June 24, 2019

Mr. Wyatt Pegg
Western Interlock
10095 Rickreall Road
Rickreall, Oregon 97371

Subject: Tiered Retaining Wall System Report

Dear Mr. Pegg:

As we discussed, wall installers have been confused regarding the required setback of the upper tier wall not to surcharge the lower wall. In this report, we will document the rationale for using a 2 horizontal to 1 vertical (2H:1V) setback distance, if the upper wall surcharge is ignored in design of the lower wall.

BACKGROUND AND METHODS

It is usually unrealistic to set the upper tier wall far enough from the lower wall to induce zero additional horizontal forces on the lower wall. However, the industry standard to avoid significant surcharge of the lower retaining wall is to use a 2H:1V setback of the upper retaining wall (wall face to wall face) for non-sloped soils when the lower wall height is greater than or equal to that of the upper wall, as illustrated in Figure 1. This will result in negligible horizontal forces on the lower portion of the lower wall. Calculation of these additional horizontal forces and inclusion in the stability calculations of the lower wall are not necessary. If a 2H:1V or greater setback is not desired or possible, the methods discussed below can be used to calculate the effect of the surcharge from the upper tier on the lower tier.

For gravity walls, the linear elastic analysis shows that the lateral stresses induced on the lower wall, and hence the additional lateral forces, are negligible when the recommended setback is maintained. For Mechanically Stabilized Earth (MSE) walls, the justification for the 2H:1V setback to avoid significant horizontal forces on the lower wall comes from the National Concrete and Masonry Association's (NCMA) design manual. The NCMA method is also validated by the linear elastic analyses.

For MSE walls, the NCMA's Design Manual for Segmental Retaining Wall Design details a quantitative procedure for approximating the percent influence of the upper wall bearing pressure on the lower retaining wall. This method reasons that the retained soil is strong enough to distribute the bearing pressure from the upper retaining wall applied behind the failure plane of the retained soil such that no significant additional lateral load is acting on the lower retaining wall. NCMA Section 5.9.2 states: "Generally, if a tiered retaining wall is placed within a horizontal distance (wall face to wall face) less than twice the height of the underlying wall, a load will be applied to the lower wall." This rule assumes that there are no slopes below, between, or above the tiered structures and that there are reasonably competent soils.

Our design examples will utilize two 4'-0" high walls. The friction angle of retained soil is assumed to be 26° and the friction angle of backfill soil is assumed to be 36°. These values are typical for many soils and backfills found in the Northwest.

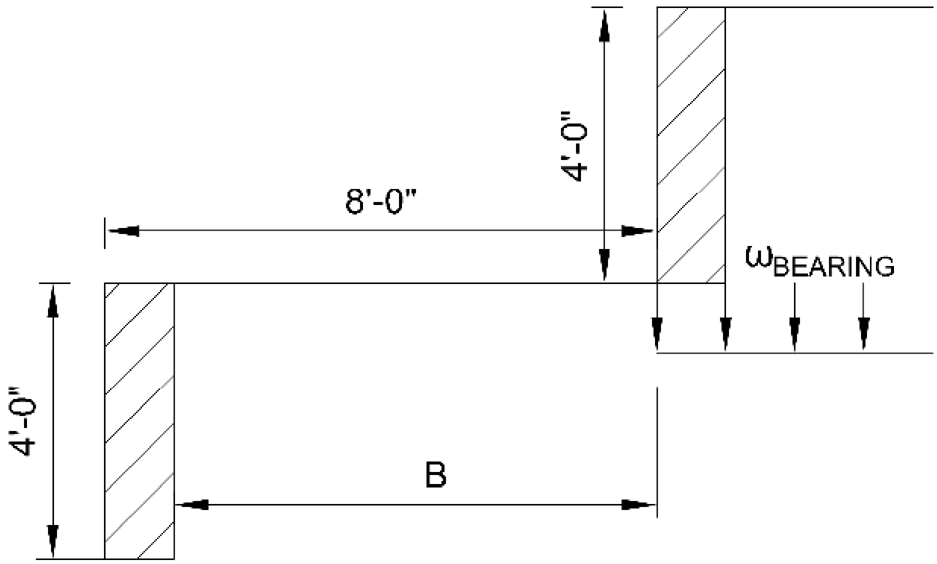


Figure 1: Section View of Tiered Retaining Wall System

CALCULATIONS

Gravity Walls
METHOD – Linear Elastic Stress Distribution Analysis.
Winterkorn and Fang, Foundation Engineering Handbook (1975) Figure 4.21.

