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## PROPOSITION OF DESIGNING METHOD FOR BARRETTES AS A NON-DIRECT FOUNDATION OF ENGINEERING CONSTRUCTION

### PROPOZYCJA PODEJŚCIA PROJEKTOWEGO DLA POSADOWIENIA OBIEKTÓW INŻYNIERSKICH W SPOSÓB POŚREDNI NA FUNDAMENTACH SZCZELINOWYCH

#### Abstract

The paper presents barrettes, which are a useful method of designing non-direct foundations of engineering construction. The methodology is based on the distribution of forces acting on a foundation capping slab into each barrette, which depends on its stiffness. To determine the proper stiffness of an individual barrette comprising the foundation system, the transformational function of a pile with large diameter was used. Finally, the stiffness of each barrette as an element of foundation system was corrected in view of the group's impact.

*Keywords: barrette, transformational function, settlement*

#### Streszczenie

W artykule przedstawiono metodę projektowania fundamentów pośrednich obiektów inżynierskich, jakimi są baretty. Metoda opiera się na rozdzieleniu siły przyłożonej na płytę oczepową fundamentu na poszczególne baretty, co zostało uzależnione od sztywności każdej baretty. W celu oszacowania sztywności każdej baretty będącej elementem fundamentu pośredniego, użyto funkcji transformacyjnych zdefiniowanych dla pali wielkośrednicowych skorygowanych ze względu na ich pracę w grupie.

*Słowa kluczowe: bareta, funkcja transformacyjna, osiadanie*

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## 1. Fundamentals of barrette application

Section 7 of PN-EN 1997-1 [1], Eurocode 7 concerns the design of pile foundations. The provisions presented there apply to end-bearing piles, friction piles, tension piles and transversely loaded piles. They apply to piles installed by driving, jacking and screwing or boring, and piles installed with or without grouting. Reference is made in Eurocode 7 to other CEN standards that are relevant to the design of pile foundations (for example for the structural design of steel piles [3] – EN 1993-5: Eurocode 3, Part 5: Design of Steel Structures – Piling). Reference is also made to the execution standards for the carrying out of piling work like EN 1536:1999 [2] – Execution of special geotechnical work – Bored Piles.

Using this information, barrettes are used for the foundations of engineering construction like bridge supports in accordance with the European/Polish Standard PN-EN 1997-1 [1], Eurocode 7 and PN-EN 1536, Bored piles [2]. The latter Standard establishes general principles for the execution of bored piles as well as barrettes treated as bored piles which are formed in the ground by excavation and are structural members used to transfer actions and/or limit deformations. PN-EN 1536 applies to barrettes with the least dimension  $\geq 0.4$  m ( $\geq 0.3$  m for precast elements), a length to width ratio between its largest and its least dimensions  $\leq 6$  and a cross-sectional area  $\leq 15$  m<sup>2</sup> columns.

## 2. Design principles

PN-EN 1997-1 [1] states that the design of piles shall be based on one of the following approaches:

- a) The results of static load tests, which have been demonstrated, by means of calculations or otherwise, to be consistent with other relevant experience,
- b) Empirical or analytical calculation methods whose validity has been demonstrated by static load tests in comparable situations,
- c) The results of dynamic load tests whose validity has been demonstrated by static load tests in comparable situations,
- d) The observed performance of a comparable pile foundation, provided that this approach is supported by the results of site investigation and ground testing.

The most important limit states that the bearing resistance failure of the pile foundation (ultimate limit state, ULS) and excessive settlement (serviceability limit state, SLS) need to be considered in the design of piles.

The equilibrium equation to be satisfied in the ultimate limit state design of axially loaded piles in compression is:

$$F_{c,d} \leq R_{c,d} \quad (1)$$

where:

$F_{c,d}$  – the design axial compression load,

$R_{c,d}$  – the pile compressive design resistance.

Piles in a group should be checked for failure of the piles individually and acting as a block. The design resistance shall be taken as the lower value caused by these two mechanisms.

For the serviceability limit state designs the inequality to be checked is:

$$E_d \leq C_d \quad (2)$$

where:

$E_d$  – the design value of the effect of the actions, the settlement of foundation,

$C_d$  – the limiting value of the effect of an action, the limiting value of foundation movement.

