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MSE WALL DESIGN FOR BRIDGE ABUTMENT BY DETERMINATION OF CRITICAL PARAMETERS

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Abstract

Bridges are essential and very important element of transportation structures. Therefore, their design and performance become important aspect of transportation projects. Bridge abutments are constructed over retaining structures. In this paper, design of mechanically stabilized wall supporting bridge abutment is investigated with respect to load and resistance factor, - considering different fill material and reinforcement properties.

Keywords

MSE wall, geosynthetic, geotextile, bridge abutment

1 INTRODUCTION

Mechanically stabilized earth walls (MSE) are started to be using instead of traditional retaining walls, because of their economic advantages and ease of construction. Mechanically stabilized earth walls are also less susceptible to settlements that may occur throughout their service life. Therefore, construction of MSE walls are started to be encountered in case of railway and highway projects. Failure of MSE walls during operation not only causes economical loss but also lives. Due to potential catastrophic effects in case of failure, many researchers have studied how to design MSE walls. Feng Chen et al. [2014] conducted stability analysis of reinforced soil wall constructed over thick clay layer using stress reduction method. T.S. Quang et al. [2009] presented a new method to design and stability analysis of reinforced earth wall, which is a multiphase approach, which accounts soil – strip failure condition. Ömer Bilgin [2009] studied various conditions, which affect reinforcement length. He used American association of state highway and official method (AASHTO) (2002) in his study. J.Han and D. Leshchinsky [2010] investigated effect of distance between two reinforced walls and wall's height. They also considered quality of backfill soil. Results are presented considering critical failure surface, tension loads on reinforcement and development of earth pressure. A. Sengupta [2012] numerically investigated possible reason for a failure of reinforced earth wall and concluded that, failure occurred due to overestimated strength of foundation soil. Yonggui Xie and Ben Leshchinsky [2015] investigated optimum reinforcement density in case of MSE walls as bridge abutments. L. Belabed et al. [2011] compared effect of possible failure wedges and earth pressure distribution into reinforcement loads and safety of the reinforced earth wall. V.A. Barvashov and I. M. Iovlev [2010] established a new calculation method

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for reinforced soil mass, especially for soil nails. Ben Leshchinsky [2014] conducted a parametric study to reveal effect of reinforcement density, strength of reinforcement and setback distance of footing to the behaviour of MSE wall. H. Ahmadi and M. Hajialilue-Bonab [2012] studied effect of reinforcement depth, reinforcement number and place of footing to reinforcement depth, reinforcement number and place of footing to behaviour of reinforced soil wall. G. D. Skinner and R. Kerry Rowe [2004] researched effect of reinforced earth wall constructed over yielding foundation with abutment and traffic loading. Richard J. Bathurts et al. [2005] introduced a new method to calculate reinforcement loads. D. Leshchinsky et al. [2014] presented a framework for limit state design of geosynthetic reinforced walls. R. Baker and Y. Klein [2003] presented how to design a reinforced soil walls with fully integrated limit equilibrium method.

It is seen from literature that, most of the researchers study internal design of reinforced earth walls. However, the bridge abutments were considered by very few researchers. Therefore, in this paper, reinforced earth wall, which is supporting a bridge abutment, is designed according to US Federal Highway Association (FHWA-2009) method. Forces acting on bridge abutment, reinforcement are evaluated. Forces acting on bridge abutment, external and internal stability of MSE wall are evaluated with respect to different abutment set back distance, reinforcement length, reinforced soil properties and retained soil properties in this paper.

2 METHOD

In order to design reinforced wall, load and resistance factor design (LRFD) methodology is used as described in FHWA. Loads that may cause failure of structures are increased with relevant load factors, while loads that act against failure are decreased by relevant load factors. Those load factors are determined according to maximum strength state of structure, minimum strength state of structure and service state of structure. Therefore, forces acting on structure are determined for all cases. After all those forces are determined, the most unfavourable conditions are taken into consideration. Unfavourable conditions are determined as taking maximum strength state of loads that may cause failure, while taking minimum strength state of loads that are against failure.

In order to conduct this research, a hypothetical reinforced wall and bridge abutment are considered. The selected design height of the wall is 6 m. The relevant dimensions of the footing and the chosen dead and live loads due to bridge is shown in Figure 1. The relevant values related to footing dimensions and height of the wall is given in Table 1.

Tab. 1 Relevant dimensions for footing and MSE wall

Item	Dimension
b_1 (m)	0.5
b_2 (m)	0.5
b_3 (m)	0.5
b_4 (m)	0.3
b_5 (m)	1.6
h_1 (m)	0.5
h_2 (m)	1.2
h_3 (m)	1.5
h_b (m)	0.024
h (m)	3.2
b_f (m)	3.4
H_a (m)	5
d (m)	1
H (m)	6

