On the Problem of the Dynamic Stability of Soils

A Propos du Problème de la Stabilité Dynamique du Sol

G.SPERLING Dr.-Ing.,
H.HAUSNER Dr.-Ing., VEB Baugrund Berlin, G.D.R.

SYNOPSIS

The paper deals with the parameters, which are characteristic of the dynamic stability behaviour of cohesionless soils (sands), exited stationary by machine foundations. Analyses on machine footings, performed in a wide range, resulted in empirical relations between the dynamic and soil mechanics parameters.
These analyses were carried out on dynamically loaded machine foundations resting on a ground consisting of uniform sands (fine sands, medium sands, and coarse sands, respectively).

INTRODUCTION

Damages, occuring in connexion with machine foundations on cohesionless soils (sands), detect, that the problem of the dynamical stability of cohesionless soils is not satisfactorily solved to date.
Hitherto a solution of this problem was generally tried by subjecting sands or other granular materials to a dynamical loading. Thereby the material was in containers fixed on a vibrating table. These tests led to empirical functions, relating changes in the compactness and the void ratio, respectively to the applied dynamic parameters.
However, all tests carried out under laboratory conditions are disadvantageously, for they are relative far away off the conditions, actualy found in praxis.
The problem under consideration was therefore treated under a different aspect, namely by an investigation of the dynamic and soil mechanics parameters of machine foundations in the case of stability or instability immediatedly in situ.

INVESTIGATIONS IN SITU

For establishing a relation between the dynamic and soil mechanics paramters, measurements of the vibrations of about 400 foundations of machine with stationary excitation of the ground were performed (reception of the vibrations on a piezoelectric base). On each machine foundation were placed 6 to 10 measuring stations (Fig. 1), in which the following frequency-independent dynamic parameters were measured:

- total velocity : $\tilde{v}$ mm/s
- total acceleration: $\tilde{b}$ m/s^2
- total path : $\tilde{a}$ μm

The total velocity $\tilde{v}$ is thereby defined as the effective value of the vibrating velocity as follows:

$$\tilde{v} = \left[\frac{1}{T} \int_0^T v^2(t)\, dt \right]^{\frac{1}{2}}$$

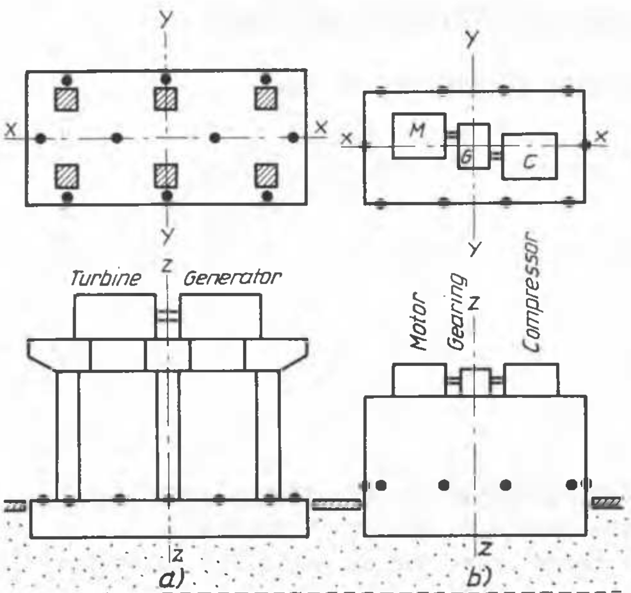

Fig. 1
Arrangement of the measuring stations on the machine foundations
a) Frame foundation of a steam turbine
b) Monolithic foundation of a turbo-compressor

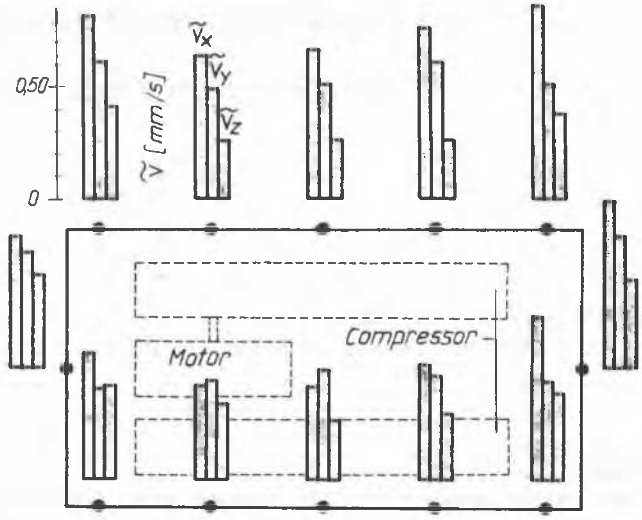

Fig. 2
Representation of the total velocities $\tilde{v}_x$, $\tilde{v}_y$, and $\tilde{v}_z$ in mm/s, recorded from the monolithic foundation of a twin-compressor

Herein is:

$\tilde{v}$:Effective value of the vibrating velocity

v (t):Instantaneous value of the vibrating velocity

T :Duration of a period

The definitions for the total accleration b and the total path a are analogous equation (1).

