Strength of Sand During Vibration

La Résistance des Sables Pendant la Vibration

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Summary

The results of shear tests of sand, subjected to vibration, differ substantially from one another. We believe that this difference is caused by the fact that the shear forces and normal forces can interchange in different ways. Therefore, it is necessary to investigate each problem separately.

For the purpose of machine foundations we investigated the bearing capacity of sand on a small-scale model which was subjected to vibration by a small vibrator. The adjacent surface of the sand was loaded by means of small plates.

The following results of these tests were obtained: (a) at the static tests as well as at the dynamic tests a considerable influence of the density of sand on the bearing capacity appeared (taking no account of the settlement); (b) the bearing capacity of a foundation is considerably reduced if the surrounding surface is only a little loaded, but if this loading is considerable (the depth of the foundation level great) there is no difference in bearing capacity at the static and dynamic tests.

Sommaire

Les résultats des essais de résistance au cisaillement pendant la vibration diffèrent considérablement. Nous supposons que cette différence peut être expliquée par le fait que les forces de cisaillement aussi bien que les forces normales peuvent changer réciproquement d'une manière très variée. C'est pourquoi chaque problème doit être traité d'une manière individuelle.

Dans le but d'étudier les fondations pour machines, nous avons fait des essais sur la charge de rupture du sable sur un modèle réduit; il fut soumis à des vibrations produites par un vibrateur. La surface du sable environnant fut chargée par plusieurs dalles.

Les résultats principaux des essais sont les suivants: (a) les essais statiques aussi bien que les essais dynamiques ont montré l'influence considérable de la densité du sable sur la charge de rupture de la fondation (en négligeant les différences dans le tassement); (b) si les environs de la fondation sont peu chargés, la charge de rupture de la fondation pendant un essai dynamique est considérablement plus petite que pendant un essai statique. Si la charge sur les environs de la fondation est considérable (la profondeur de la fondation assez grande), il n'y a pas de différence dans la charge portante dans l'essai statique ou dynamique.

Importance of Measurement

The problem of the strength of sand during vibration is of great importance for the structural engineer when designing machine foundations, retaining walls, etc. In these designs should we take into account a considerable reduction in the strength of sand? Different viewpoints are to be found in the technical literature: for example, L'HERMITE and TOURNON (1948) present the results of box shear tests, according to which the strength during vibration has sunk nearly to zero, while, on the other hand, KREY (1936) asserts that the angle of the natural slope at vibrations was only about 1½ degrees smaller than the one at rest.

We suppose that the variety of results is caused by the fact that in each different case an individual change of normal stresses and shear stresses occurs. Both stresses can originate from different external forces, which can vibrate in different phases. Thus it is possible, for instance, for the normal stress to diminish at the same time when the shear stress grows. It is possible that the results of the different tests would correspond if we knew in each individual case the law according to which the normal and shear stresses change.

As we do not know such a law we therefore think that for each practical problem we have to introduce a test in the form of a small model of a given structure. We thus set ourselves a task, to find how the bearing capacity of sand changes when subjected to the pressure of a machine foundation, and have tried to substitute a small-scale model, having relatively reduced dimensions, for a foundation. As variability of normal and shear forces originates from the same source, namely the pressure of the foundation, we presumed that the reduction of the strength of sand would not be too considerable.

Testing Apparatus

Testing apparatus is shown schematically in Fig. 1. In a 40 × 10·2 × 22·4 cm box, filled with sand, a 6 × 10 cm loading plate was installed. The loading force was introduced by means of a rod which was pulled by a screw and the force was measured by means of a loading ring. When carrying out dynamic tests a rotating vibrator was set up on the loading