Given:

ω = 500 psf
h = 4'-0"
B = 7'-0" – The block is assumed to be 1 foot deep. This method finds the horizontal stress on the back face of the lower wall due to the surcharge from the upper wall.

For this method, a length for the walls is required and assumed to be 80' (20 times the height of the lower wall). The calculation is relatively insensitive to changes in the wall length when the wall length is at least 1.3 times the height of the wall.

Find:
Calculate the additional horizontal pressure at the center (lengthwise) of the lower wall at depths of 4' and 2'.

Solution:
Figure 3 is used to calculate the increase in vertical stress under the corner of a rectangular loaded area.

In our problem the critical case is Point Z at the center (lengthwise) of the lower wall as shown in Figure 2. Since this point is not at the corner of the area loaded by the upper wall, we use superposition to find the answer.

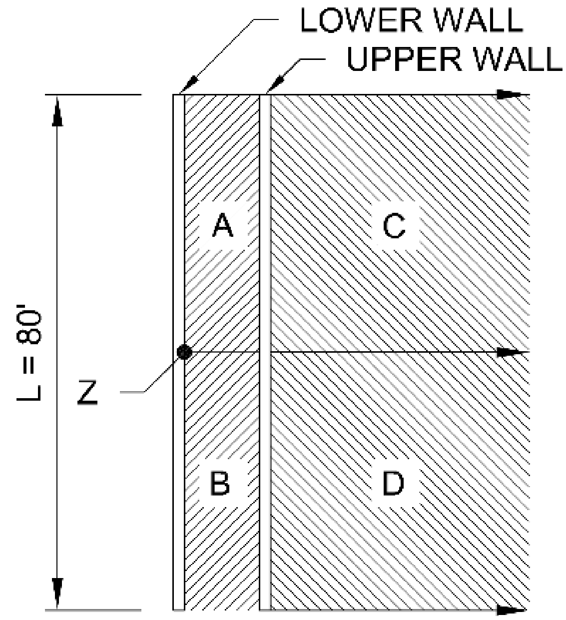


Figure 2: Plan View of Tiered Retaining Wall.

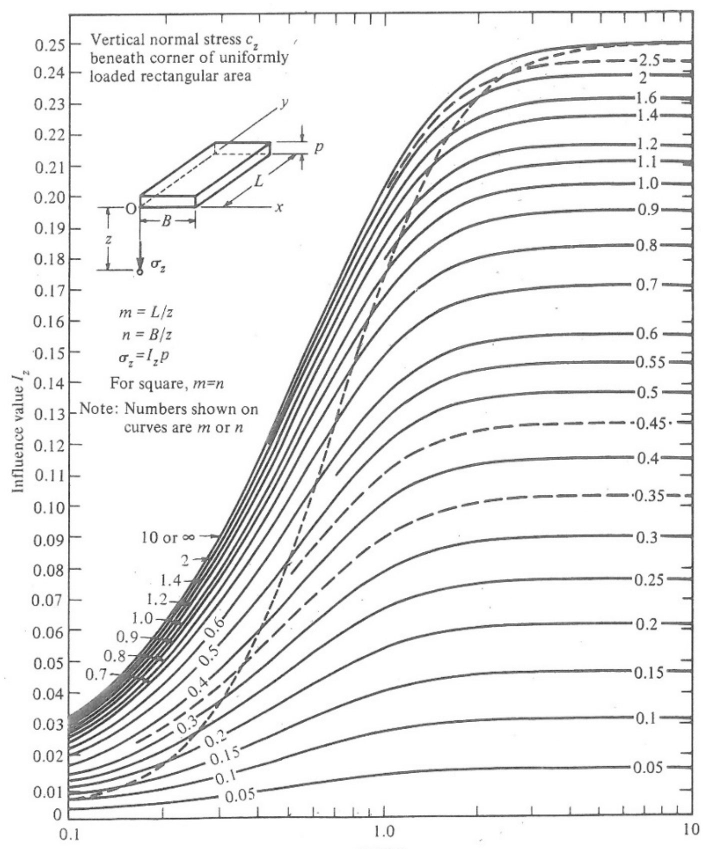


Figure 3: Influence diagram for vertical normal stress at a point within elastic half-space beneath corner of uniformly loaded rectangular area (after Fadum, 1948; Foundation Engineering Handbook, Figure 4.21).

