### 3.4.3.1 HPS T-Wall Design Procedure

**Description**

This design method evaluates the improvement in global stability by including the allowable shear and axial force contributions from the foundation piles together with the soil shear resistance in a limit equilibrium slope stability analysis (Spencer method of analysis). This procedure has the ability to account for both the reinforcing effect the piles have on the foundation soils and ability to determine safe allowable shear and axial forces for the piles**.** This design procedure is a supplement to existing Hurricane and Storm Damage Reduction System design criteria and EM 1110-2-2906, which shall govern for design aspects not specifically stated herein.

The design procedure requires an initial pile layout to get started. The initial pile layout is designed similarly to the current MVN procedure in that slope stability is checked for the T-wall configuration neglecting piles, and also the water loads directly on the wall, and a balancing force is computed to achieve the required global factor of safety (termed the unbalanced force). A portion of the unbalanced force is applied to the pile cap and a CPGA analysis is completed.

The initial CPGA based design is verified by applying the unbalanced force as an equivalent "Distributed Load" to the foundation piles in an Ensoft Group Version 7.0 model (Group 7). Loads are also applied to the wall base and stem and the axial and shear responses for each pile are then compared with the allowable pile forces found from load tests or from computations. Limiting axial and lateral loads according to load test data helps minimize deflection to tolerable limits. Deflections of the T-wall computed from the Group 7 analysis are also compared to allowable deflections and bending moments and shear are checked to verify that they are within allowable pile limits.

Note that all CPGA designs shall include unfactored service loads and the Group 7 input shall include unfactored soil properties.

**Design Steps**

For any design the subsurface characteristics must be properly identified. This includes stratigraphy, material properties and groundwater conditions. Material properties for wall design include unit weight, shear strength (drained or undrained depending on loading condition), and horizontal soil modulus. To complete the pile design, proper group reductions must also be considered. Reductions of soil stiffness are applied for pile group effects in accordance with the HSDRSDG. No reductions are recommended for cyclic loading for several reasons:

- Analyses to date indicate that wall and soil loadings are transmitted axially to the foundation piles and changes in the lateral soil stiffness do not significantly impact the design.

- The Young's modulus of the soil between the wall base and the critical failure surface is reduced in this design procedure based on the global stability. Where global stability factors of safety are below one, the soil stiffness in this zone is neglected. Where the factors of safety exceed criteria, full soil stiffness is used. The soil stiffness is linearly proportional between these limits when the computed factor of safety is between one and the required factor. In this way the soil stiffness is already being reduced and further reduction is felt to be too conservative.
- In most instances the T-walls are above normal water levels and are not routinely subjected to wave, tide or pool fluctuations and the associated large number of loading cycles.

# TYPICAL T-WALL CRITERIA

GENERAL. The procedure is applicable to T-Walls. Adaptations for drainage structures, floodgates, and extended foundations are discussed in para. 3.4.3.3. Fronting walls, constructed separate from existing structures (i.e Pump Stations), present other analysis concerns that are discussed in para. 3.4.3.4.

Step 1. Initial Slope Stability Analysis

1.1. Determine the critical **non-circular failure** surface from a slope stability analysis for loading to the SWL and to the Top of Wall using a software program capable of performing Spencer's method with a robust search procedure (hereinafter termed Spencer's method). Sufficient deterministic and finite element analyses have been completed on varying soil profiles to assure that the non-circular surfaces shall govern the stability assessment. Furthermore, numerical modeling has indicated that soil displacement is nearly horizontally along the critical failure surface. The slope stability analysis should be performed with only water loads acting on the ground surface flood side of the heel of the T-wall because these are the loads that the foundation must resist to prevent a global stability failure. The analysis should not include any of the water, soil, or surcharge loads acting directly on the structure because these loads are presumed to be carried by the piles to deeper soil layers.

Global stability of T-walls includes the foundation materials on the protected side of the wall. If those materials were removed the walls would be required to support a larger unbalanced load. If the foundation on the protected side of the T-wall (like an existing slope towards an inland ditch or canal) is not stable or does not satisfy required factors of safety it must either be improved to meet criteria or be partly removed from the global stability model when calculating the unbalanced load. Landward berms and channel local slope stability analysis shall satisfy the applicable FOS listed in Table 1, Chapter 3 of the HSDRSDG in order to be included in the global stability analysis.

1.2. If the factor of safety of the critical failure surface is greater than required (see MVN Hurricane and Storm Damage Reduction System Design Guidelines, HSDRSDG, for slope stability criteria), a structural analysis of the T-wall system shall be completed using a group pile analysis program (like CPGA or Group 7) using only the water loads and at rest pressures applied directly to the structure. If the lowest factor of safety is less than required, then proceed to Step 2. The factor of safety and defining failure surface coordinates should be noted for use in Step 2.

