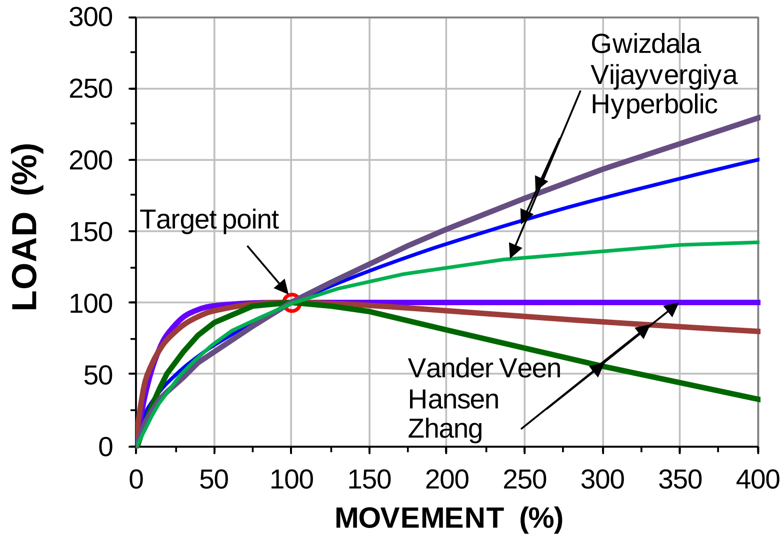

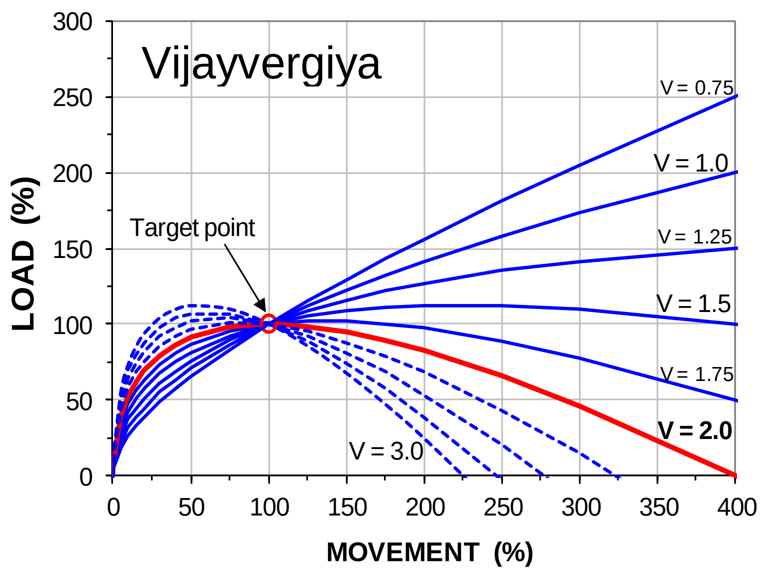

384. Fellenius, B.H., 2018. Development of axial pile load transfer curves based on instrumented load tests. Discussion*), ASCE J. of Geotech. and Geoenviron. Engng., 44(2) 4 p.

*) Discussion on: Bohn, C., Lopes dos Santos, A., and Frank R., 2017. Development of axial pile load transfer curves based on instrumented load tests. ASCE J. of Geotech. and Geoenviron. Engng., Vol. 42(1) 15 p.

Discussion of "Development of Axial Pile Load Transfer Curves Based on Instrumented Load Tests" by Cécilia Bohn, Alexandre Lopes dos Santos, and Roger Frank

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In Figs. 7(a–c) the authors presented the results of a static loading test on a pile with five strain-gauge levels, indicating load distributions for each of 12 load levels [Fig. 7(b)]. Each of the gauge levels provided records of load movement or shear stress versus movement (determined from telltale records) and represents the response of a pile element, though the authors showed only one such load-transfer diagram [Fig. 7(c)]. However, I am puzzled by the fact that the maximum movement in this shaft shear diagram is larger than that shown for the maximum movement of the pile head and pile toe [Fig. 7(a)].

