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Research Paper

Deformational behaviour of steel sheet piles during jacking

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ABSTRACT

In geotechnical engineering the simulation of penetration processes is an important tool for the prediction of the bearing capacity of structures and of the soil behaviour in the near field. Generally the numerical analysis of penetration processes is limited to penetrating bodies, which experience no deformation during simulation. The reason for this limitation is determined by the enormous computational costs. This paper presents a novel method to simulate the penetration process considering the deformation behaviour of slender profiles with relatively low bending and torsional stiffness such as sheet piles. The numerical analyses are carried out using the Coupled Eulerian-Lagrangian (CEL) approach. The modelling method is validated by 1*g*-model tests. Applying this method to the jacking simulation of sheet piles, in particular U- and Z-sections, it can be shown, that the stress state between the surfaces of web and flange increases due to soil plugging. Hence, higher shaft resistance in the corner regions forces the profile to deform. The influence of the profile's deformation on the reaction forces is significant and must be considered.

1. Introduction

During penetration of profiles into the subsoil, the surrounding soil is displaced and locally compacted or loosened depending on the soil properties, effective density and installation method. In the case of jacking or impact driving of open-ended piles (e.g. tubes) or sheet piles (U- or Z-sections) the stress state of the granular soil between the profile surfaces increases, which can result in arching or plugging as presented in e.g. [1]. Soil plugging enhances the base resistance due to increased horizontal stresses on the inner profile surface. Depending on the particular geometry of the profile as well as the profile's stiffness, the increase of the horizontal stress state during penetration may lead to deflection and deformation of the profile. Sheet piles especially are concerned due to their asymmetric geometry and relatively low bending and torsional stiffness. This deformation behaviour is observed from salvaged sheet piles as presented in Fig. 1. These Z-sections were installed into sandy subsoil by a pitch-and-drive jacking operation. With depth the Z-sections are widened and slightly twisted.

In this paper the deformation behaviour of sheet piles is investigated in 1*g*-model tests and in numerical analyses. The model tests are described at a glance to show the principle deformation mechanism. The focus of this paper is the numerical modelling. Obviously a modelling of sheet piles is required, which reproduces the deformation behaviour of the profile during penetration. The discretisation of slender profiles with volume elements usually leads to a very small critical time step size in explicit analysis.

Therefore, a novel method is presented, which combines shell and volume elements by the use of kinematic coupling. This method opens up the possibility to simulate the penetration process considering the deformation behaviour of slender profiles within acceptable computational costs.

By the use of this technique the interaction between soil and structure is investigated in comparison to conventional modelling with volume elements. This modelling method is applied to simulate the jacking of a U- and a Z-section into sand. The change of the stress state of the surrounding soil as well as the deformation of the sheet piles due to penetration are analysed. Furthermore the jacking forces and the reaction forces on the guidance are compared. In order to investigate the influence on the resistance, the sheet piles are modelled as either rigid or deformable. Furthermore the consequence of such deformation behaviour is evaluated regarding pitch-and-drive installation of Z-sections.

2. Model tests

In order to investigate the deformation behaviour of slender profiles 1*g*-model tests were conducted. A U- and a Z-section were jacked into sand with a velocity of $v = 10\,\mathrm{mm/s}$. The profiles are idealised by neglection of the clutches. The U-section is derived from an AU18-700. The Z-section represents an AZ18-700. The scale is 1:4.5. Deviating

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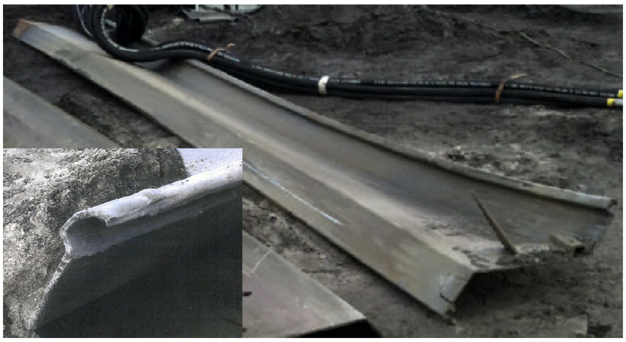

Fig. 1. Deformed steel sheet pile and deformed clutch (left) after jacking.

