Lecture 32

Reinforced Soil Retaining Walls-Design and Construction

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Example calculation

An 8 m high wall is to be built using sand fill and polymer-grid reinforcement. The sand has $\phi' = 30^0$, γ= 18 kN/m^3 and is to be used for the wall and the backfill. A surcharge loading of 15 kPa is to be allowed for, and the maximum safe bearing pressure for the foundation soil is 300 kPa. Two grids of different design strength are available: grid A at 20 kN/m and grid B at 40 kN/m (both have a bond coefficient f_b of 0.9). The fill will be compacted in layers 250 mm thick.

External stability (sliding)

K_a = (1 – sin 30^0) / (1+ sin 30^0) = 0.333
$\mu = f_b \tan\phi = 0.9 \times \tan(30) \approx 0.5$.

For a factor of safety against sliding of 2.0, the minimum length of layers is:

$$L_{min} \geq \frac{F_S K_{ab} H (\gamma_w H + 2w_S)}{2\mu(\gamma_w H + w_S)}$$

$$L \geq \frac{2x0.333 \times 8 \times (18 \times 8 + 2 \times 15)}{2 \times 0.5 \times (18 \times 8 + 15)} \geq 5.83m.$$

Therefore adopt a length of 6m.

External stability (Overturning)

Overturning moments about the toe = $(k_{ab}\gamma_b \frac{H^3}{6} + k_{ab}\frac{w_s H^2}{2})$

Restoring moments about the toe = $(\gamma_\omega \frac{HL^2}{2}) + (\frac{w_s L^2}{2})$

Factor of safety against overturning = $\frac{3(\gamma_w H + w_s)}{k_{ab}(\gamma_b H + 3w_s)(H/L)^2}$

$$FS = \frac{3(18x8 + 15)}{0.333(18x8 + 45)(8/6)^2} = 4.26 > 2$$

Bearing pressure

Using trapezoidal distribution,

$\sigma_{v\ max}$ = (18 × 8 + 15) + 0.333 × (18 × 8 + 45) $(8/6)^2$ = 159 + 112 = 271 kPa. (< 300 kPa)

Check that contact stresses at the base of reinforced zone are compressive everywhere (i.e. no tension):

$\sigma_{v\ min}$ = 159 – 112 = 47 kPa. (> 0)

$$T = \sigma'_h S_V = K\sigma'_v S_V$$

$$\sigma_v = (\gamma z + w_S) + K_a (\gamma z + 3w_S)(z / L)^2$$

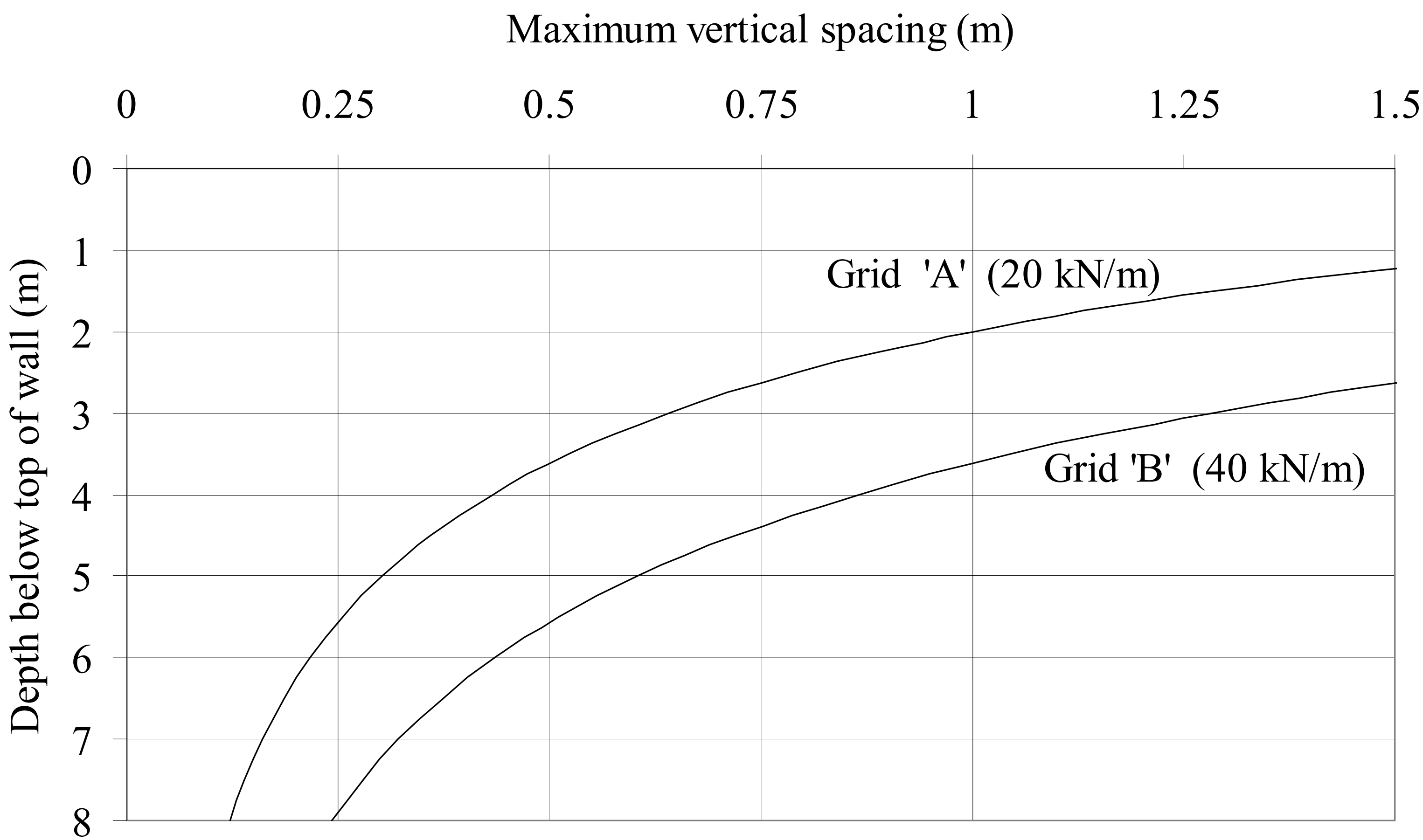
$$T_i = 0.333 \; [(18z + 15) + 0.333\,(18z + 45)\,(z/6)^2]\, S_V$$

$$(S_v)_{max} = \frac{P_d}{0.333\left[(18z+15)+0.333(18z+45)(z/6)^2\right]}$$

Two different grids that are available the use of above equation results in the values presented in the Table.