1.3. As stated in paragraph 1.1 above, only non-circular failure planes shall be investigated and shall be horizontal along the critical failure surface. This horizontal distance is referred to as the neutral block. **The neutral block shall have a minimum dimension of the <u>greater</u> of 0.7 H or the base length of the T-Wall or structure. H is defined as the vertical distance from the failure surface to the intersection of the failure plane with the ground surface (see Figure 1).**

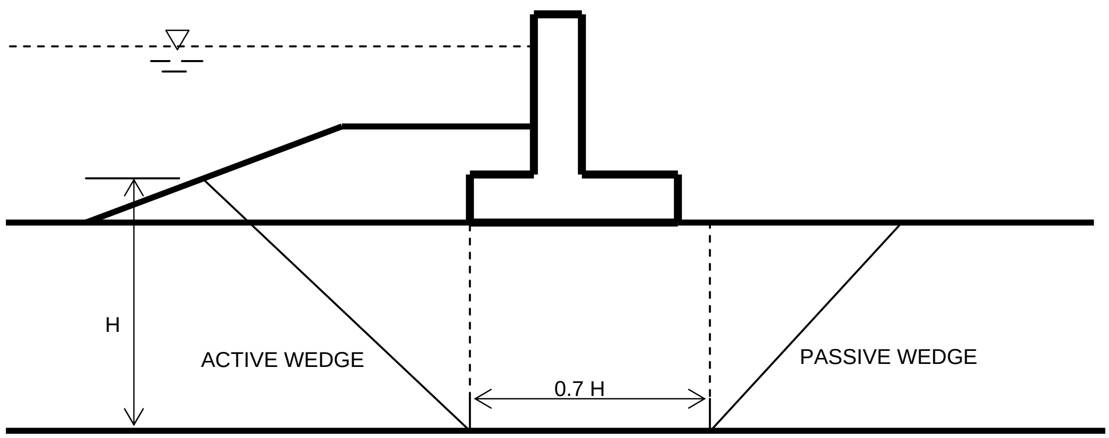



Figure 1. Typical Failure Plane Beneath a T-Wall

1.4. Designers shall also perform a Method of Planes (MOP) analysis as a design check. This is required regardless if an unbalanced load exists or not. The MOP Factors of Safety are 1.3 for water at the Still Water Level (SWL) and 1.2 for water at Top of Wall (TOW). MOP results (including final factors of safety, failure surface geometries, and any unbalanced loads) shall be compared to the Spencer's analysis that utilize a FOS of 1.5 with Water at SWL and 1.4 with Water at TOW. The Spencer's method remains the design tool.

Step 2. Unbalanced Force Computation

2.1. Determine the unbalanced forces (for both loading to StillWater Level (SWL) and Top of Wall (TOW)) required to achieve the target factor of safety using Spencer's method with a non-circular failure surface search. The unbalanced force shall be applied as a horizontal line load at a location having an X-coordinate at the heel of the wall or simply beneath the base of the wall. The Y-coordinate shall be located at an elevation that is half-way between the ground surface at the heel of the wall and the lowest elevation of the critical failure surface beneath the wall base from Step 1.

The unbalanced load is arrived at through a trial and error process where the load is varied until the desired factor of safety is achieved. The failure surface found in Step 1 is "reanalyzed" with the specified line load so that the largest unbalanced force is computed. The unbalanced load is determined for both conditions: the slip surface with lowest factor of safety and the slip surface with the highest unbalanced load. The unbalanced load and the defining failure surface coordinates should be noted for use in subsequent steps. The largest unbalanced load does not necessarily coincide with the failure surface with the lowest factor of safety, therefore, multiple failure surfaces at various elevations must be analyzed to determine those corresponding unbalanced forces. The unbalanced load is determined for both conditions: the slip surface with lowest factor of safety and the slip surface with the highest unbalanced load. The unbalanced load and the defining failure surface coordinates should be noted for use in subsequent steps.

**2.2. The critical failure plane is defined as the failure surface that produces the greatest unbalanced load. This failure surface is NOT necessarily the failure surface with the lowest factor of safety. Where unbalanced loads are present, all axial pile capacity developed above the critical failure plane shall be disregarded.**

Step 3. Allowable Pile Capacity Analyses

3.1. Establish allowable single pile axial (tension; compression) capacities. Axial capacity shall be determined according to chapter 3 of the HSDRSDG. Axial capacities must be determined for tensile and compressive piles. The contribution of skin friction should not be accounted for above the critical failure surface found in Step 2 in the determination of the axial capacity. Allowable axial loads may also be found using data from pile load tests and applying appropriate factors of safety after the ultimate load has been reduced to neglect the skin friction effects capacity above the critical failure surface. No cyclic reductions need to be applied to the capacities.

