FDOT Concrete Box Culvert (CBC) LRFR Code Summary

FDOT Bridge Load Rating Manual, 2019 (BLRM)
FDOT Structures Design Guidelines Volume 1, 2019 (SDG)
AASHTO LRFD Bridge Design Specifications, 8th Ed. 2017 (LRFD)
AASHTO Manual for Bridge Evaluation, 3rd Ed. 2018 with 2019 Interims (MBE)

$RF = \dfrac{\text{"}C \pm \gamma DC \pm \gamma DW \pm \gamma EV \pm \gamma EH \pm \gamma ES\text{"}}{\text{"}\gamma LL(1 + IM) \pm \gamma LS\text{"}}$ - 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, cast-in-place box (MBE 6A.5.12.6 & **LRFD Table 12.5.5-1**).

$\psi_{Shear} = 0.85$ - strength reduction factor for shear, cast-in-place box (MBE 6A.5.12.6 & **LRFD Table 12.5.5-1**). Neglect LRFD 5.5.4.2.

R_n - nominal resistance.

$R_{n.Moment} = F_s \cdot (d - 0.5 \cdot a)$ - nominal moment capacity, simplified as singly-reinforced (**LRFD Eq. 5.6.3.2.2-1**).

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

- nominal shear capacity for $D_{fill} \geq 2ft$ (**LRFD 5.12.7.3**).

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

- nominal shear capacity for $D_{fill} < 2ft$ (**LRFD 5.7.3.4.1**).

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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 6A.5.12).

$DC = 150pcf\cdot A_g$ - 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).

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

η_{max} and η_{min} - redundancy factor (LRFD 1.3.4) adjusted to 1.00 in 2022.

γ_{EVmax} and γ_{EVmin} - vertical earth load factors (**LRFD Table 3.4.1-2** at rigid buried, MBE Table A10.12.2-1, BLRM 6A.5.12).

$EV = \gamma_{Soil}\cdot D_f = 120pcf\cdot D_f$ - vertical earth pressure (LRFD Table 3.5.1-1, **SDG 3.15.4.B**, and BLRM 6A.5.12); D_f - depth of fill.

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

η_{max} and η_{min} - redundancy factor (LRFD 1.3.4),adjusted to 1.00 in 2022.

γ_{EHmax} and γ_{EHmin} - vertical earth pressure load factors (**BLRM 6A.5.12**), 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**).

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

"γLLwIM ± γLS" = 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 6A.5.12**).

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

$DF = \dfrac{ft}{E}$ - 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)

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

$mpf_{HL93} = 1.20$

$mpf_{Legal} = 1.00$

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

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

mpf - single-lane multiple presence factor (**BLRM 6A.5.12**).

W_c - barrel width, length of clear span.

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

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

$LL = \dfrac{\Sigma AXLE\_LOAD}{\Sigma SPACING + 10in + DF\cdot D_f}$ - 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 $\gamma_{LLmax}\cdot IM\cdot\dfrac{32kip}{E(mpf)}$