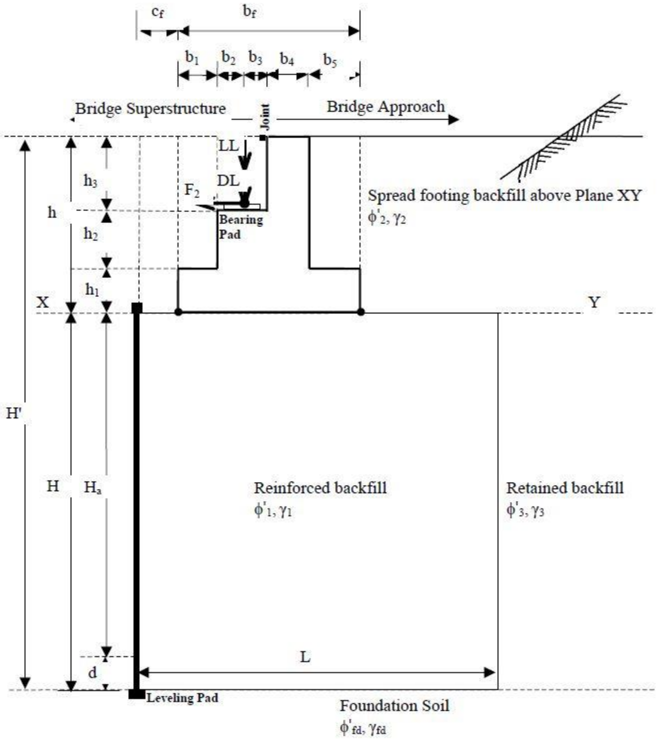

Fig. 1 Cross Section of MSE wall

Loads from bridge abutment which are shown in Figure 1, are also given in Table 2.

Tab. 2 Loads from bridge abutment

Load Type	Magnitude
Dead Load DL (kN/m)	155
Live Load LL (kN/m)	83
Friction Load F_2 (kN/m)	12

Foundation soil properties are chosen in order that they represent unfavourable condition in case of bearing capacity. Unit weight of foundation soil equals to 14.5 kN/m^3. The selected angle of friction is 27^0. Reinforced and retained soils' properties are changed to understand their effect on behaviour of reinforced wall with footing. Reinforcement length (L) and set back distance of footing (c_f) are also changed. Values considered for c_f and L in this paper are given in Table 3. It should be noted that reinforcement length is determined with respect to design height (H) of MSE wall.

Tab. 3 Setback distances for footing and reinforcement length

c_f (m)	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
L	0.7H	0.8H	0.9H	1H	1.1H	1.2H	-	-

Reinforced soil and retained properties are chosen such as that each one of them represent weak, average and strong strength conditions. Strength conditions are defined with angle of friction and unit weight of soil together. Selected values are given in Table 4. Table 4 also shows unit weight and angle of friction for spread footing fill. Chosen unit weight of footing is 24 kN/m^3, which is common unit weight for concrete structures.

Tab. 4 Soil properties for base case

	γ [kN/m^3]	Φ[^{0}]
Reinforced Soil	14.5	27
	16	37
	17.4	47.38
Retained Soil	14.5	27
	16	37
	17.4	42
Spread Footing Fill	17.4	47.38

Since general description and dimensions of the considered project are given, we can begin to calculate forces acting on reinforced soil wall. In order to calculate forces, it would be better construct force diagram. Constructed force diagram is given in Figure 2.

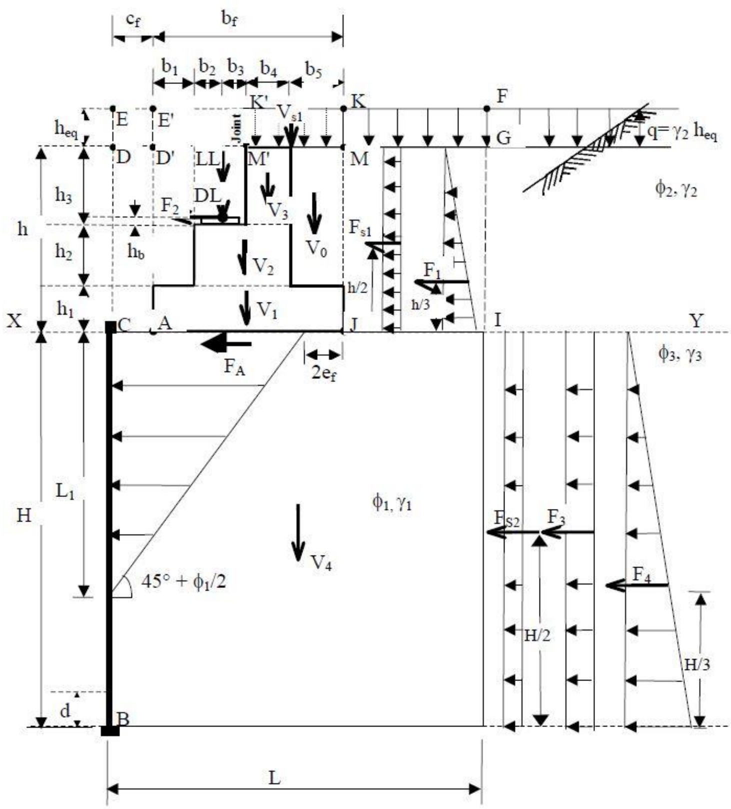

Fig. 2 Cross section of MSE wall with loads

The presented forces, which are acting on reinforced wall, can be computed as given in Table 5. Load factor is also given in Table 5 for each load part of the structure.