The authors used the Vijayvergiya function (Vijayvergiya 1977) with the coefficient V fixed (preset) to 2 to fit calculated load move-ments to measured test records. (I assume that the records show the response measured at a certain depth in a test pile, i.e., at a pile element.)

$$Q = Q_{trg}\left(V\sqrt{\frac{\delta}{\delta_{trg}}} - (V-1)\frac{\delta}{\delta_{trg}}\right) \tag{1}$$

where Q = applied load; Q_{trg} = target load or resistance; V = function coefficient >0; δ = movement associated with Q; and δ_{trg} = target movement (mobilized at Q_{trg}).

The authors' Fig. 8 presents results of fitting the strain-softening Vijayvergiya function to test records, labeling the fit excellent agreement. Beyond the maximum test load, the authors assumed plastic response (ultimate resistance) as opposed to strain softening. Indeed, up to the maximum movement measured, about 7 mm, the fit is good and so are the agreements obtained by fitting the Chin-Kondner, Vander Veen, Hansen, and Zhang functions, as shown in Fig. 1, applying function coefficients $C1 = 0.065$, $a = 0.007$, $C1 = 0.013$, and $b = 0.85$, respectively. Details on the mathematics of the quoted functions and the range of function coefficients are presented in Fellenius (2017).

I have determined a best fit of a few of the general $t\,z/q\,z$ functions to the authors' examples, as follows.

The Vijayvergiya function according to Eq. (1) (dashed curve) shows a strain-softening trend beyond the maximum load that may or may not be representative for the actual test had the test continued beyond the maximum movement. The plots show that a back calculation only addressing an initial portion of the records can achieve an excellent agreement with any function.

Fig. 2 shows shaft-resistance response presented in the authors' upper graph in Fig. 10 with predicted fit and the discusser's results from fitting the Vijayvergiya, Hansen, and Zhang functions (Vijayvergiya 1977; Hansen 1963; Zhang and Zhang 2012), all three being strain-softening t-z functions. The measured records show a last reading, single non-strain-softening response (a final measured point) that, I believe, is a questionable reading. The authors' predicted curve applies the American Petroleum Institute (API) curve, which is a preset three-point curve with a shape adjustment per soil type and as tweaked to a perceived ultimate resist-

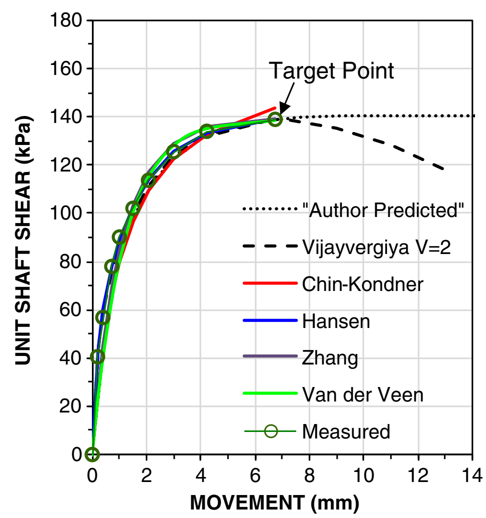

Fig. 1. Measured records and the authors' fit using Vijayvergia (1977) $V = 2$ function and supplemented with curves fitted to Eqs. (1)–(6) functions (adapted from Fig. 8 of the original paper)

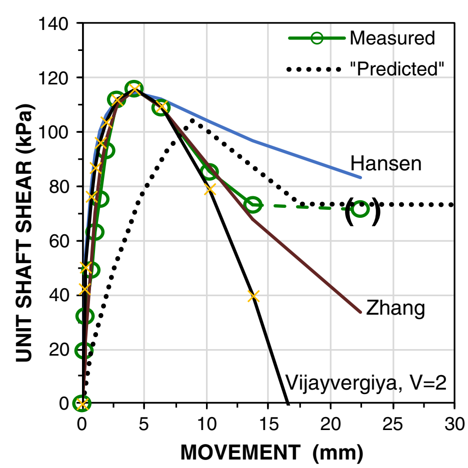

Fig. 2. Measured records fitted per the authors' predicted curve with Hansen (1963), Zhang and Zhang (2012), and Vijayvergiya (1977) functions fitted to the measured curve (adapted from Fig. 10 of the original paper)

