

CHAPTER 6.0 DESIGN OF PILE GROUPS

6.1 INTRODUCTION

The design of a group of piles must consider the axial load carrying capacity of the pile group as well as the settlement of the pile group. In group pile design it is convenient to refer to the efficiency of a group (η_g) of piles as the ratio of the ultimate capacity of the group to the sum of the ultimate capacity of the individual piles in the group. The group efficiency is expressed as follows:

$$\eta_g = Q_{ug} \div (nQ_u) \quad (6-1)$$

where: Q_{ug} = Ultimate capacity of the pile group
 n = Number of piles in the pile group
 Q_u = Ultimate capacity of each individual pile in the group

It is recommended that a maximum pile to pile spacing of 3 pile diameters be used for all pile groups.

6.2 AXIAL PILE CAPACITY OF PILE GROUPS IN COHESIONLESS SOILS

For timber piles driven in cohesionless soils with a center-to-center spacing of less than 3 pile diameters, the ultimate capacity of the group is greater than the ultimate capacity of the sum of the individual piles (i.e., $\eta_g > 1$). This is due to the effect of soil compaction between piles; when the piles are spaced this closely together, the compaction effect on the soil is overlapped. Piles at spacings greater than 3 pile diameters act as individual piles.

6.3 AXIAL PILE CAPACITY OF PILE GROUPS IN COHESIVE SOILS

Use the following procedure for the determination of the ultimate capacity of timber pile groups in cohesive soils. The lesser of the four calculated ultimate group capacities using the following four steps should be used (FHWA-HI-97-013).

- 1.) For pile groups driven in clays with undrained shear strengths less than 2 ksf and the pile cap **not** in firm contact with the ground, use a group efficiency of 0.7. If the center-to-center spacing is greater than 6 pile diameters, then a group efficiency of 1.0 may be used.
- 2.) For piles in clays with an undrained shear strength less than 2 ksf and the pile cap in firm contact with the ground, use a group efficiency of 1.0.
- 3.) For pile groups in clays with undrained shear strength greater than 2 ksf, use a group efficiency of 1.0.

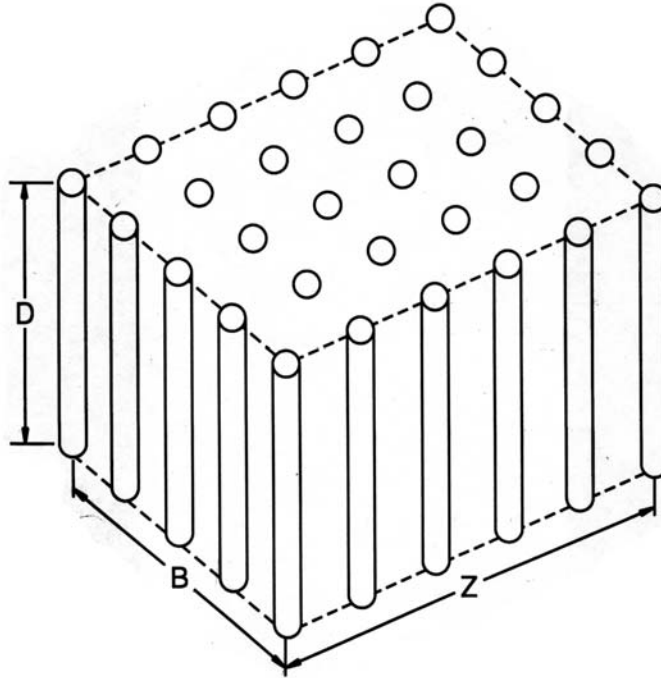


Figure 6-1: Three Dimensional Pile Group Configuration (after Tomlinson, 1994)

4.) Calculate the ultimate pile group capacity against block failure.

Block failure is generally only a concern for pile groups in soft cohesive soils. The ultimate capacity of a pile group against block failure (Figure 6-1) is determined from the following equation:

$$Q_{ug} = 2D(B + Z)c_{u1} + BZc_{u2}N_c \quad (6-2)$$

where:

D	= Embedment length of piles
B	= Width of pile group
Z	= Length of pile group
c_{u1}	= Weighted average of the undrained shear strength over the depth of the pile embedded in the cohesive soil along the pile group perimeter
c_{u2}	= Average of the undrained shear strength of the cohesive soil at the base of the pile group to a depth of $2B$ below the pile toe
N_c	= Bearing capacity factor (for rectangular pile groups)

The bearing capacity factor, N_c , for a rectangular pile group is generally 9. However, for pile groups with small pile embedment depths and/or large widths, N_c , should be calculated from the following equation.

$$N_c = 5 [1 + D / 5B][1 + B / 5Z] \leq 9 \quad (6-3)$$

Pile driving in cohesive soils may generate large excess pore water pressures, which may result in short-term (i.e., 1 to 2 months after installation) group efficiencies on the order of 0.4 to 0.8. As the excess pore water dissipates the group efficiency will increase.