Maximum spacing of geogrids, $(S_v)_{max}$		
z (m)	Grid A (P_d=20 kN/m)	Grid B (P_d=40 kN/m)
0.5	2.46	4.93
1.0	1.73	3.46
1.5	1.29	2.58
2.0	1.00	2.00
2.5	0.79	1.59
3.0	0.64	1.28
3.5	0.52	1.05
4.0	0.43	0.86
4.5	0.36	0.72
5.0	0.30	0.60
5.5	0.26	0.51
6.0	0.22	0.44
6.5	0.19	0.37
7.0	0.16	0.32
7.5	0.14	0.28
8.0	0.12	0.24

Spacing versus depth plot for grids A and B



Wedge stability check

Select trial wedges at depths, 1 to 8 m below the top of the wall and calculate the total required force T. Carry out check with and without surcharge w_s. For critical wedge angle β = (45^0 - $\phi'_w/2$ = 30^0 for a wedge of height h, the total tension force T is given by

$$T = \frac{h \tan 30^0 \left(18h + 2 \times 15\right)}{2 \tan \left(30^0 + 30^0\right)} = 3h^2 + 5h$$

For a reinforcing layer at depth z below the top of the wall, the pullout resistance is given by

$P_P = 2\,[L - (h - z) \tan \beta] \times (\gamma z + w_s) \times 0.9 \times \tan 30^0 / 2$.

The factor 2 in the numerator denotes the upper and lower surfaces on either side of the geogrid and factor 2 in the denominator refers to the factor of safety.

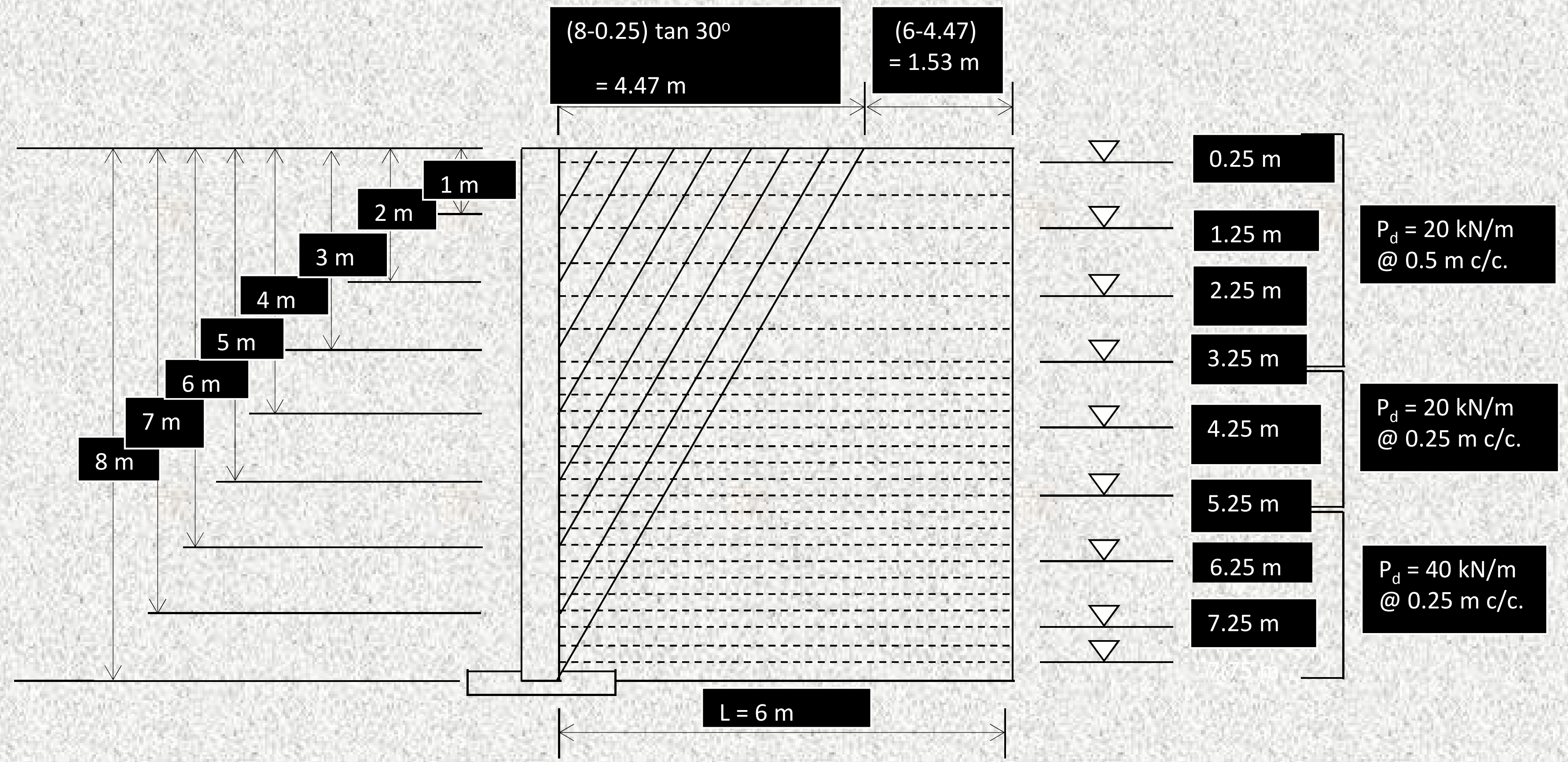
$$P_P = 2\ [6 - (h - z)\ \tan 30^0] \times (18z + 15) \times 0.9 \times \tan 30^0\ /\ 2.$$

For each reinforcement intersected, the available force is taken as the lesser of the pullout resistance P_P and the design tensile strength P_d. For all wedges and both load cases, available force is greater than required force, T. A suitable reinforcement layout is arrived at based on the above considering the thickness of compaction lifts.

