Ministry of
Transportation and
Communications
Ontario

REPORT EM-39

AN EVALUATION OF COMPACTION CONTROL OF GRANULAR BASE AND SUBBASE AGGREGATES

Engineering
Materials
Office

EM-39

AN EVALUATION OF COMPACTION CONTROL OF GRANULAR BASE AND SUBBASE AGGREGATES

by

A.K. Barsvary, P. Eng.

and

M. MacLean, P. Eng.

SOILS AND AGGREGATES SECTION
ENGINEERING MATERIALS OFFICE

MARCH 1981

TABLE OF CONTENTS

ABSTRACT

An introductory procedure for the determination of compaction of granular and earth materials was implemented on all contracts in the 1980 construction season. The new procedures called for compaction acceptance on a lot basis; a lot is subdivided into four equal sublots and one random density test is taken on each sublot. A granular lot was acceptable for compaction if the mean of the four tests within a lot was at least 100% of the corresponding One Point Proctor (OPT) maximum density, provided that no single test resulted in less than 95% of the maximum density.

A special provision using the "control strip" density for target was incorporated into four contracts in 1980, in order to evaluate the validity of this method of compaction control of granular bases and subbases. The target density for compaction is the economically achievable average maximum density, obtained through closely controlled compaction on a test strip provided that this achieved density is equal to or greater than 95% of the OPT maximum density. Acceptance of each specified course is made where the mean dry density of the four tests within a lot is 97% or greater than the target and where each test is 95% or greater than the target density.

This report deals with the statistical analysis and evaluation of the compaction data collected during the 1980 construction season, for both the special provision and the introductory procedure.

As a result of the analysis, it is concluded that the acceptance requirements for compaction by the special provision are too lenient, when compared with the statistical dispersion of the actual data.

The analysis also proved that full compliance for acceptance, recommended by the introductory procedure, could not be met. Some 13% to 16% of the compacted lots had less than 100% OPT densities.

It has also been noted that neither of the acceptance procedures fully recognize the variability of densities within the lot. To resolve the above shortcomings, a new acceptance plan is proposed, which would be applicable to both methods of compaction control. The proposed method called "the percentage within tolerance" (or the percentage defective) sets the acceptance level to be a certain portion of the lot having less than the acceptable minimum degree of compaction.

It is recommended that the control strip technique be employed to establish the target density in those cases where the OPT maximum density value cannot be achieved.

1. INTRODUCTION

A Special Provision utilizing the control strip technique for compaction control of granular base and subbase courses was implemented in three contracts during the 1980 construction season. Those that included the Special Provision were:

Contract 80-10 - Hwy. 7 & 12, Port Hope District
Contract 80-27 - Hwy. 17 New & 29, Ottawa District
Contract 79-112 - Hwy. 7169 & 401, London District

While not specified, the control strip special provision was also used in Contract 79-102 in Central Region. At this contract, considerable difficulties were experienced compacting the base and subbase aggregates to 100% Proctor density. The use of the control strip target density solved the problems.

The objective of including the Special Provision in selected contracts was to evaluate the validity of the control strip technique for MTC base and subbase course aggregates, amend or refine the method if necessary and to reach a decision as to whether or not this method should be adopted as a MTC standard procedure.

An introductory procedure for compaction control was used on all the rest of the 1980 contracts. The procedure called for acceptance by lots, specifying a minimum compaction equal to 100% of the One Point Proctor test for the mean of four nuclear tests within base and subbase course lots. 95% compliance was specified for earth compaction. The bulk of this report deals with the discussion and evaluation of the control strip special provision and the new procedure for compaction control.

2. BACKGROUND

It has been known for some time that the conventional MTC method of compaction control of earth and granular materials does not recognize the variability of materials and the precision of tests. The large variability of the laboratory moisture-density test, the variation of the field density within a relatively small area and the fact that the maximum dry density does not always represent the material being compacted, rendered the compaction control by means of one single target value of laboratory Proctor test in many instances meaningless.

In recognition of the shortcomings of the MTC method of compaction control, there were several new developments to improve the technique during the past years. These are briefly listed as follows:

2.1 After almost two years of data collection and computer analyses of laboratory Proctor test results, the Engineering Materials Office published a short-cut method in 1979 to determine the maximum dry density and optimum moisture content. The new procedure, called the One Point Proctor Test (OPT), takes only about 20% of the time required for a standard test, and it is usually carried out right at the job-site. The OPT has gained wide acceptance by construction and quality assurance personnel.

2.2 A study conducted in 1979 on the variability of the laboratory Proctor density test revealed the large dispersion of the results. (See Report EM-32) The study demonstrated that, even with a well controlled Granular A aggregate, the result of one Proctor test may vary from the true maximum density (the mean of the population) by as much as ±41.65 kg/m^3 (±2.6 PCF). It was concluded that a reliable determination of the degree of field compaction cannot be made by using one "representative" Proctor test as the target.

2.3 During the 1979 construction season, the Soils and Aggregates Section conducted some 13 field compaction pilot studies using the control strip technique on base and subbase aggregates. As a result of the studies, it was found that, regardless of the close control of roller passes and water applications, the maximum Proctor (OPT) density could be achieved only in 30% of the cases. The field tests again demonstrated that, after a certain number of roller passes (usually 5 to 8), further passes are rather detrimental and thus, a waste of money. Studies on moisture contents have clearly proven that the conventional method of water application (spraying over a partially compacted lift) will invariably produce uneven distribution of water within the lift and will result in erroneous values of field density.

2.4 Using the experience gained during the pilot studies, it was proposed that the control strip technique be implemented province wide. The acceptance level for compaction was proposed to be 97% of the control strip density for the mean of four tests within a lot, and 95% for individual tests.

2.5 At a meeting with the Quality Assurance Committee, the Section Heads expressed some concern as to the proposed apparent relaxation of the existing acceptable degree of compaction. It was the concensus of the parties that new guidelines should be drawn which would keep the existing level of acceptance for the average of four tests within a lot. Section Heads were supporting the principle that the target density be established by the mean of the three OPT-s prior to commencement of the field compaction. It was also recommended that the control strip concept and the proposed new acceptance level of compaction be introduced by special provision, to be tested at a few selected contracts. (Special Provision is attached as Appendix 'A')

2.6 The introductory procedure was developed according to the recommendations and implemented province wide during the 1980 construction season. The procedure has retained the requirements for 100% maximum dry density for base and subbase aggregates and 95% for earth. The Soils and Aggregates Section was charged to monitor the achieved compaction on each contract, and to carry out statistical analyses in order to determine what percentage of the particular contract was outside specification limits.

The control strip Special Provision was tested in three contracts as mentioned earlier. One additional control strip project was carried out by Central Region (Contract 79-102).

3. EVALUATION OF THE CONTROL STRIP SPECIAL PROVISION

3.1 Construction of the Control Strips

The target densities for compaction control on contracts using the Special Provision were established by the control strip technique.

The control strips were constructed in conformity with the requirements of the Special Provision.

Detailed description of control strip construction for each contract and for each course is given in Appendix 'B'.

During the control strip constructions, auxiliary observations were made to study the variation in the obtained densities and final moisture contents within the depth of the particular lift. Although the control strips were compacted with very close control of moisture contents and roller passes, the above variations were found to be considerable. The interested reader is referred to the discussions in Appendix 'B' (sections 1 and 3).

From the construction of control strips, the following conclusions can be drawn:

a) No major problems were experienced in constructing the control strips.

b) Among the ten control strips, an economical and reasonable degree of compaction was attained after eight roller passes in eight cases, whereas ten passes were required in the other two.

c) With the conventional MTC method of water application, and with the available rollers, the 100% OPT maximum dry density could be reached only in three control strips; the attainable density in seven cases was between 95% and 100% of the mean OPT maximum density.

d) More than ten passes with the available rollers have no effect on the improvement of compaction of granular bases and subbases. Since more than ten roller passes may be detrimental to the already attained compaction, excessive roller passes should be strongly discouraged.

e) In many instances, the OPT maximum densities cannot be achieved on account of the variation of water content within the lift or the difficulties in raising the moisture to the optimum level. In these cases, the only viable alternative is the determination of target density by a control strip.

f) Specifying that a particular material be compacted to a certain percentage of the control strip target density appears to be logical and reasonable. In such a case, the contractor is requested to reach a density that had already been achieved.

3.2 Compaction Control Using the Control Strip Target Density

In order to statistically analyse the compaction data from the four contracts having the Special Provision, first the results were collected and organized.

The number of lots tested and accepted on the basis of the control strip target densities on each contract are given in Table 1.

Region	Contract #	Aggregate Course	# of Lots Tested
South-Western	79-112	Granular A	8
		Granular B	7
Central	80-10	Granular A	26
		Granular C	54
Eastern	80-27	Granular A	25
		Granular C	OPT Densities Used for Acceptance
Central	79-102	Granular A	56
		Granular B	27

TABLE 1

It is to be noted that the number of lots given in Table 1 does not include those lots which were tested on a temporary detour and on culvert backfills. While the compaction of these lots was equal to or higher than the acceptable 97% of the target density, it was felt that these results were not part of the population of base and subbase courses. Consequently, backfill and detour compaction data was not included in the statistical analysis.

The gradation of Granular C aggregates on Contract 80-27 was so variable that one control strip did not represent the whole range of gradations. Instead of constructing more control strips, as specified by the special provision, the project supervisor decided to use One Point Proctor tests, to determine target densities. New sets of OPT's were used for the target value where gradation change of the Granular C was noticed. The compaction results of this subbase course was also excluded from the analysis.

The Special Provision for compaction control states:

> *"The density of the specified course will be tested on a lot basis. Each lot will be subdivided into four equal sublots and one nuclear density and moisture test shall be carried out at random locations within each sublot ...Acceptance of each specified course will be made where the mean dry density of the four tests is 97 percent or greater than the target density and where each test is 95 percent or greater than the target density."*

Interpreting the above specification statistically, we can say that, in extreme cases, we will accept a lot having half of the lot compacted below the acceptable limit of 97%. Within such a lot, more than 13% of the lift will have compaction less than 95% of the target density. The validity of accepting such a rather "inadequate" compaction may be questioned. Consideration has therefore been given to increase the level of acceptance.

A full statistical analysis was carried out on the lot and sublot data of the four contracts, the results of which are presented on histograms in Figures 1 to 7 inclusive on pages 19 to 25.

By studying the histograms, we may say that, in order to achieve the 97% target density for the lot values and the 95% for the sublots, the grand mean of the population of each contract must be over 100% compaction. On those contracts where the population mean was less than 100%, certain percentages of the lots and individuals did not meet the Special Provision requirements (e.g., Figures 6 and 7). The histograms depict the statistics of the actual lot and sublot test results. They do not, however, tell us the probable variation of compaction within the quantity of aggregates represented by a lot.

To obtain further insight into the statistical variation of compaction of each contract, Tables 2 and 3 were prepared. The tables give the computed means ($\bar{x}$) and standard

GRANULAR 'A'

CONTRACT	n	$\bar{X}$	σ	% COMPACTION MEETING 95	96	97	98
				% OF THE TARGET DENSITY			
79-102	56	99.3	1.6	99.6	98.0	92.4	79.1
80-10	26	99.9	2.2	100	96.2	90.6	80.5
80-27	25	101.7	1.7	100	100	99.7	98.5
79-112	8	100.4	1.7	100	99.5	97.7	92.0
WEIGHTED MEAN	115	100.0	1.78	100	98.7	95.5	87.0
GRANULAR B & C							
79-102	26	98.7	1.7	98.5	94.4	84.1	65.9
80-10	54	101.6	2.6	99.4	98.4	96.1	91.6
79-112	7	105.7	2.0	100	100	100	100
WEIGHTED MEAN	87	101.1	2.3	99.6	98.7	96.5	91.2
GRAND MEAN				99.8	98.7	96.0	89.1

Table 2
Lot Compaction Comparisons

GRANULAR 'A'

CONTRACT	n	$\bar{X}$	σ	% COMPACTION MEETING 95	96	97	98
				% OF THE TARGET DENSITY			
79-102	223	99.3	2.5	95.7	90.7	82.1	69.8
80-10	104	100.1	2.6	97.5	94.2	88.3	79.0
80-27	100	101.76	2.4	99.7	99.2	97.6	94.1
79-112	32	100.4	2.7	97.7	94.8	89.6	81.3
WEIGHTED MEAN	459	100.1	2.5	97.9	94.9	89.2	79.9
GRANULAR B & C							
79-102	104	98.7	3.1	88.3	80.8	70.9	58.7
80-10	211	101.9	3.4	97.9	95.8	92.5	87.4
79-112	28	105.7	2.8	100	100	100	99.7
WEIGHTED MEAN	343	101.2	3.3	97.0	94.2	89.8	83.4
GRAND MEAN				97.5	94.5	89.5	81.7

Table 3
Sublot Compaction Comparisons

deviations (σ) for the lot and sublot values by contracts and show the weighted averages separately for base and subbase aggregates. The tables also show what percentage of compaction was reached and what was the variation of compaction within a particular contract.

We can see, for instance (Table 2) that, on Contract 80-10, a little more than 90% of the Granular A course was compacted to 97% of the target density or higher. More than 9% of the Granular A, however, had less than the specified 97% compaction for the lot values. Taking the grand mean of the base and subbase courses of all the contracts, it can be concluded that 96% of the lot densities (the mean of the four sublots) reached or exceeded the required 97% of the target density. Even if it is assumed that the acceptance limit is raised to 98% of the control strip target density, only about 11% of the overall compaction would have been less than the acceptance level. Similar conclusions may be drawn for the individual test data by studying Table 3. Again using the grand mean of the sublot statistics, it is seen that 97.5% of all the compaction met the required compaction of 95% target density. If we raised the acceptance level from 95% to 96% target density for the sublots (for single test), only about 5.5% of the compaction would not have met this higher limit.

During the analysis of the large amount of compaction data, it became clear that the acceptance plan does not fully recognize and control the variation of compaction within the lot. As long as the mean of the four tests within a lot is equal to or greater than 97% and sublot values are not less than 95% of the target, the lot is accepted. Whether the range of the four tests (the difference between the highest and the lowest values) is 2, 5 or 6 has no direct influence on the acceptance. This is a shortcoming of the present acceptance procedure of both the Special Provision as well as the introductory procedure, because it is known that the range within a lot will have a profound bearing on the overall variation of compaction of the entire lot.

An improved acceptance plan recognizing the mean compaction as well as the variation within the lot will be addressed under Section 5.

4. EVALUATION OF THE INTRODUCTORY PROCEDURE FOR COMPACTION

4.1 General

The introductory procedure for compaction was issued to the Regional Offices in the Spring of 1980. (Attached in Appendix 'C')

The procedure requires the target density to be set by the mean of three One Point Proctor Tests. The tests are to be done at the beginning of compaction of the particular material using samples obtained from the already placed aggregates or soil. Compaction control of each course was to be on a lot by lot basis with each lot being divided into four equal sublots. The acceptance level for compaction on granular materials was set at 100% for the mean of the four sublots and 95% for individual sublots.

In order to evaluate the introductory procedures for compaction of granular materials, all data up to and including August 31, 1980 was collected and organized. Frequency histograms were prepared for lot (n=4) and sublot (n=1) data for Granular A, B and C. These histograms are shown in Figures 8 to 10 (see Pages 26 to 28) along with the key statistics, mean and standard deviation. It is emphasized that the data contains only lots/sublots that were accepted. In certain instances, compaction did not meet the requirements of the procedures, but was accepted because the field staff was of the opinion that no further compaction was possible. The data does not include compaction on sewer bedding and certain structure/culvert backfill areas where contract documents specifically exclude the requirement for 100% compaction.

4.2 Granular Base Course Compaction

The average compaction for the 460 lots of Granular A tested was 101.6% with a standard deviation of 1.6%. Approximately 14% of the lots had a mean of less than 100%. The compaction of the latter lots should have been rejected had the procedure been strictly enforced. Assuming the requirements were modified to reject lots with less than 99% compaction, then only 5% of the lots would have been rejected. Since experience based on the control strip projects indicates that, in many instances, 100% conformance with the OPT densities cannot be achieved, the 99% criterion appears to be more reasonable.

The population mean for Granular A compaction, estimated by 1834 sublot tests, is 101.6% with a standard deviation of 2.3%. There were 0.3% of the sublots which had less than 95% compaction (the acceptance requirements of the procedures). In reviewing the mean and the statistical dispersion ($\bar{x} - 3\sigma$) of the sublots, it appears that the requirement is too lenient. Even if the guideline acceptance limit is increased to 96% for sublots, only 1% of the sublots would be unacceptable.

4.3 Granular Subbase Compaction

The average lot compaction of the subbase course materials (combined Granular B and C) is 102.2% based on 470 lots with a standard deviation of 2.1%. About 14% of the lots had a mean of less than 100% compaction. These lots were accepted because no further compaction could be attained. Again taking 99% instead of 100% for an acceptance limit, then only 6% of the lots would not meet the requirements.

The grand mean compaction for sublots was 102.2% with a standard deviation of 3.3%. Approximately 1.5% of the sublots had less than 95% compaction. About 4% of the sublot population had less than 96% compaction.

4.4 Conclusions

The guidelines specify that the lots should be accepted if the mean of the four sublot tests is equal to or greater than 100% target density. Some 13-14% of the lots did not meet these requirements in 1980.

The acceptance limit of 95% target density for individual tests appears to be too lenient, on the basis of the 1980 compaction data.

In order to set the specification to be binding to both parties, the acceptance limit for the mean of the lots should be lowered and the limit for single tests raised.

5. NEW PROPOSAL FOR COMPACTION CONTROL

5.1 Introductory Procedure

The principal purpose of the compaction procedure was to obtain better data on achieved compaction so that a statistically valid and realistic acceptance plan can be developed. The preceeding discussion has confirmed that the acceptance limits have to be modified in order to make the specification binding.

According to the procedure, a lot having a mean compaction of 100% target density is acceptable. In fact, half of such a lot does not meet the 100% criterion.

If the acceptance limit is reduced to 99%, then a lot with a mean of 99% would be acceptable. Naturally, 50% of this lot will have less than the required compaction. Hence, simply lowering the acceptance limit of the lot would reduce the quality level required in 1980.

In order to maintain the 1980 quality level, and to have a binding specification, an acceptance plan had to be developed that provided protection against accepting a lot with an excess percentage of defective material. Such an acceptance plan was studied and adopted in the new proposal, based on the method of estimating the percentage of compaction in a lot within certain limits (or percentage defective).

While the proposed plan will maintain the present quality level, it is designed in such a fashion that it will be reasonably attainable and thus can be binding. The method involves the simple calculation of the quality index of the lot (Q_i), which is governed by the mean of the four tests and the range within a lot. The acceptance plan recognizes the fact that a uniform compaction is more desirable from the performance point of view than a somewhat higher degree of compaction with large variations within a lot. A uniformly compacted lot, even with an average density less than 100% of the target, will have superior performance and will be subject to smaller differential pavement distortion than a lot with widely ranging compaction.

