Western Bridge Engineers' Seminar

PRACTICAL SOLUTIONS TO
BRIDGE ENGINEERING CHALLENGES

September 9–11, 2015 | Peppermill Hotel | Reno, Nevada

SESSION -8B

Significant Changes in Design and Construction Cost of Earth Retaining Structures Caused By Recent Changes to AASHTO LRFD Design Criteria

Authors:

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AECOM

OUTLINE

- Geometry & Cost Comparison ASD/LRFD
- LRFD Design Method – Strength & Service
- LRFD Design Method – Seismic
- Limitations on Design Approach
- Summary of AASHTO LRFD Changes 2007-2014
- Conclusion

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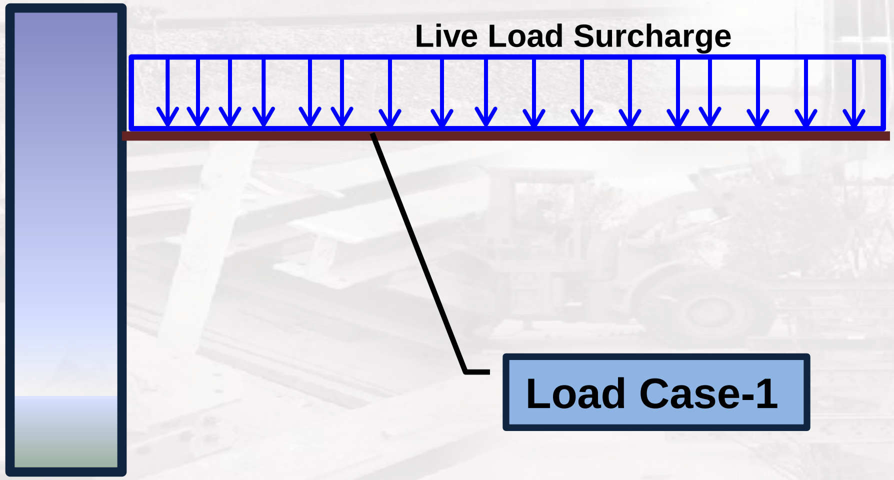
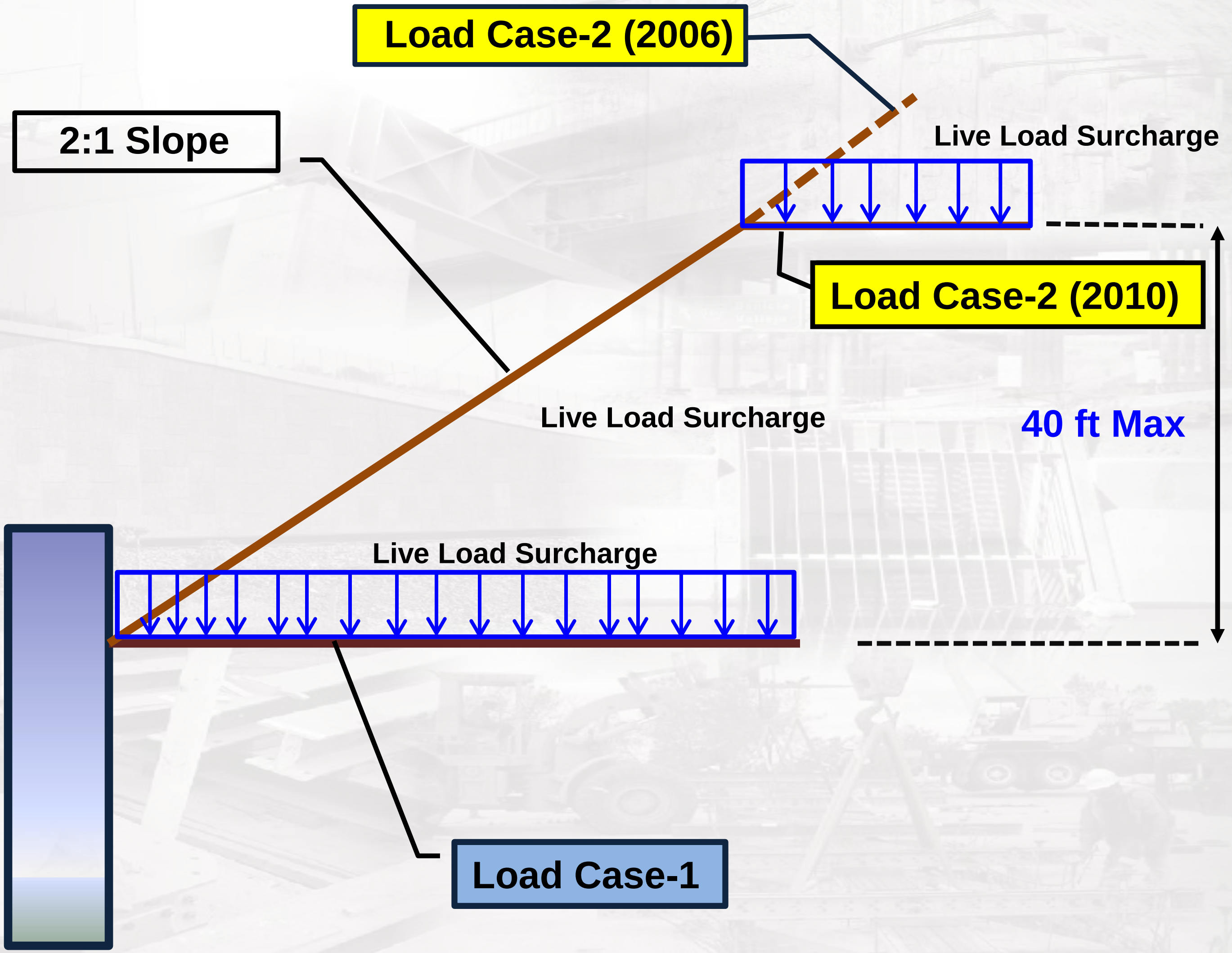
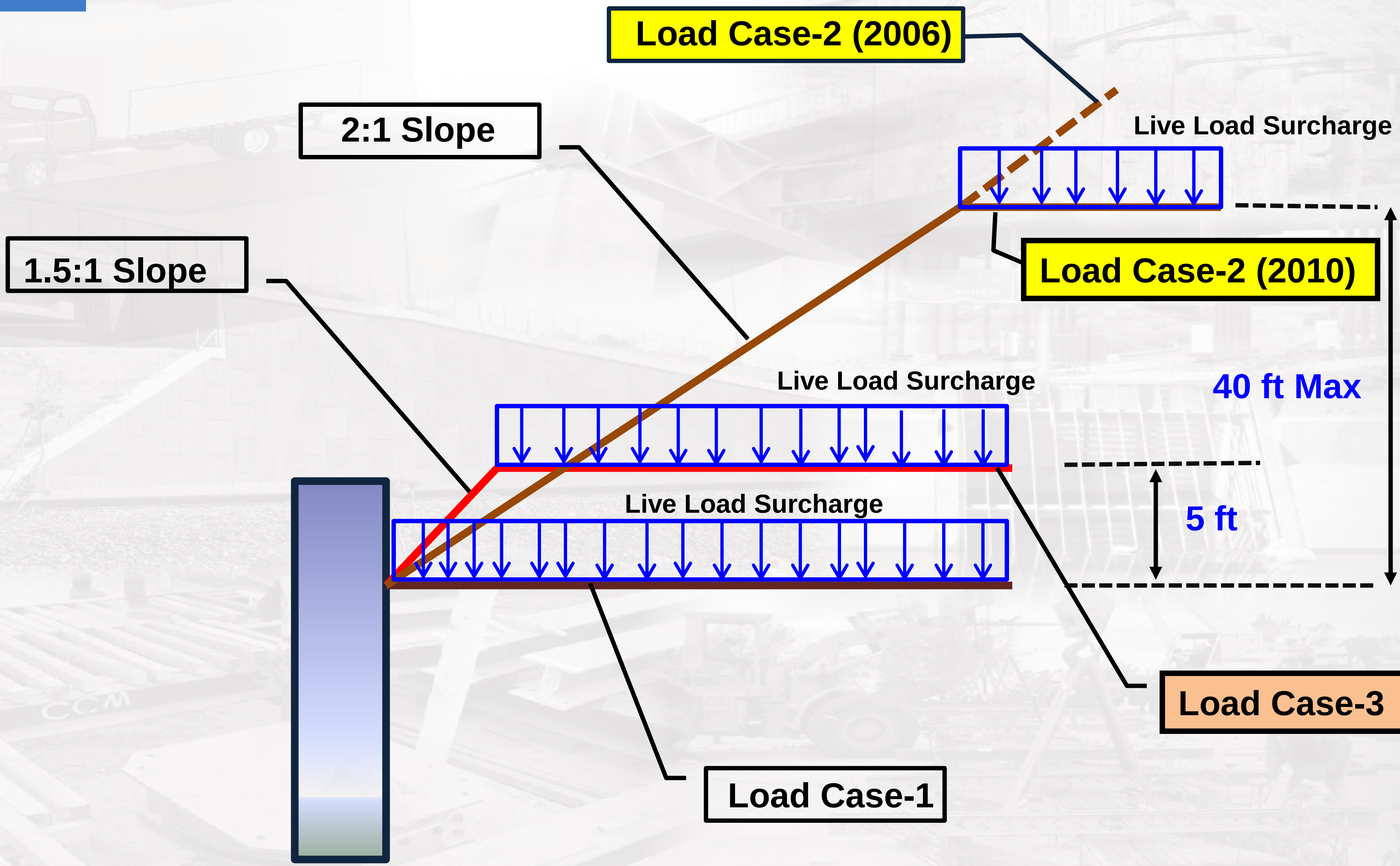
Caltrans Typical Load Cases



