SECTION III

FIELD INVESTIGATIONS

SUB-SECTION III a

BORING AND SAMPLING

III a 5 SAMPLING DISTURBANCE AND ITS EFFECT ON ANALYTICAL SOLUTIONS TO SOIL PROBLEMS

JAMES D. PARSONS
Consulting Engineer Moran, Proctor, Freeman & Mueser
New York, N. Y.

SUMMARY

The applicability of analytical solutions to foundation problems depends largely on the degree to which the soil properties assumed therein approximate those of the soils in situ. Since these properties are usually determined from laboratory tests on undisturbed samples, the techniques and equipment employed in these operations have an important bearing on their reliability. The following discussion pertains to sample disturbance, and its effect on analytical solutions to soil problems.

Since, in most cases, the essential information regarding the location, extent, and physical characteristics of soil formations are obtained from soil borings and laboratory analyses of samples recovered therefrom, the importance of accuracy in this phase of soil mechanics is self-evident. The choice of boring methods and sampling devices to be utilized for any one investigation depends largely on:-

(a) Available information on the character and uniformity of the soil conditions prevailing.
(b) Whether the exploration program is preliminary or final.
(c) The nature of the structures considered for the area in question.
(d) The purpose for which the soil samples are taken.
(e) The character of the soil.

The methods in common use today may be briefly summarized as follows:-

(a) Soil Sounding Methods
(b) Wash Sample Borings
(c) Auger Borings
(d) Geophysical Methods
(e) Test Pits
(f) Core Borings
(g) Dry Sample Borings
(h) Undisturbed Sample Borings

With the possible exception of "Wash Sample Borings", all these methods have very definite places in our exploratory programs.

Analytical solutions to foundation problems require certain data pertaining to the physical properties of the soils involved.Such data are usually obtained from laboratory tests of soil samples recovered by undisturbed sampling methods. Only within the last ten to fifteen years have suitable sampling and testing techniques and equipment been.devised to permit the determination of properties which closely approximate those of soils in situ. The application of such methods, however, has been limited to common plastic and cohesive soils, and the following discussion is limited therefore to this group.

The term "undisturbed samples" is actually a misnomer, since it is impossible to get truly undisturbed specimens of soil, because of the change in the stress conditions of the samples as a result of their removal from the ground. Fortunately, we are able in many cases to evaluate this change.

Since the type of sampler utilized for securing undisturbed samples has an important bearing on the quality of sample recovered, a brief discussion of sampler design and operation follows:-

UNDISTURBED SAMPLING EQUIPMENT

In the design of samplers the most important features to be considered are:-

1. Inside Clearance
2. Area Ratio

The definition of each is included in Figure 1, with the corresponding figures for the samplers shown.

Inside clearance controls, to a large degree, the amount of friction developed between the walls of the sample tube and sample. While this friction assists to retain the sample during withdrawal from the ground, it should be a minimum, to avoid disturbance of the sample.

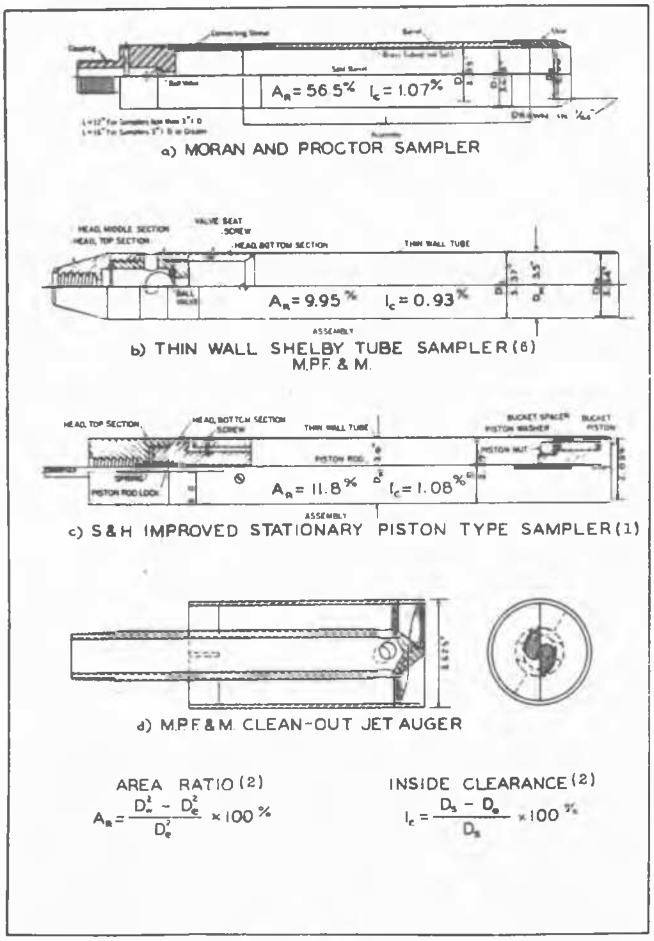
With an increase in sampler wall thickness, there is a pronounced increase in the resistance to penetration, and increasing danger of excess soil entering the sampler. It is important that the area ratio be as low as possible.

