Load Rating of Metal Structures & Concrete Arches Under Fill






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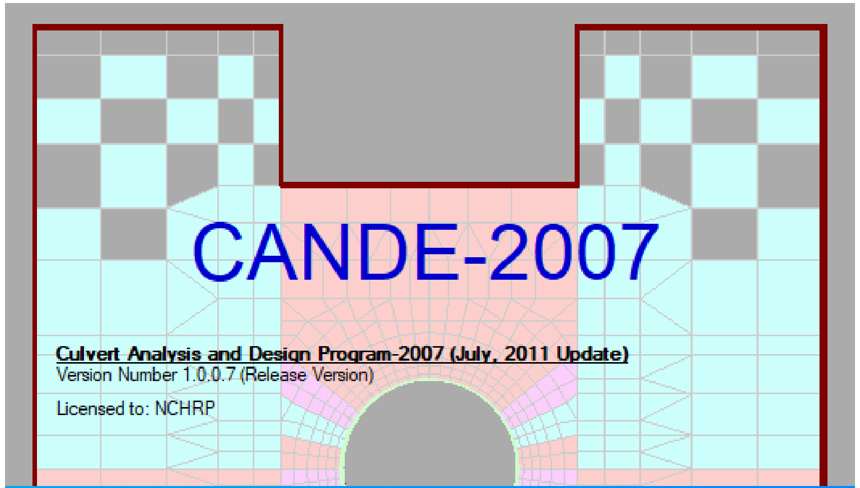
Under Fill Load Rating Progress & Application Development

- **2011** AASTHO/TRB sponsored upgrades to CANDE-2007
- **2011-2012** Load ratings performed to generate H20 and HS20 Inventory and Operating LFR ratings for all under fill structures using CANDE: **C**ulvert **AN**alysis and **DE**sign.

  > 900 Under Fill Structues
  ~ 470 CANDE Models
- **~2015** AASHTOWare BrR introduced the Culvert Analysis engine for reinforced concrete under fill slab structures.
- Ohio Department of Transportation shared a Metal Culvert spreadsheet with other DOTs.
- **2020** FHWA deadline for INDOT to complete and document all legal load ratings for all bridges.
- **2022** CANDE Tool Box companion program useful for load rating.
- **2022** AASHTOWare BrR version 7.3 introduced Metal Culvert engine.



Culvert Load Rating Research

- **NCHRP Project 15-28:** Mlynarski, M., M.G. Katona, and T.J. McGrath. NCHRP Report 619: Modernize and Upgrade CANDE for Analysis and Design of Buried Structures. Transportation Research Board of the National Academies, Washington, D.D., 2008.
  - The product of this research is CANDE-2007.
  - In 2011, the CANDE-2007 software was updated to run on current versions of Windows
- **NCHRP 15-54:** Mlynarski, M., M.G. Katona, T.J. McGrath, and C. Clancy. **Proposed** Modifications to AASHTO Culvert Load Rating Specifications, Submitted July 2019.
  - Developed and executed full scale field tests on seven culverts. (Maryland, Massachusetts, Ohio, & Pennsylvania)
  - Developed and executed full analysis of subject culverts in both 3D and 2D.
  - Surveyed DOTs for current practices related to culvert rating. Ohio DOT and Michigan DOT provided Metal Culvert Spreadsheets.
  - Review current specification to determine where improvements could be made to the rating process.
  - 2022 CANDE Tool Box and revisions to CANDE analysis engine were developed to facilitate research.
  - Concrete Box models compared with AASHTOWare BrDR

Under Fill Structures Missing Plans and/or Necessary Details

~190 Underfill structures, missing plans and/or necessary details rated using engineering judgment.

INDOT inspection assess culvert condition.

Select design vehicle based on year of construction. Use simple span moment comparison to generate all legal load rating factors.

Manual for Bridge Evaluation, *3rd Edition, Section 6.1.4 – Bridges with Unknown Structural Components*

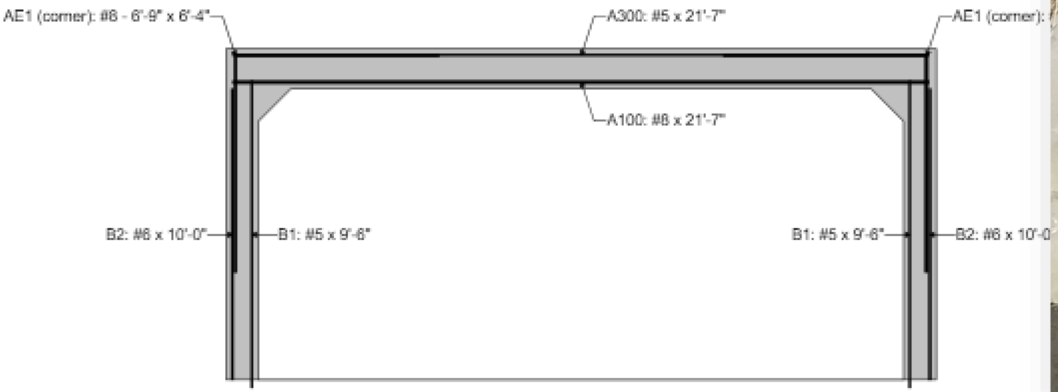
Average SU7 Legal RF = 1.6 *(INDOT)*

Span Length	EJ Design RF	Design Vehicle			Legal Vehicles												Emergency Vehicle		
(ft)	HS20-44	H20-44	HS20-44	Min	H20-44	HS20-44	Alternate	AASHTO T	AASHTO T	AASHTO T	Lane-Type	SU4	SU5	SU6	SU7	Min RF	EV2	EV3	Min RF
10		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
20	1.0	1.0	1.0	1.00	1.7	1.7	1.4	1.9	2.1	2.4		1.7	1.6	1.5	1.5	**1.37**	2.0	1.4	**1.35**
30		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
40		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
50		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
60		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
70		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
80		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
90		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
100		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	
110		0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	

Reinforced Concrete Slabs & Box Structures Under Fill

~180 Underfill slab structures, previously rated using CANDE

Converted to AASHTOWare BrR following the introduction of the Culvert Analysis engine for under fill slab structures.



Average SU7 Legal RF = 2.8 *(INDOT)*

Metal Pipe Structures Under Fill

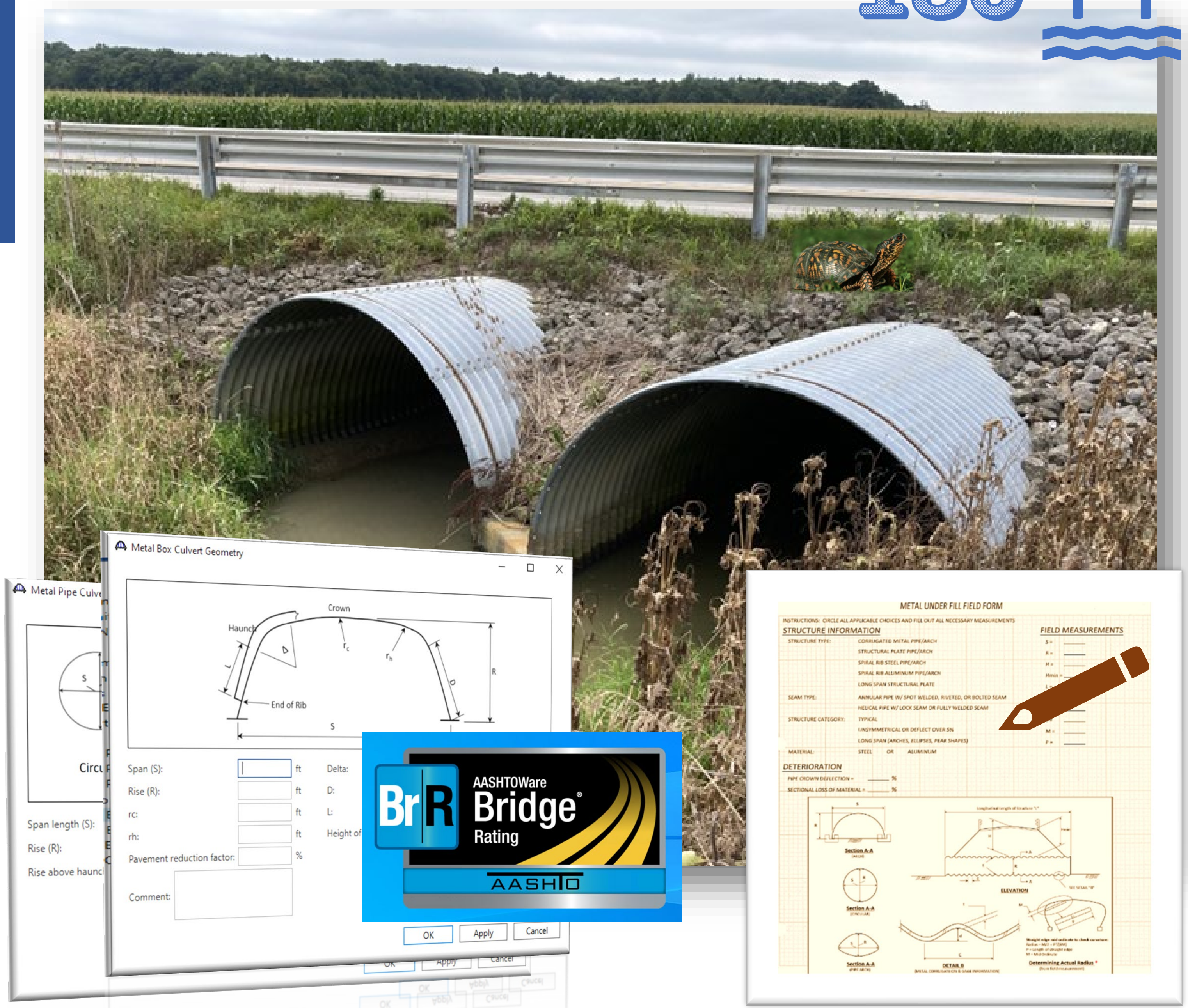
~180 Pipe structures rated using spreadsheet developed based on Design Data Sheet No. 19

Coordinated with INDOT inspection to collect field measurements.

Average SU7 Legal RF = 11.6 *(INDOT)*

Chris Andrzejewski, PE
Project Team Leader
United Consulting

2022 AASHTOWare BrR 7.3 introduced Metal Culvert engine.



Reinforced Concrete Arch Structures Under Fill

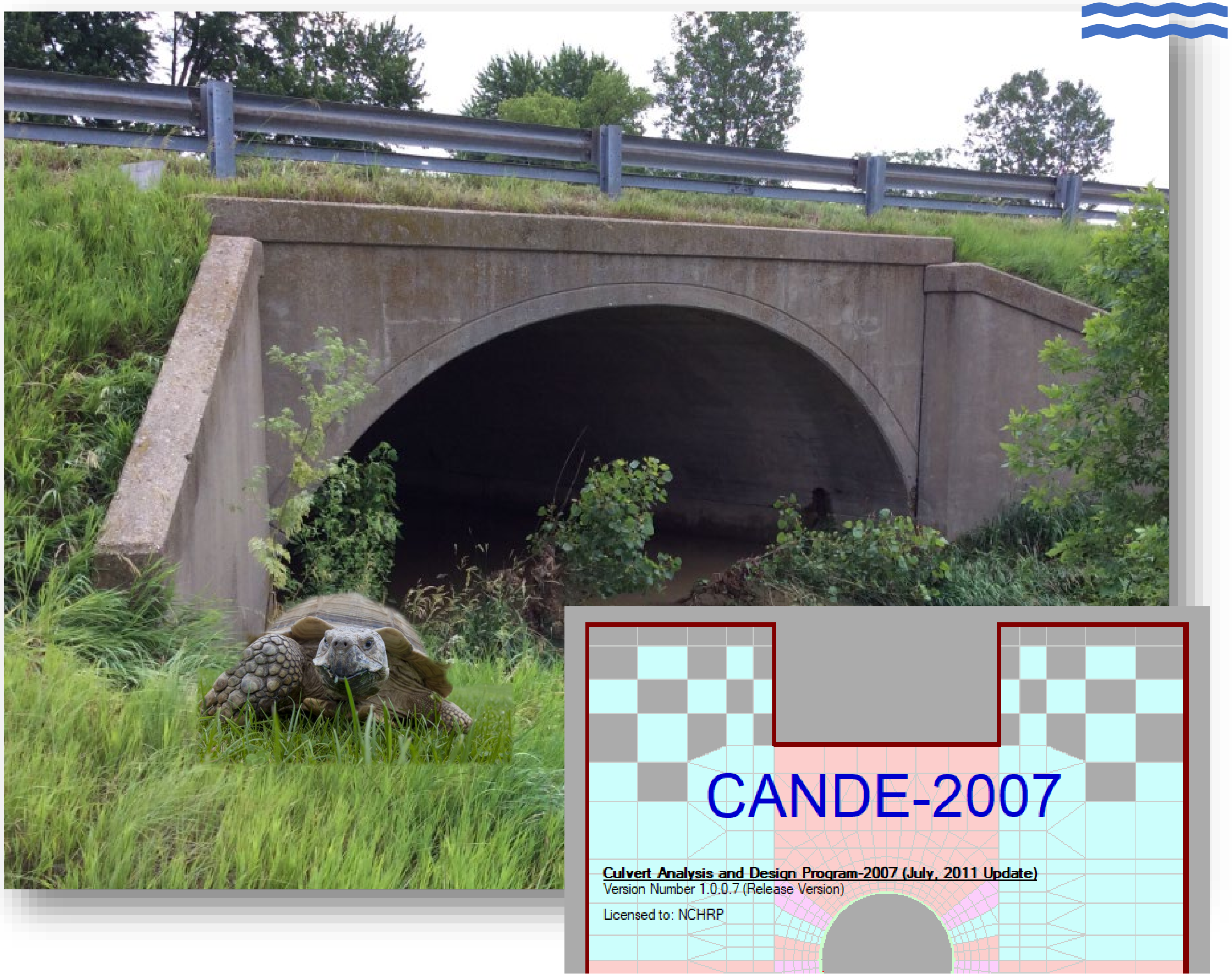
~410 Rated using existing CANDE models & 2022 CANDE Tool Box.

2D FEA program developed for the structural design and analysis of soil bridges, buried culverts and underground structures.