Point Z is directly under the corner of the two areas, A plus C and B plus D. We can calculate the increase in stress assuming this entire area is loaded, then subtract the increase in stress contributed by areas A and B (which are not loaded). The resulting stress is that induced by the upper wall and the soil retained behind it. Because the upper wall retains a horizontal area of soil, we assume the loaded areas C and D extend a great distance. This is a conservative assumption.

Find Influence factors, I_z for a depth of 4' (base of lower wall).

For Areas A and C combined (also for Areas B and D combined):

m = L/z = 40/4 = 10
n = B/z - since B for Areas C and D is assumed very large, n is assumed to be equal to 10 as values of B/z greater than 10 do not affect the results.
I_z = 0.25 (from Figure 3)

For Areas A and B:

m = L/z = 40/4 = 10
n = B/z = 7/4 = 1.75
I_z = 0.233 (from Figure 3)

If we subtract 0.233 from 0.25 and multiply by 2 we get I_z at 4' equals 0.034.

Increase in vertical stress equals 500 psf x 0.034 = 17.0 psf at depth of 4' on the lower wall.

Using the coefficient of active earth pressure $K_a = \tan^2 (45 – phi/2) = 0.26$.

Increase in horizontal stress equals 17.0 x 0.26 = 4.4 psf.

Find Influence factors, I_z for a depth of 2' (mid-height of lower wall):

m = L/z = 40/2 = 20
n = B/z - since B for Areas C and D is assumed very large, n is assumed to be 10 as values of B/z greater than 10 do not affect the result.
I_z = 0.25 (from Figure 3)

For Areas A and B:

m = L/z = 40/2 = 20
n = B/z = 7/2 = 3.5
I_z = 0.249 (from Figure 3)

If we subtract 0.249 from 0.25 and multiply by 2 we get I_z at 4' equals 0.002.

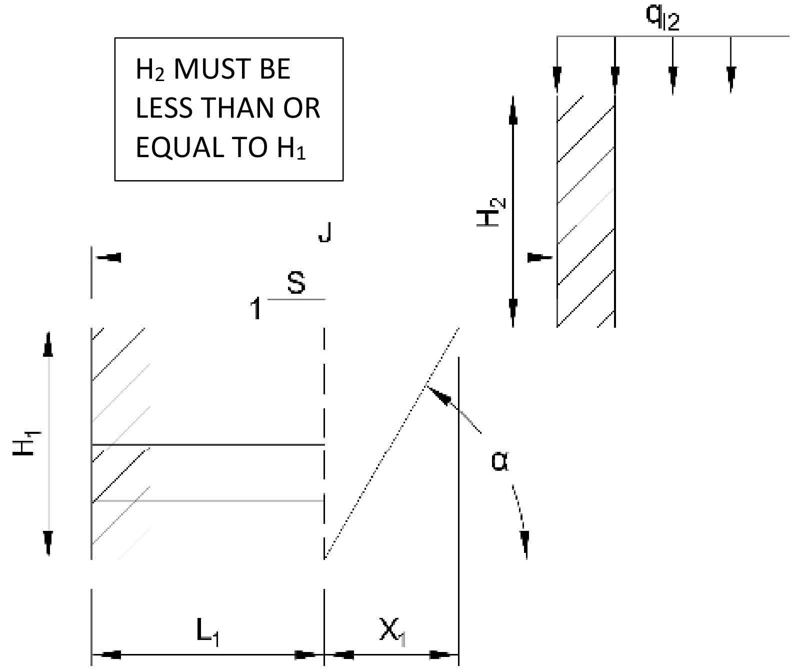
Increase in vertical stress equals 500 psf x 0.002 = 1 psf and increase in horizontal stress is < 1 psf.