3.2. Compute allowable shear loads on the pile at the critical failure surface. Lateral shear loads have historically not been computed; instead deflections are calculated at a working stress level and are required to be less than specified limits. For this procedure, in addition to the traditional check of pile cap displacements, allowable lateral loads are now used as a design check. The Ensoft program LPILE or the Corps program COM624G can be used to compute allowable lateral shear in the pile using these steps:

a. Analyze the pile with a free head at the critical failure surface. To account for overburden pressure, make the top foot a layer with a unit weight equal to the effective stress due to the overburden.

b. Run a series of progressively higher lateral loads on the pile, with moment equal to zero, and plot load vs. deflection results. The pile will fail when deflections increase greatly with increasing load. The load vs. deflection curve should be terminated at the load at which yield in the pile is reached. Draw lines roughly tangent to the initial and final portions of the curve. The point of intersection of the two tangent lines is the ultimate shear strength . An example of this is shown in Figure 2.

c. Divide the shear load by the same factors of safety used to compute allowable axial capacity from calculated ultimate values, as described in Chapter 3 of the HSDRSDG.

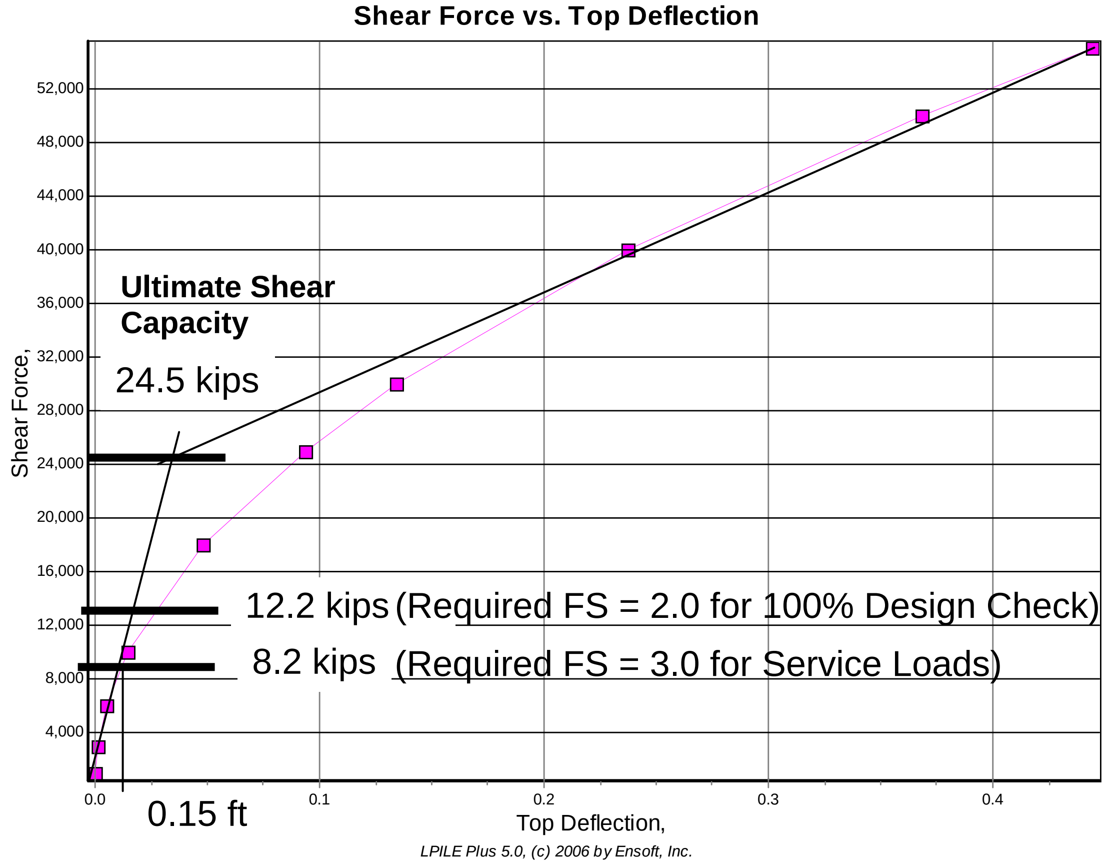



Figure 2. Example of computation of ultimate shear load in the pile from a load vs. deflection curve developed using LPILE. FS varies depending on load case.

