CHAPTER 4.0
STATIC ANALYSIS DESIGN PROCEDURES

4.1 INTRODUCTION

Static analysis methods are simplified analytical techniques used to model the very complex soil-structure interaction between driven piles and the surrounding soils. The analysis techniques that are presented in this manual have been selected because they have been proven to provide reasonable agreement with full scale field results. The techniques that will be presented here include the Meyerhof Method and the Nordlund Method for piles founded in cohesionless soils, the Alpha (α) Method and the Effective Stress Method for cohesive soils, and the Nottingham Schmertmann Method when CPT data is available. These methods have also been selected for presentation because they are relatively straightforward to use, and are the techniques that are recommend by the Federal Highway Administration (FHWA-HI-97-013).

It is strongly recommended that prior to using any of the static methods presented in this chapter that the user be familiar with the limitations of that analytical technique. In conjunction with static analysis, it is also recommended that static load tests be conducted to further calibrate the empirical models for the regional geology, to perform wave equation analysis and to perform dynamic monitoring during installation. These tools are essential in assuring that the design objectives are accomplished.

4.2 SOIL/PILE INTERACTION

The ultimate capacity of a pile is limited by the structural capacity of the pile (Chapter 3) and the capacity of the surrounding soil to support the loads transferred from the pile. This transfer of stress between the soil and pile is quantified by two components: the resistance that is developed along the shaft of the pile (R_s = shaft resistance) and the resistance that is developed at the bottom (toe) of the pile (R_t = toe resistance).

The process of driving piles affects the soil/pile interaction. The effects of this installation disturbance on the soil/pile interaction is briefly explained here. Timber piles are considered to be a displacement type pile (versus a non-displacement pile (i.e., H pile). In cohesionless soils, displacement piles disturb a zone around the pile by a lateral distance of 3 – 5.5 pile diameters and 3 – 5 diameters below the tip of the pile (Broms, 1966). Figure 4-1 shows the limits of this pile disturbance. For loose cohesionless soils, the disturbance from driving the displacement pile increases the relative density of the soil. This increased relative density increases the capacity of single piles and pile groups and is a major advantage of timber piles driven into cohesionless soils.

The pile driving process can, also in addition to increasing the density of loose cohesionless soils, generate high positive porewater pressures in saturated loose to medium fine sands. Positive pore pressures temporarily reduce the soil shear strength and the pile capacity; as the pore pressure dissipates, the pile capacity increases. This phenomenon is called “pile set up” and is generally quicker for sands and silts than for clays, because these types of soils are more permeable than clays, and pore pressures dissipate more rapidly.

In dense cohesionless soils, the disturbance from the pile driving may decrease the relative density of the surrounding soil. In these dense soils, the increase in horizontal stress in the soil adjacent to the pile during driving may be lost by “relaxation”. This phenomenon occurs as the negative pore pressure generated during the driving dissipates. The negative pore pressure occurs because of the dilation of the dense sand into a lower relative density. The negative pore pressure temporarily increases the soil shear strength by effectively increasing the normal stress on the failure surface. As the negative pore pressure dissipates, the shear strength and pile capacity decrease.

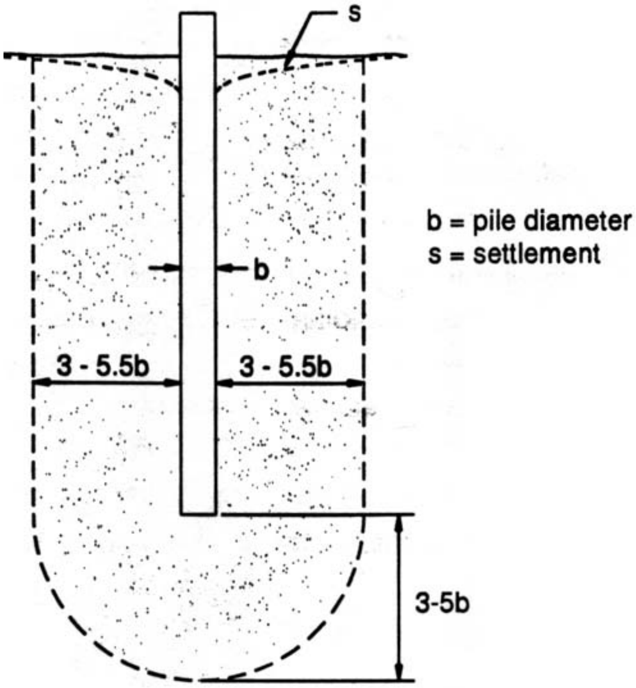

Figure 4 - 1 Compaction of Cohesionless Soils During Driving of Piles (Broms, 1966)

For cohesive soils, the soil pile interaction is different than for cohesionless soils. Soft, normally consolidated clays have a zone of disturbance around the pile both laterally, and at the toe of the pile, of approximately one pile diameter (Figure 4-2). The process of driving displacement piles in cohesive soils typically generates high positive pore water pressure. This increase in pore water pressure temporarily decreases the shear strength of the soil and the load carrying capacity of the pile. Reconsolidation of the cohesive soil and dissipation of the excess pore pressure results in an increase in shear strength and pile capacity. This is commonly referred to as “pile setup”.