Other features in the design of samplers are:-

(a) The ratio of length to diameter (L/D).
(b) Method and rate of forcing sampler into the ground.
(c) Escape of water during driving, and the relief of pressure during withdrawal.

The above factors are influenced by the nature of the soil being sampled, and no one sampler is suited to all soils.

Figure 1 shows three widely used "undisturbed" sampling spoons. Without going into a technical discussion of each, it may be seen



a) MORAN AND PROCTOR SAMPLER

b) THIN WALL SHELBY TUBE SAMPLER (6) M.P.F. & M.

c) S&H IMPROVED STATIONARY PISTON TYPE SAMPLER (1)

d) M.P.F.& M. CLEAN-OUT JET AUGER

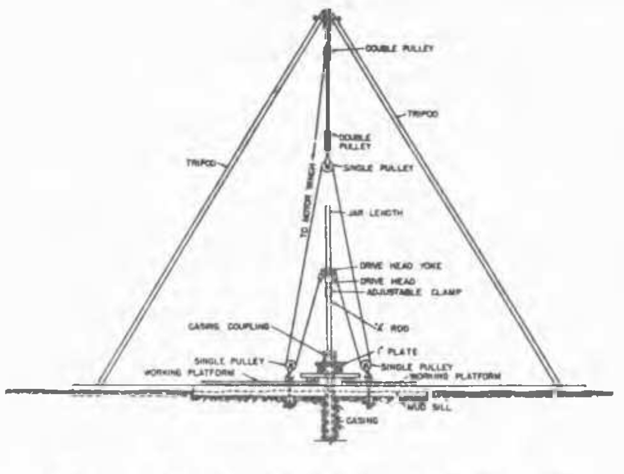
AREA RATIO (2)

$$A_R = \frac{D_w^2 - D_e^2}{D_e^2} \times 100\ \%$$

INSIDE CLEARANCE (2)

$$I_c = \frac{D_s - D_e}{D_s} \times 100\ \%$$

FIG. 1



RIGGING FOR CONTINUOUS DRIVE OF SAMPLER BY MEANS OF A WINCH AND BLOCK AND TACKLE

FIG. 2

that the walls of (a) are thicker than those of (b) or (c). While (a) was considered one of the best samplers of its time, research has shown that its area ratio of 56.5% is too high to obtain good undisturbed samples.

Sampler (b), (A_r = 9.9%) a considerable improvement over (a), consists of a head and a short section of pipe to which a thin walled tube is attached. The tube is sharpened and drawn in at the end and may be in various lengths. This spoon will recover most cohesive soils practically free from disturbance. The inside clearance and L/D ratio utilized depends on the consistency of the soil and is varied accordingly.

While sampler (c) was not designed specifically for extremely soft soils, its performance in this connection is outstanding. It is essentially like (b), except for a piston with rods extending to the surface. The piston is clamped flush with the cutting edge, while sampler is lowered into the hole. At the desired sampling location the piston rod is unclamped from the sampler rods and clamped to the casing. The piston is held stationary while the sampler is forced into the soil, thus permitting a determination of the length of sample and the stroke of the sampler.

