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EXPERIMENTAL ANALYSIS OF THE DYNAMIC STRESS DISTRIBUTION AT THE SOIL FOUNDATION INTERFACE

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ABSTRACT

This paper presents the dynamic stresses within the soil-foundation interface zone measured by an experimental process. The cubic foundation prototype is subjected to a cyclic loading directly generated by the testing machine at the foundation center. The stress enhancement induced by the dynamic loading may lead to a partial confinement with an eventuality of instability risks or resistance loss; showed by a particle rearrangement. The tests have been conducted on two soil samples namely dense and medium dense sand. Experimental displacements, measured at the soil foundation interface are represented, as a function of the number of cycles, for a constant stress level. The dynamic behaviors of used sample soils are analyzed and some concluded remarks are presented.

Keywords: Interaction soil-structure; dynamic loading; stresses; displacement; density

1. INTRODUCTION

The generated soil vibrations may be very important, causing by the way great source of annoyance for structures such as fatigue, and settlement phenomena; the interaction soil-structure will be important phenomena to take into account while analyzing the real behavior of a structure.

Many seismic table experimentations have been conducted on structures supported by surface foundation [1-2]. These tests have shown that the foundation uplift play an insulating role reducing the base forces.

Special tests much more appropriated are recommended for a consistent force case (centrifuge test, cyclic triaxial test, etc.) [3-7]. However, these laboratory tests require the confinement and the soil consolidation in order to recreate real site conditions. Within the laboratory test category, the dynamic centrifuge tests have been currently used to study complex boundary problems related to the soil structure interaction [8-9]. Also the effects of foundation mass, foundation size, foundation shape, foundation embedment depth, and soil density on load deformation have been explored by this technique. Experimental data collected from these tests are used to compare the numerical predictions from different finite element codes. The effect of the foundation mass, shape, soil density and the deformation load have

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explicitly been shown in order to determine their impact on the dynamic response [10-13].

This article presents the experimental determination of the dynamic stresses distribution generated at the soil foundation, measured during the test. The stresses are obtained directly from the dynamic displacement collected trough a displacement captor, Figure 1. The experimental approach used herein is similar to the simple case of foundation disposed on homogenous elastic soil as it is specified by the European program framework (TRISEE 98) [14] for dynamic cyclic tests performed on a superficial square foundation.

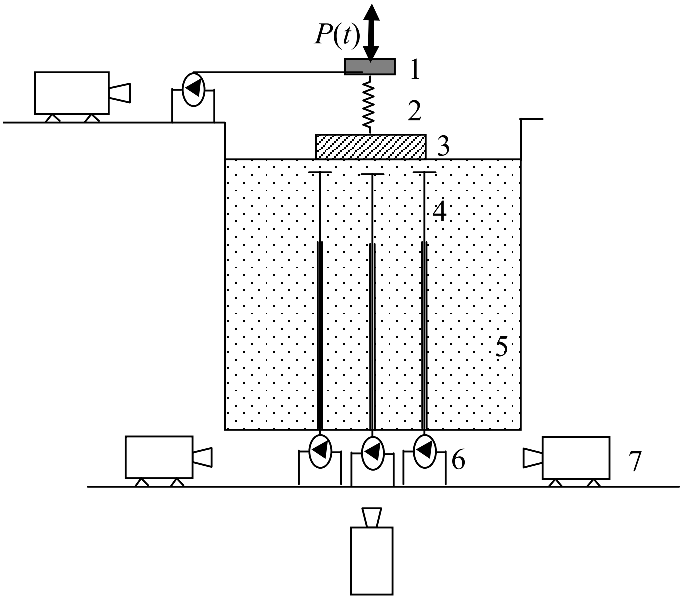

Figure 1. Testing model for measurement of dynamic displacement

1: Repartition steel plate
2: Spring
3: Foundation prototype
4: Measuring rod with guiding system
5: Soil sample
6: Displacement transducer
7: Video recorder

The test will establish the comparison with cyclic tests conducted on dense (SSD) and medium dense (SSMD) sands [15] under different vertical stresses.