Calculation of mobilizing and resisting forces for wedge stability

Wedge Depth (m)	Force to be resisted T (kN/m)		Grids Involved	Design Tensile force, P_d (kN/m)	Pullout resistance P_p (kN/m)		Available force (kN/m) (minimum of P_d & P_p)	
	$w_s = 0$	$w_s = 15$ kPa			$w_s = 0$	$w_s = 15$ kPa	$w_s = 0$	$w_s = 15$ kPa
1	8	3	2A	40	42	16	40	16
2	22	12	4A	80	141	80	80	80
3	42	27	6A	120	318	213	120	120
4	68	48	9A	180	732	548	180	180
5	100	75	13A	260	1495	1189	260	260
6	138	108	15A+2B	380	2538	2092	380	380
7	182	147	15A+6B	540	3905	3301	540	540
8	232	192	15A+10 B	700	5639	4859	700	700

Reinforcement Layout



Provisions of FHWA

Stress transfer mechanisms; Friction, passive resistance

Mode of reinforcement action: Tension is the common mode, Shear and bending in stiff reinforcements are also useful

Pull out tests are useful to assess the performance

Provisions of FHWA

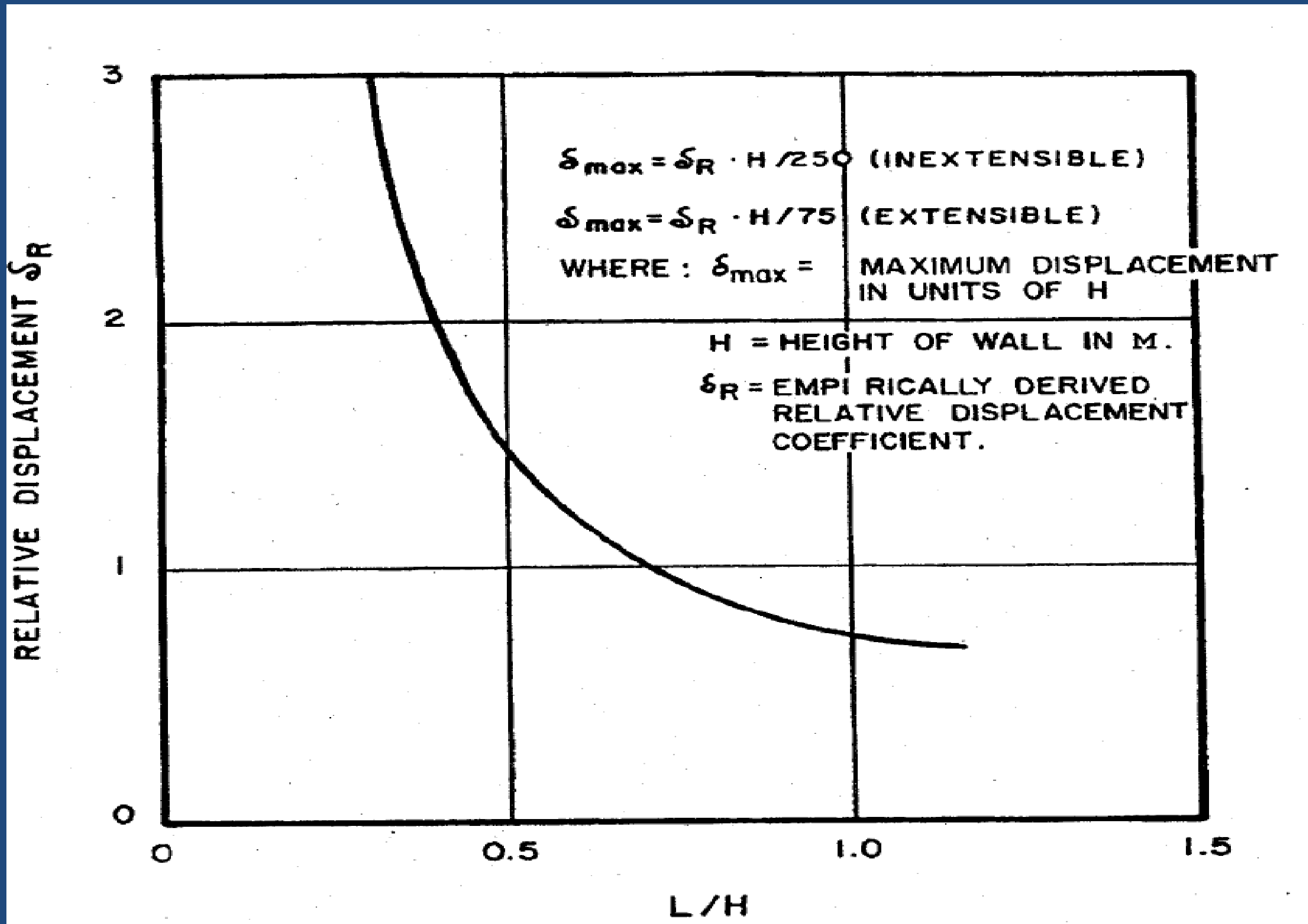
Recommended minimum factors of safety with respect to External failure modes

Sliding	F.S >= 1.5 (MSEW); 1.3 (RSS)
Eccentricity e, at Base	<= L/6 in soil, L/4 in rock
Bearing Capacity	F.S. >= 2.5
Deep Seated Stability	F.S >=1.3
Compound Stability	F.S. >= 1.4
Seismic Stability	F.S. >= 75% of static F.S.

Recommended minimum factors of safety with respect to internal failure modes

Pullout Resistance	F.S. >= 1.5 (MSEW and RSS)
Internal Stability for RSS	F.S >= 1.3
Allowable Tensile Strength	
(a) For steel strip reinforcement	0.55 Fy
(b) For steel grid reinforcementpanels	0.48 Fy (connected to concrete Panels or blocks)

A number of reduction factors considering damage, environmental conditions, long terms strength requirements etc. (total factor = 7)



Empirical curve for estimating probable anticipated lateral displacement during construction for MSE walls

Recommended backfill requirements for MSE & RSS construction

U.S Sieve Size	% Passing
For MSE Walls (PI less than 6)	
102 mm	100
0.425 mm	0-60
0.075 mm	0-15
Cu ≥ 4	
For RS slopes For MSE Walls (PI less than 20)	
20mm	100
4.76mm	100-20
0.425mm	0-60
0.075mm	0-50

Recommended backfill requirements for MSE & RSS construction

- The material shall be free of shale or other soft, weak particles, organic matter etc
- Light compaction shall be used close to the wall proximity,
- Good backfill in terms of friction and drainage (crushed stone) may be used in the backfill next to wall facings.
- Backfill compaction should be based on 95% density and ± 2% of optimum M.C. (AASHTO T 99: Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5-kg Rammer and a 305-mm drop.
- Peak shear strength parameters, a minimum friction angle of 34^{o} shall be adopted.

