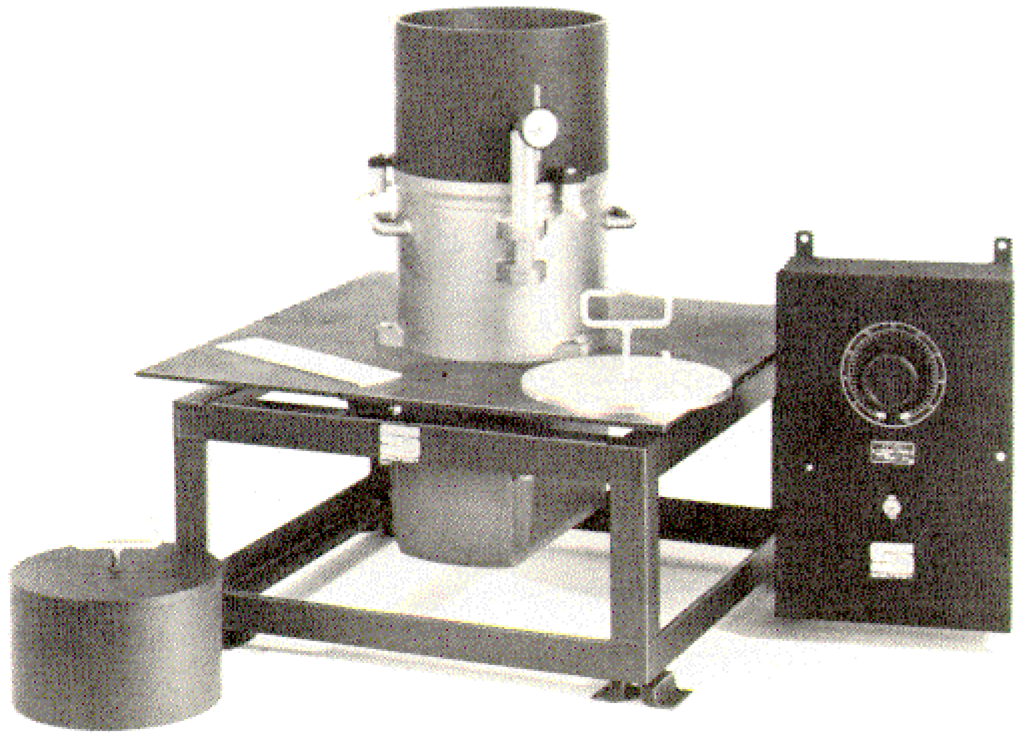


Figure 2.2 Vibratory table and mold assembly

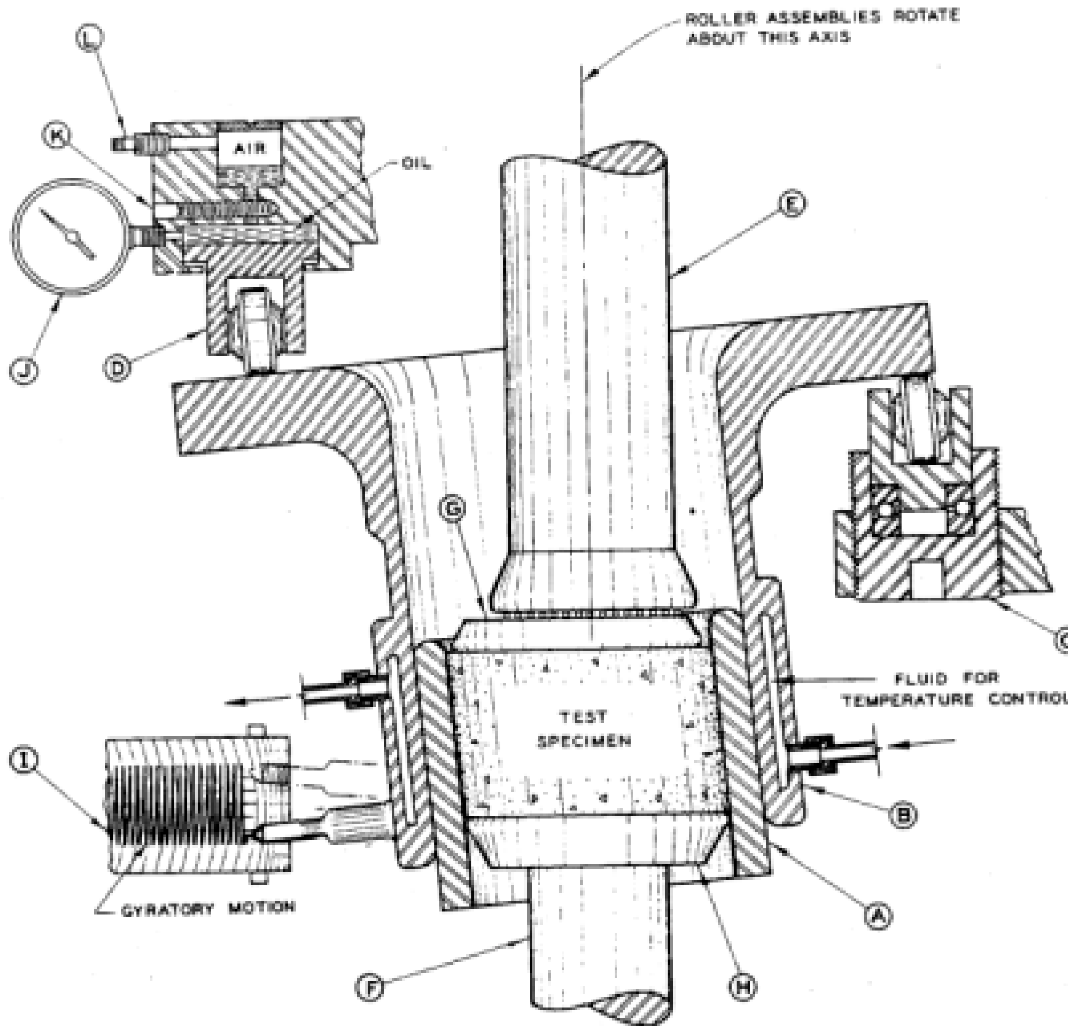


Figure 2.3 Schematic illustration of gyratory testing machine
(U.S. Army Corps of Engineers)

CHAPTER 3

FIELD COMPACTION CHARACTERISTICS

3.1 Introduction

The main objective of this study is to evaluate the applicability of laboratory gyratory compaction for simulating field compaction. Correlations are necessary between the density produced in samples of soil material compacted by the gyratory compaction and the density produced in the field compaction. Therefore the field test was the first step in this research study.

Three field test sections were carried out for this study. The materials used in these field test sections were compacted in the laboratory with the gyratory compaction in order to develop a compaction curve that serves as a comparison to field compaction data. Through this comparison, determinations were made on the effectiveness of current construction specifications. The field tests focused on construction sites utilizing sandy soils as embankment or stabilized subgrade materials. These test sites were selected for two reasons, first, sandy subgrades are very common in Florida and second, sandy soils proved to be the most difficult to use with the current impact compaction standards.

3.2 Thomasville Road Field Test

The first field test was conducted on August 25, 1999. The test section was part of the reconstruction of Thomasville Road (U.S. 319) in Tallahassee, Florida.

3.2.1 Thomasville Road field test procedure

For the Thomasville Road field test, the stabilized subgrade was placed on five test strips, each approximately 300 feet long and 25 feet wide (Figure 3.1). The test strips were compacted at increasing levels of water content, using an identical compaction pattern with two different compactors. The first was a Dynapac CA 251 padfoot vibratory roller. This compactor weighs approximately 25,000 pounds and features a 60 inch drum with four inch pads. The second compactor was a Caterpillar CS 563C smooth drum vibratory roller. It also weighed 25,000 pounds and had a 61 inch drum. The first test section was mixed, to a depth of 12 inches, at the in-situ moisture content (approximately 7%). Once the subgrade was mixed, it was compacted using four passes of the sheepsfoot roller followed by four passes with the smooth drum roller. One pass is defined as both the forward and backward motion of the roller. This compaction pattern was the standard pattern being used by the contractor on the rest of the project site. After compaction, density was measured at three locations along the test strip. Density measurements were accomplished using a nuclear density gage at depths of six and 12 inches. In addition to the nuclear density tests, a speedy moisture test was conducted to determine the moisture content at each location. Once the density and moisture measurements were taken, the strip was compacted again using the same pattern. Density and moisture measurements were repeated following the second compaction.

After the completion of the first test strip, work moved to the second strip. The moisture content on the second test strip was raised, from the in-situ moisture, by running a water truck over the strip. Running the water truck over the strip one time resulted in an increase in moisture content by approximately two percent. The test strip was then mixed and compacted using the same technique used on the first, with density and moisture measurements taken in the same manner described earlier. This procedure was repeated on the five test strips with each strip receiving more water than the previous one.

3.2.2 Thomasville Road field test results

The density and moisture data obtained during the field test was used to develop field compaction curves at the two different energy levels. The energy levels corresponded to the number of compactor passes applied to the test strips. The first energy level represented four passes each by the sheepsfoot roller and the flat drum roller. The second energy level reflected an additional four passes (eight total) by each of the compactors. Although nuclear density measurements were taken at depths of 12 and six inches, the 12 inches measurements proved to be more consistent and therefore were used to analyze the field test results. The compaction curves for the two energy levels are shown in Figure 3.2. The soil is A-3 fine sand with about five percent fines (Figure 3.3).

Evaluation of the field compaction data indicated some variability. This variability of the data may have been caused by the discrepancy of the compacted material at different conditions. Figure 3.2 shows that the increase in compactive energy during the field test had little effect on the maximum dry density and the optimum moisture content of the subgrade soil. In future field tests, it may be necessary to start with a lower initial compactive effort, in order to better define the relationship between compactive energy and the maximum density and OMC.

3.3 Sun Coast Parkway Field Test

In February 2000, a second field test was conducted at the Sun Coast Parkway construction site, near Brooksville, Florida. The field test procedures follow:

3.3.1 Sun Coast Parkway field test procedures

The test procedures at the Sun Coast Parkway site were slightly different than that used at the Thomasville Road site due to the limitations of the test site area. The length of the test site would not allow for the test strips to be aligned adjacent to each other. To accommodate this limitation, test strips were constructed in lifts on top of each other. Three different adjacent areas were used to construct these lifts. The first three lifts were constructed in Area one (Figure 3.4), Area two was the site of two lifts, and Area three was the site of the final lift. The six test lifts were approximately 200 feet long and 50 feet wide. The lifts were constructed so that the after compaction thickness was approximately 12 inches. The soil used during the field test was a yellow-brown sand with approximately three percent fines, classifying it as A-3 in the AASHTO classification system (Figure 3.3). The soil was compacted with an Ingersoll-Rand SD 100 smooth drum vibratory compactor. This compactor is very similar to the smooth-drummed vibratory roller that was used for the Thomasville Road field test. The compactor was operated at its highest vibratory frequency and at maximum speed, in accordance with the contractors usual operation.

The first test lift was compacted at the in-situ moisture content at approximately four percent. After six passes of the vibratory roller, density and moisture measurements were taken at two locations in the center of the test strip. Both the density and moisture measurements were conducted using a nuclear density gage at depths of six and 12 inches. After the measurements were completed the test strip was compacted with an additional four passes (10 total) of the compactor. Following the second compaction, the density and moisture content of the strips were retested. After the second set of measurements were taken, the second test lift was constructed on top of the first. Once the soil had been loosely placed, a water truck was used to raise the moisture content of the test strip. The second lift was then compacted in the same manner as the first, and density and moisture measurements were conducted after six and 10 passes. Using this same procedure, the third test lift was constructed on top of the second.

After the third test lift had been completed, the work moved to the second test area. Test Area 2 was the site of the next two test lifts. These lifts were put on embankment soil that had been placed there previously by the contractor. The embankment soil had been compacted to the density required in the construction specifications and provided the same support to the test lifts as was experienced in Test Area 1. The fourth and fifth test lifts were completed using the same procedure as described above, with each test lift having a higher moisture content than the previous one. The final test lift was constructed in the third test area, on top of the previously compacted embankment material. A summary of the compaction method and test results is presented in Table 3.2

For the Sun Coast Parkway field test a compactive energy study was conducted simultaneously on the same test lifts by Ardaman & Associates, Inc. The test procedure and test results can be found in a report submitted by Ardaman & Associates, Inc (Ardaman & Associates, 2001). A schematic plan and profile of this program for Test Site 1 is presented in Figure 3.4. As shown, one earth pressure cell was installed at the base of each lift, aligned with the approximate centerline of the roller track.

3.3.2 Sun Coast Parkway field test results

As previously described for the Thomasville Road field test, the density and moisture measurements taken during the Sun Coast Parkway field test were used to develop field compaction curves. During the Thomasville Road field test, very little increase in density was achieved after eight passes of the compaction equipment. For this reason, it was determined that the compaction curves for the second field test would start at a lower compaction level. The first compaction curve for the Sun Coast Parkway field test represented a level of compaction equivalent to four to six passes of the field compactor. The second compaction curve used data points taken after 10 to 12 passes. The Sun Coast Parkway compaction data covered a wider range of moisture content than the Thomasville Road compaction data. This helped in constructing more complete compaction curves. By using lower compaction energy levels than those used in the first field test, a better correlation was made between density and the number of roller passes in the field. Although nuclear density measurements were taken at depths of six and 12 inches, only the 12-inch measurements were used for the compaction curves. As was experienced during the Thomasville Road field test, nuclear density measurements taken at a depth of six inches proved to be inconsistent.

The low fine content of the soil presented a problem which was keeping the test strips at the water content above approximately eight percent during the field test. The free draining soil would not hold large amounts of water unless an excessive amount of water was applied. As a result, the moisture measurements during the field test tended to be on the low side of optimum. Even with this phenomenon, the contractor did not experience any difficulty bringing the soil to the required density; once again showing that the current construction specifications for sandy soils are not representative of field conditions. In addition to the low moisture contents, several density measurements taken from the first test lift had to be disregarded. Several of the 12-inch density measurements taken from the first test lift were excessively high suggesting that the test depth was at or near the interface between the natural ground and the fill soil. The remaining data points were used to develop the compaction curves seen in Figure 3.5.

As can be seen in Figure 3.5, the maximum density on the four to six pass compaction curve is 107 lbs/ft^3 and the optimum moisture content is approximately twelve percent. When the compactive energy was increased to 10 to 12 passes of the compactor, the maximum density increased to 110 lbs/ft^3. The highest density on the 10 to 12 pass curve occurred at a slightly lower moisture content than the maximum density on the four to six pass curve. This result is consistent with the hypothesis presented in the literature review of this report.

The magnitude of the peak dynamic impact stress measured during the roller pass is plotted versus the number of passes and compactor travel speed in Figure 3.6.

As shown, the peak stress tends to increase slightly at the first three passes. This observation may reflect that a slight increase in soil stiffness accompanying the increasing dry density is causing slight increases in the vertical roll displacement and thus the apparent increase in the applied dynamic stress amplitude.

The data in Figure 3.6 suggest that the peak stress is not highly dependent on the compactor travel speed when the compactor is operated at conventional speeds (i.e., between 4 and 6 feet per second or about 3 to 4 mph). However, considerably higher peak dynamic stress magnitudes were measured at travel speed slower than about 2 feet per second. Considering an average vibration frequency of 28.5 Hertz, the impact spacing at travel speeds less than about 2 feet per second is less than one inch. As illustrated in Figure 3.6, a slight heave of the fill surface was observed just ahead of the roller (which is typically expected for cohesionless materials). Since this surface “heave” is likely less stiff which may have a higher damping potential, lower peak stresses may be expected at higher travel speeds (i.e., where the impact spacing increases such that the drum impacts the heaved surface).

Peak impact stresses measured during low and high amplitude vibratory compaction at conventional travel speeds (4 to 6 feet per second) are also plotted versus depth in Figure 3.6. The relationship of dry unit weight versus number of passes is plotted in Figure 3.7.

3.4 State Road 56 Field Test

The third and final field test was conducted on November 20, 2000. The location of the field test was the State Road 56/I-75 interchange construction site near Land O'Lakes, Florida. As was the case with the Sun Coast Parkway field test, Ardaman & Associates, Inc. conducted a compactive energy study concurrently with the field test.

3.4.1 SR 56 field test procedures

The field test was conducted in an area where the contractor was placing embankment material. The embankment material used was a native soil excavated on site and placed as roadway fill. The excavated soil was an A-3 loamy sand with approximately two percent fines. The soil was placed in test lifts that were approximately 300 feet long and 50 feet wide and to a depth of 12 inches after compaction. Due to the fact that the soil was excavated immediately prior to being placed on the test lifts, the initial moisture content of the soil was wet of optimum (approximately 13 to 14 percent). Soil for the first test lift was placed loosely at this high moisture content. The field equipment used to compact the test lifts was a Dynapac CA 251 smooth-drummed vibratory roller. This is the same model compactor used during the Thomasville Road field test, with the exception of the drum type.

Initial compaction of the first test lift was accomplished by making four passes with the compactor. One pass is considered the forward and backward travel motion of the roller. After the four passes had been completed, density and moisture measurements were taken at a central location in the test lift. The density measurement was conducted using a nuclear density gage at a depth of 12 inches and the moisture measurement was made with a speedy moisture gage. After the density and moisture levels were documented, an additional four passes (eight total) were made with the compactor. After the eighth pass, the density and moisture were again checked. At this point the density still failed to reach the required density for roadbed material, due to the high moisture content. The compactor continued to make passes on the test lift in order to bring the density up to the specification requirements. After making 20 passes with the compactor, the lift still failed to reach the required density and therefore could not be left in place. Because compacting the soil at such a high water content proved to be ineffective along with the desire to conduct test lifts at lower moisture contents, the first test lift was milled up and allowed to dry overnight. In addition to the first test lift, a second lift was placed loosely in an adjacent area so that the soil could dry overnight.

After drying, the moisture content of the soil from the first test lift dropped approximately three percentage points. The loose soil was smoothed out and compacted in the same manner previously described. The resulting lift was considered the second test lift. After four passes of the compactor were completed, density and moisture measurements were taken at several locations along the test lift, in order to provide a wider range of moisture contents. Several density and moisture measurements were also taken after eight passes had been completed. Reaching the required density proved to be much easier at the lower moisture content. The additional soil that was dried overnight was then placed on top of the completed second lift. This third test list was compacted using the same procedure as the rest with density and moisture measurements taken at several locations along the lift, after four and eight passes of the compactor. Due to the amount of time required to dry additional soil, the third lift was the final lift of the field test.

3.4.2 SR 56 field test results

The density and moisture measurements taken during the State Road 56 field test were once again used to construct field compaction curves. One difference between the State Road 56 field compaction curves and the other field curves is that the moisture range was considerably smaller. Due to the fact that the in-situ moisture content of the field soil was above optimum, compaction data was only available over a small range. The compaction data corresponding to four and eight passes of the compactor can be seen in Figure 3.8.

Although proper field compaction curves could not be established, comparisons are still useful between the peak densities achieved during the field tests with those found using the Modified Proctor laboratory test. The maximum density obtained from the Modified Proctor test is approximately 113 lbs/ft^3. This density is 0.5 lbs/ft^3 less than the peak density achieved after four passes of the field compactor and 1.0 lbs/ft^3 lower than the eight passes peak density. If current stabilized subgrade construction specifications were applied to this Modified Proctor result, the required density would be 110.4 lbs/ft^3, much lower than the densities obtained during the field test. Due to the small moisture range tested in the field, comparisons are difficult between the effect of moisture content for this soil, although the field test results clearly show that densities greater than those required by current specifications can be achieved.

Table 3.1 Thomasville road field compaction results

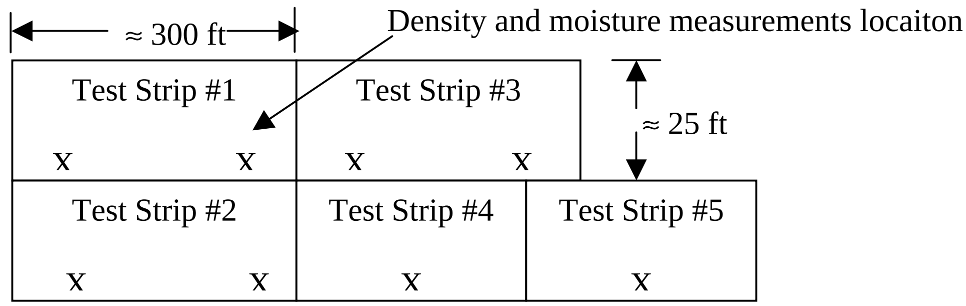
Number of Passes	Water Content (%)	Dry Unit Weight (pcf) at 12" Depth
8 passes	7.0	111.6
	8.6	111.5
	10.6	111.3
	10.6	112.5
	10.8	113.8
	10.8	113.9
	11.9	111.5
	12.2	109.0
	12.9	106.7
16 passes	9.1	108.9
	10.6	110.9
	10.6	111.5
	10.8	112.8
	11.0	112.7
	11.2	113.6
	12.2	111.5
	14.1	110.1

Table 3.2 Summary of compaction test method and results for Sun Coast Parkway

Test Area No.	Lift No.	Pass No.	Frequency (vpm)	Amplitude	Travel speed (ft/sec.)	Water Content (%)	Dry Unit Weight (pcf)	Remarks
1	1	1-6	1710	High	3.7	5.0	106.6	
		7-12	1715	High	3.7	4.4	108.6	
		13-16	1735	High	3.7	13.9	105.9	Water was added to meet the Lab optimum MC
	2	1-6	1710	High	6.2	6.2	106.1	
		6-12	1710	High	6.3	5.4	109.3	
		13-16	1710	High	6.3	15.8	104.9	Water was added to meet the Lab optimum MC
	3	1-4	1620	High	4.3	6.8	105.3	
		5-9	1620	High	1.3	5.8	109.3	
		10-15	1750	High	1.3	5.7	110.1	
2	4	1-6	1840	Low	6.3	10.9	103.5	
		7-12	1840	Low	6.3	7.8	108.0	
	5	1-6	1840	Low	6.3	12.8	103.0	
		7-12	1840	Low	6.3	9.4	107.7	
3	6	1-6	1710	High	6.3	8.0	106.8	
		7-12	1710	High	6.3	7.0	110.0	
Compactor type: Ingersoll-Rand SD 100 smooth drum vibratory compactor								

Table 3.3 State Road 56 field test results

Number of Passes	Water Content **(%)**	Dry Unit Weight (pcf) at 12″ Depth
Field 4 passes	9.7	113.6
	10.3	112.1
	10.4	111.9
	10.6	112.8
	11.7	113.2
	11.7	111.7
	11.7	109.7
	12.8	106.4
Field 8 Passes	10.8	112.7
	11.9	114.1
	12.6	110.6
	13.5	107.6



Thomasville Road Field Test Layout

Dynapac CA 251 PD Specifications:

Drum diameter (inch)	60
Drum width (inch)	93
Drum module weight (lb)	14,690
Speed range (mph)	0-6
Nominal amplitude (inch)	
High	0.064
Low	0.031
Centrifugal force (lb)	
At high amplitude	56,025
At low amplitude	32,870

Caterpillar CS-563C Specifications:

Drum diameter (inch)	60
Drum width (inch)	84
Drum module weight (lb)	12,540
Speed range (mph)	0-8
Nominal amplitude (inch)	
High	0.067
Low	0.034
Centrifugal force (lb)	
Maximum	56,025
Minimum	32,870

Figure 3.1 Thomasville Road field test layout, density and moisture test

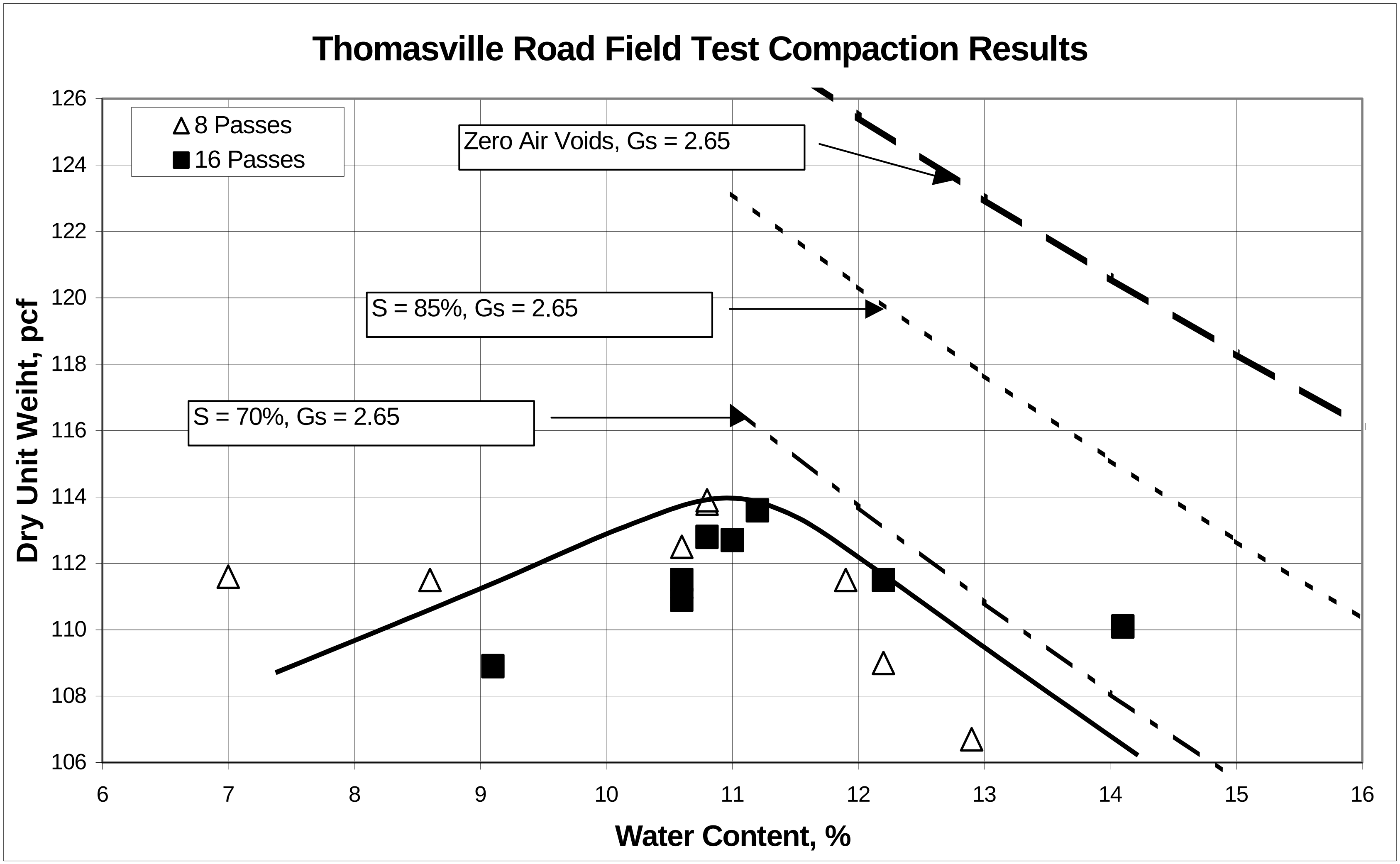


Figure 3.2 Thomasville Road field compaction results

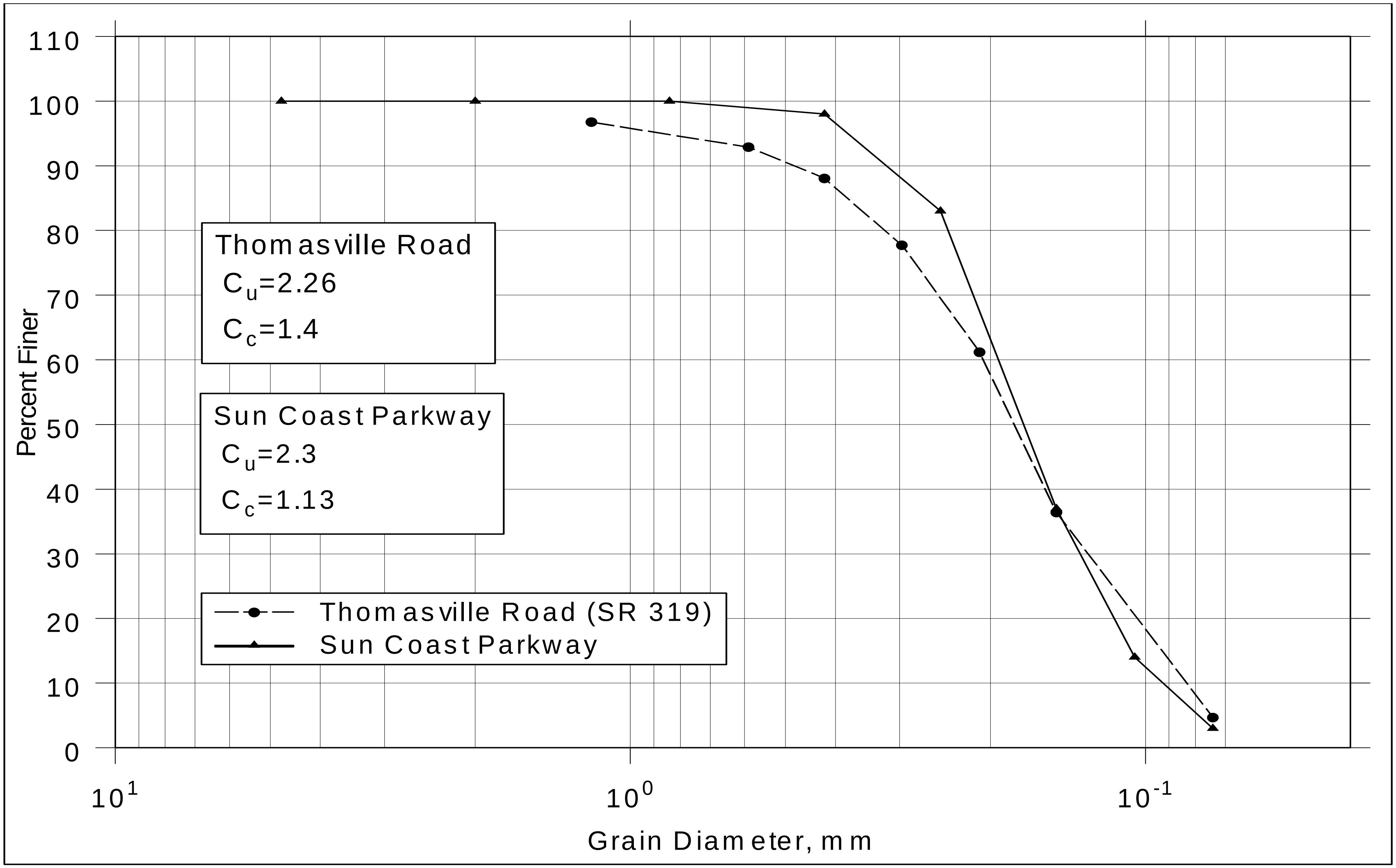
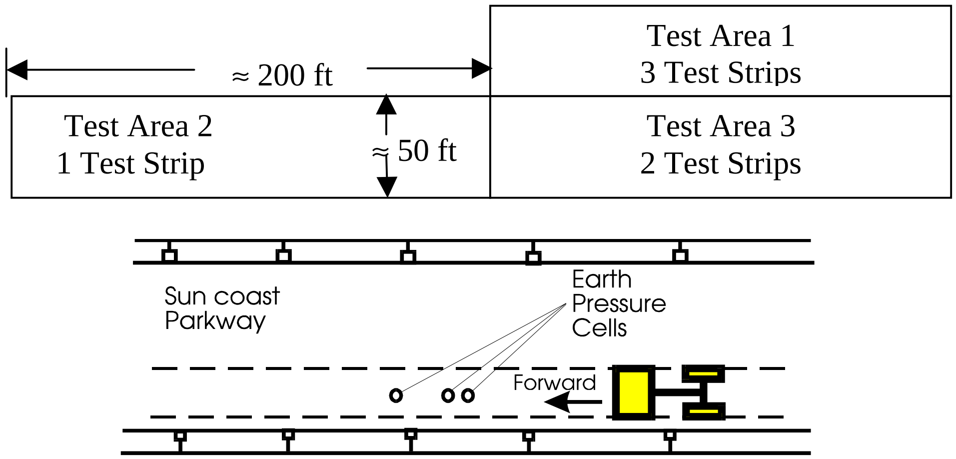
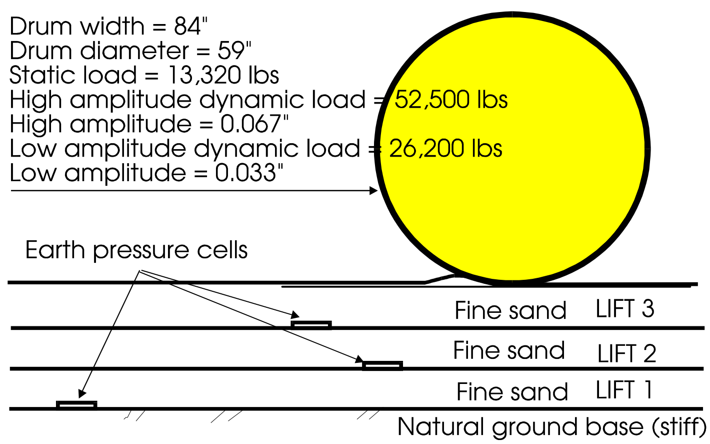


Figure 3.3 Grain size distribution



Schematic test site plan



Test site profile

Earth pressure cell

Figure 3.4 Sun Coast Parkway field test layout and earth pressure cell

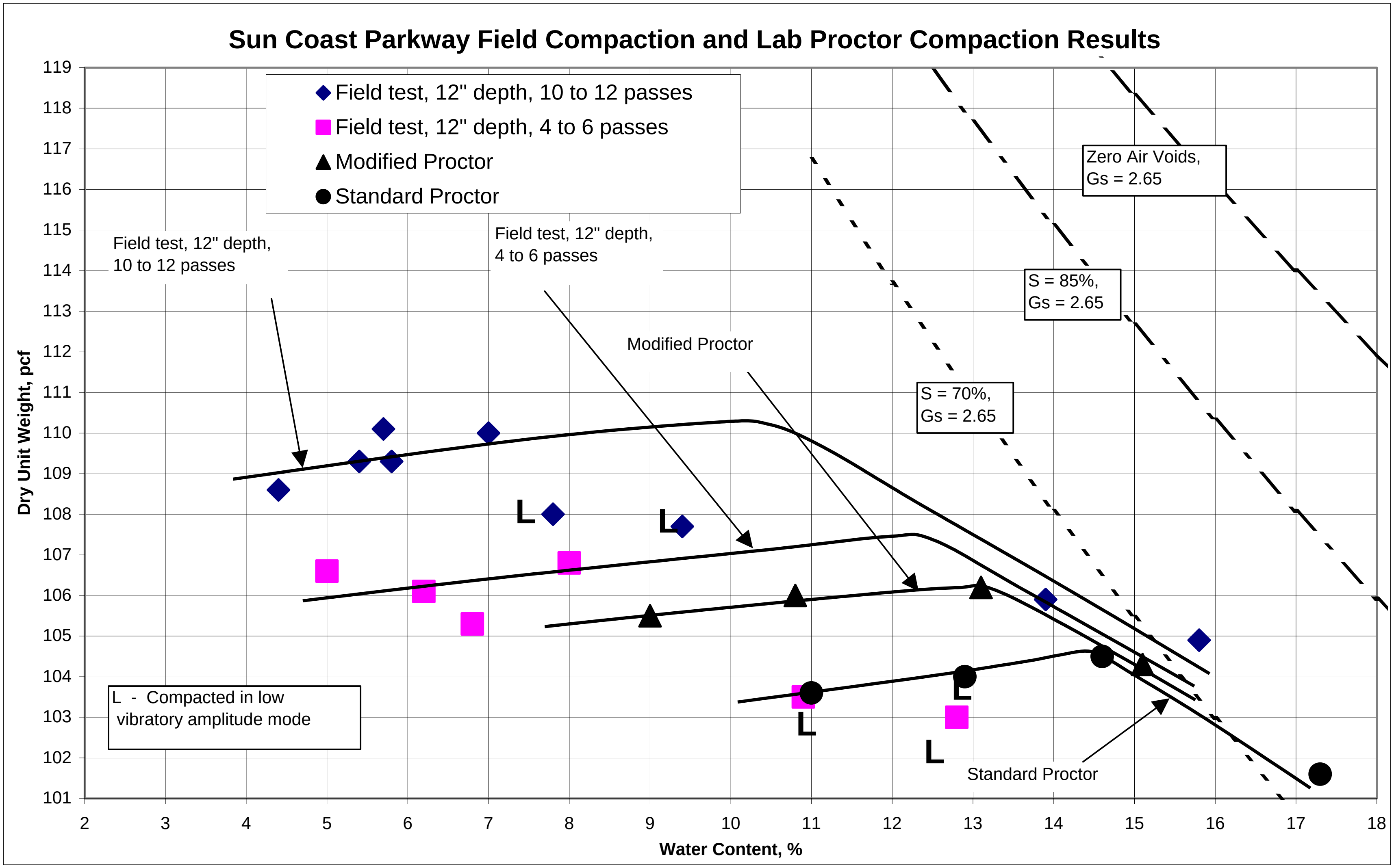


Figure 3.5 Sun Coast Parkway field test results

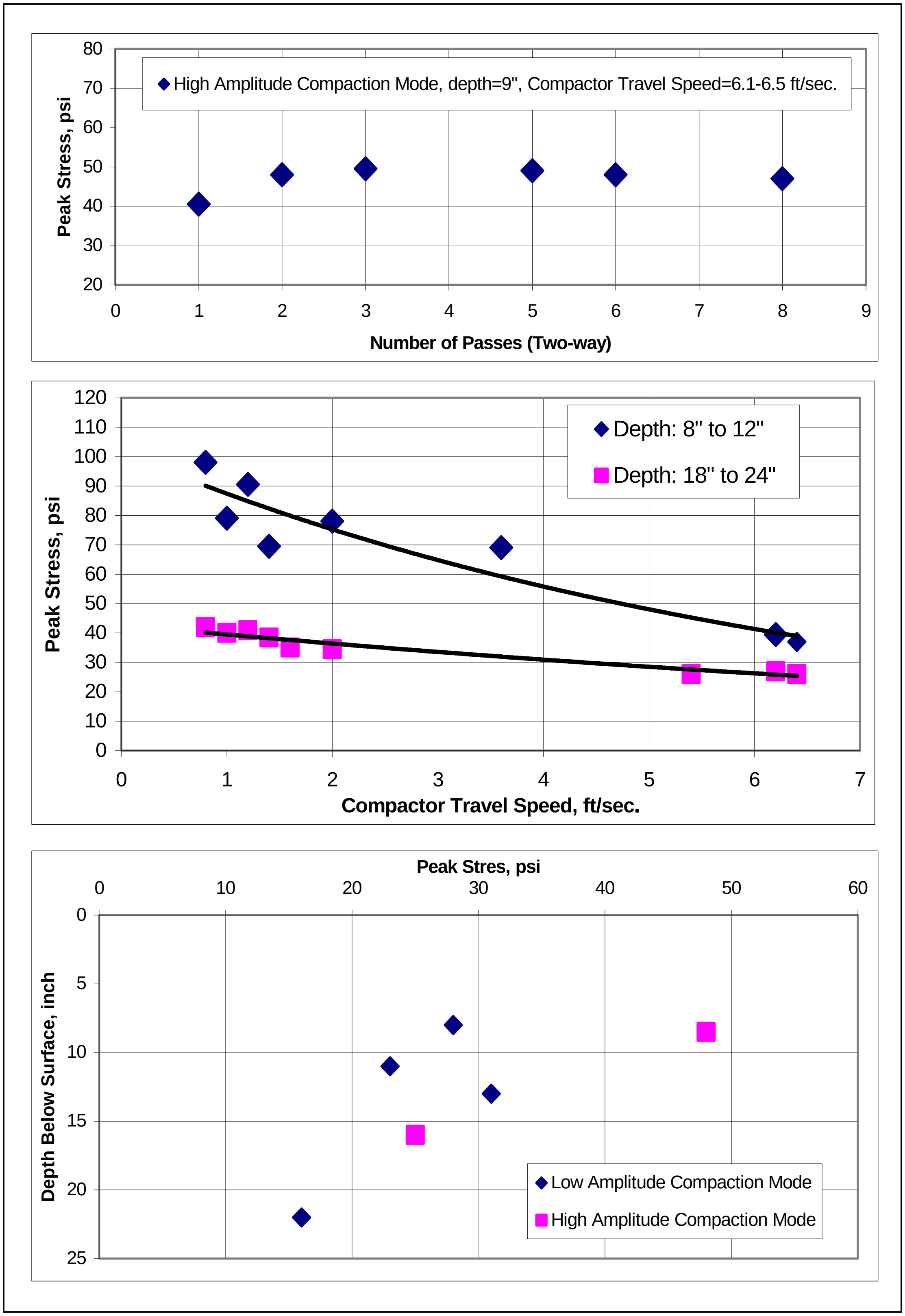


Figure 3.6 Measured peak stress amplitude versus number of passes, compactor travel speed, and depth below surface

