COMPACTABILITY OF SOIL UNDER TOWED ROLLERS

By

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ABSTRACT

COMPACTABILITY OF SOIL UNDER TOWED ROLLERS

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The problem of specification of input work for soil compaction under moving rollers, in the past, has generally been addressed in terms of empirical relationships and techniques. In this study the amount of energy required to compact a particular soil to a certain density by means of rigid rollers is viewed in terms of the minimum amount of input energy required to produce no further change in soil density, or roller resisting force. The effect of roller surface configuration on compactability of the soil is investigated, and the results are compared with the results of Proctor tests. The study shows that the compactability of the soil is only a function of the compaction energy and is independent of the method of compaction.

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CHAPTER 1

INTRODUCTION

1.1 Field Soil Compaction

The purpose of field soil compaction using towed rollers is to provide an adequate resultant of the soil bearing capacity. Combination of the reduced permeability and at the same time the increased densification of the compacted soil produce higher compacted soil strengths to guard against slope failure, bearing capacity failure, excessive settlement, etc. for a long time duration.

Soil compaction in the field is accomplished by placing a loose layer of soil and compacting it until it reaches the specified soil density and soil strength or nearly equal to the characteristics of the underlying soil layers previously compacted. The objective of soil compaction is to obtain the desired characteristics of the compacted soil with a minimum number of roller passes or with a minimum amount of roller input energy (work done).

Generally, the compaction of layers of soil can be increased by increasing the normal stress imposed on the roller soil interface or by decreasing the thickness of soil layer to be compacted. Moreover, the normal stress can also be increased locally by providing different types of lug configurations on the roller surface. However, if the normal stress imposed on the soil roller interface far exceeds the bearing capacity of the soil, the soil will tend to extrude or flow under the roller instead of compacting.

The input energy (work done) required by a roller for the compactability of a given soil as proposed by Yong and Fattah, 1980; is a function of:

a) Roller type: towed, powered, rigid rollers, pneumatic tire roller, number of tires in the roller, arrangement, load of roller, speed, degree of slip, configuration of roller surface.

b) Soil: all the factors which influence the soil mechanical properties such as initial soil density, moisture content, soil structure, confining pressure, etc.

In this study, an analytical technique is established for the following purpose:

a) to calculate the amount of input energy required in compacting the soil per unit volume, and

b) to determine the total work done required to produce a certain soil density or permanent deformation (i.e., compacted depth) of the soil layer.

1.2 The Objective of the Project

The objective of this project is to investigate:

a) the effect of roller surface configuration, roller load on compactability of the soil

b) the compactability of the soil in terms of energy required to obtain a certain soil density.

The test results obtained from the towed roller are compared with those obtained from the Proctor tests.

The soil data obtained from the soil bin test facility is the following:

1. Soil density profile: initial (zero pass), intermediate (third and sixth pass) and final (16th pass) densities.
2. Sinkage of the roller
3. Rolling resistance of the roller
4. Water content of the soil
5. Shear strength of the soil measured by unconfined compressive and vane shear apparatus.

The data obtained from the Proctor tests is the following:

1. Total number of blows or input energy
2. Soil density
3. Water content of the soil

From the soil-bin measurements, the rolling resistance, the dry density, the calculated resultant input energy can be related to the dry density. Hence, this input energy-dry density relationship can be compared with those obtained from soil compaction using the Proctor tests. Fig. 1 shows the flow chart of the report organization which is divided into six chapters and an appendix.

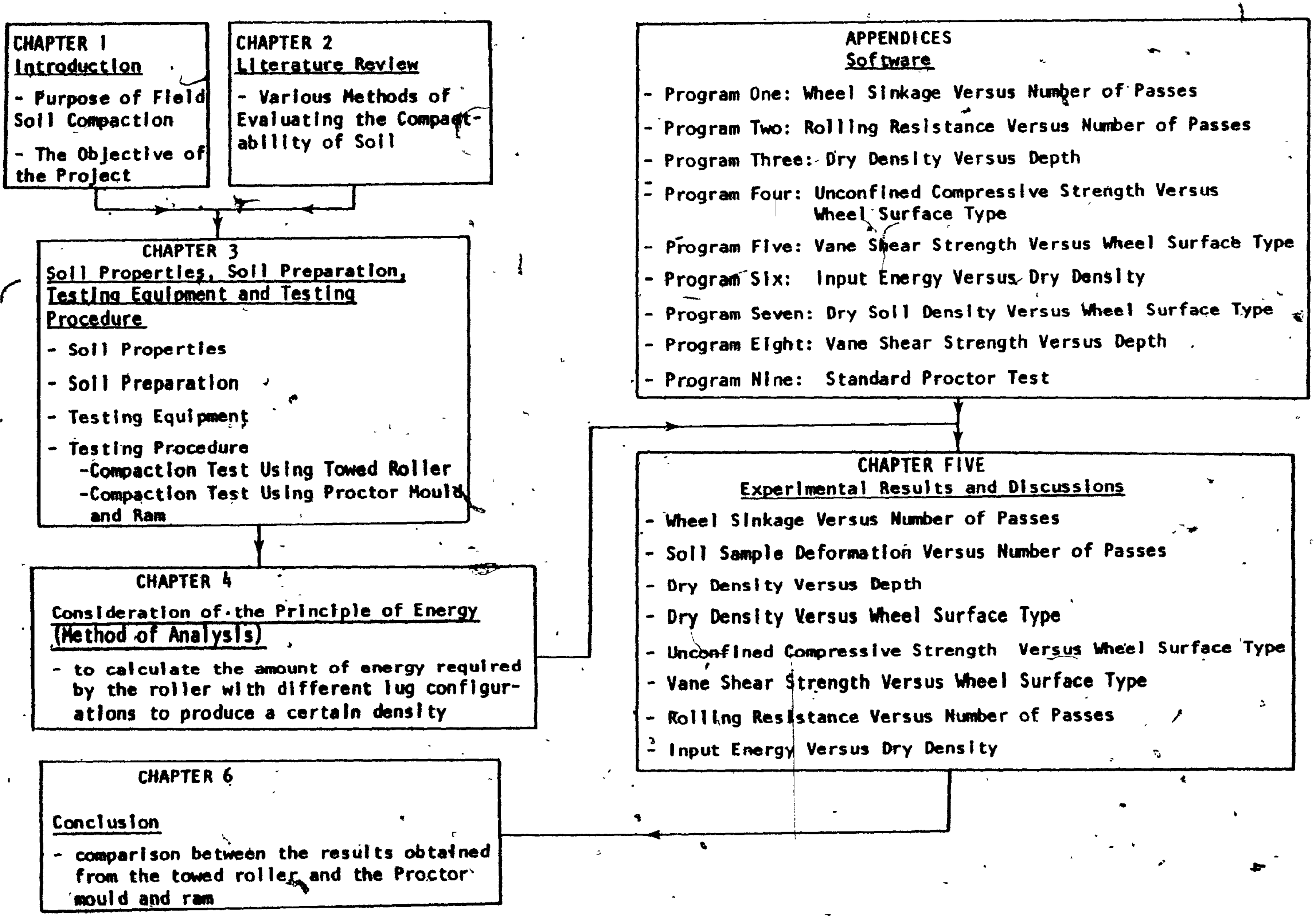


Fig. 1 Flow Chart of the Report Organization

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Work

Recent literature review shows that some investigators have done work on soil compaction and on the modeling of compaction process.

In analysing the trafficability of vehicles over soft soils, Freitag (7) used similitude modeling to predict the complex vehicle-soil interaction. Even if the criteria for soil compaction are different from those of trafficability, similitude modeling can be applied to soil compaction.

Waterways experiment station has performed many compaction tests with different soils and compactor types. Bergmann (8) made use of the raw data published by Waterways Experiment Station to construct a compaction model to predict the CBR* and the density of the soil after compaction. Bergmann postulated that in generating a CBR relationship, the model would be of the form:

$$\frac{CBR}{w/bR} = K.W_F.N_F.U_F.\omega_F.h_f.R_F.\mu_F \tag{1}$$

$$* \; CBR = \frac{\text{test unit load}}{\text{standard unit load}} \times 100$$

where

test unit load = unit load (psi) required to penetrate a certain depth of the penetration piston into a compacted soil specimen at some water content and density, and

standard unit load = unit load (psi) required to obtain the same depth of penetration as the test unit load on a standard sample of crushed stone.

where W = compactor weight, kg
b = width of compactor drum, m
R = radius of compactor drun, m
CBR = California Bearing Ratio, %
k = constant
W_F = weight factor
N_F = coverage factor
U_F = speed factor
ω_F = frequency factor
h_F = lift factor
R_F = bearing factor
μ_F = moisture factor

Very accurate results can be obtained if complete experimental data exists for a given set of experiments. However, the model performed poorly across a series of experiments reported in different documents. Bergmann also reported that the inaccuracy of the model is due to the errors in measurement and part is due to the existing inaccuracy of the model at its stage of development. A reasonable correlation could be obtained using the CBR model to predict compaction with different soil and compactor types. At the same time Bergamann (8) also formulated a density model in the form:

$$\frac{P_1}{W/bh_o R} = K\, W_F\, N_F\, \omega_F\, U_F\, h_F\, R_F\, \mu_F \qquad (2)$$

where all the parameters in equation (2) remain the same as those in equation (1) except: P_1 = dry soil density after compaction, kg/m^3. Generally, the density model is more peculiar to soil and compactor types compared to the CBR model. Therefore, the model needs some refinement before a general compaction model can be presented. However, for some types of soils the density model appears to predict better than the CBR model.

Weitzel and Lovell (9) used models developed from statistical techniques to predict density and strengths for a laboratory compacted clay. The authors presented the dry density models as follows:

$$P_d = 1338.3 + 1284.0 \sqrt{W_R}/W + 0.32 W^2\sqrt{W_R} \quad \text{(dry-of-optimum equation) and}$$

$$P_d = 961.8 + 15{,}564.6/W \quad \text{(wet-of-optimum equation)}$$

where p_d = estimated dry density, kg/m^3

W_R = average work ratio, and

W = water content, %

The strength models prediction were constructed as follows:

$$q_c = -1784.8 + 3.1 P_d \sqrt{S_i}/W + 84.0 (1-S_i/100)\sqrt{\sigma_3} \quad \text{(dry-of-optimum equation) and}$$

$$\log (q_c) = 1.70/e_i \quad \text{(Wet-of-optimum equation)}$$

where q_c = estimated compressive strength (KPa)

p_d = dry density (kg/m^3)

S_i = initial degree of saturation (%)

σ_3 = confining pressure (KPa) and

e_i = initial void ratio

All the developed models were reported to have good to excellent statistical characteristics. However, it should be realized the restriction on the use of laboratory compacted samples to predict field compacted conditions. Work on correlation between the results obtained from laboratory and field compacted samples is currently underway at Purdue university.

As most of the previous works showed that empirical relationships and techniques were used in developing the models for prediction of compaction process. Recently, an analytical model for a moving roller (rigid or pneumatic) was developed by Yong and Fattah (10). The finite element method of analysis was used to evaluate the amount of compactive energy required to produce a certain amount of permanent deformation. The soil types used in the experiment were kaolinite for rigid roller and a mixed soil consisting of fine silica and kaolinite for pneumatic roller.

2.2 Present Study

This study involved the compactability of clayey sand using rigid rollers. The data obtained from the experiments was analysed based on the principal of energy conservation. These results will be used for an analytical model at a later time.

The effect of roller surface configuration on compactability of the soil is also investigated, and the results are compared with those obtained from the Proctor tests.

CHAPTER 3

TEST SET UP AND PROCEDURE

3.1 Soil Properties

The soil used in the experiment is a mixture of "English Paper Clay" (kaolinite) and Saint Jerome "Silica Sand" at a ratio of 1 to 5, respectively.

(A) Kaolinite

The clay, originally in dry powder form, has the following properties:

Liquid limit = 54.5%

Plastic limit = 37.5%

Specific gravity = 2.62

The grain size distribution is shown in Fig. 1 with a chemical analysis by weight as shown below:

SiO_2 (Silicon Dioxide)	47.5%
Al_2O_2 (Aluminum Oxide)	37.5%
Fe_2O_2 (Iron III Oxide)	0.42
TiO_2 (Titanium Dioxide)	0.05
CaO (Calcium Oxide)	0.2
MgO (Magnesium Oxide)	0.2
K_2O (Potassium Monoxide)	1.3
Na_2O (Sodium Monoxide)	0.06

Loss on ignition 12.74

(B) Sand

The sand used for the mixture is a dry Saint Jerome silica sand with the following properties:

Specific Gravity = 2.67

Void Ratio Range = 0.905 to 0.58

The grain size distribution is shown in Fig. 2.

3.2 Soil Preparation

In order to determine the sensitivity of compactability and workability of the soil sample to be used in the experiment, several mixtures of sand and clay are made. As can be seen from the standard Proctor test results, Fig. 3, the compactability of the mixture, with respect to different ratios of sand and clay, increases as the amount of sand in the mixture increases. It does not make a difference in terms of sensitivity of compactability as to which mixture is to be used for the experiment. However, the sample of 80% sand - 20% clay is chosen for its workability.

The pure kaolinite, initially available in dry form, is powdered and thoroughly mixed with sand, also in the dry state. Each 5 kg batch of clayey sand is mixed with water (w=8.%±1%) manually. The water content is obtained from the optimum moisture content of compaction test shown in Fig. 3.

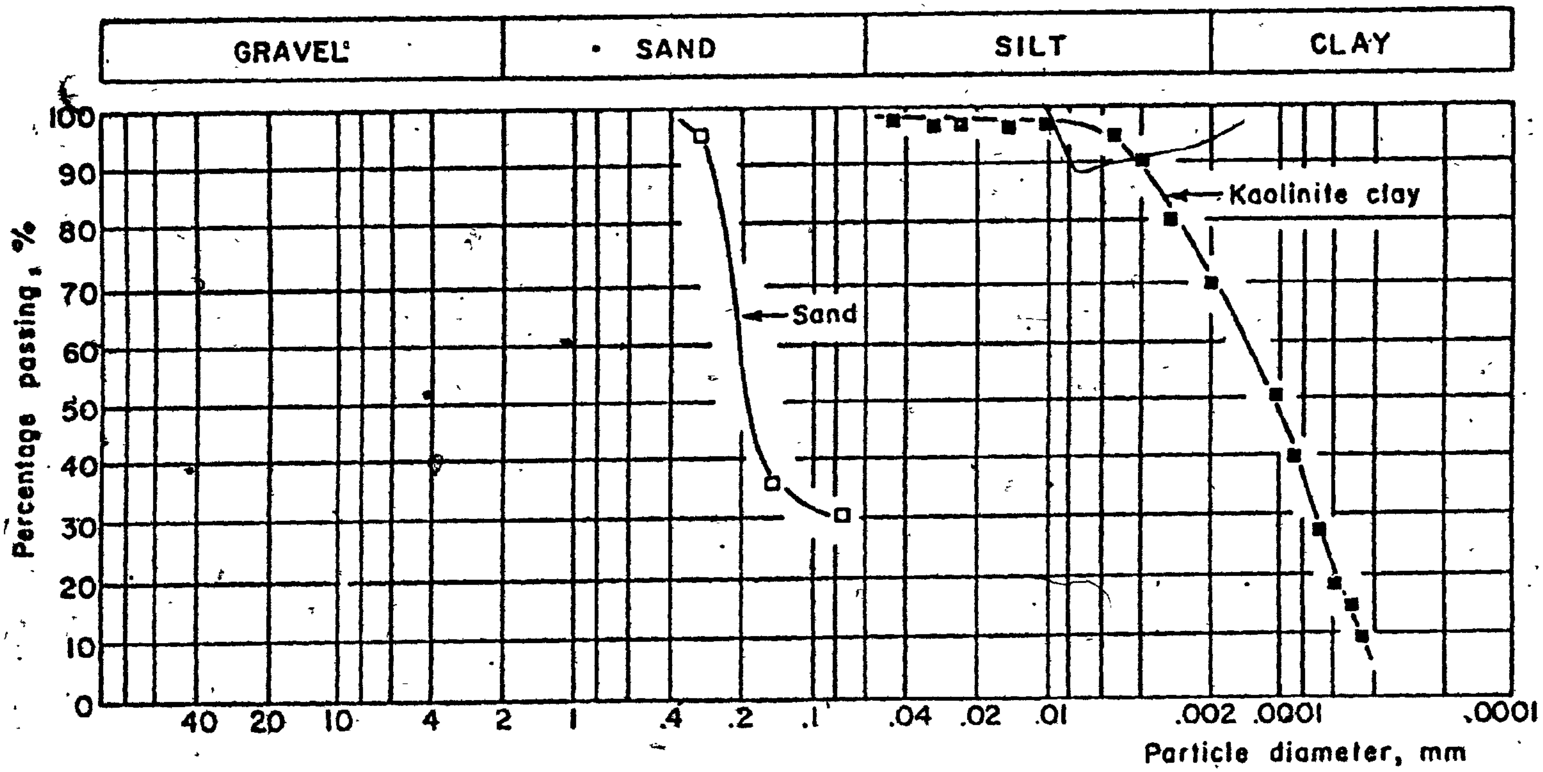


Fig. 2 Grain Size Distribution

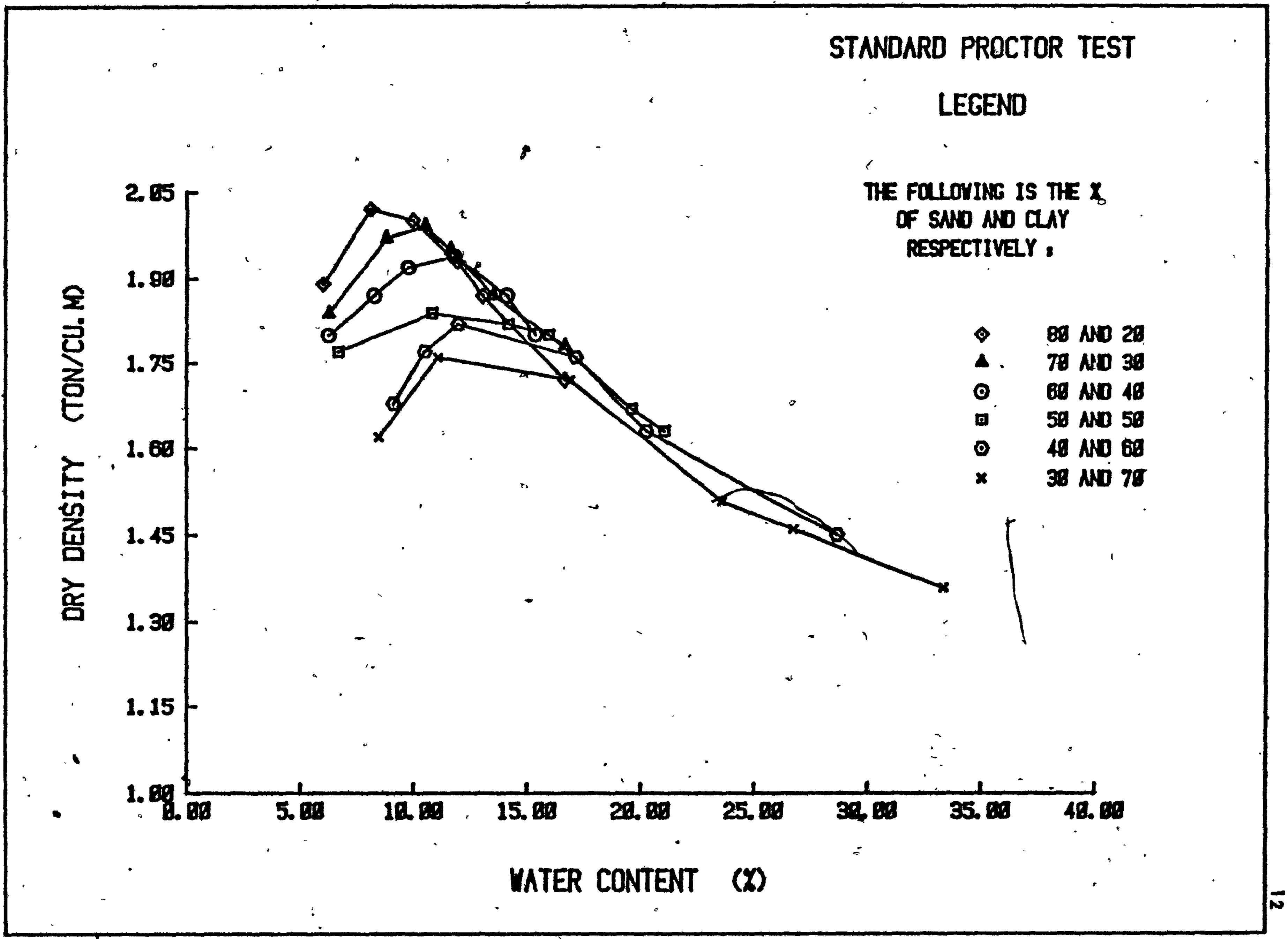


Fig. 3 Standard Proctor Test Results

3.3 Testing Equipment

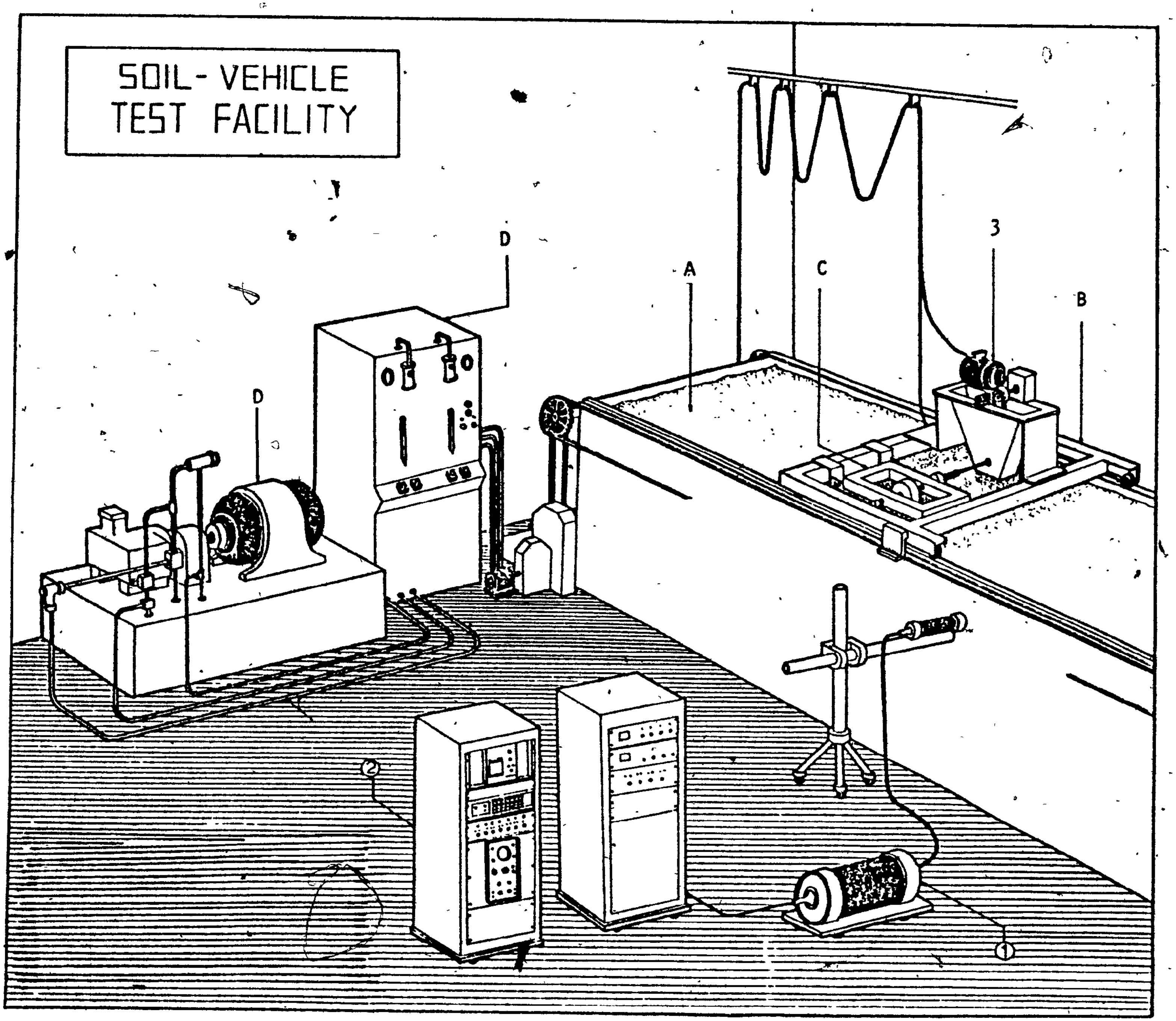
The details of the Mobility Laboratory testing equipment have been extensively reported by Windisch (1966), Yong et al (1967), and Webb (1968).

Fig. 4 shows the mobility laboratory testing equipment. Basically, for the purpose of this study the testing equipment consists of 8 components and some of them are not shown in Fig. 4:

(A) The soil bin
(B) The dynamometer carriage
(C) The flexure frame and test wheel
(D) The hydraulic drive unit for the carriage
(E) The soil sample holder
(F) The density samplers
(G) The electronic circuitry
(H) The motor drive camera

(A) The Soil Bin

The purpose of the soil bin is to provide support to the dynamometer carriage and to the sample holder. The sample holder occupies a small portion of the 6 feet wide, 4 feet deep and 32 feet long soil bin.



A SOIL BIN

B HYDRAULICALLY DRIVEN CARRIAGE

C FLEXURE FRAME, WHEEL UNDER TEST TORQUE METER & TELESCOPIC DRIVE-SHAFT

D HYDRAULIC DRIVE UNITS

1 X-RAY UNIT POWER SUPPLY, & COLD TUBE

2 RECORDER, POWER SUPPLY & AMPLIFIERS

3 D.C. ELECTRIC MOTOR, TRANSMISSION, CHAIN DRIVE & TACHOMETER

Fig. 5 Soil-Vehicle Test Facility

(B) The Dynamometer Carriage

The dynamometer carriage is used to provide a mobile anchor to the flexure frame of the test wheel and to support other equipment moving along with it. Two Z-rails and two continuous chains are used to guide and to pull the dynamometer carriage. The Z-rails are mounted on the longitudinal walls of the soil bin and the continuous chains are located along each Z-rail.

(C) The Flexure Frame and the Test Wheel

The aluminium test wheel is mounted on the aluminium flexure frame through ball bearings. Two strain gauge instrumented flexure frame pivots are used to connect the frame and the carriage. ~~The~~ deflection of the pivots are used to measure the rolling resistance. The size of the wheel is 13.5 inches in diameter and 3.75 inches in width, Fig. 5. Except for the different types of wheel surfaces used, Fig. 6, the overall wheel dimensions stay the same.

(D) The Hydraulic Drive Unit for the Carriage

A hydraulic motor is used to power the chains pulling the carriage. The direction and speed of the carriage is controlled by directional valves and flow control valves.