Recommended limits of electrochemical properties for backfills when using steel reinforcement

Property	Criteria	Test Method
Resistivity	>3000 ohm-cm	AASHTO
pH	>5<10	AASHTO
Chlorides	<100 PPM	AASHTO
Sulfates	<200 PPM	AASHTO
Organic Content	1% max	AASHTO

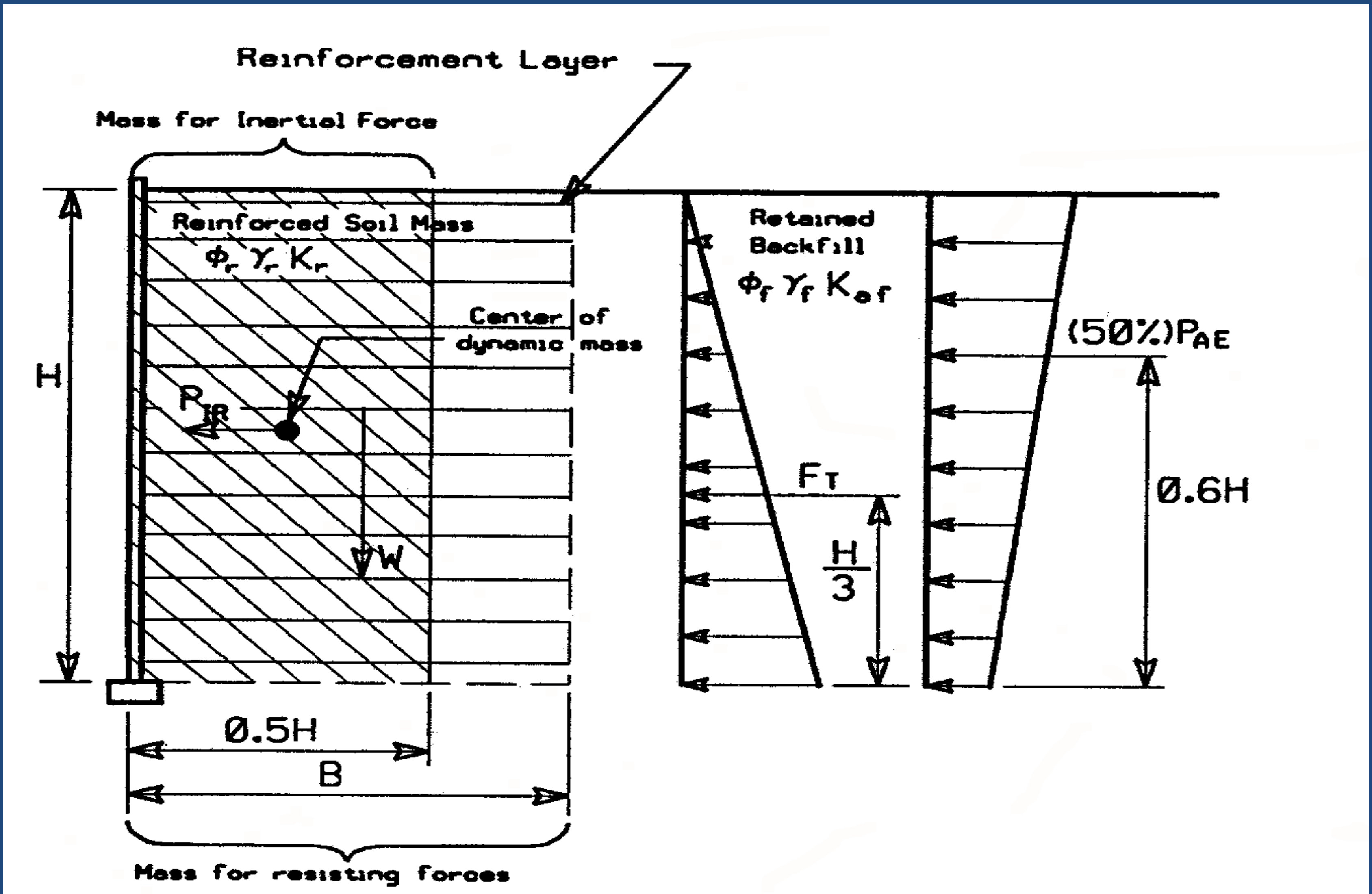
Corrosion rates and allowances specified in codes shall be followed.

Retained fill

- Engineering properties of retained fill, position of water table need to be evaluated. These properties are required for global stability evaluation.

Stability under earthquake conditions

- During an earthquake, the retained fill exerts a dynamic horizontal thrust, P_{AE}, on the MSE wall in addition to the static thrust. The reinforced soil mass is also subjected to a horizontal inertia force $P_{IR} = M\ A_m$, where M is the mass of the active portion of the reinforced wall section assumed at a base width of 0.5H, and A_m is the maximum horizontal acceleration in the reinforced soil wall.
- Force P_{AE} can be evaluated by the pseudo-static Mononobe-Okabe analysis and added to the static forces acting on the wall (weight, surcharge, and static thrust). The dynamic stability with respect to external stability is then evaluated. Allowable minimum dynamic safety factors are assumed as 75 percent of the static safety