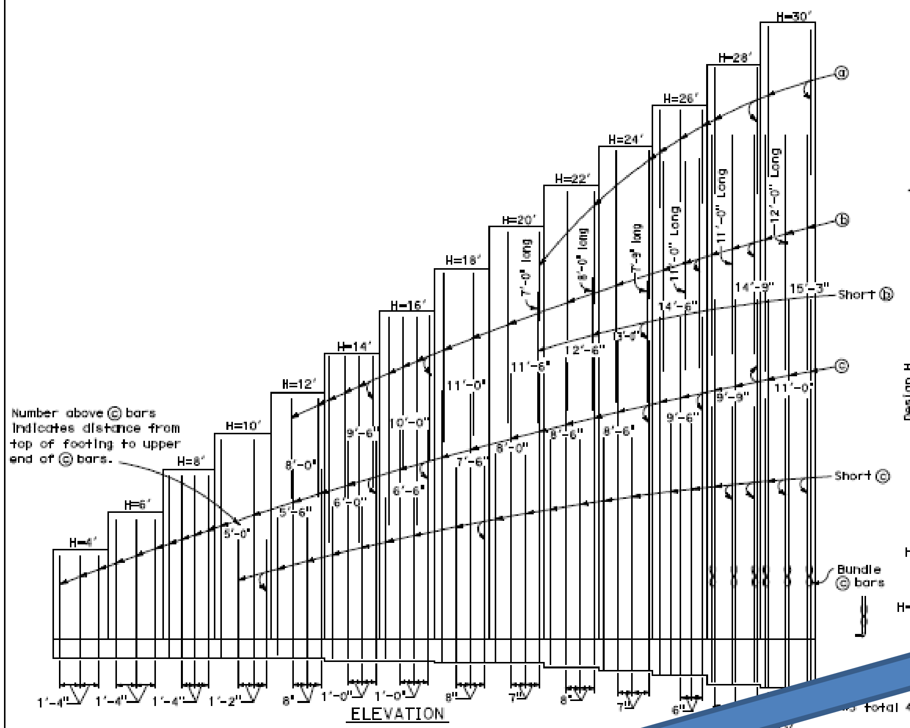
Caltrans Typical Load Cases



CALTRANS TYPICAL LOAD CASES



CALTRANS STD PLANS 2006



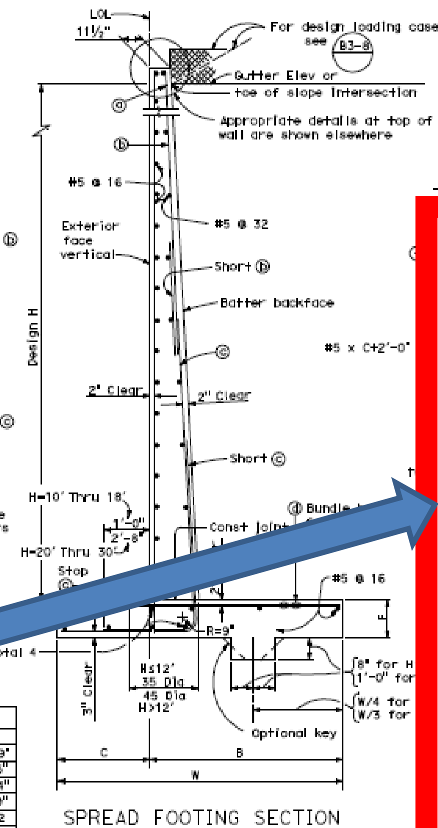


TABLE OF REINFORCING STEEL AND DATA															
Design H		4'	6'	8'	10'	12'	14'	16'	18'	20'	22'	24'	26'	28'	30'
W		3'-3"	4'-3"	5'-3"	[illegible]	[illegible]	[illegible]	9'-0"	10'-0"	11'-0"	12'-1"	13'-3"	14'-3"	15'-3"	16'-9"
C		1'-0"	1'-4"	[illegible]	[illegible]	[illegible]	2'-7"	2'-11"	3'-3"	3'-7"	3'-11"	4'-5"	4'-9"	5'-1"	5'-5"
B		2'-3"	[illegible]	[illegible]	[illegible]	4'-11"	5'-5"	6'-1"	6'-9"	7'-5"	8'-2"	8'-10"	9'-6"	10'-2"	11'-4"
F		1'-4"	[illegible]	[illegible]	1'-4"	1'-4"	1'-6"	1'-6"	1'-6"	1'-6"	1'-8"	1'-10"	2'-2"	2'-6"	2'-9"
Batter		½:12	[illegible]	½:12	½:12	½:12	½:12	½:12	½:12	½:12	½:12	⅝:12	¾:12	¾:12	⅞:12
ⓐ bars		—	—	—	—	—	—	—	—	#5 @ 28	#5 @ 32	#5 @ 28	#5 @ 12	#5 @ 20	#8 @ 20
ⓑ bars		—	—	—	—	#5 @ 16	#5 @ 12	#5 @ 12	#6 @ 16	#8 @ 14	#8 @ 16	#8 @ 14	#8 @ 12	#8 @ 10	#9 @ 10
ⓒ bars		#5 @ 16	#5 @ 16	#5 @ 16	#6 @ 14	#6 @ 8	#8 @ 12	#9 @ 12	#9 @ 8	#9 @ 7	#11 @ 8	#11 @ 7	#11 @ 6	#11 @ 10	#11 @ 10
ⓓ bars		#5 @ 16	#5 @ 16	#5 @ 16	#5 @ 14	#5 @ 8	#8 @ 12	#9 @ 12	#9 @ 8	#9 @ 7	#11 @ 8	#11 @ 7	#11 @ 6	#11 @ 10	#11 @ 10
Total ⓔ bars		6-#6	6-#6	6-#6	12-#6	12-#6	12-#6	12-#6	8-#6	8-#6	8-#6	6-#6	6-#6	6-#6	6-#6
Total ⓕ bars		—	—	—	6-#6	6-#6	6-#6	6-#6	6-#6	6-#6	6-#6	4-#5	4-#5	4-#5	4-#5
Loading Case I	Toe Pressure ksf	1.7	1.9	2.2	2.5	2.8	3.3	3.5	4.0	4.3	4.6	4.9	5.3	5.7	6.3
Loading Case II	Toe Pressure ksf	1.1	1.5	2.0	2.3	2.7	3.3	3.7	4.2	4.7	5.5	6.0	6.5	7.1	7.5
Loading Case III	Toe Pressure ksf	1.4	1.7	2.1	2.5	2.9	3.4	3.8	4.3	4.8	5.4	5.8	6.5	7.2	7.5

Ⅱ Denotes a bundle of 2 bars

Design H		4'
W		3'-3"
C		1'-0"
B		2'-3"
F		1'-4"
Batter		½:12
ⓐ bars		—
ⓑ bars		—
ⓒ bars		#5 @ 16
ⓓ bars		#5 @ 16
Total ⓔ bars		6-#6
Total ⓕ bars		—
Loading Case I	Toe Pressure ksf	1.7
Loading Case II	Toe Pressure ksf	1.1
Loading Case III	Toe Pressure ksf	1.4

NOTES:

1. For details not shown and drainage notes see B3-8
2. For wall stem joint details see B0-3 3-3 and B0-3 3-4
3. For pile footing for design H=4' use same footing dimensions as for design H=6'.

REGISTERED CIVIL ENGINEER

May 1, 2006

PLANS APPROVAL DATE

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

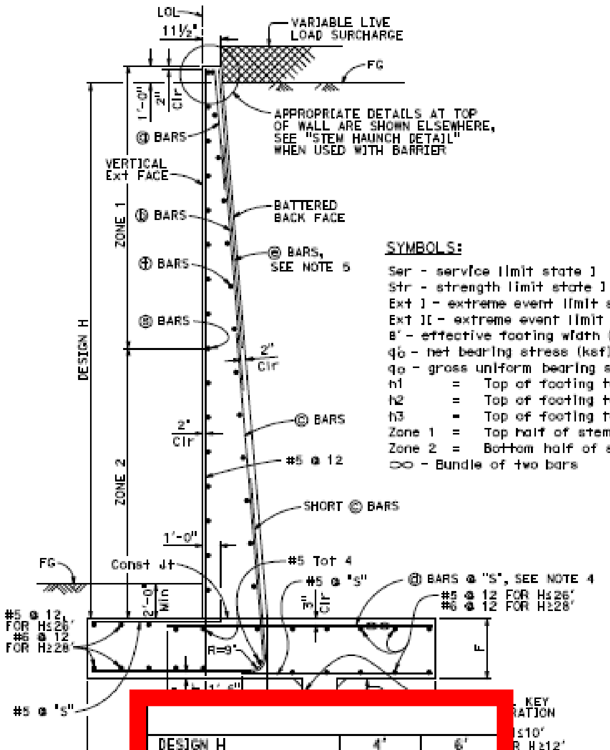
RETAINING WALL TYPE 1 H=4' THROUGH 30'

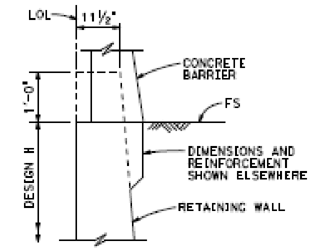
NO SCALE

B3-1

2006 STANDARD PLAN B3-1

CALTRANS STD PLANS 2010





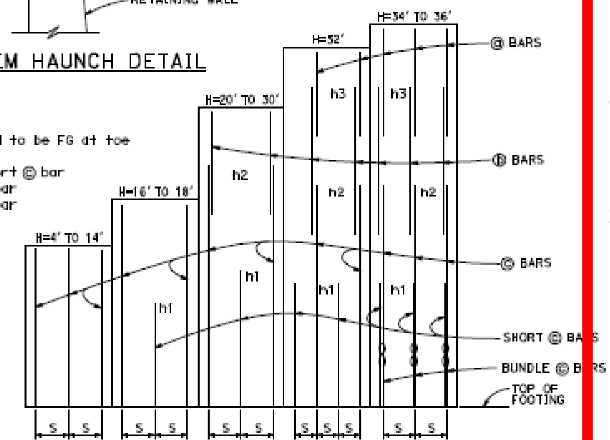
STEM HAUNCH DETAIL

DESIGN CONDITIONS:

Design H may be exceeded by 6" before going to the next size. Special footing design is required where foundation material is incapable of supporting bearing stress listed in the table.

SYMBOLS:

Ser - service limit state I
Str - strength limit state I
Ext I - extreme event limit state I
Ext II - extreme event limit state II
B' - effective footing width (ft)
q'o - net bearing stress (ksf), OG assumed to be FG at toe
qo - gross uniform bearing stress (ksf)
h1 = Top of footing to top of short Ⓒ bar
h2 = Top of footing to top of Ⓖ bar
h3 = Top of footing to top of Ⓗ bar
Zone 1 = Top half of stem height
Zone 2 = Bottom half of stem height
⊃○ - Bundle of two bars



ELEVATION

Dist	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET No.	TOTAL SHEETS

REGISTERED CIVIL ENGINEER

April 20, 2012

PLANS APPROVAL DATE

THE STATE OF CALIFORNIA OR ITS OFFICERS OR AGENTS SHALL NOT BE RESPONSIBLE FOR THE ACCURACY OR COMPLETENESS OF SCANNED COPIES OF THIS PLAN SHEET.

DESIGN NOTES: TO ACCOMPANY PLANS DATED ____

DESIGN: AASHTO LRFD Bridge Design Specifications, 4th Edition with California Amendments

LS: Varied surcharge on level ground surface

DC: Stem Architectural Treatment of thickness up to 6" of concrete (75 psf) considered

CT: 54 kip transverse force applied at He = 32", distributed over 10 feet at the top of wall and 1 : 1 distribution down and outward. Distribution below footing taken no less than 40'.

SEISMIC: k_h = 0.2, k_v = 0.0

SOIL: ϕ = 34°, γ = 120 pcf

REINFORCED CONCRETE: f'_c = 3,600 psi, f_y = 60,000 psi

LOAD COMBINATIONS AND LIMIT STATES:

- Service I: Q = 1.00DC+1.00EV+1.00EH+1.00LS
- Strength I: Q = αDC+βEV+ηEH+1.75LS
- Extreme I: Q = 1.00DC+1.00EV+1.00EH+1.00EQD+1.00EQE
- Extreme II: Q = 1.00DC+1.00EV+1.00EH+1.00CT

Where:

- Q: Force Effects
- α: 1.25 or 0.90, Whichever Controls Design
- β: 1.35 or 1.00, Whichever Controls Design
- η: 1.50 or 0.90, Whichever Controls Design
- DC: Dead Load of Structure Components
- EH: Horizontal Earth Fill Pressure
- EV: Vertical Earth Pressure from Earth Fill Weight
- LS: Live Load Surcharge
- EQE: Seismic Earth Pressure
- EQD: Soil and Structural and Nonstructural Components Inertia
- CT: Vehicular Collision Force

NOTES:

1. For det...
2. For wal...
3. At Ⓒ bar... H ≤ 6'... above... H > 6'... above
4. Bundle Ⓓ...
5. Provide... measure... location... bar leng...

