On Pluvial Compaction of Sand

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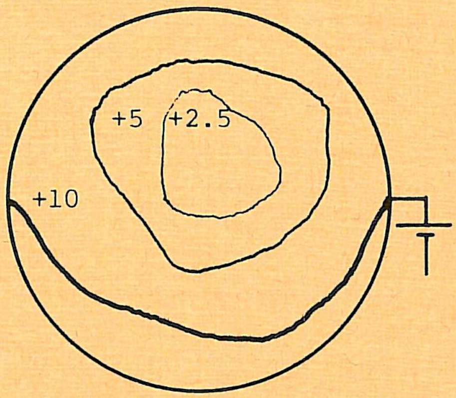

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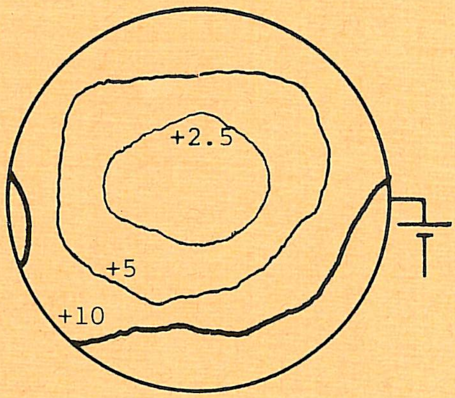

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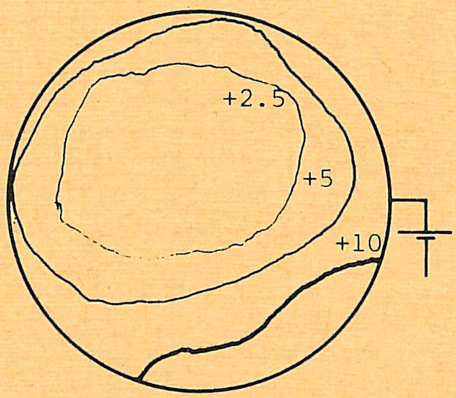

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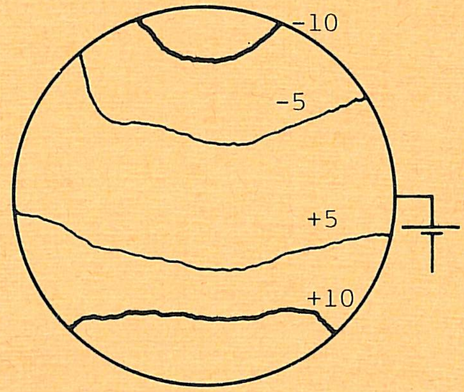

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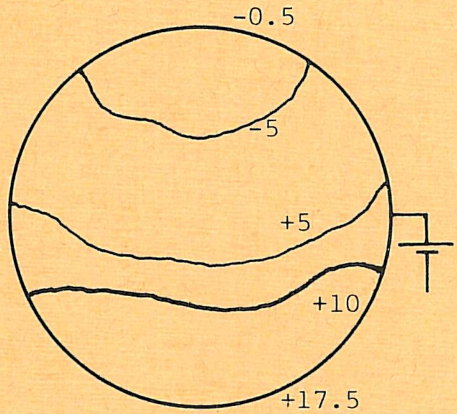

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Institute of Civil Engineering
Aalborg Universitetscenter

Rapport
no 9
Febr. 76

ON PLUVIAL COMPACTION OF SAND

Moust Jacobsen

ON PLUVIAL COMPACTION OF SAND

At the Institute of Civil Engineering in Aalborg model tests on dry sand specimens have been carried out during the last five years. To reduce deviations in test results, the sand laying technique has been carefully studied, and a sand mass spreader constructed. Preliminary results have been mentioned at the "Nordisk Geoteknikermøde 1975" in Copenhagen.

Although the sand specimen had a thickness of only 40 cm, the Norwegian Geotechnical Institute asked us to investigate the possibility of producing a homogeneous sand specimen of a height of about 2 m in a continuous process to be used in a calibration chamber for penetrometers for off-shore investigations.

The sand laying technique is the well known pluvial compaction method. The bottom plate of the sand rainer has the same shape and size as that of the sand specimen. If the sand rain has been stable and uniform a plane, horizontal sand surface indicates a homogeneous sand specimen. The first requirement is therefore that the vertical difference between the highest and the lowest point of the sand surface should not exceed 5 - 10 cm.

The present report deals with this problem, which has been solved in co-operation with James Holden of NGI. It contains an analysis of the sand rain technique based on 50 tests performed under different circumstances. Finally it leads to the construction of a provisional mechanism, which nearly fulfils the above mentioned condition, and may form the basis of a sand mass spreader at NGI. Most of the tests have been performed at a relative density of 0.9, but two tests at a relative density of 0.2 seem to show, that the pluvial compaction technique can be used to produce very loose sand specimens as well.

PROPERTIES OF BLOKHUS-SAND

Blokhus-sand is a fine grained, marin deposit with rounded grains (d_{50} = 0.17 mm). The specific gravity of the grains is 2.65. The extreme void ratios are e_{max} = 0.79 and e_{min} = 0.53 (on dry sand).

The salt content is very small (6.5 mg Cl^- per kg. sand).

The grain distribution curve is shown in Fig. 1.

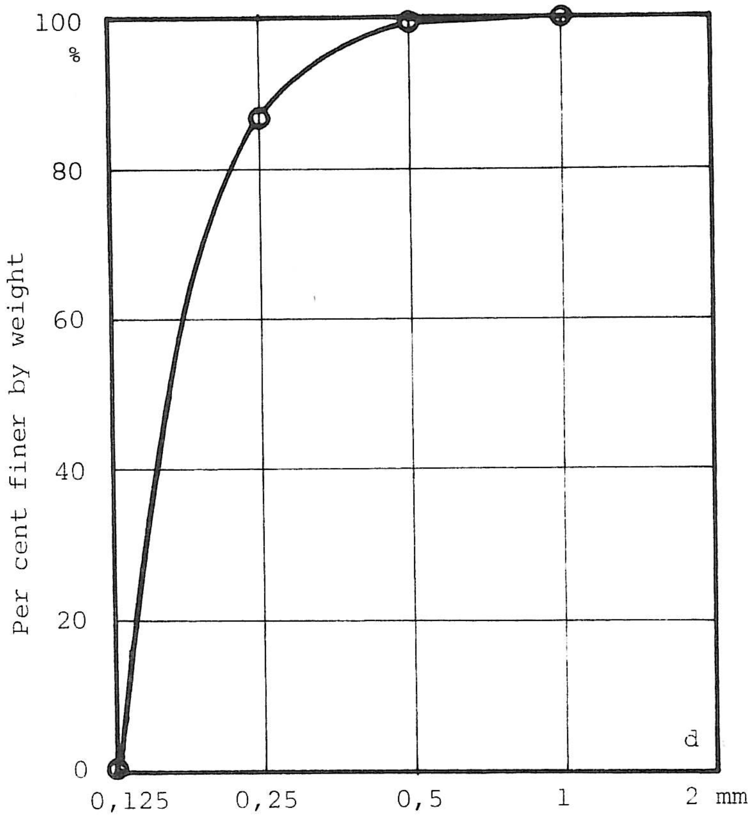


Fig. 1 Grain size distribution of Blokhus Sand

THE AUC MASS SAND SPREADER

In the tests described in paper [3], a very cheap mass sand spreader was used. The new sand spreader is based on our experience from these test series, but has never been used before. It is constructed with the purpose of filling a concrete sand box (L•B•H < 150•90•100 cm) with dense sand, homogeneously distributed. It consists of a sand silo big enough to fill the sand box in a continuous operation and implies the sand rain to be so uniform, that there is no need to level the sand surface during the laying. The bottom plate of the sand silo is a thin steel plate supported by ribs and perforated by 7 mm drilled holes in a quadratic 8 cm pattern, yielding a porosity of 0.6 per cent. The supporting ribs are placed on the upper side of the bottom plate between two rows of holes. A shutter plate is placed 2 cm below the bottom plate and perforated in exactly the same way. During the opening- or closing procedure, which takes 10 sec, it is moved 4 cm. The shutter system is not sensitive to sand dust.

10 cm underneath the shutter plate a sand diffuser is placed, consisting of two steel sieves (mesh width 2 mm, distance between sieves 5 cm) stretched out by a frame.

The pluvial compaction was planned to be at a falling height varying from 1.2 to 0.2 m, but in practice only 0.7 m to 0.3 m were used. If the sieves are not totally plane, or not placed exactly in position the sand surface will not be even. We had planned to close some of the holes until a perfect sand surface was achieved. But - of course - the very serious requirement from the NGI forced us to find a better way to do it.

