The role of amplification in low-strain impact testing

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Principles of the method

Piling is arguably the most popular foundation method. However, once constructed, piles, as a rule, are hidden in the ground with their integrity uncertain. Testing pile integrity by low strain impact (ASTM D5882) is fast and inexpensive, with millions of piles tested annually by this method around the world.

The testing principle is very simple: press a sensor against the top of the pile and hit the top with a handheld plastic hammer to create a downward moving compressive wave. When the wave reaches the end it is reflected upwards as a tensile wave. The whole process is recorded by the sensor and the plot of the pile head velocity versus time reveals the length of the pile and the existence (or lack) of flaws. As a rule, the analysis is based on the one-dimensional wave theory.

Attenuation - the effect of skin friction

Since the pile is embedded in soil, the wave loses energy due to skin friction on its travel along the pile. To visualize the effect of skin friction, let us consider the case of a compressive axial force wave P_1 traveling downwards in a pile element Δx subject to a friction force F acting in the opposite direction (Figure 1).

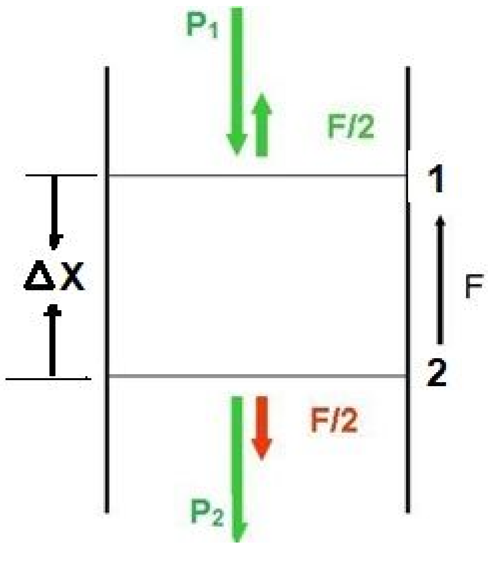

Figure 1: Influence of skin friction on a downgoing wave

The friction force F gives rise to a pair of waves, each with a force magnitude of F/2: A compressive component that will travel back to the pile head and a tensile component that will travel down and reduce the compressive axial force by F/2. The net result is a weakening, or attenuation, of the wave as it moves on.

The same reasoning applies also to the toe reflection as it travels upward to be intercepted by the sensor. Beyond a certain amount of attenuation, the toe reflection becomes too weak to identify and pile length impossible to establish.

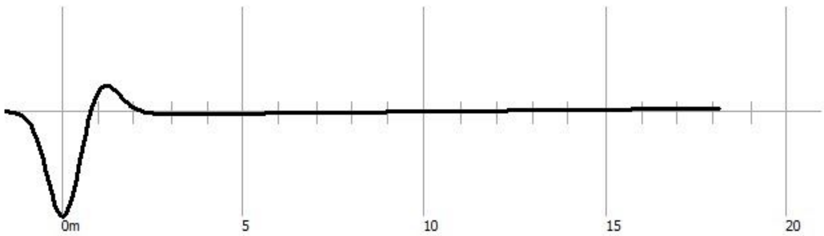

Figure 2: Raw reflectogram

The need for amplification

ASTM D5882 refers to this issue as follows: "*The apparatus shall be able to apply increasing intensity amplification...to enhance the interpretation*". Before testing any pile, testers have to ask themselves what is the proper amount of amplification to apply.

In homogeneous soil, the total attenuation of the toe reflection is given by the following equation (Paquet 1992):

$$A = e^{\frac{4L}{D} \cdot \frac{\rho_S}{\rho_C} \cdot \frac{V_S}{V_C}} \qquad (1)$$

Where L is the pile length, D is the pile diameter, ρ_s and ρ_c respectively are the soil and pile densities, v_s is the shear wave speed in the ground, and v_c the wave speed in the pile.