KEY ...RATION ...≤10' ...R H≥12'

DESIGN H	4'	6'
W	6'-10"	7'-0"
C	2'-2"	2'-3"
B	4'-8"	4'-9"
F	1'-4"	1'-4"
BATTER	½: 12	½: 12
SPACING "S"	9"	9"
Ⓓ BARS	-	-
Ⓗ BARS	-	-
Ⓒ BARS	#6	#6
Ⓖ BARS	#5	#5
h1	-	-
h2	-	-
h3	-	-
ZONE 1 Ⓢ BARS	#5 @ 18	#5 @ 18
ZONE 2 Ⓢ BARS	#5 @ 18	#5 @ 18
ZONE 1 Ⓕ BARS	#4 @ 18	#4 @ 18
ZONE 2 Ⓕ BARS	#4 @ 18	#4 @ 18
Ser: B', q'o	6.8, 0.7	6.5, 1.0
Str: B', qo	6.6, 1.6	5.0, 1.8
Ext I: B', qo	5.2, 1.1	4.7, 1.5
Ext II: B', qo	2.6, 2.2	2.7, 2.6

TABLE OF REINFORCING STEEL, DIMENSIONS AND DATA

DESIGN H	4'	6'	8'	10'	12'	14'	16'	18'	20'	22'	24'	26'	28'	30'	32'	34'	36'
W	6'-10"	7'-0"	7'-3"	7'-7"	8'-4"	9'-7"	10'-9"	12'-0"	13'-3"	14'-6"	15'-9"	17'-1"	18'-5"	19'-10"	21'-2"	22'-7"	24'-0"
C	2'-2"	2'-3"	2'-3"	2'-4"	2'-6"	3'-0"	3'-6"	4'-0"	4'-6"	5'-0"	5'-5"	6'-0"	6'-6"	7'-2"	7'-8"	8'-2"	9'-0"
B	4'-8"	4'-9"	5'-0"	5'-3"	5'-10"	6'-7"	7'-3"	8'-0"	8'-9"	9'-6"	10'-4"	11'-1"	11'-11"	12'-8"	13'-6"	14'-5"	15'-0"
F	1'-4"	1'-4"	1'-4"	1'-4"	1'-6"	1'-8"	1'-8"	1'-9"	1'-9"	1'-11"	2'-2"	2'-5"	2'-10"	3'-3"	3'-6"	4'-0"	4'-3"
BATTER	½: 12	½: 12	½: 12	½: 12	½: 12	½: 12	½: 12	½: 12	½: 12	½: 12	⅝: 12	⅝: 12	¾: 12	⅞: 12	1 : 12	1 : 12	1 : 12
SPACING "S"	9"	9"	9"	9"	9"	7"	6"	5"	6"	6"	6"	6"	6"	6"	6"	10"	8"
Ⓓ BARS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#7	#7	#6
Ⓗ BARS	-	-	-	-	-	-	-	-	#7	#7	#7	#7	#7	#7	#9	#9	#8
Ⓒ BARS	#6	#6	#6	#6	#6	#6	#7	#7	#8	#9	#9	#10	#10	#10	#11	#11	#11
Ⓖ BARS	#5	#5	#6	#6	#6	#6	#9	#8	#8	#9	#9	#10	#10	#10	#11	#11	#11
h1	-	-	-	-	-	-	5'-9"	5'-10"	8'-0"	9'-0"	10'-1"	11'-0"	12'-1"	13'-0"	13'-0"	12'-7"	11'-6"
h2	-	-	-	-	-	-	-	-	10'-5"	13'-0"	14'-7"	17'-6"	19'-0"	20'-5"	19'-0"	18'-0"	20'-2"
h3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21'-2"	21'-10"	24'-0"
ZONE 1 Ⓢ BARS	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12
ZONE 2 Ⓢ BARS	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 18	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12	#5 @ 12	#6 @ 12	#6 @ 12	#6 @ 12	#7 @ 12	#7 @ 12
ZONE 1 Ⓕ BARS	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 18	#4 @ 12	#4 @ 12	#4 @ 18	#4 @ 12	#4 @ 12	#4 @ 12	#4 @ 12
ZONE 2 Ⓕ BARS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ser: B', q'o	6.8, 0.7	6.5, 1.0	6.2, 1.3	6.0, 1.6	6.3, 2.0	7.5, 2.1	8.6, 2.2	9.8, 2.3	11.0, 2.4	12.1, 2.5	13.2, 2.8	14.4, 2.9	15.5, 3.1	16.8, 3.3	18.0, 3.5	19.2, 3.7	20.6, 3.7
Str: B', qo	6.6, 1.6	5.0, 1.8	3.6, 2.3	3.0, 3.3	3.2, 4.0	4.3, 3.8	5.3, 3.7	6.4, 3.7	7.4, 3.8	8.2, 4.1	9.0, 4.4	9.9, 4.6	10.7, 4.9	11.7, 5.2	12.6, 5.4	13.6, 5.8	14.6, 5.9
Ext I: B', qo	5.2, 1.1	4.7, 1.5	3.9, 2.2	3.1, 3.4	2.8, 4.8	3.2, 5.3	3.6, 5.7	4.1, 6.1	4.6, 6.4	5.0, 6.9	5.3, 7.6	5.8, 8.1	6.1, 8.9	6.7, 9.4	7.1, 10.0	7.5, 10.7	8.2, 10.9
Ext II: B', qo	2.6, 2.2	2.7, 2.6	2.8, 5.1	2.9, 3.6	3.7, 3.6	5.2, 3.3	6.7, 3.1	8.3, 3.0	9.8, 3.0	11.2, 3.1	12.5, 3.2	13.9, 3.4	15.2, 3.6	16.7, 3.8	18.0, 4.0	19.3, 4.2	20.8, 4.3

DEPARTMENT OF TRANSPORTATION

RETAINING WALL TYPE 1 (CASE 1)

NO SCALE

RSP B3-1A DATED APRIL 20, 2012 SUPPLEMENTS THE STANDARD PLANS BOOK DATED 2010.

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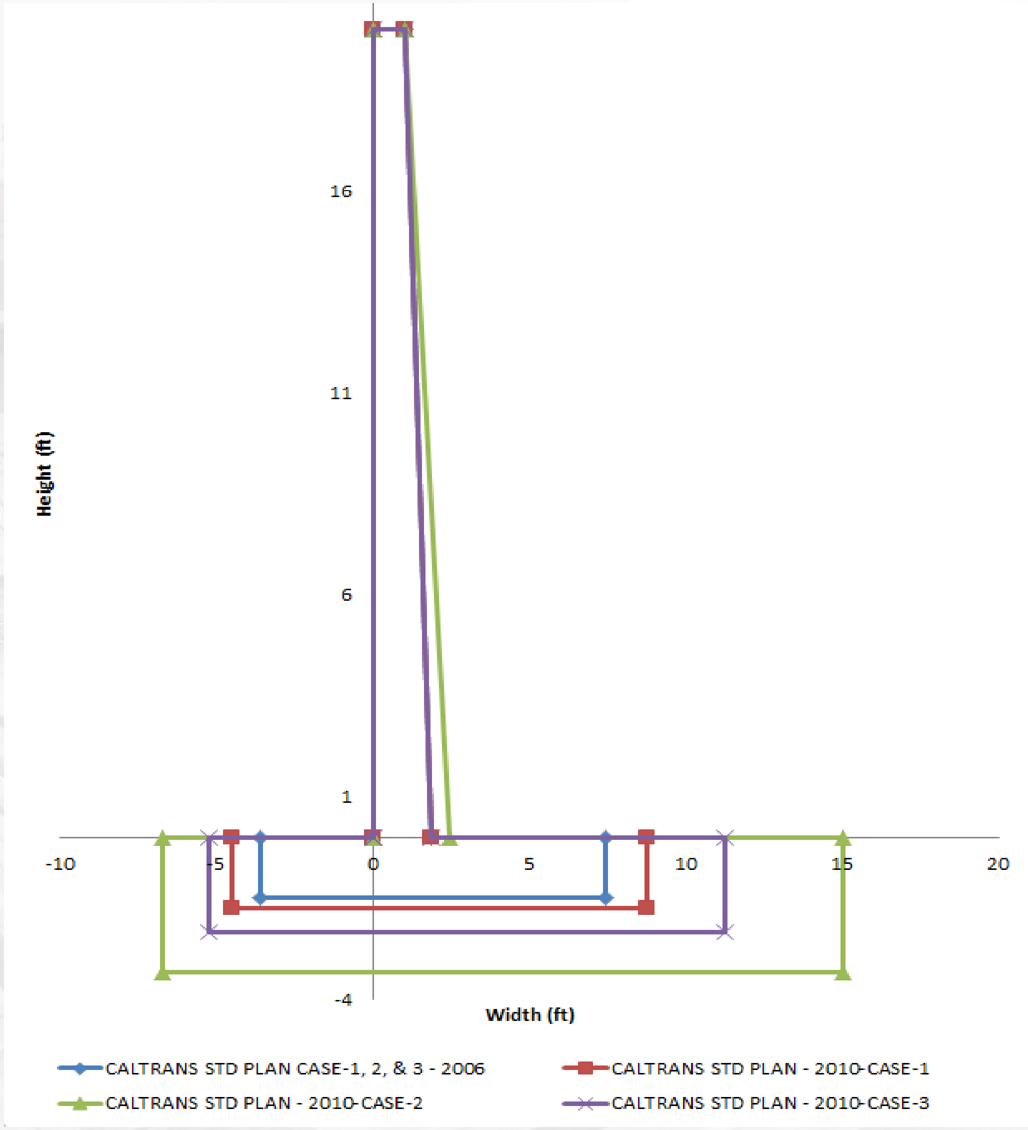
GEOMETRY COMPARISION CALTRANS STD PLANS 2006 vs 2010

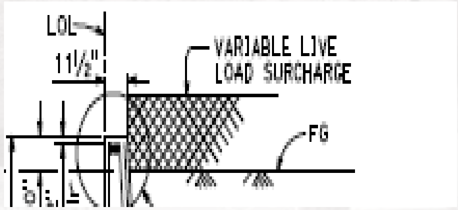
AECOM

Description	CALTRANS STD PLAN			
	2006 All Load Cases	2010 Load Case-1	2010 Load Case-2	2010 Load Case-3
H - Height -ft	20.00	20.00	20.00	20.00
W -Footing Width -ft	11.00	13.25	21.75	16.50
T -Wall Top -ft	1.00	1.00	1.00	1.00
Batter (1: xx)	½:12	½:12	5/8:12	½:12
F -Footing thickness -ft	1.50	1.75	3.33	2.33
C -Toe to Back Face -ft	3.58	4.50	6.75	5.25

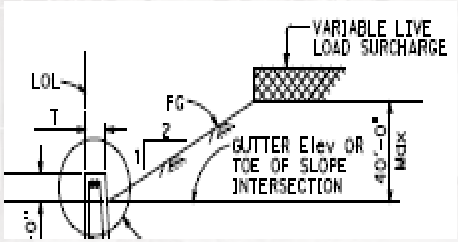
GEOMETRY COMPARISION ASD/LRFD – CALTRANS STD PLANS 2006 vs 2010



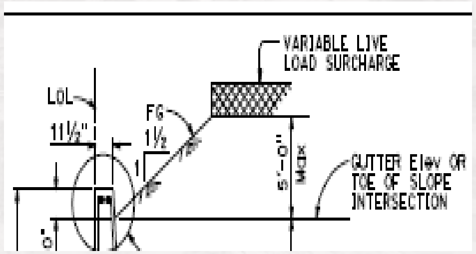
LOAD CASE - 1



LOAD CASE - 2



LOAD CASE - 3



Western Bridge Engineers' Seminar

QUANTITY & COST COMPARISION ASD/LRFD – CALTRANS STD PLANS 2006 vs 2010

AECOM

EXCAVATION PER LINEAR FT OF RETAINING WALL				
Description	CALTRANS STD PLAN			
	2006 All Load Cases	2010 Load Case-1	2010 Load Case-2	2010 Load Case-3
Excavation - CY	46.00	58.00	127.00	81.00
Increase - %	0 %	26 %	178 %	76 %

BACKFILL PER LINEAR FT OF RETAINING WALL				
Description	CALTRANS STD PLAN			
	2006 All Load Cases	2010 Load Case-1	2010 Load Case-2	2010 Load Case-3
Backfill - CY	26.00	31.00	50.00	38.00
Increase - %	0 %	20 %	95 %	50 %

Western Bridge Engineers' Seminar

AECOM

QUANTITY & COST COMPARISION ASD/LRFD – CALTRANS STD PLANS 2006 vs 2010

CONCRETE PER LINEAR FT OF RETAINING WALL				
Description	CALTRANS STD PLAN			
	2006 All Load Cases	2010 Load Case-1	2010 Load Case-2	2010 Load Case-3
Concrete - CY	237	244	300	260
Increase - %	0 %	3%	27%	10 %

