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MIX DESIGN FOR OPEN GRADED INTERLAYER COURSE TO MINIMIZE REFLECTION CRACKING

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MIX DESIGN METHOD FOR OPEN GRADED INTERLAYER COURSE TO MINIMIZE REFLECTION CRACKING

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ABSTRACT

Open graded interlayers are often used to minimize reflection cracking. However, there is no standard mix design for that type of bituminous mixtures. This study analyses the use of a modified Marshall method to determine the optimum asphalt content in such mixes. The number of blow to minimize aggregate crushing is evaluated as well as a vibrating device. The use of a surface area method with a minimum film thickness of bitumen is also studied and compared to the modified Marshall method. The Marshall stability is used to choose the best combination of aggregate as well as the optimum asphalt content. The density and the voids characteristics are not important in the determination of the optimum asphalt cement content. The study has been done with 101,6 and 152,4 mm diameter briquets with the same height of 63,5 mm. Both sizes briquets lead to the approximate same optimum asphalt cement content. A group of 101,6 mm briquets were compacted with 40 blows of the Marshall hammer and an other group with the vibrating device during 2 1/2 minutes. The 152,4 mm briquets were compacted only by the vibrating device. All Marshall stabilities were made at a temperature of 30^{o}C. A higher temperature is impossible, because of a lack of stability of the open graded mixes.

With the Marshall compaction the maximum stability is 6,7 kN at 3,0% asphalt content and with the vibrating compaction the maximum stability is 5,3 kN at 2,7% asphalt content. That difference is explained by the fact that Marshall compaction creates fines in breaking aggregate. With the 152,4 mm briquets, the Marshall stability is 8,5 kN at 2,7% asphalt content, which is an increase of about the ratio of the diameters.

Special jaws have been made to determine the Marshall stability of 152,4 mm briquets.

In conclusion, the vibrating device should be used to prepare briquets because of much less aggregate fractionning than the Marshall hammer and it is closer to what happen on the road. The asphalt content at the maximum stability is recommended to be chosen as the optimum asphalt content for open graded mixes use as interlayers of base course.

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INTRODUCTION

The use of an open graded mix to reduce reflective cracking was introduced by Tennessee in 1950 and developped by Arkansas with the help of the Asphalt Institute (1); the mix is made with three different maximum rock sizes 76, 64 or 50 mm. Furthemore, it must be 90 mm thick and covered with a dense intermediate mix of 50 mm before the 40 mm thick wearing course is applied. According to Hensley (2), this method has yielded excellent results in Tennessee during the last 23 years and in Arkansas for the last 10 years. In Quebec, open mixes are finer: the nominal sizes of aggregates used here are 37 mm on Route 175 (3) and 19 mm on Route 161 (4). Moreover, the intermediate layer is eliminated, which allows appreciable savings. Finally, open mixes were applied over old bituminous pavements, whereas in the United States they were applied mostly on concrete. Ontario (5) started testing open mixes only in 1980, and their mix was slightly finer and denser than the one used in Quebec: in fact, the maximum size of aggregate is 16 mm; 5 to 15% of the aggregate passes a 4,75 mm sieve and 0 to 4% passes 75 mm sieve; they contain between 2,5 and 3,5% bitumen.

The effectiveness of open mixes to reduce reflective cracking is demonstrated not only in United States but also in Quebec (6), by the experimental sections on Routes 175 and 161 and by experience in Ontario. However, there is no standard mix design for that type of bituminous mixture.

This report proposes a method to determine the optimum asphalt content in open graded mixes used as interlayers to minimize reflection cracking. To do so, a brief state-of-the-art on mix design practices for different kinds of open-graded mixes, is first presented. Secondly, the MTQ modified Marshall mix design method for open graded mixtures is described. Finally, a general discussion examines the possibilities and the limitations of the MTQ method.

STATE-OF-THE-ART ON MIX DESIGN FOR OPEN-GRADED MIXES

In open-graded mixes asphalt content is not so critical as that of dense mixes, because the large void space accomodates a little excess of asphalt, which eventually settles on the bottom without surface bleeding. A lack of asphalt is more harmful because it lead to a weak cohesion and a poor workability of the mix. Therefore selection of the optimum asphalt content have been done mostly by experience on the rich side instead of using a formal mix design.

However for open-graded asphalt friction courses, asphalt constant is a little more critical than for interlayers or base course. That is why the Asphalt Institute proposed two asphalt content selection methods in their construction leaflet CL-10 (7): the pan method and the surface capacity method.

The pan method consists of mixing trial batches in the laboratory and store than overnight at 60°C: the proper asphalt content is the one from which a small amount of asphalt drains to the botton of the pan and the mix still appears glossy. The asphalt content is selected by eye and this makes the method very subjective.

The surface capacity method is a more objective one: the coarse aggregate in the mix represented by the fraction passing the 9,75 mm sieve and retained on the 4,75 mm sieve is immersed in SAE No 10 lubricating oil and the amount of oil retained after draining for 15 minutes at 60°C is measured; using the surface constant Kc chart of HVEEM method of mix design, the estimated optimum asphalt content is determined as follow:

$$AC = 2,0\ Kc + 4$$

Where:

AC = Asphalt content % by weight of aggregate

Smith and al (8) completed the surface capacity method with voids content of vibratory compacted samples, and resistance to effect of water and observation of the amount of asphalt drainage occuring at the temperatures corresponding to asphalt cement viscosity ranging from 700 to 900 centistokes. This method has also been published with some minor differences by the Asphalt Institute (9).

The surface capacity formula used by Kandhal and al (10) is slighly modified and gives a little lower asphalt content:

$$AC = 1.5\ kc + 3.5$$

They recommended to use a minimum air voidsof 25% instead of 15% according to the FHWA design procedure (8).

Three mix design procedure for open-graded asphalt emulsion mixes (Chevron USA, Inc; U.S. Forest Service Region 6; and FHWA Region 10) are summarized and discussed by Hicks and al (11). They concluded "Mix design adopted by different agencies are essentially a trial-and-error process since a universally acceptable design procedure is still not available... Design strength criteria are badly needed".

For hot-mix open-graded binder or interlayer course fives mix-designs have been studied by Sergio Then de Barros (12): specific-area method, Marshall, static compression, mixing pan and glass-plate methods.

The specific-area methods is the Duriez formula for cold mixtures modified to apply to aggregates that had 100 percent passing a 50 mm sieve and less than 5 percent of fines passing a 2,0 mm sieve. The modified formula is as follows:

$$S = 0.01\ (7 + 0.07P_1 + 0.19P_2 + 0.48P_4 + 1.89P_{10})$$

Where:

S = specific surface area (m^2/kg).
P_1 = percent passing 25 mm (1-in) sieve,
P_2 = percent passing 12.5 mm (0-5-in) sieve (or, alternative, 1.10 x percent passing 9.5 mm (0.38-in) sieve),
P_4 = percent passing 4-8 mm (no 4) sieve, and
P_{10} = percent passing 2-0 mm (no 10) sieve,

The asphalt content in percentage of aggregates=

$p^1 = = 3.5\ ^5$

and for asphalt content in percentage of total mix:
$p = 100\ p\ \ /100 + p\ )$

It seem that the results obtained by this formula are remarkably accurate for such a simple method, and they agree fairly well with other methods and with construction practice.

On the Marshall method, Mr de Barros made the following comments:

"The Marshall method of mix design is not applicable to open-graded mixes. The molding of test specimens by dynamic impact in the Marshall apparatus, even with only 50 blows per face, causes considerable aggregate breakage, which affects the mix conditions. It is almost impossible to extract the specimens from the mold. Most samples fall apart during extraction or soon afterward at room temperature. An alternative method is to calculate the density by measurement and weighing of samples inside the Marshall mold without extraction. Specimens compacted with 50 blows on each face gave density values comparable with those obtained in samples drilled from the road and close to values obtained by static compression."

The static compression method is not a real design method, but static compression is a useful process of making specimens for density and permeability tests. Density values seems to be close to those obtained from cores on the road, and compaction temperature is not critical for this type of mix just like field experience.

The "Mixing-pan method" differs slightly from the Asphalt Institute pan method (7): it has the following procedure:

1. Prepare a series of trial mixtures at 150°C in an open pan, starting with a low asphalt content of 2 percent and increasing by 0.2 percent in each mix;

2. Compare the visual aspect of the mixes side by side, increasing in order from lean to rich;

3. Determine the lowest asphalt content that completely covers the aggregate particles with a continous film, without any free asphalt; and

4. Add 0.4 percent to obtain the optium asphalt content.

According to Mr de Barros, this method is the most reliable.

The glass-plate method is essentially a verification check to be used in connection with the mixing-pan method. The procedure is very simple and has the following six operations:

1. Spread 500 g of each of the previously prepared mixes on a thick, transparent glass plate 30 x 30 cm.

2. Cool the plates at room temperature for 1 h.

3. Raise and fix the plates in an upright position.

4. Observe the adherence of the mixes to the plates. (Lean mixes drop down in a few minutes; rich mixes adhere much longer.) The optimum asphalt content should keep the mix in place for at least 0.5 h.

5. Observe the plates by transparency from the reverse side. The optimum asphalt content should present no bleeding or free asphalt on the plate.

6. Adjust asphalt content accordingly.

The first method MTQ used to determine the optimum asphalt content in open-graded mixes for interlayers or base course was a surface area method which differs from the de Barros specific area method.

The MTQ surface area method determines the surface area by calculation shown in the Hveem method of mix design described in Asphalt Institute Manual Series No 2 (13) and provides for a minimum Asphalt film thickness of 12 um. The optimum asphalt content is 0.4% (variation permitted on production) higher then the asphalt content which gives a film thickness of 12 um.

This method gives good results with cubic aggregates, but when flat and elongated aggregates are present in a significant amount (15% and more) the surface area calculated is too small and the asphalt content determined gives a lean mix. An other weakness of this formula is that it does provide a fixed value for the aggregated larger than the 4,75 mm, and for open-grades mixes, those aggregates are at least 80% of the total aggregate.

Because of those weaknesses and also because the other methods described formerly were not enough precise or objective, a study of a mix design was initialed in the Central Laboratory of the MTQ. And, since all the laboratories of the MTQ or working for the MTQ had Marshall apparatus, a modified Marshall mix design was the object of the research.

MTQ MODIFIED MARSHALL MIX DESIGN METHOD FOR OPEN -GRADED BITUMINOUS MIXES.

Knowing by experience and by the work of Mr. de Banos (12) that normal Marshall compaction can cause considerable aggregate breakage, two types of modification in the molding of test specimen were considered: reduction of the number of blows with the Marshall compactor, and utilisation of a vibratory compaction apparatus.

Marshall apparatus

The Marshall compactor used in the study is the double mechanical compactor with rotating bases. Figure 1 shows a picture of that apparatus.

For determination of stability, the normal jaws were used with the 101,6 mm diameter specimens. But for the 152,4 mm diameter specimens, special jaw were made. Figure 2 gives a picture of those jaws.

Vibratory compaction apparatus

The vibratory compactor is similar to the one described in the British Standard method BS 1377 test 14 (14) used for granular soil. It consist of a Kango 638 hammmer supported by a frame which it firmly and vertically maintained over a concrete base during operation. Figure3 illustrates well the complete apparatus. The Asphalt Institute gives in the pamphlet MISC-78-3 (9) a description of a vibratory compaction apparatus which has many similarities. However the MTQ vibratory compactor differs significatively from the one built by the French engineers (15) which vibrates the lateral wall of the mold and uses a compression stress.

Parallel study

A parallel study was run with the same aggregates and asphalt cement.

The aggregate were a limestone from a guarry in Quebec City and the asphalt cement was an 85-100 supplied by Ultramar rafinery in metro Quebec. Detailed characteristics of the aggregate and the asphalt cement are given respectively in tables 1 and 2.

The design was for an open-graded mix used mainly as a crack relief interlayer on old bituminous concrete roads. The specifications of that mix are given in table

3. The study was done with three differents grading: the unferior, the median and the superior line of the specification as shown in figure 4.

A preliminary study was done to determine the proper number of blow for compaction and the adequate temperature to run the Marshall stability test. For this purpose, test were made with the gradings where aggregate breakage was expected to be the greatest, that is inferior and median line of specifications. These grading would also give the lowest stability and so guide us to choose the adequate temperature for stability test.

Marshall briquets with a 101,6 mm diameter and a 63,5 mm height were compacted with 40, 50, 60 and 75 blows by the mechanical double rotating bases compactor. Figure 5 shows the evolution of the bulk specific gravity with the number of blows.