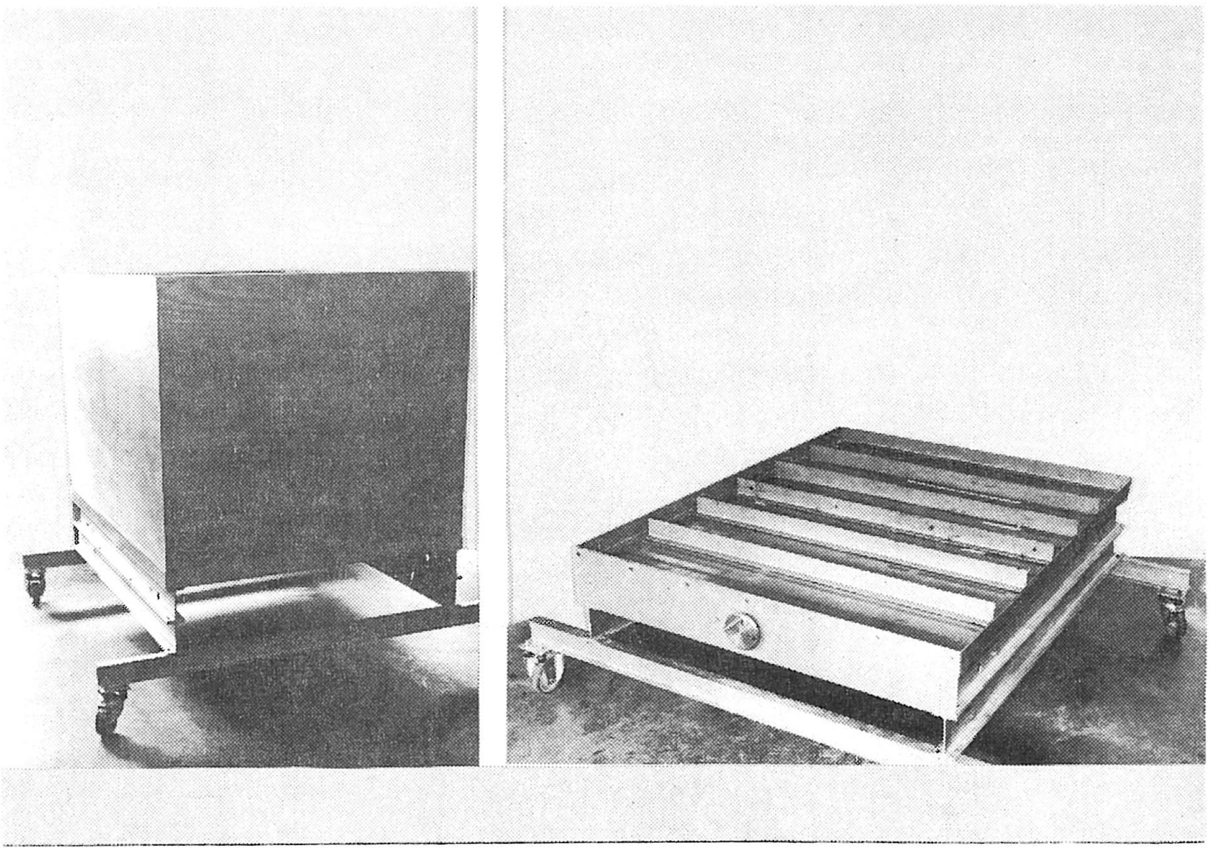


Fig. 2 The AUC sand mass spreader

THE TEST EQUIPMENT

The test equipment consists of the mass sand spreader standing on top of a timber construction 3.5 m above the floor and a specimen cylinder 80 cm in diameter and 2.5 m in height placed on the timber construction 0.7 m above the floor. The cylinder comprises three sections of steel 1 m, 0.5 m and 0.5 m high respectively and an observation cylinder 0.5 m high, made of perspex. The gap between the cylinder and the mass sand spreader was at the beginning closed by a cardboard screen to prevent dust from coming out into the laboratory.

To remove the sand a shutter mechanism in the bottom of the cylinder was used. The sand runned down in buckets and was lifted up into the silo by a crane.

After the test the sand surface levels were determined and a map was drawn showing the topography of the surface. In the last part of this report most of the tests are described.

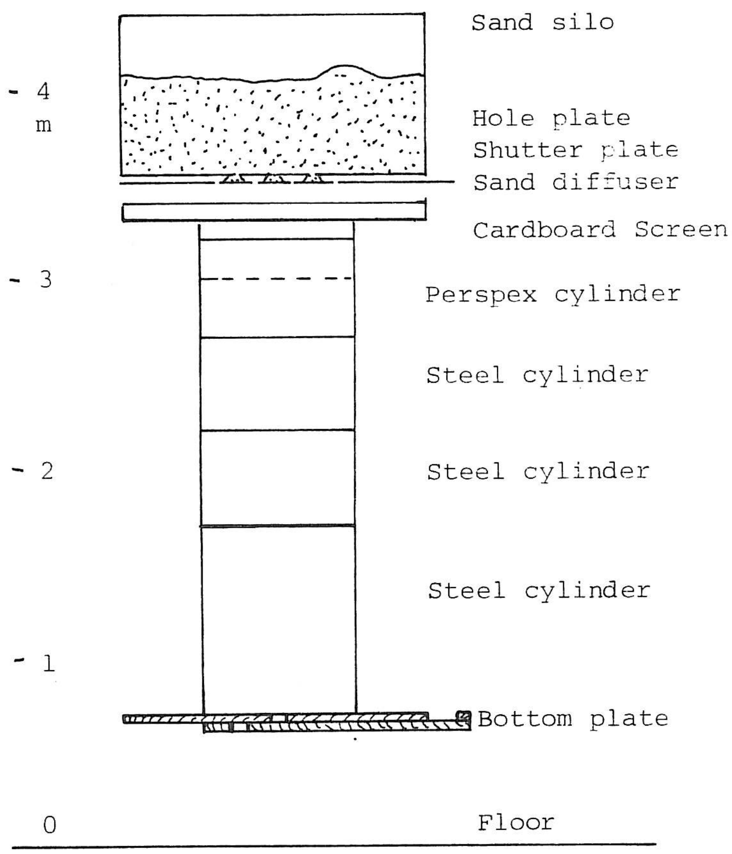


Fig. 3 Sketch of test equipment

ANALYSIS OF THE SAND RAIN MECHANISM

The pluvial compaction technique is based on the assumption, that a body falling through water or air accelerates until a final state is attained in which the resistance against the motion