Taking into account that the load settlement characteristics depend on the position of the pile in the pile group and one can distinct corner pile, boundary pile and inner pile, the general provisions of PN-EN 1997-1 [1] concerning verification for “compressive ground resistance” of pile groups were detailed in German Standard DIN 1054 [4], for ULS and SLS respectively:

$$F_{c,d}(\text{ULS}) \leq \sum R_{c,d,i}(\text{ULS}) \quad (3)$$

where:

$\sum R_{c,k,i}$  – the resistance of the pile group as the sum of all piles considering their individual resistance according to their position in the pile group

$$F_{c,k}(\text{SLS}) \leq \sum R_{c,k,i}(\text{SLS}) \quad (4)$$

where:

$F_{c,k}$  – the characteristic axial compression load,

$R_{c,k,i}$  – the characteristic pile resistance considering group effects

or

$$s_{e,k}(\text{SLS}) \leq s_{a,k}(\text{SLS}) \quad (5)$$

where:

$s_{e,k}$  – the estimated average settlement of foundation,

$s_{a,k}$  – the acceptable settlement of foundation.

According to DIN 1054 [4], for determination of  $\sum R_{c,k,i}(\text{SLS})$ ,  $\sum R_{c,d,i}(\text{ULS})$  and the estimated value of average settlement  $s_{e,k}$  of a pile group, an approximation procedure with nomograms for bored piles presented in Recommendations on piling [5] might be used. This method defines the group effect for individual piles taking into account their position in the pile group, soil conditions, pile group geometry and type of pile based on the load settlement characteristic of a single pile. In other words, the resistance of a single pile  $R_{c,k,i}$  is modified by the pile group factors for resistance defined for a different level of settlement. Alike, the average settlement of the bored pile group due to the average load (in each step of the load) is estimated as the product of settlement of single pile and the pile group factors for settlement.

Alternatively to the procedures suggested by DIN 1054 [4], a very useful approximation for the settlement ratio developed by Randolph [6] can also be used. In this case, it is suggested for typical floating pile groups in which the centre-to-centre spacing is about 3 diameters, the pile group factor for settlement is approximately  $n^{0.5}$  for clays and  $n^{0.33}$  for

sands, where  $n$  is the number of piles in the group. The imperfection of this method compared to that proposed by DIN is the unification of the load settlement characteristic of each pile in the group (independently to pile position in the pile group). All the same, the settlement group factor can easily be defined, enabling fast estimation of load settlement relationships for a pile in the group. In order to illustrate this methodology, assume that the secant stiffness of the single pile ( $K_p$ ) for hyperbolic pile load  $V_p$  – settlement  $s_p$  relationship is expressed as follows:

$$K_p = K_{pi} (1 - R_{fp} V_p / V_{pu}) \quad (6)$$

where

$K_{pi}$  – initial axial stiffness of a single pile (based on the results of static load tests, the results of FEM analysis or the estimation by transformational function, see Chapter 3), kN/m,

$V_p$  – pile load, kN,

$V_{pu}$  – ultimate capacity of a single pile = characteristic maximal resistance of single pile (in the moment of  $q_b$  and  $t_{max}$  mobilization),

$R_{fp}$  – hyperbolic factor for single pile, 0,80-0,85.

For a given load carried by pile  $V_p$ , the pile head settlement of pile group  $s_{pg}$  can be calculated using the modified initial axial stiffness of a single pile:

$$s_{pg} = V_p / \left\{ \left( K_{pi} / n^w \right) \times \left( 1 - R_{fp} V_p / V_{pu} \right) \right\} \quad (7)$$

Finally, we can obtain the load  $V_p$  – settlement  $s_{pg}$  characteristic of a pile working in the pile group.

### 3. Load settlement characteristic of a single barrette

#### 3.1. Transformational functions

According to the recommendations by Gwizdała [7], the load-settlement of a single bored barrette head can be determined with sufficient accuracy using the power function for the shaft and barrette tip resistance, respectively:

$$t = t_{max} \left( \frac{z}{z_v} \right)^{\beta_1} \quad \text{for } z \leq z_v \quad (8)$$

where:

$\beta_1$  – 0.5 for cohesionless and 0.25 for cohesive soil,

$t_{max}$  – the maximal unit shaft resistance of barrette, kPa,

$z$  – the settlement of barrette head, m,

$z_v$  – the barrette head settlement required to mobilize maximal resistance along the shaft,  $0.01 \times D$ , m,

$D$  – the barrette diameter, m.

$$q = q_b \left( \frac{z}{z_f} \right)^{\beta_2} \quad \text{for } z \leq z_f \quad (9)$$

where:

- $\beta_2$  – 0.5 for cohesionless and 1/3 for cohesive soil,
- $q_b$  – the maximal unit barrette tip (base) resistance, kPa,
- $z$  – the settlement of barrette head, m,
- $z_f$  – the barrette head settlement required to mobilize resistance in the bottom of the barrette, 0,05xD, m,
- $D$  – the barrette diameter, m.