Most undisturbed borings are made in pipe casing driven to the location of the samples required, the material from within being removed by washing, and the samples recovered immediately below the casing bottom. Important in this method is the complete removal of material from within the casing without disturbance to the soil below, so that the samples will be free from extraneous material. With open wash rods the jet velocities often become so high that holes are jetted below the casing. Sections through a sample so effected are shown in Figure 3 (d). The clean-out jet auger, Figure 1 (d), was designed to overcome this difficulty It is close fitting in the casing, to remove soil adhering to the casing. Its jet holes are inclined upward and protected from jetting below. It functions as a wash rod to within a few inches of the bottom of the casing, after which the jets may be stopped, and the auger rotated, permitting the remaining material to be cut into the bucket.

Figure 2 shows a set-up for a continuous drive of the sampler by means of a winch and block and tackle. The continuous drive eliminates the objectionably strong vibrations produced by a hammer, and the samples so obtained are much less disturbed than when a hammer is used.

In spite of the precautions taken to recover good samples, they are often rendered unusuable by the affects of shock in transportation and handling. Most soft inorganic and organic silts are particularly sensitive to shock.

VISUAL EVIDENCE OF DISTURBANCE

Disturbance, as well as stratification and homogeneity, can usually be demonstrated by cutting thin sections from samples and allowing them to dry under atmospheric conditions. Figure 3 shows four thin sections cut and dried from so-called undisturbed samples in the above manner. Specimens (a) and (b) are from a silty clay deposit. Specimen (a) was obtained in Sampler (a), (Figure 1) by driving with a hammer, while Specimen (b) was obtained in 3 inch sampler, Figure 1 (b). The sample spoon utilized for obtaining Specimen (b), however, was forced into the soil in one smooth continuous drive. The distortion of Specimen (a) resulted from excessive inside wall friction attributed to the entrance of excess material into the spoon and to vibration caused by the hammer, Specimen (b) demonstrates the improved results associated with the use of thin walled samplers pushed into the soil by the continuous drive method.

Specimen (c) of Figure 3 demonstrates the successful use of samplers of the "piston type" in sampling soft soils. This specimen was of

a. Varved clay recovered with sampler (a) figure 1

b. Same varved clay recovered with sampler (b) figure 1

c. Very soft river mud recovered with sampler (c) figure 1

d. Overjetting with open type wash pipe

Photographs of thin sections from samples

FIG. 3

organic silt which was so soft that unconfined compression tests could not be performed thereon.

EFFECT OF DISTURBANCE ON LABORATORY STRENGTH DETERMINATIONS

In problems pertaining to soil stability, no soil property plays as important a part as shearing strength. The several laboratory tests developed for determining this property are the unconfined compression, direct shear and triaxial compression tests. The unconfined compression test, because of its simplicity and applicability, is perhaps the most widely used. The results of all three types of tests are significantly effected by sample disturbance.

Figure 4 shows the results of direct shear, triaxial and unconfined compression tests of undisturbed samples of organic silty clay from Sparrows Point, Maryland, indicating a variation in the angle of internal friction, depending on the testing procedure, from 5° to 29.5°. The three types of triaxial compression and shear tests which were performed to obtain this range were:- the slow, consolidated-quick and quick tests.

To show the effect of disturbance on one specific type of triaxial compression or shear test, the failure envelope for a series of consolidated-quick tests on remolded specimens is included in Figure 4. As may be seen, sample disturbance has a tendency to increase the φ value from 17° to 21°, depending on the degree of disturbance. Hence, by using consolidated-quick test results which have been affected by disturbance, we are on the unsafe side insofar as most of our analytical solutions are concerned. The range between the undisturbed and disturbed results may well be in excess of the margin normally allowed for the factor of safety.

