9/28/12 JAK

MDOT CMP LFR

1) BUCKLING STRENGTH REDUCTION FACTOR

NCSPA DESIGN DATA SHEET No. 19 UPDATED, CG

PAGE 7, FIGURE B.1.1 * MISSING

2) CMP RATING CALCULATIONS

DESIGN CALCULATIONS

CG AASHTO Std 12.6.1.3 ϕ_1 = CAPACITY MODIFICATION FACTOR FOR WALL AREA AND BUCKLING

* NOTE WHERE TO LOOK UP IN CODE

CG AASHTO STD. SP. 12.6.1.3 ϕ_2 = CAPACITY MODIFICATION FACTOR FOR SEAM STRENGTH

* NOTE WHERE TO LOOK UP IN CODE

CALCULATE THE T_{CAP}

CG * FOR CONSISTENCY IN FORMULA REPLACE A WITH A_s

DESIGN DIMENSIONS

CG * PROVIDE DEFINITION - "LONG SPAN STRUCTURE"

- Defined from NCSPA definition of Design Dimensions, 3. for all long span structures ...

GENERAL COMMENT

IF IN THE FUTURE IT WOULD BE POSSIBLE TO PROVIDE THE ABILITY TO CLEAR THE FORM OF USER INPUTS (GREEN CELLS) IT MIGHT MINIMIZE THE POTENTIAL FOR MIXING OLD AND NEW DATA.

* NOTE THAT IN EXAMPLE CROSS SECTION PROPERTIES & SEAM STRENGTH ARE BASED ON 10 GAGE INSTEAD OF 3 GAGE MATERIAL

CHECK CALCULATION FOR ORIGINAL EXAMPLE

FOR F_{cr} $\quad S = 10 ft = 120 in$

$$\text{IF} \quad S < \frac{0.6840}{0.22}\sqrt{\frac{24(29{,}000)}{45}} \Rightarrow 45 - \frac{(45)^2}{48(29{,}000)}\left(\frac{0.22(120)}{0.6840}\right)^2$$

OK

$120 < 387$ THEN $F_{cr} = 42.83$ ksi

FOR T_{CAP} $\quad$ LESS OF

$(1.0)(1.00)(33)(2.003) = 66.1$

$(0.95)(1.0)(1.00)(42.83)(2.003) = 81.5 \qquad 85.8$ OK

* f ONLY USE IF C&H IS UNSYMMETRICAL OR DEFLECT OVER 5%

$(0.67)(62) = 41.5$

$T_{CAP} = 41.5$

FOR T_E $\quad$ HIGHER OF

$(0.120)(3.6)(10/2) = 2.16$

$(0.120)(3.6)(15) = 6.48$

$T_E = 6.48$

FOR $RF_{o\text{-}w}$

$$\frac{41.5 - 1.95(6.48)}{7.84} = 3.68 \text{ OK}$$

(HS20 TRUCK)

ADDED NOTE REGARDING THIS CG

USE NO

IF ≤ 1.0 USE NUMBER
IF ≥ 1.0 USE 1.00

FOR RF_o

$$C = 2.36\left(\frac{3.6}{10}\right) + 0.528 = \boxed{1.38} \leq 1.0 \quad \cancel{\text{THEN}} = 1.00$$

