A STUDY OF THE RAPID METHOD OF EARTHWORK CONSTRUCTION CONTROL

BY

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MAY, 1991

DECLARATION

I hereby declare that this dissertation has been composed by myself and that it is a record of my own research work. It has not been previously submitted for a higher degree or any other qualification.

References are made to the work of other investigators and are duly acknowledged.

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CERTIFICATION

This thesis entitled "A study of the Rapid Method of Earthwork Construction Control" by John Isaac Kwofie, meets the regulations governing the award of the Master of Science degree of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To the memory of my late Father, Mr. J.I. Kwofie, who encouraged me to pursue this programme, but unfortunately passed away only three days after it has began.

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I wish to thank all my supervisors, especially my main supervisor, Mr. D.P. Katale for his meticulous scrutiny of every aspect of the work.

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Thank you Mrs Vicky N. Kwofie. You were more or less my "internal" examiner.

I am grateful to ANSTI (UNESCO-ROSTA) for the fellowship.

J. I. KWOFIE.

MAY, 1991

ABSTRACT

In earthwork construction the parameter used to **check** the effectiveness of compaction is the Relative Compaction, a parameter which cannot be evaluated until field density tests and laboratory compaction tests on representative portions of the material have been performed. The Standard Method of arriving at this value of Relative Compaction is time - consuming because the Standard Method of performing the laboratory compaction test (to obtain the Optimum Moisture Content, OMC, and Maximum Dry Density, MDD) requires airdrying, ovendrying to determine moisture contents, and five points to plot a compaction curve- The overall effect is that the OMC and MDD will not be known until the following day. This is a shortcoming in earthwork construction where time is, indeed, money. The Rapid Method can give accurate values of OMC and MDD about an hour after digging a density hole, and hence a much faster means of assessing the effectiveness of compaction.

The object of this research has been to check the accuracy of the OMC and MDD values determined by the Rapid Method. Thirty five soil samples were used, and statistical analysis carried out on the results of the OMC and **MDD** obtained using the two methods on each sample, indicated that the Rapid Method is not only faster, but as accurate as the Standard Method.

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LIST OF SYMBOLS AND ABBREVIATIONS USED

W_f = Natural/field moisture content (%)

W_o = Optimum Moisture Content (OMC)

$W_o - W_f$ = Difference between OMC and NMC

W = Moisture Content (zero datum)

W' = $W - W_f$ = Percentage added water

Pb = Bulk density

$$Pd = \frac{Pb}{1 + W} = \text{Dry Density}$$

$$Pd' = \frac{Pb}{1 + W'}$$ Dry density with respect to the field/natural moisture content

W_w = Mass of water in the Soil

W_s = Mass of soil solids

W = Total mass of soil

WWC = Wet Weight Correction

Graph. = Graphical Method

Math. = Mathematical Method

Unc. = Uncorrected

C'ted = Corrected

Class. = Classification

Stnd. = Standard Method

M_1 = Mass of container (g)

M_2 = Mass of container and wet soil (g)

M_3 = Mass of container and dry soil (g)

LL = Liquid Limit (%)

PL = Plastic Limit (%)

PI = Plasticity Index (%)

CHAPTER 1

INTRODUCTION

1.1 The Standard Method of Earthwork Construction Control

The effectiveness of earthwork construction is determined by the Relative Compaction which is a ratio of the field dry density to the laboratory maximum dry density (MDD). To arrive at the Relative Compaction requires the performance of field density and laboratory compaction tests. The field density can be determined by the Sand Replacement Test, the Balloon Test, or by nuclear methods.

There are several different standard laboratory compaction tests. The test selected for use as the basis of compaction will depend upon the nature of the work, the type soil, and the type of equipment used on site. The Proctor Test, the method use in this research, consists of dropping a 2.5kg hammer with a 5.1cm diameter face from a height of 0.3m onto a soil specimen confined in a 10.2cm diameter mould. The soil is compacted in three equal layers, each receiving 25 blows. Actual test procedure is detailed in BS 1377: 1975 Test 12 (Ingles[11], Head[2])

A plot is made of the moisture content versus dry density, and the result will be of a form similar to the curve shown in Fig. 1. The coordinates at the peak of the curve give OMC and MDD. The MDD gives the maximum expected density i.e. the density to be used by the designer and the density to strive for in field compaction. The Relative Compaction is then given by the percentage ratio of the

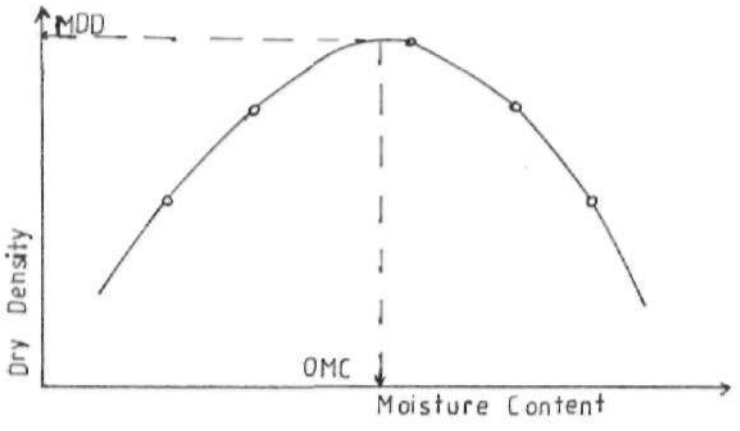


Fig.1: STANDARD MOISTURE - DENSITY RELATIONSHIP

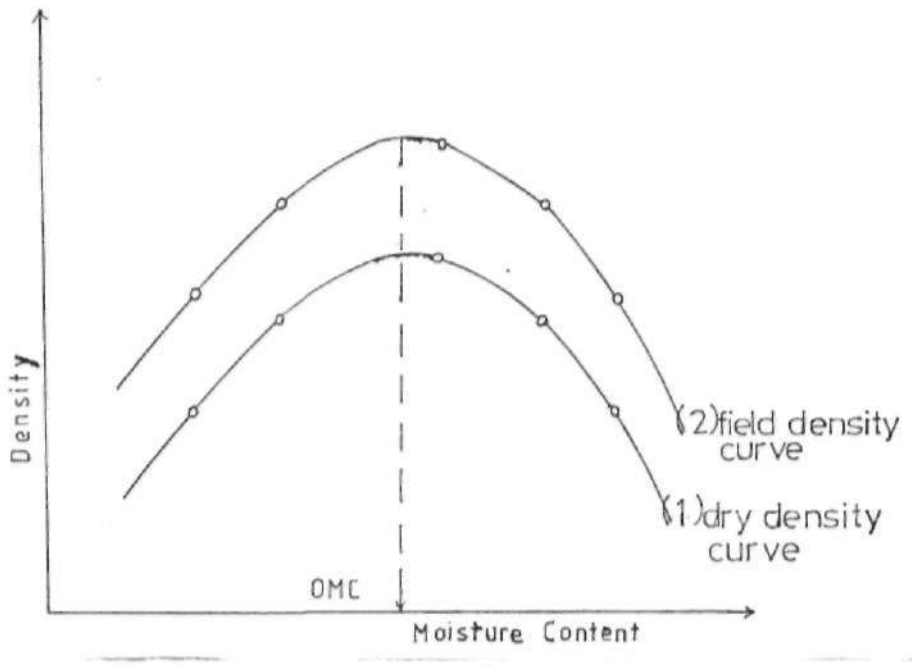


Fig.2: COMPARISON OF MOISTURE-DENSITY RELATIONSHIP OF THE STANDARD AND RAPID METHODS.

field dry density to the laboratory MDD. Usually in earthwork construction a Relative Compaction of between 95% to 100% is desired (Liu and Evett[1]).

1.2 Objective

It can be inferred from section 1.1, that for effective compaction, the compaction must be carried out at or near the OMC. It is also evident that the OMC and MDD can only be determined after compaction tests have been carried out on a representative portion of the material. In other words, the OMC and MDD will not be known until one has gone through the time-consuming process of air-drying the sample (or even oven-drying), waiting overnight (at least 16 hours) to determine moisture contents (Howard[7], Head[2]), and carrying out the compaction test in the five steps necessary to determine the five points needed to draw the compaction curve. In earthwork construction, where the cost of equipment is multiplied through by the minute, any move to determine OMC and MDD as accurately as possible and within the shortest possible time cannot but be welcome. The Rapid Method of Earthwork Construction Control seeks to redress the above-mentioned shortcomings of the Standard Method.

The object of this research, therefore, has been to check the authenticity of the Rapid Method by comparing the results of OMC and MDD determined using the Rapid Method on thirty-five soil samples, with the OMC and MDD obtained using the Standard Method on the same samples.

The laboratory work was planned to ascertain;

1) if the Rapid Method of moisture content determination is as accurate as the standard ovendrying method.

2) If the OMC and MDD obtained using the Rapid Method are as accurate as those obtained using the Standard Proctor Method.

3) The types of soil for which the test is applicable.

4) If the presence of organic matter has any effect on the results of the test.

CHAPTER 2

LITERATURE REVIEW

Perhaps the single most important task in any earth work is to ensure good compaction. The objective of any compaction operation is to improve the engineering properties of the fill. In foundation works, the properties of most interest are strength and compressibility, and because they are related to soil density and in situ density measurement involves comparatively simple test procedures, it is common practice to write compaction specifications in terms of a required density. Once the compacted density has been specified, the engineer or contractor must still select the method for processing and compacting the fill to meet specifications at the least cost. Thus in addition to establishing compaction criteria, proper design of a compaction operation involves selecting a technique best suited to achieve that criteria (D'appolonia and Whitman)[10]

2.1 Basic Principles of Compaction

It is a common fallacy (Ingles [11]) that heavy machinery will effect compaction according to its size and weight, whereas infact the relevant factor is the bearing pressure exerted at the soil surface. One obvious instance is the poor compaction effort of an elephant. Thus the first principle of compaction is to ensure a substantial contact pressure with the soil.

The earliest forms of earthen construction tacitly recognized the need for compaction. One of the earliest references surviving is that of the Chinese engineer Chia Shan (178 B.C) who wrote in the Chih Yen, "The road was made very thick and firm at the edge, and tamped with metal rammers." It was, moreover, quickly apparent that there existed a common aid to the compaction of almost any dry soil, - i.e water. Too much water was undesirable, as the soil became too sticky. Too little was equally undesirable; and clearly a certain level of moistness gave the easiest and best compaction. Thus the second principle of compaction is that the moisture content at which the soil is compacted determines the effectiveness of the contact pressure applied. This moisture content is known as the Optimum Moisture Content and for a given compactive effort is a unique property of each soil.

The effects of particle crushing due to rolling may be included as part of a more general third principle of compaction; i.e. highest densities are achieved by mixtures of different particle sizes. All compaction, which relies for its density on good grading of the compacted material is essentially achieved by filling the voids between the larger particles with particles of progressively smaller sizes until the finest voids have been filled. Overworking and re-use of soil can create excessive fines, drop the shear strength and occasionally destroy natural cohesion in a soil such that loss of density occurs. Ingles[11] states one

further essential requirement if any compaction is to be effective, and that is, the existence of a constraining layer around and below the soil being compacted. This leads to the fourth principle of compaction which is that, the shear stresses in the soil must be confined, if compaction is to be achieved. The confining mass may well be the soil itself, but where a layer of saturated soil or other soil of low bearing capacity underlies the layer to be compacted, it is obvious that no real compaction can be achieved because the soft layer will offer no reaction to the load and will deform, negating much of the applied compactive effort. In such circumstance and indeed in all good compaction practice, stage compaction is adopted - i.e. the soil is first rolled with light rollers to develop its own strength, then heavier rollers are applied to complete the compaction.

Although the four principles discussed above represent the major considerations for soil compaction, many other lesser factors have been established. These include particle shape, chemical status of the soil water, temperature and mode of application of the compaction force (such as roller speed, vibration rate) *inter alia*.

Natural particles vary both in form and in surface roughness. Particles with a flat and flaky habit normally pack much more densely than those with rounder form. The flat sheets of clay particles and micas possess considerable surface repulsion forces because of their small size, and thus resist compaction so effectively that they fall among the most difficult earthen materials to compact. In

addition particles with smoother surface will pack more easily than rough and angular particles due to the lower interparticle friction (But they are also displaced more easily under shear forces).

The compaction aid used, be it water or other fluid additive, e.g. bitumen, salt solutions etc also affects the response to a given compactive effort in varying degrees and ways. One such important effect is that of various ionic additives in the soil water on clayey soils, due to the reaction of the ions with the primary clay particles causing greater (anionic and dispersive additives) or lesser (cationic additives) shear strength in the soil. Where water-immiscible additives are used (such as bitumen) the effect on compaction is broadly the same as for water itself (Ingles and Metcalf). Increased temperature yields slightly better compacted densities for the same effort (Hogentogler).

Many of the uncertainties surrounding vibratory compaction arise due to the large number of variables that are involved in the operation of compactors as well as the variables associated with the granular material being compacted. These include roller size and weight, roller operating frequency and forward speed, lift height, number of roller coverages, sand particle size and gradation, water content etc. Surface compaction of in-situ granular deposits with light vibratory rollers is not effective for achieving high densities at depths greater than four or five

feet. The compacted density at any depth increases with the number of roller coverages but after about five passes, a large increase in the number of passes is required to achieve a significant increase in density. On a project involving a two-storey structure, where it was required to replace a 3.3m (10ft) layer of compressible organic silt with sand backfill, the bottom of the compressible layer being approximately 2.3m (7ft) below the watertable, Moorhouse and Baker[12] report that consideration was given to compacting the entire layer of sand by applying repeated coverages of a CT-60 vibratory compactor at the surface of the backfill, rather than the more expensive option of dewatering the excavation so that the backfill could be placed and compacted in thin lifts. Results showed that eight coverages of the vibratory compaction achieved relative densities in excess of 70% to a depth of 1.83m (51/2ft) and relative densities in excess of 50% to a depth of 3.3m (10ft.). Settlement plate data and standard penetration tests indicated that additional coverages continued to densify the sand and that for more than 8 coverages the effect per coverage was substantially less than 8 coverages.

When sand fill is placed in lifts, the lift height should be small enough so that a loose layer is not trapped near the interface between lifts. Roller operating frequency has a large effect on compacted density. Compacted density as well as ground acceleration and dynamic stress increase with operating frequency. Operating

frequency should be at least as large as the resonant frequency to obtain the most efficient use of the vibratory roller (D'Appolonia and Whitman)[10].

The mode of application of the compaction force is said to influence in two main ways. Firstly, if it is unidirectional, it will usually produce a compacted state with preferred orientation of the voids - i.e. an earthwork whose properties are anisotropic (especially strength, permeability etc). Compacting sand under static loading produces irregular density variations which can cause relatively large differential settlement, even though the total settlement of structures on sand is small (D'Appolonia and Whitman). Generally, it should be anticipated that the strength of fill materials will be anisotropic (Blight)[13]. Secondly, a static force is usually less effective than a dynamic force of the same magnitude since the internal shearing caused by pseudoelastic recovery of soil materials under repeated load causes densification in a much shorter time than would be achieved by steady creep under a fixed load. Shear forces provide more rapid compaction than compressive forces, and vibratory forces often provide the most rapid compaction of all.

Standard laboratory procedures used for determining the compaction characteristics of soil samples (AASHTO and PROCTOR) are often referred to as 'modified' and 'standard' compaction respectively. The proctor test consists of dropping a 2.5kg hammer with a 5.1 cm diameter face from a

height of 0.30m unto the soil specimen confined in a 10.2 cm diameter mould. The soil must be compacted in 3 equal layers, each layer to receive 25 blows of the hammer. The modified (AASHTO) test uses a 4.54 kg hammer, and a drop of 0.46 m; the same number of blows is applied but 5 layers are specified. The modified test thus gives a higher compaction than the standard. The above procedures require large amounts of soil, so a number of miniature tests have also arisen, the most important being the Dietert and Harvard, the results of which do not necessarily match those of the standard but can be related to them by experience and practice. (Ingles)[11].

2.2 Compaction with Heavy Machinery

In its earliest mechanical form, compaction was achieved with heavy smooth-wheel rollers. However many new types of rollers are now available for special soils or for special purposes. These include rubber-tyred rollers, sheepsfoot rollers, grid rollers, vibratory rollers etc. Their preferred uses are as shown in Table 1. The most important features of roller compaction are that:

1. repeated passes of the same roller rapidly lose compaction effect at the same moisture content (the increase in densification of a medium heavy clay fell of logarithmically with the number of passes (Morris and Tynan). This behaviour is not surprising since increase in density leads to increases in both internal

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Table 1. ROLLER TYPES AND THEIR USES (INGLES)[11]

Roller type	*Usual weight (approx.) kg*	*Usual roll (approx.) dia.*	*Usual roll width (approx.) m*	*Contact load kN*	*Remarks†*
Smooth wheel	8100–12 200	1.5 (rear)	1.9	0.35–0.61 per cm width	Better for granular materials. Will operate successfully above O.M.C. (if not too wet).
Grid	6100 unballasted 13 200 ballasted	1.7	1.6	Very high	Should be operated at as fast a speed as possible. Chiefly used for breaking down oversize stones and forcing them below the surface to give a better surface finish.
Vibratory	4050	1.2	1.8	0.21 per cm width	Better for granular materials than smooth wheel rollers; since only half the weight gives equal compaction. Frequency about 2000 Hz cycles/min.
Sheepsfoot	3050–5050 unballasted 5050–7100 ballasted	1.5	1.7	480–1725 per m² (on the feet)	60–120 ft per drum. Best suited for clays, especially in semi-arid zones. The foot pressure may be too high for saturated high moisture clays and too low for very dry clays.‡
Pneumatic tyre	8100–12 200	—	2.3	345–390 per m² (inflation pressure)	4–11 wheels with 9–22 kN per tyre. Best for cohesionless and low cohesion soils, and for surface finishing.

friction and cohesion, hence resistance to further compaction becomes progressively greater for a given compactive effort. (Moorhouse and Baker)[12].

2. the speed of the roller has little effect on the compaction achieved (Markwick).
3. a sheepsfoot roller requires more passes than other rollers because of its limited bearing area and hence poor coverage.
4. different rollers are better suited to different materials. Thus the kneading sheepsfoot or smooth steel rollers are most suitable for clays, but vibratory, smooth or grid rollers are for sands and gravels. In particular vibratory rollers are found to be as effective on sandy soils as non-vibratory rollers of twice their weight (Scala).
5. the heaviest roller compatible with the restrictions of principle four ante, will give the best compaction in every case. (i.e use of the heaviest roller which does not cause subgrade failures is always recommended).
6. the roller pressure should be greater than the tyre pressure of the earthmoving plant.

All the rollers in Table 1 are designed to compact soil in layers, at the surface. Thus they are applied to the construction of roads and embarkments, but not to the compaction of deep soils in situ. Moreover they must preferably operate on soils at or below optimum moisture content since they are not suited for the compaction of

loose or weak saturated soils in which they are likely to bog. When applied to highway or embarkment construction, it is usual to restrict the depth of each new layer to be such that, after passage of the roller, the new layer thickness does not exceed 15 to 25cm.

Earthen materials for which roller compaction is unsuited comprise chiefly the weak saturated soils, the highly organic (peaty) soils and some very micaceous soils. Organic and micaceous soils often possess large elastic recovery (rebound) which make rolling inefficient. For those soils for which conventional drainage is difficult, slow or impossible and particularly for soils which must be compacted in considerable depth, other methods other than rolling may be applied to effect consolidation (Ingles)[11].

2.3 Compaction by chemical means

Reference has already been made to the importance of water as aid to compaction. In addition to anionic additives, any addition to the soil which reacts with the clay fraction in such a way as to deflocculate or coagulate the clay fraction of the soil, will aid the compaction of a soil dry-of-optimum. All inorganic salts or organic additives which act as dispersants for clays (Sodium Chloride, Sodium Phosphates, Sodium Carbonate, Sulphonic acid derivatives etc) are thus powerful aids to compaction if added to the soil water. In sandy soils, the soil particles carry little or no surface charge, and dispersing

agents are not effective unless some clay cohesion remains. Agents capable of either reducing interparticle friction, or the residual cohesive forces are, however, effective aids for sand compaction.

The above methods are generally effective only where mechanised mixing of soil and additive is possible, since only in very permeable soils (sands) will sprays penetrate to any appreciable depth. For soils which cannot be mixed prior to compaction, other chemical methods are available based on the unique properties of quicklime hydration reaction.

The reaction is

$$CaO + H_2O = Ca(OH)_2 + 15.5 \text{ kcals.}$$

It follows that if quicklime is allowed to react with water in a confined environment, substantial pressure and temperature are simultaneously generated. This fact can be turned to advantage for the compaction of deep soft soils by the simple technique of drilling or driving holes with shallow casing, filling the holes with quicklime (or if desired for economy, lime sand mixes, may be used) withdrawing the casing and sealing the hole. The heat of the reaction increases the fluidity of the soil water, leading to more rapid extraction from the soil, and the extraction of the water is accompanied by a simultaneous lateral consolidation of the soil under the expansive forces generated by the lime hydrate. This method of deep compaction is now practiced for major works in Japan and Taiwan, the soils particularly suitable being silts and

light loams rather than sands or heavy clays (Itoh).

The sandwich method is another method, also based on quicklime, by which the accelerated consolidation of a saturated clay may be obtained. In this method alternate layers of soft clay (up to 70 cm deep) are laid separated by thin layers (5cm) of quicklime spread between the two thin sheets of special drain cardboard. For better economy,the lime may be laid on a grid pattern rather than in one continuous layer. The drainage of water (which in this case flows out from the cardboard drains) is speeded both by the temperature and pressure generated in the reaction, and consolidation is considerably accelerated (Yamanouchi) (Ingles[11], Mitchel[14]).

2.4 Compaction by Shock

Numerous methods for deep soil compaction based on impact or shock waves have been successfully applied in practice.

The simple extension of the ramming principle to depth may be accomplished by what has been termed 'direct power compaction' or by 'vibroflotation'. The former consists of a driven hollow pile, the end of which is opened or closed, as desired, by remote control so that strata at any selected depth can be compacted by alternately slightly raising and then ramming with the closed head. Vibroflotation likewise consists of a driven hollow pile, though in this case the initial driving can be assisted by

water jets. Having reached the requisite depth the pile is withdrawn slowly while gravel or crushed stone is supplied down the shaft and a heavy vibratory action applied to the gravel as it is placed. In both cases, the driving of the hollow shaft itself causes a compaction of the soil, and this effect is increased and intensified through the subsequent impact ramming by the head.

Another such technique is sandpiling which is rather similar to vibroflotation, but for economy utilizes sand rather than gravel, and relies in part on the drainage characteristics of the sand piles to produce settlement after placement of the columns.

Direct application of explosive shock waves has been practiced on many soils to achieve compaction with varying success. The consolidation of sandy soils, especially in dams, has been attempted in this way, as also has the settlement of highway formations across peat bogs. The latter process, known as 'bog blasting' is not intended to compact the peat, but rather to displace it from under the surcharged fill, allowing the fill to settle into the area from which the organic soil has been displaced. Where sand compaction is attempted by the detonation of explosives, the presence of silt or clay substantially diminishes the effect. Blasting as a means of in-situ densification is said to be only effective in saturated granular soils (Mitchel, [14] Ingles[11]).

The construction of a three-storey office building at the Treasure Island Naval Station in San Francisco, provided Basore and Boitano, [15] the opportunity to evaluate the effectiveness of both vibroflotation and compaction piles (direct power compaction) in densifying 10m (30ft) of loose to medium dense sandfill. An evaluation of the response of the site to a major earthquake indicated that the loose, saturated sandfill was subject to liquefaction. In order to improve the safety of the site against liquefaction, it was decided to densify the sand under the entire building area. Results indicated that both vibroflotation and compaction piles were effective methods of densifying the sandfill, if proper spacing between compaction points were used. Experience gained on the project indicated that vibroflotation produced a more uniformly dense fill. It was also realised that compaction piles had to be spaced closer together than vibroflotation compaction points to densify sand to the same relative density. The cost of installing a compaction pile was much less than performing a vibroflotation compaction point. However, it appeared vibroflotation was more economical than compaction piles in terms of cost per cubic metre. Densification of the building site by compaction piles spaced 1.3 or 7m (4 or 5ft) on centres produced a fill with an average relative density in excess of 75%. The densification process was not completely uniform and several tests fell below the specified minimum relative densities of 75% beneath footings and 65% below floor areas. It is known that soils above

about 70% relative density are not subject to liquefaction (Ingles and Grant). An alternative method of impact compaction for loose, wet sandy soils is by electric shock (Mitchel[14]).

2.5 Compaction Control in the Field

Perhaps one of the most important questions to be answered if the engineer is to obtain a satisfactory and predictable performance from his work is, how should compaction be controlled during placement and rolling of the soil?

As earlier mentioned density is normally the parameter used to determine the effectiveness of compaction, since the other desirable parameters like strength and compressibility are related to it, and density is comparatively easier to determine in the field. However, density is far from being a universally adopted measure of performance in service. Some of the tests used in compaction control are:

1. *Control by density*

Sand Replacement	(BS 1924: 1967 Tests 7,8)
	(ASTM, 1964 D 1556 - 64).
Core Cutter	Australian Standard
	AS A89 - 1966
Rubber Balloon	ASTM, 1964, D2167-63T.

2. Control by Moisture Content

Speedy Moisture Metre

Neutron Moisture Metre

3. Other Controls

CBR test	Australian Standard A89 - 1966, Test 14
Deflection	Benkelmann Beam (Ingles and Metcalf).

Head[2] lists the following as other methods of drying soils aside of ovendrying.

1. Infra-red Cabinet:

This is useful for the rapid drying of large samples of granular soil in preparation for particle size or compaction tests. However, it is not suitable for determining moisture content especially if organic matter is present, because there is no means of temperature control.

2. Microwave Oven:

Microwave heating with forced air convection gives a very rapid method of drying but without temperature control. This method is also not suitable for the determination of moisture content.

3. Warm Air Blower:

A handheld electric blower providing a stream of air

at a nozzle temperature of 100°C is useful for rapidly reducing the moisture content of small quantities of soil. However it is not suitable for the determination of moisture content.

4. Electric hot-plate

They are useful for the rapid drying of non-cohesive soils spread on trays, but the uneven distribution of heat requires that the soil be constantly watched and agitated. Hot plates may be used for the determination of the moisture content of some soils by the sandbath method.

The reliability of nuclear methods in determining moisture content and density has been reported by Kersten and Skok,[17] Todor and Gartner[18], Long and French[19], Anon[23] etc. The Speedy Moiture Metre is a chemical method of determining moisture content using Calcium Carbide as a reagent. The principle involved is that a given quantity of moisture will react with Calcium carbide to produce a specificed volume of acetylene. This gas is confined in a pressure vessel, the gas pressure being read on a gauge, calibrated to read in percentage of moisture based on the wet weight of the sample. Calibration curves are then used to convert the moisture readings to the equivalent moisture content that will be obtained by oven-drying (Blystone *et al*)[20].

Moisture control has distinct advantage over density control in that each moisture content corresponds to a unique density, whereas each density point may represent

either of two moisture contents. However, the rapid field measurement of moisture content is less readily performed than that for density. Joint use of moisture content and density is by far the best indirect compaction control parameters, since together they allow the supervising engineer to determine what residual air voids are still present, and reducing air voids below 5% should be the objective of all good compaction work. Moreover control on both parameters allows a more effective statistical control of the work than control on one parameter only (Ingles). In all cases the best means of ensuring good compaction in the sense of reliable and predictable performance is by statistical control of the testing and acceptance. (Kantey and Morse, [21], Mathews and Hardman[22] etc). Recognition by civil engineers of the random variation of pertinent soil properties in earth work construction such as moisture content and density has generated considerable interest in the statistical evaluation of these variables. The classical statistical approach to quality control is first to define the parameter variability in terms of a mean value and a standard deviation from the mean. Where values have to be fixed, they will normally be fixed to keep the risk that an acceptable product will be wrongly rejected, very low, say 0.1%. Many earth structures, have been constructed in a satisfactory manner without the use of statistical analysis, but because of the uncontrolled random variation, there is an element of unrealism in past practice of setting

absolute minimum or maximum limits or both, on measured soil properties. Typical variations of soil properties have been experienced in successfully constructed earthfills and these variations are greater than have been thought acceptable by many engineers for satisfactory behaviour of structures (Turnbul et al [24], Ingles[11]).

CHAPTER 3

THE RAPID METHOD OF EARTHWORK CONSTRUCTION CONTROL

3.1 Purpose

Determining the moisture content of a soil by the oven-drying method requires a minimum of sixteen hours (Head)[2]. The result is that the dry density of an in-situ density test is not known until the following day. In many cases, the construction may be progressing rapidly so that the field density test site may be covered with several metres of fill, consequently making it impossible to recompact an area containing a test that did not meet specifications. The Rapid Method of Earthwork Construction Control will give accurate values of Relative Compaction and the difference between OMC and the natural (field) moisture content ($w_o - w_f$) about an hour after digging a density hole (Howard)[7].

3.2 Basis

The Rapid Method is based on the fact that a Proctor Compaction curve constructed with the densities calculated with respect to the natural moisture content, w_f, is similar to the dry density curve (Fig. 2). If the compaction curve in Fig. 1 were to be reconstructed with the same moisture contents now written with reference to w_f, not zero, the result will be another compaction curve translated a fixed

distance above the original curve. It is worth noting the two curves will be similar, with the same axis (hence the same OMC), while the MDD can be determined from curve (2) by a straightforward interpolation using the factor $\frac{1 + w'}{1 + w}$

where w' is the moisture content using w_f as datum (or the added water) and

w is the moisture content using zero as datum.

This implies that if only curve (2) had been drawn, the OMC and MDD could still have been obtained by back analysis.

The Rapid Method furthermore utilizes only three points A, B, and C, the middle point, B, having a higher density that the points A and C. The three points are assumed to lie on a parabola, then the graphical or mathematical method is applied to determine $(w_o - w_f)$, leading to the determination of OMC and MDD. (Howard)[7].

3.3 The Graphical Method

3.3.1 Unequal added Water Increments

Fig. 3 illustrates the graphical method for determining OMC and MDD, using the data below for sample HA-12-11.

w'	0	+9	+16	
Pb	1.51	1.90	1.99	
Pd'	1.51	1.75	1.71	w_f = 2.25%

where Pb is the bulk density and

Pd' the dry density with respect to the natural (field) moisture content.

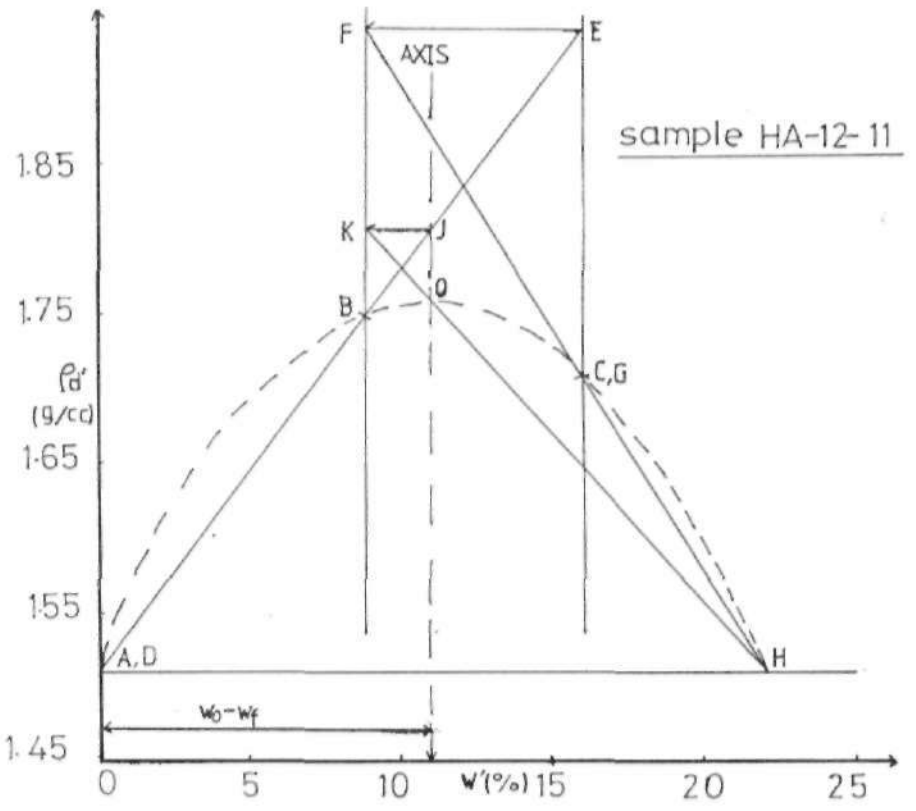


Fig. 3: GRAPHICAL METHOD FOR UNEQUAL WATER INCREMENTS

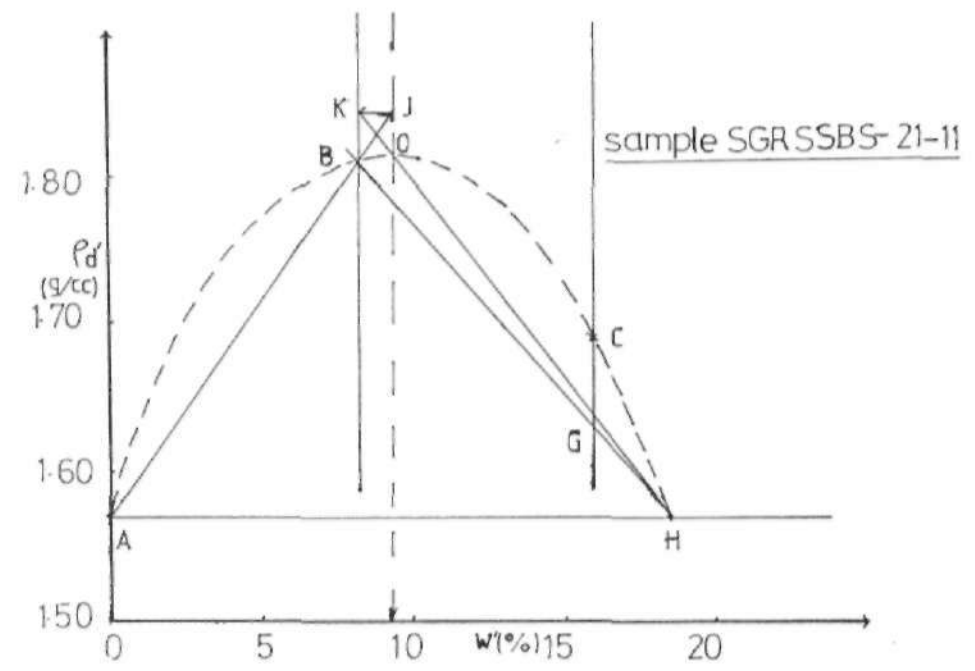


Fig. 4: GRAPHICAL METHOD FOR EQUAL WATER INCREMENTS

The procedure is as follows:

1. Draw a horizontal baseline through the left point A and draw vertical lines through the points B and C.
2. Draw line DE parallel to AB: Point D is at the intersection of the horizontal baseline and the zero added waterline: Point E lies on the vertical line through point C; Project E horizontally to establish point F on the vertical line through B.
3. Draw line DG parallel to AC; Point G lies on the vertical line through point C.
4. Line FG intersects the baseline at H. Axis of the parabola bisects AH; Draw the axis.
5. Intersection of line AB with the axis is at J; Project J horizontally to K, which lies on the vertical line through point B.
6. Line KH intersects the axis at O, maximum density point (vertex) (Howard)[7].

In Fig. 3, $w_o - w_f = 11.00\%$

$\therefore$ OMC = 2.25 + 11.00 = 13.25%

Pd' max. = 1.765 g/cc

$$\therefore \text{M.D.D.} = 1.765 \times \frac{(1 + 0.11)}{(1 + 0.1325)} = 1.73 \text{g/cc}$$

3.3.2 Equal Added Water Increment

If points A, B and C are spaced equally horizontally, steps 2 and 3 are eliminated. Point F coincides with point B and point G is halfway between the baseline and point C.

Hence point H is obtained by drawing BG and point O is obtained by steps 5 and 6 as usual (Howard)[7].

This is shown in Fig. 4 using the data below for sample SGRS SBS-21-11

w'	0	+8	+16	
Pb	1.57	1.96	1.96	
Pd'	1.57	1.81	1.69	w_f = 3.7%

From the plot, $(w_o - w_f)$ = 9.4%

OMC = 3.7 + 9.4 = 13.1%

Pd'max = 1.815 g/cc

$$MDD = 1.815 \times \frac{(1 + 0.094)}{(1 + 0.131)} = 1.76 \text{ g/cc}$$

3.4 The Mathematical Method

Once three points on a parabolic curve are known, the other properties of the curve can be mathematically determined. The peak of the parabola corresponds to the maximum laboratory density and the OMC. Howard, A.K. of the US Bureau of Reclamation, who developed the Rapid Method evolved charts to locate the peak point using the three compaction points. However, these charts were not utilized in this research because they are only valid for added water (w') in even increment of 1% or 2%. In this research, a mathematical solution has been developed to handle all cases of added water.