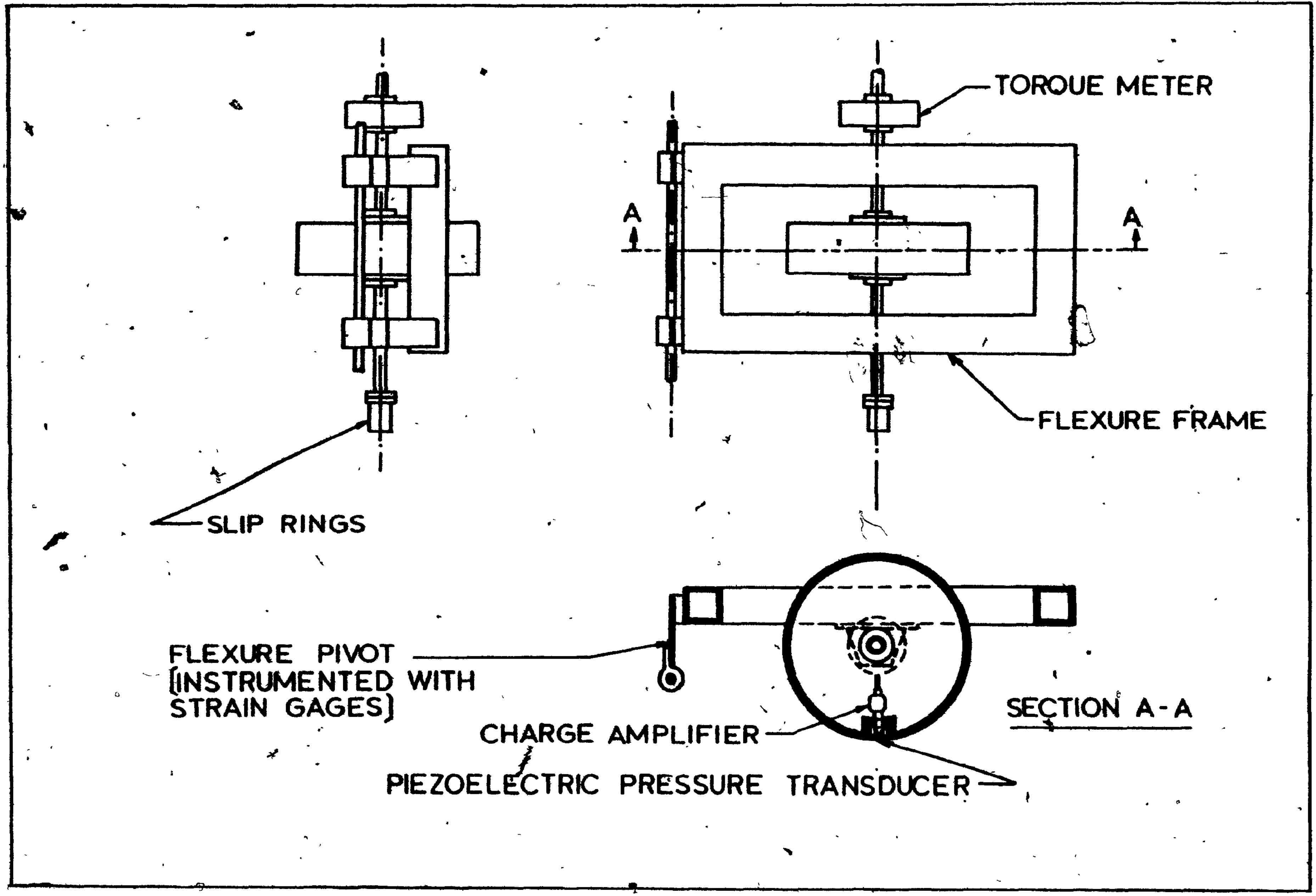
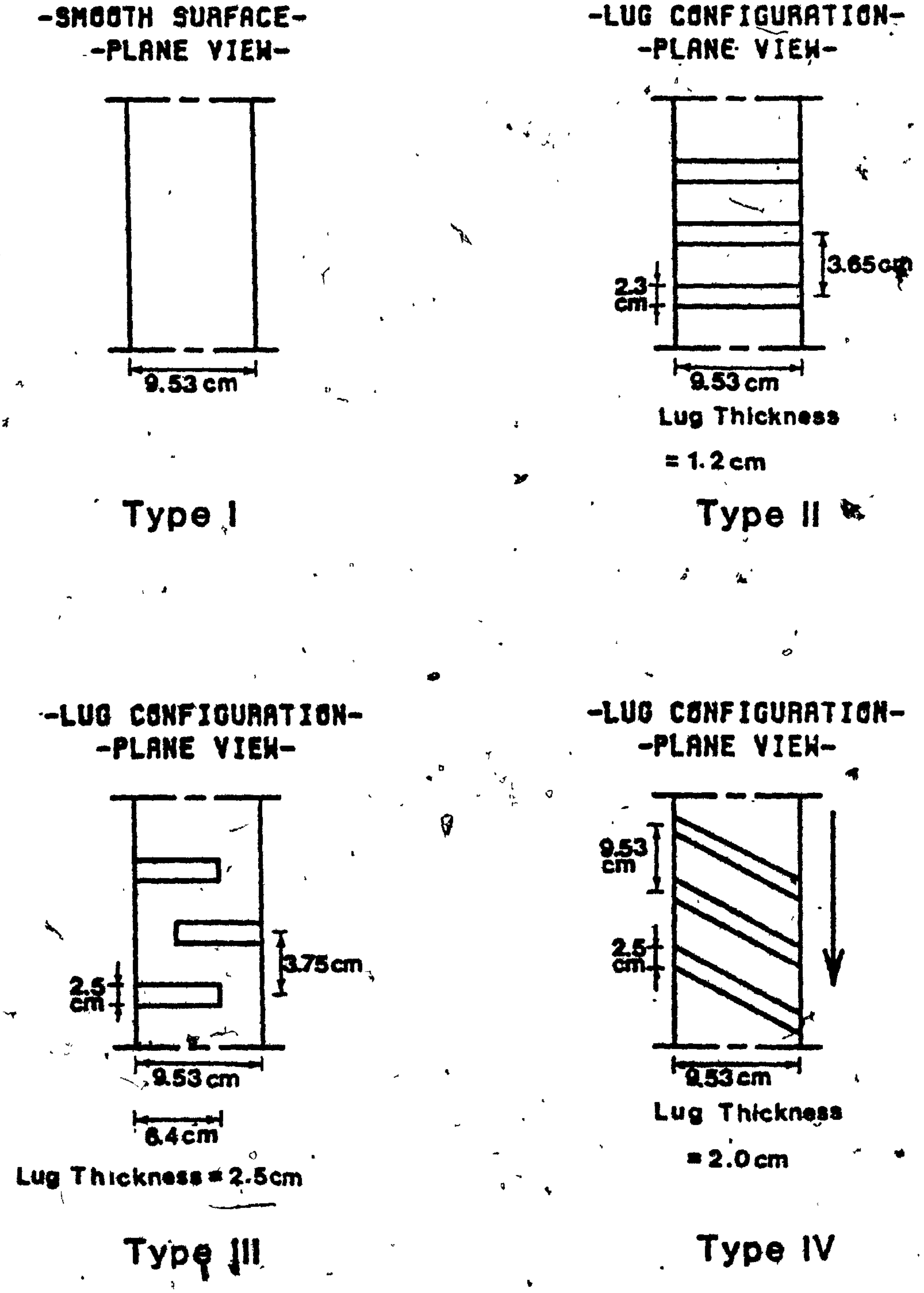


Fig. 5 Flexure Frame



Type I

Lug Thickness = 1.2 cm

Type II

Lug Thickness = 2.5cm

Type III

Lug Thickness = 2.0 cm

Type IV

Fig. 6 Wheel Surface Configuration

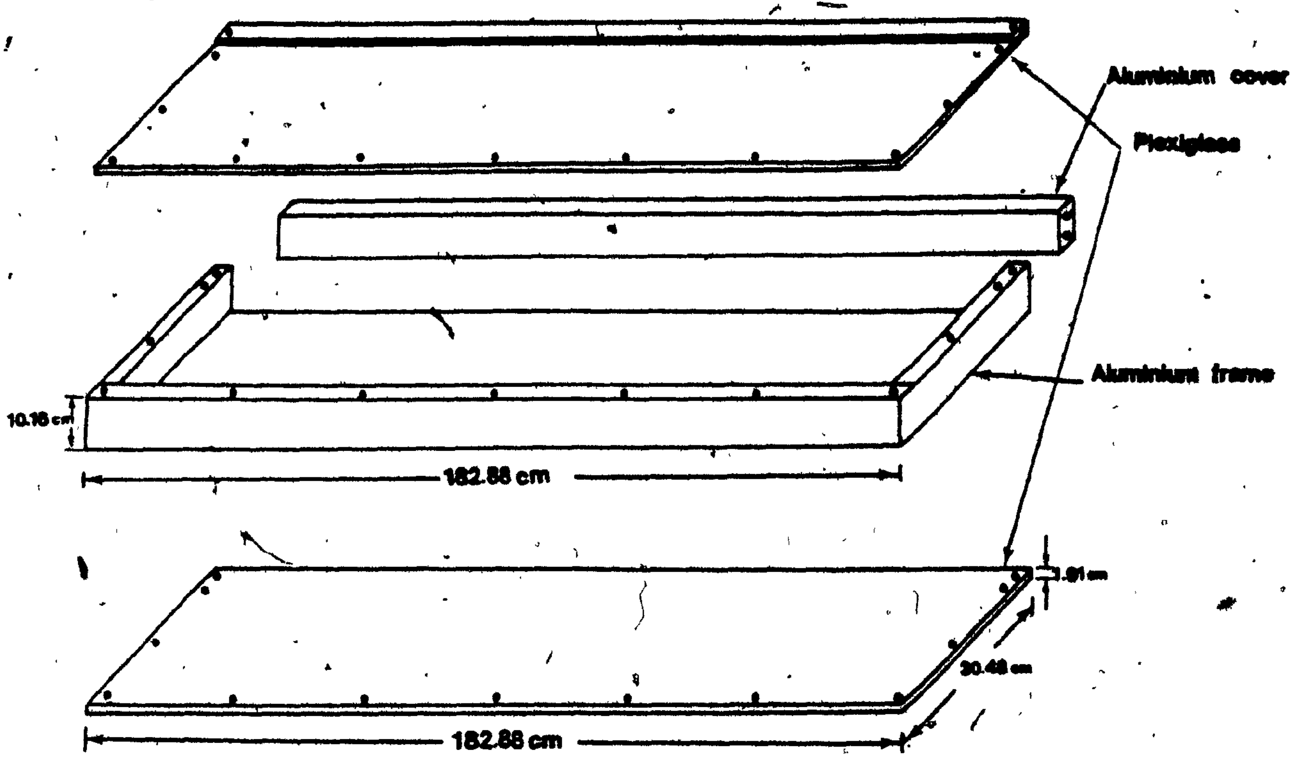


Fig. 7 Soil Sample Holder

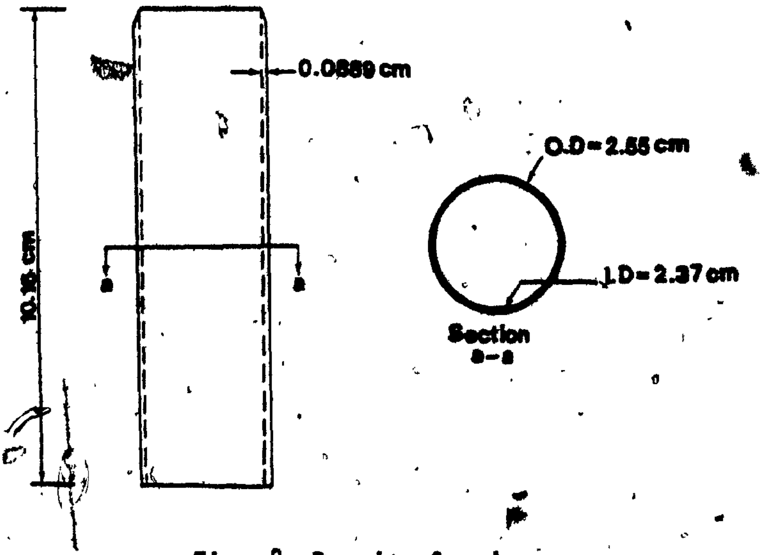


Fig. 8 Density Sampler

(E) The Soil Sample Holder

A 6 foot long, 4 inch wide and 1 foot deep rectangular box is used as the soil holder. The rectangular box consists of an aluminium frame, an aluminium cover and 2 pices of plexiglass, one for each longitudinal side of the box, Fig. 7. One sheet of plexiglass is removable to provide easy access to the soil during any phase of the experiment.

(F) The Density Samplers

Metal cylinders shown in Fig. 8 are used to determine the initial, intermediate and final soil densities of the experiment. One end of the sampler is bevelled to produce a sharp edge. The inner and outer surfaces of the samplers are coated with a dry film lubricant, to reduce their penetration friction upon insertion into the soil.

(G) The Electronic Circuitry

Figure 9 shows the electronic circuitry used for measuring the torque, the draw bar pull (right and left hand flexure pivots) and the wheel sinkage. However, due to the limitation of this study, only the rolling resistance circuitry is used.

Two 6 volt D.C. power supplies, the amplifiers and a six-channel ultraviolet recorder are used to complete the circuitry.

(H) The Motor Drive Camera

In order to study the deformation of the sample under the same wheel with four different wheel surfaces at two different loading cases, i.e. heavy (45.81 kg) and light (31.75 kg), a camera (Canon, type A-1) equipped with motor drive (3½ frames/second, and 5 frames/second) adjusted to the speed of 3½ frames/second is used.

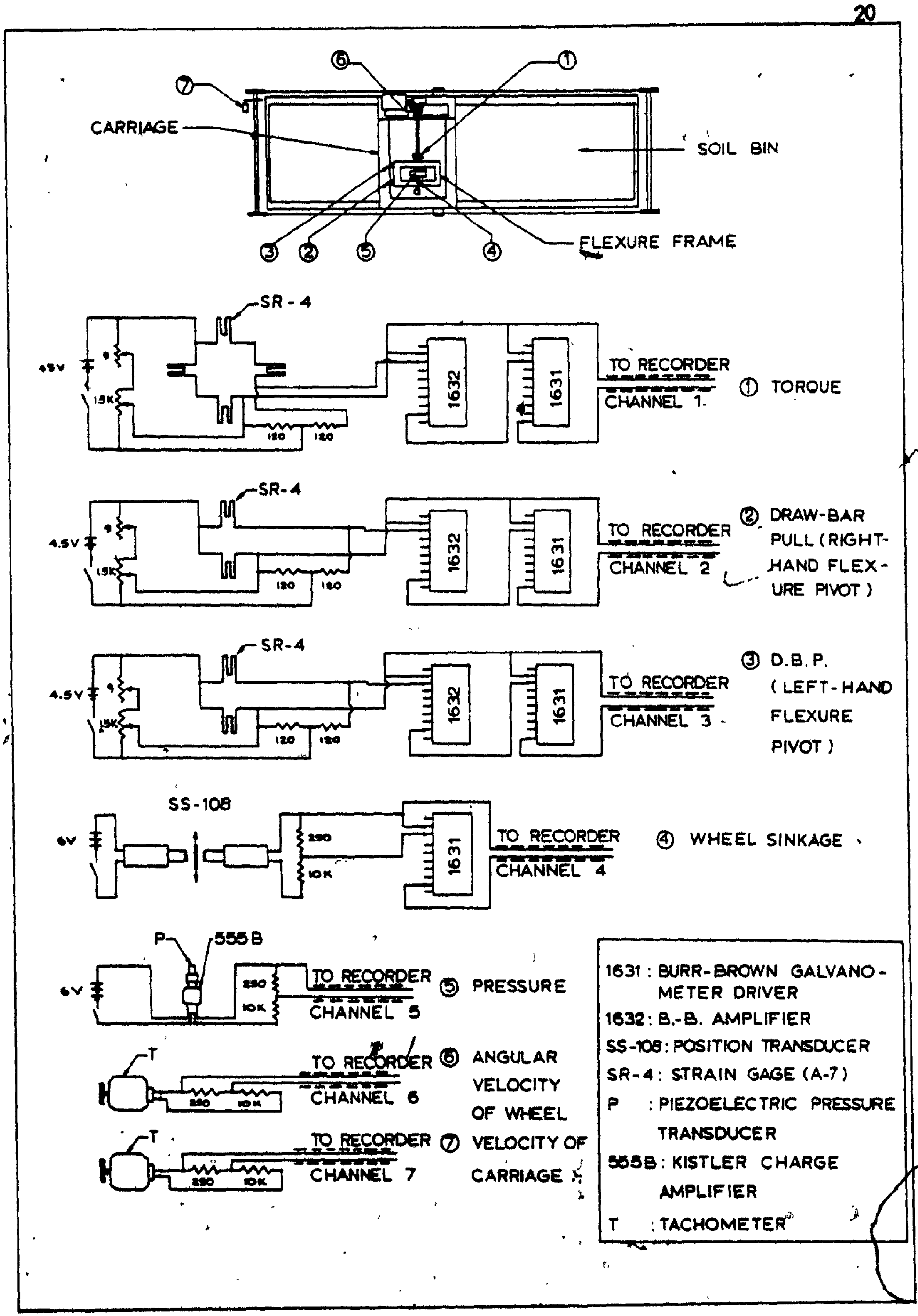


Fig. 9 Electrical Signal Circuitry of Soil-Vehicle Test Facility

3.4 Testing Procedure

Figure 10 shows the flow chart of testing procedure. As given in this figure the test procedure is divided into two sections. The first part deals with the compactability of the clayey soil under the towed roller using four different wheel surface configurations. The second deals with compactability of an identical clayey soil using the Proctor tests.

3.4.1 Soil compaction tests using towed roller

The clayey sand is placed loosely ($\gamma_w \approx 1$ ton/m^3) in the sample holder for a depth of 10" or [illegible] depending on the wheel load. After placement of the soil sample to the desired depth, the top opening of the sample holder is closed using the aluminium cover. Then, the sample holder is turned on its side to remove the plexiglass wall.

Three density samplers are inserted into the soil sample, one located near the surface, one in the middle and one near the bottom (Fig. 11). These density samplers will be taken out at the end of each experiment.

A one-half inch grid network is made on the soil surface using a black paint sprayer, Fig. 11. Before the paint is sprayed, a thin layer of white powder is sprayed uniformly on the surface of the soil to be gridded, so that the grid network can be seen clearly after spraying. After a slotted plexiglass sheet is placed over the coated soil surface, black paint is sprayed over it. Once the paint is sufficiently dary, the slotted plexiglass is rotated 90-degrees. The black pain is sprayed once more, completing the one-half inch of the grid.

After the laying of the grid network the vane shear tests, as located in Fig. 11, are performed to measure the initial soil shear strength.

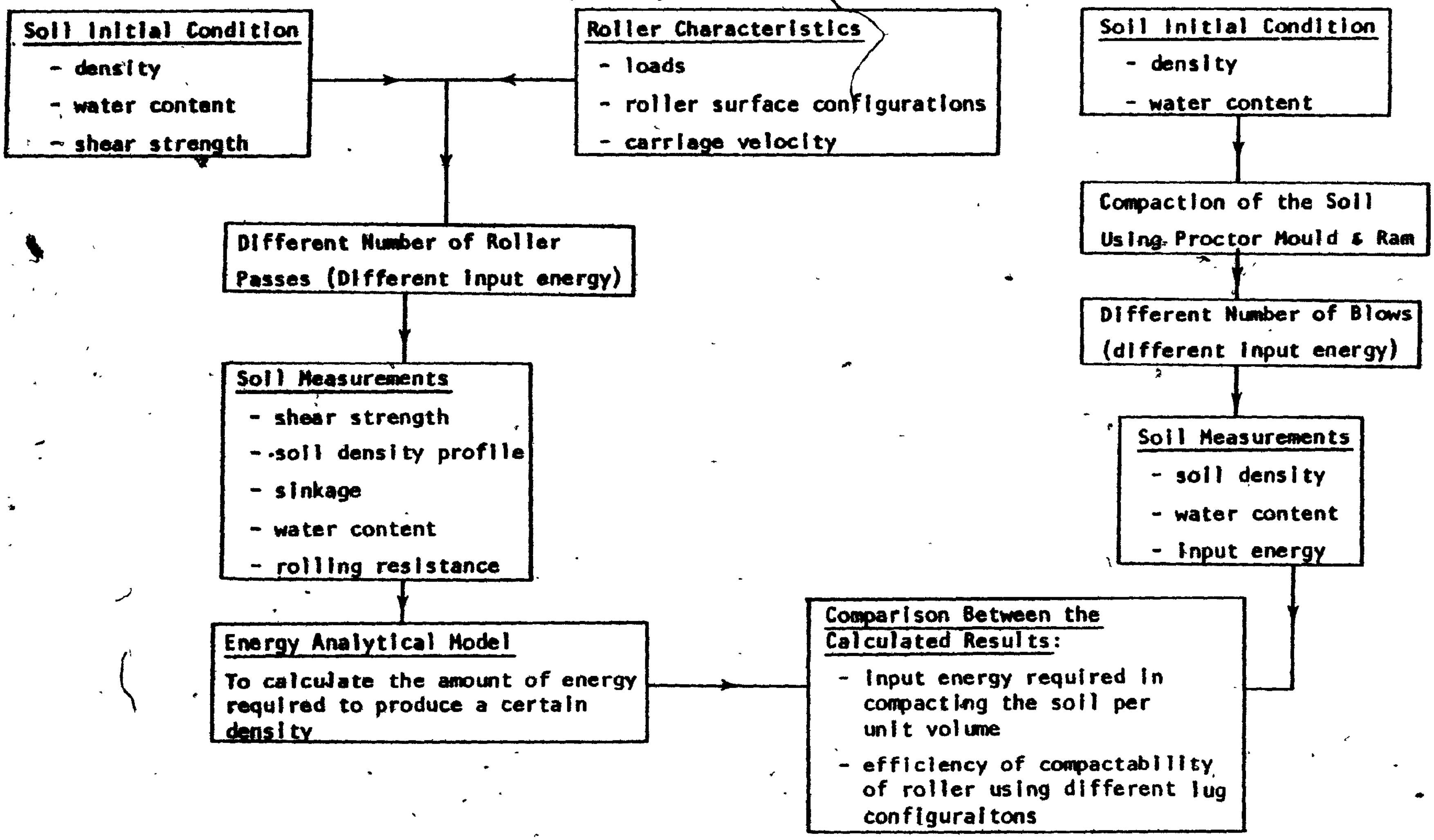


Fig. 10 Flow Chart of the Testing Procedure

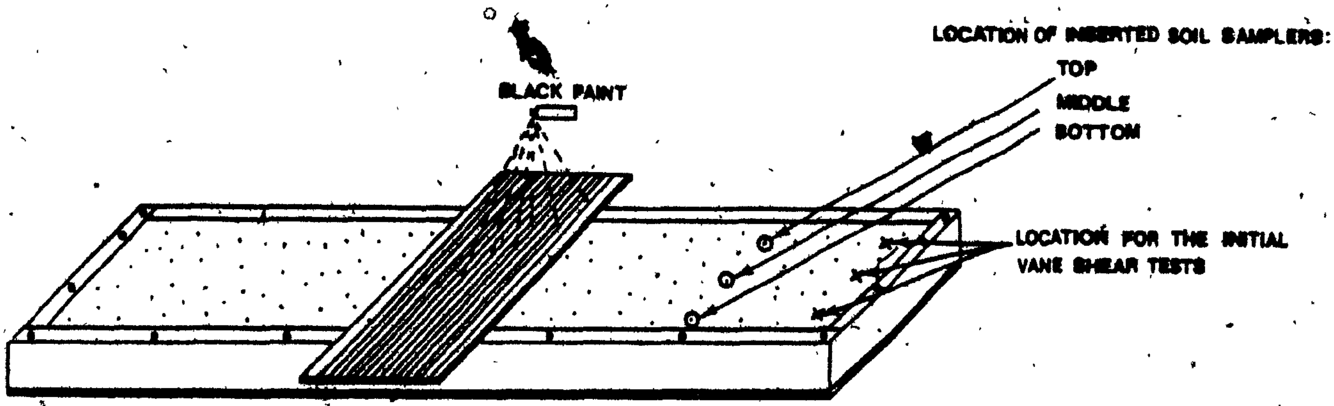


Fig. 11 Initial Locations for Vane Shear Tests and Soil Densities

Then the plexiglass wall is remounted onto the sample holder and righted to the position shown in Fig. 12. A one-half ton capacity crane is used to lift and lower the sample holder into the soil bin, Fig. 12. The sample holder is carefully placed into the soil bin so that the painted grid network is clearly visible from the bin window. After a motor driven camera is set in front of the window to photograph the soil deformations during the progress of the experiment, the aluminium cover of the sample holder is removed. The roller is positioned on the soil sample holder and subsequently loaded with dead weights (heavy or light weight case). Fig. 13 shows a typical set up of the loaded towed roller. The experiment, is completed when 16 full passes of the roller are performed.

Due to the short travel distance of the roller, the speed of the carriage is set at 17.27 cm/sec, taking approximately 11 seconds to complete one pass. During the compaction, the wheel is always pulled in one direction, i.e. after each pass the wheel is brought back to the initial starting position until 16 total passes are completed.

The accumulated rolling resistance is electronically recorded while the wheel sinkage is visually measured per pass. For the first 4 passes, photographs of the soil deformation (i.e. grid deformation) are taken. Since the soil sample showed little deformation after 4 passes, there were no pictures taken thereafter.

Besides the initial placement, 3 density samplers are inserted into the compacted soil sample after each sixth, twelfth, and sixteenth passes of the roller. The sampler installation procedure is the same as that described earlier, with the sample holder first lifted out from the soil bin.