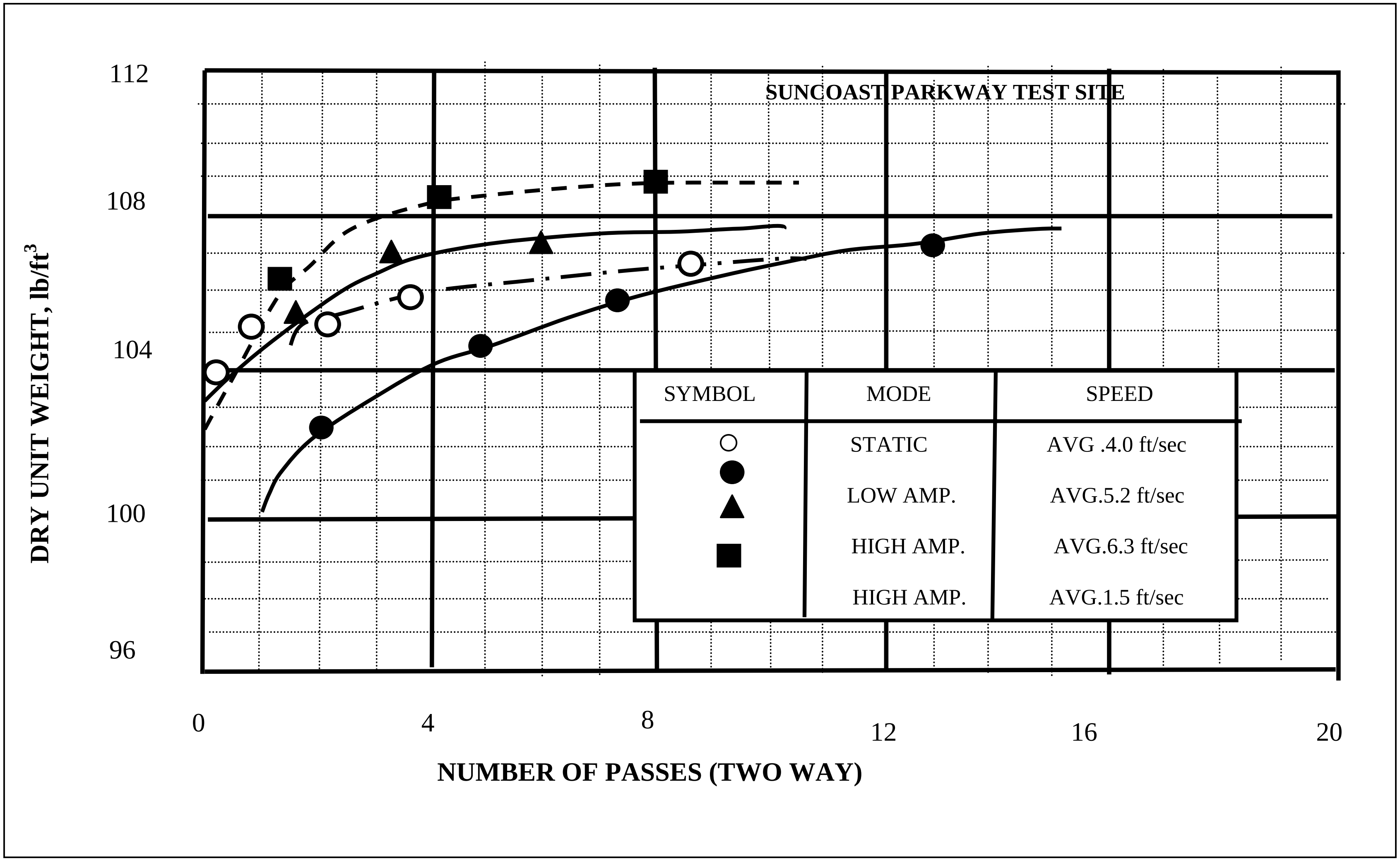


Figure 3.7 Dry unit weight versus number of passes at Sun Coast Parkway field test

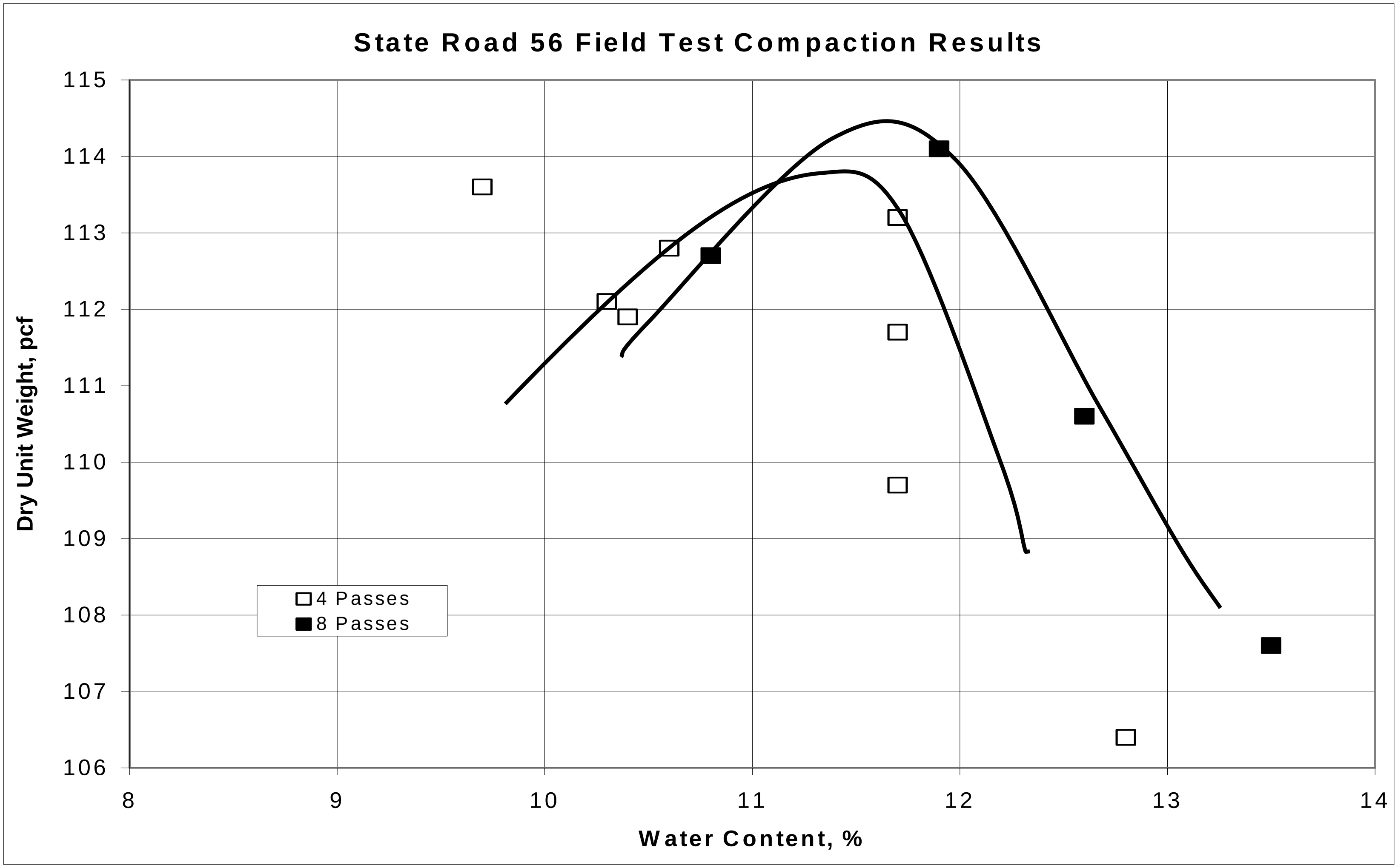


Figure 3.8 State Road 56 field test results

CHAPTER 4

LABORATORY COMPACTION CHARACTERISTICS

4.1 General

After the field test study of the Sun Coast Parkway and Thomasville Road sites, the next step was to develop a comprehensive laboratory test program to evaluate the most suitable compaction test procedures for soil compaction. The primary objective of this chapter is to evaluate the compaction characteristics of soils obtained from the field study. In this chapter, experiments were focused on the characteristics of gyratory compaction and test program. In addition, other two widely used laboratory compaction techniques, impact compaction method and a vibratory compaction method were also examined for the comparison.

4.2 Laboratory Testing Program

Several soil types were used during the laboratory evaluation. The soils were chosen to represent the types of material that are commonly used for stabilized subgrade in Florida. These soils included the silty sand, and the fine sand from State Road 319 and Sun Coast Parkway. The basic properties of the soils are listed in Table 4.1.

For the first two A-3 soils, field tests were available to compare with the results of laboratory compaction test. But for the two A-2-4 soils, no corresponding field test exists. Therefore, the Modified Procter test and vibratory compaction test were used as the comparison curves.

In the laboratory experimental program, several test methods were used:

- Impact compaction test method
- Vibratory compaction test method
- Gyratory compaction test method

In these three test methods, the gyratory compaction method was the main focus for evaluation. The impact and vibratory compaction methods were used for comparisons.

4.3 Impact Compaction Method

As stated earlier in this report, impact compaction is the most common type of laboratory compaction used today. The popular impact compaction test procedures are the Standard and Modified Proctor tests (AASHTO T 90 and T 180). A majority of the states use results obtained from these two test procedures to specify density requirements for roadway construction. Currently, Florida requires stabilized subgrade to be compacted to 98 percent of the maximum dry density determined from the Modified Proctor test, and embankment materials to be compacted to 100 percent of the maximum Standard Proctor density.

The field and laboratory compaction curves of the Thomasville Road A-3 soil and the Sun Coast Parkway A-3 soil are presented in Figures 4.1 and 4.2 following the modified Proctor compaction test. The modified Proctor compaction curve does not simulate the field compaction curve very well, due to too much difference between them. The laboratory optimum moisture content was much higher than the OMC in the field, and the maximum dry unit weight was much lower than the field test value.

4.3.1 Modification of impact compaction method

From the literature study, the two factors that affect the soil compaction are the water content and compaction efforts applied to the soil. With the increase of compaction efforts, the maximum dry unit weight would increase and the OMC would decrease, e.g., the change from

Standard Proctor to Modified Proctor compaction. If the impact compaction test procedure is further modified from the Modified Proctor Compaction, it may still be a good technique to simulate field results. Thus, in this study the compaction effort was further increased to conduct other higher energy compaction curves. The test soils included a silty sand (A-2-4) from Alford City, a clayey sand (A-2-6) from Clay County, and a fine sand (A-3) from Lake City. The test procedures for the modified impact compaction methods in this study are the following:

- 10 lb hammer with 25 blows per layer (Modified Proctor),
- 10 lb hammer with 50 blows per layer (Augmented Modified Proctor A),
- 15 lb hammer with 25 blows per layer (Augmented Modified Proctor B),
- 15 lb hammer with 50 blows per layer (Augmented Modified Proctor C),

The laboratory investigation of the soil began by producing a Modified Proctor compaction curve for the soil. After this, an additional compaction curve was created by increasing the number of hammer drops on each lift of soil from 25 to 50. Compaction curves were also developed at two other energy levels. These included a 15 lb hammer at 25 blows per lift, and a 15 lb hammer at 50 blows per lift.

4.3.2 Impact compaction test results

The impact compaction test results are summarized in Tables 4.2, 4.3, 4.4 and are shown in Figures 4.3, 4.4, 4.5 for Alford City A-2-4 soil, Clay County A-2-6 soil, and Lake City A-3 soil, respectively. From these figures, for the A-2-4 Alford City soil and A-2-6 Clay County soil, with the increase of the compaction effort, an increase of the maximum dry unit weight and decrease of the water content occurred. However, for the A-3 Lake City soil, increasing the weight of the hammer had little or no effect on the maximum density. Due to a lack of cohesion in pure sand made using impact compaction difficult. The bell-shaped compaction curve could not be developed. The inability of the impact compaction to consistently produce the bell-shaped compaction curve for the cohesionless soil was the primary drawback.

The impact compaction test results for four additional soils are summarized in Tables 4.5, 4.6, 4.7, 4.8 and shown in Figures 4.6, 4.7, 4.8. The compaction curves showed little effect from the increased hammer weight. This result was consistent with the A-3 soils that had been tested in the laboratory previously. As can be seen in Figure 4.6, the maximum dry density that was achieved in the laboratory was approximately 113 lbs/ft^3 for the Thomasville Road A-3 soil.

4.4 Vibratory Compaction Method

The vibratory test method is used to determine the dry unit weight of the cohesionless free-draining soils for which impact compaction will not produce a well-defined moisture-density relationship curve. In this study the vibratory table and test procedure (ASTM D4253) were used to develop the compaction curves.

4.4.1 Vibratory compaction test results

The vibratory compaction test results for the four types of soil are summarized in Tables 4.5, 4.6, 4.7.and 4.8. The water content and density relationship curves are plotted for the Sun Coast Parkway and Thomasville Road soils, shown in Figure 4.9. These curves were also plotted in Figures 4.1 and 4.2 with the other three compaction curves. From these figures, the results show that the densities from the vibratory compaction are much lower than the field test results and the corresponding OMC is much higher than the field OMC. If the laboratory OMC is used to compact the soil in the field, it will not reach the desired dry unit weight in the field as in the laboratory since the laboratory OMC is much higher than the corresponding field OMC. In order to be comparative, another two soils, A-2-4 with 12% fines and A-2-4 with 24% fines were also compacted to develop compaction curves using the vibratory table. The compaction curves for the A-2-4 soils are shown in Figure 4.10. The data show that the vibratory compaction may be suited for compacting A-2-4 silty sand.

4.4.2 Concerns about vibratory compaction

During the vibratory test, two disadvantages resulted:

1. The time to conduct this test was lengthy. At least six minutes were needed after filling the soil into the mold to create evenly distributed soil and at least an additional eight minutes to perform the test. The mold and surcharge set up was quite complicated. The whole test took at least 30 minutes.
2. Due to the unmovable bottom of the mold, difficulty was encountered in removing the sample from the mold. It is not similar to the impact and gyratory methods that use some tool or air pressure to remove the soil specimen easily.

The vibratory test has not been widely used recently. Due to the above disadvantages it may not be a suitable technique for further development.

4.5 Gyratory Compaction Method

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From the above laboratory compaction investigation, apparently both the impact compaction and vibratory compaction methods have some problems needing further improvements. Therefore an alternative technique is needed to better simulate the field compaction characteristics.

As mentioned previously in this report, gyratory compaction is one laboratory compaction method that has shown considerable promise. History on the development of gyratory compaction equipment and its testing procedures are provided in Chapter 2 of this report. Some initial work has been done (Leonard, 2002). The gyratory compaction curves are presented in Figures 4.1 and 4.2. From these curve comparisons, the results show that the gyratory compaction has much potential to simulate the field test results. Currently, no published test procedures exist for compacting soils with a SUPERPAVE gyratory compactor. To date, the majority of research conducted on using gyratory compaction has focused on the characteristics of SUPERPAVE asphalt mixtures. In the following sections of this chapter, an initial study is presented for evaluating the characteristics of gyratory compaction variables, and an attempt is made to develop a gyratory standard test procedure to simulate the field test results.

4.5.1 Gyratory compactor

The gyratory compactor used in this study was supplied by the Industrial Process Controls Ltd. (IPC) Servopac Gyratory Compactor (Figure 4.11). The Servopac is a fully automated, servo-controlled gyratory compactor originally designed to compact asphalt mixes by means of the gyratory compaction technique. Compaction is achieved by simultaneous action of static compression and the shearing action resulting from the mold being gyrated through an angle about its longitudinal axis.

The Servopac was designed to automatically compensate (under servo-feedback control) and to maintain the gyratory angle constant during compaction, and to provide a means to simply and quickly adjust the critical parameters. The servo-feedback control enables it to provide more accurate and consistent results, provides a powerful tool to evaluate optimum parameter settings, and allows ready adjustment should future work indicate that settings be changed.

In plan view (Figure 4.12), three actuators are located 120 degrees apart around the outside diameter of the mold carrier ring. To each of these actuators, the electronic control system sends a sine wave via a servovalve. The three sine waves are out of phase from each other by 120 degrees. The amplitude of the sine wave controls the angle, and the frequency of the sine wave controls the gyration rate. The feedback signal comes from the displacement transducer which bears directly on the bearing that connects the actuator rod to the mold.

Since the Servopac uses servovalves for both gyratory angle and vertical load, the response time is generally faster than systems that use electromechanical drives. The servo-control operation of the machine allows the vertical stress, gyratory angle, and gyration rate to be quickly modified from a hand-held pendant or personal computer(PC). An optional PC ‘Windows’ interface (Figure 4.13) provides a screen to place data on test parameters and display and plot either height, density, or angle against gyratory cycles in real time. Test data may be stored and retrieved or transferred to other analyses packages. The Servopac is designed to comply with SHRP SUPERPAVE asphalt mix design requirements.

When compacting specimens using gyratory compaction, four factors influence test results. These factors are the gyration angle used, the vertical pressure applied, the rate of gyration, and the number of gyration cycles. The Servopac is capable of producing gyration angles between zero and three degrees, gyration rates up to 60 gyrations per minute, and vertical pressures as high as 600 kPa for as many as 999 gyration cycles.

4.5.2 Initial investigation of gyratory variables

The gyratory machine has four variables which are the main factors effecting the compaction characteristics. The variables are gyration angle, gyrations, vertical pressure, and gyration rate. Therefore, the initial study conducted for this project concentrated on the influence of these variables during laboratory compaction.

4.5.2.1.Vertical pressure

From the reference (U.S.Army, 1969), an increase in vertical pressure causes a consistent increase in unit weight during compaction. Therefore, for laboratory compaction, the vertical test pressure should be set equivalent to the anticipated, approximate tire contact pressure to which the pavement will be subjected. The vertical stress in the soil compaction should be close to the soil stress developed in the field compaction test.

The field measured soil peak stress amplitudes versus the number of passes are shown in Figure 4.14. From this figure, the data show that for both SR 56 and Sun Coast Parkway soils, the peak stress achieved is about 40 psi which is approximately 280 kPa. Therefore in this study the 100 kPa, 200 kPa, 300 kPa, 400 kPa, 500 kPa were chosen as the range of vertical pressures for evaluation.

4.5.2.2.Gyration angle

Researchers usually acknowledge that a gyratory angle has some effect on soil compaction. Early work (Kadar,1992) indicated that the setting of the gyratory angle is more sensitive at the lower gyratory angles used by some European groups than as specified by SHRP (1.0° - 1.25°). SUPERPAVE specification uses a 1.25 degree angle for compacting asphalt mixtures.

From the literature study, a 1.25 degree angle is a reasonable value to choose. This value is for compacting asphalt concrete material. For the soil the gyration angle should not be higher than 1.25 for its lower stiffness than the asphalt concrete material. For the Servopac Gyratory test machine, the recommended minimum gyration angle is 1.0. If it is less than 1.00 degree, it requires an adjustment of the PID controls of the Servopac for the best response. When the gyration angle is lower than the 1.00, the void is increased too much with the increase of the gyration angle. When it is between 1.00 degree and 2.00 degrees, the void ratio becomes more stable. So in this project a range of 1.00-1.25 degrees was chosen to be the range of gyration angle.

4.5.2.3. Number of gyrations

Notations from the literature show that by increasing the number of gyrations, a consistent increase of the unit weight is produced. The gyrations needed to be adjusted to get the desired dry unit weight. In order to test the characteristics of the range of gyrations in this project, 30,60,90 gyrations were chosen to test each of two field test soils.

4.5.2.4.Rate of gyration

The effect of the rate of rotation was evaluated with a series of tests on A-2-4 soil where all other parameters were held constant with the exception of the rate of gyration, which was varied. The per-minute rates of gyrations selected were 10, 20 and 30. The results are summarized in Table 4.9 and are shown in Figure 4.15. The results confirmed previous SHRP work (Cominsky et al, 1994), that little variation was obtained through different rates of rotation and this appeared to be applicable at any angle. For this study 20 gyrations/minute were chosen which took 4.5 minutes to finish one test at 90 gyrations, a reasonable time for the test.

4.5.3 Test conditions

A gyratory testing program was conducted using soils from two of the field tests and two types of A-2-4 soil that is the popular Florida subgrade soil. From the above investigation of Servopac Gyratory machine variables, ten different test conditions were used for the gyratory compaction. The test conditions included combinations of two different gyration angles (1.0 degree and 1.25 degrees), five different levels of vertical stresses (100 kPa and 200 kPa, 300 kPa, 400 kPa, 500 kPa), and three types of gyrations (30,60,90).

During compaction, two of the three variables were held constant while the third was allowed to vary through a given range of values. This procedure was repeated for each of the three variables.

4.5.4 Test procedure

One issue that came to light during the initial testing program was the loss of water experienced by those samples having a high water content. At lower compactive energies the water seepage was not as severe, but a higher water content could not be maintained during the gyratory compaction process, particularly at the high compaction efforts. The water was squeezed out of the sample, and frequently final water contents were two to three percent lower than the initial water content. For the A-3 and A-2-4 soil, generally when the water content was higher than 11%, the water began to seep out of the soil sample. As the test energy and most importantly the test duration was increased, water loss became a major problem in determining proper dry unit weights.

The PC based software used to determine wet densities of the samples after compaction, bases the wet density on the weight of the sample prior to compaction. If significant water loss is experienced during compaction, the post-compaction sample weight is considerably less than the pre-compaction weight. Therefore, the wet density provided by the Servopac software may be inaccurate. If the wet density, based on the pre-compaction weight, is used in conjunction with the moisture content calculated after compaction, the resulting dry density will be higher than the actual density achieved during the test.

This problem was experienced in samples with moisture contents wet of optimum. This phenomenon resulted in a compaction curve that did not peak but rather flattened out when the moisture content reached optimum. If the water loss was too excessive, the curve did not peak at all but rather continued to rise over the entire moisture content range. This result can be seen in several of the compaction curves developed during the initial program (Figure 4.16).

Because of this problem, the densities of samples cannot be used for comparison with other laboratory and field test results. To remedy this situation, tests conducted after the initial phase of the program did not use the wet density provided by the Servopac software. Instead, the following modified test procedure was used.

After the gyration was finished, the data file was saved and the height of the sample recorded. The sample was removed from the mold and the soil sample was weighed.

About 100 g of soil were needed from the middle of the sample to measure the water content.

From the weight, height, diameter, and water content, the dry unit weight was obtained.

$$\gamma = \frac{W}{\left(\pi \times \left(\frac{D}{2}\right)^2 \times H\right) \times (1+w)}$$

γ = *dry unit weight of soil sample*
W = *weight of soil sample*
D = *diameter of mold* $D = 150\ mm$
H = *height of soil sample*
w = *water content of soil sample*

The height of the sample after compaction was obtained from the software, in order to calculate the after compaction volume of the sample. This volume was then used with the after compaction weight of the sample to calculate the appropriate wet unit weight and dry unit weight.

4.5.5 Gyratory compaction test results

The Gyratory test results for the four types of soil are summarized in Tables 4.10, 4.11, 4.12, and 4.13. The results are presented in Figures 4.17, 4.18, 4.19, and 4.20, for the Thomasville Road soil, Sun Coast Parkway soil, A-2-4 soil with 12% fines, and A-2-4 soil with 24% fines, respectively.

During the initial investigation for the two field test soils from Thomasville Road and Sun Coast Parkway, the compaction test was conducted with different levels of gyrations while the sample was in the mold. Only one sample was used with each mixing water content, to record the different height from the PC software to get different dry unit weights with 30, 60, and 90 gyrations. After consideration of the water seepage during compaction, the procedure was changed. Because the water seeped during the test, the water content and weight of the sample were not equal to the water content and weight of sample when the test was finished. Therefore, in order to get a more accurate test results, during the test of A-2-4 12% and A-2-4 24% soil compaction, different samples were used for each level of gyrations at 30, 60 or 90. When the gyration reached the preset number, the water content and weight of the samples were measured to obtain the unit weight. The gyratory test results are further analyzed in the next chapter.

Table 4.1 Soil materials for laboratory evaluation

Location	Visual Description	AASHTO Classification	% Passing No. 200
Sun Coast Parkway	Fine Sand	A-3	3%
Thomasville Road (SR 319)	Fine Sand	A-3	6~8%
Silty sand1	Silty Sand	A-2-4	12
Silty sand2	Silty Sand	A-2-4	24

Table 4.2 Summary of impact compaction data for Alford City A-2-4 soil

Test Procedure	Water Content (%)	Dry Unit Weight (Pcf)
10 lb Hammer, 25 Blows/layer (Modified Proctor)	5.3	122.00
	6.4	124.80
	7.2	126.64
	8.1	128.14
	9.4	126.30
10 lb Hammer, 50 Blows/layer (Augmented Modified Proctor A)	5.4	126.66
	6.3	129.20
	7.4	130.60
	8.2	130.71
	9.1	127.40
15 lb Hammer, 25 Blows/layer (Augmented Modified Proctor B)	5.3	126.32
	5.9	129.12
	6.1	130.80
	6.8	132.08
	7.8	130.50
	8.4	129.76
15 lb Hammer, 50 Blows/layer (Augmented Modified	5.1	131.11
	5.7	133.66
	6.2	134.49

Modified Proctor C)	7.2	134.38
	7.9	132.40
	8.2	131.09

Table 4.3 Summary of impact compaction data for Clay County A-2-6 soil

Test Procedure	Water Content (%)	Dry Unit Weight (Pcf)
10 lb Hammer, 25 Blows/layer (Modified Proctor)	7.8	121.73
	8.0	122.36
	9.0	124.86
	9.2	125.29
	9.6	127.29
	11.4	123.61
10 lb Hammer, 50 Blows/layer (Augmented Modified Proctor A)	7.4	125.23
	7.7	126.98
	8.9	130.72
	9.2	130.47
	9.5	129.41
	11.3	124.29
15 lb Hammer, 25 Blows/layer (Augmented Modified Proctor B)	7.1	128.04
	8.1	130.00
	8.3	129.95
	9.1	129.69
	10.4	126.55
15 lb Hammer, 50 Blows/layer	7.3	132.20
	8.3	133.16

(Augmented Modified Proctor C)	8.6	132.60
	8.8	132.50
	11.0	124.72

Table 4.4 Summary of impact compaction data for Lake City A-3 soil

Test Procedure	Water Content (%)	Dry Unit Weight (pcf)
10 lb Hammer, 25 Blows/layer (Modified Proctor)	8.8	104.59
	10.1	104.81
	10.9	105.13
	11.9	104.98
	12.4	105.15
10 lb Hammer, 50 Blows/layer (Augmented Modified Proctor A)	8.8	106.20
	9.8	105.85
	11.0	106.37
	11.6	106.38
	12.5	106.55
15 lb Hammer, 25 Blows/layer (Augmented Modified Proctor B)	8.9	103.65
	9.9	104.45
	11.1	104.76
	11.5	104.89
	13.0	105.26
	103.7	105.85

15 lb Hammer 50 Blows/layer (Augmented Modified Proctor C)	104.5	105.88
	104.8	106.18
	104.9	106.07
	105.3	107.33
	103.7	106.96
	104.5	106.39

Table 4.5 Summary of lab compaction test results for Thomasville Road project

Compaction Test	Water Content (%)	Dry Unit Weight (pcf)
10 lb hammer, 25 blows/layer (Modified Proctor Test)	8.2	109.82
	9.1	109.43
	9.6	109.48
	10.6	110.51
	11.7	111.05
	12.2	110.67
	13.2	109.23
	13.5	108.93
10 lb hammer 50 blows/layer (Augmented Modified Proctor A)	8.2	111.37
	9.1	111.88
	10.4	112.61
	11.2	112.95
	11.9	112.3
15 lb hammer 25 blows/layer (Augmented Modified Proctor B)	9.2	109.69
	9.9	110.25
	10.1	110.71
	11.4	110.89
	12.8	109.04
15 lb hammer 50 blows/layer (Augmented Modified Proctor C)	8.9	110.98
	10.4	112.53
	11.0	112.65
	11.4	112.67
	12.5	110.67
Vibratory Compaction	8.0	107.76
	10.1	109.66
	12.0	109.51
	12.6	105.5
Initial Gyratory Compaction	8.3	110.53
	9.0	112.02
	10.2	112.40
	11.0	113.22
	12.3	111.06

Table 4.6 Summary of lab compaction test results for Sun Coast Parkway project

Test Procedure	Water Content (%)	Dry Unit Weight (pcf)
Lab Standard Proctor	11.0	103.60
	12.9	104.00
	14.6	104.50
	17.3	101.60
Lab Modified Proctor	9.0	105.50
	10.8	106.00
	13.1	106.20
	15.1	104.30
Vibratory Compaction (Laboratory)	8.3	104.00
	10.0	105.60
	12.1	105.30
	13.5	100.00
Initial Gyratory Compaction	7.8	106.97
	9.6	107.15
	10.7	107.44
	11.8	107.07

Table 4.7 Lab Impact and vibratory compaction test results (A-2-4 12% soil)

Test Procedure	Water Content (%)	Dry Unit Weight (Pcf)
Modified Proctor Compaction Test	7.4	110.89
	10.3	111.32
	12.0	111.97
	12.5	110.11
Vibratory Compaction Test	9.0	106.32
	10.3	111.42
	11.9	111.48
	12.3	110.03

Table 4.8 Lab impact and vibratory compaction test results for A-2-4 24% soil

Test Procedure	Water Content (%)	Dry Unit Weight (pcf)
Modified Proctor Compaction Test	7.8	115.61
	9.3	116.48
	11.3	116.52
	12.5	113.72
Vibratory Table Compaction Test	7.5	106.75
	9.1	108.60
	10.3	111.89
	11.3	110.77

Table 4.9 Data for characterization of gyration rate (Alford City A-2-4 soil)

		Dry Unit Weight, pcf (Water Content = 5.0%)			Dry Unit Weight, pcf (Water Content = 5.5%)		
Gyration Rate (gyrations/minute)		10	20	30	10	20	30
Number of Gyrations	30	105.90	106.10	105.40	104.70	103.50	104.30
	60	108.50	108.70	107.90	107.20	106.20	106.90
	90	109.80	109.80	109.30	108.50	107.50	108.30

Table 4.10 Gyratory compaction test results for Thomasville Road soil

Test Procedure	Gyrations = 90		Gyrations = 60		Gyrations = 30	
	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)
Vertical Pressure=100 kPa Angle=1.0°	8.6	110.02	8.6	108.73	8.6	106.16
	10.6	110.37	10.6	109.07	10.6	106.48
	10.9	112.74	10.9	111.64	10.9	109.32
	11.8	112.90	11.8	111.79	11.8	109.91
	12.5	112.45	12.5	111.61	12.5	110.05
Vertical Pressure=100 kPa Angle=1.25°	7.8	109.17	7.8	108.05	7.8	105.77
	9.1	111.29	9.1	110.07	9.1	107.62
	9.4	111.33	9.4	110.48	9.4	108.92
	11.4	113.23	11.4	112.16	11.4	110.45
	11.7	110.16	11.7	109.12	11.7	107.24
Vertical Pressure=200 kPa Angle=1.00°	6.3	107.72	6.3	106.53	6.3	104.22
	9.0	109.15	9.0	107.92	9.0	105.48
	9.5	111.19	9.5	109.75	9.5	107.08
	11.0	113.12	11.0	111.72	11.0	108.98
	11.3	112.26	11.3	111.25	11.3	108.67
Vertical Pressure=200 kPa Angle=1.25°	8.3	110.24	8.3	109.10	8.3	106.82
	8.9	112.25	8.9	111.05	8.9	108.67
	9.5	113.09	9.5	111.95	9.5	109.88
	10.9	113.28	10.9	112.36	10.9	110.70
	11.1	111.57	11.1	110.43	11.1	108.51
Vertical Pressure=300kPa Angle=1.25°	_	_	8.3	110.53	_	_
	_	_	9.0	112.03	_	_
	_	_	10.2	112.40	_	_
	_	_	11.0	113.23	_	_

Table 4.11 Gyratory compaction test results for Sun Coast Parkway soil

Test Procedure	Gyrations = 90		Gyrations = 60		Gyrations = 30	
	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)
Vertical Pressure=100 kPa Angle=1.0°	8.4	105.21	8.4	104.17	8.4	102.01
	9.4	105.25	9.4	104.23	9.4	102.04
	10.5	105.33	10.5	104.27	10.5	102.12
	10.7	105.88	10.7	104.88	10.7	102.69
	11.1	107.59	11.1	106.58	11.1	104.60
	11.8	107.12	11.8	106.11	11.8	104.27
Vertical Pressure=100 kPa Angle=1.25°	8.7	106.05	8.7	105.13	8.7	103.17
	10.2	106.45	10.2	105.49	10.2	103.51
	11.2	107.96	11.2	107.09	11.2	105.13
	11.8	107.84	11.8	106.66	11.8	105.21
	14.3	105.40	14.3	104.50	14.3	102.78
Vertical Pressure=200 kPa Angle=1.00°	7.7	106.77	7.7	105.74	7.7	103.68
	10.6	107.27	10.6	106.23	10.6	104.16
	11.0	107.30	11.0	106.30	11.0	104.22
	11.8	106.93	11.8	105.99	11.8	104.24
Vertical Pressure=200 kPa Angle=1.25°	8.5	106.97	8.5	106.03	8.5	104.25
	10.0	108.77	10.0	107.87	10.0	106.00
	10.9	109.65	10.9	108.74	10.9	106.97
	11.2	108.83	11.2	107.89	11.2	106.38
	11.7	108.11	11.7	107.47	11.7	105.74

Test Procedure	Gyrations = 90		Gyrations = 60		Gyrations = 30	
	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)
Vertical Pressure=300 kPa Angle=1.25^o	_	_	7.8	106.98	_	_
	_	_	9.6	107.15	_	_
	_	_	10.7	107.44	_	_
	_	_	11.8	107.08	_	_
Vertical Pressure=400 kPa Angle =1.25^o	_	_	7.7	106.85	_	_
	_	_	10.0	107.16	_	_
	_	_	10.5	108.42	_	_
	_	_	10.9	107.85	_	_
Vertical Pressure=500 kPa Angle =1.25^o	_	_	7.6	106.47	_	_
	_	_	10.2	107.47	_	_
	_	_	10.7	107.59	_	_
	_	_	11.0	107.58	_	_
	_	_	11.1	107.36	_	_

Table 4.12 Lab gyratory test data for A-2-4 12% soil

Test Procedure	Gyration angle = 1.25°		Gyration angle =1.00°	
	Water Content (%)	Dry Unit Weight (pcf)	Water Content (%)	Dry Unit Weight (pcf)
Vertical Pressure=100 kPa Gyrations=90	7.8	109.44	7.6	109.68
	9.2	110.09	9.5	109.90
	10.3	112.45	10.8	112.38
	10.9	112.30	11.9	112.27
	_	_	12.0	111.91
Vertical Pressure=200 kPa Gyrations=90	8.3	110.42	9.1	110.85
	9.7	113.84	9.4	111.06
	10.1	113.32	10.2	113.80
	10.6	113.21	10.7	112.91
	11.0	113.19	12.6	112.55
Vertical Pressure=200 kPa Gyrations=60	7.4	110.16	_	_
	9.8	111.12	_	_
	10.2	112.26	_	_
	10.4	112.53	_	_
	10.8	112.91	_	_
	10.8	112.91	_	_
	11.1	112.39	_	_
Vertical Pressure=200 kPa Gyrations=30	6.9	107.91	_	_
	9.5	108.83	_	_
	11.0	109.16	_	_
	11.5	109.54	_	_
	11.9	110.22	_	_
	12.6	109.30	_	_
Vertical Pressure=300 kPa Gyrations=90	9.3	111.68	8.4	111.13
	9.5	113.30	9.4	112.16
	9.7	113.61	9.4	113.75
	9.9	113.82	10.0	113.54
	10.5	113.73	10.8	113.51

Table 4.13 Lab gyratory test data for A-2-4 24% soil

Test Procedure	Gyration angle = 1.25°		Gyration angle =1.00°	
	Water Content (%)	Dry Unit Weight, (pcf)	Water Content (%)	Dry Unit Weight (pcf)
Vertical Pressure=100 kPa, Gyrations=90	8.2	111.37	8.3	110.39
	8.2	112.92	9.5	112.62
	10.6	114.62	10.1	113.02
	11.1	114.76	11.0	114.59
	12.6	113.65	11.9	113.35
Vertical Pressure=200 kPa, Gyrations=90	8.9	114.46	8.7	113.18
	9.4	115.99	9.8	115.06
	10.1	116.12	10.9	115.47
	10.4	116.15	12.0	114.67
	10.7	116.25	_	_
	12.2	115.14	_	_
Vertical Pressure=200 kPa, Gyrations=60	8.0	114.36	_	_
	10.0	114.47	_	_
	11.3	115.16	_	_
	12.5	114.59	_	_
Vertical Pressure=200 kPa, Gyrations=30	8.0	111.57	_	_
	10.8	112.06	_	_
	11.3	112.87	_	_
	13.1	112.47	_	_
Vertical Pressure=300 kPa, Gyrations=90	9.0	115.49	9.2	114.24
	9.5	116.46	9.9	115.82
	10.5	117.09	10.3	116.33
	11.2	116.87	11.6	115.40

