Sheet-Pile Walls-Cantilevered and Anchored

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Abstract: This presents methods to analyze and design cantilever and anchored sheet-pile structures. Types of materials used for sheet piles are also given as background for this chapter and the following chapters, which consider other foundation structures built with sheet piling. This will present briefly the classical methods of analyzing cantilever and anchored sheet piles, then proceed to the finite-element method, which has been shown by the author [Bowles (1974a)] to be the most rational method of analysis of sheet-pile walls. This method can be extended to obtain the best currently available method of analyzing braced excavations, as will be shown. The finite-element is quite similar to the finite-difference (sometimes called beam-column) method used by some organizations. The finite-element method has the advantage over the classical methods of directly applying "moment reduction" during the analysis and of obtaining the deflections and bending moments at the nodal points of the wall. The classical methods made simplifying assumptions and implicitly assumed dredge-line deflections were zero, and the moments computed were, generally, too large and required moment reduction for design. The finite-element procedure also gives directly the soil pressure required for wall stability for comparison with the bearing ability of the soil.

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Introduction

Sheet-pile walls are widely used for both large and small waterfront structures ranging from small pleasure-boat launching facilities to large oceangoing ship dock facilities. Piers jutting into the harbor consisting of two rows of sheetpiling as in are widely used. Sheetpiling is also used for slope stability and erosion protection.

The sheet-pile problem is one of lateral earth pressure with the Coulomb or Rankine methods being directly applicable. In particular, the Coulomb method is recommended since a sheet-pile wall is sufficiently flexible to produce large lateral displacements so that relative slip occurs between wall and soil. Friction resistance is developed from soil slip at the interface to reduce the earth-pressure coefficient K_a. The Rankine method is also commonly used since the earth-pressure coefficient is more conservative, i.e., slightly larger.

1. The soil may be obtained from dredging operations and placed-often hydraulically-so that the resulting ϕ angle is uncertain. The SPT data may be used to estimate the ϕ angle for other granular backfill. Recovered SPT samples may be dried and poured (through water if necessary) in a pile to obtain the approximate ϕ angle from the angle of repose. The angle of repose is the approximate lower limit of ϕ. A laboratory shear test would have to be done at the placing density to have significance; this placing density is difficult to estimate without careful compaction control.

2. If the wall is driven as in trench shoring, the in situ soil is retained and backfill is not used. In this case the soil parameters are likely to be from SPT or other in situ methods and cohesion $c = q_u/2$. Quality tube samples are not often used unless the wall is high or the location/safety requirements can justify the additional expense.

3. If the wall is driven along a waterfront a limited backfill zone is likely to be obtained. Again the existing soil parameters are most likely to be determined from an SPT.[1]

4. Sheet-pile walls are, with few exceptions, either temporary supports for excavations, or for waterfront structures or other cases where lateral distortion of the wall is not critical and aesthetics is not a factor. If the soil parameters are slightly unconservative for these cases, an excessive wall bulge is likely to be the worst event.

5. The overall stability of the wall is usually based on a "safety factor" of 1.25 to 1.5 which coupled with conservative estimates of ϕ provides adequate safety of public and property in most cases.

If laboratory tests are performed they would be of the CD type for sand and either CU or U tests for other materials. The triaxial ϕ value may be converted to a plane-strain value (1.1 ϕ_{tr}) if the wall is long. The ϕ angle is often estimated as from 28 to 32° where the backfill is granular or silty-granular from dredgings. Sheet piles for trenches and similar structures in ϕ-c soils should use the modified pressure diagram. The effective stress is used in all earth-pressure computations for these walls.

The angle of wall friction may be estimated for; however, for Z or deep web shapes part of the friction is soil to soil and about half is soil to sheet pile. Where this is the case use

$$\tan\delta' = \frac{\tan\phi + \tan\delta}{٢}$$

The δ value is from Table 11-6, and ϕ is the angle of internal friction of backfiil.