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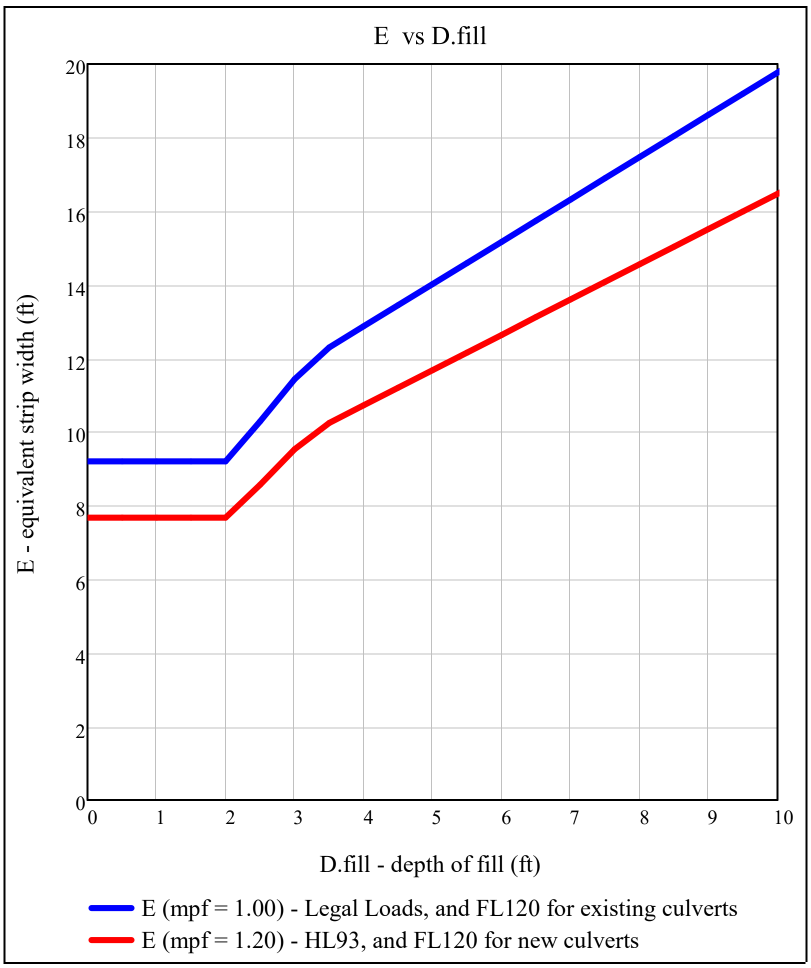
LIVE LOAD, VERTICAL - EQUIVALENT LATERAL DISTRIBUTION STRIP WIDTH "E"

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

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

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

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



E = (matrix, in ft)

"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

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LIVE LOAD, HORIZONTAL

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

γ_{LLmax} - live load factors (**BLRM 6A.5.12**).

$\gamma_{LLmin} = 0$ - neglect axles not contributing the effect (**LRFD 3.6.1.3.1** & BLRM 6A.5.12).

$60pcf \cdot h_{eq}$ - horizontal pressure from vertical live load surcharge (**SDG 3.15.4.B** & BLRM 6A.5.12).

$h_{eq}(h) := \mathrm{if}\left[h < 5ft, 4ft, \mathrm{if}\left[h > 20ft, 2ft, \mathrm{linterp}\left[\begin{pmatrix} 5 \\ 10 \\ 20 \end{pmatrix} ft, \begin{pmatrix} 4 \\ 3 \\ 2 \end{pmatrix} ft, h\right]\right]\right]$ - 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.

Discuss "E" - Equivalent Lateral Distribution Strip Width (page 1 of 2)

$ii := 1..19$ $\quad D_{fill.plot_{ii}} := \frac{ii-1}{18}\cdot 6ft$ $\quad D_{fill.plot} := \mathrm{csort}\left[\mathrm{stack}\left[D_{fill.plot}, \begin{pmatrix}1.99ft\\2.01ft\end{pmatrix}\right], 1\right]$ $\quad$ mpf **=** "multiple presence factor for one lane loaded"

2012 LRFD uses the best/largest strip of (shallow-fill slab-like equivalent strip distribution, and deep-fill earth distribution). It considers:
1. Equivalent strip widths for box culverts (LRFD Eq. 4.6.2.10.2-1. Try 1 truck, and inform this equation with the applicable mpf.
2. 1-lane distribution through tires (LRFD 3.6.1.2.5) and earth (LRFD 3.6.1.2.6). Try 1 wheel alone, and 2 wheel-lines from the same truck.
3. 2-lane distribution through tires (LRFD 3.6.1.2.5) and earth (LRFD 3.6.1.2.6). Try 2 wheel-lines from adjacent trucks, and 2 fully overlapped trucks.

$$E_{2012.LRFD.3.6.1.2.6}(mpf, W_c) := \left| \begin{array}{l} E(D_f) \leftarrow \max\left[(8ft + 0.12W_c)\cdot\frac{1}{mpf}, \min\left[\left[\begin{matrix}2\cdot(20in + 1.15\cdot D_f)\\ 1\cdot(20in + 1.15\cdot D_f + 6ft)\end{matrix}\right]\cdot\frac{1}{mpf}, \left[\begin{matrix}1\cdot(20in + 1.15\cdot D_f + 4ft)\\ 0.5\cdot(20in + 1.15\cdot D_f + 16ft)\end{matrix}\right]\right]\right] \\ \overrightarrow{E(D_{fill.plot})} \end{array}\right.$$