Average SU7 Legal RF = 3.2 *(INDOT)*

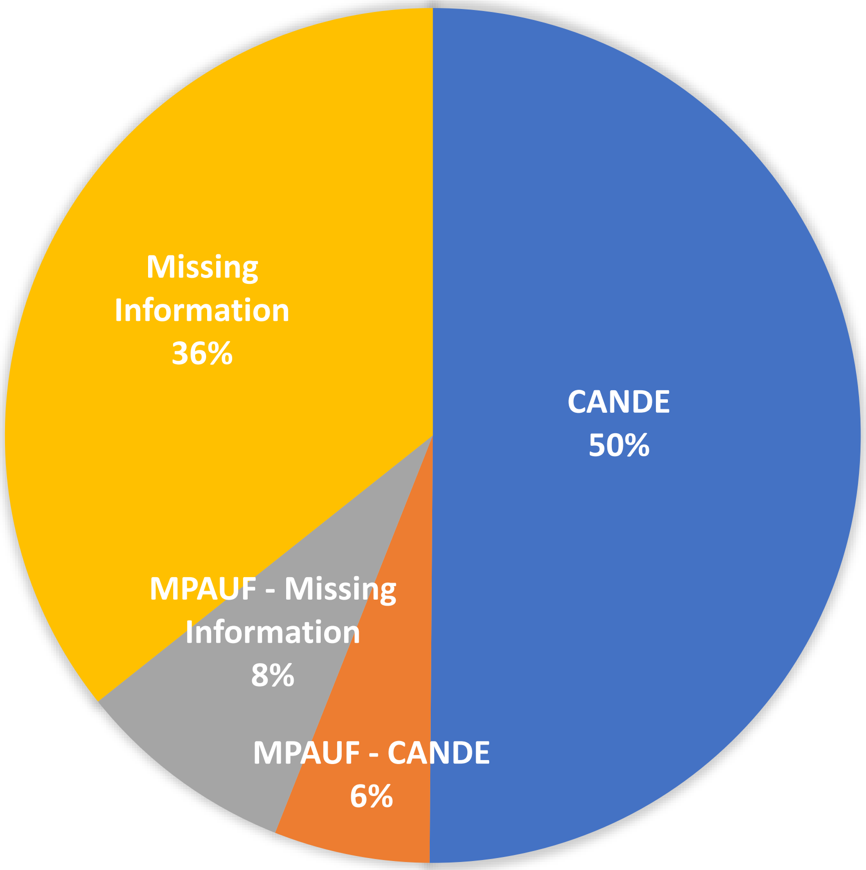
Amy Huebschman, PE
Structures Service Lead
EMCS, Inc

Future AASHTOWare BrR Enhancements planned to develop Concrete Arch engine.

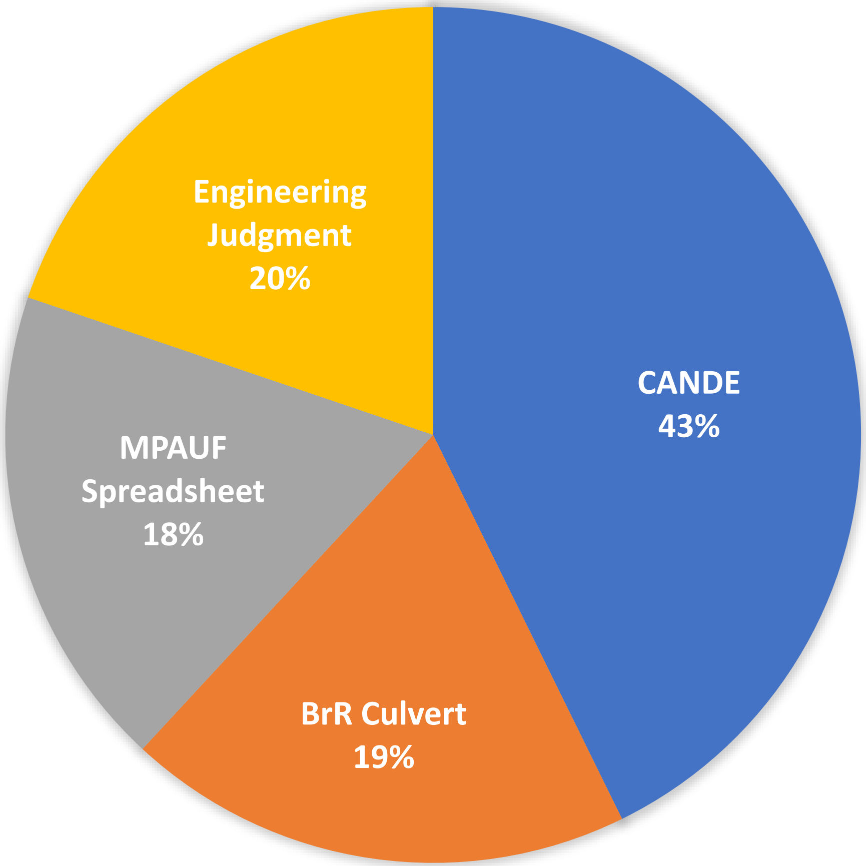


Progress of Under Fill Evaluations

2012

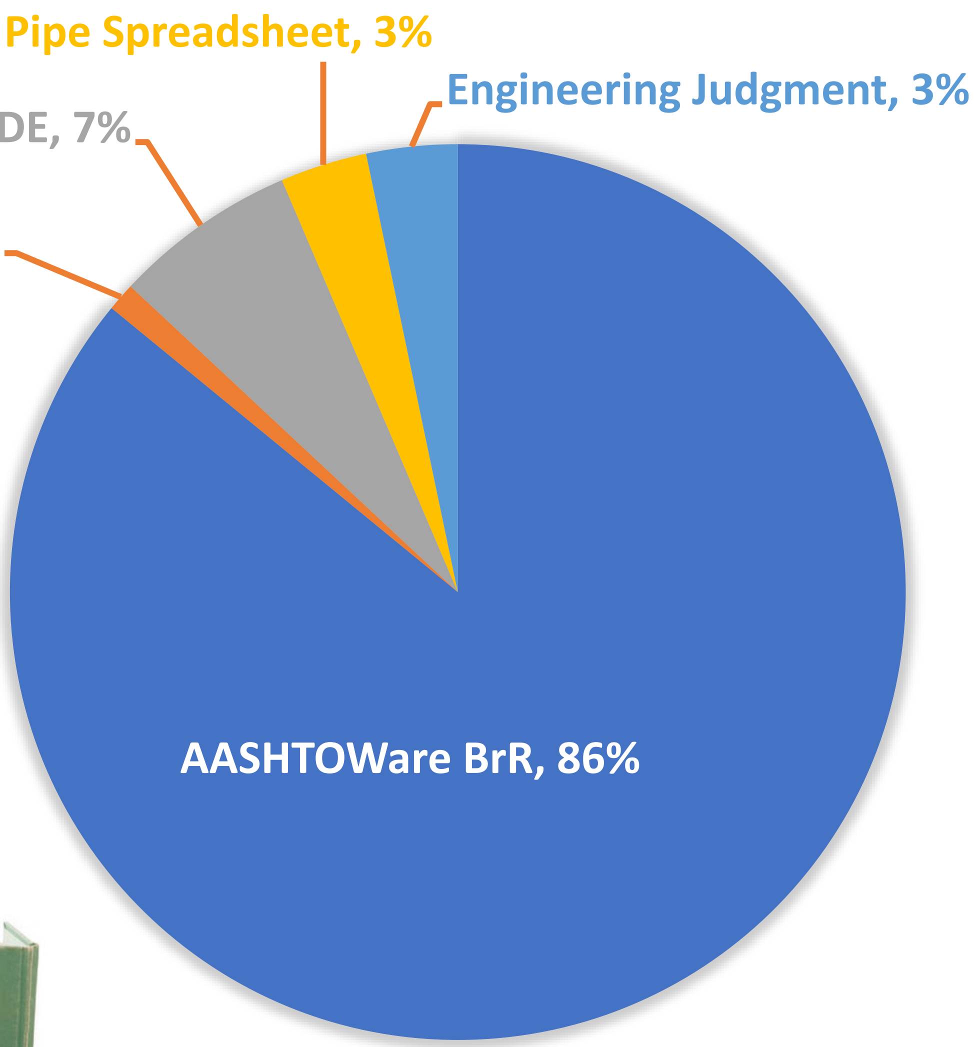


2022



Legal load ratings generated & decreased number of load ratings performed using Engineering Judgment

2023 Rating Program Used for INDOT Bridges



Load Rating Metal Structures Under Fill

Load Rating Metal Structures Under Fill

Which Structure Types?

- Corrugated Metal Pipes
- Long Span Structures
  - Horizontal ellipses
  - Low and high profile arches
  - Inverted pear shapes and pear arches
- Structural Plate Box Culverts

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Why?

- Because Jennifer Hart said so?
- INDOT Bridge Inspection Manual (BIM) 3-5.0

3-5.0 METHODS

Analytical methods should be used for load rating whenever possible. Engineering judgment may be used to supplement calculations. If necessary, when bridge geometry or material properties are not available and cannot be obtained economically, then engineering judgment may be used in place of analytical methods. In addition, a more conservative rating may be determined at the discretion of the Bridge Owner; this may mean posting the bridge at a lower tonnage than required by analysis.

AASHTOWARE Bridge Rating (BrR) shall be used to perform load ratings whenever possible. It is permissible to use other programs and/or engineering judgment in cases where the use of BrR is insufficient or not plausible due to program limitations. Additional resources are available on the bridge design website including a list of programs that may be used to supplement BrR.

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Background Information

- Load Rating Method
  - LRFR Methodology (Strength Limit State per LRFD 12.5.3)
  - Based on ODOT's CMP and Structural Plate Box Culvert Spreadsheets
    - Made public for use and modification
- Spreadsheet Assumptions
  - Ignores culvert skew to the roadway
  - Constant cover depth
  - Distributed load width is less than the culvert length
  - Single lane loaded only (including MPF) per LRFD 3.6.1.2.6a

Load Rating Metal Structures Under Fill

Topics Covered

- Required information from field inspection notes and/or plans
- Overview of Spreadsheets
  - Changes needed to ODOT's spreadsheets
  - Methodology
- NCHRP 15-54: Proposed Changes to AASHTO Culvert Rating Specifications
- Incorporation into AASHTOWare BrR Version 7.3

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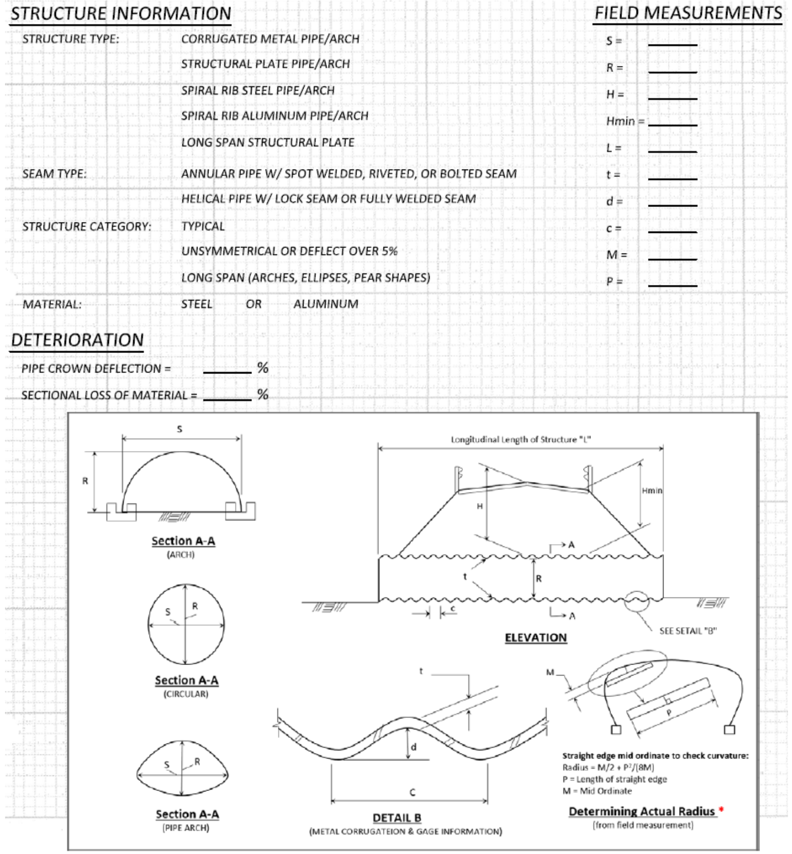
Required Information for Pipes and Long Spans

- Dimensions and properties
  - Structure type, seam type, span, rise, top radius, length, corrugation, metal thickness
- Cover*
- Deterioration*
  - Section loss
  - Deflection in the top
  - Seam failure (missing bolts/rivets)

*Within the travel way


STRUCTURE INFORMATION

STRUCTURE TYPE: CORRUGATED METAL PIPE/ARCH
STRUCTURAL PLATE PIPE/ARCH
SPIRAL RIB STEEL PIPE/ARCH
SPIRAL RIB ALUMINUM PIPE/ARCH
LONG SPAN STRUCTURAL PLATE

SEAM TYPE: ANNULAR PIPE W/ SPOT WELDED, RIVETED, OR BOLTED SEAM
HELICAL PIPE W/ LOCK SEAM OR FULLY WELDED SEAM

STRUCTURE CATEGORY: TYPICAL
UNSYMMETRICAL OR DEFLECT OVER 5%
LONG SPAN (ARCHES, ELLIPSES, PEAR SHAPES)

MATERIAL: STEEL OR ALUMINUM

FIELD MEASUREMENTS

S = ____
R = ____
H = ____
Hmin = ____
L = ____
t = ____
d = ____
c = ____
M = ____
P = ____

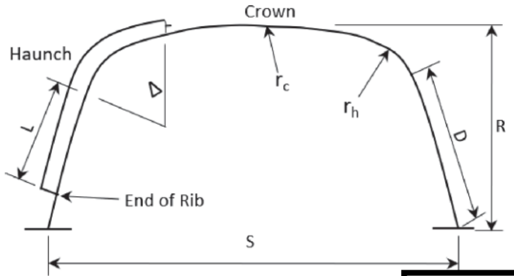
DETERIORATION

PIPE CROWN DEFLECTION = ____ %
SECTIONAL LOSS OF MATERIAL = ____ %

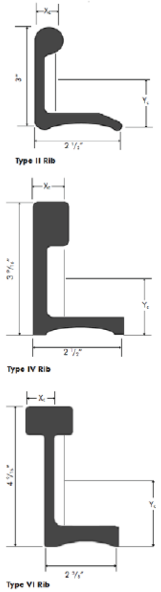
Required Information for Boxes

- Dimensions and properties
  - Span, rise, length, corrugation, metal thickness (crown AND haunch), inside bolt spacing (crown AND haunch)
- Cover*
- Deterioration*
  - Section loss
  - Deflection
  - Seam failure (missing bolts)

*Within the travel way



Geometry of Box



# of N
Crown ________
Haunch ________
Leg ________
Total ________

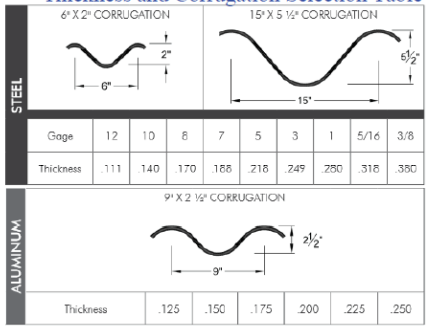
N = bolt spacing (as seen on underside of box)

Three of the these measurements are required. Crown N is the easiest to obtain. Leg measurement is also important. Leg measurement is from the bottom of the box to the start of the radius (will be a X.5 N).