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The solution is based on the fact that the equation of a parabola is $y = a x^2 + bx + c$. In this case $X \equiv w'$, $Y \equiv Pd'$ while a, b and c are constants.

Assuming the coordinates of point A, B and C are (x_1, Y_1), (X_2, Y_2) and (x_3, Y_3) respectively, then

$$Y_1 = ax_1^2 + bx_1 + c$$

$$Y_2 = ax_2^2 + bx_2 + c$$

$$Y_3 = ax_3^2 + bx_3 + c \quad \text{or}$$

$$\begin{vmatrix} Y_1 \\ Y_2 \\ Y_3 \end{vmatrix} = \begin{vmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ x_3^2 & x_3 & 1 \end{vmatrix} \begin{vmatrix} a \\ b \\ c \end{vmatrix}$$

Applying Cramer's Rule (Sokolnikoff and Heffer)[4]

$$a = \frac{\begin{vmatrix} Y_1 & x_1 & 1 \\ Y_2 & x_2 & 1 \\ Y_3 & x_3 & 1 \end{vmatrix}}{\begin{vmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ x_3^2 & x_3 & 1 \end{vmatrix}} \quad b = \frac{\begin{vmatrix} x_1^2 & Y_1 & 1 \\ x_2^2 & Y_2 & 1 \\ x_3^2 & Y_3 & 1 \end{vmatrix}}{\begin{vmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ x_3^2 & x_3 & 1 \end{vmatrix}} \quad c = \frac{\begin{vmatrix} x_1^2 & x_1 & Y_1 \\ x_2^2 & x_2 & Y_2 \\ x_3^2 & x_3 & Y_3 \end{vmatrix}}{\begin{vmatrix} x_1^2 & x_1 & 1 \\ x_2^2 & x_2 & 1 \\ x_3^2 & x_3 & 1 \end{vmatrix}}$$

At the peak, $\frac{dy}{dx} = 0$

$$\frac{dy}{dx} = 2ax + b = 0 \text{ and } X_{max} = \frac{-b}{2a}$$

$$X_{max} \equiv (w_o - w_f)$$

$$Ymax = a\left(\frac{-b}{2a}\right)^2 + b\left(\frac{-b}{2a}\right) + c$$

$Ymax \equiv Pd',max.$

Using the data of Section 3.3.1, gives

X_{max} = 11.09% OMC = 2.25% + 11.09 = 13.34%

Y_{max} = 1.76 g/cc M.D.D. = $1.76 \times \frac{1.1109}{1.1334}$ = 1.72g/cc

3.5 Determination of Natural Moisture Content

To arrive at the OMC and MDD, the only moisture content required to be determined is the natural (field) moisture contents. The NMC is also rapidly determined using the following procedure.

(a) A representative sample of the soil is placed in a tray.

(b) The weight of the wet soil is noted.

(c) The tray is then placed over a source of heat, like a kerosene stove, and the soil stirred at intervals.

The heat from the kerosene stove will drive out the moisture. Intermittently, a watch glass is held over the soil sample. If there's still moisture evaporating, it will condense on the watchglass due to its colder surface. When no moisture condenses, it is assumed that all the moisture has evaporated.

(d) The weight of the dry soil is determined.

(e) The moisture content is calculated as usual (BS1377: 1975, Test 1 (A) (Sluder)[26].

3.6 Compaction Curves

The process of determining OMC and MDD may take any of the three forms shown in Fig. 5, depending on the natural moisture content, w_f. Where the moisture content is required to be below w_f, moisture may be driven away from the soil, using the same rapid drying method used for the natural moisture content determination.

3.7 Wet Weight Correction

Moisture contents, in the Rapid Method, are determined on the basis of the fact that if the NMC of a soil is a% and water, b% of the dry weight of the soil, is added to it and thoroughly mixed, the new moisture content is (a + b)%.

In reality, however, the amount of water added is based upon the wet weight of the soil rather than the dry weight, since the soil is not allowed to dry. This introduces an error in the moisture content values which must be corrected for by the application of the wet weight correction. Howard in his booklet "Rapid Method of Earthwork Construction Control" has developed correction charts for some cases of added water.

For the kind of soils dealt with in this research, the charts were not useful thus appropriate corrections had to be calculated from first principles.

Using $\frac{w_f}{100} = \frac{W_w}{W_s}$ and $w_s + w_w = W$

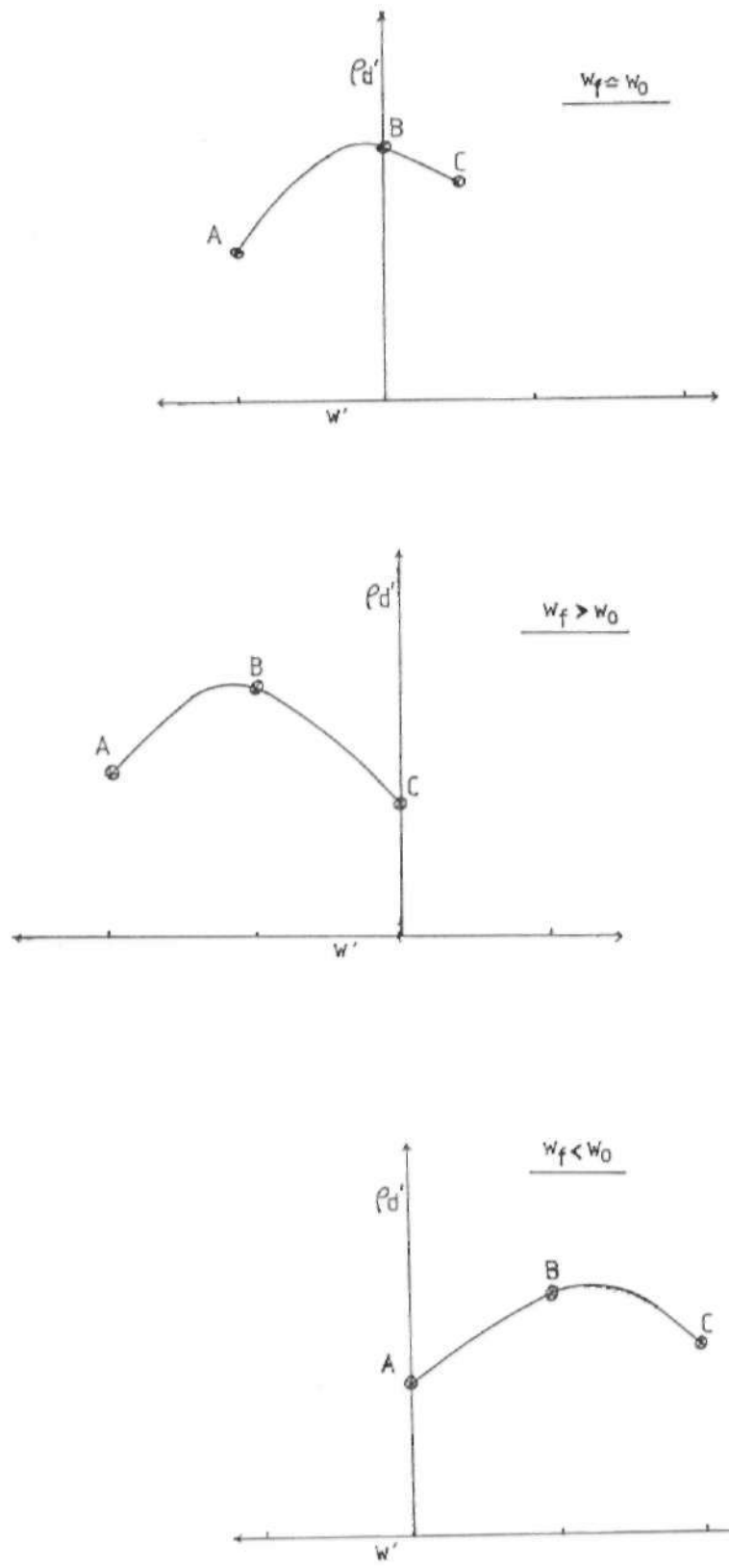


Fig: 5 COMPACTION CURVES (RAPID METHOD)

Where W_w is the weight of water in the soil, W_s, the weight of soil solids and W, the total weight of the soil.

$$W_S + \frac{W_f W_s}{100} = W$$

$$\Rightarrow W_s \left(1 + \frac{W_f}{100}\right) = W$$

$$W_s = \frac{W}{\left(1 + \frac{W_f}{100}\right)}$$

Since the total weight W, is greater than the weight of soil solids, W_s,

$x\%$ of $W > x\%$ of W_s

but $(x + \Delta x)\%\ W_s = (W).x$ where Δx is the wet weight correction (%).

$$\text{Thus } (x + \Delta x) \frac{W}{\left(1 + \frac{w_f}{100}\right)} = W.x$$

$$\frac{(x + \Delta x)}{\left(1 + \frac{W_f}{100}\right)} = x$$

$$\therefore \Delta x = \frac{W_f}{100} .x$$

In other words, 10% of the wet weight of a soil whose w_f is 3.3% is in reality 10.3% (i.e. 10 + (0.03 x 10)) of the dry weight of the soil. As such, wet weight corrections

must be applied to the values of $(w_o - w_f)$ before adding to the N.M.C., w_f to obtain the O.M.C.

3.8 Summary of Procedure

(1) Perform the field density test.

(2) Determine the natural moisture content.

(3) Screen the soil.

(4) Compact a mould with soil at field/natural moisture content, Calculate density.

(5) Add the appropriate amount of water to the soil (say 2%). Compact a mould. Calculate density. Convert density to field/natural water content density Pd'.

(6) Plot the first two points. Decide whether water is to be added or subtracted for the third point.

(7) Add more water or subtract as appropriate. Compact a mould. Calculate density. Convert density to field/natural water content density. Plot the third point.

(8) If points on both legs of a parabola are not obtained add or subtract more water. When the three points are established, find the maximum density and optimum moisture content by either the graphical or mathematical method (Howard)[7].

CHAPTER 4

EXPERIMENTATION

4.1 Scope

4.1.1 Samples

Samples used for the tests were obtained mostly from the Ahmadu Bello University Campus. Actual locations are indicated by the prefixes:-

HA	-	Human Anatomy	FA	-	Fine Art
DR	-	Danfodio Roundabout	KIL	-	Kashim Ibrahim Library
EE	-	Electrical Engineering	ICSA H1	-	ICSA Hall One
E	-	Engineering	ICSA H2	-	ICSA Hall Two
JSQ	-	Junior Staff Quarter	SGRS ADMN	-	School of General and Remedial Studies, Administration Block.
AE	-	Adult Education	SGRS SBS	-	Old School Business Studies (School of General and Remedial Studies).
P	-	A.B.U. Press	CH	-	Chemistry
D	-	Danfodio	MB	-	Microbiology
CC	-	Computer Centre	CHE	-	Chemical Engineering
B	-	Biology			

All the other samples with the prefix Rd - came from Katsina State. In all thirty-five soil samples were tested. Classification and details can be found in Table 2 and Appendix 1 respectively.

4.1.2 Natural Moisture contents

The standard oven-drying method of determining moisture content (BS 1377: 1975, Test 1 (A)) was used and compared with the rapid drying method described in Section 3.5, where the source of heat was a kerosene stove. The results are shown in Table 2, details in Appendix II.

4.1.3 Classification Tests

Howard[7] proposes the Rapid Method for cohesive soils. To investigate, it was necessary to use the method on both cohesive and cohesionless soils to ascertain the difference. The Unified Soil Classification System (Table 3) was used and the results showed that of the 35 samples, 23 were clays, 6 were sands, and 6 were gravels - i.e. 23 cohesive and 12 cohesionless soils.

4.1.4 Compaction Tests

Compaction tests on all the samples were conducted according to BS 1377: 1975, Test 12 and the procedure outlined in Section 3.8. The results are shown in Table 2 and the details, including the compaction curves for both the Standard and Rapid methods are shown in Appendix IV. The Mathematical method in section 2.4 was also used to calculate the OMC and MDD values. The Graphical method was seen to be just as good. Wet weight corrections were also calculated and applied as discussed in Section 3.7. All the results are shown in Table 2.

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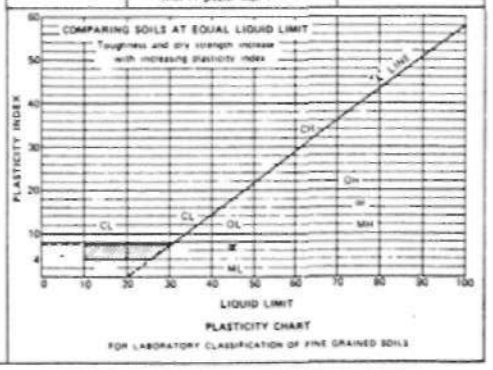
TABLE 2: RESULTS

SAMPLE NO.	CLASS	ORGANIC CONTENT (%)	N.M.C.(%) STND	N.M.C.(%) RAPID	$W_o - W_f$(%) GRAPH	$W_o - W_f$(%) MATH	WWC(%)	OMC STND (%)	OMC(RAPID) UNC.	OMC(RAPID) C'TED	MDD STND (Mg/m^3)	MDD(RAPID) UNC	MDD(RAPID) C'TED
M1-12-11	CL	2.4	1.4	2.3	11.0	11.0	0.2	14.5	13.3	13.5	1.7	1.7	1.7
DR-12-11	CL	3.7	1.3	1.8	9.3	9.3	0.2	11.0	11.1	11.3	1.9	1.9	1.9
DE-12-11	CL	2.9	1.1	1.3	9.0	8.8	0.1	11.0	10.3	10.3	1.9	1.9	1.9
P-12-11	CL	3.2	1.3	1.3	9.3	9.3	0.1	12.7	10.5	10.6	1.8	1.8	1.8
SH-12-11	CL	3.0	1.3	1.4	9.1	9.1	0.1	13.5	10.5	10.6	1.8	1.8	1.8
AE-12-11	SC	3.4	1.7	2.0	8.6	8.6	0.2	10.5	10.6	10.8	1.9	1.9	1.9
P-12-11	CL	2.4	1.9	1.7	8.4	8.9	0.2	12.2	10.1	10.3	1.7	1.8	1.8
S-12-11	CL	4.3	0.7	1.1	8.8	8.7	0.1	10.2	9.8	9.9	1.9	1.9	1.9
CC-21-11	CL	3.1	3.7	4.0	9.4	9.6	0.4	12.5	13.4	13.8	1.8	1.7	1.7
CHE-21-11	CL	3.2	3.9	5.0	9.3	9.3	0.5	12.3	14.3	14.8	1.8	1.8	1.8
FA-21-11	CL	2.6	4.9	4.6	9.2	9.3	0.4	14.5	13.8	14.2	1.8	1.8	1.8
KIL-21-11	CL	6.7	4.1	4.6	8.9	8.9	0.4	15.0	13.5	13.9	1.8	1.7	1.7
ICSA H2-21-11	CL	3.0	5.6	5.5	8.8	8.8	0.5	13.5	14.2	14.7	1.8	1.8	1.8
ICSA H1-21-11	CL	2.4	5.8	5.4	8.8	8.7	0.5	13.2	14.2	14.7	1.8	1.8	1.8
SCRS ADM1-21-11	CL	3.2	4.5	4.0	9.2	9.1	0.4	14.0	13.2	13.6	1.8	1.8	1.8
SCRS SS5-21-11	CL	3.7	3.1	3.7	9.4	9.3	0.3	12.0	13.1	13.4	1.8	1.8	1.8
CH-3-12	CL	2.5	2.7	2.9	8.6	8.6	0.2	12.2	11.5	11.7	1.8	1.8	1.8
B-3-12	CL	2.9	1.9	3.2	8.7	8.5	0.3	12.0	11.9	12.2	1.8	1.8	1.8
KIL 2-3-12	CL	3.3	2.4	3.3	8.4	8.5	0.3	11.5	11.7	12.0	1.8	1.8	1.8
FA-3-12	CL	2.7	4.9	6.3	8.9	8.8	0.6	13.5	15.2	15.8	1.8	1.8	1.8
KB-3-12	CL	2.3	2.4	2.9	9.0	8.9	0.3	12.0	11.9	12.2	1.8	1.8	1.8
CHE-3-12	CL	4.0	1.2	2.3	8.8	8.8	0.2	11.5	11.1	11.3	1.8	1.8	1.8
KIL 1-3-12	CL	2.7	4.0	4.2	8.2	8.2	0.3	13.0	12.4	12.7	1.8	1.8	1.8
CC-3-12	CL	3.3	4.4	5.0	8.9	9.0	0.4	13.0	13.9	14.3	1.8	1.8	1.8
B4 20 CH 14.3	SW	3.8	1.5	2.4	10.3	10.2	0.2	12.0	12.6	12.8	2.1	2.0	2.0
B4 18 CH 2.4	GP-GC	4.1	4.7	5.7	4.8	4.7	0.3	9.5	10.4	10.7	2.1	2.1	2.1
B4 19 CH 7.3	SP-SC	3.8	1.2	1.2	7.9	7.8	0.1	9.0	9.1	9.2	2.2	2.2	2.2
B4 20 CH 2.6	GP-GC	2.2	1.8	1.7	7.2	7.1	0.1	10.2	8.9	9.0	2.1	2.1	2.1
B4 22 CH 59.2	SC	3.8	2.7	4.1	11.9	11.8	0.5	17.5	16.0	16.5	1.8	1.8	1.8
B4 15 CH 1.3	SP-SC	3.0	1.4	2.1	8.1	9.0	0.2	12.5	10.2	10.4	2.0	1.9	1.9
B4 22 CH 43.25	GP	5.1	2.4	3.5	11.8	11.8	0.4	17.5	15.3	15.7	1.9	1.9	1.9
B4 27 CH 12.54	GC	2.1	1.0	0.9	11.0	11.2	0.1	12.3	11.9	12.0	2.0	1.9	1.9
B4 15 CH 7.2	SP-SC	2.2	0.6	0.6	9.9	10.4	0.1	11.0	10.5	10.6	2.1	2.0	2.0
B4 17 CH 5.30	SC	3.4	0.8	0.9	8.4	8.4	0.1	12.0	9.3	9.4	2.1	2.0	2.0
B4 27 CH 0.6	GC	2.7	1.1	1.2	11.2	11.0	0.1	12.2	12.4	12.5	2.0	1.9	1.9

UNIFIED SOIL CLASSIFICATION
INCLUDING IDENTIFICATION AND DESCRIPTION

FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights)				GROUP SYMBOLS (1)	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size (3)	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size (For visual classifications, the ¼" size may be used as equivalent)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; max size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information and symbol in parentheses. For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. EXAMPLE Silty sand, gravelly; about 20% hard, angular gravel particles ½ in. maximum size, rounded and subangular sand grains coarse to fine, about 15% non-plastic fines with low dry strength, well compacted and moist in place, alluvial sand, (SM)	Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP. More than 12% GM, GC, SM, SC. 5% to 12% Borderline cases requiring use of dual symbols. $C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3. Not meeting all gradation requirements for GW. Atterberg limits below "A" line, or PI less than 4. Atterberg limits above "A" line with PI greater than 7. Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols. $C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3. Not meeting all gradation requirements for SW. Atterberg limits below "A" line, or PI less than 4. Atterberg limits above "A" line with PI greater than 7. Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures		
			Plastic fines (for identification procedures see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures		
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size (For visual classifications, the ¼" size may be used as equivalent to the No. 4 sieve size)	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	SW	Well graded sands, gravelly sands, little or no fines		
			Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines		
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	SM	Silty sands, poorly graded sand-silt mixtures		
			Plastic fines (for identification procedures see CL below)	SC	Clayey sands, poorly graded sand-clay mixtures		
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye)	IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN NO. 40 SIEVE SIZE						
		DRY STRENGTH (Crushing Characteristics)	DILATANCY (Reaction to Shaking)	TOUGHNESS (Consistency near Plastic Limit)			
	SILTS AND CLAYS Liquid limit less than 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses. For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. EXAMPLE Clayey silt, brown; slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML)
		Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity	
	SILTS AND CLAYS Liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
		High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays	
		Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity	
HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel and frequently by fibrous texture				Pt	Peat and other highly organic soils	

Use grain size curve in identifying the fractions as given under field identification



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.

(2) All sieve sizes on this chart are U.S. Standard.

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Table 3 Summary of Unified Soil Classification System (adapted from U.S. Department of the Interior, Bureau of Reclamation, *Earth Manual*, Denver, 1963). (Schroeder) 27

Fig. 6 gives a pictorial view of the relationship between the Rapid and Standard Methods for the NMC, OMC and MDD values, based on the results of the graphical method.

All the compaction tests were conducted between November 12 1990 and March 22, 1991.

4.1.5 Organic Content

Any soil containing a sufficient amount of organic matter to influence its engineering properties is called an organic soil. The amount of organic matter is expressed in terms of the organic content, which is the ratio between the weight of organic matter and the ovendried weight of the sample. The weight of organic matter can be determined by heating the sample to ignite the organic substances. Natural soil deposits may contain a very small percentage of organic matter. Generally a relatively low percentage (as low as 2% in some cases) will contribute undesirable characteristics. In some special cases only a fraction of one percent may render the soil undesirable (Teng)[8].

Organic matter is derived principally from plant life and occasionally from animal remains. It is normally concentrated at depths less than 30cm but may be found at lower horizons due to leaching. The physical characteristics of a soil are not normally influenced by organic matter until its content rises above 2 - 4% (Henry)[9].

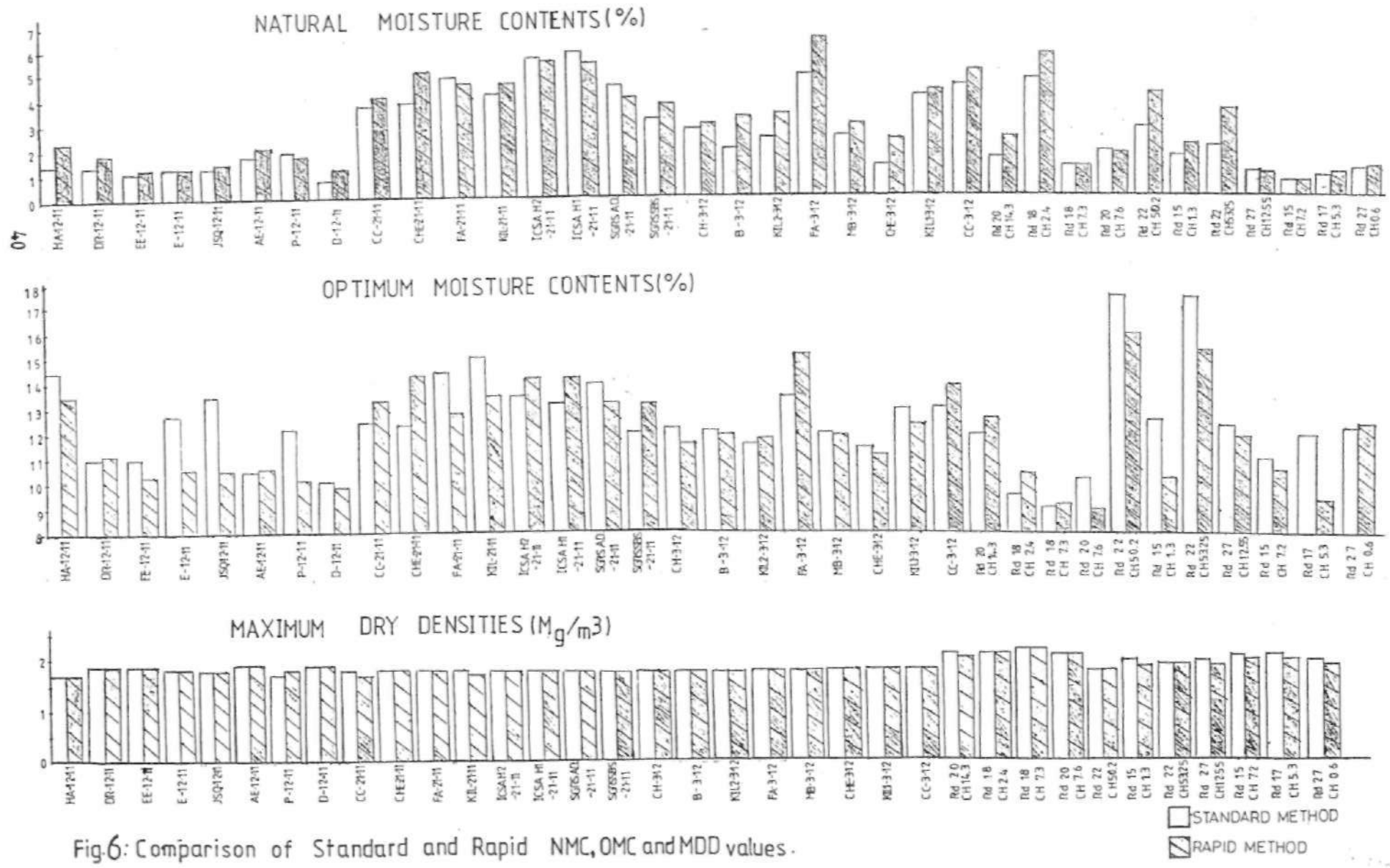


Fig.6: Comparison of Standard and Rapid NMC, OMC and MDD values.

The loss on Ignition method which was used to determine organic contents in this research, is based on the procedure given in Soil Mechanics for Road Engineers (TRRL, 1952).

$$\text{Loss on ignition} = \frac{W_2 - W_3}{W_2 - W_1} \times 100\%$$

Where W_1 = Weight of Crucible

W_2 = Weight of crucible containing the oven-dried soil (before ignition)

W_3 = Weight of crucible and soil (after ignition and cooling).

Report the result of organic matter content by loss on ignition as a percentage to the nearest 0.1%. This *method is suitable for soils which contain little or no* chalky material (Head)[2].

4.2 Results

Results of all tests conducted are tabulated in Table 2. It is noteworthy that the MDD determined for the various classes of soil fall within the ranges advocated by the Unified Soil Classification Systems shown in Table 4.

TABLE 4: COMPACTION CHARACTERISTICS AND RATINGS OF THE UNIFIED SOIL CLASSIFICATION CLASSES FOR SOIL CONSTRUCTION (Liu and Evett)[1]

CLASS	COMPACTION CHARACTERISTICS	STND. PROCTOR MDD(mg/m^3)	VALUE AS BASE COURSE
GW	Good: tractor. rubber tired. steel wheel. or vibratory roller	2.00-2.16	Good
GP	Good: tractor. rubber-tired. steel wheel. or vibratory roller	1.84-2.00	Poor to fair
GM	Good: rubber-tired. or light sheepfoot roller	1.92-2.16	Fair to poor
GC	Good: to fair: rubber-tired or sheepfoot roller	1.84-2.08	Good to fair
SW	Good: tractor. rubber-tired. or vibratory roller	1.76-2.08	Fair to poor
SP	Good: Tractor. rubber-tired. or vibratory roller	1.60-1.92	Poor
SM	Good: Rubber-tired or sheepfoot roller	1.76-2.00	Poor
SC	Good to fair rubber-tired. or sheepfoot roller	1.68-2.00	Fair to poor
ML	Good to poor: rubber-tired. or sheepfoot roller	1.52-1.92	Not suitable
CL	Good to fair: sheepfoot or rubber-tired roller	1.52-1.92	Not suitable
OL	Fair to poor: sheepfoot or rubber-tired roller	1.28-1.52	Not suitable
MH	Fair to poor: sheepfoot or rubber-tired roller	1.12-1.52	Not suitable
CH	Fair to poor: sheepfoot roller	1.28-.168	Not suitable
OH	Fair to poor: sheepfoot roller	1.04-1.60	Not suitable
PT	Not suitable	-	Not suitable

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 Wet Weight Correction

The following data was used to analyze the effect of the wet weight correction:

Sample 1: OMC (Uncorrected)
13.3,11.1,10.3,10.5,10.5,10.6,14.2,10.1,9.8,13.4,14.3,13.8,13.5,
14.2,13.2,13.1,11.5,11.9,11.7,15.2,11.9,11.1,12.4,13.9,12.6,
10.4,9.1,8.9,16.0,10.2,15.3,11.9,10.5,9.3,12.4

Sample 2: OMC (Corrected)
13.5,11.3,10.3,10.6,10.6,10.8,10.3,9.9,13.8,14.8,14.2,13.9,14.7,
14.7,13.6,13.4,11.7,12.2,12.0,15.8,12.2,11.3,12.7,14.3,12.8,
10.7,9.2,9.0,16.5,10.4,15.7,12.0,10.6,9.4,12.5

	Sample 1	Sample 2
Number of observation	$n_1 = 35$	$n_2 = 35$
Mean	$M_1 = 12.06$	$M_2 = 12.33$
Standard Deviation	$S_1 = 1.89$	$S_2 = 2.02$
Standard Error	$\frac{S_1}{\sqrt{n_1}} = 0.219$	$\frac{S_2}{\sqrt{n_2}} = 0341$

Standard Error of the difference between the means is

$$\sqrt{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)} = \sqrt{\left(\frac{1.89^2}{35} + \frac{2.02^2}{35}\right)} = 0.467$$

Test of hypotheses;

H_o: $(m_1 - m_2) = 0$, and samples are from the same population.

H_1: $(m_1 - m_2) \neq 0$, and the samples are from different

populations.

Since the mean of the individual differences is equal to the difference between the means ($m_1 - m_2$), if Sample 1 and Sample 2 both belong to the same population, then the mean of the differences should not differ significantly from zero - i.e.

$$\frac{m_1 - m_2}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} < 1.96$$

if the difference between the means is not to be significant at the 5% level of significance (Loveday[5], Spiegel[6])

$$\frac{m_1 - m_2}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}} = \frac{0.27}{0.467} = 0.578$$

thus we cannot reject the null hypothesis H_o. Therefore sample 1 and Sample 2 are from the same population so the effect of the wet weight correction has not been significant in this research.

5.2 Natural Moisture Contents

Sample 1: (Standard)	1.4,1.3,1.1,1.3,1.7,1.9,0.7,3.7,3.9,4.9,4.1, 5.6,5.8,4.5,3.1,2.7,1.9,2.4,4.9,2.4,1.2,4.0, 4.4,1.5,4.7,1.2,1.8,2.7,1.6,2.4,1.0,0.6,0.8,1.1
Sample 2: (Rapid)	2.3,1.8,1.3,1.3,1.4,2.0,1.7,1.1,4.0,5.0,4.6,5.5, 4.0,3.7,2.9,3.2,3.3,6.3,2.9,2.3,4.2,5.0,2.4,5.7, 1.2,1.7,4.1,2.1,3.5,0.9,0.6,0.9,1.2

	Sample 1 (Standard)	Sample 2 (Rapid)
Number of observation	$n_1 = 35$	$n_2 = 35$
Mean	$m_1 = 2.56$	$M_2 = 2.97$
Standard Deviation	$S_1 = 1.53$	$S_2 = 1.63$
Standard Error	$\frac{S_1}{\sqrt{n_1}} = 0.258$	$\frac{S_2}{\sqrt{n_2}} = 0.275$

Standard Error of the difference between the means is

$$\sqrt{(0.258^2 + 0.275^2)} = 0.377$$

Test of hypotheses;

H_o : $(M_1 - M_2) = 0$, and the differences are not significant.

H_1: $(M_1 - M_2) \neq 0$, and the differences are significant.

If H_o is not to be rejected at the 5% level of significance then.

$$\frac{m_1 - m_2}{\sqrt{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)}} < 1.96$$

$$\frac{2.56 - 2.97}{0.377} = 1.09 < 1.96$$

Thus we cannot reject the null hypothesis that the difference between the two samples are not significant. This implies that the natural moisture contents determined by the Rapid method are as good as those determined by the standard ovendrying method.

Regression analysis of the Standard values (Y) on the Rapid (x) gave the equation:

$$Y = -0.12 + 0.90X$$

with a coefficient of correlation $r = 0.95$. ($r^2 = 0.90$).

Testing the significance of the coefficient of correlation at the 0.1% level of significance, we have

H_o: $p = 0$, and the value $r = 0.95$ is due to chance

H_1: $p \neq 0$, and the value $r = 0.95$ is not due to chance

where p is the mean of the population of correlation coefficients.

$$\frac{r - o}{\frac{1}{\sqrt{(n - 1)}}} = 5.5 > 3.29,$$

thus we reject the null hypothesis H_o.

$\frac{1}{\sqrt{(n - 1)}}$ is the standard error of the coefficient of correlation (Yeomans)[28].

One can thus be at least 99.9% certain that the coefficient of correlation $r = 0.95$ is not due to chance.

Tests of significance were also carried out on the regression coefficients, $a = -0.12$ and $b = 0.90$, to determine whether they differ significantly from 0 and 1 respectively. This is because if the standard values (y) correlate perfectly with the rapid values (x), then the regression of y on x will give the equation $y = x$ -i.e. with zero intercept (a=o) and a slope of unity (b=1).

Test for b

H_o: B = 1 , and the difference between b = 0.90 and b = 1 is not significant.

H_1: B $\neq$ 1, and the difference between b = 0.90 and b =1 is significant.

The test statistic used is

$$t = \frac{(\hat{B}-1)\ Sx\ \sqrt{(n-1)}}{S_{Y/X}}$$

which has the t - distribution with n-2 degrees of freedom when Ho is true. B is the mean of the population of b values.

$S^2_{Y/X}$ is the sample estimate of the population variances and is given by

$$S^2_{Y/X} = \frac{(n-1)}{(n-2)} (S^2_Y - \hat{B}^2 S^2_X)$$

S^2_X is the sample variance of the X's and is given by

$$S^2_X = \left[\sum_1^n Xi_2 - \left(\sum_1^n X_i \right)/n \right] /n-1$$

Similarly the sample variance of the Y's ,S^2_y is given by

$$S^2_y = \left[\sum_1^n Y^2 i - \left(\sum_1^n Yi \right)/n \right] /n-1$$

$S^2_Y = 2.40$ $S^2_X = 2.64$ and $S^2_{Y/X} = 0.26$

$$t = \frac{(0.90-1)\ (\sqrt{2.64})\ (\sqrt{34})}{\sqrt{0.26}} = 1.86$$

Since 1.86 < $t_{33,0.975}$ = 2.035, the null hypothesis should not be rejected. (Kleinbaum and Kupper)[29].

Test for a

H_o A = o and the difference between a =-0.12 and a = o is not significant

H_1: A ≠ o,and the difference between a =-0.12 and a = o is significant.

The test statistic $$t = \frac{\hat{A} - o}{S_{y/x}\sqrt{\left(\frac{1}{n} + \frac{\bar{x}^2}{(n-1)\,S^2_x}\right)}}$$

has the t - distribution with n-2 degrees freedom when Ho is true.

A is the mean of the population of a values.

$$t = \frac{0.12 - 0}{\sqrt{0.26}\sqrt{\left(\frac{1}{35} + \frac{2.972^2}{34 \times 2.64}\right)}} = 0.66$$

Since 0.66 < $t_{33,0.975}$, the null hypothesis that the difference is not significant should not be rejected. (Kleinbaum and Kupper)[29].

5.3 Optimum Moisture Contents

Sample 1: (Standard)	14.5,11.0,12.7,13.5,12.2,10.2,12.5,12.3,14.5, 15.0,13.5,13.2,14.0,12.0,12.2,12.0,11.5,13.5, 12.0,11.5,13.0,13.0,12.0,9.5,9.0,10.2,17.5, 12.5,17.5,12.3,11.0,12.0,12.2
Sample 2: (Rapid)	13.3,11.1,10.3,10.5,10.5,10.6,10.1,9.8,13.4,14.4, 13.8,13.5,14.2,14.2,13.2,13.1,11.5,11.9,11.7,15.2, 11.9,11.1,12.4,13.9,12.6,10.4,9.1,8.9,16.0,10.2, 15.3,11.9,10.5,9.3,12.4

	Sample 1 (Standard)	Sample 2 (Rapid)
Number of observation	$n_1 = 35$	$n_2 = 35$
Mean	$M_1 = 12.49$	$M_2 = 12.06$
Standard deviation	$S_1 = 1.85$	$S_2 = 1.89$
Standard Error	$\frac{S_1}{\sqrt{n}} = 0.313$	$\frac{S_2}{\sqrt{n}} = 0.319$

Standard Error of the difference between the means is

$$\sqrt{(0.313^2 + 0.319^2)} = 0.447$$

Test of hypotheses,

H_o: $(M_1 - M_2) = 0$, and the observed differences are due to chance.