The test series for the both sand types (index of density Id = 0.7 and Id = 0.9) have been carried out in three points of the interface zone (Figure 2), (x=0 , y= 0) ; (x=3a/2 ,y=0) and (x= −3a/2 , y= −3a/2) in order to characterize the soil dynamic response generated by the foundation prototype under the cyclic loading for the following loading conditions: amplitude of the excitation load $P(t)$ = 1000 N, period = 0.6 s, contact pressure = 45 kPa.

$$Id = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \quad (1)$$

e: index of voids in the natural state
e_{max} : index of voids in the lightest state of the material
e_{min} : index of voids of the material in its most compact state

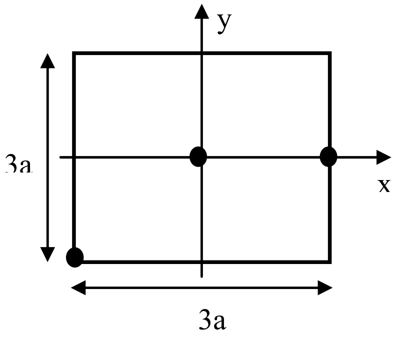

Figure 2. Measurement points at the soil foundation interface

According to Brumund and Leonards [4] the allowable load value q_u is taken within the load interval (0.3, 0.5) q_u determined from the engineering practice bases. Making sure that the contact pressures remain elastic and proportional to the vertical displacements, the ultimate vertical load capacity of the foundation may be estimated as follows:

$$q_u = \frac{w}{A_s} \tag{2}$$

w: foundation weight
A_s: foundation area

2. EXPERIMENTAL MODEL

The harmonic load is generated directly from the vertical cyclic motion of the axles of machine. The machine is able to simulate harmonic loading with different amplitudes and various operating frequencies. The harmonic motion is transmitted to the soil sample through the concrete foundation prototype, placed on the upper face of the soil sample. The soil samples used in this study, are cubic shape with cross area As (0,6 x 0,6 m^2) and a height hs = 0,60 m , giving a soil volume Vs=0,205m^3. The foundation prototype is square shaped having an area 0.15x 0.15m^2 and a thickness of 0,05m. Both foundation prototype and soil sample are correctly centered with respect to the vertical axis, before testing.

The measurement collect is based on a simple experimental process (Figure1) that consists of reading the resulting displacement established by the video recording; so the linear relation between the forces and displacements is:

$$F=KU \tag{3}$$

K: soil stiffness.
U: displacement collected by the displacement captor.

The measurement of the dynamic displacement resulting from an excitation load F with a corresponding operating frequency, recorded by video is used to establish the time related variation of the dynamic stresses in the elastic field as follows:

$$\sigma = \frac{KU}{A_s} \tag{4}$$

σ : vertical stress under the foundation.
A_S : foundation area.

The foundation is subdivided into nine sectors (Figure 3) according to the number of the disposed displacement captors, every sector having an area 0,05x0,05 m^2 .The measure of the vertical stresses will be respectively the same at the corners , at the edges and at the center .

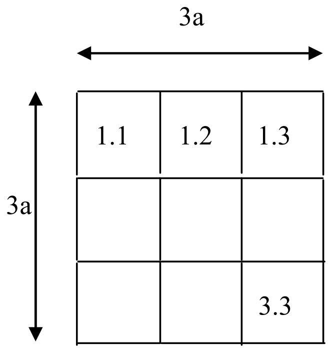

Figure 3. Subdivision scheme of the foundation prototype

The conservation of the balance with the impact load induced by the machine is obtained by a uniform distribution of vertical stresses under the prototype foundation; this state may be expressed as:

$$F = \int\int \sigma.ds \tag{5}$$

The impact load can be defined by a discrete extrapolation of the vertical stress at each sector through the form as follows:

$$F = \Sigma \sigma_i s_i \tag{6}$$

σ_i: stress within the sector i,
s_i: contact surface at the level of sector i

According to a uniform vertical stress distribution on every sector at each loading cycle within the interface zone, that is to say that the distribution will be looked along the center or along the edge as presented in (Figure 4), we notice that the value in the center is each time superior.

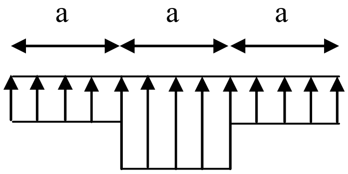

Figure 4. Vertical stress repartition

3. CHARACTERISTICS OF THE SOIL SAMPLES

The soil samples come from north east of Algeria (Constantine) at quarry of Oued Zhor for dense sand and quarry of Chaabet El Madbouh for medium sand, the essential physical soil properties have been established at Fondasoil Laboratory (Soil Mechanic Laboratory at Constantine) are presented in the Table 1.