4.2.1 Load Transfer

The ultimate bearing capacity (Q_u) of a timber pile in homogeneous soil is the sum of the shaft reisistance (R_s) and the toe resistance (R_t):

$$Q_u = R_s + R_t \qquad (4\text{-}1)$$

The shaft resistance may be expressed as the product of the unit shaft resistance (f_s) times the shaft surface area (A_s), and the toe resistance may be expressed as the product of the unit toe resistance (q_t) times the area of the toe (A_t). Equation 4-1 may be rewritten in unit resistance terms as follows:

$$Q_u = f_s A_s + q_t A_t \tag{4-2}$$

The equations presented here assume that both the pile toe and shaft have moved a sufficient distance with respect to the adjacent soil to simultaneously mobilize the ultimate shaft and toe resistance. It should be noted that the displacement needed to mobilize the shaft resistance is generally smaller than that required to mobilize the toe resistance.

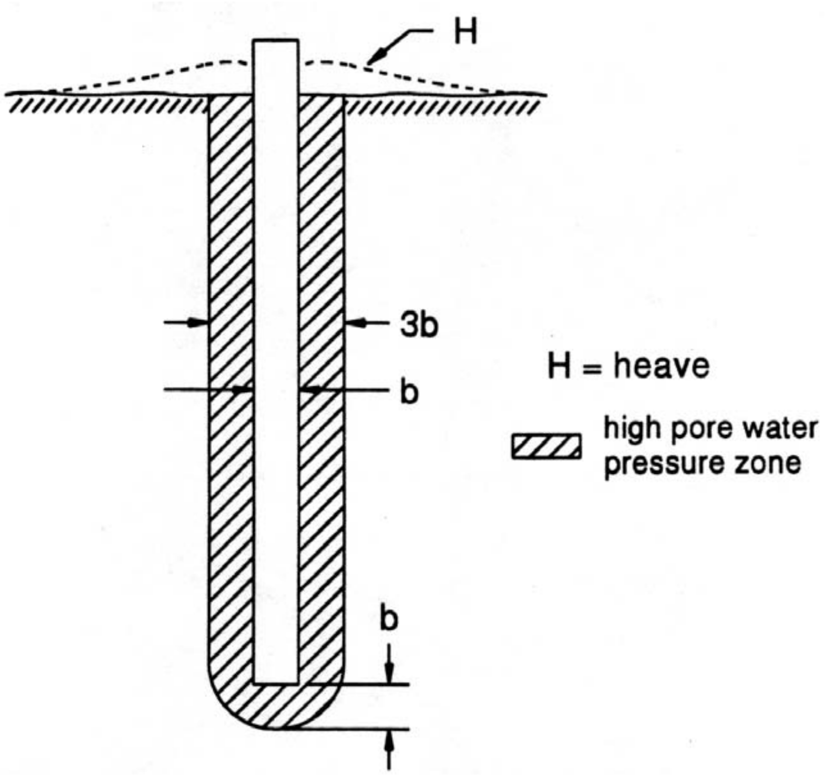

Figure 4 - 2 Disturbance of Cohesive Soils During Driving of Piles (Broms, 1966)

Figure 4-3 shows the typical load transfer profiles for piles. The axial load in the pile is a combination of the shaft resistance and toe resistance. Figure 4-3a shows the case when no shaft resistance is developed and the ultimate capacity of the pile is developed through toe resistance. Figure 4-3b shows the load transfer profile for the case where uniform shaft resistance is developed along the length of the pile. For this case, the resistance at the toe of the pile is due to the toe resistance. Moving up the pile, the ultimate resistance increases linearly due to the uniform shaft resistance until the top of the pile is reached, and is typical for piles in normally consolidated cohesive soils. Figure 4-3c shows the case for a triangular distribution of shaft resistance. This is the typical case for a pile in cohesionless soils.

