Evaluation of Existing Methods to Compute Vertical Stress for Reinforced Soil Walls

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ABSTRACT: Internal design of reinforced soil walls requires the estimation of reinforcement loads, which requires the determination of horizontal stress acting over tributary area of each reinforcement. Maximum horizontal stress at each depth depends on the vertical stress and lateral earth pressure coefficient at that particular depth. There are different internal design methods for reinforced soil walls, e.g., Coherent Gravity Method, Simplified Method, and Stiffness Method, which were developed based on different assumptions. These methods suggest different lateral earth pressure coefficient according to the global stiffness of the soil and they utilizes different approaches to calculate vertical stress at each reinforcement depth. Coherent Gravity Method assumes the reinforced soil mass is rigid and the overturning moment caused by the lateral load acting at the back of the reinforced zone increase the vertical stress at reinforcement level. On the other hand, Simplified Method and Stiffness Methods neglect the overturning effect and assume vertical stress is equal to soil overburden over the reinforcement for extensible reinforcement. This paper compares existing methods of calculating vertical stress within the wall, and proposes a simple equation, which considers overturning effect without the need to determine eccentricity separately.

Keywords: Overburden Stress, Reinforced Soil Wall, Internal Design, Reinforcement Load

1 INTRODUCTION

Internal design of reinforced soil walls requires the estimation of reinforcement loads, which requires the determination of horizontal stress acting over tributary area of each reinforcement. Maximum horizontal stress at each depth depends on the vertical stress and lateral earth pressure coefficient at that particular depth. There are different internal design methods for reinforced soil walls, e.g., Coherent Gravity Method, Simplified Method, and Stiffness Method, which suggest different lateral earth pressure coefficient according to the global stiffness of the soil and the reinforcement (Berg et al. 2009). While they suggest different lateral earth pressure coefficient, most of these methods use same approach to calculate vertical stress. This paper compares methods of calculating vertical stress within the wall, and proposes a simple equation, which considers overturning effect without the need to determine eccentricity separately.

2 METHODOLOGIES TO COMPUTE VERTICAL STRESS WITHIN WALL

2.1 *Existing Methodologies*

Several methodologies to compute the maximum vertical stress are available from the literature and a few of them are summarized as below:

$$\sigma'_{vmax} = \gamma \, . z_i \equiv \frac{W_i}{L} \quad \text{(Simple Method)} \quad (1)$$

$$\sigma'_{vmax} = \gamma \, . z_i \,[\, 1 + K_{a2}\,(\frac{z_i}{L})^2 \,] \quad \text{(Bolton et al. 1977)} \quad (2)$$

$$\sigma'_{vmax} = \gamma \, . z_i \,[\, 1 - 0.3\, K_{a2}\,(\frac{z_i}{L})^2]^{-1} \quad \text{(Schlosser et al. 1978)} \quad (3)$$

where
σ'_{vmax} = the maximum vertical stress,
z_i = the depth to the reinforcement,
γ = the unit weight of the reinforced soil,
K_{a2} = the active Rankine earth pressure coefficient resulting from the retained fill materials and geometry,
L = the length of the reinforcements.
Please note that these equations do not consider the effect of the surcharge and surcharge load (q) can be added to these equations if it is necessary.

Another methodology is the one proposed by (Meyerhof) that assumes a uniform distribution of stress over limited area of the reinforcement, which depends on eccentricity:

$$\sigma'_{vmax} = \frac{W_i + P_{av\,i}}{L - 2e_i} \quad \text{(Meyerhof, 1953)} \quad (4)$$

where
W_i = the total weight (or total vertical force over the reinforcement)
P_{avi} = the vertical component of the active earth pressure force up to a depth of z_i
e_i = the eccentricity of the application of the normal force acting at a depth of z_i
L = the length of the reinforcements

The bearing stress at the bottom of the wall is generally calculated using Meyerhof (1953), which assumes the total vertical forces act over the effective contact reinforcement length (L-2e_b , where e_b is defined as eccentricity for bearing calculation), and factor of safety against the bearing capacity failure can be calculated accordingly. While the increase in the vertical stress due to overturning, caused by the lateral force applied at the back of the reinforced zone by the retained fill, is considered in the calculation of bearing stress through the eccentricity, vertical stress calculated by simple method in the determination of reinforcement loads does not include the effect of lateral force applied by the retained fill. Sometimes simple method approximates this stress increase due to overturning by simply adding ‘’ $0.2\,\gamma\ z_i$ ‘’ to the soil overburden at each reinforcement level (z_i) for inextensible reinforcements. On the other hand, no stress increase is used with extensible reinforcements, assuming no moment is transferred through the reinforced zone with extensible reinforcements.