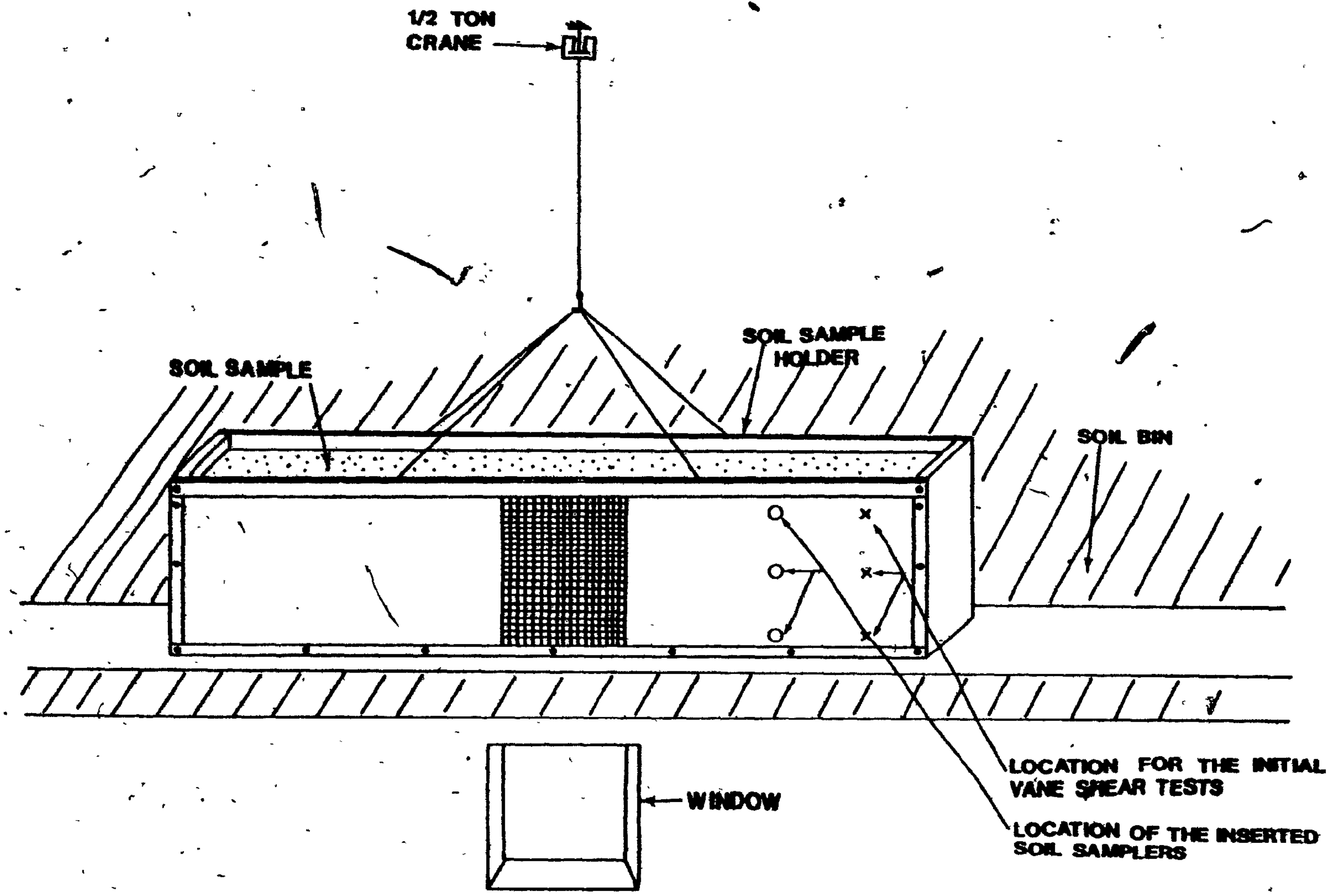


Fig. 12 Placing the Sample Holder Into the Soil Bin

Fig. 13 Typical Set Up of a Loaded Towed Roller

As soon as the full compactive effort is completed, the sample holder is lifted out from the soil bin, placed flat on its side, and the plexiglass wall removed. The 3 samplers from the sixth, twelfth and sixteenth roller pass as well as the 3 original samplers (i.e., twelve total pieces) are carefully removed. The soil retained within the samplers of known volume is weighed to determine the soil's wet density. Two representative soil samples are taken to determine the moisture content so that dry density can be determined. Vane shear tests are performed on the undisturbed portion of the soil still in the sample holder to obtain the final results of the vane shear strength after compaction. Fig. 14 shows the final location of the test. Two samples, 3 inches in height and 15 inches in diameter are taken from the compacted soil sample for the unconfined compression test. The locations of the samples taken are shown in Fig. 14.

To prepare for a new set of experiments, the compacted soil is taken out from the sample holder and remoulded manually. In order to compensate for the loss of moisture during the remoulding, testing and storing phases, water is sprinkled into the soil during remoulding. The remoulded soil is stored in two separate plastic bags, ready for the next test.

As mentioned earlier there are 4 types of wheel surfaces used in the experiment. The lugs of the various surfaces are made from commercially available rubber sheets and glued to the smooth roller surface using Contact cement. Each wheel type used for the soil compaction is tested under 2 different normal loads, 45.81 kg and 31.74 kg (i.e., "heavy" and "light", respectively).

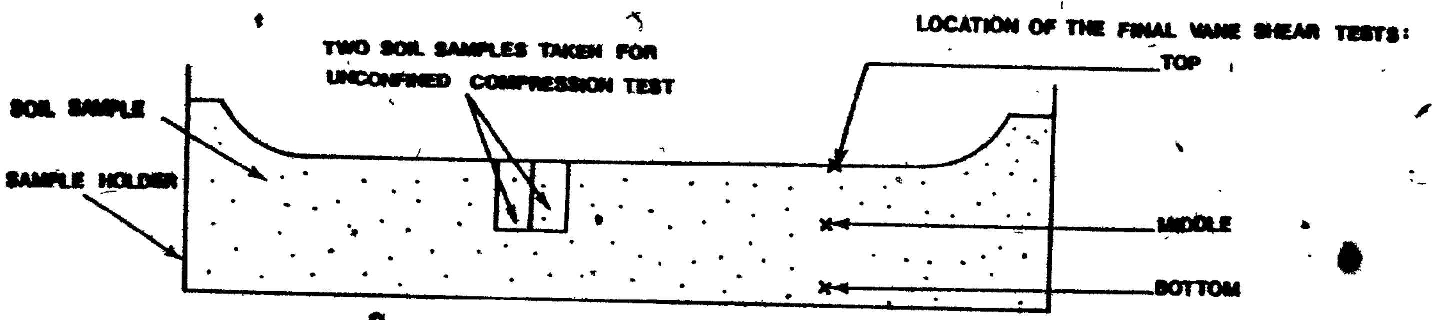


Fig. 14 Final Soil Sample Locations for Testing

3.4.2 The Compaction Test Using Proctor Mould and Ram

In order to relate the number of blows or input energy with the dry densities, the same type of clayey sand at the same water content as in part A is used again in compaction tests using the Proctor mould and ram. The detailed procedures of the Standard Proctor Test can be found in method "A" of the ASTM D1557. A brief description of the test is given below:

In order to evaluate different input energy and different dry densities, a series of tests is performed using various numbers of blows, so that the resultant input energy applied is related to the associated dry density obtained. The dry density is obtained with the following relationship:

$$\gamma_d = \frac{\gamma_w}{1+w}$$

where

γ_d = dry density (ton/m^3)

γ_w = total density (ton/m^3) and

w = water content in %

The initial density with respect to zero blows applied is obtained by filling the mould loosely with the soil and recording the weight. The testing procedure exactly follows that of the Standard Proctor test, except for the number of applied blows which is varied from trial to trial.

CHAPTER 4

CONSIDERATION OF THE PRINCIPLE OF ENERGY

The principle of conservation of energy is used to analyse the test results obtained from the roller compaction tests. Fig. 15 shows the energy conservation principle as applied to the roller-soil system. It is assumed that the input energy or pull energy required to keep the roller at a constant speed for each pass is equal to the sum of the following parasitic energy components (Yong and Fattah, 1980):

a) The energy required for compacting the soil
b) The energy dissipated at the roller-soil interface
c) The tire distortion energy dissipated. However, in the case of rigid roller, this parasitic energy is negligibly small and can be ignored.

Since the roller used in compaction is relatively wide, a plane strain analysis can be assumed where all the calculations are performed per unit width.

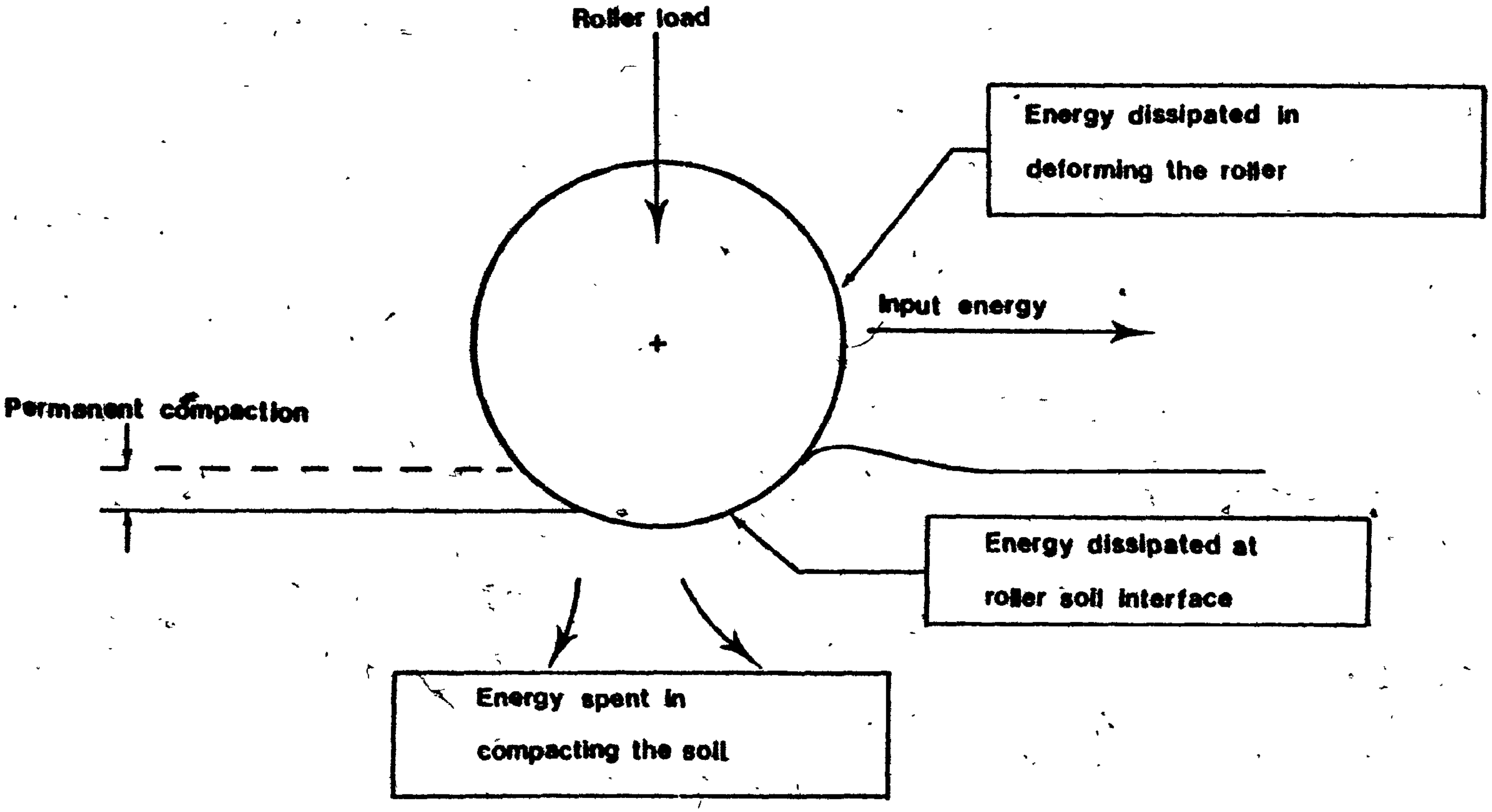


Fig.15 Towed Roller-Soil Energy System

CHAPTER 5

EXPERIMENTAL RESULTS AND DISCUSSIONS

The results and discussions are divided into ten sections, according to the type of parameters observed from both the experimental and the calculated values. Moreover, each section consists of two wheel loading cases, i.e., 45.81 kg and 31.75 kg each with four different wheel surfaces.

5.1 Wheel Sinkage versus Number of Passes

Figure 16 shows the effect of the number of passes on sinkage for the four different types of roller surfaces with the two loading cases. As was expected the initial sinkage is large, decreasing with an increased number of passes to a point where the sinkage is relatively low.

In comparing the amount of sinkage between the four types of roller surfaces, it seems that the total sinkage for roller surface Type I is higher. This may be due to the fact that the sample soil beneath the smooth roller surface extruds more easily than those of the rough surface rollers, i.e. roller types II, III and IV. Moreover, sinkage for the various rough surface rollers is almost similar.

5.2 Soil Sample Deformation

Figures 17A and B show typical deformations of the soil sample due to towed roller. The pictures are taken at the speed of 3.5 frames/sec, thus, each picture shows the deformation of the soil sample at different roller travelling locations.

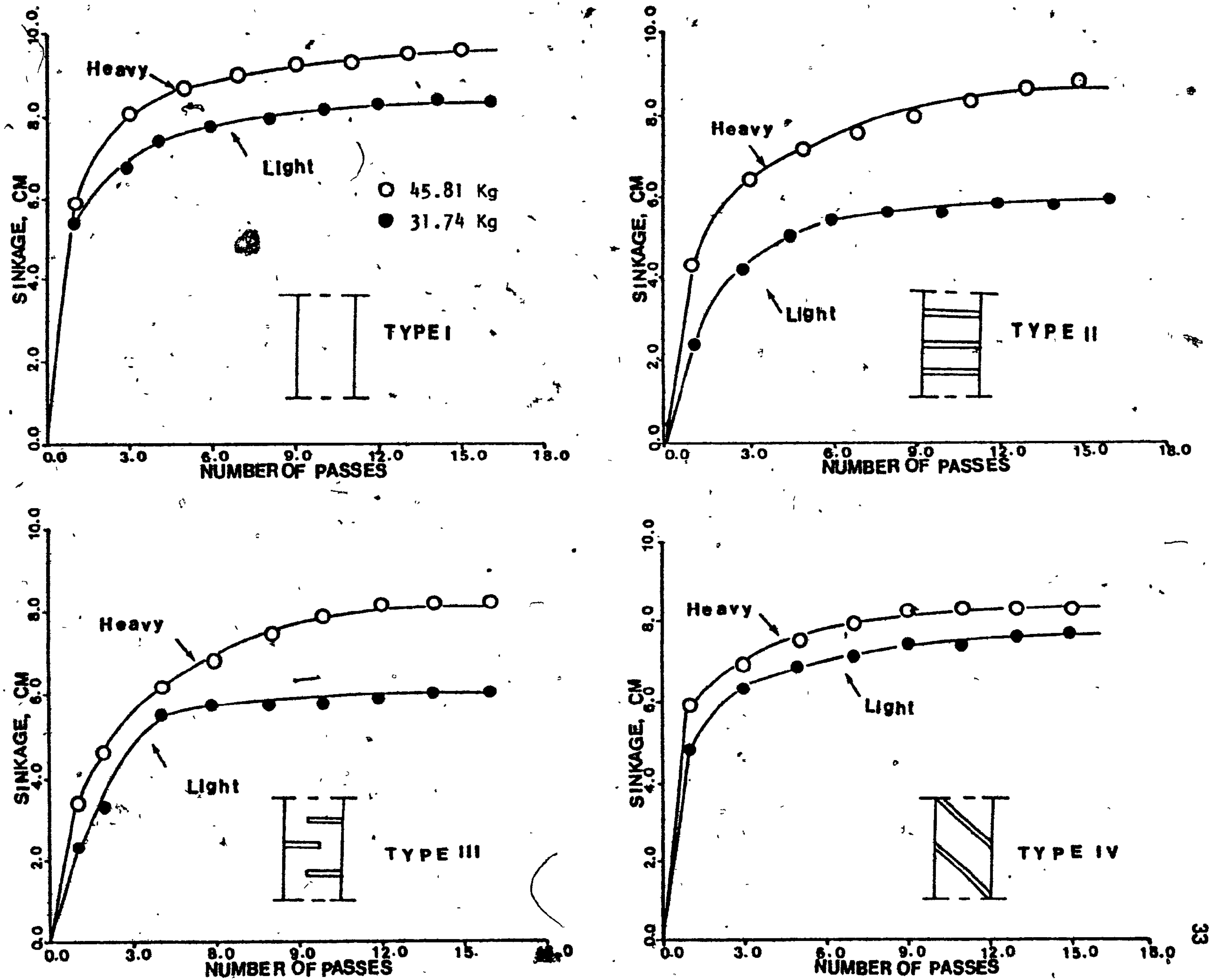


Fig. 16 Effect of Number of Passes on Sinkage

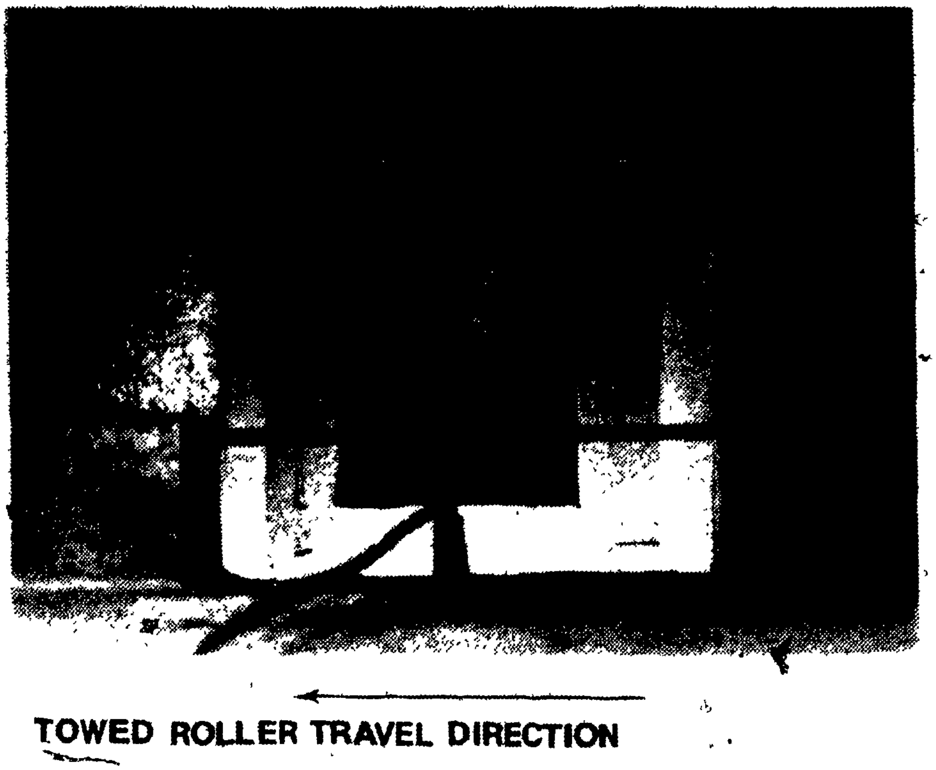


Fig. 17A & B Deformation of the Soil Due to Towed Roller

5.3 Dry Density Versus Depth

Figure 18 shows the initial and final soil density profile (before and after compacting). The results for light and heavy rollers after 16 passes are also presented. It appears that the resultant densities obtained after 16 passes decrease with respect to the depth of the compacted soil sample.

5.4 Vane Shear Strength Versus Depth

Figure 19 shows a typical distribution for vane shear strength versus depth for the initial soil conditions (before compaction). Also shown are the results after 16 passes of the two rollers (light and heavy). It appears that the results obtained after 16 passes initially decrease rapidly reaching a point at which the vane shear strength shows small relative change.

5.5 Dry Density Versus Number of Passes

Figures 20 through 27 show the dry density versus number of passes for wheel surface Type I through Type IV, respectively. The soil samples are taken from top, middle and bottom parts of the soil sample. It appears that the soil densities measured at various locations of the compacted soil sample increase rapidly for the first few passes, reaching a point where the change in density is relatively small.

In comparing the dry density obtained from various types of wheel surfaces at different depths and number of passes, it shows that wheel surface Type I produces the highest density. Whereas dry density obtained from wheel surface Types II, III and IV is almost similar.

5.6 Dry Soil Density Versus Wheel Surface Type

Figure 28 shows the dry soil densities obtained from 3 different locations (top, middle and bottom) of the compacted soil sample after 16 passes.