H_1: $(M_1 - M_2) \neq 0$, and the real differences exist between the two methods.

If the null hypothesis is not to be rejected at the 5% level of significance then:

$$\frac{12.49 - 12.06}{0.447} < 1.96$$

$$\frac{12.49 - 12.06}{0.447} = 0.96$$

Thus the null hypothesis cannot be rejected and the difference in OMC values, observed between the Standard and Rapid methods are only due to chance.

Regression analysis of the standard values (Y) on the Rapid (x) gave the equation

$$Y = 3.27 + 0.76X$$

with a coefficient of correlation $r = 0.78$ ($r^2 = 0.61$)

Test of significance on the coefficient of correlation revealed that one can be at least 99.9% certain that the coefficient of correlation r = 0.78, is not due to chance.

Tests of significance carried out on a = 3.27 and b = 0.76, however, showed that they differ significantly from a = o and b = 1 respectively.

To rectify this, the analysis was repeated with values for sample JSQ - 12-11 and Rd17CH5.30 removed from the data. This was because the difference between the Standard and Rapid OMC values for these two samples (-i.e 3% and 2.7%) were inconsistent with the general trend of about 0.5%. In other words, points for samples JSQ-12-11 and Rd17CH5.30 were outliers on the scatter diagram. With the two samples removed, the regression analysis gave the equation.

$$y = 2.23 + 0.84x$$

with coefficient of correlation r = 0.82 (r^2 = 0.67)

Test of significance carried out on the regression coefficients a = 2.23 and b = 0.84 revealed that they do not differ significantly from a = o and b = 1 respectively.

5.4 Maximum Dry Density

Sample 1: (Standard)	1.7,1.9,1.9,1.8,1.8,1.9,1.7,1.9,1.8,1.8,1.8, 1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8, 1.8, 1.8,1.8,2.1,2.1,2.2,2.1,1.8,2.0,1.9,2.0, 2.1,2.1,2.0
Sample 2: (Rapid)	1.7,1.9,1.9,1.8,1.8,1.9,1.8,1.9,1.7,1.8,1.8,1.7, 1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8, 1.8,2.0,2.1,2.2,2.1,1.8,1.9,1.9,2.0,2.0,1.9

	Sample 1 (standard)	Sample 2 (Rapid)
Number of observation	$n_1 = 35$	$n_2 = 35$
Mean	$M_1 = 1.88$	$M_2 = 1.86$
Standard deviation	$S_1 = 0.130$	$S_2 = 0.114$
Standard Error	$\frac{S_1}{\sqrt{n_1}} = 0.022$	$\frac{S_2}{\sqrt{n_2}} = 0.019$

Standard Error of the difference between the means is

$$\sqrt{(0.022^2 + 0.019^2)} = 0.029$$

Hypotheses:

H_o : $(M_1 - M_2) = 0$, and the samples are from the same population.

H_1 : $(M_1 - M_2) \neq 0$, and the samples are from different populations.

If the null hypothesis cannot be rejected at the 5% level of significance, then.

$$\frac{1.88 - 1.86}{0.029} = 0.69 < 1.96$$

Thus the differences between the Standard and Rapid MDD values are just due to chance, as such the Rapid Method determination of MDD is just as accurate as the Standard.

Regression analysis of the Standard values (y) on the Rapid (x) gave the equation

$$Y = 0.97 + 1.063X$$

with a coefficient of correlation $r = 0.93$. ($r^2 = 0.86$).

Test of significance on the coefficient of correlation revealed that one can be at least 99.9% certain that the coefficient of correlation $r = 0.93$, is not due to chance.

Tests of significance carried out on the regression coefficients $a = 0.097$ and $b = 1.063$ revealed that they do not differ significantly from $a = o$ and $b = 1$ respectively.

5.5 Soil Type

In section 5.3 and 5.4, it was proved that the Rapid Method determines the OMC and MDD just as accurately as the Standard, irrespective of the soil classification CL, SW, SP, SC, GP, and GC.

Even though the samples tested do not represent all the classes of soil of the Unified Soil Classification System, it is the author's opinion that if the Rapid Method works for CL soils it will equally work for all cohesive soils. Similarly if it works for GP, GC, SP, GW, and SC soils, then it will equally work for all granular soils.

5.6 Organic Contents

From Section 4.1.5, it was discovered that when the organic content is greater than 2 - 4%, then the physical properties of the soil are altered. It implies that the samples with organic content greater than 4% - i.e. D-12-11, KIL-21-11, Rd18CH2.4 and Rd22CH53.25 are liable to show a poor correlation between the Standard and Rapid values. Fig. 6, however, revealed that the above soil samples showed better correlation between the Standard and Rapid NMC,OMC, and MDD than some of the other samples with lower organic content. Hence no straightforward relationship was found between the organic content and the test results.

Head[2] lists the Infra-Red Cabinet, the Microwave Oven, Warm Air Blower and Electric Hot-plate as other methods of drying soils aside of the oven (Section 2.5)). However, they have generally not been recommended for moisture content determination because of the uncontrolled heating and uneven heat distribution. The above methods are very similar to the one used in the Rapid Method (i.e the Kerosene stove) thus it has the tendency to suffer the same setbacks. In the Rapid Method, however, the heating is not uncontrolled. The means of temperature control is by the use of the watchglass which is intermittently brought over the soil to check if all the moisture has evaporated or not. Since organic matter burns off at a far higher temperature (800^{o}C) than the boiling point of water (100^{o}C), and the temperature will not increase until all the water is gone,

if one ensures that the heating is just sufficient to drive out the water, the question of burning off organic matter will not arise. The other side of the matter is the uneven heat distribution which could cause temperature variation between, say the soil at the base of the tray and the top, resulting in local areas getting overheated. This problem is taken care of by stirring up the soil sample, ensuring that all parts of the soil get equally exposed to the source of heat. Thus the use of the watchglass combined with the stirring, will overcome the problems which could have otherwise made this method unsuitable for moisture content determination. It also follows that the accuracy of the moisture content value depends upon the accuracy of determining when all the moisture has evaporated and thus stopping the test, and the efficiency of stirring.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATION

With reference to Section 1.2 as regards the objectives of this research, it can be concluded that:

(1) The Rapid Method determines moisture contents just as accurately as the Standard Ovendrying method.

(2) The Rapid Method also determines OMC and MDD as accurately as the Standard Method.

(3) The Rapid Method showed no bias for the types of soils tested.

(4) Organic matter should not affect the results of the test if the soil is well-stirred and the heating is stopped as soon as the watchglass indicates that all the moisture has evaporated.

All these conclusions, however, have been reached based on the results of this research only, and since the evaluation of a significance test is much clearer when applied to a long series of similar situations (Lyon, [25] Moroney[3]) it is the author's recommendation that further research be carried out along this line, especially on the other classes of soils that were not tested in this research, to form a much stronger basis for conclusion.

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APPENDIX 1: CLASSIFICATION DETAILS

HA - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	96.11	91.72	79.83	63.54
L.L = 23.00%	P.L = 7.00%		P.I = 16.00%	
			Class:CL	

DR - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	86.71	85.01	72.55	60.19
L.L = 22.50%	P.L = 7.50%		P.I = 15.00%	
			Class:CL	

EE - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	80.60	76.88	66.32	52.79
L.L = 23.50%	P.L =6.50%		P.I = 17.00%	
			Class:CL	

E - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	80.70	77.66	68.16	55.51
L.L = 22.00%	P.L = 7.60%		P.I = 14.40%	
			Class:CL	

JSQ - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	91.52	90.36	83.01	69.33
L.L = 25.00%	P.L = 7.50%		P.I = 17.50%	
			Class:CL	

AE - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	78.17	72.13	61.50	49.75
L.L = 24.30%	P.L = 10.50%		P.I = 13.80%	
			Class:SC	

P - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	97.78	97.25	92.10	81.24
L.L = 23.50%	P.L = 8.00%		P.I = 15.50%	
			Class:CL	

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APPENDIX 1: CLASSIFICATION DETAILS (cont'd)

D - 12 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	84.98	80.51	68.92	56.12	
L.L = 22.00%	P.L = 6.70%		P.I = 15.30%		Class: CL

CC - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	100	98.93	89.07	78.56	
L.L = 20.50%	P.L = 5.50%		P.I = 15.00%		Class: CL

CHE - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	99.16	98.18	89.26	79.17	
L.L = 22.00%	P.L = 5.50%		P.L = 16.50%		Class: CL

FA - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	100	99.28	90.81	79.63	
L.L = 22.00%	P.L = 5.10%		P.I = 16.90%		Class: CL

KIL - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	100	99.64	90.76	78.87	
L.L = 20.50%	P.L = 6.70%		P.I = 13.80%		Class: CL

KSA HS - 21 -11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	100	100	91.51	76.77	
L.L = 21.00%	P.L = 6.50%		P.I. = 14.50%		Class: CL

KSA H1 - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	99.81	99.49	90.64	74.51	
L.L = 22.00%	P.L = 5.50%		P.I =16.50%		Class: CL

SGRS ADMIN - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075	
Passing(%)	98.52	97.85	89.22	76.22	
L = 23.00%	P.L = 6.70%		P.I = 16.30%		Class: CL

APPENDIX 1: CLASSIFICATION DETAILS (con't)

SGRS SBS - 21 - 11

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	95.69	94.29	84.00	68.86
L.L = 23.50%	P.L = 6.50%		P.I = 17.00%	
			Class:CL	

CH - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	98.47	97.95	89.00	74.80
L.L = 21.00%	P.L = 6.70%		P.I = 14.30%	
			Class:CL	

B - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	100	99.68	90.23	75.71
L.L = 22.00%	P.L = 7.60%		P.I = 14.40%	
			Class:CL	

KIL2 - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	100	99.51	89.45	72.10
L.L = 21.50%	P.L = 7.00%		P.I = 14.50%	
			Class:CL	

FA - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	100	99.04	89.04	77.07
L.L = 25.00%	P.L = 6.10%		P.I = 18.90%	
			Class:CL	

MB - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	100	99.24	90.42	78.82
L.L = 20.00%	P.L = 6.20%		P.I = 13.80%	
			Class:CL	

CHE - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	100	99.39	90.18	85.47
L.L = 24.50%	P.L = 7.00%		P.I = 17.50%	
			Class:CL	

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APPENDIX 1: CLASSIFICATION DETAILS (con't)

KIL1 - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	100	99.70	90.30	74.79

L.L = 20.00% P.L = 6.50% P.I = 13.50%

Class:CL

CC - 3 - 12

Sieve Sizes(mm)	4.75	2.00	0.425	0.075
Passing(%)	99.09	98.39	89.55	76.66

L.L = 25.00% P.L = 6.20% P.I = 18.80%

Class:CL

Rd20CH14.3

Sieve Sizes(mm)	25.4	4.75	2.00	0.425	0.075
Passing(%)	100	64.44	30.70	8.51	2.79

D_{60} = 4.5mm D_{30} = 1.9mm D_{10} = 0.48mm

$Cu = \frac{D_{60}}{D_{10}} = 9.38$ $Cc = (D_{30})^2/(D_{60} \times D_{10}) = 1.67$

Class: SW

IBRAHIM IBRAHIM RECEIVED

APPENDIX 1: CLASSIFICATION DETAILS (con't)

Rd18CH 2.4

Sieve Sizes(mm)	50.8	25.4	12.7	4.57	2.00	0.425	0.075
Passing(%)	100	80.50	65.00	34.33	21.32	12.62	5.88

Cu = 55; Cc = 6.9

L.L = 31.00% P.L = 13.00% P.I = 18.00% Class; GP - GC

Rd18CH 7.3

Sieve Sizes(mm)	20.00	6.35	4.75	2.00	0.425	0.075
Passing(%)	100	70.50	58.49	33.31	16.64	5.67

Cu = 30.3; Cc = 3.5;

L.L = 22.67%; P.L = 9.52%; P.I = 13.15%: Class SP - SC

Rd20CH2.6

Sieve Sizes(mm)	20.00	10.00	4.75	2.00	0.425	0.075
Passing(%)	100	63.00	47.08	32.59	18.84	5.54

Cu = 70.8; Cc = 3.00;

L.L = 27.07%; P.L = 16.20%; P.I = 10.87%; Class; GP - GC

Rd22CH50.2

Sieve Sizes(mm)	12.70	4.75	2.00	0.425	0.075
Passing(%)	100	59.20	41.86	31.96	23.54

L.L = 28.00% P.L = 10.00% P.I = 18.00% Class; SC

Rd15CH1.3

Sieve Sizes(mm)	12.70	4.75	2.00	0.425	0.075
Passing(%)	100	58.44	28.55	17.63	11.25

Cu = 63; Cc = 14.55;

L.L = 32.79% P.L = 7.80% P.I = 24.99% Class; SP - SC

Rd22CH 53.25

Sieve Sizes(mm)	20	10	4.75	2.00	0.425	0.075
Passing(%)	100	64.50	49.20	35.00	19.50	4.50

Cu = 57; Cc = 3.1; Class; GP

APPENDIX 1: CLASSIFICATION DETAILS (con't)

Rd27CH12.55

Sieve Sizes(mm)	25.4	10	4.75	2.00	0.425	0.075
Passing(%)	100	62.00	33.31	26.62	20.56	16.50
L.L = 33.42%	P.L = 9.40%		P.I = 24.02%		Class; GC	

Rd15CH7.2

Sieve Sizes(mm)	25.4	10	4.75	2.00	0.425	0.075
Passing(%)	100	62.25	29.32	18.96	12.15	8.62
Cu = 80%;	Cc = 13.8;					
L.L = 32.79%	P.L = 7.8%		P.I = 24.99%		Class; GP - GC	

Rd15CH5.3

Sieve Sizes(mm)	20	4.75	2.00	0.425	0.075
Passing(%)	100	57.20	47.42	34.29	20.32
L.L = 24.53%	P.L = 11.86%		P.I = 12.67%		Class; SC

Rd27CH0.6

Sieve Sizes(mm)	25.4	10	4.75	2.00	0.425	0.075
Passing(%)	100	75.00	43.37	29.55	20.74	17.72
L.L = 34.18%	P.L = 8.70%		P.I = 25.48%		Class; GC	

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APPENDIX II: NATURAL MOISTURE CONTENTS DETAILS

	STND (OVEN DRYING) DETAILS				RAPID METHOD (KEROSENE STOVE)			
SAMPLE NO.	M_2	M_3	M_1	AVE.W	M_2	M_3	M_1	AVE.W
HA-12-11	56.80	56.27	20.40	1.4	256.60	252.40	82.65	2.3
	48.50	48.15	21.15		226.30	223.10	65.45	
DR-12-11	55.45	55.00	20.50	1.30	276.55	272.70	82.55	1.8
	55.00	54.55	19.55	1.30	243.80	241.00	65.80	
EE-12-11	62.35	61.90	20.70	1.1	257.70	255.85	82.65	1.3
	57.30	56.90	20.75		267.80	264.90	65.45	
E-12-11	59.75	59.25	20.95	1.3	281.15	278.50	82.65	1.3
	50.50	50.15	23.15		203.50	201.85	65.45	
JSQ-12-11	52.10	51.60	14.45	1.3	293.20	290.50	82.55	1.4
	59.75	59.30	21.17		201.90	200.00	65.80	
AE-12-11	62.30	61.60	20.75	1.7	251.80	248.55	82.55	2.0
	60.00	59.30	18.00		219.10	216.15	65.80	
P-12-11	54.85	54.10	14.47	1.9	258.20	255.50	82.65	1.7
	59.00	58.30	21.15		185.90	183.70	65.45	
D-12-11	56.30	56.05	20.60	0.7	296.80	294.20	82.65	1.1
	56.00	55.75	20.10		252.10	250.35	65.45	
CHE-21-11	50.60	48.95	8.70	3.9	258.35	249.70	84.70	5.0
	42.90	41.70	8.60		236.30	229.30	84.70	
FA-21-11	45.05	43.25	8.30	4.9	254.70	247.35	84.70	4.6
	57.85	55.65	8.30		259.50	251.70	84.70	
KIL-21-11	56.49	54.30	8.60	4.1	253.90	246.50	84.70	4.6
	51.90	50.50	8.35		257.70	250.15	84.70	
ICSA H2-21-11	53.70	51.25	8.50	5.6	257.85	248.50	84.70	5.5
	48.15	46.10	8.35		254.10	245.65	84.70	
ICSA H1-21-11	57.20	54.60	8.27	5.8	257.20	248.45	84.70	5.4
	53.23	50.70	8.50		251.20	242.60	84.70	

APPENDIX II: NATURAL MOISTURE CONTENTS DETAILS (con't)

	STND (OVEN DRYING) DETAILS				RAPID METHOD (KEROSENE STOVE)			
SAMPLE NO.	M_2	M_3	M_1	Ave. W	M_2	M_3	M_1	Ave.W
SA-21-11	47.90	46.20	8.40	4.5	254.50	248.35	84.70	4.0
	55.00	53.00	8.20		221.50	215.10	66.40	
SS-21-11	56.75	55.45	8.50	3.1	255.35	249.00	84.70	3.7
	57.38	55.75	8.50		259.65	253.70	84.70	
CH-3-12	67.67	65.50	8.78	2.7	302.10	295.85	81.70	2.9
	64.30	63.00	8.50		260.60	255.20	66.45	
	56.80	55.90	8.30					
B-3-12	54.90	53.90	8.18					
	64.66	63.75	8.69	1.9	308.90	302.45	81.70	3.2
	60.65	59.70	8.16		254.10	247.91	66.45	
KIL-2-3-12	64.90	63.62	8.17					
	56.95	55.75	8.10	2.4	323.37	315.55	81.70	3.3
	53.05	52.00	8.60		233.60	228.50	66.45	
FA-3-12	63.55	61.07	8.31					
	55.80	53.70	9.00	4.9	243.30	233.70	81.70	6.3
	61.40	58.85	8.40		194.70	187.10	66.45	
MB-3-12	68.70	67.50	8.07					
	58.65	57.35	8.59	2.4	356.85	348.80	81.70	2.9
	64.41	63.05	8.40		240.64	235.80	66.45	
CHE-3-12	65.75	65.05	8.30					
	68.30	67.68	8.25	1.2	313.10	308.70	81.70	2.3
	57.85	57.30	8.18		228.40	224.20	66.45	
KIL-1-3-12	62.10	60.05	8.10					
	51.89	50.30	8.45	4.0	306.35	297.10	81.70	4.2
	54.23	52.35	8.13		254.60	247.35	66.45	
CC-3-12	72.88	70.20	8.20					
	47.90	46.25	8.95	4.4	322.20	310.60	81.70	5.0
	51.80	49.75	5.00		230.20	222.40	66.45	

APPENDIX II: NATURAL MOISTURE CONTENTS DETAILS (con't)

	STND (OVEN DRYING) DETAILS				RAPID METHOD (KEROSENE STOVE)			
SAMPLE NO.	M_2	M_3	M_1	Ave. W	M_2	M_3	M_1	Ave.W
Rd 20 CH 14.3	65.03	64.15	8.15	1.5	321.80	316.25	81.80	2.4
	60.60	59.90	8.10		320.00	314.45	79.50	
Rd 18 CH 2.4	39.30	37.80	7.95	4.7	238.40	229.65	81.80	5.7
	36.45	35.25	7.90		165.35	160.25	65.35	
Rd 18 CH 7.3	58.40	57.80	8.15	1.2	296.00	293.35	81.80	1.2
	59.50	58.90	7.85		236.80	234.80	65.35	
Rd 20 CH 2.6	79.35	78.10	8.15	1.8	265.75	262.80	81.80	1.7
	82.45	81.15	8.00		259.80	256.55	65.35	
Rd 22 CH 50.2	66.55	64.97	8.00	2.7	261.35	254.58	81.80	4.1
	68.00	66.50	8.10		205.15	199.45	65.35	
Rd 15 CH 1.3	85.15	84.10	20.67	1.6	289.20	284.70	81.80	2.1
	94.05	93.00	20.65		175.80	173.60	65.35	
Rd 22 CH 53.25	87.68	85.75	7.95	2.4	297.80	290.90	81.80	3.5
	78.50	76.85	8.10		234.26	228.25	65.35	
Rd 27 CH 12.55	67.90	67.35	8.00	1.0	296.30	294.30	81.80	0.9
	76.20	75.55	8.15		282.65	280.93	65.35	
Rd 15 CH 7.2	98.05	97.60	20.90	0.6	332.75	331.05	81.80	0.6
	98.20	97.70	20.85		288.20	287.00	65.35	
Rd 17 CH 5.30	80.80	80.10	7.90	0.8	306.35	304.05	81.80	0.9
	82.12	81.65	8.00		227.90	226.63	65.35	
Rd 27 CH 0.6	81.80	81.17	20.90	1.1	272.15	269.82	81.80	1.2
	81.80	81.17	20.90		230.60	228.70	65.35	

APPENDIX III: ORGANIC CONTENT DETAILS

Sample No.	W_1	W_2	W_3	Organic Content (%)
HA-12-11	78.40	96.60	99.10	2.4
DR-12-11	78.40	98.85	98.10	3.7
EE-12-11	78.40	98.90	98.30	2.9
E-12-11	78.40	98.30	97.67	3.2
JSQ-12-11	78.40	98.70	98.10	3.0
AE-12-11	78.40	99.00	98.30	3.4
P-12-11	78.40	99.30	98.80	2.4
D-12-11	78.40	98.36	97.50	4.3
CC-21-11	78.40	98.60	97.98	3.1
CHE-21-11	78.40	98.45	97.80	3.2
FA-21-11	78.40	98.60	98.07	2.6
KIL-21-11	78.40	99.90	98.46	6.7
ICSA H2-21-11	78.40	99.27	98.65	3.0
ICSA H1-21-11	78.40	99.15	98.65	2.4
SGRS ADMIN -21-11	78.40	98.95	98.30	3.2
SGRS SBS-21-11	78.40	99.40	98.62	3.7
CH-3-12	78.40	99.60	98.90	3.3
B-3-12	78.40	98.60	98.01	2.9
KIL-2-3-12	78.40	98.97	98.29	3.3
FA-3-12	78.40	99.10	98.55	2.7
MB-3-12	78.48	98.30	97.85	2.3
CHE-3-12	78.40	98.55	97.75	4.0
KIL 1-3-12	78.40	99.00	98.45	2.7
CC-3-12	78.40	99.60	98.90	3.3
Rd 20 CH 14.3	78.40	98.48	97.72	3.8
Rd 18 CH 2.4	78.40	99.35	98.50	4.1
Rd 18 CH 7.3	78.40	99.30	98.50	3.8
Rd 20 CH 2.6	78.40	98.90	98.44	2.2
Rd 22 CH 50.2	78.40	99.50	98.70	3.8
Rd 15 CH 1.3	78.40	99.50	98.68	3.9
Rd 22 CH 53.25	78.40	98.85	97.80	5.1
Rd 27 CH 12.55	78.40	99.50	98.70	3.7
Rd 15 CH 7.2	78.40	98.90	98.45	2.2
Rd 17 CH 5.3	78.40	99.21	98.50	3.4
Rd 27 CH 0.6	78.40	99.32	98.75	2.7

APPENDIX IV: COMPACTION DETAILS.

HA-12-11

Standard Method						Rapid Method			
W(%)	1.30	5.91	8.25	11.25	15.34	18.25	W'(%)	0	+9	+16
Pb(g/cc)	1.51	1.63	1.78	1.90	2.01	1.99	Pb(g/cc)	1.51	1.90	1.99
Pd(g/cc)	1.49	1.54	1.65	1.71	1.74	1.68	Pd'(g/cc)	1.51	1.75	1.71

DR-12-11

Standard Method						Rapid Method			
W(%)	1.30	5.65	10.81	14.57	19.81	W'(%)	0	+9	+18
Pb(g/cc)	1.61	1.75	2.07	2.08	1.95	Pb(g/cc)	1.61	2.07	1.93
Pd(g/cc)	1.59	1.65	1.87	1.82	1.63	Pd'(G/cc)	1.61	1.90	1.65

EE-12-11

Standard Method						Rapid Method			
W(%)	1.00	5.07	10.09	14.27	18.09	W'(%)	0	+9	+17
Pb(g/cc)	1.66	1.78	2.12	2.15	1.99	Pb(g/cc)	1.66	2.12	1.99
Pd(g/cc)	1.64	1.69	1.93	1.88	1.68	Pd'(g/cc)	1.66	1.95	1.70

E-12-11

Standard Method						Rapid Method			
W(%)	1.00	5.20	10.00	14.02	19.45	W'(%)	0	+8	+16
Pb(g/cc)	1.58	1.72	1.96	2.06	1.97	Pb(g/cc)	1.58	1.98	1.97
Pd(g/cc)	1.56	1.63	1.78	1.81	1.65	Pd'(g/cc)	1.58	1.83	1.70

JSQ-12-11

Standard Method						Rapid Method			
W(%)	1.00	4.87	11.86	14.05	19.25	W'(%)	0	+8	+16
Pb(g/cc)	1.61	1.72	2.00	2.06	1.98	Pb(g/cc)	1.61	2.00	1.98
Pd(g/cc)	1.60	1.64	1.79	1.81	1.66	Pd'(g/cc)	1.61	1.85	1.71

AE-12-11

Standard Method						Rapid Method			
W(%)	1.32	5.96	9.96	14.00	20.06	W'(%)	0	+8	+16
Pb(g/cc)	1.65	1.78	2.07	2.09	2.00	Pb(g/cc)	1.65	2.07	2.00
Pd(g/cc)	1.63	1.68	1.88	1.84	1.66	Pd'(g/cc)	1.65	1.92	1.72

APPENDIX IV: COMPACTION DETAILS (con't)

P-12-11

Standard Method						Rapid Method			
W(%)	1.47	6.00	12.87	15.37	19.81	W'(%)	0	+8	+16
Pb(g/cc)	1.60	1.75	1.99	1.96	1.96	Pb(g/cc)	1.60	1.99	1.96
Pd(g/cc)	1.58	1.65	1.77	1.70	1.63	Pd'(g/cc)	1.60	1.84	1.69

D-12-11

Standard Method						Rapid Method			
W(%)	0.50	5.00	9.09	12.20	17.08	W'(%)	0	+8	+16
Pb(g/cc)	1.67	1.87	2.03	2.07	2.01	Pb(g/cc)	1.67	2.03	2.01
Pd(g/cc)	1.66	1.78	1.86	1.85	1.71	Pd'(g/cc)	1.67	1.88	1.73

CC-12-11

Standard Method						Rapid Method			
W(%)	1.50	6.00	9.94	16.60	21.39	W'(%)	0	+7	+14
Pb(g/cc)	1.60	1.75	1.92	2.00	1.98	Pb(g/cc)	1.60	1.92	2.00
Pd(g/cc)	1.58	1.65	1.75	1.72	1.63	Pd'(g/cc)	1.60	1.79	1.76

CHE-21-11

Standard Method						Rapid Method			
W(%)	1.80	7.00	11.75	14.00	18.72	W'(%)	0	+8	+16
Pb(g/cc)	1.59	1.78	1.98	2.01	1.98	Pb(g/cc)	1.59	1.98	1.98
Pd(g/cc)	1.57	1.66	1.77	1.76	1.67	Pd'(g/cc)	1.59	1.84	1.71

FA-21-11

Standard Method						Rapid Method			
W(%)	1.50	8.00	12.05	14.00	19.52	W'(%)	0	+8	+16
Pb(g/cc)	1.57	1.80	1.97	2.03	1.97	Pb(g/cc)	1.57	1.97	1.97
Pd(g/cc)	1.54	1.66	1.76	1.78	1.65	Pd(g/cc)	1.57	1.83	1.70

KIL-21-11

Standard Method						Rapid Method			
W(%)	2.01	7.00	12.73	16.00	20.33	W'(%)	0	+8	+16
Pb(g/cc)	1.60	1.72	1.96	2.04	1.95	Pb(g/cc)	1.60	1.96	1.95
Pd(g/cc)	1.57	1.61	1.74	1.76	1.62	Pd'(g/cc)	1.60	1.81	1.68

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APPENDIX IV: COMPACTION DETAILS (con't)

ICSA H2-21-11

Standard Method						Rapid Method			
W(%)	2.00	8.00	12.58	14.00	20.16	W'(%)	0	+8	+16
Pb(g/cc)	1.58	1.75	2.01	2.03	1.94	Pb(g/cc)	1.58	2.01	1.94
Pd(g/cc)	1.55	1.62	1.78	1.78	1.62	Pd'(%)	1.58	1.86	1.67

ICSA H1-21-11

Standard Method						Rapid Method			
W(%)	2.00	1.75	12.18	16.00	21.46	W'(%)	0	+8	+16
Pb(g/cc)	1.57	1.73	2.04	2.04	1.94	Pb(g/cc)	1.57	2.04	1.94
Pd(g/cc)	1.54	1.61	1.82	1.78	1.59	Pd'(g/cc)	1.57	1.89	1.67

SGRS ADMN-21-11

Standard Method						Rapid Method			
W(%)	1.79	8.05	12.21	16.02	19.53	W'(%)	0	+8	+16
Pb(g/cc)	1.56	1.75	1.98	2.04	1.95	Pb(g/cc)	1.56	1.98	1.95
Pd(g/cc)	1.53	1.62	1.76	1.76	1.63	Pd'(g/cc)	1.56	1.83	1.68

SGRS SBS-21-11

Standard Method						Rapid Method			
W(%)	1.70	7.02	11.28	14.00	18.90	W'(%)	0	+8	+16
Pb(g/cc)	1.57	1.73	1.96	1.99	1.96	Pb(g/cc)	1.57	1.96	1.96
Pd(g/cc)	1.54	1.61	1.76	1.74	1.65	Pd'(g/cc)	1.57	1.81	1.69

CH-3-12

Standard Method						Rapid Method			
W(%)	1.31	6.00	11.36	14.96	19.62	W'(%)	0	+8	+16
Pb(g/cc)	1.66	1.81	2.01	2.05	1.98	Pb(g/cc)	1.66	2.01	1.98
Pd(g/cc)	1.64	1.71	1.80	1.78	1.66	Pd'(g/cc)	1.66	1.86	1.71

B-3-12

Standard Method						Rapid Method			
W(%)	1.00	6.35	11.68	14.40	19.27	W'(%)	0	+8	+16
Pb(g/cc)	1.66	1.82	2.03	2.06	2.00	Pb(g/cc)	1.66	2.03	2.00
Pd(g/cc)	1.64	1.71	1.82	1.80	1.67	Pd'(g/cc)	1.66	1.88	1.72

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KIL2-3-12

Standard Method						Rapid Method			
W(%)	1.80	6.51	11.88	14.68	19.42	W'(%)	0	+8	+16
Pb(g/cc)	1.65	1.83	2.02	2.02	1.98	Pb(g/cc)	1.65	2.02	1.98
Pd(g/cc)	1.62	1.71	1.81	1.76	1.66	Pd'(g/cc)	1.65	1.87	1.70

FA-3-12

Standard Method						Rapid Method			
W(%)	1.70	8.05	13.00	16.02	21.65	W'(%)	0	+8	+16
Pb(g/cc)	1.62	1.75	2.03	2.04	1.98	Pb(g/cc)	1.62	2.03	1.98
Pd(g/cc)	1.60	1.62	1.80	1.76	1.63	Pd'(g/cc)	1.62	1.88	1.71

MB-3-12

Standard Method						Rapid Method			
W(%)	2.00	6.20	10.81	13.40	19.47	W'(%)	0	+8	+16
Pb(g/cc)	1.63	1.79	2.00	2.04	1.98	Pb(g/cc)	1.63	2.00	1.98
Pd(g/cc)	1.60	1.68	1.80	1.80	1.66	Pd'(g/cc)	1.63	1.85	1.71

CHE-3-12

Standard Method							Rapid Method			
W(%)	1.18	4.50	8.66	12.50	18.02	20.88	W'(%)	0	+8	+16
Pb(g/cc)	1.65	1.78	1.94	2.02	2.01	1.97	Pb(g/cc)	1.65	1.94	1.97
Pd(g/cc)	1.63	1.70	1.78	1.79	1.70	1.63	Pd'(g/cc)	1.65	1.79	1.70

KIL1-3-12

Standard Method						Rapid Method			
W(%)	1.41	6.14	11.51	14.00	19.19	W'(%)	0	+8	+16
Pb(g/cc)	1.63	1.77	2.02	2.06	1.96	Pb(g/cc)	1.63	2.02	1.96
Pd(g/cc)	1.61	1.67	1.81	1.81	1.65	Pd'(g/cc)	1.63	1.87	1.65

CC-3-12

Standard Method						Rapid Method			
W(%)	2.26	6.00	12.17	14.16	19.92	W'(%)	0	+8	+16
Pb(g/cc)	1.62	1.74	2.06	2.08	2.01	Pb(g/cc)	1.62	2.06	2.01
Pd(g/cc)	1.58	1.65	1.83	1.82	1.67	Pd'(g/cc)	1.62	1.90	1.73

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APPENDIX IV: COMPACTION DETAILS (con't)

Rd20CH14.3

Standard Method						Rapid Method			
W(%)	1.40	4.53	9.09	12.50	14.94	W'(%)	0	+8	+16
Pb(g/cc)	1.99	2.24	2.24	2.34	2.33	Pb(g/cc)	1.86	2.24	2.33
Pd(g/cc)	1.83	1.91	2.05	2.08	2.03	Pd'(g/cc)	1.86	2.07	2.01

Rd18CH2.4

Standard Method					Rapid Method			
W(%)	1.36	4.71	9.76	13.19	W'(%)	0	+4	+8
Pb(g/cc)	1.90	2.00	2.26	2.26	Pb(g/cc)	2.00	2.26	2.26
Pd(g/cc)	1.87	1.91	2.06	1.99	Pd'(g/cc)	2.00	2.17	2.09

Rd18CH7.3

Standard Method					Rapid Method			
W(%)	1.20	5.42	8.91	11.60	W'(%)	0	+8	+12
Pb(g/cc)	1.90	2.03	2.35	2.35	Pb(g/cc)	1.90	2.35	2.35
Pd(g/cc)	1.87	1.92	2.16	2.11	Pd'(g/cc)	1.90	2.18	2.10

Rd20CH2.6

Standard Method						Rapid Method			
W(%)	1.79	4.37	7.00	10.61	12.32	W'(%)	0	+9	+12
Pb(g/cc)	1.98	2.04	2.16	2.31	2.31	Pb(g/cc)	1.98	2.31	2.31
Pd(g/cc)	1.94	1.95	2.02	2.09	2.06	Pd'(g/cc)	1.98	2.12	2.06

Rd22CH50.2

Standard Method						Rapid Method			
W(%)	2.67	7.86	13.00	18.25	23.92	W'(%)	0	+15	+20
Pb(g/cc)	1.65	1.83	1.98	2.16	2.14	Pb(g/cc)	1.65	2.16	2.14
Pd(g/cc)	1.60	1.70	1.75	1.83	1.73	Pd'(g/cc)	1.65	1.88	1.78

Rd15CH1.3

Standard Method						Rapid Method			
W(%)	1.56	5.64	9.59	13.58	17.51	W'(%)	0	+8	+16
Pb(g/cc)	1.76	1.89	2.14	2.24	2.15	Pb(g/cc)	1.76	2.14	2.15
Pd(g/cc)	1.73	1.79	1.95	1.97	1.83	Pd'(g/cc)	1.76	1.98	1.85

APPENDIX IV: COMPACTION DETAILS (con't)

Rd22 CH53.25

Standard Method						Rapid Method			
W(%)	2.04	6.88	10.05	13.74	18.84 20.97	W'(%)	0	+16	+20
Pb(g/cc)	1.69	1.80	1.96	2.10	2.24 2.20	Pb(g/cc)	1.69	2.24	2.20
Pd(g/cc)	1.66	1.69	1.78	1.84	1.88 1.82	Pd'(g/cc)	1.69	1.93	1.83

Rd27 CH12.55

Standard Method						Rapid Method			
W(%)	0.95	5.02	9.23	12.65	15.77	W'(%)	0	+8	+16
Pb(g/cc)	1.78	1.94	2.09	2.26	2.23	Pb(g/cc)	1.76	2.09	2.23
Pd(g/cc)	1.76	1.85	1.91	2.01	1.92	Pd'(g/cc)	1.76	1.94	1.92

Rd15 CH7.2

Standard Method						Rapid Method			
W(%)	0.62	5.30	8.52	11.28	12.70	W'(%)	0	+8	+14
Pb(g/cc)	1.84	1.97	2.16	2.34	2.30	Pb(g/cc)	1.84	2.16	2.30
Pd(g/cc)	1.82	1.87	1.99	2.11	2.04	Pd'(g/cc)	1.84	2.00	1.98