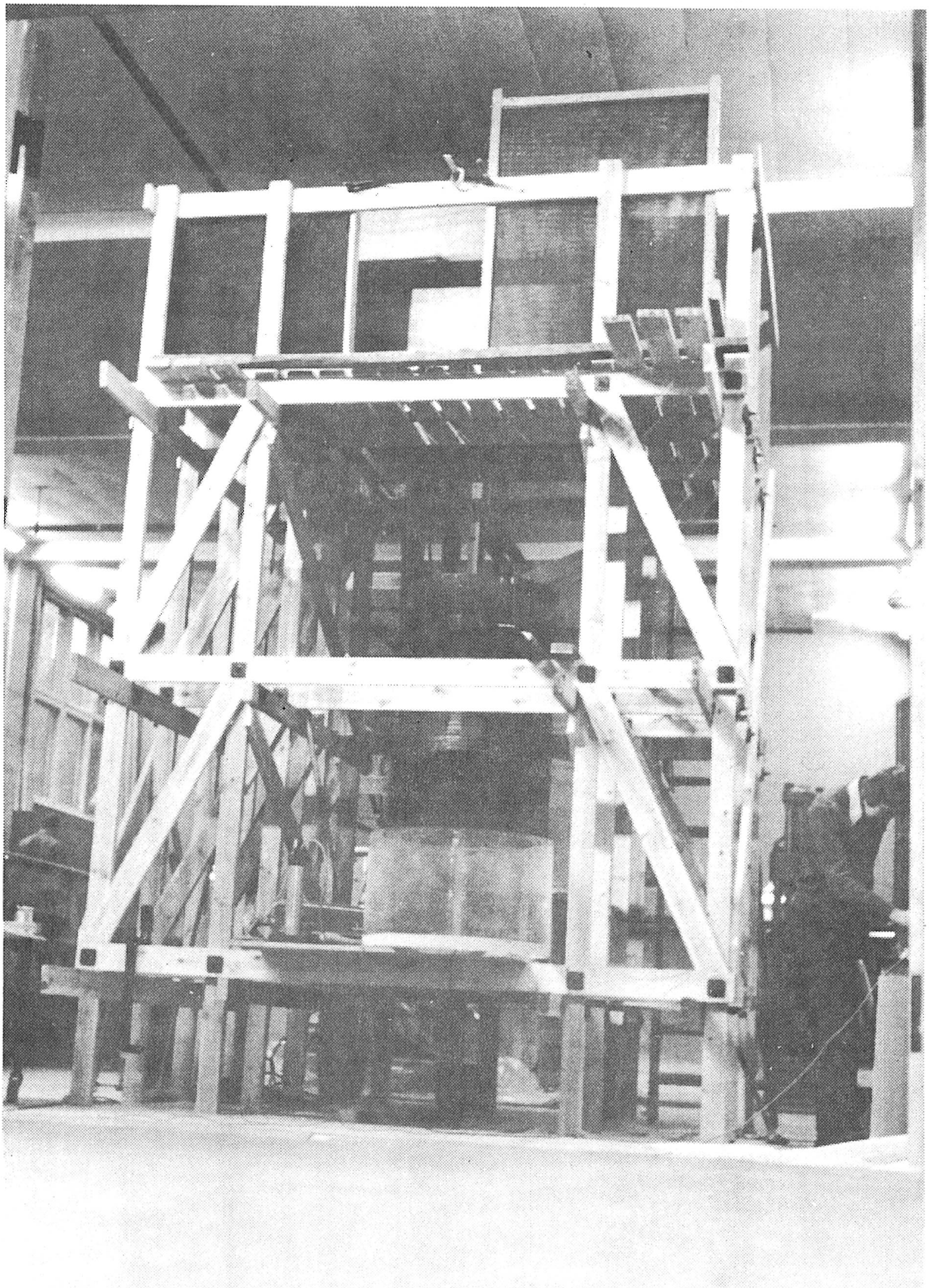


Fig. 4 Test equipment

balances the gravitational force. This is extended to be valid not only for a sand grain, but for a uniformly distributed sand rain. It means that after a certain fall length, the sand flow may have reached a nearly constant velocity, resulting in a homogeneous compaction of the sand. The fall height corresponding to a grain velocity of 98% of the equilibrium velocity is called the critical fall height. It is proportional to the square of the grain diameter.

In the paper presented at NGM 75 [3] we showed that this method could give a nearly constant dry density at fall heights exceeding 20 cm corresponding to 50% og the critical fall height. If the fall height exceeded 60 cm, the sand flow got unstable and the void ratio increased. In the new test series the sand rain got even more unstable.

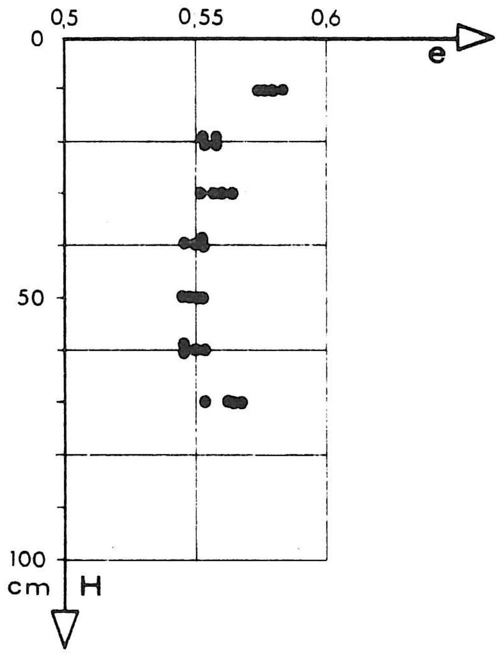


Fig. 5 Void ratio versus fall height

By means of the perspex cylinder it was possible to observe the sand rain. It appeared, that the air flow differed considerably from the flow corresponding to local displacement of air by sand. The air was swept downwards at

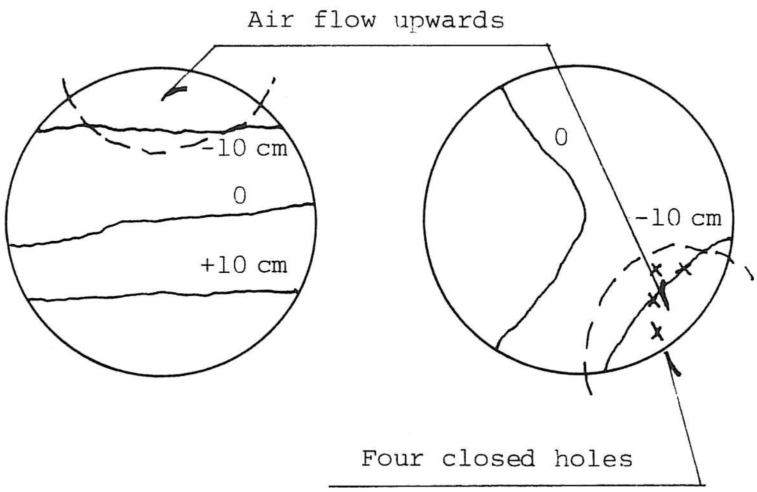


Fig. 6 The effect of closed holes

nearly the same velocity as that of the grains, and had to escape up through areas with less dense sand flow thus creating for a shorter or longer time a channel of air. Test no 5 shows that if only a few holes are closed, the sand surface alters completely (Fig. 6).

The first 30 tests showed that it might be possible to obtain an even sand surface in an unstable sand flow. This however would be unsatisfactory, because an even sand surface does not ensure the sand specimen to be homogeneous. The unstable flow might produce an even sand surface, but with unacceptable variations in the dry density.

If the fall height is reduced to 20 - 40 cm (Fig. 5) a uniform sand rain is observed, instead of a fluttering air and sand flow (test no 30). The problem could then in principle - but not in practice - be solved by placing the sand silo 30 cm above the sand surface and elevate it gradually during the test.

A better way would be to place the diffuser at a fixed height above the sand surface and let the sand fall in sand jets the first 2 m. As shown in the first 9 tests it is possible to avoid great velocities of the air flow, when the sand grains are concentrated in thin sand jets. The sand jets have to fall vertically when leaving the hole plate, and the sand must be absolutely clean. If a sand jet is partially prevented from running out of the hole, the sand jet will be "fat", the resistance from the air will spread it and the sand grains get absorbed in the other sand jets. We have seen, that a "fat" sand jet never reached the diffuser.

The main problem - the unstable sand flow - can therefore be solved, by letting thin sand jets fall 2 to 2.5 m and then be diffused by a system of sieves placed at a fixed height above the sand surface. The diffuser should then be lifted up continuously as the sand specimen grows. Or the diffuser may be lifted in steps, because a variation in fall height of 10 cm does not influence the density of the sand. (Fig. 5).

The best result obtained in the present test series is no 41 (shown on page 18). The AUC mass sand spreader is constructed for rectangular specimens and therefore the quadratic hole pattern does not fit the circular shape, especially along the boundaries. (Nor does a triangular pattern). A proposed circular hole pattern is shown in Fig. 11.

Most of the tests have been performed by means of a perforated plate with a porosity of 0.6 per cent as already mentioned in page 2. A 1 m high specimen of dense sand (I_D = 0.9) was then produced in twenty minutes.

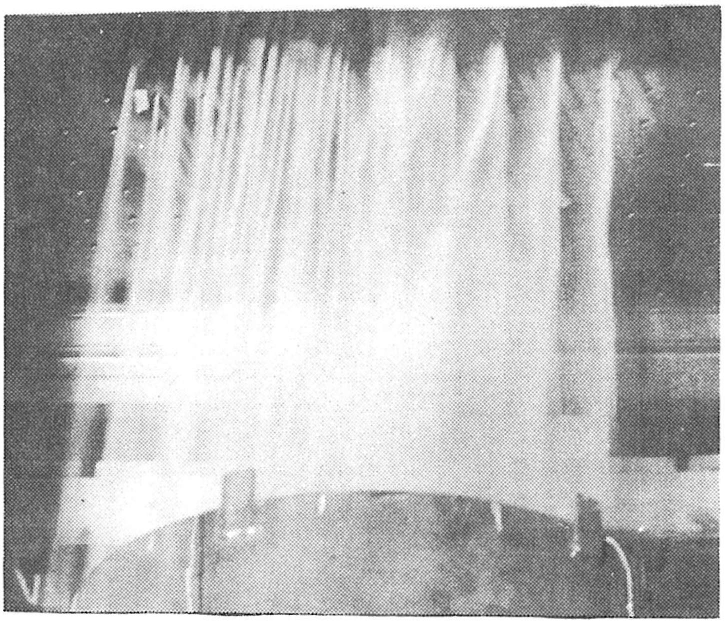


Fig. 7 Fat sand jets

In three tests a perforated plate with 20 mm holes in a quadratic 8 cm pattern was used (Fig. 9). A 1 m high specimen of very loose sand (I_D = 0.2) was produced in one minute. The sand might not have been perfectly clean. Even nails and screws fell through the perforations in the plate!