For typical concrete piles in common soil, $\rho_s = 18kN/m^3$, $\rho_c = 24kN/m^3$, and v_c= 4,000 m/s. Therefore,

$$A = e^{\frac{L}{D} \cdot \frac{V_S}{1333}} \qquad (2)$$

The attenuation A is equal to the amount of exponential amplification necessary to enhance the presentation of the toe reflection and bring it to the apparent size of the hammer blow (Figure 3)

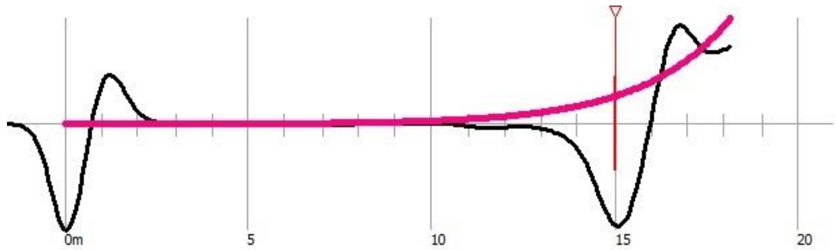

Figure 3: A well-balanced reflectiogram (amplification 47x)

For a given site, the value of v_s is not always known. However, it can be estimated from the SPT resistance value N (Fatehnia et al. (2015)):

$$V_s(m/s) = 77.1 \cdot N^{0.355} \quad (3)$$

Equations (2) and (3) were combined to obtain the necessary amplification for piles of various slenderness ratios embedded in soils of different rigidities (Figure 4).

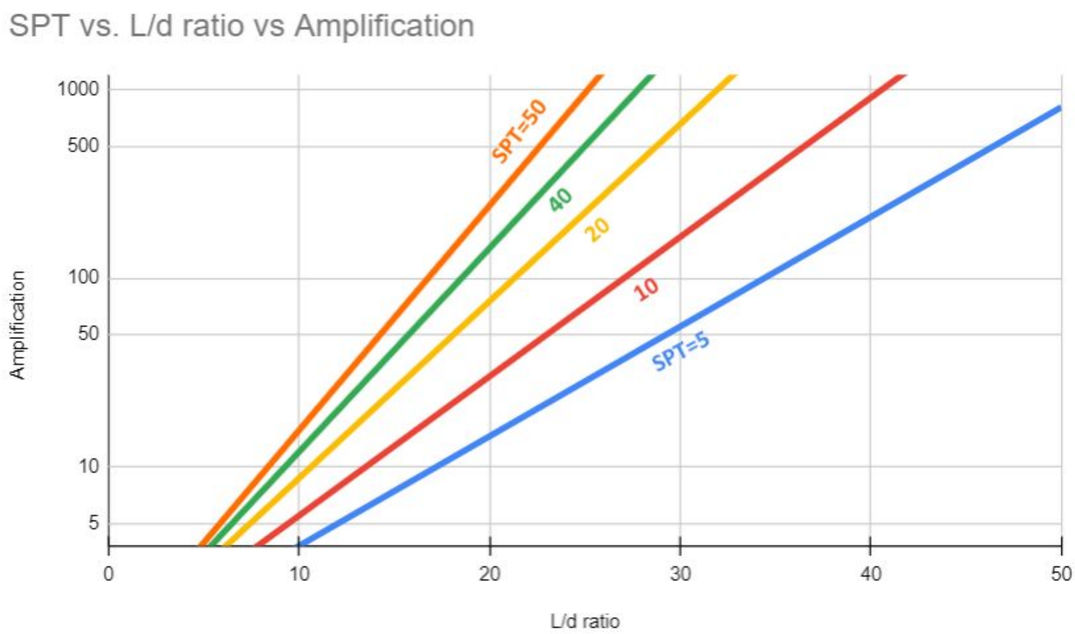

figure 4: Slenderness vs. attenuation in soils of different rigidities

Conclusions

Skin friction is a major component of pile load-carrying capacity. Regarding low strain impact testing, however, it reduces the energy carried by the waves and makes signal interpretation difficult. To compensate for this attenuation and enhance the reflecogram, the signal is treated by exponential amplification. The amount of required amplification depends on the slenderness ratio L/d and the rigidity ration c/v_s. Based on these values Figure 4 suggests the proper amplification for a given situation. Once a certain number of good blows has been collected, amplification may be further adjusted to make the apparent size of the toe reflection the same size as the hammer blow.

References

- Paquet, J., (1992): Pile integrity testing - the CEBTP reflectogram. Piling - European practice and worldwide trends (M.J. Sands, ed.), ICE, London, pp. 206-216
- Fatehnia, M., Hayden, M. and Landschoot, M. (2015): Correlation between Shear Wave Velocity and SPT-N Values for North Florida Soils, EJGE January