Rd17 CH5.30

Standard Method						Rapid Method			
W(%)	0.80	4.51	9.34	12.57	14.25	W'(%)	0	+8	+14
Pb(g/cc)	1.88	1.99	2.20	2.31	2.25	Pb(g/cc)	1.88	2.20	2.25
Pd(g/cc)	1.86	1.90	2.02	2.05	1.97	Pd'(g/cc)	1.88	2.04	1.97

Rd27 CH0.6

Standard Method						Rapid Method			
W(%)	1.05	4.88	8.57	13.31	16.65	W'(%)	0	+8	+16
Pb(g/cc)	1.68	1.84	2.04	2.21	2.16	Pb(g/cc)	1.68	2.04	2.16
Pd(g/cc)	1.67	1.75	1.88	1.95	1.85	Pd'(g/cc)	1.68	1.89	1.86

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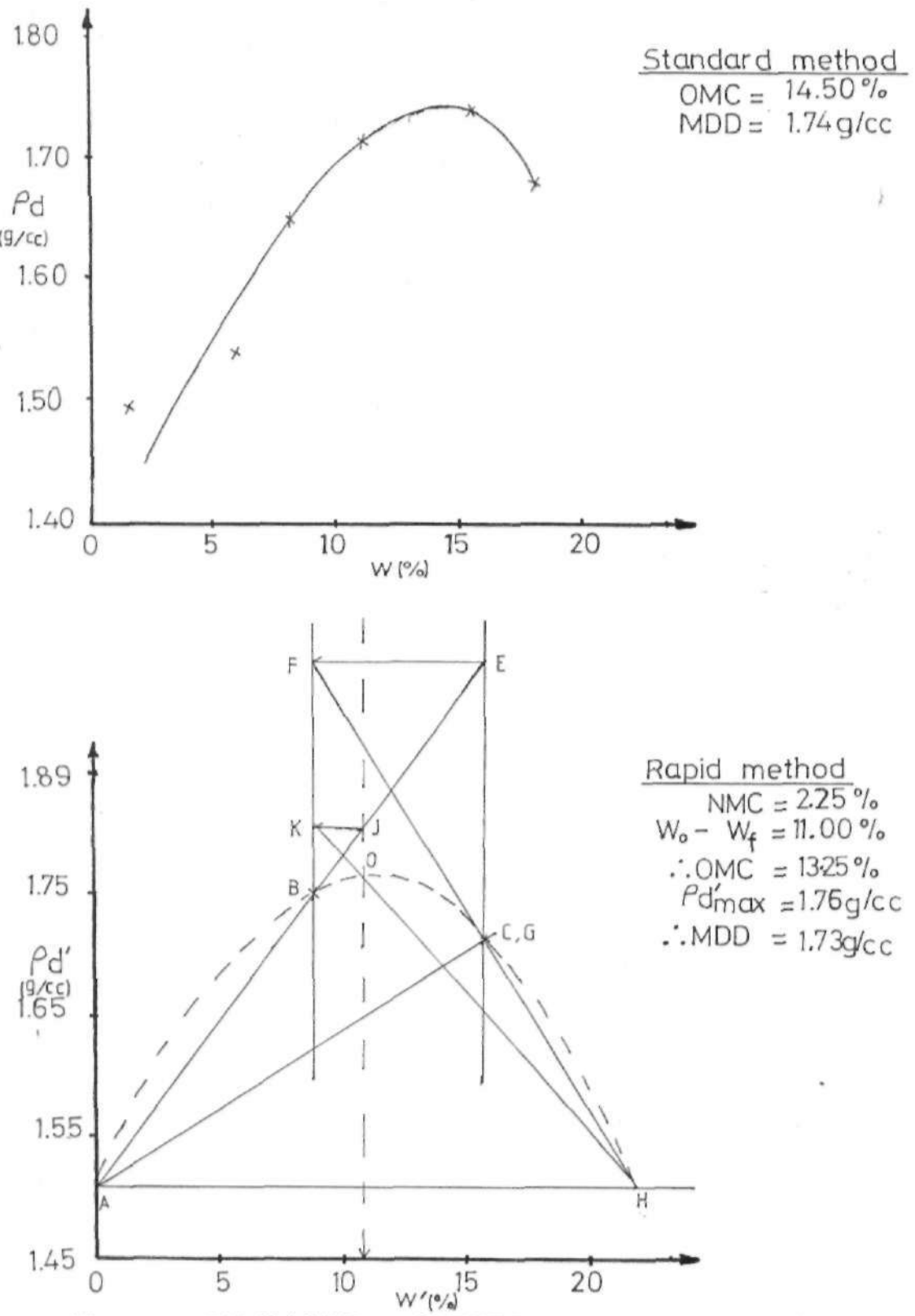
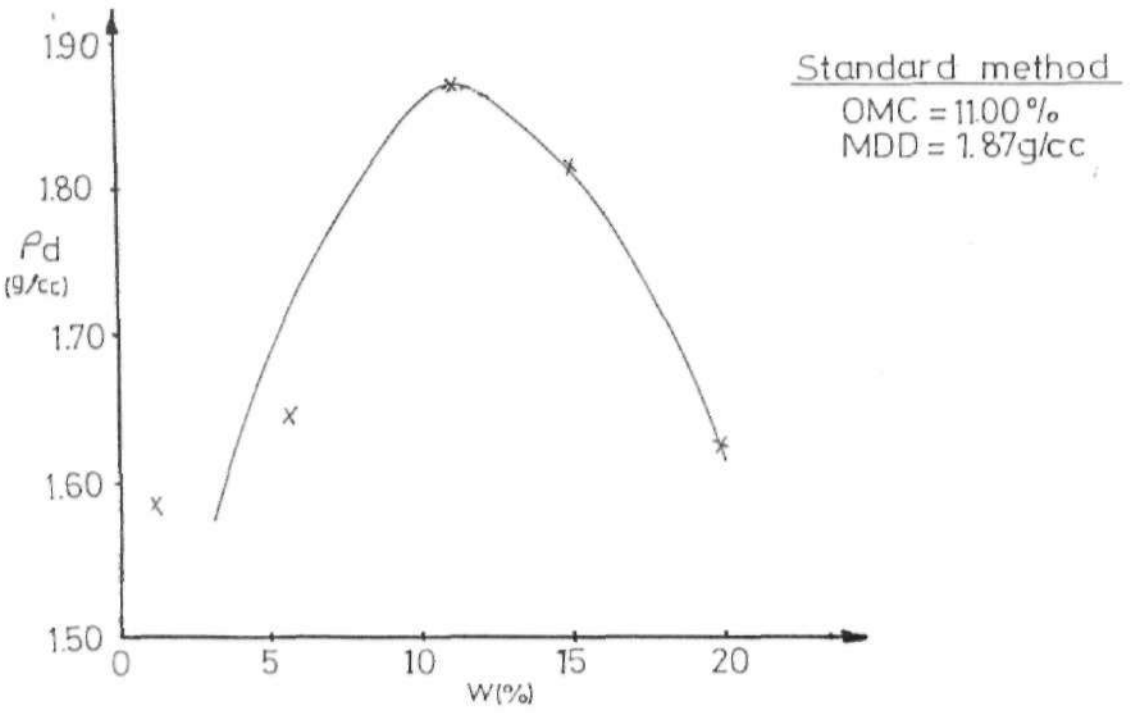


Fig. A.1 ;COMPACTION CURVES FOR SAMPLE HA-12-11



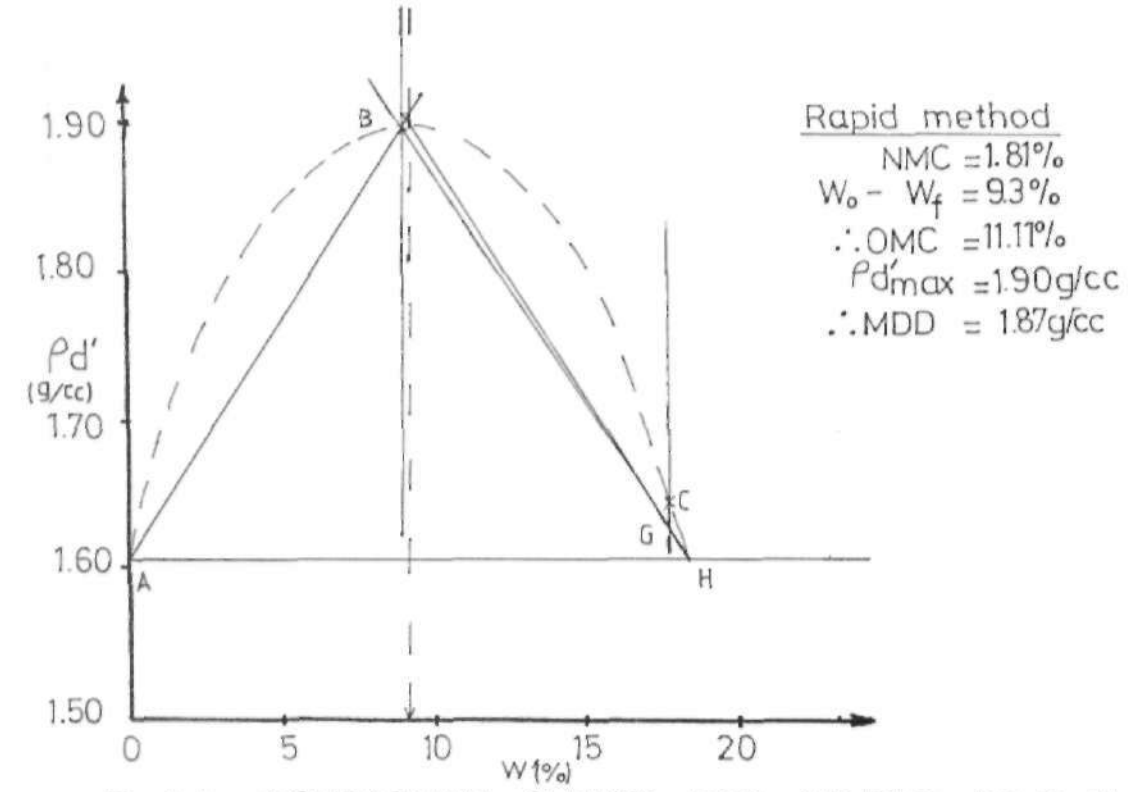


Fig. A.2 ;COMPACTION CURVES FOR SAMPLE DR-12-11

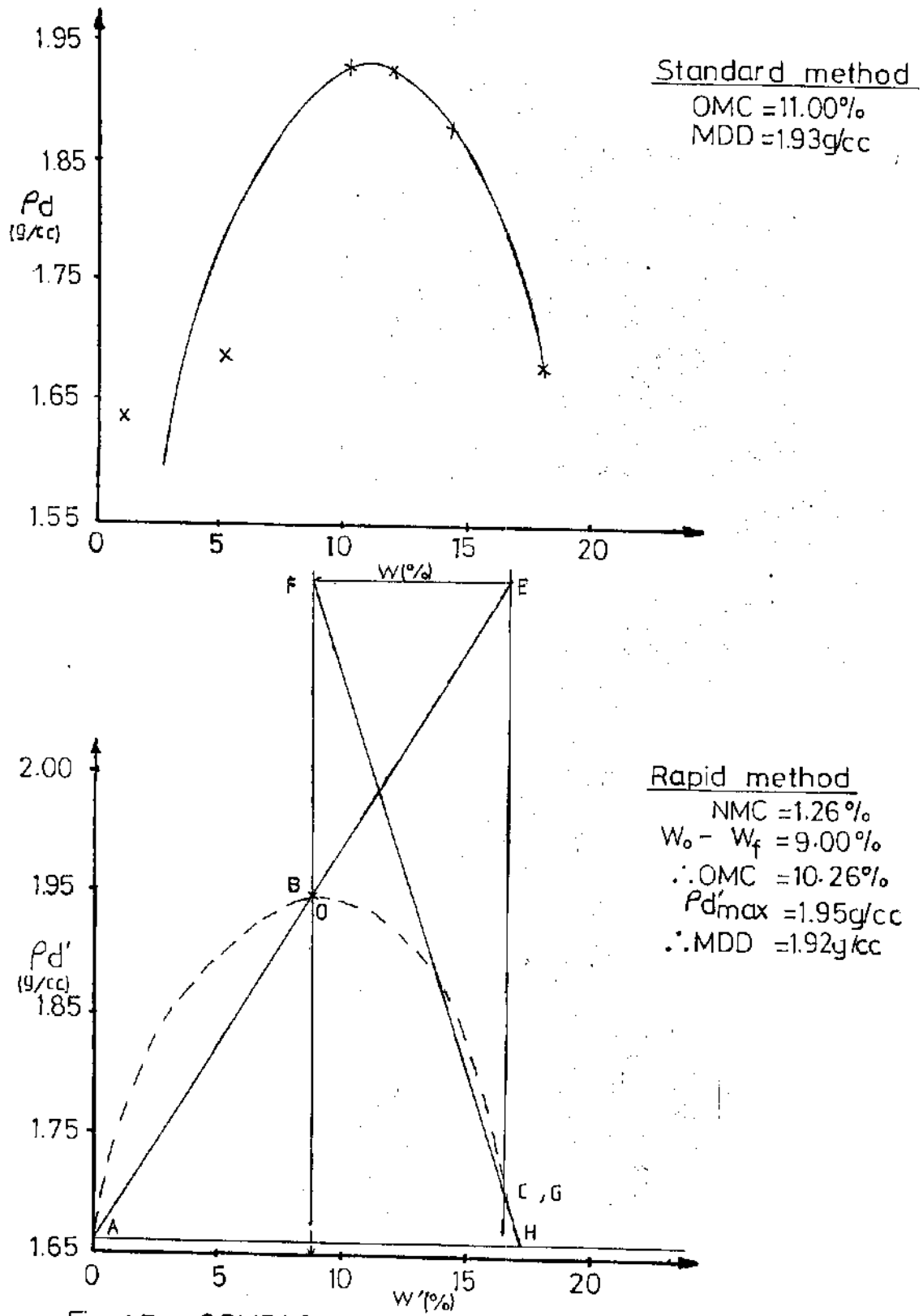
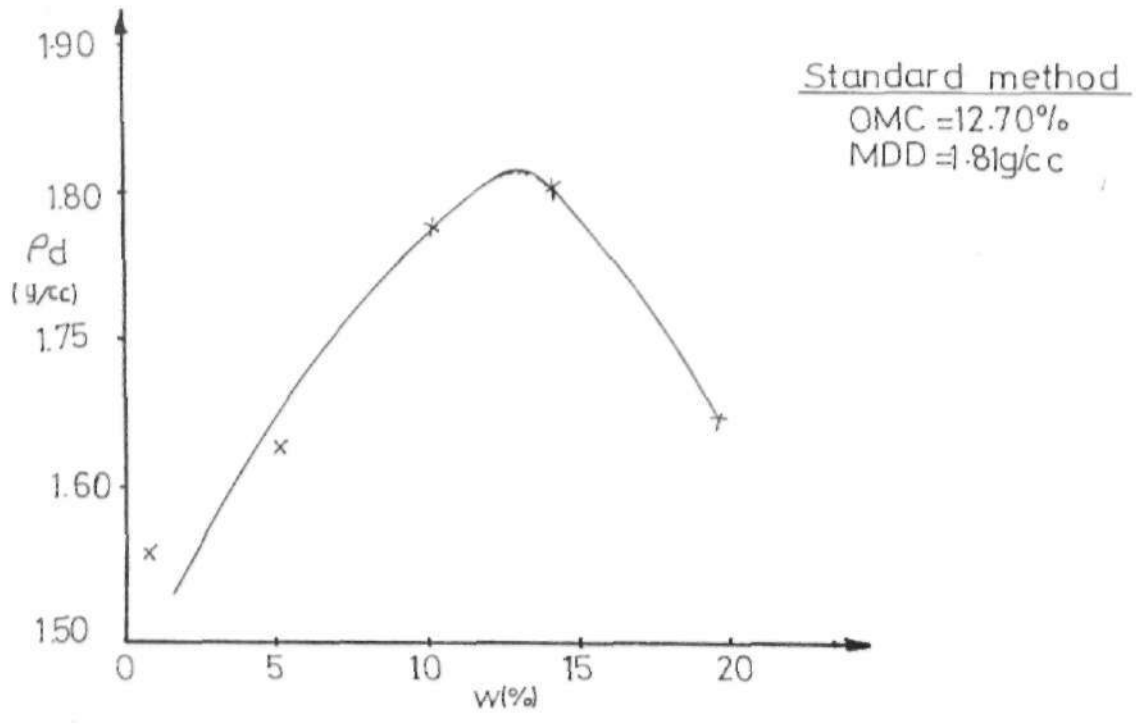


Fig. A3 ;COMPACTION CURVES FOR SAMPLE EE-12-11

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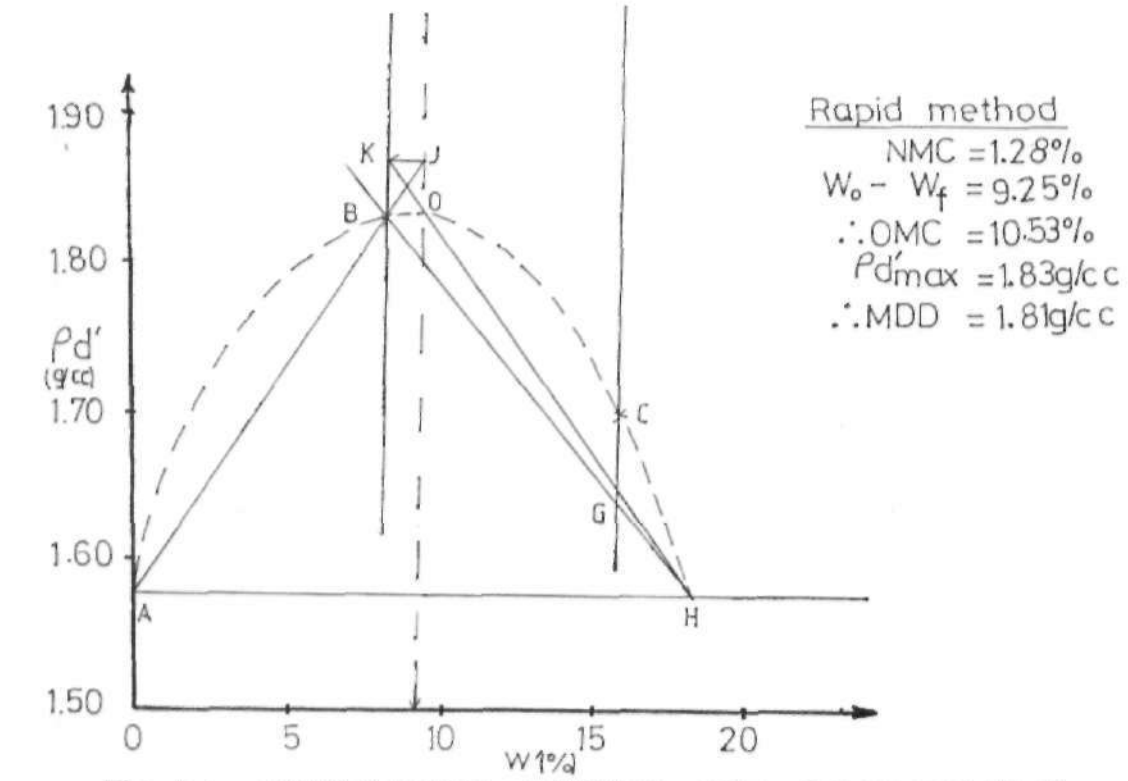


Fig. A-4 ;COMPACTION CURVES FOR SAMPLE E-12-11

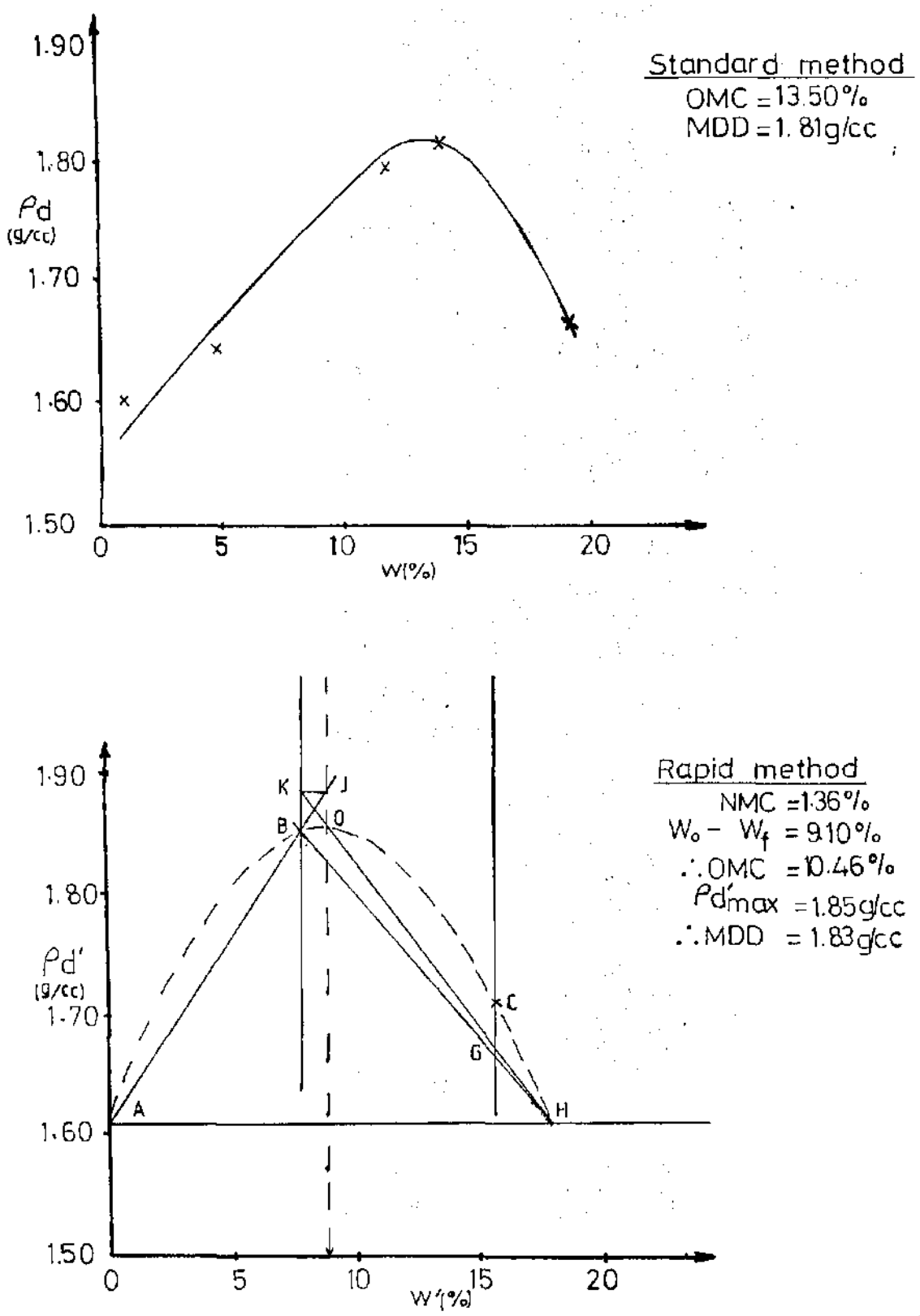
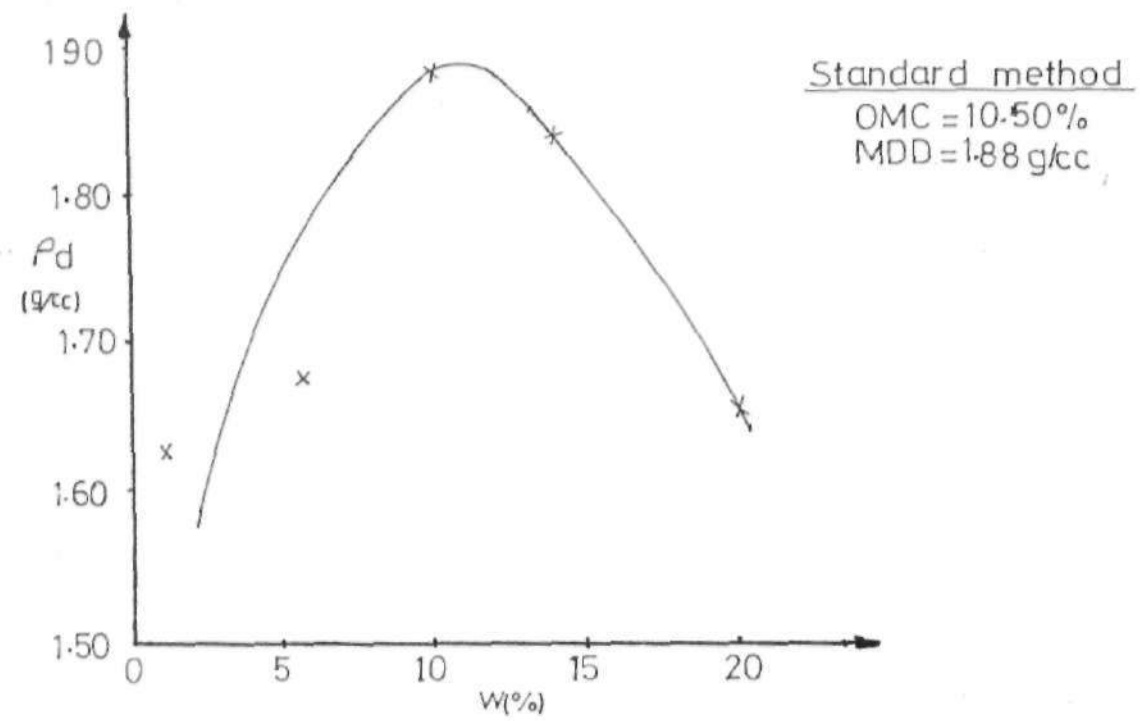


Fig. A.5 ;COMPACTION CURVES FOR SAMPLE JSQ-12-11



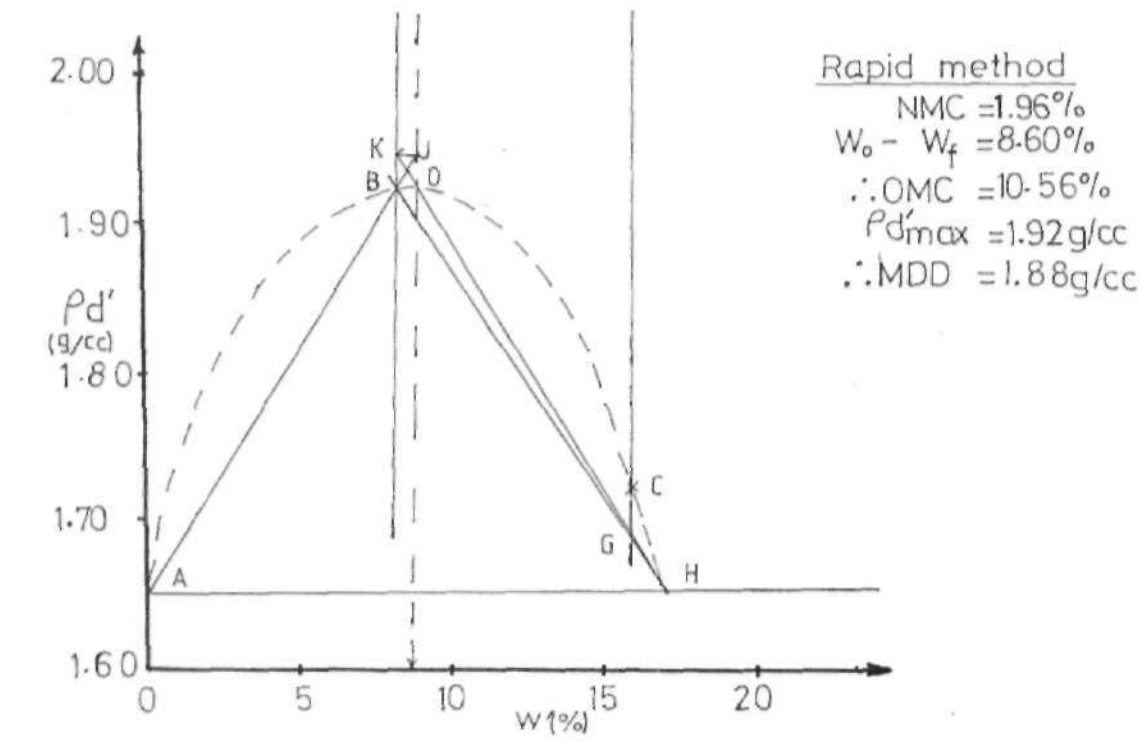
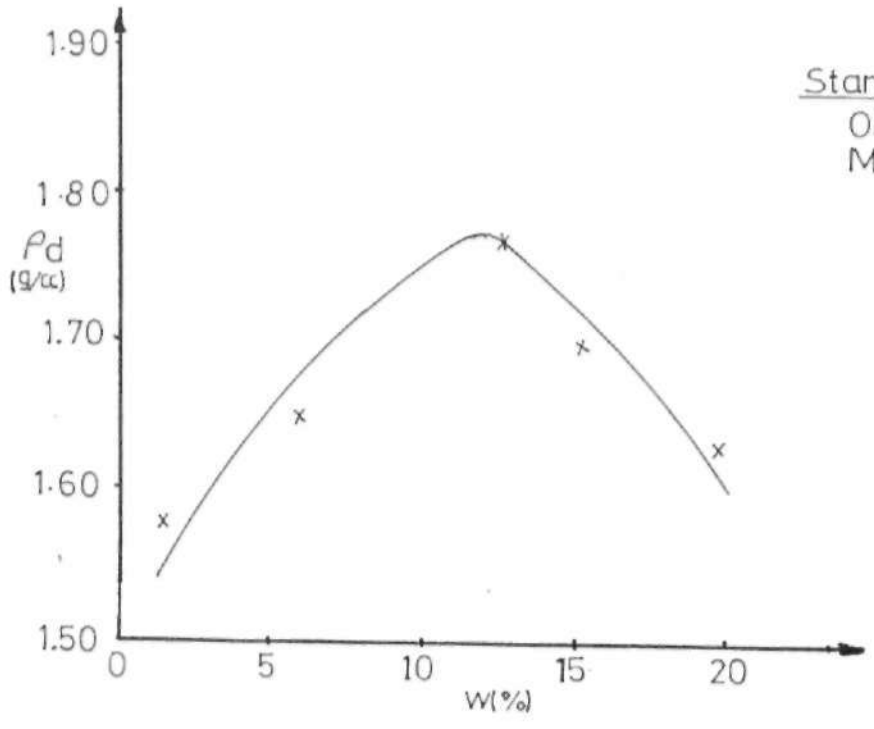
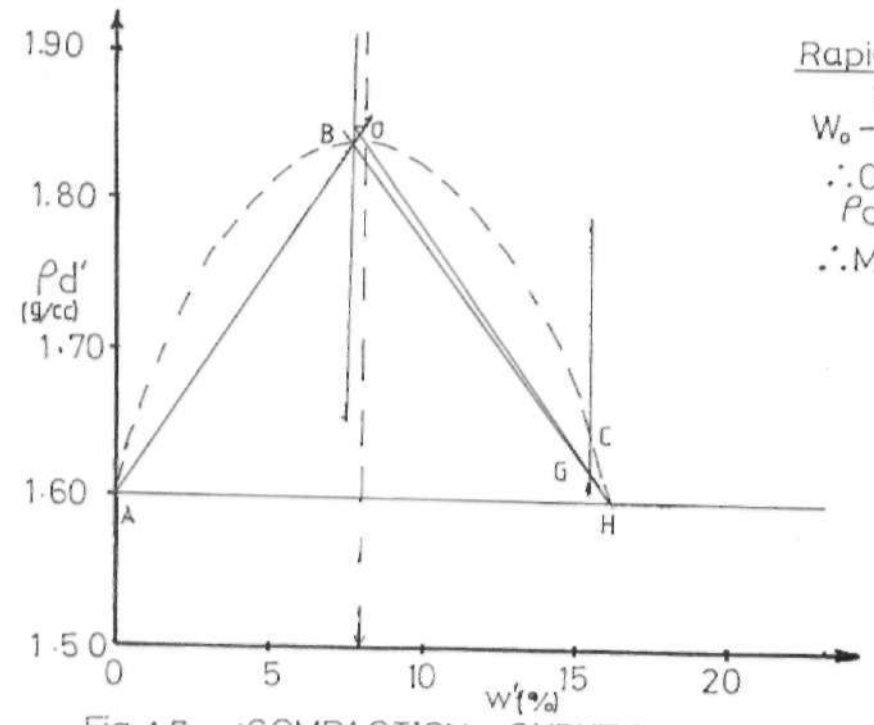


Fig. A.6 ;COMPACTION CURVES FOR SAMPLE AE-12-11

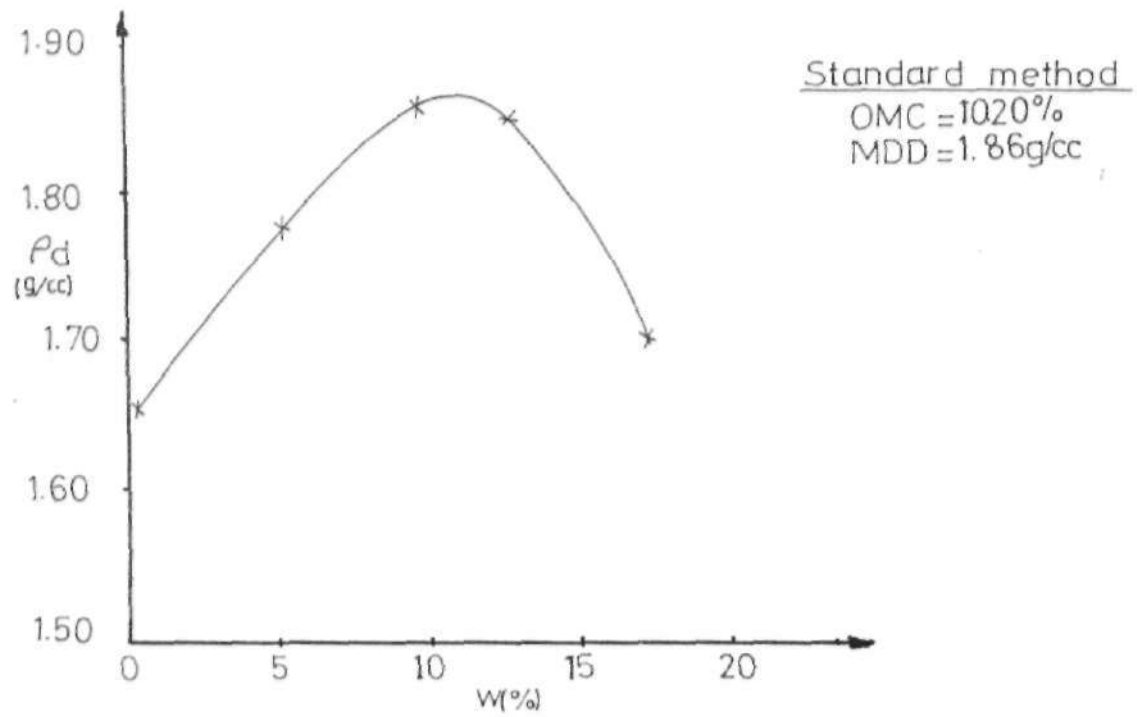


Standard method
OMC =12.20%
MDD =1.77g/cc

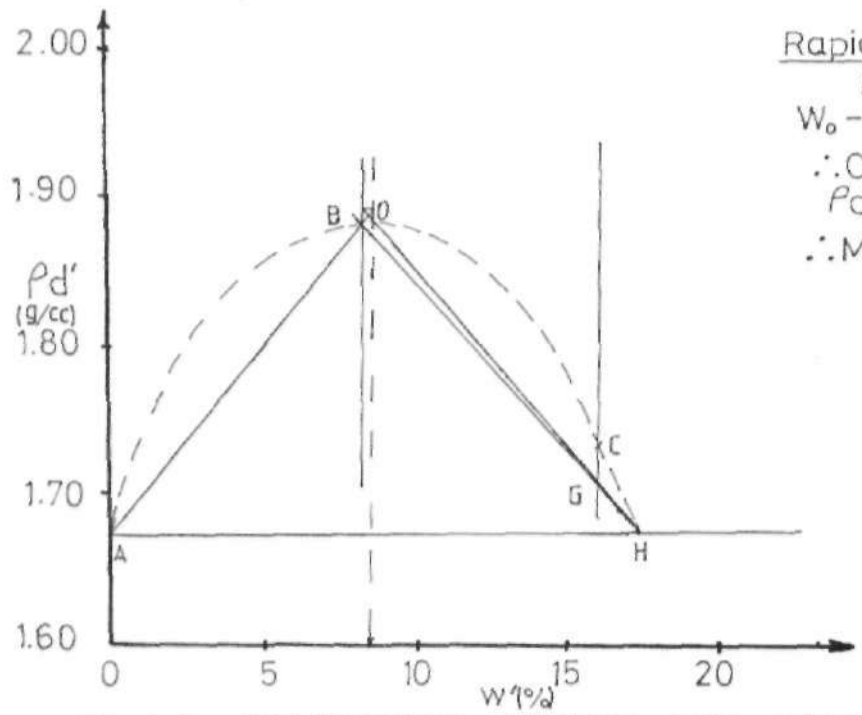


Rapid method
NMC =1.71%
$W_o - W_f$ =8.40%
∴OMC =10·11%
$\rho d'_{max}$ =1.84g/cc
∴MDD =1. 81g/cc