Fig. 2 shows the total velocity measured on a machine foundation.
In addition the frequency - dependent dynamic parameters were measured at the individual measuring points in the frequency range of $f < 5$ Hz (fig.3).
The following soil mechanics parameters were evaluated:

- Density index I_D
- non - uniformity U
- Particle size
- Particle shape

In general the density index showed results in the range $0.10 < I_D < 0.70$ and the uniformity coefficient in the range of $1.2 < U < 3.8$

EVALUATION OF THE MEASUREMENTS

The dynamic parameters measured at the machine foundations were related to the corresponding soil mechanics parameters.
It had to be ascertained, whether a legal relation exists between the parameters in the cases of stability and that of instability.
For this purpose the following conceptions are defined as follows:
Case of stability:
The grain skeleton of the sands remains stable when subjected to dynamical forces, i.e. the sands below the machine foundation will not compact.
Case of instability:
The dynamic action causes, that the sands vibrate, i.e. a dynamic caused settlement of the machine foundation takes place.

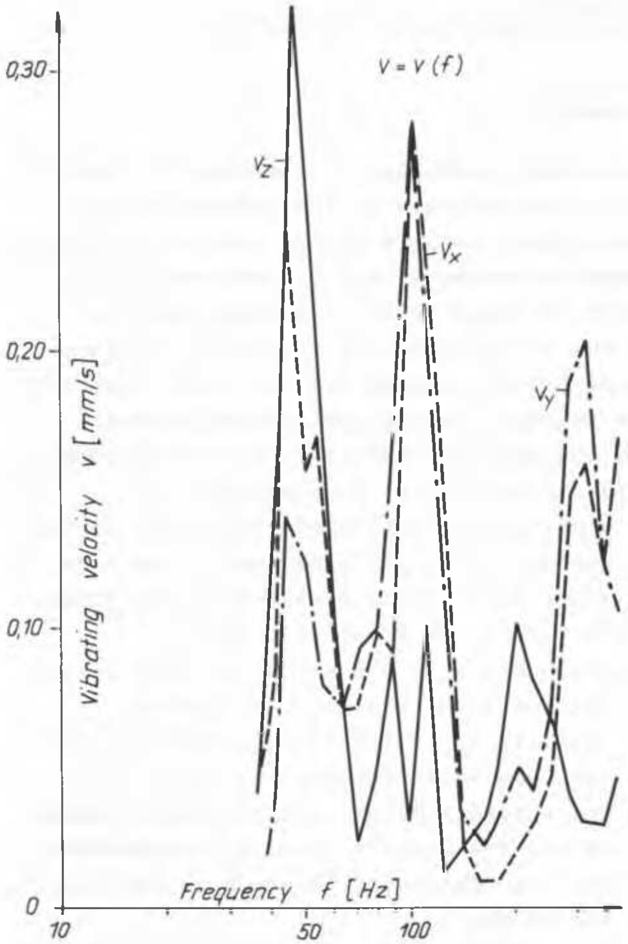

Fig. 3
Frequency - velocity - diagram of the monolithic foundation of a turbo-compressor

The corresponding dynamic and soil mechanics parameters $\left[I_D; \tilde{v}_R\right]$, $\left[I_D; \tilde{b}_R\right]$ and $\left[I_D; \tilde{a}_R\right]$ were plotted in a specific semi-logarithmic coordinate system. The index R indicates the space vector, for example

$$\tilde{v}_R = \left[\tilde{v}_x^{\,2} + \tilde{v}_y^{\,2} + \tilde{v}_z^{\,2}\right]^{\frac{1}{2}}$$

The figure 4 shows the relation based on the vibration velocity.
A curved line can be drawn the total velocities of the cases of stability and those of the cases of instability, which can be defined as a stability limit.
The total velocity corresponding to this stability limit is identical with the concept of the "critical velocity" or the "limiting velocity" /1/.