2013 MBE uses the best/largest strip of (shallow-fill slab-like equivalent strip distribution, and deep-fill earth distribution). It considers:
1. Equivalent strip widths for box culverts (LRFD Eq. 4.6.2.10.2-1. Try 1 truck, and inform this equation with the applicable mpf.
2. 1-lane distribution through tires (LRFD 3.6.1.2.5) and earth (LRFD 3.6.1.2.6). Try 1 wheel alone, and 2 wheel-lines from the same truck.
Normally, Legal loads use MBE mpf = 1.20 (MBE C6A.4.1). However for Legal loads in culverts, MBE mpf = 1.00 (2014 MBE 6A.5.12.10.3).

$$E_{2013.MBE.6A.5.12.10.3a}(mpf, W_c) := \left| \begin{array}{l} E(D_f) \leftarrow \max\left[(8ft + 0.12W_c)\cdot\frac{1}{mpf}, \min\left[\begin{matrix}2\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f)\\ 1\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f + 6ft)\end{matrix}\right]\cdot\frac{1}{mpf}\right] \\ \overrightarrow{E(D_{fill.plot})} \end{array}\right.$$

2013 LRFD uses slab-like equivalent strips for fill heights less than 2 feet; otherwise use several equations that vary by load type. It considers:
1. Equivalent strip widths for box culverts (LRFD Eq. 4.6.2.10.2-1. Try 1 truck, and inform this equation with the applicable mpf.
2. 1-lane distribution through tires (LRFD 3.6.1.2.5) and earth (LRFD 3.6.1.2.6). Try 1 wheel alone, and 2 wheel-lines from the same truck.
3. Deck strip widths for moment (LRFD Table 4.6.2.1.3-1, wherein the equations do include a mpf; use 1.20/mpf to remove it, for the permit).
Below, use $E_{2013.LRFD.3.6.1.2.6a\_pM}$ for positive moment, $E_{2013.LRFD.3.6.1.2.6a\_nM}$ for negative moment, and $E_{2013.LRFD.3.6.1.2.6a\_V}$ for shear.

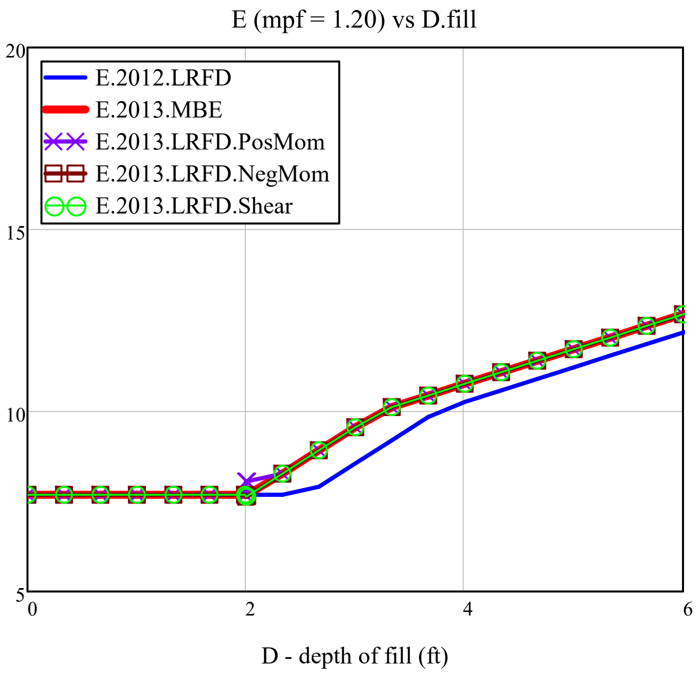
$$E_{2013.LRFD.3.6.1.2.6a\_pM}(mpf, W_c, S) := \left| \begin{array}{l} E(D_f) \leftarrow \mathrm{if}\left[D_f < 2ft, (8ft + 0.12W_c)\cdot\frac{1}{mpf}, \max\left[\min\left[\left[\begin{matrix}2\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f)\\ 1\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f + 6ft)\end{matrix}\right]\right]\cdot\frac{1}{mpf}, \left(26in + \frac{6.6}{12}\cdot S\right)\cdot\frac{1.20}{mpf}\right]\right] \\ \overrightarrow{E(D_{fill.plot})} \end{array}\right.$$