Fig. A-7 ;COMPACTION CURVES FOR SAMPLE P-12-11

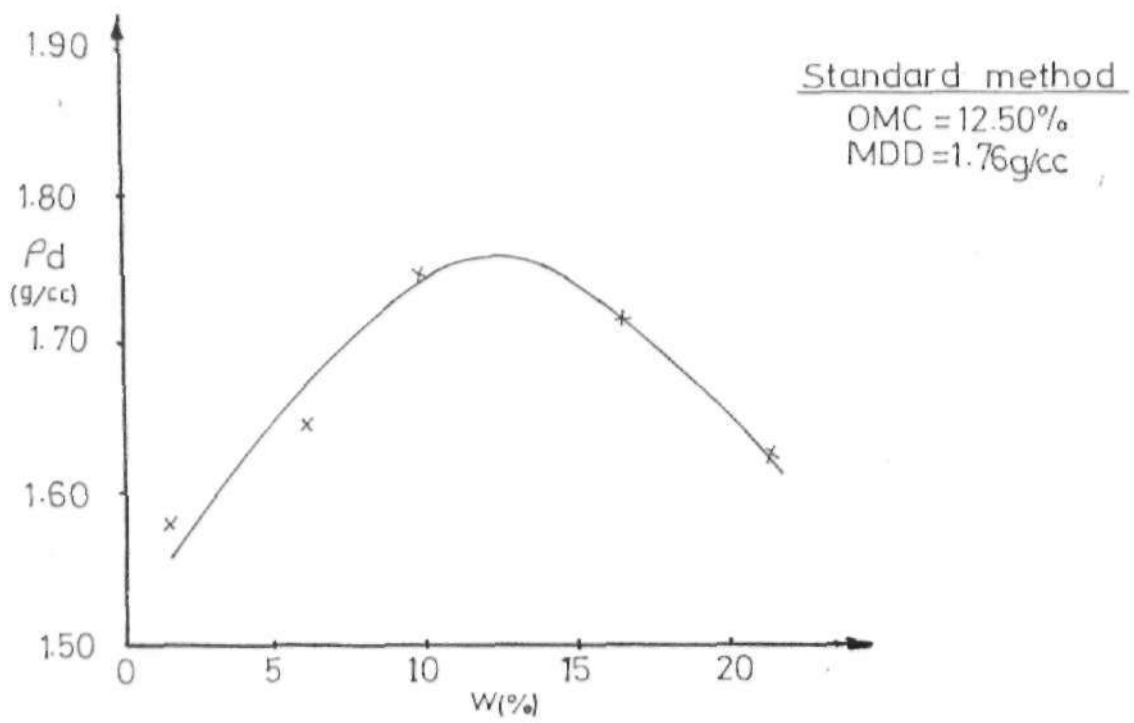


Standard method
OMC = 10.20%
MDD = 1.86g/cc



Rapid method
NMC = 10.9%
$W_o - W_f$ = 8.75%
∴ OMC = 9.84%
$\rho d'_{max}$ = 1.88g/cc
∴ MDD = 1.86g/cc

Fig. A-8 ;COMPACTION CURVES FOR SAMPLE D-12-11



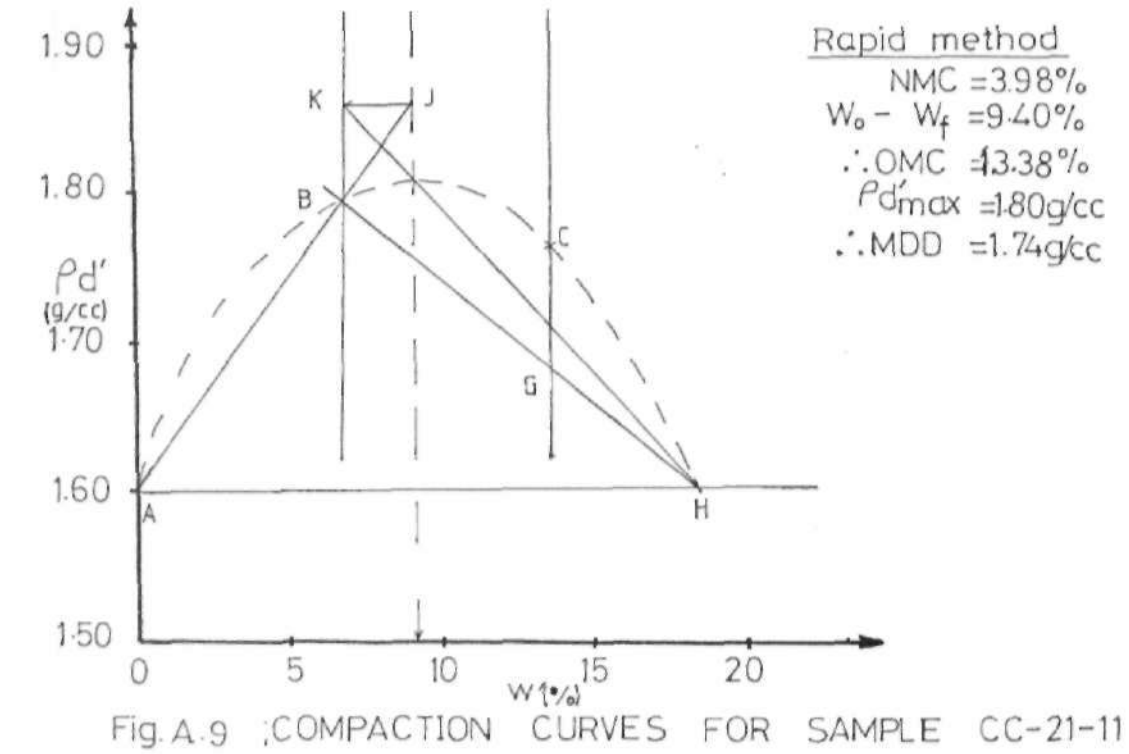
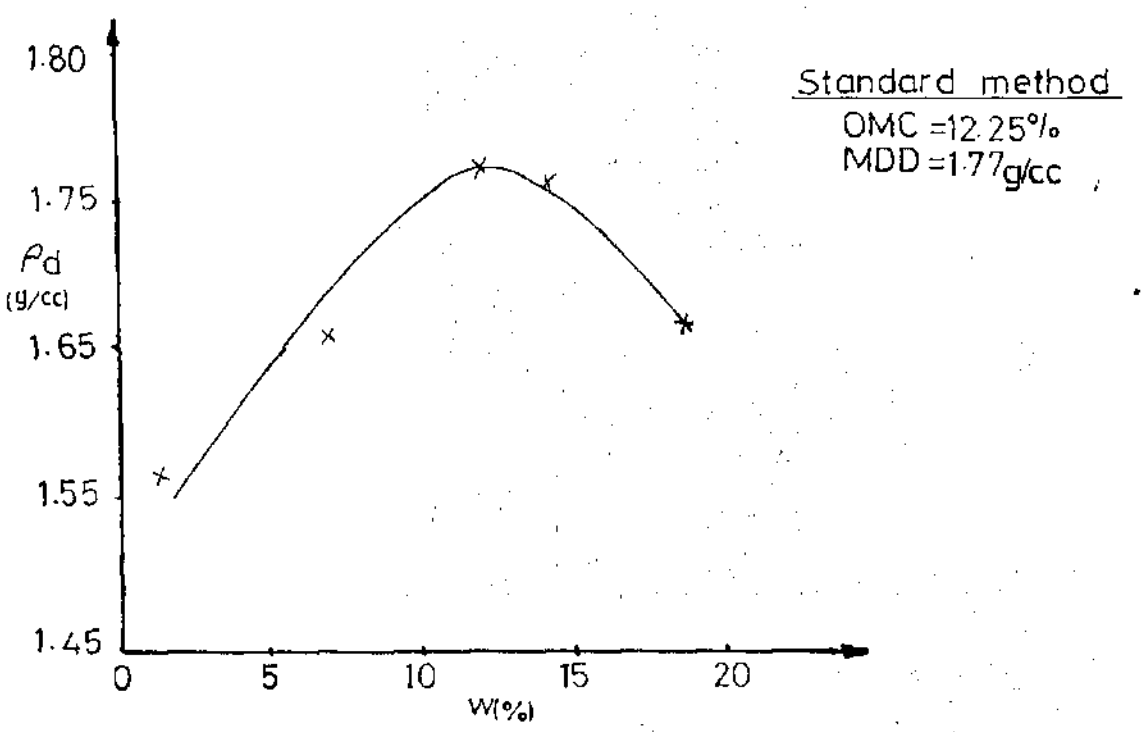


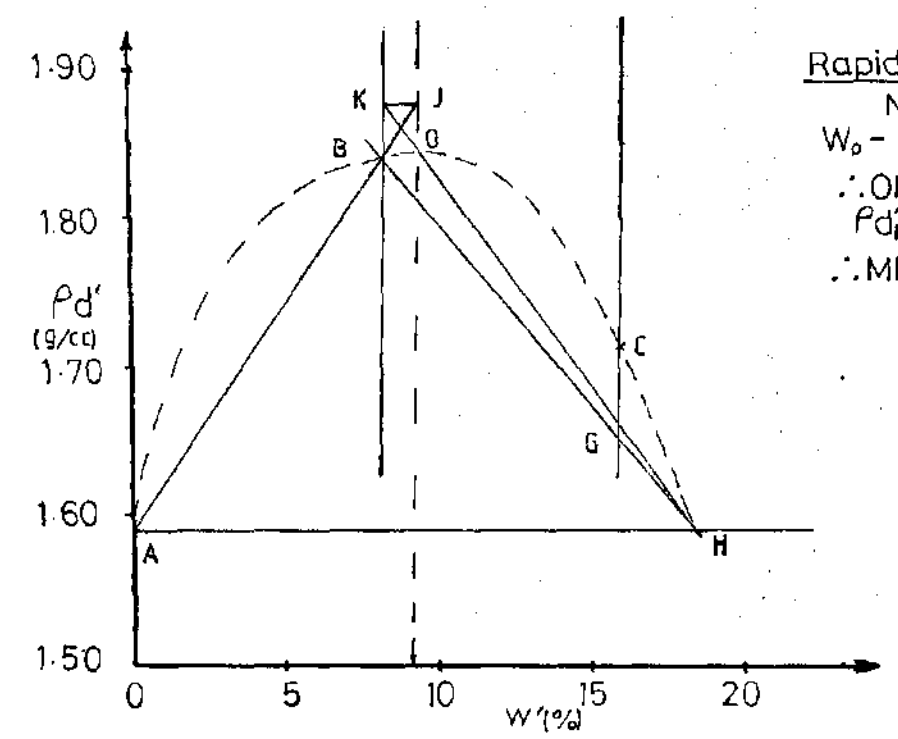
Fig. A.9 ;COMPACTION CURVES FOR SAMPLE CC-21-11



Standard method

OMC =12.25%

MDD =1.77g/cc



Rapid method

NMC =5.04%

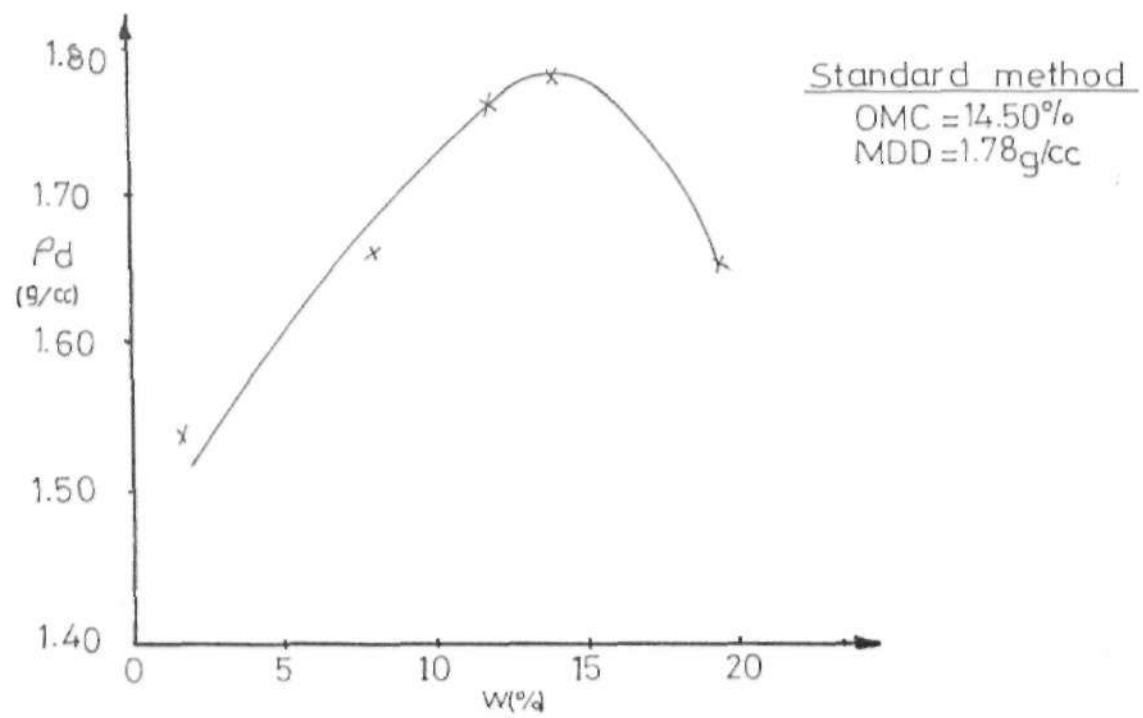
$W_o - W_f$ =9.25%

∴OMC =14.29%

$\rho d'_{max}$ =1.84g/cc

∴MDD =1.76g/cc

Fig. A.10 ;COMPACTION CURVES FOR SAMPLE CHE-21-11



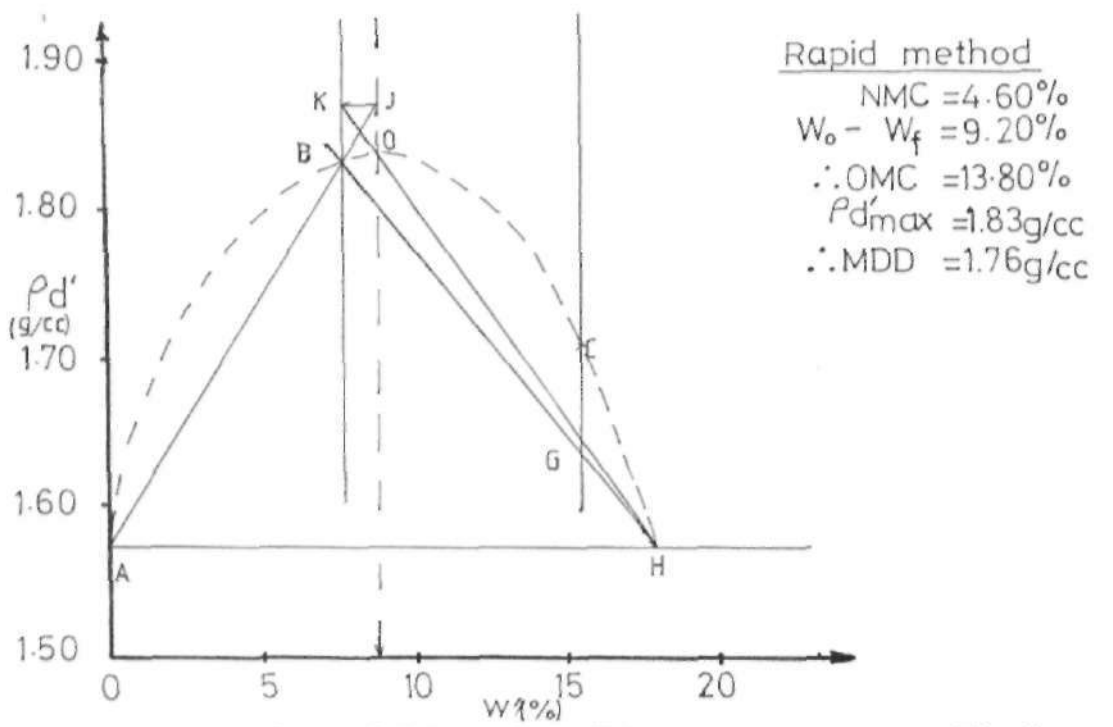
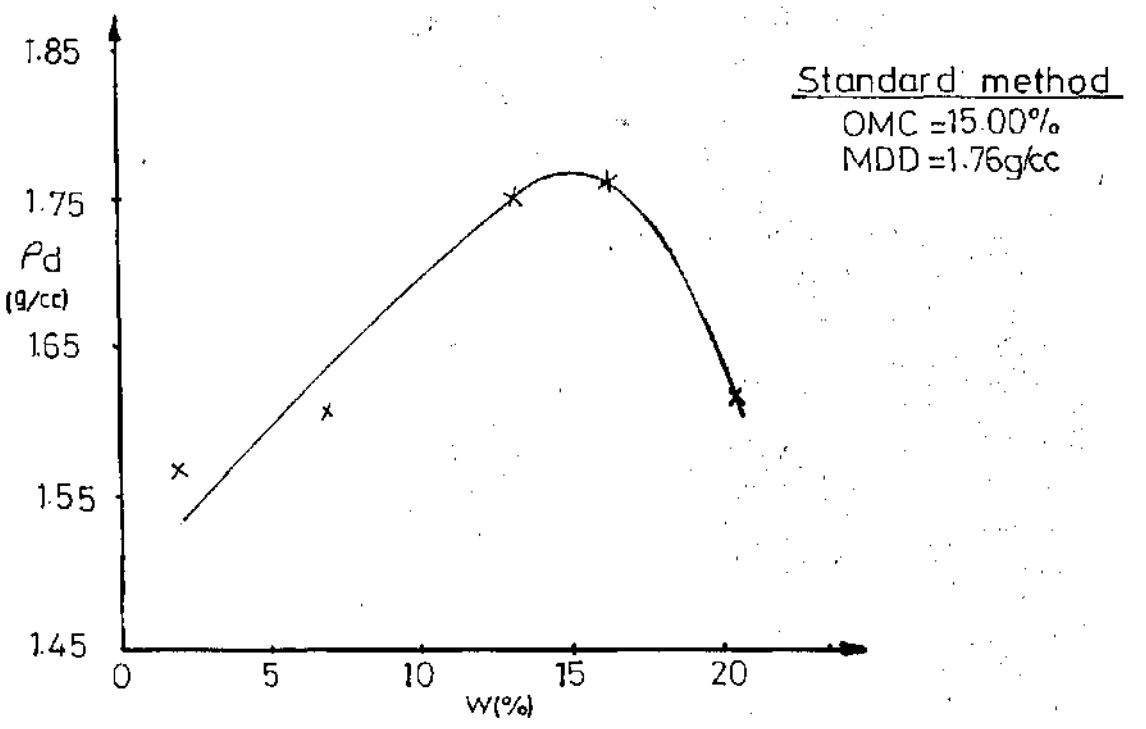


Fig.A.11 ;COMPACTION CURVES FOR SAMPLE FA-21-11



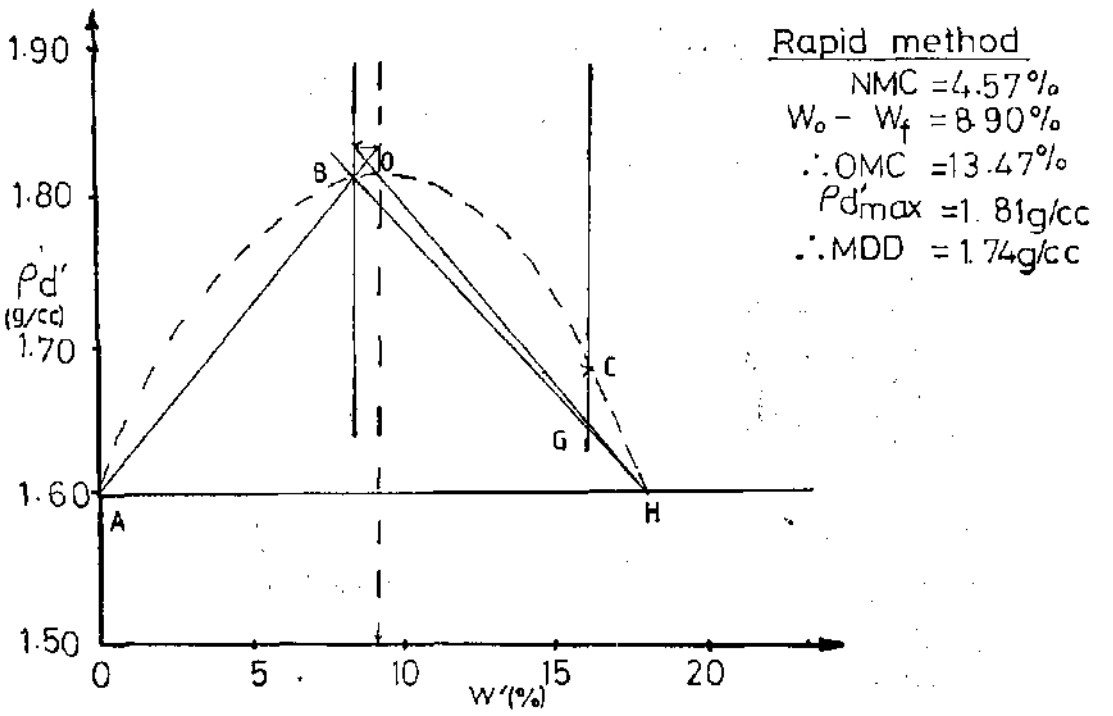
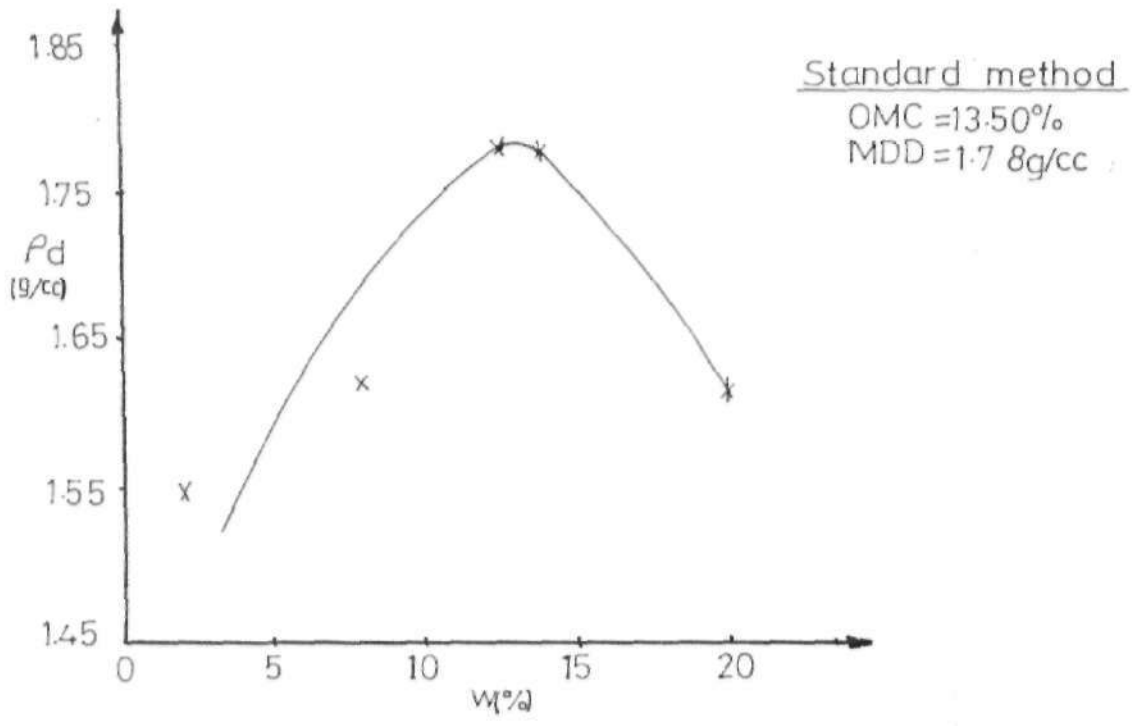


Fig. A.12 ;COMPACTION CURVES FOR SAMPLE KIL-21-11



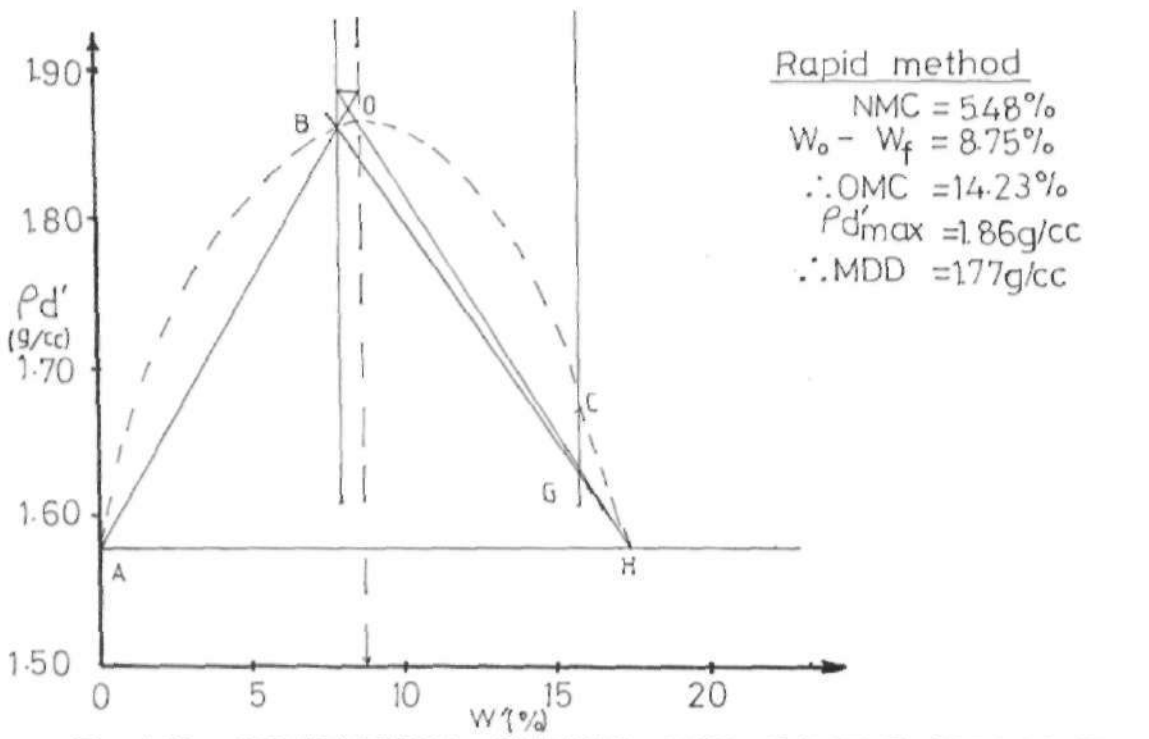


Fig. A.13 ;COMPACTION CURVES FOR SAMPLE ICSAH2-21-11

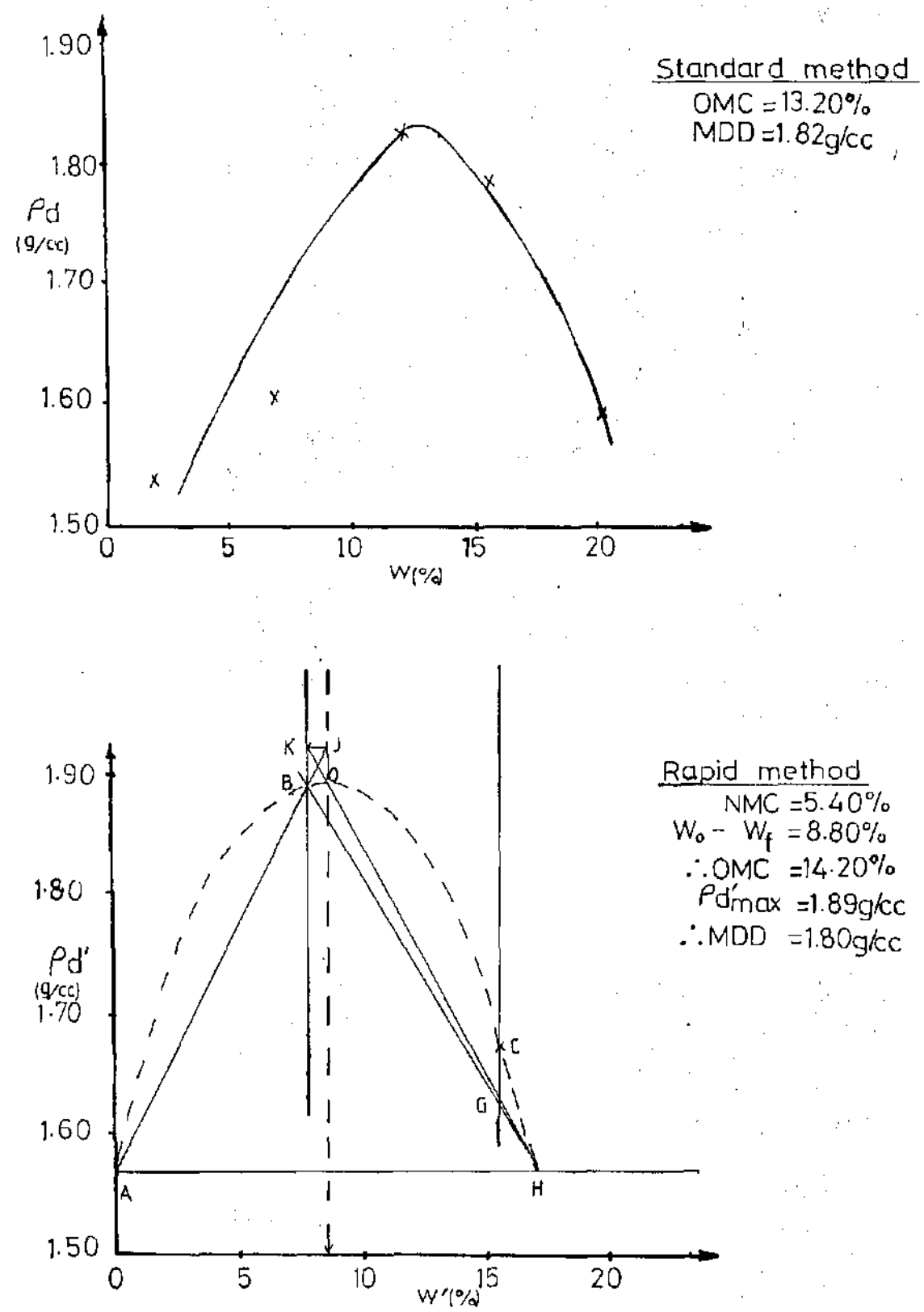
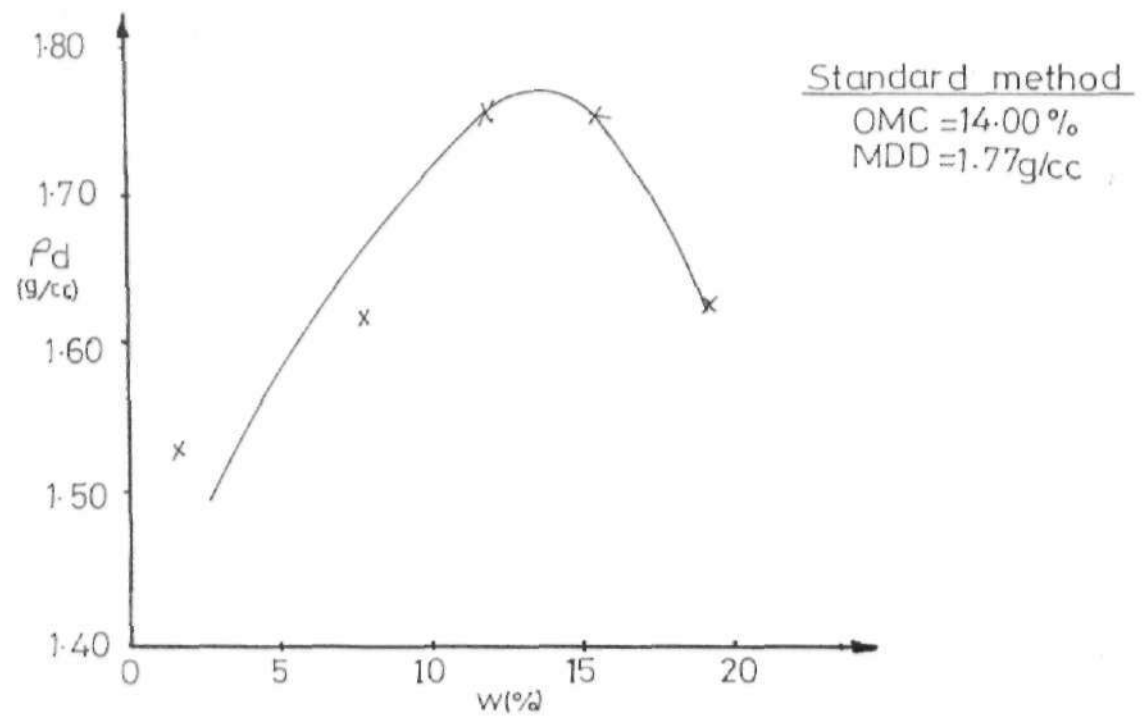