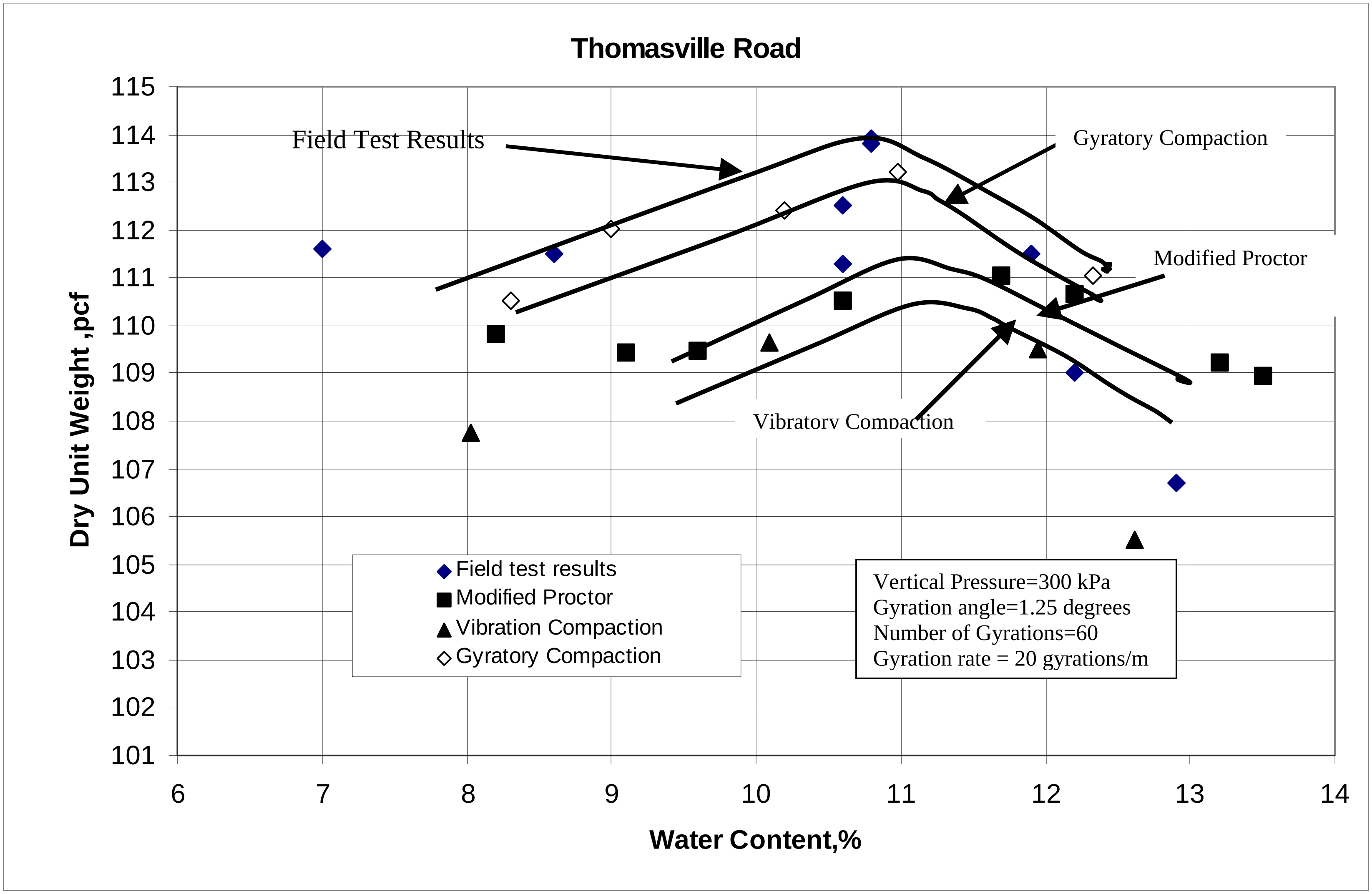


Figure 4.1 Field and lab compaction curves for Thomasville Road A-3 soil

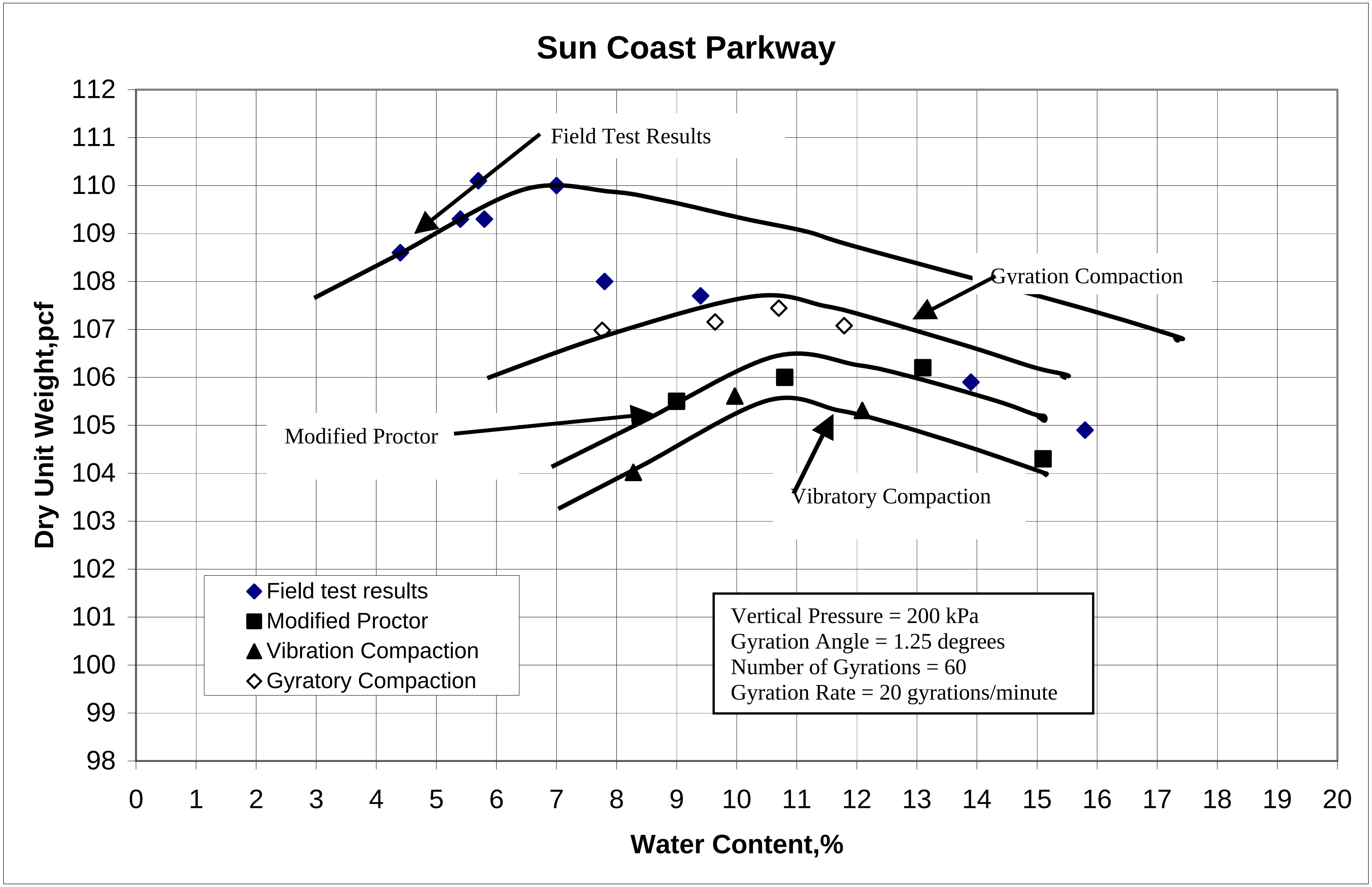


Figure 4.2 Field and lab compaction curves for Sun Coast Parkway A-3 soil

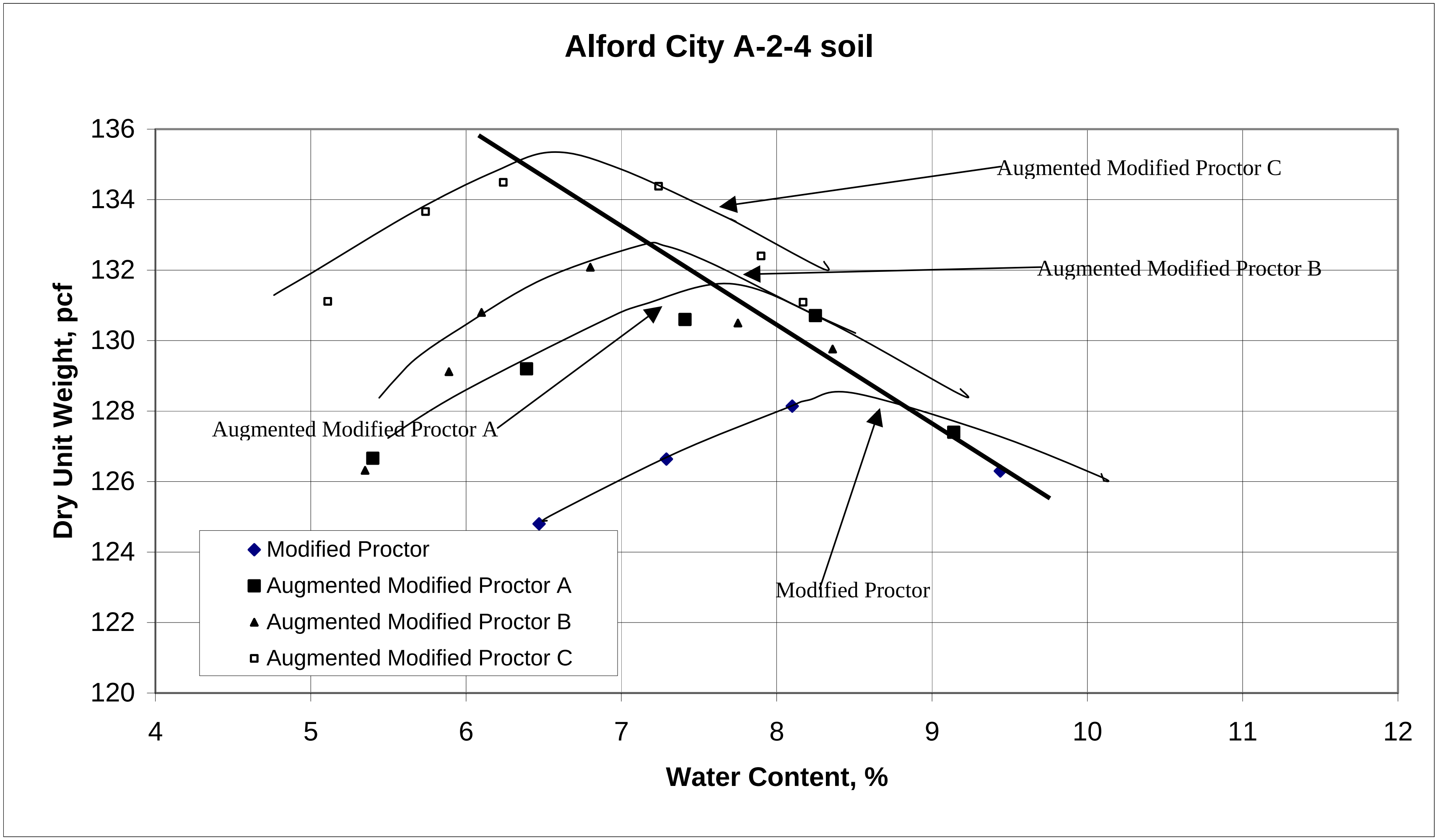


Figure 4.3 Impact compaction method investigation (Alford City A-2-4 soil)

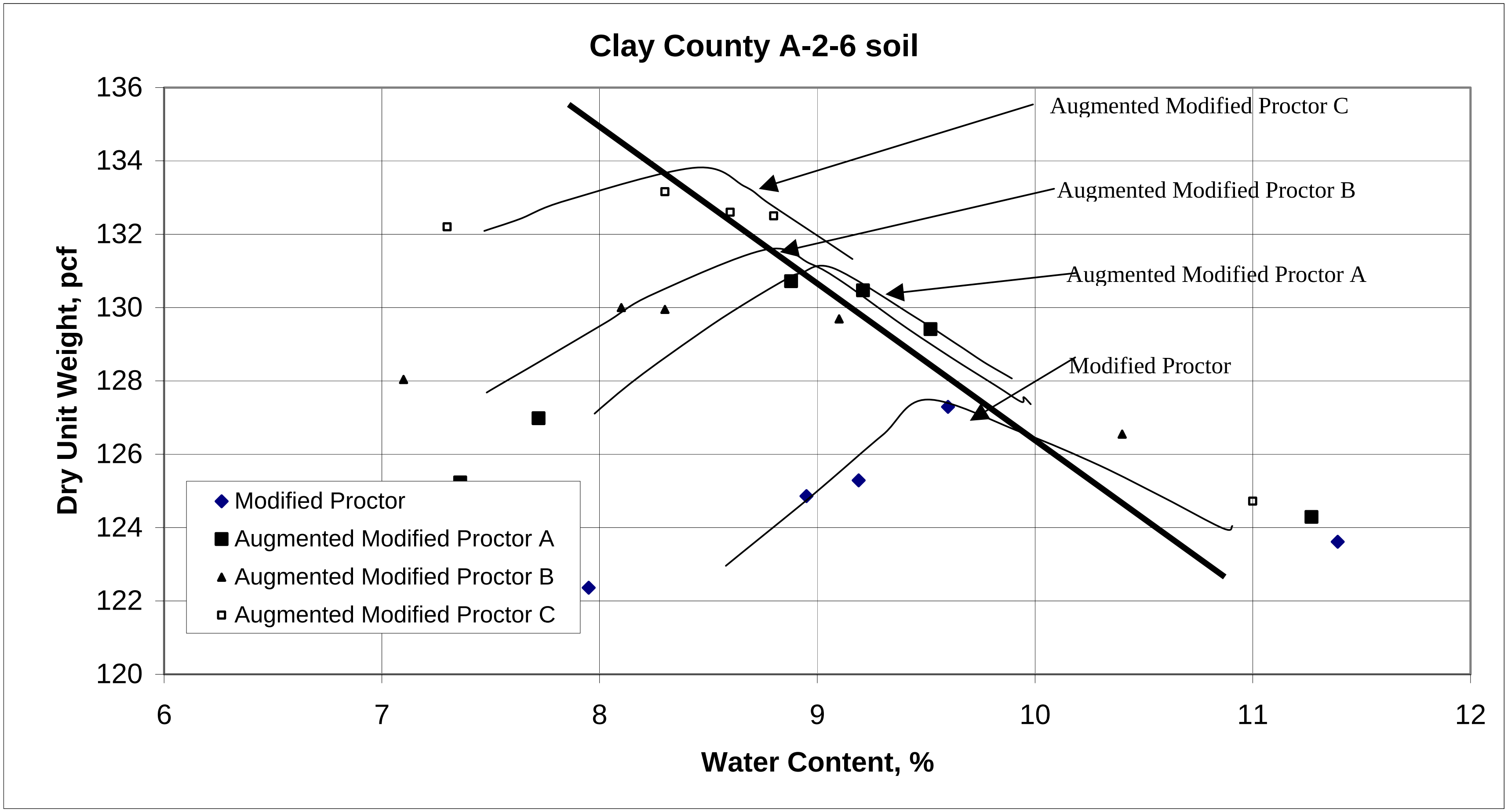


Figure 4.4 Impact compaction method investigation (Clay County A-2-6 soil)

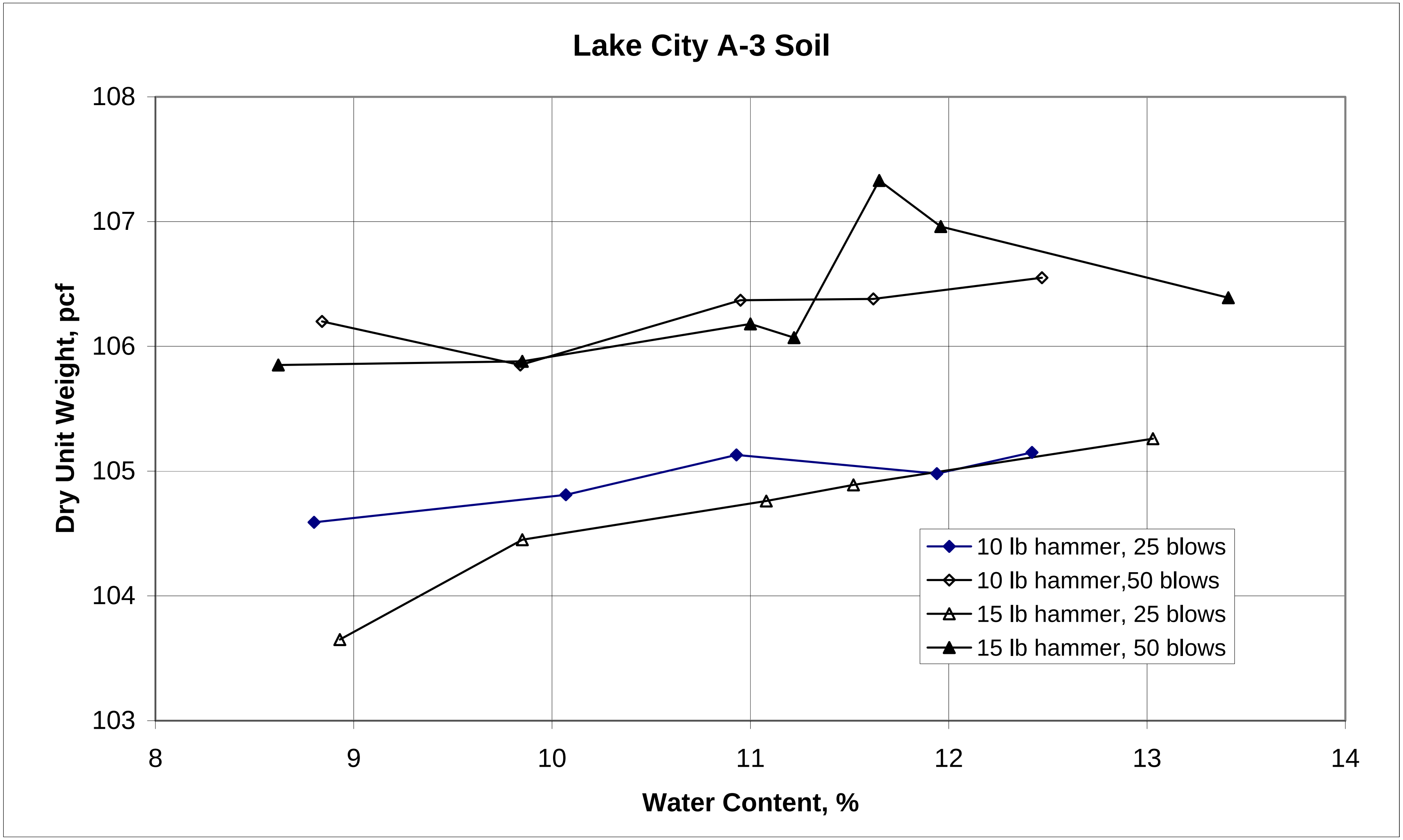


Figure 4.5 Impact compaction test results (Lake City A-3 soil)

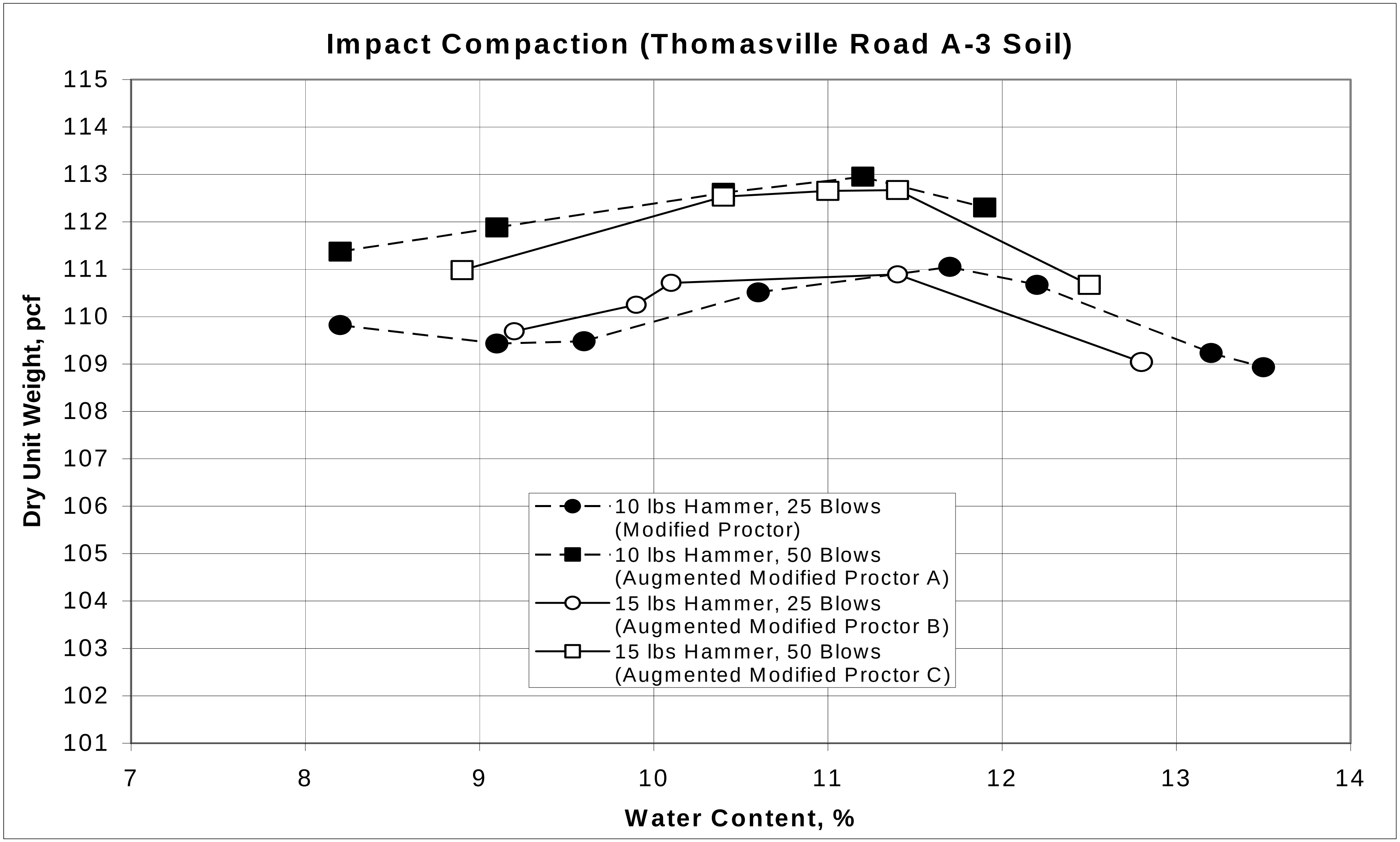


Figure 4.6 Laboratory impact compaction curves for Thomasville Road A-3 soil

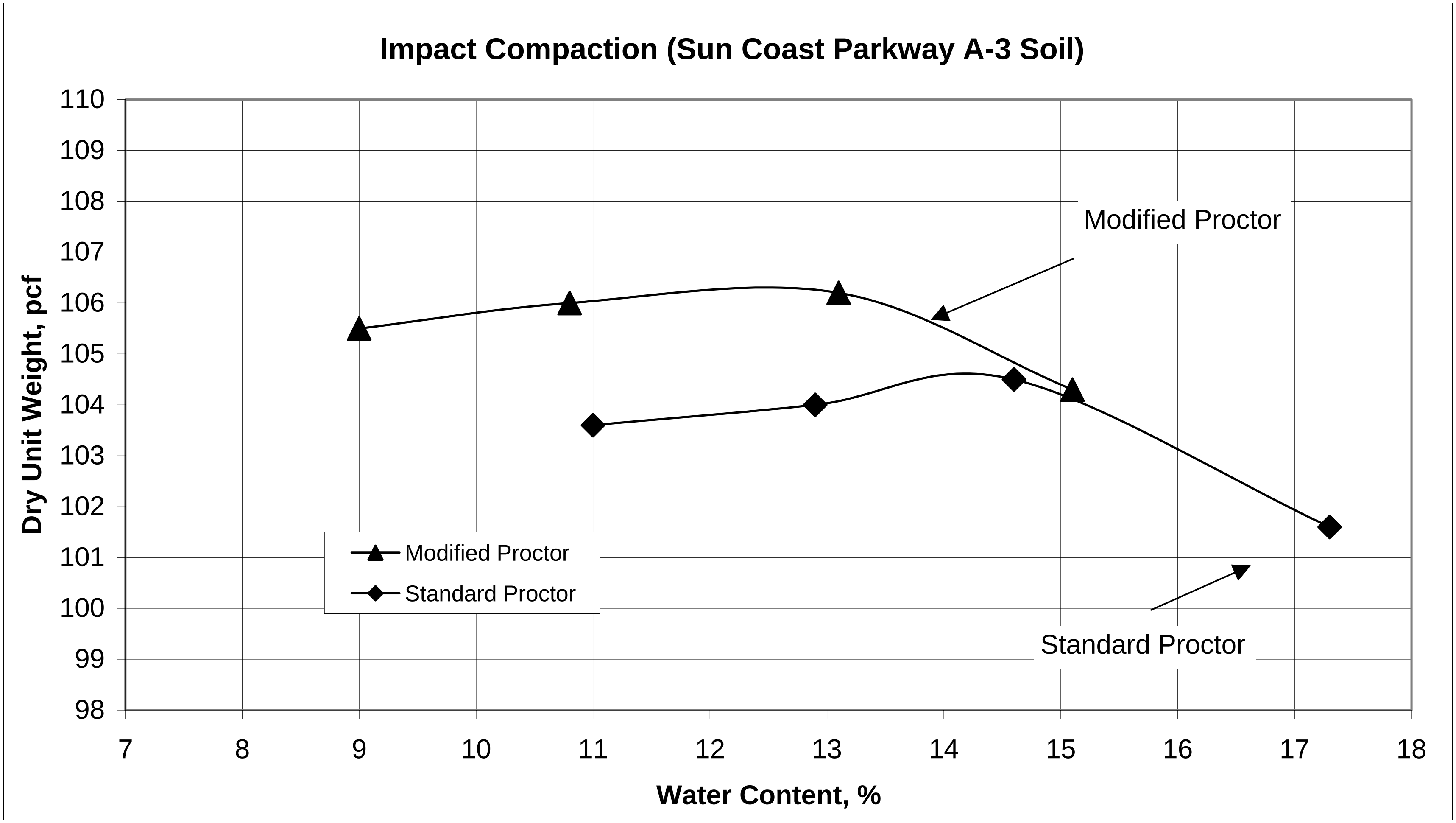


Figure 4.7 Laboratory impact compaction curves for Sun Coast Parkway A-3 soil

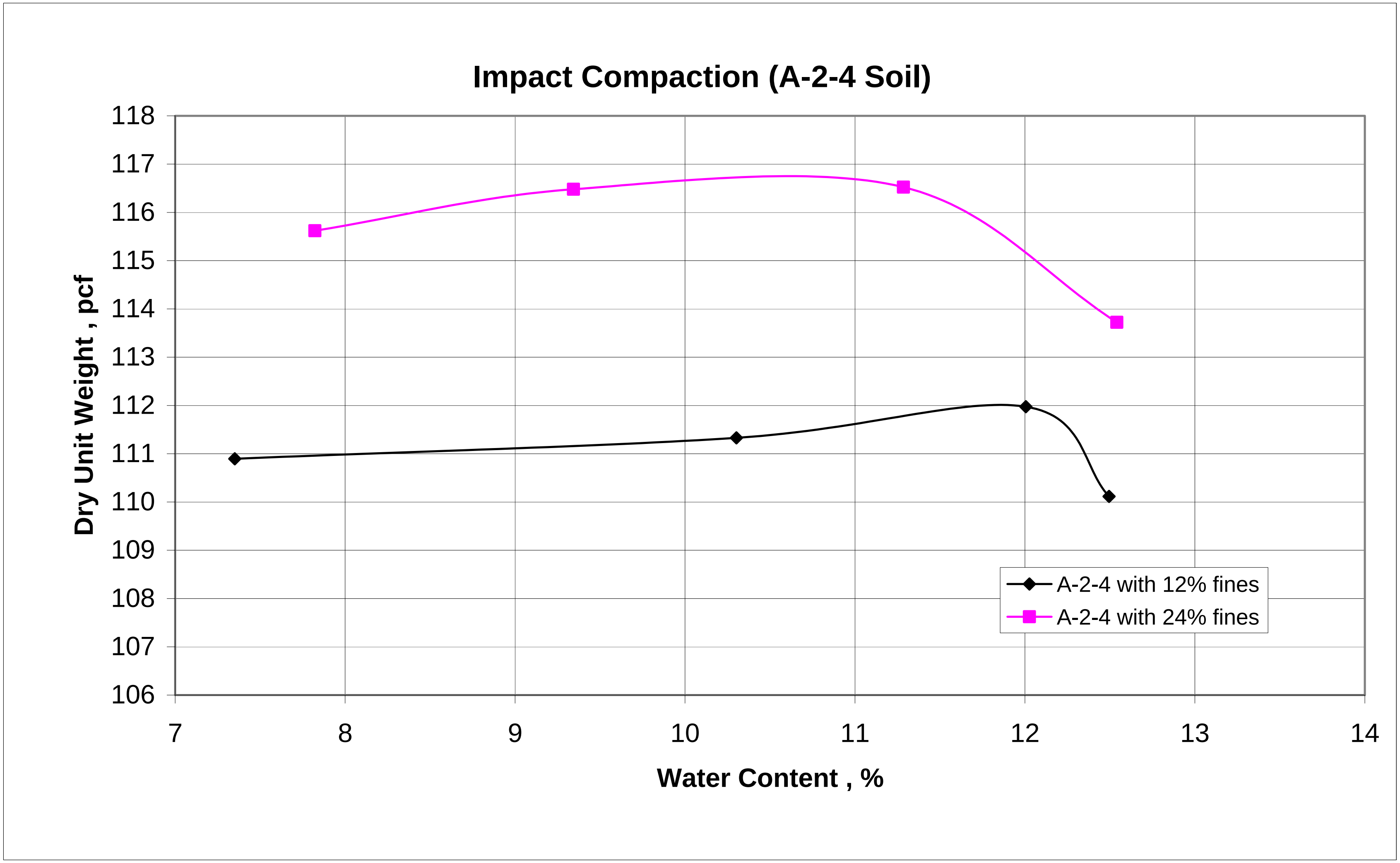


Figure 4.8 Modified Proctor compaction test for A-2-4 soil

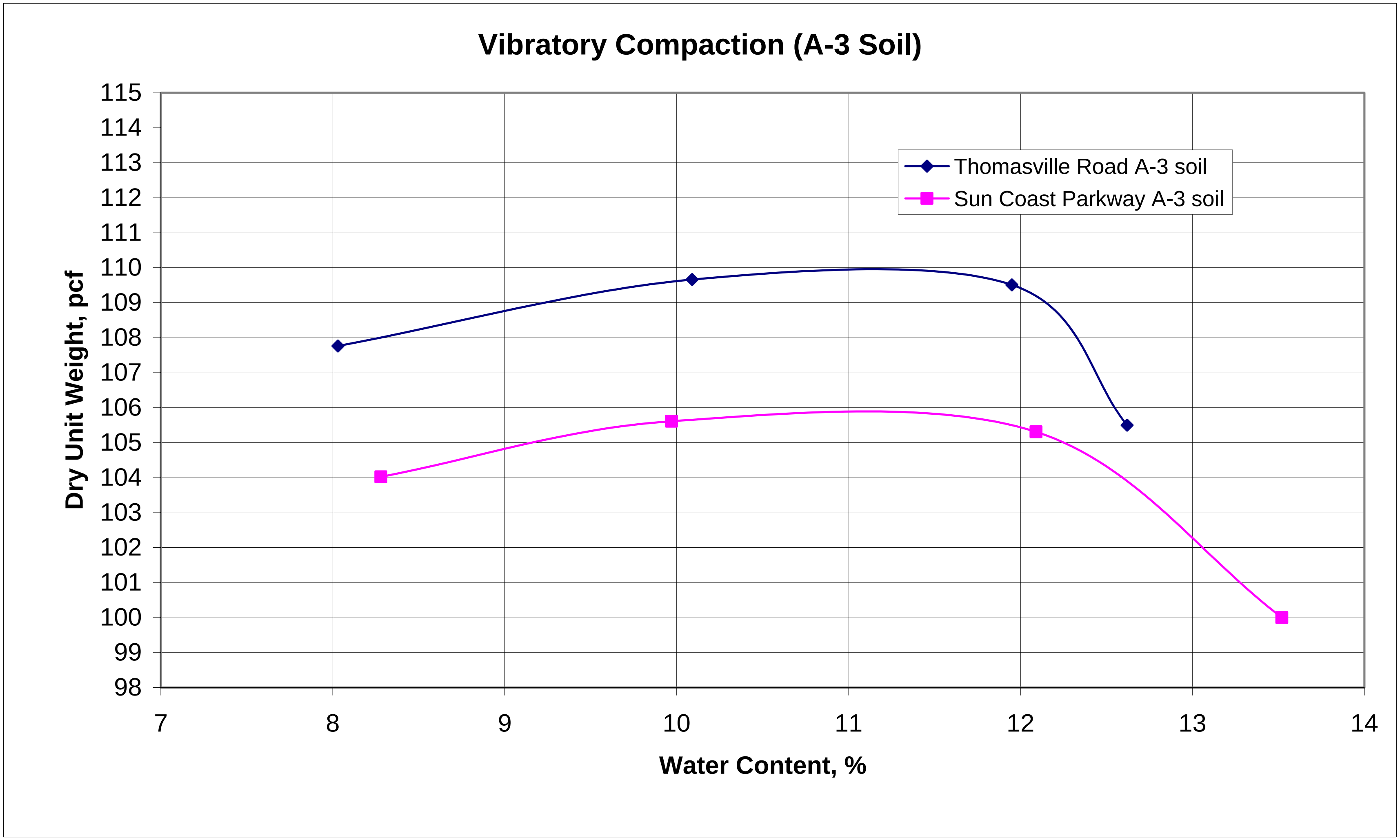


Figure 4.9 Vibratory compaction for Sun Coast Parkway and Thomasville Road A-3 soils

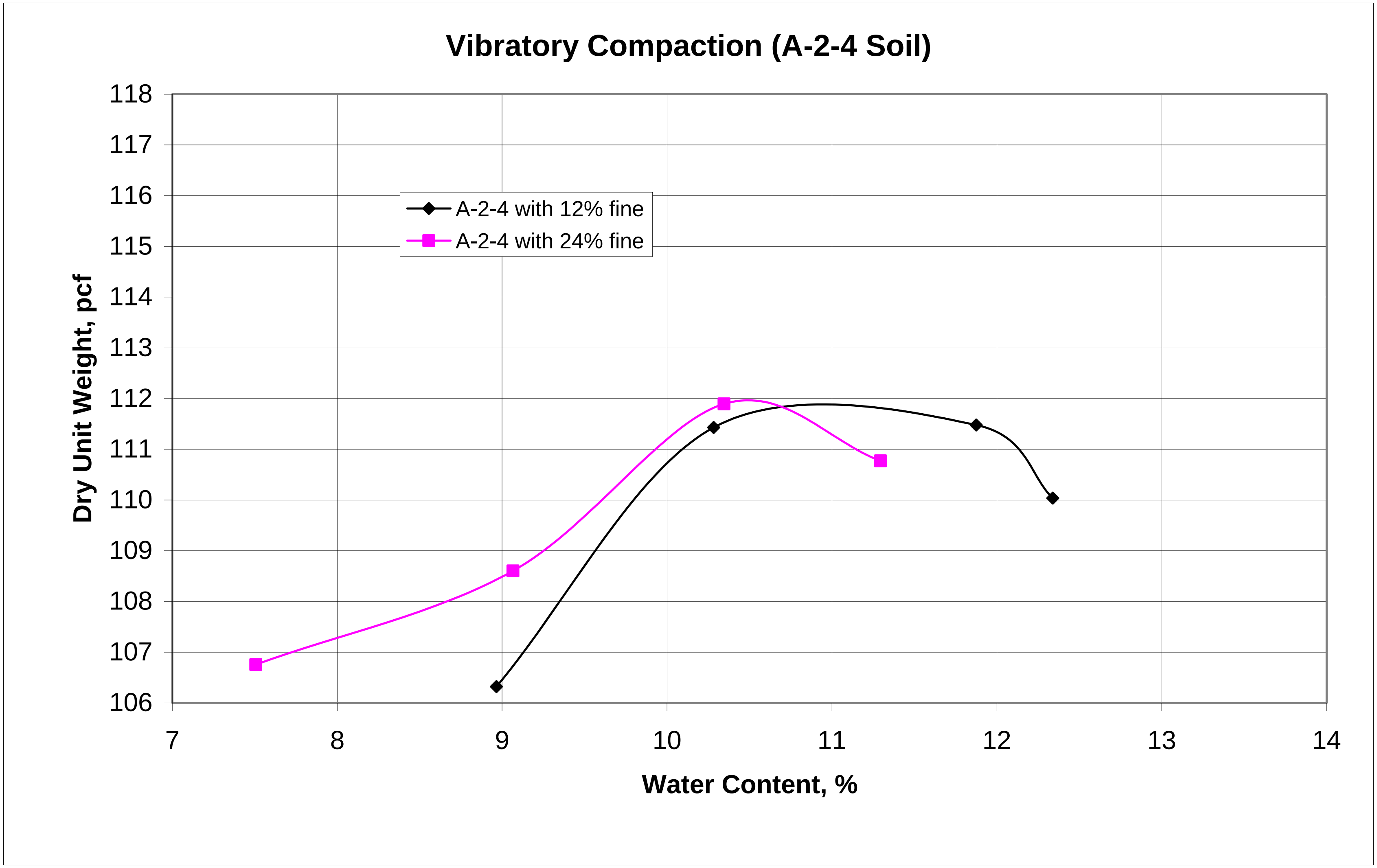


Figure 4.10 Vibratory compaction for A-2-4 with 12% fines and A-2-4 with 24% fines soil

