DETECTION LIMITS OF INTEGRITY TESTING.

A.J.G. Schellingerhout and T.K. Muller
IFCO BV Limaweg 17 2743 CB Waddinxveen The Netherlands.

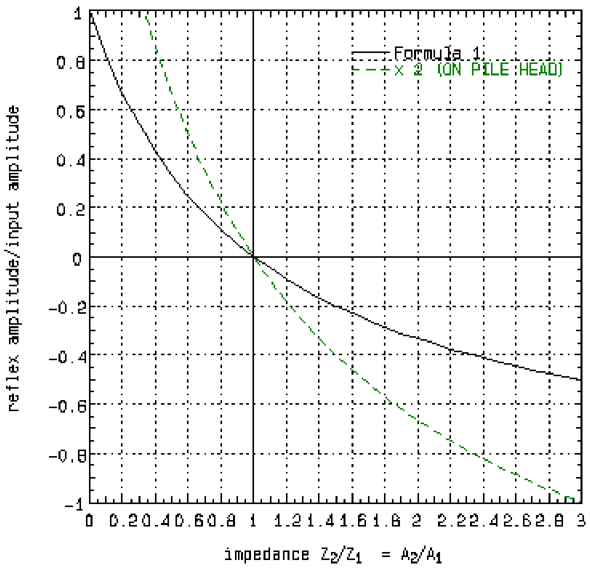
Abstract

Integrity testing is a widely used measurement method to characterise pile diameter changes. This paper discusses a type of defect which consists of a reduction of pile cross section over a short length. The results are obtained by computer model simulation based on the one dimensional wave propagation theory. The simulations show that the spring stiffness of the pile defect is a better predictor for the reflection amplitude than the impedance change. Also is shown that defects with an equal stiffness have an almost identical reflection shape and amplitude which makes the unique determination of the shape of the defect in the pile impossible.

Introduction

Integrity testing is a widely used method to check the integrity of a concrete pile by means of a low strain shock wave. The reflections of the pile toe and/or changes in pile diameter give information on the integrity of the pile shaft. The method is popular because of its speed and low cost; little preparation of the pile top is necessary and the only apparatus to generate the shock wave is a hand held hammer.

Figure 1. The amplitude of the reflex as a function of the impedance ratio of the defect and the pile. The dashed line gives the amplitude measured at the pile head.



Modern test equipment all store their data digitally which makes computerized processing very convenient. The aim of the processing is to quantify the size of possible defects to be sure that the pile is capable of transferring its load to the bearing layers.

Calculations

The interpretation of pile integrity test measurements is based on the 1 dimensional wave theory [1]. This theory shows that a transmitted wave reflects on a change of impedance.

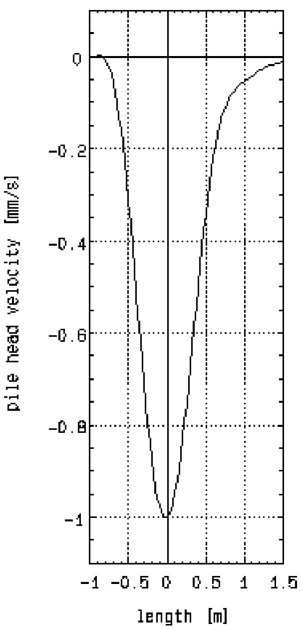
The amplitude of the reflection is given by:

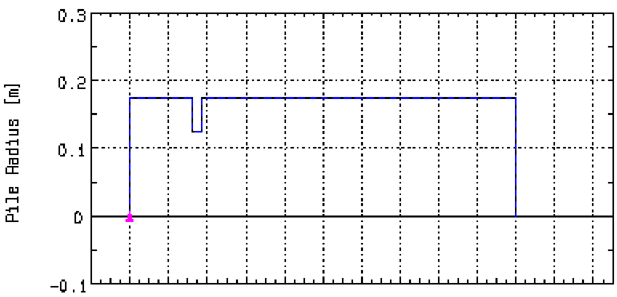
$$v_{reflex} = \frac{Z_1 - Z_2}{Z_1 + Z_2} \cdot v_{in} \qquad \text{with} \qquad Z = A\sqrt{E\boldsymbol{r}} \qquad (1)$$