Also shown in Figure 4 are the results of unconfined compression tests on remolded, disturbed, and undisturbed specimens. The compressive strength of the undisturbed specimen is 1.5 kg/cm^2, which is approximately five times that for the remolded specimen. Many clays exhibit as much as 50 percent loss of strength due to minor disturbances alone. It may therefore be stated that disturbance has a tendency to lower the unconfined compressive strength of most cohesive soils. For this reason the re-

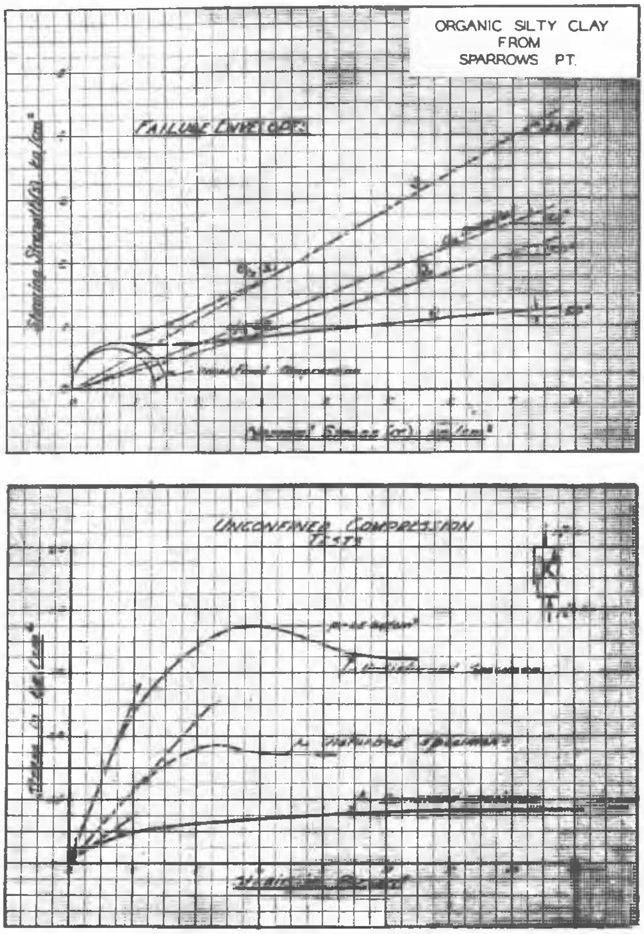
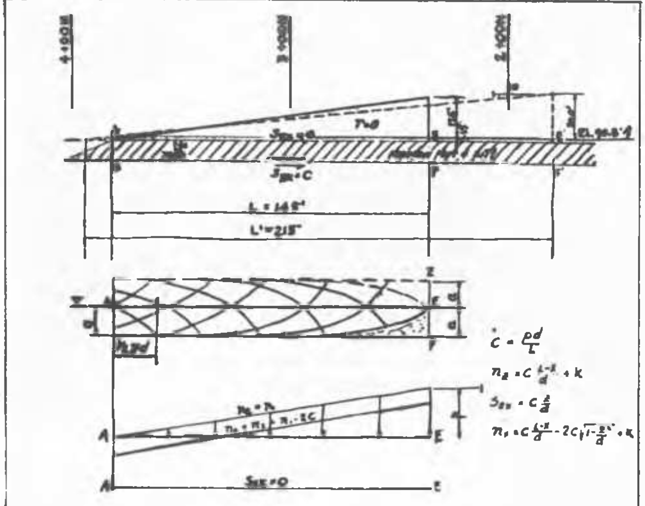


FIG. 4



$c = \frac{pd}{L}$

$n_z = c\,\frac{L-x}{d} + k$

$S_{zx} = c\,\frac{z}{d}$

$n_x = c\,\frac{L-x}{d} - 2c\sqrt{1-\frac{z^2}{d^2}} + k$

Wt of fill above Elev. 90.3 = 108 #/ft³
" " " below " " = 122 #/ft³ $\qquad p = 17.5 \times 108 + 1.5 \times 122 = 2073$ #

Symbols: n_1 ; n_2 ; s = principal normal stresses & principal shearing stress
n_x ; n_z ; S_{zx} = normal & shearing stress in z & x planes
p = external pressure
c = shearing strength
T = tensile strength at embankment base