Table 1: Geotechnical soil characteristics

Type	**Density**	**Poisson' coefficient**	**Water content %**	**Void index e**
Dense sand	2.09	0.33	19	0.51
Medium dense sand	1.99	0.37	25	0.67

3. RESULTS

The Figure 5 shows the vertical displacement evolution for the two types of sand at the foundation center, as a function of the number of cycles, under a contact pressure of 45 kPa. The displacement captors disposed in the interface zone at the distance hs/10 from the contact surface revealed that the displacement in the medium dense sand case is more important than the displacement in the dense sand case, and the established curves show approximately the same standard deviation as those elaborated by Bian and Nishimura [15] for the same sand types and a loading value of 100 kPa. We also notice that the displacement reduces with the increase of the density index (Id), Table 2. Our dense sand stands out rapidly but with little displacement variations because of an important density.

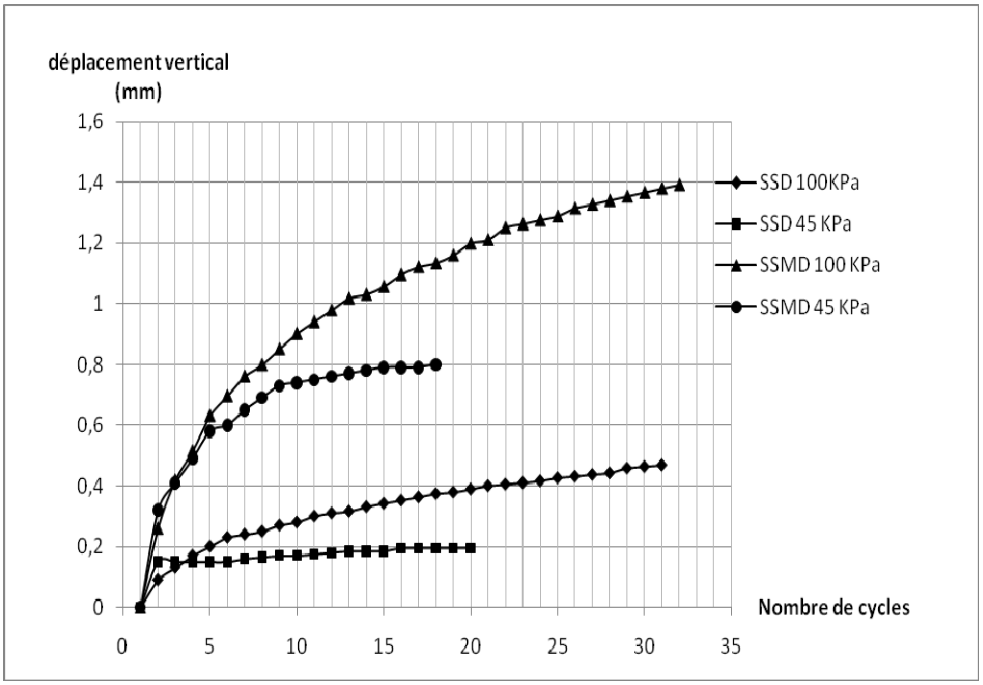

Figure 5. Vertical displacement at the foundation center versus the number of cycles (SSD: dense dry sand; SSMD: medium dense dry sand)

Table 2: Curve Identification

Authors	Series	Density index	Soil nature	Loads
BIAN	SSMD	Id = 0.6	Medium dense sand	100 kPa
BIAN	SSD	Id = 0.9	Dense sand	100 kPa
Present study	SSMD	Id = 0.7	Medium dense sand	45 kPa
Present study	SSD	Id = 0.95	Dense sand	45 kPa

4. STRESS ANALYSIS

The Figures 6 and 7 show the vertical stress dimensionless variations under dynamic loading in the interface zone. These stresses have been estimated from the experimental measurement data in the interface zone for the previously specified points (Figure 2) for our two types of sand.