Tab. 5 Forces acting on MSE wall and their load type

Force	Formula	LRFD Load Type
V_0 (kN)	$(\gamma_2)*(h_2+h_3)*(b_5)$	EV
V_1 (kN)	$(\gamma_c)*(b_f)*(h_1)$	DC
V_2 (kN)	$(\gamma_c)*(b_2+b_3+b_4)*(h_2)$	DC
V_3 (kN)	$(\gamma_c)*(b_4)*(h_3)$	DC
V_4 (kN)	$(\gamma_1)*(H)*(L)$	EV
V_5 (kN)	$(\gamma_2)*(h)*(L)$	EV
V_s (kN)	$(q_F)*(L)$	LS
V_{s1} (kN)	$(\gamma_2)*(h_{eqF})*(b_4+b_5)$	LS
DL (kN)	-	DC
LL (kN)	-	LL
F_1 (kN/m)	$(1/2)*(K_{a2})*(\gamma_2)*(h^2)$	EH
F_2 (kN/m)	-	FR
F_3 (kN/m)	$(K_{a3})*[(\gamma_2)*(h)]*H$	EH
F_4 (kN/m)	$(1/2)*(K_{a3})*(\gamma_3)*(H^2)$	EH
F_{s1} (kN/m)	$(K_{a2})*[(\gamma_2)*(h_{eqF})]*(h)$	LS
F_{s2} (kN/m)	$(K_{a3})*[(\gamma_2)*(h_{eqM})]*H$	LS
F_A	F1+F2+Fs1	-

Load types are used to determine necessary load factor coefficients. Definitions of those load types may be given as follows:

- EH - horizontal earth loads,
- EV - Vertical pressure from dead load of earth fill,
- DC - components and attachments,
- FR - friction load, and
- LS - live load surcharge.

K_a stands for active lateral earth pressure and can be calculated as;

$$K_a = tan^2(45 - \frac{\emptyset}{2}) \quad (1)$$

Load factor values are given in Table 6 for maximum strength, minimum strength and service condition.

Tab. 6 Load factors for different load types

Load Factors according to AASHTO						
Load combination	EV	DC	LL/LS	ES	EH	FR
Strength I (max)	1.35	1.25	1.75	1.5	1.5	1
Strength I (min)	1	0.9	1.75	0.75	0.9	1
Service I	1	1	1	1	1	1

Since it is demonstrated how to compute forces, we may calculate overturning and resisting moments around toe of footing (Point A) and toe of MSE wall (Point B). Moment calculation formulas are given in Table 7.

Tab. 7 Calculation of moments required for the design of MSE wall

Moment (kN/m)	Point A	Point B
M_{V0}	$\gamma_2*(h_2+h_3)*b_5*((b_5/2)+(b_f-b_5))$	$\gamma_2*(h_2+h_3)*b_5*((b_5/2)+(b_f+c_f-b_5))$
M_{V1}	$\gamma_c*b_f*h_1*(b_f/2)$	$\gamma_c*b_f*h_1*(c_f+(b_f/2))$
M_{V2}	$\gamma_c*(b_2+b_3+b_4)*h_2*(b_1+((b_2+b_3+b_4)/2))$	$\gamma_c*(b_2+b_3+b_4)*h_2*(c_f+b_1+((b_2+b_3+b_4)/2))$
M_{V3}	$\gamma_c*b_4*h_3*((b_4/2)+b_1+b_2+b_3)$	$\gamma_c*b_4*h_3*(c_f+(b_4/2)+b_1+b_2+b_3)$
M_{V4}	-	$\gamma_1*H*L*(L/2)$
M_{V5}	-	$\gamma_2*h*L*(L/2)$
M_{Vs}	-	$q_F*L*(L/2)$
M_{Vs1}	$\gamma_2*h_{eqF}*(b_4+b_5)*(((b_4+b_5)/2)+b_1+b_2+b_3)$	$\gamma_2*h_{eqF}*(b_4+b_5)*(c_f+((b_4+b_5)/2)+b_1+b_2+b_3)$
M_{DL}	$DL*(b_1+b_2)$	$DL*(c_f+b_1+b_2)$
M_{LL}	$LL*(b_1+b_2)$	$LL*(c_f+b_1+b_2)$
M_{F1}	$0.5*Ka_2*\gamma_2*h^2*(h/3)$	$0.5*K_{a2}*\gamma_2*h^2*((h/3)+H)$
M_{F2}	$F_2*(h_1+h_2+h_b)$	$F_2*(h_1+h_2+h_b+H)$
M_{F3}	-	$K_{a3}*\gamma_2*h*H*(H/2)$
M_{F4}	-	$0.5*K_{a3}*\gamma_3*H^2*(H/3)$
M_{Fs1}	$(K_{a2})*[(\gamma_2)*(h_{eqF})]*(h)*(h/2)$	$K_{a2}*\gamma_2*h_{eqF}*h*(h/2)+H)$
M_{Fs2}	-	$K_{a3}*\gamma_2*h_{eqM}*H*(H/2)$
M_{FA}	-	$(F_1+F_2+F_{s1})*H$
		$(F_1+F_2+Fs_1)*(H-(L_1/3))$

Calculation of loads and moments are shown until this point. Since all the forces and moments are given, stability calculations may be made. Stability checks will be started from footing. After that, external stability of the MSE wall will be given. Internal stability check will be final stage of the design.