STEEL PER LINEAR FT OF RETAINING WALL				
Description	CALTRANS STD PLAN			
	2006 All Load Cases	2010 Load Case-1	2010 Load Case-2	2010 Load Case-3
Steel - lbs	304	287	376	330
Increase - %	0 %	- 6 %	24 %	9 %

QUANTITY & COST COMPARISION ASD/LRFD – CALTRANS STD PLANS 2006 vs 2010

Concrete	$ 150 /CY
Steel	$ 2 /CY
Excavation	$ 50 /CY
Backfill	$ 75 /CY

COST PER LINEAR FT OF RETAINING WALL				
Description	CALTRANS STD PLAN			
	2006 All Load Cases	2010 Load Case-1	2010 Load Case-2	2010 Load Case-3
Cost per ft	$ 2075	$ 2100	$ 2800	$ 2350
Increase - %	0.00%	2 %	34 %	14 %

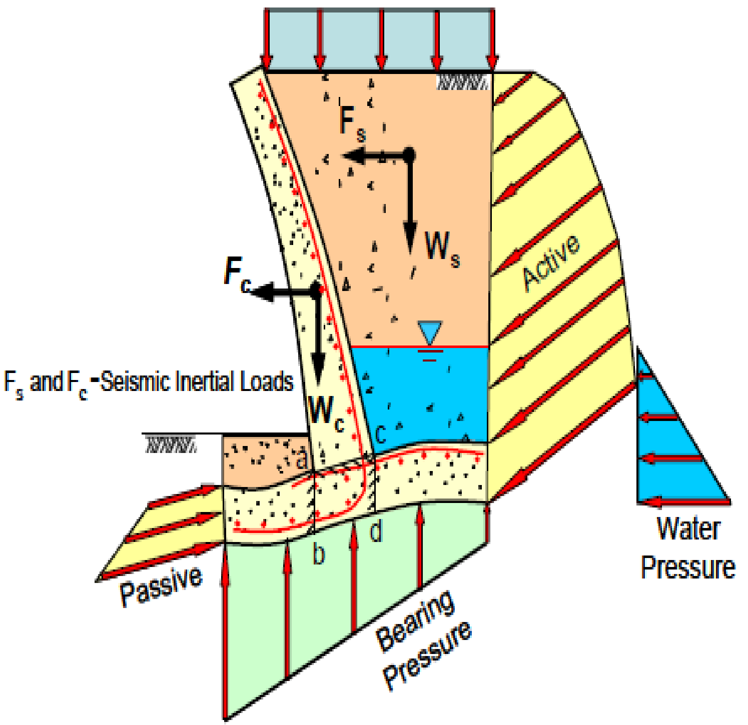
Western Bridge Engineers' Seminar

AECOM

OUTLINE

- Geometry & Cost Comparison ASD/LRFD
- **LRFD Design Method – Strength & Service**
- LRFD Design Method – Seismic
- Limitations on Design Approach
- Summary of AASHTO LRFD Changes 2007-2014
- Conclusion

LRFD DESIGN CRITERIA

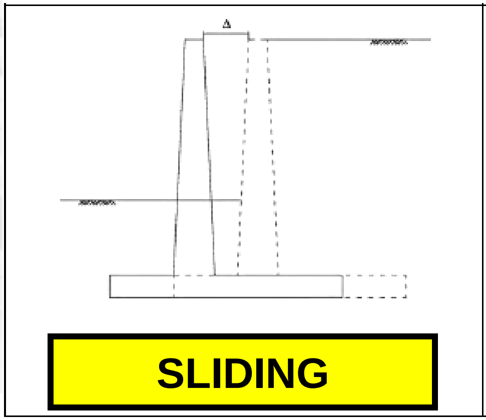


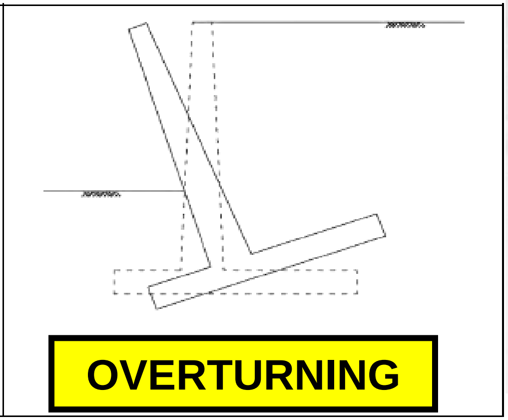
a. Loading

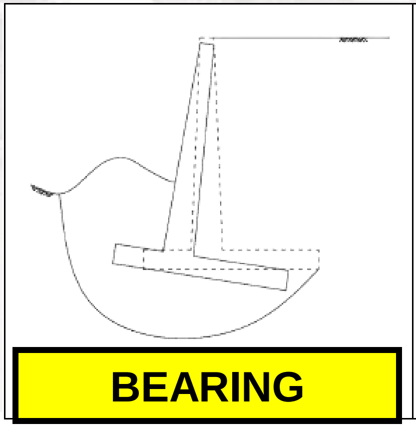
b. External Stability

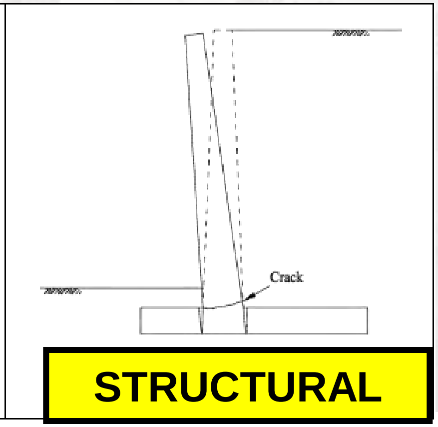
c. Structural Design

REF: FHWA-NHI-11-032









AASHTO LRFD REQUIRED CHECKS

Service Limit State –

Overall Stability, Settlement, Rotation, Deflection, Structural Service Requirements

Strength Limit State –

Bearing, Sliding, Eccentricity & Structural Capacity Analysis

Extreme Limit State –

Overall Stability, Bearing, Sliding, Eccentricity & Structural

CALTRANS REQUIRED CHECKS

Minimum Analyses for Earth Retaining System Design

Limit State	Service 1	Strength 1a	Strength 1b	Extreme Event 1	Notes
Settlement Analysis	X				For the case of proprietary system design, this analysis will be the responsibility of the project designer(s).
Overall or Global Stability Analysis	X			X	For the case of proprietary system design, these analyses will be the responsibility of the project designer(s).
Nominal Compression Bearing Resistance Analysis		X	X	X	Meeting the bearing requirements under all three limit states effectively eliminates need of an eccentricity check under the strength and extreme limit states.
Tilting/ Rotation Analysis	X				Limiting eccentricity: - B/6 for soil and intermediate geo-materials - B/4 for rock foundations
Sliding Failure Analysis			X	X	The vertical component of EH is factored by 1.0 for both the Strength 1b and Extreme limit states.
Structural Service Performance Analyses	X				These analyses will vary according to ERS type and technology as generalized in the following.
Structural Capacity Analyses		X	X	X	These analyses will vary according to ERS type and technology as generalized in the following.

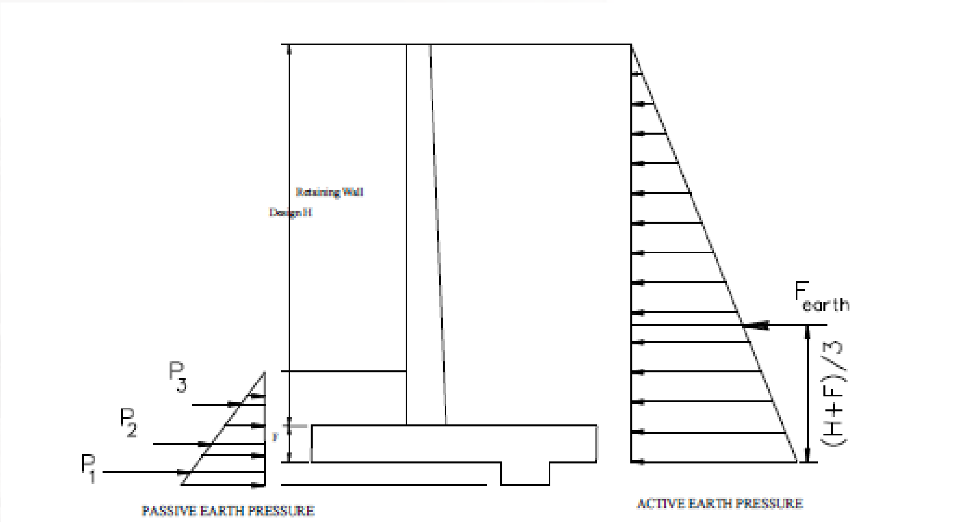
CALTRANS REQUIRED CHECKS

Service Limit State –
Overall Stability, Eccentricity, Settlement, Rotation, Deflection, & Structural Service Requirements

Strength Limit State –
Bearing, Sliding & Structural Capacity Analysis

Extreme Limit State –
Overall Stability, Bearing, Sliding, Eccentricity & Structural Capacity Analysis

STATIC EARTH PRESSURE



Coulomb Theory

$$K_a = \frac{\cos^2(\phi - \theta)}{\cos^2\theta\cos(\delta+\theta)\left(1+\sqrt{\frac{\sin(\delta+\phi)\sin(\phi-\beta)}{\cos(\delta+\theta)\cos(\beta-\theta)}}\right)^2}$$

$$K_p = \frac{\cos^2(\phi + \theta)}{\cos^2\theta\cos(\delta-\theta)\left(1-\sqrt{\frac{\sin(\delta+\phi)\sin(\phi+\beta)}{\cos(\delta-\theta)\cos(\beta-\theta)}}\right)^2}$$

Trial Wedge Method

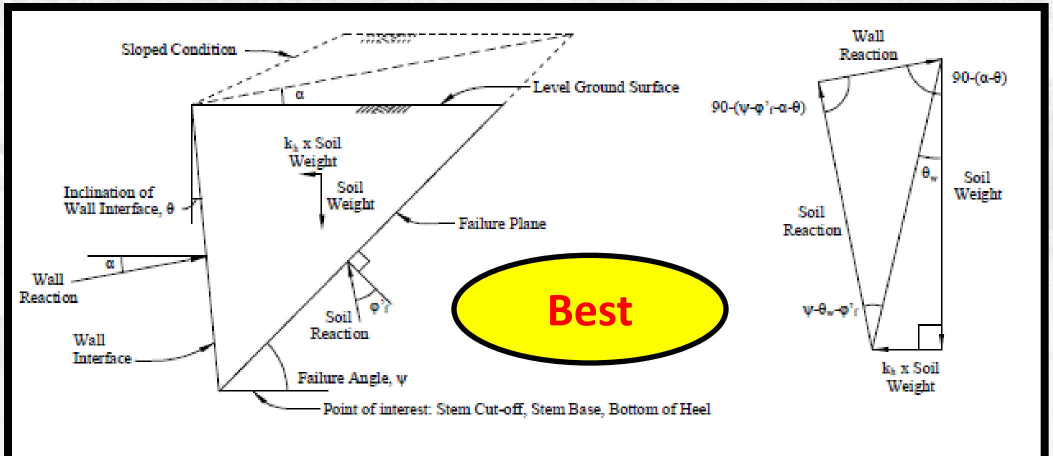


Figure 1.1.1-5 Trial Wedge Terminology

Rankine Theory

$$K_a = \cos\beta\frac{\cos\beta - (\cos^2\beta - \cos^2\phi)^{1/2}}{\cos\beta + (\cos^2\beta - \cos^2\phi)^{1/2}}$$

$$K_p = \cos\beta\frac{\cos\beta + (\cos^2\beta - \cos^2\phi)^{1/2}}{\cos\beta - (\cos^2\beta - \cos^2\phi)^{1/2}}$$