$$RF_{o\text{-}c} = \frac{(3.6)^2}{\cancel{1.38}(1.25)^2}$$

$$= \cancel{6.04} \; 8.29$$

* ADD NOTE TO CLARIFY WHAT C VALUE TO USE BASED ON $\leq$

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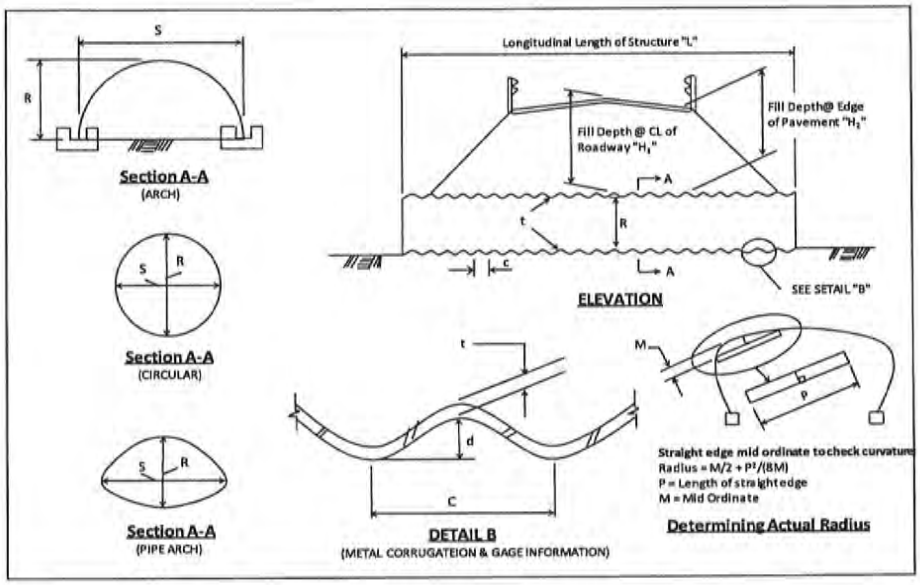
USING PORTIONS OF KENT CRC DATA
WITH ASSUMPTIONS FOR MISSING INFORMATION

OWNER		SHEET NO	1	OF	1
SECTION		COMP. BY	JAK	DATE	9/24/2012
DESCRIPTION	Test 1	CHECK BY		DATE	

MDOT

Load Factor Rating (LFR):
CORRUGATED METAL STRUCTURE (CIRCULAR & PIPE ARCH) & ARCHES

Adapted by MDOT from the original spreadsheets developed by the Ohio DOT



* For unsymmetrical structures, structures deflected more than 5% from design shape, or those that show localized distortions require that the actual maximum radius be determined in those distorted areas as show above. Use two times the actual maximum radius rather than the span in structural design checks. Typically this provides a conservative evaluation of the structure. Calculate maximum existing top radius by taking measurements around the upper periphery of the culvert using a ruler of length "P" to obtain values of "M". This should be done at selected stations along length of culvert, particularly at locations with noticeable sag.

Structure Information (from existing bridge plans & field measurements) :

Structure Type (to determine Minimum Cover):	Corrugated Metal Pipe (AASHTO 12.4)	← : choose from a drop-down list
Seam Type (to determine Seam Strength):	Annular pipe w/ spot welded, riveted or bolted seam	← : choose from a drop-down list
Structure Category (based on NCSPA Design Data Sheet No. 19)	Typical (NCSPA design data sheet No. 19, II. A. 1.)	← : choose from a drop-down list
Fill Depth at Centerline of Roadway "H_1" (ft) =	7.00	ASSUMED
Fill Depth at Edge of Pavement "H_2" (ft) =	7.00	
Span Length "S" (ft) =	15.33	
Rise "R" (ft) =	9.25	
Longitudinal Length of Structure "L" (ft) =	114.00	
Clear Roadway Width (Face to face of gaurdrail) (ft) =	43.00	
Determine Actual Top Radius "R_t" (ft) = (can be determined by field measurements* or hand calculations)		see * above
Metal Corrugation & Gage Information:	Metal Type:	Steel ← : choose from a drop-down list
	* Corrugation (if known):	(6 x 2 (steel structural plate pipe)) ← : choose from a drop-down list
	Gage number (if known):	10 ← : choose from a drop-down list
	c (in) =	
	d (in) =	
	t (in) =	
Pipe Crown Deflection ** (if any) =	0%	
Metal Loss based on materials field evaluation (if any) =	0%	

ASSUMED

Note: if corrugation & gage number are known, leave the input cells for "c", "d" & "t" blank; if corrugation & gage number are unknown, field measurements of "c", "d" & "t" are required.