Since the load of the fill will contribute to the strength of the silt only at the rate consolidation proceeds, the criterion of plasticity will then be s = c

Required shearing strength in meadow mat & silt just prior to failure (or F.S. = 1.0):

$$c = \frac{pd}{L} = \frac{2073 \times 9.0}{145} = 135\ \#/□'$$

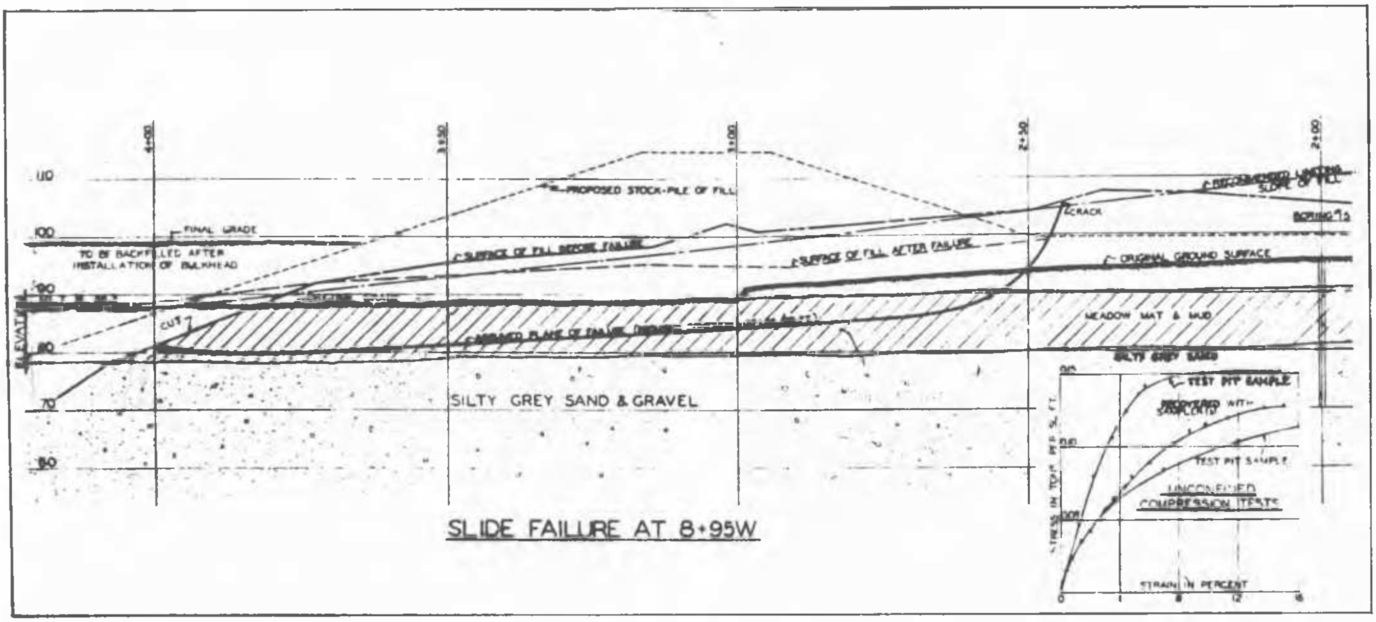
Since the carrying power of the meadow mat & silt is in all cases proportional to L/d, if the slope of the fill is reduced to 1 on 10 as shown, $c' = \frac{pd}{L'} = \frac{2333 \times 9}{215} = 97.6\ \#/□'$

F.S. for recommended 1 on 10 slope $= \frac{c}{c'} = \frac{135}{97.6} = 1.382$

ANALYSIS USING PRINCIPLE OF EQUILIBRIUM IN PLASTIC STATE (3)

SLIDE AT STATION 8+95W

FIG. 6



SLIDE FAILURE AT 8+95W

FIG. 5

sults of such tests are preferred whenever there is any question regarding the validity of the general strength determinations, since, by so doing, our analytical solutions will yield results on the safe side.

