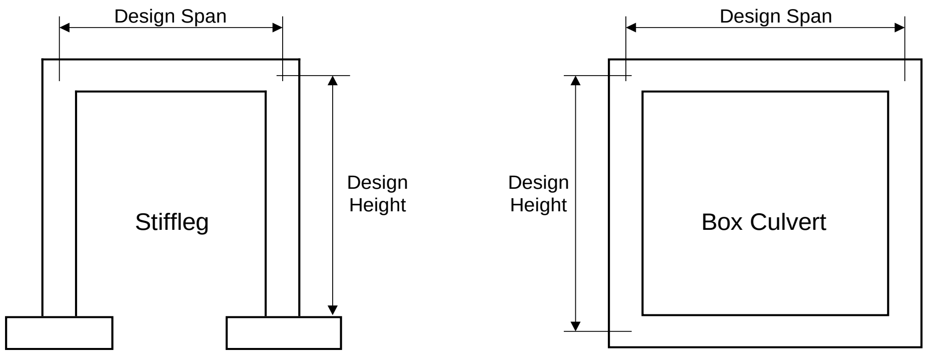
DESIGN GUIDELINES FOR CAST-IN-PLACE STIFFLEGS AND BOX CULVERTS

The design of concrete cast-in-place culverts shall be in accordance with the AASHTO LRFD Bridge Design Specifications as summarized in the following procedure.



Maximum Span for Stiffleg = 25 feet

Maximum Span for Box Culvert = 15 feet

When the maximum span for the structure type is exceeded, a different structure type or multiple cells should be evaluated.

Class 40 concrete and Grade 60 reinforcement should be used on all designs. Class 40B should be used for the footings or floors, barrel walls and wing walls. Class 40A should be used for deck slabs with less than 2’ of fill and Class 40B when the fill is 2’ or greater.

When the distance between the finished grade and the top of deck is less than 4” between the paved shoulders the concrete cover over the top layer of reinforcement should be 2½” and all reinforcement within 4” of the surface should be epoxy coated. When the fill is greater than 4” but less than 2’ the cover over the top layer of reinforcement should be 2½” however no epoxy steel is required. When the fill is 2’ or greater the cover should be 2” with no epoxy steel.

Main reinforcement for skews greater than 25° (Article 9.7.1.3) should be placed perpendicular to the centerline of the culvert. For skews 25° or less, the main reinforcement should be placed on the skew and the design span measured along the skew.

Fillets should have a minimum leg of 6”.

Walls should be double reinforced and have a minimum thickness of 10”.

Slab thickness should be a minimum of 8” or (S +10)/30 whichever is greater (Table 2.5.2.6.3-1). The span length to determine the minimum thickness is the clear span between walls.

Construction joints with keyways should be placed transverse to the barrel and should be located in the walls, top slab, and bottom slab. Joint spacing should not exceed 40’. In lieu of a construction joint in the walls, the contractor may substitute an approved contraction joint.

The minimum footing width for stifflegs should be 2’ on rock and 3’ on other materials.

The design of culverts should meet the criteria for **Strength - 1** and **Service - 1** limit states.

Design Loads and Factors

(Table 3.4.1-1 & 2)	Strength – 1 Max. Factor	Strength – 1 Min. Factor	Service – 1 Factor
Concrete Member D.L.	1.25	0.9	1.0
Wearing Surface	1.50	0.0	1.0
Earth Fill D.L.	1.30	0.9	1.0
Earth Pressure (at rest, for barrel)	1.35	0.5 (Art. 3.11.7)	1.0
Earth Pressure (active, for wings)	1.50	0.9	1.0
Earth Surcharge (at rest, for barrel)	1.50	0.5 (Art. 3.11.7)	1.0
Earth Surcharge (active, for wings)	1.50	0.75	1.0
Live Load Surcharge	1.75	0.0	1.0
Live Loads	1.75	0.0	1.0
Water Pressure	1.00	0.0	1.0

Concrete D.L. Assume 150 lbs/ft^3 for the concrete and reinforcement (Table 3.5.1-1 & C3.5.1).

Wearing Surface Assume a future overlay of 6" with a weight of 140 lbs/ft^3 (Table 3.5.1-1).

Earth Fill D.L. Use the density given in the Phase IV report. When not given assume 140 lbs/ft^3 (rolled gravel from table 3.5.1-1). The earth loads should be modified to account for soil-structure interaction. The soil-structure interaction factor is as follows (Art. 12.11.2.2):

For embankment installations (the typical case),

$F_e = 1 + 0.2(H/B_c)$ — F_e shall not exceed 1.15 for installations with compacted fill along the sides of the box section, or 1.40 otherwise.