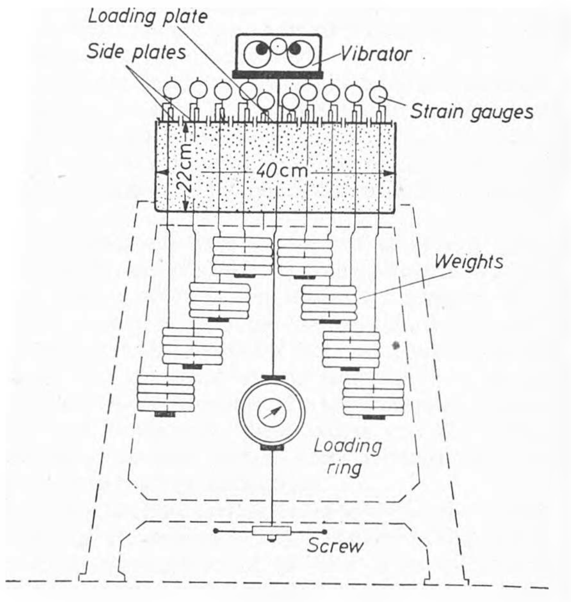

Fig. 1 Testing apparatus
Appareil d'essai

plate. The sand surface near the loading plate was loaded by means of small plates (4 × 10 cm) so that the slip surface could originate quite freely. These small plates were loaded by means of weights; the loading of the sand surface was from 0·17 to 0·55 kg/cm².

The sand used for the test had round-shaped grains, measuring from 0·5 to 2 mm in diameter; when freely poured, the dry sand stayed at an inclination from 35 to 36 degrees.

During the test the movements of the plates were measured by means of strain gauges. The bearing capacity of the central loaded plate was considered to be surpassed when one of the side plates began to rise. In nearly all cases it was the external plate; never was it a plate adjacent to the central plate, as the Fröhlich theory would indicate. On the contrary, this plate sank in each case with the central plate and inclined towards it.

At the dynamic tests frequencies of 1500 and 3000 per min were used. The rotating weight of the vibrator involved a vibrating force of 3·9 kg in the former case and 15·7 kg in the latter; this represents nearly 2 to 4 per cent of the total weight of the sand, plates, weight and vibrator. We presume that these relations correspond to those of machine foundations; nevertheless, the vibrating force is not included in the magnitudes in the following diagrams, where only a mean reading of the loading ring is given.

During each test, static as well as dynamic, the central plate was pushed into the sand at the same speed. One test lasted for about 5 to 6 min.

As the density of sand greatly influences bearing capacity the sand after each test was prepared again so as to have the required porosity. On the whole, 66 tests were performed.

Test Results

Static tests—In Figs. 2 and 3 the results of static tests are reproduced by a continuous line and marked by an abbreviation Stat. Fig. 2 shows a dependence of bearing capacity q upon

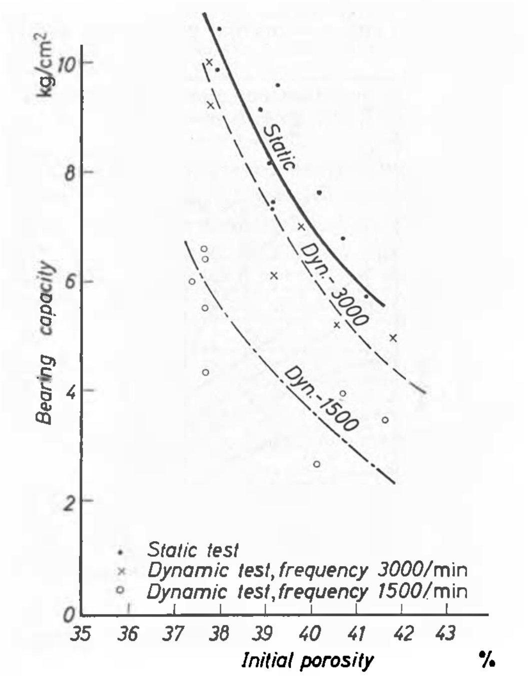

Fig. 2 Influence of initial porosity on bearing capacity; $p = 0{\cdot}3$ kg/cm²
Influence de la porosité initiale sur la force portante: $p = 0{\cdot}3$ kg/cm²

the density (porosity at the beginning of the test), the side loading being $p = 0{\cdot}3$ kg/cm². Great influence of the porosity of sand is to be noticed. Fig. 3 shows a dependence of bearing capacity upon loading of the side plates p at the porosity of 38 and 40 per cent (at the beginning of the test).