ALUMINUM ARCHES
Rise (R) ________
Span (S) ________
Fill ________
Crown Thickness ________
Haunch Thickness ________
Crown Rib Spacing ________
Haunch Rib Spacing ________
Rib Type (Picture) ________

STEEL ARCHES
Rise (R) ________
Span (S) ________
Fill ________
Crown Thickness ________
Haunch Thickness ________
Crown Rib Spacing ________
Haunch Rib Spacing ________
Rib Dimensions ________

Thickness and Corrugation Selection Table



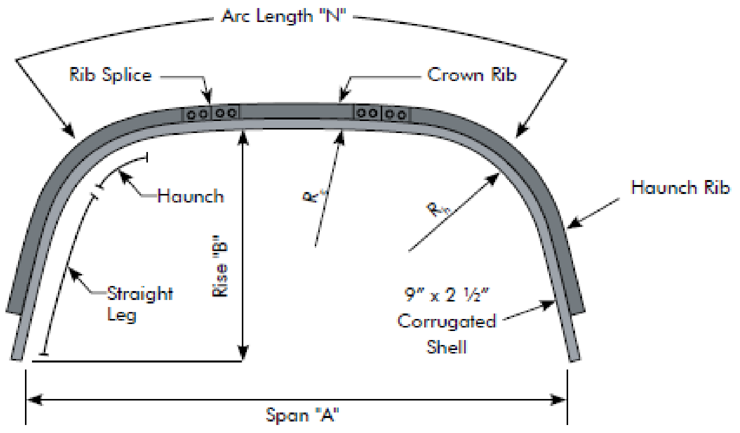
STEEL									
Gage	12	10	8	7	5	3	1	5/16	3/8
Thickness	.111	.140	.170	.188	.218	.249	.280	.318	.380

ALUMINUM						
Thickness	.125	.150	.175	.200	.225	.250

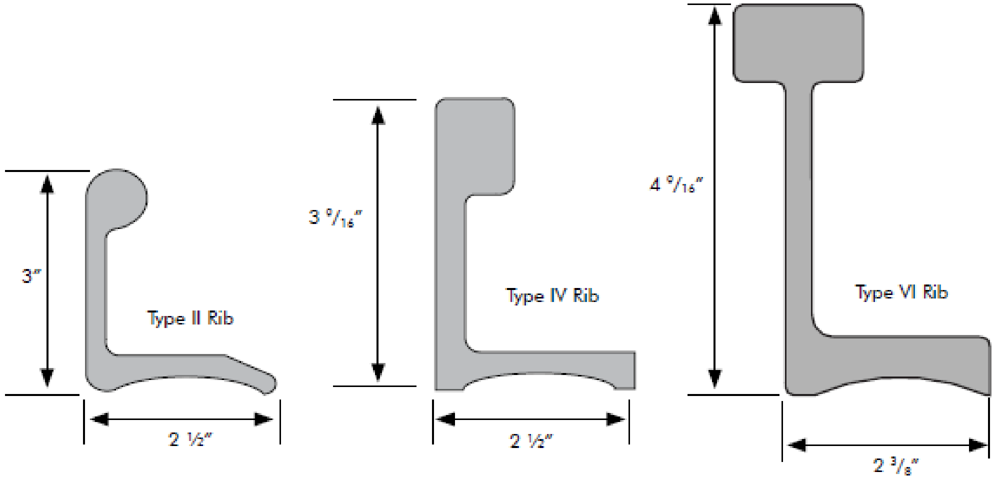
Load Rating Metal Structures Under Fill

Deeper Dive into Structure Identification

- Contech's Structural Plate Design Guide
- Parts: Crown, Haunch, Rib, Leg, Arc
- Bolt spaces - (N)
- Required Information
  - Arc Length (N) or Crown Plate (N) or Crown Rib Length (N)
  - Haunch Plate (N) or Haunch Rib Length (N)
  - Straight Leg Length (N)



Box Culvert Shell Cross Section
(see page 70)



Box Culvert Rib Geometry

Image from Contech's Structural Plate Design Guide

Corrugated Metal Pipe (and Long Span) Load Rating Spreadsheet Overview

- Utilizes NCSPA procedure (NCSPA Design Data Sheet No. 19)
- LRFD 12.7 for calculating capacity and loads
- Rating Factors based on Capacity:

$$RF = \frac{C \pm \gamma_{dc} DC \pm \cancel{\gamma_{DW} DW} \pm \gamma_{EV} EV \pm \cancel{\gamma_{EH} EH} \pm \cancel{\gamma_{ES} ES}}{(\gamma_{LL})(LL + IM) \pm \cancel{(\gamma_{AW})(AW)}}$$

$$C = \varphi_c \varphi_s \varphi R_n$$

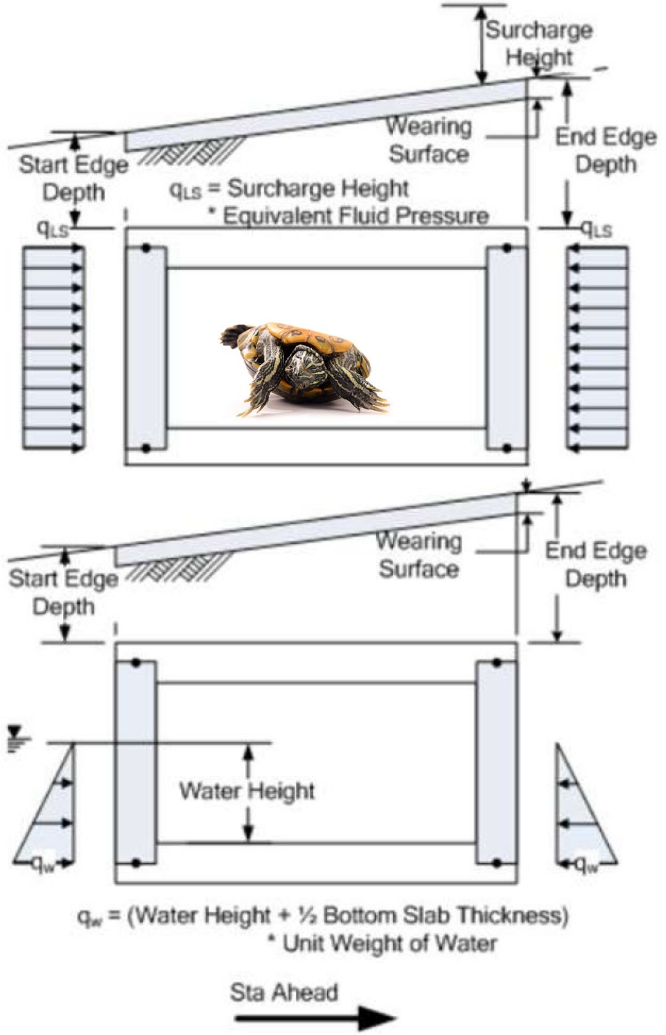
- Rating Factor based on AASHTO Minimum Cover Requirements:

RF = $H^2/(C \times h^2)$

Load Rating Metal Structures Under Fill

BrR 7.3 vs CMP Load Rating Spreadsheet

- Includes the ability for additional thrust due to the wearing surface and hydrostatic/saturated soil
- Allows multiple lanes loaded and varying fill depth
- Will ignore live load effects if criteria in LRFD 3.6.1.2.6a* is met (RF --> 99)
    - *NCHRP 15-54 has proposed changes to this criteria



Load Rating Metal Structures Under Fill

CMP Load Rating Spreadsheet Overview

- Input Tab – Structure dimensions and information
- Output Tab – Calculations and rating factors
- Reference Tabs – Code references, section properties tables, steam strength tables, NCSPA Design Data Sheet No. 19, Critical Load Parameter

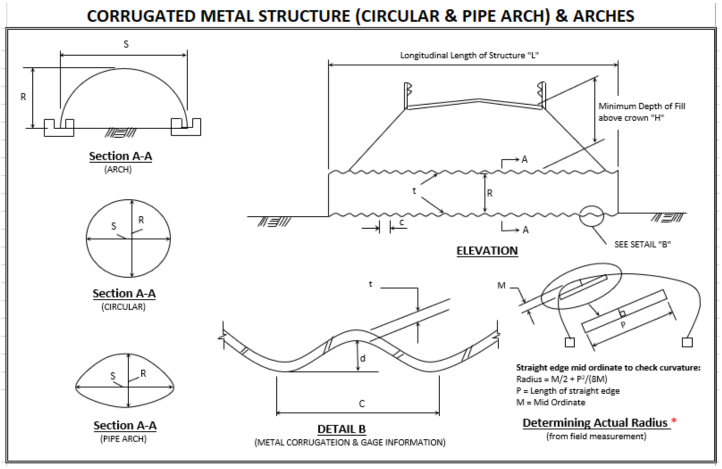


Table A12-1—Corrugated Steel Pipe—Cross-Section Properties

1 ½ × ¼ in. Corrugation			
Thickness (in.)	A (in.^{2}/ft)	r (in.)	$I \times 10^{-3}$ (in.^{4}/in.)
0.028	0.304	—	—
0.034	0.380	—	—
0.040	0.456	0.0816	0.253
0.052	0.608	0.0824	0.344
0.064	0.761	0.0832	0.439
0.079	0.950	0.0846	0.567
0.109	1.331	0.0879	0.857
0.138	1.712	0.0919	1.205
0.168	2.098	0.0967	1.635

NCSPA DESIGN DATA SHEET NO. 19 — **LOAD RATING AND STRUCTURAL EVALUATION OF IN-SERVICE, CORRUGATED STEEL STRUCTURES**

serviceability.

a. Bolt torque is not critical to strength as long as bolts are tight and the plates are properly nested.

b. Missing bolts should be replaced. They can be accounted for in structural calculations by a ratio of the number of bolts present to the number assumed in tabulated strength values.

c. If there is metal loss in the seam area, reduce seam strength by interpolating between the seam strength for adjacent gage thicknesses vs. actual thickness.

C. Design Calculations

1. Follow AASHTO Bridge Specification Methods as referenced. *Flexibility Factor evaluations, which bear only on installation stiffness, are not applicable since the structure is already in place.*
2. Evaluate each section of the structure along its length.
   a. Sections are determined by:
      1) Thickness (gage) changes in pipe walls or plates.
      2) Changes in shape or material condition.
   b. Check each section at points of:
      1) Maximum cover
      2) Minimum cover in areas subject to traffic. *Minimum cover requirements do not apply in sections without traffic loads.*
3. Where less than minimum cover conditions exist in traffic areas with special backfill materials, load relief slabs, or special design, a special analysis is required.

III. LOAD RATING
(Applicable only to sections carrying traffic. Follow all structure evaluation guidance and base calculations on H20, 32 KIP axle)

A. Basic AASHTO Equations:

Max. Strength = 1.3 [βD + RF (L+I)] - Operating Load

Max. Strength = 1.3 [βD + $\frac{5}{3}$ RF (L+I)] - Inventory Load

1. Where:
   a. Maximum Strength is the maximum design strength
   b. RF = Rating Factor
   c. D = Dead Load
   d. L + I = Live Load + Impact
   e. 1.3 = Load Factor γ
   f. β = Load Factor.
      Note: β = 1.0 *for conventional bridges;* β > 1.0 *for flexible pipes.*
2. For corrugated steel structures
   a. Maximum strength is:
      1) Max. allowable thrust (T_{cap}) for ring compression structures.
      2) Maximum allowable moment (M_{cap}) for box culverts.
   b. Dead load is the earth cover load:
      1) T_E; earth load thrust for ring compression structures.
      2) M_E; earth load bending moment for box culverts.
   c. Total earth load, load factor (β x γ) required is:
      1) 1.95 for ring compression structures. Therefore, β = 1.5
      2) 1.50 for box culverts. Therefore, β = 1.15

4

Table A12-7—Minimum Longitudinal Seam Strength Corrugated Aluminum and Steel Pipe—Riveted or Spot Welded

2 × ½ and 2 ⅔ × ½ in. Corrugated Aluminum Pipe			
Thickness (in.)	Rivet Size (in.)	Single Rivets (kip/ft)	Double Rivets (kip/ft)
0.060	5/16	9.0	14.0
0.075	5/16	9.0	18.0
0.105	3/8	15.6	31.5
0.135	3/8	16.2	33.0
0.164	3/8	16.8	34.0

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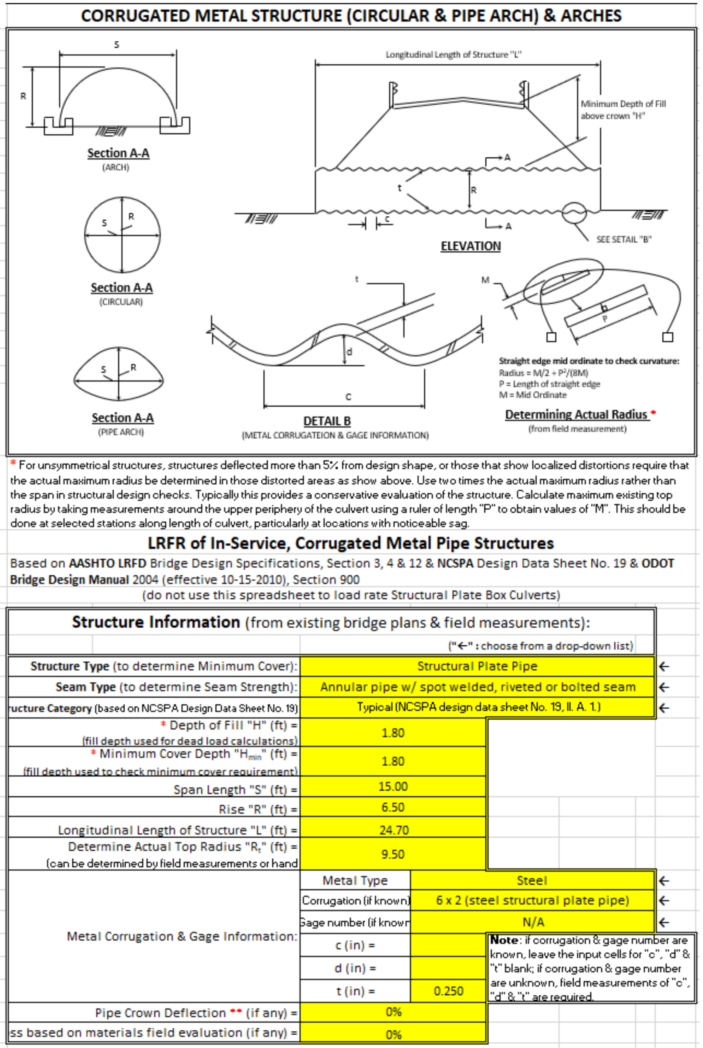
CMP Load Rating Spreadsheet Overview – Input Tab

- Fill in yellow cells with measurements and structure information
- Refer to tables on the side and reference tabs for information



CORRUGATED METAL STRUCTURE (CIRCULAR & PIPE ARCH) & ARCHES

* 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.