Step 4. Initial T-wall and Pile Design

4.1. Use CPGA to analyze all load cases and perform a preliminary pile and T-wall design comparing computed pile loads to the allowable values found in the preceding step. For this analysis the unbalanced force is converted to an "equivalent" force applied to the bottom of the T-wall. It is calculated by a ratio derived by computing equivalent moments at the location of the maximum moment in the pile below the critical failure surface. The location of maximum moment is approximated from Figure 6.9 of "Pile Foundations in Engineering Practice" by Shamsher Prakash and Hari D. Sharma as being about equal to the stiffness factor, R, below the ground surface. The equivalent force (excluding the unbalanced force above the base of the T-Wall), $F_{cap,}$ is calculated as shown below (see Figure 3):

$$F_{cap} = F_{ub}\left[\frac{\left(\frac{L_p}{2}+R\right)}{\left(L_p+R\right)}\right]\frac{L_p}{L_u} \qquad (1)$$

Where

$F_{ub}$ = unbalanced force computed in step 2.

$L_u$ = distance from top of ground to the lowest El. of critical failure surface (in)

$L_p$ = distance from bottom of footing to lowest el. of crit. failure surface (in)

R = $(EI / Es)^{1/4}$ (2)

E = Modulus of Elasticity of Pile ($lb/in^2$)

I = Moment of Inertia of Pile ($in^4$)

Es = Modulus of Subgrade Reaction ($lb/in^2$) below critical failure surface. In New Orleans District this equates to the values listed as $K_HB$.

$K_HB$ is calculated as shown in Section 3.

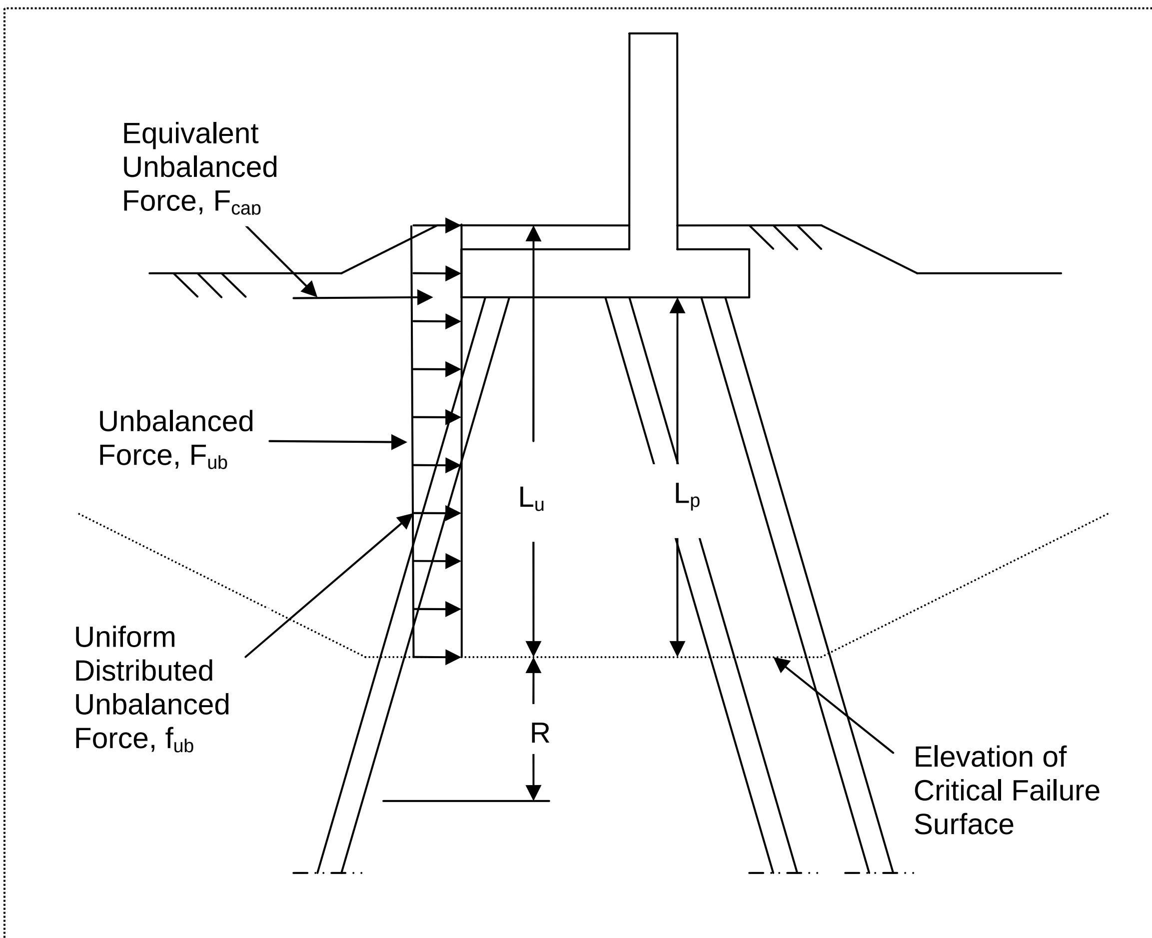



Figure 3. Unbalanced Forces.