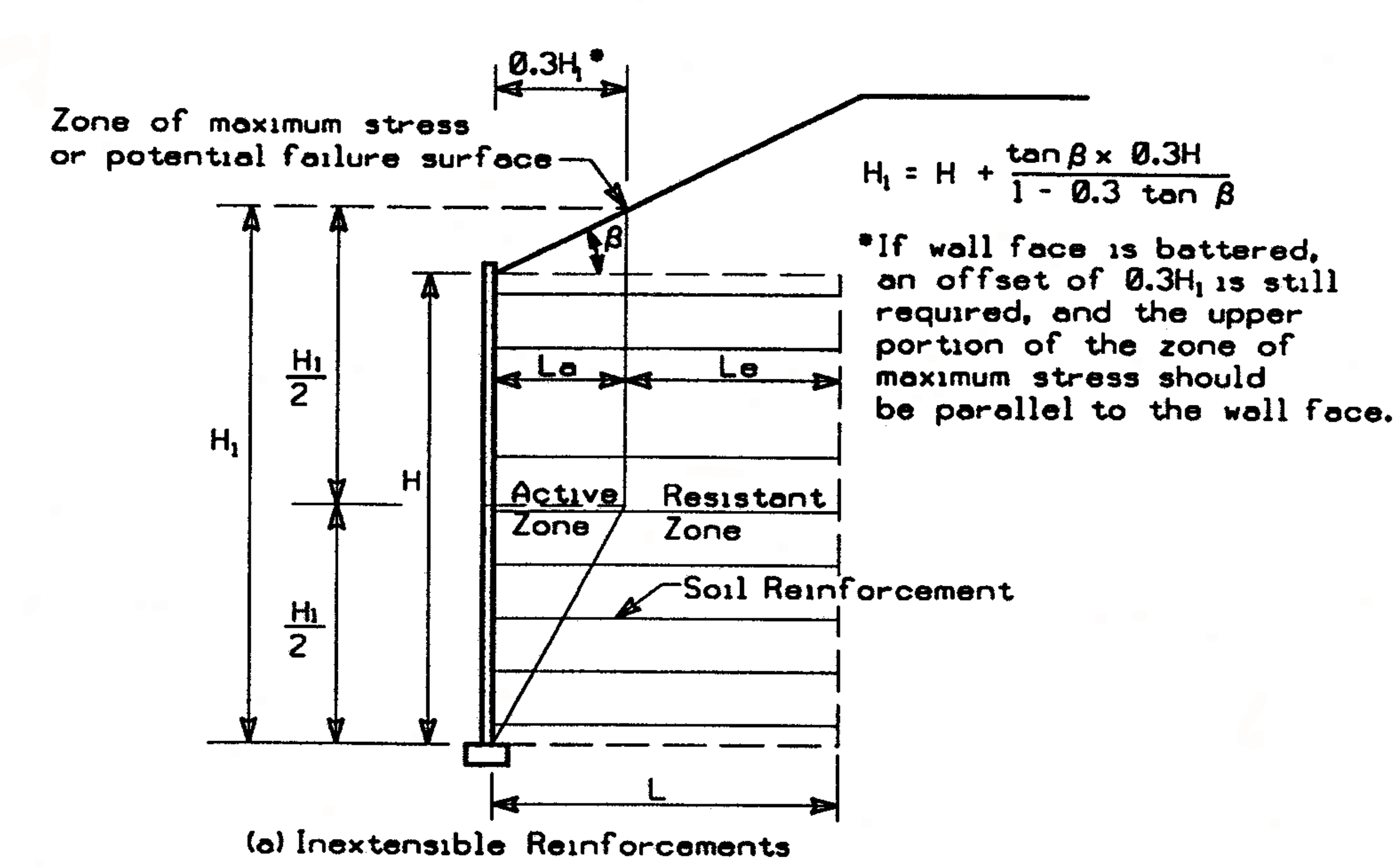
Seismic external stability of a MSE wall under level backfill condition

- Select a horizontal ground acceleration (A) based on design earthquake
- Calculate maximum acceleration (A_m) developed in the wall using $A_m = (1.45 - A)A$
- Calculate the horizontal inertial force (P_{IR}) and the seismic thrust (P_{AE}) using

