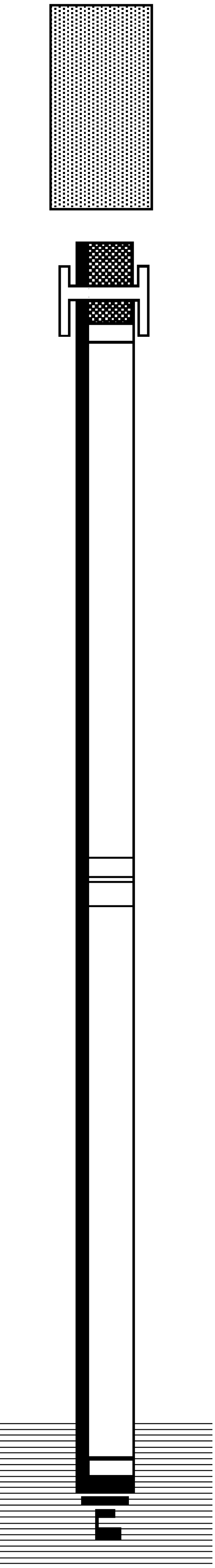

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STRUCTURAL CAPACITY OF PILES SUBJECTED TO TRANSVERSE LOADING– RECOMMENDATIONS FOR THE REVISION OF EUROCODE 7

Utförd av

Gary Axelsson, ELU-konsult
Fredrik Resare, ELU-konsult
Anders Beijer, ELU-konsult

Förord

Pålkommissionen publicerar PM om transversalbelastade pålar. PM är framtagen av Fredrik Resare, Anders Beijer och Gary Axelsson.
Rapporten utgör rekommendationer för revidering av Eurokod 7.
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Upprättat av
Fredrik Resare
Anders Beijer
Gary Axelsson

Structural capacity of piles subjected to transverse loading– recommendations for the revision of Eurocode 7

General

Pile foundations are seldom entirely transversally loaded. Normally, the axial load is the main load. Pile foundations subjected to high transversal loads will often be designed using inclined piles as shown in Figure 1b. Here, the main pile load will be axial. If the transversal load is relatively small, the piles can be installed vertically as shown in Figure 1a. The bending moment due to the transversal load is normally deducted from the moment capacity when calculating the axial capacity of the pile. A common problem in Scandinavia is settlement around inclined piles. Such a case often gives rise to large additional moments as depicted in Figure 1b. Another common situation is transversal soil displacement due to adjacent piling or excavation during the construction phase as shown in Figure 1c.

Calculation models for transverse loading are presented in the Pile Commission report no. 101, which are regarded as national recommendations. Design values for the bedding modulus and material properties are the same as for buckling and material yield of axially loaded piles.

Transversal loads in STR

For the ultimate bearing capacity of a pile all possible loads should be considered. Horizontal loads can appear in slender piles for several reasons. It is therefore important to consider whether the partial coefficients should be used to increase or decrease the geotechnical material properties used in the calculations. The total capacity of the pile is calculated using the following interaction equation:

$$\frac{N}{N_d} + \frac{M+\sum M_H}{M_d} \leq 1 \qquad (1)$$

Where N is the applied normal force and M_H is the induced bending moment due to transversal loading. Also, when designing the piles, the increased deflection of the pile due to the transverse loading needs to be considered.

Different transversal loads

Transversal loading normally occurs in two main situations; either the pile moves relative to the soil or vice versa. Nevertheless, the transversal loads are calculated in the same way, using the relative displacement between the pile and the soil.

Illustrated in Figure 1 below are some of the transversal loading situations:

(a) due to a load in the pile top, (b) due to a settlement in the surrounding soil for an inclined pile, and (c) due to transversal soil movements from an excavation or adjacent piling.

