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Model testing has proven to be an effective tool in the study of soil-structure systems. While primarily used in research work, this method of evaluation is also applicable to the solution of many types of complex design problems. Because of its workability and relatively simple characteristics, sand is the most applicable soil type.

The major difficulty encountered in the development of a model testing apparatus is the preparation of a uniform soil medium. For an effective test apparatus utilizing cohesionless soils, the method of soil placement must be capable of reproducing uniform deposits over a large range of relative densities.

The purpose of this study was to investigate a sieving technique of sand placement. The apparatus was evaluated for its ability to produce sand bed uniformity and vary density by varying sieve sizes. A uniform fine sand and two sieve sizes were used in the evaluation.

Test results indicate that the device provides an effective method of sand placement at two or possibly three densities over an estimated range of relative densities of 50 to 75 percent. Closer control of sand density does not appear possible due to the critical relationships between sieve size, sand gradation and particle size.

Design and Evaluation of a Foundation Model Testing Device

by

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INTRODUCTION AND SUMMARY

Soil mechanics is defined by Taylor (1948) as "The science dealing with all phenomena which affect the action of soil in a capacity in any way associated with engineering." To evaluate the action of soil, three basic tools are used. These are: (1) experience, (2) laboratory tests and investigations and (3) theory.

Within the second category, model testing has evolved as an integral part of the solution of many soil mechanics problems. It is used in the solution of specialized problems as well as in basic research. Common examples of model studies include the use of earth dam models to determine flow nets, foundation models to study settlement and bearing capacity, and model retaining walls to investigate lateral earth pressures and wall movement.

In the case of foundation problems, another method of investigation is the prototype field test. Model testing has several advantages over this type of evaluation. First, it is much less expensive and usually faster. Perhaps more important is that the model may easily be modified to fit design changes or to investigate certain variables. The main disadvantage of model testing is the difficulty of reproducing soil conditions where a specific location and soil stratum are being investigated.

Historically, model testing apparatus have been designed with one of two main objectives in mind. Model studies have been oriented toward investigating either the movement of the underlying soil (e. g., the shape of a failure surface) or the movement or capacity of a soil-structure system. In the first case, the objective may be realized by utilizing a two dimensional model in which the soil movement is observed or photographed through a glass plate acting as a boundary. One method of satisfying both objectives while maintaining a three dimensional model test involves the use of layers of colored sand mixed with concrete. After testing, water is injected into the cement-sand mix which, after hardening, is sawn for examination of the soil movement (Spencer, 1964).

Sand is generally used as the soil medium in model testing because of the difficulties in the preparation of quantities of cohesive soils and because of their complex time effects. With cohesionless soils, the properties are more easily controlled.

Although sands are easier to work with, the placement of the soil medium for model testing on sand is still the most difficult and critical part of the operation. Because of the small scale, a greater uniformity of density is required than can usually be found in nature. Another criterion is reproducibility. In model studies, a series of tests at the same soil conditions are usually required.

The overall objective of this project was to provide a suitable device for the performance of model studies of foundation types on sand. The specific purpose of this research, however, was the design, construction, and testing of an apparatus capable of reproducibly placing uniform beds of sand. Design of the apparatus was limited, therefore, to the sand placement operation and did not include means of applying a load to a model foundation.

Placement of sand from a large sieve was selected as being the simplest and most economical method likely to provide versatility in formation of the sand bed. Much of the hardware used in the sieve placement operation was designed for possible future expansion to the roller method developed by Walker and Whitaker (1967), should it prove necessary.

The apparatus was tested with two sieve sizes and two uniform gradations of an angular sand. Results of the evaluation testing showed the density of the sand bed to be independent of the drop height for heights greater than 18 inches which was the minimum permitted by the design. On the basis of variations in measured density, apparatus, as designed, was considered to be unsatisfactory for the formation of a uniform sand bed without certain modifications. Control of sand flow and, therefore, the ability to vary density was limited due to the critical relationship between sieve size and sand gradation.

LITERATURE REVIEW

Model studies have proven to be an effective method for the investigation of soil-structure interaction and for basic research. Numerous studies in which this method has been used with sand as the soil medium are available in the literature. Detailed accounts of the method of sand placement, however, are few.

The methods available for the placement of sand may be broadly divided into two categories: 1) the free-fall method and 2) the vibration method. Several variations are possible within the groups as well as combinations of the two methods.

Free-Fall Placement

Basic research on this method of sand placement was first performed by Kolbuszewski (1948). He showed that by varying the intensity of falling sand (i. e., the amount of sand falling per unit area per unit time) and the height of drop, wide ranges in porosity (density) could be obtained. An increase in intensity resulted in a higher porosity (lower density) while increased drop height produced a lower porosity. He concluded that the increased intensity allowed the sand particles to bridge and thereby produce a more open structure.