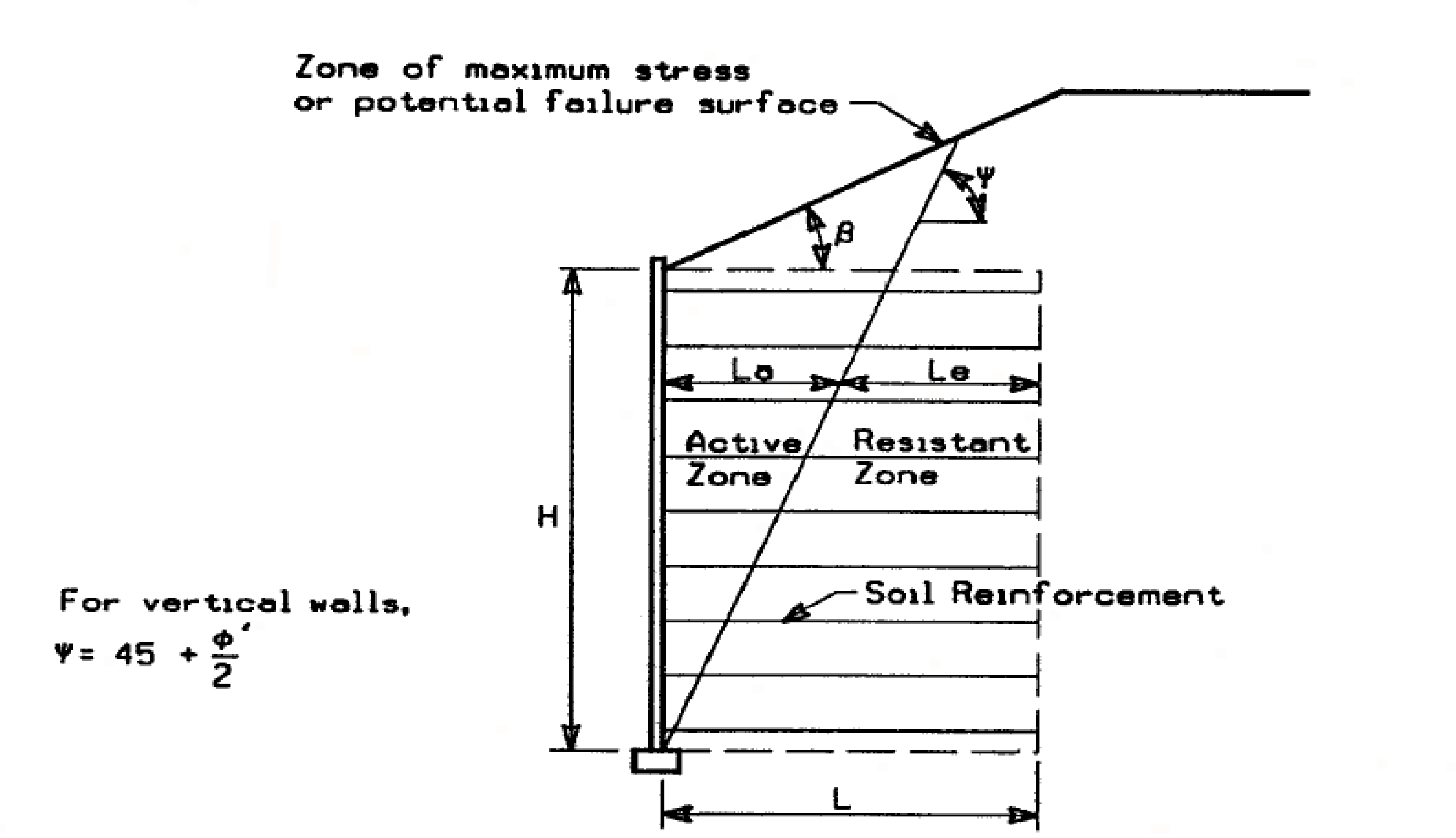
$$P_{IR} = 0.5\ A_m\ \gamma_r\ H^2$$

$$P_{AE} = 0.375\ A_m\ \gamma_f\ H^2$$

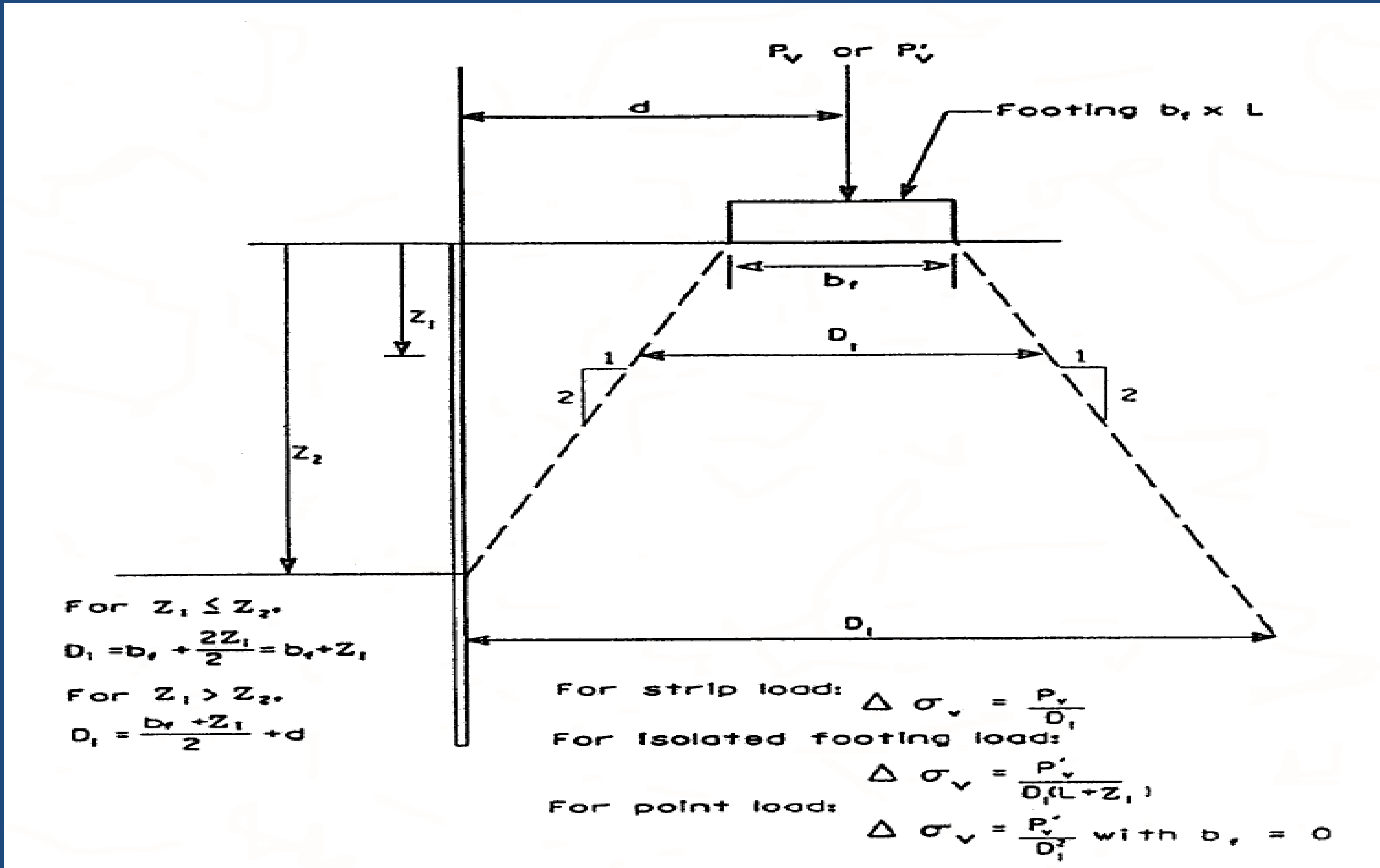
Add to static force acting on the structure, 50% of the seismic thrust P_{AE} and the full inertial; force as both forces do not act simultaneously