LRFR of In-Service, Corrugated Metal Pipe Structures

Based on **AASHTO LRFD** Bridge Design Specifications, Section 3, 4 & 12 & **NCSPA** Design Data Sheet No. 19 & **ODOT Bridge Design Manual** 2004 (effective 10-15-2010), Section 900

(do not use this spreadsheet to load rate Structural Plate Box Culverts)

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

("←" : choose from a drop-down list)

Structure Type (to determine Minimum Cover):	Structural Plate Pipe		←
Seam Type (to determine Seam Strength):	Annular pipe w/ spot welded, riveted or bolted seam		←
ructure Category (based on NCSPA Design Data Sheet No. 19)	Typical (NCSPA design data sheet No. 19, II. A. 1.)		←
* Depth of Fill "H" (ft) = (fill depth used for dead load calculations)	1.80		
* Minimum Cover Depth "H_{min}" (ft) = (fill depth used to check minimum cover requirement)	1.80		
Span Length "S" (ft) =	15.00		
Rise "R" (ft) =	6.50		
Longitudinal Length of Structure "L" (ft) =	24.70		
Determine Actual Top Radius "R_t" (ft) = (can be determined by field measurements or hand	9.50		
Metal Corrugation & Gage Information:	Metal Type	Steel	←
	Corrugation (if known)	6 x 2 (steel structural plate pipe)	←
	Gage number (if known	N/A	←
	c (in) =		
	d (in) =		
	t (in) =	0.250	
Pipe Crown Deflection ** (if any) =	0%		
ss based on materials field evaluation (if any) =	0%		

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.

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Input Tab – Deviations/Additions from ODOT

- Culvert Condition Rating (NBI Item 62) – Condition Factor
- η_R – Redundancy Factor – 1.05 --> 1.00 per LRFD 12.5.4
- EV Legal Load LLDF per INDOT Bridge Inspection Manual (BIM) Part 3 Table 6A.4.4.2.3c-1 based on NCHRP 20-07 Task 410

Table 6A.4.4.2.3c-1 - Generalized Live Load Factors γ_L for FAST Act Emergency Vehicles

EV Frequency	Traffic Volume (One Direction)	Live Load Distribution	EV2	EV3
10 EV crossings per day	ADTT < 1000 free flowing	Two or more lanes DF[a]	1.10	1.10
	ADTT > 6000 free flowing		1.40	1.10
	ADTT > 6000 congested		1.50	1.20
10 EV crossings per day	ADTT < 1000 free flowing	From Refined Analysis	1.20	1.15
	ADTT > 6000 free flowing		1.50	1.35
	ADTT > 6000 congested		1.65	1.45
1 EV crossing per day	ADTT < 1000 free flowing	Two or more lanes DF[a]	1.10	1.10
	ADTT > 6000 free flowing		1.20	1.10
	ADTT > 6000 congested		1.30	1.10
1 EV crossing per day	ADTT < 1000 free flowing	From Refined Analysis	1.20	1.10
	ADTT > 6000 free flowing		1.30	1.20
	ADTT > 6000 congested		1.45	1.30

Notes:
[a] DF = LRFD-distribution factor. When one-lane distribution factor is used, the built-in multiple presence factor should be divided out.

Table from current INDOT Bridge Inspection Manual

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CMP Load Rating Spreadsheet Overview – Output Tab

- RF = $(C - \gamma_{DC}DC - \gamma_{EV}EV)/(\gamma_{LL}(LL+IM))$
- Capacity = Lesser of:
  - Wall Yield Strength
  - Wall Buckling Strength
  - Seam Strength
- Section Loss/Deflection accounted for in Wall Yield/Buckling Strength
- No straightforward guidelines to account for seam deterioration

C. Design Calculations:

Structure Type:	Corrugated Metal Pipe
Seam Type:	Annular pipe w/ spot welded, riveted or bolted seam
Longitudinal Length of Structure "L" (ft) =	24.70
AASHTO minimum cover, "h" (ft) =	1.88
Depth of cover used to check AASHTO minimum cover requirment "H_{min}" (ft) =	2.50
ϕ_{loss} = Section Properties reduction factor on the basis of metal loss from the materials field evaluation =	1.00
ϕ_1 = Resistance Factor for **wall area and buckling** (Table 12.5.5-1)	1.00
ϕ_2 = Resistance Factor for **seam strength** (Table 12.5.5-1)	0.67
δ = Soil density (k/ft^3)	0.120
k = soil stiffness factor =	0.22
ϕ_E = Factor for Distribution of Live Load with Depth of Fill based on Backfill Type (per AASHTO LRFD 3.6.1.2.6)=	1.15

Calculate the f_{cr} (critical buckling str (AASHTO LRFD 12.7.2.4)

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) =	180.00	<	$\frac{r}{k}\sqrt{\frac{24E_m}{F_u}}$ =	391.18
Therefore,	f_{cr} =	40.24	ksi		

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

Seam Strength (k/ft) =	132.0	
T_{cap} = less of:	1. wall yield strength = $\phi_1 \phi_{loss} F_y A$ =	120.5
	2. wall buckling strength = f $\phi_1 \phi_{loss} f_{cr} A$ =	146.9
	3. seam strength = ϕ_2 x (seam strength) =	88.4
Therefore, T_{cap} =	88.4	k/ft

CMP Load Rating Spreadsheet Overview – Output Tab

- $RF = (C - \gamma_{DC}DC - \gamma_{EV}EV)/(\gamma_{LL}(LL+IM))$
- Thrust due to Live Load and Dynamic Allowance:
  - ODOT and other states follow an older version of LRFD (conservative)
  - BrR follows current LRFD 3.6.1.2.6a*
    - *NCHRP 15-54 has proposed changes to the method of distribution
- Verify maximum number of axles for each vehicle to the span length

	H20-44	HS20-44	Alternate Military	AASHTO Type 3	AASHTO Type 3S2	AASHTO Type 3-3	Lane-Type*
Heavy Axle Load (kips)	32.00	32.00	24.00	17.00	15.50	14.00	10.50
$P_{heavy\ (1+IM)}$ (kips) =	19.96	19.96	14.97	10.60	9.67	8.73	6.55
$S_{axle\ 1}$ (ft) =	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Axle 2 Load (kips)	8.00	32.00	24.00	17.00	15.50	14.00	10.50
$P_{2\ (1+IM)}$ (kips) =	4.99	19.96	14.97	10.60	9.67	8.73	6.55
$S_{axle\ 2}$ (ft) =	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Axle 3 Load (kips)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$P_{3\ (1+IM)}$ (lbs) =	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_w (ft) =	6.00	6.00	6.00	6.00	6.00	6.00	6.00
H_{int} (ft) =	5.07	5.07	5.10	5.13	5.13	5.13	5.15
W_D (ft) =	4.33	4.33	3.91	3.55	3.47	3.49	3.29
W_D (ft) =	4.33	4.33	3.91	3.55	3.47	3.49	3.29
$H_{int\text{-}p}$ (ft) =	13.25	13.25	13.25	13.25	13.25	13.25	13.25
L_D (ft) =	3.16	3.16	3.16	3.16	3.16	3.16	3.16
$A_D = W_{D(total)} \times L_{D(total)}$ =	13.69	13.69	12.37	11.22	10.97	11.06	10.40
P_D (kips) =	19.96	19.96	14.97	10.60	9.67	8.73	6.55
$\rho_{(L+IM)} = P_D/A_D$ =	1.46	1.46	1.21	0.94	0.88	0.79	0.65
F_1 =	1.42	1.42	1.42	1.42	1.42	1.42	1.42
$T_{(L+IM)}$ (k/ft) =	3.28	3.28	2.72	2.13	1.98	1.78	1.46

$\rho_{(L+IM)}$ Increased for 0.2kip/ft for a 10' lane load

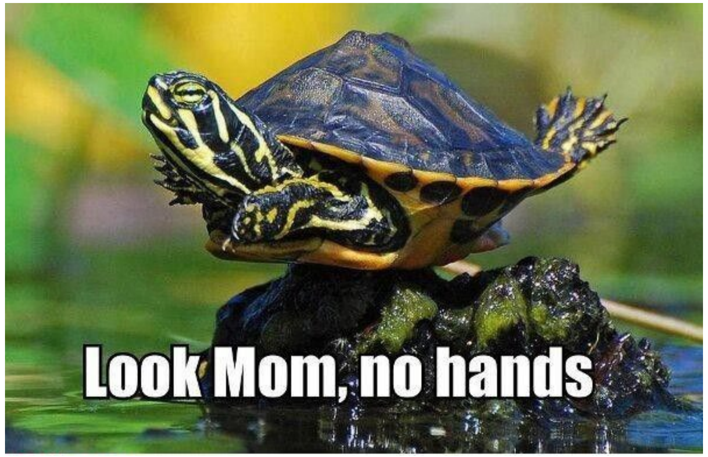
Output Tab – Deviations/Additions from ODOT

- Add INDOT Design, Legal, and Permit vehicles
- Update live load distribution to current LRFD code

Truck Configuration	LRFR Code Reference
H-20	MBE 6A.4.4.2.1a
HS-20	MBE 6A.4.4.2.1a
Alternate Military	MBE 6A.4.4.2.1a
AASHTO Type 3	MBE 6A.4.4.2.1a
AASHTO Type 3S2	MBE 6A.4.4.2.1a
AASHTO Type 3-3	MBE 6A.4.4.2.1a
Lane-Type*	MBE 6A.4.4.2.1a
EV2	MBE 6A.4.4.2.1a
EV3	MBE 6A.4.4.2.1a
NRL**	MBE 6A.4.4.2.1b
SU4	MBE 6A.4.4.2.1b
SU5	MBE 6A.4.4.2.1b
SU6	MBE 6A.4.4.2.1b
SU7	MBE 6A.4.4.2.1b

* Load and Resistance Factor Rating (LRFR) methodology only
** Not to be used for load posting. Not required for Engineering Judgment (EJ) methodology.

Figure 3-4.2 Required Legal Vehicles



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Structural Plate Box Culvert Load Rating Spreadsheet Overview

- Utilizes NCSPA procedure (NCSPA Design Data Sheet No. 19)
- LRFD 12.9 for calculating capacity and loads
- Rating Factors based on Capacity:

$$RF = \frac{C \pm \gamma_{dc} DC \pm \cancel{\gamma_{DW} DW} \pm \gamma_{EV} EV \pm \cancel{\gamma_{EH} EH} \pm \cancel{\gamma_{ES} ES}}{(\gamma_{LL})(LL + IM) \pm \cancel{(\gamma_{AW})(AW)}}$$

$$C = \varphi_c \varphi_s \varphi R_n$$

- Two Rating Factors:
  - Crown Capacity
  - Haunch Capacity

UNITED Consulting

Metal Box Load Rating Spreadsheet Overview

- Structural Plate Box Culvert Tab
  - Input: Structure dimensions and information, capacities, controlling axle group weight
  - Output: Load Rating Factor for crown and Load Rating Factor for haunch – use controlling RF
- Reference Tabs – Code references, section properties tables, NCSPA Design Data Sheet No. 19

UNITED Consulting

Continuing to Dive Deeper into Structure Identification...

- Structure Number using Table 49C
- Using Tables 48A and 48B:

  Structure Number

  + Haunch Gauge (HG)/Crown Gauge (CG)

  + Haunch Rib Spacing (HRS)/Crown Rib Spacing (CRS)

  + Cover

  => Rib Type + Verification of all information

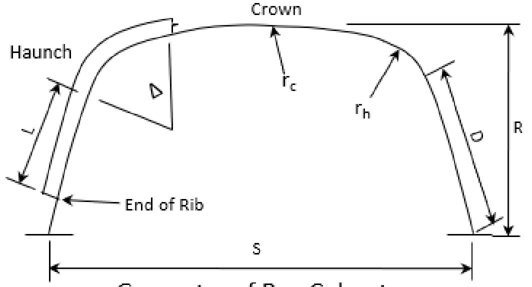
Photo showing rib bolt spacing in underside of structure

Metal Box Load Rating Spreadsheet Overview – Input

- Fill in yellow cells”
  - Structure information
  - Moment capacity
  - Axle group weight
  - Load factors
- Refer to tables on the side and reference tabs for information

LRFR of In-Service Structural Plate Box Culverts

Based on **AASHTO LRFD** Bridge Design Specifications, Section 12 & **NCSPA** Design Data Sheet No. 19 & **ODOT Bridge Design Manual** 2004 (effective 10-15-2010), Section 900



Geometry of Box Culverts

Geometric Requirements for Box Culverts		
S =	Span	8'-9" to 25'-5"
R =	Rise	2'-6" to 10'-6"
r_c =	Radius of crown	≤ 24'-9½"
r_h =	Radius of haunch	≥ 2'-6"
Δ =	Haunch radius included angle	50° to 70°
D =	Length of leg	measured to the bottom of the plate, may vary from 4¾" to 71"
L =	Minimum length of rib on leg	least of 19", (D-3.0)", or to within 3.0" of the top of a concrete footing.
H =	Height of cover from the box culvert rise to top of pavement	1.4' ≤ H ≤ 5.0'

* **Compare the actual field measurements with the geometric requirements listed here, this spreadsheet can not be used if the geometric requirements are not meet. In that case, special analysis maybe required.**