** reduction in rise divided by the span length from design shape in the unit of percentage

Drop down list contains more options than just the Standard configurations that AASHTO Gives properties for. Only AASHTO sections were reproduced, user would have to use other source for other configurations. CK

* DROP DOWN LIST FOR "CORRUGATION" AND SEAM STRENGTH TABLE (USED FOR VALUE ON PAGE 3) DO NOT CONTAIN THE SAME SECTIONS. AASHTO STD. SPEC. FOR HWY BR, DIVISION I, SECTION 12.4.2 DIFFERS FROM TABLE HERE

OWNER		SHEET NO	1	OF	4
SECTION		COMP. BY	JAK	DATE	9/24/2012
DESCRIPTION	Test 1	CHECK BY		DATE	

Load Factor Load Rating of In-Service, Corrugated Metal Pipe Structures

Based on NCSPA Design Data Sheet No. 19 & AASHTO Standard Specification for Highway Bridges
Adapted by MDOT from the original spreadsheets developed by the Ohio DOT

Spreadsheet last modified: September 28, 2012

DO NOT use this spreadsheet to load rate Structural Plate Box Culverts

Design Dimensions

1. For **typical structures**, use the actual field measured span for calculations.
2. For **unsymmetrical structures or those deflected over 5%**:
   a. use 2 x the top radius (2 R_t) in lieu of span for calculations.
   b. base critical buckling stress calculations on the theoretical design span, reducing the resulting allowable buckling stress by the appropriate multiplier to account for deflection " f " (NCSPA Design Data Sheet No. 19, Figure B.1.1).
3. For all **long span structures** (horizontal ellipse, low and high profile arches, inverted pear shapes and pear arches), as well as other horizontal ellipses, use 2 x actual top radius (2R_t) in all cases.

For typical structures :	Design Span = Actual Span "S" (ft) =	15.33
For unsymmetrical or deflect more than 5% structures:	Design Span (ft) = 2R_t =	0.00
	Pipe Crown Deflection =	0%
	Buckling Strength Reduction Factor, f =	0.95
long span structures:	Design Span (ft) = 2R_t =	0.00

Structure Category:	Typical (NCSPA design data sheet No. 19, II. A. 1.)

Then, **Span Length** used in Load Rating Calculation(ft) =	15.33	Warnings:
Then, R_t used in Load Rating Calculation (ft) =	0.00	
$R_{t\,(max)}$ * (ft) =		

* Maximum Plate Radius allowed if Long Span Structural Plate Structures Selected

Design Properties

Mechanical Properties:

Metal Type:	Steel		
F_y = Minimum Yield Point of the Metal		33	ksi
F_u = Minimum Tensile Strength of the Metal		45	ksi
E_m = Modulus of elasticity of metal		29000	ksi

Section Properties:

Corrugation:	6 x 2 (steel structural plate pipe)	
Gage Number:	10	
c (in) =		
d (in) =		Warnings:
t (in) =	0.138	
$t_{(min)}$** (in) =		

** Required Minimum Top Arc Thickness if Long Span Structural Plate Structures Selected

A_s (in^2/ft) =	***2.003***	input these values based on metal type, corrugation, gage number or pipe wall thickness, see tables in worksheet "section property tables".
r* (in) =	***0.6840***	
175	***78.175***	

* r =radius of gyration of corrugation (in)

MDOT

OWNER		SHEET NO	1	OF	4
SECTION		COMP. BY	JAK	DATE	9/24/2012
DESCRIPTION	Test 1	CHECK BY		DATE	

Design Calculations:

Structure Type:	Corrugated Metal Pipe (AASHTO 12.4)	
Seam Type:	Annular pipe w/ spot welded, riveted or bolted seam	
Longitudinal Length of Structure "L" (ft) =	114.00	Warnings:
AASHTO minimum cover, h (ft) =	1.92	
Height of cover above crown "H" (ft) = (the lowest cover over the structure in a traffic area based on field measurement)	7.00	
φ_{loss} = Section Properties reduction factor on the basis of metal loss from the materials field evaluation =	1.00	
φ_1 = capacity modification factor for wall area and buckling	1.0	
φ_2 = capacity modification factor for seam strength	0.67	
δ = Soil density (k/ft^3)	0.120	
k = soil stiffness factor =	0.22	

Calculate the F_{cr} (critical buckling stress) :

if: $S < \frac{r}{k}\sqrt{\frac{24E_m}{F_u}}, then\ F_{cr} = F_u - \frac{F_u^2}{48E_m}\left(\frac{kS}{r}\right)^2$

if: $S > \frac{r}{k}\sqrt{\frac{24E_m}{F_u}}, then\ F_{cr} = \frac{12E_m}{(kS/r)^2}$