Several different types of sand were used in the study by

Kolbuszewski with the same general results. The more angular sands investigated were found to be less sensitive to small changes in intensity than the sands possessing a high degree of sphericity. No conclusions were drawn, however, regarding the effect of different gradations. Experimental studies reported by Walker and Whitaker (1967) have shown that particle elasticity also is significant when comparing different sand types.

Characteristic of the free-fall method is the sieving technique employed by Vesič (1963). The research conducted by Vesič in his model study concerned the bearing capacity of deep foundations in homogeneous masses of sand.

The device used in the sand placement consisted of a perforated distribution pan or sieve eight feet in diameter. It was continuously fed through a flexible hose and conveyor belt system. Excavation of the sand from the 22 foot deep 8'-4" diameter test pit was accomplished by a bucket elevator and conveyor.

Control of sand density was accomplished by varying the height of drop and by vibration. Tests of the sand density showed that the maximum relative density, D_R, attainable by sieving was about 72%. It was also found that above 16 inches the height of drop did not significantly affect the density. Denser sand placement ($D_R > 0.72$) was obtained by surface vibration on four inch lifts placed by sieving. Electric vibrators with a frequency of 3,600 cpm increased the maximum relative density to about 80%.

The sand used for this work was a poorly graded medium sand having a coefficient of uniformity of 2.5. It was composed primarily of subangular quartz particles with fairly large quantities of mica. The maximum and minimum densities were determined to be 102.5 and 79.0 lb. per cu. ft. respectively.

Evaluation of the sand placement operation was made by penetrometer soundings. The sounding device, a one-half inch diameter static-cone penetrometer, was pushed into a representative sand sample by means of a screw jack. Correlations of penetrometer resistance with density and depth of embedment were established. Reliability of the sand placement method with respect to homogeneity was not discussed. The range of densities possible by this placement method was from 83 to 94 lb. per cu. ft.

Another type of free-fall device was designed and constructed by Walker and Whitaker (1967). This device was designed for continued use in the research of foundation types on sand.

The principal component of the apparatus was a three inch diameter horizontal steel roller capable of being rotated at variable speeds. The sand, fed out by the steel roller through a variable gap, was supplied by a seven cu. ft. capacity hopper. After leaving the roller in a nearly horizontal direction, the sand was deflected to a vertical direction. The entire assembly, as depicted in Figure 1, traveled back and forth above a container, forming a bed of sand with a uniform density.

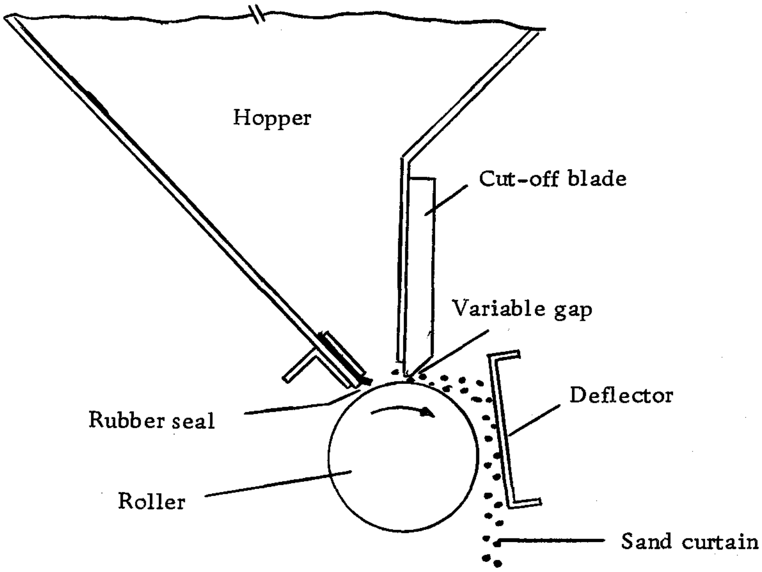

Figure 1. Profile view of roller type sand placement apparatus (Walker and Whitaker, 1967).

Vertical movement of the hopper-roller assembly was accomplished with an endless chain passing around four vertical supporting columns. The one and one-half inch diameter columns were threaded to receive the necessary bushings and chain sprockets. A variable speed electric motor was used to drive the endless chain. The device was capable of a maximum vertical speed of two inches per minute. This enabled the hopper to maintain a constant height of drop for any rate of placement investigated.

Variation in densities of the dry sand was found to be a function of the height of fall, the gap setting, and the roller speed. The intensity of deposition as controlled by the gap setting and roller speed was found to be the most significant factor while drop height proved to be relatively insignificant in the 19 to 28 inch range investigated. For the sand used, a total range of porosity of 8.9% was possible with the apparatus while less than a 1% change could be obtained by varying the height of drop. The relationship of the range of porosities to the maximum and minimum possible was not reported.