Figure 4.11 Servopac Gyratory compactor

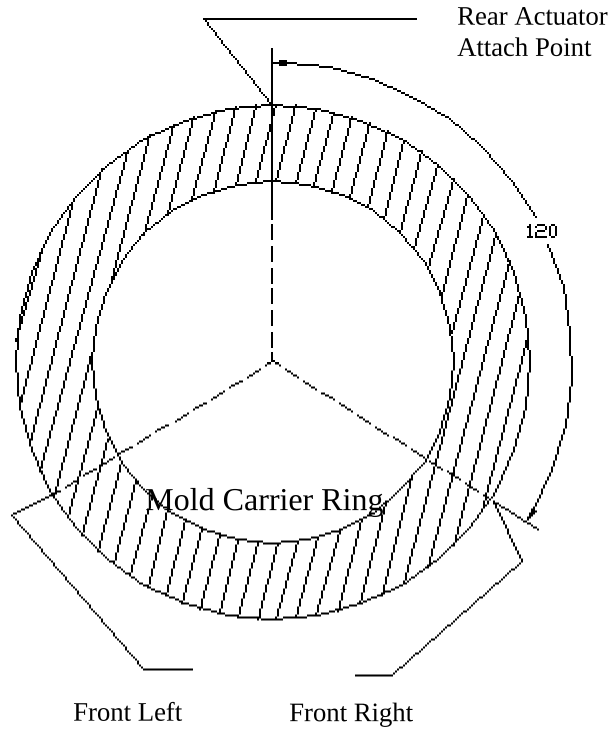


Figure 4.12 Theory of gyration angle working

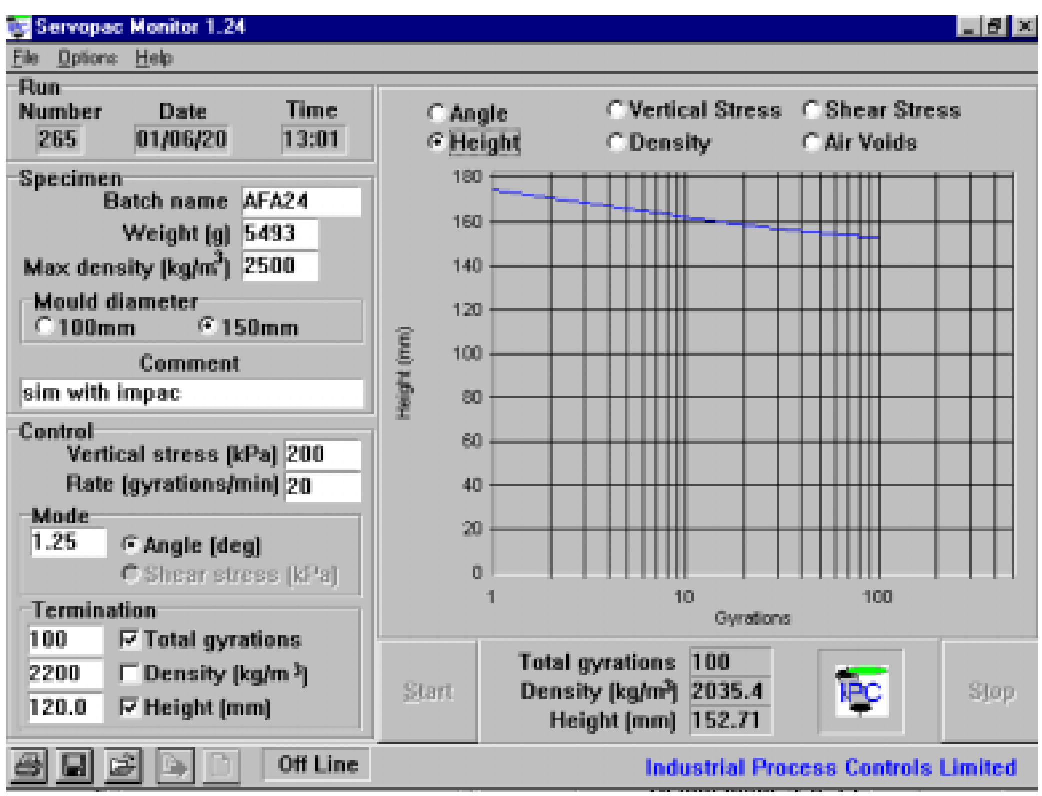


Figure 4.13 Servopac Gyratory Compactor PC window

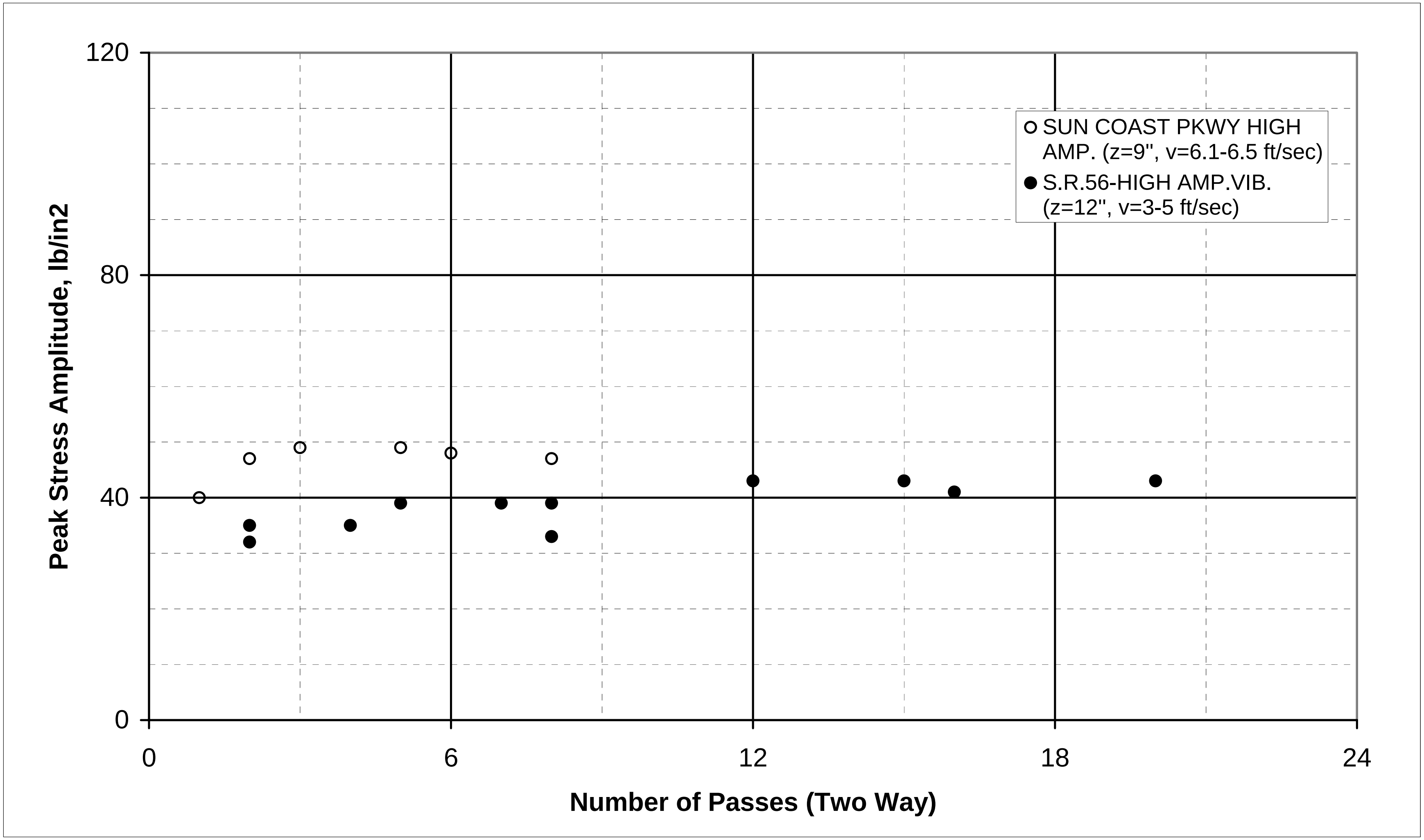
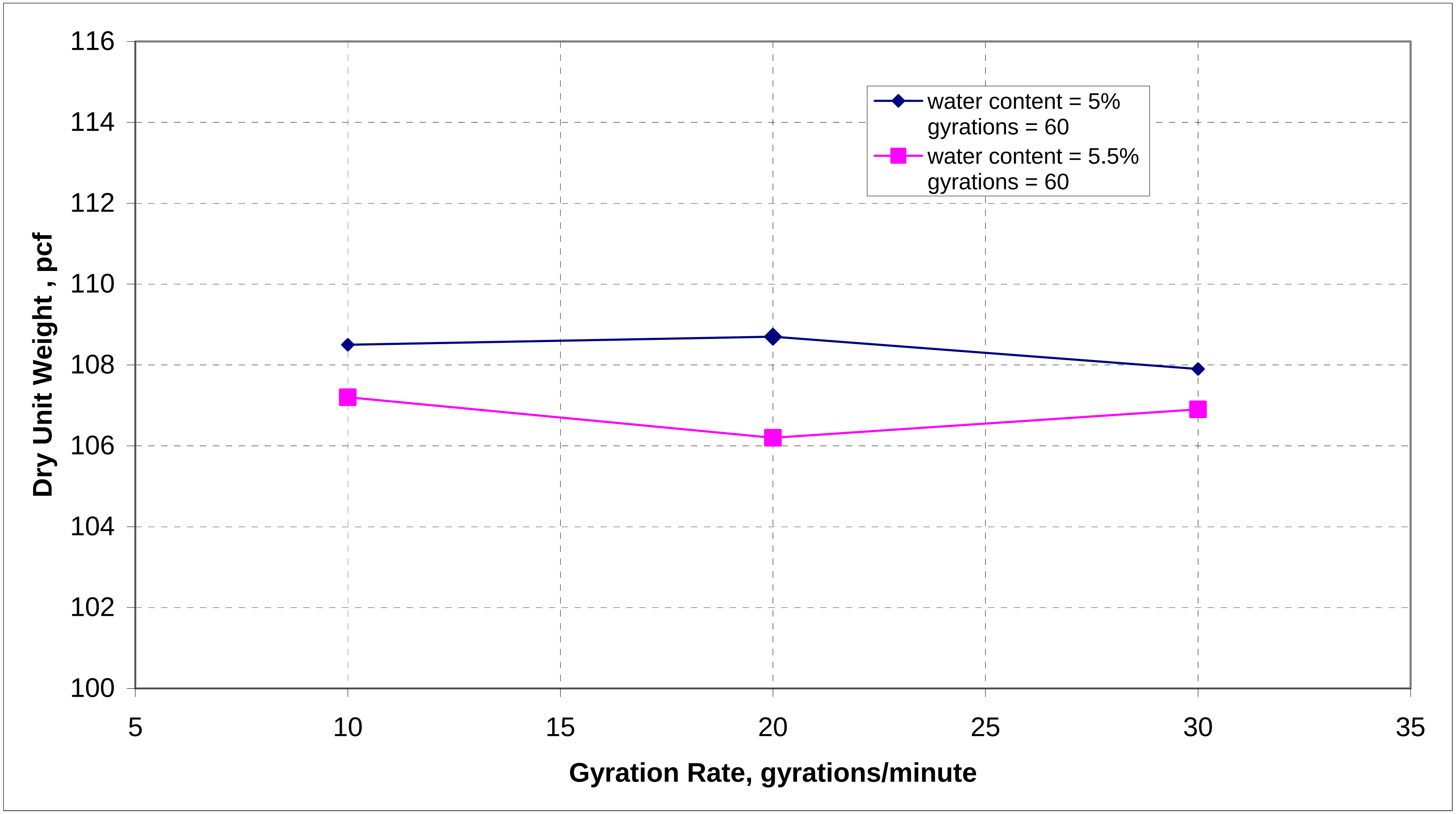


Figure 4.14 Peak stress versus number of passes during field compaction



116
114
112
110
108
106
104
102
100
Dry Unit Weight , pcf
5
10
15
20
25
30
35
Gyration Rate, gyrations/minute
water content = 5% gyrations = 60
water content = 5.5% gyrations = 60

Figure 4.15 Effect of gyration rate on compacted unit weight

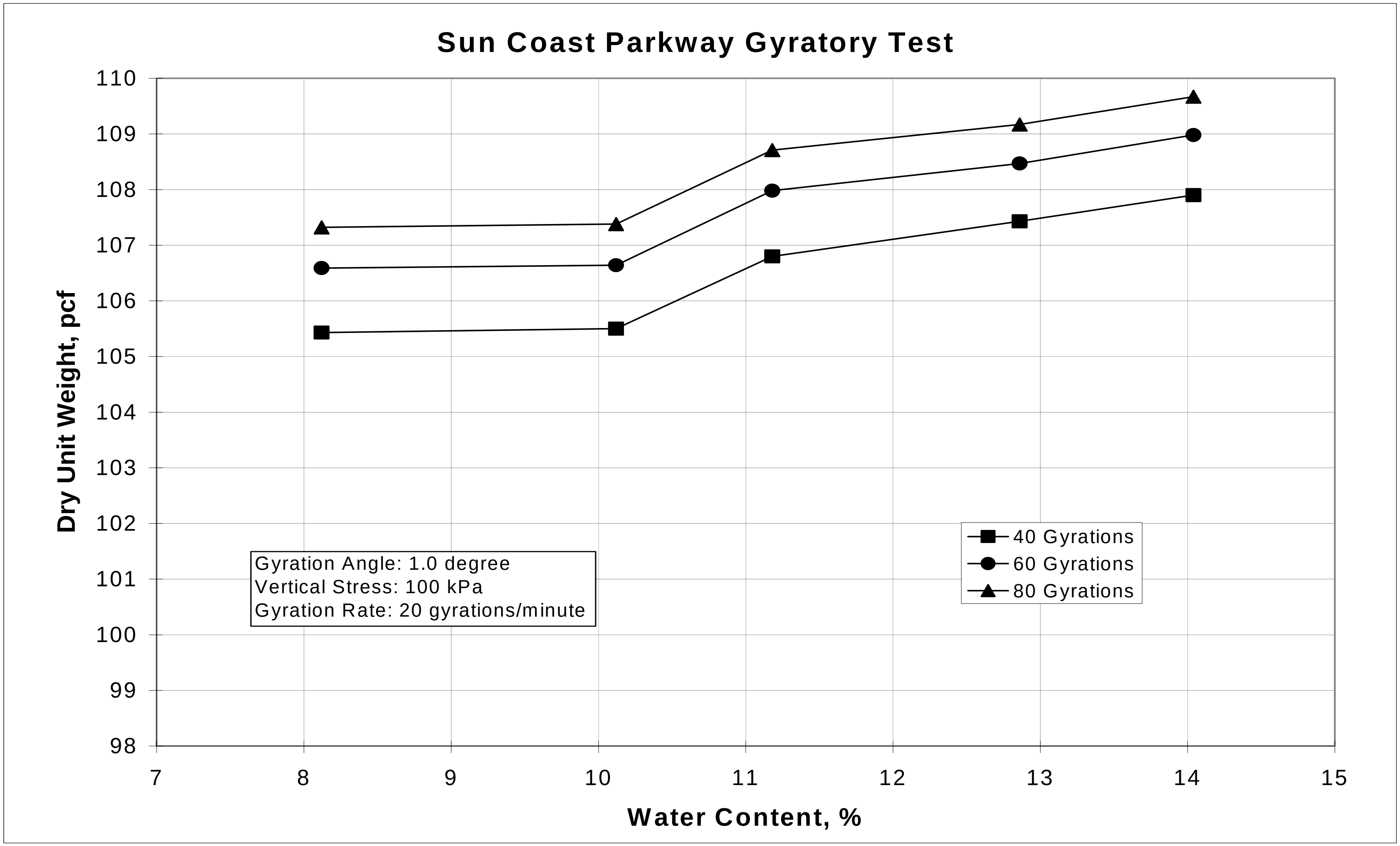


Figure 4.16 Effect of water seepage on dry unit weight during compaction

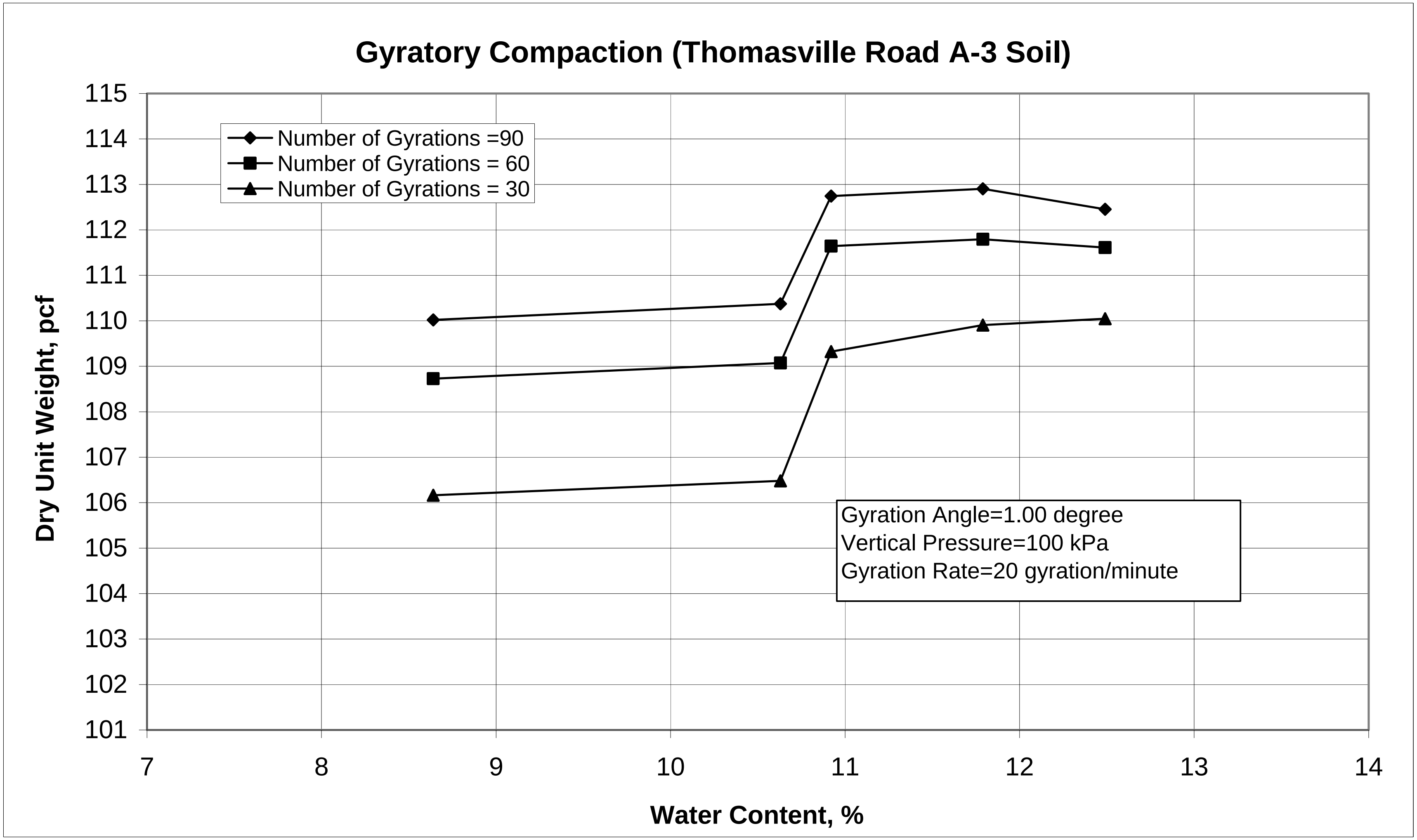


Figure 4.17(a) Compaction curves for Thomasville Road soil at 1.0 degree gyration angle, 100 kPa vertical pressure.

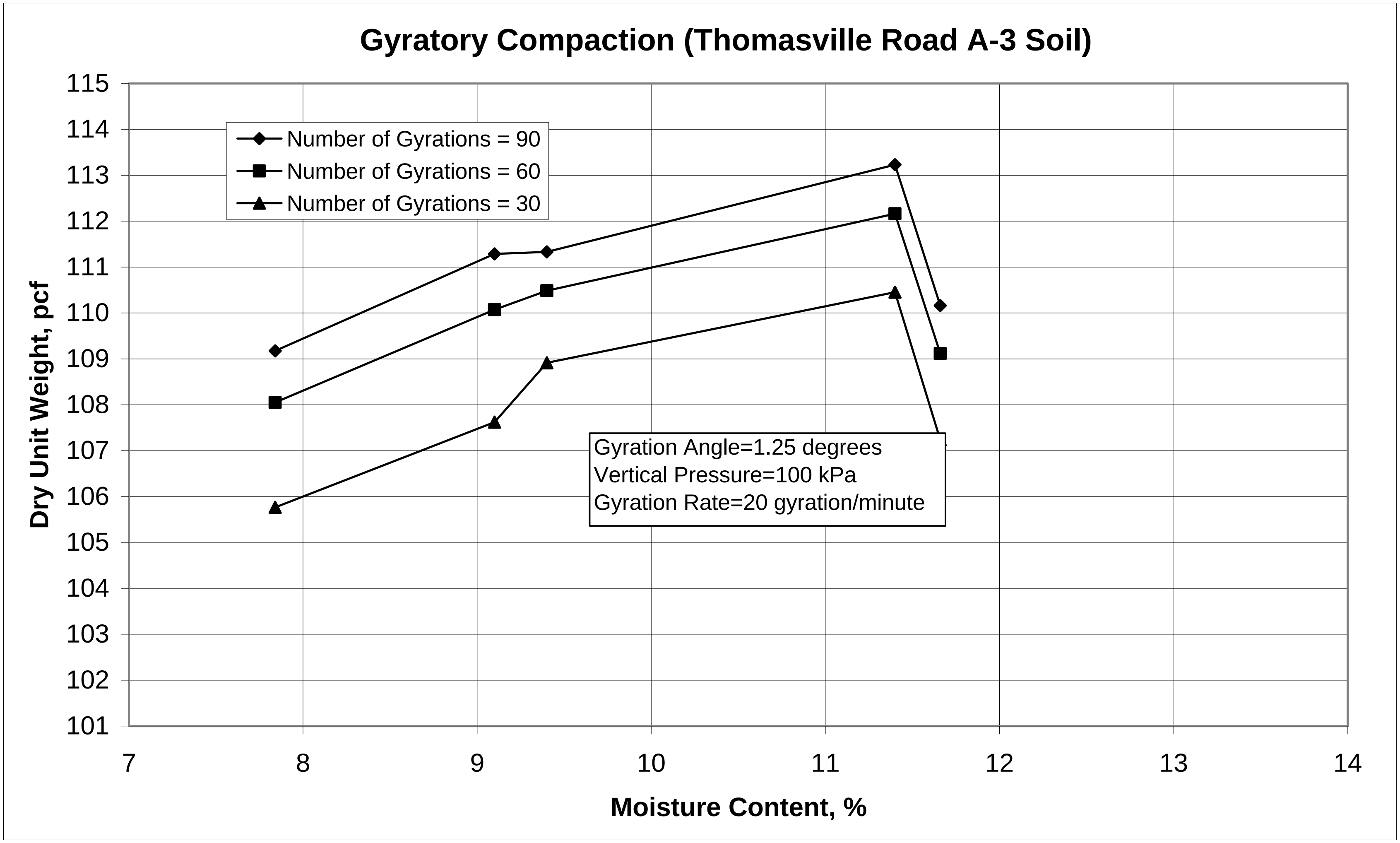


Figure 4.17(b) Compaction curves for Thomasville Road soil at 1.25 degrees gyration angle, 100 kPa vertical pressure

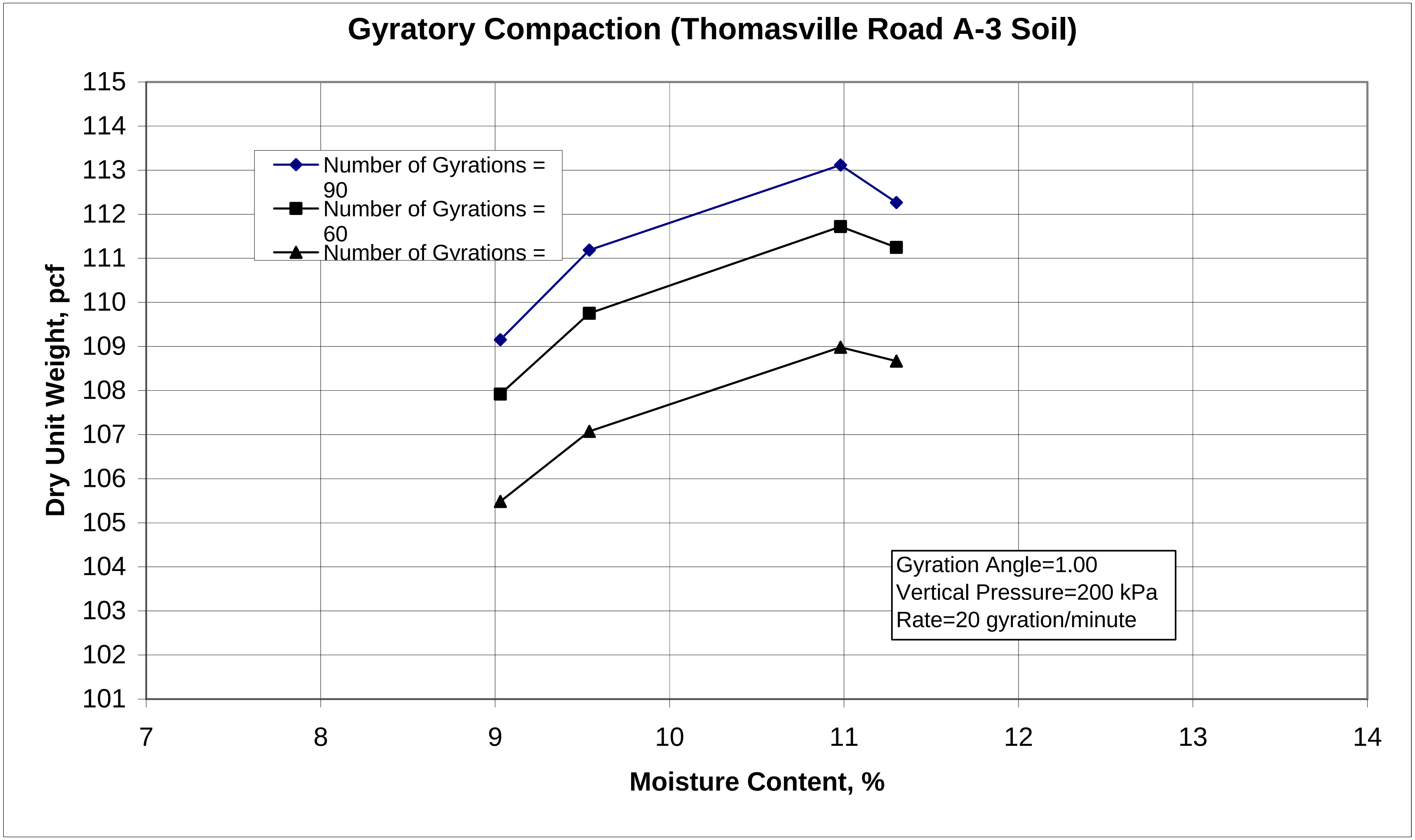


Figure 4.17(c) Compaction curves for Thomasville Road soil at 1.0 degree gyration angle, 200 kPa vertical pressure.

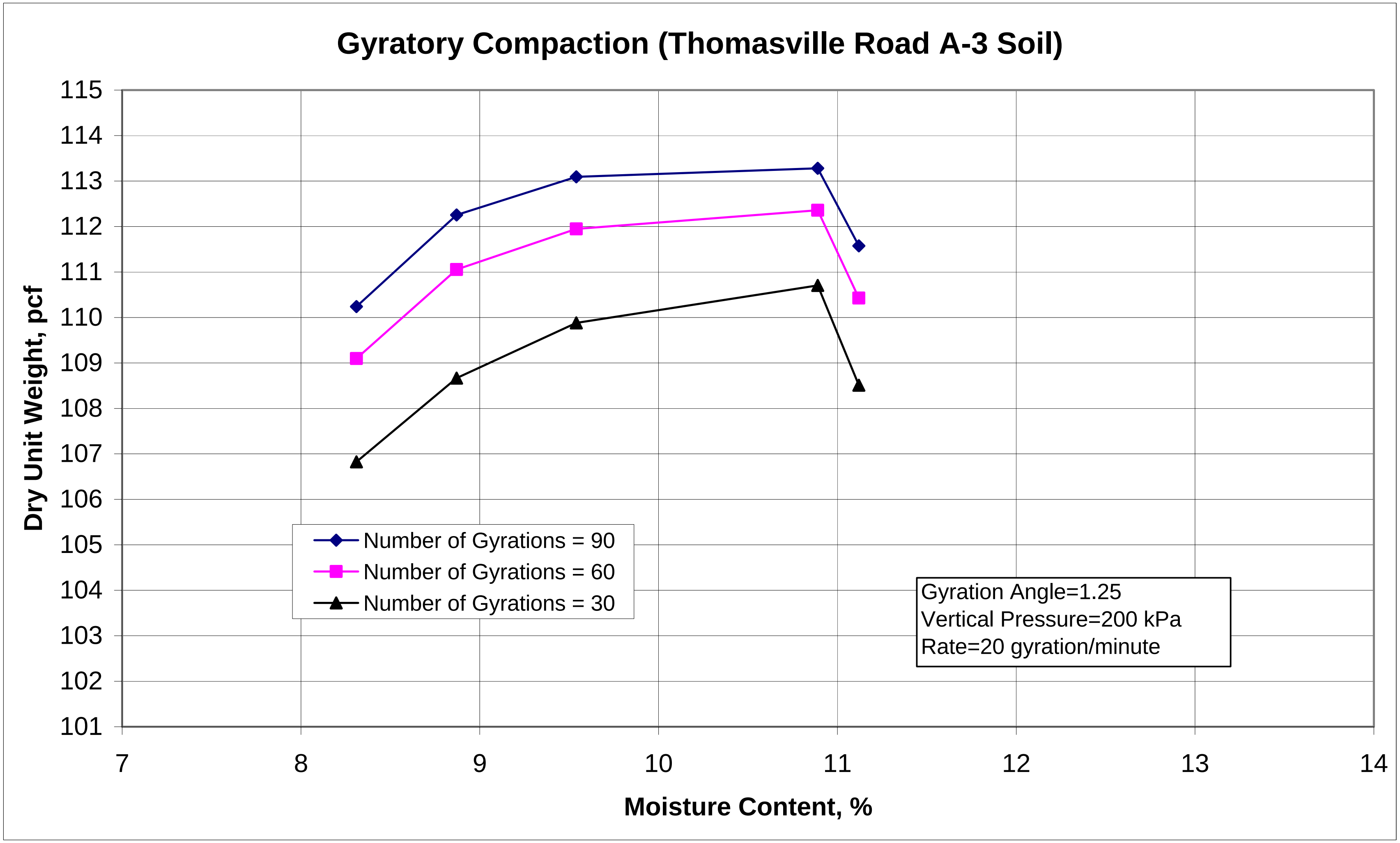


Figure 4.17(d) Compaction curves for Thomasville Road soil at 1.25 degree gyration angle, 200 kPa vertical pressure.

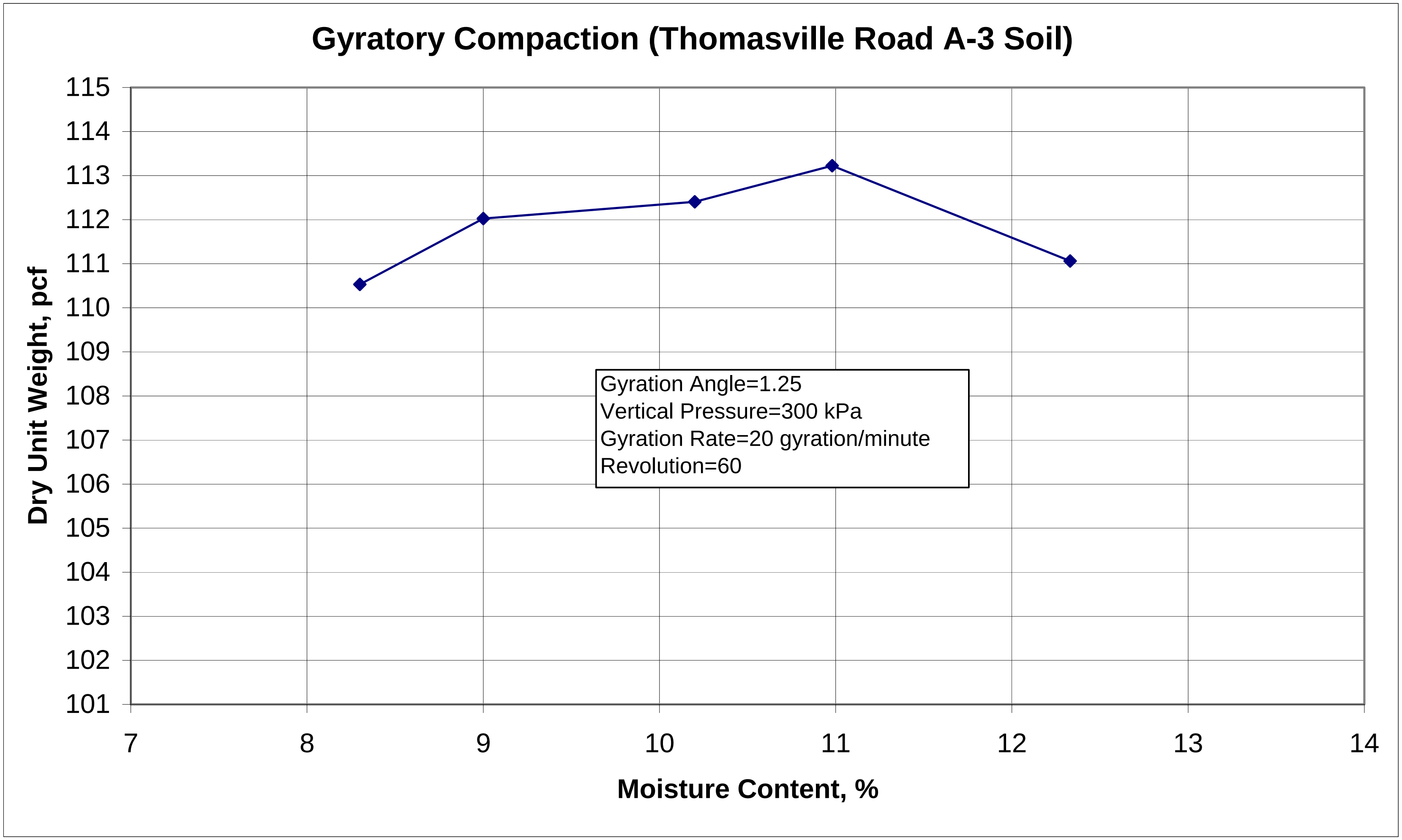


Figure 4.17(e) Compaction curves for Thomasville Road soil at 1.25 degrees gyration angle, 300 kPa vertical pressure

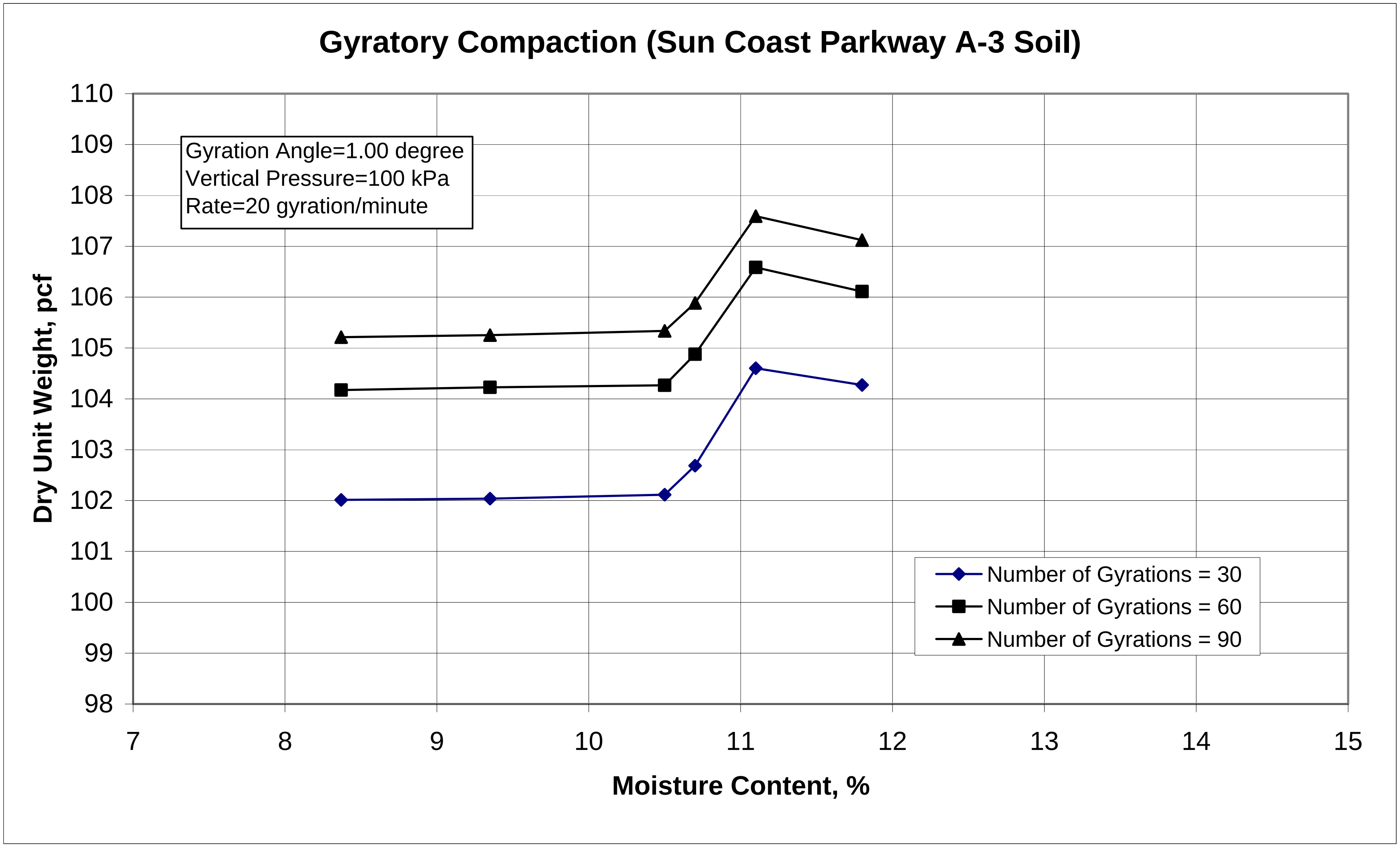


Figure 4.18(a) Compaction curves for Sun Coast Parkway soil at 1.0 degree gyration angle, 100 kPa vertical pressure

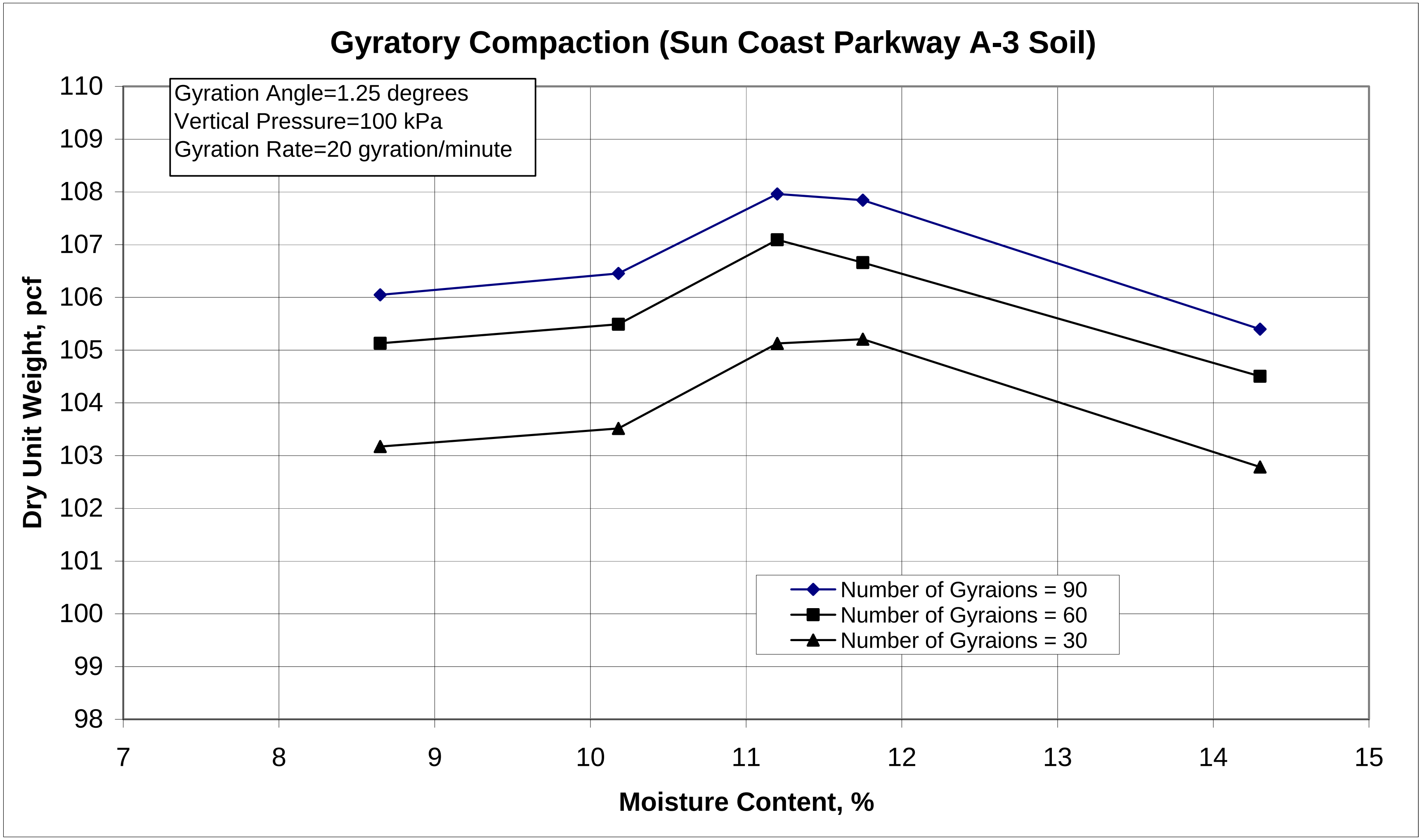


Figure 4.18(b) Compaction curves for Sun Coast Parkway soil at 1.25 degree gyration angle, 100 kPa vertical pressure.

