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ANALYSIS AND DESIGN ON VARYING THE OFFSETS IN SUPERIMPOSED MECHANICALLY STABILIZED EARTH WALLS

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ABSTRACT: Superimposed MSE walls or multi-tier MSE walls are frequently used due to their eye-pleasing, economical, and safety requirements compared with single-tall MSE walls. Designing an MSE wall requires checking the failure modes in its external stability, internal stability, and global stability. Calculating the external stability and global stability for superimposed walls is well explained. Internal stability, however, is more complicated in calculating the additional vertical stress from the upper wall as an equivalent surcharge on the lower wall with its magnitude determined by the offset distance. By varying offset distances, the additional vertical stress can be categorized into three cases. Case 1 is the maximum additional vertical from the upper wall load when the offset distance is less than $H_L tan(45-\phi_r/2)$. The additional vertical stress is zero in case 3 where the offset distance is greater than $H_L tan(90-\phi_r)$. In case 2, the additional vertical stress is a hyperbola function that can be calculated easily using the proposed equation $\sigma_i = [(H_L-z_1)/(z_2-z_1)](\gamma H_U+q)$ in Eq. (7) with geometric and algebraic explanations used through a numerical example in designing a superimposed wall.

Keywords: Additional vertical stress, Internal stability, Mechanically stabilized earth walls, Multi-tier walls, Superimposed walls.

1. INTRODUCTION

Mechanically stabilized earth walls or MSE walls are retaining walls consisting of facing units, reinforcements using metal strips or geogrids, and reinforced backfill soil. There are two MSE wall types commonly used, segmental precast concrete panel (SPCP) and modular block wall (MBW). SPCP uses precast concrete facing with metal strip reinforcement. MBW uses modular block facing with geogrid reinforcement. MSE walls can be single walls or complex geometric walls like superimposed walls. Superimposed walls or multi-tier walls are frequently used due to their eye-pleasing, economical, and safety requirements compared with single-tall MSE walls. Designing an MSE wall requires checking the failure modes in its external stability, internal stability, and global stability. FHWA [1] and AASHTO [2] provide details guidelines and clear calculation examples for designing single walls. However, [1] provides only two pages for designing superimposed MSW walls.

FHWA/TX-2 [3] suggests design methods for multi-tiered MSE retaining walls by treating the upper-tier wall as an equivalent surcharge on the lower-tier wall with its magnitude determined by the offset distance. Different offset distances determine different equivalent surcharges. In FHWA[1], there are three cases in which calculating the additional vertical stress depends on the offset distance.

FHWA/TX-1 [4] provides calculation examples but with some parts of the internal stability checking which is rather complicated and may lead to mistaken designs that are evidenced in some superimposed wall damages due to misunderstanding concepts or designs.

An example of this complicated design concept is that FHWA [1] mentions that a footing located outside case 1 is not a surcharge on the lower wall while an upper wall in case 2, that is outside case 1, is a surcharge distributed to the lower wall. This reflects the main question in designing a superimposed wall is how much the superimposed load or the additional vertical stress is at different offset distances.

Other standard codes such as BS8006 [5], NCMA [6], and Eurocode 7 [7] do not provide any example of calculating this superimposed wall. Many studies [8-14] have paid attention to retaining walls such as Phimonnok [8] in gravity walls, Nguyen [9] in modular block walls. Bari [10] is interested in the optimal cost of the retaining wall. Hossain [11] investigates the sand–geosynthetic interface behavior for this earth reinforcement. Studies [112-14] pay attention to the earth reinforcement retaining wall design such as Horpibulsuk [12] in the bearing reinforcement earth wall design and Khabbaz [13] in anchored wall design and Leshchinsky [14] in geosynthetic reinforced multitiered walls. However, these studies do not give calculation examples for this popularly used but easily to be error-prone in designing this superimposed MSE wall that leads to some slope stability failures of the ill-designed superimposed MSE walls.

This study provides concepts and proposed an easier formula than FHWA/TX [4] for calculating the additional stress imposed on the lower wall. A numerical example is used to show the calculation details of the internal stability checking for two-tiered superimposed walls at different offsets. External stability and global stability are omitted due to space limitations.

