# Summary of Rotary Cone Penetrometer Investigations

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The natural meandering tendency of the Lower Mississippi River causes major bank failures in certain types of river deposits. These failures have threatened the levees at certain locations and increased the problem of stabilizing the river banks for navigation and development purposes. In 1947, extensive potamology investigations were started to study revetment failures, their causes and methods of preventing them, and to develop new methods of riverbank stabilization.

During the period 1947 to 1952, soils investigations established that all the major bank failures occur in point bar deposits composed of a relatively thin stratum of more or less cohesive overburden materials underlain by a relatively thick stratum of fine sand. The failures, while of short duration, are progressive rather than entirely instantaneous. They are composed of a series of blocks which individually fail instantaneously, and are believed to be associated with partial to complete liquefaction of the fine sand.

It is believed that excess pore pressures develop in strata of the fine sand at subcritical densities, probably as a result of strain in the bank produced by a shear failure of the underwater toe caused by scour due to current attack, and this results in liquefaction or flow-type failures. The principal characteristics of the area after failure are:

1. Comparatively large in area.

2. Scallop-shaped with a narrow to quite narrow opening on the river side through which material flows.

3. Trees on the bank fall with the tops riverward, which is the opposite of that in ordinary shear slides.

4. Bank slopes after failure are much flatter than that which could be predicted to be unstable by conventional analysis.

As a part of the 1947-1952 program, a rotary cone penetrometer was designed to investigate economically the relative density of deep sand deposits along the river banks. Preliminary field tests with the cone penetrometer had shown promise and, therefore, beginning in 1957 additional cone studies were initiated to determine the effect of surcharge pressure, gradation and shear strength of sands on the cone thrust, with the primary objective being to develop a reliable relationship between cone thrust and relative density of the in situ fine sand deposits.

#### Program of Tests

The test program conducted to date has consisted of three series of tests. In the first series, cone penetration tests were performed on a saturated fine sand confined in a steel tank at various relative densities and subjected to various surcharge pressures to determine the effect of surcharge pressure and relative density on cone thrust.

In the second series of tests, undisturbed samples were obtained from a fine and a medium sand contained in a steel tank at various relative densities and subjected to various surcharge pressures to determine change in density caused by sampling. In both the first two series of tests, pressure cells were used to determine normal pressure in the sand specimens at depth in the tank.

In the third series of tests, cone penetration tests were made in a deep deposit of fine sand at a typical site along the Mississippi River. Undisturbed samples of the sand were obtained adjacent to each cone penetration. The purpose of the third series of tests was to compare the relative density predicted by the cone penetrometer with the relative density measured from undisturbed samples.

A fourth series of cone penetration tank tests is now under way to determine the



FIGURE 1 Rotary cone penetrometer.

effect of sand gradation and shear strength on cone thrust.

#### Cone Penetrometer

A sketch of the rotary cone penetrometer used in these investigations is shown (Fig. 1). It is designed for use with a truckmounted rotary drilling rig and consists of a sounding rod having a conical point with a base area of  $10 \text{ cm}^2$  and a sleeve which fits over a downward extension of the hollow stem of a helical auger bit on the drill rod. The cone rod is tubular above the auger bit and extends up through the drill rod and a swivel to a proving frame at tached by tie rods to the flange of the swivel.

The proving frame has a maximum capacity of about 9,100 lbs. During the operation, drilling fluid flows down the inside of the cone rods and emerges from vents above the auger. The auger is rotated during the advance but the cone does not rotate. The force on the cone is transmitted by the cone rods to the proving frame. The distance between the bottom of the auger and the cone tip was  $15\frac{1}{2}$  in. for these investigations.

#### Cone Penetrometer Tank Tests

The purposes of the first series of tests were to find the relationship between cone thrust and overburden pressure for various densities of one type of sand and to determine the minimum thickness of loose or dense strata which can be reliably detected by the cone penetrometer.

The investigation consisted of a number of calibration tests and cone penetration tests performed on specimens of saturated fine sand confined in a steel tank  $6\frac{1}{2}$  ft high by  $3\frac{1}{2}$  ft in diameter. Surcharge loads up to 100 psi were applied to the top of the specimens by three hydraulic jacks. A view of the cone penetrometer and assembled test apparatus is shown (Fig. 2).