TABLE 33. PLATE & RIB COMPOSITE SECTION PROPERTIES

Rib Type	Spacing (Inches on Center)	Metal Thickness, Inches: 0.125	0.150	0.175	0.200	0.225	0.250
		Plastic Moment Capacity, M_p (kip-ft./ft.)					
No Rib		2.65	3.18	3.71	4.24	4.77	5.30
Type II	@ 54	4.62	5.46	6.04	6.61	7.17	7.74
	@ 27	6.18	7.25	7.94	8.60	9.25	9.87
	@ 18	7.41	8.66	9.48	10.26	11.00	11.71
	@ 9	10.63	12.13	13.08	14.05	15.03	16.02
Type IV	@ 54	5.87	6.82	7.43	8.04	8.63	9.21
	@ 27	8.32	9.59	10.39	11.14	11.85	12.55
	@ 18	10.42	11.90	12.84	13.72	14.57	15.39
	@ 9	16.45	18.46	19.41	20.38	21.37	22.37
Type VI	@ 54	8.74	9.51	10.24	10.95	11.64	12.32
	@ 27	13.76	14.33	15.16	16.19	17.36	17.48
	@ 18	20.09	20.56	20.79	21.30	21.74	22.58
	@ 9	32.24	34.35	36.46	38.54	39.88	40.63

TABLE 32. SECTION PROPERTIES OF PLATES ONLY
9" X 2-1/2" CORRUGATION

Thickness (Inches)	Moment of Inertia ($In.^4$/Ft.)	Section Modulus ($In.^3$/Ft.)	Radius of Gyration (Inches)	Area of Section ($In.^2$/Ft.)	Ultimate Seam Strength (kip/ft.)
0.100	0.997	0.767	0.844	1.404	28.0
0.125	1.248	0.951	0.844	1.750	41.0
0.150	1.499	1.131	0.845	2.100	54.1
0.175	1.751	1.309	0.845	2.449	63.7
0.200	2.004	1.484	0.846	2.799	73.4
0.225	2.258	1.657	0.847	3.149	83.2
0.250	2.513	1.828	0.847	3.501	93.1

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Metal Box Load Rating Spreadsheet Overview – Input

- Capacity
  - Moment is distributed between the crown and haunch based on their relative stiffness
  - Adjust ratio of crown load to make ratios equal
- Live Load
  - Looks at axle group producing largest load

Box Culvert Moment Capacity:

$M_{cap\ (Crown)}$ =	28.00	k-ft/ft
$M_{cap\ (Haunch)}$ =	12.00	k-ft/ft

M_{cap} is the moment capacity of the crown or haunch (M_p) adjusted for condition factors as shown in the appropriate table in Appendix D of **NCSPA Design Data Sheet No. 19** for **Steel** Box Culverts, see worksheet "**steel box Mp tables**" for M_p values. For **Aluminum** Box Culverts manufactured by CONTECH, see worksheet "**CONTECH-aluminum box Mp tables**" for M_p values. For Aluminum Box Culverts manufactured by other manufacturer, please contact the manufacturer for M_p values.

Then,	P_{C-1} =	0.45	← one extreme end of the P_c allowable range
	P_{C-2} =	0.70	← the other extreme end of the P_c allowable range
	$P_{C\text{-}adjusted}$ * =	0.67	
	C_H =	1.04	
	R_h =	0.87	
	K_1 =	0.11	
	K_2 =	8.70	
	M_{DL} =	4.14	k-ft/ft
	$M_{E\ (crown)}$ =	2.88	k-ft/ft
	$M_{E\ (haunch)}$ =	1.42	k-ft/ft

Adjust this (while staying within limits)

*The total axle load and No. of axles on the bridge need to

	HL-93 Truck	HL-93 Tandem	2F1*	3F*	4F1*	5C1*	SU4*
A_L (kips) =	32.0	50.0	20.0	34.0	42.0	34.0	42.0
Number of axles in load	1	2	1	2	3	2	3
Wheels per Axle	4	4	4	4	4	4	4
C_1 =	1.00	0.80	1.00	0.80	0.80	0.80	0.80
C_2 =	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C_{LL} (kips) =	32.00	40.00	20.00	27.20	33.60	27.20	33.60
M_{LL} (k-ft/ft) =	6.09	7.61	3.81	5.18	6.39	5.18	6.39
$M_{LL\ (crown)}$ (k-ft/ft) =	4.23	5.28	2.64	3.59	4.44	3.59	4.44
$M_{LL\ (haunch)}$ (k-ft/ft) =	1.81	2.26	1.13	1.54	1.90	1.54	1.90
$M_{cap\ (Crown)}$ / $M_{cap\ (Haunch)}$ =	2.33	2.33	2.33	2.33	2.33	2.33	2.33
$M_{LL\ (Crown)}$ / $M_{LL\ (Haunch)}$ =	2.33	2.33	2.33	2.33	2.33	2.33	2.33

So that these are equal or as close as possible

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Metal Box Load Rating Spreadsheet – Deviations/Additions from ODOT

- Add Culvert Condition Rating (NBI Item 62)
- Add structure information (rib spacing, plate thickness, etc.)
- η_R – Redundancy Factor – 1.05 --> 1.00 per LRFD 12.5.4
- EV Legal Load LLDF per INDOT BIM Part 3 Table 6A.4.4.2.3c-1 based on NCHRP 20-07 Task 410

TABLE 49C. ALBC STRUCTURE AREA, PLATE AND RIB MAKE-UP

Box #	Inside Dimensions		Total (N)	Crown			Haunch		Straight Leg Length D (N)	Side Angle E (deg.)
	Span (Ft.-In.)	Rise (Ft.-In.)		Arc Length (N)	Plate (N)	Rib Lengths Long/Short (N)	Plate (N)	Rib Length (N)		
1	8-9	2-6	14		NA		14	5.5	.5	
2	9-2	3-3	16				8	6.5	1.5	
3	9-7	4-1	18				9	7.5	2.5	
4	10-0	4-10	20	5		5/3	10	7.5	3.5	15.40
5	10-6	5-7	22				11	7.5	4.5	
6	10-11	6-4	24				12	7.5	5.5	
7	11-4	7-2	26				13	7.5	6.5	
8	10-2	2-8	16				8	6.5	.5	
9	10-7	3-5	18				9	7.5	1.5	
10	10-11	4-3	20				10	8.5	2.5	
11	11-4	5-0	22	7		7/3	11	8.5	3.5	13.55
12	11-8	5-9	24				12	8.5	4.5	
13	12-1	6-7	26				13	8.5	5.5	
14	12-5	7-4	28		TWO PLATE SHELL		14	8.5	6.5	
15	11-7	2-10	18				9	6.5	.5	
16	11-11	3-7	20				10	7.5	1.5	
17	12-3	4-5	22	9		9/5	11	8.5	2.5	11.70
18	12-7	5-2	24				12	8.5	3.5	
19	12-11	6-0	26				13	8.5	4.5	
20	13-3	6-9	28				14	8.5	5.5	
21	13-0	3-0	20				10	6.5	.5	
22	13-4	3-10	22				11	7.5	1.5	
23	13-7	4-7	24	11		11/7	12	8.5	2.5	9.87
24	13-10	5-5	26				13	8.5	3.5	
25	14-1	6-2	28				14	8.5	4.5	
26	14-5	3-3	22				11	6.5	.5	
27	14-8	4-1	24				8	7.5	1.5	
28	14-10	4-10	26				9	8.5	2.5	
29	15-1	5-8	28	13	8	13/9	10	8.5	3.5	8.02
30	15-4	6-5	30				11	8.5	4.5	
31	15-6	7-3	32				12	8.5	5.5	
32	15-9	8-0	34				13	8.5	6.5	
33	15-10	3-6	24				8	6.5	.5	
34	16-0	4-3	26				9	7.5	1.5	

Box #	Inside Dimensions		Total (N)	Crown			Haunch		Straight Leg Length D (N)	Side Angle E (deg.)
	Span (Ft.-In.)	Rise (Ft.-In.)		Arc Length (N)	Plate (N)	Rib Lengths Long/Short (N)	Plate (N)	Rib Length (N)		

Table from Contech's Structural Plate Design Guide

Metal Box Load Rating Spreadsheet – Deviations/Additions from ODOT

- Add INDOT Design, Legal, and Permit vehicles
- Add Dynamic Allowance to Live Load per LRFD 3.6.2.2
- Add Multiple Presence Factor per LRFD 3.6.1.2.6a
- Change C_2, adjustment coefficient for number of wheels per axle, table reference per LRFD C12.9.4.2

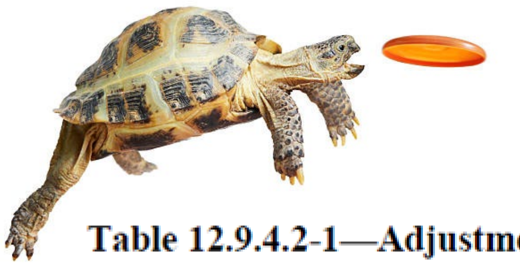

Table 12.9.4.2-1—Adjustment Coefficient Values (C_2) for Number of Wheels per Axle

Wheels per Notional Axle Group	Cover Depth (ft)			
	1.4	2.0	3.0	5.0
2	1.18	1.21	1.24	1.02
4	1.00	1.00	1.00	1.00
8	0.63	0.70	0.82	0.93

Table from LRFD 9

Metal Box Load Rating Spreadsheet – Tips for Low Ratings

- Take good photos to assist in proper structure identification
- Record accurate cover measurements (levels and string lines)
- Check plans for an accurate backfill density
- Reach out to Contech with the structure stamp information as they may have plans or additional information

Photo showing structure stamp on underside of crown plate

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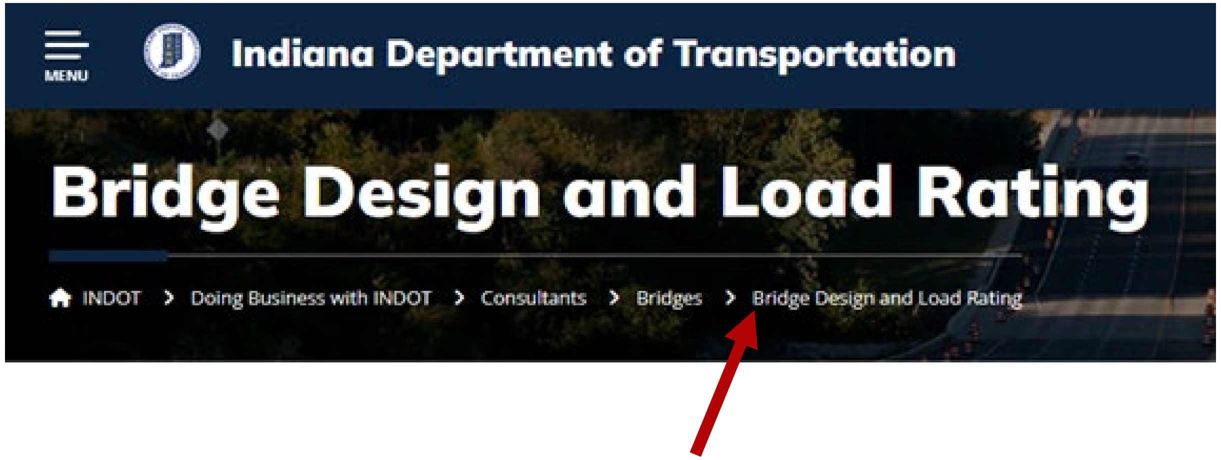
Load Rating Metal Structures Under Fill

- A link to ODOT’s webpage where the spreadsheet can be obtained will be hosted on INDOT’s Design and Load Rating page



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Oldest Bridge in the World

- Arkadiko Bridge (Kazarma Bridge)
- Est. ~1300 BC, Greece
- Greek Bronze Age, Mycenaen Period
- 72’-0” long with a 3’-0” Span



Load Rating Concrete Arches Under Fill

EMCS Load Rating Contract

- 78 Underfill Structures
- 31 Arches (New and Old)

Nabin Ghimire – EMCS

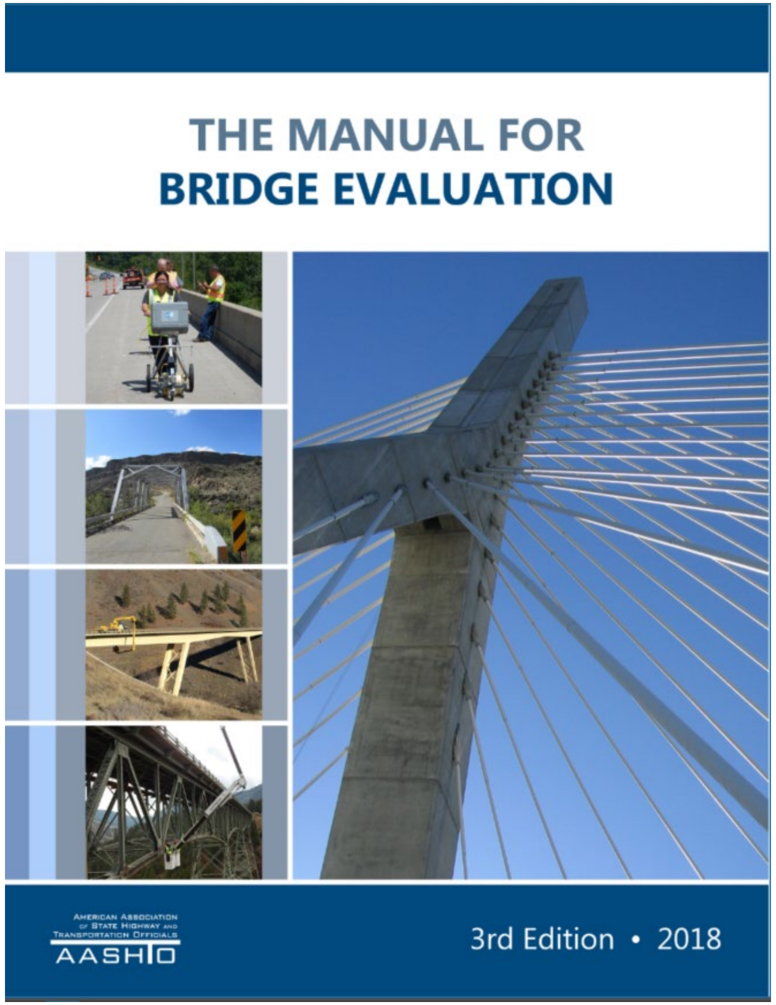
Mohamed Ahmed – Clark Dietz

emcs

Load Rating Concrete Arches Under Fill

Current Design Guidance

- INDOT Bridge Inspection Manual, Part 3 Load Rating
- AASHTO Manual for Bridge Evaluation, 3rd Edition with 2022 Interim Revisions
- AASHTO LRFD Bridge Design Specifications, 9th Edition, 2020
- CANDE – 2022 Culvert Analysis and Design Solution Methods and Formulations
- CANDE Tool-Box Manual for Load Rating