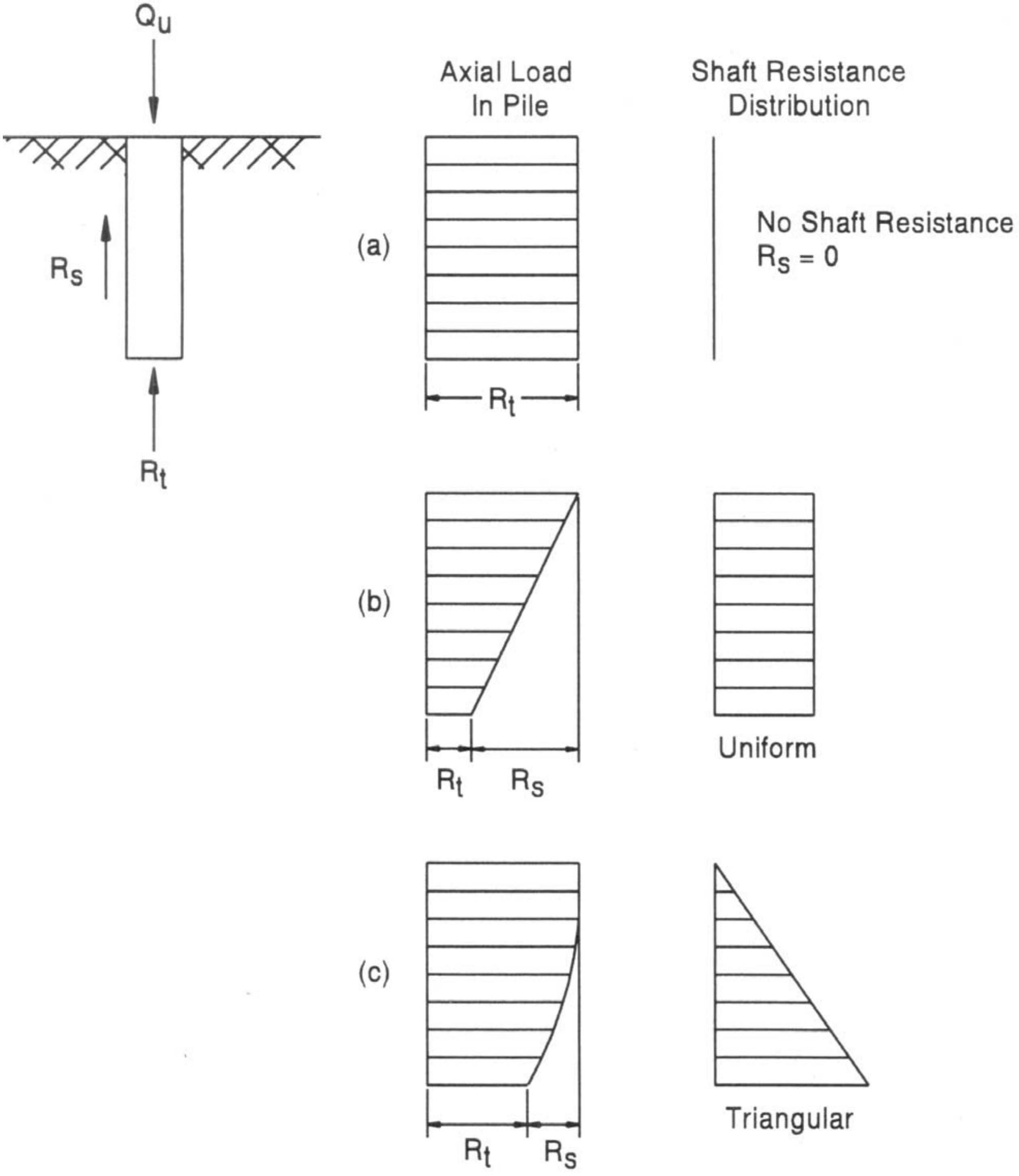

Figure 4 - 3 Typical Load Transfer Profiles

4.3 FACTORS OF SAFETY

Static analysis of piles is used to determine the ultimate capacity of a single pile or pile group. The allowable capacity of the pile is the ultimate capacity divided by a factor of safety. The factor of safety typically ranges between 2 to 4 and is dependent on:

- Level of confidence in the input design parameters
- Variability of the soil profile
- Method of static analysis
- Effects of proposed installation method
- Level of construction monitoring

The first two items typically govern the factor of safety that geotechnical engineers use for assessing the appropriate factor of safety for a geotechnical design of a shallow or deep foundation, for slope stability or for earth retaining structures. Engineering judgment should be used in evaluating the risk associated with the unknowns in a project, and then selecting the appropriate factor of safety. Many of the static analysis methods are documented in the literature with specific recommendations on the factor of safety to be used with them. These recommended factors of safety typically do not consider the variability of the soil profile, the confidence in the input parameters nor the level of construction monitoring. These items should also be considered when selecting the factor of safety for design. While the range in static factors of safety is from 2 to 4, most of the static analysis methods recommend a factor of safety of 3. It is the responsibility of the design engineer to determine the appropriate factor of safety for the specific application/project. When static load tests are performed, a factor of safety of 2.0 is often used because of the high level of confidence that the piles will perform as intended.

4.4 ENGINEERING NEWS RECORD FORMULA

The AWPI Timber Piling Council recognizes that the Engineering News Formula is still in use. However, more predictable procedures are provided in this manual for determining the static capacity of timber piles.

Some years ago, studies evaluating the degree of accuracy of this Formula demonstrated there was no satisfactory relationship between the capacity of piles determined by load tests versus calculated by the Engineering News Formula. When using the formula, the actual bearing capacity may be less than 1.2 or greater than 30 times the calculated value. “In view of these conditions the continued use of the Engineering News Formula can no longer be justified, (Terazghi and Peck, 1967).” The Engineering News formula, although not used for piling design, is used on-site as a quality control tool.