Calibration tests were made to determine the decrease in normal pressures with depth developed within the tank filled with fine sand placed at relative densities of 90, 65, and 40 per cent. Penetration tests were made on specimens constructed to the same densities as the calibration test specimens and on loose specimens with 12-, 6-, and 3-in. dense built-in strata, and on dense specimens with 12-, 6-, and 3-in. loose built-in strata. All specimens were subjected to 30-, 60-, and 100-psi surcharge pressures during testing.

The relationships between cone thrust and normal pressure for the densities of sand tested are shown (Fig. 3). Since the overburden pressure in the field can be estimated, it should be possible to determine the density in the sand tested by measuring the cone thrust and computing the overburden pressure on the basis of the depth and average unit weight of the material. The tests also showed that the presence of 12-, 6-, and 3-in.-thick built-in strata could be detected, although a 6-in. stratum probably is the minimum thickness for which the relative density may be reliably obtained. Thus the correlations desired were determined for a fine sand

### Change in Density Caused by Sampling

The second series of tests consisted of undisturbed sampling of a fine sand and a medium-fine sand, contained in the same tank used for the penetration tests. Four



FIGURE 2 View of cone penetrometer and assembled test apparatus.

specimens were prepared, two of fine sand placed at relative densities of 20 and 90 per cent, and two of medium-fine sand placed at relative densities of 24 and 90 per cent.

The relative densities were chosen to simulate the extremes of natural densities suspected to exist in the field. Pressure cells were placed in the specimens to determine pressures at certain depths within the sand placed at various densities and to determine the changes in pressure during sampling. The specimens were subjected to surcharge pressures up to 100 psi.

Three 30-in.-long undisturbed samples, one at each of three surcharge pressures, were obtained from each specimen with a 3-in.-diameter Hvorslev fixed-piston thinwalled, steel tube sampler. The samples were cut into 3-in. increments and the variation of change in density was determined with respect to surcharge pressure and



Cone thrust vs normal pressure in tank for fine sand at various densities.

height of increment in the sample tube. The analysis of data indicated that the change in density during undisturbed sampling of sand is dependent on overburden pressure and location within the sample tube. In general, loose material increased in density and dense material decreased in density during sampling.

Correction factors, based on a comparison of the measured density of sampled increments with placement density, were developed for both overburden pressure and location of the increment in the sample tube. The combined correction factor generally amounted to less than 1 pcf, or about 5 to 6 per cent in relative density for the middle 18 in. of the 30-in. sample for conditions commonly encountered in the field. It was concluded that the change in density which occurs during undisturbed sampling of sand is not a serious problem.

## Field Investigation

A field investigation was conducted on a Mississippi River bank to determine if cone penetration data obtained from the tank tests could be used successfully to determine the relative densities of deep sand deposits in the field. Two undisturbed sample borings and two cone penetrations were made in an area where the thickness of fine sand was known to be at least 35 ft. One undisturbed sample boring was located 5 ft from each cone penetration, and 30-in.-long undisturbed samples were obtained at  $3\frac{1}{2}$ -ft intervals of depth, using the same sampler



FIGURE 4 Data from boring U-1 and cone penetration C-1.

as that described previously. Cone penetration resistance was measured for each 0.1 ft of penetration.

Data from one undisturbed sample boring and one cone penetration are shown (Fig. 4). The undisturbed field samples were cut into 3-in. increments and the densities determined. The relative densities of selected 3-in. increments were determined by laboratory test and these data are shown on the right-hand plot of Figure 4. The relative densities based on cone penetration resistance and laboratory correlations shown on Figure 3 are also shown on the right-hand plot of Figure 4.

The data indicate that the relative density of fine sand estimated on the basis of cone penetration resistance can be verified within about 10 per cent by the computed relative density determined from an undisturbed sample. The cone is sensitive to changes of relative density and shear resistance, and therefore should be considered an effective tool for estimating the shear resistance of deep sand deposits.

## ABSTRACTS OF OTHER AMERICAN PAPERS

Brief resumés of subjects presented at the Soviet seminars by the exchange visitors follow. These are papers which had previously been presented or published in the United States.