APPENDIX A

Broms method for analysis of single piles under lateral loading

The method was presented in three papers published in 1964 and 1965 (Broms 1964a, 1964b, 1965). As shown in the following paragraphs, a pile can be designed to sustain a lateral load by solving some simple equations or by referring to charts and graphs.

A.1 PILES IN COHESIVE SOIL

A.1.1 *Ultimate lateral load for piles in cohesive soil*

Broms adopted a distribution of soil resistance, as shown in Figure A.1, that allows the ultimate lateral load to be computed by equations of static equilibrium. The elimination of soil resistance for the top 1.5 diameters of the pile is a result of lower resistance in that zone because a wedge of soil can move up and out when the pile is deflected. The selection of nine times the undrained shear strength times the pile diameter as the ultimate soil resistance, regardless of depth, is based on calculations with movement of soil from the front toward the back of the pile.

A.1.1.1 *Short, free-head piles in cohesive soil*

For short piles that are unrestrained against rotation, the patterns that were selected for behavior are shown in Figure A.2. The following equation results from the integration of the upper part of the shear diagram to the point of zero shear (the point of maximum moment)

$$M_{max}^{pos} = P_t(e + 1.5b + f) - \frac{9c_u bf^2}{2} \tag{A.1}$$

But the point where shear is zero is

$$f = \frac{P_t}{9c_u b} \tag{A.2}$$

Therefore,

$$M_{max}^{pos} = P_t(e + 1.5b + 0.5f) \tag{A.3}$$

Integration of the lower portion of the shear diagram yields

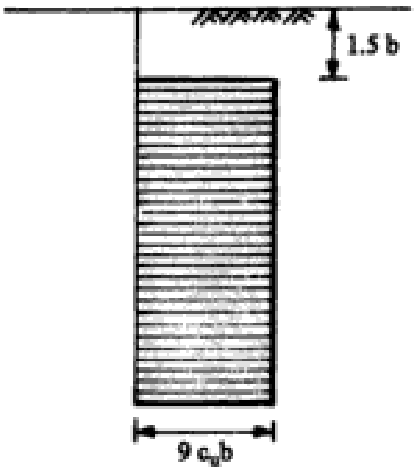

Figure A.1. Assumed distribution of soil resistance for cohesive soil.

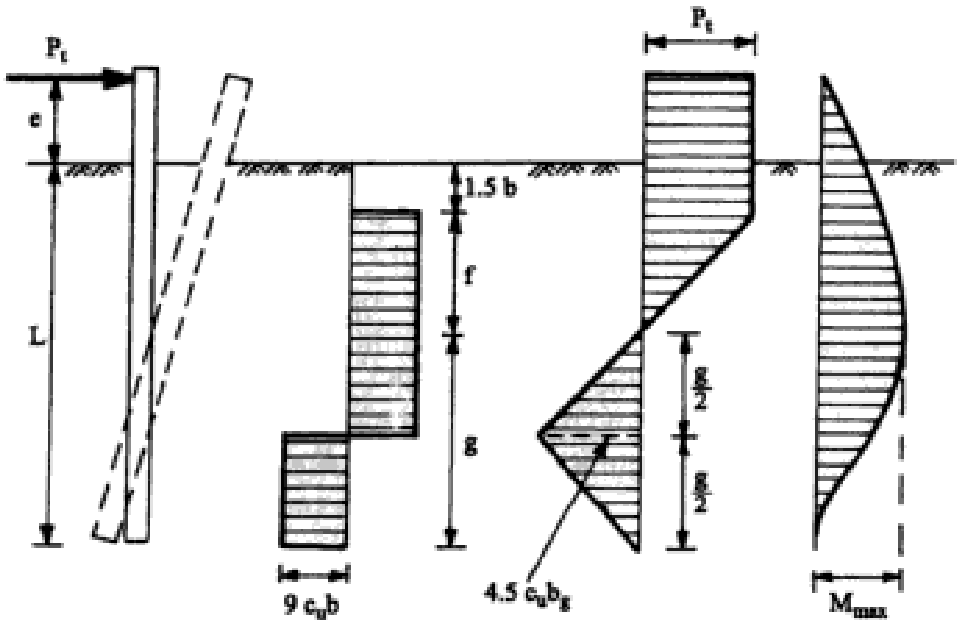

Figure A.2. Diagrams of deflection, soil resistance, shear, and moment for short pile in cohesive soil, unrestrained against rotation.

$$M_{max}^{pos} = 2.25 c_u b g^2 \tag{A.4}$$

It may be seen that

$$L = (1.5b + f + g) \tag{A.5}$$

Equations A.2 through A.5 may be solved for the load P_{tult} that will produce a soil failure. After obtaining a value of P_{tult}, the maximum moment can be computed and compared with the moment capacity of the pile. An appropriate factor of safety should be employed.

As an example of the use of the equations, assume the following:

b = 305 mm (assume 305-mm O.D. steel pipe by 19 mm wall),

$I_p = 1.75 \times 10^{-4}$ m^4, e = 0.61 m, L = 2.44 m, and

$c_u = 47.9$ kPa.

Equations A.2 through A.5 are solved simultaneously and the following quadratic equation is obtained.

$$P_t^2 + 2083P_t + 67{,}900 = 0$$

$$P_t = 59.4 \text{ kN}$$

Substituting into Equation A.3 yields the maximum moment

$$M_{max} = 59.4\left[0.61 + 1.5(0.305) + \frac{(0.5)(59.4)}{(9)(47.9)(0.305)}\right]$$

$$= 77 \text{ kN-m.}$$

Assuming no axial load, the maximum stress is

$$f_b = \frac{(77)(0.1525)}{1.75 \times 10^{-4}} = 67{,}000 \text{ kPa}$$

The computed maximum stress is tolerable for a steel pipe, especially when a factor of safety is applied to P_{ult}. The computations, then, show that the short pile would fail due to a soil failure.

Broms presented a convenient set of curves for solving the problem of the short-pile (see Fig. A.3). Entering the curves with L/b of 8 and e/b of 2, one obtains a value of P_{ult} of 60 kN, which agrees with the results computed above.

A.1.1.2 *Long, free-head piles in cohesive soil*

As the pile in cohesive soil with the unrestrained head becomes longer, failure will occur with the formation of a plastic hinge at a depth of $1.50b + f$. Equation A.3 can then be used directly to solve for the ultimate lateral load that can be applied. The shape of the pile under load will be different than that shown in Figure A.2 but the equations of mechanics for the upper portion of the pile remain unchanged.

A plastic hinge will develop when the yield stress of the steel is attained over the entire cross-section. For the pile that is used in the example, the yield moment is 430 m-kN if the yield strength of the steel is selected as 276 MPa.

Substituting into Equation A.3

$$430 = P_{ult}\left(0.61 + 0.4575 + \frac{P_{ult}}{2.53}\right)$$

$$P_{ult} = 224 \text{ kN}$$

Broms presented a set of curves for solving the problem of the long pile (see Fig. A.4). Entering the curves with a value of $M_y/c_u b^3$ of 316.4, one obtains a value of P_{ult} of about 220 kN.