The proposed acceptance plan was tested on all Granular B lots of the 1980 contracts. According to the new method, most of the accepted lots would still be accepted and the rejected lots would still be rejected. A few exceptions were however noted. Some examples of these are given below:

- A lot with the mean of 102.0% and with a minimum sublot value of 95.8% was accepted by the 1980 guidelines. The proposed plan would have rejected this lot justifiably, since 10% of the lot has compaction less than 95% target density, based on the lot range of 13.2%.
- Another lot with fairly uniform compaction and sublot values of 96.2%, 97.4%, 99.7% and 98.8% was rejected because the mean was only 98%. Since the range of this lot was only 3.5%, the new plan would accept this lot. Indeed, calculations prove that 100% of this lot had compactions over 95% and 92% of the lot was compacted to higher than 96% target density.

It is felt that the proposed acceptance plan, while quite simple and easy to follow, will pinpoint deficiencies better than the present one and will not result in any change of the current quality level of compaction.

The proposed new guidelines are given below. Upright typing was used for the guidelines, where no changes are proposed from the Introductory Procedure. New portions are typed in italics.

GUIDELINES FOR THE DETERMINATION OF
COMPACTION OF GRANULAR AND EARTH MATERIALS

1. ESTABLISHING THE MAXIMUM DRY DENSITY

A maximum dry density determination is necessary for compaction control when the following methods are used:

a) the sand-cone method (ASTM-D1556)
b) the rubber-balloon method (ASTM-D2167)
c) the nuclear gauge method (ASTM-D2922 and D3017)

Since the Constant Dry Weight (CDW) method compares field volume to one-run Proctor volume, no Proctor values are required when using this technique.

When the control of compaction is carried out by methods requiring a maximum dry density, this should be determined by means of One Point Proctor Tests (OPT). Three OPT-s should be done, on samples taken randomly from each material to be compacted, at the beginning of the compaction operation. For granular materials, these samples should be taken after the material has been placed on the road (or in backfill, etc.). The exact locations of the samples should be determined by random tables. For earth materials, samples may be taken at the source, however, it is preferable to sample the material after placement.

OPT-s should be carried out by closely following the method described in the Engineering Materials Office publication entitled "One Point Proctor Determination of Moisture

Density Relationships, using a Family of Curves". After the maximum dry density and the optimum moisture content of the three OPT-s have been determined, the arithmetic means (averages) should be computed. These mean values of maximum dry density and optimum moisture content then become the *target* values for the remainder of the course being compacted.

New *target* values should be established as described above under the following circumstances:

a) at the beginning of the construction of a new granular course;

b) if there is a perceptible change in the gradation of the particular *material* (e.g., base, subbase, subgrade, etc.);

c) after 10 lots of compaction have been accepted on the basis of one set of *target* values.

2. *COMPACTION CONTROL*

The control of compaction of each course should be carried out on a lot basis. The size of the lot should be determined on the basis of area or length of compacted lifts.

Recommended maximum lot sizes are as follows:

a) Earth compaction.
Embankment: 500 m of each layer.
Pipe and sewer backfill: 100 m of every second layer.

b) Granular compaction.
Base and subbase: 500 m of each layer.
Structure and culvert backfill: every second layer.
Pipe and sewer backfill: 100 m of every second layer.

If compaction is tested by conventional methods and not by a nuclear gauge, the above lot sizes should be used to determine the maximum size of a sublot.

Prior to acceptance testing of a lot, any visibly soft or loose areas should be corrected.

Each lot of the compacted layer should be divided into four equal sublots, and one field density and moisture test (or one CDW test) should be carried out at a randomly selected location within each sublot. Upon completion of the four tests within a lot, the average dry density should be computed. When using the CDW test, the average degree (percent) of compaction of the four tests should also be computed.

Acceptance

The compaction of granular base and subbase aggregates shall be accepted if at least 99% of the lot has in place densities equal to or greater than 95% of the target density.

The compaction of fine grained soils (earth) shall be accepted if at least 99% of the lot has in place densities equal to or greater than 90% of the target density.

The percentage of a lot within the above specified limits shall be determined by the method given below:

Calculate the quality index (Q_i) for the completed lot.

For aggregates: $Q_i = \frac{\bar{x} - 95}{R}$

For earth: $Q_i = \frac{\bar{x} - 90}{R}$

where: Q_i = *quality index*

$\bar{x}$ = *the arithmetic mean of four tests within a lot, expressed as a percentage of the target density*

R = *range. The difference between the largest and the smallest value of percent compaction in a lot.*

If Q_i is equal to or greater than 0.66, then 99% or more of the lot will have compaction above the specified limits, *thus the lot for compaction should be accepted.*

Lots will meet the acceptance criterion and may be accepted for compaction without the computation of the quality index, if the mean and the range comply with the requirements shown below:

Granular

$\bar{x}$ (% compaction)	R
> 100	<7.5
99 - 100	<6
98 - 99	<4.5

Earth

$\bar{x}$ (% compaction)	R
> 95	<7.5
94 - 95	<6
93 - 94	<4.5

If the quality index of a lot falls below the level of 0.66, the compaction of the lot should be rejected, until the above conditions are met.

In the case where, after the adjustment of moisture content and additional compaction, the in place density of the lot cannot be raised to the acceptance level, a new target density should be determined by the use of the control strip method.

Acceptance of the particular material for compaction should then be determined in accordance with the method described above by using the control strip target density.

NOTE: The quality index should be computed to two decimal points. If the quality index falls below 0.66, then the percentage of the lot not meeting the specification requirements will be so high that the lot could not be accepted.

The percentages of a lot within specification (higher than 95% of granular and 90% of earth), corresponding to various values of Q_i are given below for information purposes.

If Q_i is between the values shown	The percent within specification limits
larger than 0.66	more than 99%
0.60 - 0.66	95 - 99
0.50 - 0.59	87 - 94
0.40 - 0.49	80 - 86
0.30 - 0.39	72 - 79
0.20 - 0.29	65 - 71
0.10 - 0.19	58 - 64
0.0 - 0.09	50 - 57

e.g. A granular base or subbase lot with Q_i = 0.40 will have 20% of the material compacted to less than 95% of the target density, regardless of the average density of the lot. A lot with $\bar{x}$ = 101.4% and R = 16 will have a quality index of 0.40 ($\frac{101.4-95}{96}$ = 0.40); thus, on the basis of the extreme variation of compaction, the lot will be rejected.

5.2 Special Provision

The control strip target density is proposed to be used in those cases where the specified compaction could not be achieved by using the OPT maximum densities. The acceptance criteria of the Special Provision thus have to be amended in order to be equitable with the guidelines discussed previously.

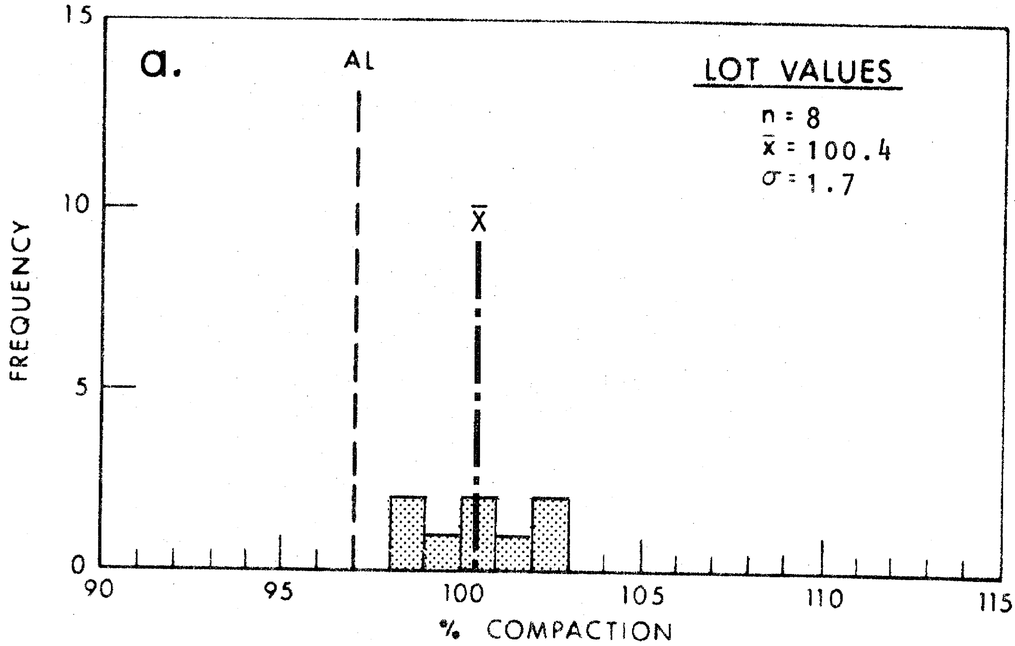
It is, therefore, recommended that the control strip Special Provision be amended and incorporated into the proposed new procedure.

6. ACKNOWLEDGEMENT

Special thanks are due to Mr. H.D. Reed who carried out all the statistical computations, designed the documentation for this report and provided guidance for the field implementations of the Special Provision.

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'A' CONTRACT 79-112 REGION S-W



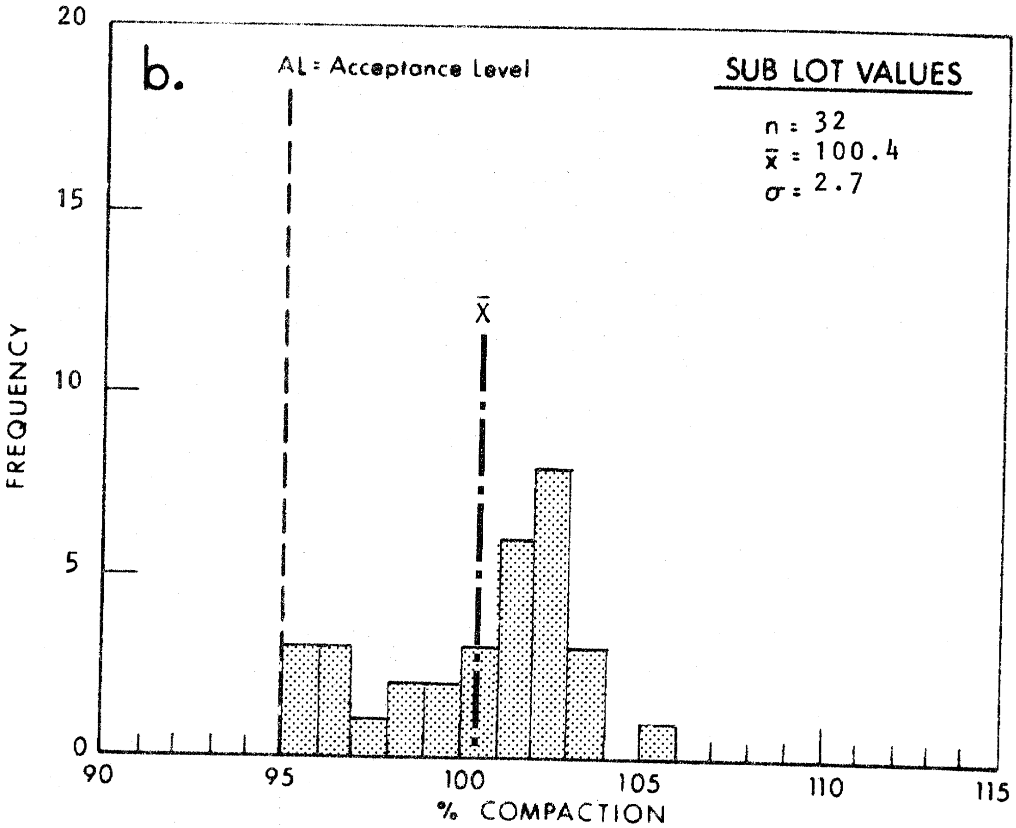


FIGURE 1

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'B' CONTRACT 79-112 REGION S-W

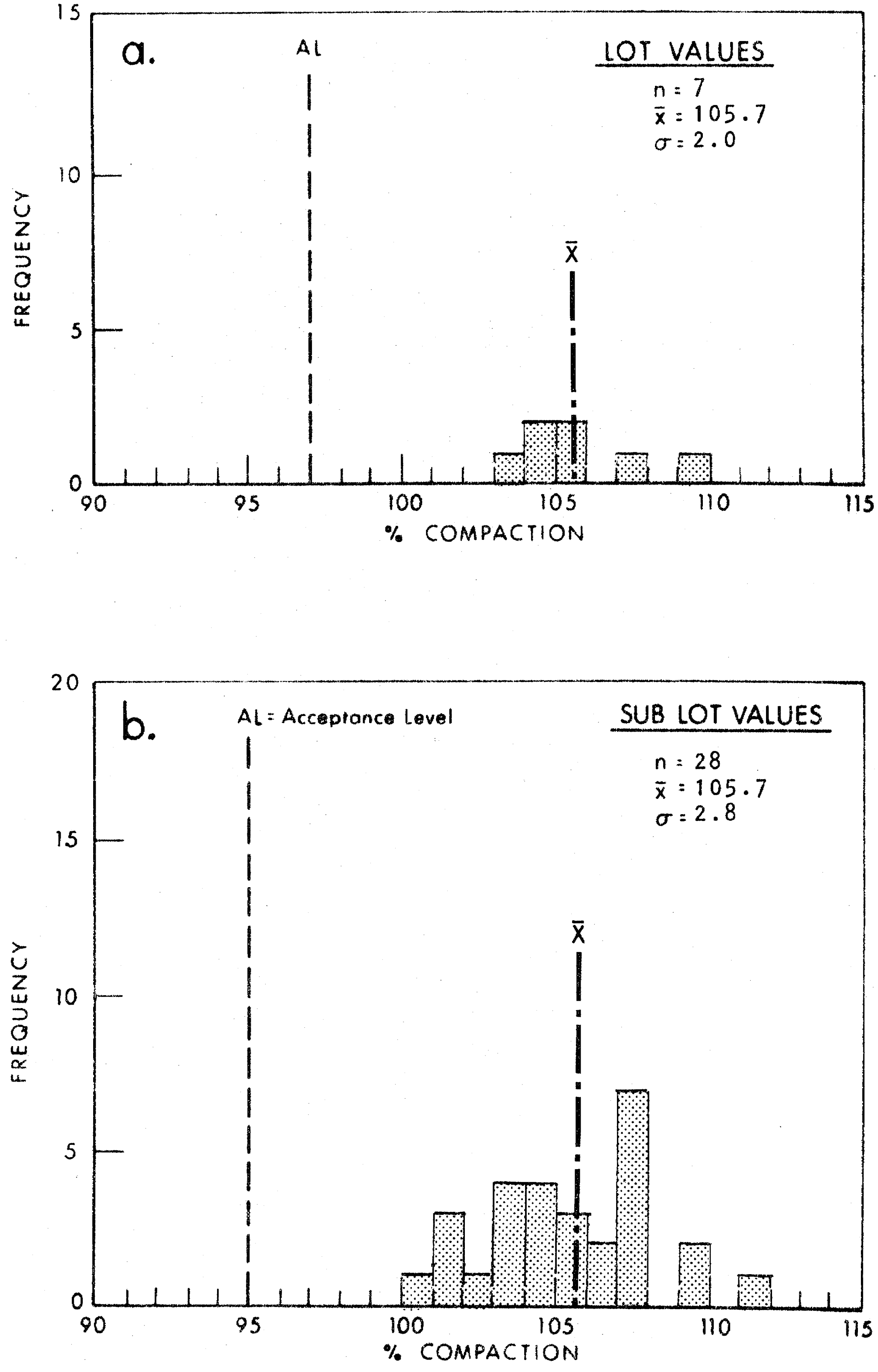


FIGURE 2

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'A' CONTRACT 80-10 REGION CENTRAL

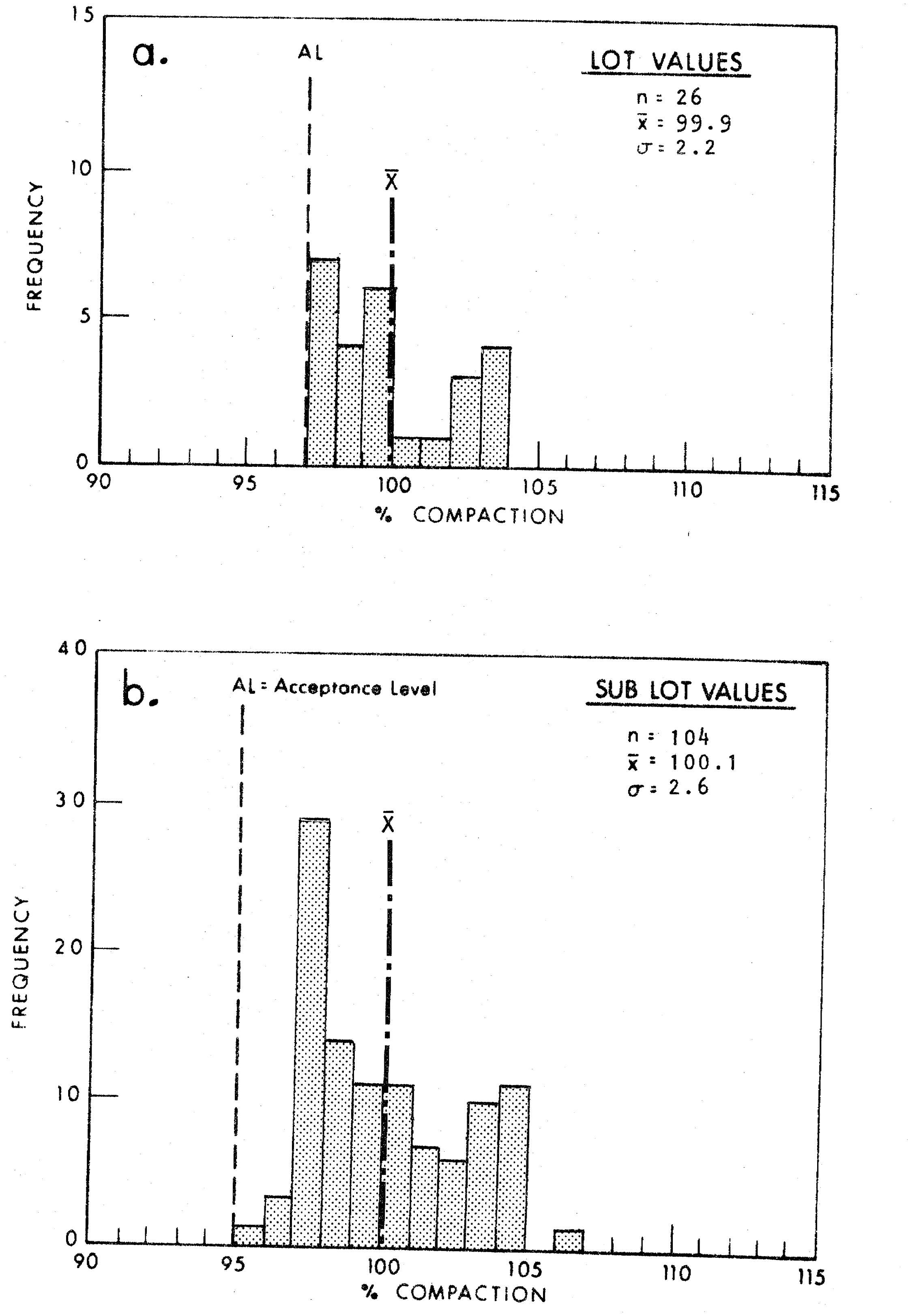
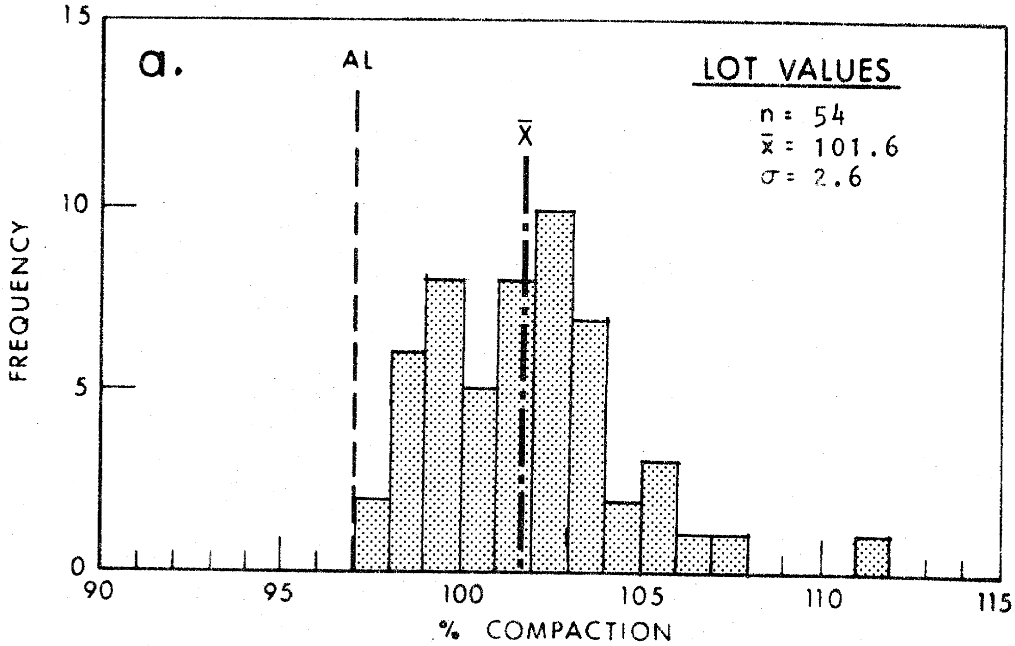