The increase in stress closer to the top of the lower wall will essentially be zero. While the calculated additional pressure behind the lower wall is not zero, the magnitude of the pressure is negligible, well within the margin of error induced by estimating soil friction angle and unit weight.

MSE Walls

METHOD – Shear Failure Plane Analysis

Design Manual for Segmental Retaining Wall Design, National Concrete and Masonry Association, 3rd Edition, 5th Printing, 2010 Internal Stability.



$X_1 = (H_1 + J/S)/\tan \alpha_{e(1)}$

S = 500 for flat (level) backfill between walls

For internal stability wall 1:

when $J \geq L_1$	No influence: $q_{l1} = 0 \quad q_{d1} = 0$
$0.3L_1 < J < L_1$	Use percentage of surcharge: $q_{d1} = \dfrac{(L_1 - J)}{L_1}(\gamma_{i(2)} H_2')$ $\quad q_{l1} = \dfrac{(L_1 - J)}{L_1}(q_{l2})$
$J \leq 0.3 \; L_1$	Use full surcharge: $q_{d1} = \gamma_{i(2)} H_2' \quad q_{l1} = q_{l2}$

For external stability wall 1:

when $J \geq (L_1 + X_1)$	No influence: $q_{l1} = 0 \quad q_{d1} = 0$
$(L_1 + 0.5X_1) < J < (L_1 + X_1)$	Use percentage of surcharge: $q_{d1} = \dfrac{(L_1 + X_1 - J)}{X_1}(\gamma_{i(2)} H_2')$ $\quad q_{l1} = \dfrac{(L_1 + X_1 - J)}{X_1}(q_{l2})$
$J \leq (L_1 + 0.5X_1)$	Use full surcharge: $q_{d1} = \gamma_{i(2)} H_2' \quad q_{l1} = q_{l2}$

Note: $0.3L_1$ and $0.5X_1$ are arbitrary but empirically based geometric limits to ensure a conservative surcharge approximation

Figure 4: Surcharge Approximation for Tiered Walls (NCMA, Figure 5-6).

Internal and External Stability

Figure 4 shows that when $J > L_1$ there is no significant influence on the internal stability of the lower wall from any surcharge by the upper wall. As J = 8' and L_1= 4' in our example, there is no influence on internal stability.

Figure 4 also shows that when $J \geq L_1+X_1$ there is no significant influence on the external stability of the lower wall from any surcharge by the upper wall.

Given:

H_1 = 4'-0"
J = 8'-0"
Φ_e = 26°
S = 500 (flat)

Find:

Quantify the influence of the upper tier retaining wall surcharge on the lower retaining wall for external stability.

Solution:

$L_1 = 0.7H_1$ = 0.7(4'-0") = 2.8', use 4'-0" min
$\delta_e = 2\Phi_e/3$ = 2(26°)/3 = 17.3°
β_{ext} = 0° (flat)
α_e = 50.87° (NCMA Eqn. 5-5)
$X_1 = (H_1+J/S)/\tan(\alpha_e)$ = (4'-0"+(8'-0")/500)/tan(50.87°) = 3'-3.2" L_1+X_1 = 7'-3.2"

Check:

$J \geq L_1+X_1$
8'-0" ≥ 7.267', No significant Influence

The above conclusions can be validated by utilizing the same linear elastic analysis that was used for gravity walls. For internal stability of the lower MSE wall, the earth pressures used in the calculations are those acting on the back face of the block wall (see Fig. 7-11, p. 95, NCMA Design Manual). These are the same pressures that were calculated for the gravity wall since the wall heights and locations, soil density, and friction angle are the same in both examples. It was already demonstrated above that the surcharge pressures caused by the upper wall are negligible. Therefore, the presence of the upper wall does not affect the internal stability of the lower wall.

For external stability of the lower wall, the surcharge pressures from the upper wall are assumed to act at the back face of the reinforced mass (see Fig. 7-2, p. 80, NCMA Design Manual). To calculate these pressures, we use the same method of superposition as for the gravity wall, except the fictitious loaded areas A and B are 4 feet in width (the distance from the back of the reinforced zone to the front face of the upper wall) rather than 7 feet.

Find Influence factors, I_z for a depth of 4' (base of lower wall).