For the case where β is 0, the above equations simplify to

$$K_a = \tan^2\left(45 - \frac{\phi}{2}\right) = \frac{1-\sin(\phi)}{1+\sin(\phi)}$$

$$K_p = \tan^2\left(45 + \frac{\phi}{2}\right) = \frac{1+\sin(\phi)}{1-\sin(\phi)}$$

SURCHARGE LOAD

Different in ASD & LRFD

Table 3.11.6.4-1—Equivalent Height of Soil for Vehicular Loading on Abutments Perpendicular to Traffic

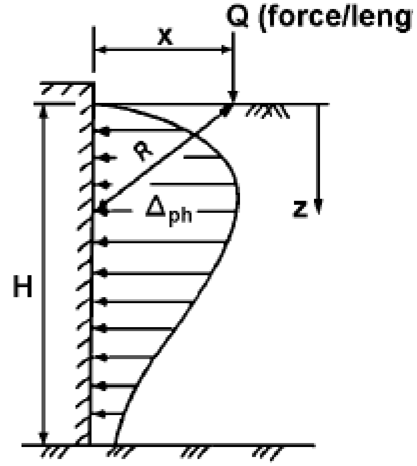
Abutment Height (ft)	h_{eq} (ft)
5.0	4.0
10.0	3.0
≥20.0	2.0

Table 3.11.6.4-2—Equivalent Height of Soil for Vehicular Loading on Retaining Walls Parallel to Traffic

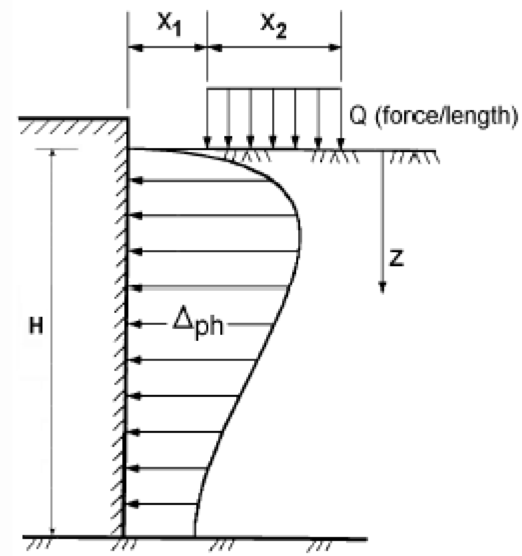
Retaining Wall Height (ft)	h_{eq} (ft) Distance from wall backface to edge of traffic	
	0.0 ft	1.0 ft or Further
5.0	5.0	2.0
10.0	3.5	2.0
≥20.0	2.0	2.0

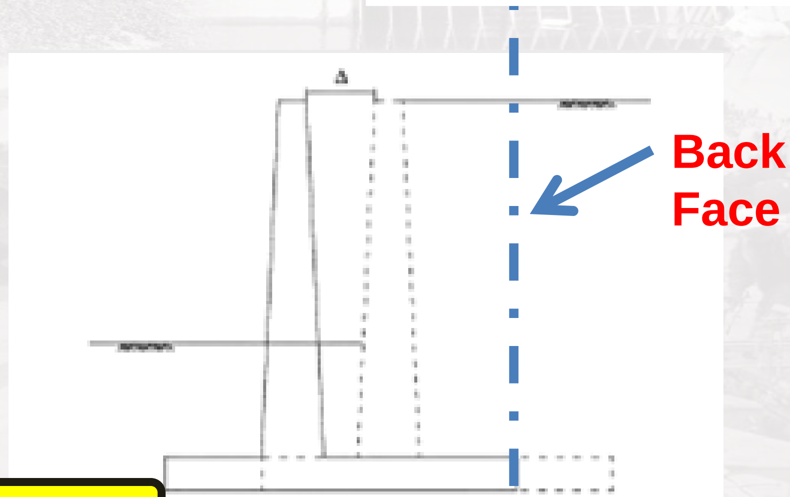
The load factor for both vertical and horizontal components of live load surcharge shall be taken as specified in Table 3.4.1-1 for live load surcharge.

Point Load



Uniform Load





ASD – 2ft Surcharge Always

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AASHTO LOAD COMINATIONS

AECOM

Table 3.4.1-1 Load Combinations and Load Factors.

Load Combination Limit State	*DC DD DW EH EV ES EL*	*LL IM CE BR PL LS*	*WA*	*WS*	*WL*	*FR*	*TU CR SH*	*TG*	*SE*	Use One of These at a Time *EQ*	*IC*	*CT*	*CV*
STRENGTH I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
STRENGTH II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
STRENGTH III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
STRENGTH IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—
STRENGTH V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20						
EXTREME EVENT I	γ_p	γEQ	1.00	—	—	1.00	—						
EXTREME EVENT II	γ_p	0.50	1.00	—	—	1.00	—						
SERVICE I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20						
SERVICE II	1.00	1.30	1.00	—	—	1.00	1.00/1.20						
SERVICE III	1.00	0.80	1.00	—	—	1.00	1.00/1.20						
SERVICE IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20						
FATIGUE— *LL, IM & CE* ONLY	—	0.75	—	—	—	—	—						

EH-Max + EV-Max

EH-Max + EV-Min

EH-Min + EV-Max

EH-Min + EV-Min

Table 3.4.1-2 Load Factors for Permanent Loads, γ_p.

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		Load Factor Maximum	Load Factor Minimum
DC: Component and Attachments		1.25	0.90
DC: Strength IV only		1.50	0.90
DD: Downdrag	Piles, α Tomlinson Method	1.4	0.25
	Piles, λ Method	1.05	0.30
	Drilled shafts, O'Neill and Reese (*1999*) Method	1.25	0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• *AEP* for anchored walls		1.35	N/A
EL: Locked-in Erection Stresses		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structure		1.30	0.90
• Rigid Frames		1.35	0.90
• Flexible Buried Structures other than Metal Box Culverts		1.95	0.90
• Flexible Metal Box Culverts		1.50	0.90
ES: Earth Surcharge		1.50	0.75

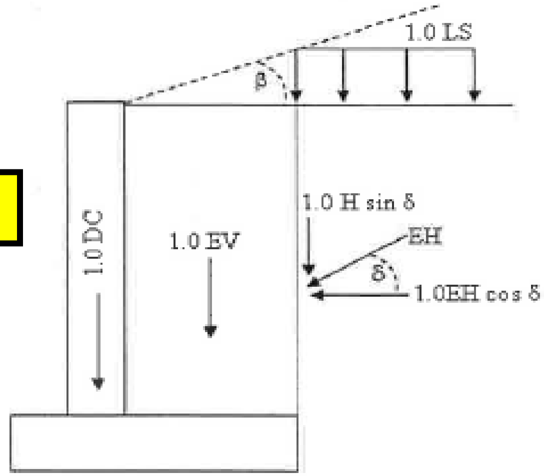
Different in ASD & LRFD

Big Envelope with Max-Min Factors

Resulted Bigger Geometry

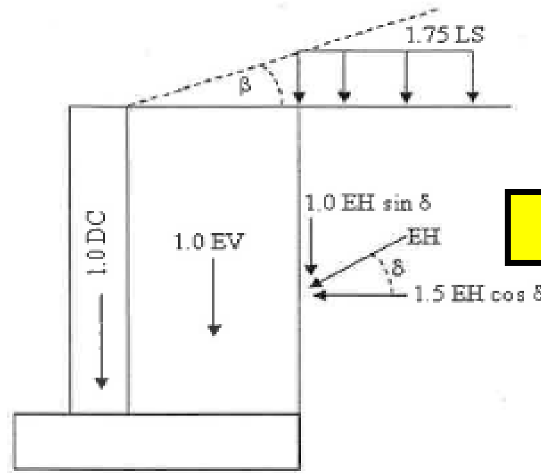
CALTRANS LOAD COMINATIONS

Service-I



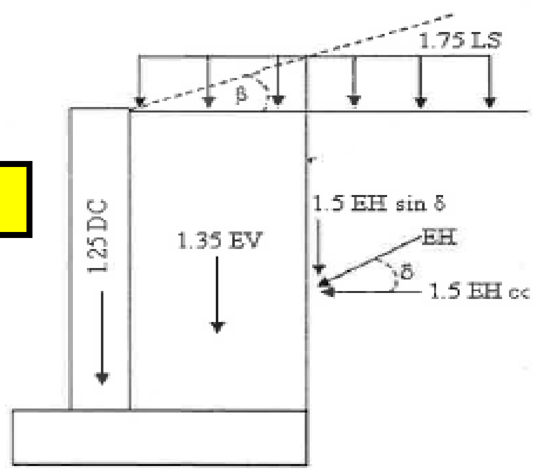
Service 1 – for eccentricity and deformation analyses

Strength – 1b



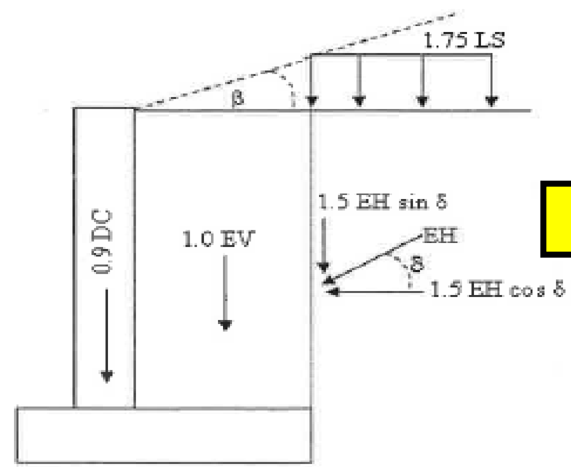
Strength 1b – for sliding failure only

Strength – 1a



Strength 1a – for bearing and structural capacity analyses

Strength – 1b

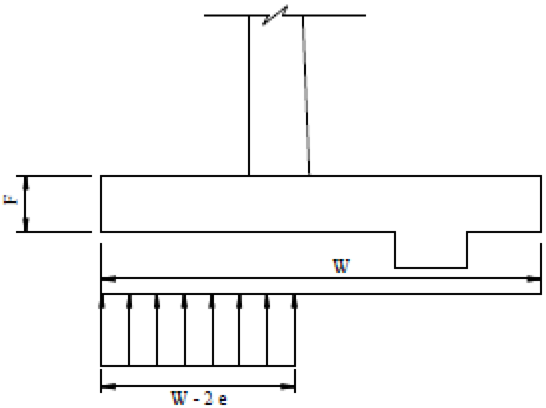


Strength 1b – for bearing and structural capacity analyses

BEARING PRESSURE

A. GEOTECHNICAL BEARING PRESSURE:

For geotechnical soil bearing pressures evaluation, soil pressure is distributed as uniformly distributed pressure below the footing for a length of (W-2e) (where e-eccentricity). Following figure shows soil pressure distribution.