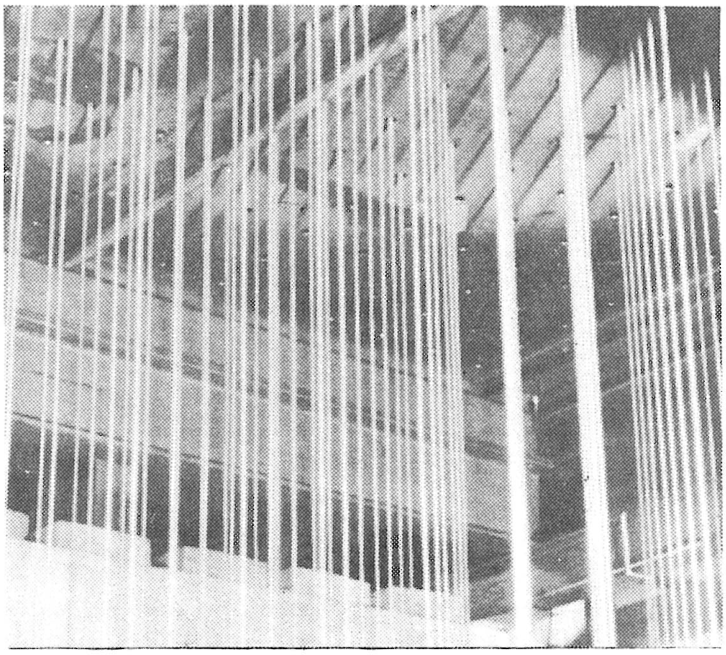


Fig. 8 Thin sand jets

The void ratio was measured by means of the socalled vacuum cleaner method used at DGI

[4] during many years. This method requires a very high degree of carefulness to give satisfactory results. With the new sand laying technique a better method has to be developed. The void ratio measurements are shown in Fig.10. The variations in dry density are 0.8 - 1.2 per cent.

CONCLUSION

The main result of our investigation on the pluvial compaction of sand is, that when using a sand mass spreader like that shown in Fig. 11, it is possible to produce a 1 m high sand specimen with a variation in dry density less than 1 per cent and with relative density I_D ranging from 0.2 to 0.9. We also believe, that it should be possible to produce 2 m high sand specimens since the difference between highest and lowest point in the best test made in the present test series (no 41) is only 2.5 cm (except for the boundaries). The dry density can

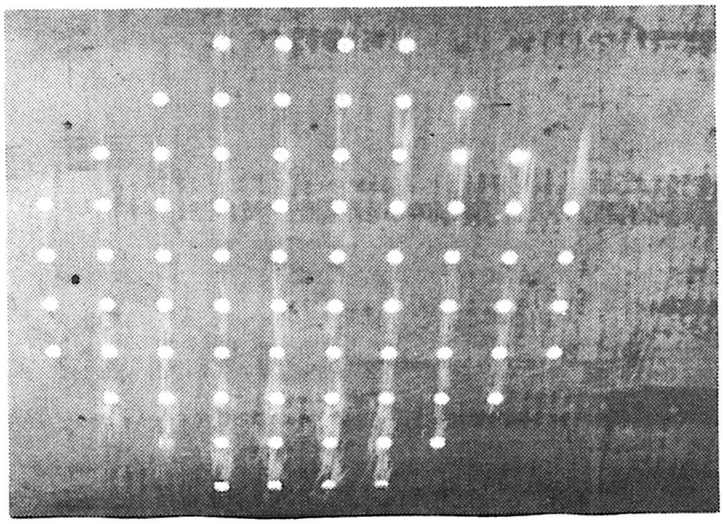


Fig. 9 Hole plate for loose sand specimens

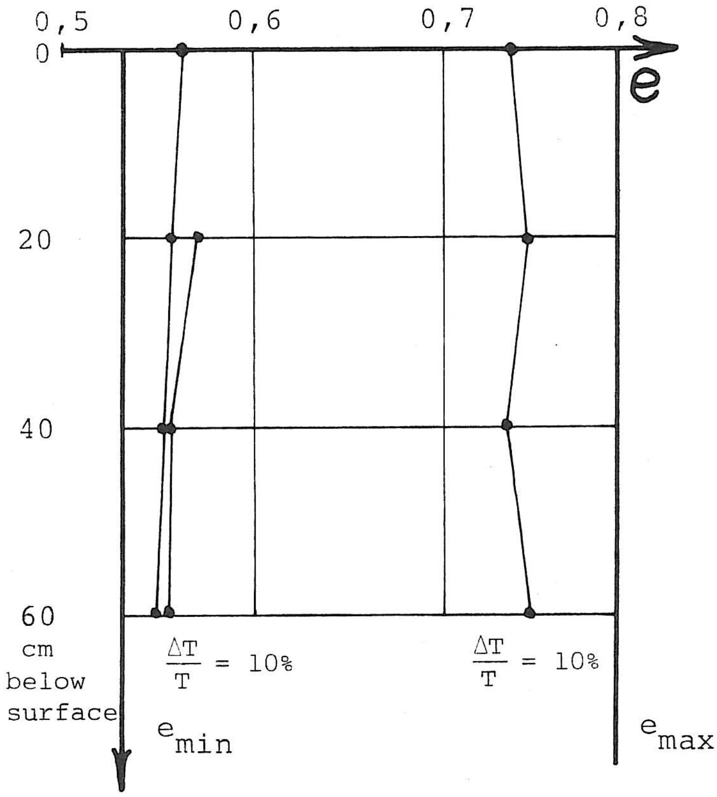


Fig. 10 Void ratio variations

be varied by changing the perforated plate. The shutter plate is proposed to be a steel plate, which can be totally removed in a few seconds. This is at least necessary when very loose sand specimens are to be produced.

Further observations have been made and are mentioned in the appendix. These results are of some importance for the detailed construction of a sand mass spreader.

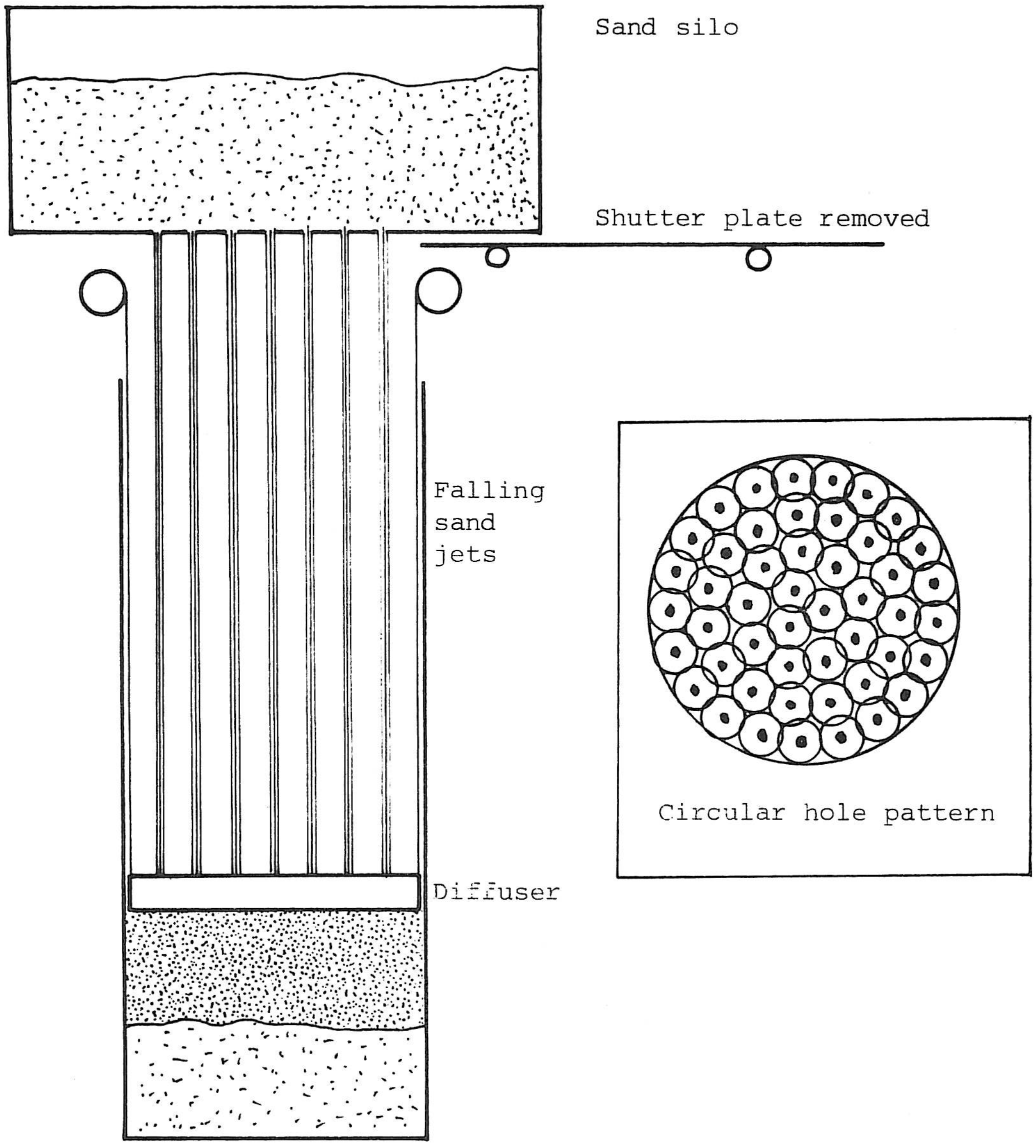


Fig. 11 Proposed sand mass spreader

LITTERATURE

[1] Bieganousky, W.A.: Uniform Placement of Sand. Report.