Table 4 illustrates the changes occuring with the median grading. The aggregate retained on the 12,5 mm sieve is the most affected: 18% of it (9/50) is broken into smaller pieces which seem to be almost evenly distributed to the 9,5 - 4,75 - 2,36 - 1,18 mm and 600 um sieves. This breakage seems to occur during the first 40 blows, and the one because there is almost no difference between grading after 40 blows and the one after 50, 60 and 75 blows. So after 40 blows no more aggregate breakage occurs only compaction varies: it increases up to 60 blows and then decreases slightly due probably to over compaction as it is the case sometimes on the road.

Since the preliminary study with the vibrating device as described earlier in this paper, shows that the maximum specific gravity obtained is around 1,73 which correspond to the one obtained by 40 blows of the Marshall compactor. That maximum specific gravity is reached after 2 1/2 minutes of vibration on a 152,4 diameter and 63,5 mm height briquet as shown by figure 6. Also the grading is very little affected by the vibrating compactor and the durationof vibration has no significant effect on grading even for the inferior line, as demonstrated by the results of table 5.

Because of those results, it was decided that the parallel study would be done on 101,6 mm x 63,5 mm briquets compacted by 40 blows of the Marshall compactor and on 152,4 x 63,5 mm briquets compacted 2 1/2 minutes by the vibrating device.

The next step of the preliminary study was to determine at what temperature the Marshall stability should be done. For that purpose two series of briquets (152,4 an 101,6 mm of diameter) were soaked is water at different temperature (25 to 50°C) and manipulated similarly as they would be for a Marshall stability. For Marshall briquets (101,6 mm diameter compacted by 40 blows of the Marshall mechanical compactor) the inferior grading type could resist to a 40°C soaking but for the vibrator briquets (152,4 mm diameter compacted by 2 1/2 minutes of vibration) 30°C soaking was the maximum temperature that the inferior grading type could resist. So this 30°C was chosen to do the Marshall stability test on both types of briquets.

Mix design procedure

Five differents asphalt contents were chosen for each type of grading: a middle point plus and minus 0,4 and 0,8 %.

For the inferior grading, the middle point was the lower limit of the specification that is 2,5%. For the superior grading, the middle point was 3,5%, the upper limit of the specifications. The median grading had a middle point of 3,0, the average of the specification limits. The briquets of both series (Marshall and Vibrator) were made for each asphalt content.

The results are presented on figures 7 to 12 by the usual Marshall graphical plots.

The test property curves do not all follow the reasonably consistent patern like dense-graded bituminous paving mixes:

a) Stability values have the same trend: as for dense graded mixes: it increase with increasing asphalt content up to a maximum after wich it decreases;

b) The flow values haves also the same trend as for dense-graded mixes: it increases with increasing asphalt content, except for Marshall briquets with inferior grading and vibrated briquets for median grading where data are very scattered;

c) The unit weight, air voids and VMA curves in some cases follow the same trend as for dense-grades mixes, but in other cases values are very scattered and follow a different strend, This is normal, considering the lesses precision in the bulk specific gravity of open-graded mix due to the large voids.

Because of the paterns followed by the test property curves, the optimum asphalt content cannot be the average of the maximum stability, the maximum unit weight and the median limits of the specification (mone already exists) for air-voids. But the asphalt content for the maximum stability appears to be a good optimum asphalt content for open-grades mixes used as interlayer or base course. However there is a slight difference in optimum asphalt content determined by the maximum stabilities of the two methods. This differences is not significant for inferior line grading, but it increases with increasing the amount of fine aggregate (paving 4,75 mm sieve).

GENERAL DISCUSSION

Since preparation of molded specimens influence the asphalt content for the maximum stability, an other modification was studied: 101,6 diameter briquets molded with the vibrating compaction apparatus. Figure 13 show the Marshall graphical plots for this type of specimen made with the median line grading.

This time, the asphalt content for the maximum stability is much closer to the one determined by the Marshall compaction specimens, and seems to be more realistic than the one determined by th 152,4 mm diameter briquets.

The results of the optimum aspphalt content, the maximum stability and the percentage or air-voids corresponding an given in table 6. A mix design on a dense graded mix MB-2 for base course has been done with the two types of briquets and the results are also given in table 6. For that mix it was the conventionnal way of calculating the optimum asphalt content and the stabilities have been done also at 30°C.

For the open graded mixes vibrated specimens gives a lower asphalt content for the maximum stability than the Marshall compacted ones. This is normal because the vibrated specimens are less affected in their grading than the Marshall specimen as it can be seem in figures 14 and 15. The dense-graded mix has also an optimum asphalt content lower when determined on 152,4 mm diameter vibrated briquets.

Calculating the optimum asphalt content by the specific area method using the modified Duriez formula as presented earlier in this paper, gives results of 2,66%, 2,97% and 3,08% respectively for the inferior, median and superior grading.

The optimum asphalt content calculated by the MTQ surface area method as described previously is respectively 1,73%, 2,87% and 3,96% for the inferior, median and superior grading. The MTQ surface area method is comparable to the modified Duriez formula only for the median grading. For coarser mixes it gives a lower asphalt content and for fines mixes it leads to higher asphalt content.

For the open-grades mixes the Marshall mix design results with the 152,4 mm diameter vibrated briquets are very much in agreement with those of the modified Duriez formula: 2,5% vs 2,66%, 3,0% vs 2,97% and 3,5% vs 3,08%. The mix design with the 101,6 mm diameter Marshall briquets is also in very good agreement with the modified Duriez formula for the inferior and median grading (2,6% vs 2,66% and 3,0% vs 2,97%), but it deviates significatively for the superior grading (3,9% vs 3,08%).

As demonstrated by figures 16 to 21, the stabilities on both types of briquets vary similarly with specific area, granulometric total and percentage of sand (passing 4,75 mm sieve). They are almost similar for open-graded mixes, but for the dense-graded mix, the 152,4 diameter briquets have a stability significatively lower.

Since, very little change in the grading occurs with the vibrated briquets, and the optimum asphalt content is in a better agreement with the modified Duriez formula, which according to Mr. de Barros (12), agree fairly well with construction practice, and also because of MTQ experience, the recommended mix design would be with those vibrated briquets and the optimum asphalt content determined by the maximum stability obtained.

CONCLUSIONS

Based on our tests results and on the previous discussions, the following conclusions appear warranted.

1. Forty blows of the Marshall hammer affect significatively the grading, but their effect decreases with increasing the amount of fine aggregate in open-graded bituminous mixes.

2. The vibratory compaction apparatus do not significatively change the grading even for the coarses bituminous mix.

3. The mix design method using the vibratory compactor and the marshall stability gives the most reliable optimum asphalt content for the open-graded bituminous mixes used for interlayers on base course.

4. A mix design with 40 blows of the Marshall mechanical compactor gives also a very reliable optimum asphalt content for the open-graded mixes used for interlayers on base course.

5. The modified Duriez formula seem to be excellent to estimate the optimum asphalt content for open-graded mixes, but it must be completed by a mix-design in order to obtain a result based on test and closes to the field specially for aggregates that are not too cubic.

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TABLE 1

CHARACTERISTICS OF AGGREGATE

NATURE	LIMESTONE
Petrographic Number	110 - 114
Soundness	0,8 - 1,5
Micro Deval	11,1 - 13,4
Absorption	0,46 - 0,55
Los Angeles	18 - 19
Flat Particules	14 - 27
Elongated Particules	38 - 55
Dynamic Fragmentation	22 - 25

TABLE 2

CHARACTERISTICS OF ASPHALT CEMENT

Penetration - At 25°C - At 5°C	 94 12
Viscosity at 60°C (P)	1405
Viscosity at 135°C (D) original after RTFO	 3,3 5,2
Softenning Pt (R + B) °C	46,4
Fraas breaking Pt (°C)	- 23°C
PVN	- 0,56
PI	- 0.62

TABLE 3

MTQ SPECIFICATIONS OF OPEN-GRADED
BITUMINOUS INTERLAYER

CHARACTERISTIC	SPECIFICATION
A) GRADING (% PASSING)	
SIEVE	MIN - MAX.
25 MM	100
19 MM	80 - 100
12,5 MM	20 - 60
4,75 MM	6 - 20
1,36 MM	2 - 10
75 μM	1 - 3,5
B) ASPHALT CONTENT (%)	2,5 - 3,5
C) MINIMUM FILM THICKNESS (μM)	12
D) MIXING TEMPERATURE (°C)	110 - 135

TABLE 4

CHANGES OCCURING WITH MEDIAN GRADING

ON 101.6 MM DIAMETER BRIQUETS AFTER MARSHALL COMPACTION

SIEVE	NUMBER OF BLOWS 0	40	50	60	75
25 MM	100	100	100	100	100
19 MM	90	91	90	90	91
12.5 MM	40	50	51	48	53
9.5 MM	29	37	36	36	37
4.75 MM	13	19	19	18	19
2.36 MM	8	11	11	11	12
1.18 MM	6	8	10	8	8
600 UM	4	5	5	5	5
300 UM	3	4	4	4	4
150 UM	2.5	3	3	3	3
25 UM	2.3	2.3	2.3	2.3	2.3
GRANULOMETRIC TOTAL	198	230	230	235	229
SURFACE AREA (M^2/KG)	1987	2221	2172	2217	2229

TABLE 5

CHANGES OCCURING WITH INFERIOR GRADING ON 152.4 MM DIAMETER BRIQUETS AFTER VIBRATING COMPACTION

SIEVE	DURATION OF VIBRATION (MINUTES) 0	2	3	4
25 MM	100	100	100	100
19 MM	80	82.5	81	81
12.5 MM	20	22	22	21
9.5 MM	16	17	17	16
4.75 MM	6	8	7	7
2.35 MM	3	5	4	4
1.18 MM	2	3	3	3
600 UM	1.5	3	2	2
300 UM	1.4	1.6	1.6	1.5
150 UM	1.2	1.4	1.4	1.3
75 UM	1.0	1.2	1.2	1.1

TABLE 6

GRADING	MARSHALL STABILITY (kN)		OPTIMUM ASPHALT CONTENT (%)		AIR VOIDS (%)	
	Marshall	Vibrator	Marshall	Vibrator	Marshall	Vibrator
INFERIOR	2,95	4,15	2,6	2,5	35,5 (1,673)	36,3 (1,742)
MEDIAN	6,63	9,49 5,33	3,0	3,0 [2,7]	25,7 (1,915)	25,7 (1,926) [27,9](1,870)
SUPERIOR	11,74	7,47	3,9	3,5	20,1 (2,030)	24,6 (1,937)
MB2	35,42	25,40	4,6	4,2	5,07 (2,395)	7,95 (2,319)