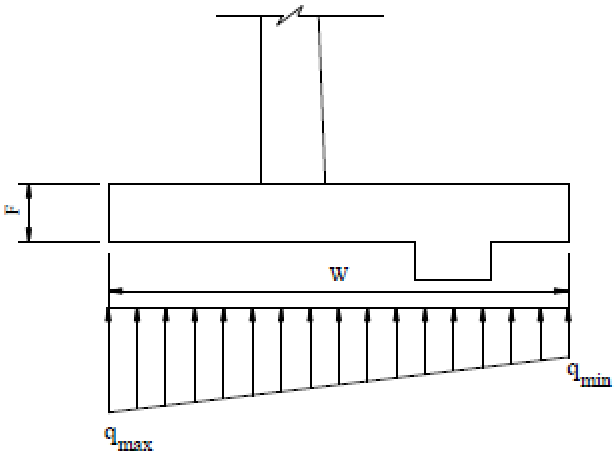


Plastic Soil – For Geotechnical Pressure Evaluation

$$\sigma_{vmax} = \frac{\sum V}{B}\left(1 + 6\frac{e}{B}\right) \quad (11.6.3.2\text{-}2)$$

$$\sigma_{vmin} = \frac{\sum V}{B}\left(1 - 6\frac{e}{B}\right) \quad (11.6.3.2\text{-}3)$$

B. SOIL PRESSURE FOR STRUCTURAL DESIGN:



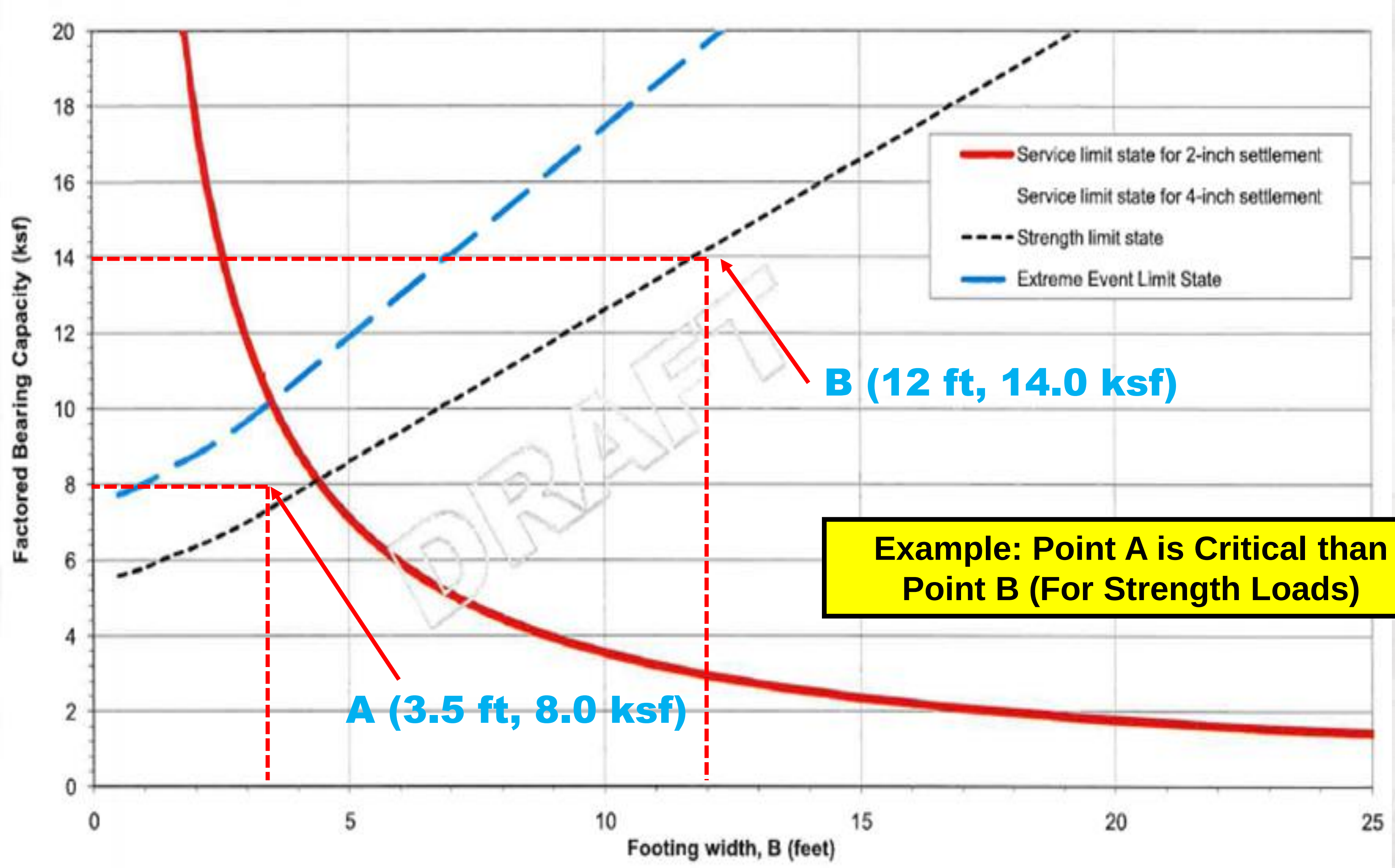
If resultant force is outside the middle one third of footing width,

$$\sigma_{vmax} = \frac{2\sum V}{3[(B/2) - e)]} \quad (11.6.3.2\text{-}4)$$

$$\sigma_{vmin} = 0 \quad (11.6.3.2\text{-}5)$$

Triangular Pressure Distribution Critical for Structural Design

LRFD BEARING CAPACITY -SAMPLE

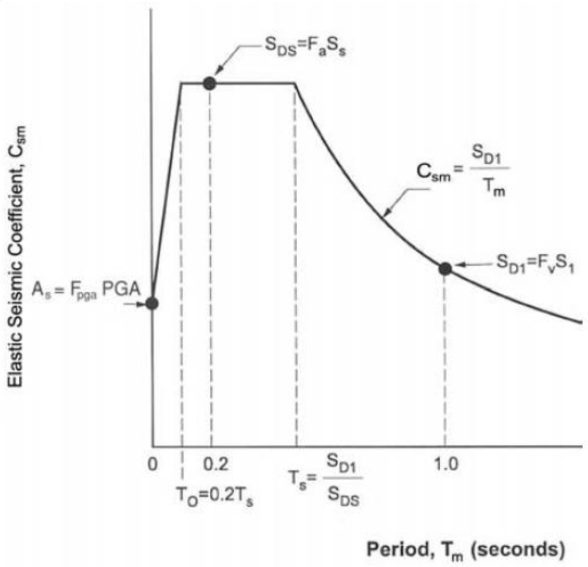


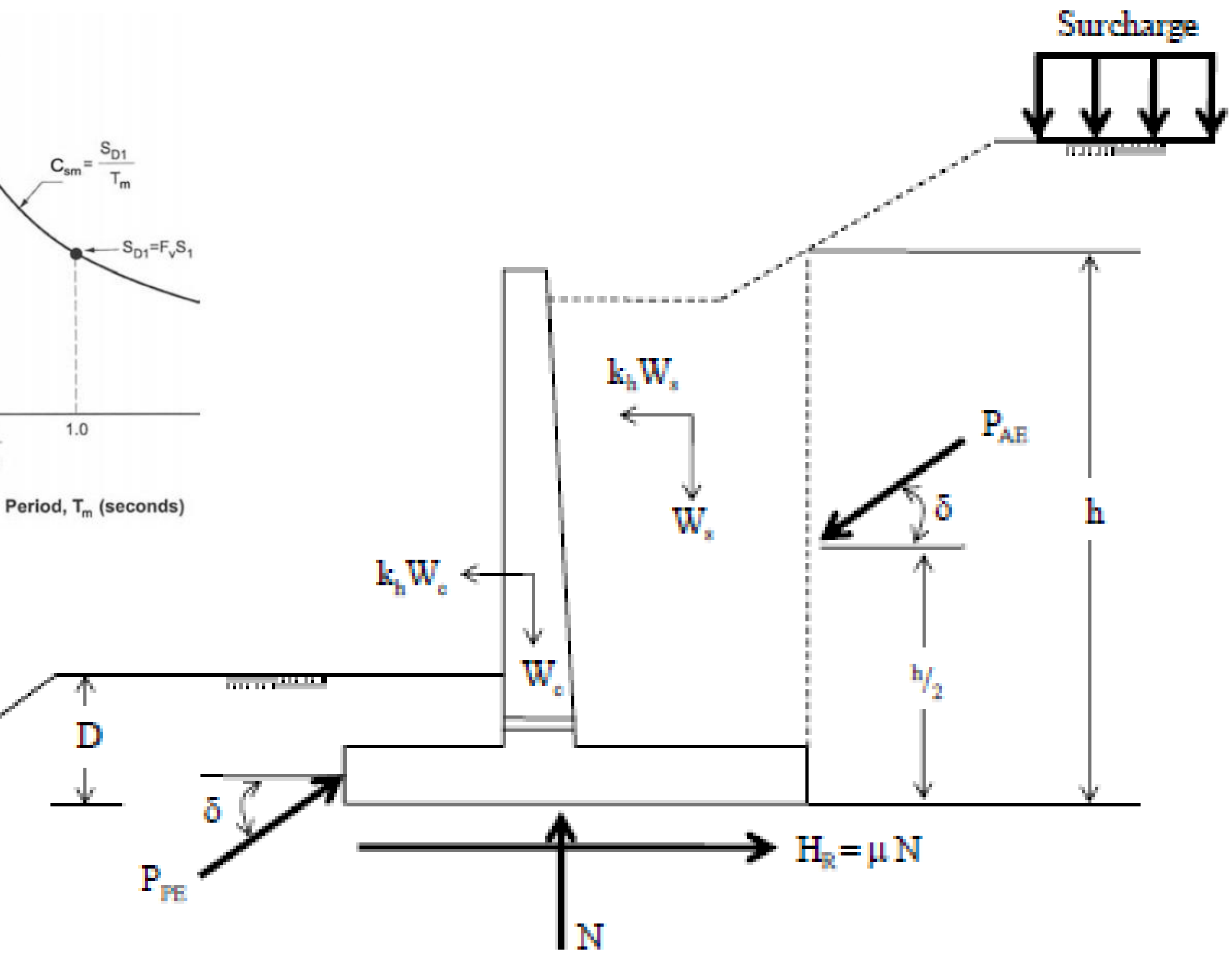
Example: Point A is Critical than Point B (For Strength Loads)

OUTLINE

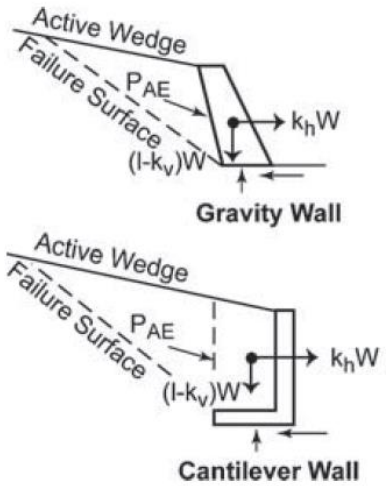
- Geometry & Cost Comparison ASD/LRFD
- LRFD Design Method – Strength & Service
- **LRFD Design Method – Seismic**
- Limitations on Design Approach
- Summary of AASHTO LRFD Changes 2007-2014
- Conclusion

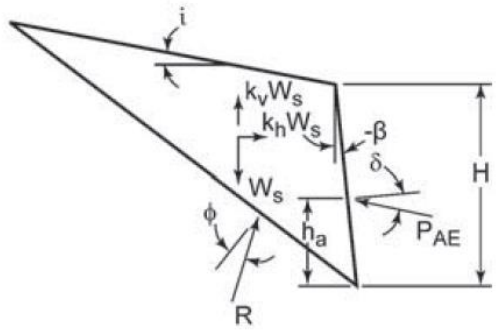
SEISMIC EARTH PRESSURE





SEISMIC EARTH PRESSURE





$$K_{AE} = \frac{\cos^2(\phi-\theta-\beta)}{\cos\theta\cos^2\beta\cos(\delta+\beta+\theta)} \times \left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta-i)}{\cos(\delta+\beta+\theta)\cos(i-\beta)}}\right]^{-2}$$

$$K_{PE} = \frac{\cos^2(\phi-\theta+\beta)}{\cos\theta\cos^2\beta\cos(\delta-\beta+\theta)} \times \left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\theta+i)}{\cos(\delta-\beta+\theta)\cos(i-\beta)}}\right]^{-2}$$

