SHORED MECHANICALLY STABILIZED EARTH (SMSE) WALL SYSTEMS DESIGN GUIDELINES

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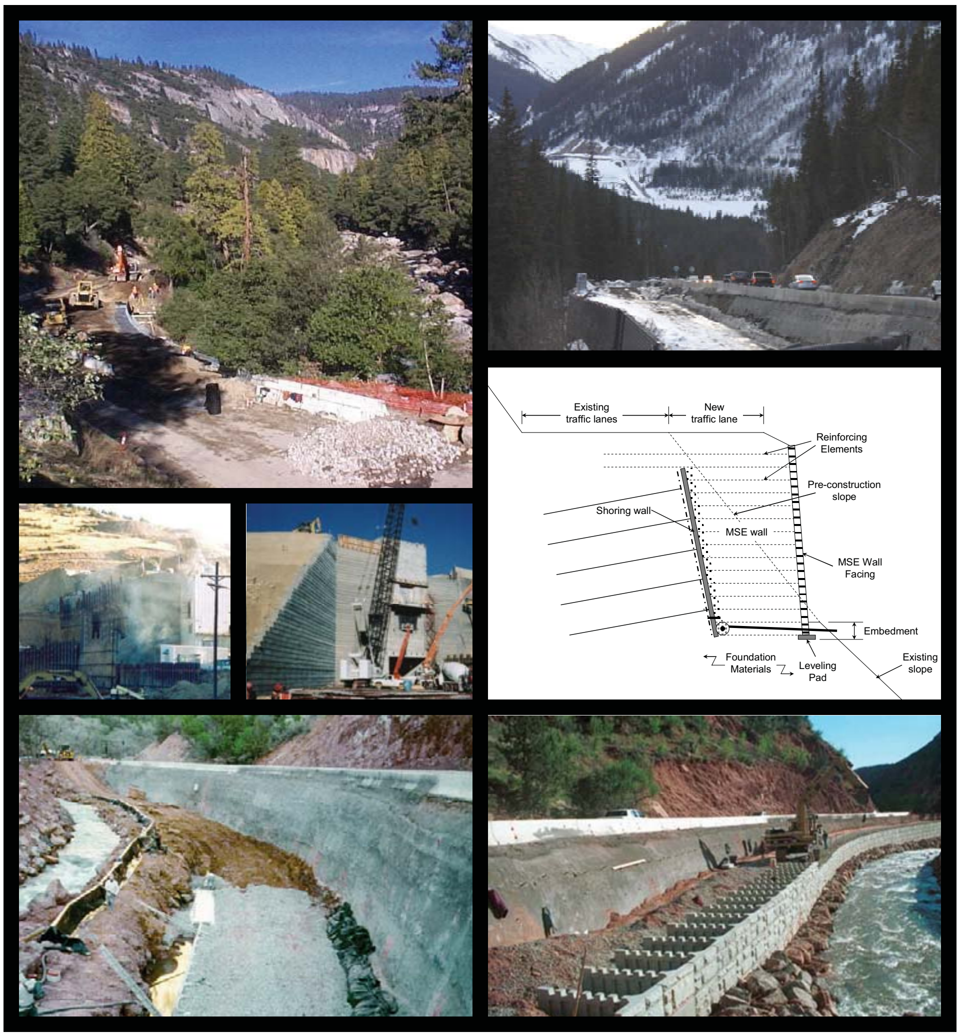

U.S. Department of Transportation
Federal Highway Administration

CTIP

Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
12300 West Dakota Avenue
Lakewood, CO 80228

FOREWORD

Federal Lands Highway (FLH) Division of the Federal Highway Administration (FHWA) is responsible for design and construction of roadways in rugged, mountainous terrain. MSE walls are frequently used to accommodate widening of existing roads or construction of new roadways. However, in steep terrain, excavation is required to establish a flat bench on which to construct the MSE wall.