Fig. A.14 ;COMPACTION CURVES FOR SAMPLE ICSAH1-21-11



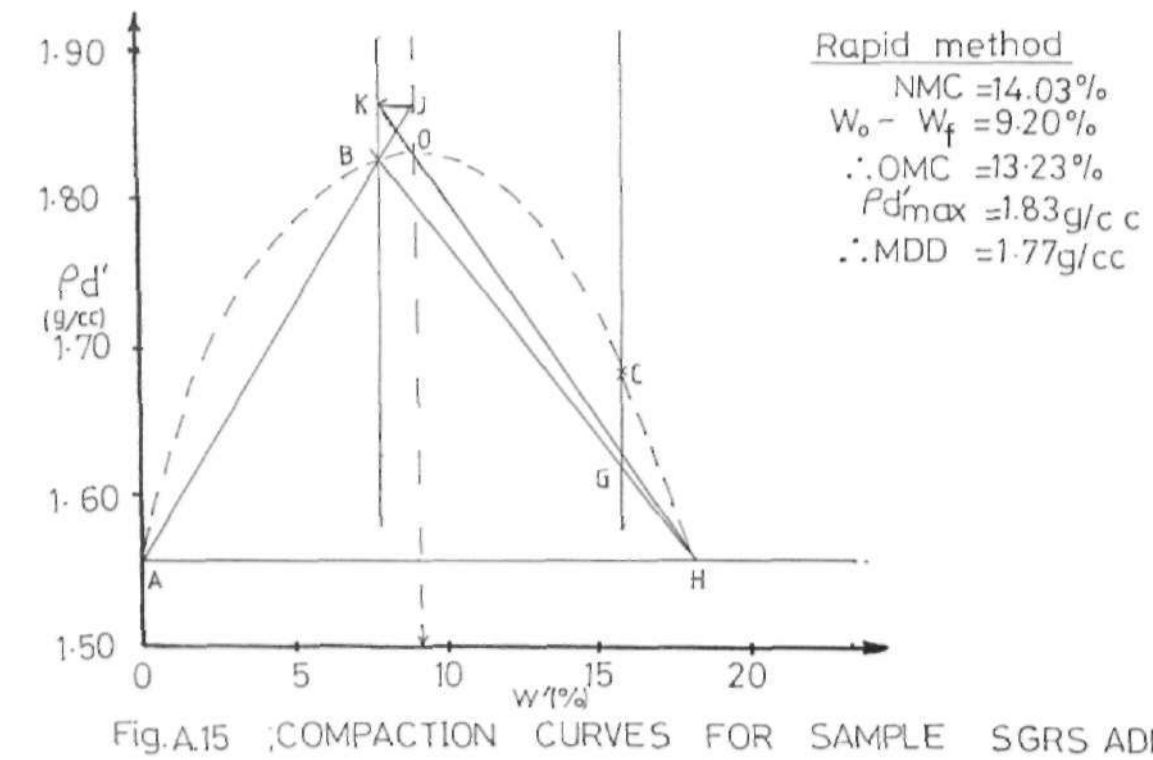
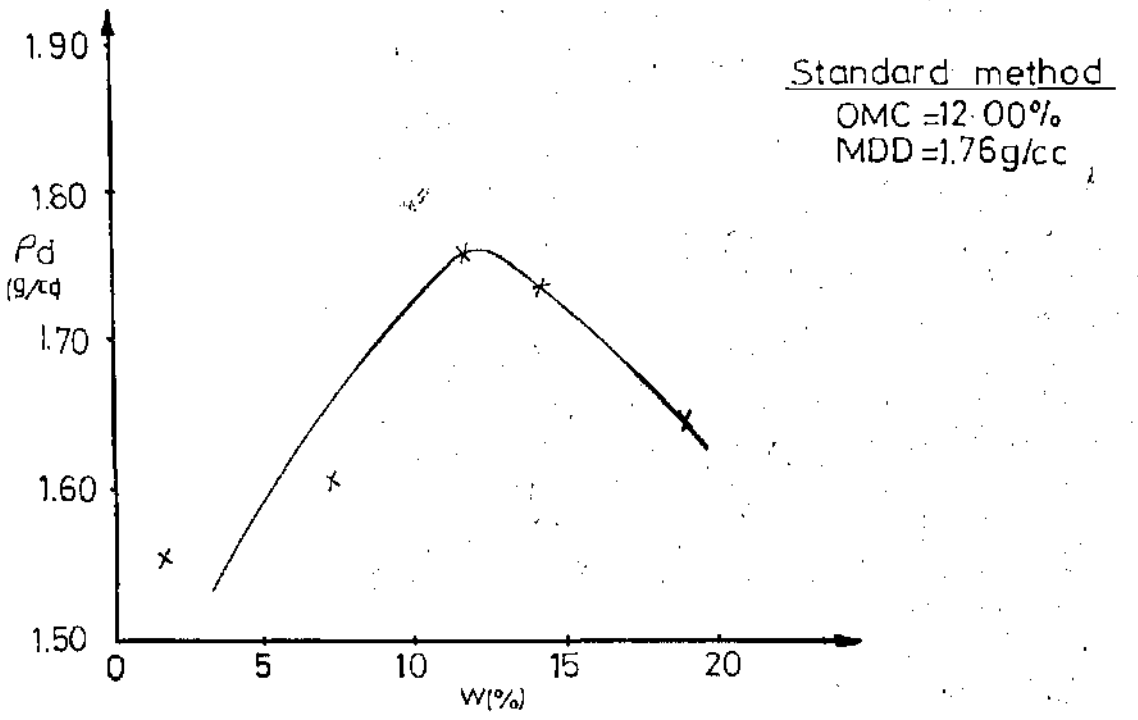


Fig. A.15 ;COMPACTION CURVES FOR SAMPLE SGRS ADMIN-21-1



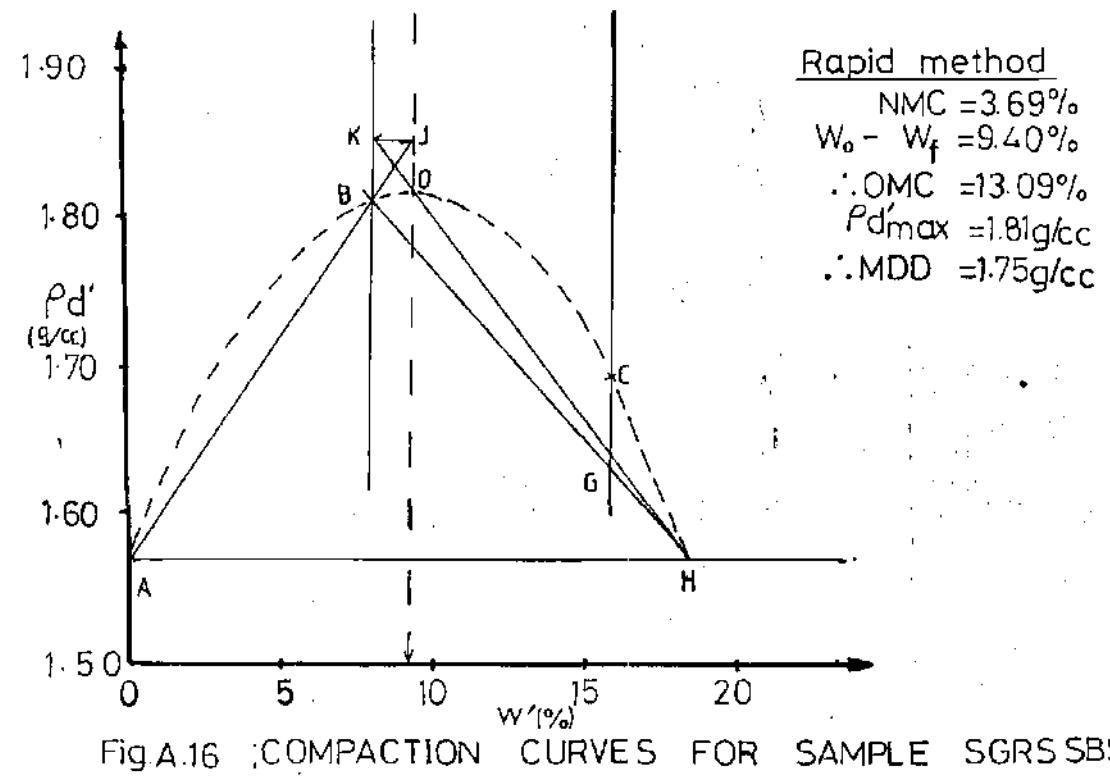
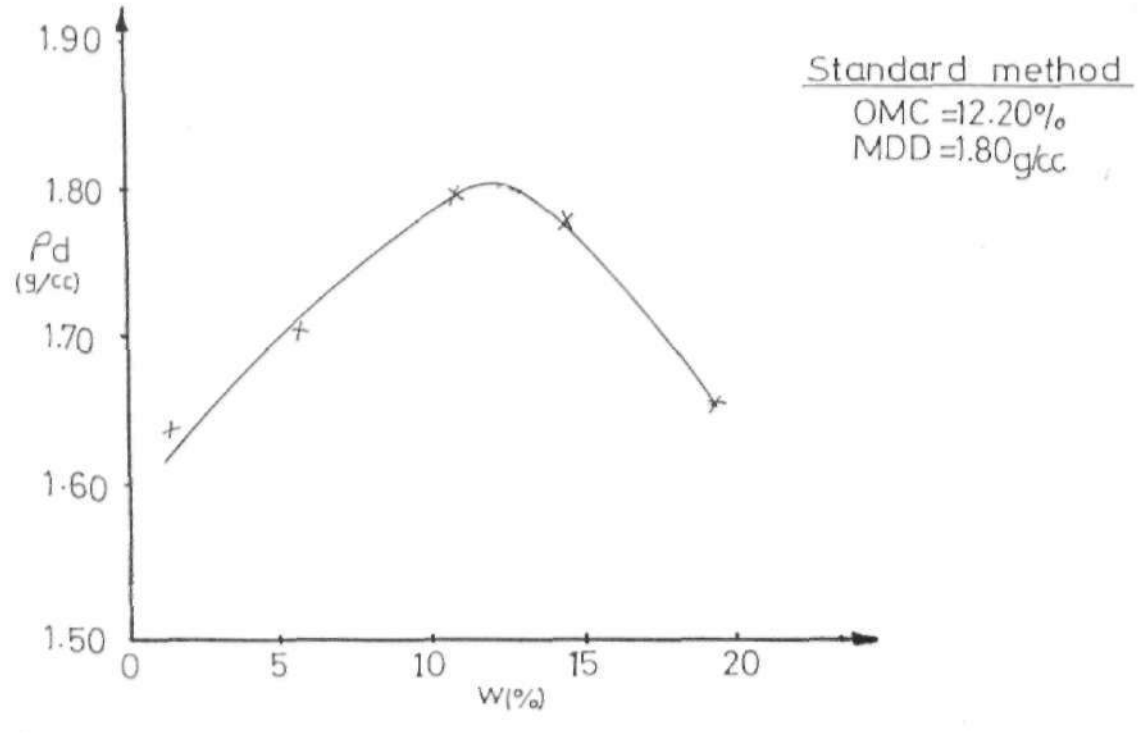


Fig.A.16 ;COMPACTION CURVES FOR SAMPLE SGRS SBS-21-11



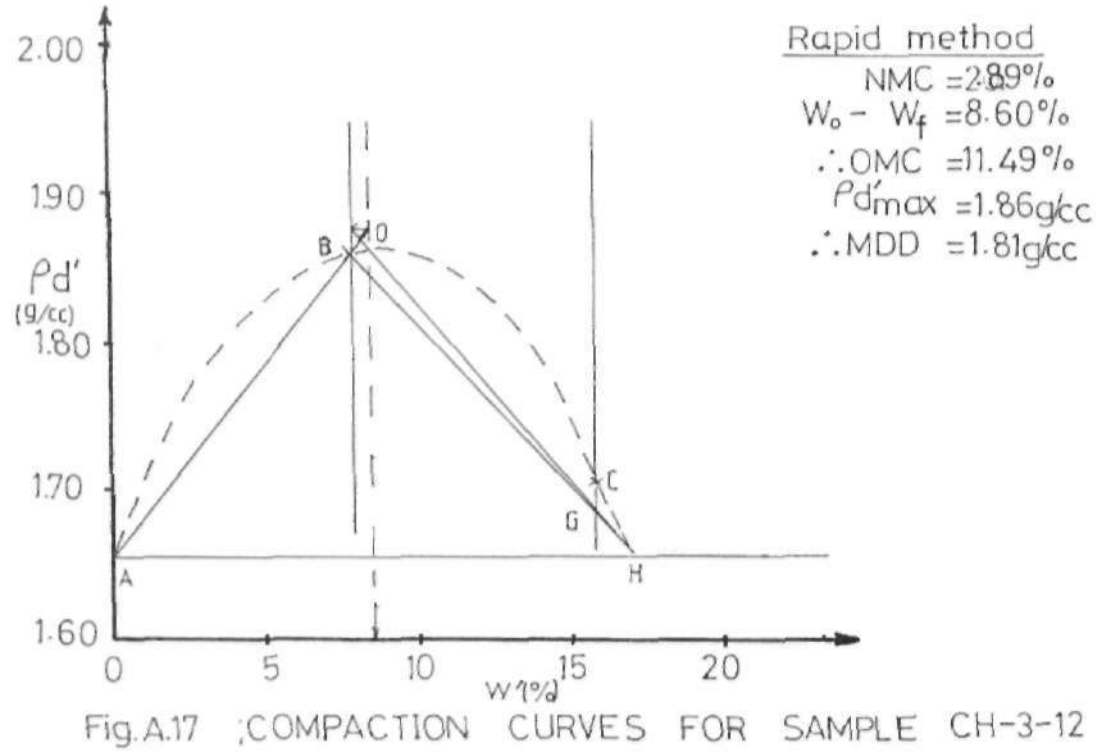
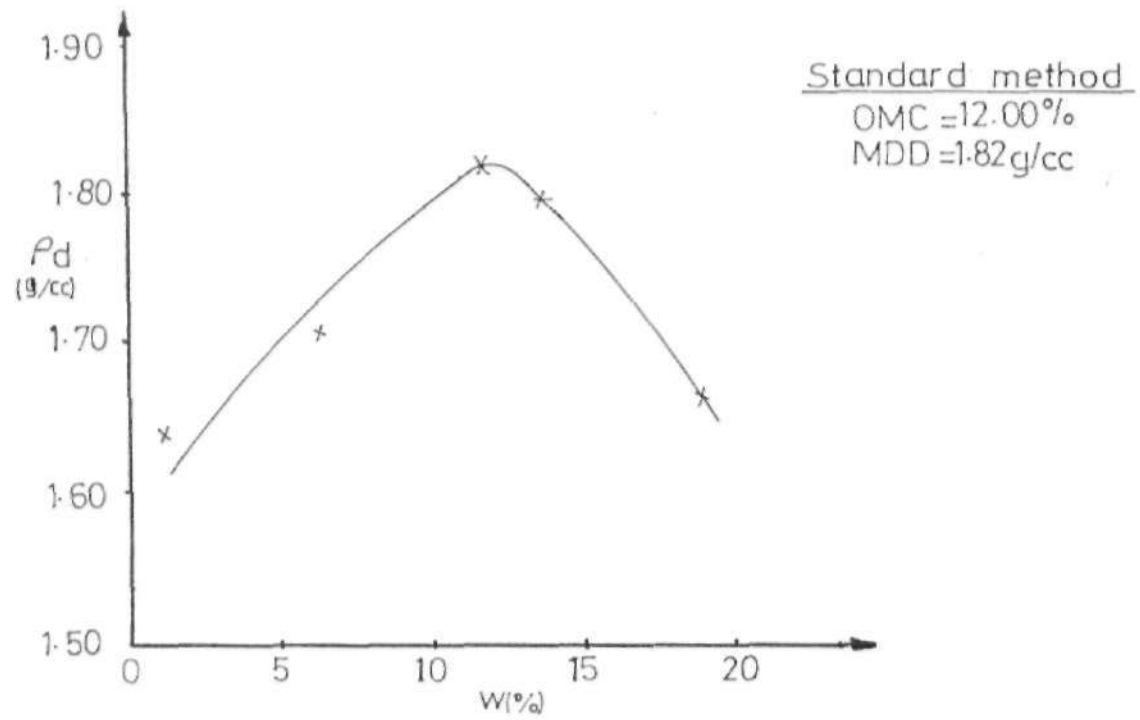


Fig.A.17 ;COMPACTION CURVES FOR SAMPLE CH-3-12



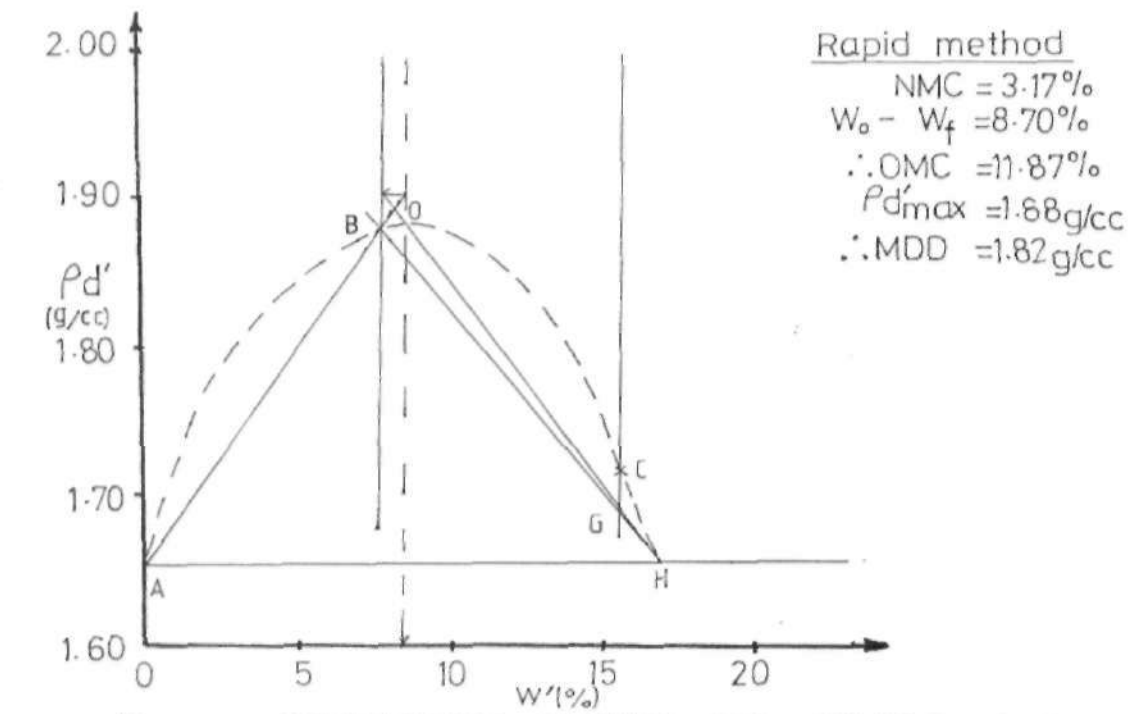
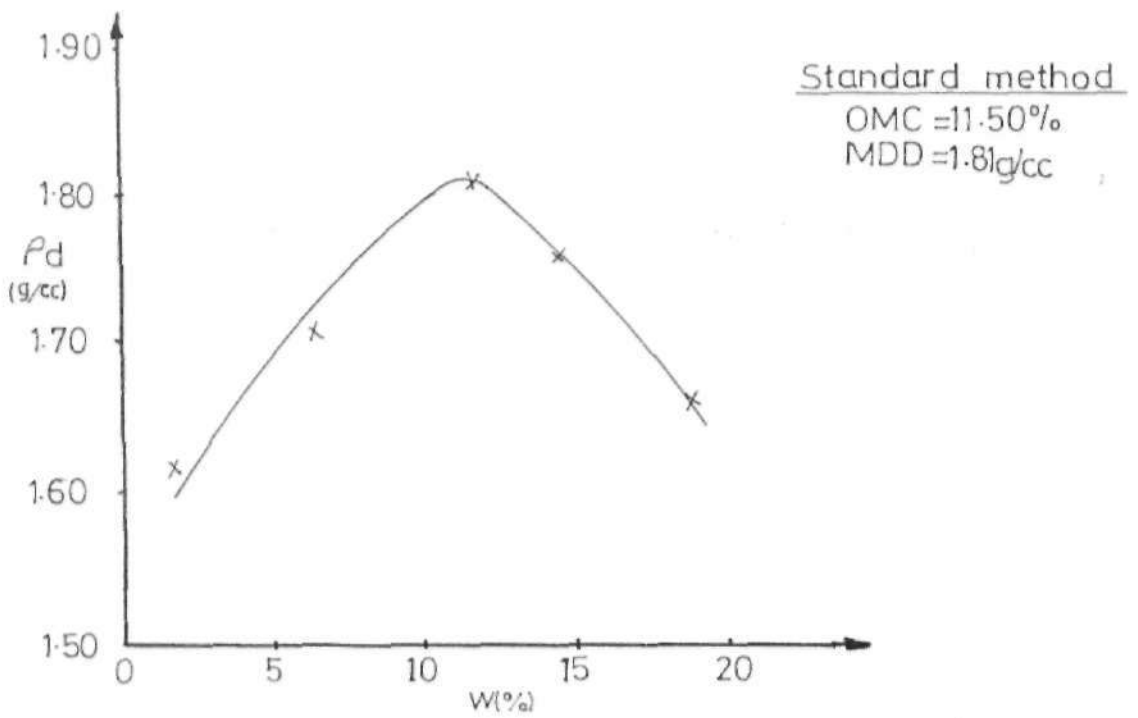


Fig. A-18 ;COMPACTION CURVES FOR SAMPLE B-3-12



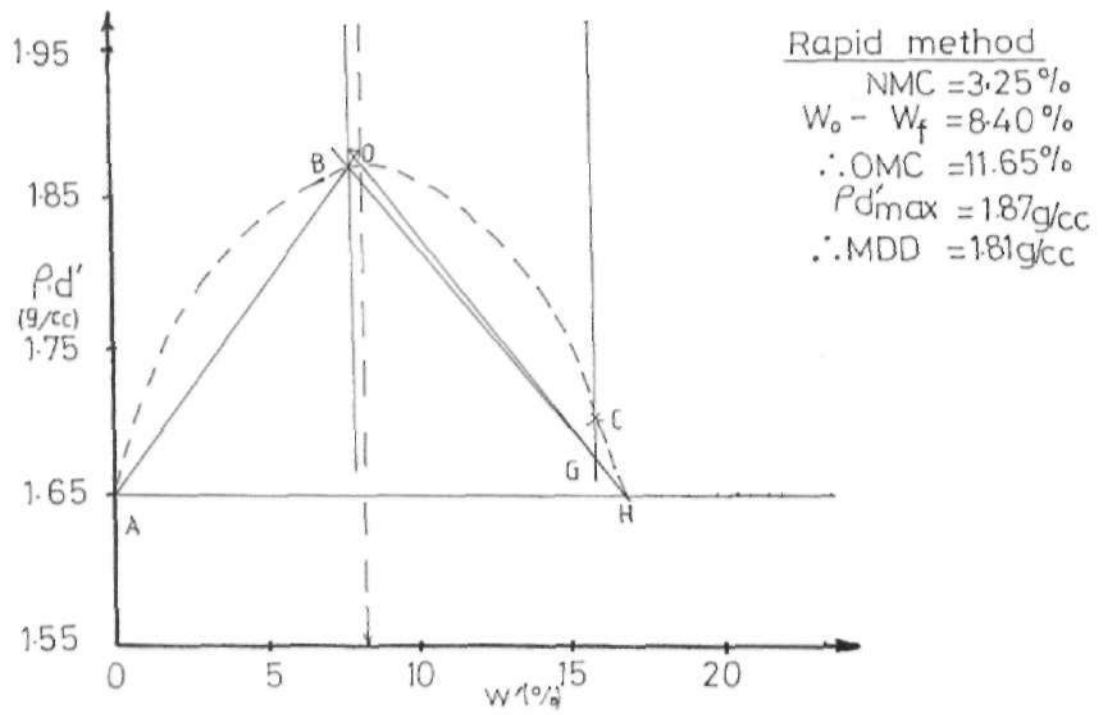
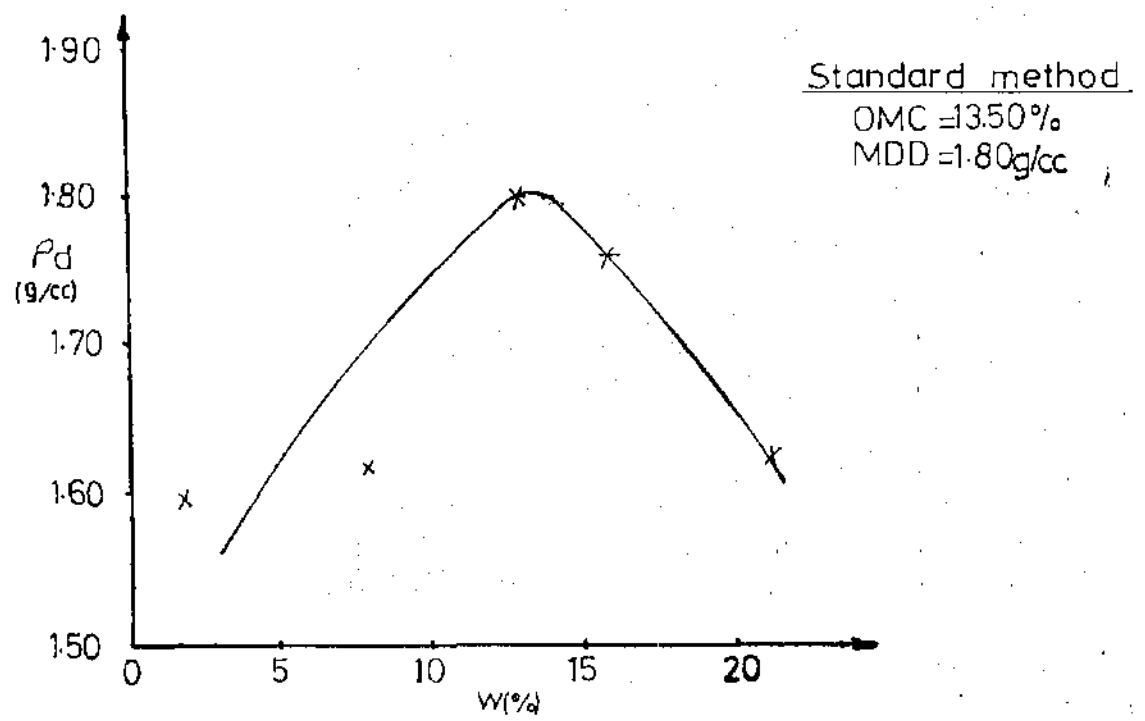


Fig.A-19 ;COMPACTION CURVES FOR SAMPLE KIL2-3-12



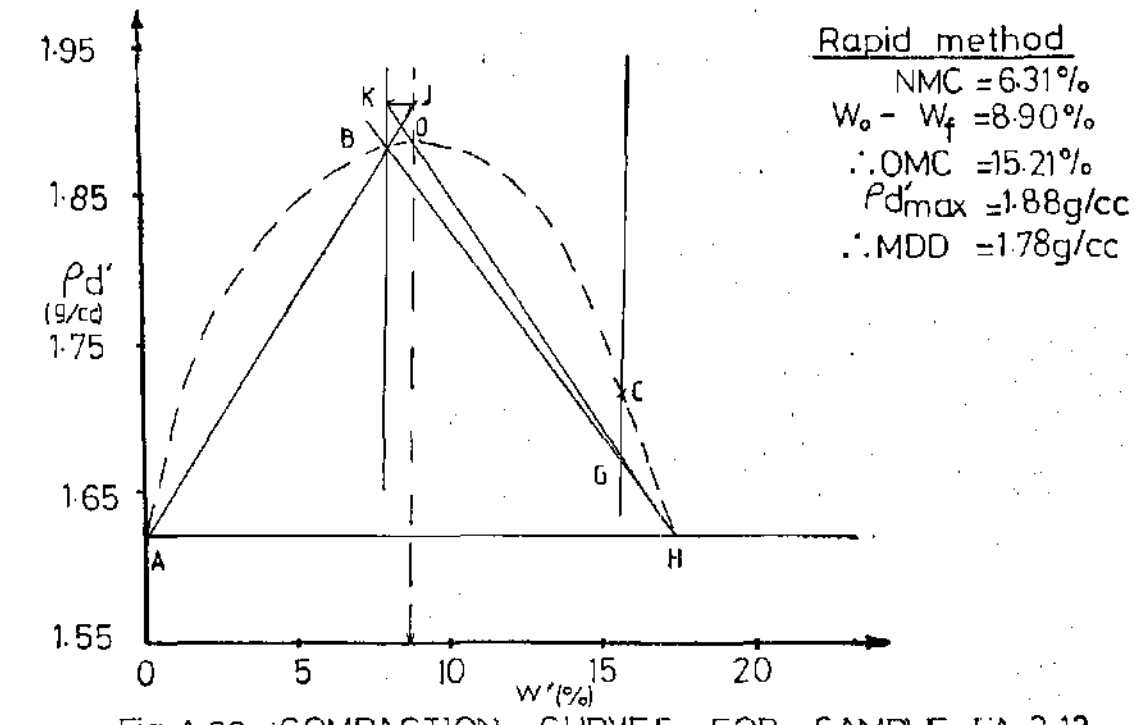
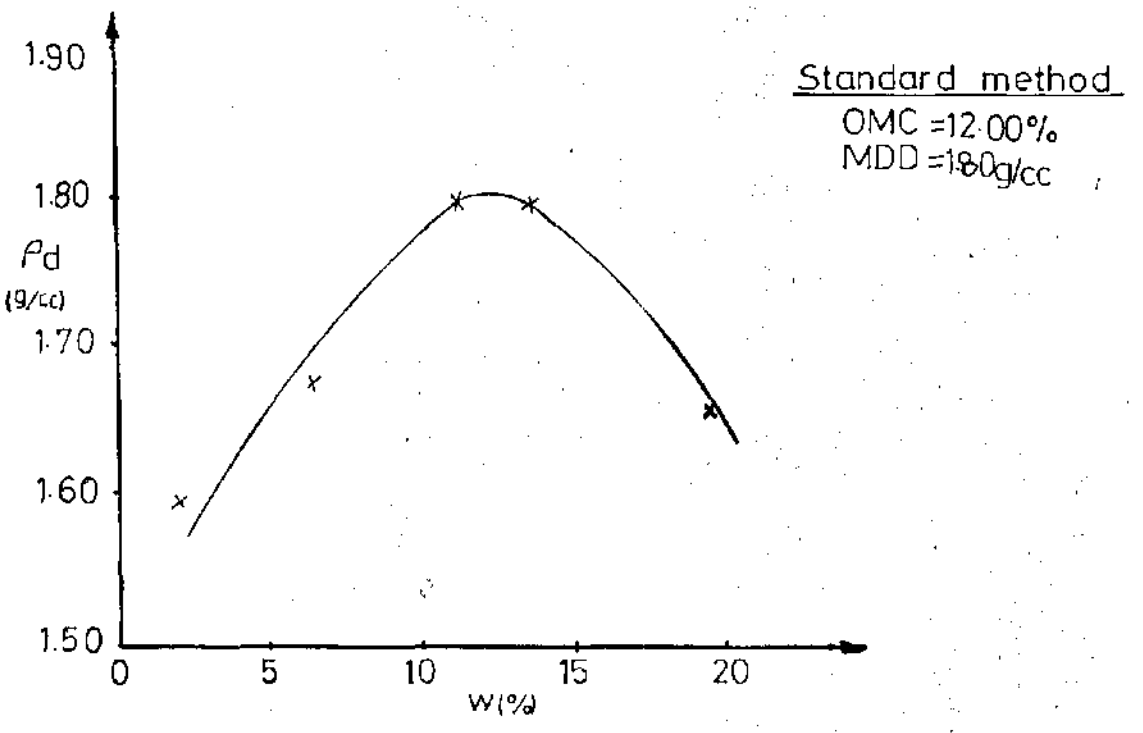


Fig. A·20 ;COMPACTION CURVES FOR SAMPLE FA-3-12



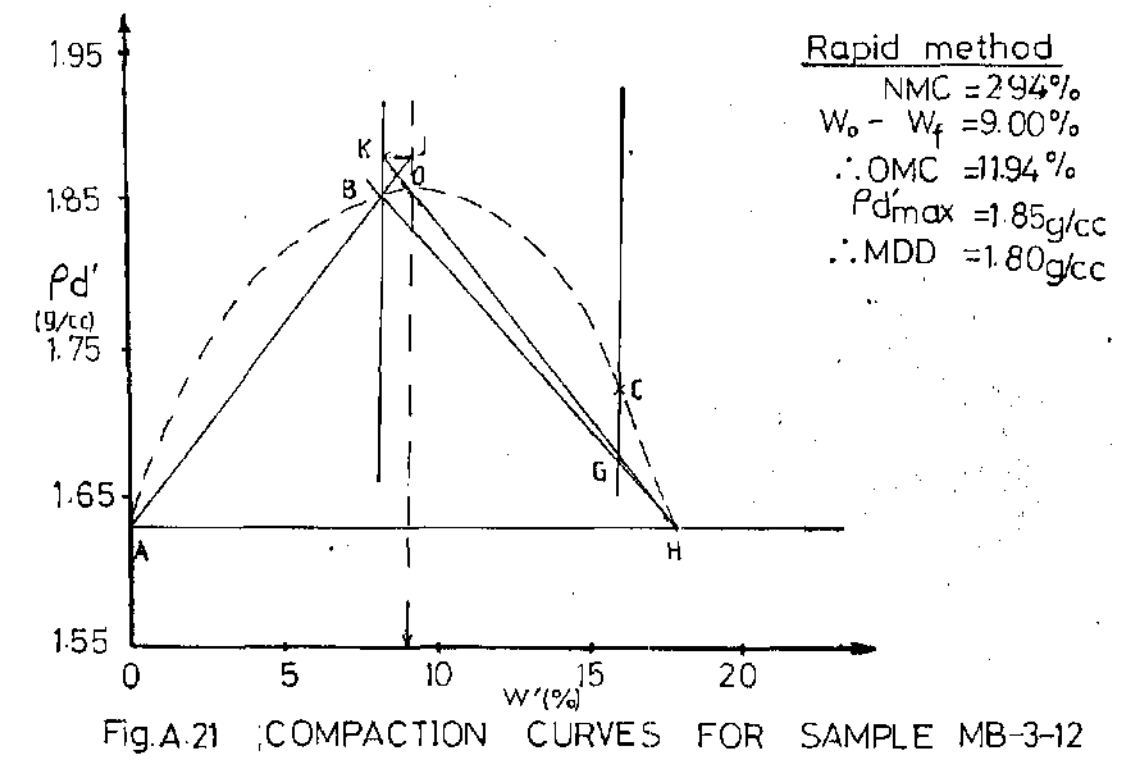
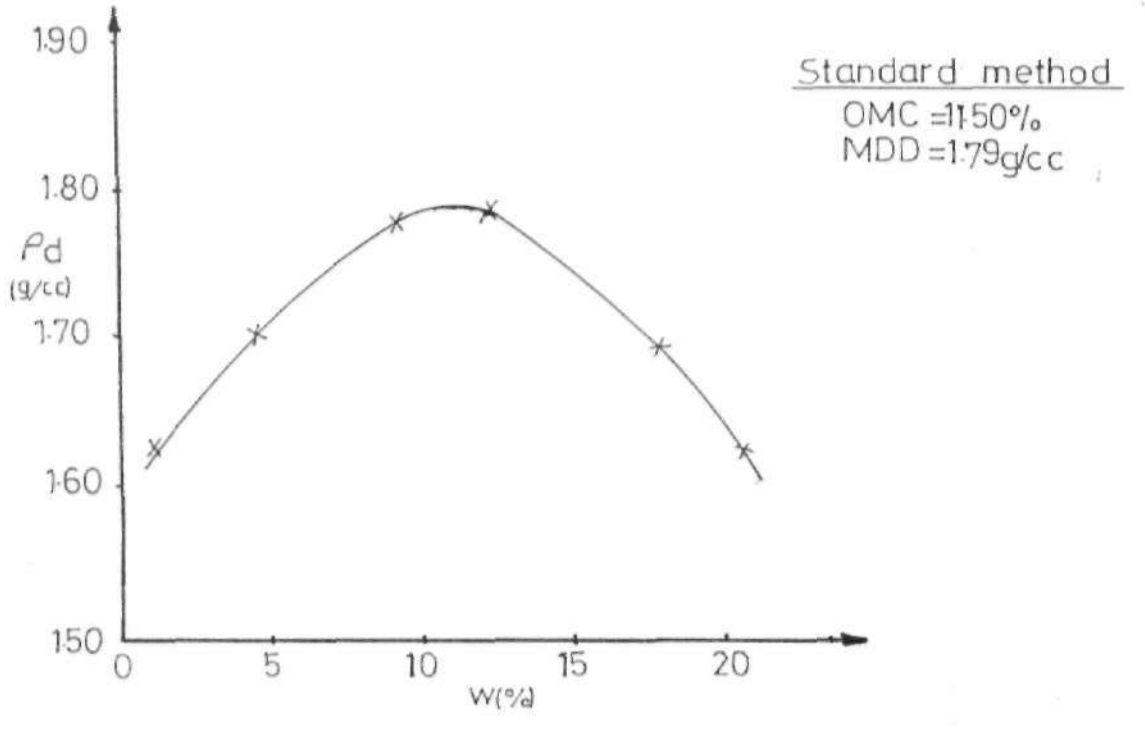


