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THE DESIGN OF COMPOSITE CONCRETE PILES

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Cross sectional changes are, as a rule, not advisable in a driven concrete pile. During the driving, every change in cross section will result in reflection of the stress wave as governed by the value of the material acoustic impedance.

$$Z = EA/c$$

where E = the elastic modulus of the pile material
A = the cross sectional area of the pile
c = the wave velocity in the pile

The wave velocity, c, is also a material property,

$$c = E/\rho$$

where ρ = the density of the pile material

When driving a pile with a cross sectional change, a reflected strain wave will be induced at the location of the change. If the change is from a larger to a smaller section, i.e., impedance value, the stress wave will reflect as a tension wave. If the change is from a smaller to a larger section, the reflected stress wave will be a compression wave. The rules of wave mechanics explain why, to avoid reflections, the acoustic impedance of the steel follower has to be equal to the impedance for the concrete section.

In practice, changes of cross section occur, when, for instance, a follower of steel is used to drive a concrete pile. The "old field rule" is that the area of the steel follower should be about a fifth of the area of the concrete pile to obtain the smoothest driving and prevent the follower from bouncing on the head of the concrete pile. (Bouncing, of course, damages the pile head and reduces the efficiency of the driving). Usual values for E and c in steel and concrete are 29,000 ksi (205 GPa), and 4,500 ksi (30 GPa), and 16,800 ft/s (5,100 m/s) and 12,500 ft/s (3,800 m/s), respectively. The requirement of equal impedance determines the area ratio, as follows.

$$\frac{A_{concr}}{A_{steel}} = \frac{(E/c)_{steel}}{(E/c)_{concr}} = \frac{(29/16.8)}{(4.5/12.5)} = \frac{1.73}{0.36} = \frac{4.8}{1} = \quad 5$$

As seen, the old field rule agrees well with the requirement that the acoustic impedance should be the same for follower and pile.

For example, when comparing the driving of a concrete pile with either a long slender hammer or a short stubby hammer of equal weight, the long hammer, having a smaller impedance, is often found to drive better and result in less damage to the pile heads, than the short, stubby hammer having then a larger impedance.

On some occasions, it is desirable to have a cross sectional change in a precast concrete pile. For instance, in the case of long piles, when it is necessary to reduce weight in transport and handling (in areas where mechanically spliced piles are not used), the bottom part of the pile is made of an H-pile section cast into, or attached to the upper apart of the pile made up of precast concrete. Composite piles of this type have been made by a lower 50 ft (15 m) long H-pile section and an upper 150 ft (45 m) long concrete section.

Practice has shown that some differences in impedance can be accepted between the steel and the concrete sections of composite piles. For mainly economical reasons, it is desirable to make the steel H-pile as light as possible. However, when the impedance ratio concrete to steel approaches or exceeds a value of 2, difficulties arise: reflected tensile waves in the concrete reach damaging magnitudes; insufficient force and energy are transmitted to the H-pile section resulting in a false termination penetration resistance and a inadequate bearing capacity. For instance, a 14HP89 (area = 26.2 in^2) has successfully been used in combination with 16.5-inch octagonal prestressed concrete piles (area = 225 in^2). The impedance ratio of this composite pile is 1.8. However, when combining the same H-pile with a 350 in^2 concrete pile, an extreme failure rate occurred. The impedance ratio of the latter combination is 2.8. When exchanging the 14HP89 for a 14HP117, improved results were obtained. This combination has an impedance ratio of 2.1.

Composite piles consisting of a long slender concrete portion and an upper shorter wider concrete section have been of particular value for marine and offshore structures, where buckling and pile weight are major problems. The bottom slender part governs the magnitude of the allowable structural load (pile bearing capacity). The upper part is used to resist the buckling in the free-standing portion of the pile, i.e., in the water and air. The two sections, or parts, of the pile are connected by means of a mechanical splice, called a transitory splice.

One main advantage of the composite concrete pile is that the longer-slender-lower-upper pile is much cheaper per unit length than the shorter-wider-upper pile. Moreover, it can be driven with a smaller driving rig and driving hammer. The latter is very important, because barges and equipment are major cost factors in marine work.

One condition for a successful driving of the composite pile is again that the impedance ratio between the upper and the lower pile sections does not exceed 2.0. Successful combinations have been a lower 160 ft long 16.5-inch octagonal prestressed pile (area = 225 in^2) driven in two 80 ft long segments conventionally spliced together by means of mechanical splices. This pile was then completed by splicing on a 60 ft long segment of either a 20-inch square pile (see the photo below) or a 22-inch octagonal pile (area for both piles is 400 in^2) using a "transitory" mechanical splice. The impedance ratio of this pile combination is 1.8.