INFLUENCE OF SAMPLE DISTURBANCE ON STABILITY ANALYSES

Figures 5 and 6 show the results of a stability analysis of soil behind a bulkhead in the New York area. The soil profile is normal to the line of the bulkhead and shows the soil formation immediately inboard from it, where a dredged slope was attempted for the installation of a rock mound. The slope cut exposed a soft deposit of meadow mat and mud. In spite of the imminence of slope failure the dredged material was stock-piled, for backfill, along the top of the slope. The failure which occurred may be viewed as a full scale shear test in which the meadow mat and mud was loaded in situ to failure, and presented an ideal set-up for studying the reliability of sampling and testing methods and their applicability to analytical solutions of this nature.

Undisturbed samples of the mud were secured from borings and test pits. Sampler (b) of Figure 1 was used in the boring operations.The results of unconfined compression tests on samples from each group, shown in Figure 5,are in close agreement, and indicate a shearing strength of 125 to 150 /sq. ft. The required strength for stability along a plane surface was found to be 137 /sq.ft., while that needed for equilibrium in the plastic state was 135 /sq. ft. (Figure 6). The three results, independently arrived at, are in sufficiently close agreement to demonstrate the reliability of the sampling and testing methods utilized. Because of their reliability an accurate measure of the effects of disturbance on problems of this nature can be determined.

Let us now consider the same embankment from the standpoint of stability. For design against failure in the plastic state of safety of 1.38. Unconfined compression tests on partially disturbed specimens of the mud, however, yielded strengths which were approximately 50 percent of those for the undisturbed state. Had they been the only source of information, the L/d requirement of the slope would have been twice that of the safe slope, since C = pd/L (Figure 6).

Similarly, the bearing capacity of the mud, based on disturbed tests, would have been 50 percent of that indicated by the undisturbed tests.

DISTURBANCE AND ITS EFFECT ON CONSOLIDATION DATA

The results of consolidation tests are presented in the form of "pressure-void ratio diagrams" which permit the determination of volume decrease, and "time- compression curves" which demonstrate the rate at which the decrease occurs. The pressure-void ratio diagram may also be utilized to determine the maximum pressure on the soil in its previous history.

As demonstrated by Rutledge 4) disturbance effects the pressure-void ratio diagrams in the following ways:-

1. It obscures the previous stress history of the soil.
2. It decreases the void ratio at which the soil will carry any vertical stress.
3. The straight-line portion of the disturbed compression curve is displaced downwards from the virgin compression curve, and the slope or the rate of decrease in void ratio with increasing stress, is less.

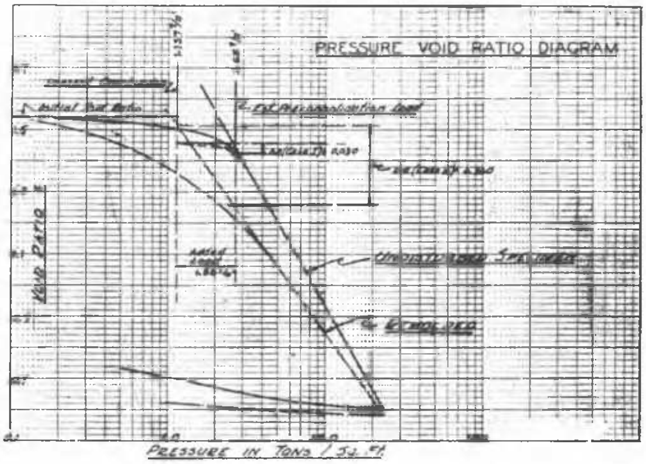


FIG. 7

Several methods for determining the preconsolidation load have been devised. The widely utilized method developed by Casagrande 5) depends largely on the curvature between the recompression and virgin branches of the pressure-void ratio diagram. The writer has found that the degree of curvature between these two branches is more seriously affected by disturbance than are the other above factors. Test results on soft cohesive soils indicate that an extremely small disturbance due to sampling or testing may be responsible for an appreciable flattening between the two branches.