2. RESEARCH SIGNIFICANCE

Superimposed MSE walls are popularly used but calculating the additional vertical stress from the upper wall to the lower wall is rather complicated and error-prone because FHWA[1] gives only two pages in explaining these superimposed MSE walls without a calculation example to follow. FHWA/TX[4] provides an example in its appendix but the example uses a series of complicated formulas and shows only one layer in calculating this additional vertical stress. This study proposes an easy formula to calculate this additional vertical stress and show that the additional vertical stress is the same for all layers.

3. DESIGN CONCEPT

Let D be the offset distance shown in Fig. 1. H_U or H_1 Fig. 1 is the upper wall height. H_L or H_2 Fig. 1 is the lower wall height. $\emptyset_r$ is the reinforced soil internal friction angle of both the upper wall and the lower wall. γ is the reinforced soil density of both the upper wall and the lower wall. q is the surcharge on the upper wall.

3.1 External Stability

For external stability checking, there are 3 cases as follows:

Case 1) If $D \leq (H_U + H_L)/20$, the wall should be designed as a single wall with a height $H = H_U + H_L$.

Case 2) If $(H_U + H_L)/20 \leq D \leq H_L tan(90 - \emptyset_r)$, the upper wall is in a surcharge acting upon the lower wall.

Case 3) If $D \geq H_L tan(90 - \emptyset_r)$, there is no superimposed load from the upper wall to the lower wall.

3.2 Internal Stability

For internal stability checking, there are 3 cases as follows:

Case 1) $D \leq H_L tan(45 - \emptyset_r/2)$, $\sigma_i = \gamma H_U$. This case includes the external stability case 1 and some part of the external stability case 2 where $(H_U + H_L)/20 \leq D \leq H_L tan(45 - \emptyset_r/2)$

Case 2) $H_L tan(45 - \emptyset_r/2) \leq D \leq H_L tan(90 - \emptyset_r)$,

$$\sigma_i = \frac{(\gamma H_U + q) - \sigma_f}{(z_2 - d_i) tan(45 - \emptyset_r/2)} L_a + \sigma_f \quad (1)$$

$$\sigma_f = \frac{d_i - z_1}{z_2 - z_1}(\gamma H_U + q) \quad (2)$$

$$z_1 = D tan\emptyset_r \quad (3)$$

$$z_2 = D tan(45 + \emptyset_r/2) \quad (4)$$

$$L_{ai} = (H_L - d_i) tan(45 - \emptyset_r/2) \quad (5)$$

L_{ai} is the active zone length of the i^th layer of reinforcement.
d_i is the depth of the i^th layer of reinforcement.
σ_i is the additional stress on the i^th layer of reinforcement caused by the upper wall.
σ_{fi} is the additional stress at the wall face on the i^th layer of reinforcement caused by the upper wall.

Equation (1) is from a similar triangle in Eq. (6). This similar triangle is also shown later in Fig 6.

$$\frac{(\gamma H_U + q) - \sigma_f}{(z_2 - d_i) tan(45 - \emptyset_r/2)} = \frac{\sigma_i - \sigma_f}{L_a} \quad (6)$$

By substituting Eq. (2), Eq. (3), Eq. (4) in Eq. (5), or Eq. (6), σ_i shown in Eq. (7) remains constant for all reinforcement layers and does not depend on the layer depths, d_i.

$$\sigma_i = \frac{(H_L - z_1)}{(z_2 - z_1)}(\gamma H_U + q) \quad (7)$$

Case 3) If $D \geq H_L tan(90 - \emptyset_r)$, $\sigma_i = 0$. This case is the same as the external stability case 3.

3.3 Combining External Stability and Internal Stability

When considering both external stability and internal stability, there are four cases to calculate additional stress (σ_i) as follows: case 1) $D \leq (H_U + H_L)/20$, case 2) $(H_U + H_L)/20 \leq D \leq H_L tan(45 - \emptyset_r/2)$, case 3)) $H_L tan(45 - \emptyset_r/2) \leq D \leq H_L tan(90 - \emptyset_r)$ and case 4) $D \geq H_L tan(90 - \emptyset_r)$.