( ) Bulk specific gravity results

[ ] 101,6 mm Diameter Vibrated briquets

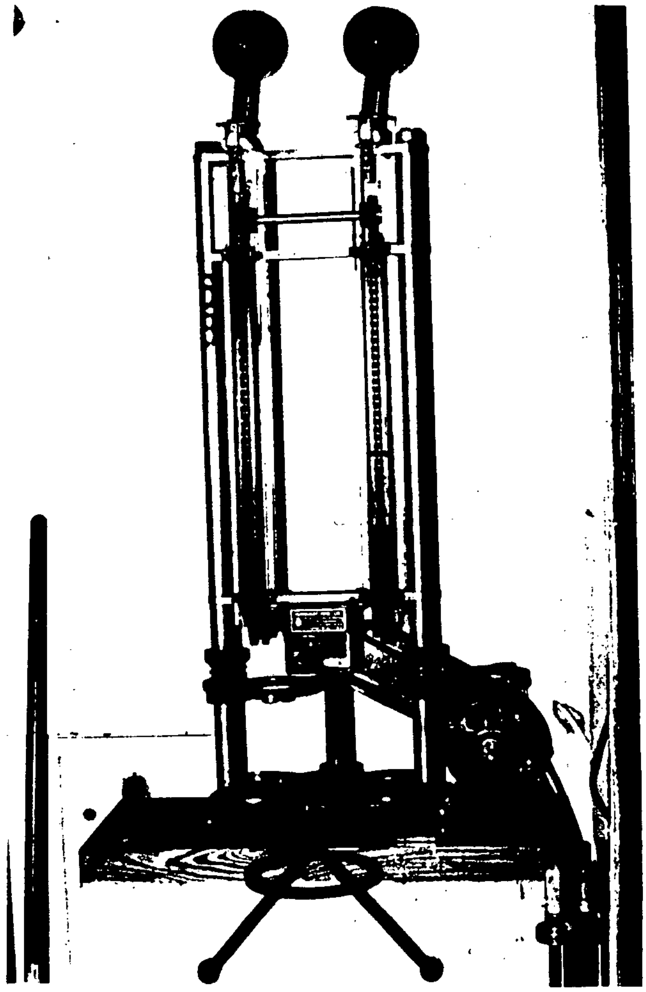


FIGURE 1: MARSHALL DOUBLE MECHANICAL COMPACTOR

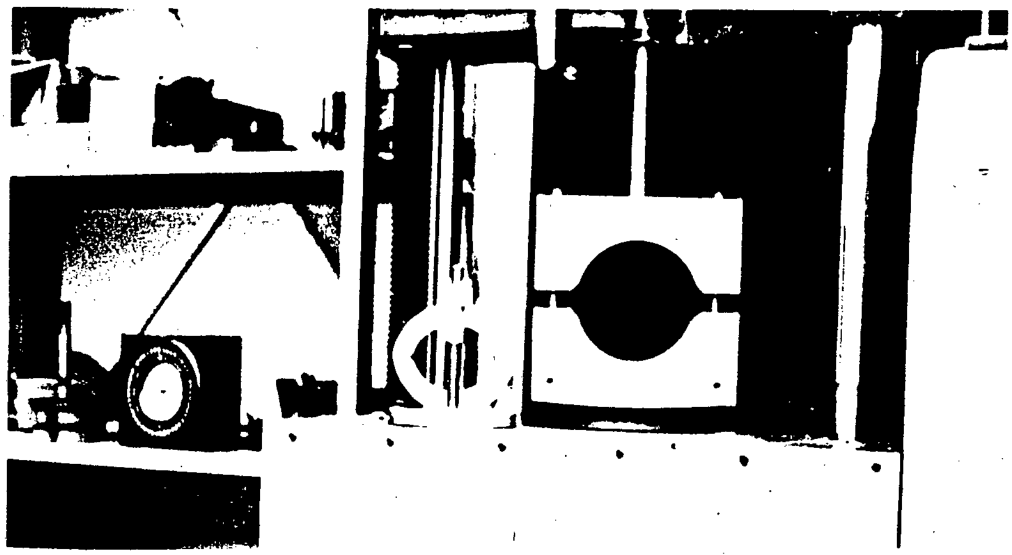


FIGURE 2: MARSHALL JAWS

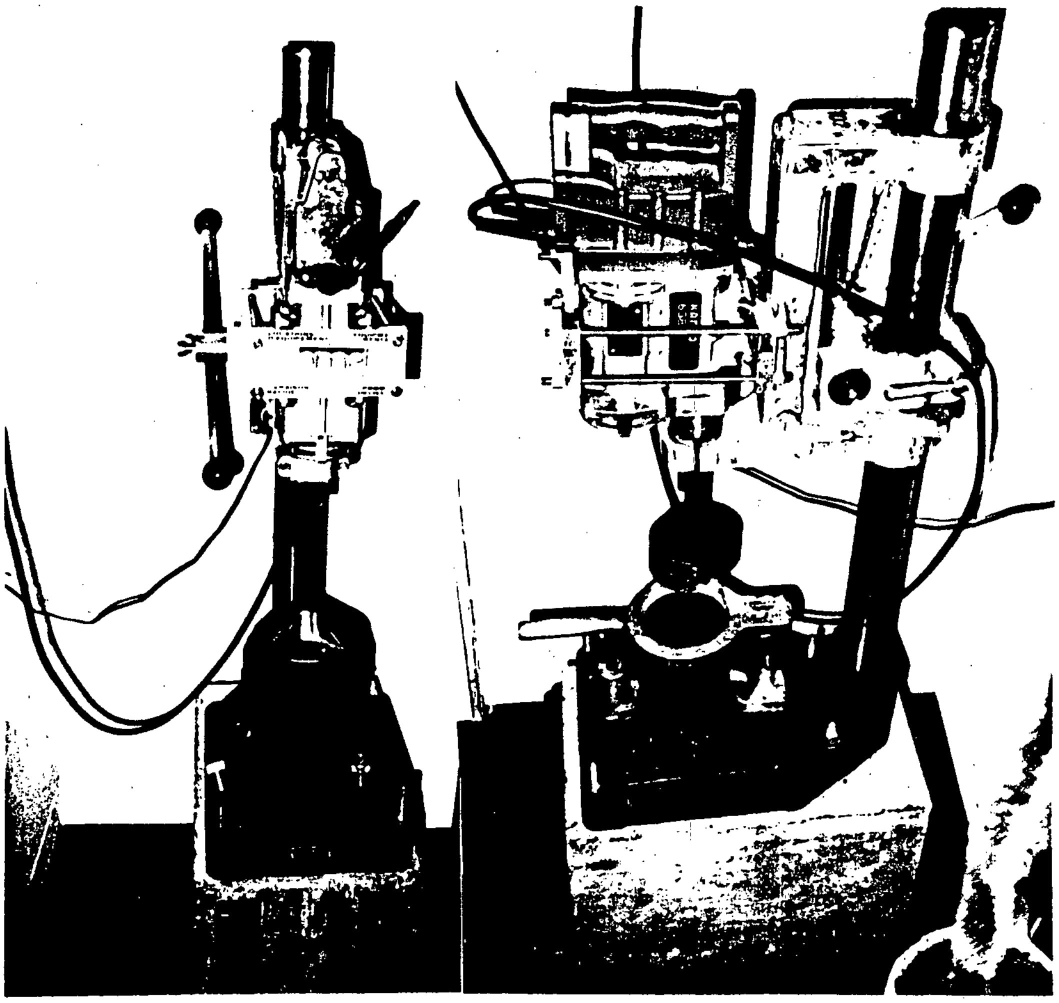
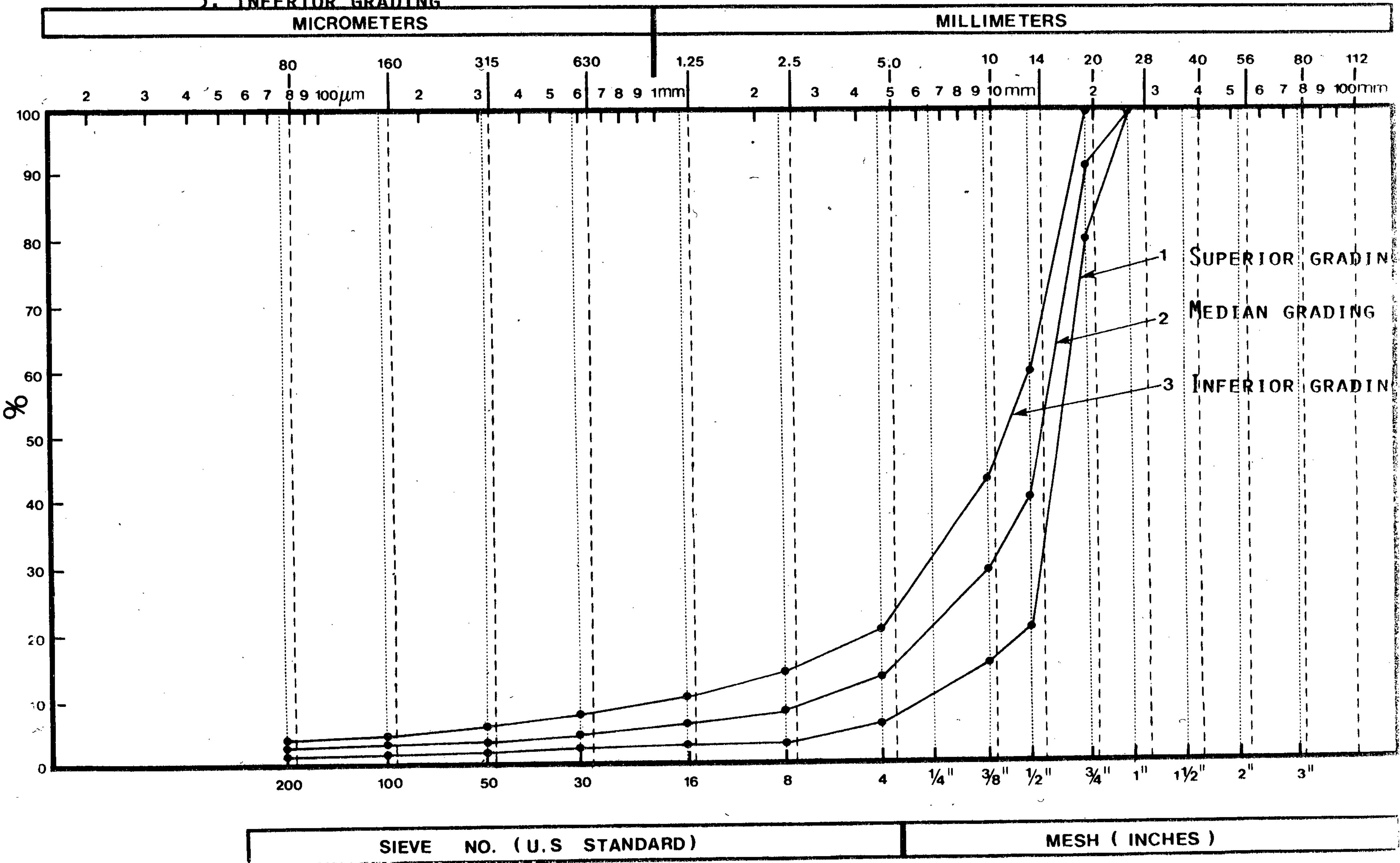