Load Rating Concrete Arches Under Fill

AASHTO MBE – 6A.10.4 Load Rating Equation for Culverts (Rev 2020)

$$RF = \frac{C \pm \gamma_{dc} DC \pm \gamma_{DW} DW \pm \gamma_{EV} EV \pm \gamma_{EH} EH \pm \gamma_{ES} ES}{(\gamma_{LL})(LL + IM) \pm (\gamma_{AW})(AW)}$$

$$C = \varphi_c \varphi_s \varphi R_n$$

Load Factors (Strength I)-

γ_{EV} = LRFD BDS TABLE 3.4.1-1

γ_{EH} = 1.35 Max, 1.00 Min (Rect. ONLY)

γ_{ES} = 1.50 Max, 0.75 Min

γ_{LL} = 2.00

γ_{AW} = 2.00 (Rect. ONLY)

- EV = Vertical Earth Pressure
- EH = Horizontal Earth Pressure
- ES = Uniform Earth Surcharge
- AW = Approaching Wheel Load

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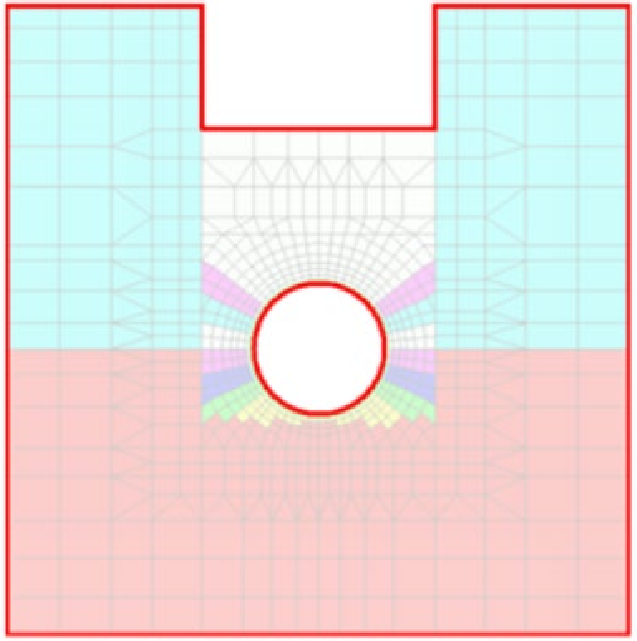
Load Rating Concrete Arches Under Fill

AASHTO MBE – 6A.10.3 Culvert Rating; Finite Element Modeling

- Finite Element Program is Routinely Used
- MBE.C6A.10.3.3, - CANDE
    - Continuous Load Scaling (CLS) – Spread Live Load Longitudinally
    - Soil Modeling - Duncan Soil Model
- LUSAS – Geotechnical Soil-Structure Interaction

LUSAS

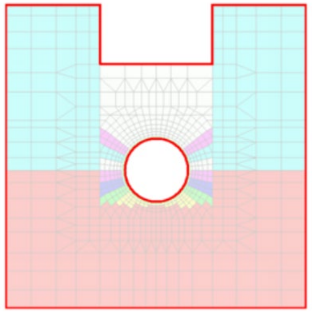
CANDE- 2022
Culvert Analysis and Design



Load Rating Concrete Arches Under Fill

CANDE Software - FHWA Sponsored Est. 1973 – 2022 (FREE)

CANDE- 2022
Culvert Analysis and Design



- https://www.candeforculverts.com/home

1. Download CANDE-2007 with 2011 Upgrade

2. Copy CANDE–2022 to Folder: C:\Program Files (x86)\CANDE-2007

This PC › Local Disk (C:) › Program Files (x86) › CANDE-2007

Name	Date modified	Type	Size
help	2/14/2023 3:17 PM	File folder	
AbanGeometry.dll	7/30/2011 12:16 PM	Application exten...	28 KB
absngnrl.dll	7/30/2011 12:16 PM	Application exten...	16 KB
CANDE_DLL.dll	6/30/2022 3:35 PM	Application exten...	2,640 KB
CANDE_InputData_ClassLibrary.dll	7/30/2011 12:16 PM	Application exten...	132 KB
CANDE_XML_ClassLibrary.dll	7/30/2011 12:16 PM	Application exten...	52 KB

3. Verify in Output Utilizing 2022

```
*** WELCOME TO CANDE-2022 (Version January, 2022) ***
```

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CANDE Overall Design Steps

1. Level 2 Half Mesh File
   - Pipe, Box and Arch
   - Auto Creates Finite Element Mesh (Nodes, Elements)
   - Many Existing Ratings in the Bridge File (ERMS)
2. Level 3 Full Mesh File via CANDE Tool Box
3. Level 3 Full Mesh File with Pavement Addition via CANDE Tool Box
4. Level 3 Full Mesh File with Moving Loads via CANDE Tool Box
5. Load Rating via CANDE Tool Box

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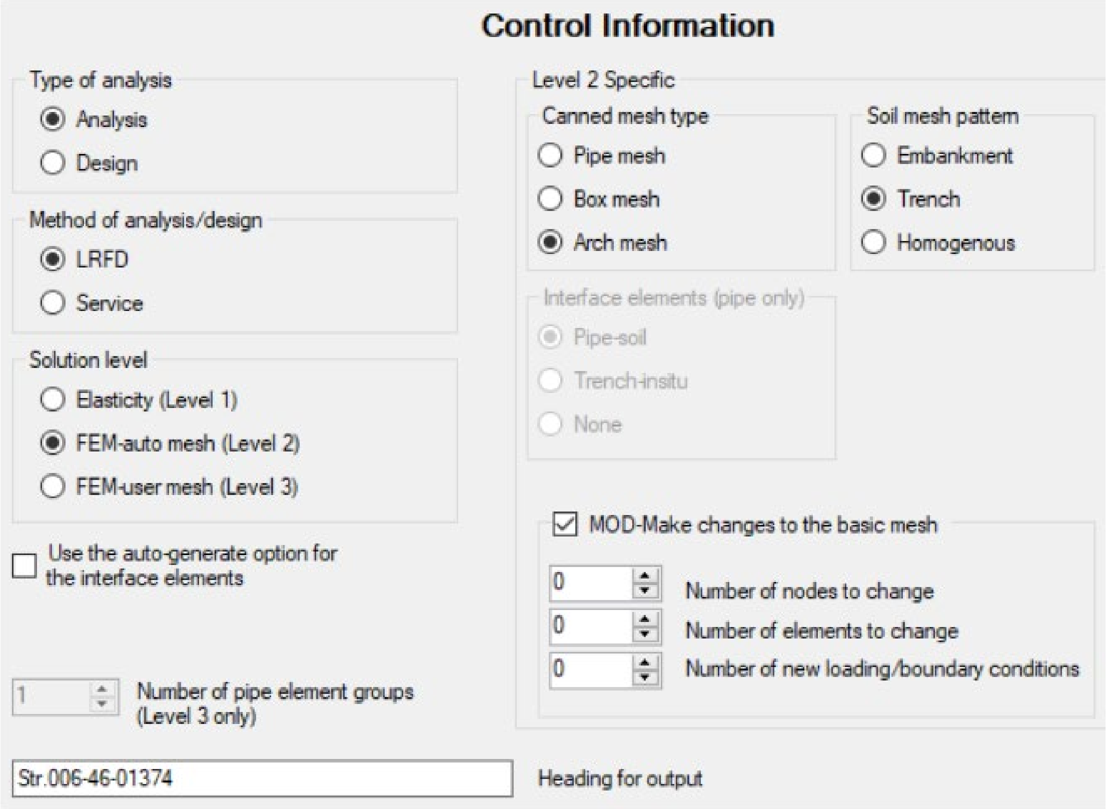
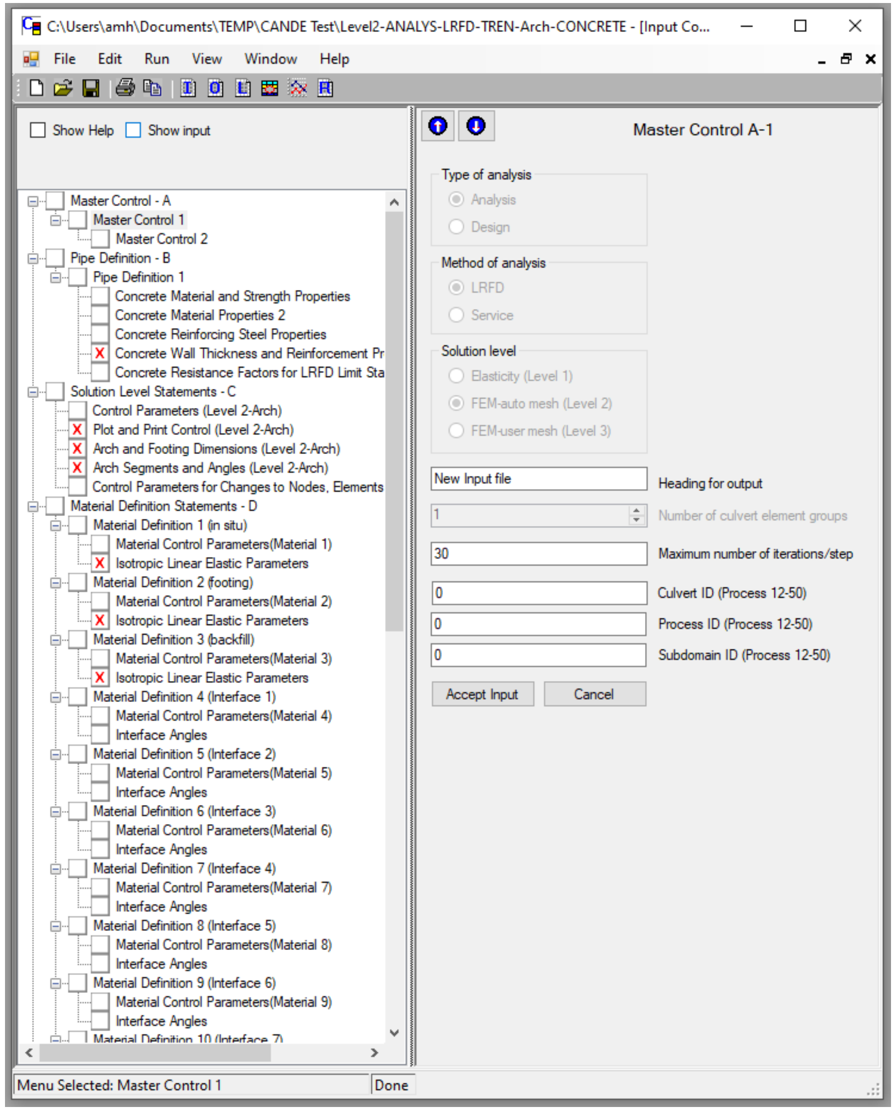
Step 1. CANDE Level 2 Half Mesh File - Geometric & Material Input

- New Model – Scratch
  - Have Template for Input
  - Arbitrary Reinforcement Shape Recommended (Varied Wall Thickness and Reinforcement)
  - CREATES LEVEL 2 with Missing Input

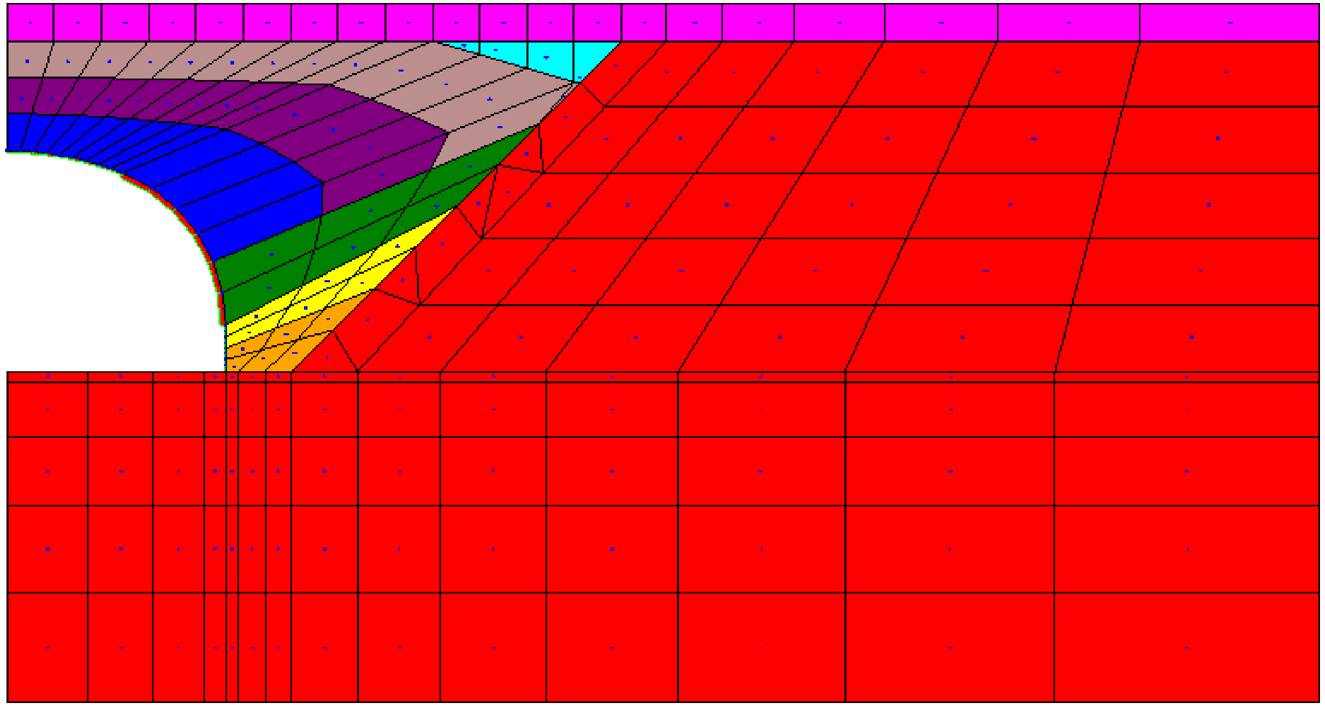
    = Level2.##-##-#####.cid
- FOLDER WITH FILES



CANDE Level 2 Half Mesh File - Geometric & Material Input



- Half Arch Mesh with Load Steps for backfill of arch



Load Rating Concrete Arches Under Fill

CANDE Level 2 Half Mesh File

- Material Properties (Pipe Definition 1)

Concrete

- Pipe Definition - B
  - Pipe Definition 1
    - Concrete Material and Strength Properties
    - Concrete Material Properties 2
    - Concrete Reinforcing Steel Properties
    - Concrete Wall Thickness and Reinforcement Properties (Arbitrary Shape)
    - Concrete Resistance Factors for LRFD Limit States