Let $D_1 = (H_U + H_L)/20, D_2 = H_L tan(45 - \emptyset_r/2), D_3 = H_L tan(90 - \emptyset_r)$.The offset distances *D₁, D₂, and D₃* are shown in Fig. 1. In case 1, D is less than D_1, and both the upper wall and lower wall will be treated as one wall. In case 4, D is greater than D_3, both the upper wall and lower wall will be treated separately as two walls. In case 2, D is between D_1 and D_2, the additional stress is simply $\sigma_i = \gamma H_U$. In case 3, D is between D_1 and D_2, the additional stress $\sigma_i = \frac{(H_L - z_1)}{(z_2 - z_1)}(\gamma H_L + q)$ is mentioned in Eq. (7).

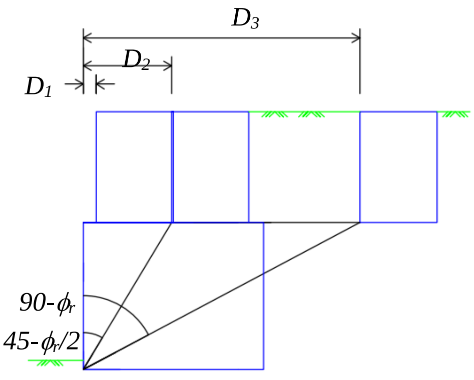

Fig. 1 Offset distances showing D_1, D_2, D_3

4. A NUMERICAL EXAMPLE

The soil parameters, surcharge, and wall geometry for this illustrated example are shown in Table 1. The total height, $H = H_U + H_L = 3 + 4 = 7$ meters. For the reinforcement length [1] with H_U = 3 meters, the upper wall reinforcement length is $L_U = 0.7H_U$ = 0.7x3 = 2.1 meters. The lower wall reinforcement length is $L_L = 0.7(H_U + H_L) = 0.7H$ = 0.7x7 = 4.9 meters. The minimum lower wall reinforcement [1] $L_L = 0.6(H_U + H_L)$ = 4.2 meters is not enough which is later shown in Table 5 at layer 8 representing the top reinforcement of the lower wall that L_T = 4.89 meters which are less than 4.2 meters. With D = 3 meters. $z_1 = D tan\emptyset_r$ = 3*tan*(28) = 1.60 meters from (3). $z_2 = D tan(45 + \emptyset_r/2)$ = 3*tan*(45+28/2) = 4.99 meters. The dimension of this two-tiered superimposed wall is shown in Fig. 2.

Compared with Fig. 1, $D_1 = (H_U + H_L)/20$ = (3+4)/20 = 0.35 meters. $D_2 = H_L tan(45 - \emptyset_r/2)$ = 4*tan*(45-28/2) = 2.4 meters. $D_3 = H_L tan(90 - \emptyset_r)$ = 4*tan*(90-28) = 7.52 meters.

5. ADDITIONAL VERTICAL STRESS

5.1 Reinforcement Layers

The reinforcement layers are shown in Fig. 4. The reinforcement spacing is 0.5 meters where the top layers at both the upper wall (layer 14) and the lower wall (layer 8) are started at 0.25 meters below their surfaces. The reinforcement layer depths are also shown as d_i in Table 4. The active zone length for each reinforcement layer is also shown in Table 4 using Eq. (5).

Table 1 Soil parameters, surcharge, and wall geometry.