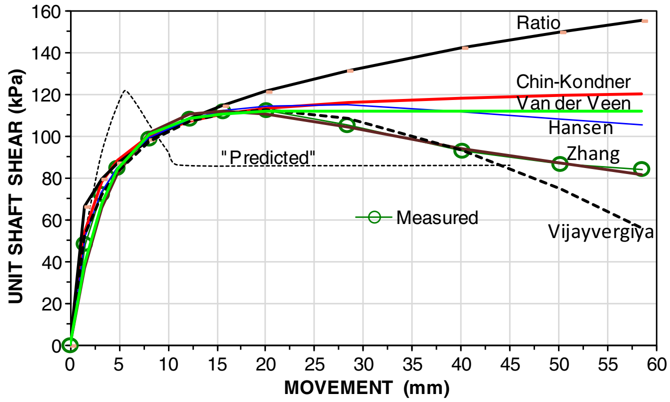

Fig. 3. Measured records and the authors' predicted curve and the curves produced by back calculations using six *t-z* functions (adapted from Fig. 10 of the original paper)

tance. As no surprise, the predicted curve does not agree with the measurements. In contrast, the Zhang function ($b = 0.0102$) agrees quite well apart from that last questionable record. The Vijayvergiya function ($V = 2$) fits the curve up to the peak and two values beyond. I was not able to obtain a good fit beyond the peak load using the Hansen function.

I obtained similar results when fitting the functions to the authors' lower graph in Fig. 10 as shown in Fig. 3. Again, the API curve (predicted curve) does not fit the test records. The Zhang function ($b = 0.0325$) agrees well all through the test records while the Hansen ($C1 = 0.00087$) function does not give a good fit. The Vijayvergiya function with $V = 2$ fits the curve up to the peak and two values beyond. The strain-hardening functions [ratio function, $\Theta = 0.23$, Chin-Kondner, $C1 = 0.00323$, and Vander Veen, $b = 0.070$; (Gwizdala 1996; Chin 1971; Van der Veen 1953)] fit the measured curve up to the peak shear stress, but, of course, not beyond, as the test results showed strain-softening response.

The authors' Fig. 18 shows measured and modeled strain-hardening load-movement response of a pile toe. Fig. 4 shows curves fitted to strain-hardening functions Chin-Kondner ($C1 = 0.00032$) and Gwizdala ($\Theta = 0.52$) strain-hardening functions. The fit by the ratio function is quite good. It is interesting to see that good fits were also reached by the Hansen ($C1 = 4E7$) and the Vijayvergiya ($V = 1.1$) functions. The authors' curves are not strain-hardening functions, but the fits were achieved assuming the respective peak values to occur after the maximum test load

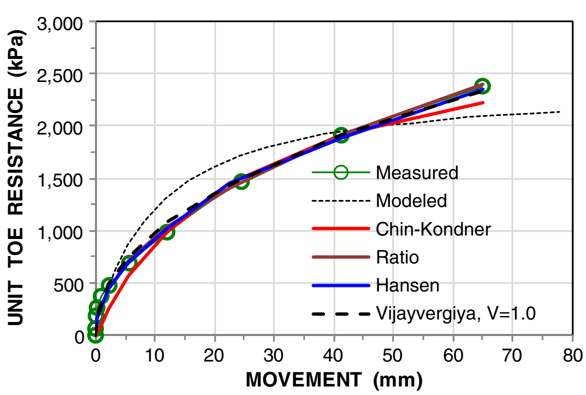

Fig. 4. Measured records and the authors' modeled curve and curves produced by back calculations using four *q-z* functions (adapted from Fig. 18 of the original paper)

Zhang and Vander Veen functions are not included as they did not provide a good fit.

In my experience, most cases will show that the best fit of a pile-toe response is achieved by the ratio function (Gwizdala 1996). The authors modeled the measured unit toe resistance by means of a preset hyperbolic curve formulated to depend on the pile diameter and a factor. The fit is not good, which can be the result of the authors' mistaken assumption that there would be a correlation between unit toe resistance and toe movement based on the pile diameter; incorporating the pile diameter in a load-transfer function is not useful.

For movement beyond a capacity, the authors applied plastic response. However, a load-transfer back calculation does not require imposing an assumed ultimate resistance. Indeed, imposing an ultimate (plastic) resistance beyond a certain value is not just unnecessary, it is wrong. Even for shaft resistance, strain-hardening response is more common than plastic or strain-softening. Load-transfer is a deformation response. This notwithstanding that a couple of the load-transfer functions can be used as reference to ultimate resistance.