Seismic Active Earth Pressure

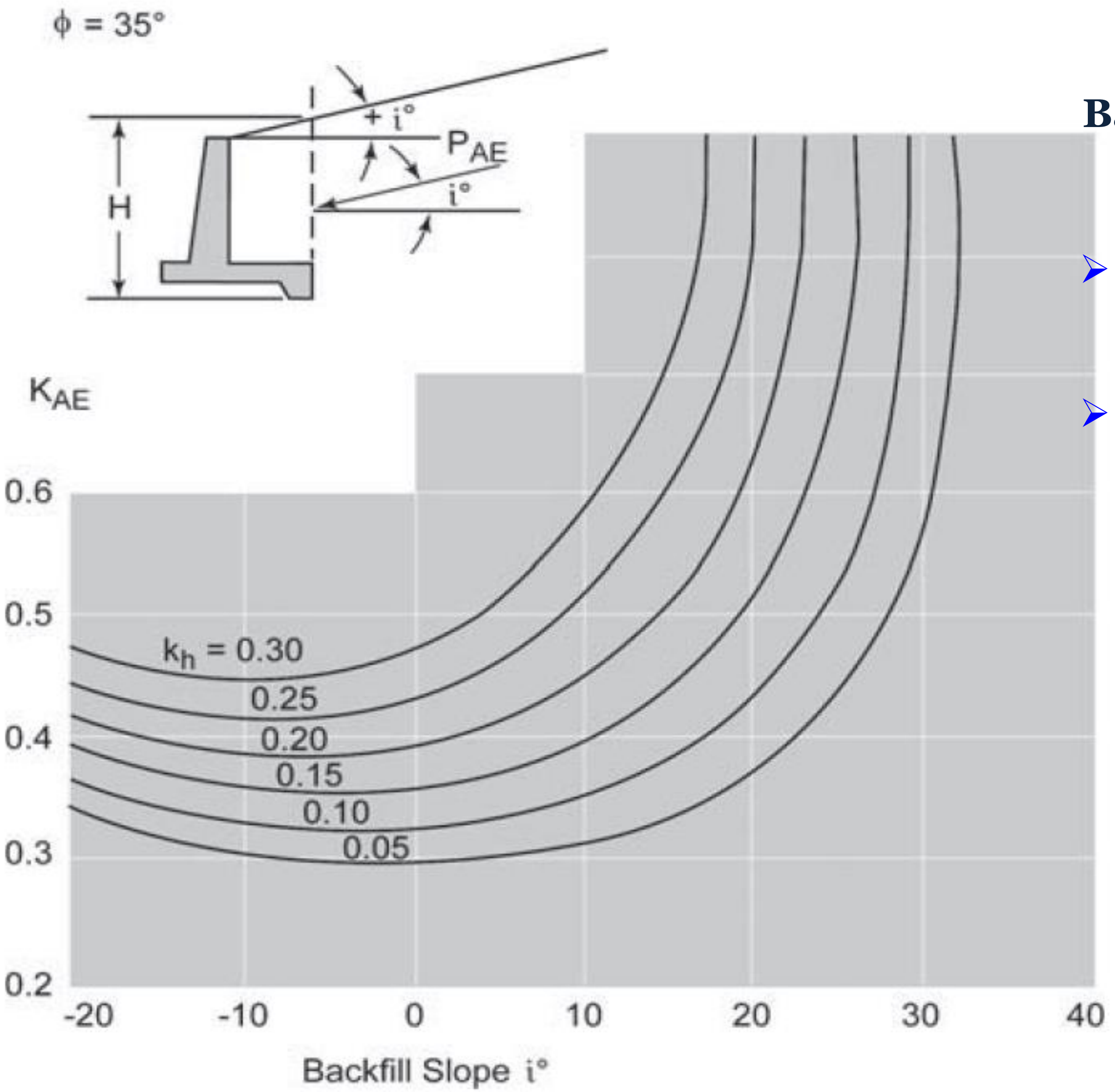
$$P_{AE} = 0.5\,\gamma\,H^2(1-k_v)K_{AE}$$

Seismic Passive Earth Pressure

$$P_{PE} = 0.5\,\gamma\,H^2(1-k_v)K_{PE}$$

γ = unit weight of soil (ksf)
H = height of wall (ft)
ϕ = friction angle of soil (°)
θ = arc tan $(k_h/(1-k_v))$(°)
δ = angle of friction between soil and wall (°)
k_h = horizontal acceleration coefficient (dim.)
k_v = vertical acceleration coefficient (dim.)
i = backfill slope angle (°)
β = slope of wall to the vertical, negative as shown (°)

SEISMIC EARTH PRESSURE vs BACKFILL SLOPE

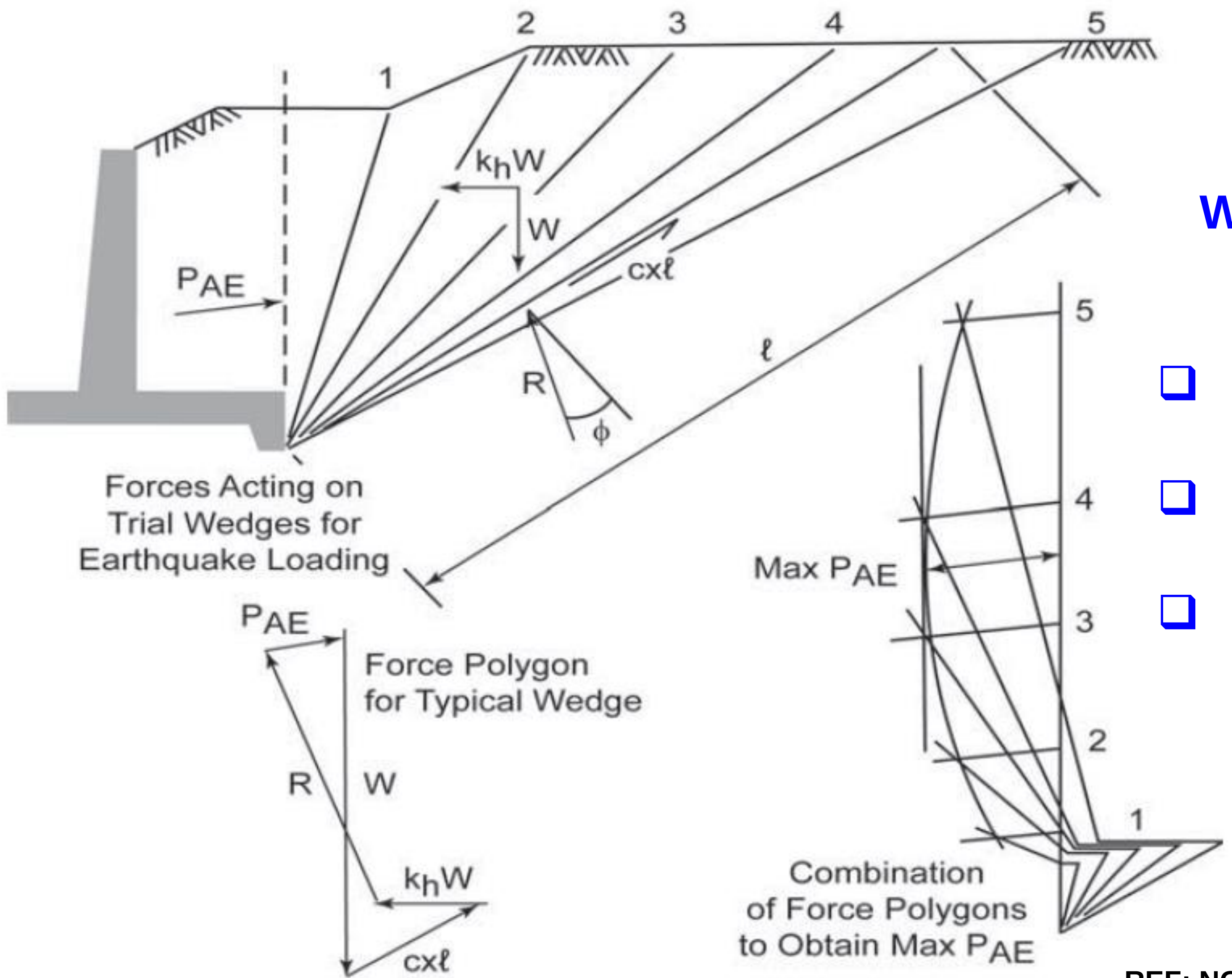


Based on Mononobe-Oakabe (M-O) Equation

- **Only Cohesion less Soils**
- **Modest Increase with Slope Angle**

REF: NCHRP Report – NR611

TRIAL WEDGE - SEISMIC

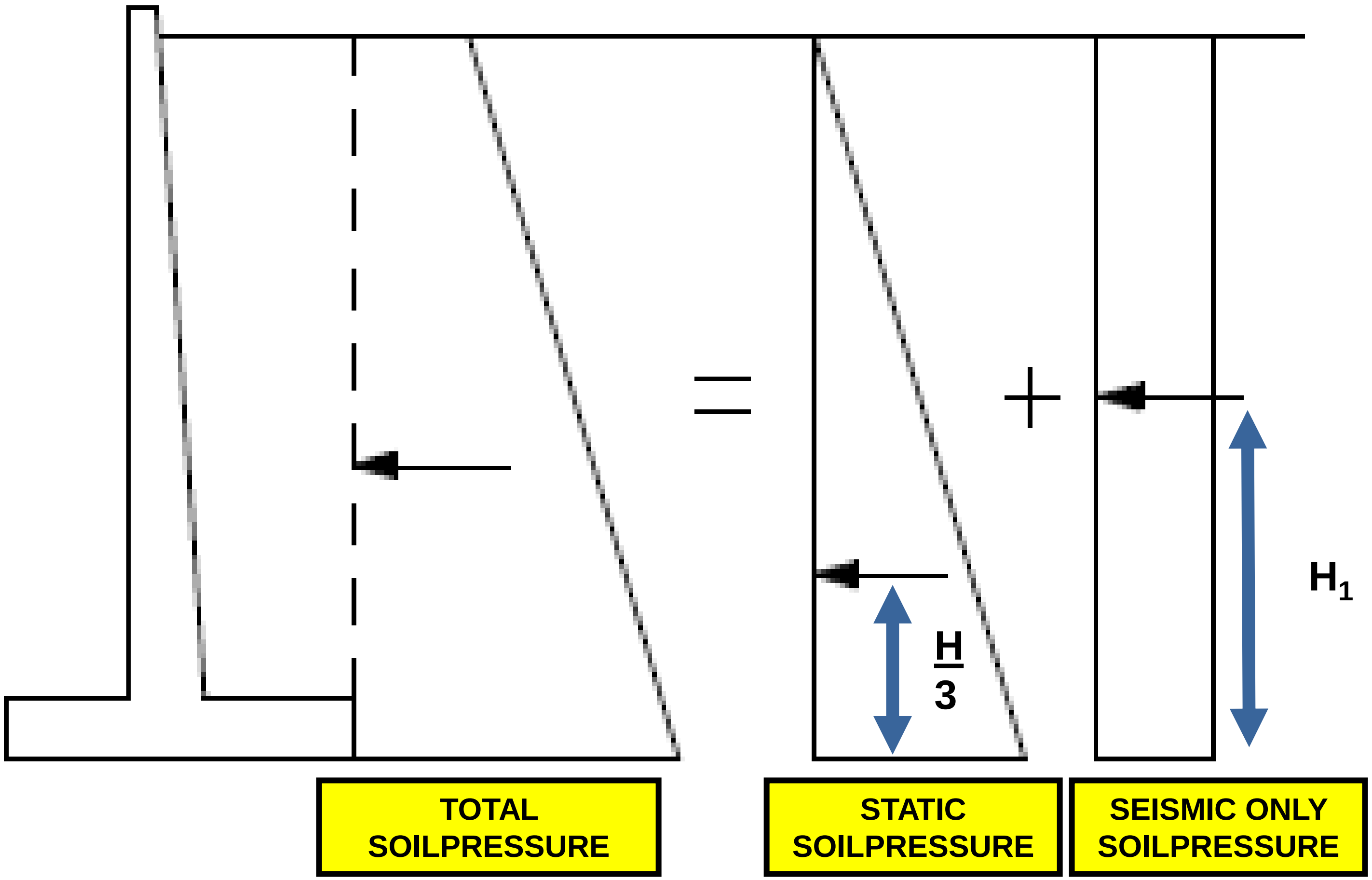


Why Trial Wedge Method?