[2] Chapman, G.A.: A Calibration Chamber for Field Test Equipment.
ESOPT Eur. symp. on pen.testing
Stockholm 1974.

[3] Jacobsen, Moust, Jørgensen, M.B., Serup Poulsen, H.:
Sands Styrke.
Proc. NGM 75, Kbh. 1975.

[4] Tejchmann, Andrzej: Skin Friction of a Model Pile Driven in Sand.
Danish Geot. Inst. Bull. no 29.

Fig. 12 View of the sand surface (with levelling points)

APPENDIX

Additional observations.

1. The perforated bottom plate of the sand silo is supported by ribs, which can be placed very close to the holes without influencing the sand jets. The thickness of the sand layer in the silo is not important, but of course the holes must be full running.

2. The holes in the bottom plate must have the same diameter to prevent variations in sand flow. The best solution is to use bushes in the holes, because turned holes can be made more accurate than drilled holes.

3. The diffuser consisted in the present tests of two sieves, but the number must be increased to avoid getting the hole pattern on the sand surface. The top sieve should be horizontal and perfectly plane, whereas it seems to be of minor importance for the other sieves. The sieves should be rotated 45^{o} relatively to each other to get a uniform Moiré-pattern, showing a uniform permeability of the diffuser.

4. Static electricity on the perspex cylinder or on the rubber lining does not seem to have any influence, although we had great problems at that point, when our first mass sand spreader was constructed.

5. Draughts in the laboratory does not seem to be of any importance. It is not necessary to make the cylinder air proof or to protect the falling sand jets by screens.

Tests without diffuser

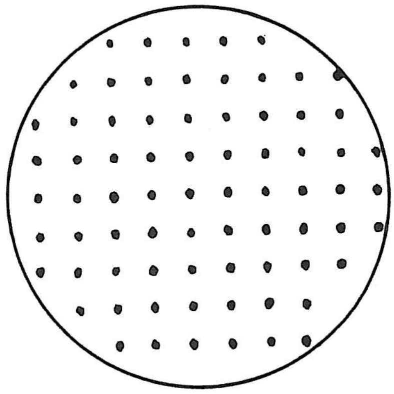
Levels are cm.

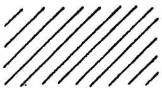
Test no 1 - 5.

Analysis of the air flow.

The unstable air flow changes completely, when some of the holes stop.

Hole pattern no 1

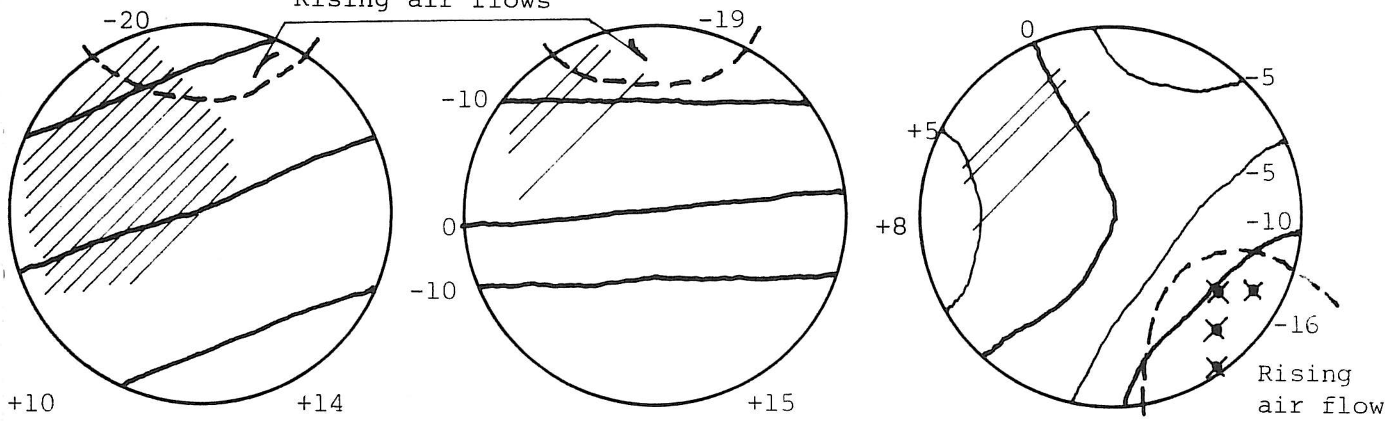




Fat sand jets

Stopped holes

Test no 3 — Rising air flows — Test no 4 — Test no 5



Test no 6 - 9.

Test no 6: Symmetrical hole pattern.

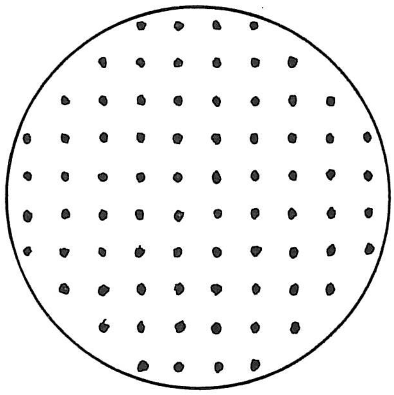
Test no 7: Repetition, but earthed.

Test no 8: Gap between testcylinders tightened.

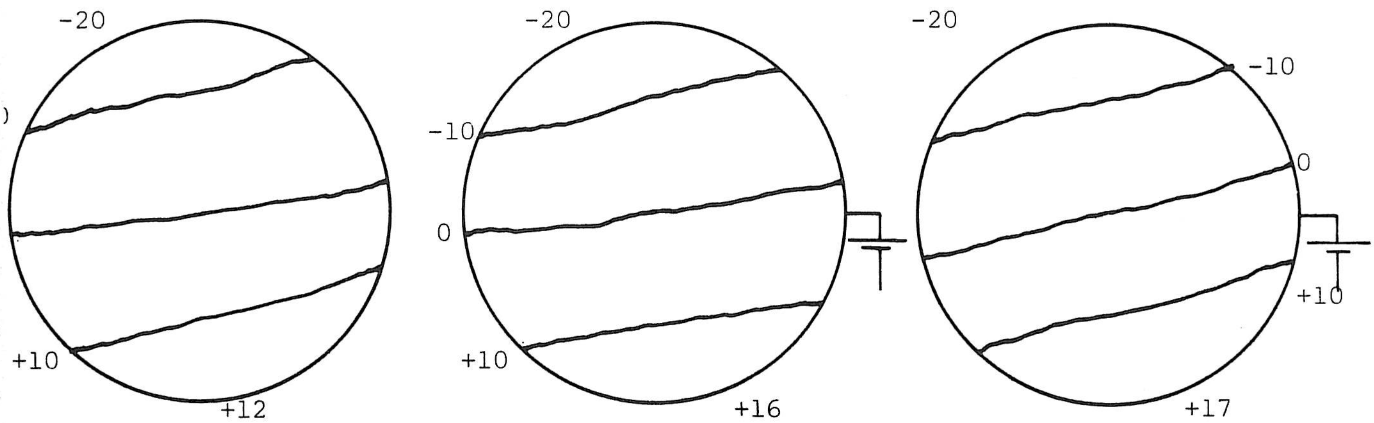
Test no 9: One of the steel cylinders rotated.

No effect of these variations in test conditions can be observed.

Hole pattern no 3



Test no 6 — Test no 7 — Test no 8 and 9



Tests with horizontale, plane diffuser, placed 10 cm below the shutter.

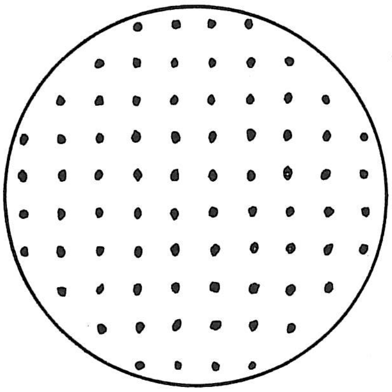
The effect of different hole patterns.