Item	Symbol	Value	Unit
Soil cohesion	c	0	kN/m^2
Soil internal friction	ϕ_r	28	degree
Soil density	γ	18	kN/m^3
Surcharge	q	10	kN/m^2
Upper wall height	H_U	3	meter
Lower wall height	H_L	4	meter
Offset distance	D	3	meter

Note: All the retained soil, reinforced backfill soil, and foundation soil have the same properties

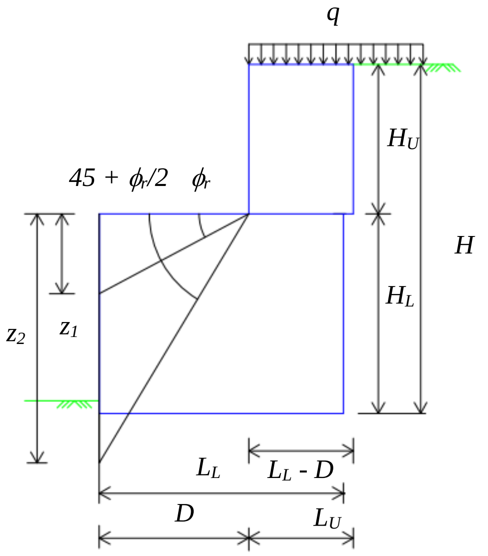

Fig. 2 Dimension of the superimposed wall example

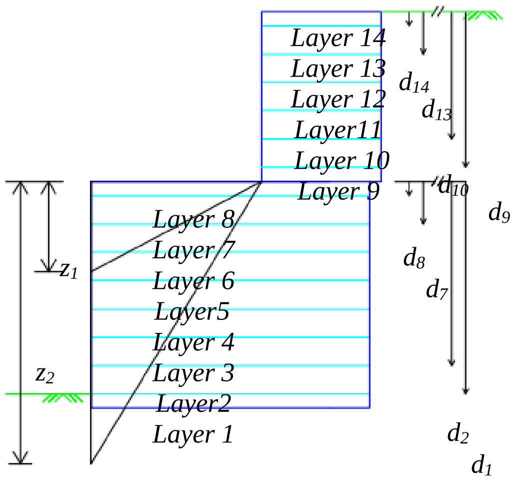

Fig. 3 Reinforcement layers for internal stability

The reinforcement depths for 14 layers in both walls are shown in Fig. 3 denoted as d_1 to d_{14} where the lower wall has layers 1 to layer 8 and the upper wall has layers 9 to layer 14. z_1 from Eq. (3) and z_2 from Eq. (4) is also included.

5.2 Calculating the Additional Vertical Stress (σ_i)

For the superimposed lower wall, all reinforcement layers 1 to 8 fall into the internal stability case 2 because $D_2(=2.4) \leq D(=3.0) \leq D_3(=7.52)$. The additional vertical stress can be calculated using either Eq. (7) or Eq. (1) in any layer. All give the same result as shown as follows. For example,

Using Eq. (7), $\sigma_i = \frac{(H_L - z_1)}{(z_2 - z_1)}(\gamma H_U + q)$

$= \frac{(4-1.60)}{(4.99-1.60)}(18x3 + 10) = 45.30$ kN/m^2.

Using Eq. (1) for layer 6 as shown in Fig. 4.

From Eq. (2), $\sigma_f = \frac{d_i - z_1}{z_2 - z_1}(\gamma H_U + q)$

$= \frac{1.25-1.60}{4.99-1.60}(18x4 + 10)$ = - 6.50 kN/m^2.

From Eq. (5), $L_a = (H_L - d_i)tan(45 - \emptyset_r/2)$

$= (4 - 1.25)tan(45 - 28/2)$ = 1.65 m.

From Eq. (1), $\sigma_i = \frac{(\gamma H_U + q) - \sigma_f}{(z_2 - d_i)tan(45 - \emptyset_r/2)} L_a + \sigma_f$

$= \frac{(18x4+10)-(-6.50)}{(4.99-1.25)tan(45-28/2)} 1.65 + (-6.50)$

= 45.30 kN/m^2.

Using Eq. (1) for layer 3 as shown in Fig. 4.

From Eq. (2), σ_f = 21.75 kN/m^2 at d_i = 2.75 m.

From Eq. (5), L_a = 0.75 m.

From Eq. (1), σ_i = 45.30 kN/m^2.

As shown in Table 4 and in Fig. 4, the additional vertical stress at the wall face, σ_f, is negative if the reinforcement depth, d_i, is less than z_1. σ_f is positive if d_i is greater than z_1.