The sand used in this study was an air-dried river sand having particles from 0.15 to 0.3 millimeters in diameter. Porosity was measured by placing calibrated cylinders, three inches in diameter by three inches in height, at different points in the container. Several conditions were evaluated and at all porosities the values lay within ± 0.3% of the mean.

Placement by Vibration

The densification of cohesionless soils by vibration is a relatively simple and rapid method of sand density control. In the construction industry, vibratory compactors have proved to be the most effective method of compaction for sand fills. The mechanism associated with vibratory compaction is the movement of particles and the subsequent reduction of the intergranular friction. With the reduced frictional forces, gravitational or other forces can move the particles closer together.

thereby increasing the density (Leonards, 1962).

Vibratory techniques of sand placement for model studies have, in many cases, been used to supplement other methods of placement as described earlier in the discussion of the method employed by Vesič. This is because vibration of the material produces a denser structure than is attainable by the free-fall approach.

Vibration of sand for model testing can be subdivided into the general classifications of internal and external. These two divisions are based simply on the location of the vibrating source and, therefore, indirectly on the type of vibrator used.

Internal vibration is accomplished by inserting a vibrating flexible probe (concrete vibrator) into the soil. This method of densification was used, among others, by Gibbs and Holtz (1957) in their study of penetration testing and by Selig and McKee (1961).

Vibration of sand by external sources includes: 1) surface vibration in which a vibratory compactor is placed on or passed over a layer of sand and 2) vibration of the container. With the latter, sand may be densified by attaching a vibrator to the container or, in small scale model studies, the container may be placed on a vibrating table. Where vibration of the container is utilized, a surcharge is usually applied to the surface. Model studies in which external vibration has been employed include the work of Hanna (1963), Gibbs and Holtz (1957) and Spencer (1964).

Discussion of Techniques

The choice of a method of sand placement for a specific model study primarily depends on the degree of uniformity desired and the economical limitations of the work. Were complete homogeneity of the sand not a requirement, the use of a vibratory technique would be satisfactory. This would also be true if a rapid, inexpensive method were needed.

Free-fall techniques provide a greater degree of uniformity and more latitude in the placement of sand to different densities than vibratory methods. This is particularly true of the rotating cylinder design of Walker and Whitaker. With this apparatus, layers of the same type and gradation of sand may be formed at varying densities in the same container. One disadvantage of the free-fall placement is that a very dense structure cannot be obtained.

The sieving method of sand placement could be improved to include both of the variables discussed by Kolbuszewski. A greater variation in densities might be obtained if, in addition to the height of drop, the intensity could be altered. This would involve a change in sieve size and probably a corresponding change in sand size or gradation.

LABORATORY STUDIES

Introduction

Several methods of sand placement were considered for study in this research. It was felt that vibratory techniques, while being the easiest to implement, would not offer the control over density nor the homogeneity of sand bed desired. Development of the sand placement device designed by Walker and Whitaker was considered prohibitive due to available time. A free-fall technique similar to that employed by Vesić was ultimately selected as the method most likely to meet the criteria of uniformity and reproducibility in a reasonable length of design and construction time. An additional factor in the decision was the adaptability of parts of such a system to either of the other techniques discussed above.

Although sand fall height was shown by Vesić to be an effective means of density control, it was considered unsuitable for this study. The use of this method would have required either movement of the sieve within the sand bed container or a reduction in the container height. The first alternative would have resulted in a nonhomogeneous deposit at the container edges, thereby limiting the useable test area. The use of several containers, four or five inches in height, was considered prohibitive due to the increased complexity of the placement operation and probable reduction in sand bed uniformity. Study of density control with this apparatus was limited, therefore to varying the intensity of deposition. Selected as the most likely method of controlling this parameter was a variation in mesh size.

Equipment Design

Lateral confinement of the sand bed was provided by a circular container fabricated from one-quarter inch ASTM A-36 steel. The container was built to an outside diameter of 36 inches and a height of 18 inches. The size was selected for minimum boundary effects on loaded areas up to six inches square. Larger model footings would also risk distortion of the failure surface. For testing of pile and deep foundations, two of the 18 inch containers were constructed. Because of vertical space limitations, however, the apparatus was made operational for only one container height. Ceiling height in the work area measured 15 feet with two feet of the vertical spacing unuseable due to a beam and corbel.

A one-half inch steel plate 54 inches square was used as a base for the sand bed. The thickness was chosen for maximum protection against deflection during the loading of a model foundation. It was elevated from the concrete floor by four heavy legs 23 inches in length. This distance was necessary to allow for the removal of sand through a small opening in the table (base). To reduce the possibility of vibrations affecting the sand bed, the four legs were placed on approximately one inch of heavy, shock absorbent rubber.