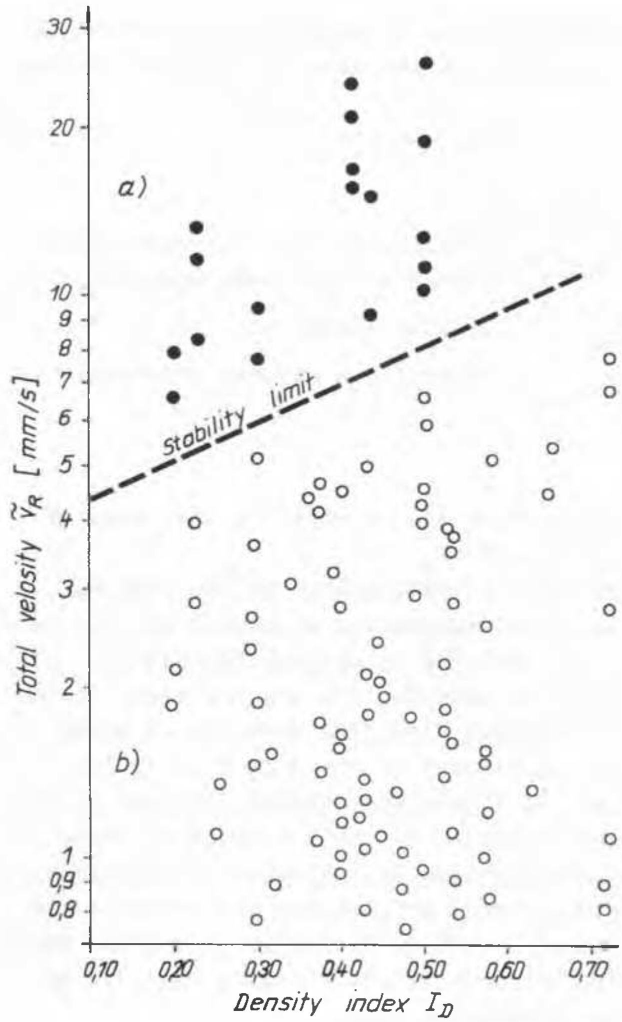

Fig. 4
Maximum space vector of the total velosity $\tilde{v}_R$ of machine foundations in the case of stability as a function of the density index I_D of uniform sands
a) Range of the dynamic instability of the subsoil
b) Range of the dynamic stability of the subsoil

With the critical velocity of a cohesionless soil is meant the vibrating velocity, at which for a certain compactness the

sand is just beginning to vibrate, i.e. the dynamic compaction starts.
Thereby one gets the following result:
It is possible to evaluate by approximation the critical velocity of a cohesionless soil, excited stationary by a machine foundation, by an exponential function in dependence of the density index as follows:

$$\tilde{v}_{R\ crit} = 3.71 e^{1.54\ I_D}$$

Herein is:

$\tilde{v}_{R\ crit}$: Critical velocity in mm/s (space vector of the total velocity)

I_D : Density index

e : Base of the natural logarithm

The equation (2) is valid in the range of about $0.10 < I_D < 0.70$
Analogic investigations on the base of the total acceleration as well as the total path had no satisfying result.
From the equation (2) one can argue, that the dynamic stability behavior of sands is independent of the direction of the applied vibrations. BARKAN /2/ came to the same results. Within the scope of these investigations an influence of the particle size as well as the particle shape on the dynamic stability behaviour of uniform sands was not ascertained. This is regarded as an interesting fact.
SCHAFFNER /3/ could prove under laboratory conditions that the particle size is not influencing the dynamic compaction of granular materials.

APPLICATION

The existing experiences have shown that the measures for the judgement of the dynamic stability behaviour of uniform sands, established on the basis of the total velocity, enable a safe and economical design of machine foundations on a cohesionless soil with satisfactory accuracy.

SUMMARY

Analyses, performed on the basis of extensive measurements of the vibrations on stationary excited foundations of different types of machine, led in the case of uniform sands to the following results:

- Out of the group of frequency - independent dynamic parameters the total velocity is suitable for an approximate estimate of the dynamic stability of uniform sands, underlying machine foundations.
- A satisfactory accurate judgement of the dynamic stability behaviour of uniform sands is possible by means of the space vector of the total velocity.
- The equation of the stability limit, i.e. the function relating the limiting velocity $\tilde{v}_R$ to the density index I_D has the form of an exponential law
- The compactness of uniform sands, expressed by the density index I_D, represents the main parameter of the soil mechanics parameters
- The particle size and the particle shape have no detectable influence on the dynamic stability of uniform sands.
- The stability behaviour of uniform sands is independent of the direction of the applied vibrations.

REFERENCES

/1/ HAUSNER, H. (1971)
"Dynamic stability of cohesionless soils, stationary excited by machine foundations", Dissertation, Technische Universität Dresden

/2/ BARKAN, D.D. (1959)
"Vibrational method in civil engineering",
Gosstrojizdat, Moscow

/3/ SCHAFFNER, H.J. (1965)
"Diminution of the slope angle and settlements of soil aggregates when dynamic excited in relation to the particle and structure properties", Mitteilungen der FAS, Heft 15