FIGURE 3: VIBRATORY COMPACTION APPARATUS

FIGURE 4: GRADINGS USED IN THE STUDY

1. SUPERIOR GRADING
2. MEDIAN GRADING
3. INFERIOR GRADING



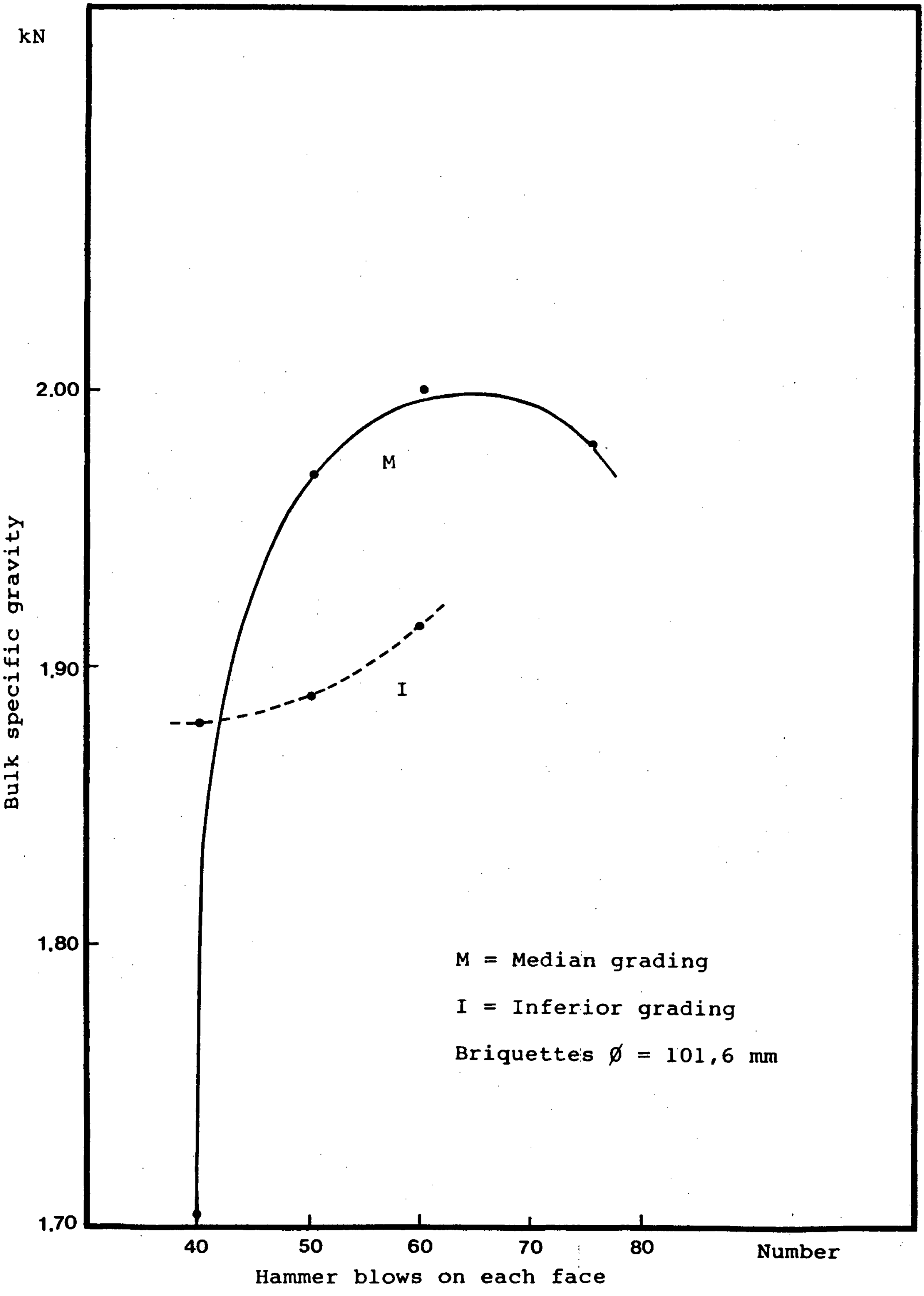


FIGURE 5: BULK SPECIFIC GRAVITY VERSUS HAMMER BLOWS

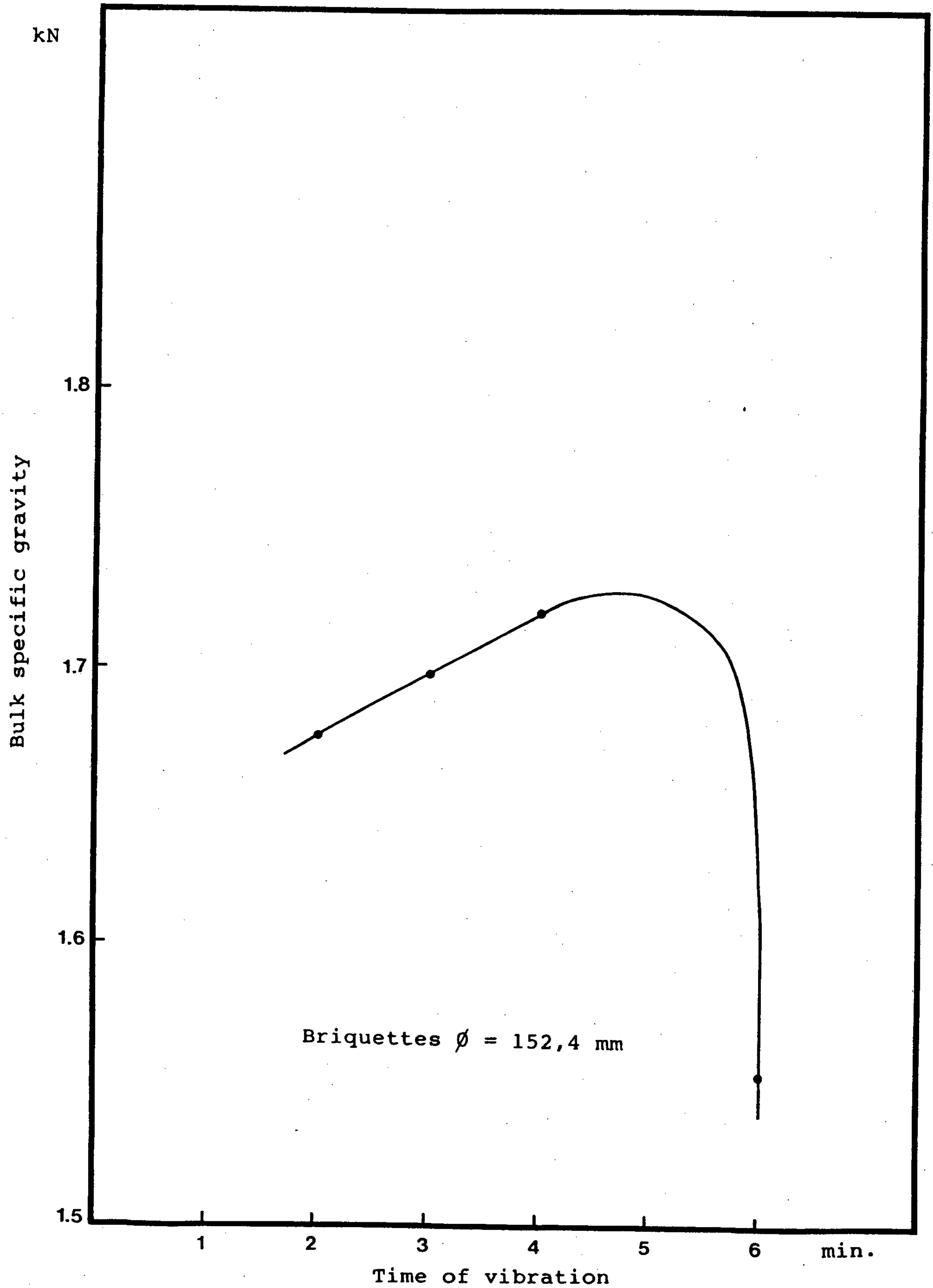
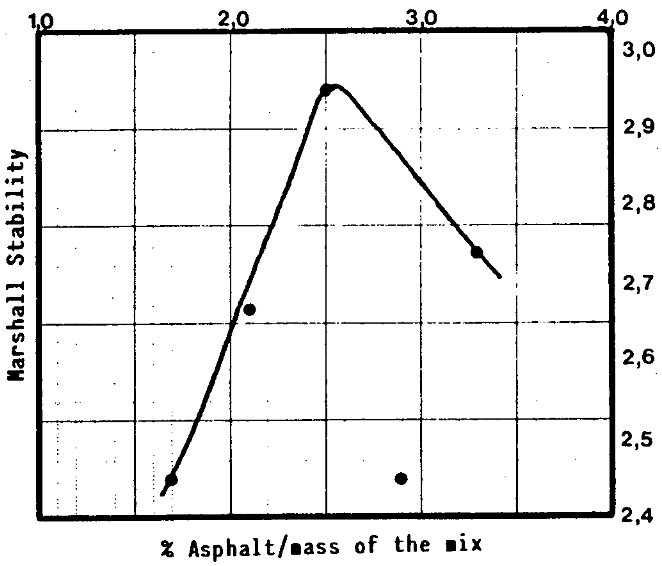


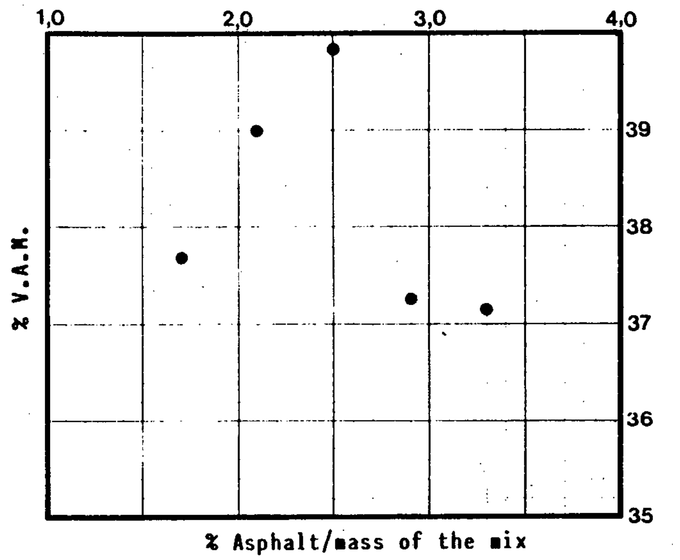
FIGURE 6: BULK SPECIFIC GRAVITY VERSUS TIME OF VIBRATION

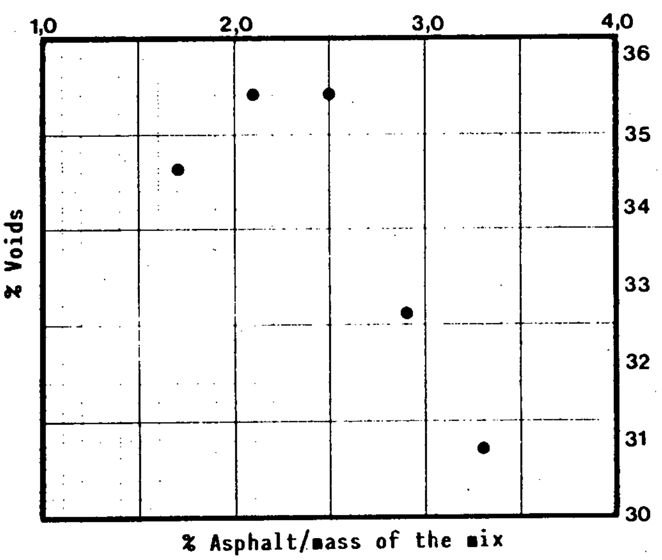
FIGURE 7

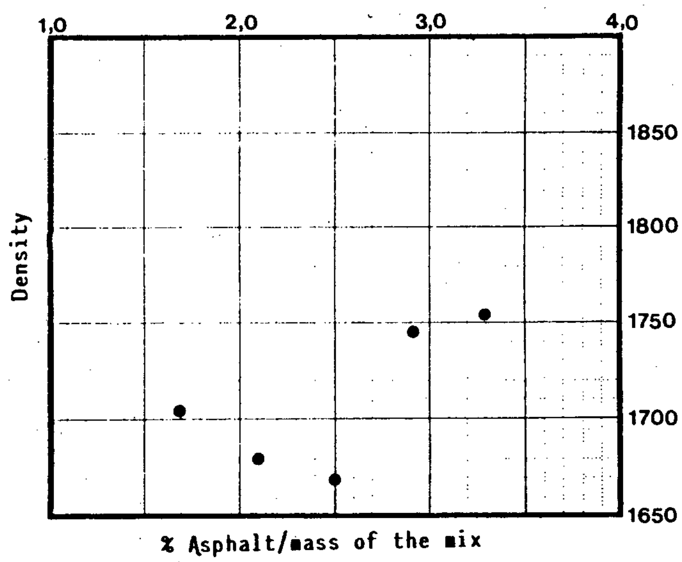
INFERIOR GRADING

(MARSHALL BRIQUETTES Ø 101,6 MM)









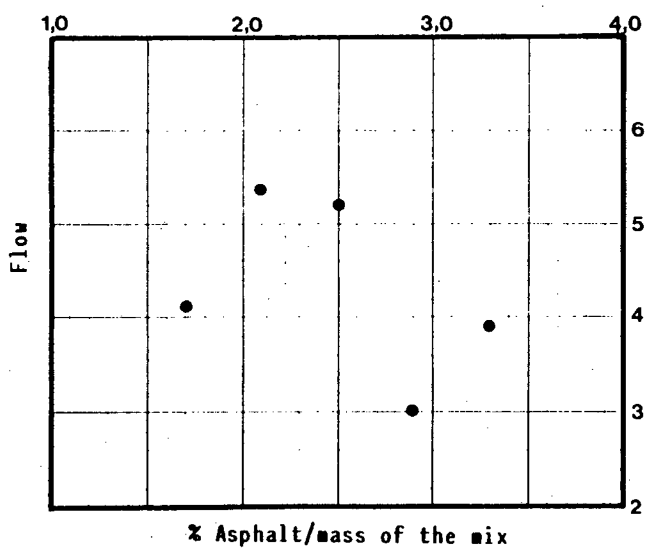


FIGURE 8

MEDIAN GRADING

(MARSHALL BRIQUETTES Ø 101,6 MM)