2.1 Stability Check for Footing

Stability check of footing is made in three steps. In the first step, eccentricity of footing under given loading conditions is found and compared with limiting eccentricity value. Since, footing is also under effect of horizontal forces, sliding check is done at second step. Finally, bearing capacity of the footing is compared with maximum bearing capacity determined by FHWA (2009).

The overturning and resistive moments around Point A and vertical force acting over footing should be computed without considering live loads in case of limiting eccentricity check. Those moments and vertical loads can be computed using formulas given in Table 8.

Sliding forces acting on the footing are equal to forces acting on the footing. Resisting forces are calculated as friction force between footing and reinforced soil. Therefore, vertical loads should be determined. Computed resisting forces should also be factored. Load factor for resistive sliding force is given as 0.8 by FHWA. Computation of safety of footing against sliding can be done as described in Table 9.

Tab. 8 Calculation of eccentricity of footing

M_{oa}	**$M_{F1}+M_{Fs1}+M_{F2}$**
M_{ra}	$M_{V0}+M_{V1}+M_{V2}+M_{V3}+M_{DL}$
M_a	$M_{ra}-M_{oa}$
V_a	$V_0+V_1+V_2+V_3+DL$
a_{nl}	M_A/V_A
e_f	$0.5*b_f-a_{nl}$
Critical Values	
M_{oa-c}	maximum strength condition
M_{ra-c}	minimum strength condition
M_{a-c}	$M_{ra-c}-M_{oa-c}$
V_{a-c}	minimum strength condition
a_{nl}	M_{a-c}/V_{a-c}
e_f	$0.5b_f-a_{nl}$
e	$b_f/4$

Tab. 9 Calculation of sliding forces acting on bridge abutment

F_A	**$F_1+F_{S1}+F_2$**
V_A	$V_0+V_1+V_2+V_3+DL$
V_N	$V_A*\tan\phi_1$
V_F	ϕ_s*V_N
CDR	V_F/F_A
Critical Values	
Minimum strength condition	
Maximum strength condition	
$V_{fmin}>F_{Amax}$	YES/NO
CDR	V_{fmin}/F_{Amax}

During calculation of bearing stress of footing, live loads are taken into consideration because, live loads impose additional stress. The calculation process is similar to computation of limiting eccentricity. Calculation steps for bearing capacity of footing are given in Table 10.

2.2 External Stability of MSE Wall

Since stability of footing is evaluated, external stability of MSE wall can now be evaluated. External stability analysis of MSE wall can be done by considering limiting eccentricity, sliding resisting and bearing capacity of the wall.
Limiting eccentricity of the MSE wall consists of computing overturning moments, resistive moments and acting vertical force along MSE wall. Limiting eccentricity check can be done by following the methodology given in Table 11.

Tab. 10 Calculation of bearing stress exerted by bridge abutment

$\mathbf{M_{oa}}$	$\mathbf{M_{F1}+M_{F2}+M_{Fs1}}$
$\mathbf{M_{ra}}$	$M_{V0}+M_{V1}+M_{V2}+M_{V3}+M_{DL}+M_{LL}+M_{VS1}$
$\mathbf{M_{A}}$	$M_{ra}-M_{o}$
$\mathbf{V_{ab}}$	$V_0+V_1+V_2+V_3+DL+LL+V_{S1}$
$\mathbf{a_{wl}}$	M_A/V_{ab}
$\mathbf{e_f}$	$0.5b_f-a_{wl}$
$\mathbf{b_{f'}}$	b_f-2e_f
$\boldsymbol{\sigma}$	$V_{ab}/(b_f-2e_f)$
$\mathbf{L_1}$	$(c_f+(b_f-2e_f))*\tan(45+\phi_1/2)$
Critical Values	
$\mathbf{M_{oa-c}}$	maximum strength condition
$\mathbf{M_{ra-c}}$	minimum strength condition
$\mathbf{M_{a-c}}$	$M_{ra-c}-M_{oa-c}$
$\mathbf{V_{a-c}}$	minimum strength condition
$\mathbf{a_{wl}}$	M_{a-c}/V_{a-c}
$\mathbf{e_f}$	$0.5bf-a_{wl}$
$\mathbf{b_{f'}}$	b_f-2e_f
$\boldsymbol{\sigma}$	$V_{ab-c}/(b_f-2e_f)$
$\mathbf{q_r}$	335

Sliding of the MSE wall means horizontal translational movement of the wall. Safety against sliding of depends on magnitudes of horizontal forces acting on MSE wall and resistive forces between wall and foundation soil. Safety against sliding can be checked by following Table 12.