Compare: S (in) = 183.96 < $\frac{r}{k}\sqrt{\frac{24E_m}{F_u}}$ = 386.66

So: F_{cr} = 39.91 ksi

Calculate the T_{cap} (thrust capacity of the wall) :

Seam Strength (k/ft) = 62.0

Input the seam strength value based on metal type, corrugation, gage number or pipe wall thickness, see tables in worksheet "seam strength tables"

T_{cap} = less of:	1. wall yield strength = $\varphi_1\ \varphi_{loss}\ F_y\ A$ =	66.1
	2. wall buckling strength = f $\varphi_1\ \varphi_{loss}\ F_{cr}\ A$ =	79.9
	3. seam strength = φ_2 x (seam strength) =	41.5

So: T_{cap} = 41.5 k/ft

Calculate the T_E (pipe wall thrust due to earth cover) :

T_E = higher value of :	1. δ H (S/2) =	6.44	k/ft
	2. δ H R_t =	0.00	k/ft

So: T_E = 6.44 k/ft

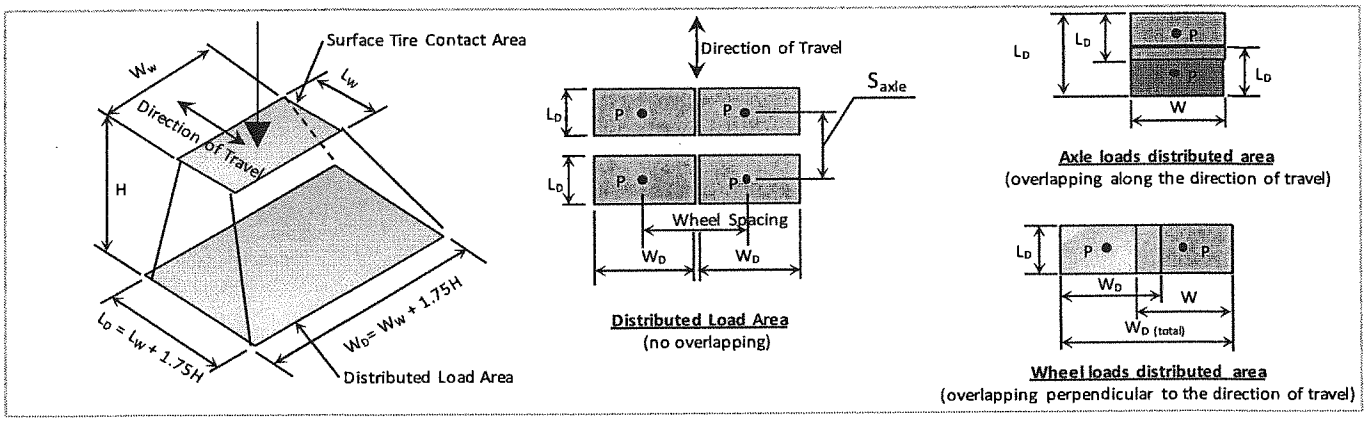
Calculate the $T_{(L+I)}$ (pipe wall thrust due to live load plus impact) :

$T_{(L+I)}$ = higher value of :	1. $\rho_{(L+I)}$ (S/2) =	k/ft
	2. $\rho_{(L+I)}$ R_t =	k/ft

Based on **AASHTO 3.8.2.3**:	Live load Impact, I =	30%	for 0'-0" < H < 1'-0"
		20%	for 1'-1" < H < 2'-0"
		10%	for 2'-1" < H < 2'-11"
		0%	for H ≥ 3'-0"

So, for this structure: Depth of Fill, H=	7.00	ft
I =	0%	
(1+I) =	1.00	

OWNER		SHEET NO	1	OF	4
SECTION		COMP. BY	JAK	DATE	9/24/2012
DESCRIPTION	Test 1	CHECK BY		DATE	



Pressure on the tire contact area is distributed on the culvert through the cover depth, Dimension as:

$W_D = W_W + 1.75H$

$L_D = L_W + 1.75H$

The surface tire contact area for HS20 loading (per AASHTO 3.30):

W_W = 20" =	1.67	ft
L_W = 10" =	0.83	ft

The tire surface contact area for Legal MI Trucks is assumed to be the same as the HS 20 truck.