FIGURE 3

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'C' CONTRACT 80-10 REGION CENTRAL



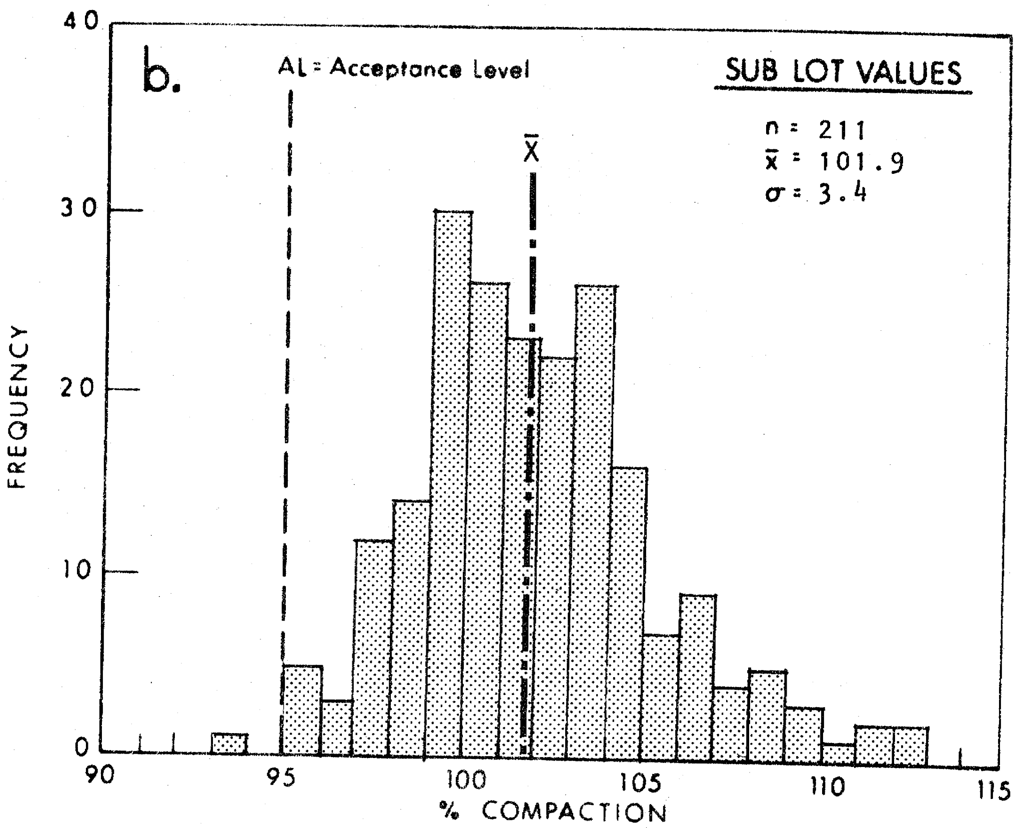


FIGURE 4

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'A' CONTRACT 80-27 REGION EASTERN

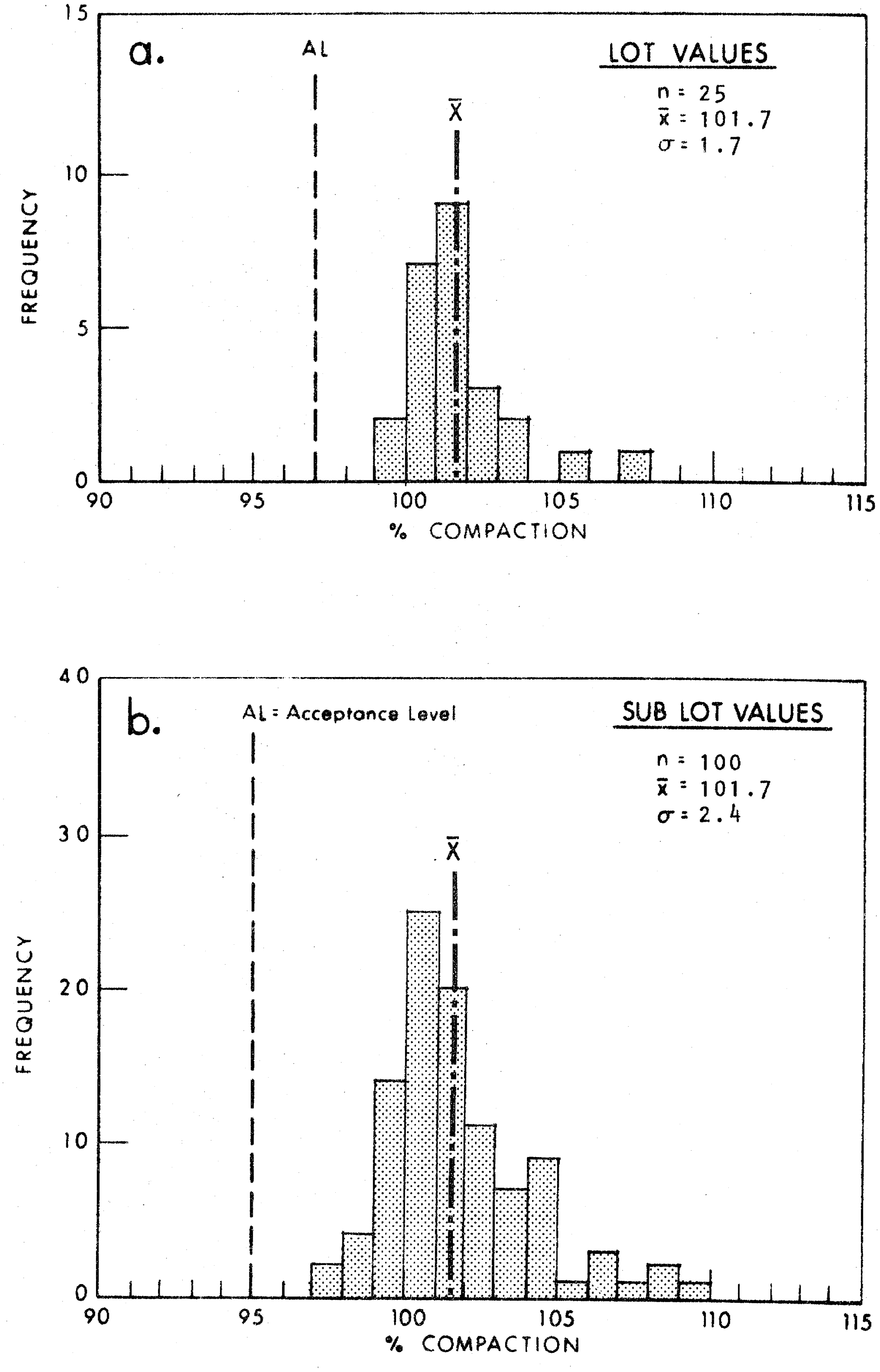
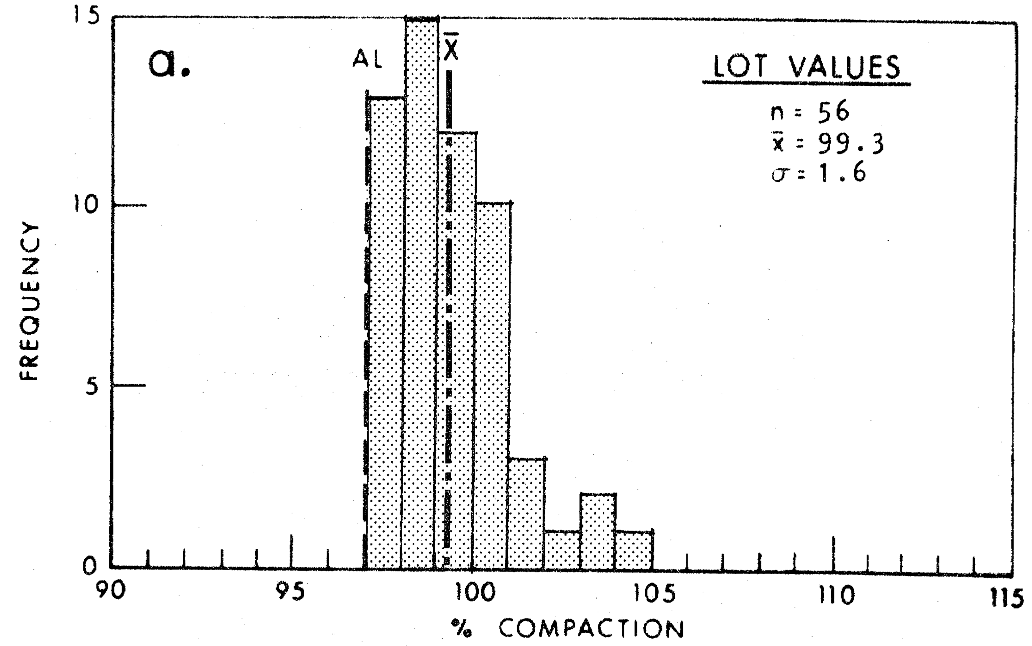


FIGURE 5

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'A' CONTRACT 79-102 REGION CENTRAL



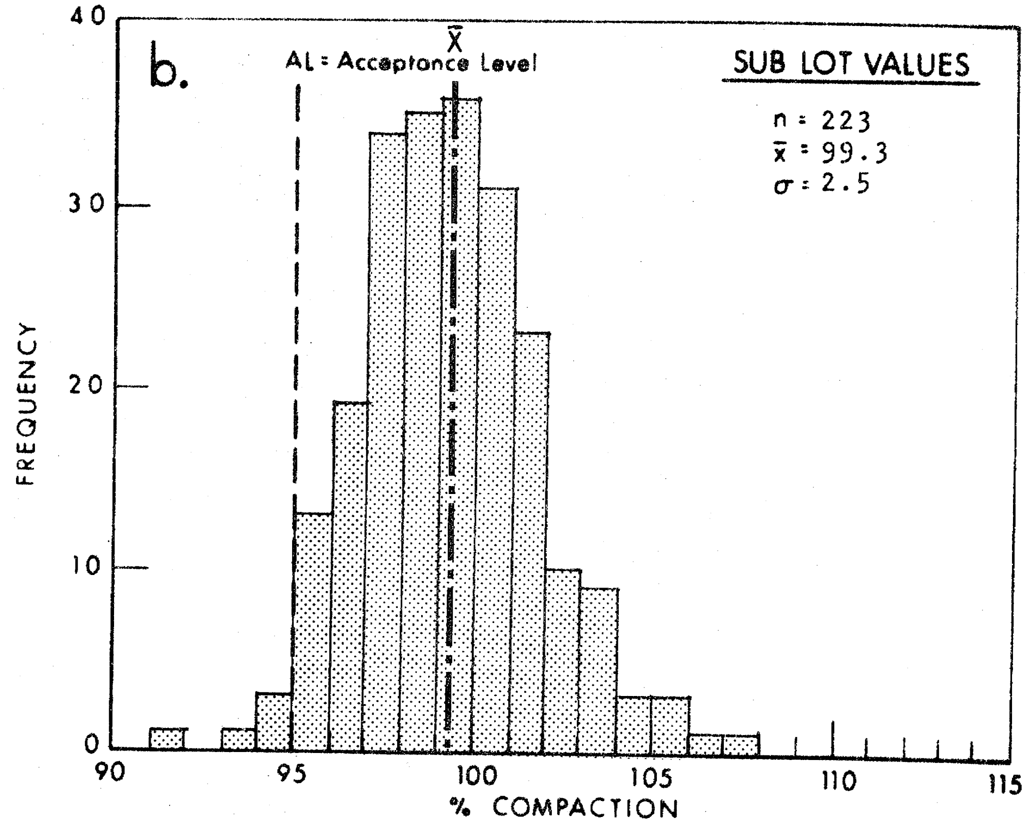


FIGURE 6

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'B' CONTRACT 79-102 REGION CENTRAL