To demonstrate the affects of disturbance on settlement estimates, pressure-void ratio diagrams from consolidation tests of undisturbed and remolded specimens from the same clay sample are shown in Figure 7. The curvature between the recompression and virgin branches for the undisturbed specimen is sharp, readily permitting the estimated preconsolidation determination of 2.65 tons/ sq. ft., but the remolded specimen shows no appreciable break, and in this instance the initial void-ratio is the only guide for estimating the preconsolidation load (1.0 tons/sq.ft.). If the present overburden were taken as 1.14 tons per sq.ft., and the average load increase as 1.58 tons/sq. ft., the resulting void change on the basis of the remolded specimen would be approximately 0.26. However, because of the knowledge obtained from the undisturbed specimen regarding preconsolidation, the true void change would only be 0.030. The settlement, on the basis of the remolded specimen, would therefore be 8.5 times that determined from the undisturbed specimen, demonstrating rather forcefully the effect of disturbance in these considerations.

CONCLUSIONS

1) The purpose of undisturbed sampling and laboratory testing of soils is to obtain data on the physical properties of the soils which approximate those in situ.
2) It is impossible to get truly undisturbed specimens of soil, because of the change in stress as a result of their removal from the ground. The effect of the change, however, may be evaluated.
3) The techniques and equipment utilized in

sampling and testing have an important bearing on the degree of disturbance associated with these operations.

4) Where test pits cannot be utilized for securing undisturbed samples, thin walled sampling spoons of the open or piston type are the best equipment presently available for this purpose.

5) Visual evidence of soil disturbance may be demonstrated by cutting thin sections from the samples and allowing them to dry under atmospheric conditions.

6) A small disturbance due to sampling and testing operations may have an appreciable effect on the reliability of the laboratory test results.

7) The applicability of analytical solutions to foundation problems depends, to a large degree, on the reliability of the laboratory test results used therein.

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SUB-SECTION III c

MEASUREMENTS OF PRESSURES AND DEFORMATIONS

III c 6

INSTRUMENTATION FOR FIELD MEASUREMENTS OF DEFLECTIONS AND PRESSURES FOR AIRPORT PAVEMENTS

JOHN M. GRIFFITH

Engineer, Flexible Pavement Branch, Soils Division, Waterways Experiment Station,
Mississippi River Commission, Corps of Engineers, Department of the Army, Vicksburg, Miss.

E.H. WOODMAN

Engineer, Chief of Instrumentation Branch, Waterways Experiment Station,
Mississippi River Commission, Corps of Engineers, Department of the Army, Vicksburg, Miss.

SYNOPSIS

This paper describes operation and installation of one type of earth pressure cell and two types of deflection gages used by the Waterways Experiment Station in measuring stresses and strains in flexible pavement structures under standing and moving wheel loads and under plate-bearing loads. Also contained in this paper is a brief description of installations in three test sections utilizing these pressure cells and deflection gages.

The Flexible Pavement Branch of the Waterways Experiment Station was established by the Corps of Engineers during the early part of World War II to conduct research on the design of flexible type pavement. A part of the research conducted by this Branch has involved the measurement and study of stresses and strains induced in bases and subgrades beneath flexible pavements. This paper is confined to the mechanics and installation of pressure cells and deflection gages developed by the Instrumentation Branch of the Experiment Station as used in three experimental test sections: Flexible Pavement Tests, Marietta, Georgia; Stress Distribution Test Section, Waterways Experiment Station; and Stockton No. 2 Test Section. In these first two test sections all pressure cells and deflection gages were designed and constructed by the Experiment Station, while in the Stockton No. 2 Test Section pressure cells only were by the Experiment Station.

In all three of the above test sections, only one type of pressure cell was installed, and this is referred to hereinafter as the WES cell. The WES cell is used for measuring subsurface pressures under standing or moving loads. In the two test sections conducted by the Experiment Station, two basically different types of deflection gages have been used, one called the cantilever type gage and the other the selsyn motor gage. The selsyn gage is at present adapted to measurement of surface or subsurface deflections under standing loads only, while the cantilever gage is capable of measuring these deflections under both standing and moving loads.

The WES cell has been made in several