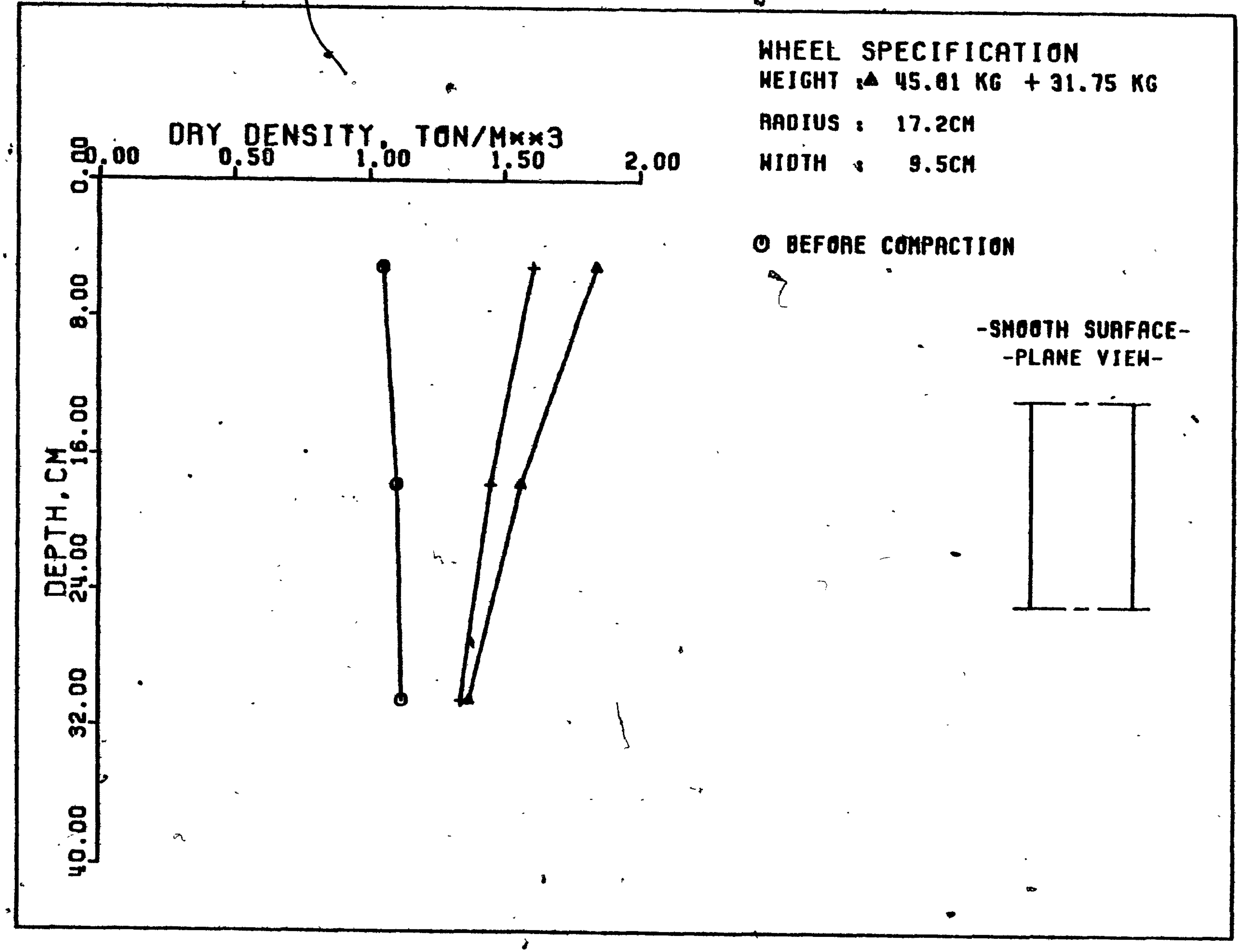


Fig. 18 Dry Density Versus Depth

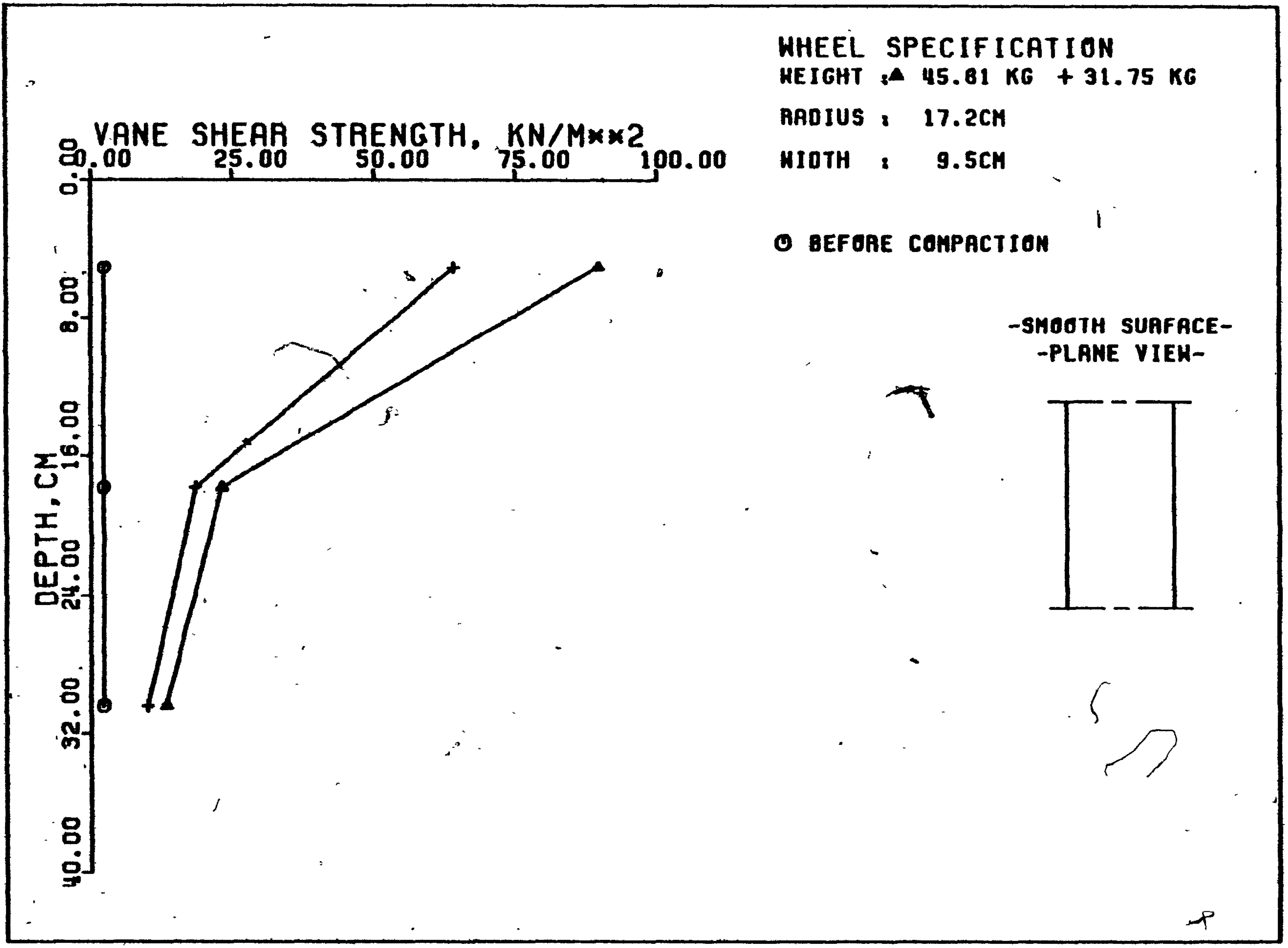


Fig. 19 Vane Shear Strength Versus Depth

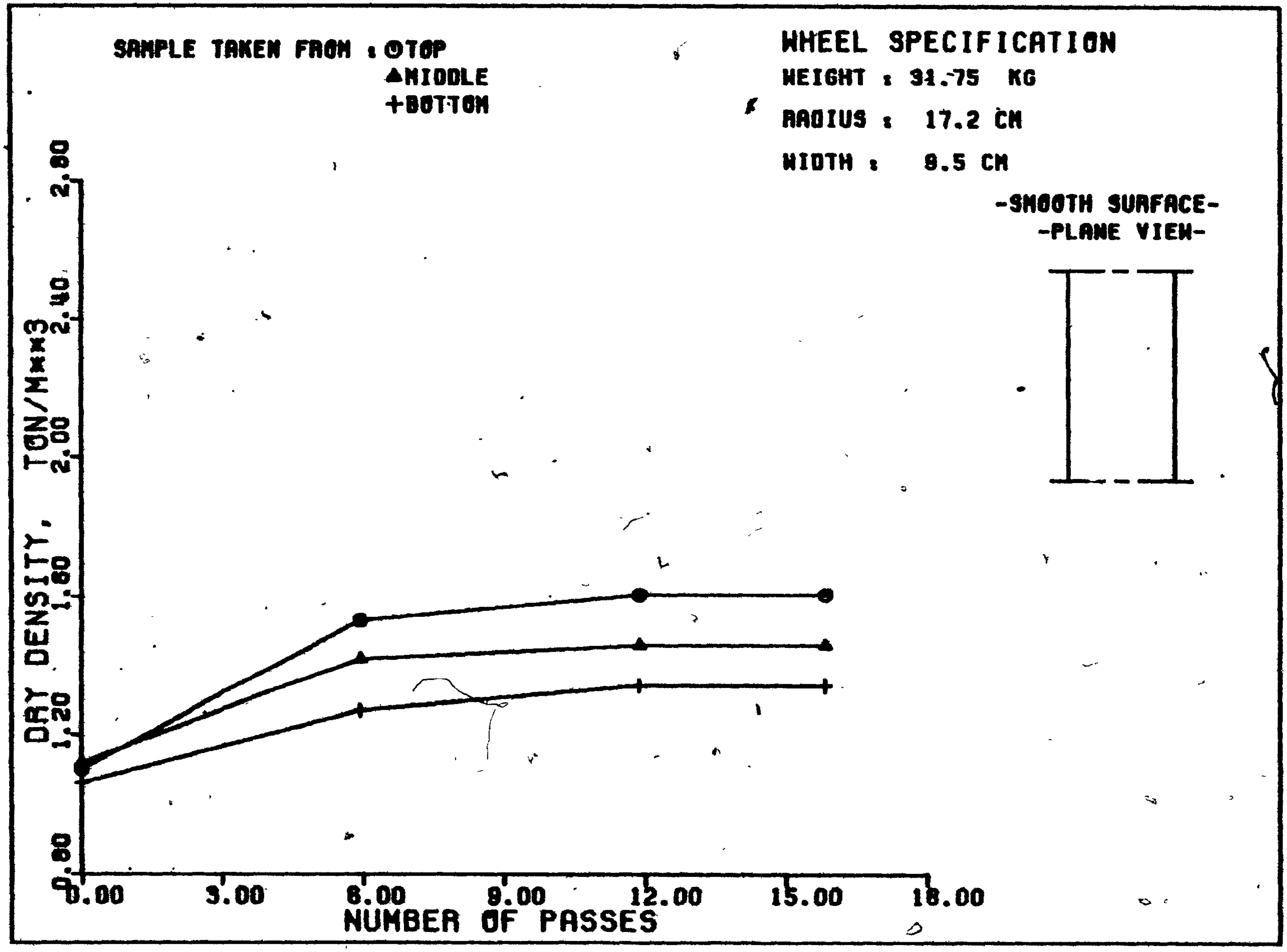


Fig. 20 Dry Soil Density Versus Number of Passes

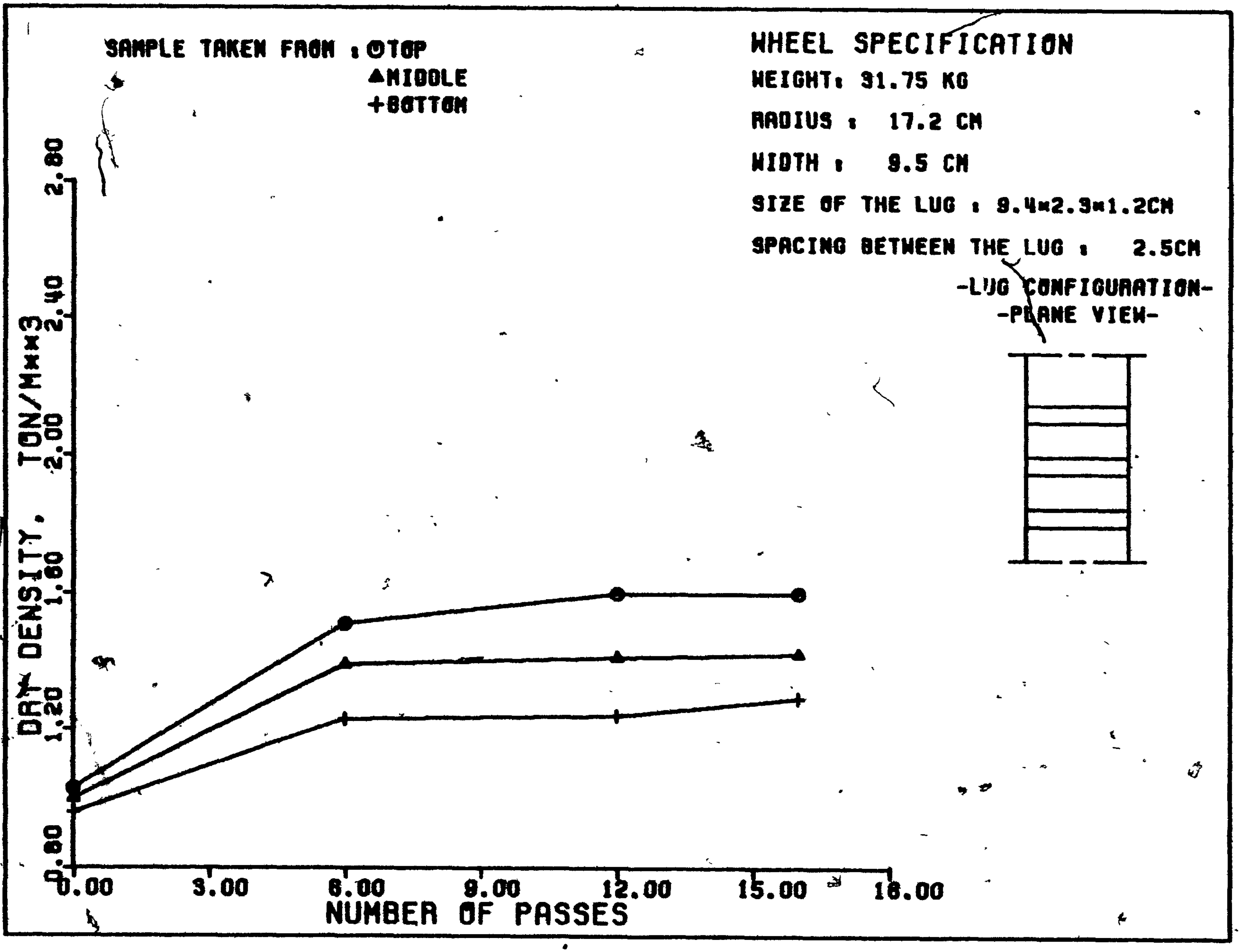


Fig. 21 Dry Soil Density Versus Number of Passes

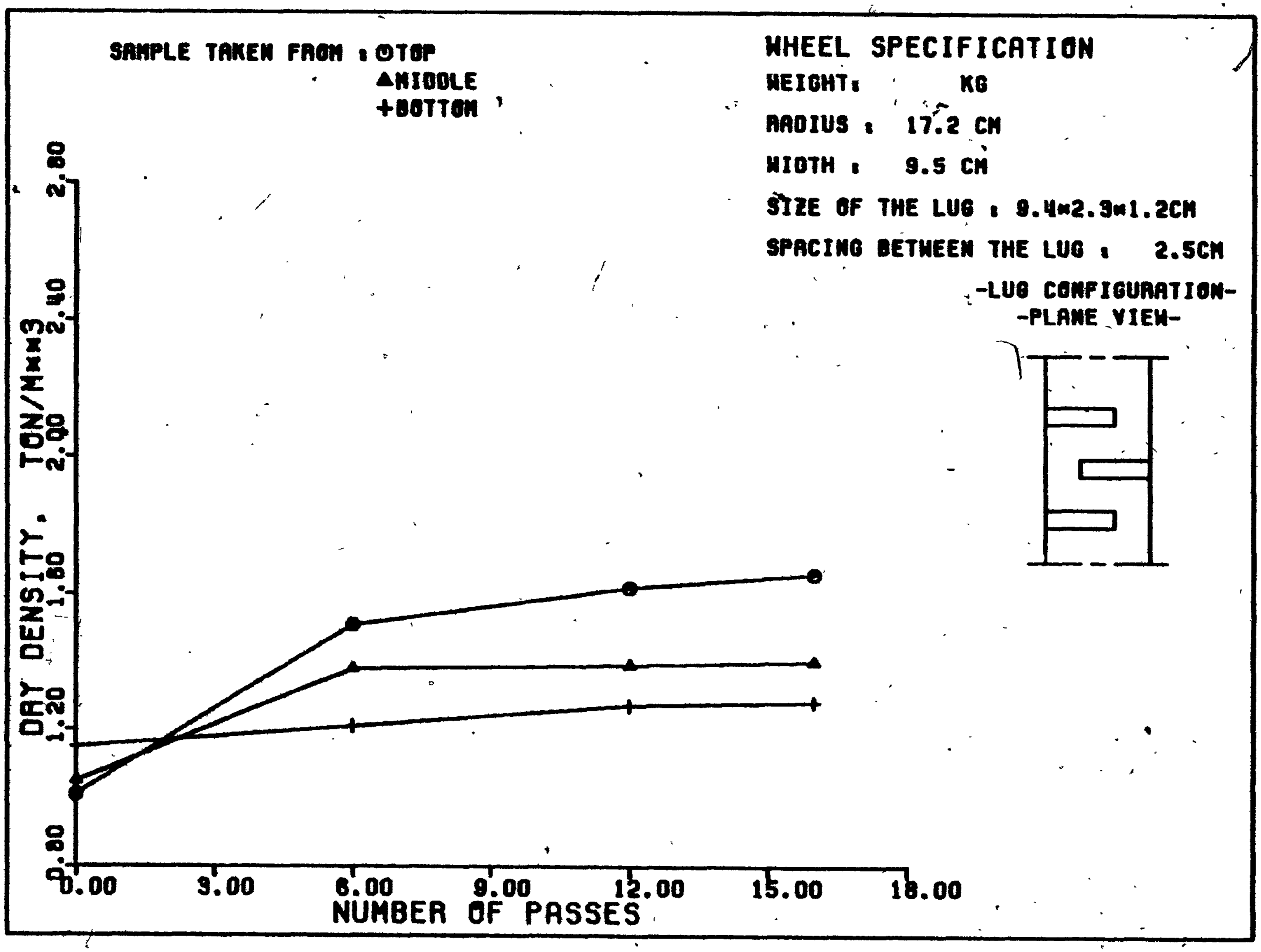


Fig. 22 Dry Soil Density Versus Number of Passes

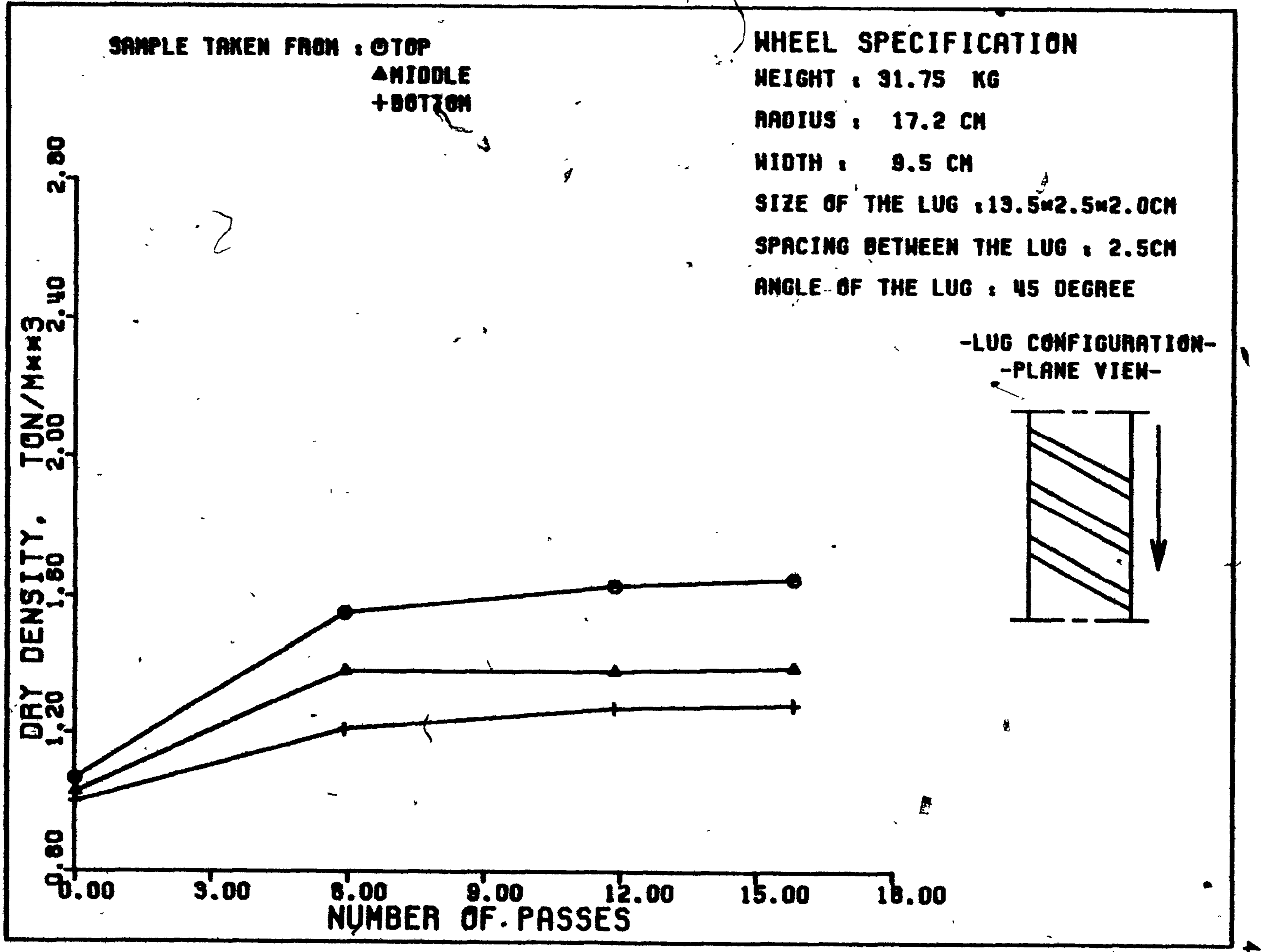


Fig. 23 Dry Soil Density Versus Number of Passes

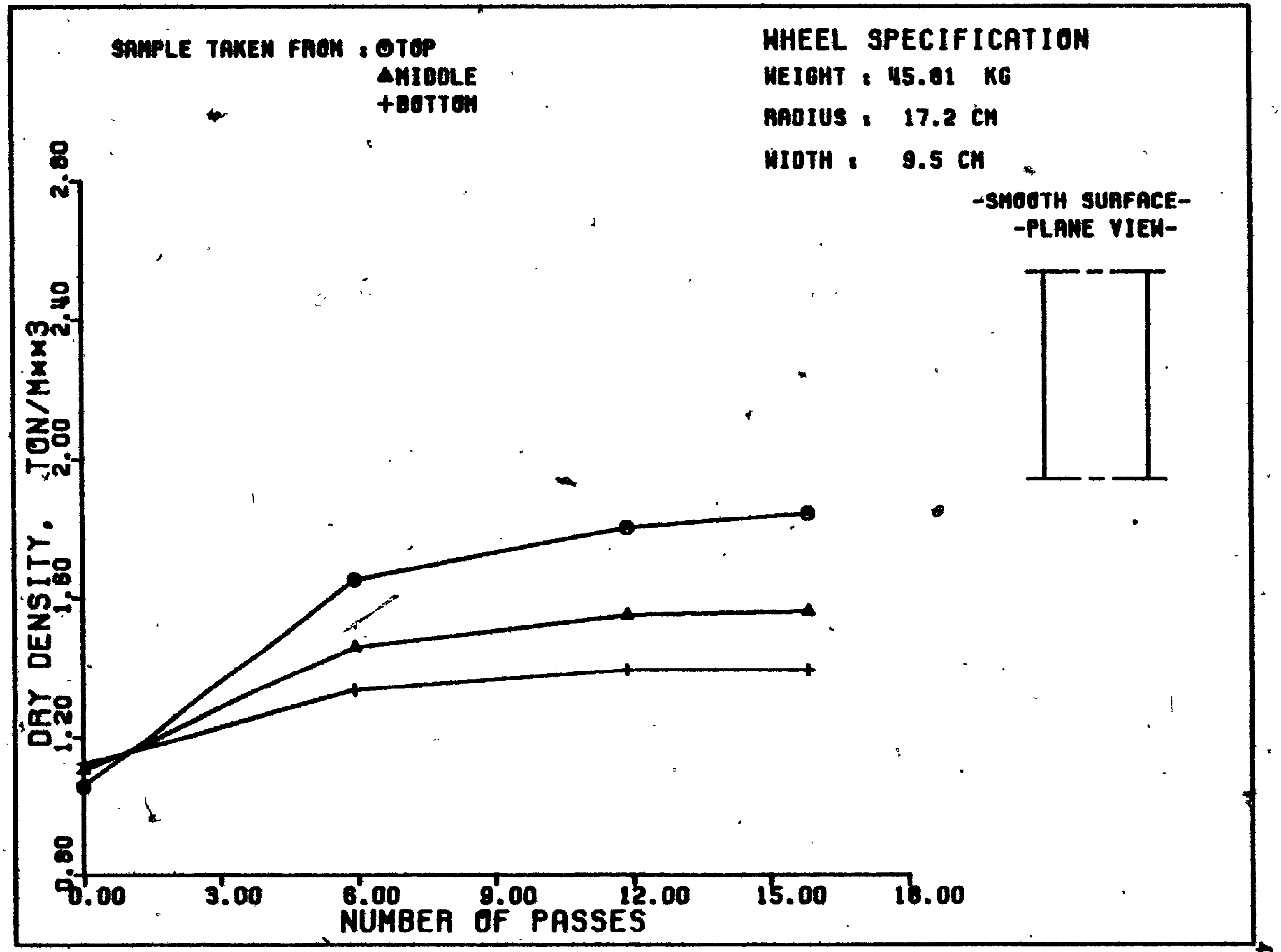


Fig. 24 Dry Soil Density Versus Number of Passes

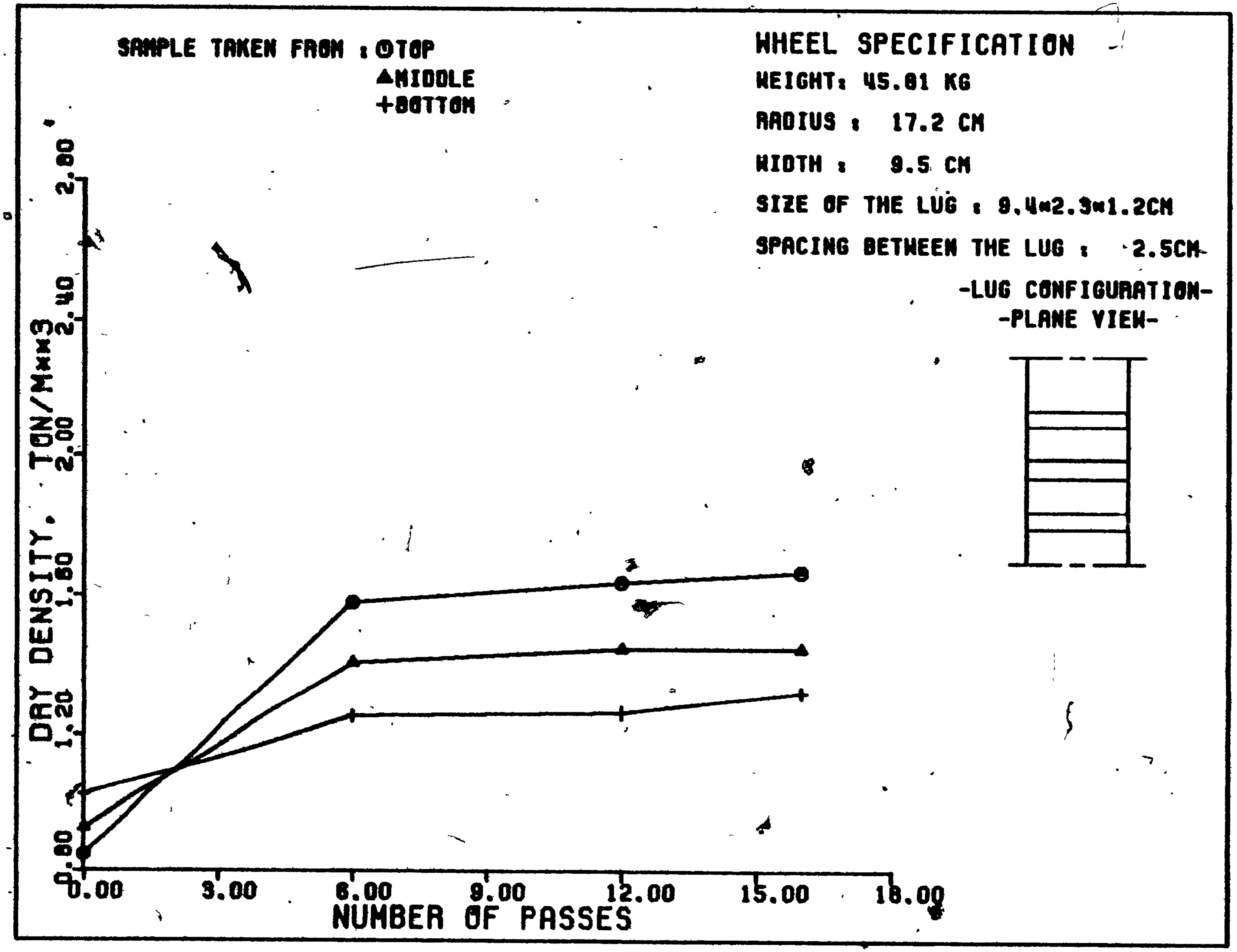


Fig. 25 Dry Soil Density Versus Number of Passes

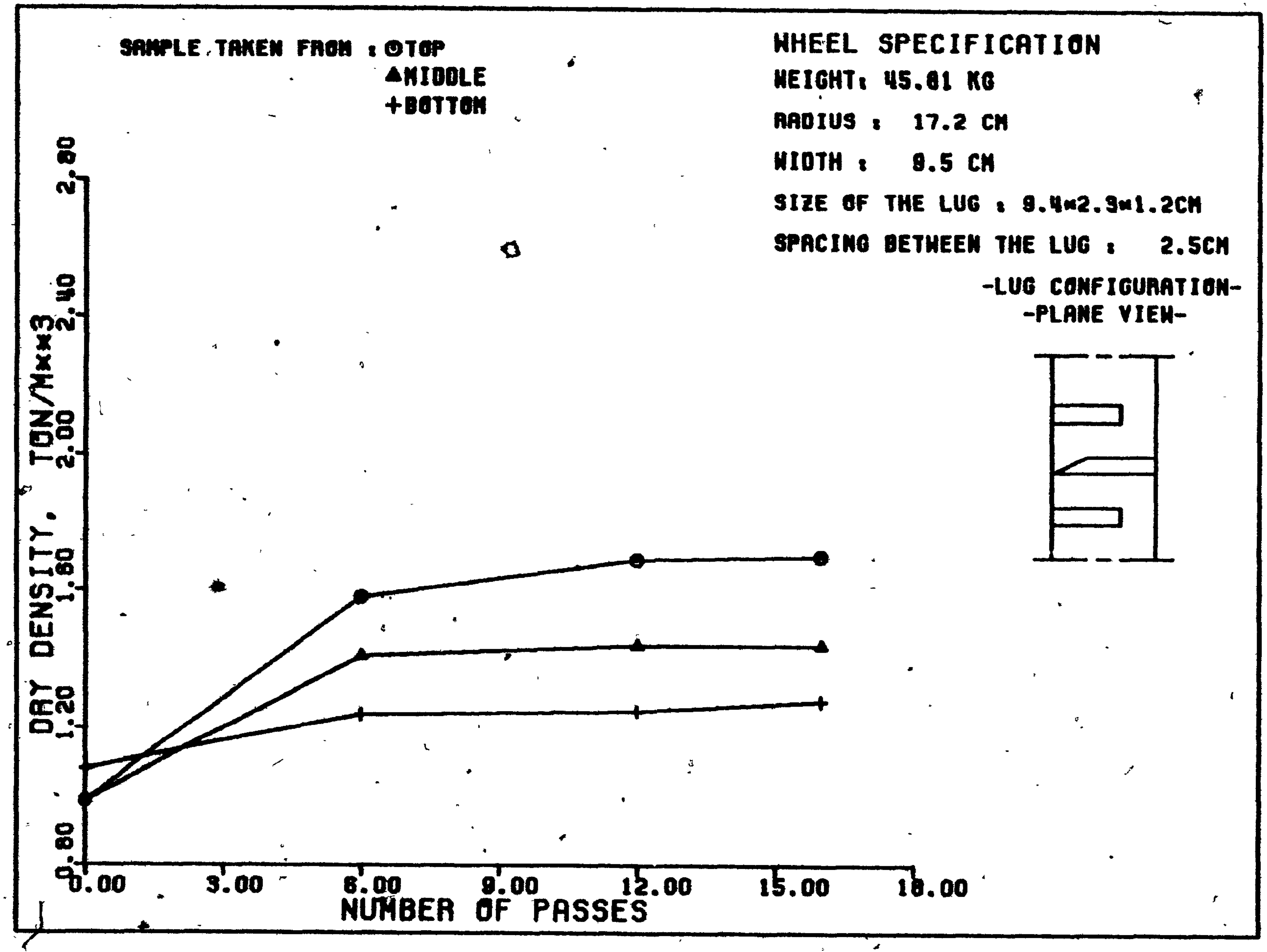


Fig. 26 Dry Soil Density Versus Number of Passes

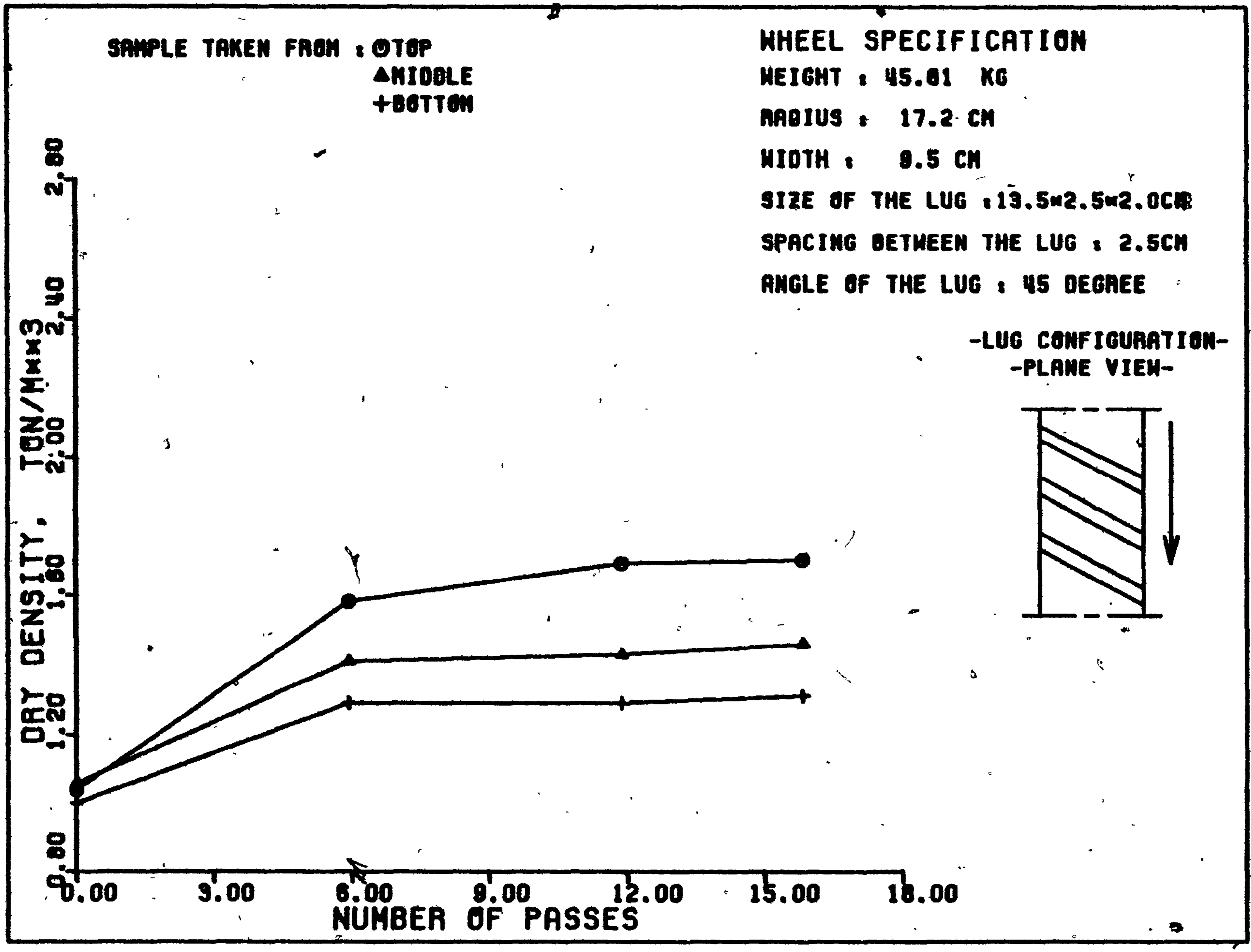
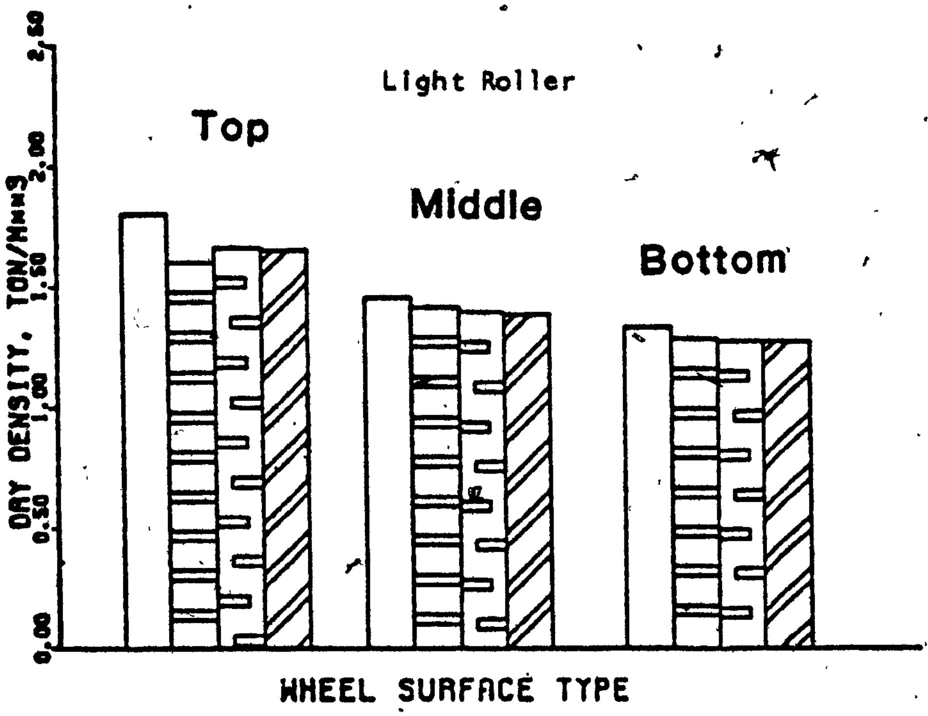