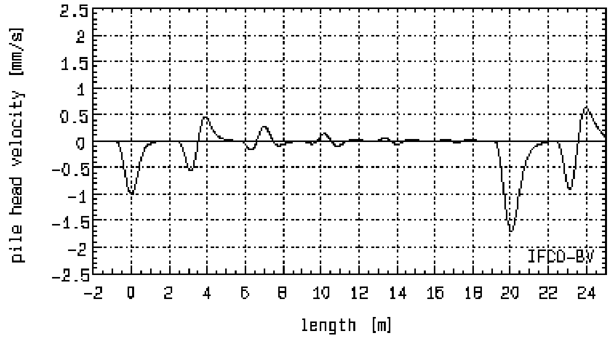
with v_{reflex}= the amplitude of the reflected wave, v_{in} the amplitude of the incoming wave, A the pile area, ρ the density, and *E* the Young's modules of the pile material.

Formula (1) is shown in figure 1. A change in pile diameter causes a reflection of the incoming low strain shock wave. This reflection is detected in an integrity test measurement to observe a possible defect in the pile. Figure 1 also shows the amplitude detected at the pile head. This doubling is caused by the pile head being a free end which causes a doubling of the reflection generated by the defect.

Figure 2. Pile radius as a function of length together with the calculated integrity test signal. The length of the reduction in pile radius is the defect length L_d. The input shock wave which is used in the simulation has been magnified in an extra graph.



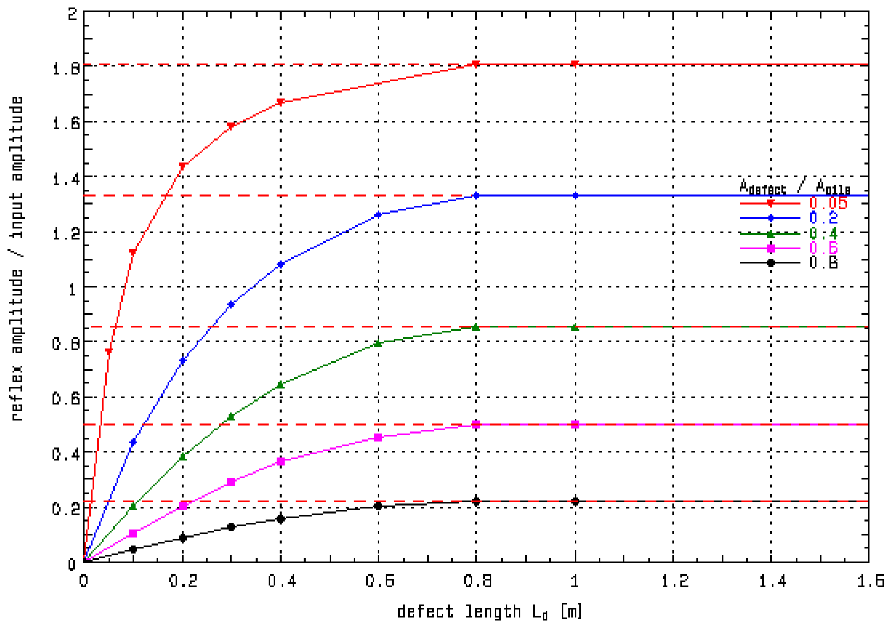




The pile defect which is studied in this paper is shown in figure 2. The pile has an abrupt change in diameter over length L_d. After the reduction the pile diameter changes to its original diameter.

The amplitude of the reflected wave has been calculated by numerical simulation as a function of the defect length L_d and ratio of the defect area to the pile area. No soil models were used during the calculations, so there is no wave damping in the model. The results of the calculation are shown in figure 3. The parameters in the calculations are a propagation speed c =4000 m/s and a Young's modules E of 40 GPa.

Figure 3. Reflex amplitude as a function of defect length L_d for several ratios of A_{defect} and A_{pile} . The dashed lines show the value given by formula 1.



The results in figure 3 show that the amplitude of the reflected wave goes to zero for short defect lengths L_d. Below a certain length the reflected amplitude is well below the amplitude predicted by formula (1), which is shown in figure 3 by the dashed line. This reduction of amplitude occurs when the defect is shorter than approximately a quarter of the length of the incoming wave. So the shape of the curves in figure 3 are dependent of generated shock wave. The simulations use an incoming wave which was sampled from an integrity test measurement on a precast concrete pile. Details of the incoming wave and a complete simulation are shown in figure 2.