Where, H = fill height above the deck surface
B_c = out-to-out dimension of the culvert span

For trench installations,

$F_t = C_b B_d^2/HB_c \leq F_e$ — Where, C_b = coefficient from figure 12.11.2.2.1-3
B_d = horizontal width of trench

Earth Pressure Shall be assumed to be linearly proportional to the depth of the soil based on the at rest pressure coefficient taken as $k_o = 1 - \sin \varphi_f$ where φ_f is the internal friction angle of the soil (Art. 3.11.5.2).

Earth Surcharge When the structure is buried the fill above the deck is considered an earth surcharge and a constant uniform horizontal earth pressure shall be applied in addition to the basic earth pressure. The uniform horizontal pressure due to earth surcharge should be based on the at rest coefficient k_o (Art. 3.11.6.1).

Live Load Surcharge At the barrel wall live load surcharge shall be determined as follows (based on table 3.11.6.4-1):

Up to 5' H:	h_{eq} = 4.0'
From 5' to 10' H:	h_{eq} = 4'- 0.2(H-5')
From 10' to 20' H:	h_{eq} = 3'- 0.1(H-10')
Higher than 20' H:	h_{eq} = 2.0'

Where h_{eq} is the equivalent height of soil in feet and H is the distance between the surface and the bottom of the footing in feet.

Live Loads Where the span exceeds 15 feet (Art. 3.6.1.3.3) the live loads shall be either a design truck in combination with a lane load or the design tandem in combination with a lane load (Art. 3.6.1.2). Where the span does not exceed 15 feet, only the axle loads of the design truck or design tandem shall be applied (Art. 3.6.1.3.3). The live load applied shall be a single loaded lane with the single lane multiple presence factor applied to the load (Art. 12.11.2.1).

Impact shall be $0.33(1.0 - 0.125D_E)$ but shall not be less than 0.0 where D_E is the minimum depth of earth cover over the structure (Art. 3.6.2.2). Impact shall only be applied to the truck or tandem (Art. 3.6.2.1).

<u>Fill less than 2’ (Article 4.6.2.10):</u>

Case 1. Traffic Travels Parallel to the Span (normal case)

Analysis shall be based on a single loaded lane with the single lane multiple presence factor.

The axle load shall be distributed to the top slab for moment, thrust, and shear as follows:

$E = 96 + 1.44(S)$

$Espan = Lt + LLDF(H)$

Where E = lateral distribution width perpendicular to the span (inches)
Espan = longitudnal distribution length parallel to the span (inches)
S = the clear span length (ft)
Lt = length of the tire contact area parallel to the span, 10 inches (Art. 3.6.1.2.5)
H = depth of fill from top of culvert to top of pavement (inches)
LLDF = fill distribution factor of 1.15 or 1.00 (Art. 3.6.1.2.6)

The equivalent strip width used for the top slab should also be used for the walls and floor (Art. 12.11.2.3).

Shear strength may be considered adequate when the slab is designed by the above procedure (see commentary).

Case 2. Traffic Travels Perpendicular to the Span

Live load shall be distributed according to Article 4.6.2.1 for concrete decks with primary strips perpendicular to the direction of traffic.

<u>Fill greater than 2’:</u>

Wheel loads may be considered to be uniformly distributed over a rectangular area with sides equal to the dimension of the tire contact area increased by 1.15 times the depth of fill in granular backfill, or the depth of fill in all other cases. The lane load may be distributed over 12 feet in all cases. The tire contact area is 20 inches wide and 10 inches long. Where such areas overlap the total load shall be uniformly distributed over the area within the resultant perimeter. Multiple presence factors shall be used where applicable. Live load may be neglected where the depth of fill is over 8 feet and exceeds the total length of the structure. Where the live load moment based on distribution through fill depths more than 2’ exceeds the moment calculated by Art. 4.6.2.10, the moment calculated by Art. 4.6.2.10 should be used. (Art. 3.6.1.2.6)

Shear design when fill is greater than 2’ (Art. 5.14.5.3): $\phi V_c > V_u$ $\phi = 0.85$

$V_c = [0.0676(f_c`)^{0.5} + 4.6(A_s/bd_e)(V_u d_e/M_u)]bd_e$ (in kips)

But V_c shall not exceed $0.126(f_c`)^{0.5}(bd_e)$

where: A_s = area of tension steel (in^2)
d_e = effective depth from extreme compression to tension centroid (in)
V_u = shear from factored loads (kips)
M_u = moment from factored loads occurring simultaneously with V_u (kip-in)
b = design width (in)

For single span stifflegs and single cell boxes only, V_c need not be less than $0.0948(f_c`)^{0.5}(bd_e)$

V_u may be calculated at either the distance d_v (Art. 5.8.3.2) from the face of the wall or at the end of the fillet. d_v = center of compression force to center of tension force but not less than $0.9d_e$ or 0.72h.