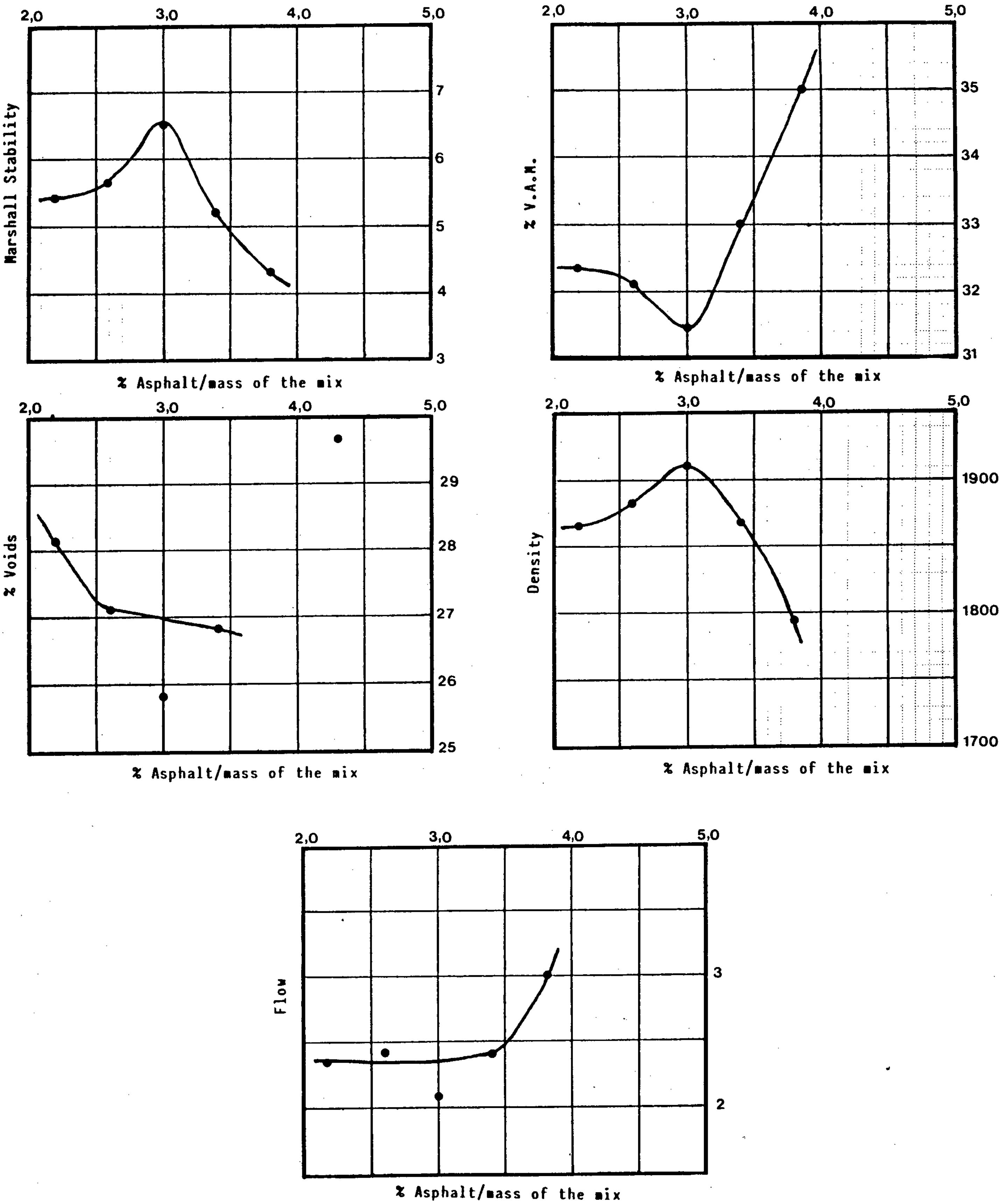
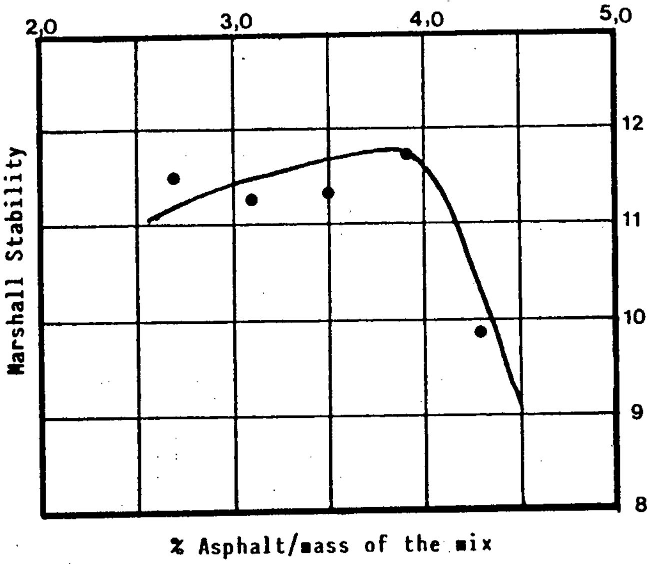
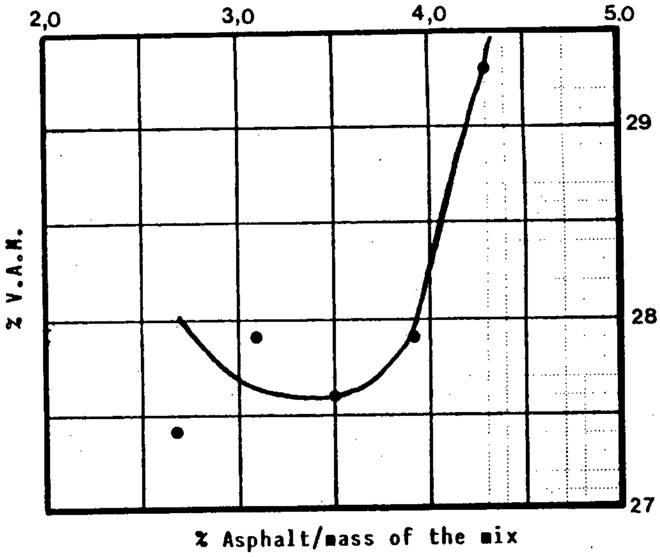


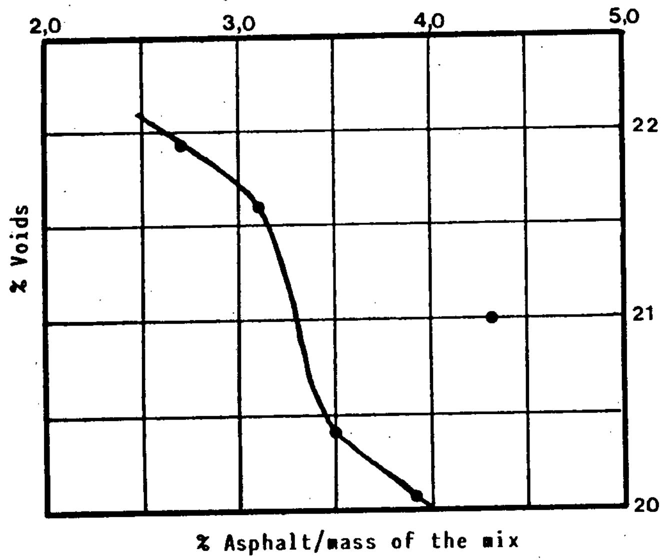
FIGURE 9

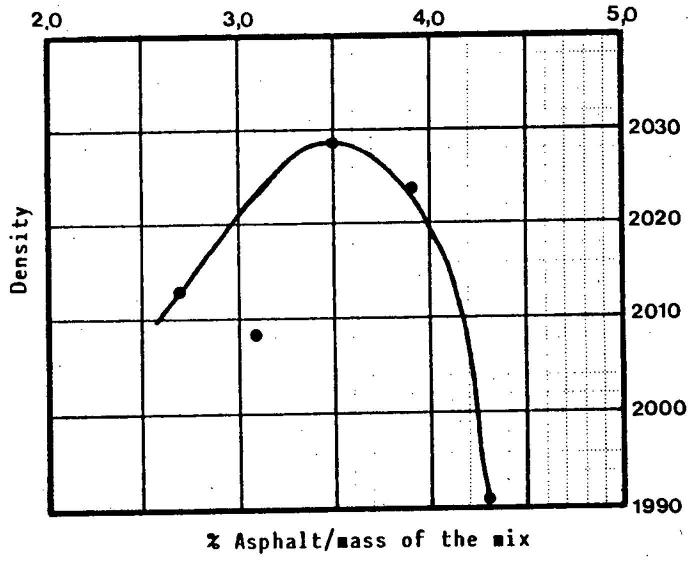
SUPERIOR GRADING

(MARSHALL BRIQUETTES Ø 101,6 MM)









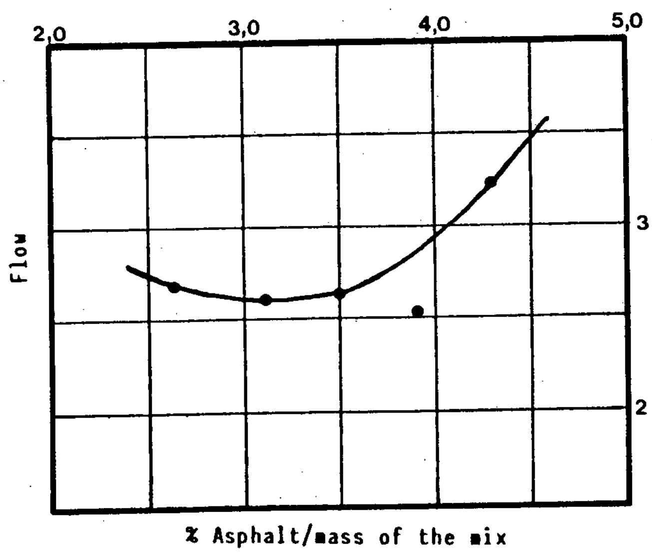


FIGURE 10

INFERIOR GRADING

(VIBRATED BRIQUETTES Ø 152,4 MM)

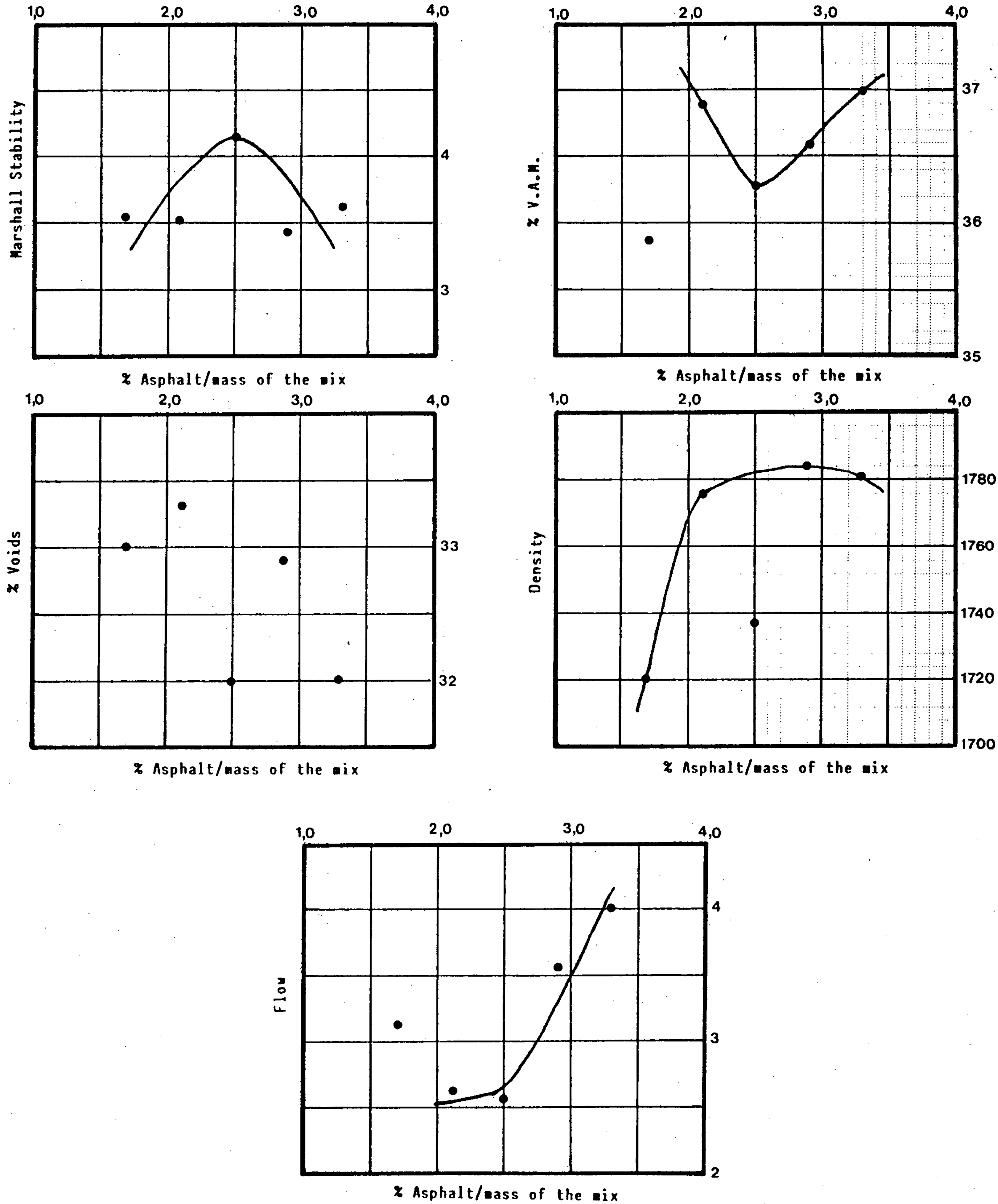


FIGURE 11

MEDIAN GRADING

(VIBRATED BRIQUETTES Ø 152,4 MM)