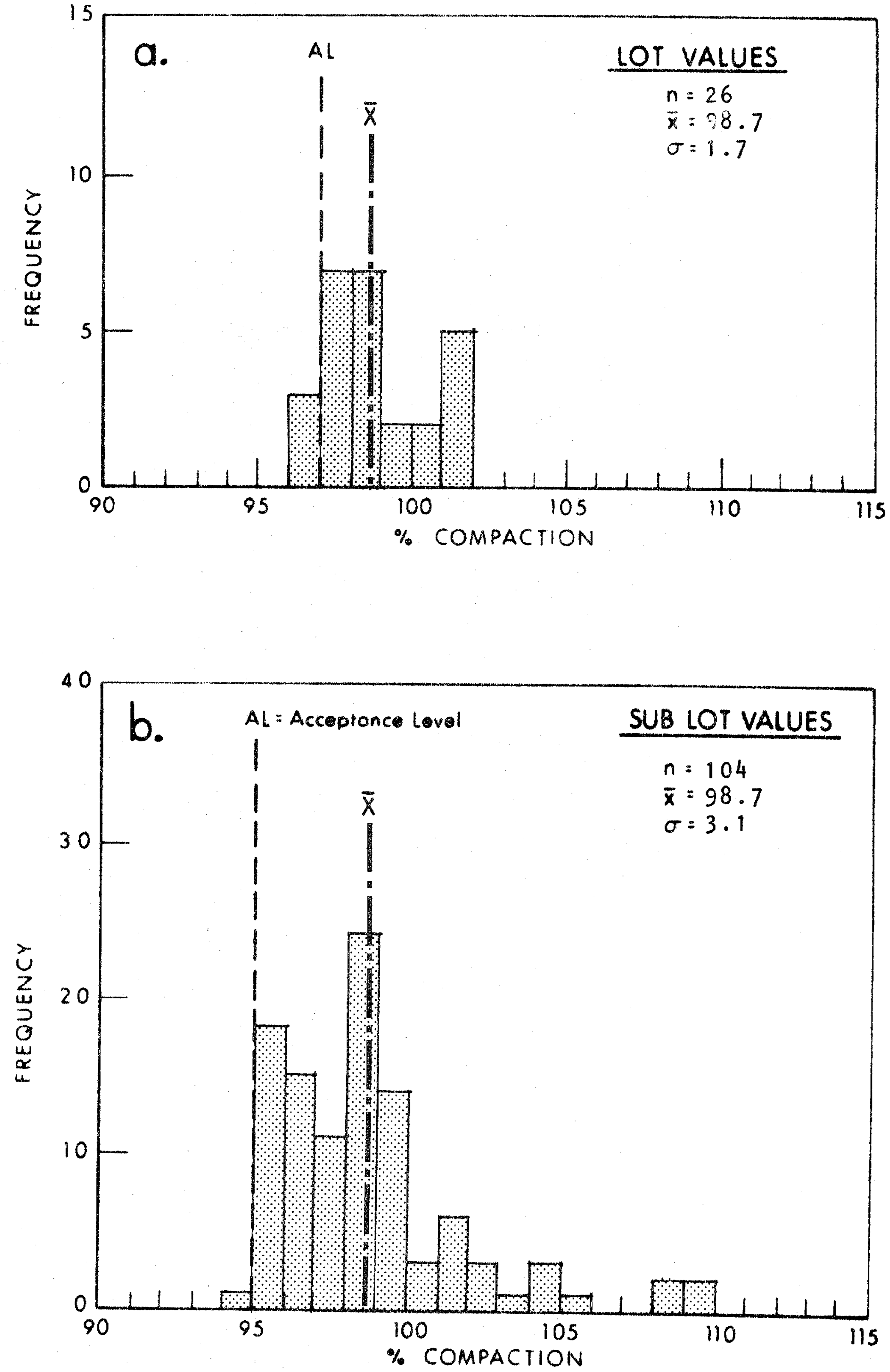


FIGURE 7

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'A' REGION ALL

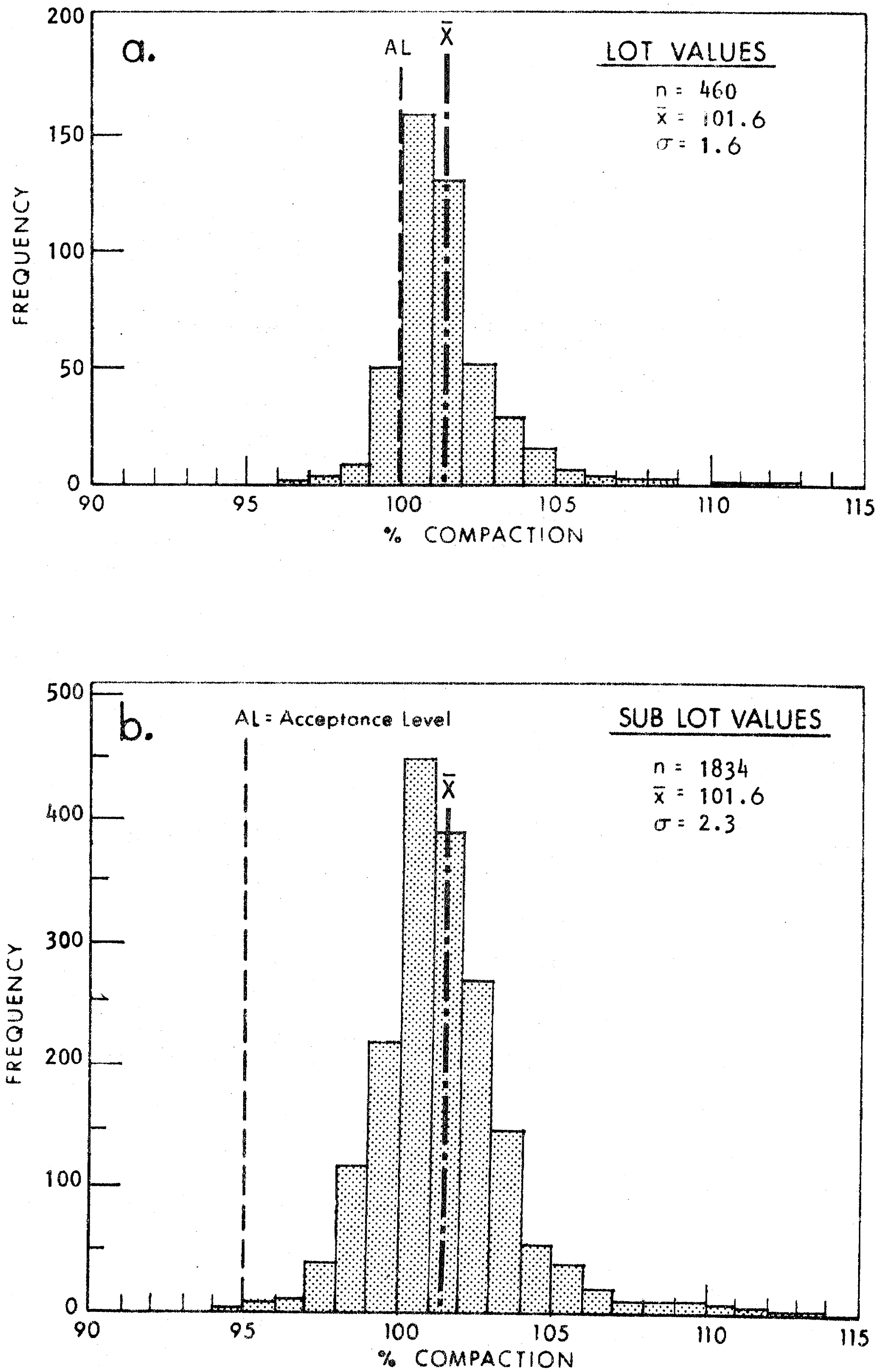
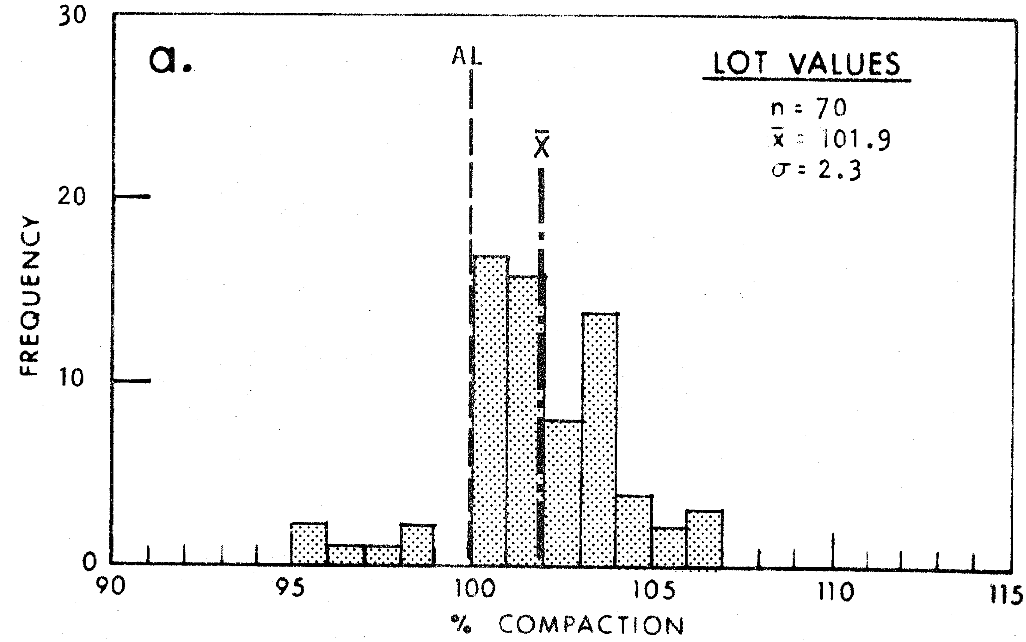


FIGURE 8

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'B' REGION ALL



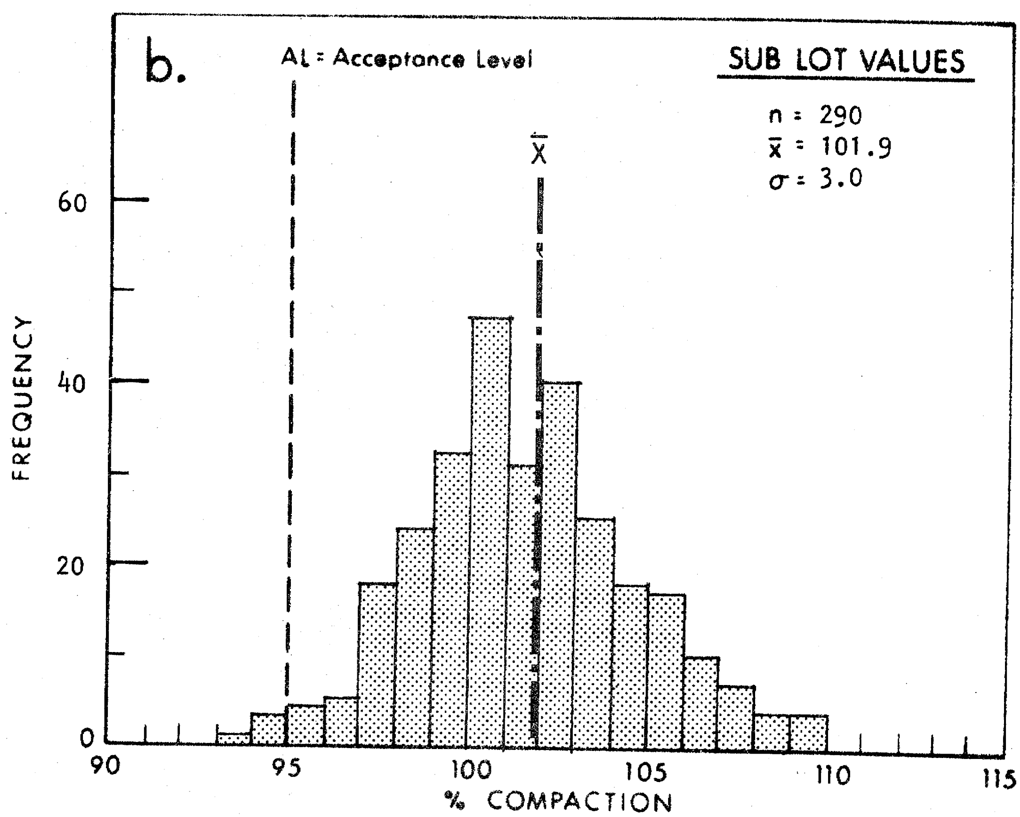


FIGURE 9

HISTOGRAMS OF FIELD COMPACTION

GRANULAR 'C' REGION ALL

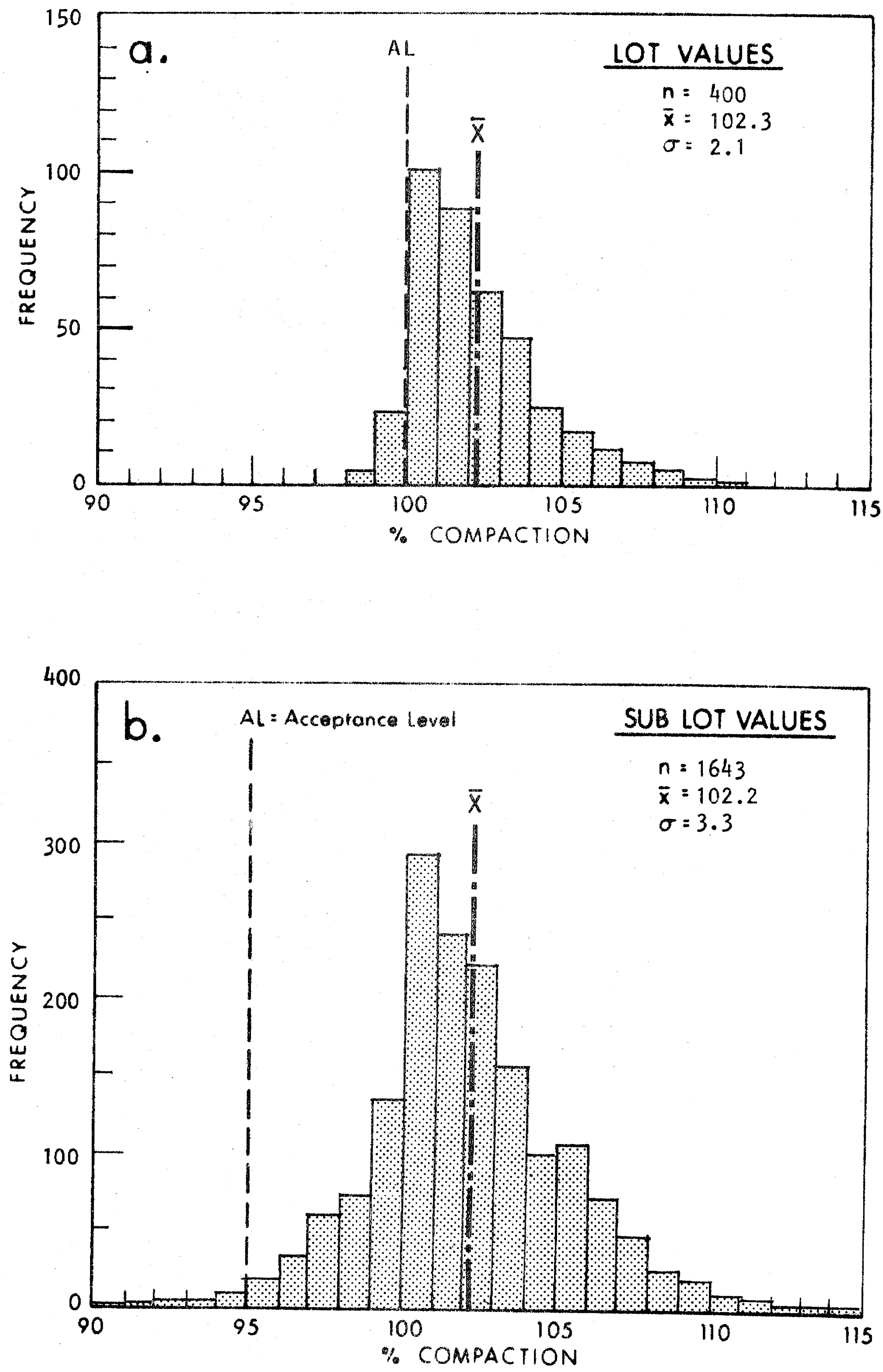


FIGURE 10

APPENDIX A

SPECIAL PROVISION FOR THE CONTROL OF COMPACTION OF GRANULAR BASE AND SUBBASE

SCOPE

This special provision covers the Ministry requirements for control strips and the testing and method of compaction of granular base and subbase materials.

MATERIAL

The material used in each control strip shall come from the same source and be of the same type used in the remainder of the course represented by the control strip.

EQUIPMENT

The equipment used in the construction of the control strip shall be of the same type and mass as that used on the remainder of the course represented by the control strip.

CONSTRUCTION

A control strip shall be constructed at the beginning of work on each material. A control strip shall be approximately 400 m^2 in area.

Prior to commencement of compaction on the control strip, the Engineer shall take three one point Proctor tests on material collected randomly from the control strips using moisture content values obtained by nuclear gauge. The mean maximum dry density and optimum moisture content shall be computed. The moisture content of the control strip shall be adjusted so that the field moisture content falls within -20% and +10% of the optimum.

After the samples for the three one point Proctor tests have been taken, the compaction equipment shall make six passes over the entire surface.

The Engineer shall then take three density and moisture tests at randomly selected locations by means of the nuclear gauge. The mean of the three tests shall be used in the calculation of the dry density which will then be used as the reference value. Two additional passes of the equipment over the entire surface shall then be made and a further three density and moisture tests performed. Providing the average dry density does not increase by more than 32 kg/m^3 from the reference value and providing the dry density is not less than 95 percent of the mean of the one point Proctor maximum dry densities, the compaction will be considered satisfactory.

Where the dry density does increase by more than 32 kg/m^3 then further passes of the equipment will be required until the above conditions are met.

Upon completion of the compaction of the control strip, seven further density tests shall be taken at random locations and the mean density will be determined by averaging the results of the seven tests and the last three mentioned previously. The mean density of the control strip shall be the target density for the remainder of the course which it represents.

New control strips may be required when:

a) A change in the material is made;
b) Ten lots have been accepted without construction of a new control strip;
c) There is reason to believe that a control strip density is not representative of a material being placed.

COMPACTION OF COURSES

Compaction of the material shall be done by the same type of equipment as was used for the control strip.

QUALITY ASSURANCE

The density of the specified course will be tested on a lot basis. Each lot will be subdivided into four equal sublots and one nuclear density and moisture test shall be carried out at random locations within each sublot. Each lot will be a maximum of 10 000 m^2.

Acceptance of each specified course will be made where the mean dry density of the four tests is 97 percent or greater than the target density, and where each test is 95 percent or greater than the target density. Where the sub-lot or lot does not meet the above requirements, compaction will be continued until the requirements are met.

BASIS OF PAYMENT

The cost of constructing the control strips and any costs caused by the performance of the compaction tests shall be included as part of the work and at the bid contract price for placing the appropriate material.

A P P E N D I X B

DISCUSSION AND EVALUATION OF CONTROL STRIP CONSTRUCTION

1. CONTRACT 79-112, SOUTH-WESTERN REGION

Two control strips were built for this contract, one on the Granular B subbase and one on Granular A base. The location of both control strips were at the new construction of the east to north ramp of Hwy. 401 and Oxford County Rd. 9.

The Granular B control strip was constructed on 80 07 14 on an area of 480 m^2. Half of the width of the ramp was designated for the test section so that construction traffic was not held up.

The Granular B was placed by trucks and immediately graded to an average layer thickness of 27 cm (approximately 11"). The material was extracted from a wayside pit, known as WISEMAN pit, some 10 km from the construction site. The Granular B was classified as a well-graded gravelly sand with silt (SW-SM). A gradation envelope of four laboratory sieve analyses is shown in Figure 1B. The material appeared to have very small dispersion, but some oversize between 106 mm and 150 mm was noticeable.

The reference density was determined by performing three OPT-s on randomly selected samples from the control strip, prior to compaction. The mean of the three tests were: maximum dry density (MDD) = 2178 kg/m^3 (136.0 PCF) and the optimum moisture content (w_{opt}) = 7.8%. For the sake of curiosity, two laboratory 5 point Proctor tests were also carried out resulting in a mean of MDD = 2123 kg/m^3 (132.55 PCF) and w_{opt} = 8.1%.

Water was applied to the control strip, prior to the initial roller passes, by conventional means. After six passes of a "GALION" - 84 vibratory self propelled smooth drum roller, three random nuclear moisture-density tests were taken. The mean of the tests were calculated to be:

dry density = 2057 kg/m^3 (128.4 PCF)

w = 6.3%

The additional passes were then made according to the special provision, after which the mean of the three new random moisture-density tests yielded the following results:

dry density = 2081 kg/m^3 (129.9 PCF)

w = 6.4%

Since the increase of density after the additional two roller passes was less than 32 kg/m^3 (2 PCF), and the attained density was larger than 95% of the average MDD of the three OPT-s, the compaction was deemed to be acceptable. The roller pattern is shown in Figure 2B.

In order to determine the target density for the rest of the Granular B course 7 additional random density tests were taken and the mean of the 10 tests (seven and the previous three) computed.

The average target density was 2043 kg/m^3 (127.6 PCF). To demonstrate the very large variation in density and moisture content even when the compaction is carried out with a great deal of care and very close control, the ranges of the 10 test results were examined. They are as follows:

	Largest Density		Smallest Density		Range	
Density	kg/m^3	PCF	kg/m^3	PCF	kg/m^3	PCF
	2175	135.8	1922	120.0	253	15.8

Range of moisture content = 8.5% - 4.1% = 4.4%

The very large variation of the moisture contents is especially striking, again emphasizing that the conventional MTC water application seldom, if ever, achieve uniform moisture within the layer.