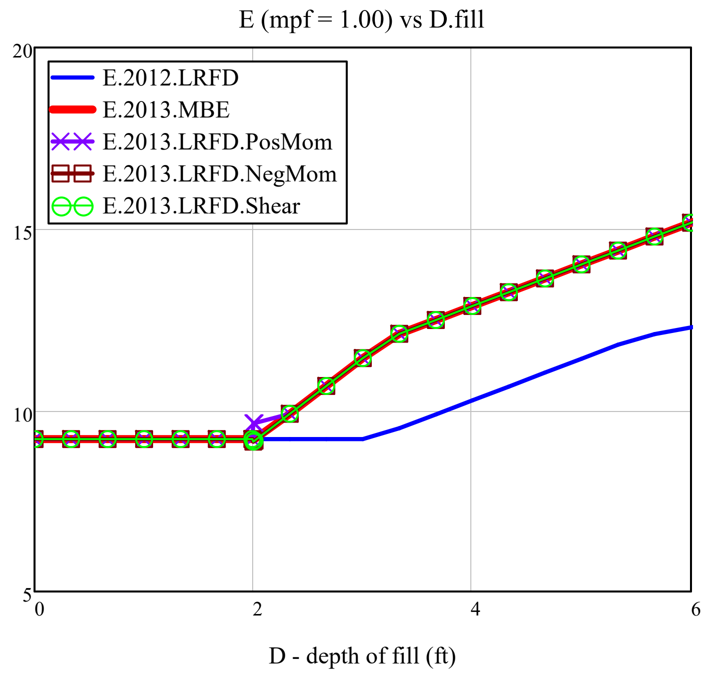
$$E_{2013.LRFD.3.6.1.2.6a\_nM}(mpf, W_c, S) := \left| \begin{array}{l} E(D_f) \leftarrow \mathrm{if}\left[D_f < 2ft, (8ft + 0.12W_c)\cdot\frac{1}{mpf}, \max\left[\min\left[\left[\begin{matrix}2\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f)\\ 1\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f + 6ft)\end{matrix}\right]\right]\cdot\frac{1}{mpf}, \left(48in + \frac{3.0}{12}\cdot S\right)\cdot\frac{1.20}{mpf}\right]\right] \\ \overrightarrow{E(D_{fill.plot})} \end{array}\right.$$

$$E_{2013.LRFD.3.6.1.2.6a\_V}(mpf, W_c, S) := \left| \begin{array}{l} E(D_f) \leftarrow \mathrm{if}\left[D_f < 2ft, (8ft + 0.12W_c)\cdot\frac{1}{mpf}, \min\left[\left[\begin{matrix}2\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f)\\ 1\cdot(20in + 0.06\cdot W_c + 1.15\cdot D_f + 6ft)\end{matrix}\right]\right]\cdot\frac{1}{mpf}\right] \\ \overrightarrow{E(D_{fill.plot})} \end{array}\right.$$

Discuss "E" - Equivalent Lateral Distribution Strip Width (page 2 of 2)

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





Synopsis, distribution strip width "E."

The 2013 MBE revisions (1) increased the effective strip width by 0.06*W.c per wheel line, (2) removed two-lane distribution, and (3) applied a single-lane multiple presence factor of 1.00 to Legal Loading, which contradicts MBE 6A.4.1.

The distribution strip widths within 2013 LRFD and 2013 MBE are nearly identical. The lone exception occurs among fills between 2.0 and 2.5 feet, when barrel widths exceed 9 feet, where E.2013.LRFD is less conservative than E.2013.MBE. Otherwise E.2013.LRFD is equivalent to E.2013.MBE. Avoid interjecting extraneous deck strip widths from LRFD 4.6.2.1.3; **adopt the distribution strip width from 2013 MBE.**