Fig. 27. Dry Soil Density Versus Number of Passes



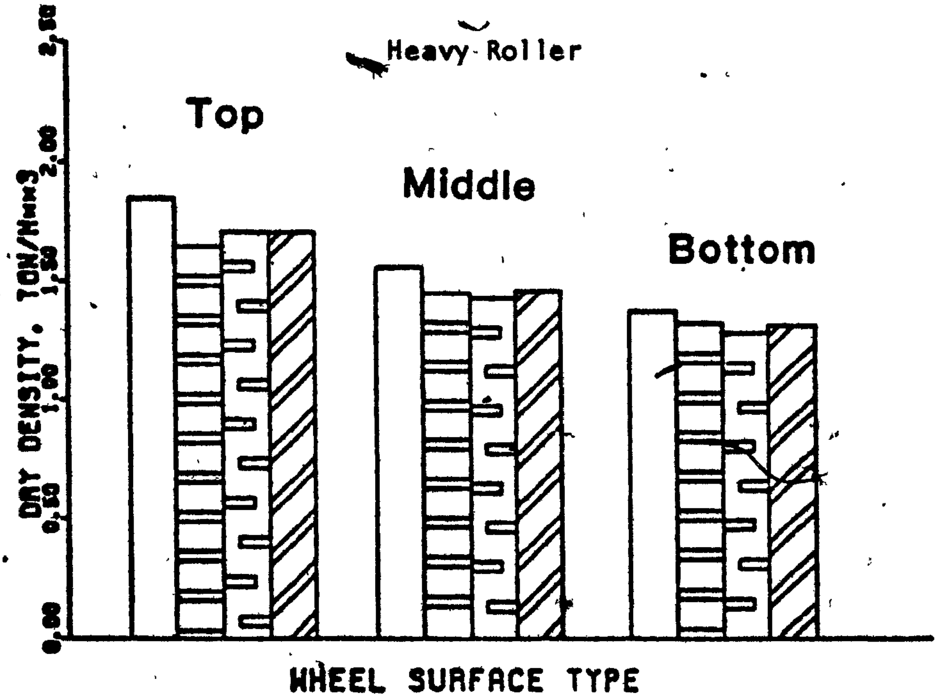


Fig. 28 Dry Density After 16 Passes

From the test results shown, wheel surface type I consistently produced the highest final soil density regardless of location within the soil sample. Soil densities for the other types of wheel surfaces show little differences. Moreover, the same effects are noticed for the soil dry density, as described above irrespective of the roller weight (i.e., heavy or light).

5.7 Unconfined Compressive Strength Versus Wheel Surface Type

Figure 29 shows the unconfined compressive strength of the soil obtained after 16 roller passes for different roller surface types. Both heavy and light rollers are considered. The unconfined compression tests are carried on 1.5 inch diameter by 3 inch height soil samples cut from the top of the compacted soil after the final roller pass. It appears that wheel surface type IV produces the highest unconfined compressive soil strength regardless of the roller weight used (i.e., heavy or light). Intermediate unconfined compressive soil strength are obtained from wheel surface type I, with types 2 and 3 resulting in the lowest values.

5.8 Vane Shear Strength Versus Wheel Surface Type

Figure 30 shows the vane shear strength measured at the top, middle and bottom parts of the compacted soil after 16 passes for heavy and light rollers. As the test results show the soil sample from wheel surface type IV yields highest vane shear strength. The test results show that rapid decrease of vane shear strength occurs between top and middle layer of the compacted soil sample and gradually thereafter.

5.9 Rolling Resistance Versus Number of Passes

Figures 31 through 34 show the rolling resistance measured from every roller pass and each graph shows two curves obtained from heavy and light rollers.

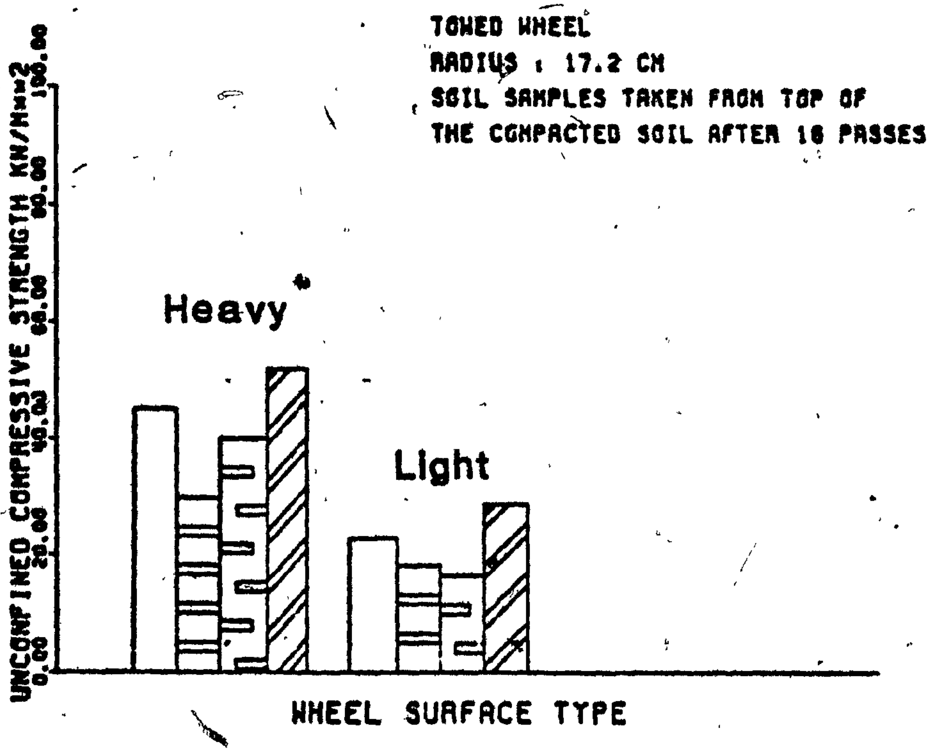


Fig. 29 Soil Strength After 16 Passes

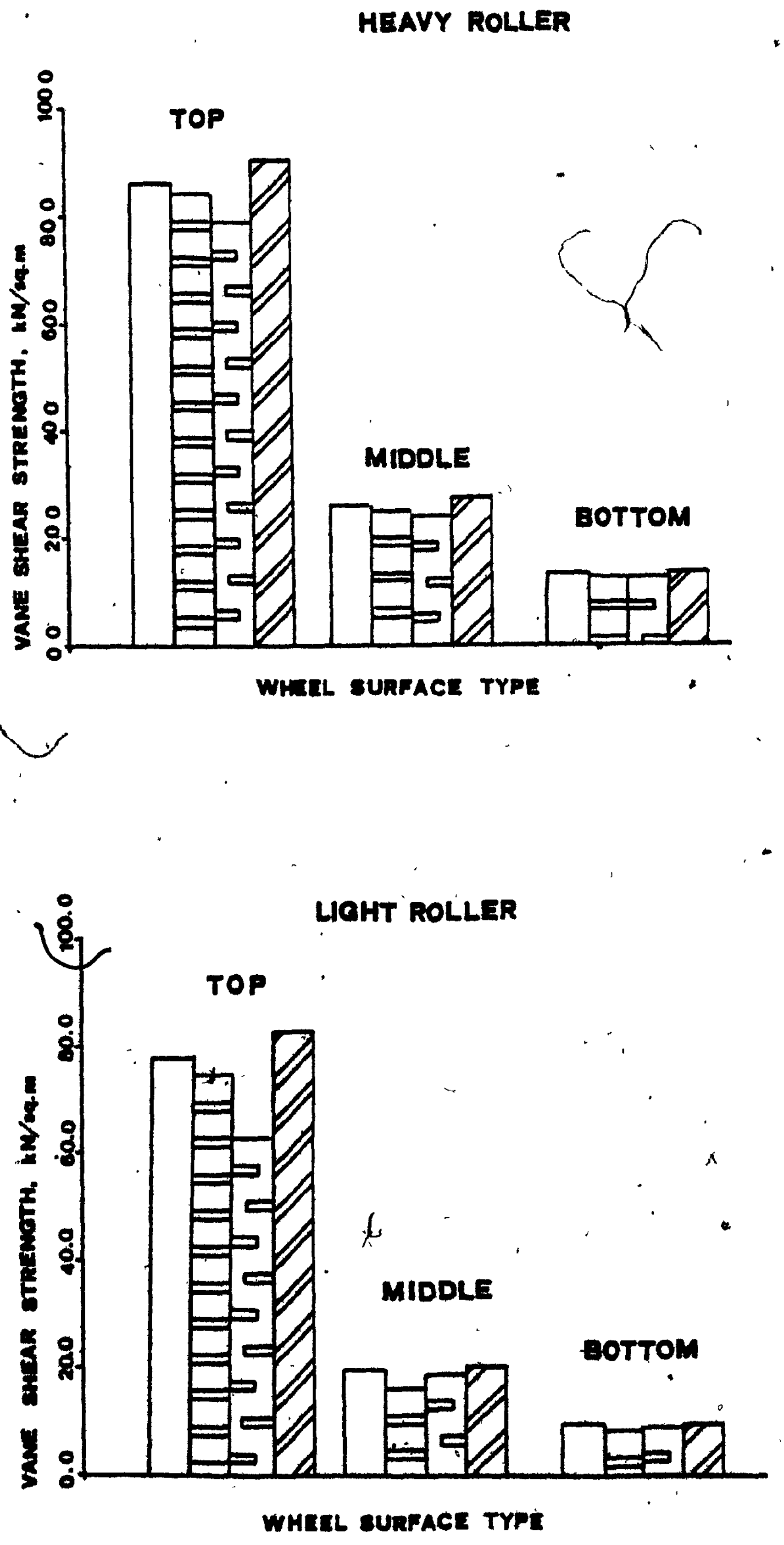


Fig. 30 Soil Strength After 16 Passes

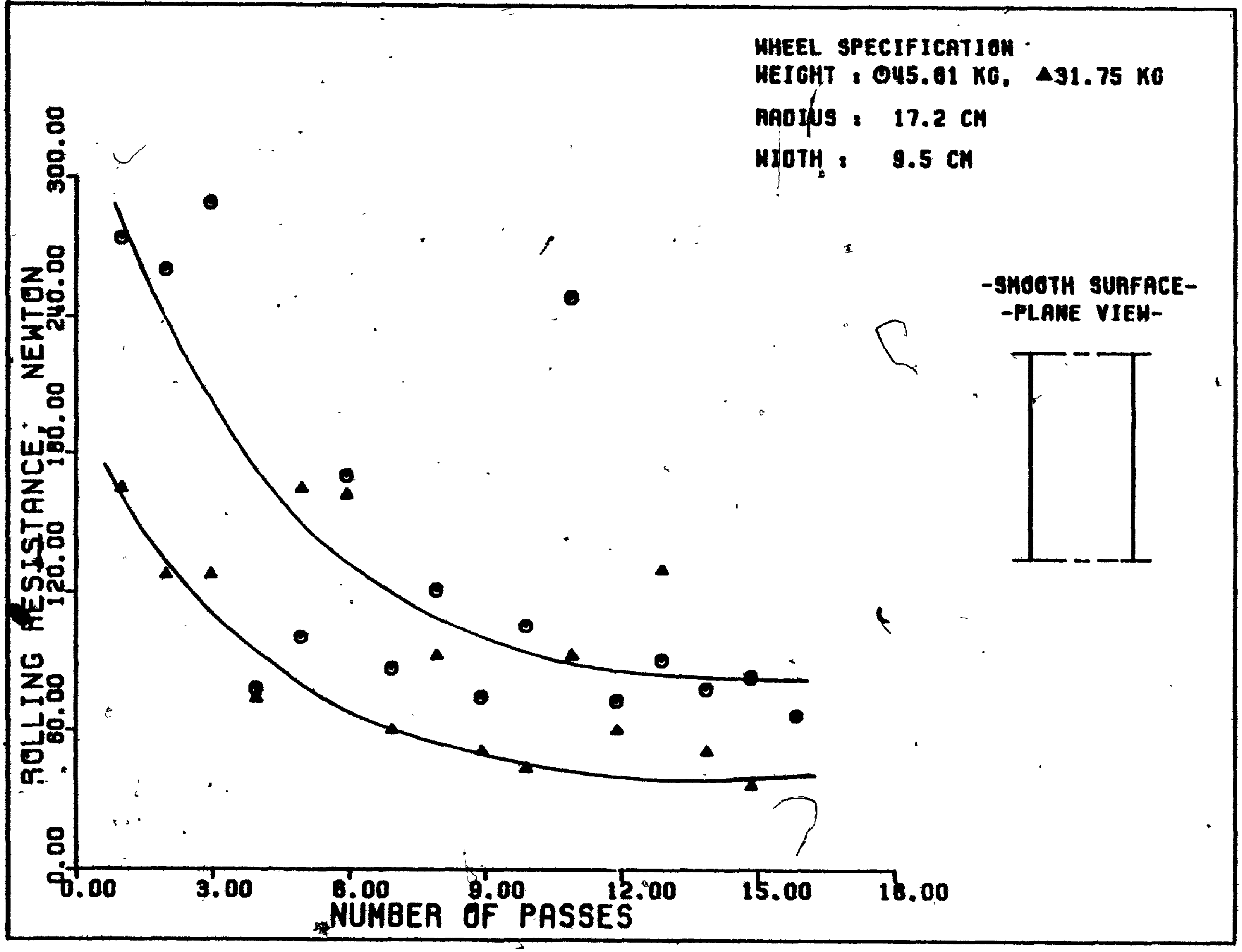


Fig. 31 Rolling Resistance Versus Number of Passes

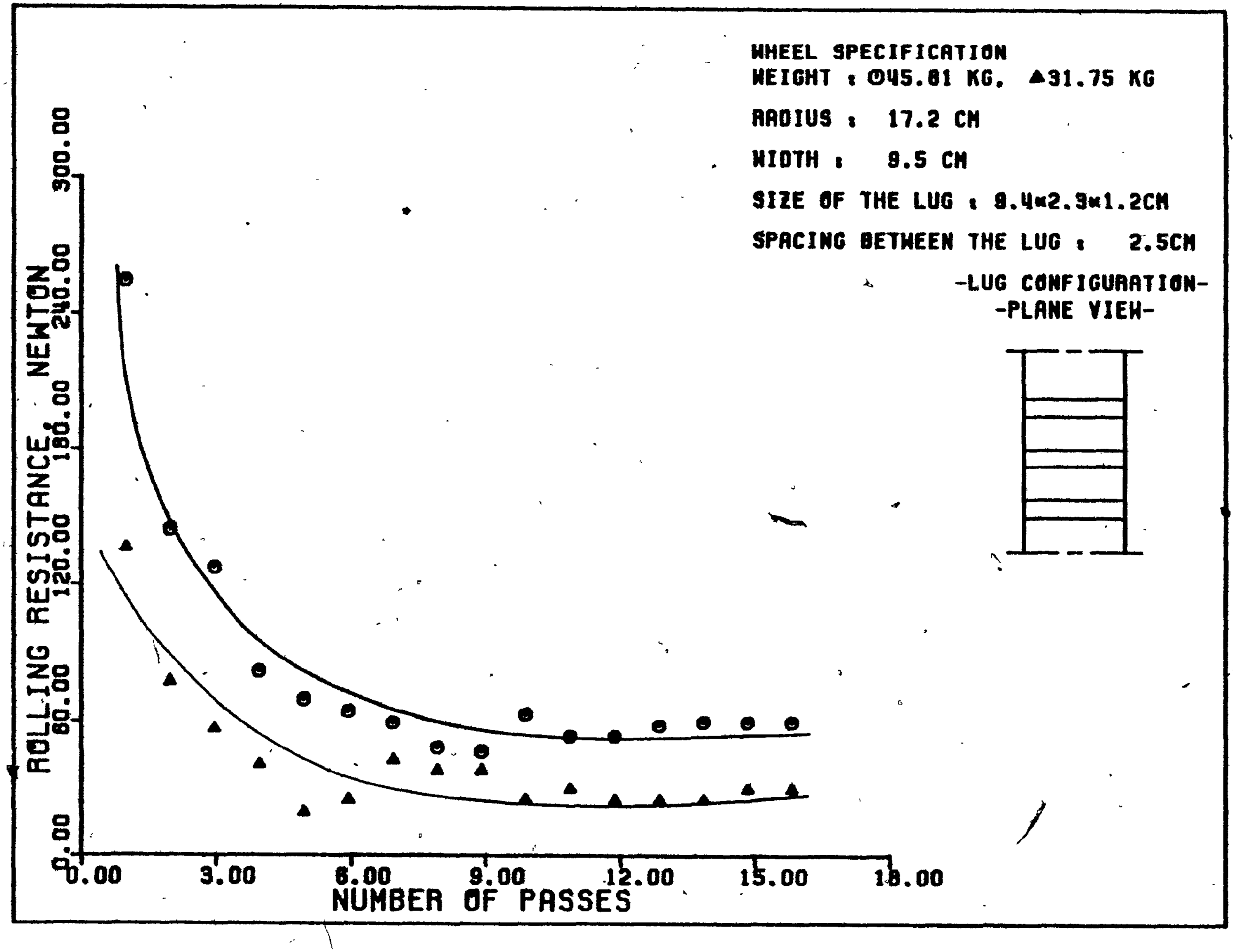


Fig. 32 Rolling Resistance Versus Number of Passes

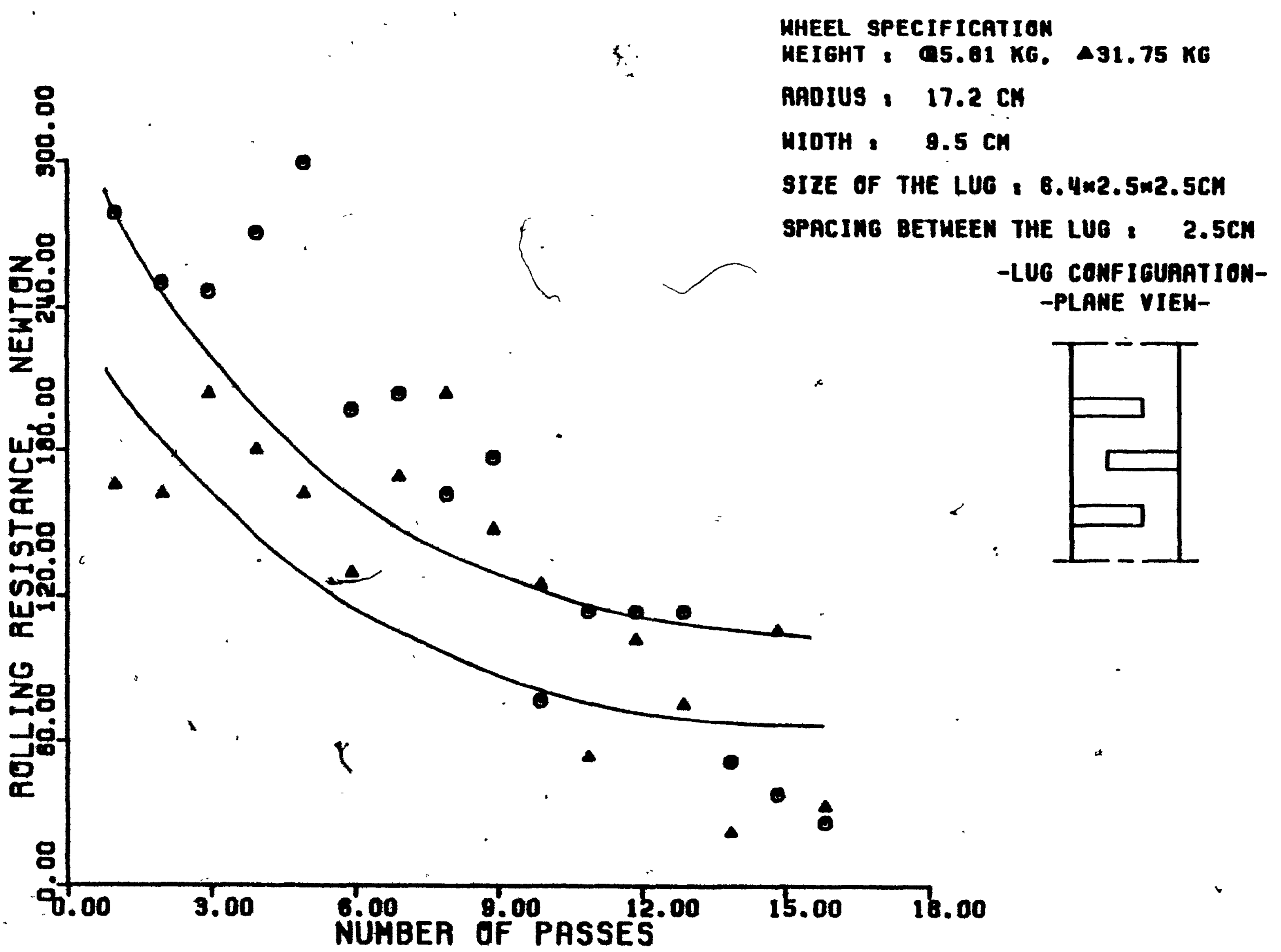


Fig. 33 Rolling Resistance Versus Number of Passes

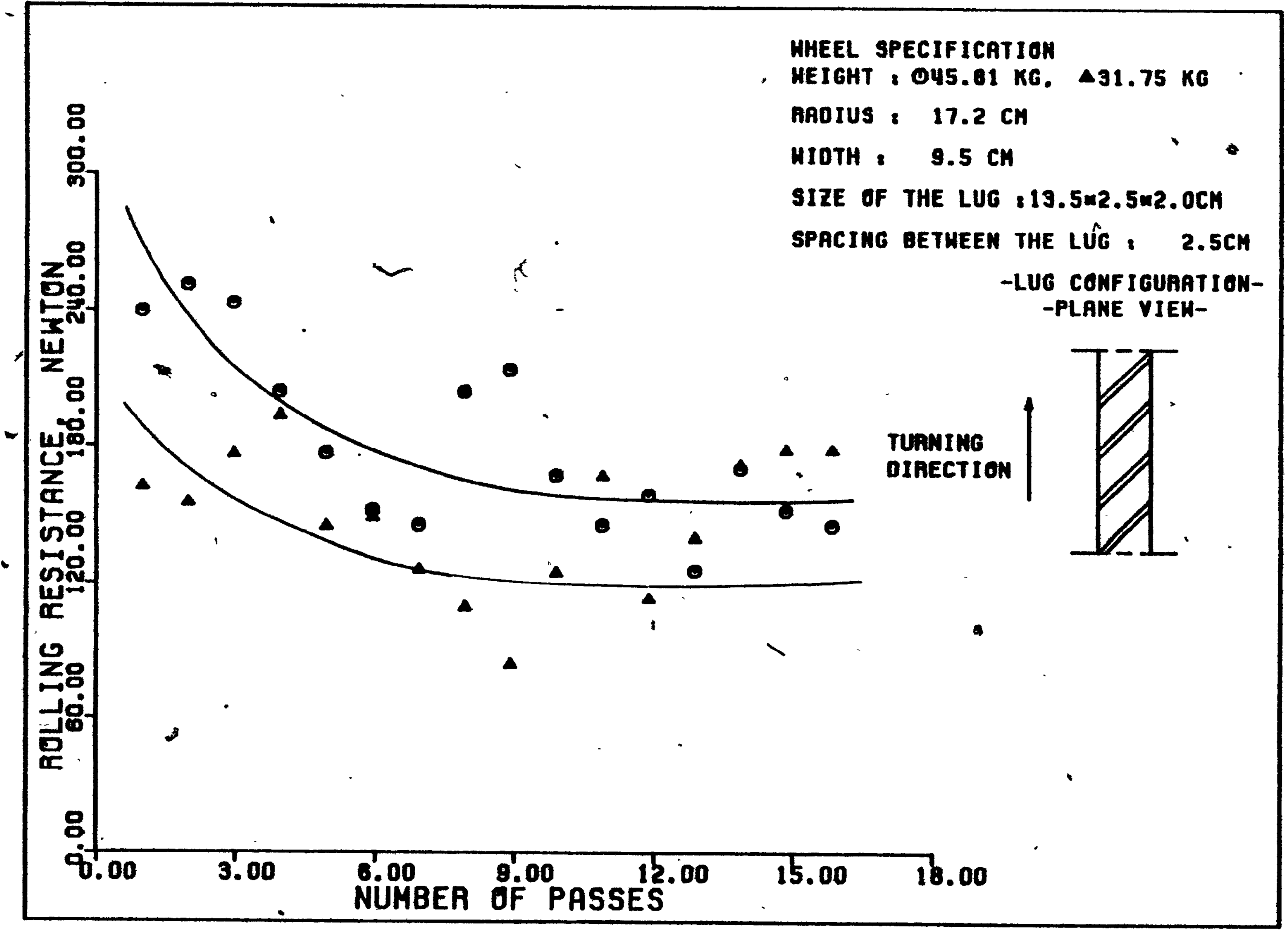


Fig. 34 Rolling Resistance Versus Number of Passes

As expected, the initial rolling resistance for the first few passes are high, this is due to the fact that initial sinkage is high and causes higher rolling resistance. However, after a number of passes the rolling resistance, remains constant. Because the sinkage is less and the energy required by the roller to travel is less. The results also show that the rolling resistance for compacted soil, wheel surface Type IV, is higher than those obtained from different wheel surfaces. This may be due to the large contact area of the lugs mounted on the wheel surface.