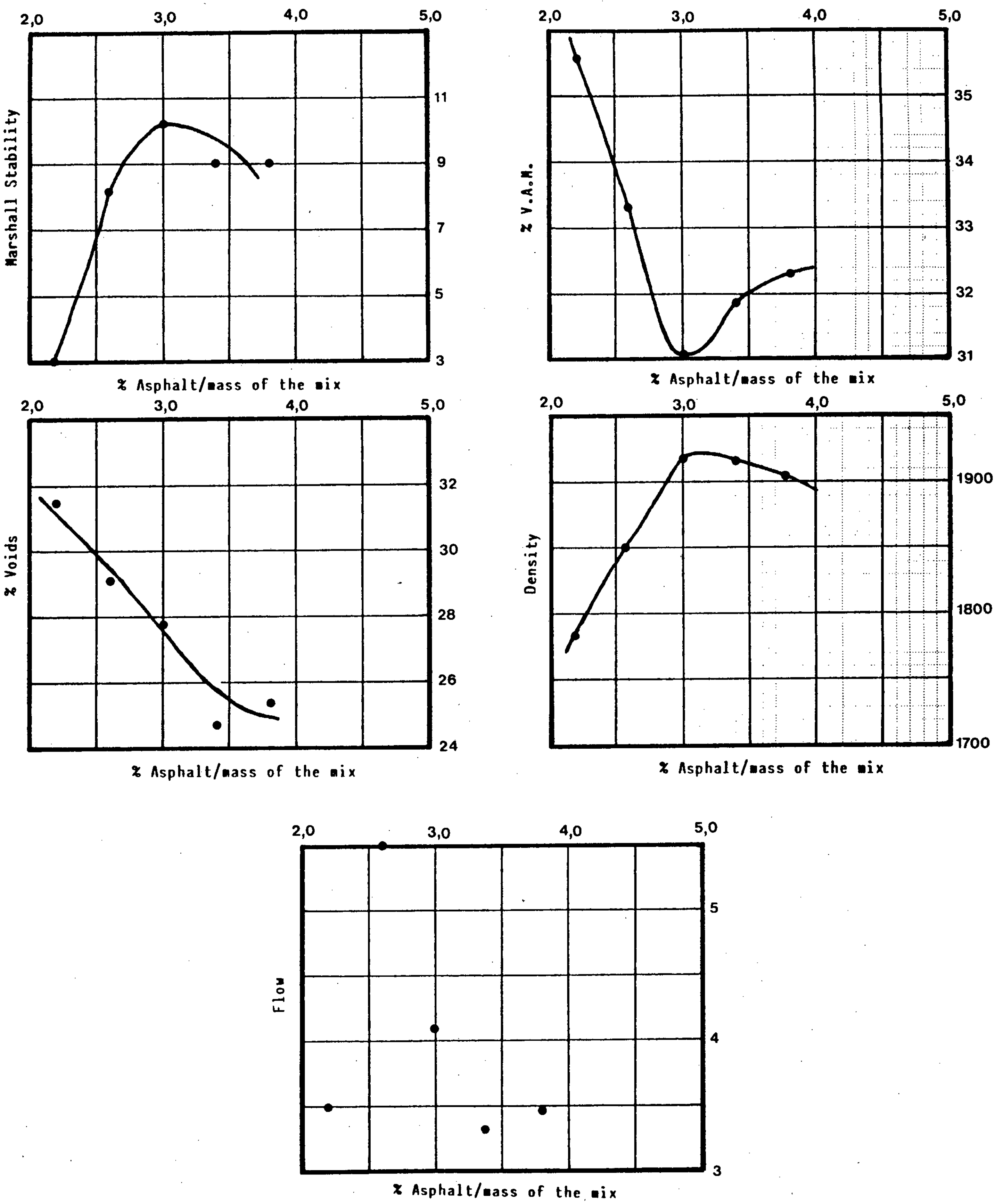


FIGURE 12

SUPERIOR GRADING

(VIBRATED BRIQUETTES Ø 152,4)

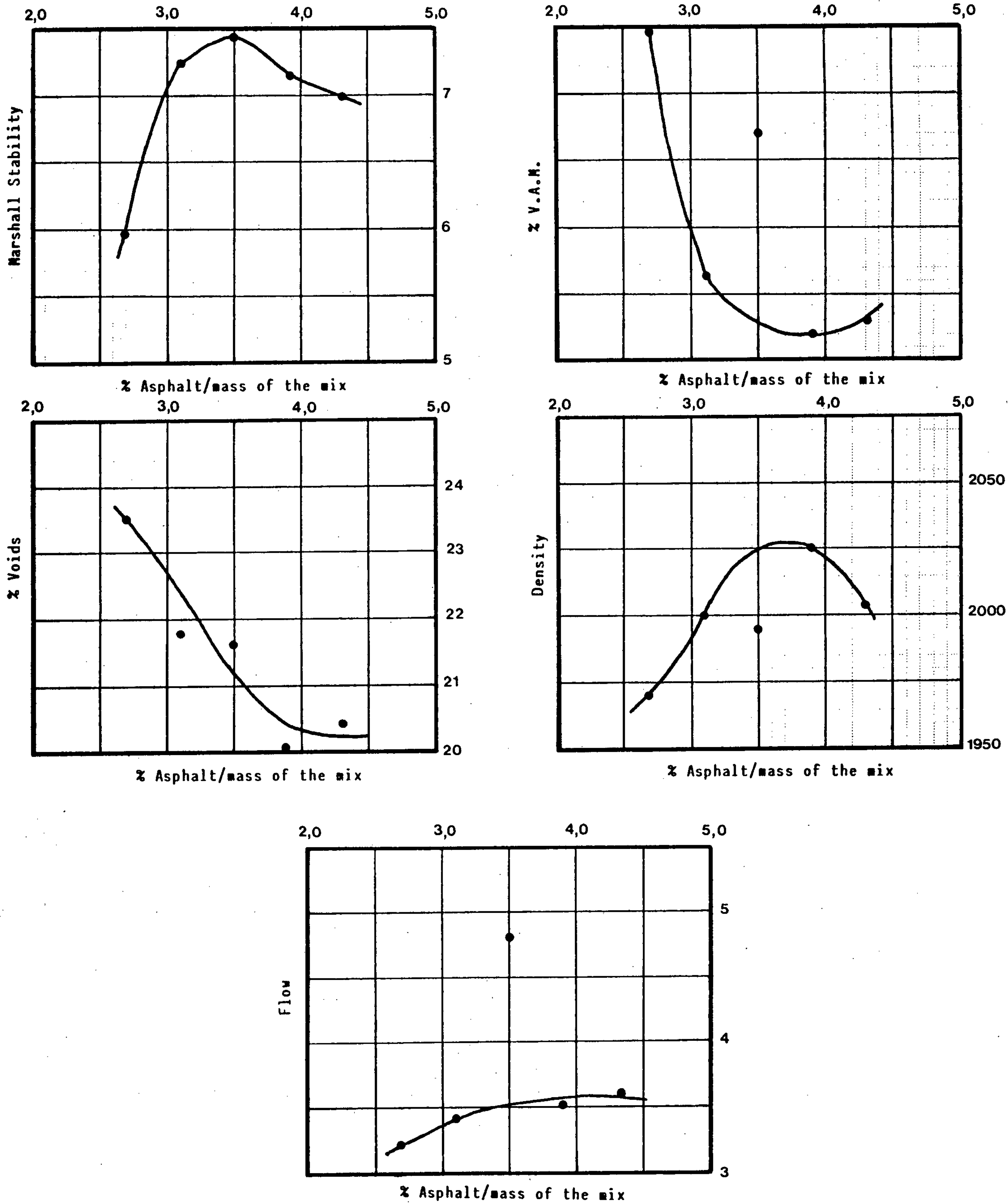
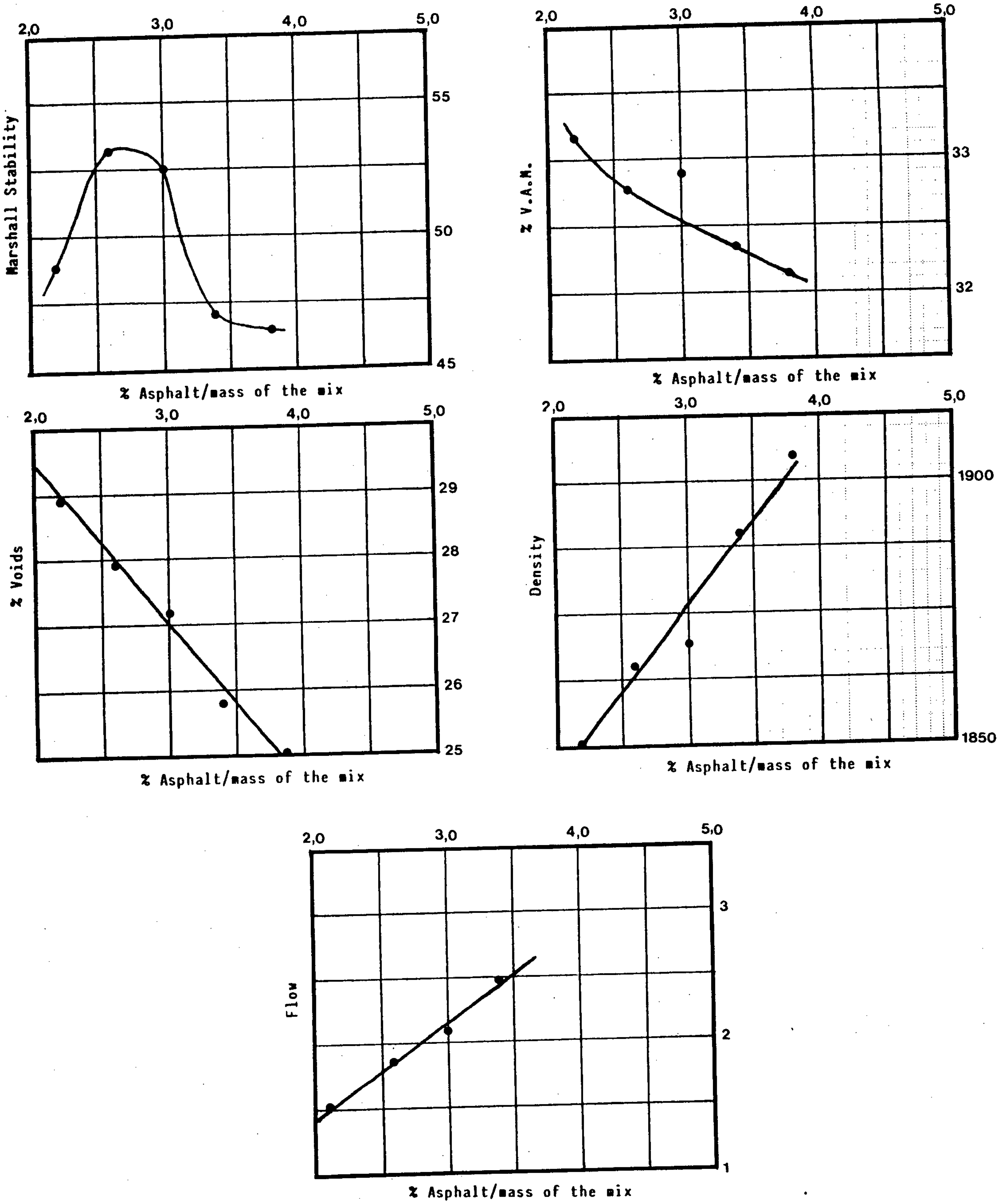


FIGURE 13

MEDIAN GRADING

(VIBRATED BRIQUETTES Ø 101,6 MM)