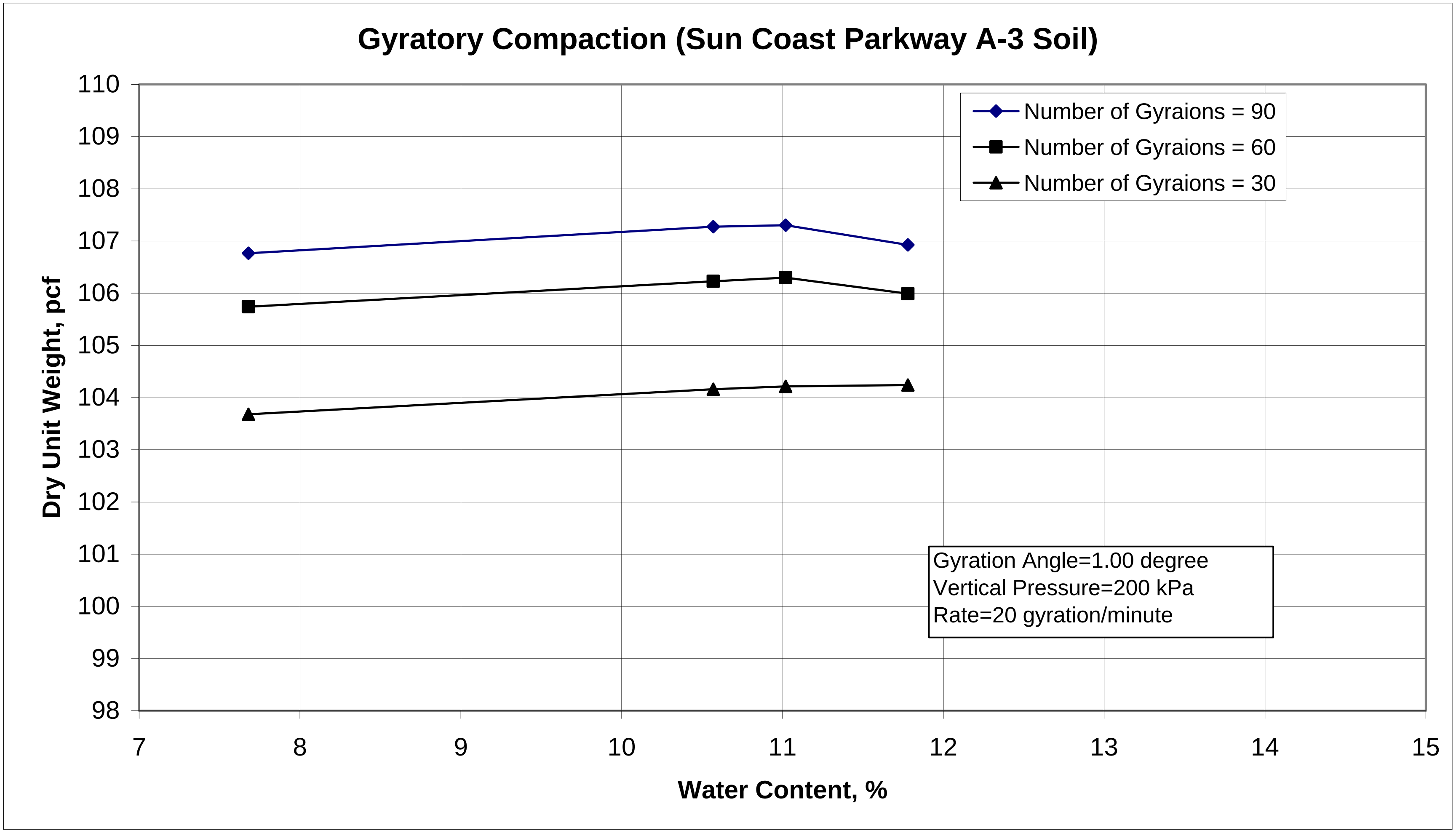


Figure 4.18(c) Compaction curves for Sun Coast Parkway soil at 1.00 degree gyration angle, 200 kPa vertical pressure.

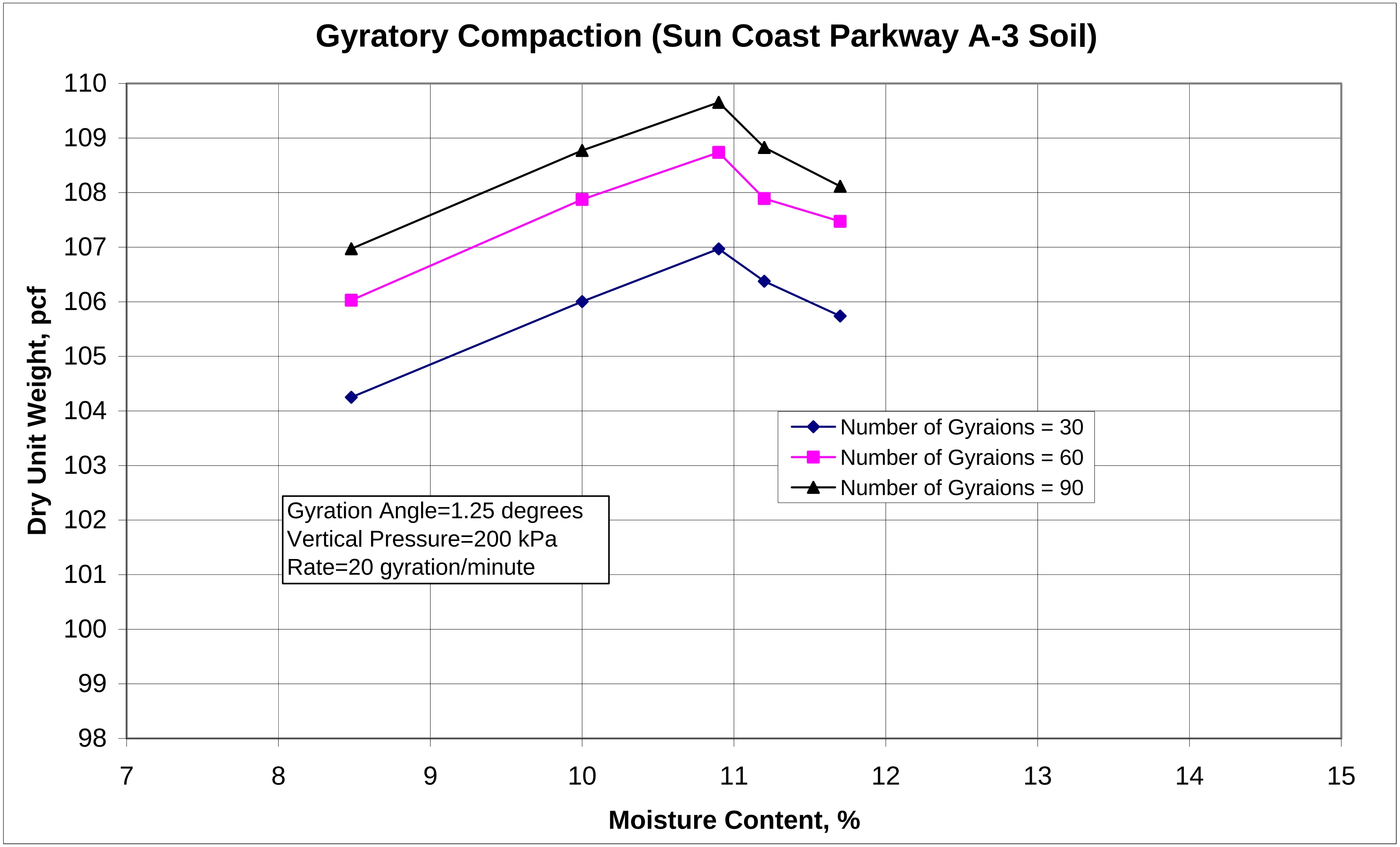


Figure 4.18(d) Compaction curves for Sun Coast Parkway soil at 1.25 degree gyration angle, 200 kPa vertical pressure.

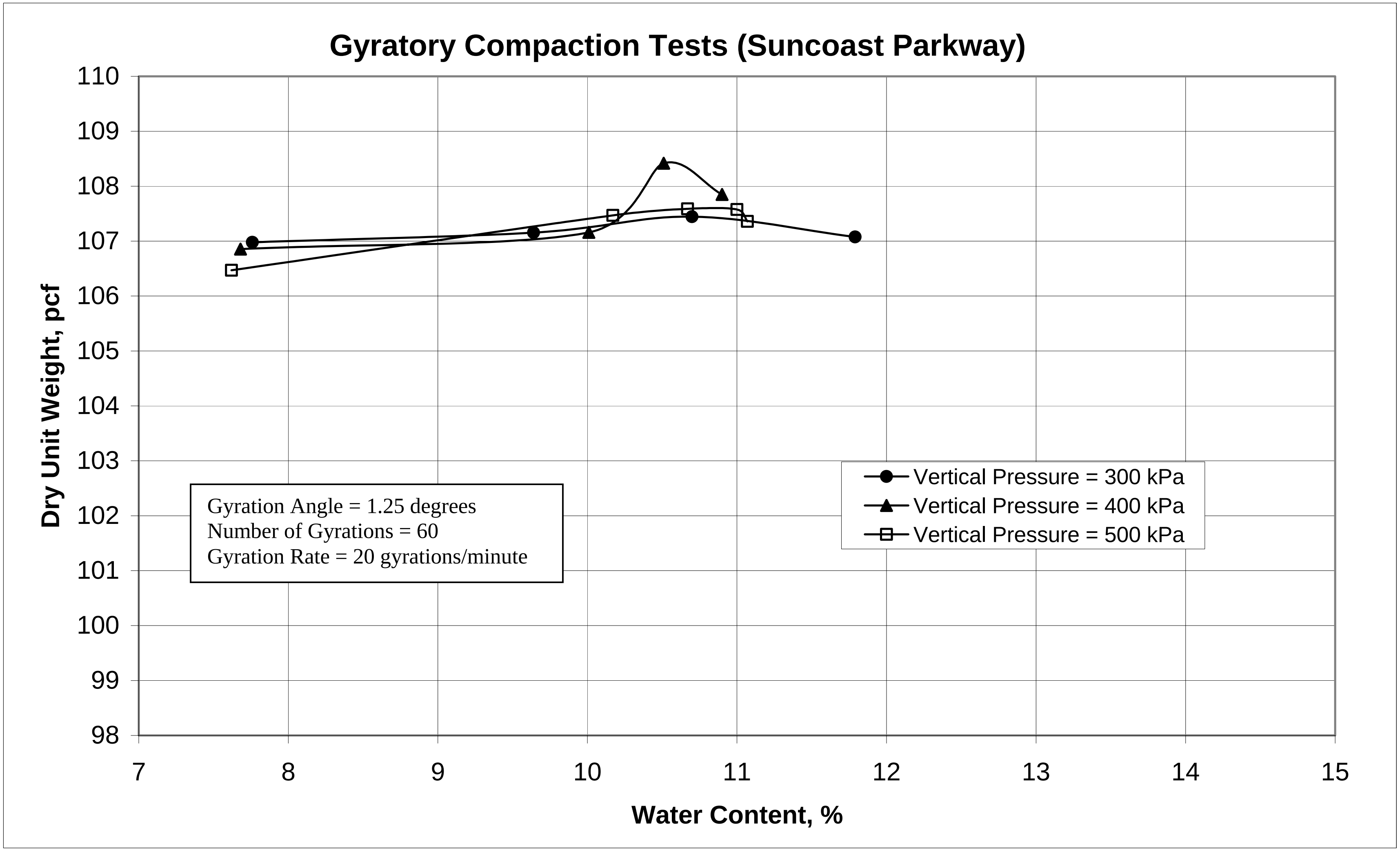


Figure 4.18(e) Compaction curves for Sun Coast Parkway soil at 1.25 degrees gyration angle, and different vertical pressure

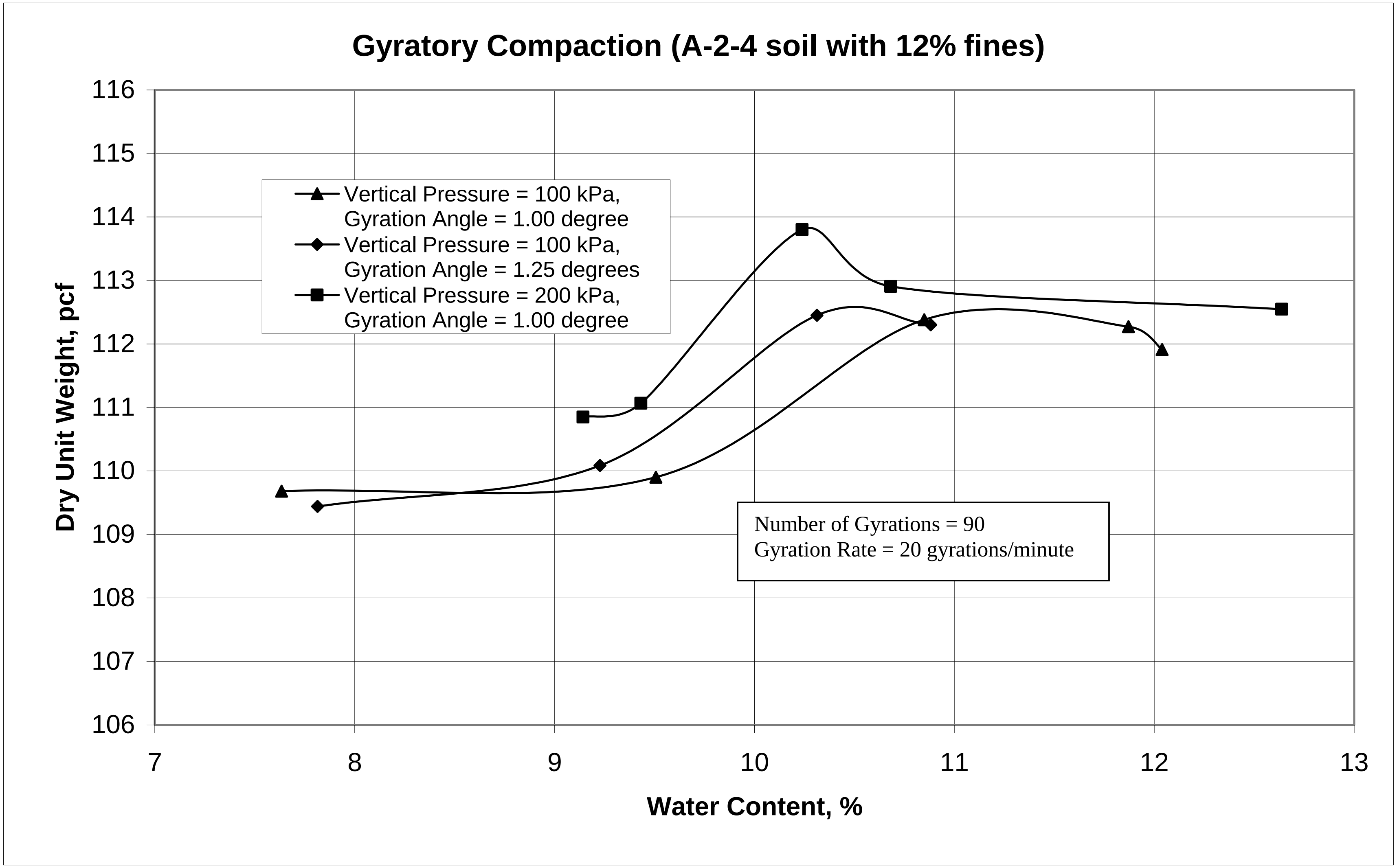


Figure 4.19(a) Compaction curves for A-2-4 soil with 12% fines at different vertical pressures and gyration angles

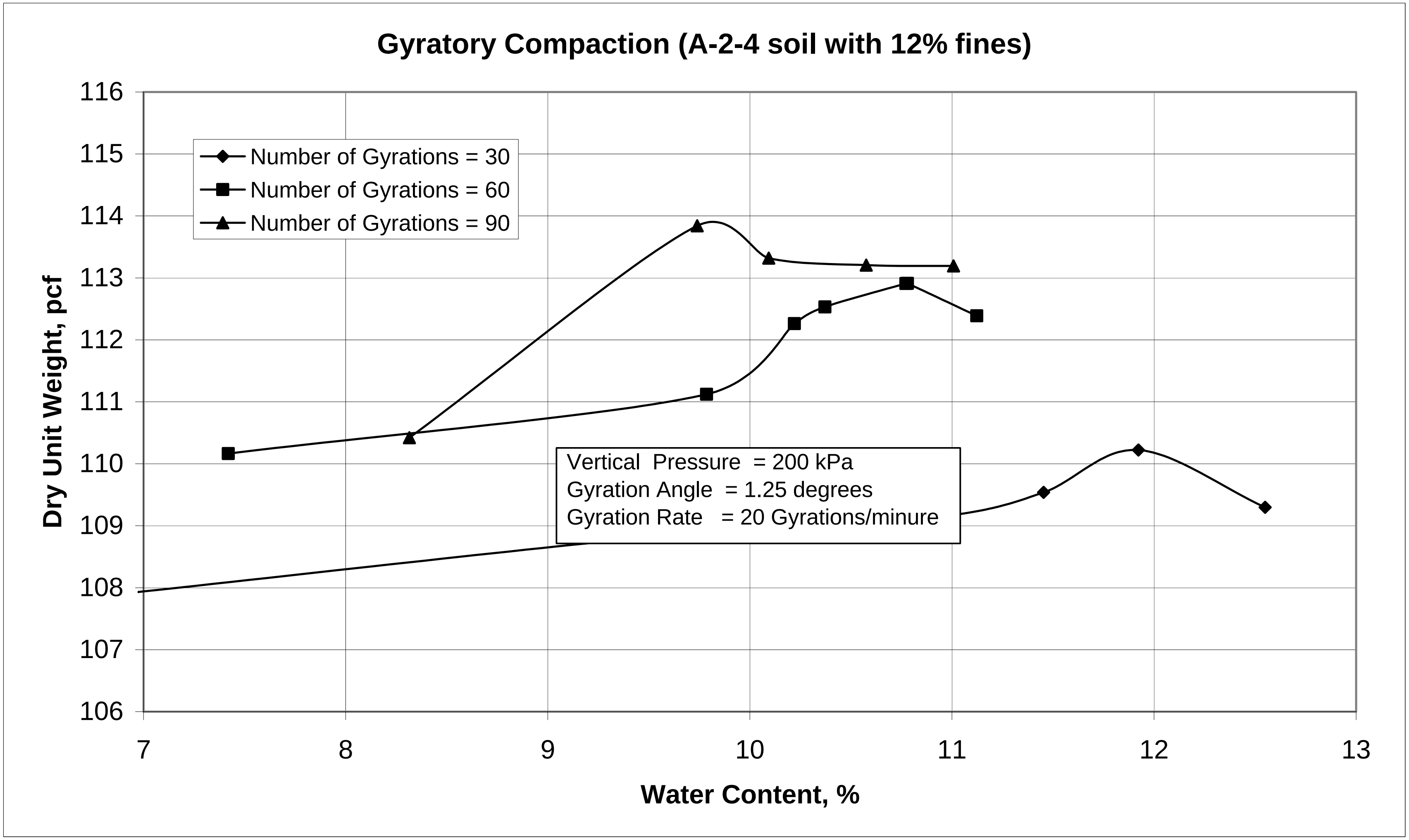


Figure 4.19(b) Compaction curves for A-2-4 soil with 12% fines at 1.25 degree gyration angle, and 200 kPa vertical pressure

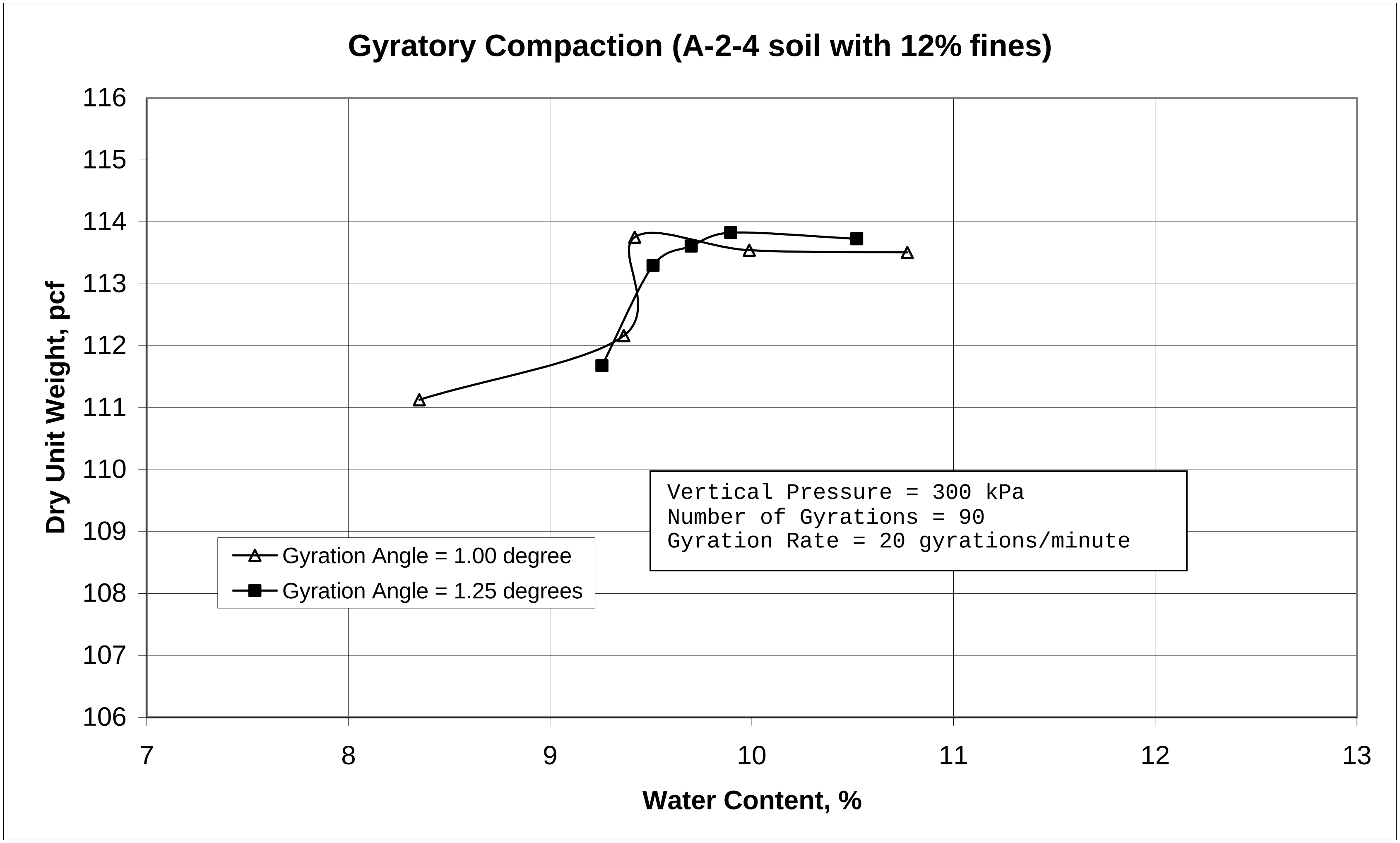


Figure 4.19(c) Compaction curves for A-2-4 soil with 12% fines at 300 kPa vertical pressure and different gyration angle

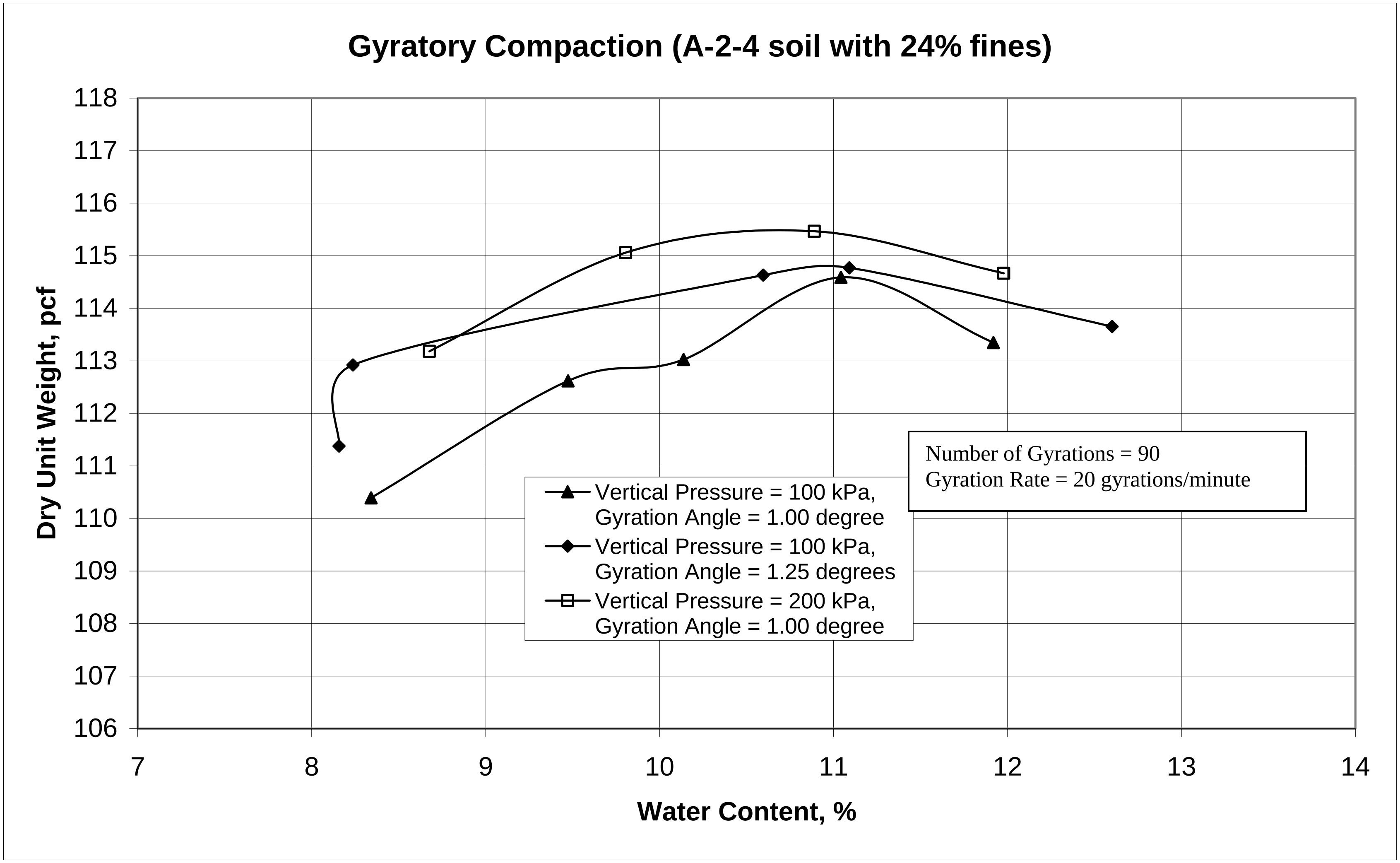


Figure 4.20(a) Compaction curves for A-2-4 soil with 24% fines at different vertical pressures and gyration angles

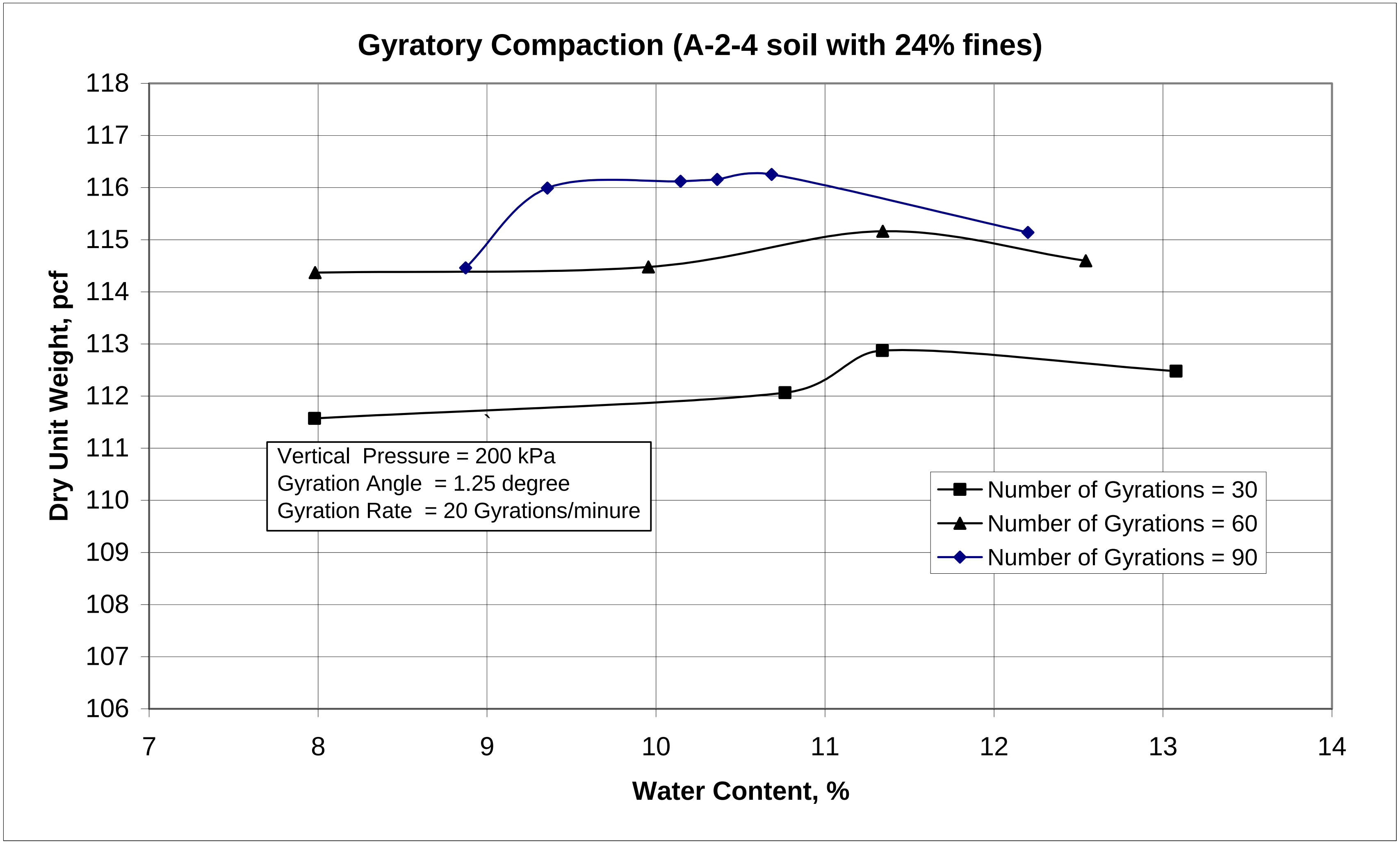


Figure 4.20(b) Compaction curves for A-2-4 soil with 24% fines at 1.25 degree gyration angle, and 200 kPa vertical pressure

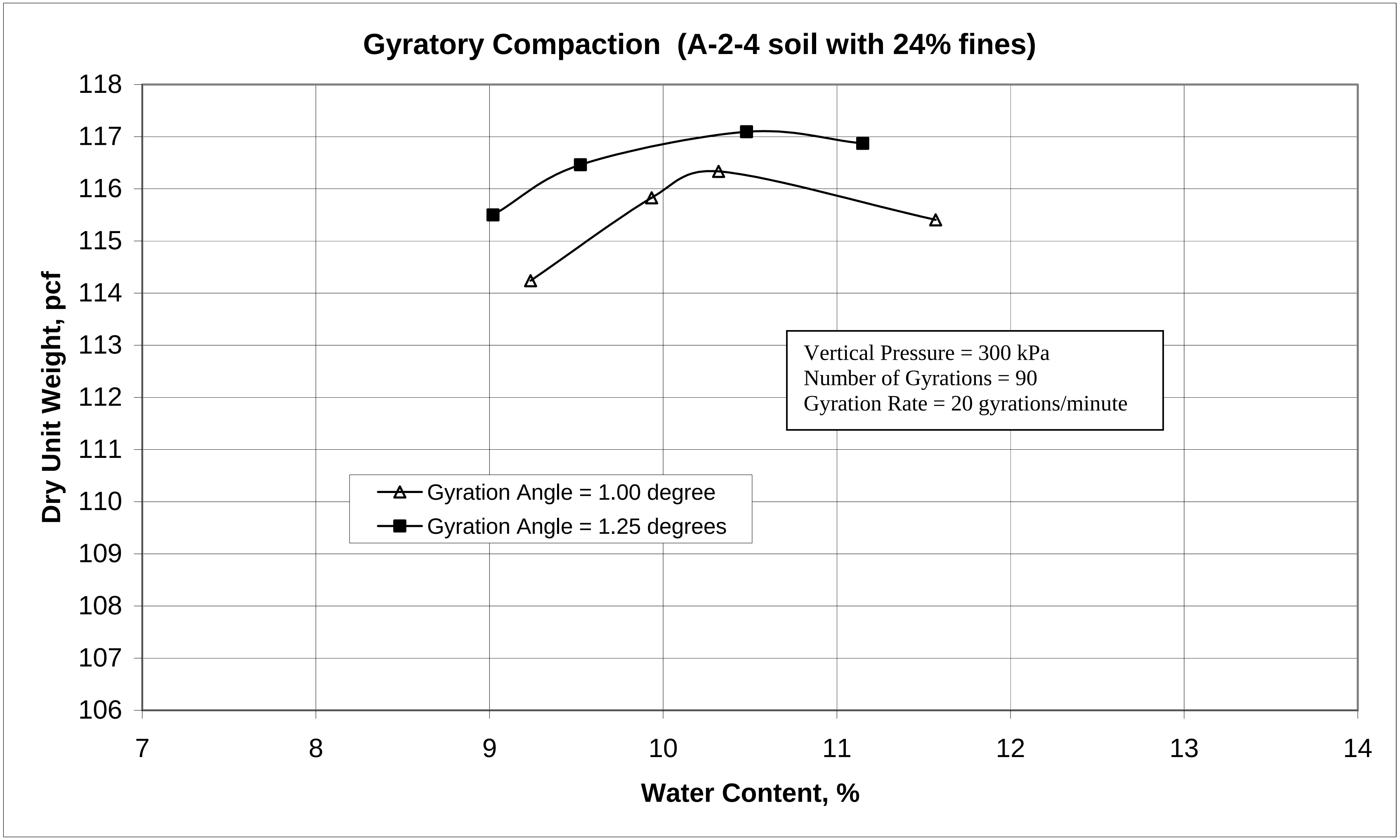


Figure 4.20(c) Compaction curves for A-2-4 soil with 24% fines at 300 kPa vertical pressure and different gyration angles

CHAPTER 5

SUMMARY AND ANALYSIS OF EXPERIMENTAL RESULTS

5.1 Comparison of Laboratory and Field Compaction

The laboratory compaction curves (gyratory, impact, and vibratory compaction) are further compared with the field compaction curves in Figures 5.1 and 5.2. From these figures, the modified Proctor compaction test results show significant difference from the field test results.

For the Thomasville Road soil, the OMC from the modified Proctor test was 12% and the maximum dry unit weight was 110.5 pcf, while the field OMC was 10% and the maximum dry unit weight was about 113.8 pcf. About a 2% water content and a 3 pcf maximum dry unit weight were the differences between the modified Proctor and field compaction. According to the recent specification 98% of the modified Proctor dry unit weight is 108 pcf, about a five pcf difference. Also for the Sun Coast Parkway soil, the laboratory maximum dry unit weight was 106.5 pcf at 13% water content, and the field maximum dry unit weight was

110 pcf at 8% water content. The modified Proctor maximum dry unit weight at 98% for field specification is 104 pcf, about a 6 pcf difference from the field test results.

These results showed that the current construction specifications drastically underestimate the maximum achievable field density for sandy soils. Therefore, the modified Proctor is not a reasonable test procedure to specify the density requirement for the sandy soil.

The gyratory test parameter setting used 200 kPa vertical pressure (optimum vertical pressure), a gyration angle of 1.25 degrees and 90 gyrations may be compared with the field test results. From these comparisons, these gyratory parameter settings show considerable promise for simulating the field test results.

According to the above comparison of the laboratory results with the field test results, the gyratory compaction is shown to be a better test method to simulate the field test results. Thus, the characteristics of three variables of the gyratory compaction should be studied further to find the most suitable test procedure. The gyratory compaction procedure is further evaluated as follows.

5.2 Further Evaluation of Gyratory Compaction Procedure

The three Servopac Gyratory Compactor variables were further evaluated in the laboratory. The results are summarized in this section.

5.2.1 Number of gyrations

The effect of gyrations on the dry unit weight for the four soils are shown in Figures 5.3 and 5.4. From these two figures, the results show that with the increase of the gyrations there was an increase of dry unit weight and a decrease of water content. But from Figure 5.3, due to the shortcoming of the test procedure, the problem of water seepage was not adjusted in determining the proper water content for the Thomasville Road and Sun Coast Parkway soils. That is the reason why the OMC was exactly the same for the different number of gyrations.

Also observed from these figures, the dry unit weight increased more than 2 pcf from 30 to 60 gyrations, but from 60 to 90 gyrations, the dry unit weight increased only about 1 pcf. The results show that the number of gyrations had significant influence on the OMC and the maximum dry unit weight. When the number of gyration was small, the dry unit weight was sensitive to the gyrations.

5.2.2 Gyration angle

The effect of the gyratory angles on the dry unit weight for the four soils are shown in Figures 5.5, 5.6, 5.7, 5.8. From these figures, it can be seen that the gyration angle had much less influence on the dry unit weight than the gyrations.

The gyration angle had some effect on the dry unit weight when the gyration cycles were low. However, the effect became insignificant when the gyration cycles were high.

When the soil had less fines, the value of the gyration angle had more influence on the dry unit weight. When the fines in the soil were increased, the influence became less significant. For example, the Sun Coast Parkway A-3 soil had 3% fines and the Thomasville Road soil had 6~8% fines. Hence the gyration angle had more influence on the dry unit weight for Sun Coast Parkway soil than that for the Thomasville Road soil.

5.2.3 Vertical pressure

The effect of the vertical pressures on the dry unit weight for the four soils are shown in Figures 5.9, 5.10, 5.11, 5.12, 5.13, and 5.14. The results show that when the vertical pressure was higher than 200 kPa, the dry unit weight did not increase significantly with the increase of the vertical pressure. This is similar to the Lake City A-3 sandy soil that was compacted with the impact compaction method. When the impact compaction effort was increased by increasing hammer weight, the dry unit weight did not increase accordingly (Figure 4.5). From these figures, 200 kPa is chosen as the optimum vertical pressure for the gyratory compaction. This corresponds to the field peak stress, about 30 psi under field compaction equipment.

5.2.4 Further comparison of gyratory compaction

The compaction curves obtained from the gyratory, modified Proctor, and vibratory compaction were further compared for the four soils and are shown in Figures 5.15, 5.16, 5.17, and 5.18. The results show that for the A-3 sandy soil (Thomasville Road and Sun Coast Parkway), the modified Proctor compaction generated much lower dry unit weight values than the field test. The gyratory compaction with 200 kPa vertical pressure, 1.25 degrees gyration angle, and 30 gyrations could achieve similar results with the modified Proctor and vibratory compaction. The gyratory compaction with a higher number of gyrations could be used to simulate the field test. The gyrations should be higher than 30 gyrations to match the maximum dry unit weight in the field test.

The impact compaction method worked well for the more silty soil. For the A-2-4 soil with 12% fines, a gyratory setting at 200 kPa vertical pressure, 1.25 degrees of gyration angle, and 60 gyrations can almost simulate the modified Proctor compaction curve (Figure 5.17). For the A-2-4 soil with 24% fines, the number of gyrations should be at least 90 in order to simulate the modified Proctor compaction curve (Figure 5.18).

From these figures, vibratory compaction does not work very well for compacting silty soil. This corresponds to the findings in the literature study, that vibratory compaction is better suited for compacting cohensionless soil.

5.2.5 Selection of critical number of gyrations

In order to develop a general gyratory test procedure for compacting the soils common in Florida, and to simulate the field compaction, the required number of gyrations should not be less than 90 from the above comparison. From the above comparison, 200 kPa was the optimum vertical pressure and it corresponded to the peak stress in the field test. A gyration angle of 1.25 degrees was a reasonable value to use and it corresponded to the SUPERPAVE specification. For the number of gyrations, it was recommended to be at least 90. It should be adjusted to match the desired dry unit weight.