The tire surface contact area for MI overload vechicles is considered to be part of the measurement for wheel spacing on axle (out to out)

Fill depth, H (ft)	7.00
Structure Total Length, L (ft)	114.00
Clear Roadway Width (Face to face of gaurdrail) (ft)	43.00
Lane Width (ft)	12.00
Number of Lanes	3

Factored Truck Load at Depth

	HS20	MI 1-Unit	MI 2-Unit	MI 3-Unit	MI Overload
Controling Truck	**1-Axle**	**Truck 4**	**Truck 17**	**Truck 23**	**Class A** ←
wheel spacing on axle	6.00	6.00	6.00	6.00	8.00
$W_{D\ wheel}$ (ft)	13.92	13.92	13.92	13.92	
$W_{D\ axle(total)}$	19.92	19.92	19.92	19.92	20.25
Max W_D/lane provided by structure	13.42	13.42	13.42	13.42	55.25
Rating W_D	13.42	13.42	13.42	13.42	20.25
FACTORED Operating Truck Line Load + Impact (k/ft)	3.18	2.87	3.60	3.12	7.00
Factored Load on Culvert, $\rho_{(L+I)}$	0.24	0.21	0.27	0.23	0.35
Factored $T_{(L+I)}$ (k/ft)	1.82	1.64	2.06	1.78	2.65

Transverse pressure overlaps are considered. Longitudinal pressure overlaps are considered for each MI truck configuration

MDOT

OWNER		SHEET NO	1	OF	4
SECTION		COMP. BY	JAK	DATE	9/24/2012
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Load Rating Factors for Ring Compression Structures:

Operating Load Rating Factor (RF_O):

a. RF_O based on wall strength

$$RF_{O-W} = \frac{T_{cap} - 1.95\,T_E}{T_{(L+I)}}$$

*Note: $T_{(L+I)}$ is factored

b. RF_O based on minimum cover requirements

$$RF_{O-C} = \frac{H^2}{C(h)^2}$$

Where, $C = 2.36\frac{H}{S} + 0.528 \le 1.0 =$ 1.00

So, RF_{O-C} = 13.34

Note: The equation has an upper limit of 1.0, therefore if the calculation is greater than 1.0 a value of 1.0 is to be used.

Operating Load Rating Factors, RF_O					
	HS20	MI 1-Unit	MI 2-Unit	MI 3-Unit	MI Overload
T_{cap}	41.54	41.54	41.54	41.54	41.54
T_E	6.44	6.44	6.44	6.44	6.44
Factored $T_{(L+I)}$	1.82	1.64	2.06	1.78	2.65
Is culvert burried deep enough to neglect LL?	NO	NO	NO	NO	NO
RF_{O-W}	15.96	17.70	14.10	16.24	10.94
RF_{O-C}	13.34	13.34	13.34	13.34	13.34
RF_O	13.34	13.34	13.34	13.34	10.94

Note:

2. Inventory Load Rating Factor (RF_I):

a. RF_I based on wall strength

$$RF_{I-W} = \frac{3}{5} RF_{O-W}$$

b. RF_I based on minimum cover requirements

$$RF_{I-C} = \frac{H^2}{h^2}$$

Inventory Load Rating Factor, RF_I	
	HS20
RF_{I-W}	9.57
RF_{I-C}	13.34
RF_I	9.57

Load Rating Summary:				
		Controling Truck	Rating Factor	Warnings:
Inventory	Federal	HS20	RF=9.57	
Operating	Federal	HS20	RF=13.34	
	MI 1-Unit	Truck 4	RF=13.34	
	MI 2-Unit	Truck 17	RF=13.34	
	MI 3-Unit	Truck 23	RF=13.34	
	MI Overload	Class A	RF=10.94	

9/28/12 JAK

MDOT CMP LEFR

INPUT - STRUCTURE INFO

LOAD FACTORS

REMOVE g_{LL} (OHIO LEGAL LOADS - OPERATING - BASED ON AADT,

FROM SPREADSHEET & LEFR LOAD FACTORS TABLE

gLL could be removed because it is different for each MI truck and was removed for CG state specific vehicles, not for the design truck