For Areas A and C combined (also for Areas B and D combined):

m = L/z = 40/4 = 10
n = B/z - since B for Areas C and D is assumed very large, n is assumed to be equal to 10 as values of B/z greater than 10 do not affect the results.
I_z = 0.25

For Areas A and B:

$m = L/z = 40/4 = 10$
$n = B/z = 4/4 = 1.0$
$I_z = 0.203$

If we subtract 0.203 from 0.25 and multiply by 2 we get I_z at 4' equals 0.094.

Increase in vertical stress equals 500 psf x 0.094 = 47 psf.

Using the coefficient of active earth pressure $K_a = \tan^2 (45 – phi/2) = 0.26$.

Increase in horizontal stress equals 47 x 0.26 = 12.2 psf.

Find Influence factors, I_z for a depth of 2' (mid-height of lower wall):

$m = L/z = 40/2 = 20$
n = B/z - since B for Areas C and D is assumed very large, n is assumed to be 10 as values of B/z greater than 10 do not affect the result.
$I_z = 0.25$

For Areas A and B:

$m = L/z = 40/2 = 20$
$n = B/z = 4/2 = 2.0$
$I_z = 0.239$

If we subtract 0.239 from 0.25 and multiply by 2 we get I_z at 4' equals 0.022.

Increase in vertical stress equals 500 psf x 0.022 = 11.0 psf and increase in horizontal stress is 2.9 psf.

We can now compare the magnitude of the horizontal surcharge force to the horizontal force from the soil retained by the lower wall. Assuming that the horizontal surcharge force varies linearly from 12.2 psf at the base of the wall to zero at 2.62' above the base, the force equals 0.5 x 12.2 psf x 2.62' = 16 plf. The force from the retained soil equals 0.5 x 500 psf x 4' x .26 = 260 plf. Therefore, the surcharge load adds approximately 6.1% to the total, small enough to be neglected in most circumstances.

DISCUSSION

Gravity Walls

When vertical stresses are present in soils, horizontal stresses are induced. The upper wall will induce vertical and horizontal stresses on the back face of the lower wall. However, if the upper wall is set back sufficiently far, these pressures only act on the lower portion of the lower wall, and are insignificant. Linear elastic theory provides a method of calculating the horizontal earth pressure induced on the lower wall as a function of the location of the upper wall, and the surcharge load induced by the upper wall and the ground it retains. The calculations above show that a 2H:1V setback for the upper retaining wall produces only negligible horizontal pressure at the base of the lower wall, and essentially zero additional pressure at mid-height and above. In circumstances where a smaller setback than 2H:1V is required for tiered gravity walls, the linear elastic method allows for the calculation of actual pressures on the lower wall as a function of depth.

MSE Walls

The NCMA Manual, Section 5.9.2, actually references the industry standard 2 horizontal to 1 vertical height of the lower wall. In the example above, the upper wall would have to be closer than 7'-3.2" from the toe of the lower retaining wall in order for the upper wall bearing pressure to influence the stability of the lower wall. A 2H:1V (8'-0": 4'-0") setback for the upper retaining wall in a tiered wall system will not result in significant additional lateral load on the lower retaining wall. A linear elastic analysis demonstrates the validity of this method for the tier wall system analyzed above.

If a designer is interested in finding the influence of an upper tier retaining wall outside of these assumptions, the Design Manual for Segmental Retaining Wall Design (3rd Edition, 5th Printing, 2010) published by the NCMA details the equations and procedures to do so in Section 5.9.2. Alternatively, a linear elastic analysis can be performed.

CONCLUSIONS AND RECOMMENDATIONS

A 2H:1V setback of the upper tier wall from the lower tier wall is sufficient for both MSE and gravity walls to ignore the surcharge horizontal load from the upper wall in the calculation of the stability of the lower wall provided: there are no slopes below, between, or above the tiered structures; and that there are reasonably competent soils (as determined by the geotechnical engineer) retained by and supporting the retaining walls.

Therefore, it is recommended, except in cases where a smaller setback is necessary, the industry standard be used and the upper retaining wall setback be 2H:1V (wall face to wall face) from the lower wall. When a smaller setback is needed, the design of the lower wall must include the calculated surcharge stresses acting on the lower wall from the loads imposed by the upper wall.

If you have any questions or concerns in this matter, please feel free to contact us.

Respectfully,

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