DIAMETER OF THE BRIQUETTES: 152,4 MM

1. SUPERIOR GRADING
2. MEDIAN GRADING
3. INFERIOR GRADING

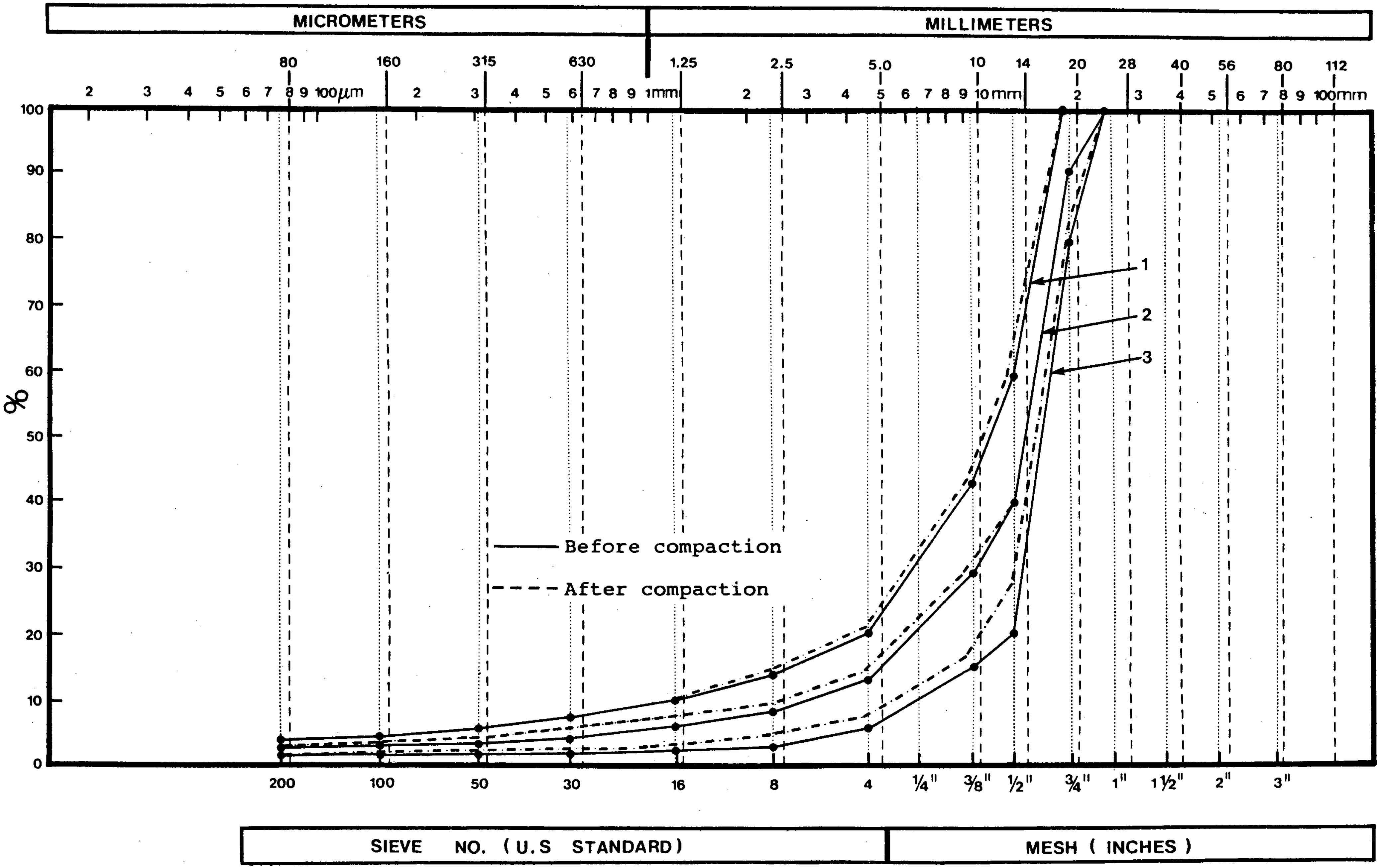


FIGURE 15

MA[redacted]HAL[redacted]OMP[redacted]IO[redacted]EF[redacted]T O[redacted]GGR[redacted]ATE[redacted]RAD[redacted]ON

DIAMETER OF THE BRIQUETTES: 101,6 MM

1. SUPERIOR GRADING
2. MEDIAN GRADING
3. INFERIOR GRADING

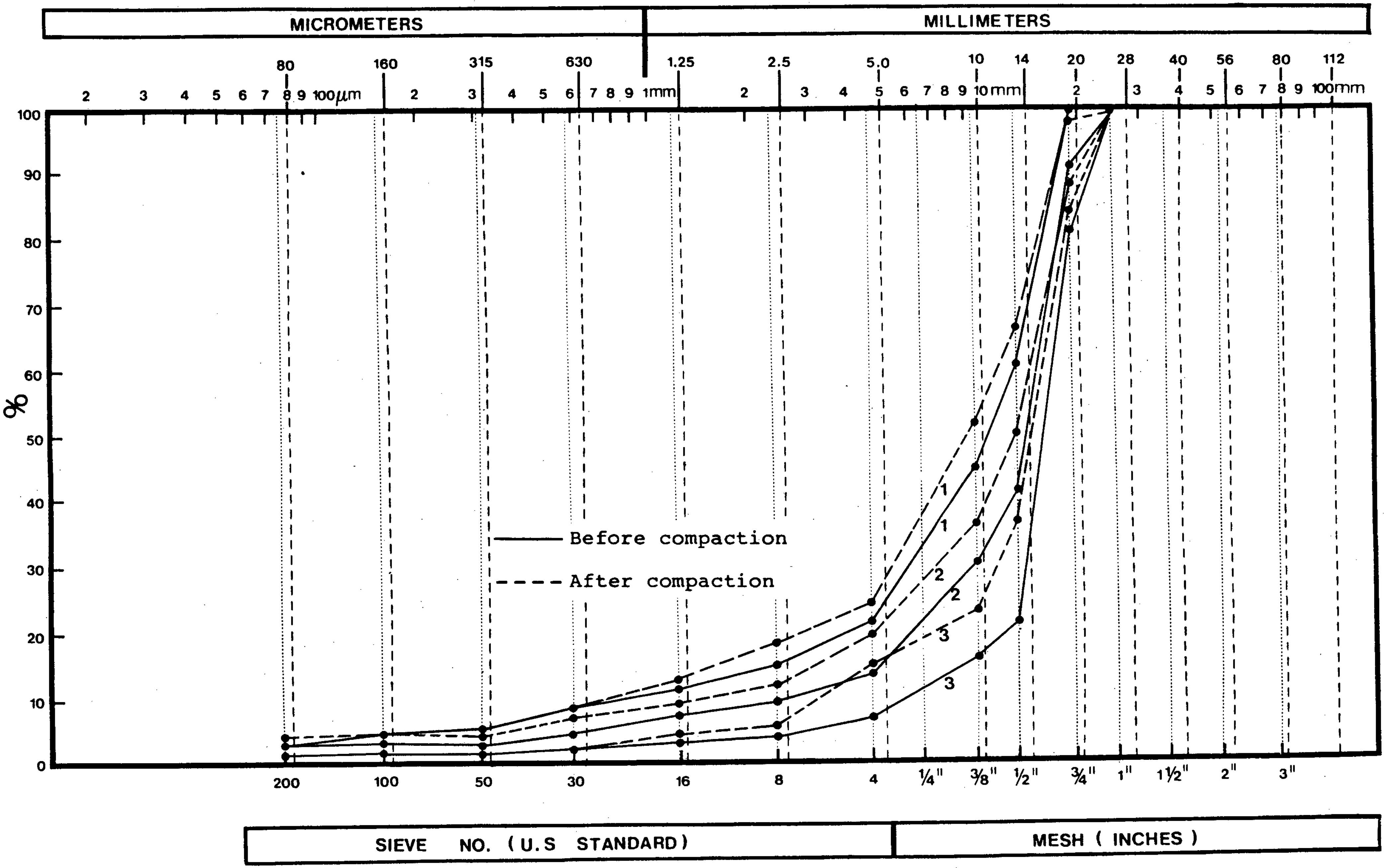
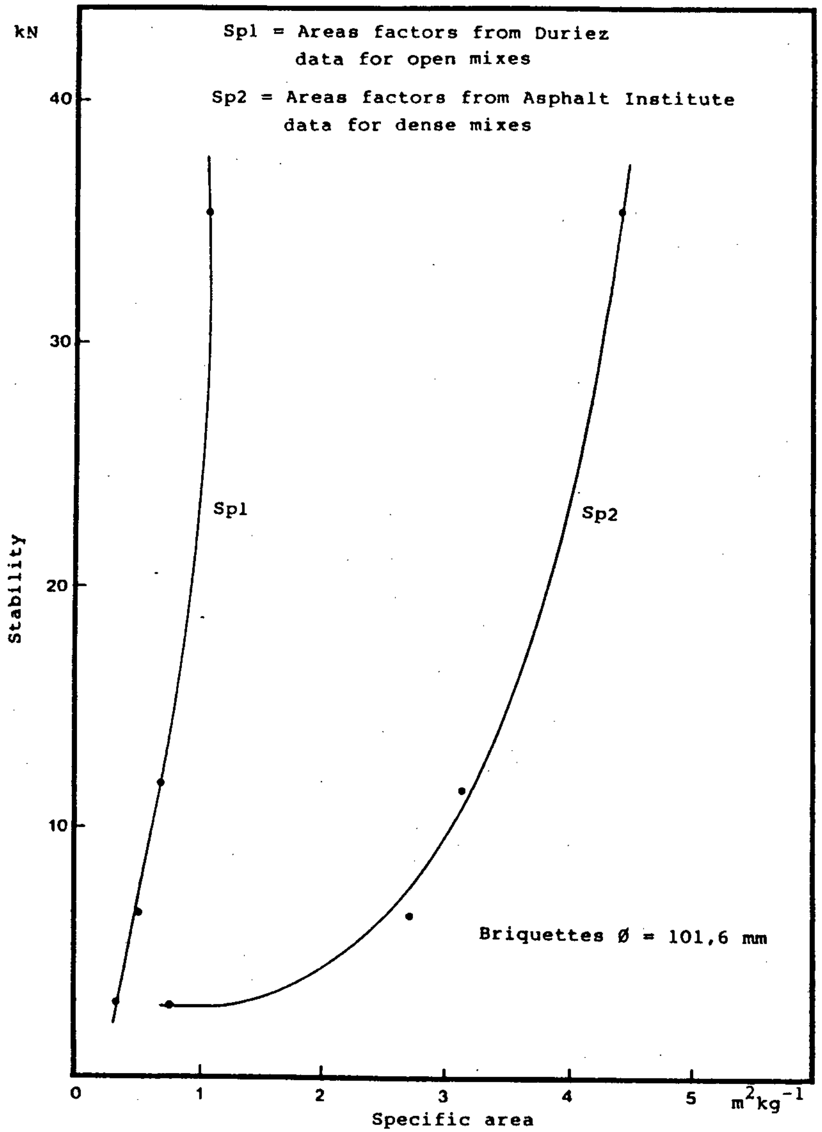
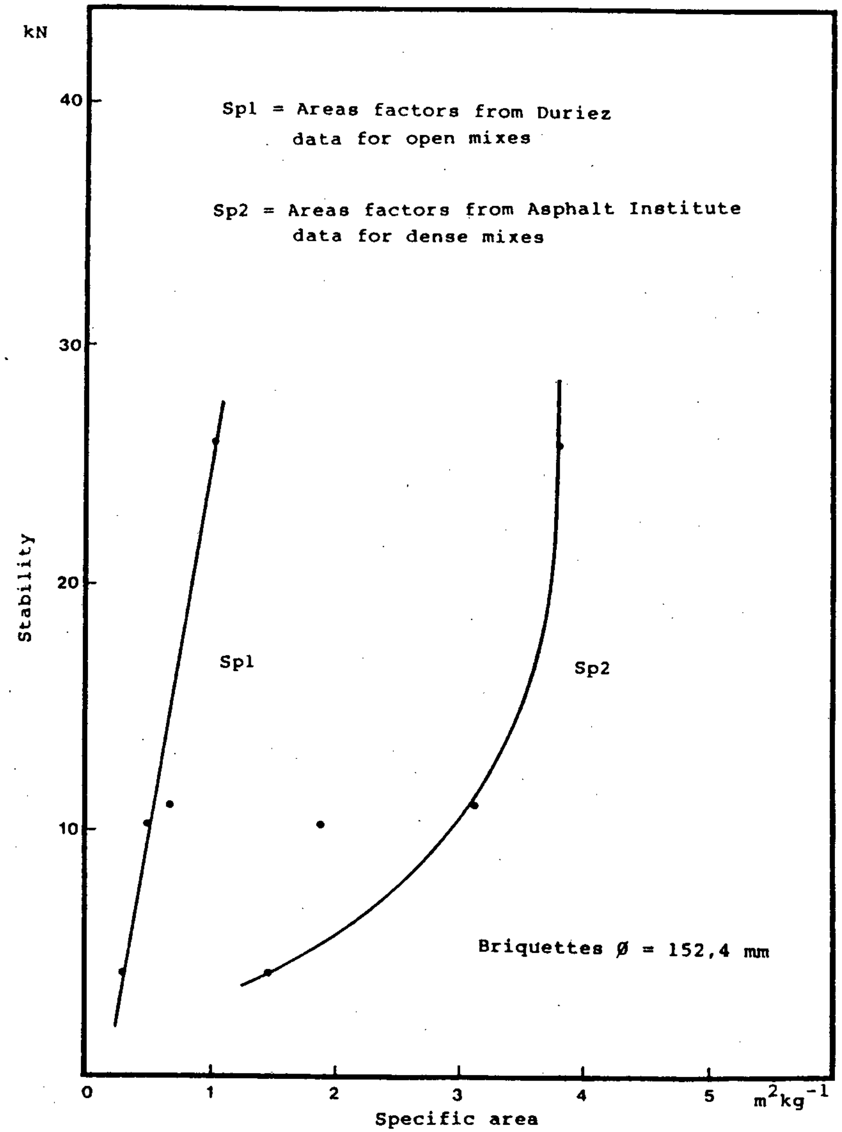