### 3.2. Barrette resistance based on CPT test results

Eurocode 7 describes three procedures for obtaining the characteristic compressive resistance  $R_{c,ki}$  of a single barrette:

- a) directly from static barrette load tests,
- b) by calculation from profiles of ground test results,
- c) by calculation from ground parameters.

In the case of procedures a) and b) Eurocode 7 provides correlation factors to convert the measured barrette resistances or barrette resistances calculated from profiles of test results into characteristic resistances. In the case of procedure c), the characteristic barrette resistance is calculated from the ground parameter values. This procedure is the most common method in some countries, for example in Poland, Ireland and the UK. The compressive resistance of a single barrette is finally determined from the ground parameters as a sum of the characteristic base  $R_{b,k}$  and shaft resistances  $R_{s,k}$  depending on barrette head settlement using the following equations given in PN-EN 1997-1 [1]:

$$R_{s,k}(z) = \sum A_{s,j} \times t_j(z) \quad (10)$$

$$R_{b,k}(z) = A_b \times q(z) \quad (11)$$

where:

- $A_b$  – the nominal plan area of the base of the barrette,
- $A_{s,j}$  – the nominal surface area of the barrette in soil layer  $j$ ,
- $t_j$  – the unit barrette shaft resistance in soil layer  $j$  depending on barrette head settlement (8),
- $q$  – the unit barrette base resistance depending on barrette head settlement (9).

In order to determine the maximal unit shaft in soil layer  $j$  ( $t_{\max,j}$ ) or maximal barrette tip (base) resistance ( $q_b$ ), the modified Bustamante and Gianceselli method presented by Gwizdała [7] can be used. This method is based on local Polish experience according to CPT test results.

#### 4. Example of design – implementation of proposed designing method

The usefulness of this proposed design method was verified during the construction of a design for viaducts over the street Army Krajowej in the Market Rakowy and Sienny in Gdansk. The load-settlement behaviour of a single bored barrette head was measured in-situ by a load test and predicted using the sum of power function for shaft (Eq. 8) and barrette tip resistance (Eq. 9), (continuous line Fig. 1), as well as the hyperbolic function of Poulos (Eq.6), (dotted line Fig. 1).

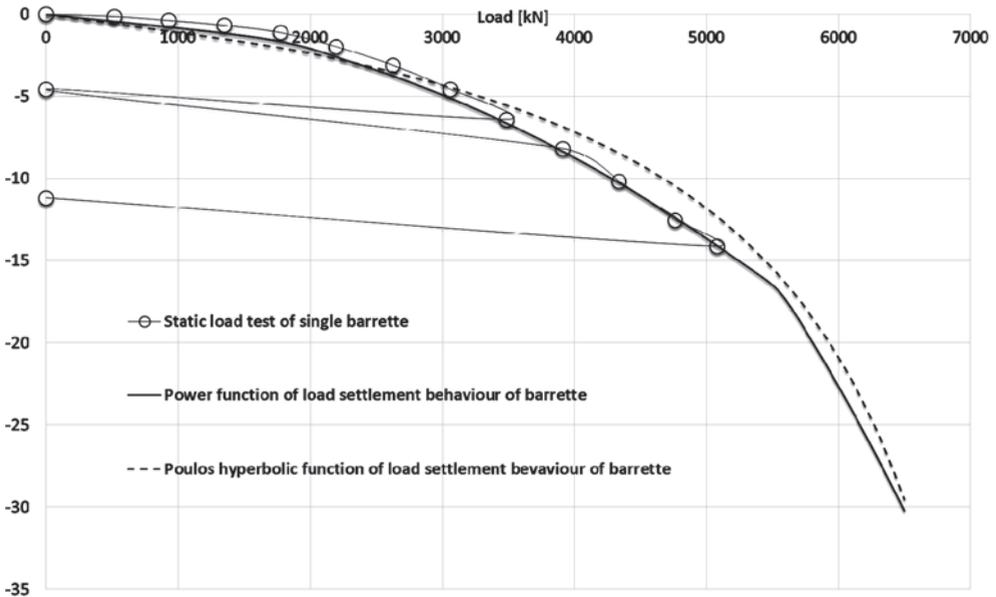


Fig. 1. Load-settlement relationship for single barrette

Finally, the load  $V_p$  – settlement  $s_{pg}$  characteristic of a barrette working in the barrette group was defined according to equation (7).

#### 5. Summary

In order to determine the load settlement characteristic of a barrette working in a barrette group used as a common type of foundation for bridges, a useful design procedure was described. This methodology is based on transformational function as an alternative to a static load test. In order to represent the real behaviour of a barrette in a barrette group (its stiffness), the author suggests using a group factor according to provision of DIN 1054 or the approximation by Randolph.

## References

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