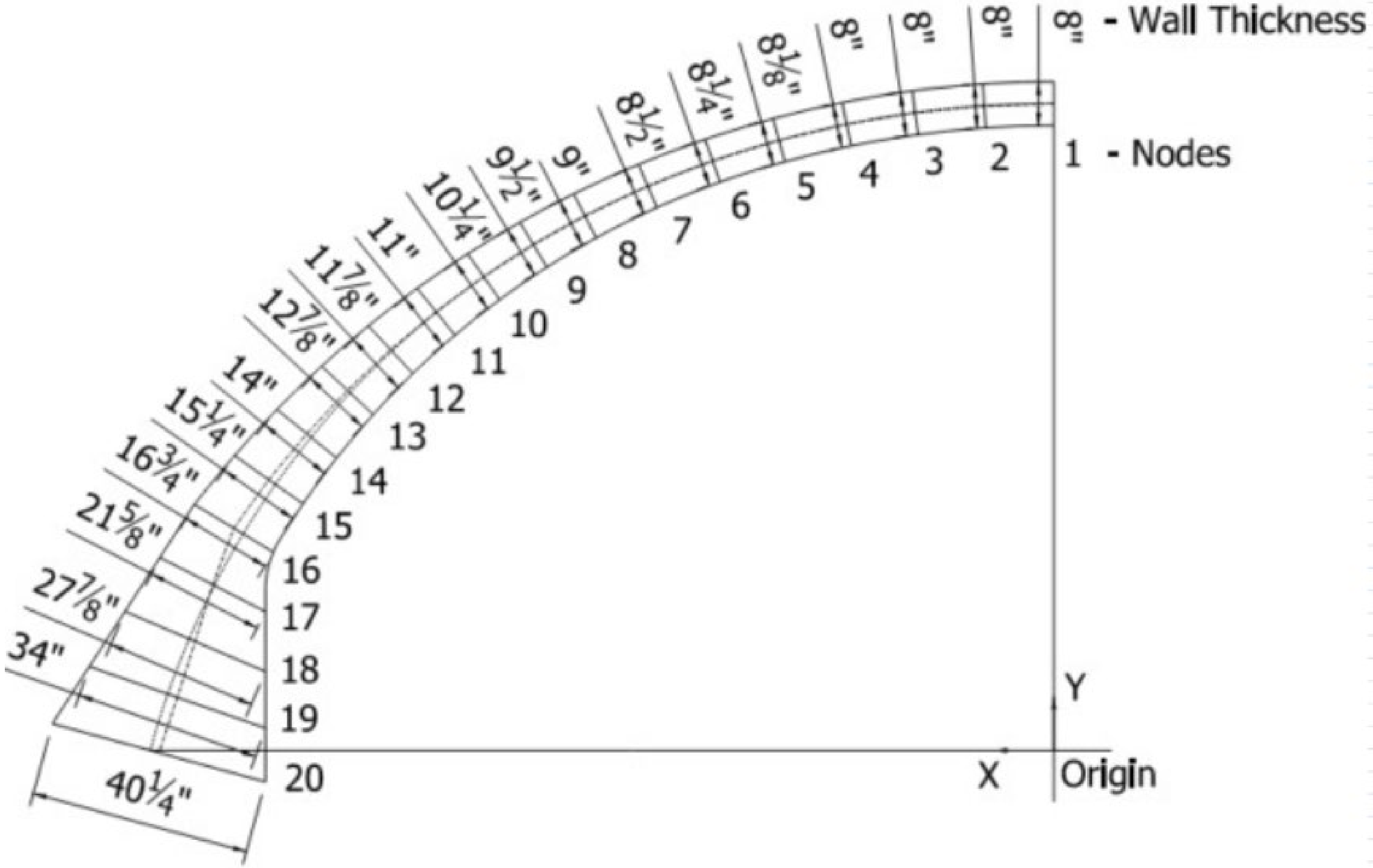
Material (Concrete) B-4

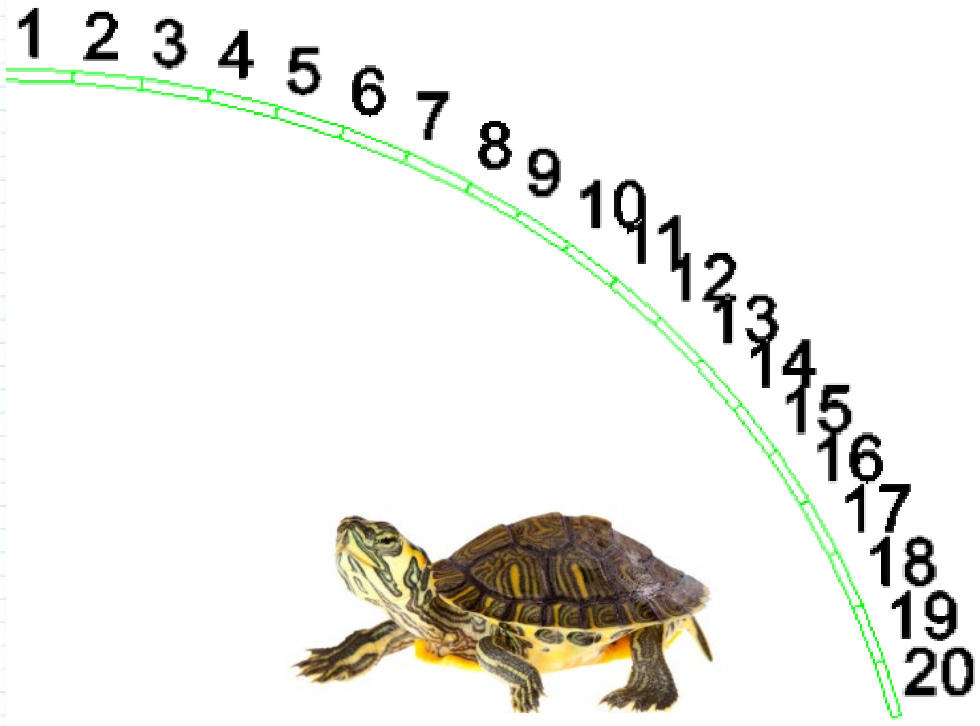
Arbitrary Specified Wall Thickness and Reinforcement Steel

	Wall thickness (in)	As Cage 1 (in^2/in)	As Cage 2 (in^2/in)	Cover Cage 1 (in)	Cover Cage 2 (in)
1	8	0.026	0.026	2	2
2	8	0.026	0.026	2	2
3	8	0.026	0.026	2	2
4	8	0.026	0.026	2	2
5	8.125	0.026	0.026	2	2
6	8.25	0.026	0.026	2	2
7	8.5	0.026	0.026	2	2
8	9	0.026	0.026	2	2
9	9.5	0.026	0.026	2	2
10	10.25	0.026	0.026	2	2
11	11	0.026	0.026	2	2
12	11.875	0.026	0.026	2	2
13	12.875	0.026	0.026	2	2
14	14	0.026	0.026	2	2
15	15.25	0.026	0.026	2	2
16	16.75	0.026	0.026	2	2
17	21.625	0.026	0.026	2	2
18	27.875	0.026	0.026	2	2
19	34	0.026	0.026	2	2
20	40.25	0.026	0.026	2	2

CANDE Level 2 Half Mesh File

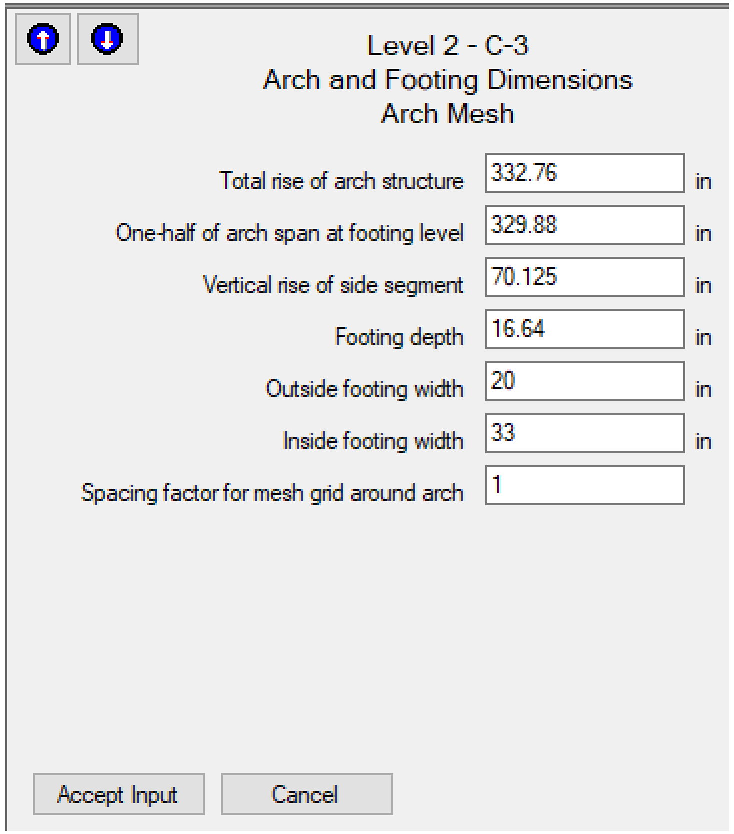
- Material Properties (Pipe Definition 1)

