FDOT Concrete Box Culvert (CBC) LRFR Code Summary

FDOT Bridge Load Rating Manual, 2016 (BLRM)
FDOT Structures Design Guidelines Volume 1, 2016 (SDG)
AASHTO LRFD Bridge Design Specifications, 7th Ed. 2014 with 2015 & 2016 Interims (LRFD)
AASHTO Manual for Bridge Evaluation, 2nd Ed. with 2011, 2013, 2014, 2015, & 2016 Interims (MBE)

$RF = \dfrac{"C \pm \gamma DC \pm \gamma DW \pm \gamma EV \pm \gamma EH \pm \gamma ES"}{"\gamma LL(1 + IM) \pm \gamma LS"}$ - rating factor equation for box culverts (**MBE Eq. 6A.5.12.4-1**).

CAPACITY

$C = \psi_c \cdot \psi_s \cdot \psi \cdot R_n$ - factored capacity.

ψ_c - condition factor. Good or satisfactory = 1.00, fair = 0.95, and poor = 0.85 (**MBE Table 6A.4.2.3-1**).

$\psi_s = 1.00$ - system factor (**MBE 6A.5.12.8**).

ψ - resistance factor, or strength reduction factor.

$\psi_{Moment} = 0.90$ - strength reduction factor for moment (MBE 6A.5.12.6 & **LRFD Table 12.5.5-1**).

$\psi_{Shear} = 0.85$ - strength reduction factor for shear (MBE 6A.5.12.6 & **LRFD Table 12.5.5-1**). For $D_{fill} < 2ft$, neglect $\psi_{Shear} = 0.90$ (LRFD 5.5.4.2.1).

R_n - nominal resistance.

$R_{n.Moment} = F_s \cdot (d - 0.5 \cdot a)$ - nominal moment capacity, simplified as singly-reinforced (**LRFD Eq. 5.7.3.2.2-1**).

$$R_{n.Shear.Deep.Fills} = \left| \begin{array}{l} \sigma \leftarrow \text{if}\left(\text{cells} = 1, 2.5 \cdot \sqrt{f_c \cdot psi}, 0\right) \\ \sigma \leftarrow \max\left(\sigma, 2.14 \cdot \sqrt{f_c \cdot psi} + 4600 \cdot psi\, \rho \cdot \min\left(1, \dfrac{|Vu| \cdot d}{|Mu|}\right)\right) \\ \min\left(\sigma, 4.0 \cdot \sqrt{f_c \cdot psi}\right) \cdot ft \cdot d \end{array} \right.$$

- nominal shear capacity for $D_{fill} \geq 2ft$ (**LRFD 5.14.5.3**).

$$R_{n.Shear.Shallow.Fills} = \left| \begin{array}{l} \varepsilon_s \leftarrow \dfrac{\dfrac{\max\left(|Mu|, |Vu| \cdot d_v\right)}{d_v} + |Vu|}{29000ksi \cdot A_s} \\ "\text{For s.xe, assume max agg size} = 0.375in." \\ s_{xe} \leftarrow \max\left(12in, d_v \cdot \dfrac{1.38}{0.375 + 0.63}\right) \\ \beta \leftarrow \dfrac{4.8}{1 + 750 \cdot \varepsilon_s} \cdot \dfrac{51in}{39in + s_{xe}} \\ \dfrac{4.8}{1 + 750 \cdot \min\left(\varepsilon_{s.min}(Mu, Vu), 6 \cdot 10^{-3}\right)} \cdot \sqrt{f_c \cdot psi} \cdot ft \cdot d_v \end{array} \right.$$

- nominal shear capacity for $D_{fill} < 2ft$ (**LRFD 5.8.3.4.2**).

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DEAD LOAD

While LRFR does apply simultaneous minimum (γ.min = 0) and maximum (γ.max = γ.LL) live load factors among a given element or span (extreme effects, neglecting axles not contributing to the force under consideration, and patch lane loading), LRFR does not vary minimum and maximum permanent load factors for one load type, within the same calculation. "In the application of permanent loads, force effects for each of the specified six load types should be computed separately. It is unnecessary to assume that one type of load varies by span, length, or component within a bridge" (LRFD C3.4.1). At a two-span culvert, for example, when considering positive moment in the top slab of span 1, maximize vertical dead load throughout the entire top slab. Consistently apply maximum component (DC) and vertical earth (EV) load factors to both spans. However since EH is a separate load type, use the minimum horizontal earth (EH) pressure, if its effects benefit the top slab with axial force.