A ring, six inches high and 42 inches in diameter, was constructed of heavy sheet metal to function as support for the sieve mesh. Further support was afforded by a metal screen welded under tension to the ring. The support screen had a one by two inch mesh and a wire diameter of two mm. The device was found to provide adequate support for approximately four inches of sand. At this load, a deflection of less than one-half inch was measured at the center. Stability of the sieve during sand placement was insured with two one-half inch diameter guide rods fixed to the lower sand bed container. Ten removable brackets provided for easy removal of a sieve mesh from the support.

For a continuous sand supply to the sieve, a storage hopper of approximately 10 cubic feet capacity was utilized. The base of the reinforced sheet metal container was sloped toward a six inch diameter opening for minimum impairment of the sand flow. A three inch flexible steel hose was connected to the opening for movement of the sand to all parts of the sieve. The sieve support was attached to the storage hopper as shown in Figure 2. This arrangement was found necessary for an adequate supply of sand to the sieve.

Another container of similar construction was used for transfer of sand to the storage hopper. The base of the 10 foot capacity

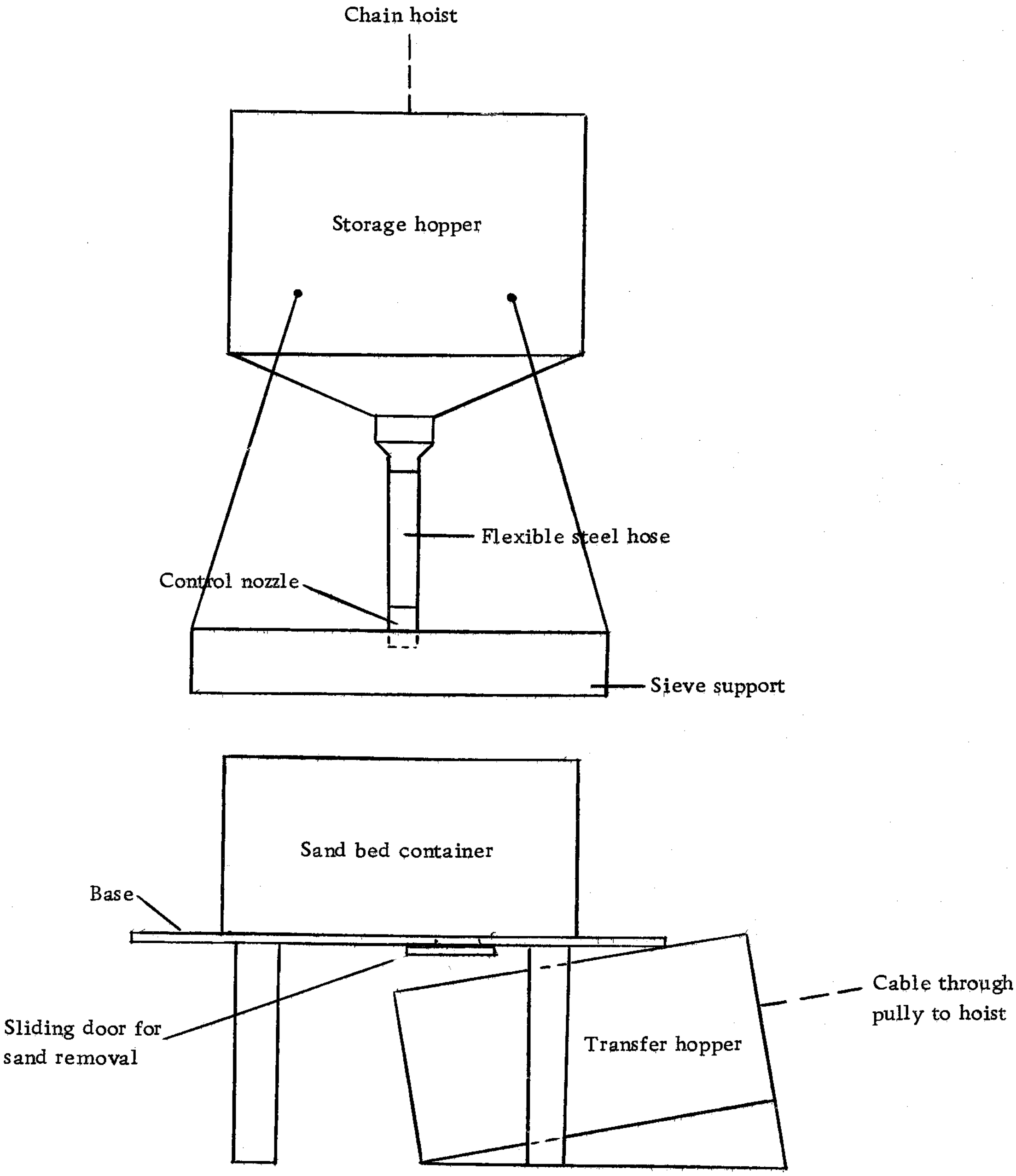

Figure 2. Arrangement of equipment.

transfer hopper was sloped and one side of its lift rigging lengthened to produce an inclination approximately equal to the sand's angle of repose. Thus the container could be essentially emptied with minimum operator aid. A sliding door at the low end of the hopper base provided control of flow rate. As with the storage hopper, a bracing system was bolted to the interior of the sheet metal container for added strength.