It is seen, that the diffuser has a favourable effect.

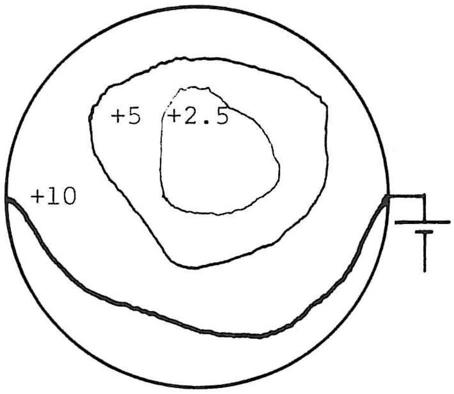
Hole pattern no 4 seems to be the best one and is used in test no 35 - 50.

Hole pattern no 5 is used in test no 13 - 33.

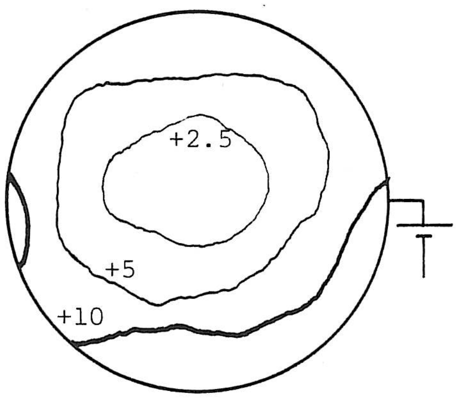
Hole pattern no 3



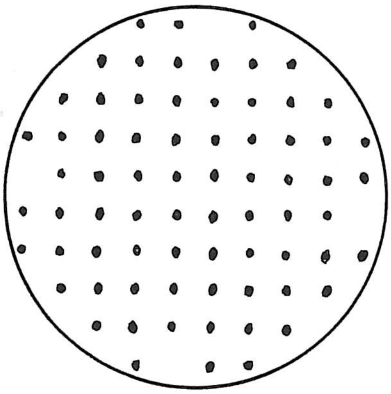
Test no 10



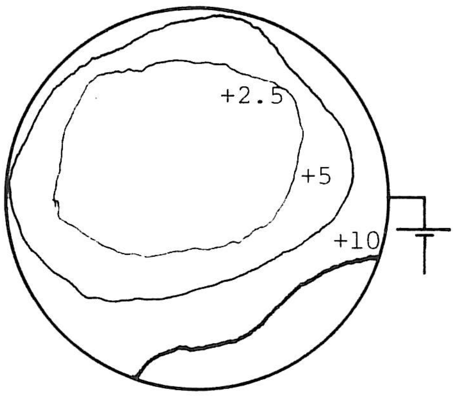
Test no 11



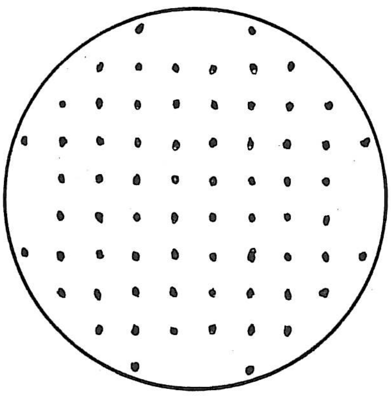
Hole pattern no 4



Test no 12



Hole pattern no 5



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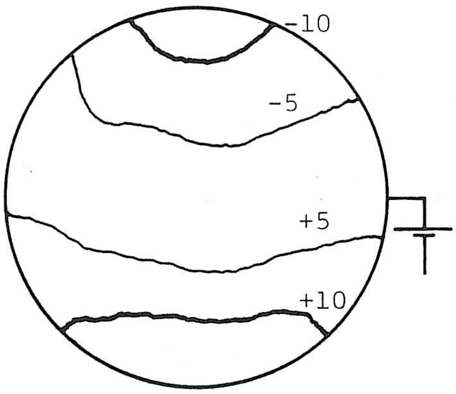

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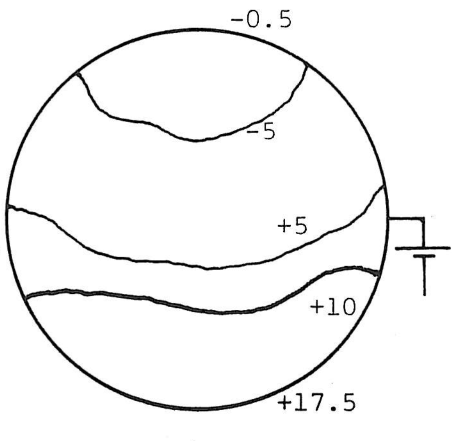
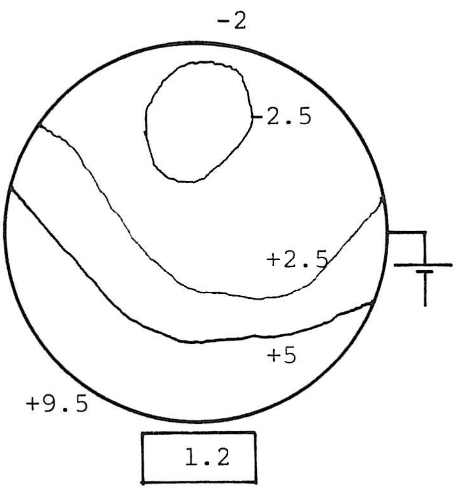


Tests with inclined, plane diffuser

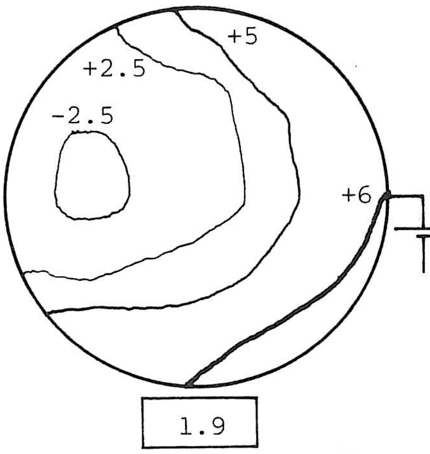
It is not possible to get a horizontale surface by inclining the diffuser.

▭ Number of cm above horizontal level.

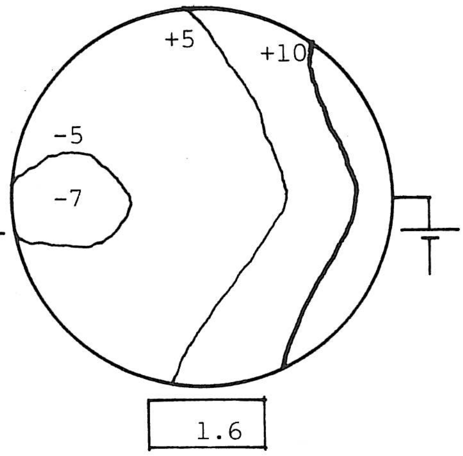
Test no 15



Test no 16



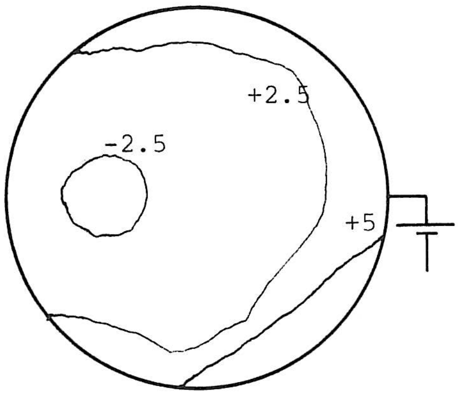
Test no 17



Tests with horizontale diffuser.

Analysis of shutter plate.

Test no 18



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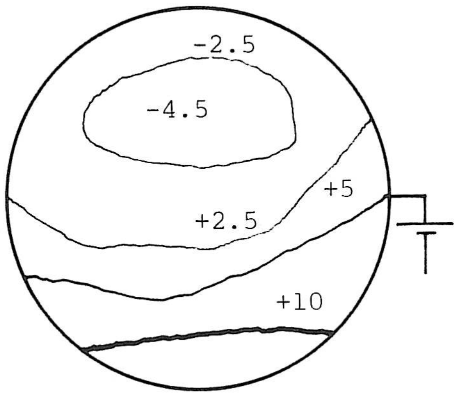

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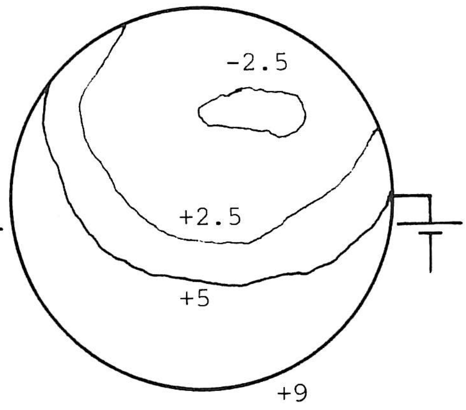
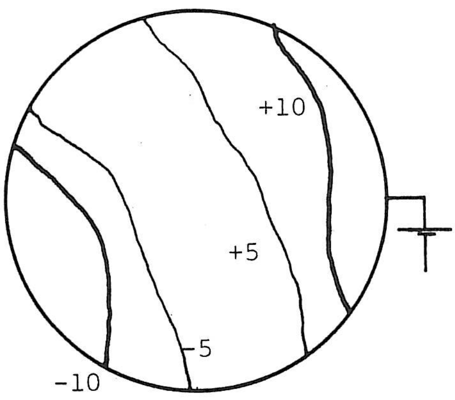


Test no 20



In test no 20 another part of the shutter plate has been used, which made the sand jets "fat", though the diffuser was used.