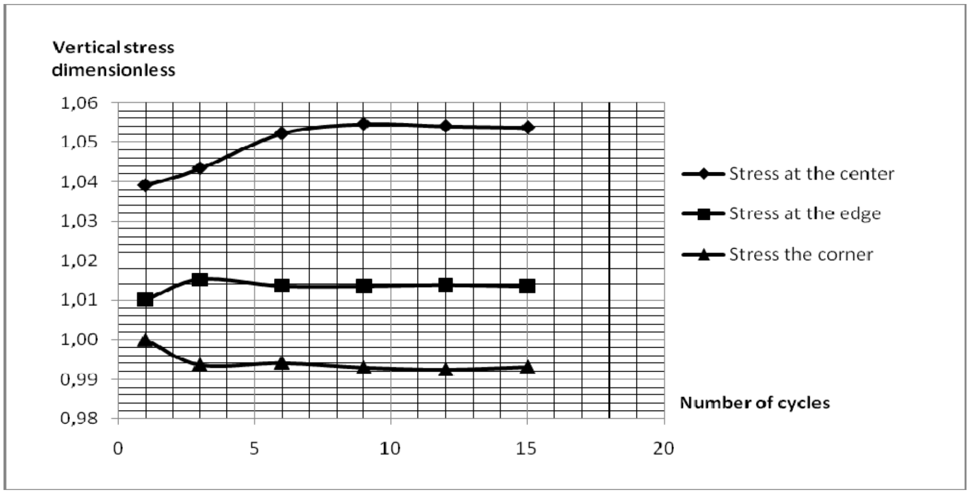

Figure 6. Vertical stress variation versus the number of cycles for the medium dense sand.

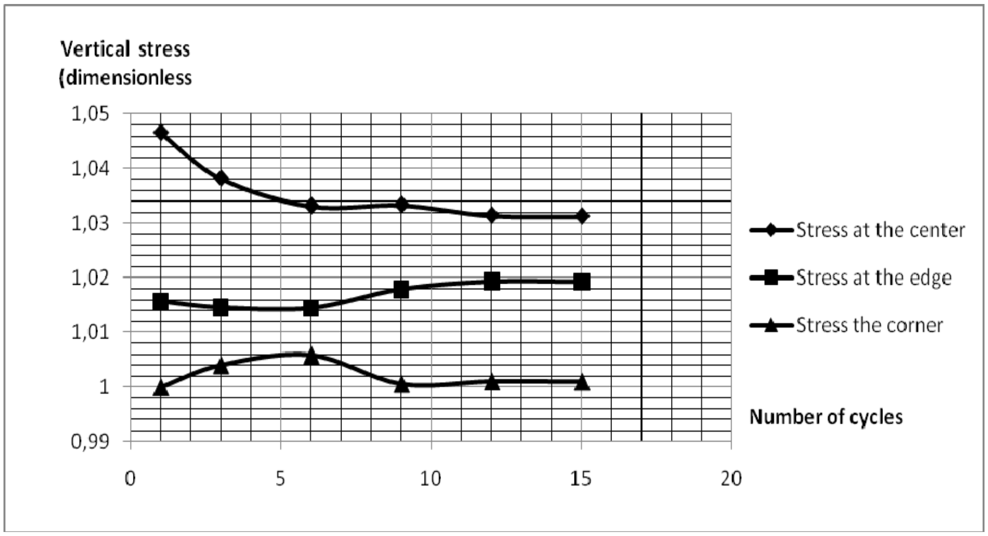

Figure 7. Vertical stress variation versus the number of cycles for the dense sand

We notice from Figures 6 and 7 when the SSMD is considered that the centre stresses increase considerably for the nine first cycles (500pa) and stabilize at the end (18th cycle) . In the same manner for the edge stresses where the increase is very important for the three first cycles (200Pa) reaching their stabilization rapidly. However, the corner stresses diminish for the three first cycles before to reach their stabilization. It is also shown when the SMD (dense sand) case is considered that the axial stress diminishes in a non negligible manner until the 6th cycle (400Pa) before to stabilize. The corner stress exhibits the same behavior with much more variation (200Pa) for the first six cycles before to stabilize. A stress enhancement is registered at the corner until the 6th cycle (200Pa) before the stability is reached. The dense sand would have a tendency to transmit the stress excess towards the foundation corner.

5. CONCLUSION

Laboratory tests presented within this paper are used to estimate soil dynamic stress induced by a vibrating foundation prototype and thus for three specific points of the foundation–soil interface zone. The testing prototype used gives satisfying results for simulating a superficial foundation behavior under a cyclic and dynamic loading. The influence of soil density has been studied and two types of sand have been considered (dense and medium dense).The obtained results at different locations of the foundation prototype show that an increase in the density for the medium dense sand due to the particle retightening at the central zone level leading to an increase in its density. In the dense sand case the axial overstresses would have the tendency to be transmitted to the corners because of the initial confinement.

The dynamic settlement test gives the possibility to envisage specific tests in the design process of industrial installations with reduced costs, enabling a better understanding of the future soil behavior under vibrating machines. Besides the classic tests, the presented test offer more facilities than in situ tests. Nevertheless, much more research work is needed concerning the apparatus dimensions and its sophistication.

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