Lifting of the sand hoppers and hardware was accomplished with two types of hoist systems. A one-half ton capacity electric hoist, mounted on an I-beam spanning two columns, was used for moving the loaded transfer hopper. The sieve and storage hopper were manipulated with a stationary chain hoist. The chain hoist was found necessary to control the sieve speed and to reduce vibrations.

Lift rigging for all of the movable equipment was constructed of one-eighth inch diameter aircraft cable. For leveling of the sieve, adjustable eye-bolts were used as connection pieces with the lift rigging. With the hoppers, the rigging was attached directly to the bracing systems.

The assembled apparatus is shown in Figure 3.

Operational Procedure

The sand placement portion of the procedure required the control of two persons. Movement of sand to the storage hopper, however, could be handled by one person. During the sand placement operation, one operator was needed for distribution of sand to the sieve while another was required for control of sieve height above the sand bed.

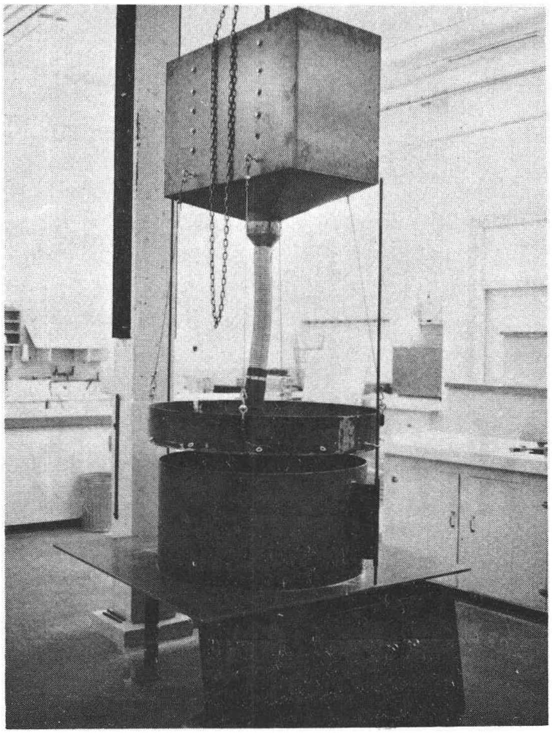

Figure 3. Arrangement of equipment for sand placement.

The placement procedure consisted of two general operations. The first step involved the removal of sand from the test container and its placement in the storage hopper. Loading of the sand into the transfer hopper took place beneath the test apparatus and was controlled by a small sliding door mounted in the apparatus base.

Preparatory to the actual sand placement, a two piece fiber board platform was placed on the sand bed container and the sieve, while resting on this platform, was loaded with approximately four inches of sand. A continuous placement of sand was then started with removal of the platform.

Evaluation Testing

The sand used for evaluation of the apparatus was a plastering sand known commercially as Del-Monte sand. It was chosen mainly for its availability and particle angularity. Particle shape was important for two reasons. First, a wider range of densities may be obtained with a more angular sand and secondly, since an angular sand is more difficult to sieve, the apparatus would be evaluated in the most positive manner.

The type of Del-Monte sand purchased was composed only of particles passing the number 30 sieve (0.6 mm). The lower limit of grain size was 0.073 mm with approximately 10% passing the number 100 sieve (0.17 mm). The sand was poorly graded, white in color and primarily composed of quartz grains and a small amount of mica.

Several gradations of sands were prepared by sieving the Del-Monte sand described above and tested for their ability to flow through different sieve sizes. These tests showed that the very uniform gradations provided the largest variation in flow rate. Selected for use in the study was that portion of the original Del-Monte sand passing the number 40 screen and retained by the number 60. The number 14 and the number 16 sieve sizes were also selected on the basis of the tests for use with the -40+60 gradation.

The -40+60 gradation, herein referred to as type I, was obtained by sieving with a Gilson aggregate shaker. Because of the large amount of time required to obtain the required amount of sand by this method, another sieving method was tried. In this second method, the material was passed through a series of screens on a continuous sieving apparatus. This procedure yielded a slightly different gradation called type II sand. Laboratory classification data are presented in Table 1 for both types of sand and the gradation curves are shown in Figure 4.

Table 1. Laboratory Classification Data

Sand Type	Coefficient of Uniformity, C_u	Coefficient of Curvature, C_c
I	1.6	1.0
II	1.6	1.2
Original Del-Monte sand	2.2	1.2

Maximum and minimum densities of the two types of sand were determined by the modified providence vibrated density test (U. S. Army Corps of Engineers, 1965). The test was altered slightly by using a 0.114 cubic foot container in place of the specified 0.16 cubic foot mold. Results of the test are presented in Table 2.