The diameter of the shutter holes must be increased from 10 to 12 mm.

Tests with horizontale diffuser.

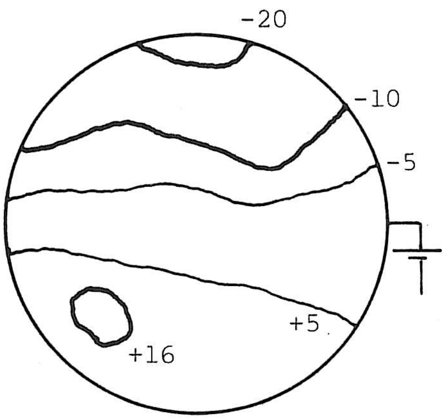
The fall height changed from 2.8-2.3 to 1.8-1.3 m.

Test no 25: Diffuser with two sieves.

Test no 26: Diffuser with three sieves.

Test no 27-30: Diffuser with six sieves.

Test no 25



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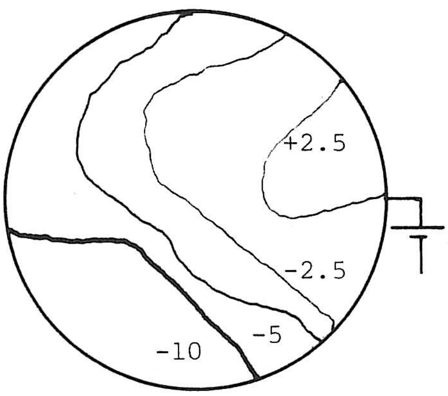

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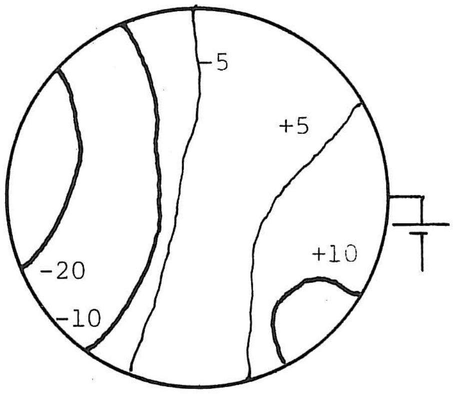


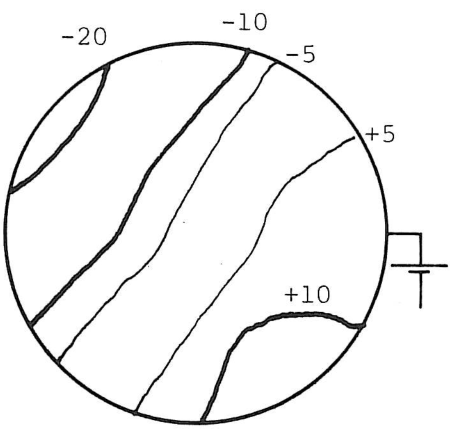
Tests with different fall heights.

Test no 28: 1.8 - 1.3 m.

Test no 29: 1.3 - 0.8 m.

Test no 30: 0.8 - 0.3 m.

Test no 28



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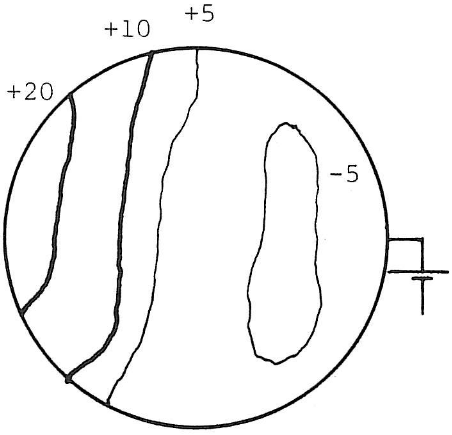
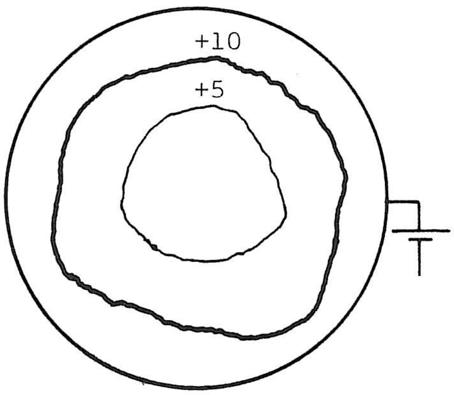


Test no 30

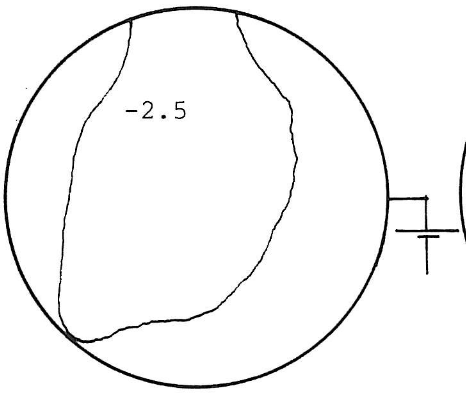


Tests with thin sand jets falling circa 2 m.

Diffuser placed 0.5 m above the bottom plate. The sand rain falls 0.5 - 0.1 m.

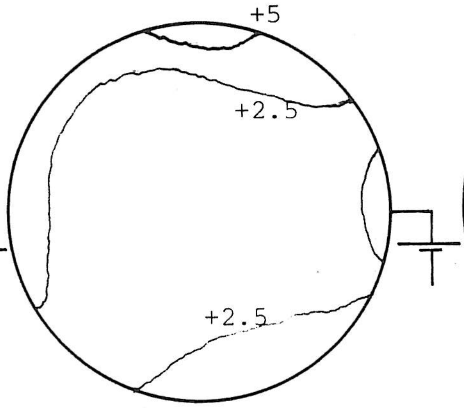
Test no 33

Hole pattern no 5



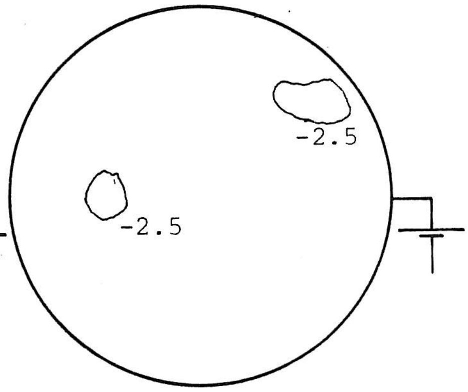
Test no 34

Hole pattern no 3



Test no 35

Hole pattern no 4



The height of the sample increased to 1 m.

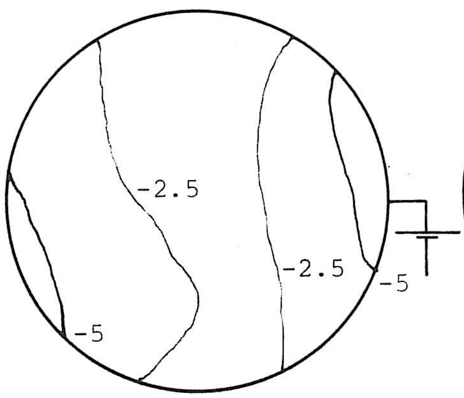
New circular diffuser placed inside the steel cylinders.

The diffuser consists of two sieves at a distance of 20 cm.

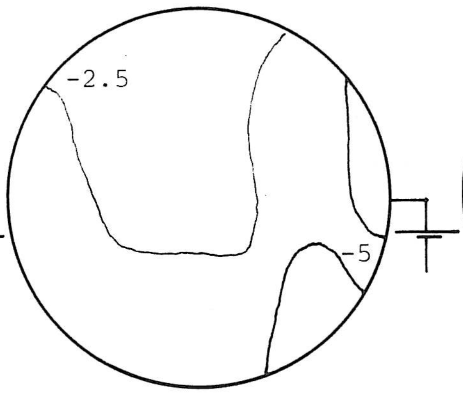
The mesh width is about 2 mm.