5.10 Input Energy Versus Dry Density

Figure 35 through 42 show the Input Energy versus Dry Density curves obtained for four different wheel surfaces from heavy and light rollers. Each graph shows average soil densities obtained from the towed roller and within the same figure a curve obtained from the soil compaction using Proctor test is also presented for the purpose of comparison.

The input energy per unit volume for soil compaction using Proctor mould and ram is obtained as follows:

$$E = \frac{W \times L \times N_B \times N_L}{V}$$

where E = input energy per unit volume

W = weight of hammer

L = height of hammer drop

N_B = number of blows per layer

N_L = number of layers = 3.0

V = volume of mould

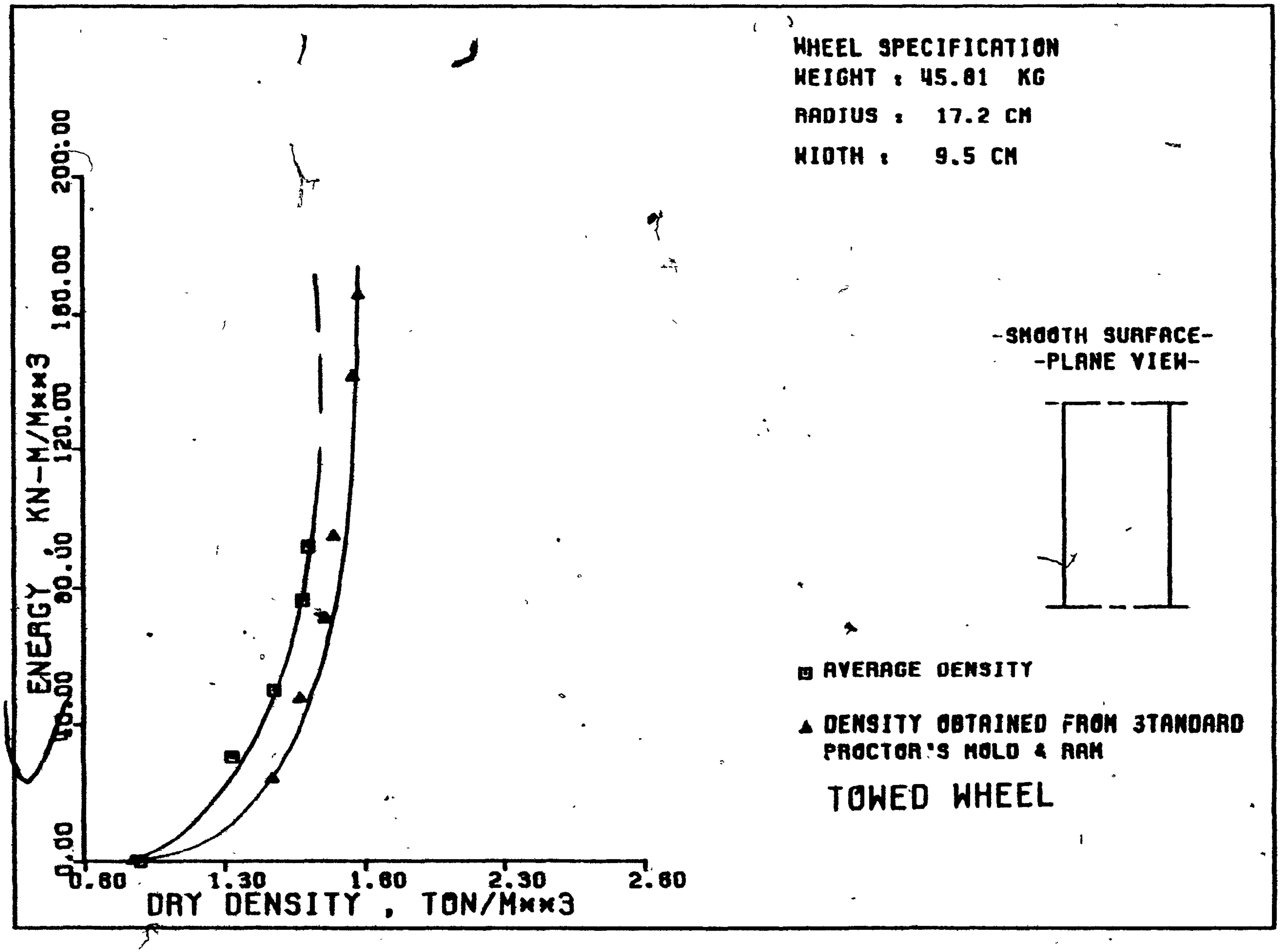


Fig. 35 Input Energy Versus Dry Density

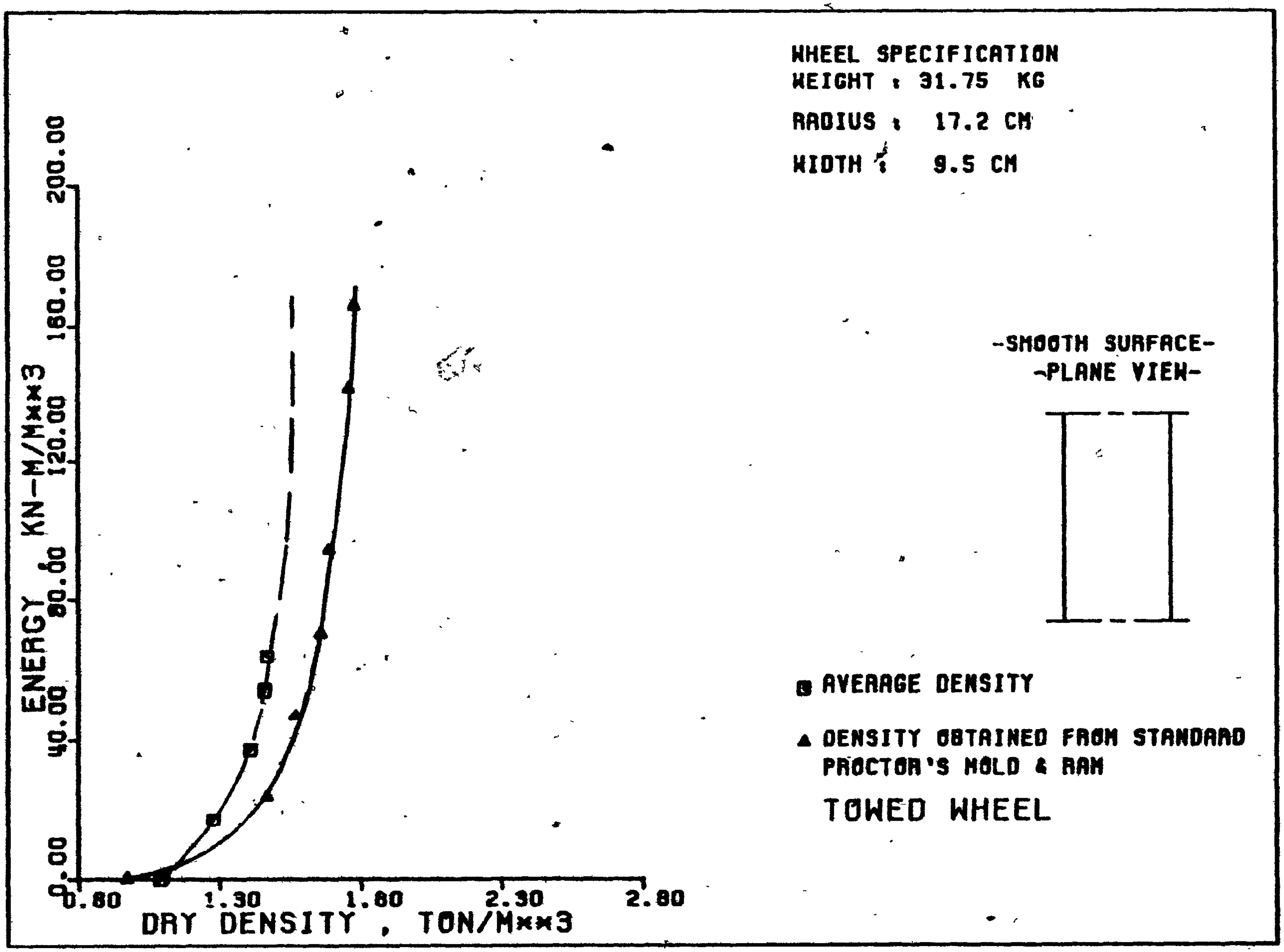


Fig. 36 Input Energy Versus Dry Density

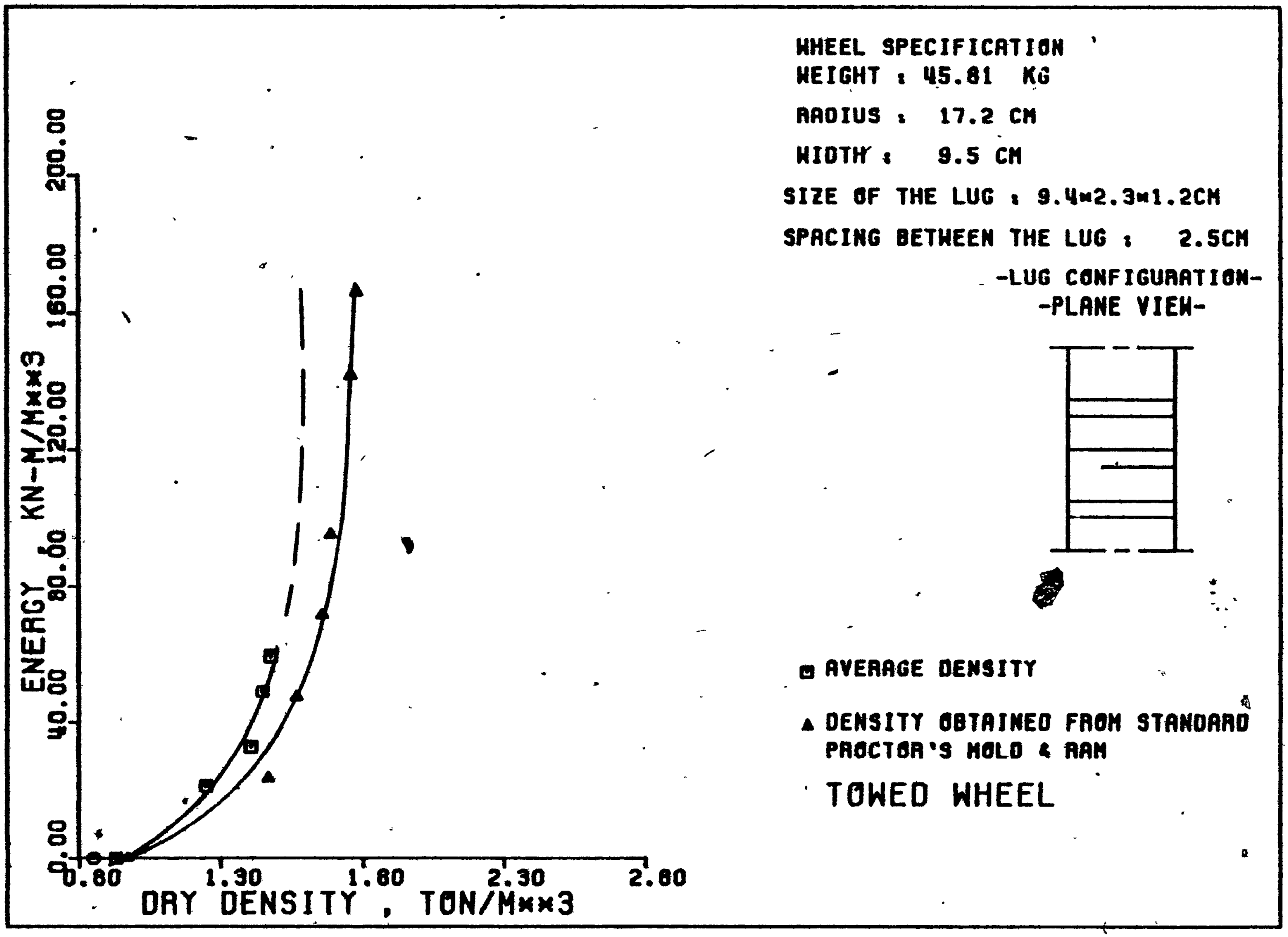


Fig. 37 Input Energy Versus Dry Density

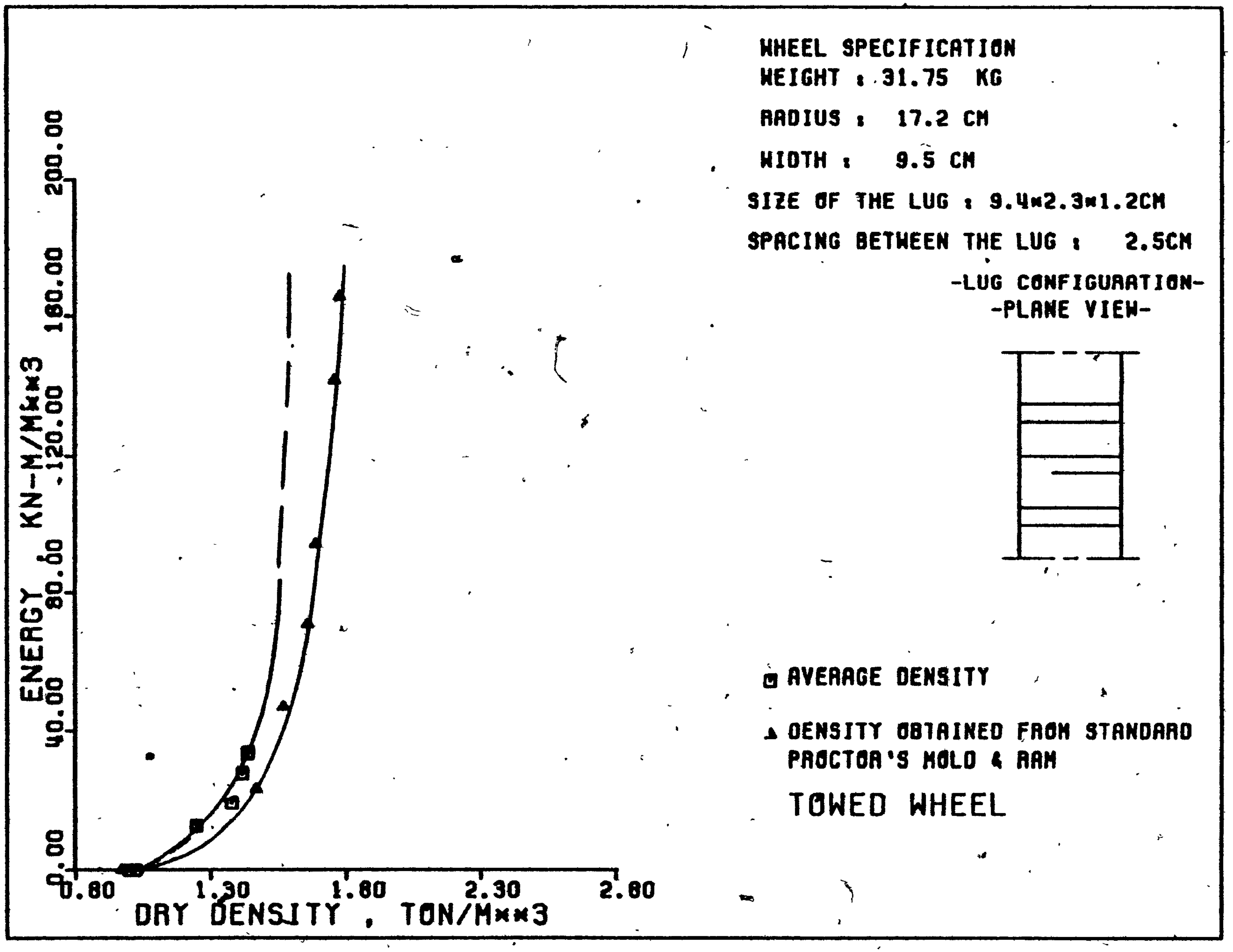


Fig. 38, Input Energy Versus Dry Density

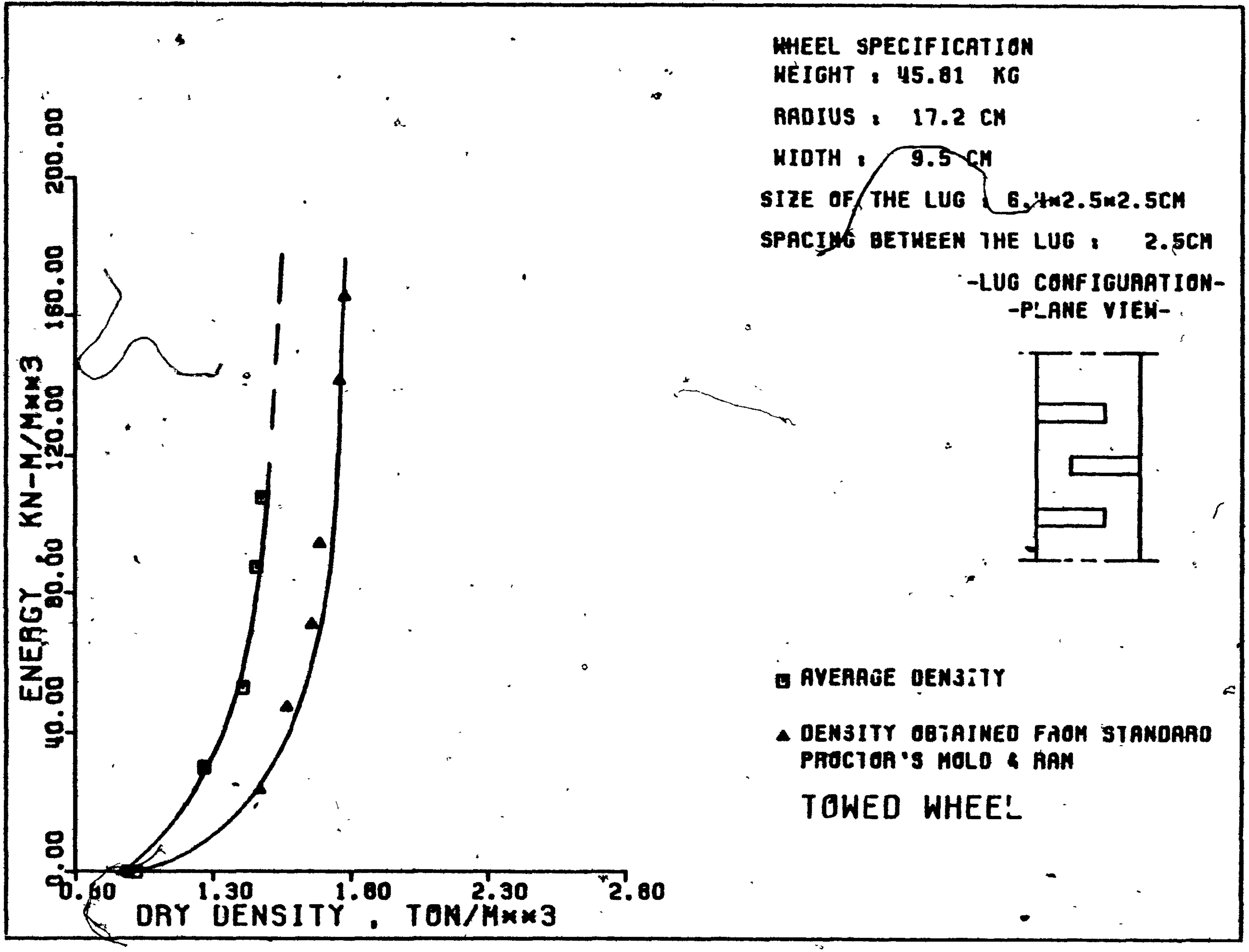


Fig. 39 Input Energy Versus Dry Density

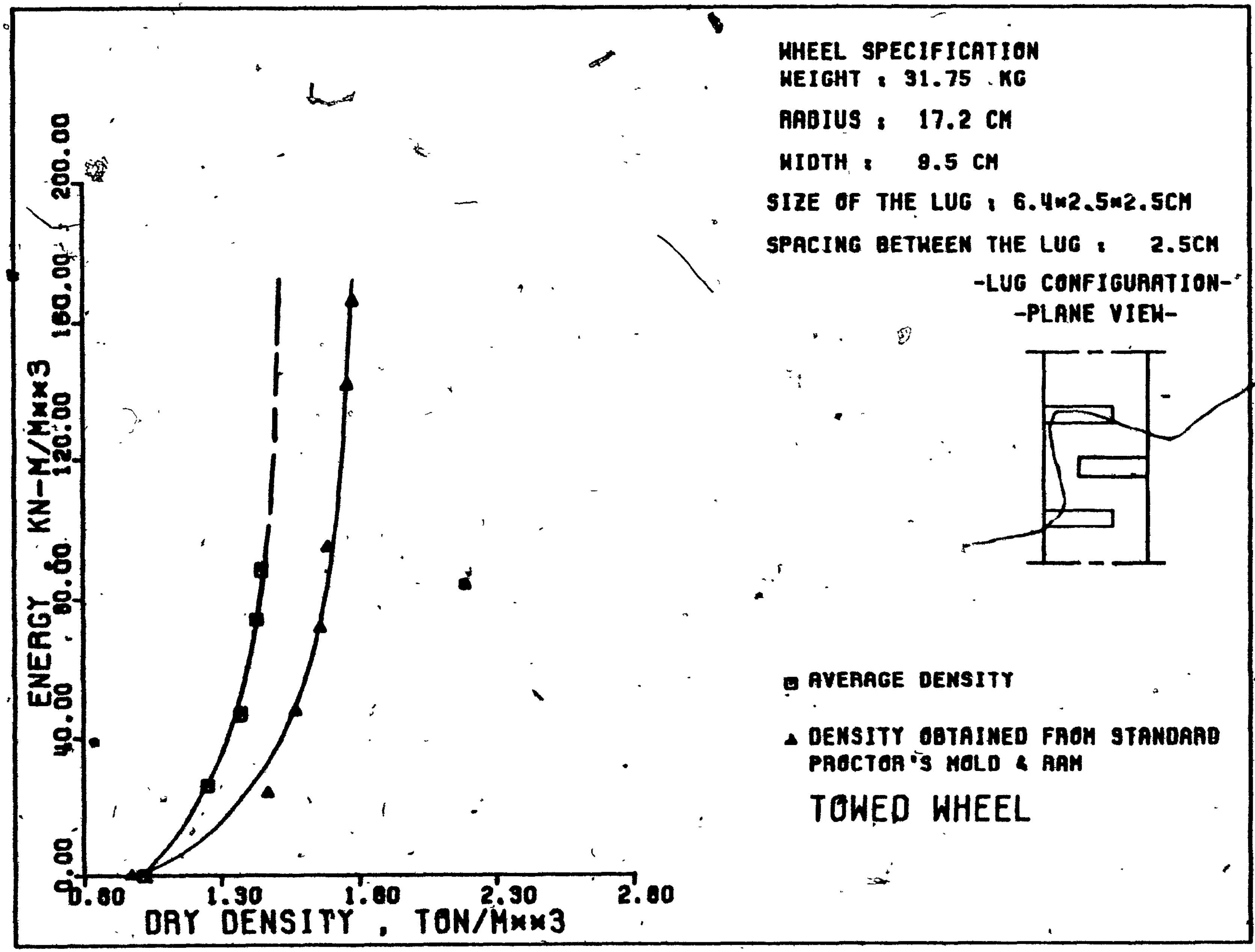


Fig. 40 Input Energy Versus Dry Density

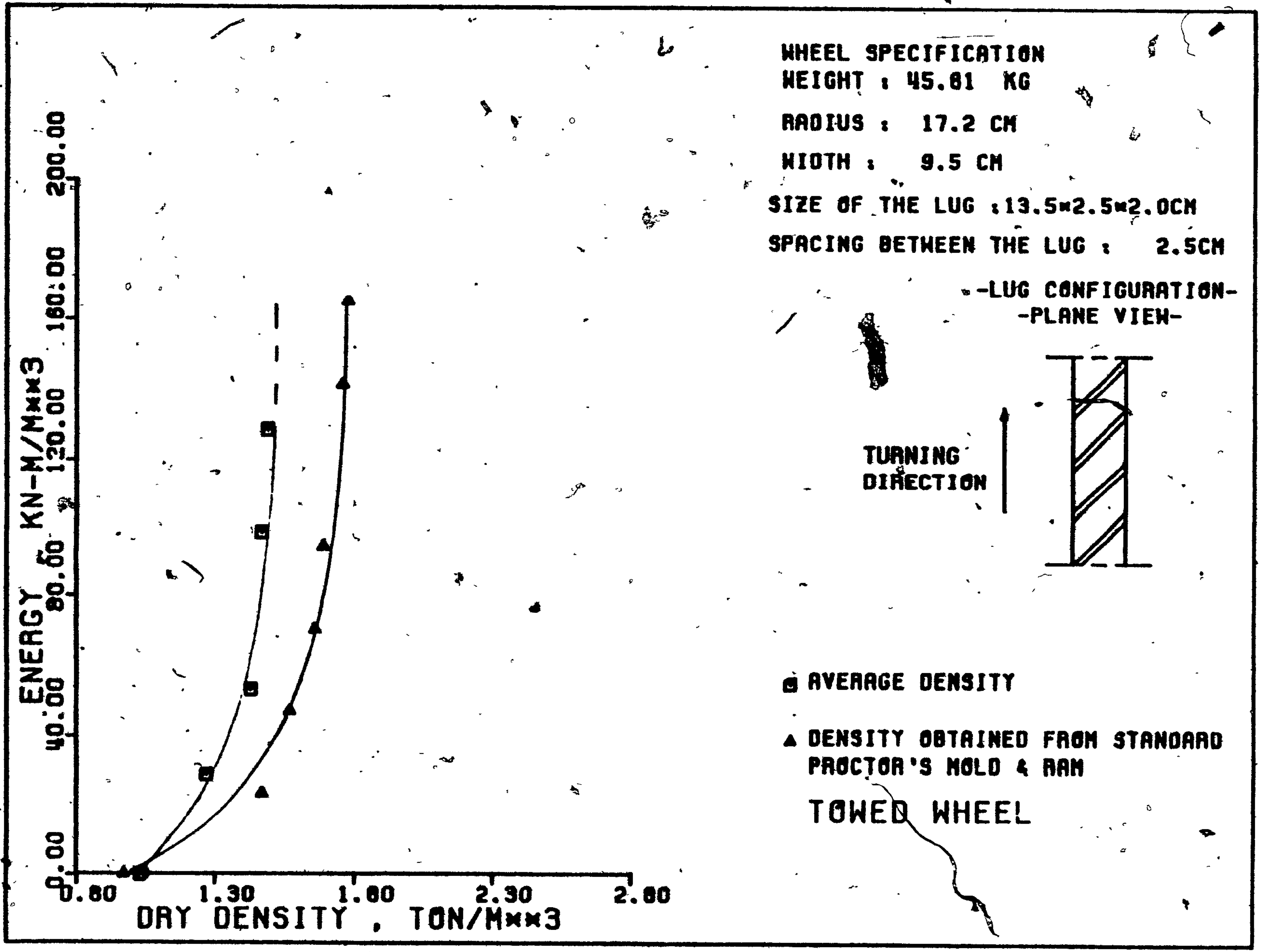


Fig. 41 Input Energy Versus Dry Density

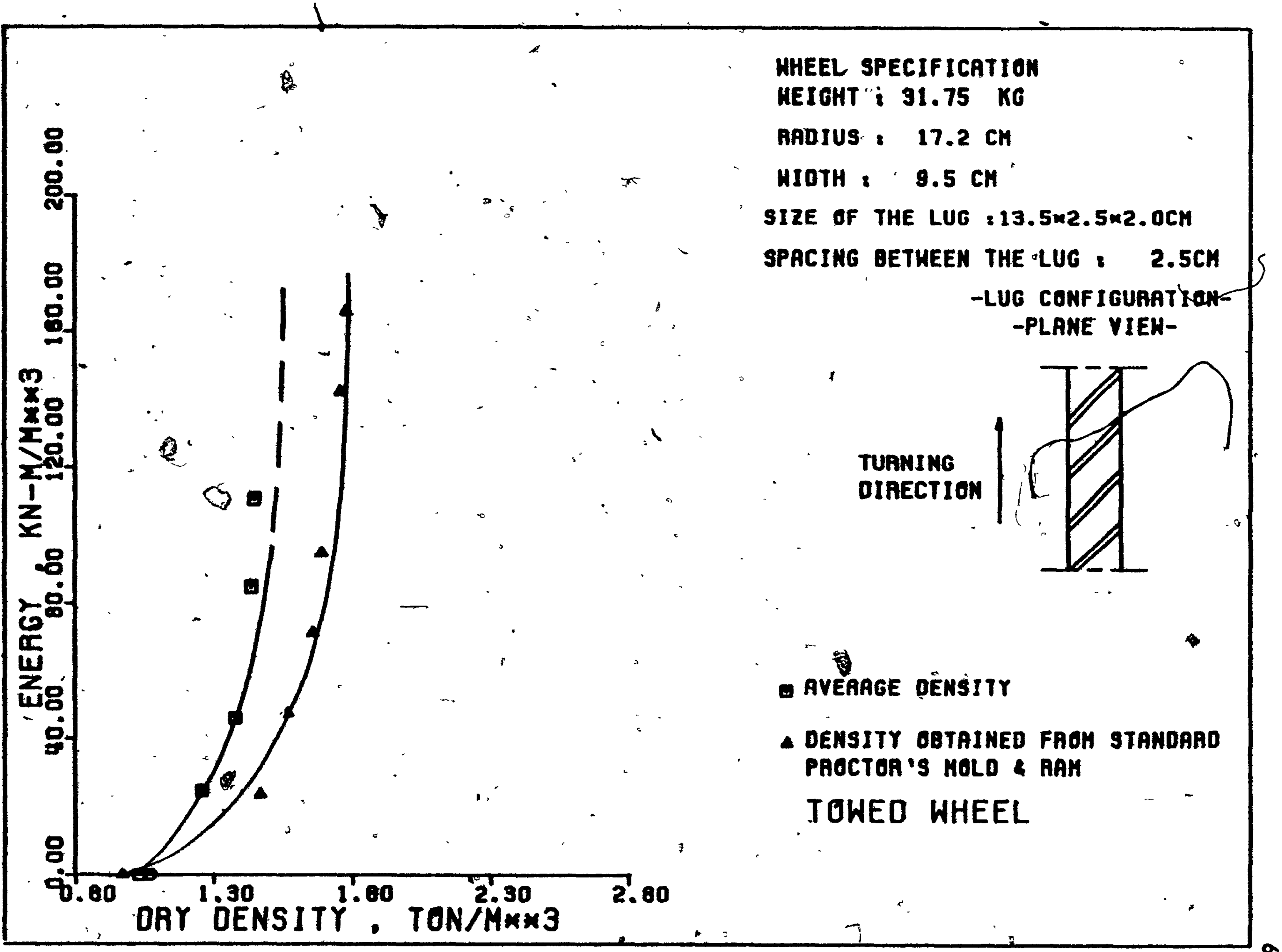


Fig. 42 Input Energy Versus Dry Density

The input energy per unit volume for the towed roller is calculated as follows:

$$E = \sum_{i=1}^{N} \frac{R_i}{V_i}$$

where E = input energy per unit volume

N = number of passes

V_i = volume of compacted soil at pass i

R_i = rolling resistance at pass i x unit distance travel

CHAPTER 6

CONCLUSIONS

Experimental results (Sections 5.1 and 5.5) have shown that in order to obtain effective compaction with the given soil used in the experiment, rigid rollers with smooth surface (Type I) should be used.

Due to the intrinsic properties of the soil used in the experiments, the results show that regardless of the methods used in compacting the soil, it should yield the same density with a given input energy per unit volume. Thus, the difference in the results obtained is due to the difference in the energy intensities produced by the towed roller and that of the Proctor tests. In order to obtain effective compaction, the intensity of the input energy has to be larger than the threshold energy of the soil.

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10. R.N. Yong, E.A. Fattah, Analysis of Soil Compactability by Rollers, Proceedings ASCE Conference on Generalized Stress-Strain Application in Geotechnical Engineering, Hollywood, Florida, October 1980.

APPENDIX A

SOFTWARE

SOFTWARE

Nine programs are written to reduce the data obtained from the experiment. The data for the first eight programs is stored in the computer while the developed programs manipulate and plot the results on the Calcomp Digital Plotter. The programming language used is Fortran with many plot routines incorporated.

Program one is listed and documented in Appendix I. The results of sinkage vs. number of passes for both heavy and light rollers for wheel surface types I through IV are stored in the file. Program two is listed and documented in Appendix II. The results of rolling resistance vs. number of passes for heavy and light rollers for wheel surface types I through IV are stored in the file. Program three is listed and documented in Appendix III. The results of dry density vs. wheel surface type for the top, middle and bottom parts of the compacted soil sample after sixteen passes for heavy and light rollers are stored in the file. Program four is listed and documented in Appendix IV. The results of unconfined compressive strength vs. wheel surface type taken from the compacted soil sample after sixteen passes for both the heavy and the light rollers are stored in the file. Program five is listed and documented in Appendix V. The results of vane shear strength vs. wheel surface type for the top, middle and bottom parts of the compacted soil sample after sixteen passes for the heavy and light rollers are stored in the file. Program six is listed and documented in Appendix VI. The results of energy vs. dry density for the roller and the Proctor Mould and Ram are manipulated and stored in the file. Program seven is listed and documented in Appendix VII. The results of dry density vs. depth for the initial and the final conditions for both heavy and light rollers are stored in the file.

Program eight is listed and documented in Appendix VIII. The results of vane shear strength vs. depth for the initial and the final conditions for both heavy and light rollers are stored in the file. These programs are used to read and to plot the data stored in the associated files.

Program nine is listed and documented in Appendix IX. The developed program uses the micro computer HP85 to plot the results on the HP7225B plotter. The programming language used is Basic with many plot routines incorporated. The dry density vs. water content obtained from the Standard Proctor test is plotted using this program.

Appendix I

WHEEL SINKAGE VERSUS NUMBER OF PASSES

```
                                                            MAY 25, 1981
      DIMENSION XX(25), YY(25), X(25), Y(25)
      CALL PLOTON
      CALL SYMBOL(4.0,0.3,0.125,4HFIG.,0.0,4)
      CALL SYMBOL(4.625,0.3,0.125,2H  ,0.0,2)
      CALL SYMBOL(2.0,0.13,0.125,33HWHEEL SINKAGE VS NUMBER OF PASSES,0.
     *,33)
      CALL PLOT(0.0,0.65,-3)
       CALL PLOT(0.0,6.75,2)
      CALL PLOT(9.0,6.75,2)
      CALL PLOT (9.0,0.0,2)
      CALL PLOT (0.0,0.0,2)
      CALL SYMBOL (5.5,6.45,0.125,19HWHEEL SPECIFICATION,0.0,19)
      CALL SYMBOL(5.5,6.200,0.1,17HWEIGHT:   31.75KG,0.0,17)
      CALL SYMBOL(6.25,6.25,0.1,1,0.0,-1)
      CALL SYMBOL(7.3,6.2,0.1,11H,   45.81KG,0.0,11)
      CALL SYMBOL(7.45,6.25,0.1,2,0.0,-1)
      CALL SYMBOL(5.5,5.90,0.100,18HRADIUS :  17.2 CM ,0.0,18)
      CALL SYMBOL(5.5,5.600,0.100,18HWIDTH :    9.5 CM  ,0.0,18)
      CALL SYMBOL(5.5,5.3,0.1,31HSIZE OF THE LUG :13.5*2.5*2.0CM,0.0,31)
      CALL SYMBOL(5.5,5.0,0.1,31HSPACING BETWEEN THE LUG : 2.5CM,0.0,31)
      CALL SYMBOL(5.5,4.7,0.1,28HANGLE OF THE LUG : 45 DEGREE,0.0,28)
      CALL SYMBOL(7.0,4.3,0.1,19H-LUG CONFIGURATION-,0.0,19)
      CALL SYMBOL(7.3,4.1,0.1,12H-PLANE VIEW-,0.0,12)
      CALL PLOT(7.375,3.85,3)
      CALL PLOT(7.75,3.85,2)
      CALL PLOT(7.83,3.85,3)
      CALL PLOT(7.92,3.85,2)
      CALL PLOT(8.0,3.85,3)
      CALL PLOT(8.375,3.85,2)
      CALL PLOT(8.25,3.85,3)
      CALL PLOT(8.25,2.35,2)
      CALL PLOT(8.375,2.35,3)
      CALL PLOT(8.0,2.35,2)
      CALL PLOT(7.92,2.35,3)
      CALL PLOT(7.83,2.35,2)
      CALL PLOT(7.75,2.35,3)
      CALL PLOT(7.375,2.35,2)
      CALL PLOT(7.5,2.35,3)
       CALL PLOT(7.5,3.85,2)
      CALL PLOT(7.5,3.725,3)
      CALL PLOT(8.25,3.35,2)
      CALL PLOT(8.25,3.225,3)
      CALL PLOT(7.5,3.625,2)
      CALL PLOT(7.5,3.350,3)
      CALL PLOT(8.25,2.95,2)
      CALL PLOT(8.25,2.825,3)
      CALL PLOT(7.5,3.225,2)
      CALL PLOT(7.5,2.95,3)
      CALL PLOT(8.25,2.55,2)
      CALL PLOT(8.25,2.425,3)
      CALL PLOT(7.5,2.825,2)
      CALL AROHD(8.45,3.75,8.45,2.725,0.2,0.1,14)
      CALL PLOT(0.5,0.5,-3)
      CALL AXIS(0.0,0.0,16HNUMBER OF PASSES,-16,6.0,0.0,0.0,3.0)
      CALL AXIS(0.0,0.0,11HSINKAGE, CM,11,5.0,90.0,0.0,2.0)
      K=0
 59   K=K+1
      N=17
```

MAY 25, 1981

```
      READ(5,25) (XX(I),YY(I),I=1,N)
25    FORMAT(2F6.2)
      DO 100 I=1,N
      WRITE(6,25)XX(I),YY(I)
100   CONTINUE