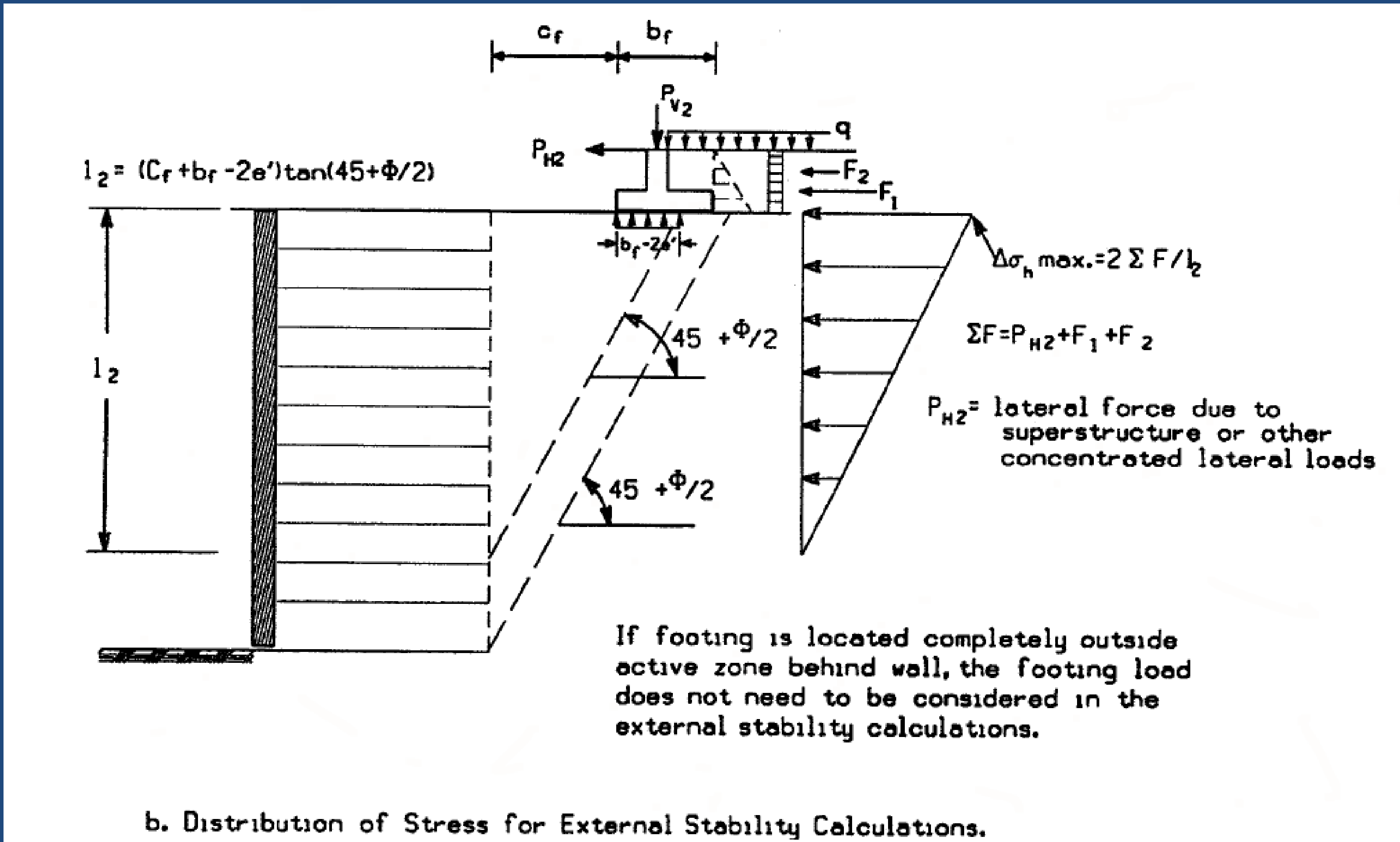
Location of potential failure surface for internal stability design of MSE walls



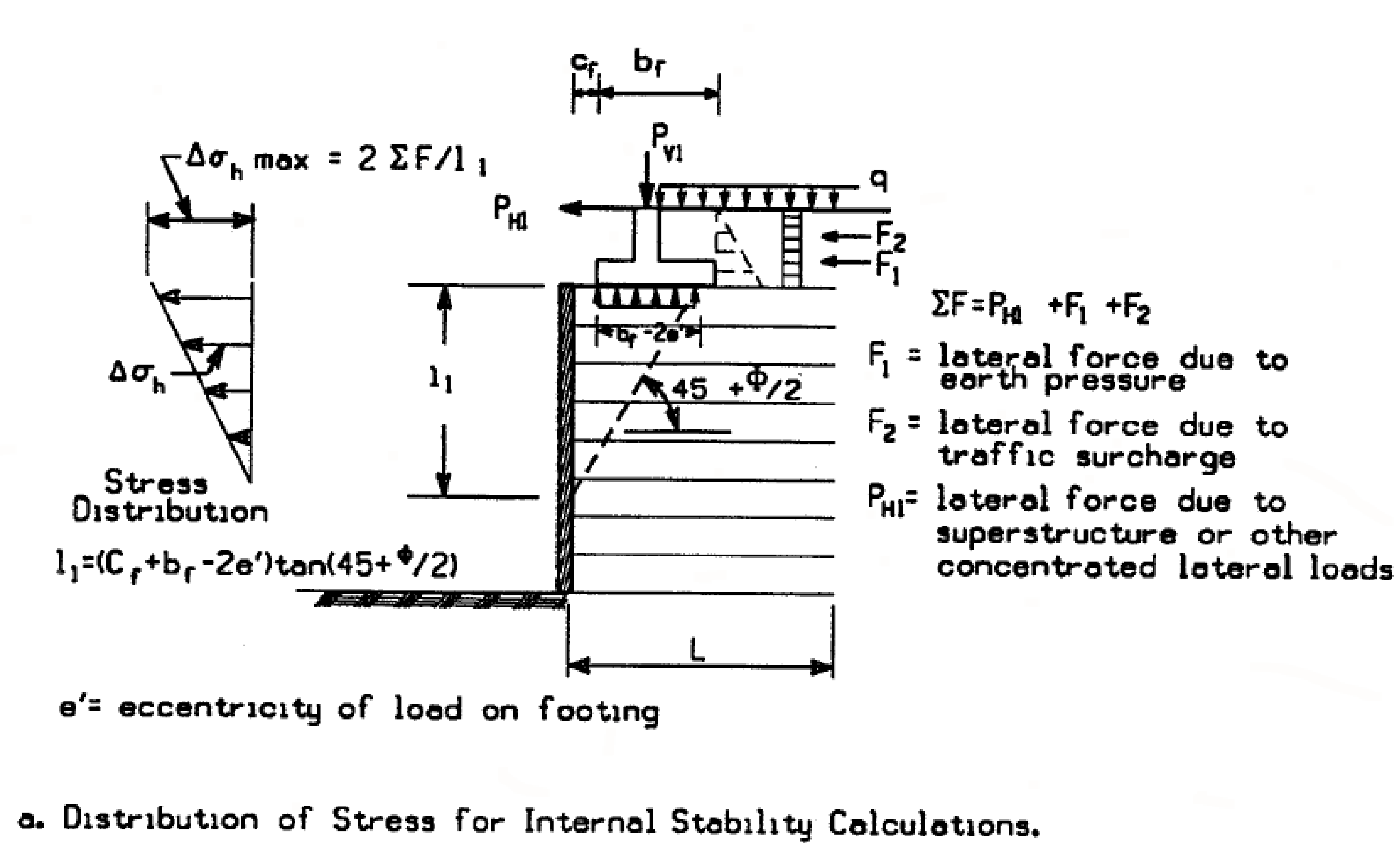
Location of potential failure surface for internal stability design of MSE walls for extensible reinforcement



Distribution of stress from concentrated vertical load P_v for internal and external stability calculations.