The results from the gyration compaction test can be used to select an optimum number of gyrations to simulate the field compacted condition. The gyratory test results are summarized in Tables 5.1 and 5.2 for the Thomasville Road soil with 7.7% water content and at OMC, respectively. The data in Figure 5.19 show that with the increase of the number of gyrations, there is a consistent increase of the dry unit weight. In Figure 5.20, the compaction curve is shown with the initial condition at optimum water content (OMC). The shape of the curve is not as consistent as in Figure 5.19, because when the initial water content was around 11%, the water began to seep out during the higher number of gyrations. It was very difficult to get exactly the same water content for the soil samples under the different numbers of gyrations. The water content of the data points in the curve were very close to the optimum water content, but might deviate a little due to seepage of water. From this investigation, the number of gyrations should be chosen the most suitable number in order to get the desired dry unit weight. The selection of an optimum number of gyrations is demonstrated in Figure 5.21. From the figure, 90-gyration is the optimum number of gyrations to be selected to simulate the field compaction.

5.3 Gyratory Compaction Energy

The compaction effort is the work done by compacting the soil with a compactor. For the impact compaction technique, the energy is transferred through the hammer to the soil. The impact compaction energy is determined by the hammer weight, the height of drop, the number of layers, the number of blows per layer, and the volume of the mold. For the gyratory compaction, the method to estimate the energy level produced by a gyratory compactor was evaluated in this study. The method of estimating the energy using a gyratory compactor is presented in Appendix A.

5.4 Recommended Gyratory Testing Procedure

The gyratory compaction was more reliable than the impact compaction when used on sandy soils in the laboratory. The gyratory test procedure with 200 kPa vertical pressure, a 1.25 degree gyration angle, 90 gyrations, and 20 gyrations per minute showed considerable promise for simulating field compaction. Use of the gyratory test procedure may be suitable for specifying the optimum water content and maximum dry unit weight for the field construction of the popular Florida subgrade soils. The detail of a proposed gyratory test procedure is presented in Appendix B for reference.

Table 5.1 Effect of gyrations on dry unit weight for Thomasville Road A-3 soil with 7.7% water content

Number of Gyrations	Water Content (%)	Dry Unit Weight (pcf)
30	7.7	107.64
60	7.7	109.95
90	7.7	111.09
120	7.7	111.80
150	7.7	112.30
180	7.7	112.67
210	7.7	112.96
240	7.7	113.19
270	7.7	113.40
300	7.7	113.58

Table 5.2 Effect of gyrations on dry unit weight for Thomasville Road A-3 soil at optimum water content

Number of Gyrations	Water Content (%)	Dry Unit Weight (pcf)
30	10.9	110.70
60	10.9	112.36
80	11.0	112.90
90	10.9	113.27
100	10.8	113.79
120	10.7	114.74

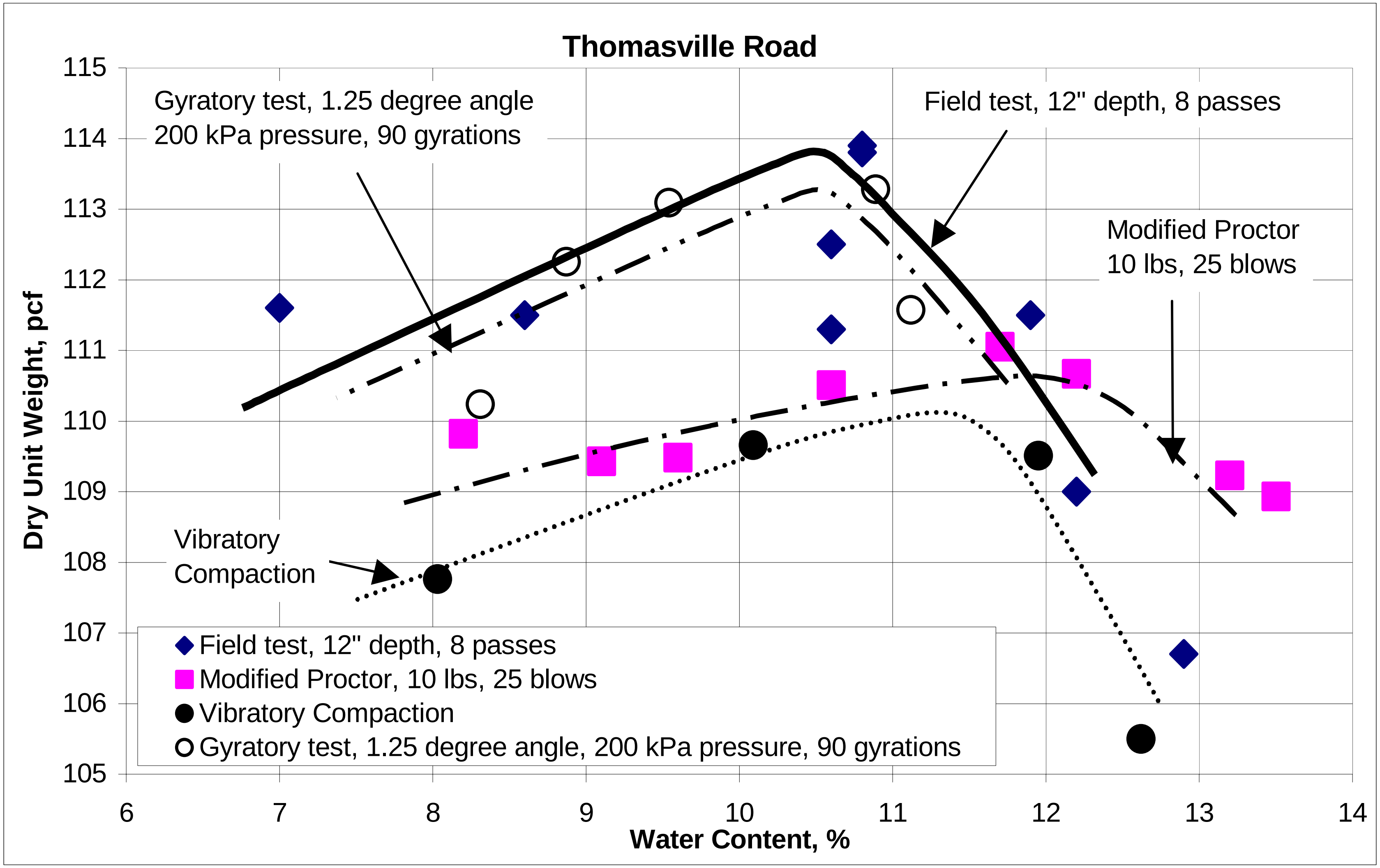


Figure 5.1 Correlation of field and laboratory test results for Thomasville Road soil

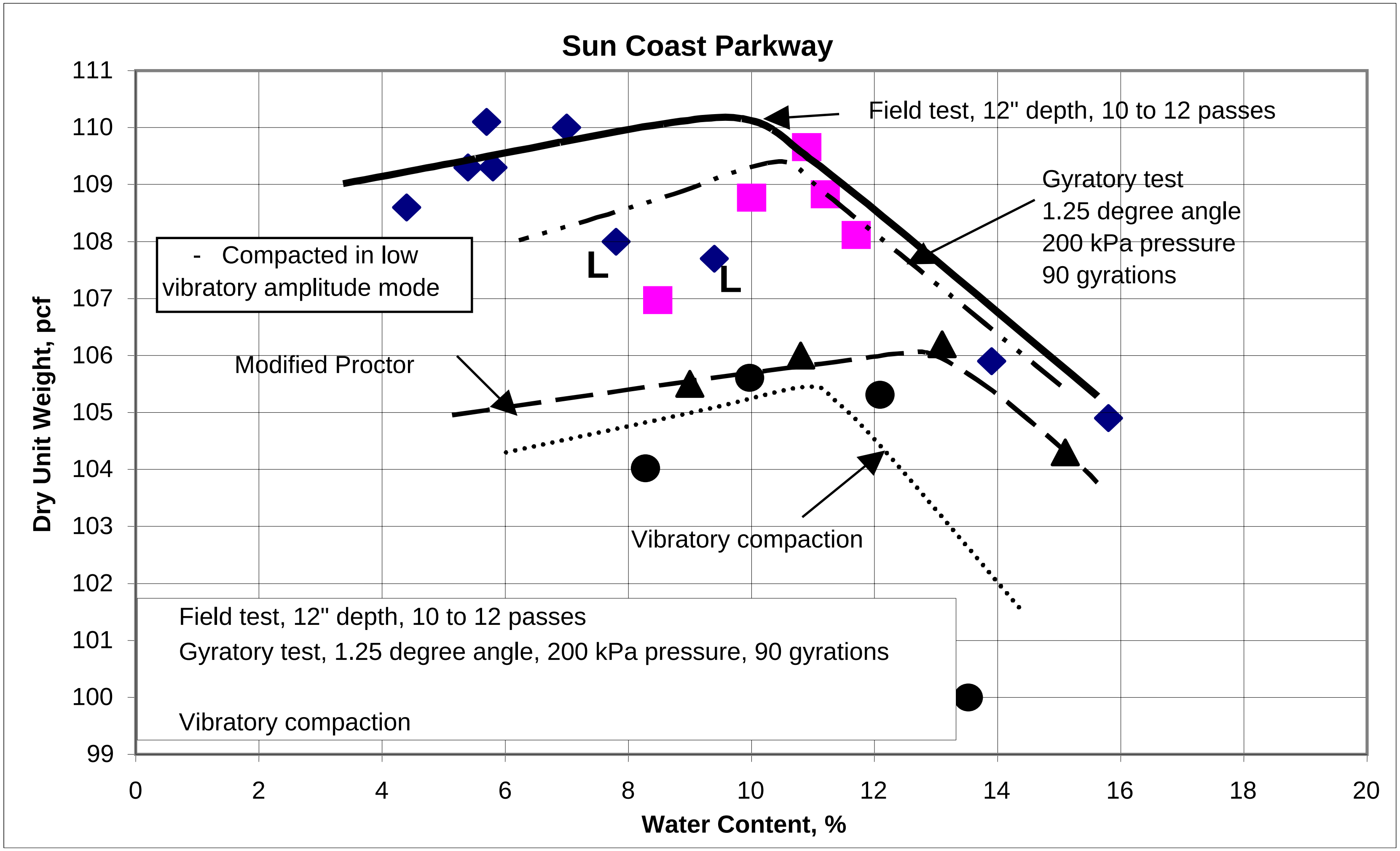


Figure 5.2 Correlation of field and laboratory test results for Sun Coast Parkway soil

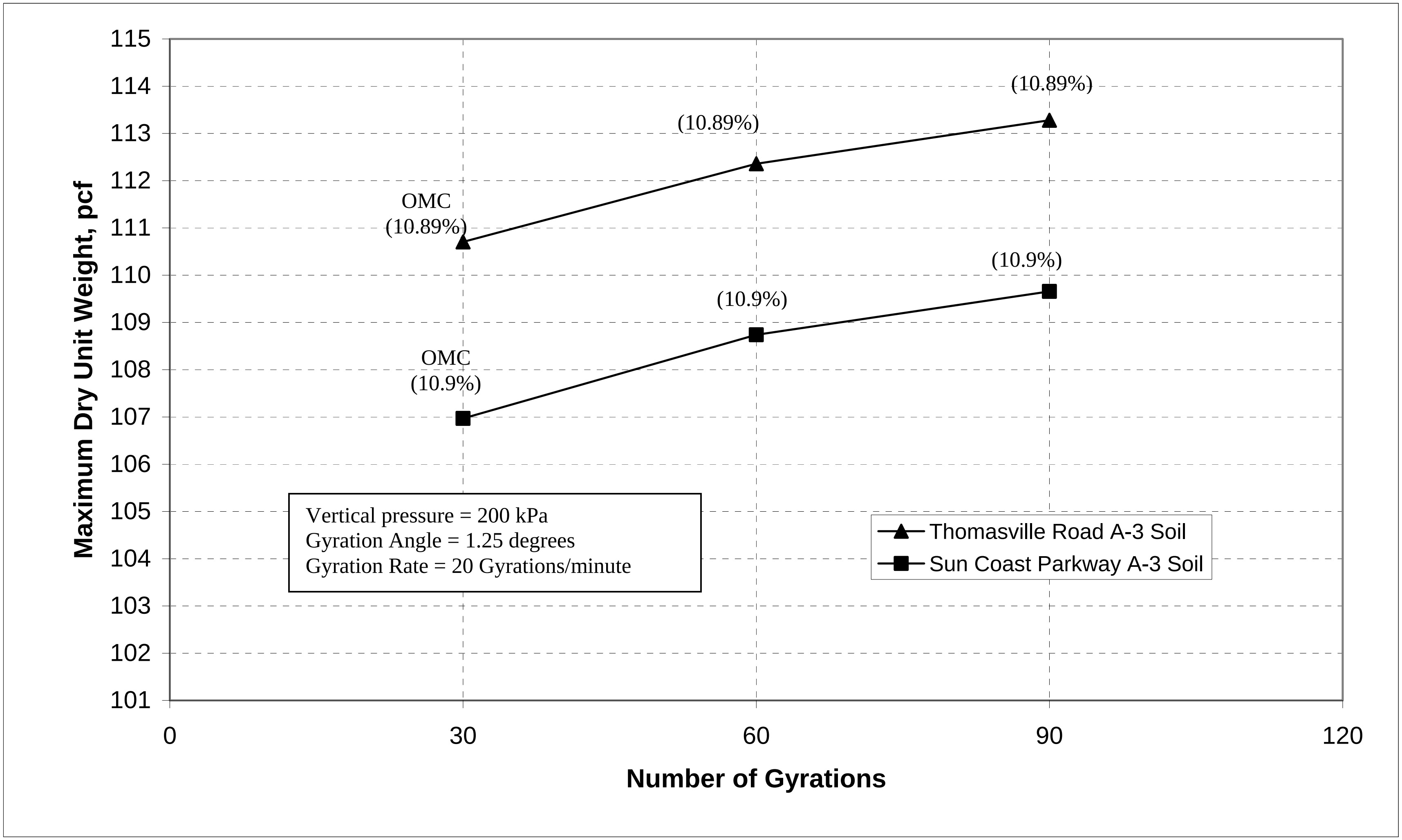


Figure 5.3 Effect of gyrations on dry unit weight for Thomasville Road and Sun Coast Parkway soils

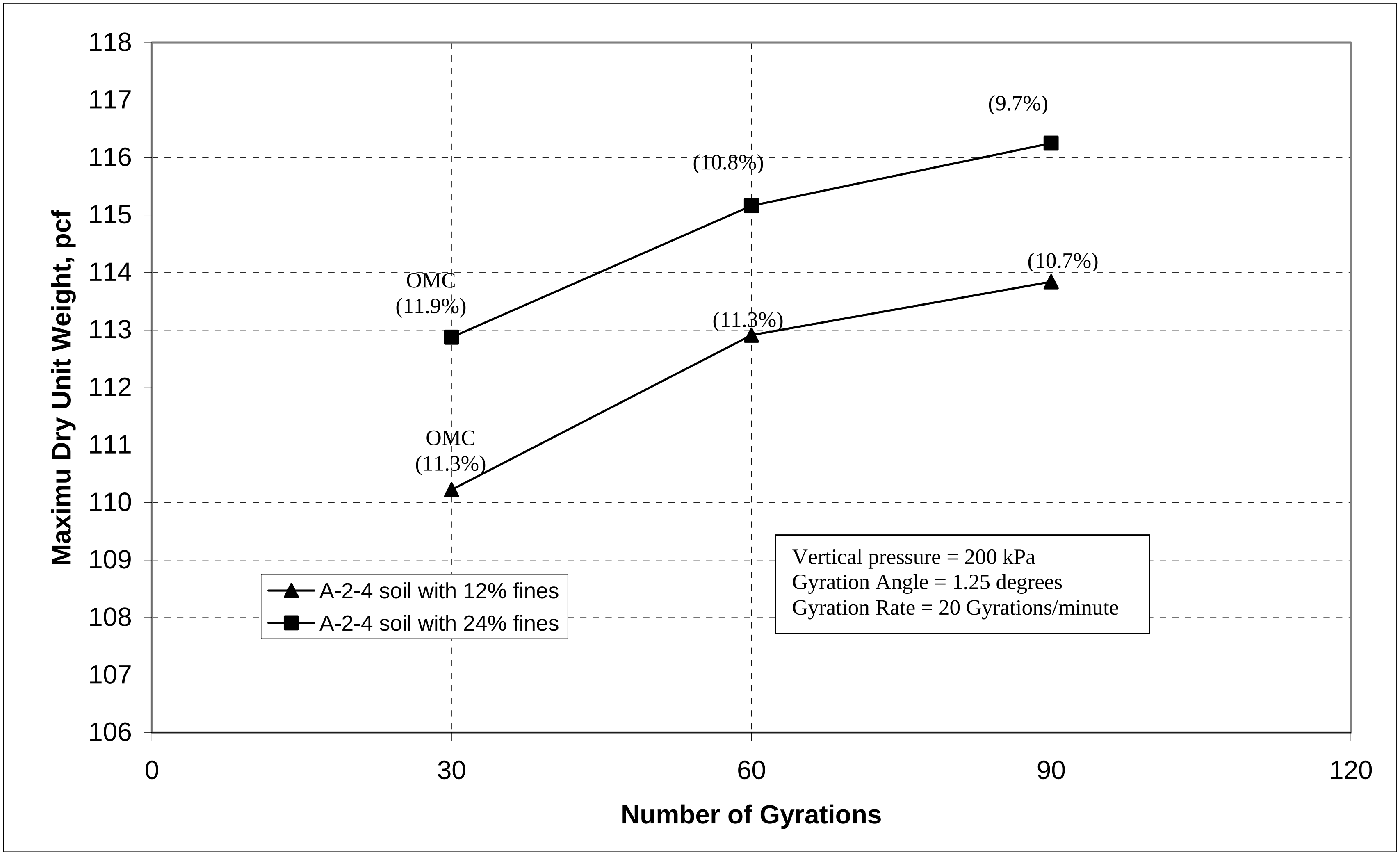


Figure 5.4 Effect of gyrations on dry unit weight for A-2-4 soil with 12% and 24% fines

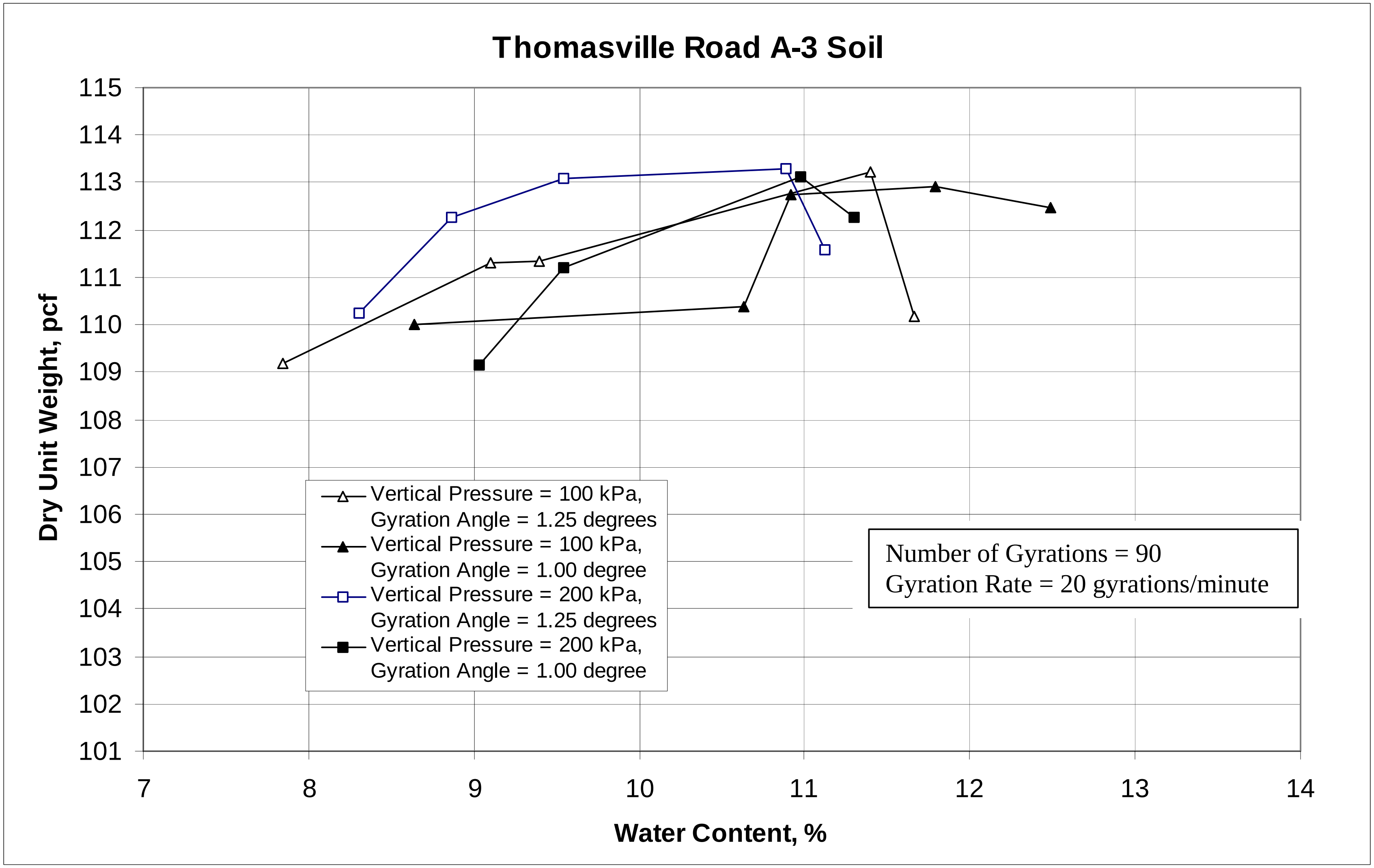


Figure 5.5 Effect of gyration angle on dry unit weight for Thomasville Road soil

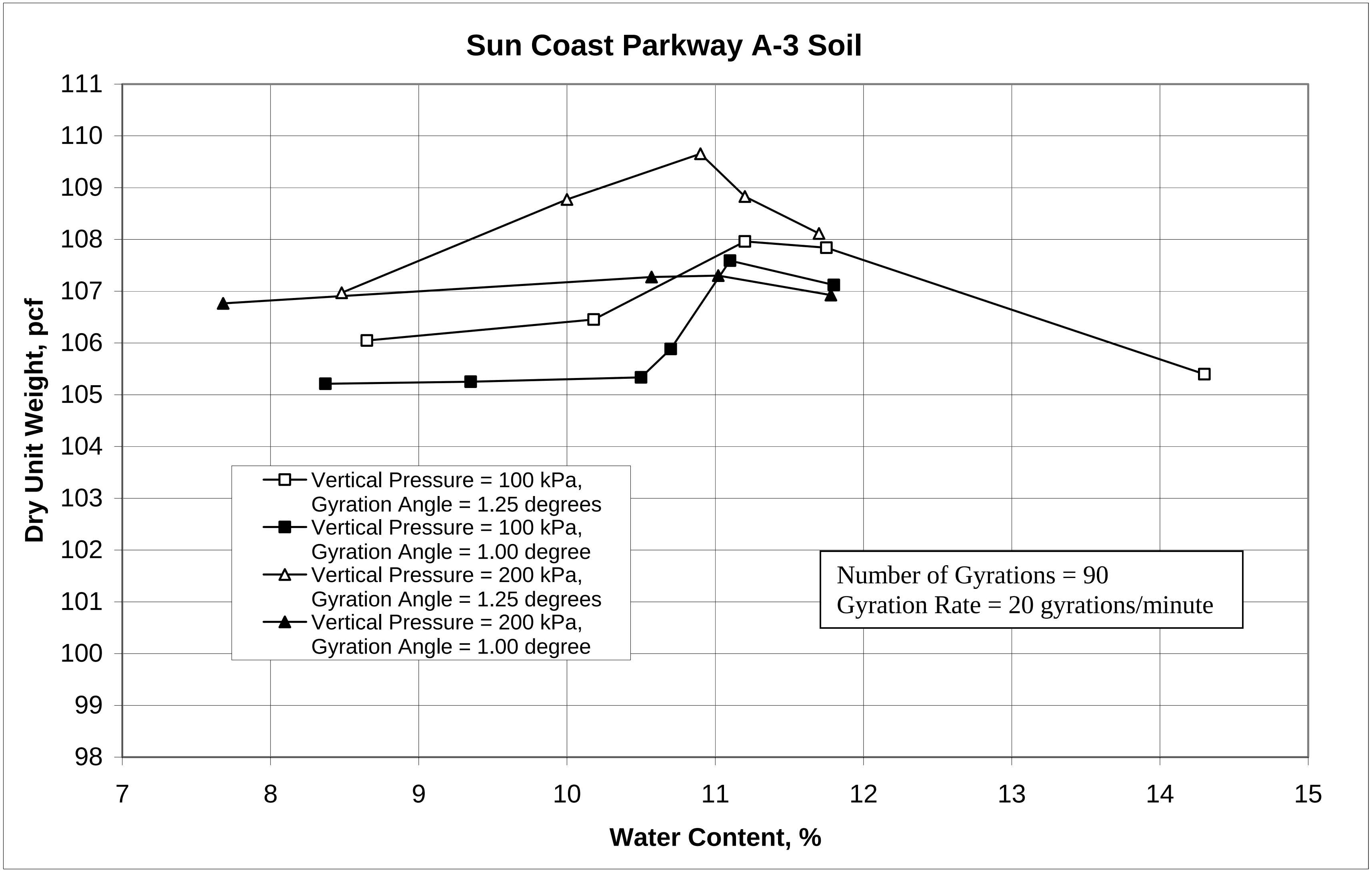


Figure 5.6 Effect of gyration angle on dry unit weight for Sun Coast Parkway soil

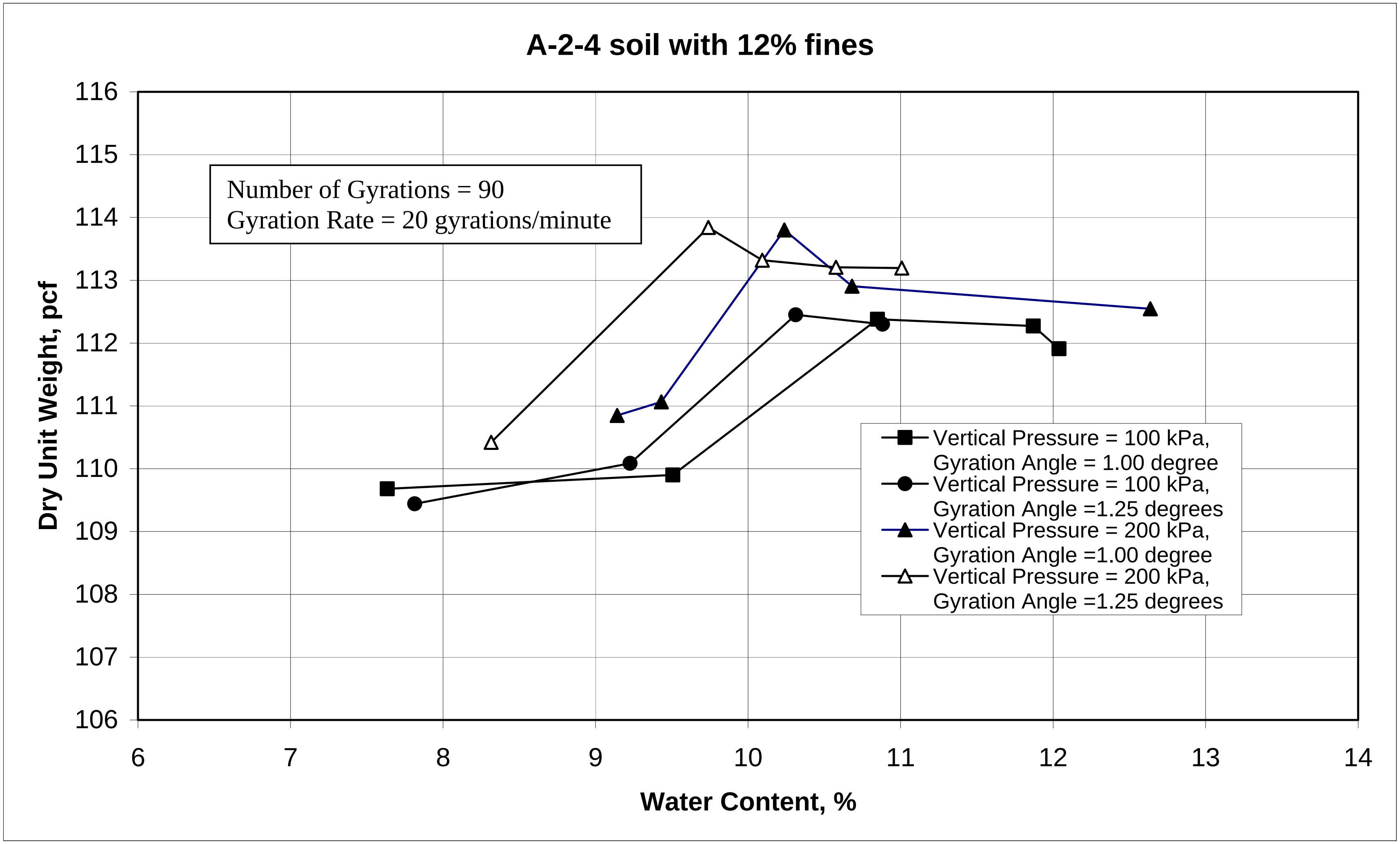


Figure 5.7 Effect of gyration angle on dry unit weight for A-2-4 soil with 12% fines

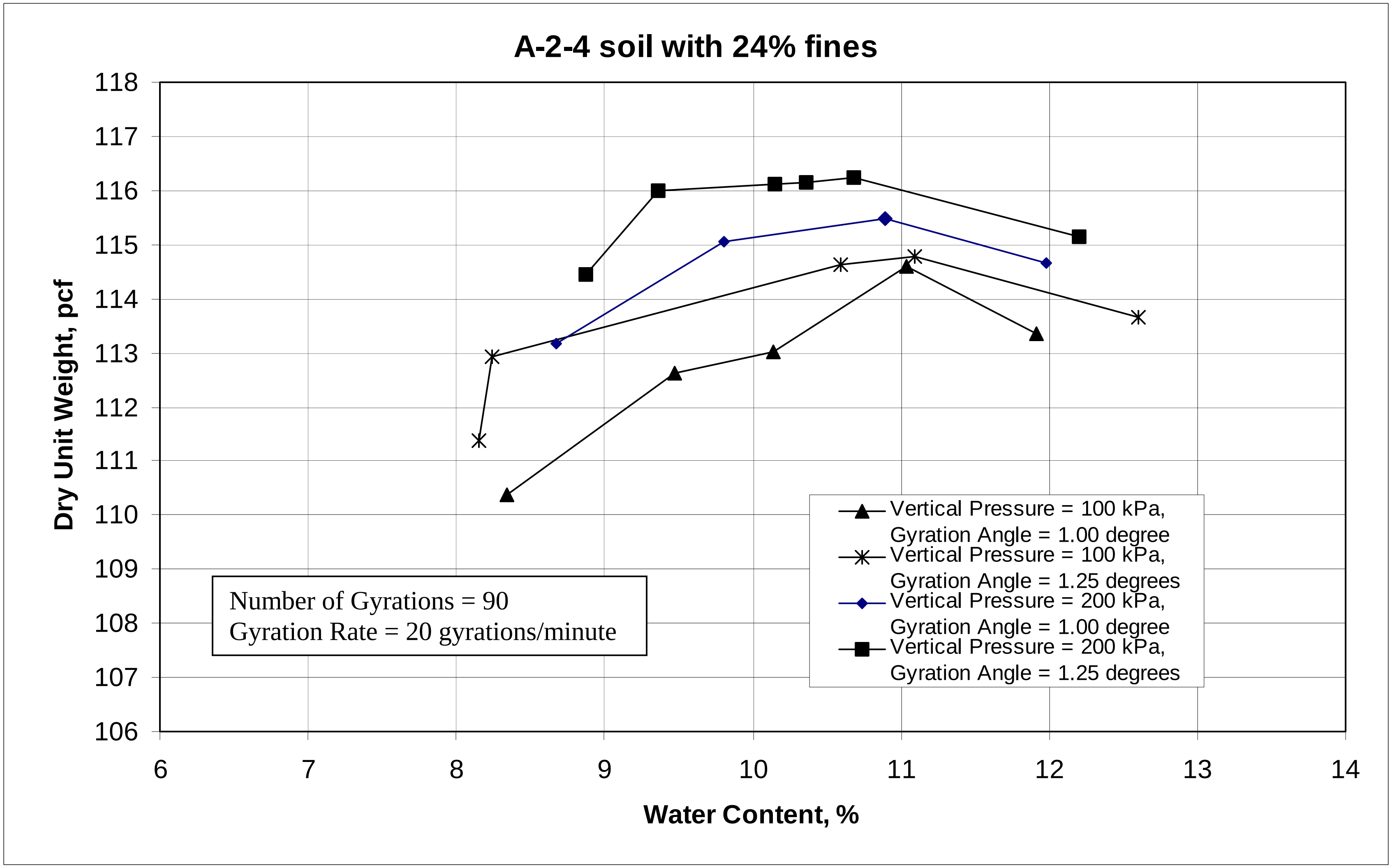


Figure 5.8 Effect of gyration angle on dry unit weight for A-2-4 soil with 24% fines

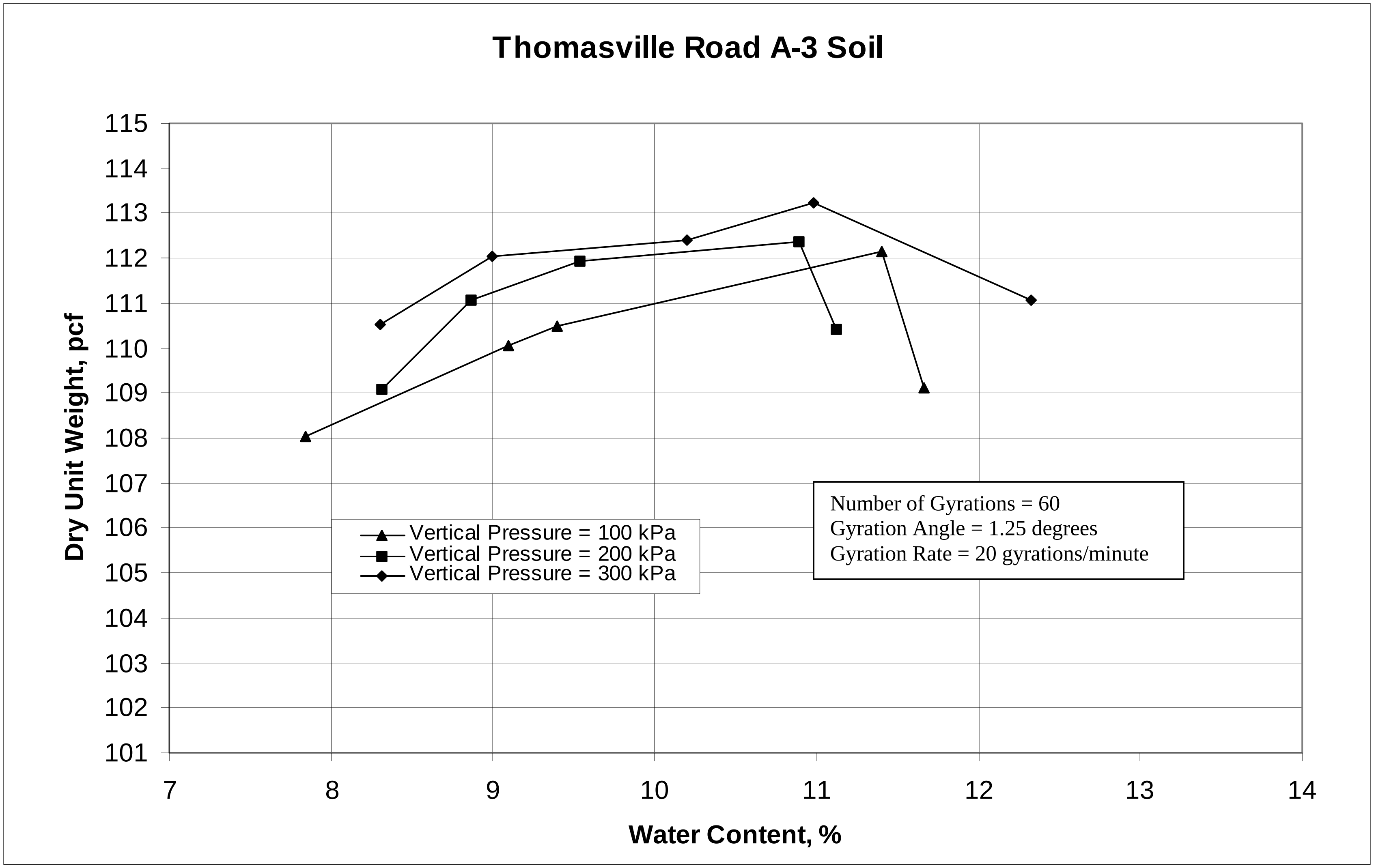


Figure 5.9 Effect of vertical pressure on dry unit weight for Thomasville Road soil

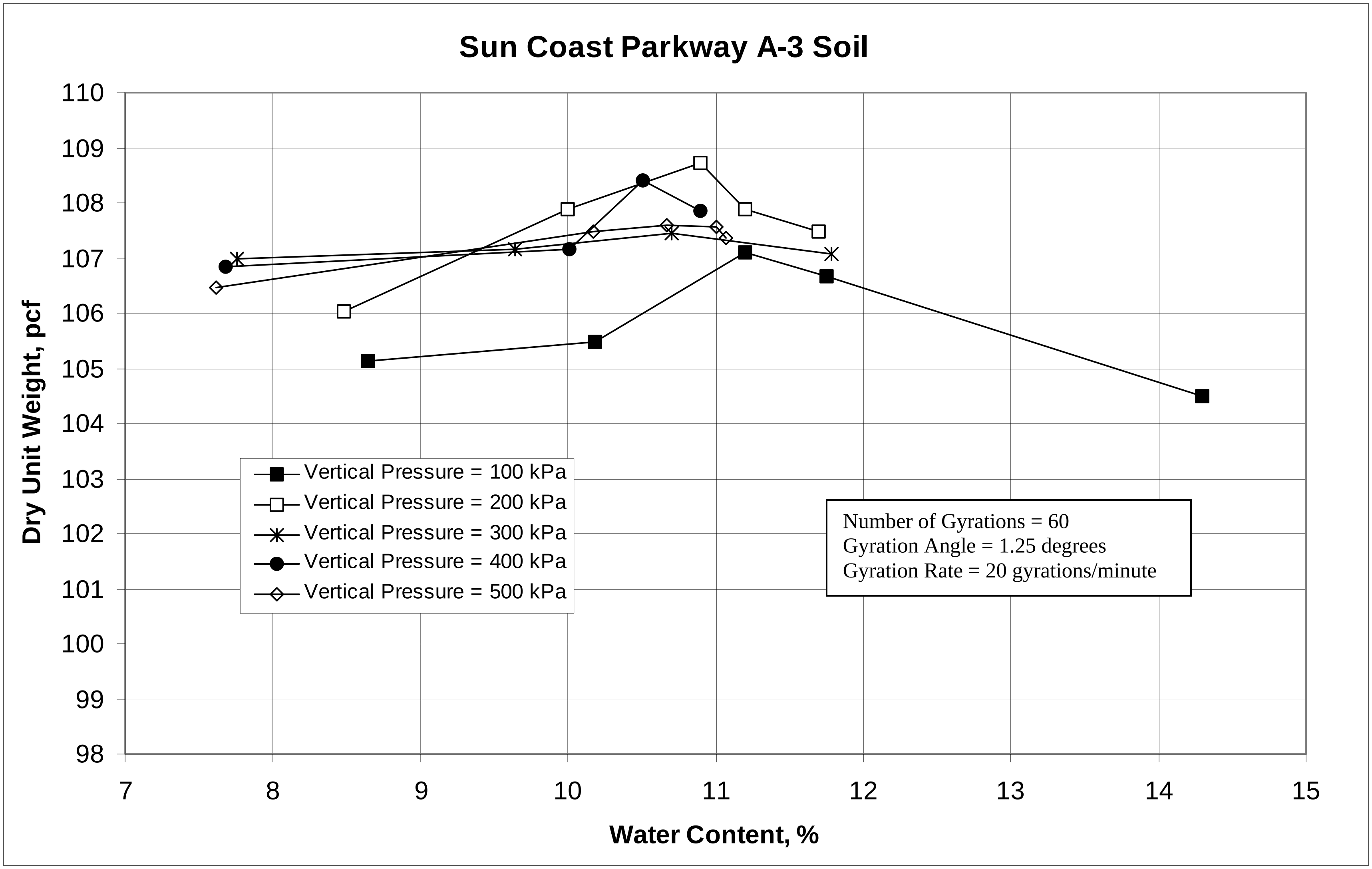


Figure 5.10 Effect of vertical pressure on dry unit weight for Sun Coast Parkway soil