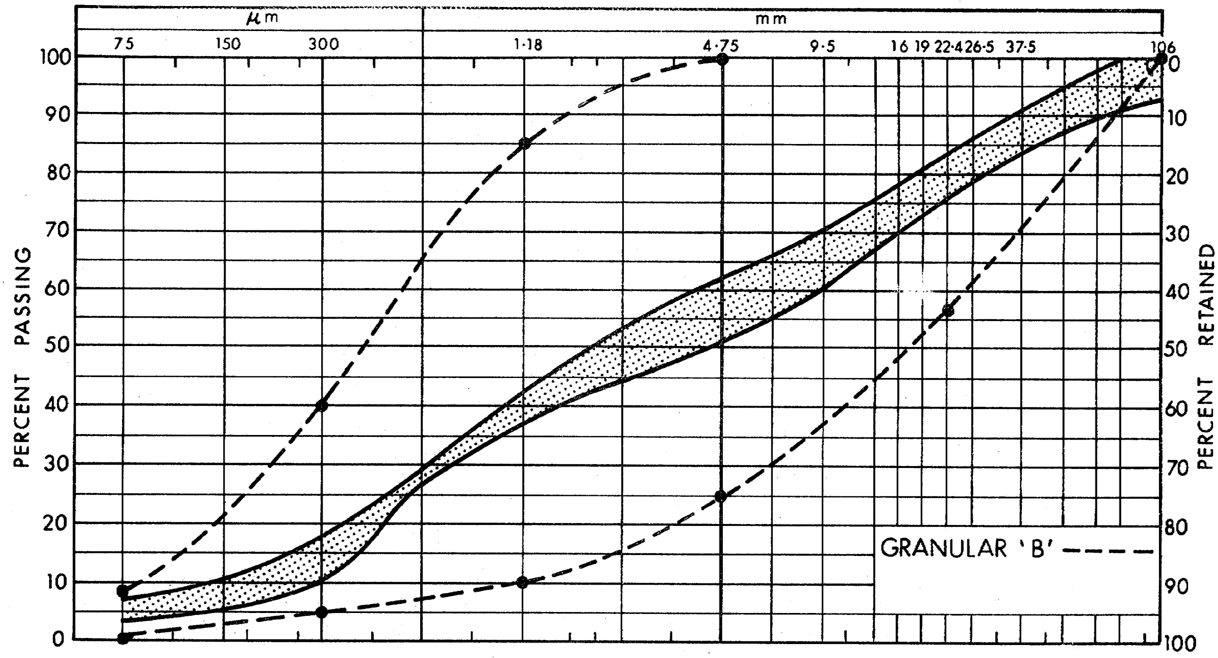


FIG. 1B
ENVELOPE OF 4 TESTS

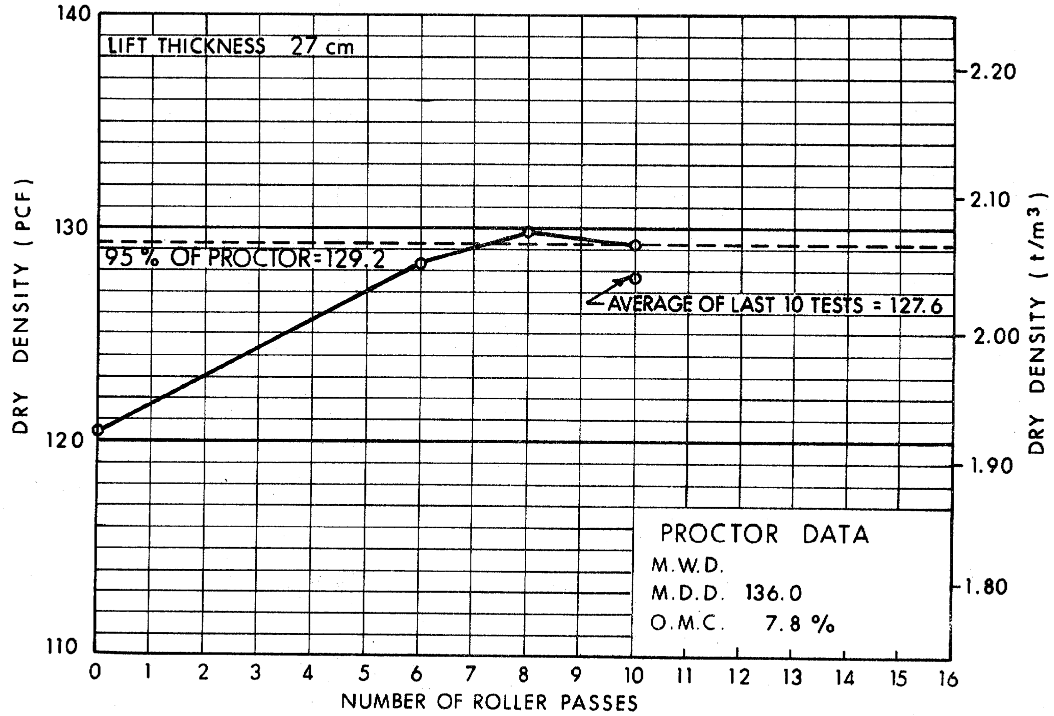
CONTROL STRIP TEST DATA

CONTRACT 79-112 HWY. 7176 REGION SOUTHWESTERN

LOCATION HWY. 401 NORTHERLY TO OXFORD CO. RD. 9

TEST AREA : RAMPS - LENGTH 120 m WIDTH 4 m

MATERIAL GRANULAR 'B' SOURCE WISEMAN PIT



REMARKS TARGET VALUE 127.6 PCF

FIG. 2B

While not part of the special provision requirements, two additional roller passes were applied to see if further compaction could be attained. In Figure 2B, the result of the additional two passes is plotted, clearly showing that further roller passes had a detrimental effect yielding lower density than after eight passes.

The Granular A control strip was constructed on 80 07 22, the area being 484 m^2. The material was processed from the same source as the Granular B, and was compacted with the same GALION vibratory roller.

The result of two sieve analyses on the Granular A are shown in Figure 3B, indicating some 2-3% deficiency of the retained 4.75 mm sieve portion. The material was placed by trucks and graded by a small bulldozer to an uncompacted depth of 23 cm (9").

Three randomly selected samples were taken for the OPT-s, and the average of the three tests computed as follows:

average MDD = 2233 kg/m^2 (139.4 PCF)
average w_{opt} = 7.2%

Since the field moisture content as measured for the OPT-s was only 5.5%, water was applied prior to compaction. It was decided to raise the field moisture above the OPT optimum moisture of 7.2%. This was done in order to test the validity of some published data, according to which granular materials should be sopping wet to attain the best compaction. (e.g., J.K. McDonald 1979. Compendium 10, TRB, Washington, D.C. pp. 109-122).

The mean density of the control strip before compaction was 2068 kg/m^3 (129.1 PCF). (The roller pattern is shown in Figure 4B)

After six passes of the roller, the three random nuclear moisture-density tests resulted in a mean dry density of 2194 kg/m^3 (136.96 PCF) and a field moisture of 9.2%. The

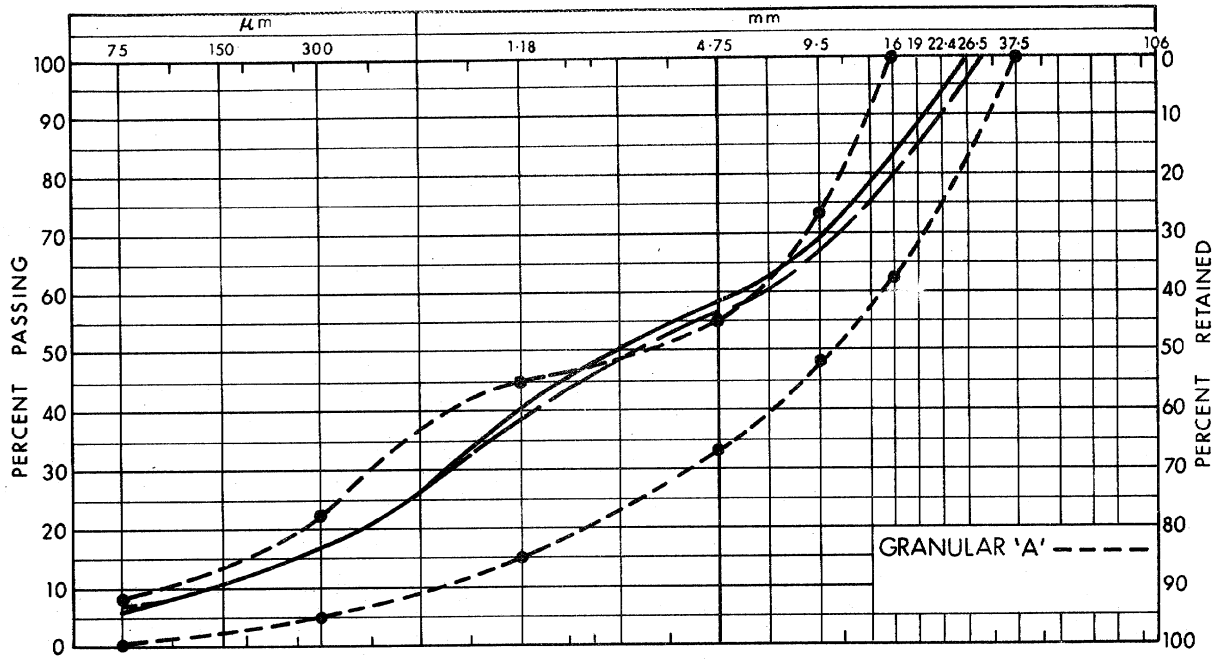


FIG. 3B

TWO GRADATION TESTS ON GRANULAR 'A'

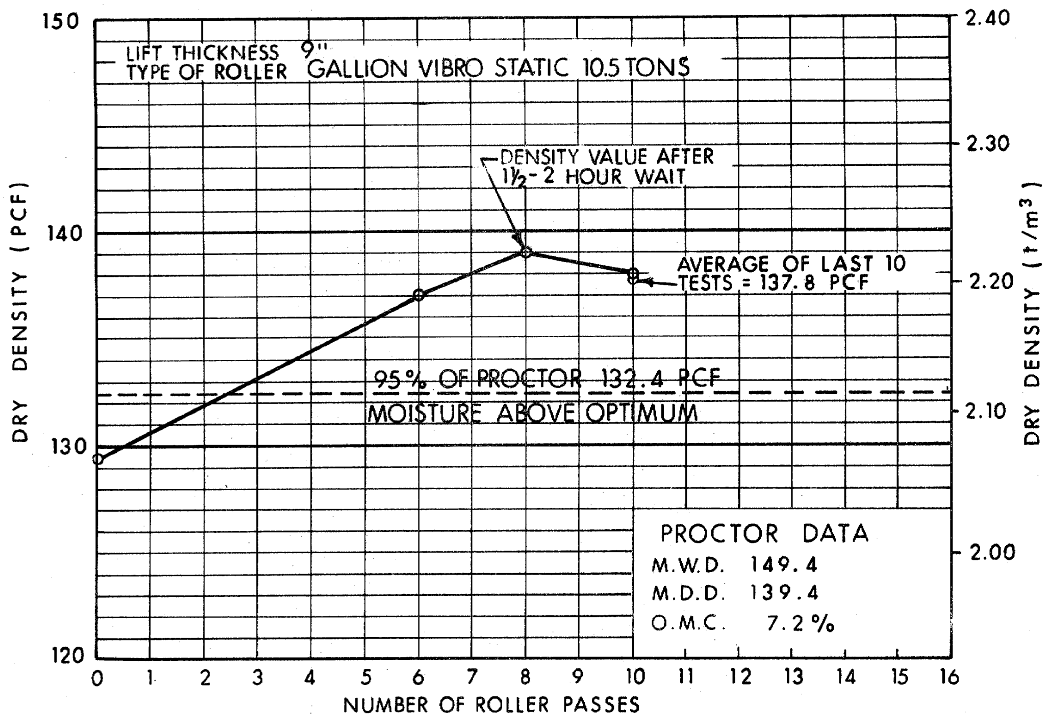
CONTROL STRIP TEST DATA

CONTRACT 79-112 HWY. 7169 REGION SOUTHWESTERN

LOCATION HWY. 401 NORTHERLY TO OXFORD CO. RD. 9

TEST AREA : STA. 10+285 TO STA. 10+405 WIDTH 4m±

MATERIAL GRANULAR 'A' SOURCE WISEMAN PIT



REMARKS DURING COMPACTION MOISTURE WAS AT THE SURFACE. NO WATER WAS ADDED ONCE COMPACTION STARTED. TARGET VALUE 137.8 PCF

FIG. 4B

surface of the aggregates was visibly too wet and it was quite obvious that more time would be needed for the water to percolate through the layer. Consequently, the two additional roller passes were applied after a waiting period of two hours (lunch time). The mean of the three tests after the additional passes was:

$$\text{dry density} = 2227 \text{ kg/m}^3 \text{ (139.0 PCF)}$$
$$w = 7.5\%$$

The increase of density after the two last roller passes was 33 kg/m^3 slightly larger than the 32 kg/m^3 specified for acceptance, thus, two more passes were carried out. The mean field dry density after the 9th and 10th passes dropped to 2211 kg/m^3 (138 PCF).

Because the attained density was more than 95% of the mean OPT (in fact it was 99%), the compaction was considered to be satisfactory. After seven more random tests, the target density was computed by the average of the last 10 tests as 2207 kg/m^3 (137.8 PCF).

2. CONTRACT 80-10. CENTRAL REGION

This contract was located just north of Manchester along Hwy. 7 and 12. Two control strips were carried out, one on the Granular C subbase and one on Granular A. Compaction was done by a BOMAG BW-210 vibratory roller on both sections.

The Granular C control strip was constructed on 80 05 15. The material was hauled from Hancock Sand and Gravel, a commercial gravel pit. Figure 5B is the gradation envelope of the means of 30 lots, showing very small variation of the uniformly graded fine to medium sand (SP). In Figure 6B, the roller pattern is plotted, together with the OPT data. We will see that, after a steady increase of density, the 95% of the average OPT was reached after 10 roller passes. At this point, the compaction could have been terminated, because the increase between the 8th and 10th passes was

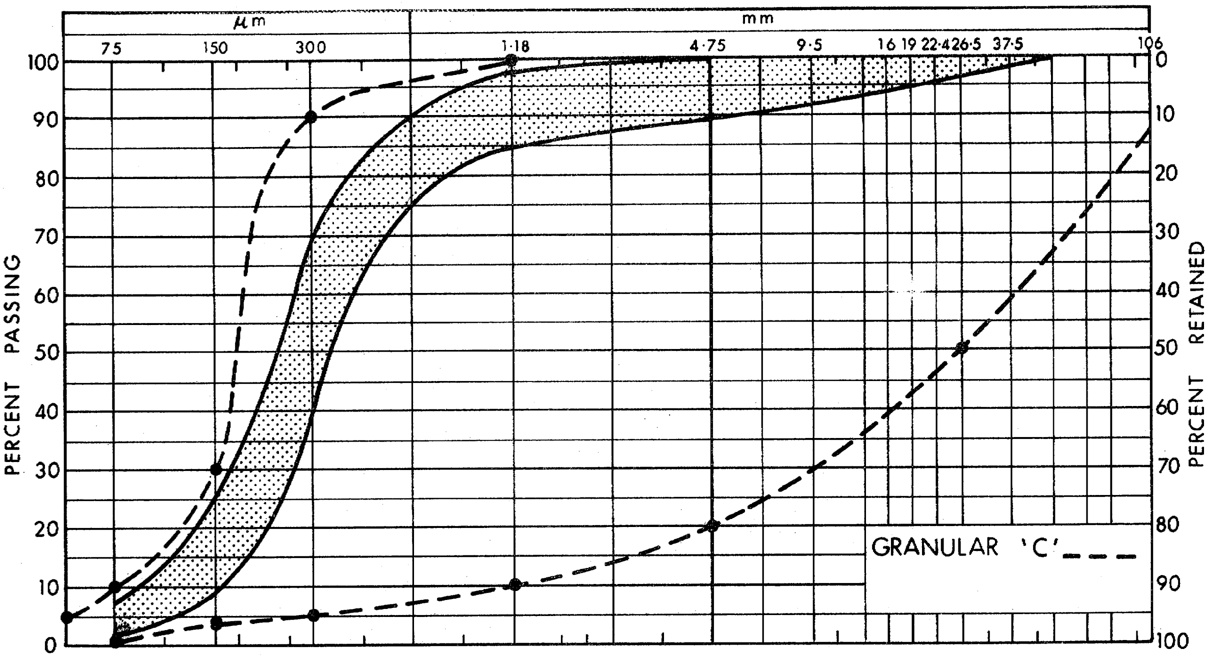


FIG. 5B
ENVELOPE OF 30 LOT GRADATIONS

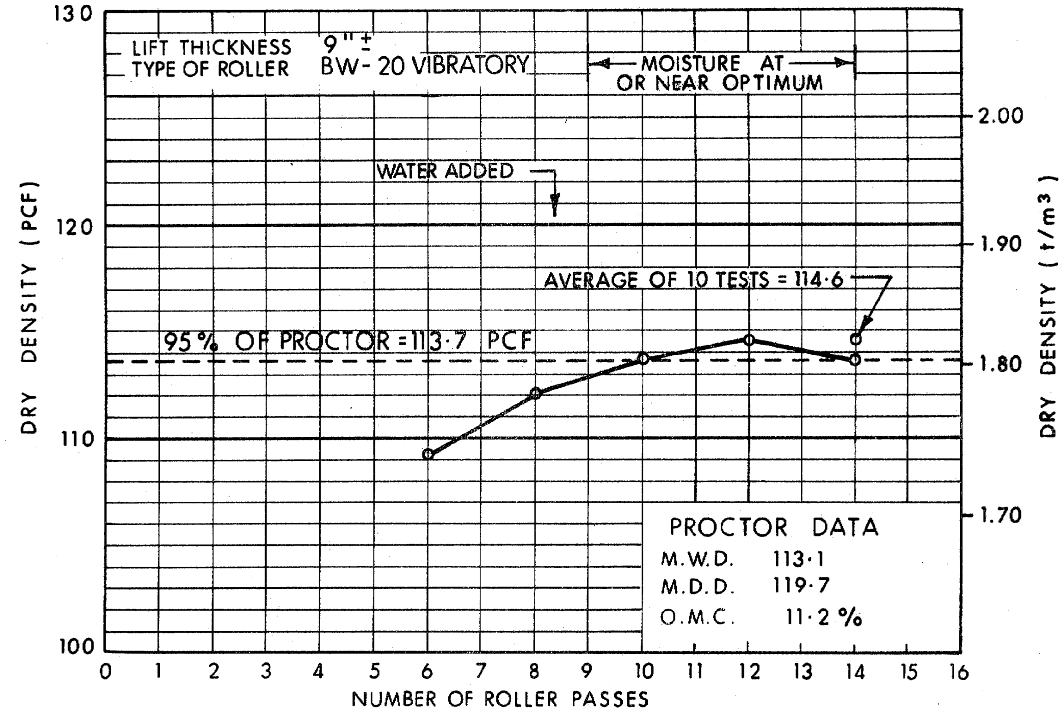
CONTROL STRIP TEST DATA

CONTRACT 80-10 HWY. 12 & 7 REGION CENTRAL

LOCATION MANCHESTER NORTHERLY

TEST AREA : STA. 306+00 TO STA. 308+00 WIDTH 20' ±

MATERIAL GRANULAR 'C' (SANDY) SOURCE HANCOCK PIT



REMARKS GRANULAR 'C' MATERIAL WAS COMPRISED OF BRICK SAND BLENDED WITH OPEN FACE MATERIAL TARGET VALUE 114·6 PCF

FIG. 6B

less than 32 kg/m^3. The four additional passes (from 10 to 14) which were carried out for purposes of study and checking, demonstrated that, while an insignificant increase occurred after 12 passes, the final compaction was very similar to the one achieved after 10 passes (1835.7 kg/m^3 and 1821.3 kg/m^3).

The Granular A control strip was carried out on 80 05 26. The source of the aggregates was the same as for the Granular C.

The gradation band of 25 lots is plotted in Figure 7B illustrating that the material was very close to the fine limit of the acceptable level.

At the beginning of compaction, the material was on the dry side of the optimum, as usual, so that water had to be added during the roller passes, as shown in Figure 8B.

The moisture content of the control strip was more than 2% lower than the optimum, even after the additional application of water. By examining Figure 8B, it can be concluded that, with the available moisture content, the maximum attainable density was 2249 kg/m^3 (140.4 PCF) which was only 97% of the average OPT of 2324 kg/m^3 (145.1 PCF). The maximum attainable field density was reached after 8 roller passes. The increase of density due to the last two roller passes was less than 32 kg/m^3 and the density was higher than 95% of the mean OPT, so that conformance with the requirements of the special provision was obtained.