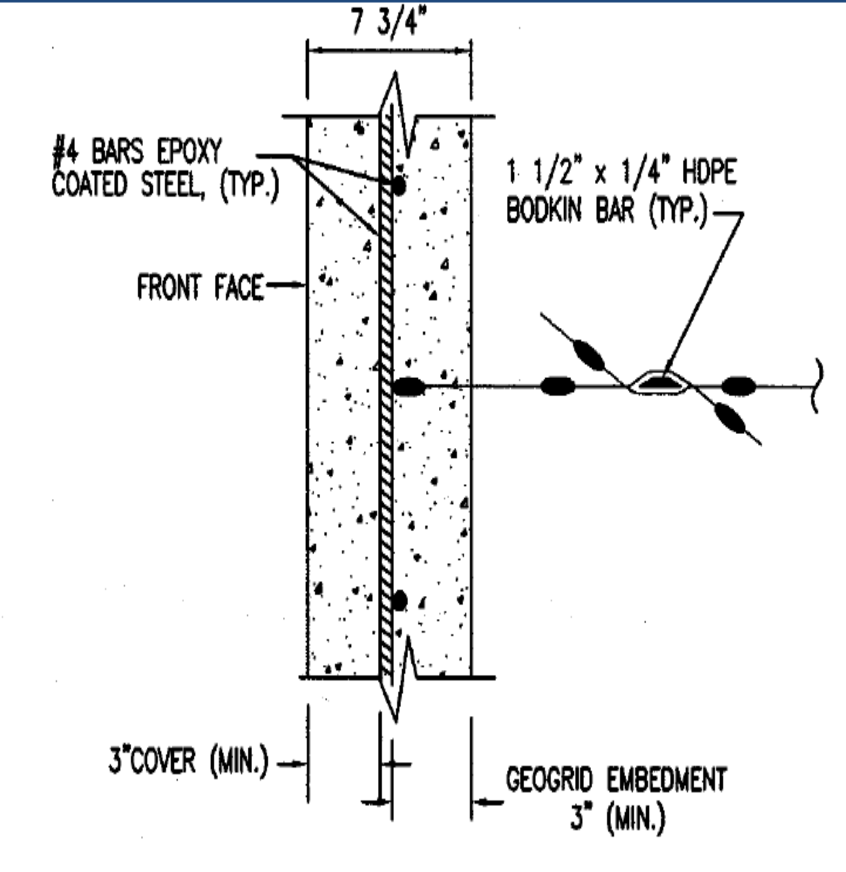


Distribution of stresses from concentrated horizontal loads for external stability.

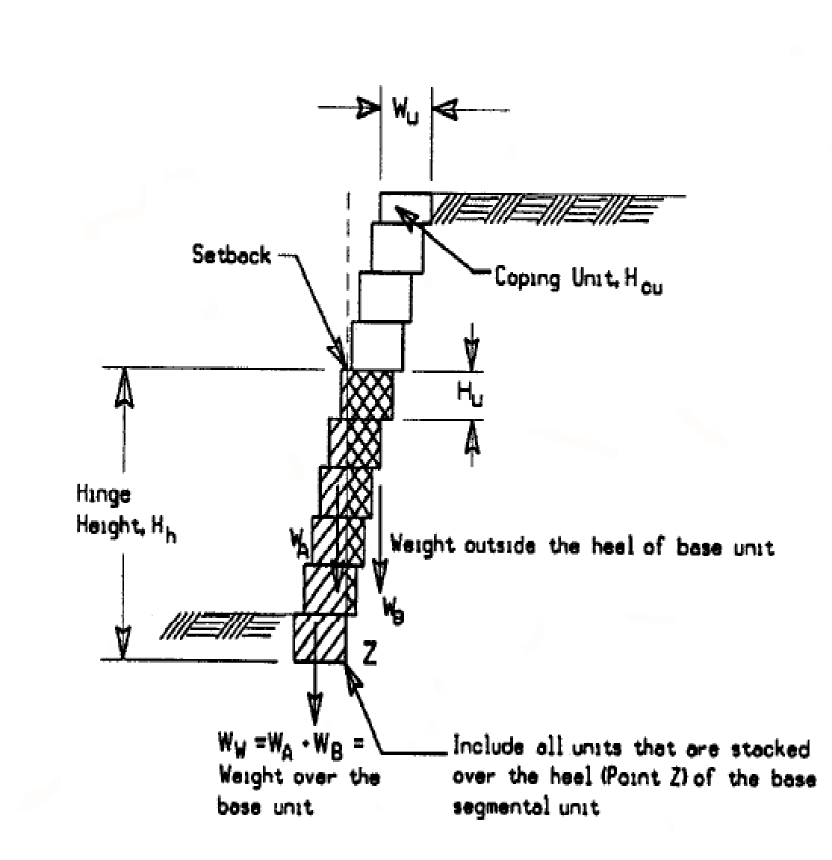


Distribution of stresses from concentrated horizontal loads for internal stability.

- Additional horizontal stress due to earthquake needs to be calculated and tensile force needs to be evaluated.
- Connection strength issues need to be properly addressed.



7 3/4"
#4 BARS EPOXY COATED STEEL, (TYP.)
FRONT FACE
1 1/2" x 1/4" HDPE BODKIN BAR (TYP.)
3"COVER (MIN.)
GEOGRID EMBEDMENT 3" (MIN.)



Wu
Setback
Coping Unit, Hcu
Hu
Hinge Height, Hh
WA
Weight outside the heel of base unit
WB
Z
WW = WA + WB = Weight over the base unit
Include all units that are stacked over the heel (Point Z) of the base segmental unit

Concluding remarks

- Reinforced retaining walls have evolved as viable technique and contributed to infrastructure in terms of speed, ease of construction, economy, aesthetics etc.
- It is a technology that needs to be understood well in terms of its response, construction features etc. Failures of RE walls have also been noted in a few places due to lack of understanding of behavour of RE walls.
- FWHA, NCMA guidelines need to be studied in detail for seismic stability and deformation issues.

THANK YOU