Dynamic pre-loading for large diameter bored piles

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ABSTRACT: Foundations on large diameter bored piles in soft and medium dense non-cohesive soils will become more economic if the soil beneath the pile is densified and if the stiffness of the soil is measured in a real-time process. The process comprises several steps, among them a preliminary design, excavation to preliminary pile point elevation, dynamic treatment of the bottom of excavated borehole while acceleration/retardation and strains are recorded, and an iterative calculation of static deformability of the soil based on the dynamic deformability. The dynamic loading is transferred to the soil by means of a heavy ram dropped onto a steel body instrumented with accelerometers and strain gauges.

KEYWORDS: bored piles, pre-loading

1. INTRODUCTION

Foundations on large diameter bored piles in soft and medium dense non-cohesive soils will become more economic if the soil beneath the pile is densified and if the dynamic stiffness of the soil is measured and interpreted to the static stiffness.

By dynamic pre-loading non-cohesive soils are densified and the load settlement relation is analyzed in a real-time process after excavation before casting the concrete.

The process is presented in Diagram 1 and comprises the following details.

1 A preliminary pile design results in a preliminary pile length, allowable skin friction resistance and required pile point resistance.

2 Allowable pile settlement and settlement difference between piles due to the expected loading situation is decided.

3 Excavation is made to the preliminary pile point elevation.

4 Dynamic treatment is performed of the bottom of the excavated borehole. Data on acceleration/retardation and strains are recorded.

5 Dynamic deformability of the soil is achieved in a first step of analysis.

6 Static deformability of the soil is interpreted from the dynamic deformability in an iterative analysis.

7 Acquired load and settlement data is compared with requirements. If requirements are fulfilled the process is ended and the pile is cast. If requirements are not fulfilled the pile design is revised with a lower pile point elevation and the process starts all over.

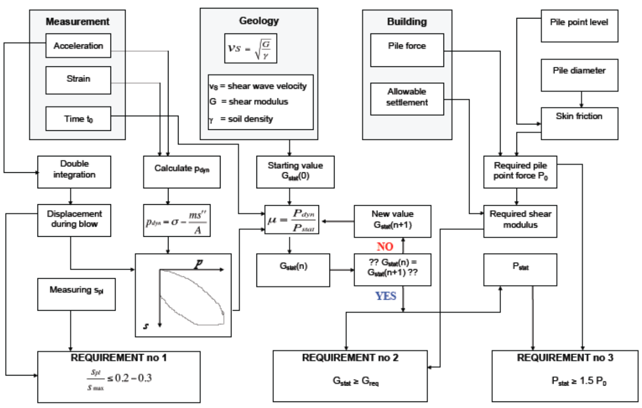

Diagram 1 Dynamic preloading process

2. EQUIPMENT

The dynamic loading can be transferred to the soil in the bottom of the excavated borehole by means of a heavy ram dropped onto a steel body instrumented with accelerometers and strain gauges.

The equipment comprises

- Hammer, 4 tons, 4 m length
- Steel body, diameter 0.85 m, with an instrumented unit
- Data acquisition and processing unit

The instrumented unit is equipped with accelerometers and strain gauges. In the data acquisition unit an oscilloscope and a computer is used for processing.

3. DATA RECORDING AND PROCESSING

The contact pressure between the steel body and the soil and the displacement during loading is calculated from recorded data.

$$p_{dyn} = \sigma_x - \frac{m_x \cdot s''}{A} \quad (1)$$

$$s = \iint s''\,dtdt \quad (2)$$

In case of a stiff body on an elastic half-space the shear modulus of the soil is expressed as

$$G = \frac{p}{s} \cdot \frac{D}{4} \cdot \frac{1-\upsilon}{2} \quad (3)$$

where

p static contact pressure

D diameter of the body

υ Poisson's ratio

Calculation starts from an initial empirical value $G_{stat}(0)$ of the shear modulus and results in a shear modulus $G_{stat}(1)$ and is repeated until in- and out-going moduli are the same.

The dynamic pre-loading has reached its purpose when requirements of static force and settlement are achieved. Required safety margin to bearing capacity failure is achieved when

- soil is hardening (decreasing plastic ratio)
- maximum displacement is close to linear at maximum dynamic force.