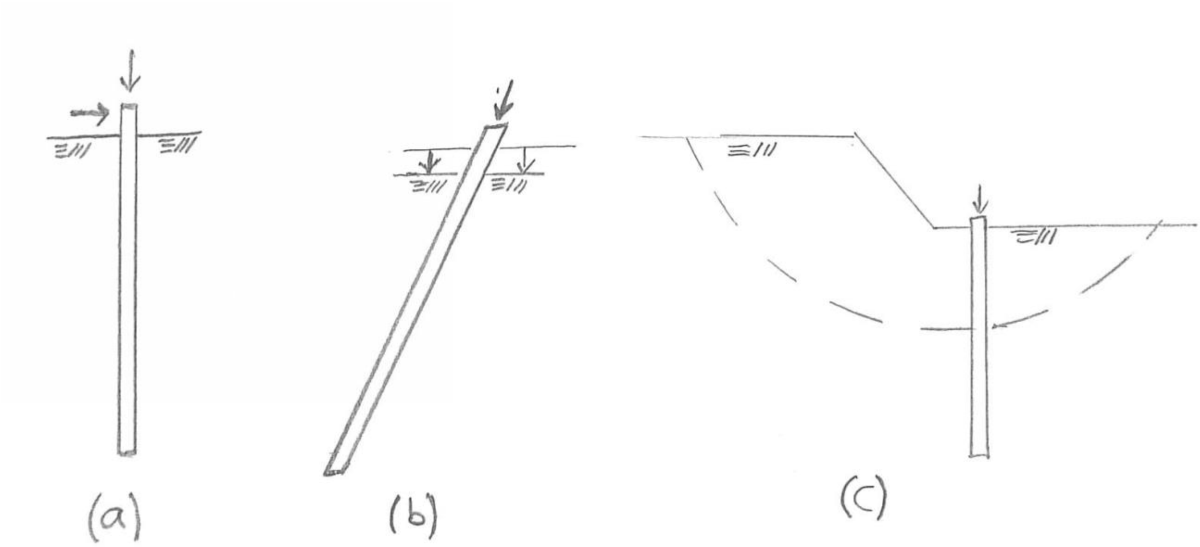

Figure 1: Typical load cases where a transversal and axial load is acting on a pile.

Failure modes

For long and slender piles, the failure mode is the structural failure of the pile. For short piles, on the other hand, the geotechnical capacity is normally mobilized before the structural failure. As piles in Sweden are normally long and slender, it is unusual to have the short pile type of failure mode.

Calculation models

The calculation of a transversally loaded pile can be performed by either an analytical method or by a numerical method. The focus of this report will solely be on the analytical method for calculating the bending moment in the pile and the deflection caused by transverse loading.

Soil properties

The soil modulus could be calculated from either the friction angle or the undrained shear strength of the soil as described in "Structural pile capacity of piles in Sweden – recommendations for the revision of Eurocode 7".

The pile resistance to transversal loads is highly dependent on the properties of the surrounding soil. Piles in soils with a high strength and stiffness have a greater resistance against external transversal loads but, as such, are more vulnerable to induced deformations in the ground, e.g. through ground settlement.

Upprättat av
Fredrik Resare
Anders Beijer
Gary Axelsson

Structural pile capacity

The calculation model for transversally loaded piles, presented in Pile Commission report no. 101, utilizes the undrained shear strength as an input parameter for calculation of the bedding modulus and the limit soil pressure. Since the surrounding soil provides both transversal support as well as an external deformation for soils undergoing settlement, the calculation of the design values of the soil strength and stiffness is not straightforward. In practical design, both upper and lower bound values must be used in the calculation of the pile buckling resistance.

The structural bearing capacity of the pile is calculated through the intersection of the buckling resistance curve and the material yield capacity curve as shown in Figure 2. The material yield curve is calculated by the standard interaction formulation, see equation (1). The buckling resistance curve is calculated as a function of the induced bending moment from second order effects while taking into consideration the initial deformation caused by the transversal loading. The additional bending moment induced by a transversal deformation or load is added as an offset M_H of the buckling curve as shown in Figure 3.

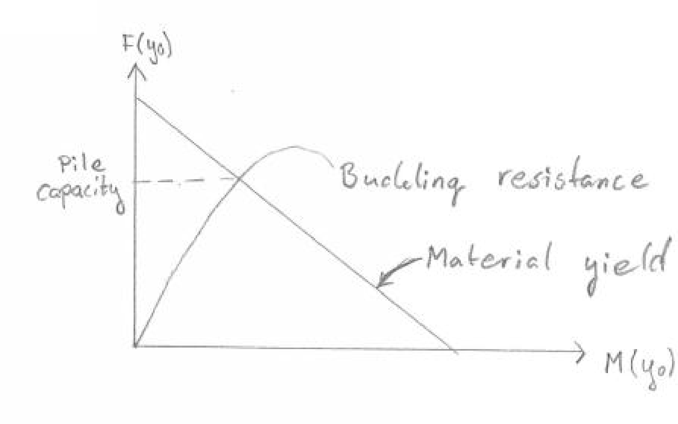

Figure 2: M/N-envelope for a pile where no transverse load is acting on the pile.