Shoring has often been employed to stabilize the backslope (or back-cut) for the MSE wall, and an MSE wall has been designed and constructed in front of it. Where a shored MSE wall system is determined to be the best alternative for wall construction, design of the MSE wall component should take into consideration the retaining benefits provided by the shoring component, as well as the long-term behavior of each individual wall system. The purpose of this design guideline is to serve as the FLH standard reference for roadway projects using shored MSE walls.

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Federal Highway Administration
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16. Abstract

As an FHWA design reference for highway projects, this report was prepared to enable the engineer to identify and evaluate potential applications of shored mechanically stabilized earth (SMSE) walls. Included in this design guideline are a literature review on similar construction and the results and interpretation of field-scale testing, centrifuge modeling, and numerical modeling of an SMSE wall system. Results of the centrifuge modeling and field-scale testing show that reduction of the reinforcement length to as little as 25 percent of the wall height (0.25*H*) provides sufficient wall stability, even under a considerably high degree of surcharge loading.

Using the results of the modeling and field testing research, this design guideline recommends a minimum reinforcement length equivalent to as little as 30 percent of the wall height (0.3*H*) for the MSE wall component, provided that the MSE reinforcement length is greater than 1.5 m. The benefit of attaching reinforcement to the shoring wall is found to be small and is generally not recommended except by way of the upper two layers of reinforcement. If possible, these layers of reinforcement should overlap the shoring wall and have a total length of 0.6*H*. If this is not possible, then these layers should be attached to the shoring wall.

Internal design requirements of the MSE wall component for an SMSE wall system differ from that of a traditional MSE wall. Equations presented in this design guideline have been developed specifically to address these requirements. The benefits of increased retaining abilities provided by the shoring wall, such as reduction in lateral load acting on the MSE wall component and contribution to global stability, are considered in the design process.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO – American Association of State Highway and Transportation Officials
A_f – area of load footing
A_M – maximum horizontal acceleration
ASTM – American Society for Testing and Materials

b – gross width of the strip, sheet or grid; or bench width
b_f – length of load footing measured perpendicular to wall face
B – width of MSE wall measured from wall face

c_f – cohesion of foundation soil
C – reinforcement effective unit perimeter
C_c – coefficient of consolidation
C_u – uniformity coefficient (D_{60}/D_{10})
C_v – compression index

d – foundation or toe embedment depth of MSE wall
D_f – footing embedment depth
D_r – relative density
D_1 – diameter of influence from footing load
D_{10} – particle size which 10 percent of material passes
D_{30} – particle size which 30 percent of material passes
D_{60} – particle size which 60 percent of material passes
DOT – Department of Transportation

e – eccentricity
EA – axial stiffness
EI – bending stiffness
E_{50}^{ref} – reference secant modulus for deviatoric loading
E_{oed}^{ref} – reference secant modulus for primary compression
E_{ur}^{ref} – reference secant modulus for unloading/reloading

F – maximum tensile force
F^* – pullout resistance factor
F_H – concentrated horizontal load
F_V – concentrated vertical load
F_q – embedment bearing capacity factor
F_{PO} – pullout resistance
FHWA – Federal Highway Administration
FLH – Federal Lands Highway
FS – factor of safety to account for uncertainties
FS_{bc} – factor of safety against bearing capacity failure
FS_c – factor of safety against compound failure
FS_{cs} – factor of safety with regard to connection strength

FS_{ex}	–	factor of safety against external instability
FS_g	–	factor of safety against global failure
FS_{is}	–	factor of safety against interface shear instability
FS_{ot}	–	factor of safety against overturning failure
FS_p	–	factor of safety against MSE reinforcement pullout failure
FS_{PO}	–	factor of safety against soil nail pullout
FS_r	–	factor of safety against reinforcement rupture
FS_{sc}	–	factor of safety against internal shear failure
FS_{sl}	–	factor of safety against base sliding
FS_t	–	nail tensile capacity factor of safety
g	–	gravitational acceleration
H	–	horizontal distance
H	–	vertical wall height
H_s	–	slope height for bearing calculation
HDPE	–	high density polyethylene
i	–	slope inclination angle
kN	–	kiloNewton
K	–	the horizontal force coefficient acting on the back of the wall face
K_a	–	active lateral earth pressure coefficient
K_r	–	lateral earth pressure coefficient
K_r/K_a	–	lateral stress ratio
kPa	–	kiloPascal
L	–	length of reinforcement
L_B	–	reinforcement length at base of MSE wall
L_{ei}	–	length of embedment in the resisting zone at the i^{th} reinforcement level
L_f	–	length of load footing
L_T	–	reinforcement length at top of MSE wall
L_w	–	length of truncated failure wedge; wall length
L_z	–	nail length at depth, z
LRFD	–	load and resistance factor design
LVDT	–	linear variable displacement transducer
m	–	meter(s)
mm	–	millimeter(s)
m	–	power for stress-level dependency of stiffness
M	–	mass of active soil
MSE	–	mechanically stabilized earth
N	–	coefficient of gravitational acceleration
N_1	–	reaction force normal to failure surface
N_2	–	reaction force normal to shoring wall