Tab. 11 Calculation of eccentricity of MSE wall

Item	**Formula**
Un-factored Soil Weight in Block CDMJ in the abutment footing area	$W = h*(bf+cf)*\gamma_{sfb}$
Load factor for soil weight in block CDMJ [EV]	
Factored Soil Weight in block CDMJ in Abutment footing area	
Un-factored LL Weight on Block CDMJ in Abutment Footing	$LL=(b_f+c_f)*\gamma_{sfb}*h_{eqF}$
Load factor for LL on Block CDMJ [LS]	
Factored LL weight on block CDMJ in abutment footing area	
Vertical weight due to soil weight and LL in block CDMJ	
Vertical weight from abutment footing including soil on heel and LL	$V_{Ab}=V_0+V_1+V_2+V_3+DL+LL+V_{S1}$
Vertical weight from abutment footing including soil on heel and no LL	$V_A=V_0+V_1+V_2+V_3+DL+V_{S1}$
Net load, P, on base of spread footing from the bridge (with consideration of LL) Pwl	$P_{wL} =V_{ab\text{-}h}*\gamma_{sfb}*(b_f+c_f)$
Net load, P, on base of spread footing from the bridge (no LL) Pnl	$P_{nL} =V_{ab\text{-}h}*\gamma_{sfb}*(b_f+c_f)$
Moment arm of net load Pnl from Point B	$L_p=a_{nL}+c_f$
Resisting Moment at Point B due to net load P	$M_{PnL}=P_{nL}*(l_p)$
Vertical Load at the base of MSE wall without LL	$V_B=V_4+V_5+P_{nL}$
Resisting moments about Point B without LL surcharge	$M_{RB}=M_{V4}+M_{V5}+M_{PnL}$
Overturning moments about Point B	$M_{OB}=M_{FS2}+M_{F3}+M_{F4}+M_{FA}$
Location of the Resultant force on base of MSE wall from point B	$b=(M_{RB}-M_{OB})/V_B$
Eccentricity at base of MSE wall	$e = L/2-b$
Limiting Eccentricity	
Is the Resultant within limiting Value of e_l	
Critical Values Based on Max/Min	
Overturning Moments about Point B $M_{ob,c}$	maximum strength condition
Resisting moments about Point B $M_{Rb,c}$	Minimum strength condition
Net Moment about Point B	$M_{Rb\text{-}c}-M_{ob\text{-}c}$
Vertical Force $V_{B,c}$	Minimum strength condition
Location of Resultant from Point b	$M_{B\text{-}C}/V_{B\text{-}C}$
Eccentricity from Centre of Footing	$e_l=L/2-b$
Limiting Eccentricity	$e=L/4$
Is the Limiting Eccentricity Satisfied	

Tab. 12 Calculation of sliding forces acting between MSE wall and foundation soil

Item	**Formula**
Lateral Load on MSE wall	$H_m=F_1+F_2+F_3+F_4+F_{S1}+F_{S2}$
Vertical Load at base of MSE wall without LL surcharge	$V=V_4+V_5+P_{nL}$
Nominal sliding resistance at base of MSE wall	$V_{Nm}=\tan\phi_d*(V_4+V_5+P_{nL})$
Factored sliding resistance at base of MSE wall	$V_{Fm}=\phi_s*V_{Nm}$
Is $V_{FM}>H_m$	
Capacity Demand Ratio	V_{Fm}/H_m
Critical Values Based on Max/Min	
Minimum V_{FM}	
Maximum H_M	
IS $V_{fmin}>H_{mmax}$	
Capacity Demand Ration V_{fmmin}/H_{mmax}	

The last step to evaluate external stability of MSE wall consists of evaluating safety against bearing capacity of foundation soil. Load bearing capacity of foundation soil is compared with vertical loads due to MSE wall. Safety against bearing capacity of MSE wall can be determined by using Table 13.

2.3 Internal Stability of MSE Wall

Stability check of footing and external stability of MSE wall is evaluated until now. In order to finish design of MSE wall, internal stability of it should also be checked. Internal stability of MSE wall covers, safety against pull – out of reinforcements from soil and safety against rupture of reinforcement. It should be noted that, pull – out occurs when acting tensile forces are higher than the reinforcement can transfer to soil. Reinforcement fails when tensile forces higher than its strength. Therefore, we will establish relationships to calculate tensile forces acting over the reinforcement and check if it can carry those loads safely.

First step can be taken as determining placement of geosynthetics for internal stability check. In this study, first layer of geosynthetic is placed to depth of 0.4 meter. Following layers are placed at 0.4-meter intervals. After that, vertical stresses are determined for each reinforcement layer. Horizontal stresses are computed from vertical stresses. Additional horizontal stresses are computed due to footing and surcharge loads. All computed forces are summed to find total force acting on geosynthetic layer. After determination of forces acting on geosynthetic, pull – out capacity of each layer is determined by formula (2).

$$P_r = F^*\alpha\sigma_v L_e C \quad (2)$$

In this formula P_r represents pull-out capacity, L_e represents length of reinforcement in resisting zone, C equals to reinforcement effective unit parameter and F^* stands for pull out resistance factor.