When using bearing capacity factor $N_q = q/p$ and taking for N_q values given by Meyerhof, an angle of shear of about $\phi = 33$ to 34 degrees corresponds to bearing capacity for a line with porosity of 38 per cent. For a line with porosity of 40 per cent a shear angle of about 29 to 32 degrees corresponds.

Dynamic tests—In Figs. 2 and 3 the results of dynamic tests are marked by an index Dyn., with annotated frequencies of 1500 or 3000 per min. Fig. 2 shows again a considerable dependence of bearing capacity upon the porosity.

Fig. 3 shows a dependence of bearing capacity upon the side loading p. The test with a vibrator frequency of 1500 per min gave a smaller bearing capacity than the one with a frequency of 3000 per min, because of the signs of resonance at 1500 per min.

Fig. 3 shows that at small side-loading p the reduction of bearing capacity in dynamic tests was considerable. When the total weight of the sand, plates, weights and vibrator was nearly 100 kg and when the vibrating force was 4 kg, bearing capacity fell to 60 per cent. When taking N_q according to Meyerhof,

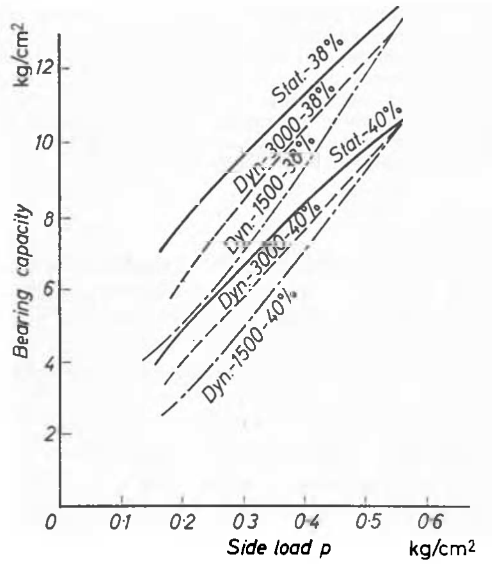

Fig. 3 Influence of loading p on the surface adjacent to the loading plate on bearing capacity
Influence des charges énvironnantes p sur la force portante

the corresponding reduction of ϕ is from 32 to about 18 degrees. When the total weight of the influenced masses was about 220 kg and the vibrating force was 4 or 16 kg, the bearing capacity remained nearly the same at the static and dynamic tests.

Porosity—For the sake of completeness the dependence of the results upon porosity at the time of reaching the bearing capacity was also studied; approximately similar results to those encountered in dynamic tests were obtained.

Summary of Results

(a) When testing bearing capacity of the plate laid upon sand there results a great influence of the porosity both at the static as well as at dynamic tests.

(b) When loading the surface adjacent to the loading plate by only a small pressure (e.g. 0·2 kg/cm²) the bearing capacity at the dynamic tests diminished to about 60 per cent. It is the same as if ϕ diminished from 32 to about 18 degrees.

(c) When loading the surface adjacent to the loading plate by a considerable pressure (e.g. 0·5 kg/cm²) the bearing capacity at the dynamic test was the same as at the static one. This indicates how considerable the influence of the side loading p is in the design of machine foundations.

References

L'Hermite, M. R. and Tournon, M. G. (1948). La vibration du béton frais. *Annales de l'Institut Technique*

Krey, H. (1936). *Erddruck, Erdwiderstand und Tragfähigkeit des Baugrundes*, p. 16. Ernst, Berlin