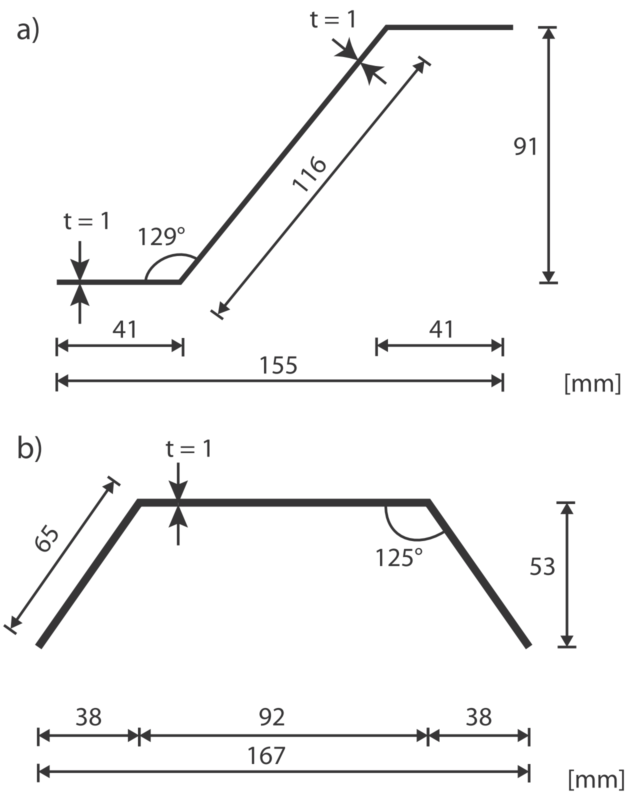

Fig. 2. Dimensions of Z-section (a) and U-section (b).

from that, the thickness of the profiles is 1 mm and the material is Aluminium with a Young's modulus E of 69,000 MPa. Hereby the profiles are assessed as soft in relation to torsion and bending. The dimensions of the profiles are illustrated in Fig. 2.

In order to measure the deflections of the flanges during jacking, the sensor *IMU Breakout BNO055* is mounted to the corner of the profile, see Fig. 3. The sensor contains an accelerometer, gyroscope and

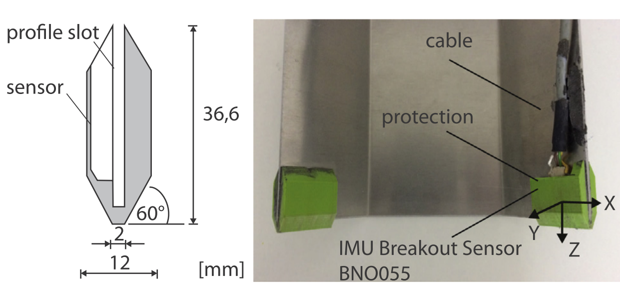

Fig. 3. Dimensions and application of protection and profile as well as orientation of sensor (right).

Fig. 4. Appearance of hoppers at soil surface due to jacking of U-section (left) and Z-section (right).

magnetometer. By this the absolute orientation of the flange can be calculated by inclination and rotation. A sensor protection is applied on both flanges for a symmetric tip resistance.

The profiles are jacked into *Hamburger Sand*, which is a uniform semi-fine sand with an internal friction angle φ_c of 32°. The sand is gently sprinkled into the container by a distributor unit. During this procedure a cone builds up in the center of the container, which may lead to a higher density in the center and a lower density towards the rim. Still, this filling process ensures reproducibility of the sand distribution and equal conditions in every test. The overall initial relative density D is equal to 0.15.

During jacking the sand is compacted, which can be observed in Fig. 4 by the appearance of a hopper at the soil surface. Furthermore a twist of the Z-section becomes visible, see Fig. 4 (right).

Both profiles are jacked four times while the rotation of the flanges is measured. The rotation of the sensors during jacking is illustrated in Figs. 5 and 6. The flange of the U-section rotates about the vertical axis by 20–50° depending on the penetration depth. The corners between flange and web widen and the profile's base elongates. Related to rotation the flange inclines about the horizontal axes by 5–25°. As a consequence the U-section deviates parallel from the initial vertical plane.

The Z-section shows a similar mechanism as illustrated in Fig. 6. The flange of the Z-section rotates about the profile's axis by up to 10°. Due to the asymmetrical cross section the whole Z-section is twisted over the penetration depth. Besides, the flange inclines about the horizontal axes

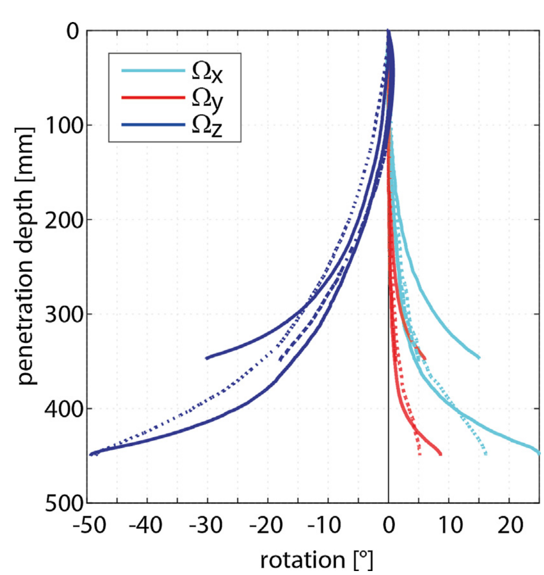

Fig. 5. Rotation of flange measured during jacking of U-section into loose sand.