Fig.A.21 ;COMPACTION CURVES FOR SAMPLE MB-3-12



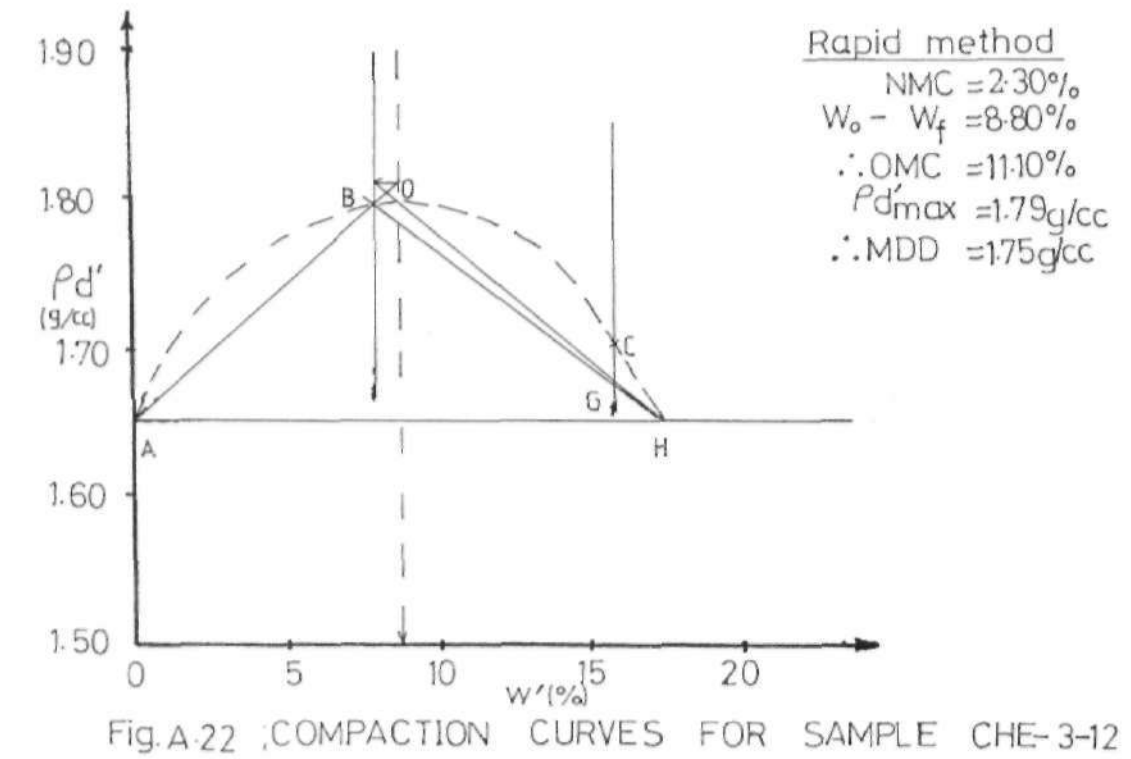
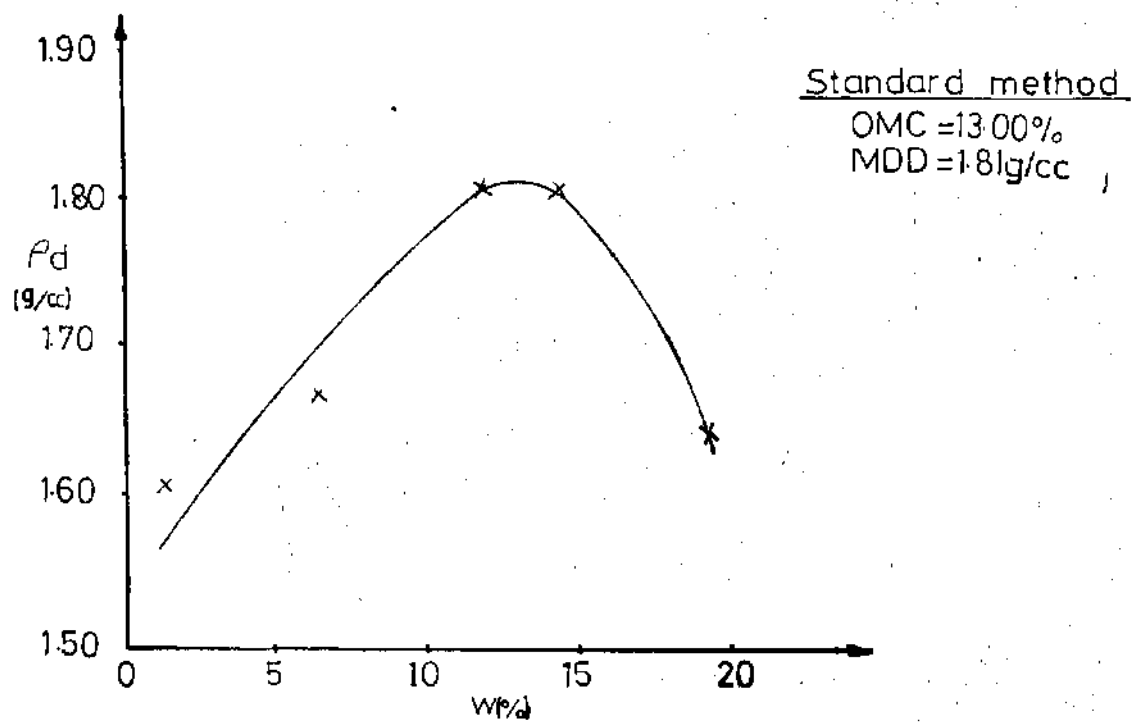


Fig. A.22 ,COMPACTION CURVES FOR SAMPLE CHE-3-12



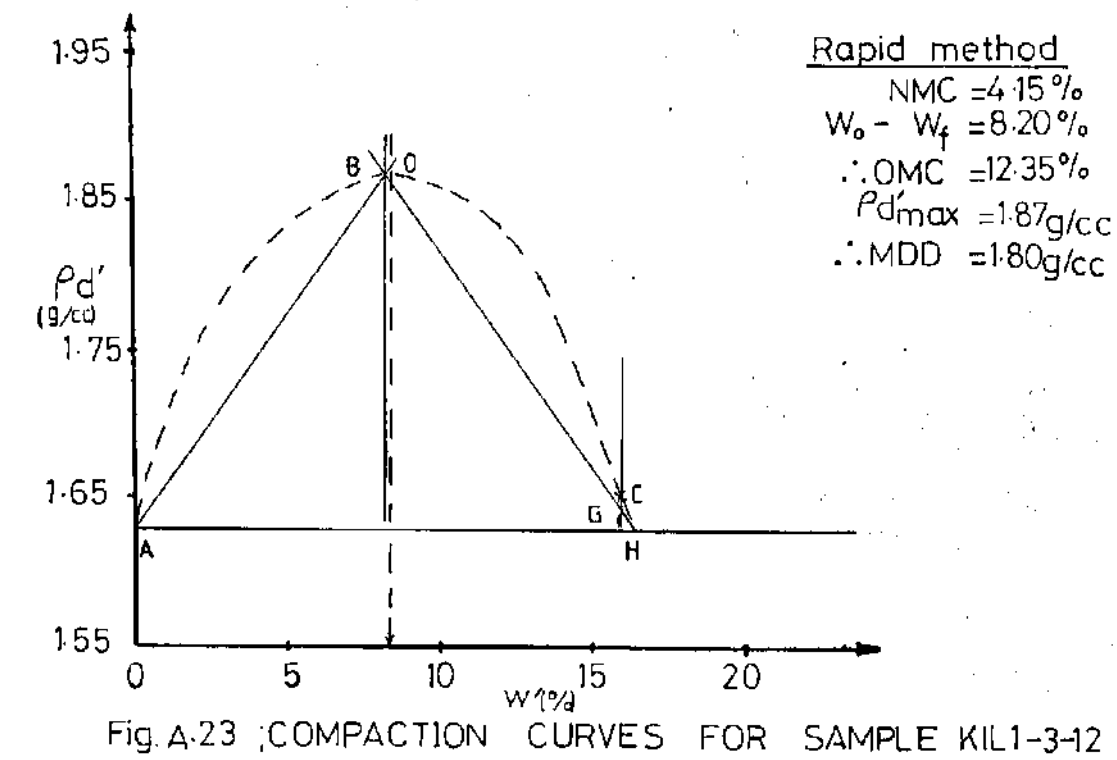
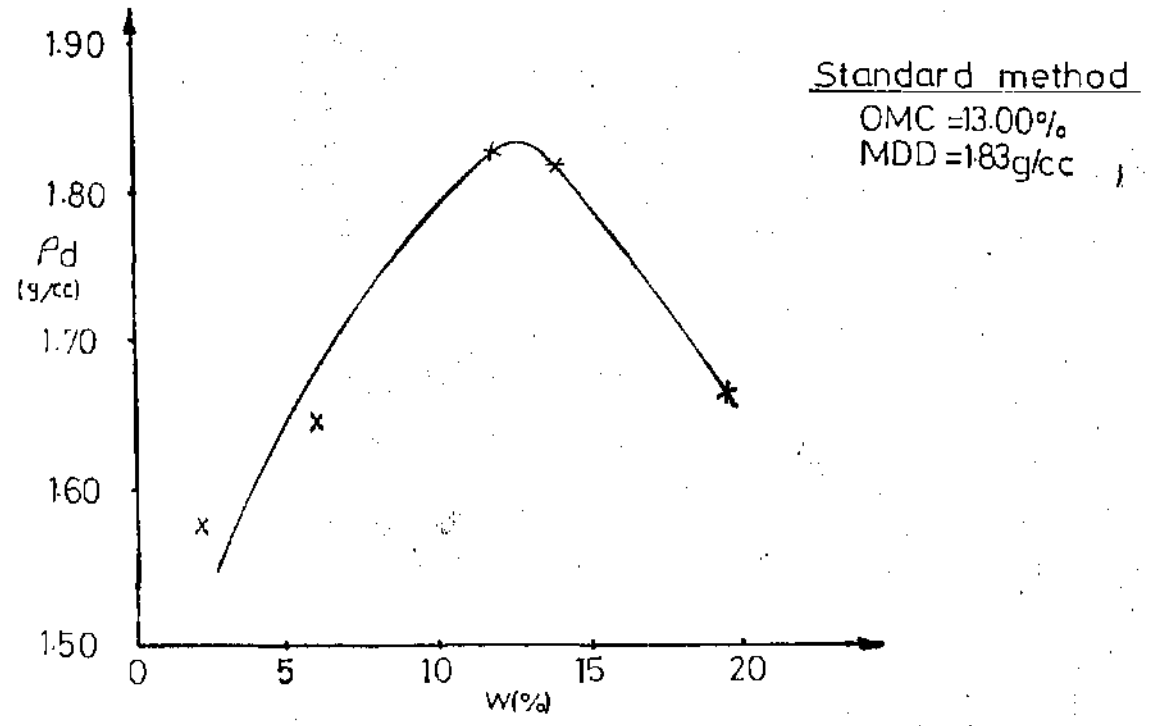


Fig. A.23 ;COMPACTION CURVES FOR SAMPLE KIL1-3-12



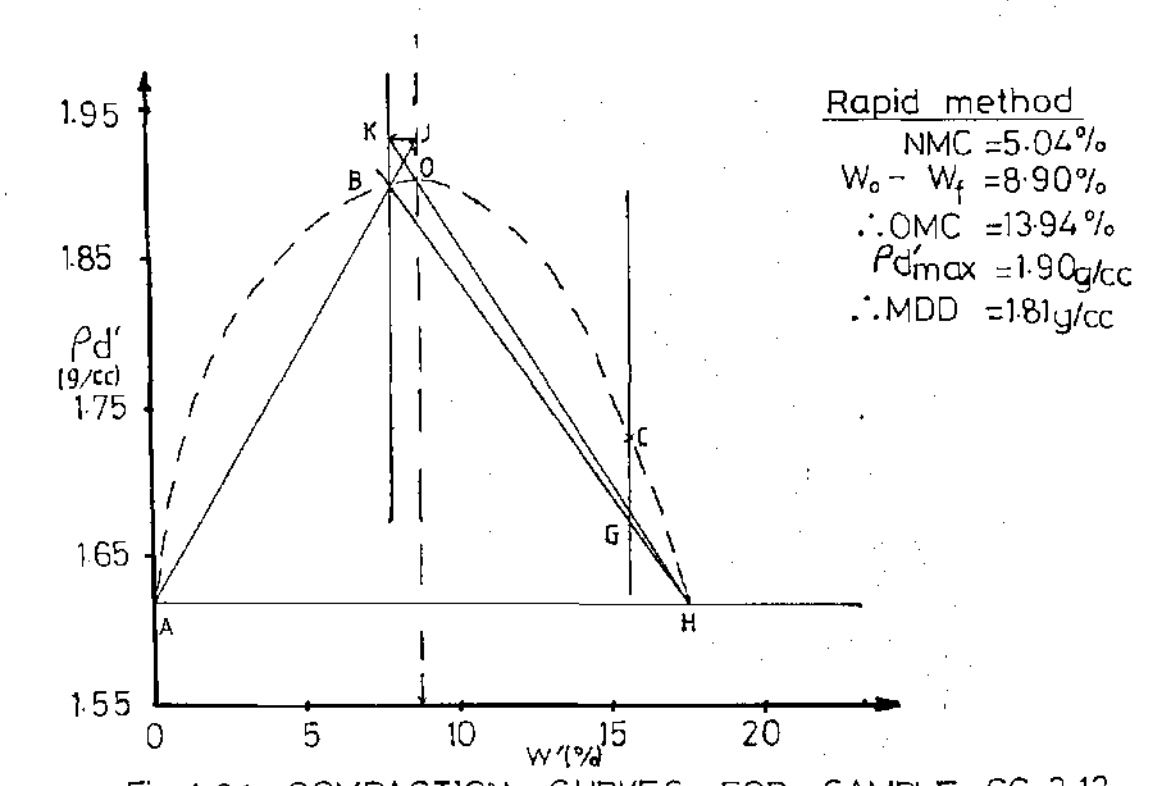
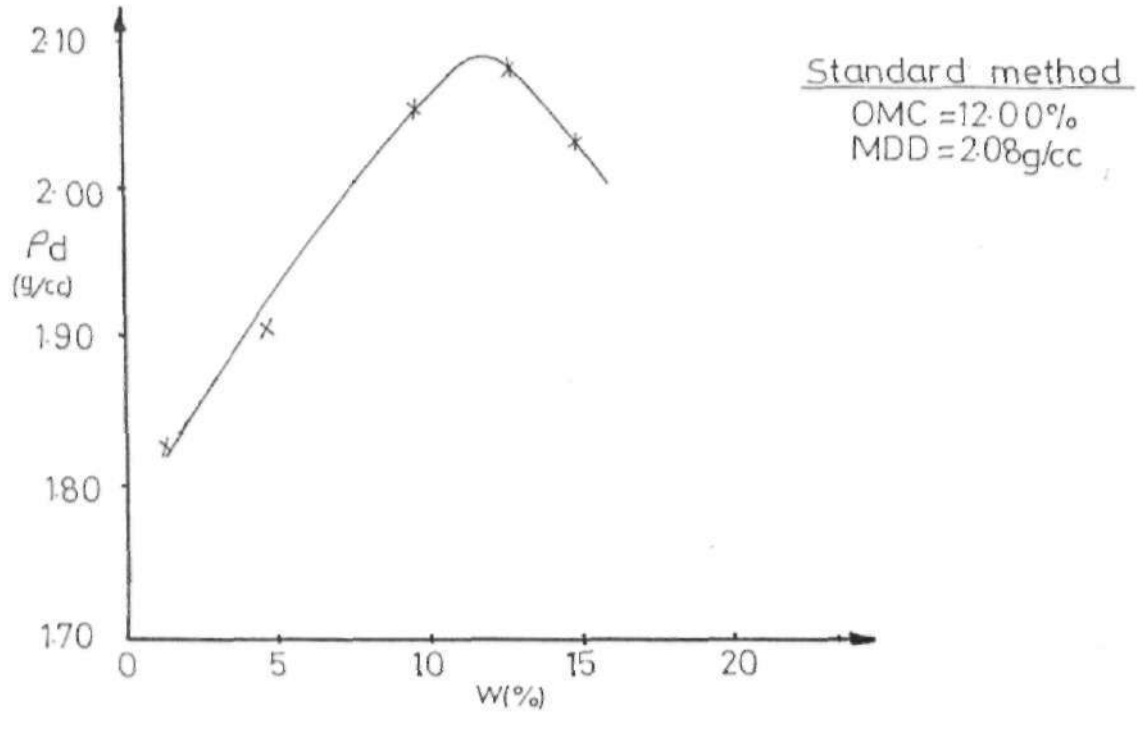


Fig.A.24 ;COMPACTION CURVES FOR SAMPLE CC-3-12



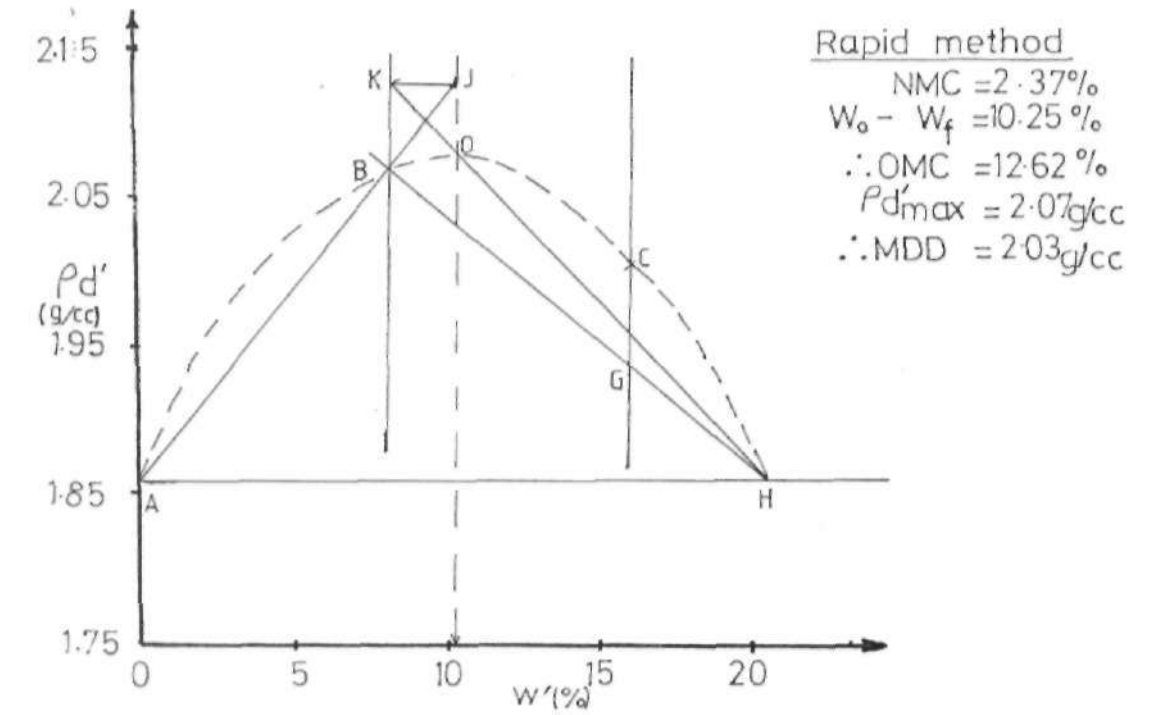
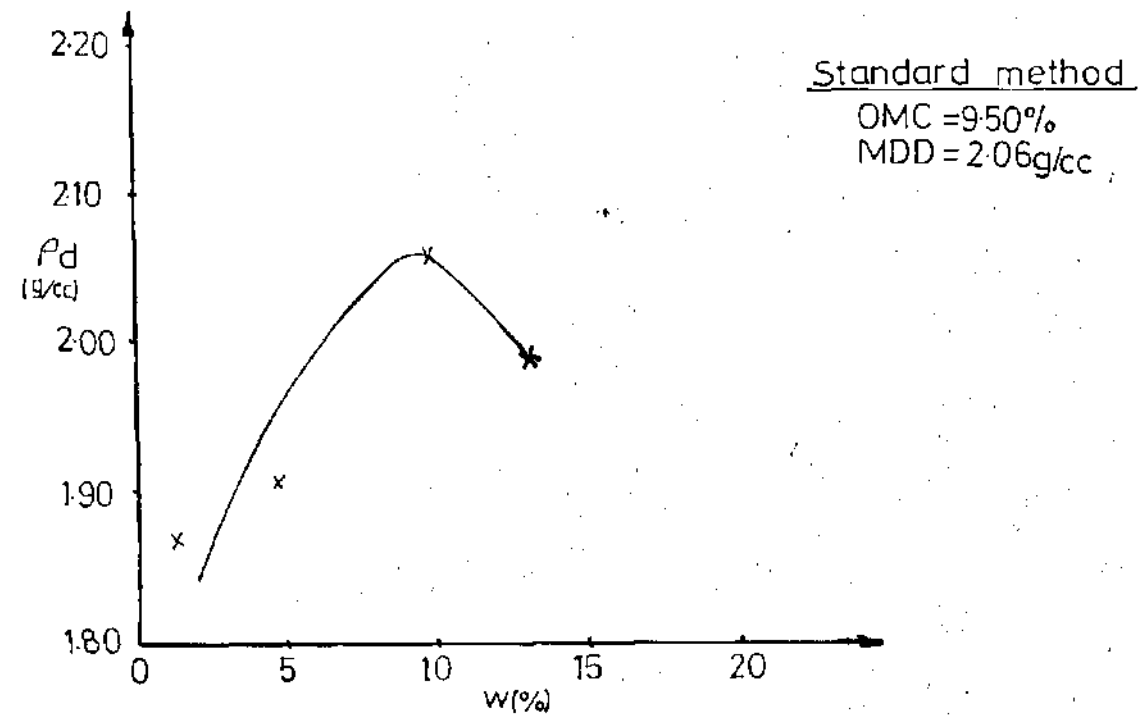


Fig. A·25 ;COMPACTION CURVES FOR SAMPLE Rd20CH14·3



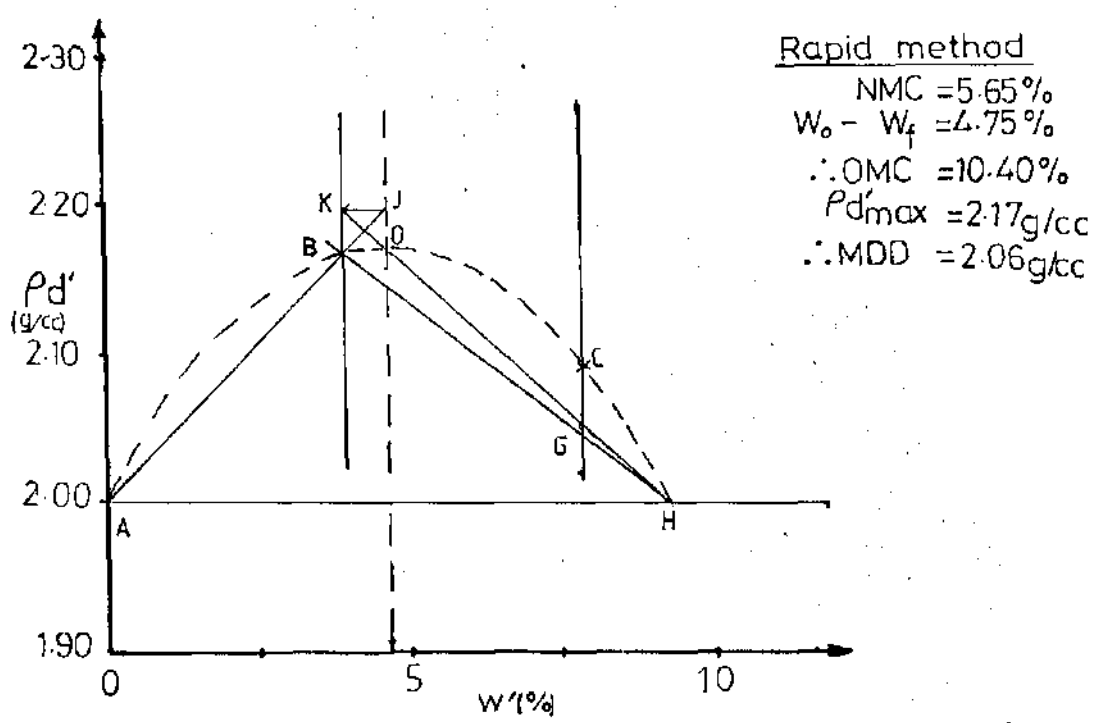


Fig. A·26 COMPACTION CURVES FOR SAMPLE Rd18CH2 4

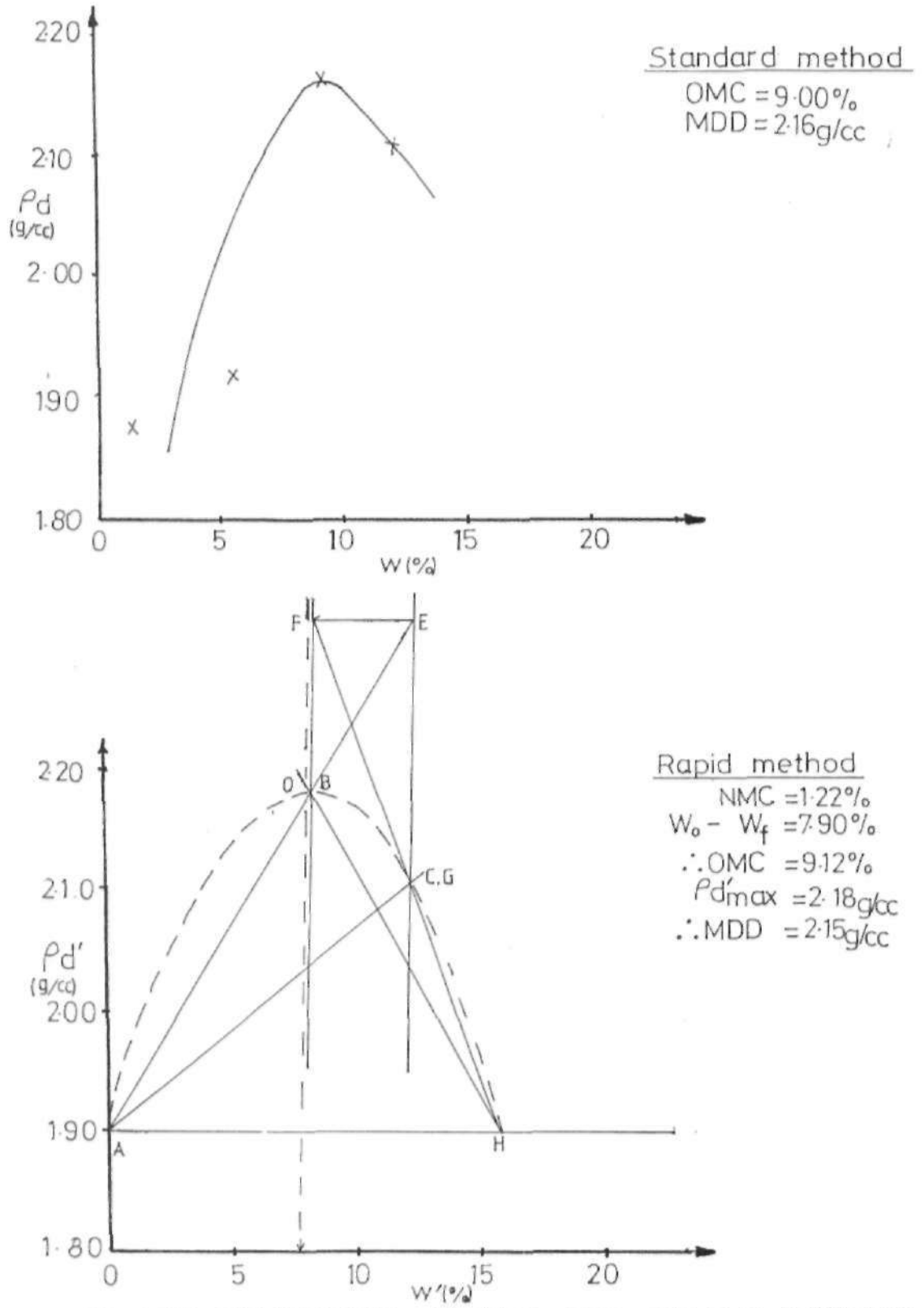
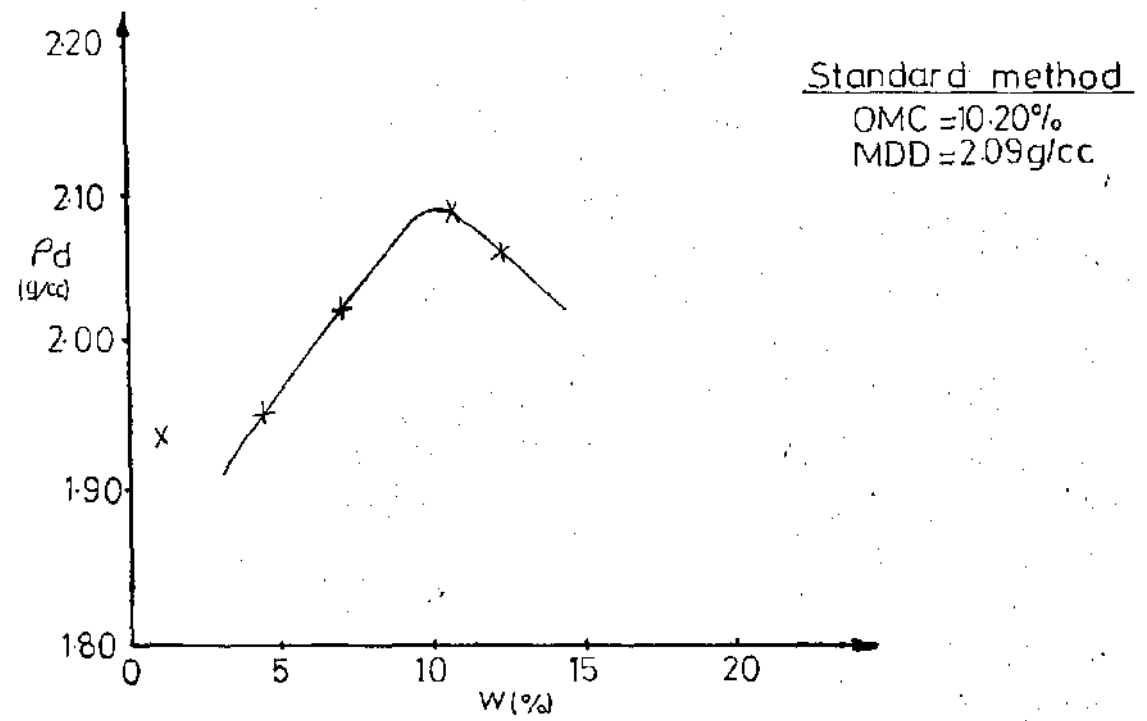


Fig. A-27 ;COMPACTION CURVES FOR SAMPLE Rd18CH7-3

318948



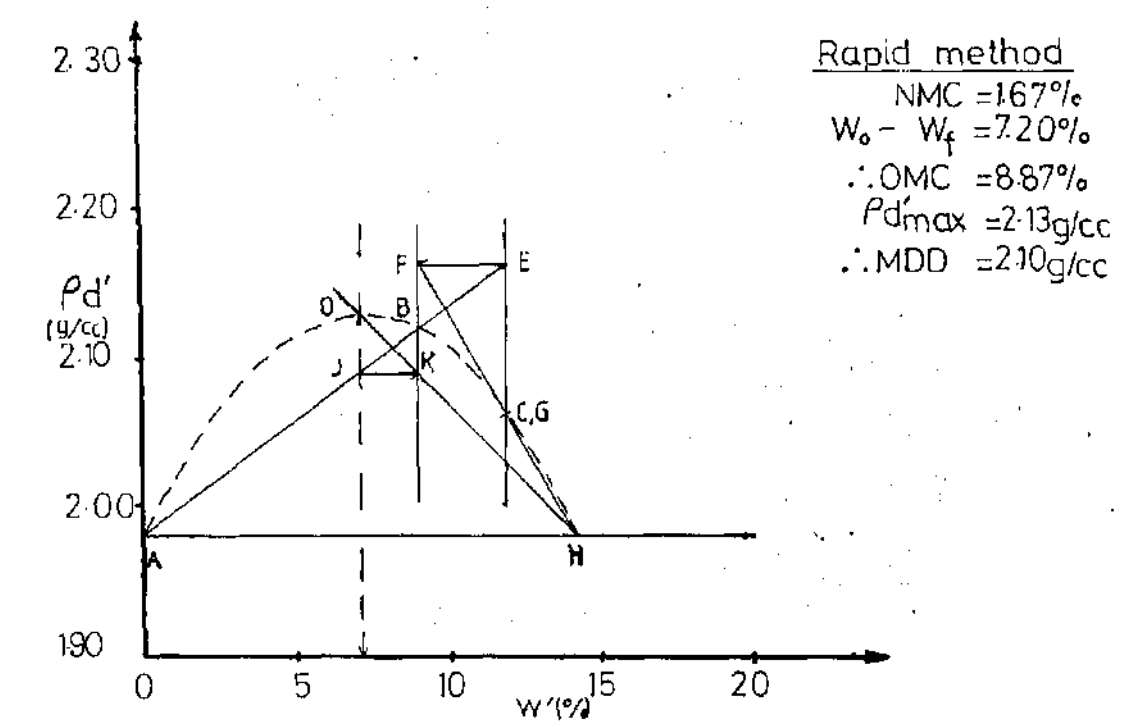
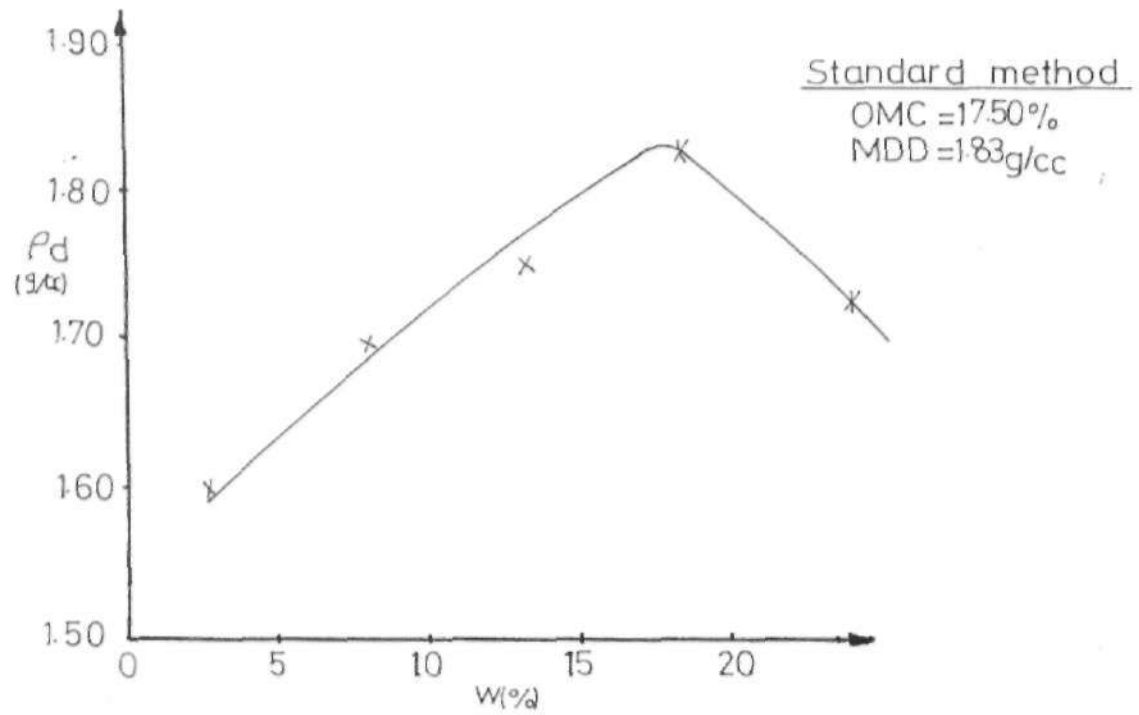