Comments:

a. The above procedure does not directly account for the unbalanced force that's transferred down the pile and into the soil below the critical failure surface by lateral soil resistance. This procedure has been found to be adequate for computing axial loads in the piles in order to determine a preliminary pile layout. Forces not accounted for with this procedure will be computed directly in Step 5.

b. The lowest elevation of the critical failure surface is used, regardless of where the computed failure surface actually intersects the piles. This simplification is made because the soil-structure modeled with this procedure is an approximation and research shows that the presence of the piles will influence the actual location of the critical failure surface so it is something like that shown in Figure 3. This procedure is considered to provide acceptable design forces in the piles.

4.2. In CPGA, the top of soil will be modeled at the ground surface, and the subgrade modulus, Es, is reduced with reduced global stability factors of safety to account for lack of support from the less stable soil mass located above the critical failure plane. For cases where the global factor of safety without piles is less than 1.0, Es is input at an extremely low value, such as 0.00001 ksi (CPGA will not run with Es set at 0.0). For conditions where the factor of safety is between 1.0 and the target factor of safety, Es is computed by multiplying the percentage of the computed factor of safety between 1.0 and the target factor of safety by the actual estimated value of Es. For example, if the FS = 1.0, Es is input as 0.00001. If the FS = 1.2, the target factor of safety is 1.5, and the estimated value of Es below the foundation is 100 psi, Es is input at 40% of the actual estimated value, 40 psi. This accounts for the fact that with higher factors of safety the unbalanced force is a small percentage of the total force, and the soil is able to resist some amount of the lateral forces from the wall. Although Es is reduced, the full pile length is considered braced provided the FOS is above 1.0 or the sheet piling is extended as stated in para. 4.4 below. One reduced value of Es is used throughout the depth of the pile. There is no distinction in values between the leading and trailing rows.

For certain cases with shallow critical failure surfaces, the procedure in the previous paragraph may not match well with the Group results found in later steps. For these cases, the CPGA model may be created with the ground level set at the level of the critical failure surface and the T-wall suspended above it at the actual footing elevation. The soil modulus at the critical failure surface is used for this model. There is no reliable method to account for factors of safety greater than 1.0 with this method however.

4.3. No reductions to the subgrade modulus are required for cyclic loading. Group reductions based on pile spacing are also applicable. However, for monoliths containing battered piles, further refinement of the Es value for Step 4 calculations may not be required for several reasons:

- The horizontal component of Battered Piles provide most of the lateral resistance.

- The ES reduction used in the para 4.2 conservatively uses the same reduced Es for trailing rows as leading rows.
- The governing load cases will be more accurately analyzed in Step 5.

When used, Group reduction factors (Rg) to be applied to subgrade modulus shall be computed as shown below:

Subgrade Modulus reductions are computed as follows:

For loading perpendicular to the loading direction:

$$Rga = 0.64(s_a/b)^{0.34} \quad ; or \ = \ 1.0 \text{ for } s_a/b > 3.75$$

Where:
$s_a$ = spacing between piles perpendicular to the direction of loading (parallel to the wall face). Normally piles should be spaced no closer than 5 feet on center.
$b$ = pile diameter or width

For loading parallel to the loading direction:

For leading (flood side) piles:

$$Rg_{bl} = 0.7(s_b/b)^{0.26} \quad ; or \ = \ 1.0 \text{ for } s_b/b > 4.0$$

For trailing piles, the reduction factor, $Rg_{bt}$ is:

$$Rg_{bt} = 0.48(s_b/b)^{0.38} \quad ; or = 1.0 \text{ for } s_b/b > 7.0$$

Where:
$s_b$ = spacing between piles parallel to the direction of loading (perpendicular to the wall face. Note: $s_b$ can be measured 5 pile diameters below the bottom of the cap, making pile rows trailing others battered in the opposite direction to normally be able to be considered as leading piles.
$b$ = pile diameter or width

4.4. Sheet piling shall be included and designed to control seepage. Sheet pile shall be designed for seepage in accordance with Chapter 3, HSDRSDG. When unbalanced loads exist, cutoff sheet piling shall be extended 5' below the critical failure plane determined in Step 2. The sheet piling shall be a PZ-22 section or equivalent, structural analysis is not required. The sheet piling curtain wall provides the added benefit of confining the soil wedge such that the pile shall be considered braced full length about both axis regardless of the stability factor of safety.