3. <u>CONTRACT 80-27. EASTERN REGION</u>

The general location of this contract was near the town of Arnprior, consisting of various sections of Hwy. 17N diversion, Hwy. 17, Hwy. 29 and Renfrew County Rd. 2. The Granular C subbase aggregates were extracted from two gravel sources, thus two control strips were built for compaction control.

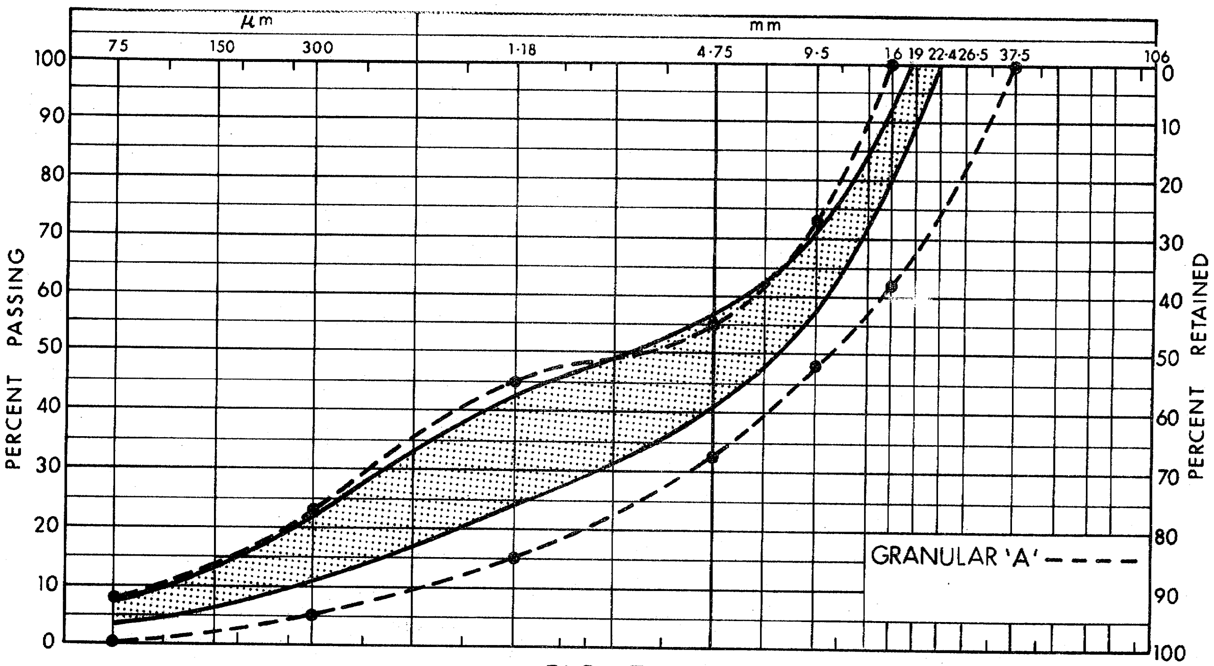


FIG. 7B
ENVELOPE OF 25 LOT GRADATIONS

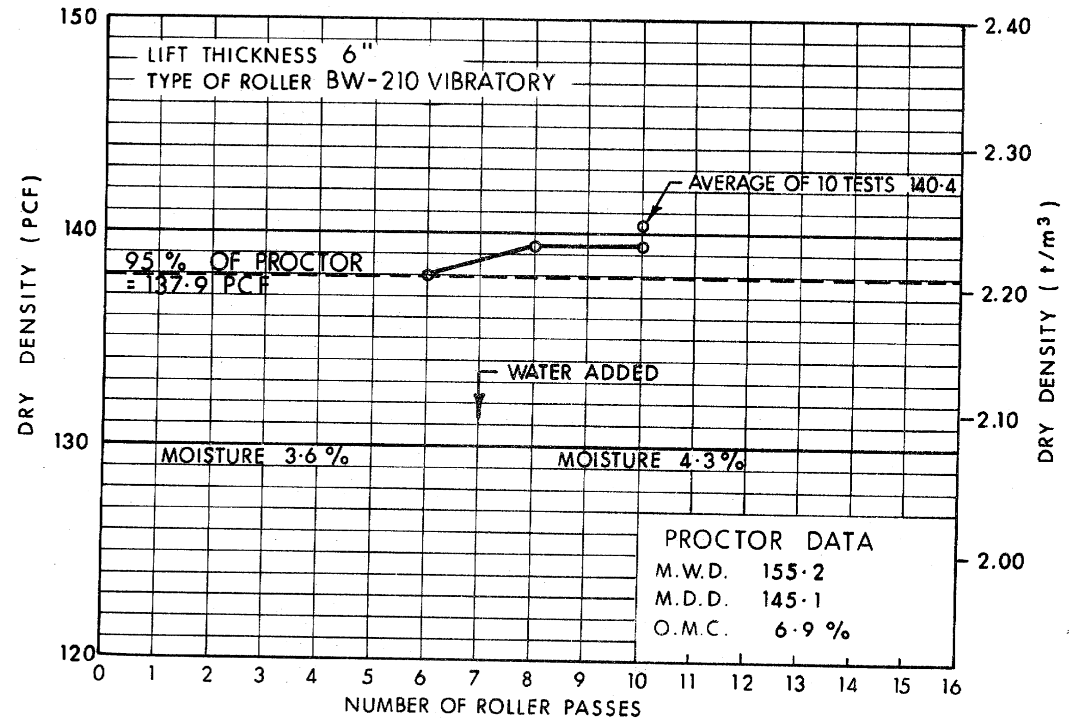
CONTROL STRIP TEST DATA

CONTRACT 80-10 HWY. 12 & 7 REGION CENTRAL

LOCATION MANCHESTER TO GREENBANK

TEST AREA : STA. 313 + 50 TO STA. 315 + 50 WIDTH 20 ±

MATERIAL GRANULAR 'A' SOURCE HANCOCK SAND & GRAVEL



REMARKS GRANULAR 'A' GRADE WAS CONSTRUCTED AT 6% SLOPE THIS MADE IT DIFFICULT TO ADD WATER AFTER COMPACTION OF THE MATERIAL

TARGET VALUE 140·4 PCF

The first Granular C control strip was constructed, using material from a wayside pit known as Taylor Pit (A5-39) on 80 06 18.

Compaction was carried out by a RAY GO RASCAL A410 vibratory roller. Area of control strip was 390 m^2.

Prior to compaction, two passes of water were applied, bringing the moisture content near to optimum. The poorly graded gravelly sand (SP) Granular C with very little fines exhibited a fairly wide variation of gradation as shown in Figure 9B.

As illustrated in Figure 10B, two additional roller passes, after the basic compaction of 6 passes, attained the requirements for acceptance so that the compaction was terminated. The relevant data is as follows:

Mean value of three OPT's.	MDD	=	2085 kg/m^3
	w_{opt}	=	8.7%
Field dry density after 6 passes		=	2026 kg/m^3
Field dry density after 8 passes		=	2036 kg/m^3

(increase less than 32 kg/m^3, density larger than 95% OPT maximum dry density)

Target dry density based on the average of ten density measurement = 2053 kg/m^3, 98.5% of the mean OPT maximum dry density.

The second Granular C control strip on materials extracted from a gravel pit known as CARSS (SMITH) Pit (A5-13) was constructed on 80 08 07. The area of the control strip was 372 m^2, having an uncompacted thickness of the lift of 25 - 36 cm.

In order to enable the water truck to drive over the test area, two roller passes were carried out. This project was utilized to further study the effect of the application of water by simply spraying the surface (conventional MTC method) as opposed to mixing the water throughout the layer. To this end, the control strip was sub-divided into two

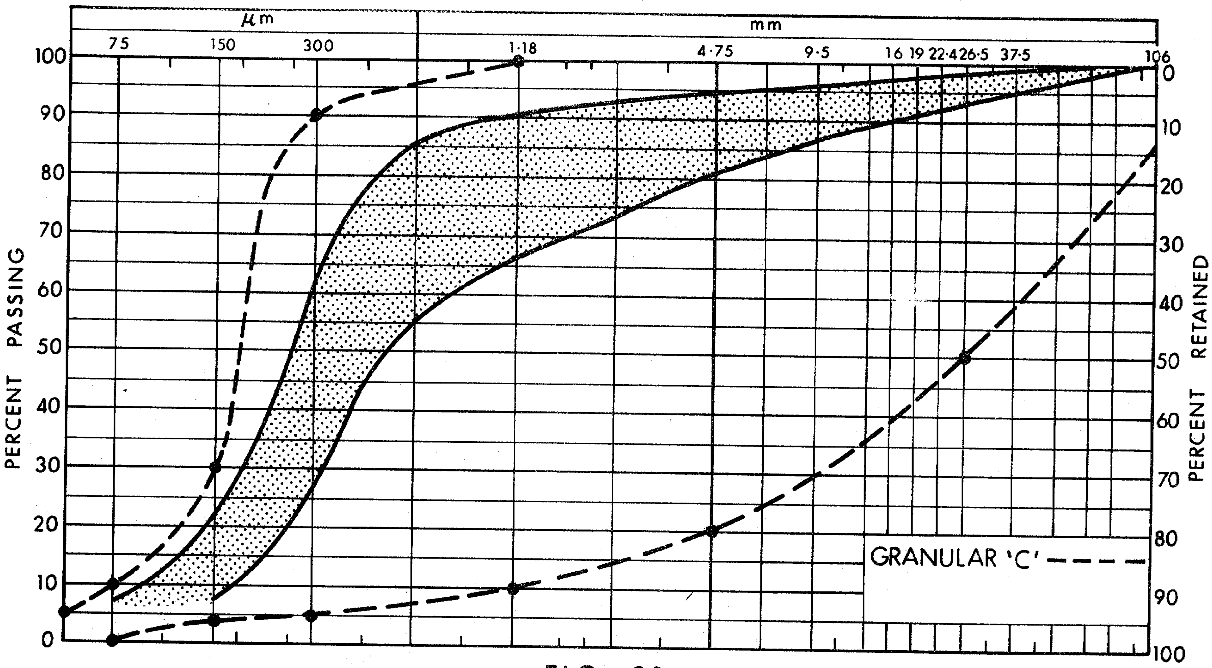


FIG. 9B
ENVELOPE OF 11 LOT GRADATIONS

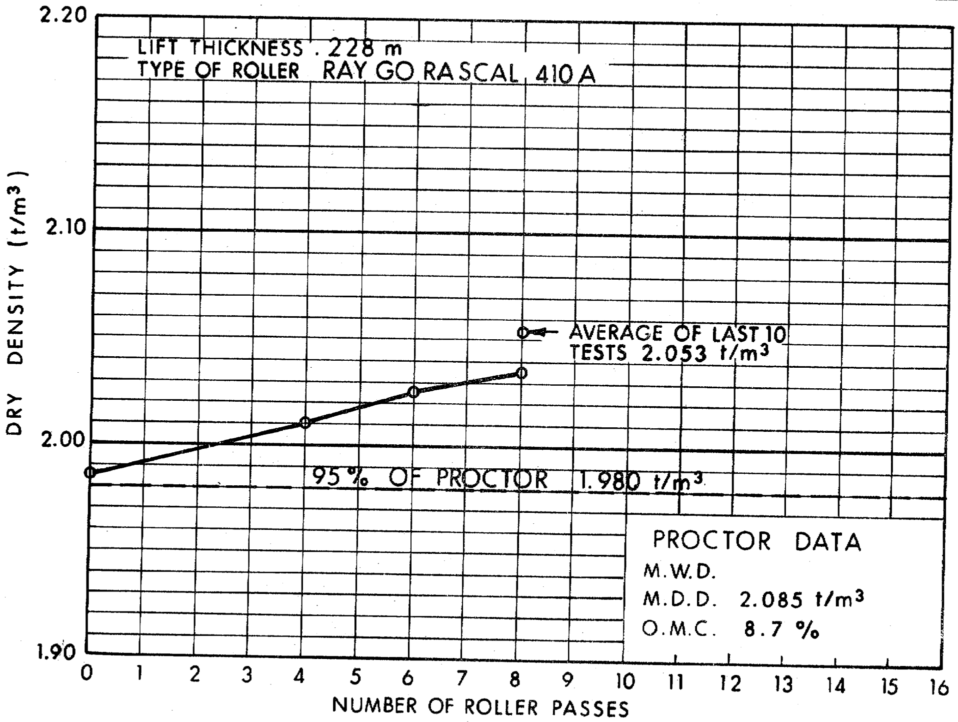
CONTROL STRIP TEST DATA

CONTRACT 80-27 HWY. 17N REGION EASTERN

LOCATION ARNPRIOR DIVERSION

TEST AREA : STA. 718+00 TO STA. 720+00 WIDTH 6.40 m

MATERIAL GRANULAR 'C' SOURCE TAYLOR PIT (A5-39)



REMARKS MOISTURE NEAR OPTIMUM TARGET VALUE 2.053 t/m³ halves, each treated as a separate entity. On the first half of the area, the water was sprayed conventionally; on the second, the water was added and then mixed into the lift by a grader after application. Samples were taken from both areas and the laboratory oven dried moisture determined throughout the lift separately for 0"-2", 2"-4", 4"-6" and 6"-8" depths. In Table 1B, the actual moisture contents, averages ($\bar{x}$), ranges (R) and standard deviations (σ) are given.

Depth (in.)	Conventional Water Application				Water Mixed in Lift			
	Actual w%	$\bar{x}$	R	σ	Actual w%	$\bar{x}$	R	σ
0 - 2	9.5				9.6			
2 - 4	8.6	7.93	2.9	1.2	11.1	10.28	1.5	0.7
4 - 6	7.6				10.6			
6 - 8	6.6				9.8			

TABLE 1B

From the table, the following conclusions may be drawn:

a) The average moisture content of the mixed-in area is more than 2% higher than that of the unmixed. The loss of water is caused by surface run-off and probably larger evaporation.

b) Ranges and standard deviations of the unmixed area are almost twice as large as the mixed, demonstrating the high variation of moisture within the lift, if water is applied only on the surface.

c) After only two passes of the roller, the material had such low permeability that the surface application of water could not penetrate down to the lower depths of the lift. The difference in moisture content between the surface and

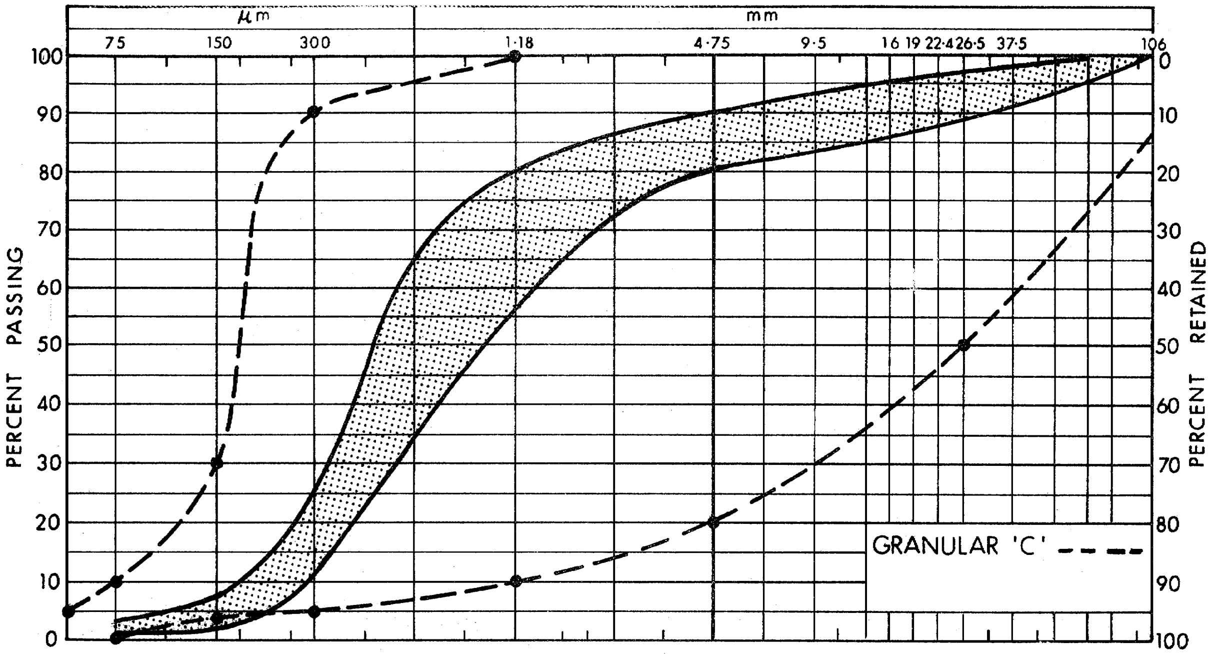


FIG. 11B
ENVELOPE OF 4 LOT GRADATIONS

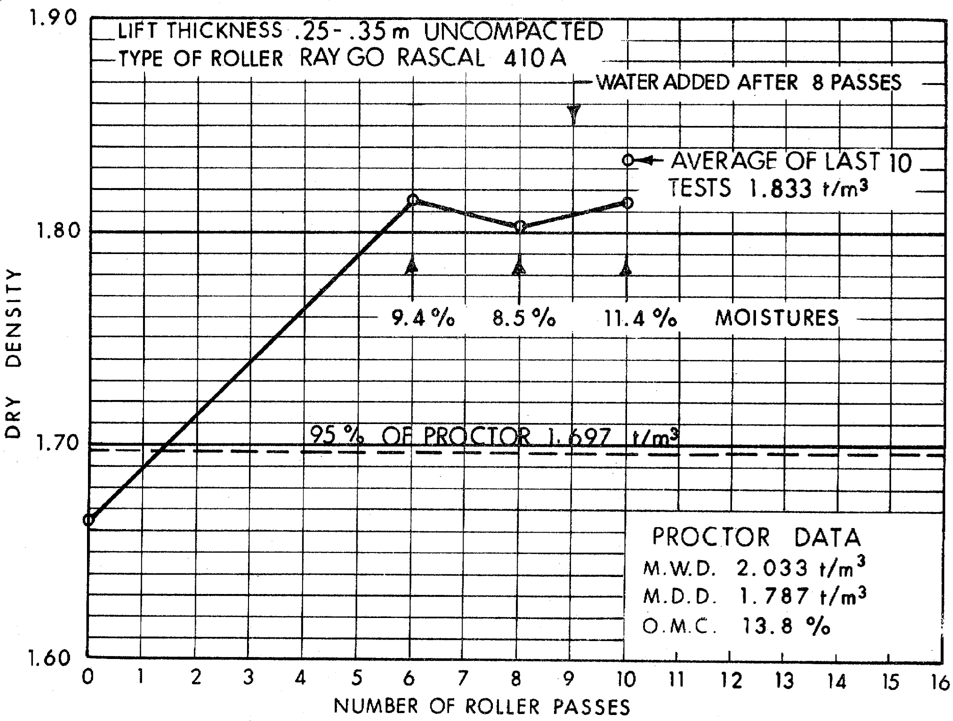
CONTROL STRIP TEST DATA

CONTRACT 80 - 27 HWY. 17N REGION EASTERN

LOCATION ARNPRIOR DIVERSION

TEST AREA : STA. 111 + 43 TO STA. 112 + 04 WIDTH 6.09

MATERIAL GRANULAR 'C' SOURCE CARSS (SMITHS) PIT



REMARKS THE GRANULAR 'C' MATERIAL WAS MIXED & TURNED OVER BY THE GRADER OPERATOR AFTER 2 PASSES OF THE WATER TRUCK OVER ½ OF TEST STRIP & BEFORE COMPACTION STARTED. AVERAGE OF LAST 10 TESTS = 1.833 t/m³ (TARGET VALUE) the bottom layer was measured to be about 3%. It should be noted that the pass 75 μm portion of this Granular C was only 1-3% (Figure 11B) so that aggregates containing a larger percentage of fines would exhibit even less permeability.