"$\gamma DC \pm \gamma DW \pm \gamma EV \pm \gamma EH \pm \gamma ES$" - factored dead load, which simplifies to "$\gamma DC \pm \gamma EV \pm \gamma EH$"

$\gamma DC = \left(\gamma_{DCmax} \cdot DC \vee \gamma_{DCmin} \cdot DC\right) = \left[1.25 \cdot \left(150pcf \cdot A_g\right) \vee 0.90 \cdot \left(150pcf \cdot A_g\right)\right]$ - factored component dead load.

γ_{DCmax} and γ_{DCmin} - load factors (**LRFD Table 3.4.1-2**, BLRM Table 6A.5.12.5-1).

$DC = 150pcf \cdot A_g$ - component dead load (**SDG 3.15.4**); A_g - area of concrete.

$\gamma DW = \gamma ES = 0$ - factored wearing surface & utilities, vertical (DW) and horizontal (ES). Assume the roadway is soil (**SDG 3.15.4.A,** BLRM 6A.5.12.5-1).

$\gamma EV = F_e \cdot \left(\eta_{max} \cdot \gamma_{EV.max} \cdot EV \vee \eta_{min} \cdot \gamma_{EV.min} \cdot EV\right) = F_e \cdot \left[1.05 \cdot 1.30 \cdot \left(120pcf \cdot D_f\right) \vee 1.00 \cdot 0.90 \cdot \left(120pcf \cdot D_f\right)\right]$ - factored earth load, vertical pressure.

$F_e = \min\left(1.15, 1 + 0.20 \cdot \frac{H}{B_c}\right)$ - earth interaction factor. Assume an embankment installation (**LRFD Eq.12.11.2.2.1-2** & BLRM 6A.5.12.5-1).

η_{max} and η_{min} - redundancy factor (LRFD 1.3.4), interpreted by FDOT as non-redundant (**SDG 3.15.3** & BLRM 6A.5.12.5-1).

γ_{EVmax} and γ_{EVmin} - vertical earth pressure load factors (**LRFD Table 3.4.1-2** at rigid buried, MBE Table A10.12.2-1, BLRM 6A.5.12.5-1).

$EV = \gamma_{Soil} \cdot D_f = 120pcf \cdot D_f$ - vertical earth pressure (LRFD Table 3.5.1-1, **SDG 3.15.4.B**, and BLRM 6A.5.12.5-1); D_f - depth of fill.

$\gamma EH = \left(\gamma_{EH.max} \cdot EH \vee \gamma_{EH.min} \cdot EH\right) = \left[1.05 \cdot 1.35 \cdot \left(60pcf \cdot D_f\right) \vee 1.00 \cdot 1.00 \cdot \left(30pcf \cdot D_f\right)\right]$ - factored earth load, horizontal pressure.

η_{max} and η_{min} - redundancy factor (LRFD 1.3.4), interpreted by FDOT as non-redundant (**SDG 3.15.3** & BLRM 6A.5.12.5-1).

γ_{EHmax} and γ_{EHmin} - vertical earth pressure load factors (**BLRM 6A.5.12.5-1**), but when using $EH_{min} = 30pcf$ use $\gamma_{EH.min} = 1.00$ (**LRFD 3.11.7**)

$EH_{max} = 60pcf \cdot D_f$ and $EH_{min} = 30pcf \cdot D_f$ - horizontal earth pressure (LRFD 3.11.7, MBE Table A10.12.2-1, SDG 3.15.4.B, and **BLRM 6A.5.12.5-1**).

Do not apply earth interaction factor F_e to EH (**MBE A10.5**). Top slabs in hinged-end culverts may conservatively neglect EH.

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LIVE LOAD, VERTICAL

"$\gamma LLwIM \pm \gamma LS$" = factored vertical live load with impact, ± factored equivalent vertical surcharge.

$\gamma LLwIM = \left(\gamma_{LLmax} \cdot DF \cdot IM \cdot LL \vee \gamma_{LLmin} \cdot DF \cdot IM \cdot LL\right)$ - factored live load with impact.

γ_{LLmax} - live load factors (**BLRM Table 6A.5.12.5-1**).

$\gamma_{LLmin} = 0$ - neglect axles not contributing to the effect under consideration (**LRFD 3.6.1.3.1**).