      DO 7 I=1,N
      X(I)=0.33333*XX(I)
      Y(I)=YY(I)/2.0
7     CONTINUE
      X(N+1)= 0.0
      X(N+2)= 1.0
      Y(N+1)= 0.0
      Y(N+2)= 1.0
      CALL LINE(X,Y,N,1,1,K)
      IF(K.LT.2) GO TO 99
      CALL ENDPLT
      STOP
      END
```

Appendix II

ROLLING RESISTANCE VERSUS NUMBER OF PASSES

```
                                                            MAY 25, 1981
      DIMENSION PASS(20),DBP(20),X(20),Y(20)
      CALL PLOTCN
      CALL SYMBCL (4.25,0.35,0.125,5HFIG :,0.0,5)
      CALL SYMBCL (2.0,0.12,0.125,38HROLLING RESISTANCE VS NUMBER OF PAS
     *SES,0.0,38)
      CALL PLOT (0.0,0.65,-3)
      CALL PLOT (0.0,6.75,2)
      CALL PLOT (9.0,6.75,2)
      CALL PLOT (9.0,0.0,2)
      CALL PLOT (0.0,0.0,2)
      CALL SYMBCL (5.5,6.4,0.1,19HWHEEL SPECIFICATION,0.0,19)
      CALL SYMBCL(5.5,6.2,0.1,30HWEIGHT :  45.81 KG,   31.75 KG,0.0,30)
      CALL SYMBCL(6.4,6.25,0.1,1,0.0,-1)
      CALL SYMBCL(7.6,6.25,0.1,2,0.0,-1)
      CALL SYMBCL(5.5,5.90,0.100,18HRADIUS :  17.2 CM ,0.0,18)
      CALL SYMBCL(5.5,5.600,0.100,18HWIDTH :   9.5 CM  ,0.0,18)
C     CALL SYMBCL(5.5,5.3,0.100,31HSIZE OF THE LUG : 6.4*2.5*2.5CM,0.0,3
C    *1)
C     CALL SYMBCL(5.5,5.000,0.100,26HSPACING BETWEEN THE LUG : ,0.0,26)
      CALL SYMBCL(8.20,5.0,0.1,6H 2.5CM,0.0,6)
C     CALL SYMBCL(5.5,4.7,0.1,30HDEGREE OF SLIP:        PERCENT,0.0,30)
C     CALL SYMBCL(7.20,4.700,0.100,6H 20.0 ,0.0,6)
C     CALL SYMBOL(7.10,4.75,0.1,1,0.0,-1)
C     CALL SYMBCL(7.2,4.5,0.1,6H 31.0 ,0.0,6)
C     CALL SYMBCL(7.1,4.55,0.1,2,0.0,-1)
C     CALL SYMBCL(7.2,4.3,0.1,6H 50.0 ,0.0,6)
C     CALL SYMBCL(7.1,4.35,0.1,3,0.0,-1)
C     CALL SYMBCL(7.2,4.1,0.1,6H 55.0 ,0.0,6)
C     CALL SYMBCL(7.1,4.15,0.1,4,0.0,-1)
      CALL SYMBCL(7.15,4.7,0.1,16H-SMOOTH SURFACE-,0.0,16)
      CALL SYMBCL(7.3,4.5,0.1,12H-PLANE VIEW-,0.0,12)
      CALL PLOT(7.375,4.25,3)
      CALL PLOT(7.75,4.25,2)
      CALL PLOT(7.83,4.25,3)
      CALL PLOT(7.92,4.25,2)
      CALL PLOT(8.0,4.25,3)
      CALL PLOT(8.375,4.25,2)
      CALL PLOT(8.25,4.25,3)
      CALL PLOT(8.25,2.75,2)
      CALL PLOT(8.375,2.75,3)
      CALL PLOT(8.0,2.75,2)
      CALL PLOT(7.92,2.75,3)
      CALL PLOT(7.83,2.75,2)
      CALL PLOT(7.75,2.75,3)
      CALL PLOT(7.375,2.75,2)
      CALL PLOT(7.5,2.75,3)
      CALL PLOT(7.5,4.25,2)
C     CALL PLOT(7.5,3.875,3)
C     CALL PLOT(8.0,3.875,2)
C     CALL PLOT(8.0,3.75,2)
C     CALL PLOT(7.5,3.75,2)
C     CALL PLOT(8.25,3.5,3)
C     CALL PLOT(7.75,3.5,2)
C     CALL PLOT(7.75,3.375,2)
C     CALL PLOT(8.25,3.375,2)
C     CALL PLOT(7.5,3.0,3)
C     CALL PLOT(8.0,3.0,2)
C     CALL PLOT(8.0,3.125,2)
```

```
                                                                  MAY 25, 1981
C         CALL PLOT(7.5,3.125,2)
          CALL PLOT (0.5,0.5,-3)
          CALL AXIS (0.0,0.0,16HNUMBER OF PASSES,-16,6.0,0.0,0.0,3.0)
          CALL AXIS (0.0,0.0,27HROLLING RESISTANCE,  NEWTON,27,5.0,90.0,0.0,
         *60.0)
          K=0
 99       K=K+1
          N=16
          READ(5,25) (PASS(I),DBP(I),I=1,N)
  25      FORMAT(2F6.2)
          DO 7  I=1,N
          X(I)=0.33*PASS(I)
          Y(I)=(1.0/60.0)*DBP(I)
   7      CONTINUE
          X(N+1)=0.0
          X(N+2)=1.0
          Y(N+1)=0.0
          Y(N+2)=1.0
          CALL LINE(X,Y,16,1,-1,K)
          IF(K.LT.2) GOTO 99
C         N=12
C         READ(5,26) (PASS(I),DBP(I),I=1,N)
C26       FORMAT(2F6.2)
C         DO 8  I=1,N
C         X(I)=0.33*PASS(I)
C         Y(I)=(1.0/60.0)*DBP(I)
C  8      CONTINUE
C         X(N+1)=0.0
C         X(N+2)=1.0
C         Y(N+1)=0.0
C         Y(N+2)=1.0
C         CALL LINE(X,Y,12,1,-1,4)
          CALL ENDPLT
          STOP
          END
```

Appendix III

DRY DENSITY VERSUS DEPTH

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```
C/LOAD FORTG1
C THIS IS A PROGRAN TO PLOT DRY DENSITY VS DEPTH
C
       DIMENSION XX(25),YY(25),X(25),Y(25),YYY(25)
       CALL PLOTCN
      CALL SYMBCL(4.0,0.3,0.125,4HFIG.,0.0,4)
      CALL SYMBCL(4.625,0.3,0.125,2H  ,0.0,2)
      CALL SYMBOL(2.0,0.13,0.125,20HDRY DENSITY VS DEPTH,0.,20)
      CALL PLOT(0.0,0.65,-3)
       CALL PLOT(0.0,6.75,2)
      CALL SYMBOL(5.5,6.4,0.125,19HWHEEL SPECIFICATION,0.0,19)
      CALL SYMBCL(5.5,6.200,0.100,18HWEIGHT :           KG,0.0,18)
      CALL SYMBCL(6.400,6.200,0.100,6H 45.81,0.0,6)
      CALL SYMBCL(6.3,6.25,0.1,2,0.0,-1)
      CALL SYMBCL(7.5,6.25,0.1,3,0.0,-1)
      CALL SYMBCL(7.65,6.2,0.1,8H31.75 KG,0.0,8)
      CALL SYMBCL(5.5,5.90,0.100,18HRADIUS :          ,0.0,18)
      CALL SYMBCL(6.400,5.90,0.100,7H 17.2CM,0.0,7)
      CALL SYMBCL(5.5,5.600,0.100,18HWIDTH   :          ,0.0,18)
      CALL SYMBCL(6.400,5.600,0.100,7H  9.5CM,0.0,7)
C     CALL SYMBCL(5.5,5.3,0.100,30HSIZE OF THE LUG :                ,0.0,3
C    *0)
C     CALL SYMBCL(7.30,5.3,0.100,14H 6.4*2.5*2.5CM,0.0,14)
C     CALL SYMBCL(5.5,5.000,0.100,26HSPACING BETWEEN THE LUGS :,0.0,26)
C     CALL SYMBCL(8.20,5.000,0.100,6H 2.5CM,0.0,6)
C     CALL SYMBEL(5.5,5.3,0.1,30HDEGREE OF SLIP  :        PERCENT,0.0,30)
C     CALL SYMBCL(7.3,5.3,0.1,5H31.0 ,0.0,5)
      CALL SYMBOL(5.5,5.05,0.1,1,0.,-1)
      CALL SYMBCL(5.7,5.0,0.1,17HBEFORE COMPACTION,0.0,17)
C     CALL SYMBOL(5.5,4.75,0.1,2,0.,-1)
C     CALL SYMBCL(5.7,4.7,0.1,16HAFTER COMPACTION,0.0,16)
      CALL SYMBOL(7.1,4.4,0.1,16H-SMOOTH SURFACE-,0.0,16)
      CALL SYMBCL(7.3,4.2,0.1,12H-PLANE VIEW-,0.0,12)
      CALL PLOT(7.375,3.9,3)
      CALL PLOT(7.75,3.9,2)
      CALL PLOT(7.83,3.9,3)
      CALL PLOT(7.92,3.9,2)
      CALL PLOT(8.0,3.9,3)
      CALL PLOT(8.375,3.9,2)
      CALL PLOT(8.25,3.9,3)
      CALL PLOT(8.25,2.40,2)
      CALL PLOT(8.375,2.40,3)
      CALL PLOT(8.0,2.4,2)
      CALL PLOT(7.92,2.4,3)
      CALL PLOT(7.83,2.4,2)
      CALL PLOT(7.75,2.4,3)
      CALL PLOT(7.375,2.4,2)
      CALL PLOT(7.5,2.4,3)
      CALL PLOT(7.5,3.9,2)
C     CALL PLOT(7.5,2.875,3)
C     CALL PLOT(8.0,2.875,2)
C     CALL PLOT(8.0,2.75,2)
C     CALL PLOT(7.5,2.75,2)
C     CALL PLOT(8.25,2.5,3)
C     CALL PLOT(7.75,2.5,2)
C     CALL PLOT(7.75,2.375,2)
C     CALL PLOT(8.25,2.375,2)
C     CALL PLOT(7.5,2.0,3)
```

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```
C       CALL PLOT(8.0.2.0.2)
C       CALL PLOT(8.0.2.125.2)
C       CALL PLOT(7.5,2.125,2)
        CALL PLOT(0.0.6.75,3)
        CALL PLOT(9.0,6.75,2)
        CALL PLOT(9.0.0.0.2)
        CALL PLOT(0.0.0.0.2)
        CALL PLOT(0.6.0.5,-3)
        CALL AXIS(0.0.5..21HDRY DENSITY. TON/M**3,21.4..0..0..0.5)
        CALL AXIS(0.0.0.0.8HDEPTH.CM.8.5..90.,40..-8.)
         N=3
        READ(5.25)(YY(I).XX(I).I=1.N)
        DO 100 I=1.N
        WRITE(6.25)XX(I).YY(I)
100     CONTINUE
25      FORMAT(F6.2.F12.7)
        DO 7 I=1.N
        X(I)=XX(I)/0.5
        Y(I)=0.125*YY(I)*2.54
        YYY(I)=5.-Y(I)
        WRITE(6.26)X(I).Y(I).YYY(I)
26      FORMAT(3F12.7)
7       CONTINUE
        X(N+1)= 0.0
        X(N+2)= 1.0
        YYY(N+1)= 0.0
        YYY(N+2)= 1.0
         CALL LINE(X.YYY.N.1.1.1)
         N=3
         READ (5.25)(YY(I).XX(I).I=1.N)
        DO 200 I=1.N
        WRITE(6.25)XX(I).YY(I)
200     CONTINUE
        DO 8 I=1.N
        X(I)=XX(I)/0.5
        Y(I)=0.125*YY(I)*2.54
        YYY(I)=5.0-Y(I)
8       CONTINUE
        X(N+1)= 0.0
        X(N+2)= 1.0
        YYY(N+1)= 0.0
        YYY(N+2)= 1.0
        CALL LINE(X.YYY.N.1.1.2)
        N=3
        READ(5.25)(YY(I).XX(I).I=1.N)
        DO 9 I=1.N
        X(I)=XX(I)/0.5
        Y(I)=0.125*YY(I)*2.54
        YYY(I)=5.0-Y(I)
9       CONTINUE
        X(N+1)= 0.0
        X(N+2)= 1.0
        YYY(N+1)= 0.0
        YYY(N+2)= 1.0
        CALL LINE(X.YYY.N.1.1.3)
        CALL ENDPLT
        STOP
        END
```