The roller pattern of the control strip is shown in Figure 12B. The maximum attainable density was reached by 6 roller passes, after which only slight variations occurred. In fact, after 8 passes, an insignificant drop in density was measured.

The compaction data is given below:

Mean of three OPT's. MDD $= 1787\ kg/m^3$

$w_{opt} = 13.8\%$

Field dry density after 6 passes $= 1815\ kg/m^3$

Field dry density after 8 passes $= 1805\ kg/m^3$

(slight decrease in density, yet field density is larger than the mean OPT dry density).

Target density after the additional seven density checks = 1833 kg/m^3, 102.6% of the mean OPT maximum dry density.

The first Granular A control strip was constructed on 80 07 07. The gradation envelope of three lots of the material is plotted in Figure 13B. The source of the aggregates was the SMITH (LEMIEUX) Quarry (A5-166); the roller, a RAY GO RASCAL, 410 A vibratory equipment. The roller pattern shown in Figure 14B illustrates again that the density reached its highest value after 6 passes of the roller. Since the additional two passes resulted in a slightly decreased density, and the attained compaction was already higher than the mean OPT value, the control strip was terminated.

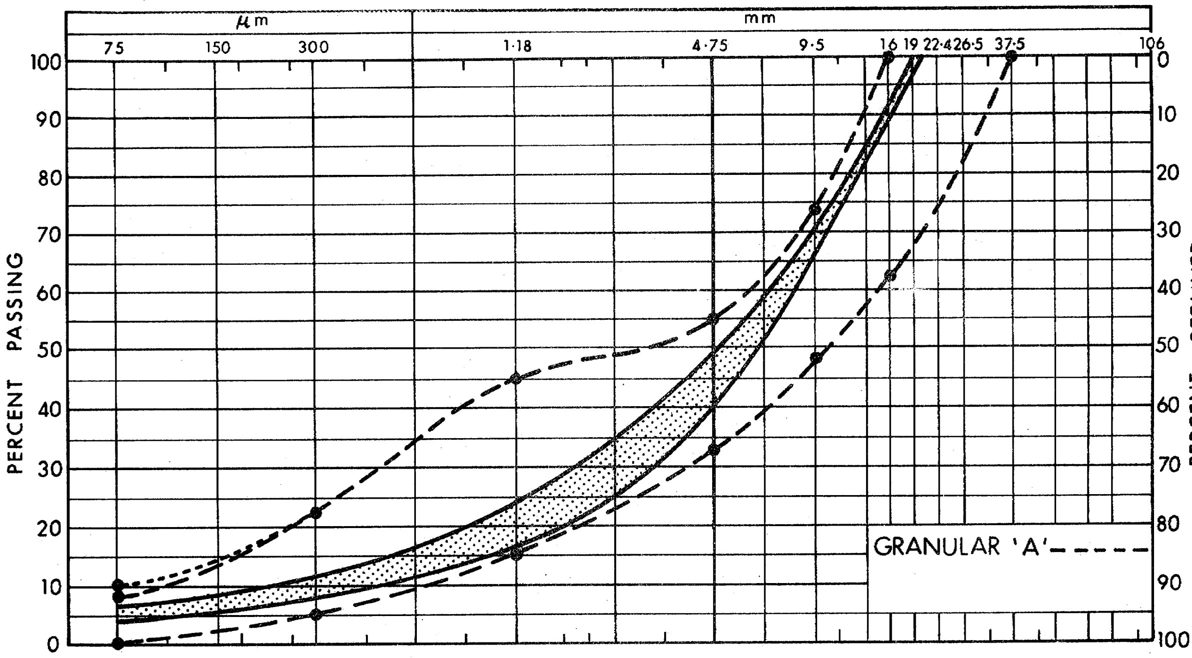


FIG. 13B

ENVELOPE OF 3 LOT GRADATIONS

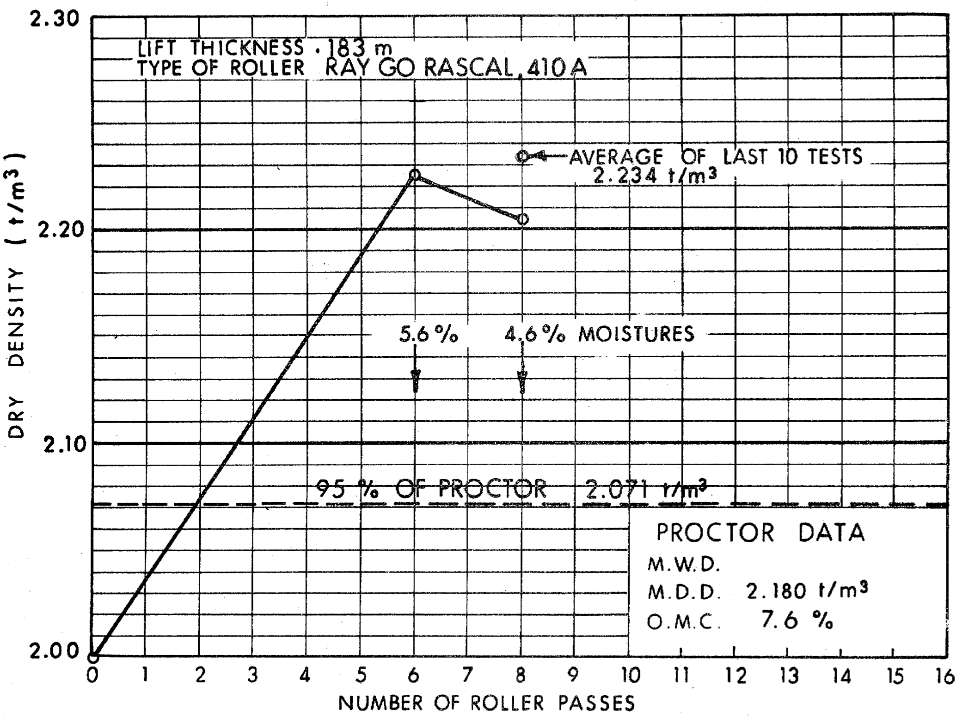
CONTROL STRIP TEST DATA

CONTRACT 80 - 27 HWY. 17 N REGION EASTERN

LOCATION ARNPRIOR DIVERSION

TEST AREA : STA. 773+00 TO STA. 775+00 WIDTH 6.7 m

MATERIAL GRANULAR 'A' SOURCE SMITH (LEMIEUX) BRAESIDE QUARRY



REMARKS MOISTURE CONTENT 4.6% (AVERAGE OF LAST 10 TESTS)

TARGET VALUE 2.234 t/m³

The compaction values were as follows:

Mean of the three OPT's. MDD = 2180 kg/m^3

w_{opt} = 7.6%

Field dry density after 6 passes = 2225 kg/m^3

Field dry density after 8 passes = 2205 kg/m^3

Target density, the average of 10 tests = 2234 kg/m^3, 102.5% of the mean OPT dry density.

A second Granular A control strip was carried out on aggregates processed from a source known as Smith Construction Company (PAKENHAM) Quarry (A5-83) on 80 09 08.

The gradation band of the mean of seven lots is shown in Figure 15B and the roller pattern is plotted in Figure 16B.

The results of the compaction were similar to the first control strip, achieving densities higher than the OPT value after the initial 6 roller passes. After 8 passes, the compaction could be terminated.

The obtained data is listed below:

Mean of the three OPT's. MDD = 2162 kg/m^3

w_{opt} = 7.9%

Field dry density after six passes = 2230 kg/m^3

Field dry density after eight passes = 2247 kg/m^3

Target density (mean of ten tests) = 2255 kg/m^3

(i.e., 104.3% of the mean OPT density)

4. NOT SPECIFIED CONTROL STRIP PROJECT. CENTRAL REGION

One additional contract (79-102) was reported to this office where, while not specified, the control strip technique was used to obtain target densities. On this contract, considerable difficulties were experienced in bringing the base and subbase aggregates up to the optimum moisture level, on account of the rather unstable subgrade and the small percentage of fines in the aggregates. As a consequence, the OPT maximum density was impossible to achieve by the available BROS vibratory single drum roller.

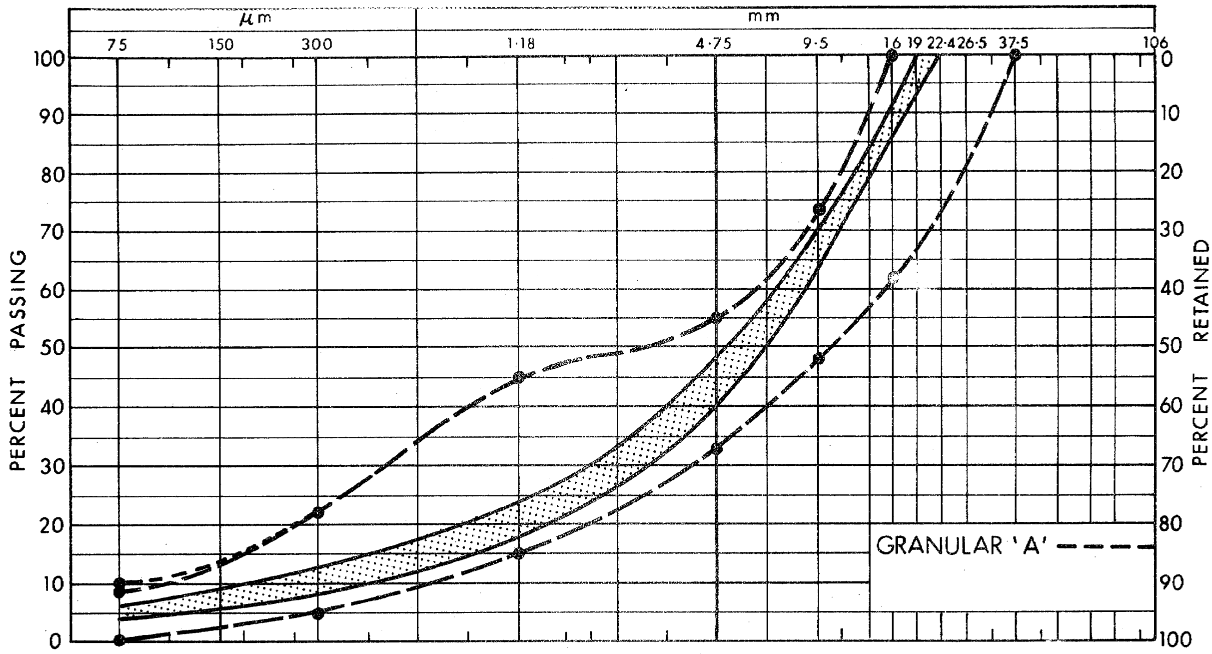


FIG. 15B
ENVELOPE OF 7 LOT GRADATIONS

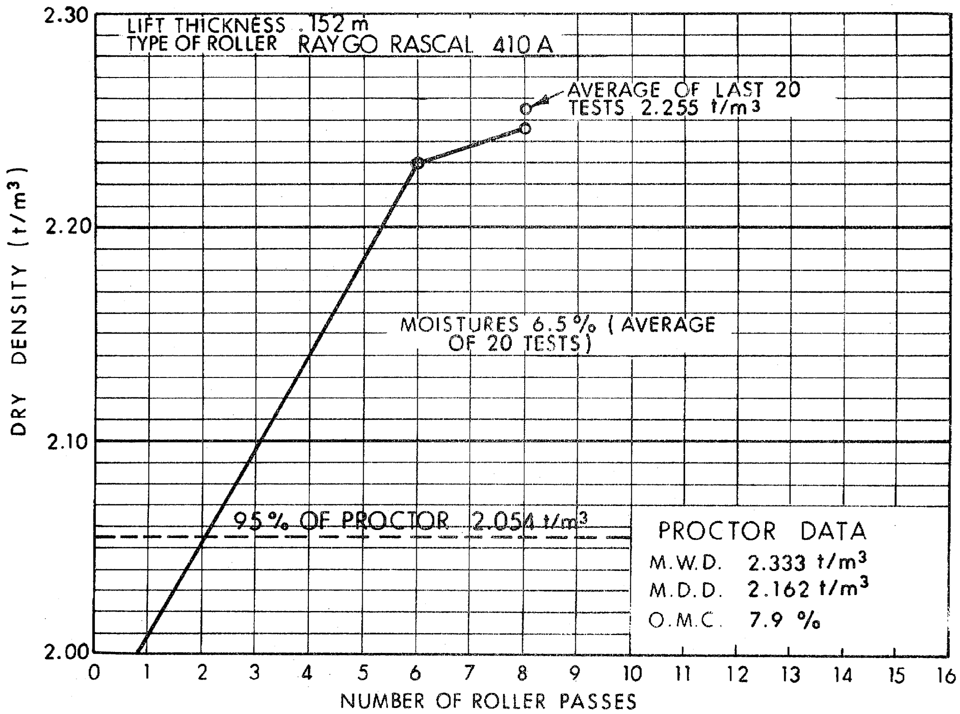
CONTROL STRIP TEST DATA

CONTRACT 80-27 HWY. 17 N REGION EASTERN

LOCATION ARNPRIOR DIVERSION

TEST AREA : STA. 815+00 TO STA. 817+00 WIDTH 6.10 m

MATERIAL GRANULAR 'A' SOURCE SMITH CONST. CO. (PAKENHAM)



REMARKS THIS MATERIAL WAS MIXED & LEVELED BY GRADER OVER ½ OF TEST STRIP BEFORE COMPACTION TARGET VALUE 2.255 t/m³

Vern Max of the Central Region Quality Assurance Section, on his own initiative and after discussion with the contractor, requested control strips on both Granular A and B courses, to determine target densities. The economically attainable maximum compaction was reached after eight passes of the roller at both control strips, and the new target densities were 97.2% and 96.2% of the OPT maximum densities.

These new targets were used for the control of compaction for the rest of the courses according to the requirements of the Special Provision. Gradation envelopes and roller patterns of both Granular A and B courses are shown on Figures 17B to 20B inclusive.