$DF = \frac{ft}{E}$ - lateral distribution factor, axles per unit foot.

E - effective lateral strip width (**MBE 6A.5.12.10.3a**, LRFD 3.6.1.2.6, & LRFD 4.6.2.10)

$$E(mpf) = \left| \begin{array}{l} E_{slab} \leftarrow \min\left(E_{TotalWidth.of.Slab}, 8ft + 0.12W_c\right) \\ E_{earth} \leftarrow \min\left[\begin{bmatrix} 2\cdot\left(20in + 0.06\cdot W_c + 1.15\cdot D_f\right) \\ 1\cdot\left(20in + 0.06\cdot W_c + 1.15\cdot D_f + 6ft\right) \end{bmatrix}\right] \\ \frac{\max\left(E_{slab}, E_{earth}\right)}{mpf} \end{array} \right.$$

$mpf_{HL93} = 1.20$

$mpf_{Legal} = 1.00$

$mpf_{FL120.Existing.Culvert} = 1.00$

$mpf_{FL120.New.Culvert.or.New.Extension} = 1.20$

mpf - single-lane multiple presence factor (**BLRM Table 6A.5.12.5-1**).

W_c - barrel width, length of clear span.

D_f - covering fill depth, roadway surface to top of top slab .

$IM = \min\left[1.00, 1 + 0.33\cdot\left(1 - \frac{D_f}{8ft}\right)\right]$ - live load impact factor (**LRFD Eq. 3.6.2.2-1**).

$LL = \frac{\Sigma AXLE_LOAD}{\Sigma SPACING + 10in + DF\cdot D_f}$ - longitudinally distributed live load (**LRFD Eq 4.6.2.10.2-2**) with10in tire length (**LRFD 3.6.1.2.5**).

$\Sigma AXLE_LOAD$ - the sum of the axle loads within an overlapping group, "interacting wheels" (nomenclature, **LRFD Eq. 3.6.1.2.6b-7**).

$\Sigma SPACING$ - the sum of the axle spacings within an overlapping group, "interacting wheels" ((nomenclature, **LRFD Eq. 3.6.1.2.6b-7**).

For exterior wall assessment, vertical live load effects in the top slab causing tension in the wall may be simplified to $\gamma_{LLmax} \cdot IM \cdot \frac{32kip}{E(mpf)}$

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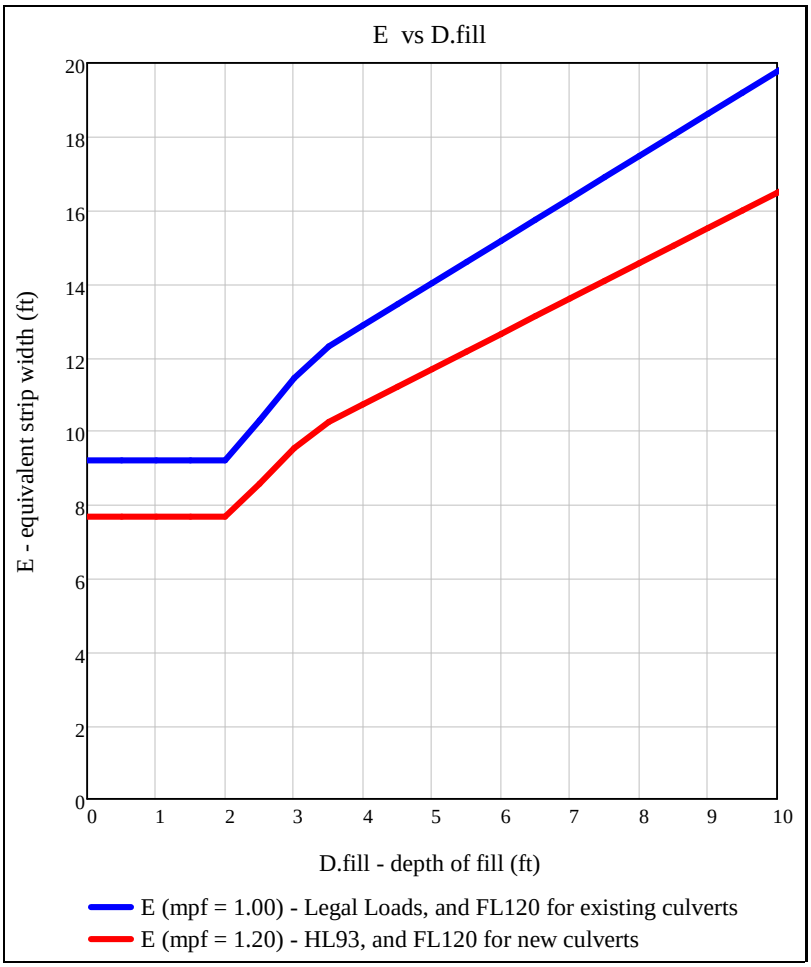
LIVE LOAD, VERTICAL - EQUIVALENT LATERAL DISTRIBUTION STRIP WIDTH "E"