FIGURE 16



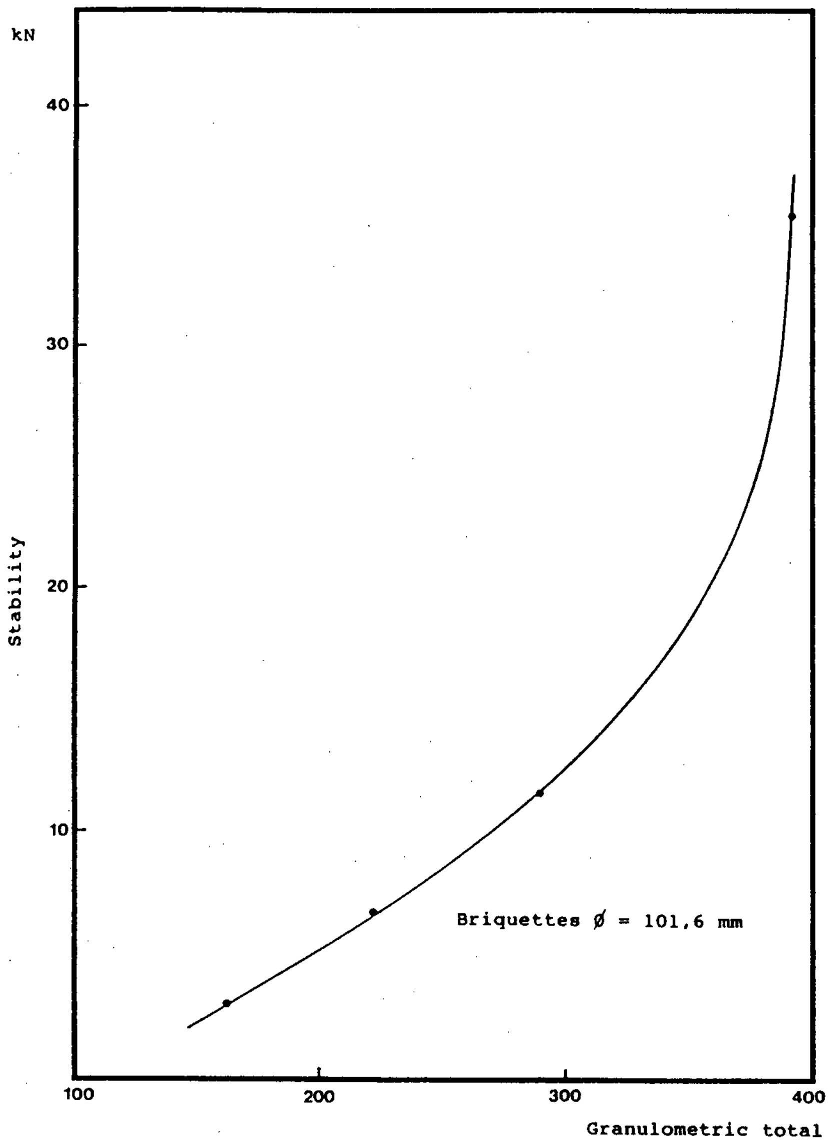
STABILITY VERSUS SPECIFIC AREAS OF MIXES

FIGURE 17



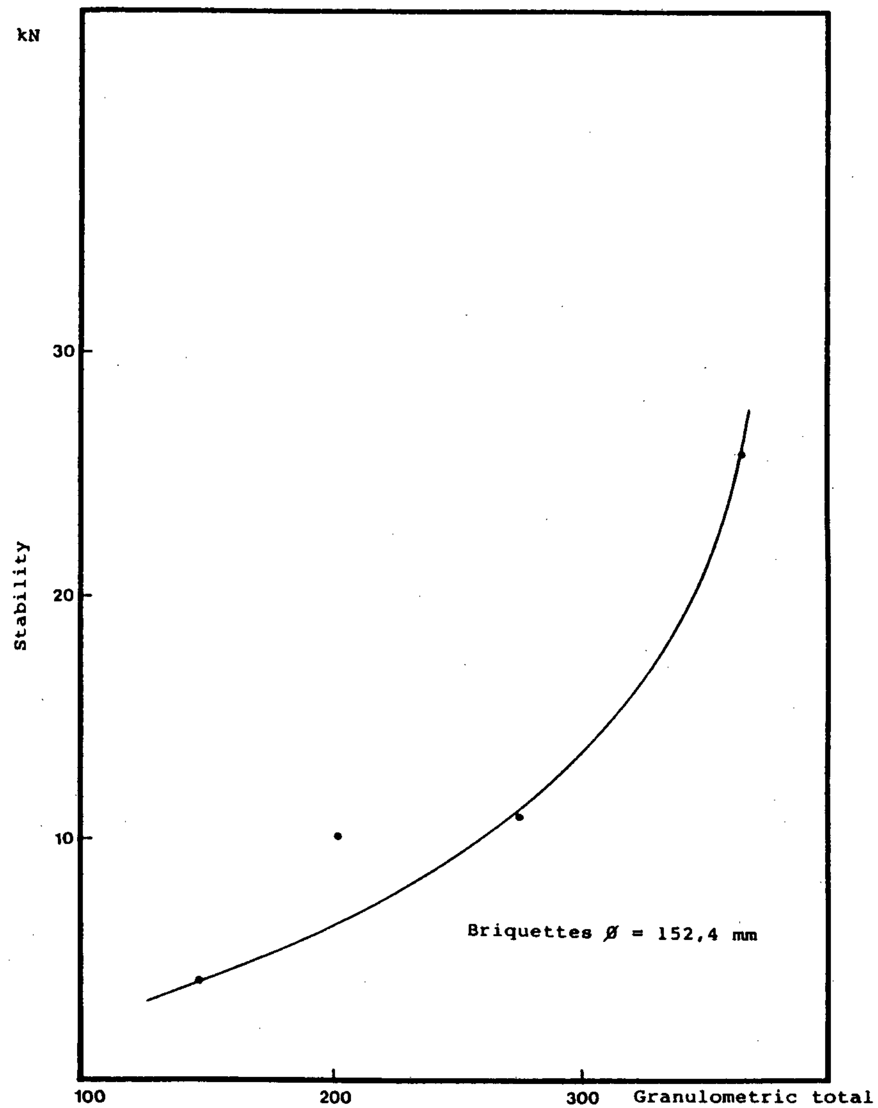
STABILITY VERSUS SPECIFIC AREAS OF MIXES

FIGURE 18



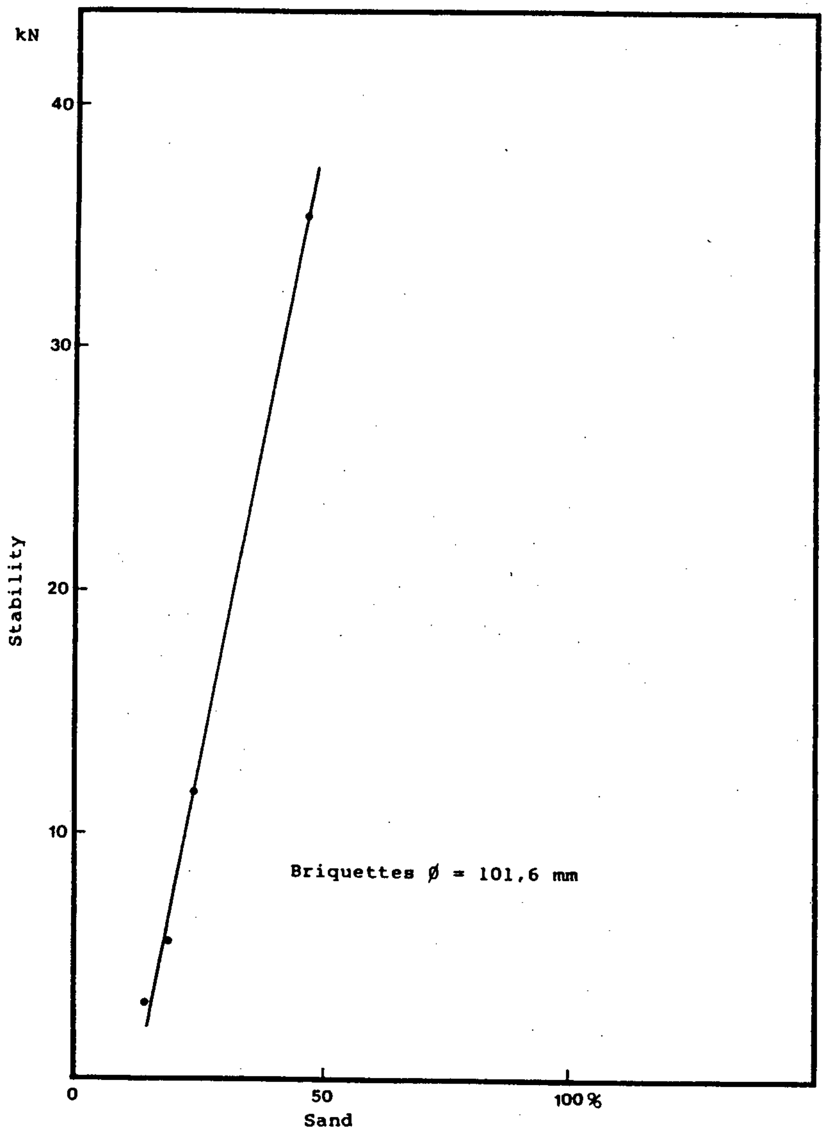
STABILITY VERSUS GRANULOMETRIC TOTAL

FIGURE 19



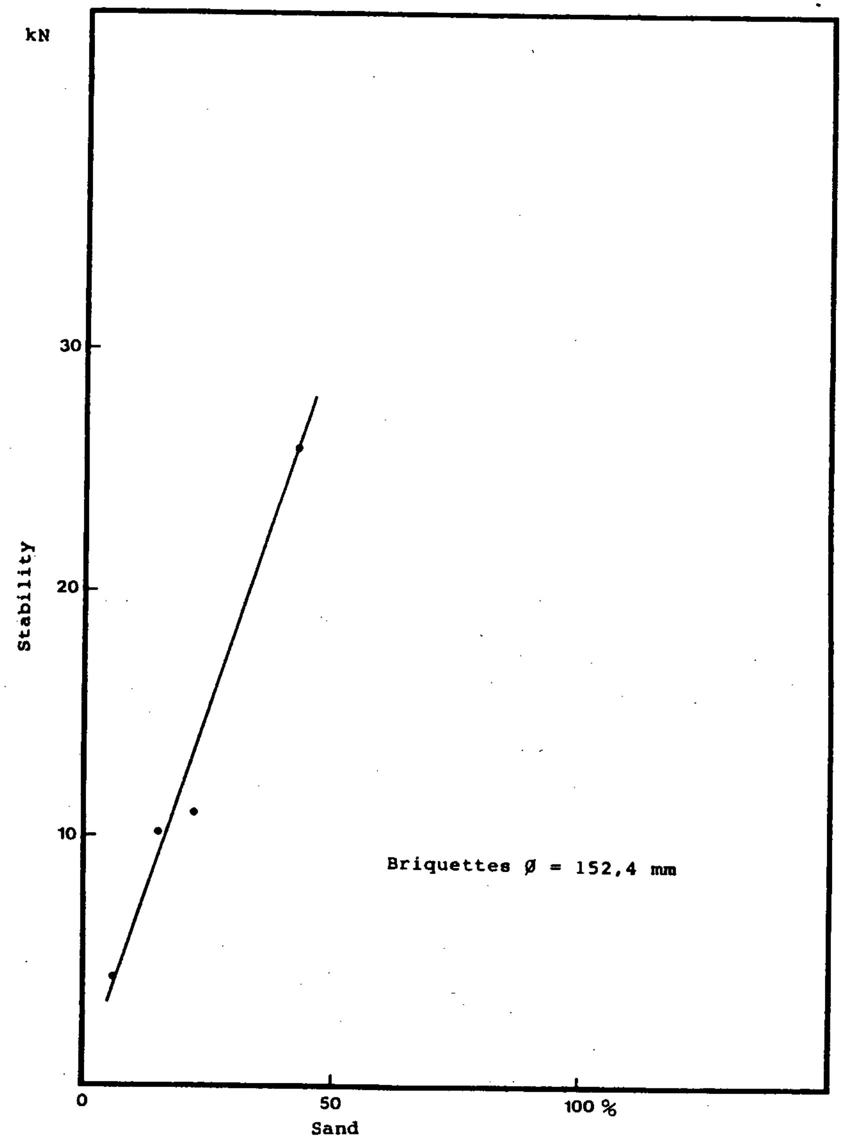
STABILITY VERSUS GRANULOMETRIC TOTAL

FIGURE 20



STABILITY VERSUS PERCENTAGE OF SAND

FIGURE 21



STABILITY VERSUS PERCENTAGE OF SAND