A simple Excel template that considerably speeds up a back-calculation effort can be downloaded (Fellenius 2016a).

The authors' applied preset load-transfer functions to the measured pile-element records. Preset refers to either a specific function with predetermined coefficients and an assumed ultimate (plastic resistance) or a function that includes coefficient determined from soil exploration information, such as the pressuremeter modulus. Good or poor fits obtained by such preset functions are of little relevance to expectations of pile response to load, i.e., design of piled foundations. Records of pile element response to load should be back-analyzed without preset coefficients. The coefficients resulting from the achieved fit can then be correlated to conventional geotechnical parameters, such as shear strength, cone stress and friction ratio, compressibility, and pressuremeter modulus, enabling a database for reference to design efforts to be produced. The conventional parameters, thus calibrated, would serve as a database for guiding the selections of functions and function coefficients to use in a specific design.

I suggest that the authors reanalyze their case records of measured pile-element load movements using the general expressions of the functions without imposing a preselected ultimate resistance and limiting the cases to those with significant movement. The functions and function coefficients that established good fits could then be correlated to the relevant soil parameters, and the range of correlations might prove to be useful toward selecting function coefficients to use in predicting the response of a given pile to an applied load.

To fit to measured pile element responses (i.e., records from the gage locations), then, a suitable computer program needs to be engaged to combine the response of all the elements making up the pile. For example, the *UniPile version 5* software (Goudreault and Fellenius 2014), which enables a calculation of the resulting pile head (and pile-toe movement) for use, say, in settlement analysis of a foundation supported on the piles (Fellenius 2016b).

The authors also applied load-transfer functions to back-calculation of the pile-head load-movement curve (authors' Fig. 22). It is difficult to see what would be gained or learned by fitting a load-transfer function to a pile-head load-movement response. That response is a summary of the responses of the series of individual pile elements along the shaft and the toe element plus the elastic shortening of the pile shaft. A characteristic point on the pile-head load-movement curve, such as peak load, does not occur at the same time as the similar characteristic points occur at the pile elements.

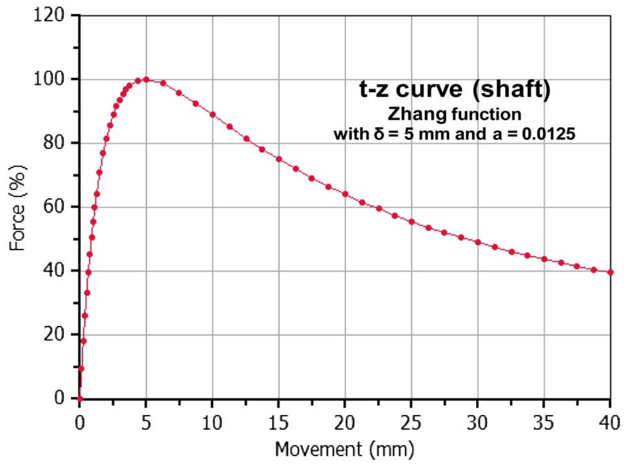

Fig. 5. Assumed shaft transfer *t-z* function for a pile element

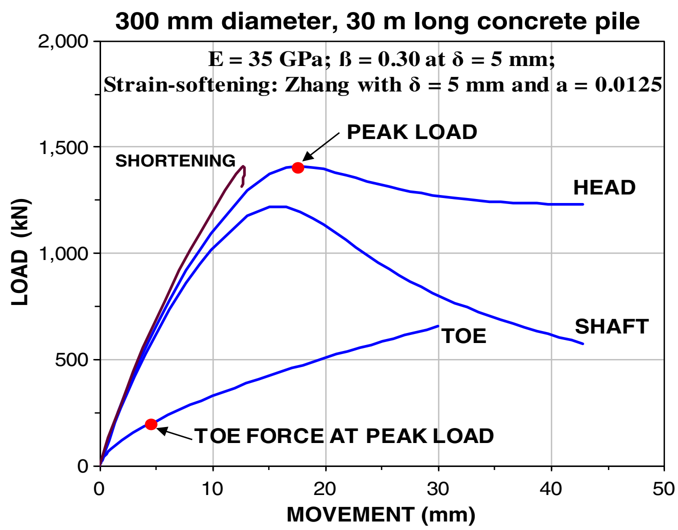

Fig. 6. Results of the static loading test

To illustrate, assume that a 300-mm-diameter, 30-m-long concrete pile is installed in a soil with a shaft strain-softening response shown in Fig. 5 and a pile-toe resistance per a ratio function. Then, a simulated static loading test would result in load-movement curves shown in Fig. 6 for the pile head, pile shaft, and pile toe. The simulation is carried out using the *UniPile version 5* soft-ware (Goudreault and Fellenius 2014).