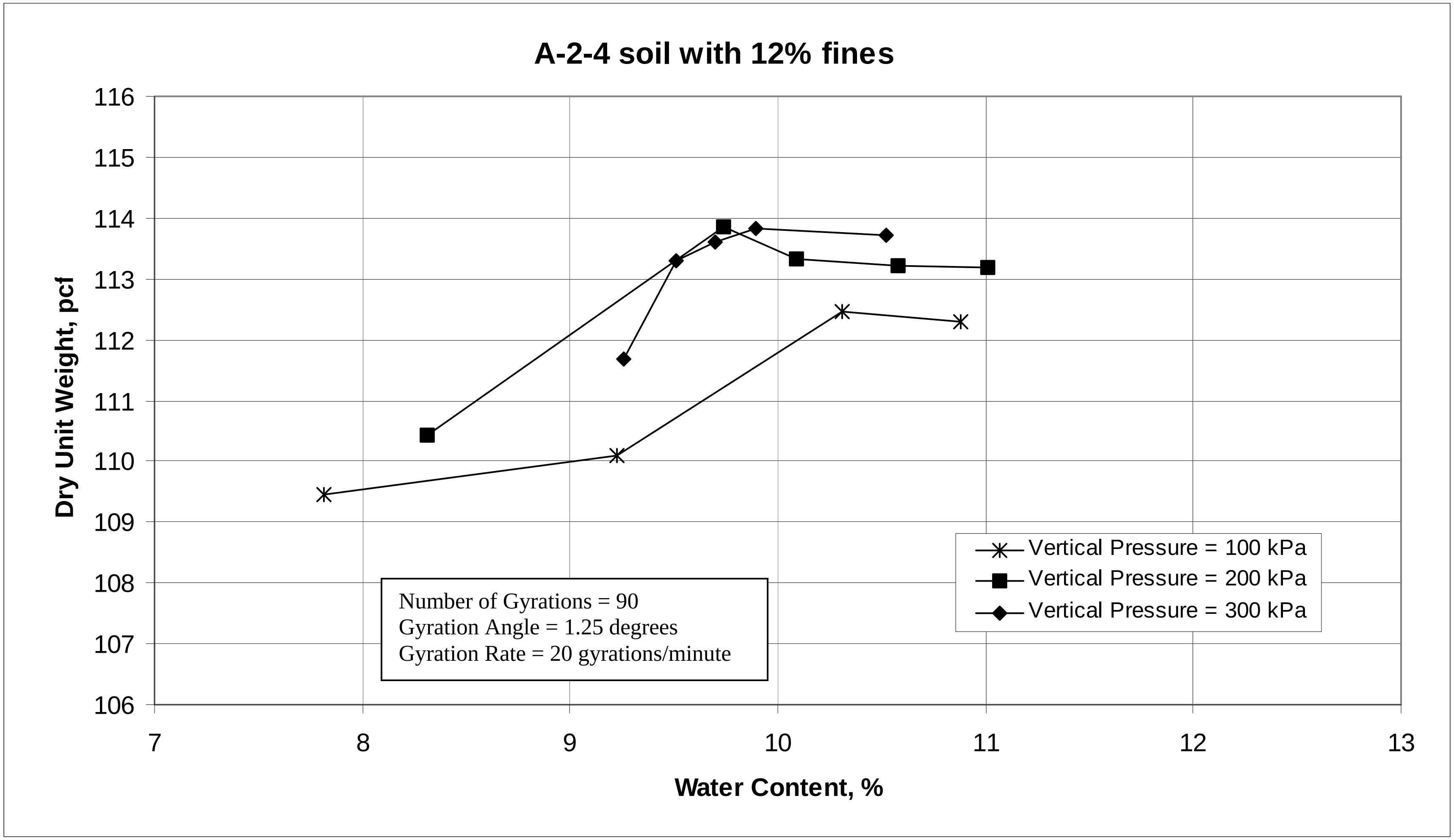


Figure 5.11 Effect of vertical pressure on dry unit weight with 1.25 degrees angle for A-2-4 soil with 12% fines

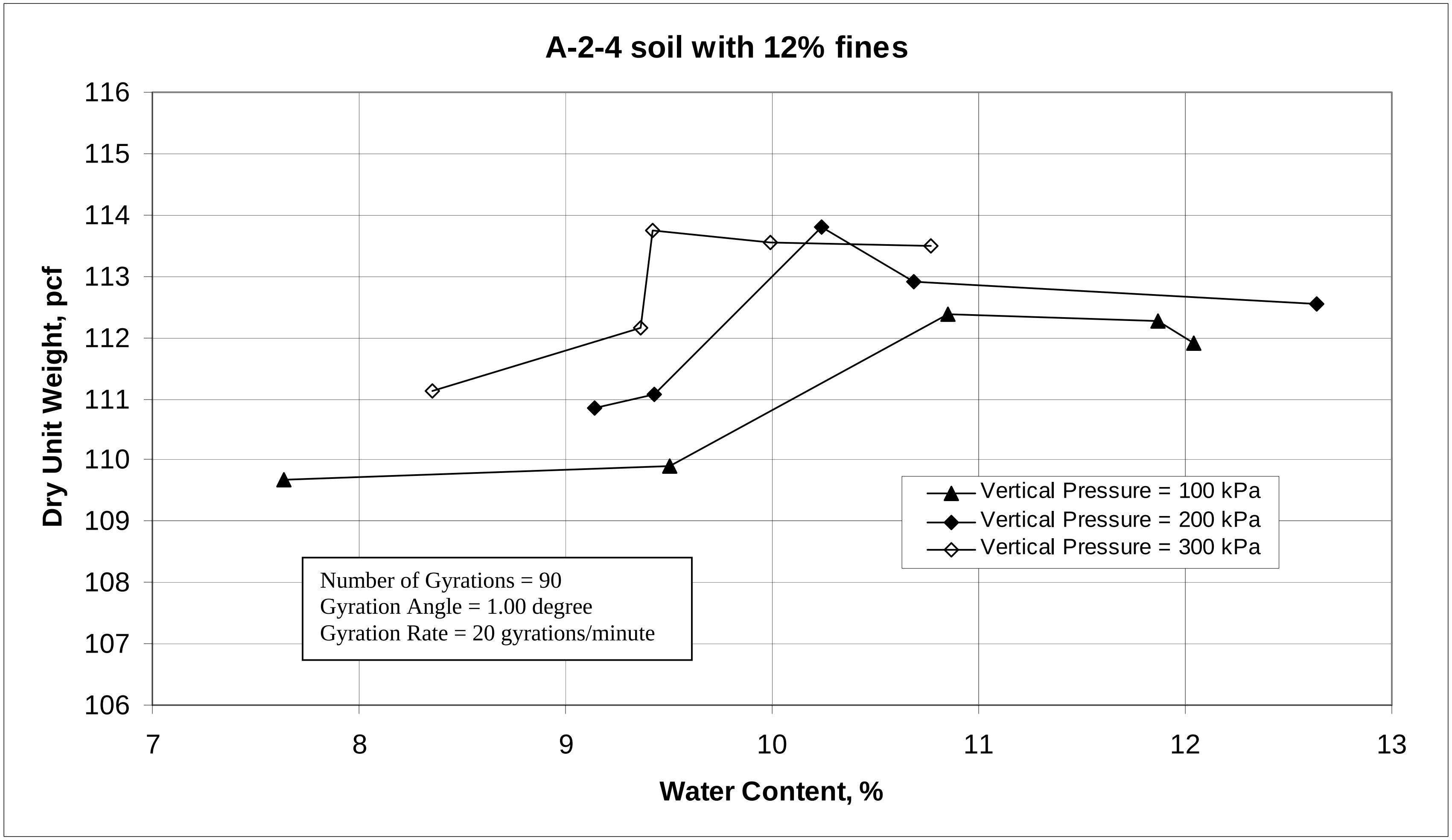


Figure 5.12 Effect of vertical pressure on dry unit weight with 1.00 degree angle for A-2-4 soil with 12% fines

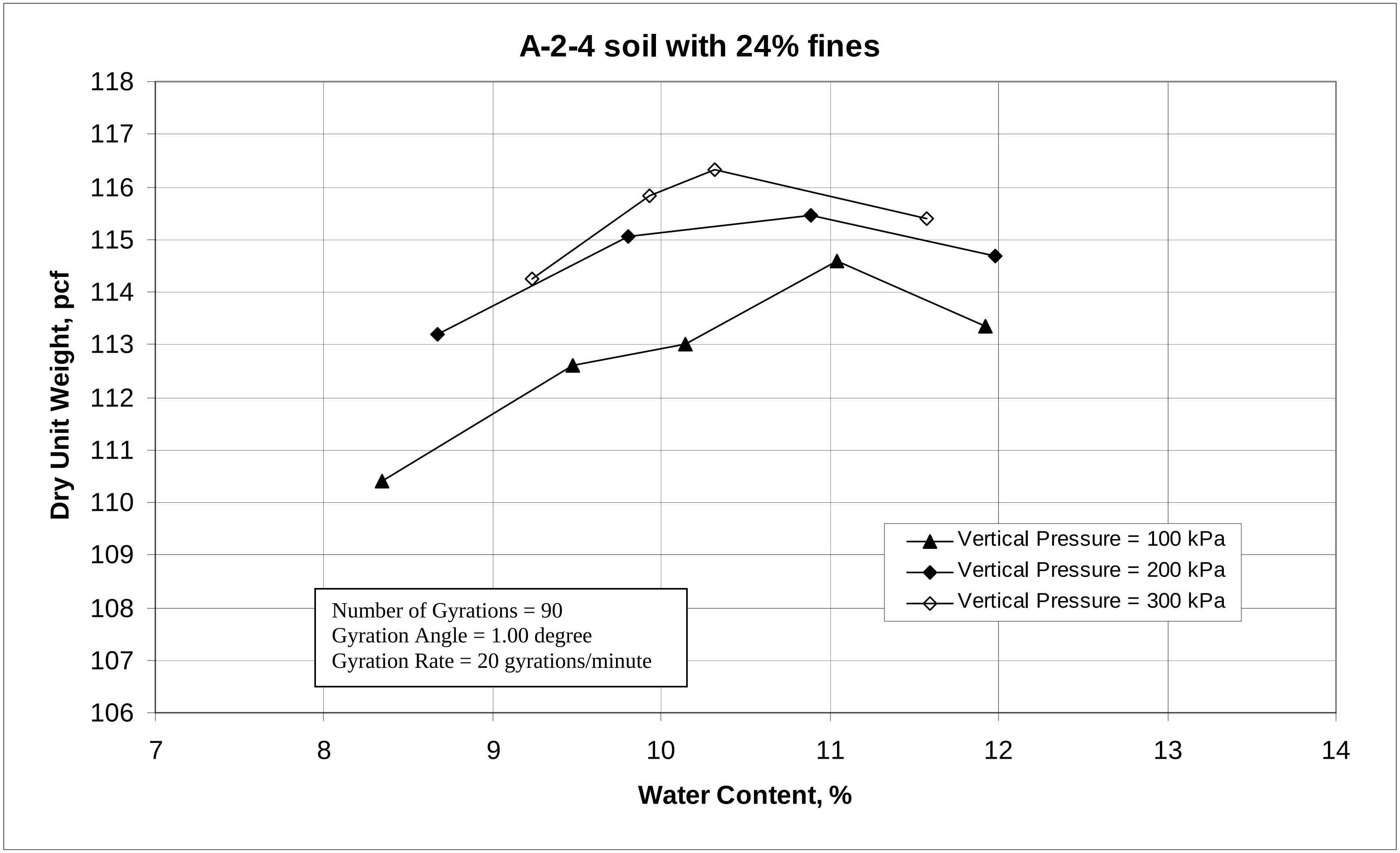


Figure 5.13 Effect of vertical pressure on dry unit weight with 1.00 degree angle for A-2-4 soil with 24% fines

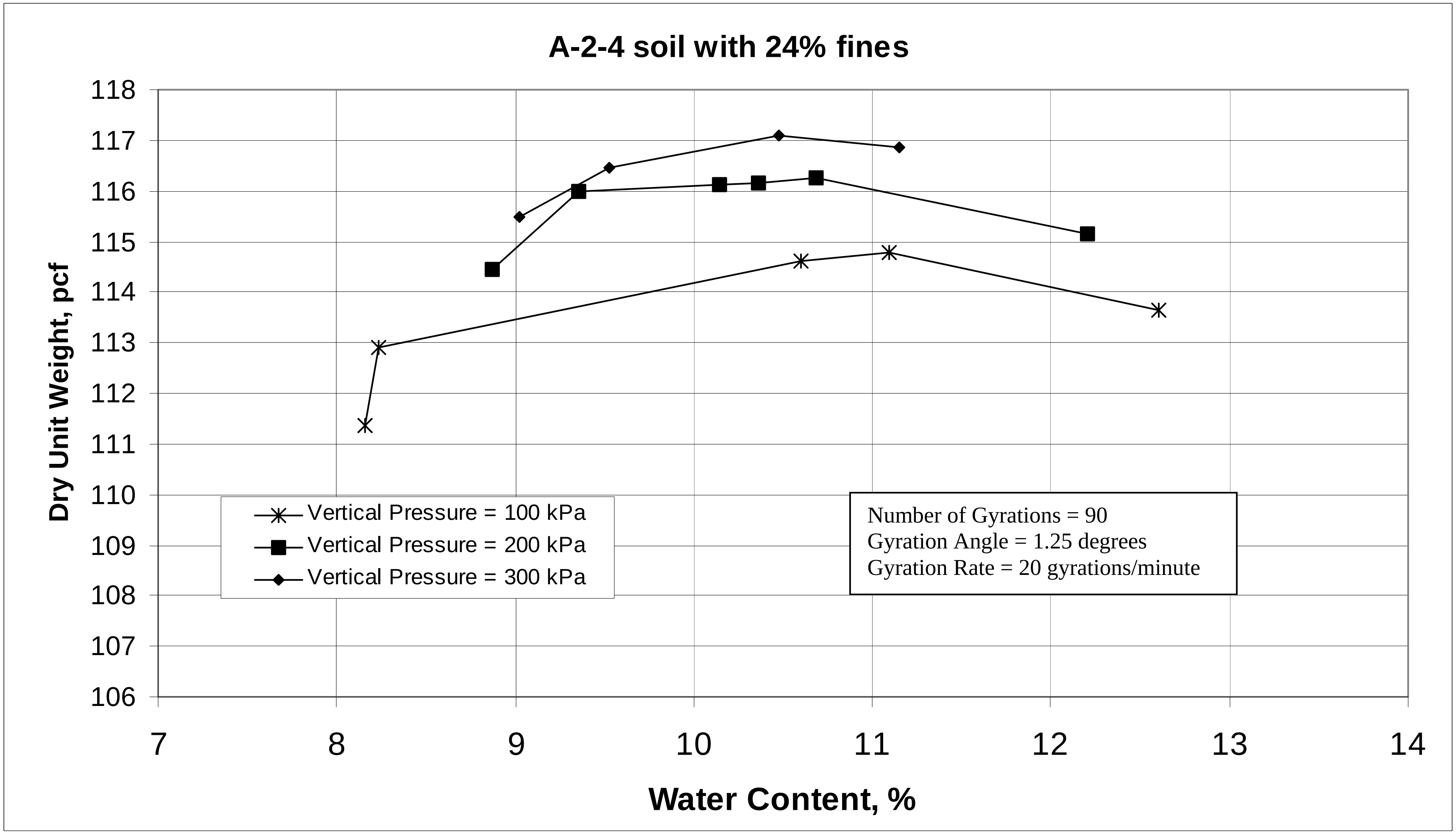


Figure 5.14 Effect of vertical pressure on dry unit weight with 1.25 degrees angle for A-2-4 soil with 24% fines

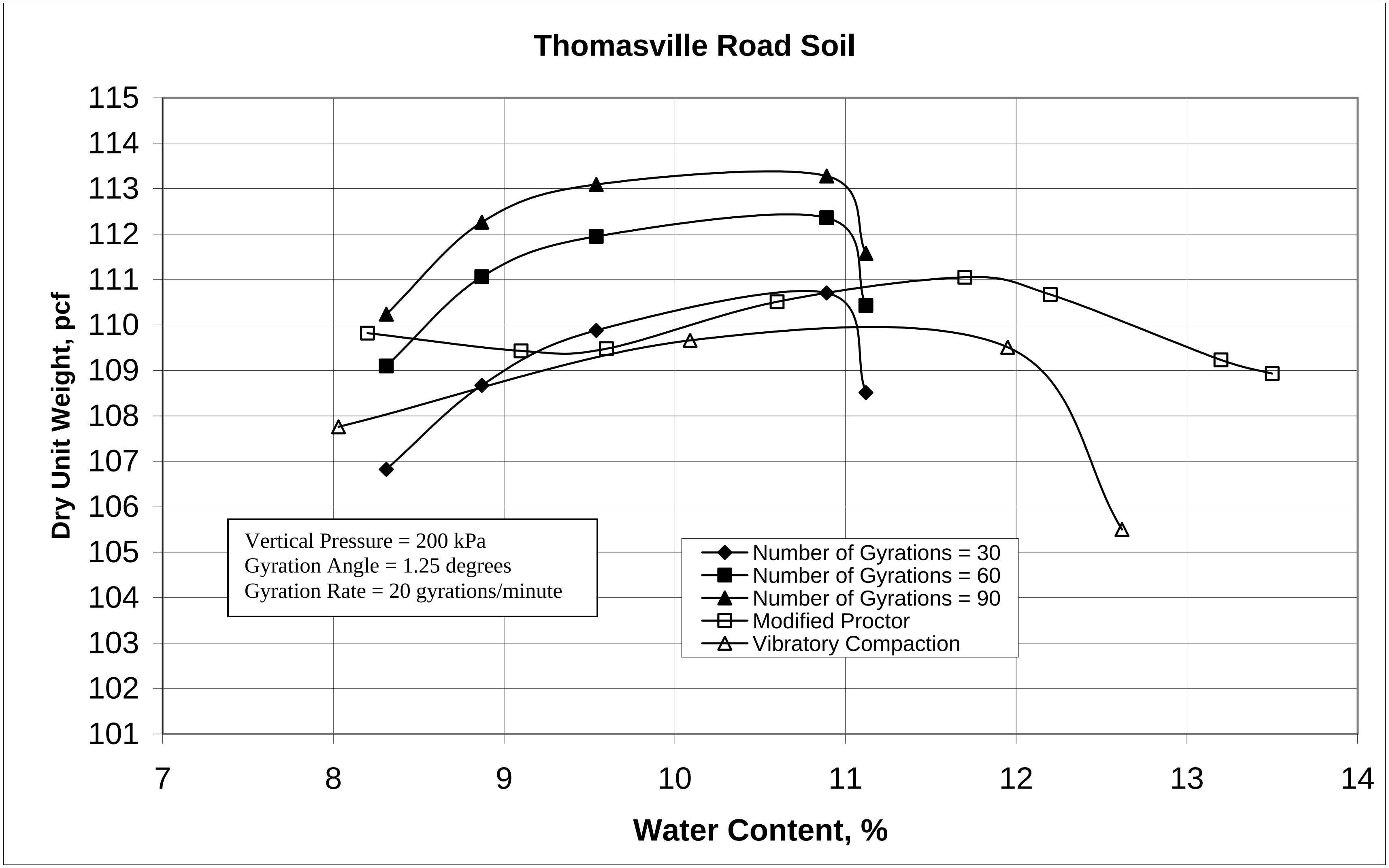


Figure 5.15 Comparison of three compaction curves for Thomasville Road soil

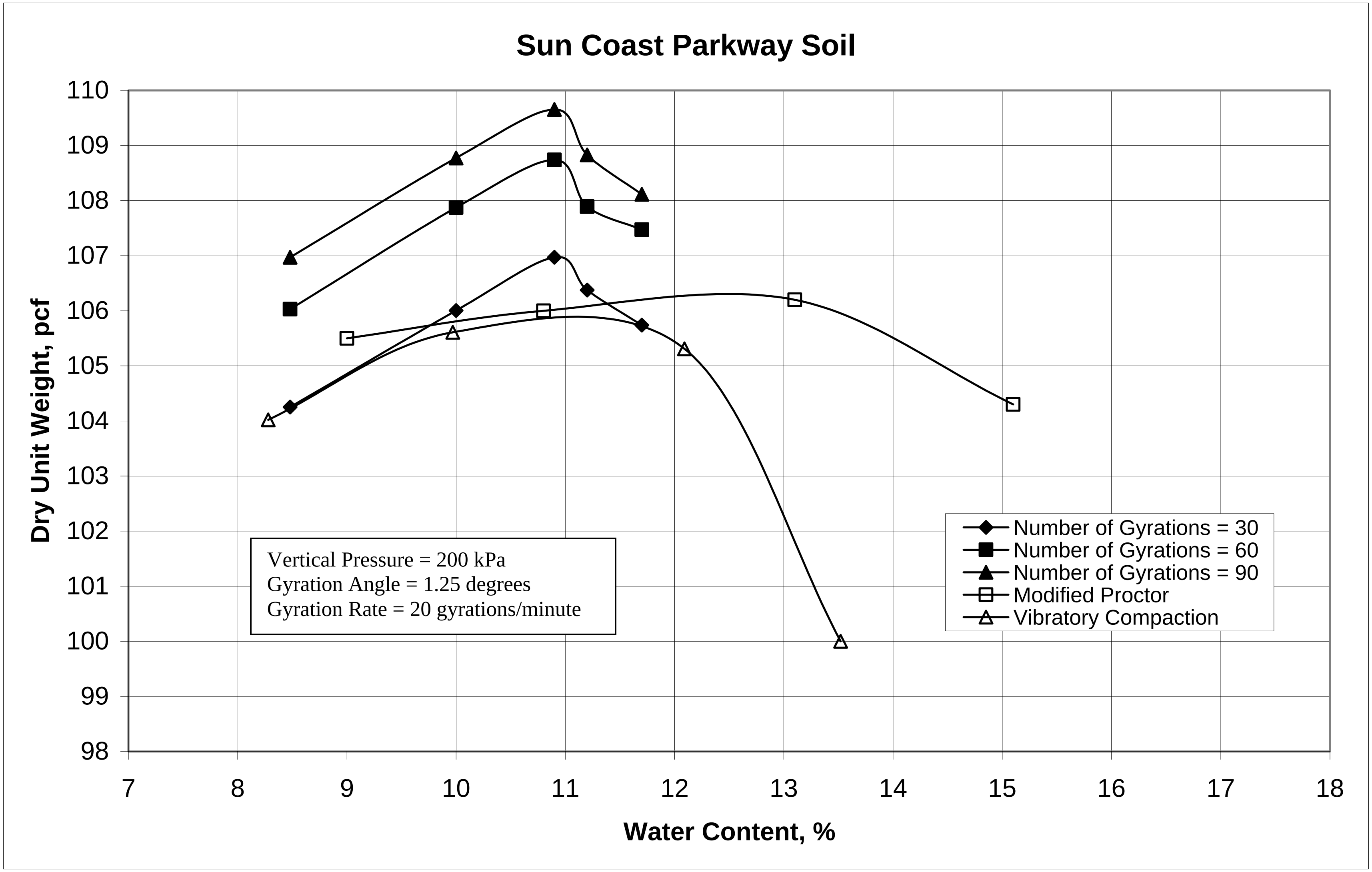


Figure 5.16 Comparison of three compaction curves for Sun Coast Parkway soil

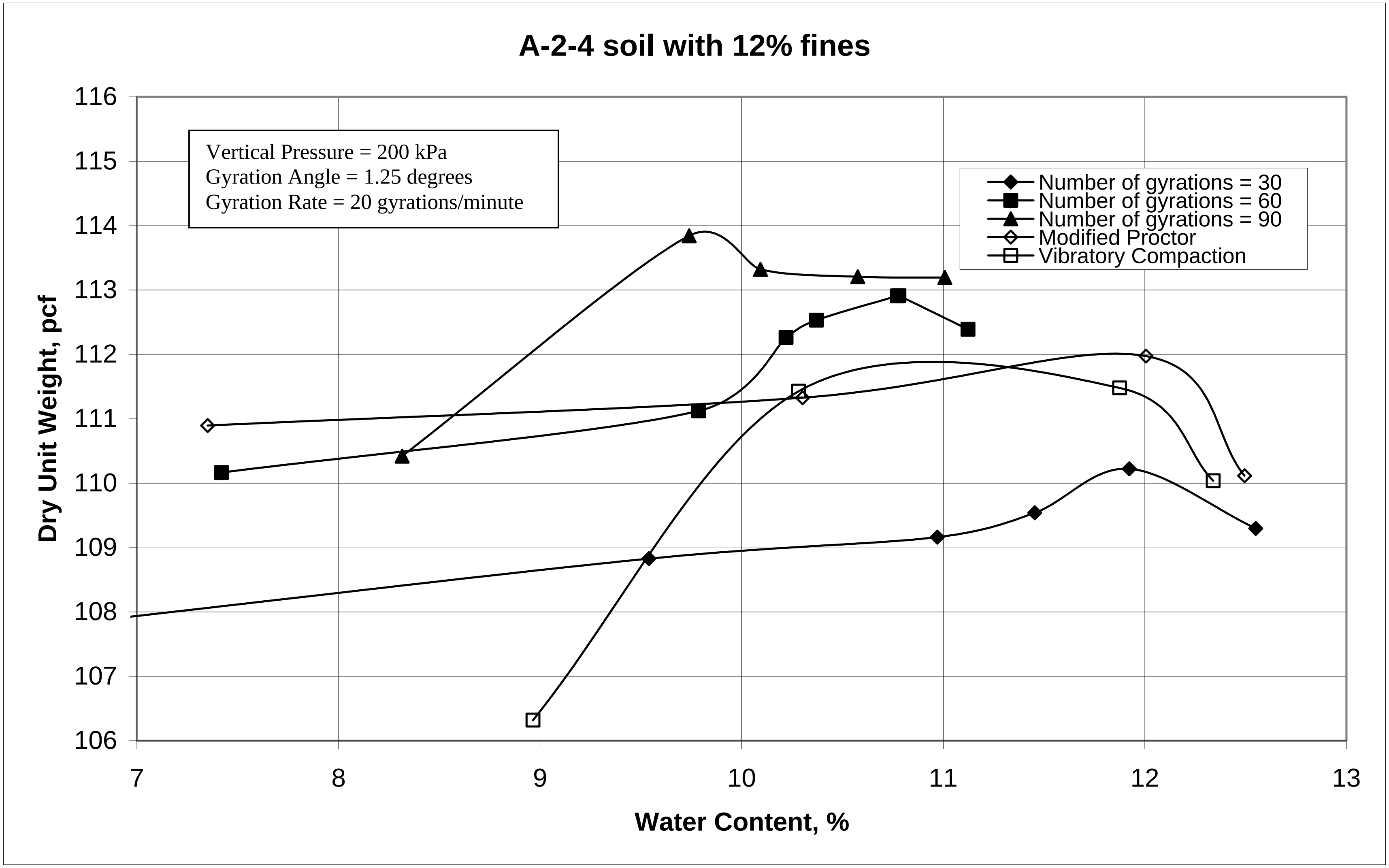


Figure 5.17 Comparison of three compaction curves for A-2-4 12% soil

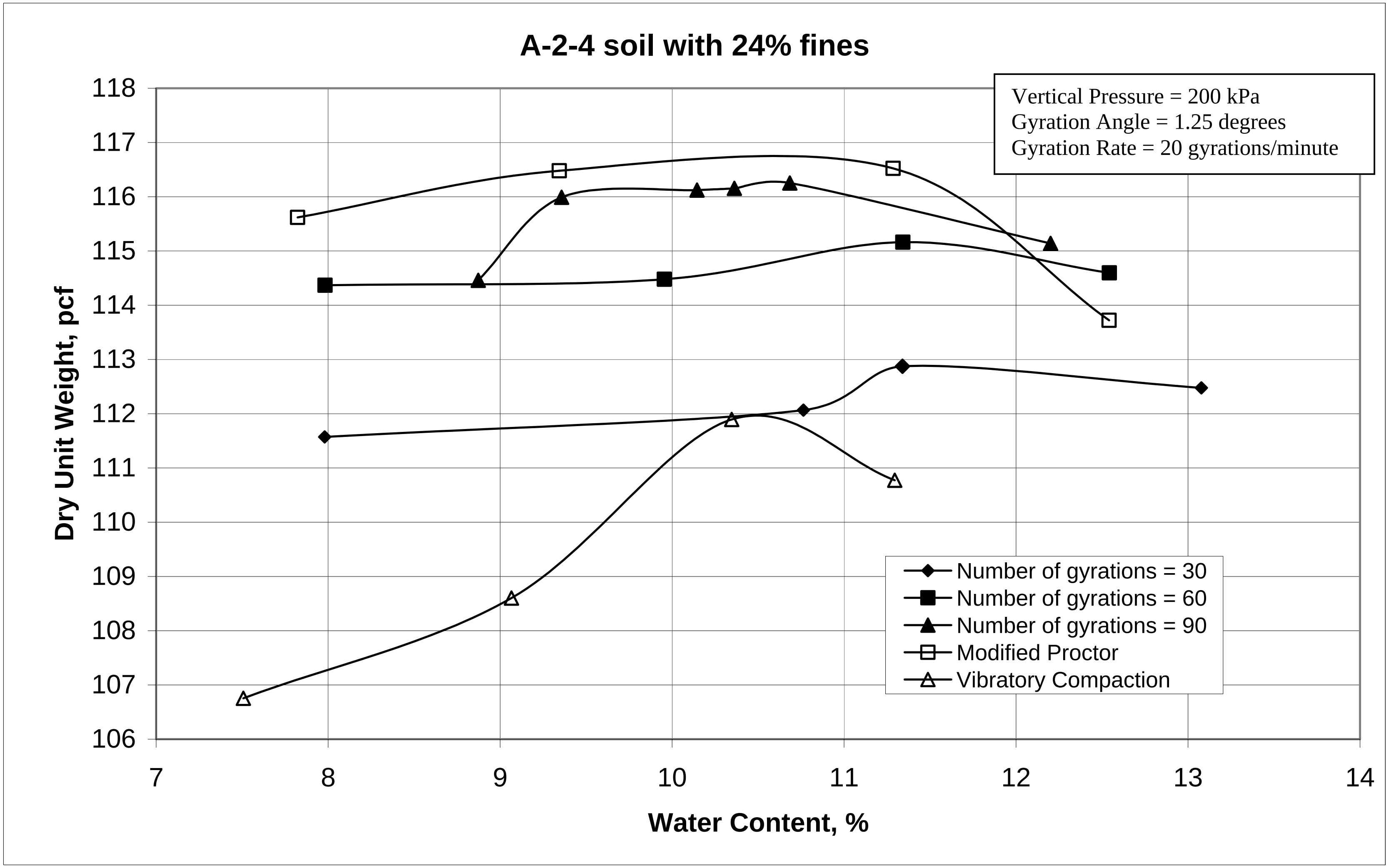


Figure 5.18 Comparison of three compaction curves for A-2-4 soil with 24% fines

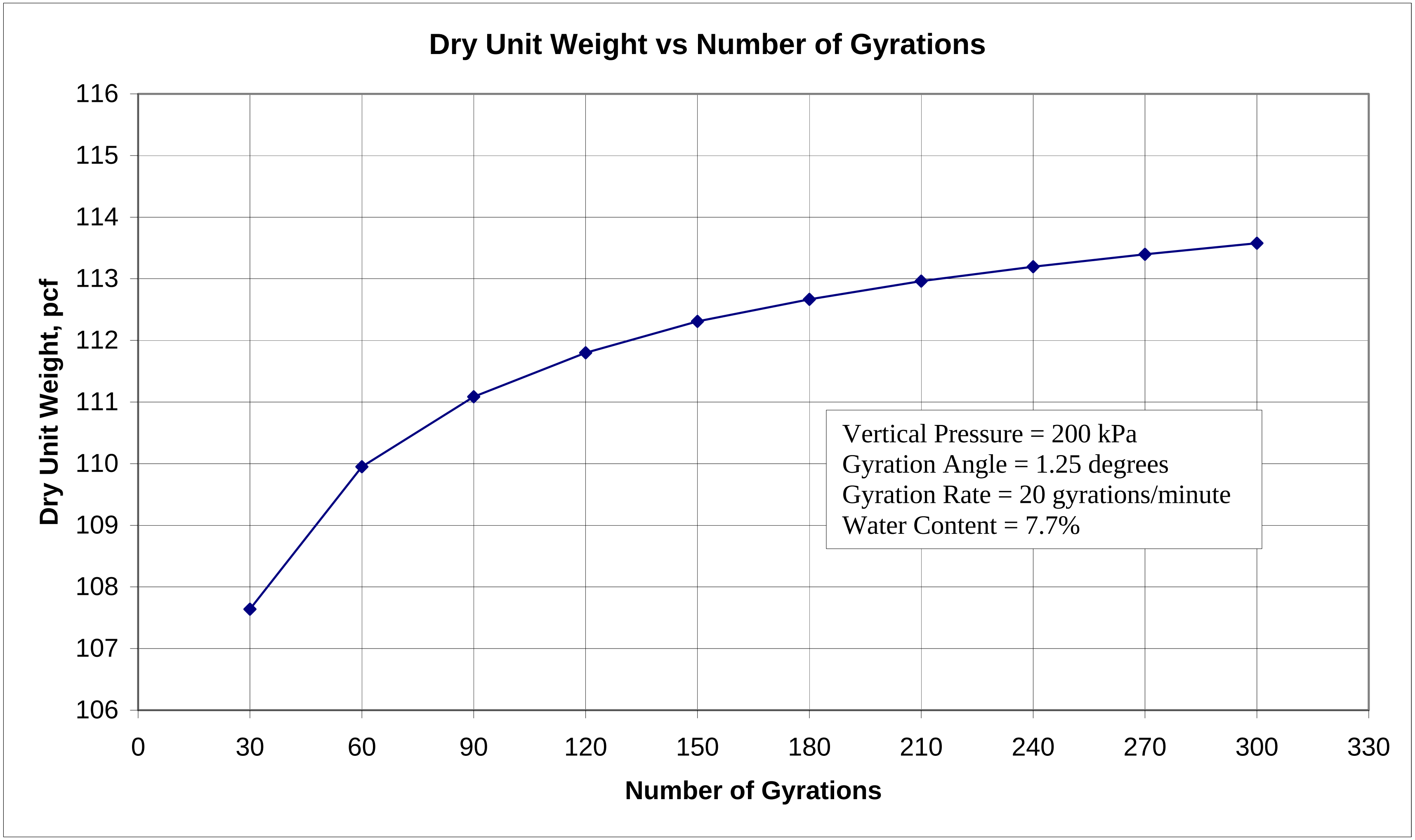


Figure 5.19 Dry unit weight versus number of gyrations for Thomasville Road A-3 soil with 7.7% water content

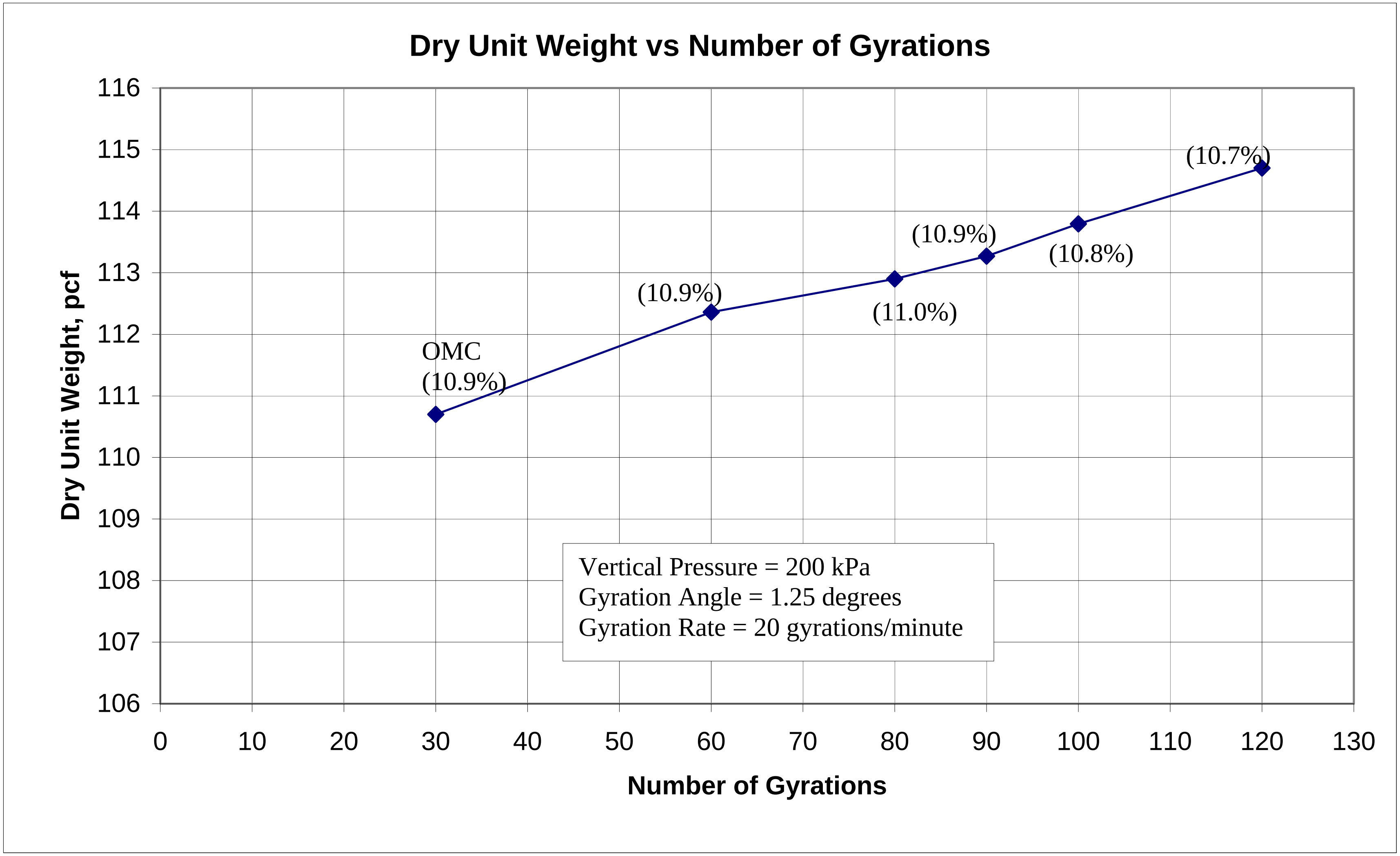


Figure 5.20 Dry unit weight versus number of gyrations for Thomasville Road A-3 soil at optimum water content

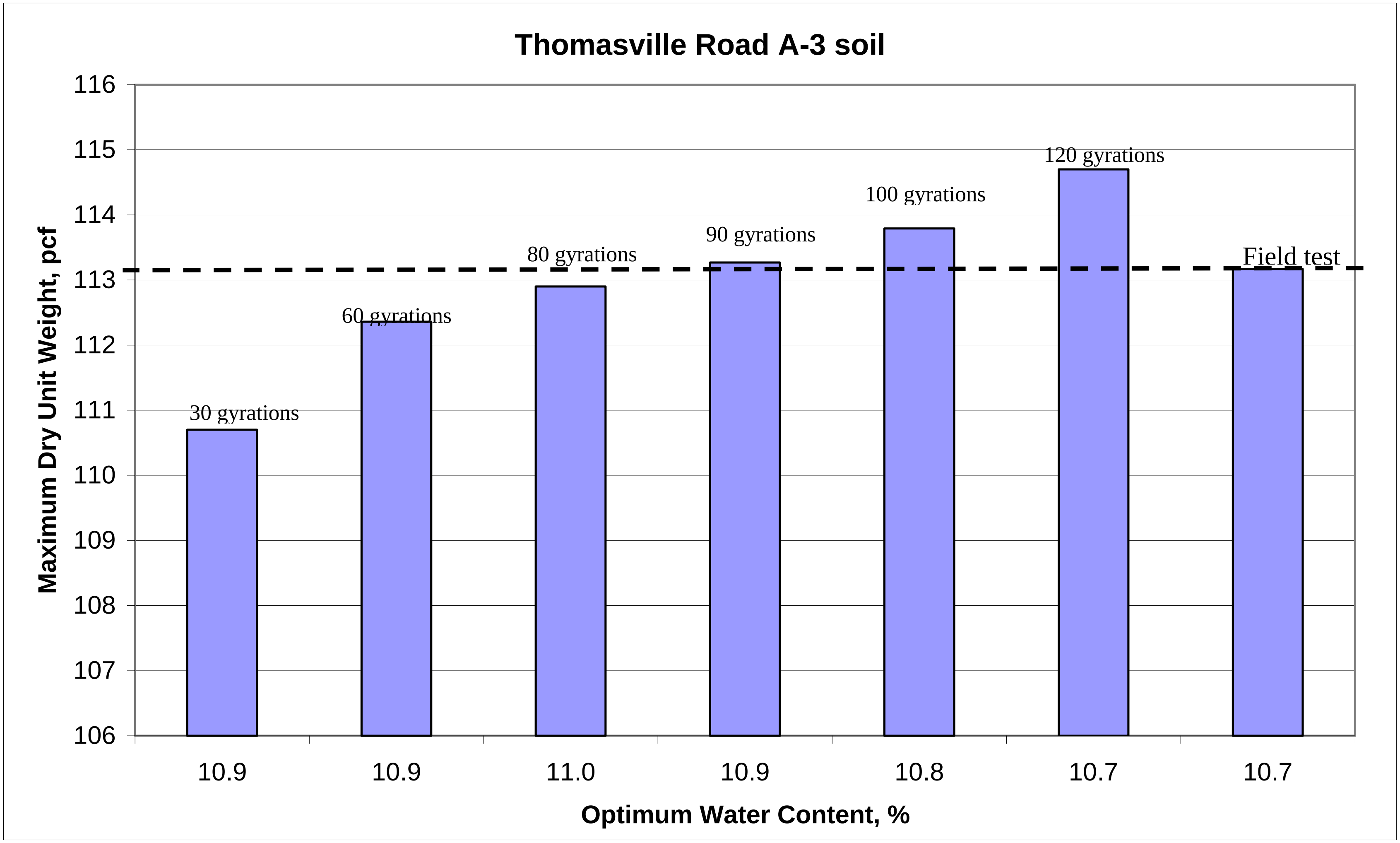


Figure 5.21 Selection of critical number of gyrations

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the analysis of field and laboratory experimental results, the following conclusions have been drawn:

1. The impact compaction method did not work well for the A-3 fine sand soil in developing the compaction curve. The standard and modified Proctor test procedures, AASHTO T 90 and T 180, respectively, were not developed for use with cohesionless soils.
2. The impact compaction method was not an adequate laboratory test procedure to specify the maximum dry unit weight and optimum water content for the field compaction of cohesionless soils. The study showed that higher field compaction efforts resulted in higher unit weights and lower optimum moisture contents than those obtained by the modified Proctor compaction test.