Water Pressure Culverts should be designed assuming static water pressure on the inside of the walls for the full design height.

Analysis The analysis should be based on the equivalent strip method assuming a rigid frame fixed against lateral movement at the base and free to side-sway at the top (classical force and displacement method). The design span length and wall height should be based on the centerline-of-member to centerline-of-member dimensions.

For simplification in determining the shears and moments in the structure the foundation soil pressure on box culverts may be considered to be uniformly distributed across the floor for all load cases (ITD Bridge Section policy).

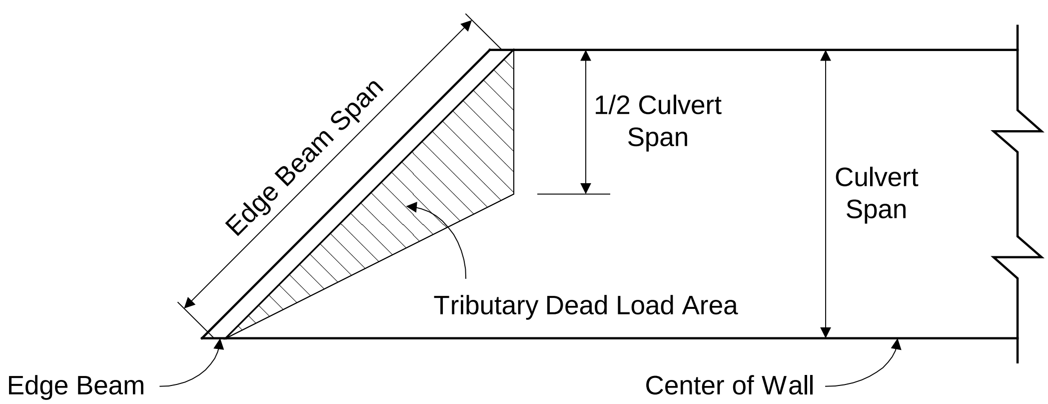
Where monolithic haunches inclined at 45° are used the negative reinforcement in the walls and slabs may be proportioned based on the flexural moment at the intersection of the haunch and uniform depth member (Art. 12.11.4.2).

Reinforcement

Minimum Reinforcement (Art. 5.7.3.3.2);	Min A_s shall be sufficient to resist $1.2M_{cr}$ or $1.33M_u$ whichever is less	
Transverse Distribution Reinforcement; (Art. 5.14.4.1)	$A_{dist} = A_s/(L)^{0.5}$	but no more than $0.5A_s$
	where A_s is the required positive moment reinforcement and L is the span length in feet	
For crack control (Art. 5.7.3.4);	$\gamma_e = 0.75$	to be used in equation 5.7.3.4-1

Note: When calculating the Service-1 limit state stresses in the reinforcement for the purpose of satisfying crack control requirements the compression thrust forces in the culvert members may be considered in order to take advantage of the resulting reduction in tensile stresses. The equations presented in the commentary for Article 12.11.3 may be used for this purpose.

Edge Beam Design The Live Load on edge beams shall be one line of wheels (either truck or tandem) plus a tributary portion of the lane load (Art. 4.6.2.1.4b). The tributary portion of the lane load shall be considered to be a uniform load of 64 lbs/ft^2 on either the effective edge beam width, or in the case where the edge beam is skewed relative to the main slab reinforcement, on the same tributary area as defined for dead load. The effective edge beam width for culverts with main slab reinforcement parallel with the edge beam shall be the distance between the edge of deck and the inside face of the barrier or curb, plus 12", plus one-quarter of the strip width, E, determined above. The effective width shall not exceed either one-half the full strip width or 72" (Art. 4.6.2.1.4b). The dead load should be the weight of all structure components and the fill on the effective width. When the end of the culvert is skewed relative to the main slab reinforcement the dead load applied to the edge beam shall also include the weight of all loads on the tributary area at the end of the culvert as shown below. These loads may be applied to the edge beam as a uniform load. The edge beam should be designed as a simple span with a span length based on center-of-wall to center-of-wall along the skew.