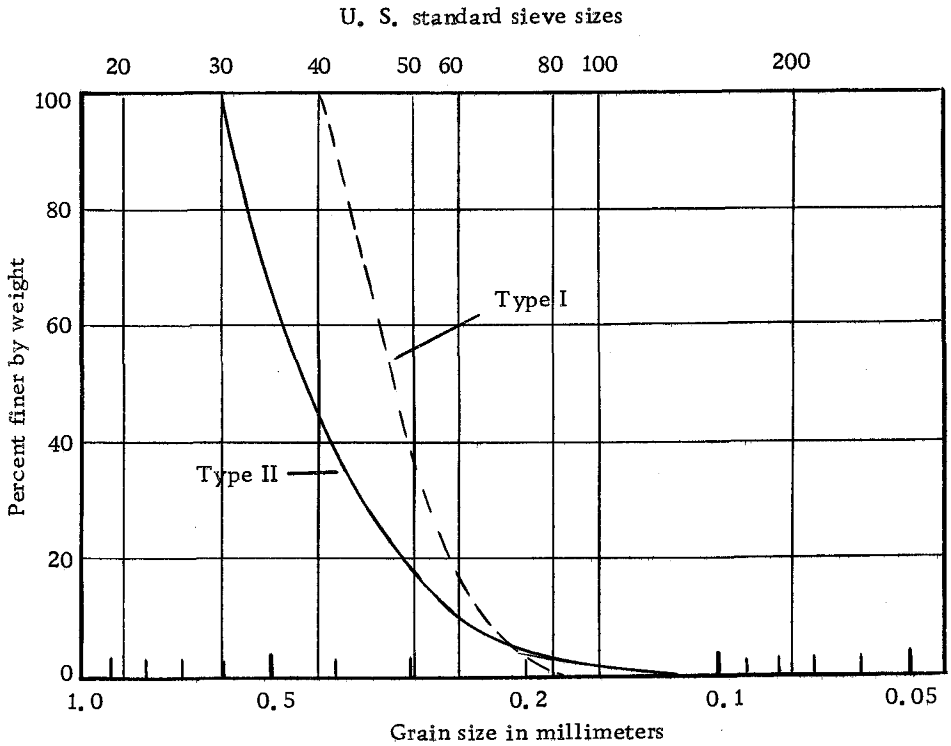

Figure 4. Gradation curves.

Table 2. Maximum and Minimum Densities

Sand Type	Minimum Density (lb/ft^3)	Maximum Density (lb/ft^3)
I	76.5	98.3
II	80.3	94.3

The sand size and gradation were found to be critical factors with respect to the flow rate during placement. The type II sand flowed rapidly through the number 14 sieve but would flow through the number 16 sieve only with induced vibration. Type I sand flowed rapidly through both of the mesh sizes.

The principal objectives of the evaluation testing were: 1) investigation of the system's reproducibility, 2) measurement of the uniformity of the sand deposit and 3) determination of the relationship between sieve size, fall height and sand bed density. Another objective of the testing was the examination of the practicality and overall effectiveness of the system.

Three methods of sand placement were used in the evaluation testing. Tests of the effect of fall height were performed by pouring Type I sand onto the number 16 sieve from a three gallon container. This method of testing was found necessary because of the difficulty of providing a uniform flow of sand at the start of placement for varying heights of drop. A sand bed of the type II material was deposited by vibrating the sieve support to investigate this method of placement. Reproducibility of the apparatus and uniformity of the sand bed were analyzed using the designed method of free fall placement. Type I sand and both sieve sizes were used with this method of sand placement to measure densities at two vertical locations and various lateral positions in the container.

Density measurements were obtained with two calibrated cylinders constructed of 20 gauge aluminum. The cylinders, five inches in diameter by approximately two and one-half inches in height, were formed to a knife edge on the container lip for minimum disturbance of the falling sand. In the three methods of sand placement employed, the cylinders were placed on the base of the sand bed container prior to the start of placement. After formation of the sand bed to approximately a six inch depth, the cylinders were removed and their contents weighed to the nearest gram.

Test Results

The results of tests at varying drop heights were in agreement with the findings reported by Vesić. The average relative density of 11 tests at drop heights between 18 and 28 inches was 63.9% (90.5 lbs. per cu. ft. with all but one of the relative densities within 0.4% of the average. For this apparatus, therefore, the density can be considered independent of drop height.

Erratic results with predominately high relative densities were obtained with vibration of the sieve support. The erratic behavior and high densities were probably due to a nonuniform vibration of the sieve and to vibrations reaching the container through the two guides used to stabilize the sieve. This method of forming a sand bed might prove to be acceptable if a method of vibrating the sieve in a uniform manner could be devised.

A total of 20 density measurements, 14 with the number 16 sieve and six with the number 14, were obtained in testing the free-fall placement method. The complete results are presented in Table 3.