Tab. 13 Calculation of bearing stress exerted to foundation soil by MSE wall

Item	**Formula**
Component 1	
Base width of stress distribution based on 1H:2V distribution and Pwl acting on $b_f'=b_f-2e_f$	$(b_f-2e_f)+(c_f+H/2)$
Bearing Stress Due to P_{wl}	$P_{wl}/(b_f-2e_f)+(c_f+H/2)$
Component 2	
Vertical load at base of MSE wall including LL on top	$V=V_4+V_5+V_S$
Resisting Moments at Point B on MSE wall	$M_{RB}=M_{V5}+M_{VS}+M_{V4}$
Overturning moments at Point B on MSE wall	$M_{FS2}+M_{F3}+M_{F4}$
Net Moment at Point B	$M_B=M_{RB}-M_{OB}$
Location of Resultant from Point B	$b=M_B/V$
Eccentricity from centre of Wall	$e_L=0.5L-b$
Limiting Eccentricity	L/4 or L/6
Is resultant eccentricity within limiting value of e_L	
Effective width of base of MSE wall	$B'=L-2e_L$
Factored bearing stress due to MSE wall	$V/(L-2e_L)$
Total bearing Stress due to Component 1 + 2	$\Delta\sigma_v+\sigma_v$
Factored bearing resistance q_r	
Is $\sigma_{max}<q_r$	
Capacity Demand Ratio	q_r/σ_{max}
Critical Values Based on Max/Min for Component 2	
Overturning moments about Point B, M_{OB-C}	Maximum strength condition
Resisting moments about Point B, M_{RB-C}	Minimum strength condition
Net moment about Point B	$M_{B-C} = M_{RB-C} - M_{OB-C}$
Vertical force, V_{Bb-C}	Minimum strenght condition
Location of resultant from Point B	$b = M_{B-C}/V_{Bb-C}$
Eccentricity from center of wall	$e_L = 0.5*L – b$
Limiting eccentricity	$e = L/4$
Is the limiting eccentricity criteria satisfied?	
Effective width of base of MSE wall	$B' = L-2e_L$
Bearing stress	$\sigma_{v-c} = V_{Bb-C} / (L-2e_L)$
Compute critical total bearing stress	
Total bearing stress due to Component 1+2	σ_{vmax-C}
Factored bearing resistance, q_R	307
Is bearing stress < factored bearing resistance	
Capacity : Demand Ratio (CDR)	$q_R:\sigma_{vmax-C}$

3 RESULTS

Design of MSE wall according to FHWA (2009) is introduced to reader. Performance of the MSE wall will be evaluated and compared with respect to abutment distance to wall facing, reinforced soil properties, reinforcement length and retained fill properties.

3.1 Effect of Abutment Distance

Abutment distance is measured from wall facing to the near edge of the footing. That distance is varied from 0.15 meter to 0.50 meter with 0.05 increments.

Calculations according to FHWA (2009) showed that changing place of footing does not affect eccentricity of footing, stress due to footing and sliding on footing. Sliding resistance of footing is computed as 256.298 kN/m while, driving force is computed as 45.827 kN/m. Bearing stress of footing is computed as 183.233 kN/m. This value is lower than the bearing stress limit stated in FHWA. Eccentricity of the footing is calculated as 0.383 m while its limit value is computed as 0.85 m.

When the external stability of MSE wall is investigated with respect to increasing footing distance from wall, it is seen that eccentricity of wall decreases slightly from 1.713 to 1.705 as distance increases from 0.15 m to 0.50 m. Decrease of eccentricity is seen when distance equals to 0.40 m. After that threshold value, wall eccentricity remains constant. Sliding force acting on MSE wall and, bearing stress exerted by MSE wall to foundation soil linearly decreases as the footing move away from the wall. Change of sliding force and bearing stress can be seen in Figure 3 given below.

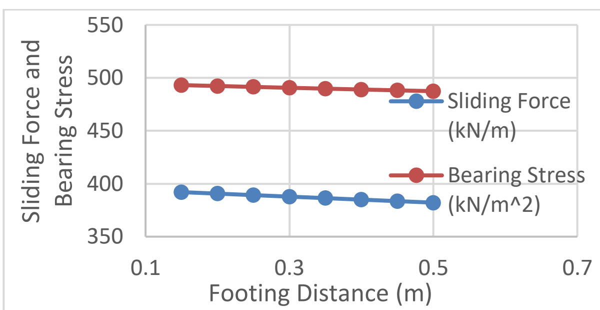

Fig. 3 Change of sliding force and bearing stress between MSE wall and foundation soil

Pull – out capacity of the first reinforcement layer is computed as 99.28 kN/m while it is calculated as 486.92 kN/m for the last reinforcement layer for all cases. Computations showed that, maximum reinforcement tension loads decrease as the footing distance increases. Maximum tension load decreases from 22 kN/m to 20 kN/m for the first reinforcement layer, while it decreases from 25.05 kN/m to 24.87 kN/m for the last reinforcement when footing distance is increased to 0.50 m from 0.15 m.

3.2 Reinforced Soil Properties

Three different cases are selected to determine effect of reinforced soil properties such as unit weight and angle of friction. Those two parameters increased or decreased together because they are related to each other. 27^0, 37^0 and 47^0 degrees is selected as angle of friction for case 1, case 2 and case 3 respectively. Unit weights are chosen as 14.5 kN/m^3, 16 kN/m^3 and 17.4 kN/m^3 respectively for case 1, case 2 and case 3.