Fig. A·28 ;COMPACTION CURVES FOR SAMPLE Rd20CH2·6



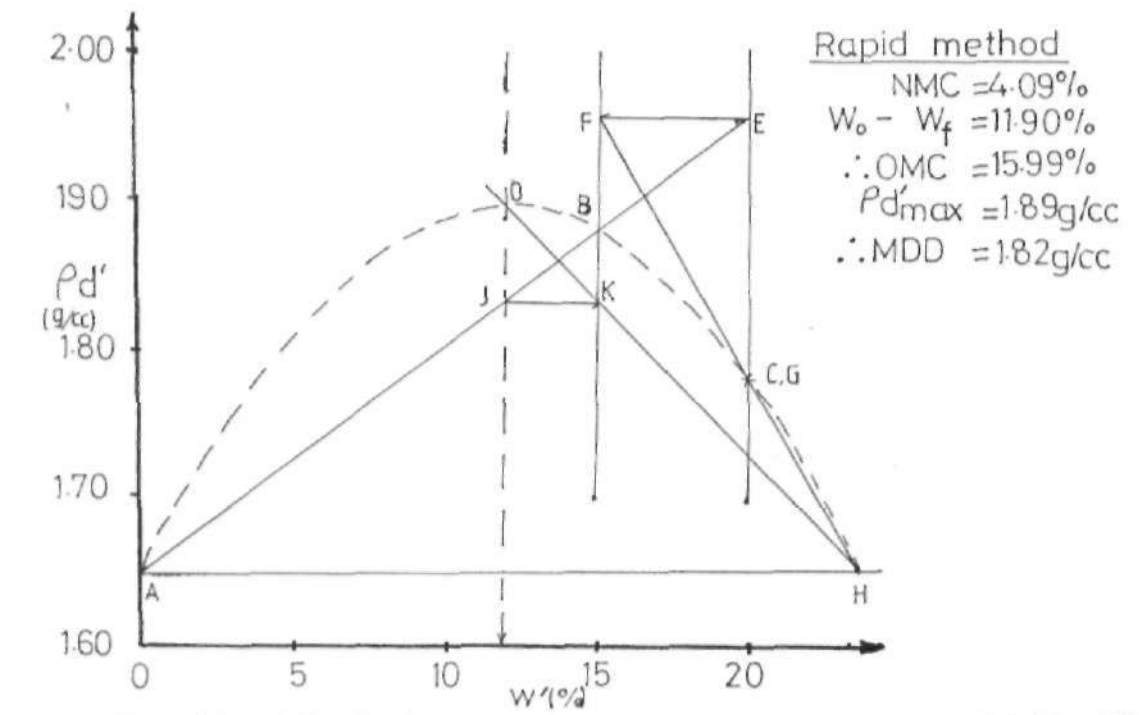
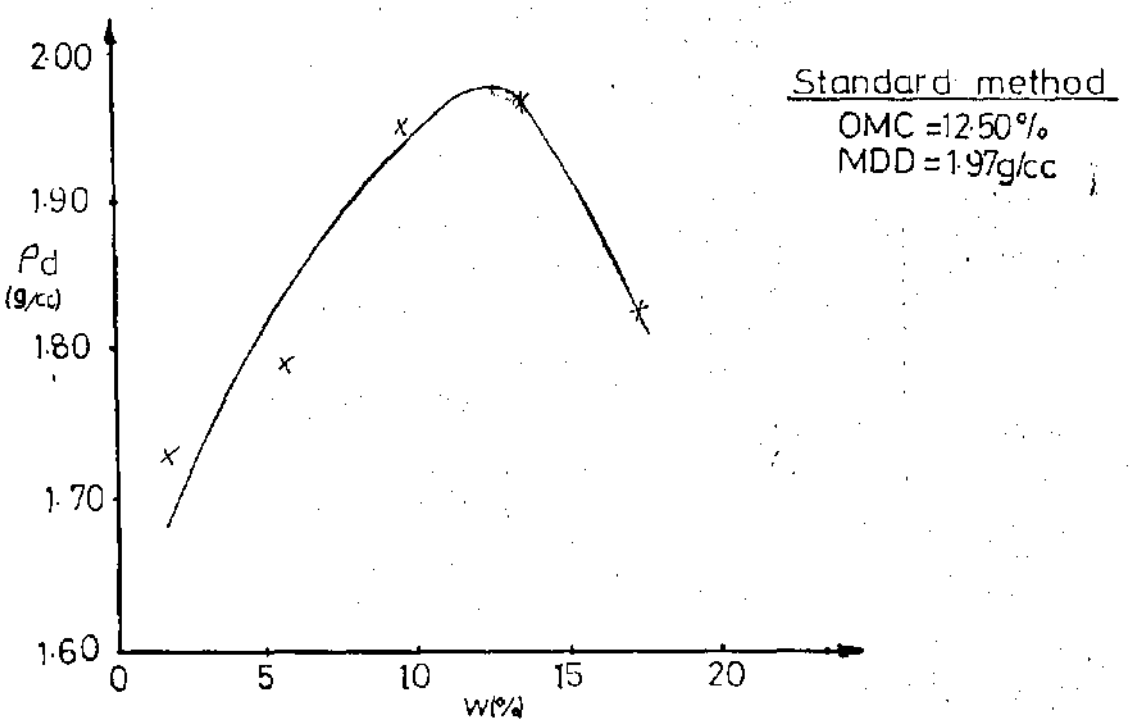


Fig.A.29 ;COMPACTION CURVES FOR SAMPLE Rd22CH50.2



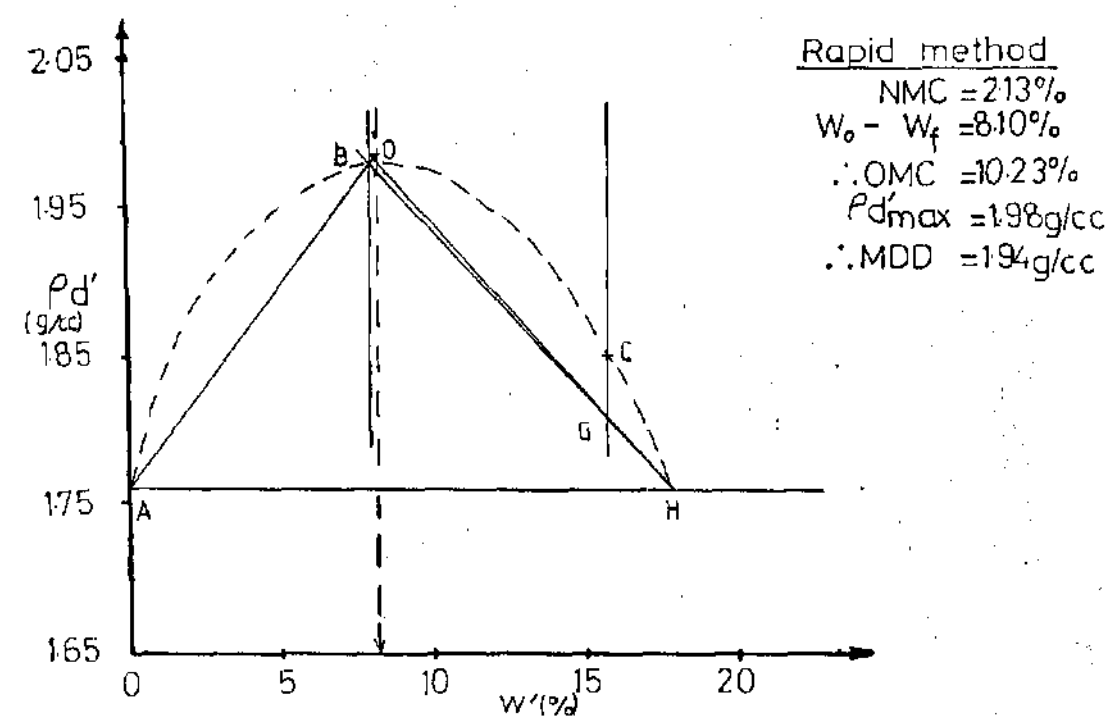
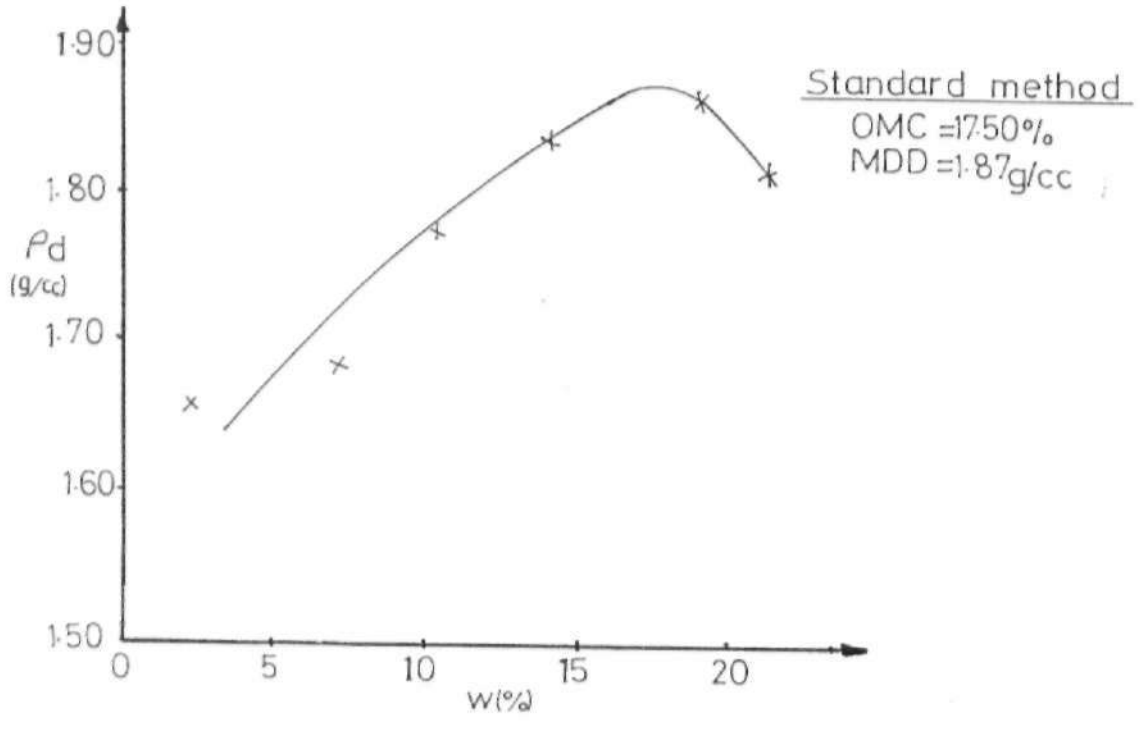


Fig. A.30 COMPACTION CURVES FOR SAMPLE Rd15CH1·3



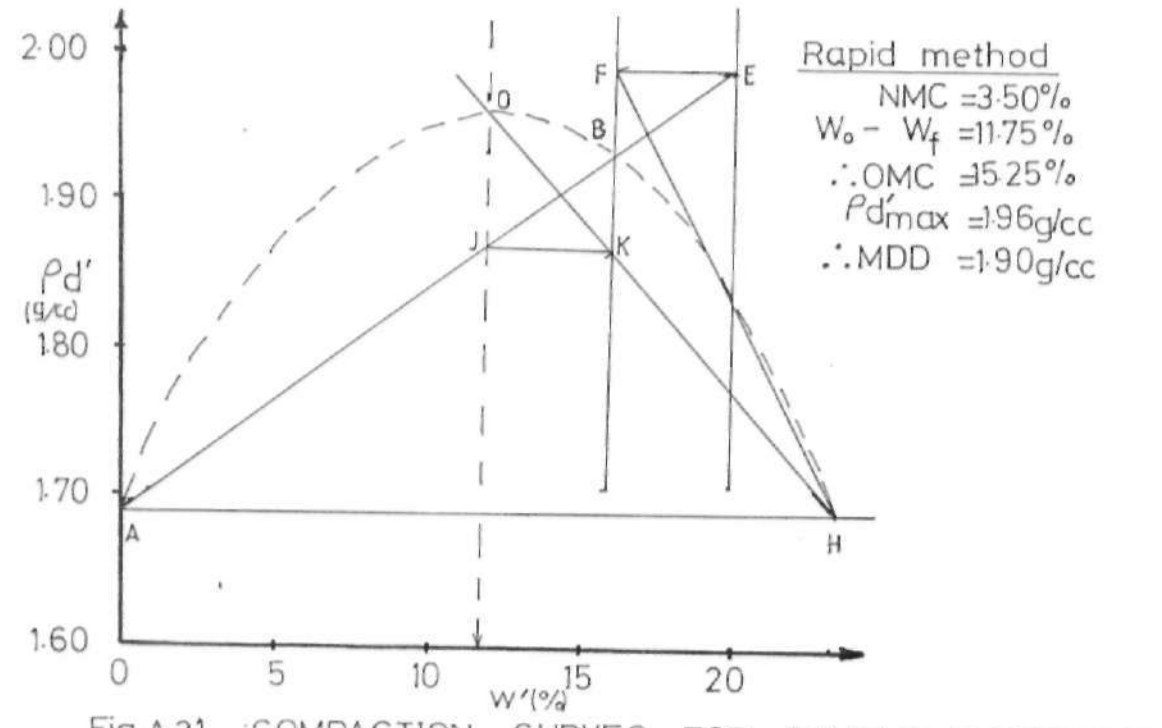
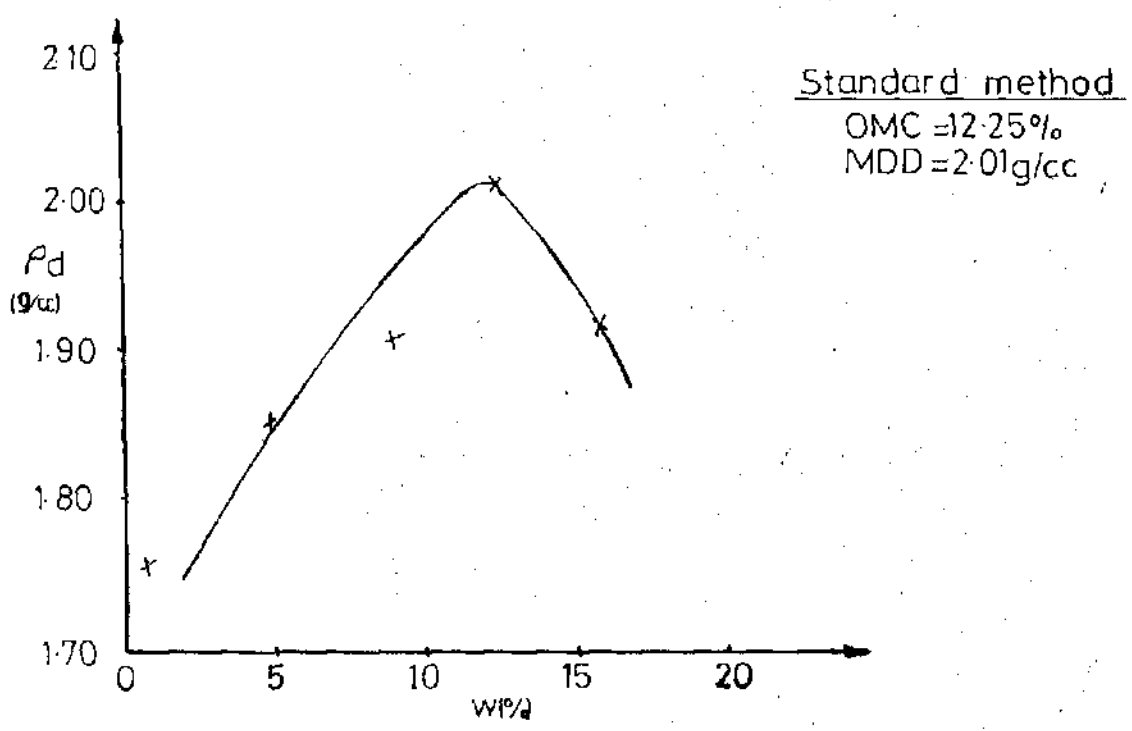
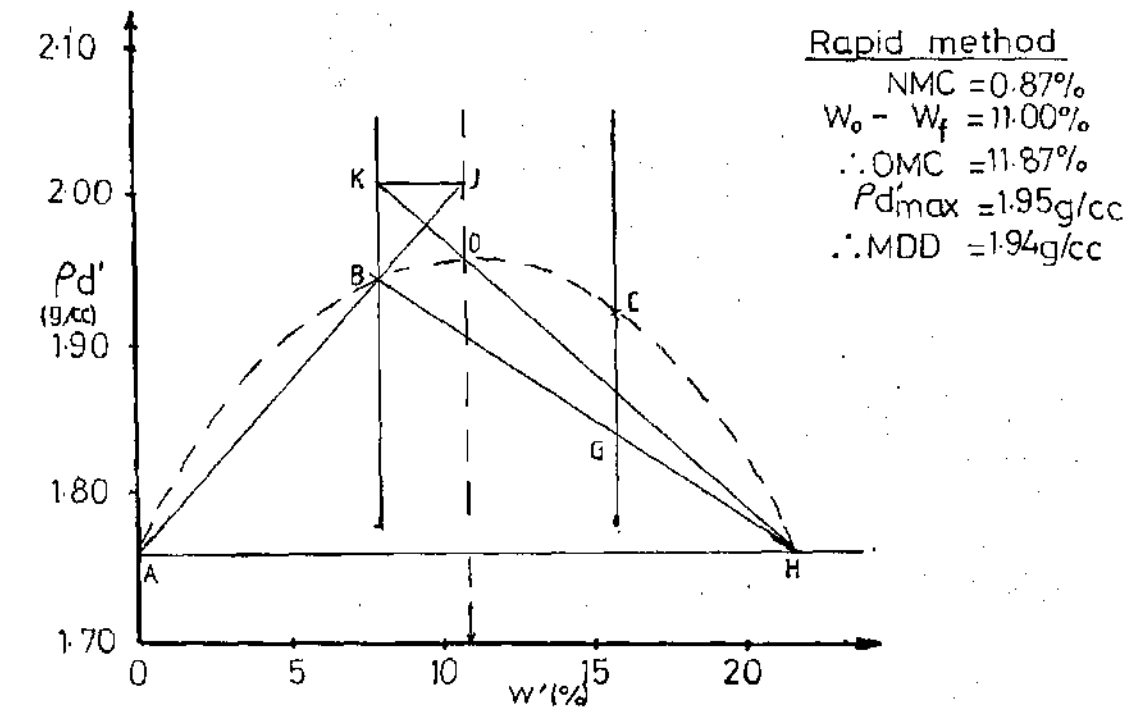


Fig.A.31 ;COMPACTION CURVES FOR SAMPLE Rd22CH53·25

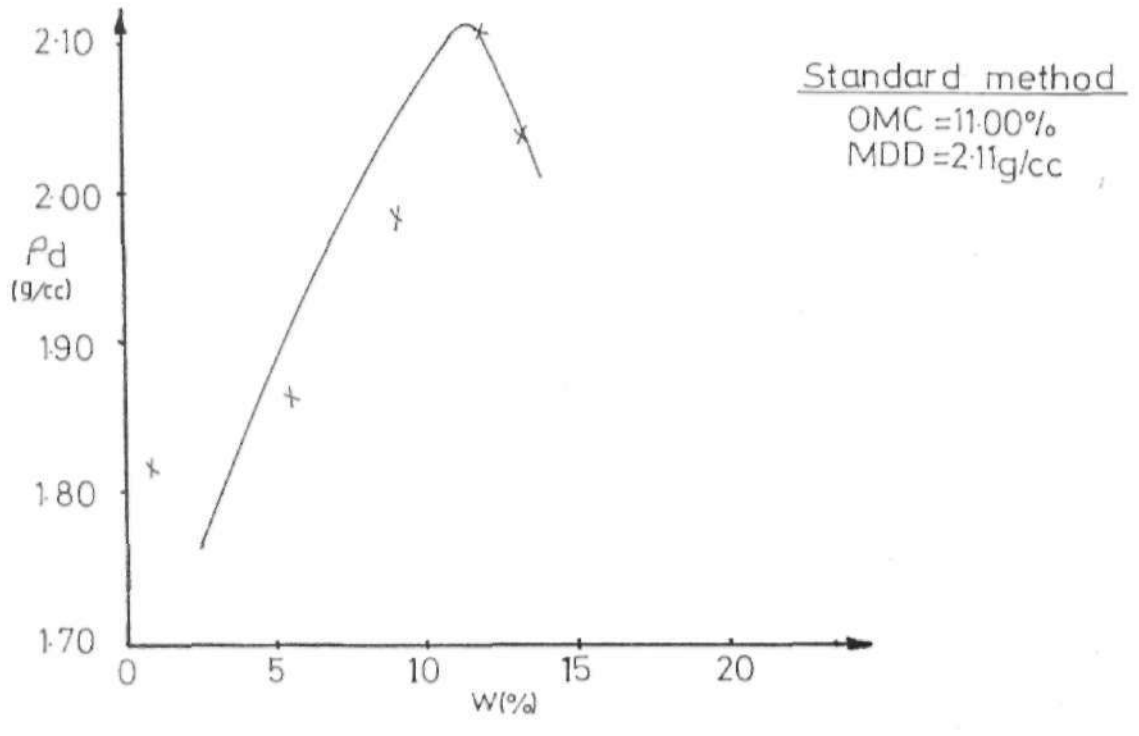


Standard method
OMC =12·25%
MDD =2·01g/cc



Rapid method
NMC =0·87%
$W_o - W_f$ =11·00%
∴OMC =11·87%
$\rho d'_{max}$ =1·95g/cc
∴MDD =1·94g/cc

Fig.A·32 COMPACTION CURVES FOR SAMPLE Rd27CH12·55



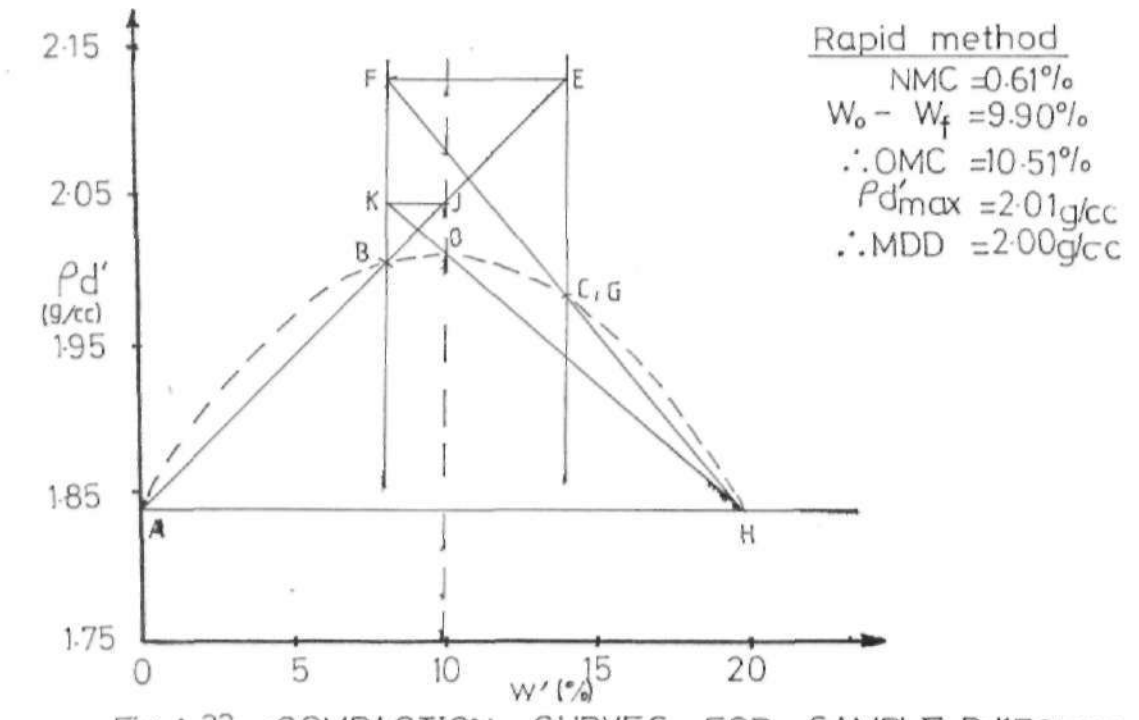
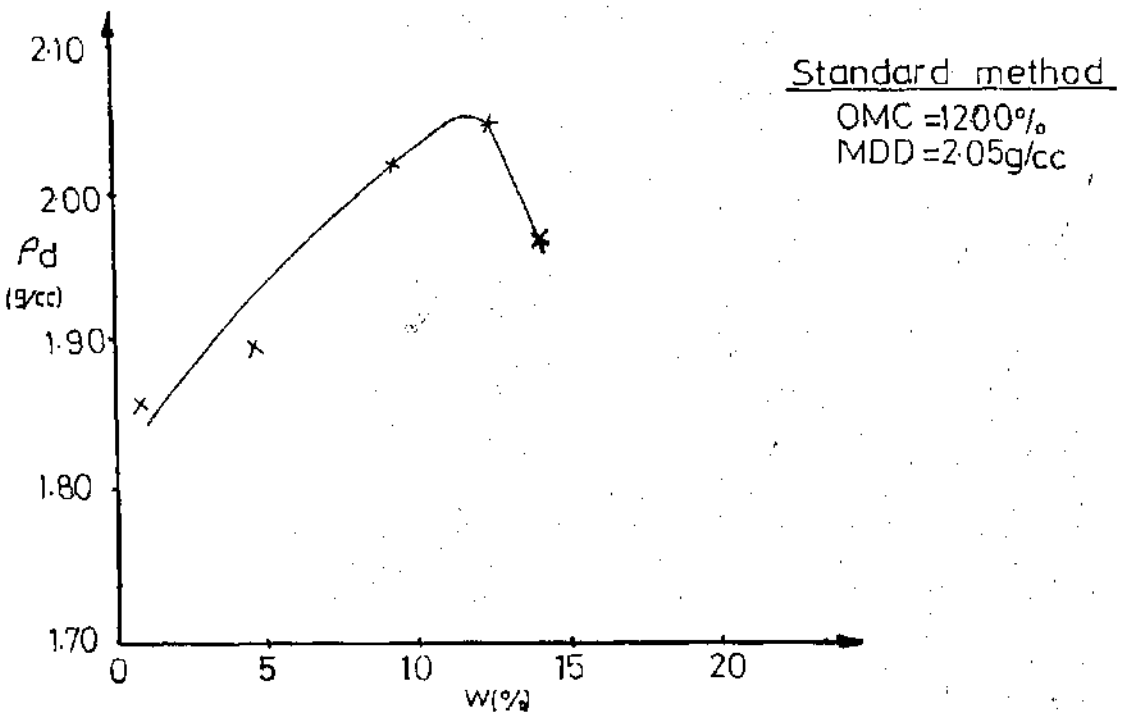
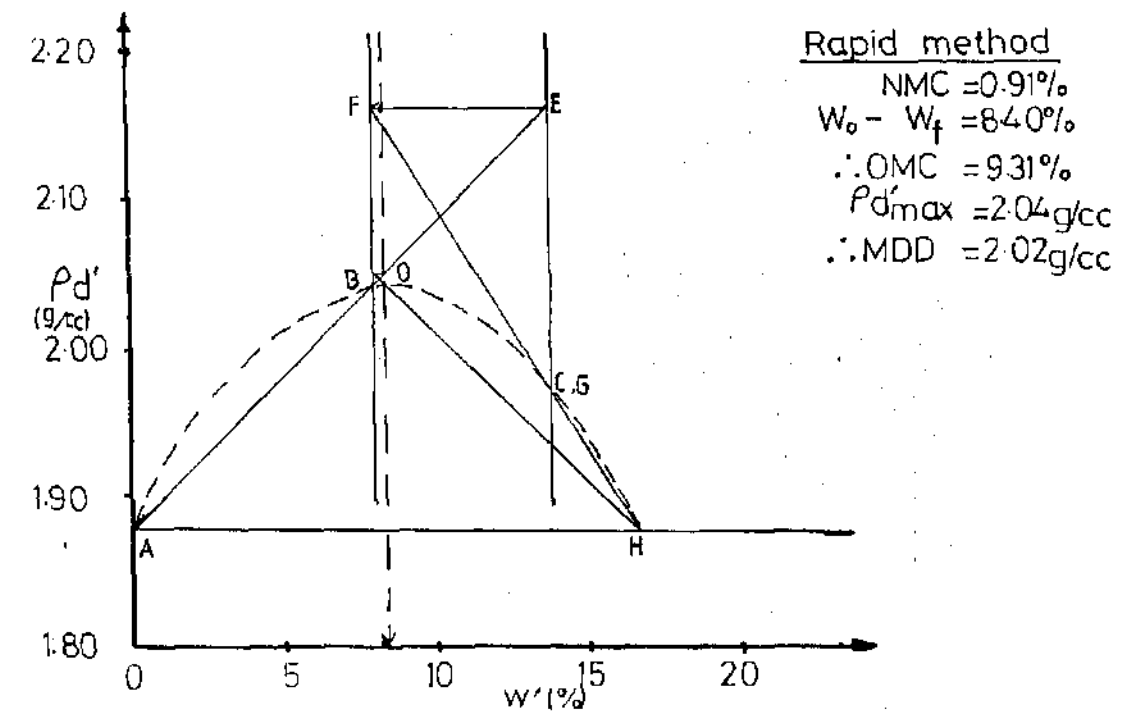


Fig.A·33 ;COMPACTION CURVES FOR SAMPLE Rd15CH7·2

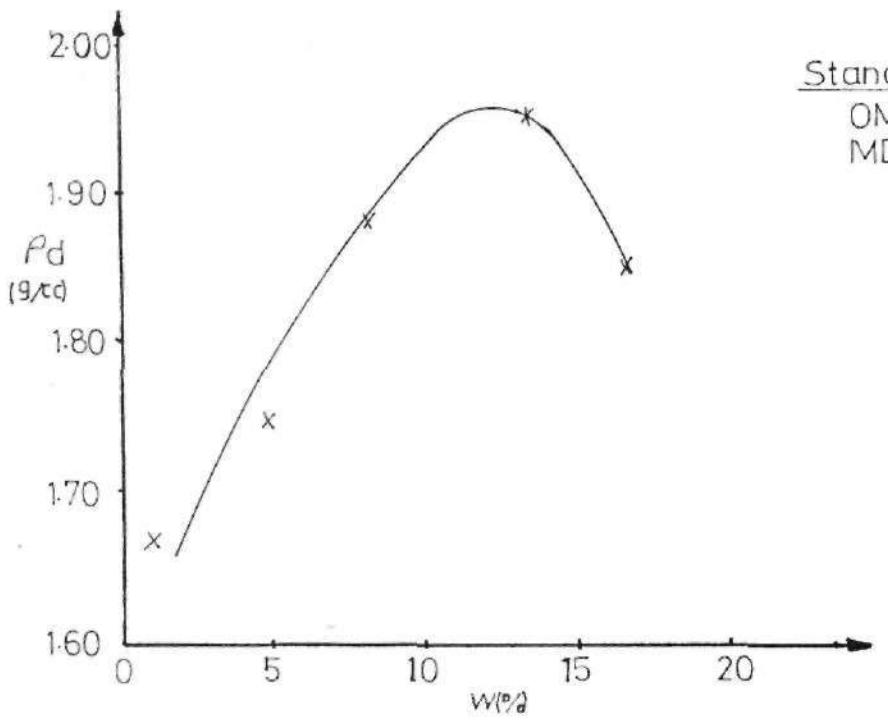


Standard method
OMC =12·00%
MDD =2·05g/cc



Rapid method
NMC =0·91%
$W_o - W_f$ =8·40%
∴OMC =9·31%
$\rho_{d'max}$ =2·04g/cc
∴MDD =2·02g/cc

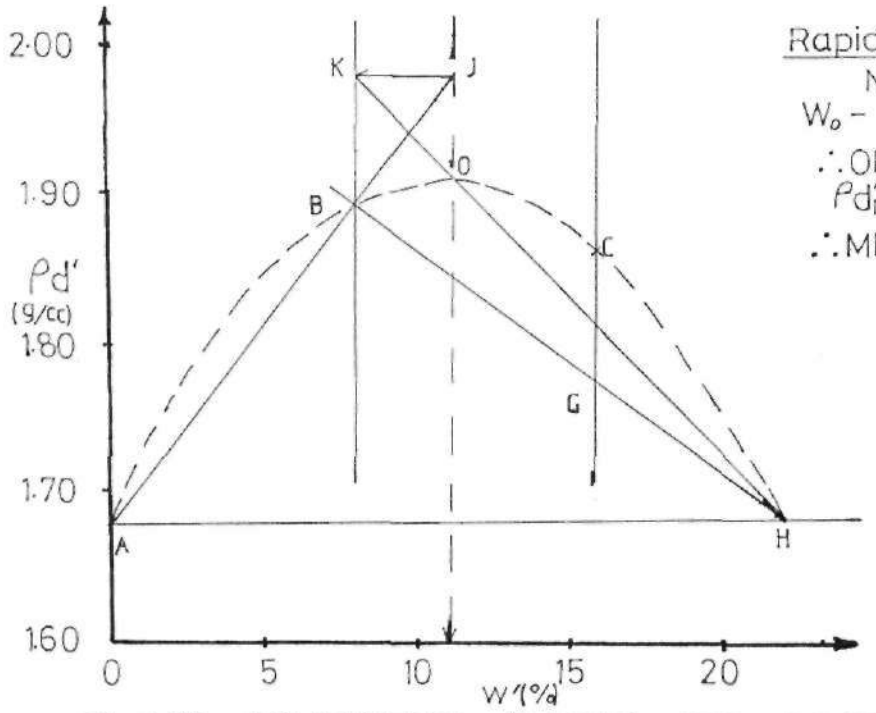
Fig.A·34 ;COMPACTION CURVES FOR SAMPLE Rd17CH530



Standard method

OMC =12·20%

MDD =1·95g/cc



Rapid method

NMC =1·20%

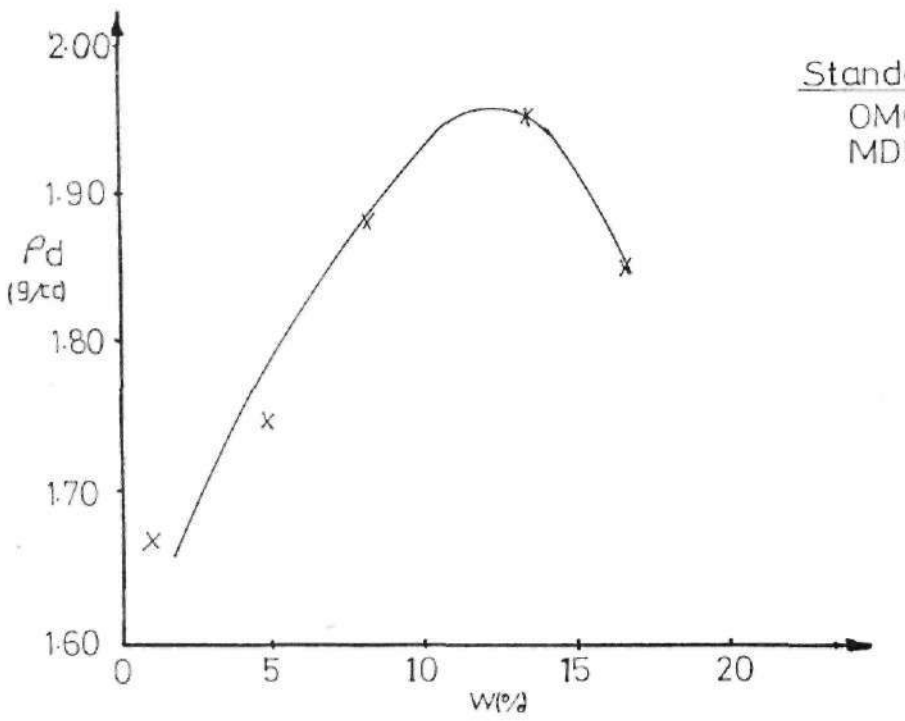
$W_o - W_f$ =11·20%

∴OMC =12·40%

$\rho d'_{max}$ =1·91g/cc

∴MDD =1·89g/cc

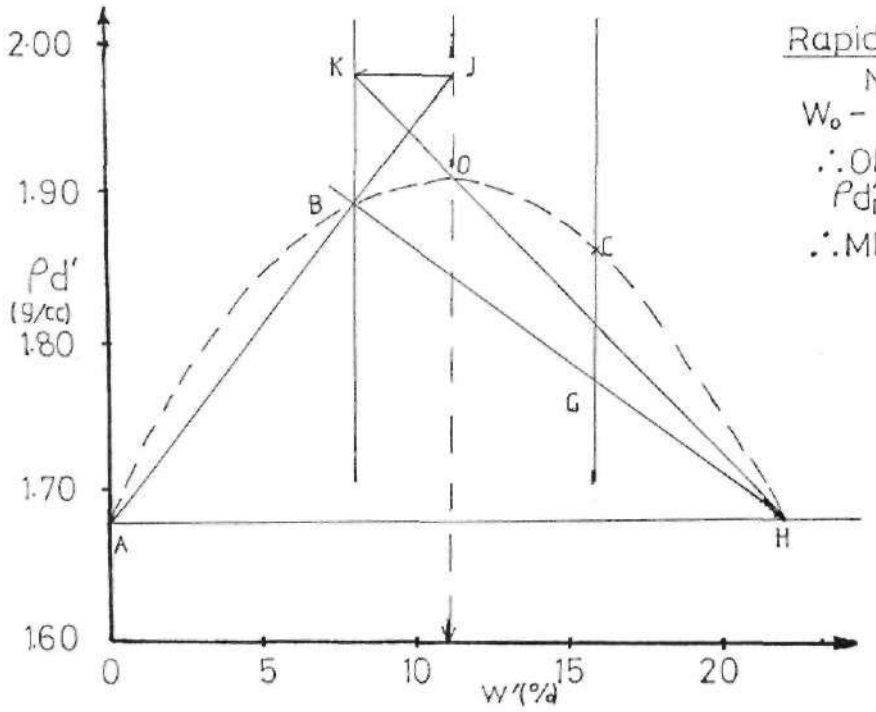
Fig.A.35 ;COMPACTION CURVES FOR SAMPLE Rd27CH0.6



Standard method

OMC =12·20%

MDD =1·95g/cc



Rapid method

NMC =1·20%

$W_o - W_f$ =11·20%

∴OMC =12·40%

$\rho d'_{max}$ =1·91g/cc

∴MDD =1·89g/cc

Fig.A.35 ;COMPACTION CURVES FOR SAMPLE Rd27CH0·6