The spread in measured densities with the smaller sieve was 6.8 lbs. per cu. ft. and with the larger sieve (number 14) 2.0 lbs. per cu. ft. Two of the 14 values obtained in tests using the number 16 sieve lay beyond the range of two standard deviations ($\pm 2\sigma_s$) of the average and were rejected. This reduced the total variation in density to 3.0 lbs. per cu. ft. The average densities were found to be 91.5 (D_R = 68%) and 88.2 lbs. per cu. ft. (D_R = 53%) for the number 16 and number 14 sieves respectively.

Table 3. Evaluation Test Results

Sieve size	Location of Test Cylinder: Below top of container (inches)	Location of Test Cylinder: Lateral position	Density (lbs. per cu. ft.)	Relative density (%)
16	18	Cntr.	91.4	68.0
16	18	W. edge	91.9	70.0
16	18	S. edge	93.0	76.0
16	18	Cntr.	91.0	66.5
16	18	S. edge	87.7[a]	52.0
16	18	E. edge	92.7	74.8
16	7	Cntr.	91.4	68.0
16	7	W. edge	91.0	66.5
16	7	S. edge	90.5	64.2
16	7	Cntr.	90.0	61.9
16	7	E. edge	92.2	72.0
16	7	W. edge	94.5[a]	83.0
16	7	N. edge	91.2	67.4
16	7	S. edge	92.0	71.0
14	18	Cntr.	87.5	50.5
14	18	E. edge	89.0	57.5
14	18	W. edge	87.0	52.0
14	18	Cntr.	88.0	52.7
14	18	Cntr.	87.7	51.5
14	18	N. edge	88.8	56.5

[a]Rejected values.

Most of the variation in density was between the center and outside edge of the container. For both sieve sizes, the average density at the edge was higher than that obtained at the center. A difference of 0.8 lbs. per cu. ft. was measured with the number 16 sieve and 0.45 lbs. per cu. ft. with the number 14 size mesh. The spread of individual values at the two general sand bed locations was also found to be significantly different. The maximum variation at the container edge was 2.5 lbs. per cu. ft. while that recorded at the center was 1.4 lbs. per cu. ft.

The number of density measurements taken at the center of the two test levels was not sufficient for comparison. A definite change was observed with the edge densities, however. At the higher test level, the average density was lower by 1.1 lbs. per cu. ft. at 91.4 lbs. per cu. ft.

Discussion of Results

The difference in average densities obtained with the two sieve sizes illustrates the possibility of some density control with the sieve technique of sand placement. The large change in relative density accompanying the change of only one sieve size, however, indicates that attaining fine control of sand bed density is doubtful with this method. Difficulties encountered in regulating the flow of the type II sand suggest that the apparatus is limited to only a small range of relative densities. With the type I sand, this range is estimated to be 50 to 75 percent. Based on the range of penetration resistance values normally found in the field, an effective model test apparatus should be capable of producing beds of sand at relative densities between the limits of 30 and 80 percent. The relationship of penetration resistance to relative density is presented in Figure 5.

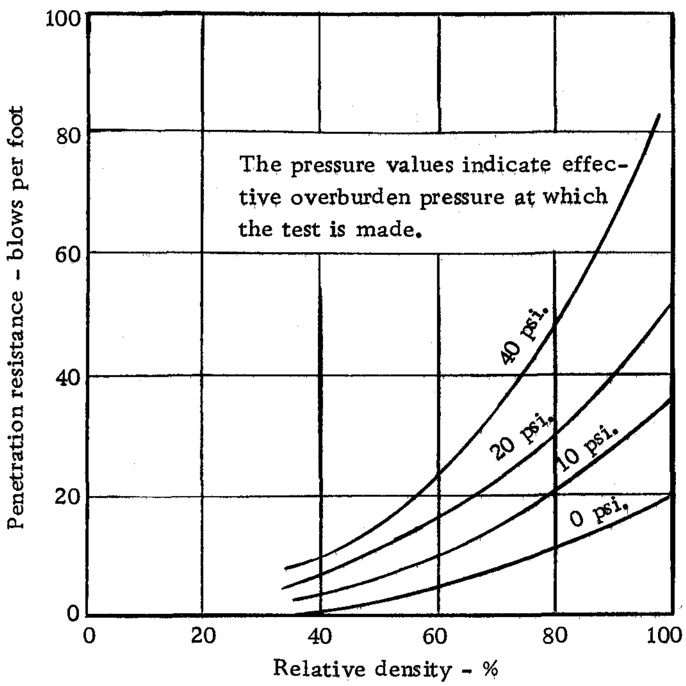

Figure 5. General relationship between penetration resistance and relative density for dry and saturated cohesionless sands (U. S. Dept. of Interior, 1963).