Figure 3 shows that the impedance change is not a suitable parameter to quantify the amplitude of defects that in reality do occur. The amplitude shows no longer a unique relation with an impedance change. The statement that integrity test measurements can measure impedance changes of 10 to 20 % is not correct. This was also experimentally shown when impedance changes of 50 % over a length of 0.01 m could not be observed by any integrity test apparatus[2].

The spring stiffness of the defect is a much better parameter to predict the amplitude of the reflected wave. This approximation can be used for the discussed defect when the defect length is below a quarter of the wave length and the reduction in diameter is large. (This approximation is equivalent to neglecting the mass of the defect.) This relation can be given by :

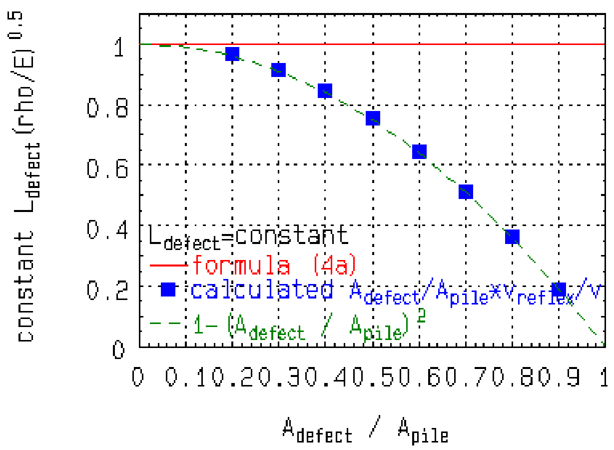
$$v_{reflex} = const \frac{Z_1}{k_{defect}} v_{in} \qquad \text{when } A_{defect} << A_{pile} \text{ and } v_{reflex} << v_{reflexmax} \quad (4)$$

$$\frac{v_{reflex}}{v_{in}} \frac{A_{defect}}{A_{pile}} = const \,.\, L_{defect} \cdot \sqrt{\frac{r}{E}} \qquad (4a)$$

with k_{defect} is stiffness of pile defect and $v_{reflexmax}$ is the maximum reflection amplitude given by formula (1).

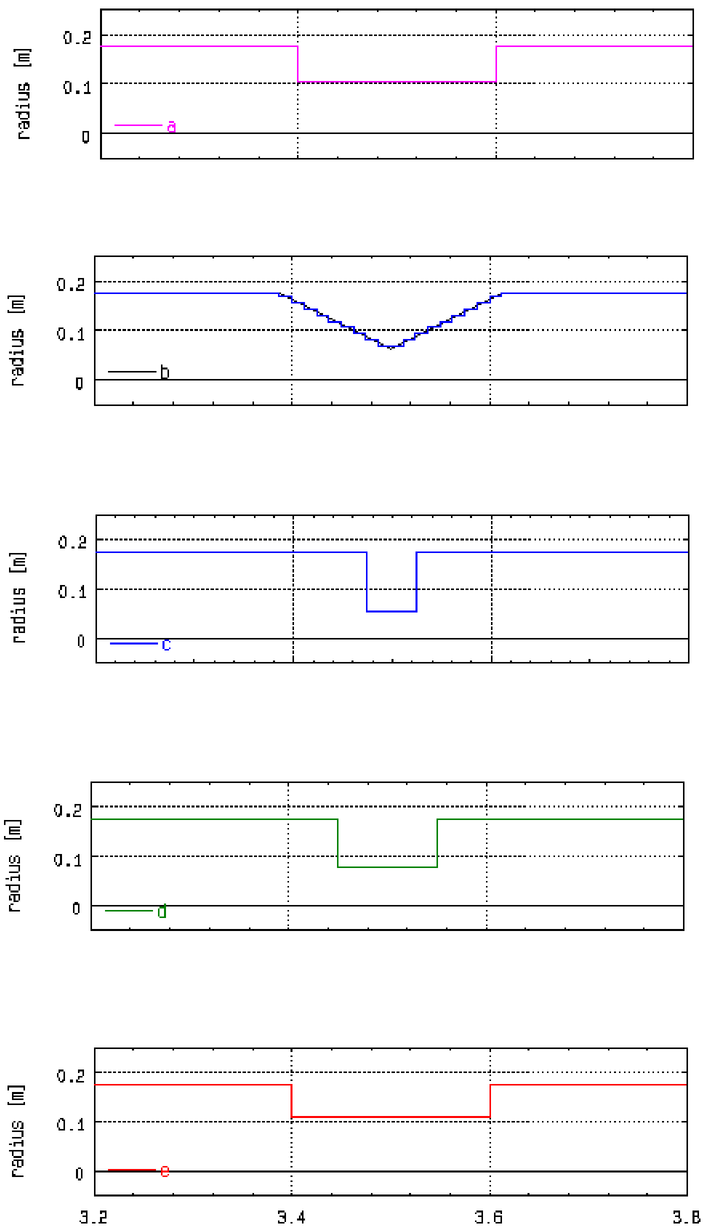
The approximation is tested by simulating different pile defects with a different area. The results are given in figure 4. The data are presented with formula (4a) which is normalized to the value 1. The figure shows that the approximation is not valid for small reductions in pile diameter. However, for large reductions the approximations are very useful. Figure 4 shows also a function which can be used to correct the approximation.