5.3 Similar Triangle of the Additional Vertical Stress

Fig. 5 shows that the additional vertical stress, σ_i, for all the layers in the superimposed lower wall gives the same value because they all possess the same similar triangle properties. In this example, σ_i for layers 1 to 8 using Eq. (1) is 45.30 kN/m^2. Fig. 5 also shows that σ_i for layers 1 to 8 have the same magnitude.

Fig. 5 also shows a similar triangle using Eq. (6) where $\frac{(\gamma H_U + q) - \sigma_f}{(z_2 - d_i)tan(45 - \emptyset_r/2)} = \frac{\sigma_i - \sigma_f}{L_a}$.

For layer 3, $y_1 = (\gamma H_U + q) - \sigma_{f3}$, $y_2 = \sigma_i - \sigma_{f3}$, and $x_1 = (z_2 - d_3)tan(45 - \emptyset_r/2)$, $x_2 = L_{a4}$

For layer 6, $y_3 = (\gamma H_U + q) - \sigma_{f6}$, $y_4 = \sigma_i - \sigma_{f6}$, and $x_3 = (z_2 - d_6)tan(45 - \emptyset_r/2)$, $x_4 = L_{a6}$

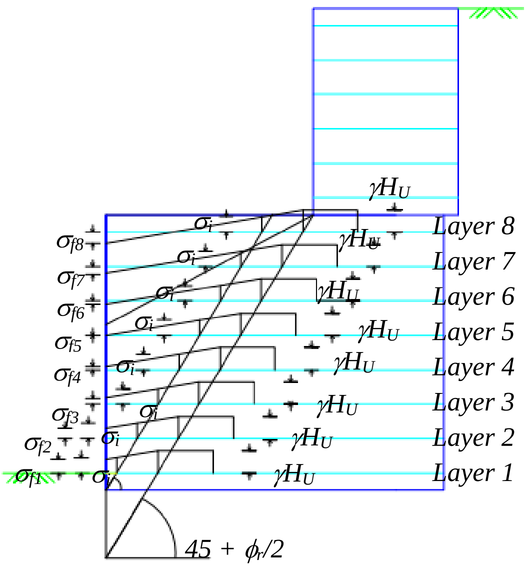

Fig. 4 Offset distances showing D_1, D_2, D_3

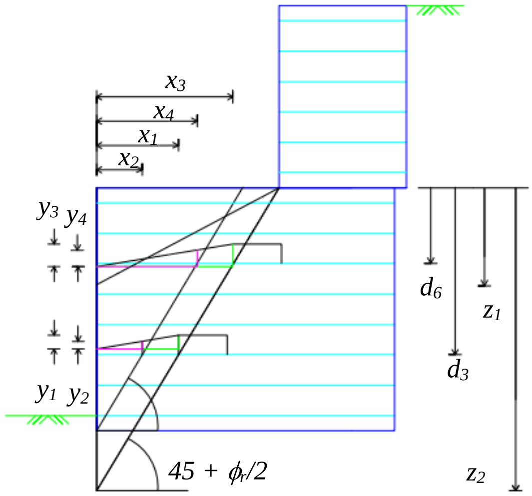

Fig. 5 Similar triangle in Eq. (6)

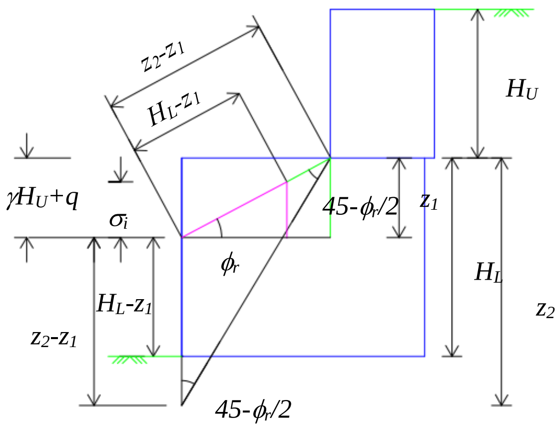

Fig. 6 Similar triangle in Eq. (7).