Upprättat av
Fredrik Resare
Anders Beijer
Gary Axelsson

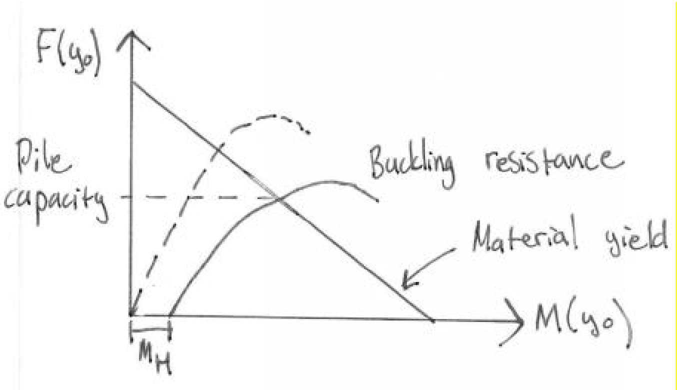

Figure 3: M/N-envelope for a pile subjected to a transverse load.

Suggested approach

The calculation of the structural capacity of piles subjected to both axial and transversal loading cannot be performed as two separate calculations. Since they affect each other, the effect of the transversal load should be included in the calculation of the axial capacity. As stated earlier, entirely transversally loaded piles are very rarely encountered. Piles are frequently installed with an inclination to make them predominately axially loaded. Inclined piles can, however, be subjected to transversal loading due to settlement of the surrounding soil. The transversal and the axial load will therefore be present at the same time, resulting in the need to combine these effects simultaneously.

Concluding remarks and recommendations

It is important to consider whether high or low values of the soil modulus and limiting soil pressure (upper/lower bound) are governing for the design of the piles. This is the case when the piles are subjected to both transversal and axial loads.

Several sections of the pile may need to be analyzed. For example, sections with maximum bending moment or maximum transversal deformation, or where the axial load, including down-drag, reaches its peak value.

The conclusions and recommendations presented in “Structural capacity of axially loaded piles in the Nordic countries – recommendations for the revision of Eurocode 7” are also applicable here, since the same basic calculation model is used. The only difference is that an extra displacement (transversal force) and bending moment is introduced, see Figure 4.

The implication of transverse loading of a pile is that the buckling curve is offset due to the induced bending moment as shown in Figure 3. Moreover, the buckling curve also decreases due to the extra deflection of the pile caused by the transverse load.

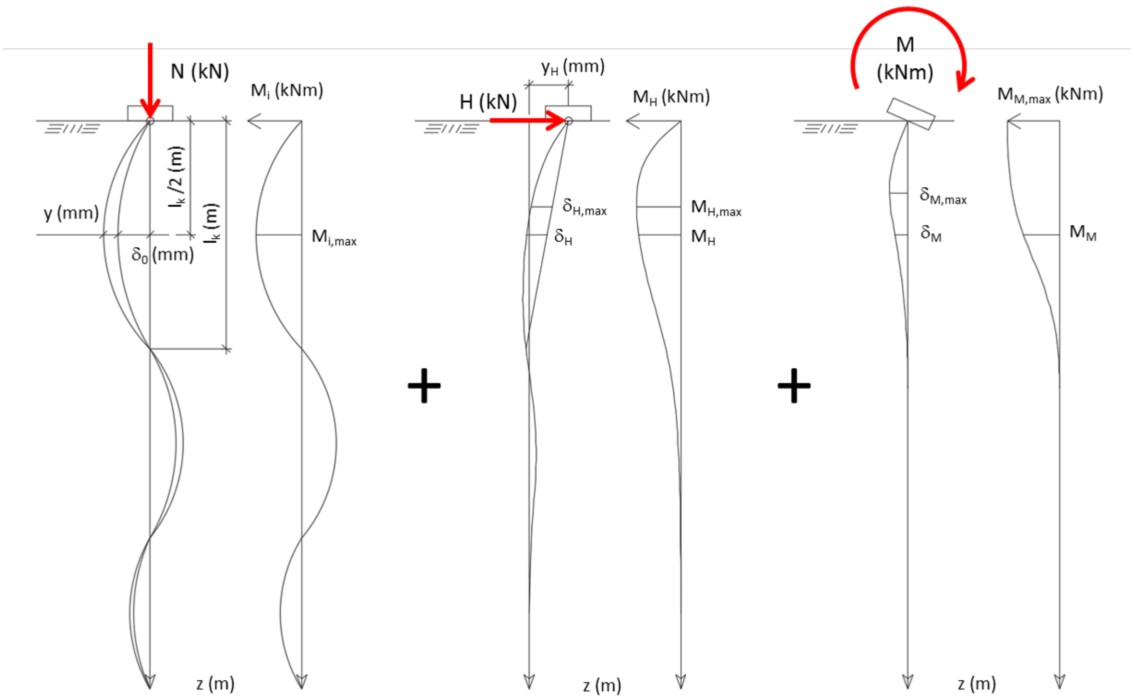

Figure 4: Pile subjected to a transversal force/deformation and moment close to the pile top.