- Broken Slope
- Cohesion
- Any Geometry

REF: NCHRP Report – NR611

SEISMIC SOIL PRESSURE APPLICATION



SEISMIC SOIL PRESSURE APPLICATION

OUTLINE

- Geometry & Cost Comparison ASD/LRFD
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- **Limitations on Design Approach**
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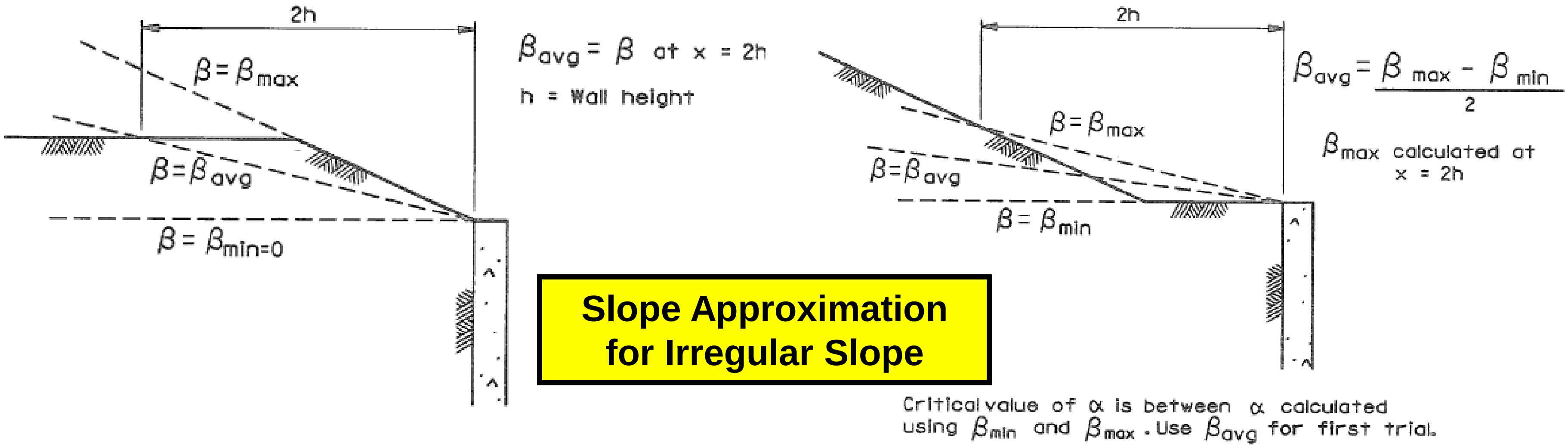
COHESION & IRREGULAR BACKFILL



Slope Approximation for Irregular Slope

$$\sigma_h = K_a \sigma_v - 2c\sqrt{K_a}$$

$$\sigma_h = K_p \sigma_v + 2c\sqrt{K_p}$$

Bells Relationship for Cohesion

LIMITATION MONONOBE-OKABE EQUATION

- The retaining wall is free to yield sufficiently to enable full soil strength or active pressure conditions to be mobilized. If the abutment is rigidly fixed and unable to move, the soil forces will be much higher than those predicted by the Mononobe-Okabe analysis.
- The backfill is cohesion-less, with a friction angle
- The backfill is unsaturated, so that liquefaction problems will not arise.
- K_{AE} is sensitive to changes in the soil friction angle,

$$\phi \geq i + \theta_{MO} = i + \arctan\left(\frac{k_h}{1 - k_v}\right)$$

OUTLINE

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ECCENTRICITY LIMITS

AASHTO	Service	Strength	Seismic
2007	NA	W/2 Soil 3W/4-Rock	Both Soil and Rock 2W/3 – EQ=0.0 8W/10 – EQ=1.0
2010	NA	W/2 Soil 3W/4-Rock	Both Soil and Rock 2W/3 – EQ=0.0 8W/10 – EQ=1.0
2012	NA	2W/3 Soil 9W/10-Rock	Both Soil and Rock 2W/3 – EQ=0.0 8W/10 – EQ=1.0
2014	NA	2W/3 Soil 9W/10-Rock	Both Soil and Rock 2W/3 – EQ=0.0 8W/10 – EQ=1.0

CALTRANS – SERVICE ONLY – Limit W/6

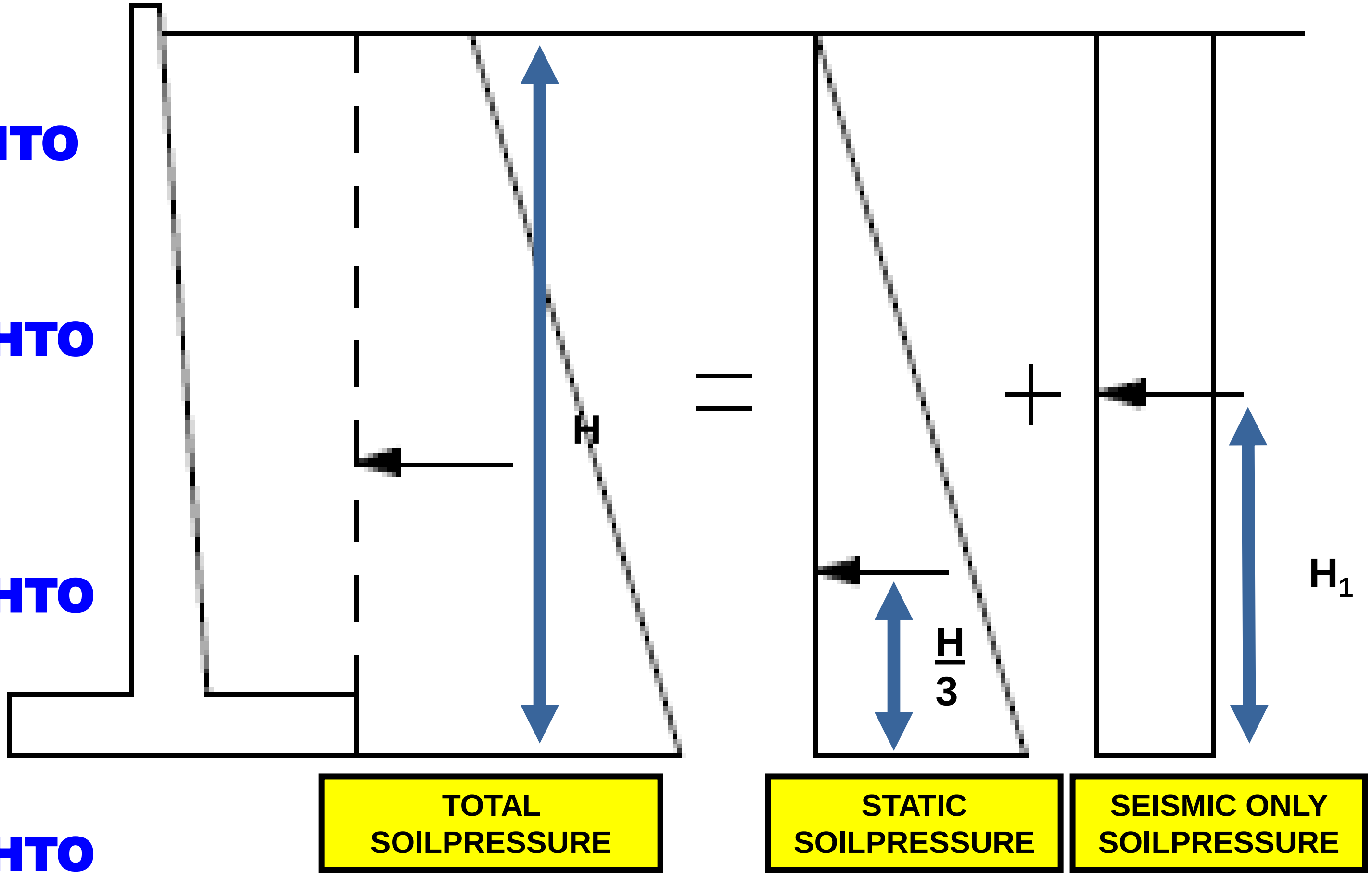
SEISMIC LOAD LOCATION

2007AASHTO
H_1=0.6H

2010 AASHTO
H_1=0.5H

2012 AASHTO
H_1=0.33H

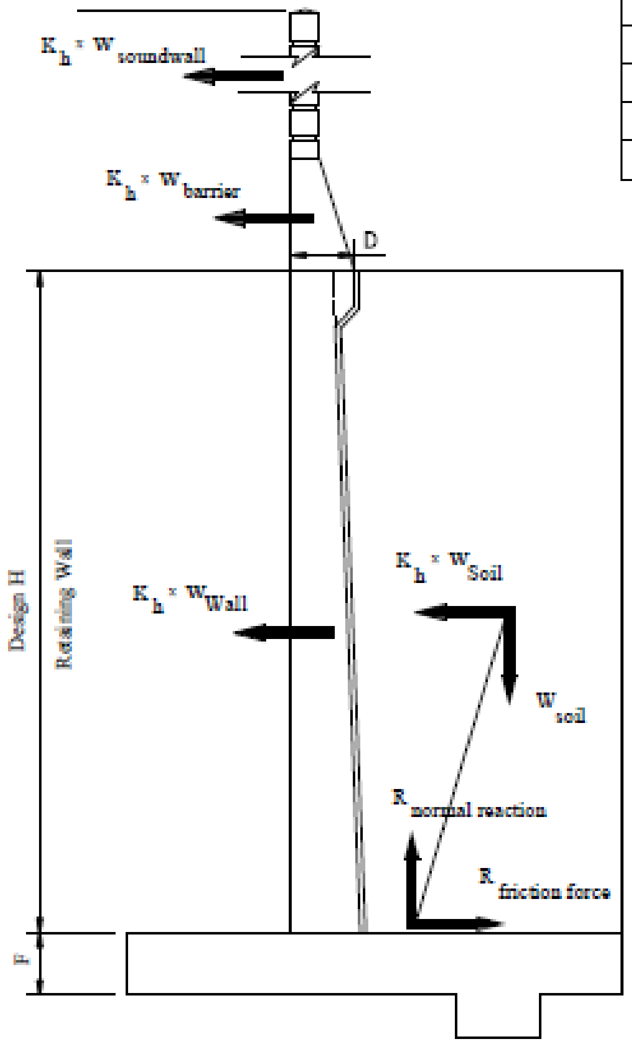
2014 AASHTO
H_1=0.33H



SEISMIC SOIL PRESSURE APPLICATION

SEISMIC INTERTIA FORCE

Caltrans Criteria



Description	External Stability	Structural Design
Inertia of Sound Wall	Yes	Yes
Inertia of Barrier	Yes	Yes
Inertia of Wall	Yes	Yes
Inertia of Soil Mass over Heel	Yes	No

2012 & 2014 AASHTO ONLY

To investigate the wall stability considering the combined effect of P_{AE} and P_{IR} and considering them not to be concurrent, the following two cases should be investigated:

- Combine 100 percent of the seismic earth pressure P_{AE} with 50 percent of the wall inertial force P_{IR} and
- Combine 50 percent of P_{AE} but no less than the static active earth pressure force (i.e., F_1 in Figure 11.10.5.2-1), with 100 percent of the wall inertial force P_{IR}.

AGENDA

- Geometry & Cost Comparison ASD/LRFD
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CONCLUSION

- Retaining Wall Geometry has significantly changed because of LRFD Design Criteria compare to ASD
- LRFD Design Criteria Constantly changed from 2007 to 2014.
- AASHTO significantly reduced Design Requirements in Recent LRFD Codes compare to 2007 LRFD Code.
- DOTs' Issues Interim Memorandums to Amend AASHTO LRFD Requirements.
- Few Design Requirements are clear in AASHTO LRFD yet (E.g: Seismic Inertia Force and related load combinations).

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