The diffuser is elevated in steps. The sand rain thus falls 0.5 - 0.4 m.

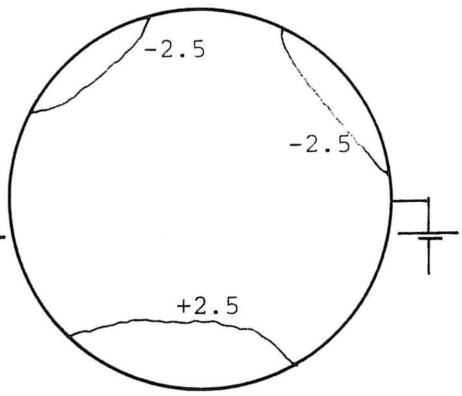
Test no 37



Test no 38



Test no 39

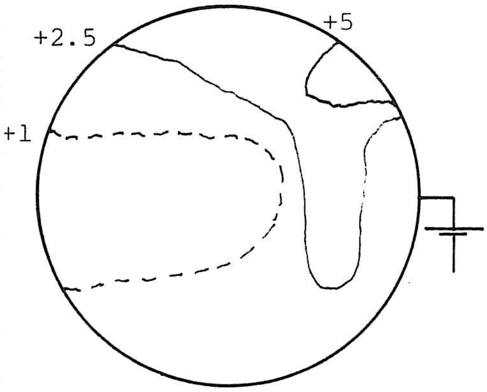


Tests with new circular diffuser.

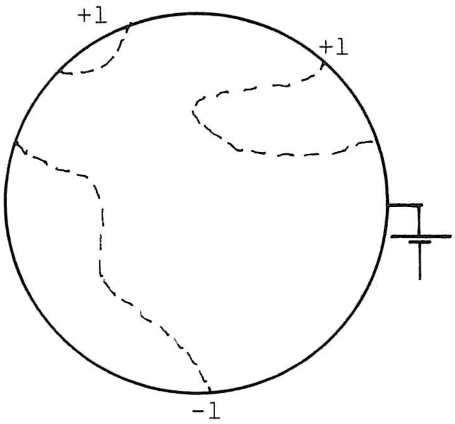
The sand rain falls 0.2 - 0.1 m.

Test no 41-45 and 49-50 carried out with at least 20 cm sand in the silo.

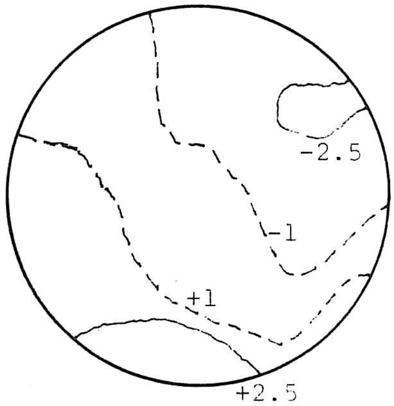
Test no 40



Test no 41



Test no 42



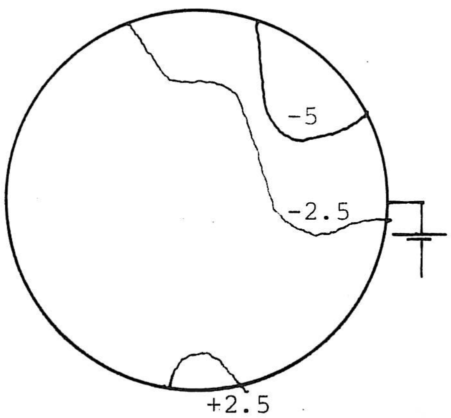
Test no 43: The lowest sieve in the diffuser rotated 90°.

Test no 44: The diffuser rotated 180°.

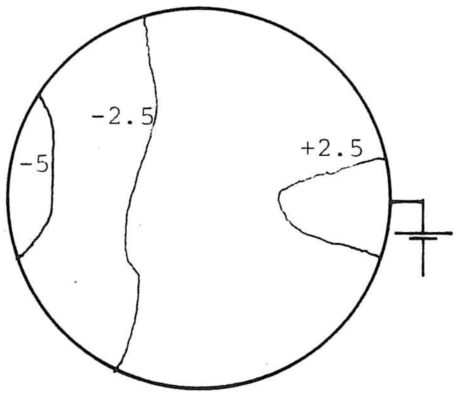
Test no 45: Rubber lining inside the steel cylinder.

In test no 44-45 a supporting rib has been placed very near a row of holes, but it does not influence the test.

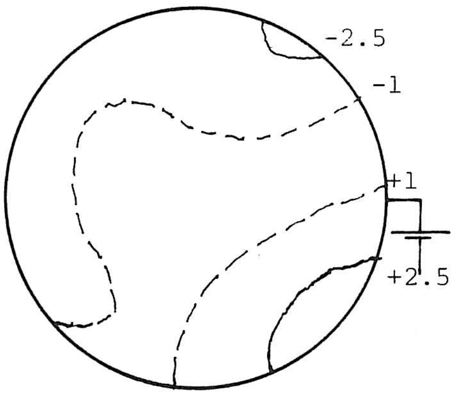
Test no 43



Test no 44



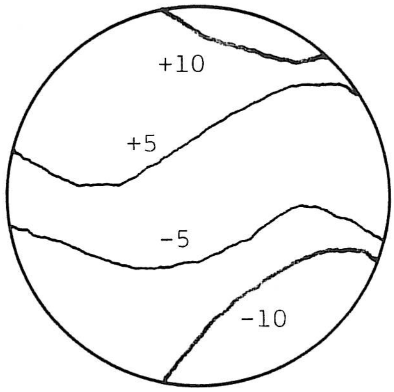
Test no 45



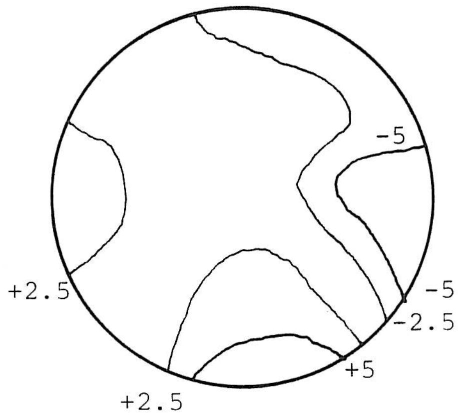
Tests with loose sand.

Test no 46-48 are carried out with a new hole plate.
Hole pattern no 4.

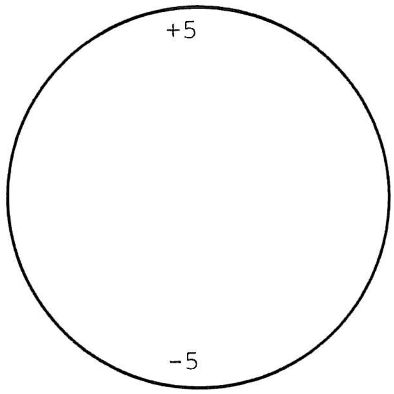
Test no 47



Test no 48



Test no 50



Test with dense sand.

Same procedure as in test no 45
but the fall height varies
from 0.4-0.3 m.

In test no 45, 48 and 50 the void ratio has been measured in different levels.

Layering no	Falling height m	Shutter plate no	Thickness mean value T cm	Max. difference ΔT cm	Test technique	ΔT/T %
1						
2		1	40	40		100
3				34	Without	85
4				34	sieves	85
5		2		24		80
6				32		110
7				36		120
8		3	30	37		125
9				32		110
10				13		45
11	2.8-2.3			11.5	With	40
12		4		13.5	two sieves	45
13				23.5	(2 mm)	50
14				25.5		50
15				13.5		25
16				11		20
17				20.5		40
18				11.5		20
19				13.5		25
20				27.5		55
21		5	50	12.0		25
22				36.5		75
23				34.5		70
24				36.5		75
25	1.8-1.3			33.5		65
26				24.5		50
27				35.5		70
28				35.0		70
29	1.3-0.8			33.0		65
30	.8- .3			19.0		40
31				8.5		15
32				6	Sand jets	10
33	.5- .1			5	falling 2.3 m	10
34		3		5.5	fixed sieves	10
35				2.5		5
36		4		3.5		5
37				7.0		5
38	.5			7.0	New sieves	5
39			100	7.0	placed in	5
40	.2	4^+		4.5	test cylinder	5
41				3.5	fixed falling	5
42				6.5	height	5
43				9.5		10
44				9.5		10
45				5.5		5
46	.4	4	120		Very loose	
47				25	sand	20
48				13		10
49	.4	4	100	10	Dense sand	10
50						