3. Gyratory compaction was more reliable than impact compaction when fine sands were compacted in the laboratory.
4. For the gyratory compact test, using the vertical stress as a means of increasing the dry unit weight was not effective when the vertical stress was higher than 200 kPa. The 200 kPa stress level was within the range of peak vertical soil stresses measured during the field compaction tests.
5. The gyration angle had some effect on the dry unit weight when the soil had lower percent of fines, and when the number of gyrations was higher. When the soil became more silty (with more than 6% fines), the influence of the gyration angle on the dry unit weight became less significant.
6. When the number of gyrations was increased, there was a continuous increase of dry unit weight, which needed to be adjusted to get the desired dry unit weight.
7. The gyration rate was not a significant factor on the dry unit weight when the gyration rate was increased.
8. The gyratory test procedure conducted with 200 kPa vertical pressure, 1.25 degree gyration angle, 90 gyrations, and 20 gyrations per minute showed

considerable promise for replicating field compaction characteristics.

9. A gyratory compaction test procedure was proposed for determining the maximum dry unit weight, and optimum water content of the granular soils with a Servopac Gyratory Compactor under conditions that simulated field compaction.

6.2 Recommendations

Based on this study, gyratory compaction was the most suitable technique to simulate field comapction for granular soils. However, the experimental program was only focused on a few sites with A-3 fine sand and A-2-4 silty sand soils. The research should be expanded to study the effect of those gyratory variables on clay soils in laboratory as well as to monitor the performance of the clay soils under field compaction.

The gyratory compaction may also be used to simulate field compaction for clay soils. In this case, the clay soil should not be overly densified or compacted, due to its tendency of volumetric expansion when the compacted soils is subjected to wetting or moisture variation. For clay soils, it would probably be adequate if the gyratory compaction procedure can produce the maxumum dry unit weight that is equivalent to the one produced by the modified Proctor test. Because in practice the modified Proctor compaction method has been working just fine for field compaction of clay soils.

In Florida, most subgrade soils are classified as A-3 fine sand and A-2-4 silty soils. The gyratory compaction procedure has great potential to be the construction specification for quality control of field compaction. A further research study is recommended for possible implementation of the gyratory compaction method in design and construction.

APPENDIX A

METHOD OF ESTIMATING GYRATORY COMPACTION ENERGY

A.1 The Force Analysis of Gyratory Machine

During the gyratory compaction, two kinds of forces work on the soil sample. One of the forces is caused by the vertical pressure which is constant during the test and it is the value set before the test. Another force is the shear force that changes with time. The shear stress is calculated from the pressure transducers. The equation used to compute the value during testing is,

$$s = 2 \times \left(\frac{P \times L}{A \times H}\right) \tag{A.1}$$

Where s is the shear stress, P is the average force on the three actuators, L is the radial distance to the point of application of the actuator load (165 mm), A is the cross sectional area of the specimen, and H is the height of the specimen. This equation is a 2D approximation to a 3D problem, and is of the same form as that used to compute shear in other compactors such as the Corps of Engineers gyratory compactor (McRae et al 1969). But the value of P comes from a totally different type of loading and is based on measurements from differential pressure transducers at each actuator.

A.2 Compaction Energy of Servopac Gyratory Machine

With a Servopac gyratory machine, the compaction energy is transferred to the soil through the vertical pressure and shear stress (Figure A.2). The method of estimating the compaction energy is presented as follows.

A.2.1. Work done by vertical pressure

From the figure provided by the Servopac gyratory machine software, the vertical pressure (stress) is not changed over time. Therefore, the work done by vertical pressure can be calculated using the following equation:

$$W_{vertical} = P_{vertical} \times \Delta H \qquad \text{(A.2)}$$

where: $W_{vertical}$ = the work done by the vertical force $P_{vertical}$ for the whole soil sample

$P_{vertical}$ = the vertical force = $p._{vertical} \times A$

$p._{vertical}$ = the vertical pressure that is set before the gyration

A = the area of the cross section of the soil sample

ΔH = the total height change during the test

= $H_{before} - H_{after}$

H_{before} = the height of the soil before the test

H_{after} = the height of the soil after the test

The unit energy caused by the vertical pressure:

$$w_{vertical} = \frac{W_{vertical}}{V_{volume}} \qquad \text{(A.3)}$$

where : $w_{vertical}$ = the unit work done by the vertical pressure

V_{volume} = the volume of the soil sample after test

= $H_{after} \times A$

The work done by the vertical force for the Sun Coast Parkway soil was calculated and is presented in Table A.1. The gyratory condition settings were as the following: vertical pressure = 200 kPa, gyration angle = 1.25 degrees, number of gyrations = 90, and gyration rate = 20 gyrations/minute.

A.2.2. Work done by shear force

For the shear stress, s, the direction changes with time. During one cycle the value of the shear force can be seen as a constant number. For one cycle the work done by the shear force can be calculated with the following method.

During the gyration (Figure A.2), the center of the top plane is moving around a circular path with a radius of R equal to H times θ. When the center moves from point A to point B, it changes the angle very little dϕ.

Then the small arch distance, $dt = d\phi \times R$ (A.4)

The distance in X direction, $dx = dt \times \sin(\phi) = R \times d\phi \times \sin(\phi)$ (A.5)

The distance change in Y direction,

$$dy = dt \times \cos(\phi) = R \times d\phi \times \cos(\phi) \quad \text{(A.6)}$$

The shear force in X direction, $S_x = S \times \cos(\phi)$ (A.7)

The shear force in Y direction, $S_y = S \times \sin(\phi)$ (A.8)

The work done in the X direction,

$$W_x = \int S_x \times dx = \int S \times \cos(\phi) \times R \times \sin(\phi) d\phi = 4 \times \int_0^{\pi/2} S \times H \times \theta \times \cos(\phi) \times \sin(\phi) d\phi$$

(A.9)

The work done in the Y direction,

$$W_y = \int S_y \times dy = \int S \times \sin(\phi) \times R \times \cos(\phi) d\phi = 4 \times \int_0^{\pi/2} S \times H \times \theta \times \cos(\phi) \times \sin(\phi) d\phi$$

(A.10)

The total work done by the shear force,

$$W = W_x + W_y = 4\int_0^{\pi/2} [S \times H \times \theta \times \sin(\phi) \times \cos(\phi) + (S \times H \times \theta \times \sin(\phi) \times \cos(\phi))] d\phi$$
$$= 4 \times H \times \theta$$

(A.11)

where:

H = height of the soil sample

S = shear force $S = s \times A$

s = shear stress from the software

A = area of the cross section, $A = \pi \times \left(\frac{D}{2}\right)^2$

D = the diameter of the cross section, $D = 150\,mm$

The details of the calculation are shown in Table A.2 for the following conditions:

Sun Coast Parkway soil

vertical pressure = 200 kPa

gyration angle = 1.25 degrees

number of gyrations = 90 gyrations

gyration rate= 20 gyrations/ minute

A.3 Comparison of Energy from Impact and Gyratory Compaction

From Tables A.1 and A.2, the energy for the gyratory compaction (vertical pressure = 200 kPa, gyration angle = 1.25 degrees, gyrations = 90) is about 30,000 lb-ft/ft^3. The maximum dry unit weight achieved under the gyratory compaction was about 109.65 pcf. However, the modified

Proctor compaction method used the energy of 56,000 lb-ft/ft^3, but the maximum dry unit weight was 106.5 pcf. The reason might be that for the impact compaction method, too much energy is lost during compaction.

Table A.1 Work done by the vertical force

Vertical pressure $p_{vertical}(N/m^2)$	200000
The height of sample before compaction $H_{before}(m)$	0.1906
The height of sample after compaction $H_{after}(m)$	0.1754
The diameter of the cross section of sample $D(m)$	0.15
The area of the soil sample $A_{sample} = \pi \times (\frac{D}{2})^2 (m^2)$	0.01766
The energy done by vertical force $U_v = p_{vertical} \times A_{sample} \times (\frac{H_{before} - H_{after}}{A_{force} \times H_{after}})(N-m/m^3)$	17330
The energy done by vertical force $U_v(lb- ft/ft^3) = \frac{U_v(N-m/m^3)}{4.7 \times 10}$	368.76

Table A.2 Work done by the shear force

Number Of Gyrations	Gyration Angle	Shear Stress (kPa)	Sample Height (mm)	Work Done (N-m)
1	1.24	93	190.76	27.330
2	1.23	112	188.6	32.541
3	1.23	122	187.05	35.155
4	1.23	126	185.87	36.079
5	1.24	131	184.9	37.315
6	1.24	135	184.07	38.282
7	1.24	137	183.37	38.701
8	1.24	140	182.73	39.410
9	1.24	143	182.16	40.129
10	1.24	144	181.65	40.297
11	1.24	148	181.2	41.314
12	1.25	151	180.76	42.049
13	1.24	153	180.35	42.5095
14	1.24	155	179.98	42.976
15	1.24	158	179.65	43.728
16	1.24	159	179.32	43.924
17	1.24	162	179.02	44.678
18	1.24	162	178.73	44.605
19	1.24	164	178.46	45.088
20	1.24	164	178.18	45.017
21	1.24	166	177.97	45.512
22	1.24	166	177.75	45.456
23	1.24	168	177.54	45.949
24	1.25	168	177.33	45.895
25	1.25	169	177.14	46.119
26	1.25	169	176.97	46.075
27	1.25	170	176.78	46.297
28	1.24	172	176.59	46.792
29	1.24	172	176.42	46.747
30	1.24	172	176.27	46.707
31	1.25	173	176.12	46.939
32	1.24	174	175.97	47.170

Number of Gyrations	Gyration Angle	Shear Stress (kPa)	Sample Height (mm)	Work Done (N-m)
33	1.24	175	175.82	47.400
34	1.25	174	175.69	47.095
35	1.25	172	175.54	46.514
36	1.24	174	175.42	47.022
37	1.24	175	175.3	47.260
38	1.24	176	175.21	47.506
39	1.24	176	175.09	47.473
40	1.24	176	174.96	47.438
41	1.24	176	174.84	47.405
42	1.24	177	174.74	47.648
43	1.25	178	174.64	47.889
44	1.24	178	174.52	47.856
45	1.25	178	174.43	47.831
46	1.24	176	174.32	47.264
47	1.24	177	174.23	47.508
48	1.24	178	174.13	47.7499
49	1.24	180	174.06	48.267
50	1.24	179	173.97	47.974
51	1.25	179	173.89	47.952
52	1.25	180	173.8	48.194
53	1.24	180	173.72	48.172
54	1.25	179	173.64	47.883
55	1.24	178	173.56	47.593
56	1.24	180	173.51	48.114
57	1.24	180	173.42	48.089
58	1.25	180	173.36	48.072
59	1.25	181	173.31	48.326
60	1.25	180	173.21	48.031
61	1.24	179	173.13	47.742
62	1.25	180	173.05	47.986
63	1.25	180	172.99	47.970
64	1.25	182	172.92	48.483
65	1.24	179	172.85	47.665

Number of Gyrations	Gyration Angle	Shear Stress (kPa)	Sample Height (mm)	Work Done (N-m)
66	1.24	180	172.79	47.914
67	1.25	181	172.74	48.167
68	1.25	180	172.66	47.878
69	1.25	179	172.6	47.596
70	1.24	180	172.52	47.840
71	1.24	180	172.47	47.826
72	1.25	179	172.39	47.5383
73	1.25	178	172.33	47.256
74	1.25	180	172.28	47.773
75	1.25	182	172.22	48.287
76	1.25	182	172.15	48.267
77	1.24	181	172.09	47.985
78	1.24	180	172.05	47.7096
79	1.25	181	172	47.960
80	1.25	182	171.93	48.206
81	1.25	182	171.86	48.186
82	1.24	181	171.81	47.907
83	1.24	182	171.76	48.158
84	1.24	182	171.7	48.141
85	1.25	182	171.67	48.133
86	1.25	184	171.63	48.650
87	1.24	183	171.59	48.375
88	1.24	184	171.53	48.622
89	1.25	184	171.48	48.608
90	1.24	184	171.43	48.594
total work done by shear stress(90 gyrations) N-m/m3				4133.777
unit work of the soil sample (90 gyrations) lb-ft/ft3				29047.602

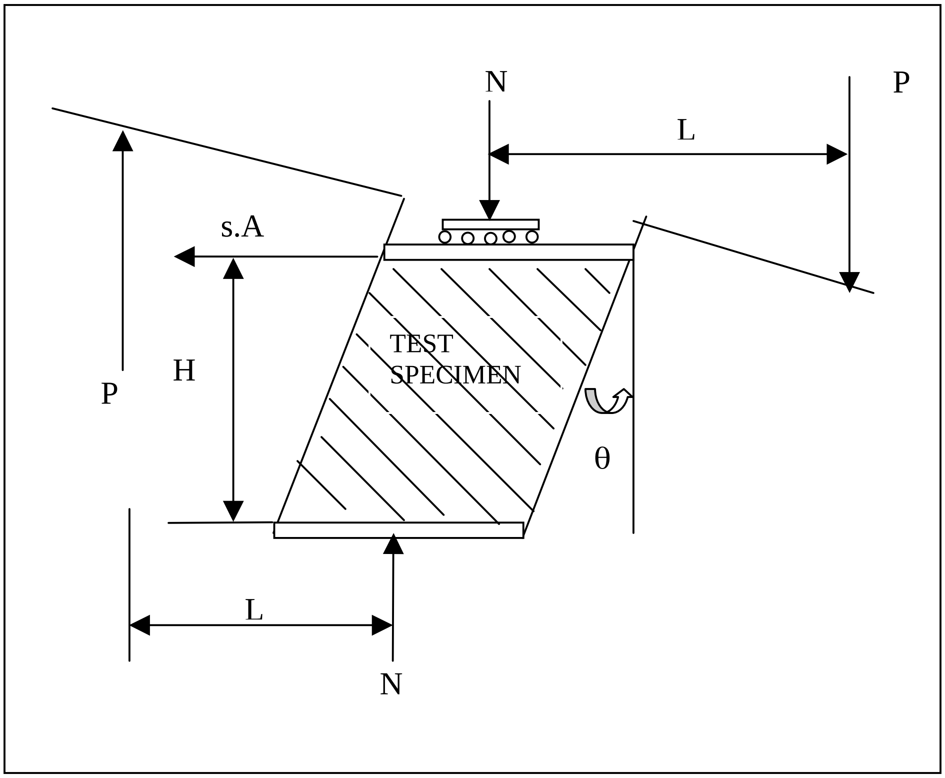


Figure A.1 The work schematic of the gyratory machine

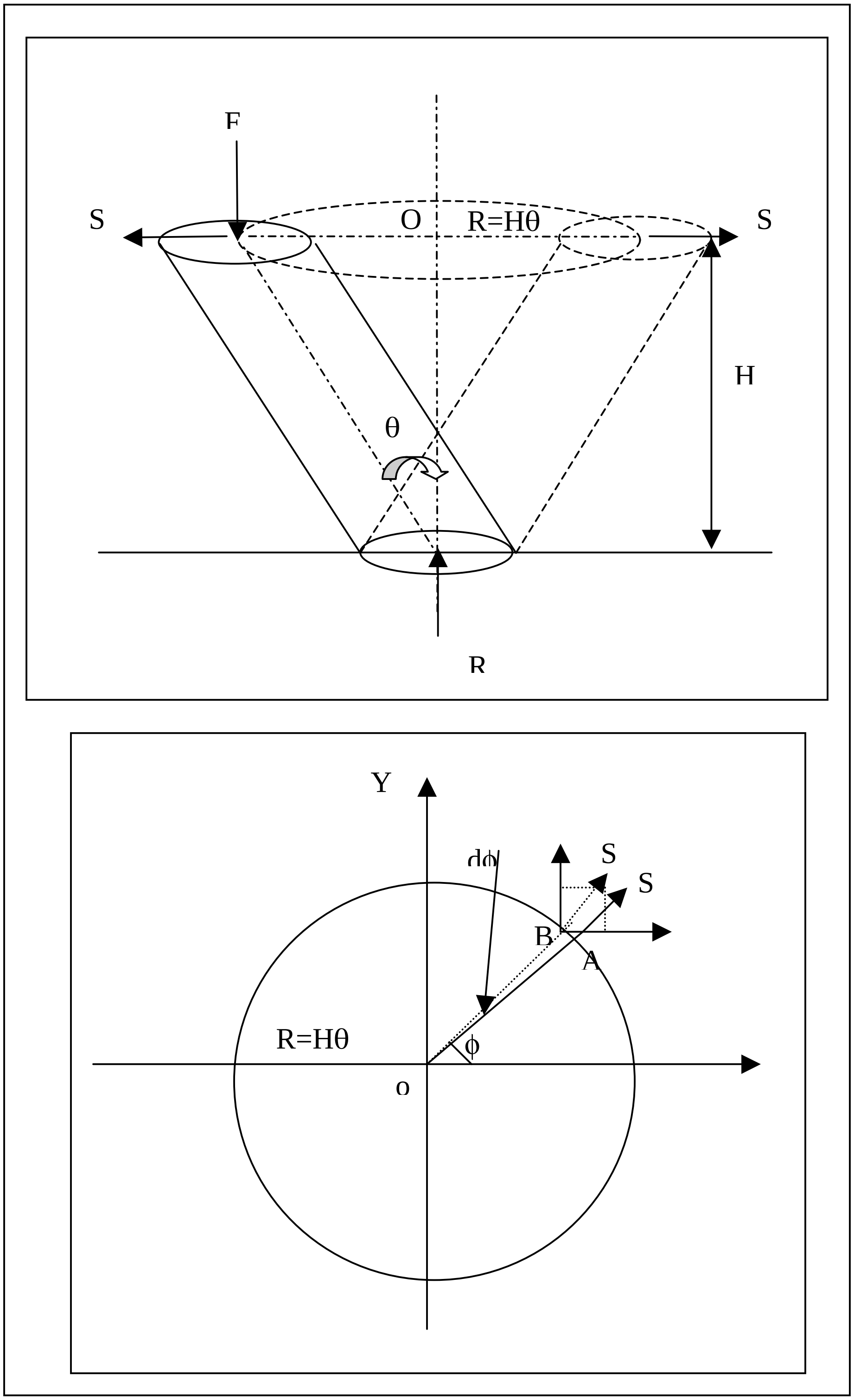


Figure A.2 Shear force and Vertical force analysis

APPENDIX B

PROPOSED GYRATORY COMPACTION TEST PROCEDURE

B.1 Proposed Scope

This proposed test procedure provides a process for determining the maximum dry unit weight, and optimum water content of the granular base/subbase materials with a SUPERPAVE Gytatory Compactor under conditions that represent a reasonable simulation of field compaction characteristics. This proposed gyratory test procedure for laboratory soil compaction is a better alternative to the Modified Proctor test procedure which did not produce the maximum dry unit weight to match the field test value and did not produce a satisfactory bell shaped compaction curve for the sandy soil. The properties (optimum water content and maximum dry unit weight) related to these procedures can be used as the specification for field compaction.

B.2 Summary of the Proposed Test Method

Gyratory compactions are repeated with fixed conditions of vertical pressure, gyration angle, gyration rate, number of gyrations, and different water content levels to produce the relation curve between the water content and dry unit weight. The maximum dry unit weight is obtained for the use of field compaction.

B.3 Significance and Use

This proposed standard test procedure for laboratory soil compaction with the SUPERPAVE Gyratory Compactor can best simulate the physical condition of the soil subjected to field compaction. Test results from this proposed procedure can significantly match the field compaction test results.

B.4 Basic Definitions

1. Moisture content (w) is also referred to as water content and is defined as the ratio of the weight of water (W_w) to the weight of solids(W_s) in a given volume of soil.

$$w = \frac{W_w}{W_s} \qquad \text{(B.1)}$$

2. Wet unit weight (γ) is the weight of soil(W) per unit volume(V).

$$\gamma = \frac{W}{V} \tag{B.2}$$

3. Dry Unit Weight (γ_d) is the weight per unit volume of soil, excluding water.

$$\gamma_d = \frac{W_s}{V} = \frac{\gamma}{1+w} \tag{B.3}$$

4. Vertical Stress is a numerical parameter that defines the vertical or axial-stress in kPa to be applied to the specimen during a compaction run.
5. Gyration Rate is a numerical parameter that defines the number of gyrations per minute of the machine during a compaction run.
6. Gyrations are the total number of cycles the mold will rotate.
7. The gyration angle is the amplitude of the mold rotating.

B.5 Proposed Apparatus

The proposed apparatus for gyratory compaction is a SUPERPAVE gyratory compactor. The gyratory compactor used for this application is a Servopac Gyratory Compactor (Figures B.1 and B.2).

The vertical force (compression) is applied using a digital servo (load) controlled, pneumatic actuator. A load cell is used to measure the vertical force and the signals are used to accurately set and maintain the vertical stress during compaction.

Three gyratory motion actuators are attached to a mold carrier that clamps the mold securely during compaction. A pneumatically operated base pedestal, located in the center of the mold carrier assembly, is used to lower the mold and its contents into position prior to clamping. The mold is unclamped and the base pedestal is raised automatically, at the completion of the compaction process.

A specimen extraction unit is located at the front of the machine. The extraction ram operates pneumatically and derives its air supply from the main unit. The connecting tube is coiled to allow the extraction unit to be detached from the main unit and rest on the floor without the need to disconnect it.

The basic machine has an LCD display and keypad, which allows the basic functions to be accessed and altered, i.e, vertical stress, angle and speed of gyration, target specimen height and/or number of gyrations; as well as displaying the specimen height and number of gyrations during the compaction process. An optional personal computer(PC) may be connected to the Servopac to access an increased number of modes and features and generate graphic plots (Figure B.3).

B.6 Testing Procedures

1. All water should be eliminated in the air pressure hose that is applied to the Servopac Gyratory Machine before the power is turned on.
2. The Servopac power is turned on, then the air pressure is applied and increased to about 100 kPa.
3. A representative sample of the soil or subbase/base course material proposed for use in the pavement is obtained.
4. The water content is selected for the test specimen. The sample of soil or subbase/base material is thoroughly mixed at the selected water content. The required water is mixed with about a 5000-g portion of

the soil. This sample is allowed to cure for a few hours or overnight in a closed container in order to obtain an even moisture distribution.

5. The bottom platen is placed in the mold, and then one of the two round disks is placed on the bottom platen. The required weight of cured material is added into the gyratory mold and hand tamped (with care that the limit line is observed). After putting in the soil material, the other round disk is placed on the top of the soil material (Figure B.4).
6. The mold and its contents are slid into the Servopac, until the mold comes to rest against the two locating pegs fitted to the mold carrier (Figure B.5).
7. The ‘MOLD LOWER’ button is pressed and careful observations verify that the mold was lowered through the center of the mold carrier.
8. The “MOLD LOCK” button is pressed.
9. The gyratory parameters in the PC program are selected as the following:

   Vertical pressure = 200 kPa

   Gyratory angle = 1.25 degrees

   Number of gyrations = 90 gyrations

   Gyration rate = 20 gyrations/minute

10. The “START” key is pressed. The door is then lowered automatically (Figure B.6).

11. When the termination conditions are satisfied, the door is opened and the mold is unlocked and raised.

12. The mold is gently pulled forward and across, over the extraction platen and the specimen is ejected by operating the “EJECT” switch (Figure B.7).

13. The specimen height is recorded, and saved in a file for later use.

14. The soil specimen is weighed (Figure B.8).

15. The soil specimen is split yielding about 100-g soil from the top, middle, and bottom of the specimen along the axle of the soil specimen. Then the samples are dried with a microwave oven about 10 minutes to obtain the water content.

B.7 Calculation

1. The moisture content is calculated.

$$w = \frac{W_W}{W_s} = \frac{W_{before} - W_{after}}{(W_{after} - W_{bowl})} \quad \text{(B.4)}$$

Where:

w = *moisture content of the soil specimen*

W_{before} = weight of the wet soil and the bowl before the soil is dried

W_{after} = weight of the dry soil and the bowl after the soil has been dried

W_{bowl} = weight of the bowl

2. The dry unit weight is calculated.

From the weight, height of soil specimen, diameter of the mold, and water content, the dry unit weight is obtained.

$$\gamma_d = \frac{W}{\left(\pi \times \left(\frac{D}{2}\right)^2 \times H\right) \times (1 + w)} \quad \text{(B.5)}$$

Where:

γ_d = dry unit weight of soil specimen
W = weight of the soil specimen
D = diameter of mold $D = 150\ mm$
H = height of soil specimen
w = water content of soil specimen

B.8 Data Presentation

Figures B.9 and B.10 illustrate the compaction curves obtained from the gyratory test procedure for A-3 soil and A-2-4 soil, respectively. From these compaction curves, the maximum dry unit weight ($\gamma_{d(max)}$) and optimum moisture content (ω_{opt}), which is the water content corresponding to

$\gamma_{d(max)}$, can be determined. The maximum dry unit weight ($\gamma_{d(max)}$) and optimum water content (ω_{opt}) can then be used for the field specification.

Figure B.1 Gyratory machine

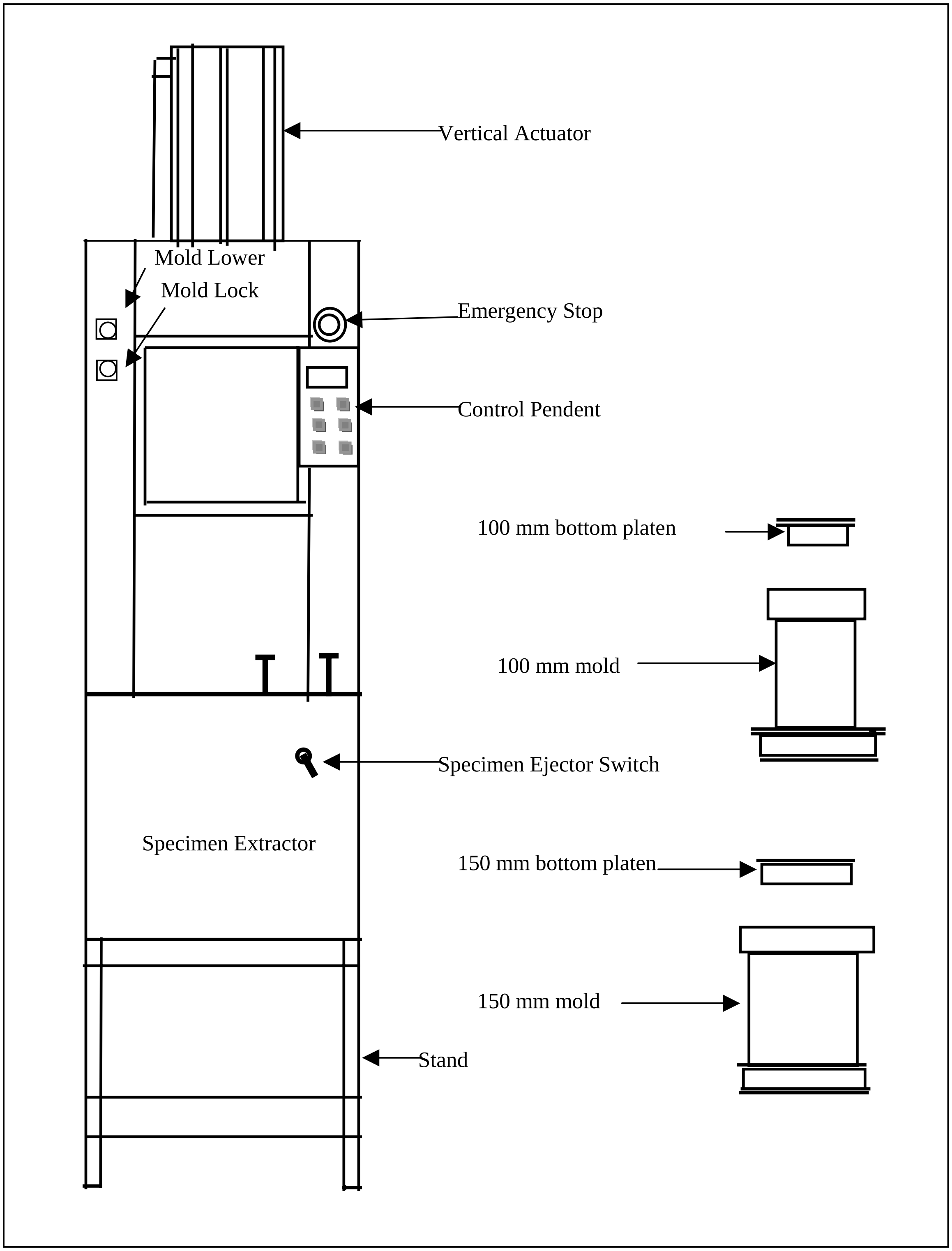


Figure B.2 Schematic of Servopac gyratory machine

Figure B.3 The gyratory system setup

Figure B.4 Filling the soil in the mold

Figure B.5 Sliding the mold on the gyratory plate

Figure B.6 Running the gyratory machine

Figure B.7 Ejecting the soil sample from the mold

Figure B.8 The soil sample after gyration

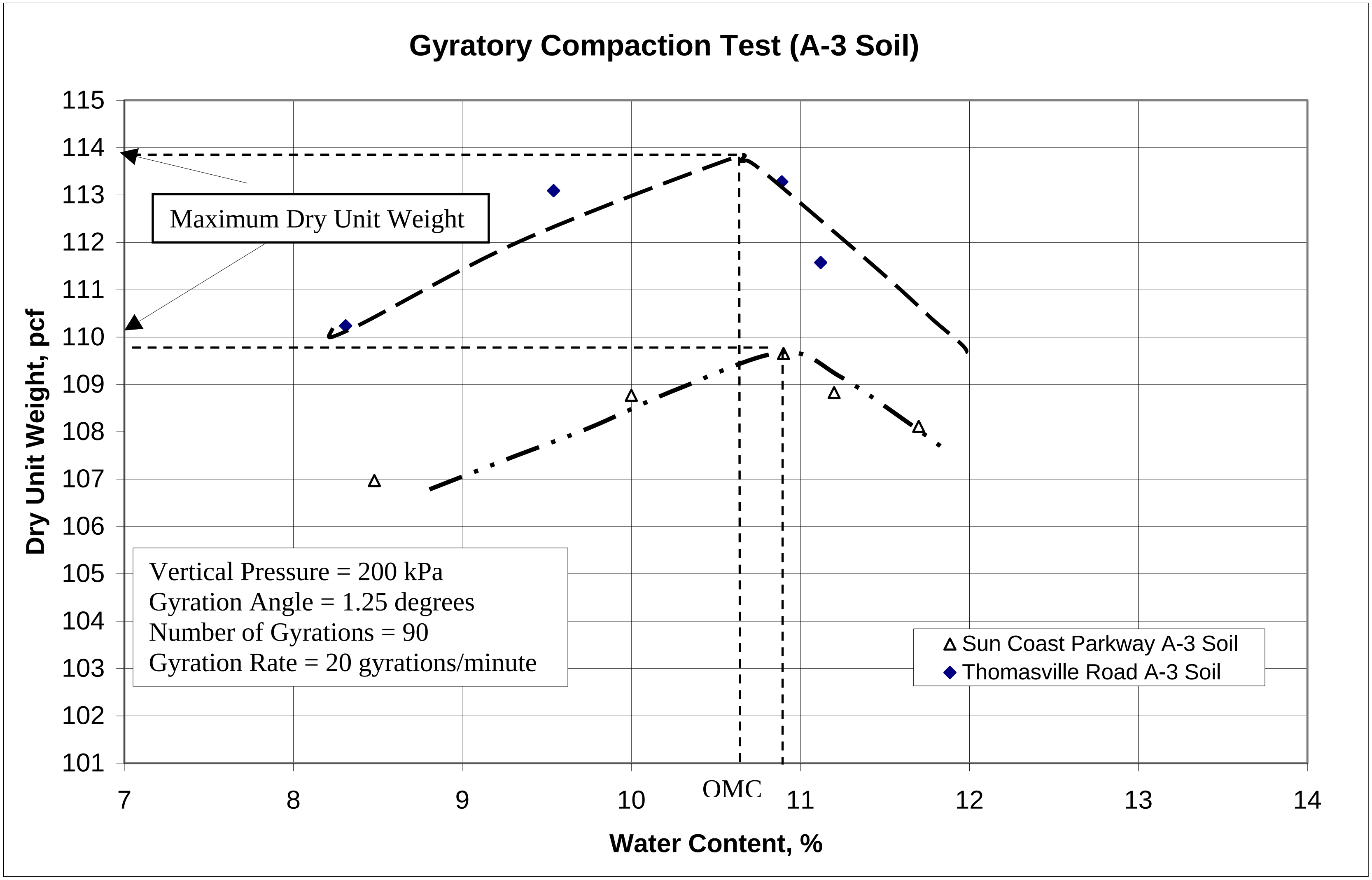


Figure B.9 Illustration of compaction test results for A-3 soil

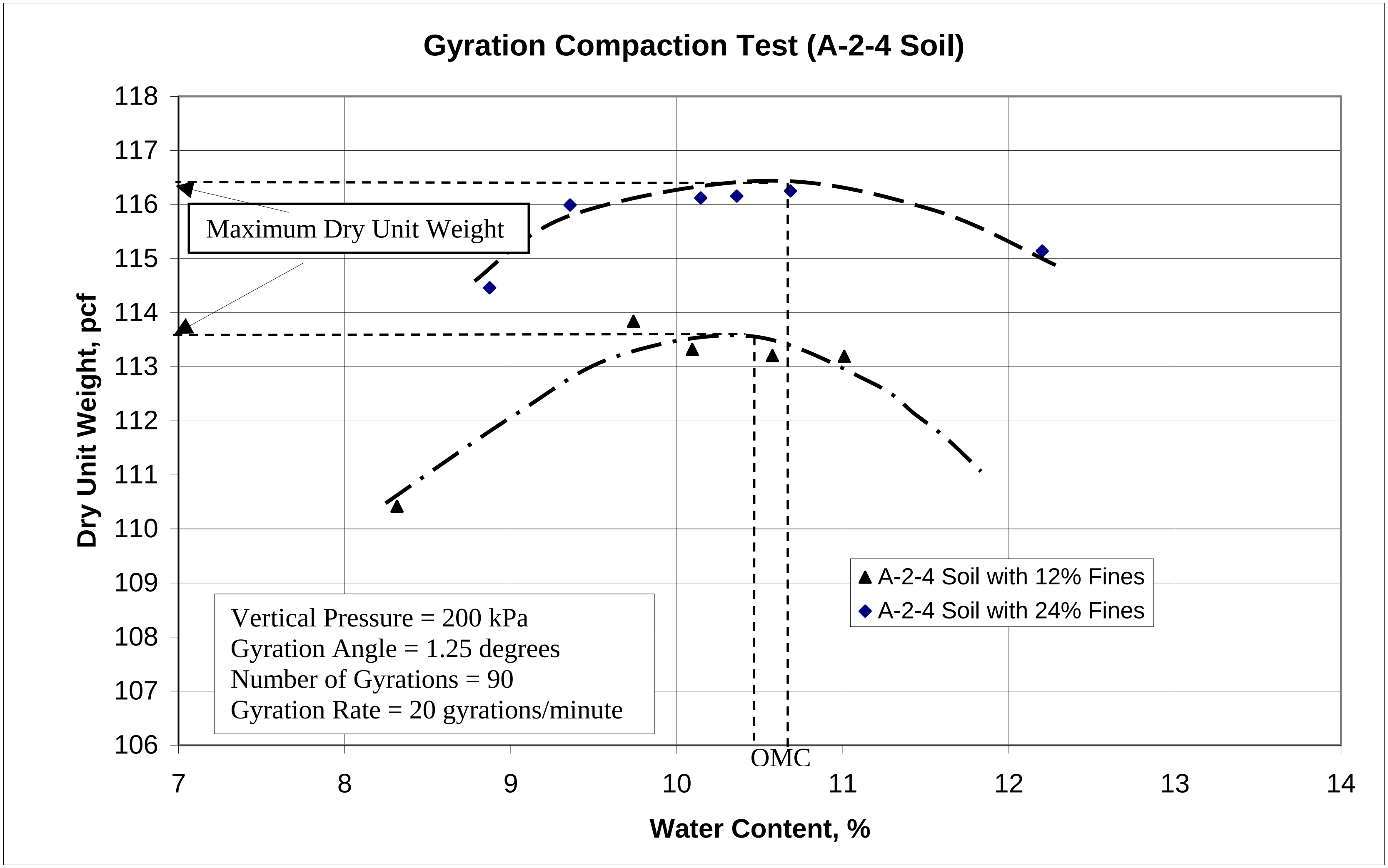


Figure B.10 Illustration of gyratory compaction test results for A-2-4 soil

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