4.5 This paragraph addresses the resistance to soil flow of the failure wedge through the pile foundation. Storm surge loading on the soil beyond the relieving base width of the T-wall superstructure results in a passive loading on the foundation piles where the soil tends to push through the piles rather than an active loading where the piles tend to push through the soil. The foundation piles need to be checked for resistance to flow through, which is a function of pile spacing, magnitude of load and soil shear strength, and number of pile rows. Pile spacing perpendicular to the load should generally be limited to no more than seven times the pile diameter. To resist flow-through, the passive load capacity of the piles ($P_{all}$) is checked against the unbalanced loading. In addition, this check will define the upper limit of possible loading on the flood side row of piles and may lead to redistribution of the unbalanced load for later Group 7 analysis. The procedure for performing this check is set up to evaluate this per monolith or by pile spacing (for uniformly spaced piles) as follows:

a. Compute capacity of the flood side pile row using a basic lateral capacity:

$$\sum P_{all} = \frac{n \sum P_{ult}}{1.5} \tag{3}$$

Where:

$n$ = number of piles in the row perpendicular to the unbalanced load within a monolith. Or, for monoliths with uniformly spaced pile rows, n = 1.

$\Sigma P_{ult}$ = summation of $P_{ult}$ over the height $L_p$, as defined in paragraph 4.1
For single layer soil is $P_{ult}$ multiplied by $L_p$
For layered soils, $P_{ult}$ for each layer is multiplied by the thickness of the layer and added over the height $L_p$

$P_{ult}$ = $Rf(9S_u b)$

$S_u$ = soil shear strength
When there are multiple soil strata between the base of the structure and the critical failure plane being analyzed, $S_u$ shall be calculated as the weighted average of $S_u$ of each stratum above that failure plane.

b = pile width

Rf = group reduction factor for pile spacing parallel to the load are as follows:

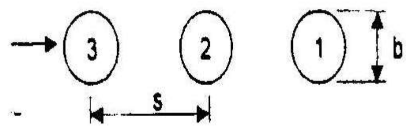
For leading (flood side) piles:

$Rf = 0.7(s/b)^{0.26}$ ; or = 1.0 for $s/b > 4.0$

For trailing piles, the reduction factor, Rf, is:

$Rf = 0.48(s/b)^{0.38}$ ; or = 1.0 for $s/b > 7.0$

Where:
s = spacing between piles parallel to the loading




No reduction is considered for the pile spacing perpendicular to the load. Group effects do not need to be considered between pile rows battered in opposite directions (battered away from each other). A trailing row staggered from a leading row may be treated as a leading row, but additional rows should be treated as trailing. The spacing between lead pile and the staggered pile (row spacing), in the direction of the load, shall be equal to or less than the column spacing of the leading piles.

b. Compute the unbalanced unit load on the piles (Fp) to check against $\sum P_{all}$:

$$F_p = w f_{ub} L_p \qquad (7)$$

$w$ = Monolith width. Or, for monoliths with uniformly spaced pile rows, $w$ = the pile spacing perpendicular to the unbalanced force ($s_t$)

$$f_{ub} = \frac{F_{ub}}{L_u} \qquad (8)$$

$F_{ub}$ = Net unbalanced force per foot from Step 4.1
$L_u$ and $L_p$ as defined in paragraph 4.1

If layered soils exist, this check can be made by summing $P_{all}$ over the length of the pile from the bottom of the wall to the lowest elevation of the critical failure surface ($L_p$, fig. 2) (i.e., $\Sigma P_{all}$) and comparing it to $f_{ub}$ multiplied by $L_p$.

c. The number of piles is adequate to resist flow-through if $\Sigma P_{all}$ for the flood side piles exceeds Fp/2. If Fp/2 exceeds $\Sigma P_{all}$ for the flood side piles, then compute $\Sigma P_{all}$ for all rows of piles. If $\Sigma P_{all}$ is less than Fp, then the pile foundation will need to be modified (decreasing transverse pile spacing and/or increasing pile rows) until this condition is met.

The flow is resisted by the full $\Sigma P_{all}$ of the floodside row and the balance distributed to all piles behind the flood side row as modified by Rf for trailing piles. Irregular pile layouts with rows that have far fewer piles than other rows should not have increased load on the pile to account for greater lateral spacing.