4. RELATIONSHIP BETWEEN DYNAMIC AND STATIC LOADING

Lysmer & Richart (1966) stated the relationship

$$\frac{P_{dyn}}{P_{stat}} = k_1 + c_1 \cdot \left(\frac{D}{2 \cdot v_S}\right) \cdot \left(\frac{s'}{s}\right) \quad (4)$$

where

P_{dyn} dynamic force
P_{stat} static force
k_1 coefficient dependent on the elastic behavior of the soil
c_1 coefficient dependent on the viscous behavior of the soil
D diameter of the foundation
v_S shear wave velocity
s displacement
s´ displacement rate

Assumptions for equation (1) are a weightless foundation and that loading is continuous and sinusoidal. Assume now that the force due to a weight dropped onto soil is sinusoidal and reach maximum after time t_0. Average displacement rate is

$$s' = \frac{s}{t_0} \quad (5)$$

Equation (4) and (5) give

$$\frac{P_{dyn}}{P_{stat}} = k_1 + c_1 \cdot \frac{D}{2 \cdot v_S \cdot t_0} \quad (6)$$

Coefficients k1 and c1 are dependent on the frequency factor a_0

$$a_0 = \omega \cdot \frac{D}{2} \cdot \sqrt{\frac{\gamma}{G}} \quad (7)$$

where

ω angular frequency of loading
γ density of soil
G shear modulus of soil

$$v_S = \sqrt{\frac{G}{\gamma}} \quad (8)$$

$$\omega = 2 \cdot \pi \frac{1}{T} = 2 \cdot \pi \frac{1}{4 \cdot t_0} \quad (9)$$

where

T period

Equation (7) and (9) give

$$a_0 = \frac{\pi \cdot D}{4 \cdot v_S \cdot t_0} \quad (10)$$

Only one diagram is needed to present the relationship between dynamic force and static force, which both give the same displacement. In Diagram 2 the diameter D_0 is 1.0 m.

For a diameter $D_1 = \alpha D_0$ the diagram is used for $v_{S1} = v_{S0} / \alpha$

5. EXPERIENCE

Experience from laboratory tests, field tests and actual foundation works can be concluded:

- The plastic ratio $\frac{s_{pl}}{s_{max}}$ is a critical parameter.
- A decreasing plastic ratio during dynamic loading tells that the soil is compressing.
- The lower plastic ratio the more elastic soil
- In laboratory $\frac{s_{pl}}{s_{max}} = 0.1$ can be obtained as minimum
- In field $\frac{s_{pl}}{s_{max}} = 0.2\text{-}0.3$ is a pragmatic limit
- Maximum obtained increase of soil stiffness is 5-10.
- Dynamic pre-loading should be performed from a starting low load followed by incremental increase
- Dynamic pre-loading is economic competitive
- Dynamic pre-loading is environmentally suitable

Dynamic pre-loading has been successfully used in the foundation of a large hospital where soil conditions were very heterogeneous.

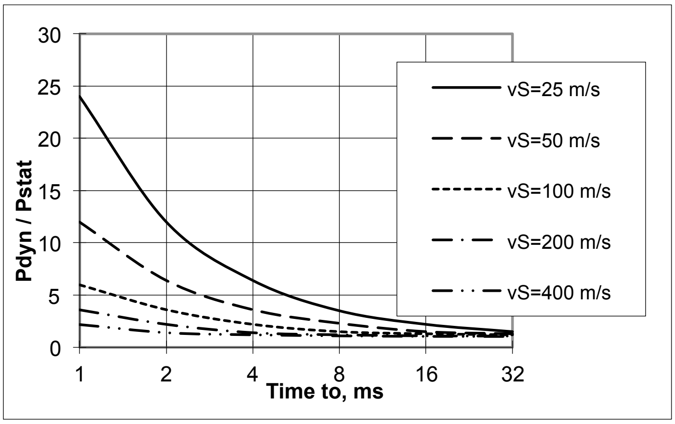

Diagram 2 Relationship between dynamic force and static force at the same displacement, the shear wave velocity v_S and time t_0 from zero to maximum force

6. REFERENCES

Lysmer, J & Richart, R E Jr (1966). Dynamic response of footings to vertical loading. *Journal of the Soil Mechanics and Foundations Division, ASCE,* Vol 92, SM1, Jan, 1966, pp 65-91.