Appendix IV

UNCONFINED COMPRESSIVE STRENGTH VERSUS WHEEL SURFACE TYPE

```
      READ (5,49) S1,S2,S3,S4
   49 FORMAT (4F6.2)
      H=20.0
      HH=0.25
      SS1=S1/H
      SS2=S2/H
      SS3=S3/H
      SS4=S4/H
      THICK=0.113
      PLUS=0.10
      CALL PLCTCN
      CALL SYMBOL (4.25,0.35,0.125,6HFIG. :,0.0,6)
      CALL SYMBOL(1.10,0.120,0.125,54HUNCONFINED COMPRESSIVE STRENGTH VS
     *. WHEEL SURFACE TYPE,0.0,54)
      CALL PLOT(0.0,0.65,-3)
       CALL PLOT(9.0,0.0,2)
      CALL PLOT(9.0,6.75,2)
      CALL PLOT(0.0,6.75,2)
      CALL PLOT(0.0,0.0,2)
      CALL SYMBOL (4.2,6.45,0.125,13HPOWERED WHEEL,0.0,13)
      CALL SYMBOL (4.2,6.15,0.125,27HDEGREE OF SLIP : 55 PERCENT,0.0,27)
      CALL SYMBOL (4.2,5.85,0.125,36HRADIUS : 17.2 CM ; WEIGHT : 45.81 K
     *G,0.0,36)
      CALL SYMBOL (4.2,5.55,0.125,30HSOIL SAMPLES TAKEN FROM TOP OF,0.0,
     *30)
      CALL SYMBOL (4.2,5.25,0.125,34HTHE COMPACTED SOIL AFTER 16 PASSES,
     *0.0,34)
      CALL PLOT (1.0,1.0,-3)
      CALL PLOT (0.0,0.0,2)
      CALL PLOT (7.0,0.0,2)
      CALL SYMBOL (1.8,-0.42,0.16,18HWHEEL SURFACE TYPE,0.0,18)
      CALL AXIS (0.0,0.0,39HUNCONFINED COMPRESSIVE STRENGTH KN/M**2,39,
     *5.0,90.0,0.0,H)
      CALL PLOT (2.5,0.0,3)
      CALL PLOT (2.5,SS1,2)
      CALL PLOT (2.875,SS1,2)
      CALL ME (2.875,3.25,SS1,SS2)
      CALL ME (3.25,3.625,SS2,SS3)
      CALL ME (3.625,4.0,SS3,SS4)
      CALL PLOT (4.0,0.0,2)
    1 SS2=SS2-HH
      IF (SS2.LE.0.03) GO TO 2
      CALL PLOT (2.875,SS2,3)
      CALL PLOT (3.25,SS2,2)
      SS2=SS2-0.08
      IF (SS2.LE.003) GO TO 2
      CALL PLOT (3.25,SS2,3)
      CALL PLOT (2.875,SS2,2)
      GO TO 1
    2 SS3=SS3-HH
      IF(SS3.LE.0.01) GO TO 3
      CALL PLOT (3.25,SS3,3)
      CALL PLOT (3.50,SS3,2)
      SS3=SS3-0.08
      IF (SS3.LE.0.01) GO TO 5
      CALL PLOT (3.50,SS3,2)
      CALL PLOT (3.25,SS3,2)
      SS3=SS3-HH
```

```
      IF (SS3.LE.0.01) GO TO 3
      CALL PLOT (3.625.SS3.3)
      CALL PLOT (3.375.SS3.2)
      SS3=SS3-0.02
      IF(SS3.LE.0.01) GO TO 9
      CALL PLOT (3.375.SS3.2)
      CALL PLOT (3.625.SS3.2)
      GO TO 2
    9 CALL PLOT (3.375.0.0.2)
      GO TO 3
    5 CALL PLOT (3.5.0.0.2)
    3 X=3.625
      XX=3.625
      XA=4.0
      SSS4=SS4
      SSS4=SSS4-PLUS
      XX=XX+PLUS
      CALL PLOT (X.SSS4.3)
      CALL PLOT (XX.SS4.2)
      SSS4=SSS4-THICK
      XX=XX+THICK
      CALL PLOT (X.SSS4.3)
      CALL PLOT (XX.SS4.2)
      XX=XA
 19   SSS4=SSS4+THICK/2.0-0.375
      SS4=SSS4+0.375
      N=2
      IF (SSS4) 33.33.35
 35   CALL PLOT (X.SSS4.3)
      CALL PLOT(XX.SS4.2)
      SSS4=SSS4-THICK
      SS4=SS4-THICK
      N=1
      IF (SSS4) 33.33.36
 36   CALL PLOT (X.SSS4.3)
      CALL PLOT (XX.SS4.2)
      GO TO 19
33    SSS4=0.0
      X=X+0.375-SS4
      CALL PLOT (X.SSS4.3)
      CALL PLOT (XX.SS4.2)
      IF (N.EQ.1) GO TO 20
      X=X+THICK
      SS4=SS4-THICK
      IF (X.GE.XA) GO TO 20
       CALL PLOT (X.SSS4.3)
       CALL PLOT (XX.SS4.2)
 20   CALL ENDPLT
      STOP
      END
      SUBROUTINE ME(X1.X2.Y1.Y2)
      IF (Y2.LE.Y1) GO TO 1
      CALL PLOT (X1.0.0.3)
      CALL PLOT (X1.Y2.2)
      CALL PLOT (X2.Y2.2)
      GO TO 2
    1 CALL PLOT (X1.0.0.2)
      CALL PLOT (X1.Y2.3)
```

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```
      CALL PLOT (X2,Y2,2)
    2 RETURN
      END
```

Appendix V

VANE SHEAR STRENGTH VERSUS WHEEL SURFACE TYPE

```
      READ (5,49) S1,S2,S3,S4
   49 FORMAT (4F6.2)
      H=20.0
      HH=0.25
      SS1=S1/H
      SS2=S2/H
      SS3=S3/H
      SS4=S4/H
      THICK=0.113
      PLUS=0.10
      CALL PLOTCN
      CALL SYMBCL (4.25,0.35,0.125,6HFIG. :,0.0,6)
      CALL SYMBCL(1.85,0.120,0.125,42HVANE SHEAR STRENGTH VS. WHEEL SURFACE
     *ACE TYPE,0.0,42)
      CALL PLOT(0.0,0.65,-3)
       CALL PLOT(9.0,0.0,2)
      CALL PLOT(9.0,6.75,2)
      CALL PLOT(0.0,6.75,2)
      CALL PLOT(0.0,0.0,2)
      CALL SYMBCL (4.2,6.45,0.100,11HTOWED WHEEL,0.0,11)
      CALL SYMBCL (4.2,6.15,0.100,36HRADIUS : 17.2 CM ; WEIGHT : 31.75 K
     *G,0.0,36)
      CALL SYMBOL (4.2,5.85,0.100,45HVANE SHEAR STRENGTH MEASURED AT THE
     * MIDDLE OF,0.0,45)
      CALL SYMBCL (4.2,5.55,0.100,34HTHE COMPACTED SOIL AFTER 16 PASSES,
     *0.0,34)
      CALL PLOT (1.0,1.0,-3)
      CALL PLOT (0.0,0.0,2)
      CALL PLOT (7.0,0.0,2)
      CALL SYMBCL (1.8,-0.42,0.16,18HWHEEL SURFACE TYPE,0.0,18)
      CALL AXIS (0.0,0.0,29HVANE SHEAR STRENGTH , KN/M**2,29,5.0,90.0,0.
     *0,H)
      CALL PLOT (2.5,0.0,3)
      CALL PLOT (2.5,SS1,2)
      CALL PLOT (2.875,SS1,2)
      CALL ME (2.875,3.25,SS1,SS2)
      CALL ME (3.25,3.625,SS2,SS3)
      CALL ME (3.625,4.0,SS3,SS4)
      CALL PLOT (4.0,0.0,2)
    1 SS2=SS2-HH
      IF (SS2.LE.0.03) GO TO 2
      CALL PLOT (2.875,SS2,3)
      CALL PLOT (3.25,SS2,2)
      SS2=SS2-0.08
      IF (SS2.LE.0.03) GO TO 2
      CALL PLOT (3.25,SS2,3)
      CALL PLOT (2.875,SS2,2)
      GO TO 1
    2 SS3=SS3-HH
      IF(SS3.LE.0.01) GO TO 3
      CALL PLOT (3.25,SS3,3)
      CALL PLOT (3.50,SS3,2)
      SS3=SS3-0.08
      IF (SS3.LE.0.01) GO TO 5
      CALL PLOT (3.50,SS3,2)
      CALL PLOT (3.25,SS3,2)
      SS3=SS3-HH
      IF (SS3.LE.0.01) GO TO 3
```

```
      CALL PLOT (3.625,SS3,3)
      CALL PLOT (3.375,SS3,2)
      SS3=SS3-0.08
      IF(SS3.LE.0.01) GO TO 9
      CALL PLOT (3.375,SS3,2)
      CALL PLOT (3.625,SS3,2)
      GO TO 2
    9 CALL PLOT (3.375,0.0,2)
      GO TO 3
    5 CALL PLOT (3.5,0.0,2)
    3 X=3.625
      XX=3.625
      XA=4.0
      SSS4=SS4
      SSS4=SSS4-PLUS
      XX=XX+PLUS
      CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      SSS4=SSS4-THICK
      XX=XX+THICK
      CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      XX=XA
   19 SSS4=SSS4+THICK/2.0-0.375
      SS4=SSS4+0.375
      N=2
      IF (SSS4) 33,33,35
   35 CALL PLOT (X,SSS4,3)
      CALL PLOT(XX,SS4,2)
      SSS4=SSS4-THICK
      SS4=SS4-THICK
      N=1
      IF (SSS4) 33,33,36
   36 CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      GO TO 19
   33 SSS4=0.0
      X=X+0.375-SS4
      CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      IF (N.EQ.1) GO TO 20
      X=X+THICK
      SS4=SS4-THICK
      IF (X.GE.XA) GO TO 20
       CALL PLOT (X,SSS4,3)
       CALL PLOT (XX,SS4,2)
   20 CALL ENDPLT
      STOP
      END
      SUBROUTINE ME(X1,X2,Y1,Y2)
      IF (Y2.LE.Y1) GO TO 1
      CALL PLOT (X1,0.0,3)
      CALL PLOT (X1,Y2,2)
      CALL PLOT (X2,Y2,2)
      GO TO 2
    1 CALL PLOT (X1,0.0,2)
      CALL PLOT (X1,Y2,3)
      CALL PLOT (X2,Y2,2)
```

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2 RETURN
END

Appendix VI

INPUT ENERGY VERSUS DRY DENSITY

```
                                                        MAY 25, 1981
      DIMENSION X(10),Y(10)
      CALL PLOTCN
      CALL SYMBCL (4.25,0.35,0.125,5HFIG 3,0.0,5)
      CALL SYMBCL (2.70,0.12,0.125,27HINPUT ENERGY VS DRY DENSITY,0.0,27
     *)
      CALL PLOT (0.0,0.65,-3)
      CALL PLOT (0.0,6.75,2)
      CALL PLOT (5.0,6.75,2)
      CALL PLOT (9.0,0.0,2)
      CALL PLOT (0.0,0.0,2)
      CALL SYMBOL(5.6,6.4,0.100,19HWHEEL SPECIFICATION,0.0,19)
      CALL SYMBCL(5.6,6.2,0.100,18HWEIGHT : 31.75  KG,0.0,18)
      CALL SYMBCL(5.6,5.90,0.100,18HRADIUS :  17.2 CM ,0.0,18)
      CALL SYMBCL(5.6,5.6,0.100,18HWIDTH :   9.5 CM  ,0.0,18)
C     CALL SYMBCL(5.6,5.3,0.075,30HDEGREE OF SLIP:         PERCENT,0.0,30
C    *)
C     CALL SYMBOL(7.35,5.3,0.075,6H 20.0 ,0.0,6)
C     CALL SYMBCL(7.20,5.35,0.075,1,0.0,-1)
C     CALL SYMBOL(7.35,5.1,0.075,6H 31.0 ,0.0,6)
C     CALL SYMBCL(7.2,5.15,0.075,2,0.0,-1)
C     CALL SYMBCL(7.35,4.9,0.075,6H 50.0 ,0.0,6)
C     CALL SYMBCL(7.2,4.95,0.075,3,0.0,-1)
C     CALL SYMBCL(7.35,4.7,0.075,6H 55.0 ,0.0,6)
C     CALL SYMBCL(7.2,4.75,0.075,4,0.0,-1)
      CALL SYMBOL(7.0,4.3,0.1,16H-SMOOTH SURFACE-,0.0,16)
      CALL SYMBCL(7.3,4.1,0.1,12H-PLANE VIEW-,0.0,12)
      CALL PLOT(7.375,3.85,3)
      CALL PLOT(7.75,3.85,2)
      CALL PLOT(7.83,3.85,3)
      CALL PLOT(7.92,3.85,2)
      CALL PLOT(8.0,3.85,3)
      CALL PLOT(8.375,3.85,2)
      CALL PLOT(8.25,3.85,3)
      CALL PLOT(8.25,2.35,2)
      CALL PLOT(8.375,2.35,3)
      CALL PLOT(8.0,2.35,2)
      CALL PLOT(7.92,2.35,3)
      CALL PLOT(7.83,2.35,2)
      CALL PLOT(7.75,2.35,3)
      CALL PLOT(7.375,2.35,2)
      CALL PLOT(7.5,2.35,3)
      CALL PLOT(7.5,3.85,2)
      CALL SYMBCL (5.65,1.87,0.08,0,0.0,-1)
      CALL SYMBCL (5.80,1.85,0.100,15HAVERAGE DENSITY,0.0,15)
      CALL SYMBCL (5.65,1.67,0.08,1,0.0,-1)
      CALL SYMBCL (5.80,1.65,0.100,15HMAXIMUM DENSITY,0.0,15)
      CALL SYMBCL (5.65,1.47,0.08,2,0.0,-1)
      CALL SYMBCL (5.80,1.45,0.100,30HDENSITY OBTAINED FROM STANDARD,0.0,
     *,30)
      CALL SYMBCL (5.80,1.25,0.100,20HPROCTOR'S MOLD & RAM,0.0,20)
      CALL SYMBCL(5.80,0.90,0.15,11HTOWED WHEEL,0.0,11)
      CALL PLOT (0.5,0.5,-3)
      CALL AXIS (0.0,0.0,22HDRY DENSITY , TON/M**3,-22,4.0,0.0,0.8,0.5)
      CALL AXIS (0.0,0.0,18HENERGY , KN-M/M**3,18,5.0,90.0,0.0,40.0)
      K=0
      N=5
    2 DO 1 I=1,N
      READ(5,25) X(I),Y(I)
```

```
25  FORMAT(2F6.2)
    X(I)=X(I)/0.5-1.0
  1 Y(I)=Y(I)/40.0
    X(N+1)=0.0
    X(N+2)=1.0
    Y(N+1)=0.0
    Y(N+2)=1.0
    CALL LINE(X,Y,N,1,-1,K)
    IF(N.EQ.7) GOTO 12
    N=N+1
    K=K+1
    GO TO 2
12  CALL ENDPLT
    STOP
    END
```

Appendix VII

DRY SOIL DENSITY VERSUS WHEEL SURFACE TYPE

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```
      READ (5,49) S1,S2,S3,S4
   49 FORMAT (4F6.2)
      H=0.5
      HH=0.25
      SS1=S1/H
      SS2=S2/H
      SS3=S3/H
      SS4=S4/H
      THICK=0.113
      PLUS=0.10
      CALL PLOTCN
      CALL SYMBCL (4.25,0.35,0.125,6HFIG. :,0.0,6)
      CALL SYMBCL(1.85,0.120,0.125,39HDRY SOIL DENSITY VS. WHEEL SURFACE
     * TYPE,0.0,39)
      CALL PLOT(0.0,0.65,-3)
       CALL PLOT(9.0,0.0,2)
      CALL PLOT(9.0,6.75,2)
      CALL PLOT(0.0,6.75,2)
      CALL PLOT(0.0,0.0,2)
      CALL SYMBCL (4.2,6.45,0.100,11HTOWED WHEEL,0.0,11)
      CALL SYMBCL (4.2,6.15,0.100,36HRADIUS : 17.2 CM ; WEIGHT : 31.75 K
     *G,0.0,36)
      CALL SYMBCL (4.2,5.85,0.100,29HSOIL SAMPLE TAKEN FROM TOP OF,0.0,2
     *9)
      CALL SYMBCL (4.2,5.55,0.100,34HTHE COMPACTED SOIL AFTER 16 PASSES,
     *0.0,34)
      CALL PLOT (1.0,1.0,-3)
      CALL PLOT (0.0,0.0,2)
      CALL PLOT (7.0,0.0,2)
      CALL SYMBCL (1.8,-0.42,0.16,18HWHEEL SURFACE TYPE,0.0,18)
      CALL AXIS (0.0,0.0,21HDRY DENSITY, TON/M**3,21,5.0,90.0,0.0,H)
      CALL PLOT (2.5,0.0,3)
      CALL PLOT (2.5,SS1,2)
      CALL PLOT (2.875,SS1,2)
      CALL ME (2.875,3.25,SS1,SS2)
      CALL ME (3.25,3.625,SS2,SS3)
      CALL ME (3.625,4.0,SS3,SS4)
      CALL PLOT (4.0,0.0,2)
    1 SS2=SS2-HH
      IF (SS2.LE.0.03) GO TO 2
      CALL PLOT (2.875,SS2,3)
      CALL PLOT (3.25,SS2,2)
      SS2=SS2-0.08
      IF (SS2.LE.0.03) GC TO 2
      CALL PLOT (3.25,SS2,3)
      CALL PLOT (2.875,SS2,2)
      GO TO 1
    2 SS3=SS3-HH
      IF(SS3.LE.0.01) GC TO 3
      CALL PLOT (3.25,SS3,3)
      CALL PLOT (3.50,SS3,2)
      SS3=SS3-0.08
      IF (SS3.LE.0.01) GO TO 5
      CALL PLOT (3.50,SS3,2)
      CALL PLOT (3.25,SS3,2)
      SS3=SS3-HH
      IF (SS3.LE.0.01) GO TO 3
      CALL PLOT (3.625,SS3,3)
```

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```
      CALL PLOT (3.375,SS3,2)
      SS3=SS3-0.08
      IF(SS3.LE.0.01) GO TO 9
      CALL PLOT (3.375,SS3,2)
      CALL PLOT (3.625,SS3,2)
      GO TO 2
    9 CALL PLOT (3.375,0.0,2)
      GO TO 3
    5 CALL PLOT (3.5,0.0,2)
    3 X=3.625
      XX=3.625
      XA=4.0
      SSS4=SS4
      SSS4=SSS4-PLUS
      XX=XX+PLUS
      CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      SSS4=SSS4-THICK
      XX=XX+THICK
      CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      XX=XA
   19 SSS4=SSS4+THICK/2.0-0.375
      SS4=SSS4+C.375
      N=2
      IF (SSS4) 33,33,35
   35 CALL PLOT (X,SSS4,3)
      CALL PLOT(XX,SS4,2)
      SSS4=SSS4-THICK
      SS4=SS4-THICK
      N=1
      IF (SSS4) 33,33,36
 36   CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      GO TO 19
  33  SSS4=0.0
      X=X+0.375-SS4
      CALL PLOT (X,SSS4,3)
      CALL PLOT (XX,SS4,2)
      IF (N.EQ.1) GO TO 20
      X=X+THICK
      SS4=SS4-THICK
      IF (X.GE.XA) GO TO 20
       CALL PLOT (X,SSS4,3)
       CALL PLOT (XX,SS4,2)
   20 CALL ENDPLT
      STOP
      END
      SUBROUTINE NE(X1,X2,Y1,Y2)
      IF (Y2.LE.Y1) GO TO 1
      CALL PLOT (X1,0.0,3)
      CALL PLOT (X1,Y2,2)
      CALL PLOT (X2,Y2,2)
      GO TO 2
    1 CALL PLOT (X1,0.0,2)
      CALL PLOT (X1,Y2,3)
      CALL PLOT (X2,Y2,2)
    2 RETURN
      END
```

Appendix VIII

VANE SHEAR STRENGTH VERSUS DEPTH

```
                                                           MAY 25, 1981
C/LOAD FORTG1
C THIS IS A PROGRAM TO PLOT THE VANE SHEAR STRENGTH VS DEPTH
C
        DIMENSION XX(25),YY(25),X(25), Y(25),YYY(25)
        CALL PLOTON
       CALL SYMBCL(4.0,0.3,0.125,4HFIG.,0.0,4)
       CALL SYMBCL(4.625,0.3,0.125,2H  ,0.0,2)
       CALL SYMBCL(2.0,0.13,0.125,28HVANE SHEAR STRENGTH VS DEPTH,0.,28)
       CALL PLOT(0.0,0.65,-3)
        CALL PLOT(0.0,6.75,2)
       CALL SYMBCL(5.5,6.4,0.125,19HWHEEL SPECIFICATION,0.0,19)
       CALL SYMBCL(5.5,6.200,0.100,18HWEIGHT :         KG,0.0,18)
       CALL SYMBCL(6.400,6.200,0.100,6H 45.81,0.0,6)
       CALL SYMBCL(6.3,6.25,0.1,2,0.0,-1)
       CALL SYMBCL(7.5,6.25,0.1,3,0.0,-1)
       CALL SYMBCL(7.65,6.2,0.1,8H31.75 KG,0.0,8)
       CALL SYMBCL(5.5,5.90,0.100,18HRADIUS :           ,0.0,18)
       CALL SYMBCL(6.400,5.90,0.100,7H 17.2CM,0.0,7)
       CALL SYMBCL(5.5,5.600,0.100,18HWIDTH  :           ,0.0,18)
       CALL SYMBOL(6.400,5.600,0.100,7H  9.5CM,0.0,7)
C      CALL SYMBCL(5.5,5.3,0.100,30HSIZE OF THE LUG :                ,0.0,3
C     *0)
C      CALL SYMBCL(7.30,5.3,0.100,14H 6.4*2.5*2.5CM,0.0,14)
C      CALL SYMBCL(5.5,5.000,0.100,26HSPACING BETWEEN THE LUGS :,0.0,26)
C      CALL SYMBCL(8.20,5.000,0.100,6H 2.5CM,0.0,6)
C      CALL SYMBCL(5.5,5.3,0.1,30HDEGREE OF SLIP  :       PERCENT,0.0,30)
C      CALL SYMBCL(7.3,5.3,0.1,5H31.0 ,0.0,5)
       CALL SYMBCL(5.5,5.05,0.1,1,0.,-1)
       CALL SYMBCL(5.7,5.0,0.1,17HBEFORE COMPACTION,0.0,17)
C      CALL SYMBCL(5.5,4.75,0.1,2,0.,-1)
C      CALL SYMBOL(5.7,4.7,0.1,16HAFTER COMPACTION,0.0,16)
       CALL SYMBCL(7.1,4.4,0.1,16H-SMOOTH SURFACE-,0.0,16)
       CALL SYMBCL(7.3,4.2,0.1,12H-PLANE VIEW-,0.0,12)
       CALL PLOT(7.375,3.9,3)
       CALL PLOT(7.75,3.9,2)
       CALL PLOT(7.83,3.9,3)
       CALL PLOT(7.92,3.9,2)
       CALL PLOT(8.0,3.9,3)
       CALL PLOT(8.375,3.9,2)
       CALL PLOT(8.25,3.9,3)
       CALL PLOT(8.25,2.40,2)
       CALL PLOT(8.375,2.40,3)
       CALL PLOT(8.0,2.4,2)
       CALL PLOT(7.92,2.4,3)
       CALL PLOT(7.83,2.4,2)
       CALL PLOT(7.75,2.4,3)
       CALL PLOT(7.375,2.4,2)
       CALL PLOT(7.5,2.4,3)
       CALL PLOT(7.5,3.9,2)
C      CALL PLOT(7.5,2.875,3)
C      CALL PLOT(8.0,2.875,2)
C      CALL PLOT(8.0,2.75,2)
C      CALL PLOT(7.5,2.75,2)
C      CALL PLOT(8.25,2.5,3)
C      CALL PLOT(7.75,2.5,2)
C      CALL PLOT(7.75,2.375,2)
C      CALL PLOT(8.25,2.375,2)
C      CALL PLOT(7.5,2.0,3)
```

```
                                                                      MAY 25, 1981
C       CALL PLOT(8.0,2.0,2)
C       CALL PLOT(8.0,2.125,2)
C       CALL PLOT(7.5,2.125,2)
        CALL PLOT (0.0,6.75,3)
        CALL PLOT(9.0,6.75,2)
        CALL PLOT(9.0,0.0,2)
        CALL PLCT(0.0,0.0,2)
        CALL PLOT(0.6,0.5,-3)
        CALL AXIS(0.0,5.,28HVANE SHEAR STRENGTH, KN/M**2,28,4.,0.,0.,25.)
        CALL AXIS(0.0,0.0,8HDEPTH,CM,8,5.,90.,40.,-8.)
         N=3
        READ(5,25)(YY(I),XX(I),I=1,N)
        DO 100 I=1,N
        WRITE(6,25)XX(I),YY(I)
100     CONTINUE
25      FORMAT(F6.2,F12.7)
        DO 7 I=1,N
        X(I)=0.04*XX(I)
        Y(I)=0.125*YY(I)*2.54
        YYY(I)=5.-Y(I)
        WRITE(6,26)X(I),Y(I),YYY(I)
26      FORMAT(3F12.7)
7       CONTINUE
        X(N+1)= 0.0
        X(N+2)= 1.0
        YYY(N+1)= 0.0
        YYY(N+2)= 1.0
         CALL LINE(X,YYY,N,1,1,1)
         N=3
         READ (5,25)(YY(I),XX(I),I=1,N)
        DO 200 I=1,N
        WRITE(6,25)XX(I),YY(I)
200     CONTINUE
        DO 8 I=1,N
        X(I)=0.04*XX(I)
        Y(I)=0.125*YY(I)*2.54
        YYY(I)=5.0-Y(I)
8       CONTINUE
        X(N+1)= 0.0
        X(N+2)= I.0
        YYY(N+1)= 0.0
        YYY(N+2)= 1.0
        CALL LINE(X,YYY,N,1,1,2)
        N=3
        READ(5,25)(YY(I),XX(I),I=1,N)
        DO 9 I=1,N
        X(I)=0.04*XX(I)
        Y(I)=0.125*YY(I)*2.54
        YYY(I)=5.0-Y(I)
9       CONTINUE
        X(N+1)= 0.0
        X(N+2)= 1.0
        YYY(N+1)= 0.0
        YYY(N+2)= 1.0
        CALL LINE(X,YYY,N,1,1,3)
        CALL ENDPLT
        STOP
        END
```

APPENDIX IX

STANDARD PROCTOR TEST

```
10 PLOTTER IS 705
20 FRAME
30 LOCATE 20,120,15,80
40 SCALE 0,40,1,2.05
50 FXD 2 @ DEG
60 LAXES -5,.15,0,1
70 FOR J=1 TO 6
80 FOR I=1 TO 6
90 READ X,Y
100 PLOT X,Y
110 NEXT I
111 X=.5
112 IF J>2 THEN X=3
120 LINETYPE J+2,X
130 PENUP
140 NEXT J
150 DATA 6.1.89,8.1,2.02,9.94,2,
    11.9,1.93,13.02,1.87
160 DATA 16.66,1.72
170 DATA 6.26,1.84,8.79,1.97,10.
    49,1.99,11.62,1.95,13.5,1.87
180 DATA 16.66,1.78
190 DATA 6.25,1.8,8.24,1.87,9.74
    ,1.92,11.78,1.94,14.08,1.87
200 DATA 15,35,1.8
210 DATA 6.68,1.77,10.81,1.84,14
    .16,1.82,15.94,1.8,19.61,1.6
    7
220 DATA 21.05,1.63
230 DATA 9.12,1.68,10.47,1.77,11
    .94,1.82,17.12,1.76,20.26,1.
    63
240 DATA 28.64,1.45
250 DATA 8.46,1.62,11.06,1.76,16
    .88,1.72,23.58,1.51,26.72,1.
    46
260 DATA 33.33,1.36
270 MOVE -5,1.45
280 LDIR 90 @ LORG 5
290 CSIZE 4
300 LABEL "DRY DENSITY  (TON/CU.
    M)"
310 MOVE 20,.85
320 LDIR 0 @ LORG 5
330 LABEL "WATER CONTENT  (%)"
340 MOVE 35,2.2
350 LABEL "LEGEND"
360 LINETYPE 1
370 MOVE 35,2.05 @ LORG 5
380 CSIZE 3 @ LABEL "THE FOLLOWI
    NG IS THE %"
390 LABEL "OF SAND AND CLAY" @ L
    ABEL "RESPECTIVELY : "
400 PLOT 30,1.8 @ PLOT 35,1.8
410 LINETYPE 3,.5 @ MOVE 40,1.8
420 LABEL "  80 AND 20"
430 PLOT 30,1.75 @ PLOT 35,1.75
440 LINETYPE 4,.5 @ MOVE 40,1.75
450 LABEL "  70 AND 30"
460 PLOT 30,1.7 @ PLOT 35,1.7
470 LINETYPE 5,3 @ MOVE 40,1.7
480 LABEL "  60 AND 40"
490 PLOT 30,1.65 @ PLOT 35,1.65
500 LINETYPE 6,3 @ MOVE 40,1.65
510 LABEL "  50 AND 50"
520 PLOT 30,1.6 @ PLOT 35,1.6
530 LINETYPE 7,3 @ MOVE 40,1.6
531 LABEL "  40 AND 60"
540 PLOT 30,1.55 @ PLOT 35,1.55
541 MOVE 40,1.55
542 LABEL "  30 AND 70"
550 BEEP
560 DISP "END OF PLOTTING"
570 END
```