4.6. For an additional flow-though mechanism check, compute the ability of the soil to resist shear failure between the pile rows from the unbalanced force below the base of the T-wall, $f_{ub}L_p$, using the following equation:

$$f_{ub}L_p \le \frac{A_pS_u}{FS}\left[\frac{2}{(s_t - b)}\right] \tag{9}$$

Where:
$A_pS_u$ = The area bounded by the bottom of the T-wall base, the critical failure surface, the upstream pile row and the downstream pile row multiplied by the shear strength of the soil within that area. For layered soils, the product of the area and $S_u$ for each layer is computed and added for a total $A_pS_u$. See Figure 4.
$FS$ = Target factor of safety used in Steps 1 and 2.
$s_t$ = the spacing of the piles transverse (perpendicular) to the unbalanced force
$b$ = pile width

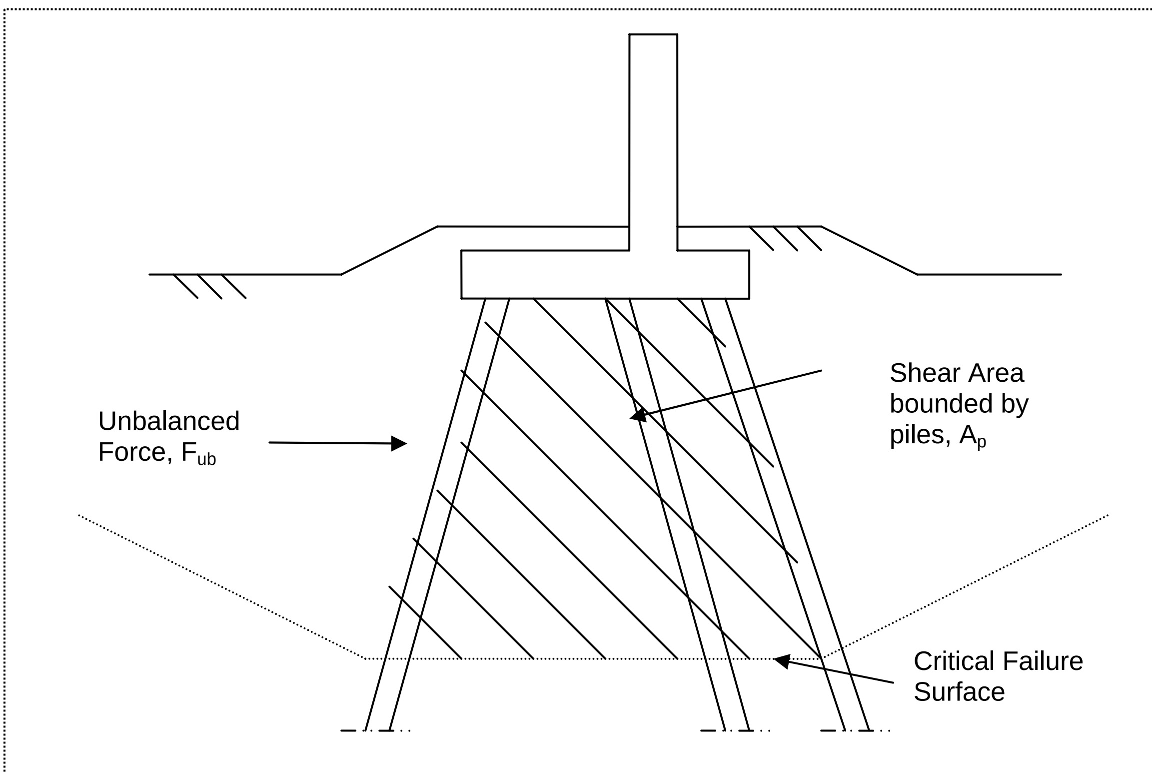



Figure 4. Area of for flow-through shear check.

Note: The sheet pile is conservatively neglected for this computation .

Step 5. Pile Group Analysis (all loads)

5.1. To verify the preliminary CPGA design, Group 7 (Ensoft Group Version 7.0) is used to check pile loads and stresses. All loads, including the unbalanced loading, are applied to the pile foundation. Only load cases controlling deflections and pile loads in Step 4 need to be checked. It is expected that the critical load cases checked will include the unbalanced force found for loading at the SWL and the Top of Wall.

5.2. Water pressures, at rest soil pressures, concrete weight, vessel impact, etc. are applied directly to the structure. The unbalanced load is applied as uniformly distributed along the length of the bearing piles located above the critical failure plane.

5.3. For the pile group analysis, develop a Group 7 model that incorporates the water and soil loads applied directly to the wall base and stem and also include the computed unbalanced force as distributed loads acting on the piles. At this point, the pile foundation has also been adjusted as needed to resist soil flow through as required in Steps 4.5 and 4.6. The total distributed load on the piles ($F_p$) was defined in paragraph 4.5. Distribution of unbalanced loading onto the rows of piles is as follows:

- If the total ultimate capacity ($n\Sigma P_{ult}$) of the flood side pile row is greater than 50% $F_p$, then 50% of $F_p$ is applied to the flood side row of piles as a uniform load along each pile equal to $0.5f_{ub}s_t$ (variables are defined in paragraph 4.5), and the remaining 50% of $F_p$ is divided evenly among the remaining piles.