The variations of up to 3.0 lbs. per cu. ft. in individual density measurements must be considered indicators of excessive nonuniformity. Data presented in Figure 6 show that this amount of density variation (13.5% change in relative density) would cause a change in the friction factor of 0.07. This corresponds to a fluctuation in the angle of internal friction of about 2.5 degrees. A change of this amount would, for an angle of internal friction of approximately 35 degrees, result in a variation in bearing capacity factors of up to 100 percent.

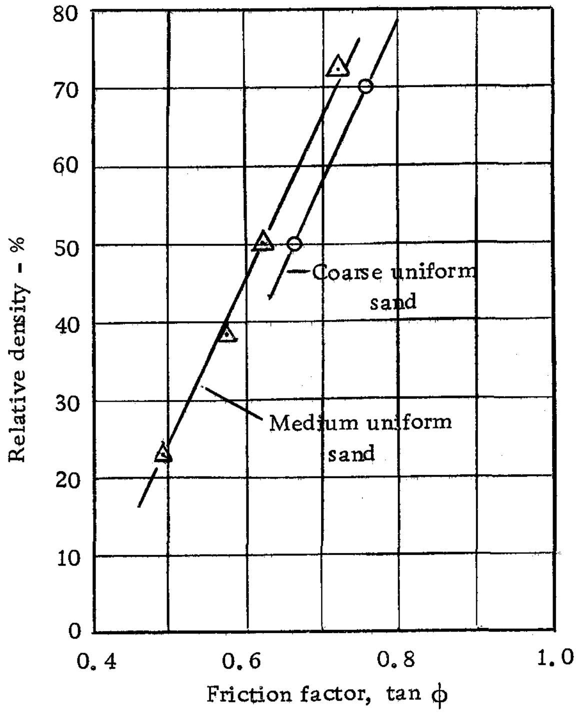

Figure 6. Effect of relative density on the friction factor for sands (U. S. Dept. of Interior, 1963).

Test results indicate that much of the density variation can be attributed to air currents caused by the falling sand. Air, forced up the container sides, affected the falling sand as shown in Figure 7. The higher, more erratic densities measured at the container edges indicate that the air currents resulted in a nonuniform decrease in the intensity of deposition in these areas. At the higher container level, the decrease in edge densities suggests that the effect of the moving air was not as pronounced. The results at varying drop heights also show the relationship of lateral confinement to sand bed uniformity.

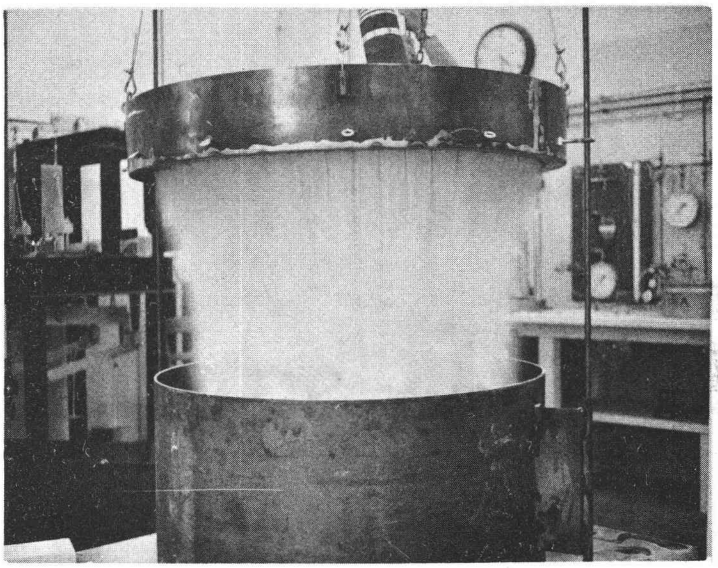

Figure 7. Disturbance from air currents.

The method of starting the sand placement operation apparently did not affect the sand bed uniformity. Density measurements taken directly below the platform joint (north and south edges) were not significantly different from those obtained at points away from the joint.

RECOMMENDED MODIFICATIONS

Several mechanical modifications would be necessary for improved performance of the apparatus. The most important of these would involve the reduction or elimination of air currents caused by the falling sand. This could be accomplished by providing vents through the sand bed container. Covered with the appropriate size mesh, the vents would not seriously affect the placement operation.

One means of gaining additional vertical working space might be afforded through the use of a high capacity vacuum cleaner to remove the sand after testing. The base could then be lowered to permit formation of the sand bed to a height of 36 inches. Feeding the sieve with a continuous belt would also permit formation of a deeper sand bed without requiring more head room.

Another modification worthy of further study would involve vibrating the sieve, effectively adding another flow rate control.

CONCLUSIONS

The sand placement apparatus presented in this study would, with the recommended mechanical changes, provide a suitable means of forming homogeneous beds of uniform sand at two or possibly three densities over an estimated range of relative densities of 50 to 75 percent. A closer control of density with this apparatus would require the inclusion of drop height as a parameter.

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