Footing Pressures The dead load footing pressures on the footings of stifflegs and the floor of box culverts may be uniformly distributed to the total footing area. The live load footing pressures may be assumed to act on a length of footing equal to the width of the design lane plus 1.15 times the distance from the surface to the bottom of the footing (this is the same distribution rate as the live load on the fill over a buried structure). Overlapping areas from more than one lane loaded shall be uniformly distributed over the length of the overlapping regions, multiple presence factors shall be applied where applicable. The total design loaded length shall not exceed the actual footing length. The footing pressure should be assumed to be uniform across the width of the footing or floor. Foundation design shall be in accordance with Section 10 of the LRFD Code.

Wing Wall Design

Live load surcharge shall be applied where vehicular load is expected to act on the surface of the backfill within a distance equal to one-half the wall height behind the back face of the wall. H_{eq}, the equivalent height of soil in feet, should be based on Table 3.11.6.4-2.

The typical wing wall on a spread footing is free to deflect at the top under soil pressure and may therefore be designed using soil pressures based on the active state. The soil pressure coefficient, k_a, may be determined by the Coulomb method from the information in the Phase IV report.

Overturning:

For foundations on soil, the location of the resultant of the factored strength-1 and extreme event-2 (vehicle collision at rail, if present) forces shall be within the middle one-half of the base. On rock the resultant shall be within the middle three-fourths (Art. 11.6.3.3).

Sliding:

For footings on cohesionless soils the factored resistance against failure by sliding may be taken as (Art. 10.6.3.4):

$R_R = \varphi_T(V \tan \varphi_f)$ where:

R_R = factored resistance
φ_T = 0.8 for strength-1 (from table 10.5.5.2.2-1)
φ_T = 1.0 for extreme event-2 (Art. 10.5.5.3)
V = total factored vertical load (minimum factors)
φ_f = internal friction angle of soil

The factored (strength-1 and extreme event-2) lateral loads shall not exceed R_R.

Wing Wall Footings:

Foundation design shall be in accordance with Section 10 of the LRFD Code.

Commentary: The LRFD design requirements for shear in slabs with less than 2 feet of fill are not consistent. Article 5.14.5.2 states that the provisions of Article 5.13.3.6 shall apply which indicates shear design is required. However if the live load distribution of Article 4.6.2.3 is used, which is a less conservative distribution than Article 4.6.2.10 for spans over about 9 feet, slabs may be considered satisfactory for shear (Art. 5.14.4.1). In addition it has been ITD practice for many years, in accordance with the Standard Specifications, to consider slabs designed with less than 2 feet of fill to be adequate for shear. Because ITD has had a good history of performance with this design procedure it will remain ITD policy. For fills over 2 feet the provisions of 5.14.5.3 shall also apply to stifflegs as well as box culverts. AASHTO is silent for the most part on cast-in-place concrete three sided frames however structurally they behave and are designed more like a four sided box culvert than a simply supported slab bridge. The culvert test results for shear shown in the commentary indicate that frame structures with the walls integral with the slab behave differently than simple slabs.

Revisions:

June 2006 The crack control requirements where revised to reflect the 2005/2006 Interim changes in AASHTO Article 5.7.3.4.

The effective edge beam width was revised to reflect the 2005 Interim changes in AASHTO Article 4.6.2.1.4b.

	The live load distribution for fills less than 2' was revised to reflect the 2005 Interim changes in AASHTO Article 12.11.2.
July 2007	Skew angle changed from 20° to 25° for orientation of main reinforcement to conform to Article 9.7.1.3
	Maximum reinforcement criteria deleted to reflect the 2005 Interim changes in AASHTO Article 5.7.3.3.1.
	Corrected the reference in Edge beam Design to Article 4.6.2.1.4b.
	Corrected the reference in Wing Wall design for Sliding to Article 10.6.3.4.
Oct. 2007	Included the provision of Article 3.6.1.3.3 that the lane load is not required for spans not exceeding 15 ft.
April 2008	Revised nomenclature for terms in sliding of wing walls to agree with the 2008 Interims.
July 2009	Added statement that slab shear strength may be considered adequate for designs with less than 2' of fill. Changed ϕ for shear from 0.9 to 0.85. Added commentary.