It is seen that computed eccentricity is not affected from reinforced soil properties. Eccentricity of footing is calculated as 0.38 m and it is lower than limiting eccentricity, which equals to 0.85 m for all the cases. Computed bearing stress due to footing also remained constant with respect to change in reinforced soil properties. However, in case of sliding resistance, it is seen that, sliding resistance increases as the reinforced soil properties increases. Increase can be seen in Figure 4.

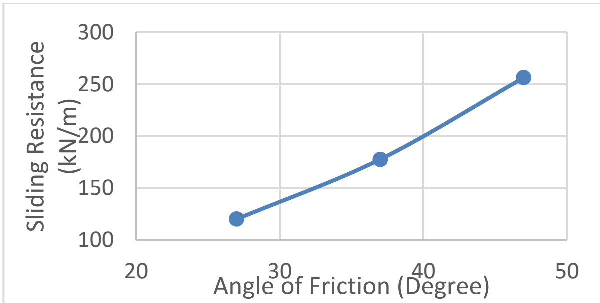

Fig. 4 Change of sliding resistance with respect to angle of friction of reinforced soil

Since forces causing sliding are constant and computed as 45.83 kN/m, it is clear that ratio between resistive forces and sliding force increases. This ratio is called capacity/demand ratio and it increases from 2.62 to 5.59 as angle of friction increases from 27^0 to 47^0.

When external stability of MSE wall is taken into consideration, it is seen that using stronger fill for reinforcement area positively contributes to limiting eccentricity, sliding and bearing resistance of MSE wall. It is seen that eccentricity of MSE wall decreases from 1.89 m to 1.71 m. It should be noted that limiting eccentricity is calculated as 1.05 m for MSE wall. It is also seen that, as the quality of reinforced soil increases, resistance against sliding increases and less stress is exerted to foundation soil. Change of resistance against sliding and bearing stress may be seen in Figure 5.

When internal design of MSE wall is investigated under different reinforced soil properties, it is seen that, as the reinforced soil gets stronger, pull-out capacity increases. Pull out capacity of first layer reinforcement is computed as 17.42 kN/m for the weakest reinforced soil properties, while 46.19 kN/m maximum tension load is computed for same reinforcement layer and same reinforced soil properties. However, as the reinforced soil gets stronger, maximum tension load on reinforcement decreases and pull out capacity increases. This behaviour may be seen in Figure 6.

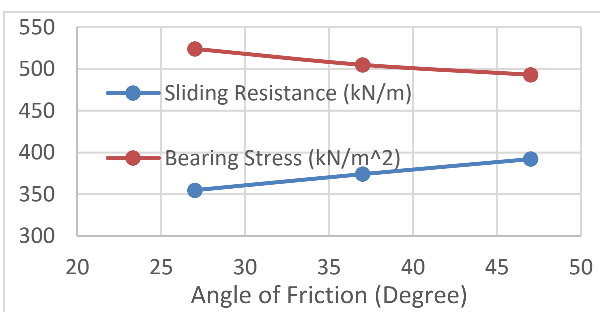

Fig. 5 Change of sliding resistance and bearing stress with respect to angle of friction of reinforced soil

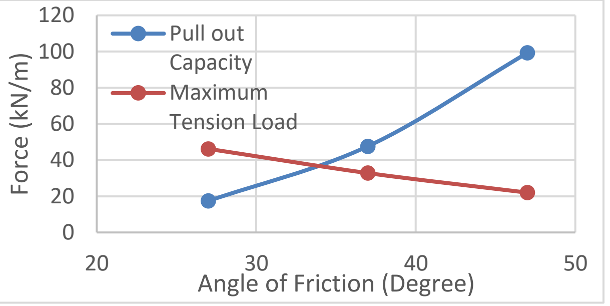

Fig. 6 Change of maximum tension on reinforcement and pull out capacity

3.3 Reinforcement Length

FHWA (2009) specifies minimum reinforcement length as 0.7H of height of the MSE wall. Therefore, reinforcement length is varied between 0.7H to 1.2H in this research. Results showed that reinforcement length does not affect footing's sliding resistance, bearing stress and eccentricity. However, it is seen that increasing reinforcement length has positive effect on MSE wall. Limiting eccentricity of MSE wall increases to 1.8 m from 1.05 m as reinforcement length increases to 1.2H from 0.7H. It should be also stated that, eccentricity of wall decreases at the same time. Change of limiting eccentricity and eccentricity of wall can be seen in Figure 7.

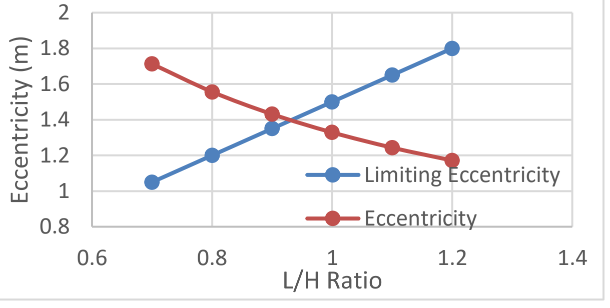

Fig. 7 Change of limiting eccentricity and eccentricity of MSE wall with reinforcement length

Similarly, resistive moments against overturning also increases as reinforcement length increases. Resistive moment is calculated as 1656.30 kNm/m for 0.7H and increases to 4867.50 kNm/m for 1.2H reinforcement length. Increase of reinforcement length decreased bearing stress exerted to foundation soil. Change of bearing stress with respect to reinforcement length may be seen in Figure 8.