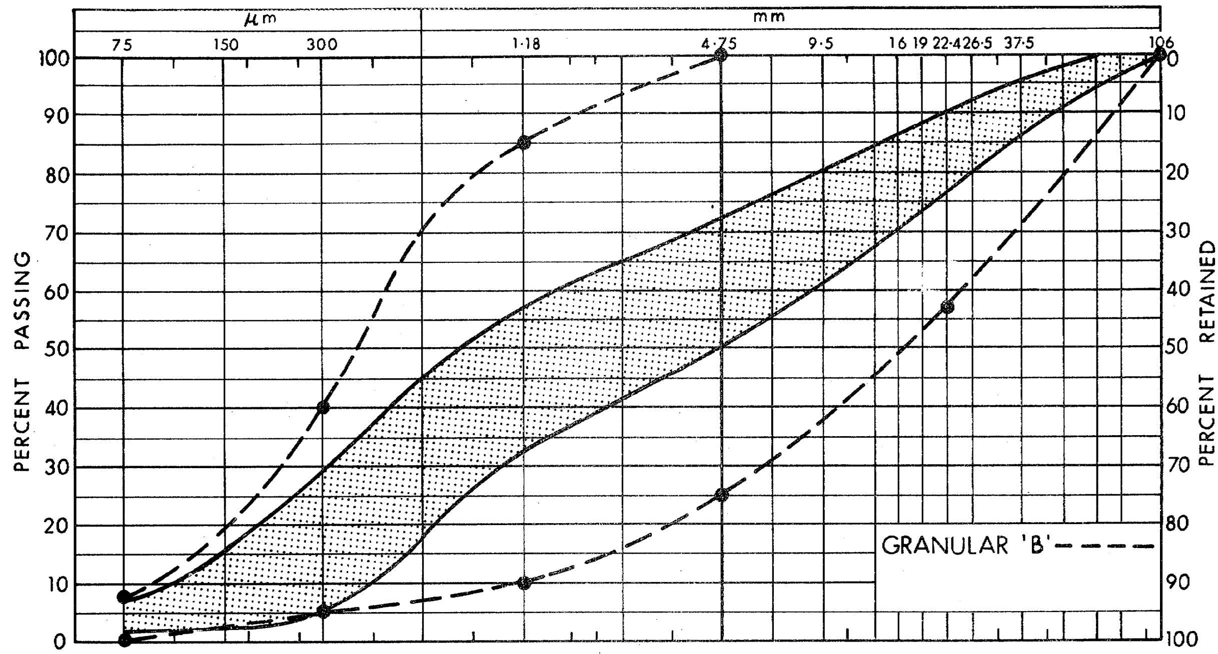


FIG. 17B

ENVELOPE OF 12 LOT GRADATIONS

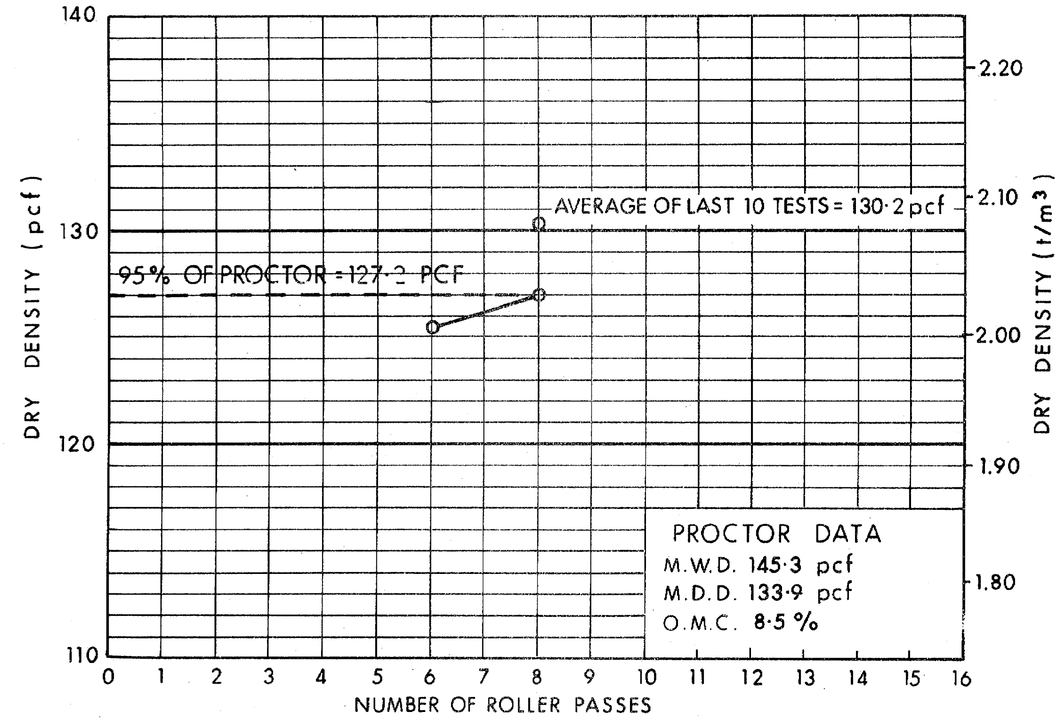
CONTROL STRIP TEST DATA

CONTRACT 79-102 HWY. 2 REGION CENTRAL

LOCATION BRANTFORD EASTERLY

TEST AREA : STA. 998+00 TO STA. 1003+00 WIDTH

MATERIAL GRANULAR 'B' SOURCE NEMETH PIT



REMARKS AVERAGE MOISTURE 6·8 % TARGET VALUE 130·2 pcf

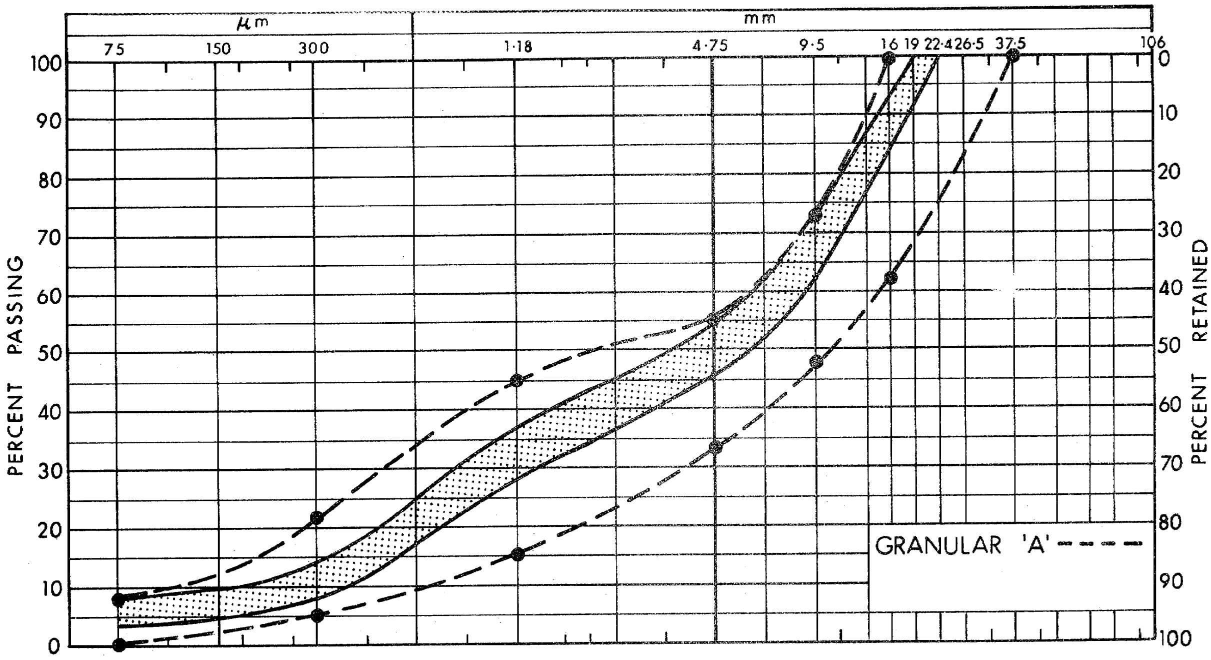


FIG. 19B

ENVELOPE OF 13 LOT GRADATIONS

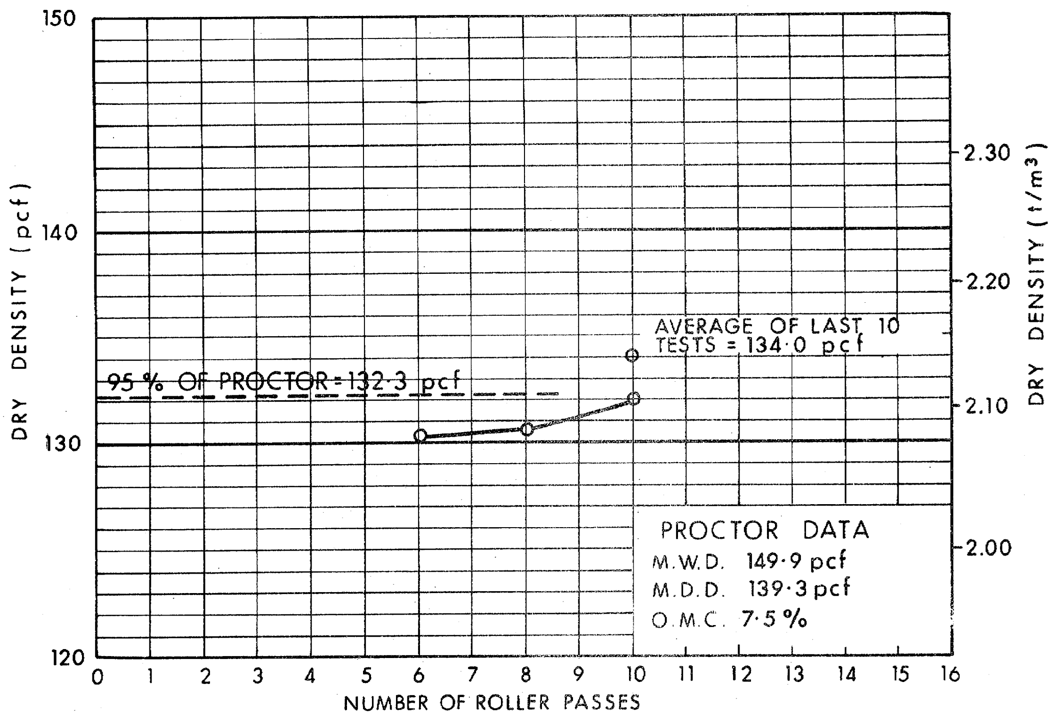
CONTROL STRIP TEST DATA

CONTRACT 79-102 HWY. 2 REGION CENTRAL

LOCATION BRANTFORD EASTERLY

TEST AREA : STA: 1031+00 TO STA. 1034+00 WIDTH

MATERIAL GRANULAR 'A' SOURCE NEMETH PIT



REMARKS AVERAGE MOISTURE - 4·7 % TARGET VALUE = 134·0 pcf

FIG. 20 B

APPENDIX C

INTRODUCTORY PROCEDURE FOR THE DETERMINATION OF COMPACTION OF GRANULAR AND EARTH MATERIALS

BACKGROUND

This procedure has been developed in order to alleviate the problems associated with determining compaction by means of laboratory Proctor moisture-density tests and single field density measurements, and to standardize the collection of compaction data across the Province.

The variability of the laboratory moisture-density test, the variation of the field density within a relatively small area and the fact that the maximum dry density does not always represent the material being compacted, are the shortcomings of the procedures generally used to date. It is realized that this improved procedure will not solve all the existing problems, but it should be a significant step in this direction, and will give us a uniform base for compaction data.

The arithmetic means (averages) of more than one test result always have a smaller dispersion than single test results. Maximum dry densities and field densities will therefore be determined by using the mean of more than one test.

To eliminate bias, sampling and testing are to be carried out on a truly random basis using tables of random numbers.

PROCEDURE

1. Establishing the Maximum Dry Density

A maximum dry density determination is necessary for compaction control when the following methods are used:
(a) the sand-cone method (ASTM-D1556), (b) the rubber-balloon method (ASTM-D2167) or (c) the nuclear gauge method (ASTM-D2922 & D3017).

Since the Constant Dry Weight (CDW) method compares field volume to a one-run Proctor volume, no Proctor values are required when using this technique.

When the control of compaction is carried out by methods requiring a maximum dry density, this should be determined by means of One Point Proctor tests (OPT). Three OPT's should be done, on samples taken randomly from each material to be compacted, at the beginning of the compaction operation. For granular materials, these samples should be taken after the material has been placed on the road (or in backfill, etc.). The exact locations of the samples should be determined by random tables. For earth materials, samples may be taken at the source, however, it is preferable to sample the material after placement.

OPT's should be carried out by closely following the method described in the Engineering Materials Office publication entitled "One Point Proctor Determination of Moisture-Density Relationships, using a Family of Curves". After the maximum dry density and the optimum moisture content of the three OPT's have been determined, the arithmetic means (averages) should be computed. These mean values of maximum dry density and optimum moisture content then become the reference values for the remainder of the course being compacted.

New reference values should be established as described above under the following circumstances:

a) at the beginning of the construction of a new granular course;
b) if there is a perceptible change in the gradation of the particular course (e.g., base, subbase, subgrade, etc.);
c) after 10 lots of compaction have been accepted on the basis of one set of reference values.

2. Compaction Control

While it is not the intent of the Ministry to control the contractor's operation, it is to be pointed out that the field moisture content should not fluctuate more than 20% below or 10% above the average optimum moisture content determined by the OPT's, in order to achieve the required compaction.

The control of compaction of each course should be carried out on a lot basis. The lot size for each course will depend on the area of the particular materiel (granular or earth) to be tested, the method of testing, and the type of construction. The minimum sampling and testing frequency tables, issued 79 07 23 by Provincial Roads Directive B-42, should be consulted for the various lot sizes.

For embankment and for base and subbase construction the frequency given in the tables for one test should be used to determine the maximum lot size, provided that testing is by nuclear gauge. Otherwise, it should be used to determine the maximum sublot size.

For backfills (sewer, pipe, structure and culvert), a lot should always be a single layer. Because of the larger number of tests necessary for the acceptance of a lot, every third or fourth layer may be tested when using the CDW method instead of the previously recommended every second layer.

To allow for the many possible circumstances, a degree of flexibility should be exercised in determining lot size. The important things, which must be adhered to, are the randomness of testing and the averaging of four tests in every lot.

Prior to acceptance testing of a lot, any visibly soft or loose areas should be corrected.

Each lot of the compacted layer should be divided into four equal sublots, and one field density and moisture test (or one CDW test) should be carried out at a randomly selected location within each sublot. Upon completion of the four tests within a lot, the average dry density should be computed. When using the CDW test, the average degree (percent) of compaction of the four tests should also be computed.

3. Acceptance

The acceptance criteria applicable to granular materials should be that the average field dry density obtained from the four sublots not be less than 100% of the maximum dry density, and that no single sublot fall below 95%.

The acceptance criteria applicable to earth materials should be that the average field dry density obtained from the four sublots not be less than 95% of the maximum dry density, and that no single sublot fall below 90%.

IT MUST BE EMPHASIZED THAT THE PRINCIPAL PURPOSE OF THE NEW PROCEDURE IN THE INTRODUCTORY YEAR IS TO OBTAIN BETTER AND MORE UNIFORM DATA ON THE LEVELS OF COMPACTION ACTUALLY BEING OBTAINED, NOT TO CAUSE A MAJOR CHANGE IN THE LEVEL OF ACCEPTANCE. JUDGEMENT SHOULD BE USED, THEREFORE, TO MAINTAIN AS CLOSELY AS POSSIBLE THE STANDARD OF ACCEPTANCE USED IN PREVIOUS YEARS. THIS CAUTION IS PARTICULARLY APPLICABLE TO GRANULAR 'A".

4. Random Sampling Technique

In order to obtain the locations for the tests, two tables of random numbers, Table 1 and 2, are attached. The tables contain columns of sets of two numbers. In determining a random location for a test, blindly choose any set. The first is used to calculate the station and the second is used to calculate the offset. If more than one random location is required, proceed down the column of sets.

a) OPT Locations:

Establish the length and width of the area from where the OPT's will be taken. 100 m should be adequate.

Example: Sta. 7+320 to 7+420 - 100 m long and 14 m wide
Random number set
e.g. .647
.068
100 x .647 = 64.7 m
14 x .068 = 0.95 m
Station of first test is 7+320 + 64.7 = 7+384.7
Offset of first test from right edge of area is 0.95 m

The procedure is then repeated to obtain the other two test locations.

b) Field Density Test Locations:

Establish the appropriate location size as in (2) above, then establish sublots as follows:

Example: Lot is from Sta. 7+320 to 7+520, 14 m wide
Subdivide the lot into 4 equal sublots.
Sublot 1 7+320 to 7+370
Sublot 2 7+370 to 7+420
Sublot 3 7+420 to 7+470
Sublot 4 7+470 to 7+520
Choose 4 sets of random numbers and calculate the station and offset of the field density test within each sublot as above.

5. Recording Test Results

Compaction test results should be reported on the following forms:

a) Field Compaction Report (CDW and conventional method), PR-CC-6 Rev. March 1980.

b) Field Compaction Report, Nuclear Gauge, PR-CC-9.

The forms are available through Stationery Stores.

TABLE OF RANDOM DIGITS

.116	.509	.936	.363	.622	.134	.975	.843	.472	.101
.427	.190	.334	.285	.757	.022	.089	.332	.680	.133
.274	.520	.937	.543	.039	.978	.508	.724	.514	.874
.383	.473	.386	.387	.582	.292	.981	.612	.747	.919
.315	.081	.548	109	.304	.105	.987	.635	.987	.633
.150	.153	.696	.517	.509	.202	.922	.663	.362	.274
.314	.475	.451	.501	.765	.977	.630	.639	.362	.170
.293	.310	.247	.535	.378	.429	.737	.731	.684	.309
.943	.057	.706	.385	.569	.784	.887	.754	.596	.221
.859	.525	.712	.866	.061	.508	.660	.430	.478	.319
.200	.033	.465	.463	.716	.444	.653	.20[illegible]	.363	.638
.165	.532	.048	.972	.381	.259	.853	.343	.306	.357
.397	.736	.101	.099	.538	.049	.647	.330	.639	.834
.633	.654	.553	.626	.746	.275	.672	.006	.475	.130
.049	.710	.894	.230	.208	.817	.865	.375	.465	.242
.658	.990	.623	.102	.736	.726	.207	.809	.925	.038
.229	.085	.439	.910	.651	.210	.050	.165	.989	.004
.615	.204	.132	.204	.230	.168	.774	.695	.440	.015
.912	.037	.961	.513	.376	.168	.504	.127	.177	.876
.166	.042	.469	.087	.726	.207	.599	.175	.267	.558
.564	.209	.937	.066	.671	.283	.088	.370	.309	.895
.589	.397	.631	.888	.178	.168	.238	.550	.815	.089
.298	.055	.601	.598	.765	.131	.014	.017	.648	.220
.303	.108	.914	.992	.253	.507	.404	.467	.729	.209
.425	.842	.236	.424	.427	.467	.956	.380	.248	.546
.242	.905	.181	.372	.145	.941	.080	.444	.792	.328
.503	.808	.528	.839	.358	.066	.192	.723	.086	.080
.896	672	.923	888	.868	.475	973	.688	.490	.872
404	.742	.097	.455	.731	151	.742	.502	.402	.818
.280	.003	.488	.924	905	.359	.447	.941	.523	.738
.417	.539	.529	.035	.099	.736	.138	.041	.594	.051
.990	.927	.534	.214	.345	.774	.477	.547	.830	.155
			Example						
.054	.264	.647	.058	.848	.684	.525	.978	.775	.099
.602	.859	.068	.926	.566	.000	.379	.131	.559	.633
.635	.810	.768	.328	.353	.489	.731	.231	.378	.678
.881	.189	.225	.873	.819	.812	.365	.484	.719	.532
.136	.618	.414	.433	.237	.770	.340	.296	.931	.327
.936	.529	.632	.641	.442	.542	.339	.142	.160	.315
.492	.494	.121	.951	.502	.838	.558	.802	.853	.269
.864	.442	.863	.614	.064	.885	.160	.014	.436	.263

TABLE I

TABLE OF RANDOM DIGITS

.884	.860	.263	.016	.052	.804	.623	.232	.857	.325
.006	.429	.845	.448	.679	.615	.791	.320	.133	.785
.153	.682	.214	.714	.768	.352	.496	.753	.529	.774
.420	.403	.911	.347	.932	.777	.516	.958	.272	.262
.630	.064	.493	.333	.495	.959	.448	.673	.916	.794
.325	.691	.890	.320	.145	.705	.588	.370	.043	.864
.395	.906	.358	.829	.937	.925	.209	.574	.657	.111
.582	.566	.604	.050	.959	.501	.886	.765	.453	.542
.564	.691	.059	.575	.851	.741	.532	.290	.074	.281
.168	.181	.882	.398	.031	.056	.433	.655	.512	.682
.965	.901	.119	.611	.753	.782	.848	.013	.050	.436
.689	.568	.604	.077	.377	.965	.854	.139	.639	.453
.267	.125	.447	.120	.836	.440	.866	.808	.091	.600
.014	.192	.586	.264	.273	.384	.552	.614	.898	.075
.795	.790	.962	.724	.212	.687	.902	.923	.162	.094
.599	.541	.386	.567	.874	.380	.884	.074	.530	.285
.890	.718	.840	.441	.479	.941	.908	.409	.391	.120
.070	.346	.454	.682	.317	.097	.804	.640	.244	.527
.852	.532	.589	.515	.024	.721	.855	.274	.795	.616
.347	.224	.750	.612	.486	.628	.626	.349	.790	.763
.455	.160	.963	.803	.648	.460	.395	.086	.182	.099
.293	.457	.008	.790	.458	.222	.110	.052	.051	.838
.150	.412	.327	.473	.646	.503	.971	.312	.029	.371
.592	.234	.551	.767	.339	.902	.397	.626	.007	.984
.171	.070	.533	.075	.068	.325	.244	.296	.977	.029
.870	.206	.232	.782	.131	.782	.405	.184	.971	.296
.660	.412	.192	.102	.338	.802	.334	.444	.232	.607
.546	.308	.039	.932	.409	.909	.207	.639	.654	.321
990	.080	.992	.800	886	.584	.523	.114	188	.453
228	.215	.173	.207	421	.172	.993	.636	204	.197
.872	.053	.957	.548	.800	.943	.715	.726	.840	.394
.613	.194	.244	.740	.197	.398	.491	.842	.018	.295
.931	.415	.859	.454	.681	.021	.738	.542	.292	.124
.803	.280	.930	.216	.326	.884	.630	.770	.931	.688
.741	.638	.712	.693	.291	.250	.239	.130	.575	.588
.313	.683	.551	.964	.206	.312	.888	.713	.130	.037
.485	.535	.647	.974	.678	.078	.342	.616	.434	.291
.978	.366	.143	.590	.326	.088	.693	.994	.811	.823
.399	.345	.475	.705	.157	.610	.817	.039	.806	.221
.838	.078	.148	.406	.439	.858	.421	.071	.130	.831

TABLE 2