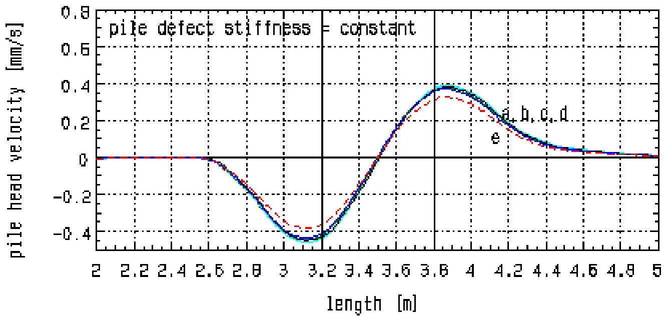
Figure 4. The prediction of formula 4a (normalized to 1) as a function of the ratio A_{defect} and A_{pile}. The approximation is not accurate for ratios close to 1.



Defects with identical stiffness have the same reflection amplitude and in addition an almost identical shape of the reflected wave. Figure 5 shows the reflected waves for several pile defects with identical stiffness. The difference between the reflections is very small and can be decreased further by applying the correction given in figure 4. The dimensions of the defects cannot be obtained by matching the reflected wave. The solution for this problem is not unique and causes a fundamental limitation to quantify defects accurately.

Figure 5. Calculated reflex for several defects with equal spring stiffness.
a = A_{defect} /A_{pile} = 0.35. L_{defect} =0.20 m (corrected as in figure 4)
b = a cone shaped defect. The second line is the approximation made by the simulation program.
c = A_{defect} /A_{pile} = 0.10. L_{defect} =0.05 m.
d = A_{defect} /A_{pile} = 0.20. L_{defect} =0.10 m.
e = A_{defect} /A_{pile} = 0.40. L_{defect} =0.20 m





Conclusions

For the discussed type of defects the following conclusions can be made:

1: The impedance is not a useful parameter to predict the amplitude of a reflection of the defect.

2: The stiffness of a defect is a better parameter to predict the reflection amplitude. Defects with an equal stiffness have approximately the same shape and reflex amplitudes.

3: The pile shape cannot uniquely be determined by an integrity test measurement. This is caused by a fundamental limitation of the wave phenomena.

4: The length of the generated shock wave during an integrity test measurement determines the smallest defect which can be detected. Only by further reduction of the shock wave length improvements of defect detection are possible.

References:

1 J.M. Seitz, B., 1992, Pile integrity by low strain impacts- A state of the art, Proceedings of Fourth International Conference on the Application of Stress Waves on Piles, The Hague, Balkema, pp 627-637.

2 Results of the integrity test contest during the Fourth International Conference on the Application of Stress Waves on Piles, The Hague, Balkema, Testbook.(to be published)

3 A.J.G.Schellingerhout, B., 1992, Quantifying pile defects by integrity testing, Proceedings of Fourth International Conference on the Application of Stress Waves on Piles, The Hague, Balkema, pp 319-324.