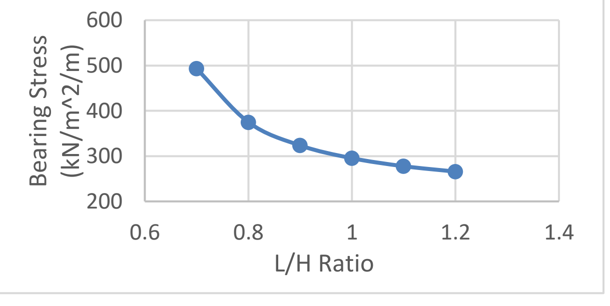

Fig. 8 Change of bearing stress exerted to foundation soil with reinforcement length

It is clear according to Figure 8 that bearing stress does not decrease linearly as reinforcement length increases.

When internal stability of wall is considered, it is seen that, maximum tension on geosynthetic layers does not change with respect to reinforcement length. However, pull out capacity increases linearly. Change of pull out capacity is showed in Figure 9 for the first layer and last layer of reinforcement.

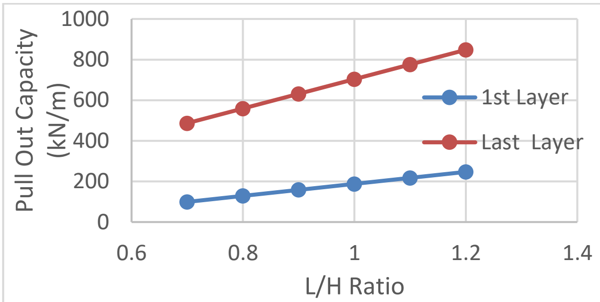

Fig 9. Pull out capacity change for the first and last layer of reinforcement with respect to reinforcement length

According to Figure 9, pull out increment is higher in case of the last layer of reinforcement. Pull out capacity is computed as 99.28 kN/m and 486.92 kN/m for the first and last layer reinforcement for 0.7H reinforcement length respectively. When reinforcement length increases to 1.2H, computed pull out capacity increases to 247.05 kN/m and 848.14 kN/m for the first layer and last layer of reinforcement respectively.

3.4 Retained Fill Properties

Effect of retained fill properties to MSE wall design was also analysed in this research. Three different cases were selected according to unit weight and angle of friction. Unit weight and angle of friction are chosen as 14.5 kN/m^3 and 27^0 for case 1, 16 kN/m^3 and 37^0 for case 2 and 17 kN/m^3 and 42^0 for case 3. Change on those properties does not affected design criteria for abutment.

If effect of retained fill properties is evaluated, it is seen that, as retained fill gets stronger, lower driving forces are observed for both over turning moment and sliding. That behaviour causes more reliable design of the MSE wall. Change of overturning moment with respect to angle of friction can be seen in Figure 10.

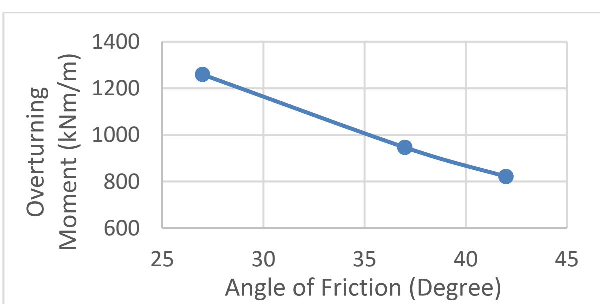

Fig. 10 Change in magnitude of overturning moment with angle of friction of retained fill

Eccentricity of wall decreases to 1.14 m from 1.71 m as angle of friction decreases. Overturning moment decreases to 821.22 kNm/m from 1259.1 kNm/m at the same time. Sliding force decreases to 258.24 kN/m from 422.88 kN/m, which causes an increase of capacity demand ratio from 0.93 to 1.52. Since overturning moment and eccentricity of MSE wall decrease, effective foundation area of MSE wall increases, which yields less bearing stress exerted to foundation soil. Therefore, bearing stress exerted to foundation soil decreases to 310.63 kN/m from 493.16 kN/m. Calculations also showed that, retained fill properties does not affect internal design of MSE wall. Therefore, no change of maximum tension or pull out capacity on reinforcement layers was computed according to FHWA (2009).

4 CONCLUSION

In this research, FHWA (2009) code is followed to design a MSE wall, which supports a bridge abutment. Abutment distance to wall, reinforcement length, reinforced soil properties and retained soil properties are changed to analyse their effect on design of MSE walls according to FHWA code. Following conclusions can be deduced from the results of this research:

- Design parameters of bridge abutment are independent from retained fill properties and reinforcement length;
- Using stronger reinforced soil zone increases resistive forces, while stronger retained fill decreases driving forces;
- Increasing reinforcement length is the most efficient way to sustain minimum safety conditions for both external and internal design of MSE wall.

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