6.4 SETTLEMENT OF PILE GROUPS IN COHEHSIONLESS SOILS

For pile groups in cohesionless soils, settlements will be immediate as the pile group is loaded. This is due to the high permeability of the soil. The settlement (s) of a pile group in homogeneous sand deposits not underlain by a more compressible soil at greater depth may be estimated using Meyerhof's (1976) approach which is based on SPT N' , values and is shown below :

$$s = (p_f \sqrt{BI_f}) \div \bar{N}' \quad (6-4a)$$

For silty sands:

$$s = (2p_f \sqrt{BI_f}) \div \bar{N}' \quad (6-4b)$$

where:

- s = Settlement in inches
- p_f = Design foundation pressure (ksf)
- B = Width of pile group (ft)
- N' = Average corrected SPT N' value within a depth B below pile toe
- D = Pile embedment depth (ft)
- I_f = Influence factor for group embedment = $1 - [D/8B] \geq 0.5$

For use of CPT data see FHWA-HI-97-013. For piles in cohesionless soils underlain by cohesive soils the method presented in the following section should be used.

6.5 SETTLEMENT OF PILE GROUPS IN COHEHSIVE SOILS

The settlement of pile groups in cohesive soils may be modeled as an equivalent footing at a depth below the pile toe as shown in Figure 6-2. Using this figure the settlement of the pile group may be determined using classical consolidation theory.

The settlement of a foundation resting on layers of normally consolidated soils ($\sigma'_p = \sigma'_{vo}$) can be computed from:

$$S_c = \sum_i^n \frac{C_c}{1 + e_o} H_o \log_{10} \frac{\sigma'_{vf}}{\sigma'_{vo}} \quad (6-5)$$

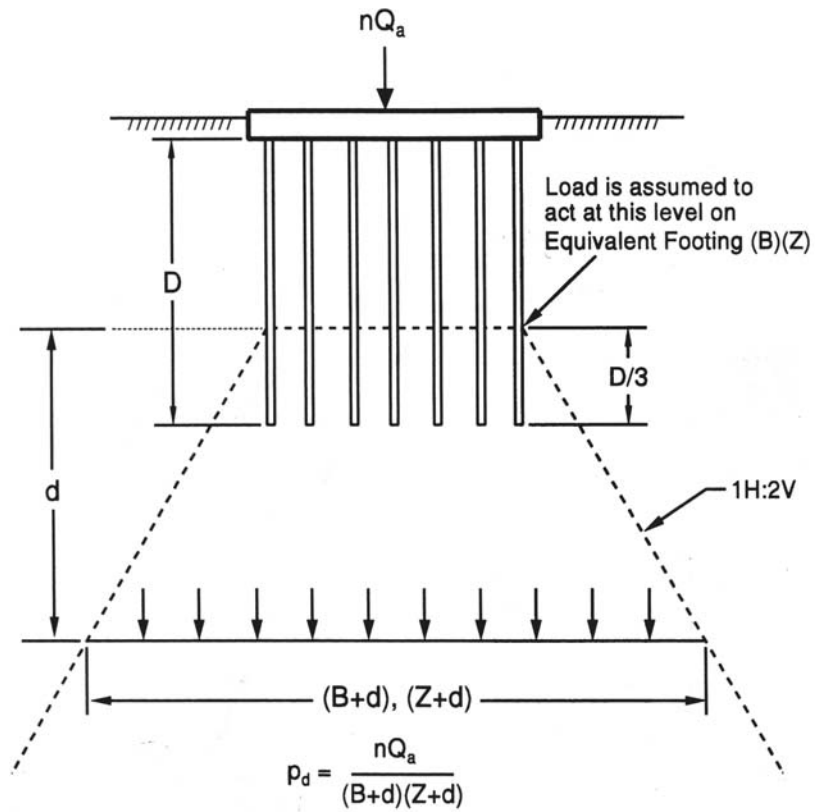
where:

- C_c = Compression index of the normally consolidated portion of the void ratio versus $\log \sigma'_v$ curve
- e_o = initial void ratio
- H_o = Layer thickness
- σ'_{vo} = Initial effective vertical stress at the center of layer n
- σ'_{vf} = Final effective vertical stress at the center of layer n .

The final effective vertical stress is computed by adding the stress change due to the foundation load to the initial vertical effective stress. The total settlement will be the sum of the compression of the n layers of soil.

Normally the slope of the virgin portion of the e - $\log \sigma'_v$ curve is determined from the corrected one-dimensional consolidation curve measured on specimens taken from each relevant soil in

the stratigraphic column. A detailed discussion on consolidation settlement analysis is beyond the scope of this manual.



Note: Pile Group has Plan Dimension of B and Z

Figure 6-2: Equivalent Footing Concept (FHWA-HI-97-013)