2.2 *Proposed Equation*

Whether it is necessary to include the overturning effect or not is beyond the scope of this paper. But when it is necessary, simple method does not truly quantify the overturning effect while Meyerhof method requires the determination of the eccentricity at each reinforcement levels (z_i). This paper proposes the use of a simpler equation (Eq. 5), which determines the state of vertical stress level within the wall considering the overturning effect without the need to determine eccentricity separately.

$$\sigma'_{vmax} = \gamma \, . z_i \, [\, 1 + sin\phi'_{min} \; K_{a2} \left(\frac{z_i}{L}\right)] \qquad (5)$$

where
ϕ'_{min} = the minimum friction angle between the reinforced and retained fill,
K_{a2} = the active Rankine earth pressure coefficient resulting from the retained fill materials and geometry

In general the retained backfill is of lesser quality compared to the reinforced soil, thus the minimum friction angle between the reinforced and the retained fill is generally the friction angle of retained fill and K_{a2} is higher than K_{a1} (the active Rankine earth pressure coefficient resulting from the reinforced fill materials and geometry). According to Equation 5, the maximum vertical stress at any reinforcement depth is function of unit weight of reinforced soil and the depth of the reinforcement, but it also depends on the friction angle of retained fill, slope of the backfill (i.e. geometry) and the length of reinforcement, although their effects are less pronounced.

2.3 *Comparison of Methodologies*

To compare different methodologies, vertical stresses were calculated for a 15 m high reinforced soil wall. The unit weight and friction angle of reinforced fill is assumed to be 20 kN/m^3 and 34 degrees, respectively. Similarly, unit weight of 19 kN/m^3 and friction angle of 30 degrees is assumed for retained fill. Figure 1 compares the vertical stress obtained by different methodologies for a 15 m high reinforced soil wall with 10.5 m long reinforcement and horizontal backslope. It can be seen how the lateral force applied by the retained fill increase vertical stresses with increasing depth to reinforcement. The difference between simple method and other methods,which considers overturning (except Bolton method), is not significant up to approximately 6 meters but it gets more pronounced as the depth increases.
Of course this figure is limited to assumed soil parameters and wall geometry. The increase in vertical stress due to the lateral force applied by the retained fill, thus the difference between the simple method and other methods, will decrease with increasing reinforcement length, while it will increase with decreasing friction angle and increasing active Rankine earth pressure coefficient for the retained fill.

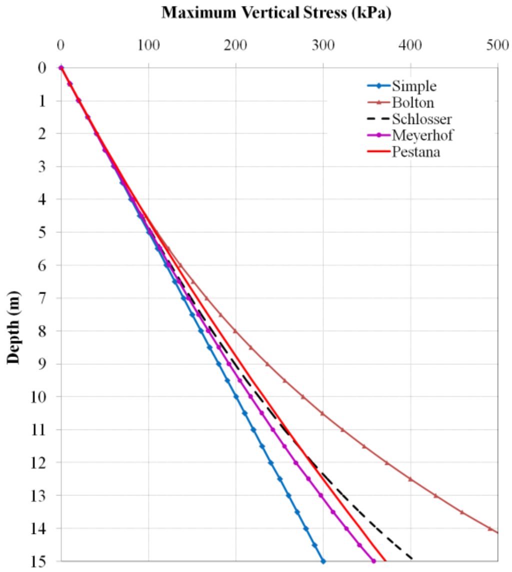

Figure 1. Comparison of vertical stresses obtained by existing methods for a 15 m high reinforced soil wall with horizontal backslope

3 CONCLUSION

Internal design of reinforced soil walls requires the estimation of reinforcement loads, which requires the determination of horizontal stress acting over tributary area of each reinforcement. Maximum horizontal stress at each depth depends on the maximum vertical stress and lateral earth pressure coefficient at that particular depth. The increase in vertical stresses due to overturning effect may range from 10 to 50 percent depending on the wall height, reinforced and retained fill properties, reinforcement length and slope geometry and the use of simple method may underestimate the reinforcement load when overturning effect should not be neglected. This paper compares existing methods of calculating vertical stress within the wall, and proposes a simpler equation, which considers overturning effect without the need to determine eccentricity separately.

4 REFERENCES

Berg, R. R., Christopher, B. R., and Samtani, N. C. (2009) Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, No. *FHWA-NHI-10-024*, Vol. I

Bolton, M. D., and Jones, C. (1977) Reinforced Earth. *Proceedings of the Institution of Civil Engineers, 62, Vol* 3, 511-516.

Meyerhof, G.G. (1951) The Ultimate Bearing Capacity of Foundations. *Geotechnique*, **Vol. 2**, 301-332.

Meyerhog, G.G. (1953) The Bearing Capacity of Foundations Under Eccentric and Inclined Loads, *In 3rd ICSMFE*, **Vol. 1**, 440-445

Schlosser, F., and Elias, V. (1978) Friction in reinforced earth. *In Symposium on earth reinforcement*, ASCE, 735-763