Fig. 6 shows that this similar triangle is also held for Eq. (7) where $\sigma_i = \frac{(H_L - z_1)}{(z_2 - z_1)}(\gamma H_U + q)$. Additionally, the similar triangle in Eq. (2) where $\sigma_f = \frac{d_i - z_1}{z_2 - z_1}(\gamma H_U + q)$ holds with Eq. (7) where $\sigma_i = \frac{(H_L - z_1)}{(z_2 - z_1)}(\gamma H_U + q)$ in which d_i in Eq. (2) is H_L in Eq. (7).

5.4 Additional Vertical Stress Outside the Internal Stability Case 2

Eq. (1) or Eq. (7) to calculate the internal stability are valid only for $D_2 \leq D \leq D_3$. Suppose that the offset distance, *D*, is 2 meters, this superimposed wall falls in the internal stability case 1 where $D \leq D_2$ at 2.4 meters.
Thus, $\sigma_i = \gamma H_U + q$ = 18x3 +10 = 64 kN/m2.

However, if the additional vertical stress, σ_i, is wrongly calculated using Eq. (1) or Eq. (7), then
Using Eq. (7), $\sigma_i = \frac{(H_L - z_1)}{(z_2 - z_1)}(\gamma H_U + q)$

From (3), $z_1 = Dtan\emptyset_r$ = 2*tan*(28) =1.06
From (4), $z_2 = Dtan(45 + \emptyset_r/2)$
=2*tan*(45+28/2) = 3.33
From (7), $\sigma_i = \frac{(4-1.06)}{(3.33-1.06)}(18x3 + 10)$
= 82.97 kN/m^2.

A layer can be picked to calculate σ_i. For example, arbitrarily pick layer 6, then
Using Eq. (1) for layer 6

From Eq. (2), $\sigma_f = \frac{d_i - z_1}{z_2 - z_1}(\gamma H_U + q)$
$= \frac{1.25-1.06}{3.33-1.60}(18x3 + 10)$ = 5.27 kN/m^2.
From Eq. (1), $\sigma_i = \frac{(\gamma H_U + q) - \sigma_f}{(z_2 - d_i)tan(45 - \emptyset_r/2)} L_a + \sigma_f$
$= \frac{(18x3+10)-(5.27)}{(3.33-1.25)tan(45-28/2)} 1.65 + 5.27$
= 82.97 kN/m^2.

This value at 82.97 N/m^2 is incorrect since the similar triangle does not hold. Eq. (1) or Eq. (7) are starting to be valid when *D* is D_2 which is 2.4.

Suppose that *D* is 8 meters which are in the internal stability case 3 where $D \geq D_3$ at 7.52 meters. Using Eq. (7) or Eq (1), σ_i = -1.79 kN/m^2 where the correct value is σ_i = 0.

In conclusion, for internal stability case 1 where $D \leq D_2 = H_L tan(45 - \emptyset_r/2)$, $\sigma_i = \gamma H_U + q$. For internal stability case 3 where $D \geq D_3 = H_L tan(90 - \emptyset_r)$, $\sigma_i = 0$

5.5 Additional vertical stress Inside the Internal Stability Case 2

The additional stress (σ_i) by varying the values of the offset distance (*D*) to be inside the internal stability case 2 or $D_2 \leq D \leq D_3$ is shown in Fig. 7. Substitute Eq. (3) and Eq. (4) into Eq. (7) leads to

$$\sigma_i = \frac{(H_L - Dtan\emptyset_r)}{(Dtan(45+\emptyset_r/2) - Dtan\emptyset_r)}(\gamma H_U + q) \qquad (8)$$

in which σ_i is a function of ϕ and *D* where $D_2 \leq D \leq D_3$, σ_i is a hyperbola function.