$W_{c.plot} := 10ft$ - barrel width, or clear span. $S_{plot} := W_{c.plot} + 8in$ - spacing of supporting components.

$$E_{eq}(D_f, mpf) := \frac{\max\left[8ft + 0.12W_{c.plot}, \min\left[\left[2\cdot(20in + 0.06\cdot W_{c.plot} + 1.15\cdot D_f) \quad 1\cdot(20in + 0.06\cdot W_{c.plot} + 1.15\cdot D_f + 6ft)\right]\right]\right]}{mpf}$$

$ips := 24$ $\qquad ii := 1..ips + 1$ $\qquad D_{fill.plot_{ii}} := \frac{ii - 1}{ips}\cdot 12ft$

$$E := stack\left[(\text{"D.fill"} \quad \text{"E, mpf=1.00"} \quad \text{"E, mpf=1.20"}), augment\left(D_{fill.plot}, \overrightarrow{E_{eq}(D_{fill.plot}, 1.00)}, \overrightarrow{E_{eq}(D_{fill.plot}, 1.20)}\right)\right]$$



E =

"D.fill"	"E, mpf=1.00"	"E, mpf=1.20"
0.0	9.2	7.7
0.5	9.2	7.7
1.0	9.2	7.7
1.5	9.2	7.7
2.0	9.2	7.7
2.5	10.3	8.6
3.0	11.4	9.5
3.5	12.3	10.2
4.0	12.9	10.7
4.5	13.4	11.2
5.0	14.0	11.7
5.5	14.6	12.2
6.0	15.2	12.6
6.5	15.7	13.1
7.0	16.3	13.6
7.5	16.9	14.1
8.0	17.5	14.6
8.5	18.0	15.0
9.0	18.6	15.5
9.5	19.2	16.0
10.0	19.8	16.5
10.5	20.3	17.0
11.0	20.9	17.4
11.5	21.5	17.9
12.0	22.1	18.4

ft

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LIVE LOAD, HORIZONTAL

$\gamma_{LS} = \left(\gamma_{LLmax} \cdot LS \vee \gamma_{LLmin} \cdot LS\right) = \left(\gamma_{LLmax} \cdot 60pcf \cdot h_{eq} \vee 0 \cdot 60pcf \cdot h_{eq}\right)$ - factored live load surcharge

γ_{LLmax} - live load factors (**BLRM Table 6A.5.12.5-1**).

$\gamma_{LLmin} = 0$ - neglect axles not contributing the effect (**LRFD 3.6.1.3.1** & BLRM Table 6A.5.12.5-1).

$60pcf \cdot h_{eq}$ - horizontal pressure from vertical live load surcharge (**SDG 3.15.4.B** & BLRM Table 6A.5.12.5-1).

$h_{eq}(h) := \text{if}\left[h < 5ft, 4ft, \text{if}\left[h > 20ft, 2ft, \text{linterp}\left[\begin{pmatrix}5\\10\\20\end{pmatrix}ft, \begin{pmatrix}4\\3\\2\end{pmatrix}ft, h\right]\right]\right]$ - equivalent height for LL surcharge (**LRFD Table 3.11.6.4-1**)

Do not apply impact to live load surcharge (**MBE A10.7.5**)

Exterior wall ratings for Legal Operating and FL120 Routine Permit Levels may be taken as:

$RF(GVW) = RF_{HL93.Inventory.ExteriorWall} \cdot \frac{1.75}{1.35} \cdot \frac{1.20}{mpf} \cdot \frac{36ton}{GVW}$ - where GVW is the gross vehicle weight of the vehicle under consideration.

GVW - gross vehicle weight of the truck under consideration; for multi-truck vehicles (i.e. truck and tandem), use the heaviest truck.

mpf - single-lane multiple presence factor. See the previous page.