The finite-element procedure uses the active-lateral-earth-pressure zone in the backfill as in the classical methods. In the passive zone, the concept of modulus of subgrade reaction is used. The author has shown [Bowles (1974a)] that this model is reasonably correct by using it to analyze full-scale field walls and for reanalyzing model sheet-pile wall studies of Tschebotarioff (1949) and of Rowe (1952). Rowe's model walls were constructed by filling both sides of the wall simultaneously, then excavating the front side. This creates an "ideal" wall which is easy to model by the finite-element procedure in spite of the fact that the subgrade modulus must be estimated. Tschebotarioff's walls were built and backfilled as one would in the field, i.e., constructing the wall, then backhlling in stages. These walls could be, modeled but with more difficulty, as one would expect. The most important advantages of the finite-element method of solution are:

1. Estimates of deflection

2. Rational evaluation of changed wall geometry (loss of dredge line, etc.)

3. Estimate of actual lateral passive pressure to see if the solution is possible 4. Effects of large increases in embedment depth

5. Ease of handling ϕ-c soils. Most texts consider either ϕ or c soils since ϕ-c or stratified soils are extremely difficult to use in classical sheet-pile analysis[2]

Estimates of the modulus of subgrade reaction can be obtained from equations given in Sec. 9-5. In general, the value will increase in depth according to Eq. (9-9):

$$k_s = A + BZ^n$$

Lateral pressure due to surcharges can be analyzed using Eq. (5-7) or with a computer program in the method outlined at the end of Sec.

Types of Sheetpiling

Sheetpiling materials may be of timber, reinforced concrete, or steel. Design stresses are usually higher than in building construction and may be from 0.6 to 0.9F_Y for steel and wood and as much as 0.75f' for unfactored loads. Actual design stresses depend on engineering judgment, effect of a wall failure, and local building codes.

Timber Sheetpiling

Timber sheetpiling is used for short spans, light lateral loads, and commonly, for temporary structures in the form of braced sheeting. If it is used in permanent structures above water level, it requires preservative treatment, and even so, the useful life is relatively short.

Timber piling probably finds its greatest use as braced sheeting for temporary retaining structures in excavations.

Driving of wood sheeting is somewhat troublesome, since a driving cap is required, and driving in hard soil with large gravel tends to split the piling. The sheeting may be pointed, generally, and placed so that the piling tends to wedge against the previously driven pile. The tongue-and-groove joints indicated will provide a reasonably well jointed wall only if small stones or soil do not get wedged into the grooves.[3]

Reinforced-Concrete Sheet Piles

These sheet piles are precast concrete members, usually with a tongue-andgroove joint. They are designed for the computed service stresses, but the handling and driving stresses, which may be considerable because of their weight, must also be taken into account. The points are usually cast with a bevel, which tends to wedge the pile being driven against the previously driven pile. Typical dimensions from which it is seen that the piles are relatively bulky, and thus displace a large relative volume of soil. This large volume displacement of soil tends to increase the driving resistance. The relatively large sizes, coupled with the high unit weight of concrete, means that the piles are quite heavy and may not be competitive with other types of piles unless they are cast in close proximity to the jobsite.

By cleaning and grouting the joints after driving, a reasonably watertight wall may be achieved. If the wall is grouted, however, it may be necessary to provide expansion joints at intervals along the wall.[4]

Steel Sheetpiling

Steel sheetpiling is the most common type used because of several advanfages over other materials. Principal advantages are as follows:

1. It is resistant to high driving stresses as developed in hard or rocky material. 2. It is of relatively light weight.

3. It may be reused several times.

4. It has a long service life either above or below water with modest protection [NBS (1962)].

5. It is easy to increase the pile length by either welding or bolting.

6. Joints are less apt to deform when wedged full with soil and stones during driving.

Conclusion

1. The arch web and Z piles are used to resist large bending moments, as in anchored or cantilever walls. The deep-arch web and Z piles are used in cases where the larger bending moments are to be resisted. Where the bending moments are somewhat less, the shallow-arch piles with corresponding smaller section moduli can be used. Straight-web sheet piles are used where the web will be subjected to tension, as in cellular cofferdams.

2. To form cofferdams, the sections may be made up or formed into certain standard joints, such as Ts, Ys, and crosses, to effect the joining of several cells or to change directions.indicates several of a large number of joints which are available or can be fabricated).

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