From Eq. (8), suppose $\sigma_{vU} = \gamma H_U + q$ is the vertical stress from the upper wall, then the additional stress ratio is defined as σ_i/σ_{vU}. Also, let's define the offset distance ratio as D/H_L. Varying both the offset distances (*D*) and the internal friction angles (ϕ) is shown in Fig. 8 where ϕ is increased by 2 degrees starting from 24 degrees to 34 degrees.

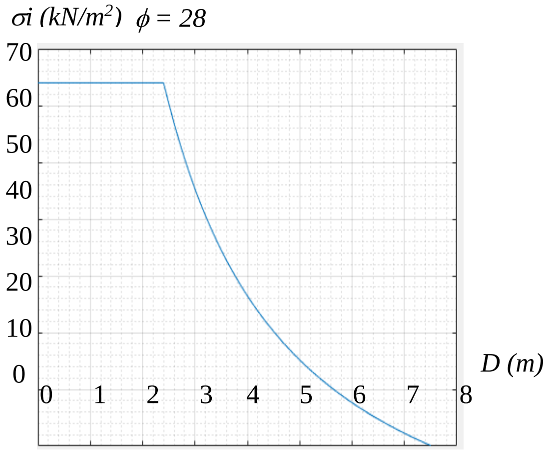

Fig. 7 Additional vertical stress by varying *D* at ϕ = 28

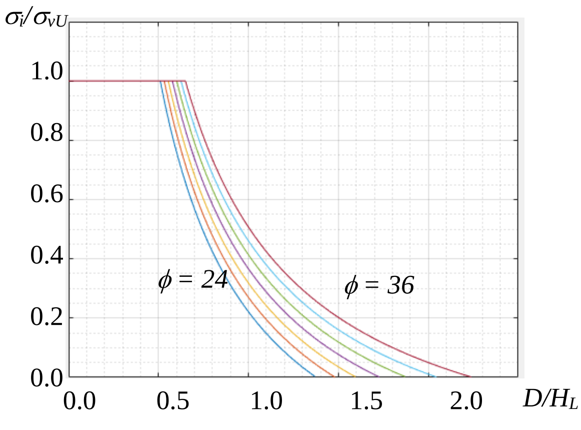

Fig. 8 Additional vertical stress ratio (σ_i/σ_{vH}) by varying offset distance ratio (D/H_L) and ϕ increment by 2°

Fig. 8 is further clarified in Table 2 and Table 3. Table 2 shows the offset distance ratios of D_2/H and D_3/H at different ϕ. At ϕ = 28 degrees, for example, the offset ratio of D_2/H_L at 0.60 means that if the offset distance (*D*) is less than 0.6 of lower wall height, the lower wall will bear the full

Table 2 Offset distance ratios of D_2/H and D_3/H at different ϕ.

ϕ	24	28	32	36
D_2/H_L	0.65	0.60	0.55	0.51
D_3/H_L	2.25	1.88	1.60	1.38

Table 3 Additional vertical stress ratio (σ_i/σ_{vU}) at different L_I/H_L and different ϕ.

ϕ	24	28	32	36
$0.7L_I/H_L$	0.90	0.79	0.68	0.57
L_I/H_L	0.51	0.41	0.32	0.22
$1.1L_I/H_L$	0.42	0.33	0.24	0.15

Table 4 Internal stability shows additional vertical stress, vertical stresses, and horizontal stresses.

Layer	d_i (m)	L_{ai} (m)	σ_{fi} kN/m^2	σ_{vi} kN/m^2	σ_{hi} kN/m^2
8	0.25	2.25	-25.34	49.80	17.98
7	0.75	1.95	-15.92	58.80	21.23
6	1.25	1.65	-6.50	67.80	24.48
5	1.75	1.35	2.91	76.80	27.73
4	2.25	1.05	12.34	85.80	30.98
3	2.75	0.75	21.75	84.80	34.23
2	3.25	0.45	31.17	103.80	37.47
1	3.75	0.15	40.59	112.80	40.72
Emb	4.0				

Note: d_i is the reinforcement layer depth. L_{ai} is the active zone length. σ_i is the additional stress at the wall face. σ_{fi} is the additional stress on the reinforcement layer. Emb is the embedment depth.