- If the total ultimate capacity ($n\Sigma P_{ult}$) of the flood side piles is less than 50% of $F_p$, then the distributed load on each pile of the flood side row is set equal to $P_{ult}$ and the remaining amount of $F_p$ is distributed onto the remaining piles according to the relative group reduction factors (Rf). Rf values are determined in accordance with para. 4.5 above.

The distribution of load to the piles has a degree of uncertainty. To assure that the piles are not structurally overstressed from combined axial and bending stresses, as well as shear stress, the Group analysis shall also be performed with 100% $f_{ub}L_p$ applied to the lead pile, but no more than $\Sigma P_{ult}$ as described previously. Pile allowables shall be increased by a 50% overstress factor. The shear strength in the soil shall also be checked, the allowable shear capacity of the soil shall be the ultimate divided by a FOS = 2.0 (see para 3.2; in Fig 2 the allowable load is 12.2 kips).

5.4. The Group analysis will yield the response of the piles to all the loads applied to the T-wall system. The Group 7 program will automatically generate the p-y curves for each soil layer in the foundation based on the strength and the soil type. Once the Group 7 run is completed, the pile shear and axial force responses are determined from the output file. These forces must be determined from the piles local coordinate system. The pile group reduction factors shown previously in paragraph 4.4 are the same as used by the Group 7 program, so the program can be left to compute them automatically.

5.5. This analysis can be made using partial p-y springs to support the piles in the volume of the critical failure mass similar to reductions for the CPGA method found in para 4.2. The partial p-y curves are interpolated on the basis of the unreinforced factor of safety determined in Step 2. If the unreinforced safety factor is less than or equal to 1 then the p-y curves inside the failure circle are zeroed out so that the soil in the failure mass offers no resistance to pile movement. If the unreinforced factor of safety is between 1 and 1.5the target factor of safety the p-y springs are partially activated based on the percentage that the unreinforced safety factor is between 1 and 1.5the target factor of safety. Thus, if the unreinforced factor of safety is 1.25 and the target is 1.5, the p-y springs are 50% activated. Fifty percent activation is achieved by reducing the shear strengths in the Group 7 soil layers by 50%.

5.6. Perform structural design checks of the piles and T-wall to ensure that selected components are not overstressed and displacement criteria is met. Include stress check for the 100% fubLp applied to the lead pile as stipulated in para 5.3

5.7. Compare the allowable axial and shear capacity loads from Step 3 to the pile responses. If the axial and shear forces in any pile exceed the allowable pile loads the piles are considered over capacity and the pile design must be reconfigured.

GUIDANCE FOR EXTENDED PILE FOUNDATIONS AND SEQUENTIAL PILE FOUNDED STRUCTURES EXPERIEINCING UNBALACED LOADS. (paras reference the HSDRSDG Chapter 3)

3.4.3.3 <u>Sector Gate and Drainage Structure Foundation Analysis</u>.
Pile foundations for Sector Gate and Drainage Structure monoliths are checked for stability using the same procedure as T-Walls except that limitations are made on the number of piles included in resisting the unbalanced load. The minimum neutral block dimensions described in Step 1.2 are applicable, this includes the full width of the base. The number of piles dedicated to resist the unbalanced load is limited to the greater of those required to satisfy the flow-through as calculated in Steps 4.5 and 4.6. In Step 4.5, the affected piles are limited to that number needed for P allowable to exceed Fp applied. In Step 4.6, the number of affected piles is limited by those bound by the Shear area (see Fig 3).

3.4.3.4 <u>Fronting T-Walls with Trailing Structures</u>. Until further analysis proves otherwise, the unbalanced load shall be conservatively resisted by only the fronting wall. Therefore, global stability will be based on the fronting wall. The neutral wedge minimum, specified in Step 1.3 as the greater of 0.7 H or the base width, shall be based on the fronting wall only. It is assumed that a failure plane would penetrate the trailing structure regardless of the structure net downward force and base shear strength capacity. The procedure for T-Walls would be fully applied to the fronting wall w/o considering the trailing structure. The benefit to this approach is that the fronting wall stabilizes the soil under the trailing structure so there is no loss in pile capacity above a critical failure plane. This is significant when considering that many of the existing trailing structures are built on timber piles with minimal capacity. Note that the protected side tailwater, where applicable such as the intake basin of a pump station, imposses a dead load. This dead load is relieved by the pile foundation and is not included in the Central Block Resistance for cohesive soils (Rb in MOP analysis). However, the tailwater head, creates a downward pressure that should be included in passive driving resistance (Dp in MOP analysis). One solution to reduce any unbalanced load with sequential structures is to locate the fronting wall further from the pump station such that a stability berm can be built between the two.