ϕ_s & TABLE 6A.4.2.4-1

DO NOT SEE A SUPERSTRUCTURE TYPE THAT

MATCHES CMP

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FORMULA FOR "OPERATING LOAD RATING FACTOR"

AND "INVENTORY LOAD RATING FACTOR" AND

OPERATING LOAD RATING FACTORS, RF_o" TABLE

updated, CG

* SYMBOLS SHOULD BE UNIFORM

$\gamma_{EV} = g_{EV}$

$\gamma_{LL} = g_{LL}$

PAGE 8 OF 10

FOR C

NOTE THAT IF ≤ 1.0 USE CALCULATED NUMBE

IF > 1.0 USE 1.00

updated, CG

LRFR SPREADSHEET HAND CALCULATIONS CHECK

CRITICAL BUCKLING STRESS

$S = 15.33' = 183.96''$

IF $S < \frac{0.6840}{0.22}\sqrt{\frac{24(29{,}000)}{45}} = 386.7$ IN

THEN $f_{cr} = 45 - \frac{(45)^2}{48(29{,}000)}\left(\frac{0.22(183.96)}{0.6840}\right)^2$

$f_{cr} = 39.91$ ✓

FOR HL-93 TRUCK TANDEM

T_{CAP}
(1.) 62.8 (3.) 41.5
(2.) 75.9

$T_{CAP} = 0.67(62) = 41.5$ ✓

$W_D = 1.67 + 1.15(7)$

$W_D = 9.72$ ✓

$L_D = 0.83 + 1.15(7)$

$L_D = 8.88$ ✓

$T_E = 6.44$ ✓
(1.) 6.44
(2.) 0.00

$\rho_{(LL+IM)} = \frac{4.04}{12.02} = 0.34$ ✓

$T_{(LL+IM)} = 0.34(15.33/2) = 2.61$

$= (0.34)(15.33) = 5.21$ ✓ 5.16 ✓ ROUNDING ISSUE

$T_{(LL+IM)}$ TRUCK LOAD DEPTH TABLE
CHECKED OTHER TRUCKS OK

OPERATING LOAD RATING FACTOR

$$RF_{O-W} = \frac{(1.00)(41.5) - 1.95(1.05)(6.44)}{1.35(2.58)}$$

$= 8.13$ ✓ 8.15 OK

OPERATING RF OK

$$RF_{O-C} = \frac{(7.0)^2}{1.00(1.92)^2}$$

$= 13.29$ ✓ 13.34 OK

✓ 66

$C = 2.36\left(\frac{7.00}{15.33}\right) + 0.52$

$= 1.61 \leq 1.00$

* ADD NOTE:
IF ≤ 1.0 USE NUMBER
IF > 1.0 USE 1.00

INVENTORY LOAD RATING FACTOR (RF_i)

$$RF_{i\text{-}W} = \frac{1.00(41.5) - (1.95)(1.05)(6.44)}{1.75\,(2.58)}$$

$$= 6.27 \checkmark \qquad 6.29 \checkmark$$

$$RF_{i\text{-}C} = \frac{(7)^2}{(1.92)^2} = 13.29 \checkmark \qquad 13.34 \checkmark$$

INVENTORY RF

OK

$$RF_i = MIN = 6.29 \checkmark$$

FOR MI OVERLOAD

$f_{cr} = 39.91$ ← FROM PREVIOUS CALC.

$T_{CAP} = 41.5$ $T_E = 6.44$

$W_{D\,WHEEL} = 9.72$

$W_{D\,AXLE} = 16.05$ ✓

OPERATING LOAD FACTOR

$$RF_{O-W} = \frac{(1.00)(41.5) - 1.95(1.05)(6.44)}{(1.00)(4.67)}$$

$= 6.06$ ✓ 6.07 ✓

$RF_{O-C} = 13.34$ FROM PREVIOUS CALC. $C = 1.00$ FROM PREVIOUS CALC

$RF_O = 6.07$ ✓ ← OPERATING

INVENTORY LOAD FACTOR

$$RF_{i-W} = \frac{(1.00)(41.5) - (1.95)(1.05)(6.44)}{(1.75)(2.58)}$$

$= 6.27$ ✓ 6.29 ✓ ← INVENTORY

$RF_{i-C} = 13.34$ ✓ FROM PREVIOUS CALC.