N_{cq}	–	dimensionless bearing capacity factor
$N_{\gamma q}$	–	dimensionless bearing capacity factor
N_s	–	slope stability factor
NCMA	–	National Concrete Masonry Association
OSHA	–	Occupational Safety and Health Association
P_{AE}	–	dynamic horizontal thrust
P_D	–	driving force
P_{IR}	–	horizontal inertia force
P_o	–	lateral reactionary force
P_R	–	resisting force
p^{ref}	–	reference pressure
PI	–	plasticity index
PVC	–	polyvinyl chloride
q	–	uniform surcharge load
Q	–	ultimate nail pullout resistance
q_a	–	allowable bearing capacity
q_{ult}	–	ultimate bearing capacity
R_c	–	reinforcement coverage ratio (b/s_h)
R_f	–	failure ratio
S_1	–	shear resistance along the failure surface
S_2	–	shear resistance along the shoring wall
s_h	–	center-to-center horizontal spacing between strips, sheets or grids for MSE wall
S_H	–	center-to-center horizontal spacing between nails for soil nail wall
SP	–	poorly-graded sand
s_v	–	vertical spacing between MSE reinforcements
S_V	–	center-to-center vertical spacing between nails for soil nail wall
S_t	–	spacing of transverse bar of grid reinforcements
SCR	–	Supplemental Contract Requirement
SMSE	–	shored mechanically stabilized earth
t	–	thickness of the transverse bar of grid reinforcement
T	–	reinforcement tensile strength
$T_{allowable}$	–	allowable strength (force per unit width) of reinforcement
T_i	–	maximum tension per unit width at i^{th} reinforcement level
T_n	–	nominal or ultimate nail tendon tensile strength
T_{max}	–	required pullout resistance
TFHRC	–	Turner Fairbanks Highway Research Center
USCS	–	Unified Soil Classification System

V – vertical distance
v – vertical component of shoring wall batter

w – width of load footing measured parallel to wall face
W – weight of the active wedge or reinforced block
W_f – width of load footing

x – distance to center of footing measured from face of MSE wall

z – depth below top of wall

γ – unit weight
γ_f – unit weight of foundation soil

ϕ – friction angle
ϕ' – effective friction angle
ϕ_f – friction angle of foundation soil
ϕ_{PS} – plane strain friction angle
ϕ_{TX} – triaxial shear friction angle

α – scale effect correction factor; aspect ratio
α_β – bearing factor for passive resistance

β – internal angle of truncated failure wedge
β_s – slope angle measured from horizontal

δ – inclination of MSE wall facing measured from horizontal starting in front of the wall
δ_i – interface friction angle

ψ – angle of the failure surface measured from horizontal
ψ_d – dilatancy angle

ν_{ur} – Poisson's ratio for unloading/reloading

ρ – soil-reinforcement interaction friction angle

$\Delta\sigma_h$ – concentrated horizontal surcharge load
$\Delta\sigma_v$ – concentrated vertical surcharge load
σ_h – horizontal stress
σ_v – vertical stress
σ_{vi} – overburden pressure at the i^{th} reinforcement level
σ_z – horizontal pressure at depth, z
$\sigma_{tension}$ – tensile strength
σ_3 – confining stress