Table 5 Internal stability showing maximum reinforcement tensions and reinforcement lengths.

Layer	d_i (m)	V_i (m)	T_{max-i} kN/m	L_{ei} (m)	L_{Ti} (m)
8	0.25	0.375	6.74	2.64	4.89
7	0.75	0.5	10.61	1.39	3.34
6	1.25	0.5	12.24	0.96	2.61
5	1.75	0.5	13.86	0.78	2.13
4	2.25	0.5	15.49	0.67	1.73
3	2.75	0.5	17.11	0.61	1.36
2	3.25	0.5	18.74	0.56	1.02
1	3.75	0.5	20.36	0.53	0.68
Emb	4.0				

Note: d_i is the reinforcement layer depth. V_i is the reinforcement tributary area active zone length of the reinforcement layer. T_{max-i} is the maximum tension of the reinforcement layer. L_{ai} is the active zone length. L_{Ti} is the minimum reinforcement length

vertical superimposed load from the upper wall (σ_{vU}). Also, D_3/H_L at 1.88 for ϕ = 28 degrees means that D must be more than 1.88 times the lower wall height to get away from the upper wall load.

Table 3 implies that at ϕ = 28 degrees, the lower wall with a typical reinforcement length (L_L) from the reinforcement ratio $0.7L_I/H_L$ to $1.1L_I/H_L$ [1] is not enough to bear the upper wall load. L_I/H_L lower wall still needs to bear the additional stress at 0.79 times the upper wall load ($0.79\sigma_i/\sigma_{vU}$).

6. INTERNAL STABILITY

The result from the internal stability calculation is shown in Table 4 and Table 5, in which

$$\sigma_{vi} = \gamma d_i + \sigma_i \quad (8)$$

$$\sigma_{hi} = k_a \sigma_{vi} \quad (9)$$

$$k_a = tan^2(45 - \emptyset_r/2) \quad (10)$$

$$T_{max-i} = \sigma_{hi} V_i \quad (11)$$

$$L_{ei} = 1.5T_{max-i}/Ctan(\emptyset_r)\gamma d_i R_c \alpha \quad (12)$$

$$L_{Ti} = L_{ai} + L_{ei} \quad (13)$$

where
σ_{vi} is the vertical stress at the i^{th} layer of reinforcement.
σ_{hi} is the horizontal stress at the i^{th} layer of reinforcement.
k_a is the active earth pressure coefficient.
T_{max-i} is the maximum tension at the i^{th} layer of reinforcement.
V_i is the tributary area at the i^{th} layer of reinforcement.
L_{ei} is the embedment length in the resisting zone at the i^{th} layer of reinforcement.
C is 2 for geogrid.
R_C is coverage ratio = 1.
α is scaling ration = 1.
L_{Ti} is the total length at the i^{th} layer of reinforcement.

The calculation detail can be followed as in [1] which is not shown here. The tensile of the reinforcement layers can be determined using Eq. (11) and the reinforcement length can be determined using Eq. (13).

The external stability needs to check the sliding, overturning, and bearing capacity. FHWA/TX-1 [4] suggests that only the part of the upper walls directly above the lower wall is treated as a surcharge. Global stability in the limit equilibrium method or finite element method is also omitted because of the space limitation.

7. CONCLUSION

The key point for internal stability checking in designing superimposed MSE retaining walls is to treat the upper wall as an equivalent surcharge on the lower wall with its magnitude determined by the offset distance. By varying offset distances, the equivalent surcharge magnitude or the additional vertical stress can be categorized into three cases. The additional vertical stress is maximum in case 1 which is the full upper wall load where the offset distance is less than $H_L tan(45-\phi_r/2)$. The additional vertical stress is zero in case 3 where the offset distance is greater than $H_L tan(90-\phi_r)$. In case 2, the additional vertical stress is a hyperbola function that can be calculated easily using the proposed equation $\sigma_i = [(H_L-z_1)/(z_2-z_1)](\gamma H_U+q)$ in Eq. (7) with the geometric and algebraic explanations.

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8. REFERENCES

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