The results can be used in a back calculation fitting load-transfer function to the curves. However, these functions would be quite different to those representing the individual pile elements. As demonstrated in Fig. 7, when the pile-head curve reaches the peak load, the peak shear resistance along the pile about a quarter of the length down is well past its peak, at midpoint the resistance is just about past the peak, and three-quarters of the length down, the peak resistance is not yet quite reached. Most important, the pile toe has hardly experienced sufficient movement to register resistance, assuming a uniform soil profile. Had the case been made up using several different layers, the importance of considering each pile element separately would have been even more obvious.

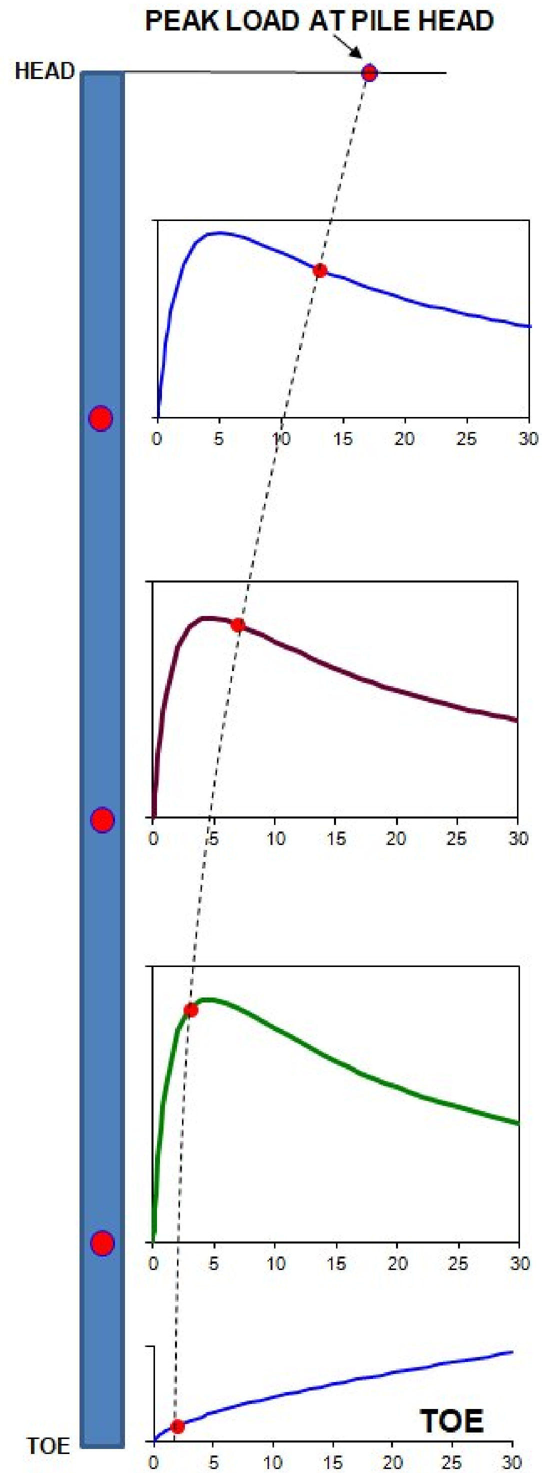

Fig. 7. Distribution of axial force with depth

Figs. 6 and 7 illustrate the futility of calculating a pile capacity as a sum of ultimate shear along pile elements, defined one way or another, and combined with a perceived ultimate toe resistance. It will not be the same as a capacity determined from the pile-head load-movement curve. Both approaches rely on the concept of pile capacity and, therefore, neither approach is particularly useful for design analysis. As mentioned, the more useful approach is to base the analysis on load-transfer functions acting at a series of pile elements. It enables a design to be carried out that addresses settlement of the single pile and pile group, the more realistic issue in piled foundation design.

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