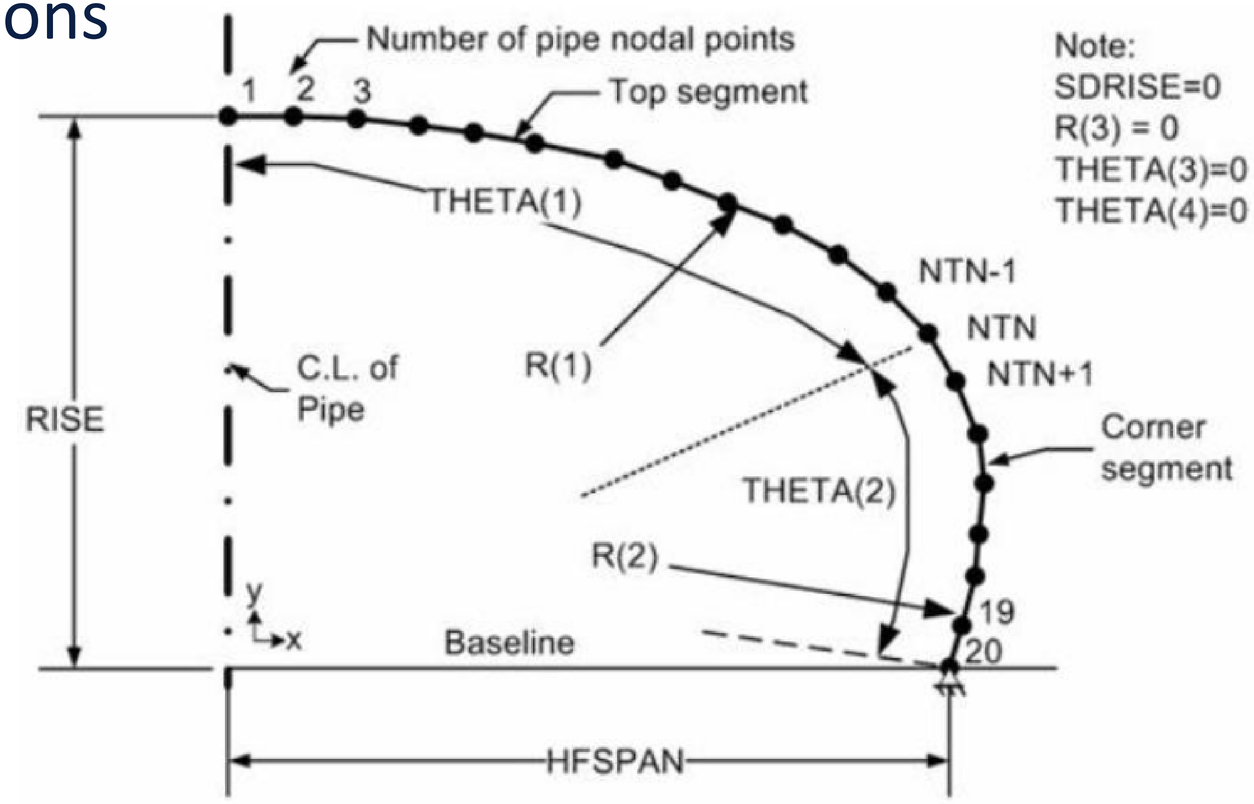




CANDE Level 2 Half Mesh File - Geometric Definitions

- Rise, ½ Span, Footing Dimensions
- Up to three Arch Segments

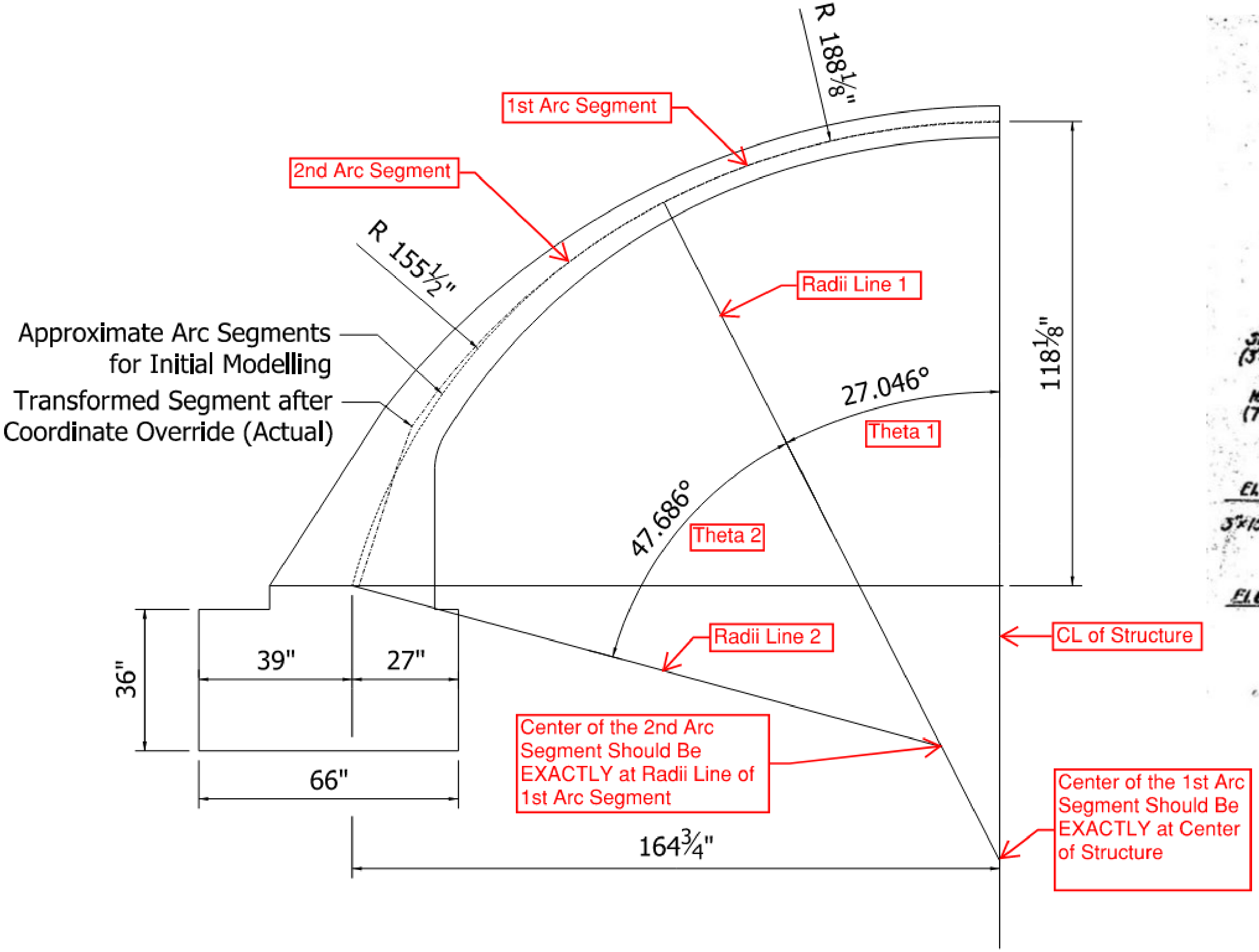


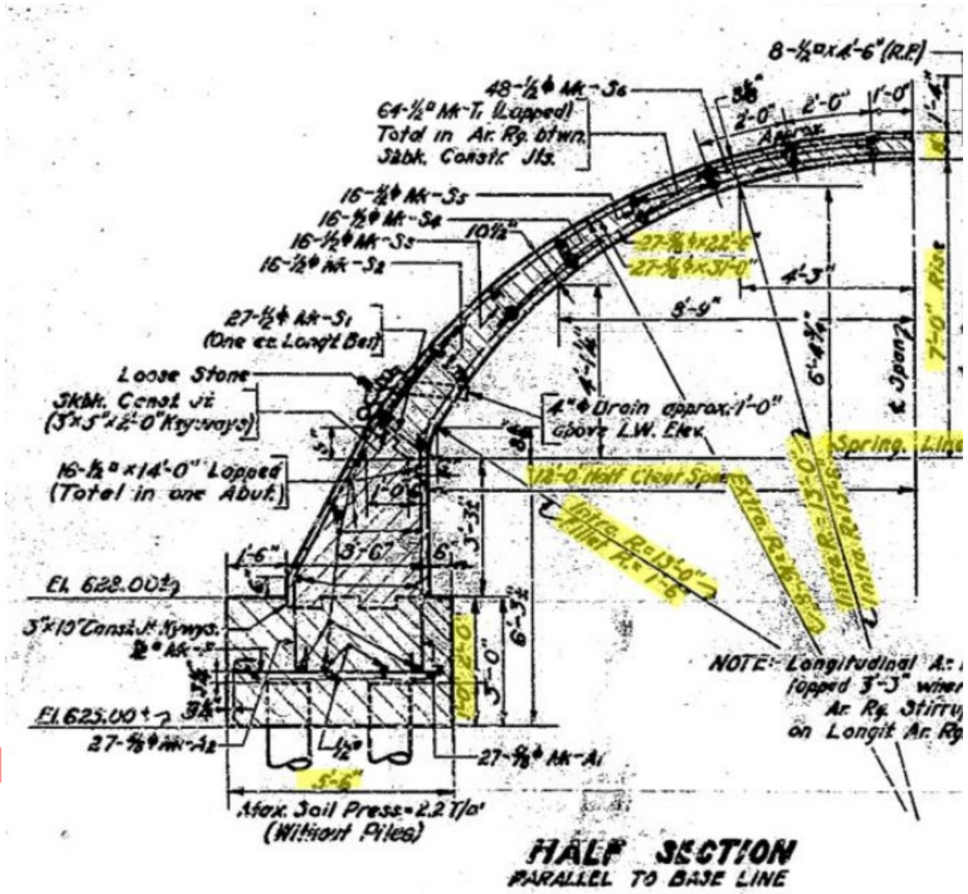


Input parameters for 2-segment arch with curved segments

Load Rating Concrete Arches Under Fill

CANDE Level 2 Half Mesh File - Geometric Definitions





CANDE Level 2 Half Mesh File - Geometric Definitions – OVERRIDES (opt.)

Level 2 - CX-1
Nodes, Elements and Boundary Condition Changes
Extended

Number of nodes to be changed with new coordinates	58
Number of elements to be changed with new properties	0
Number of new loading/boundary conditions to be added	0

Added Nodal Point Changes Input

Level 2 - CX-2
Nodal Point Number and Changed Coordinates
Extended

	Node Number	X-coordinate (in)	Y-coordinate (in)
1	198	0	118.002
2	200	0	118.002
3	199	0	118.002
4	194	12.668	117.58
5	196	12.668	117.58
6	195	12.668	117.58
7	190	25.282	116.323

Identification of interface element nodal connectivity

Number of Nodes from Crown	Pipe-soil Interface Nodes[1]	Number of Nodes from Crown	Pipe-soil Interface Nodes[1]
1	198,200,199	11	132,143,133
2	194,196,195	12	130,144,131
3	190,192,191	13	128,145,129
4	167,169,168	14	118,120,119
5	164,166,165	15	115,117,116
5	164,166,165	15	115,117,116
6	161,163,162	16	109,111,110
7	158,160,159	17	103,105,104
8	138,140,139	18	97,99,98
9	136,141,137	19	91,93,92
10	134,142,135	20	(2)

Notes:

(1) Three nodes define the pipe-soil interface at each pipe node around the arch. For every node triplet above (a, b, c),
a = pipe node IX(1)
b = soil node IX(2)
c = "free node" IX(3)

(2) Note that position #20, the arch connection into the footing, is not assigned an interface element.

Fig A-1: Pipe-soil Interface Nodes, Ref-Table 5.5-5, CANDE-2007 User Manual and Guideline

Load Rating Concrete Arches Under Fill

CANDE Level 2 Half Mesh File – Concrete Resistance Factors

1. Steel Rebar Yielding due to Tension Stress: **0.90** *(AASHTO 5.5.4.2)*
2. Concrete Crushing due to Thrust and Moment: **0.75** *(AASHTO 5.5.4.2, Compression – Controlled Section with Spirals or Ties – Two Way Action Similar Support Condition)*
3. Resistance factor for concrete shear failure: **0.90** *(AASHTO 12.5.5-1, Reinforced Concrete Pipe -Non-Direct Design)*
4. Resistance factor for radial concrete tension: **0.90** *(AASHTO 12.5.5-1, Reinforced Concrete Pipe -Non-Direct Design)*
5. Allowable crack width for service load: **0.01 in** *(AASHTO C5.6.7, Control of Cracking… Class 1 Exposure 0.017 in, NA typ)*

Load Rating Concrete Arches Under Fill

CANDE Level 2 Half Mesh File – Material (Soil) Definitions

- In Situ Soil – Below Footing and Trench, Standard Isotropic – Linear Elastic
- Footing – Concrete
- Backfill – Unknown = ML95; Sandy Silt Soil with 95% Compaction

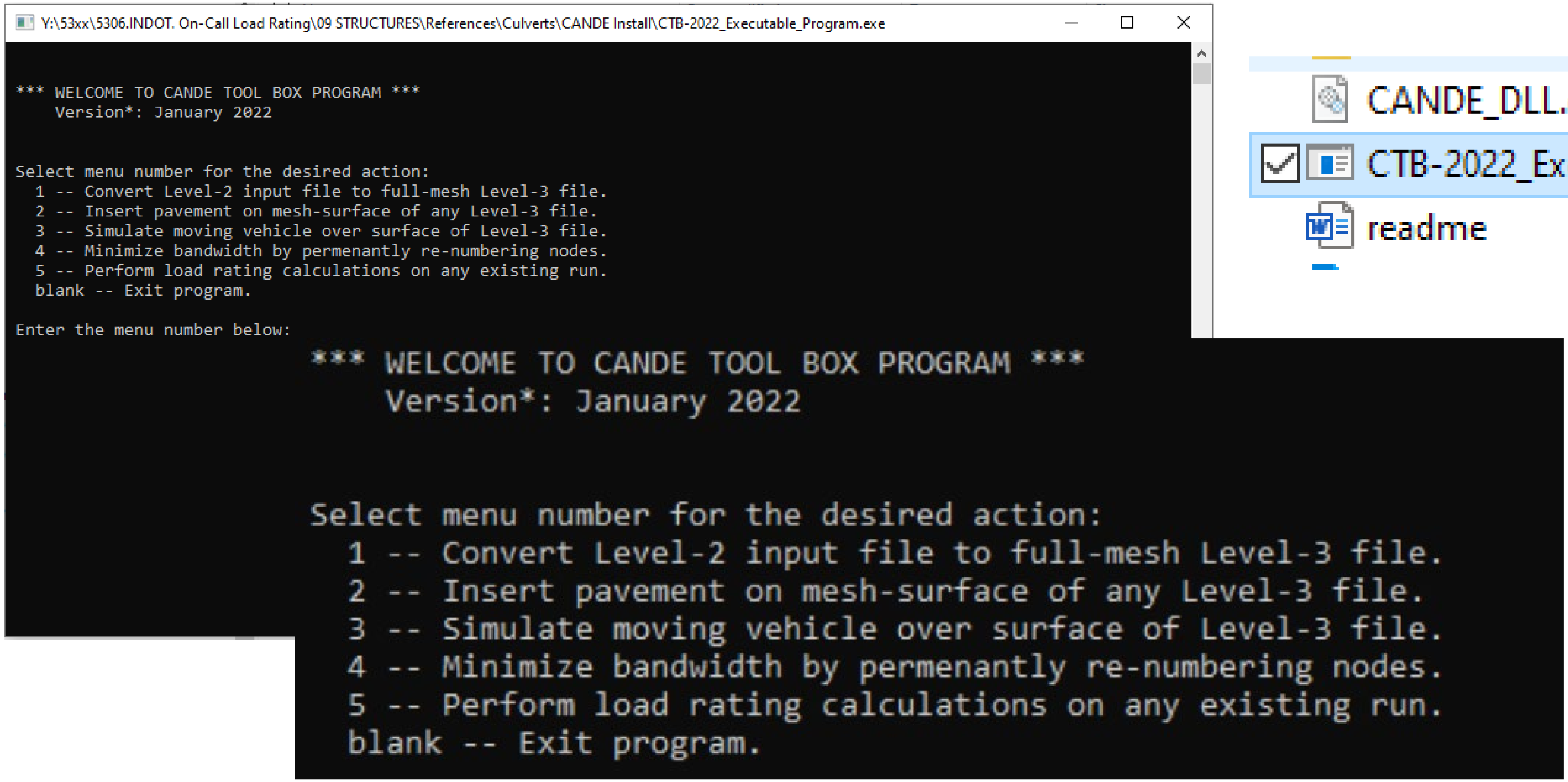
  Duncan / Selig Soil Model; Density : 125pcf - 135 pcf
- Interface 1-19 – Angle for all 19 Interfaces

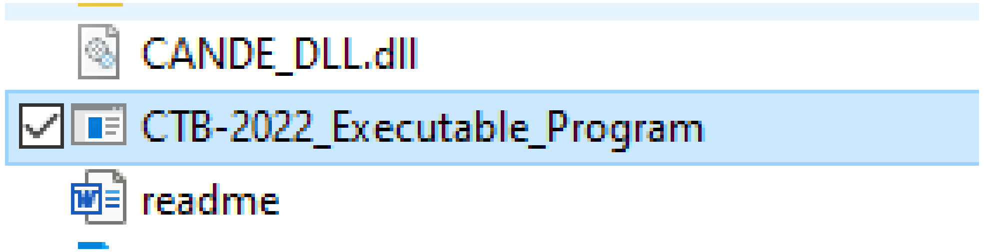
  Coefficient of Friction = 0.3 (up to 1,000 - Bonded)

  Tensile Breaking Force = 10 lb/in (up to 10,000 - Bonded)

Step 2a. CANDE Level 3 Full Mesh File – CANDE Tool Box

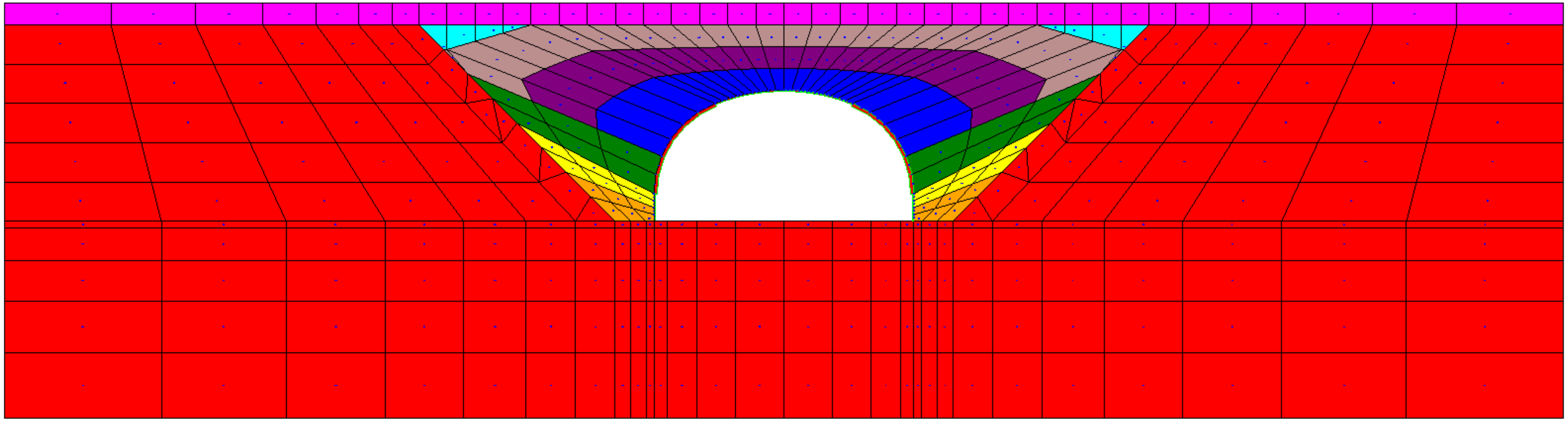
- Selection Option 1 – Convert Level-2 Input File to Full – Mesh Level -3 File





Step 2b. CANDE Level 3 Full Mesh File – CANDE

- Open Updated “Full –” .cid File in CANDE and Run



Step 3a. CANDE Level 3 Pavement / DC Loads Addition – CANDE Tool Box

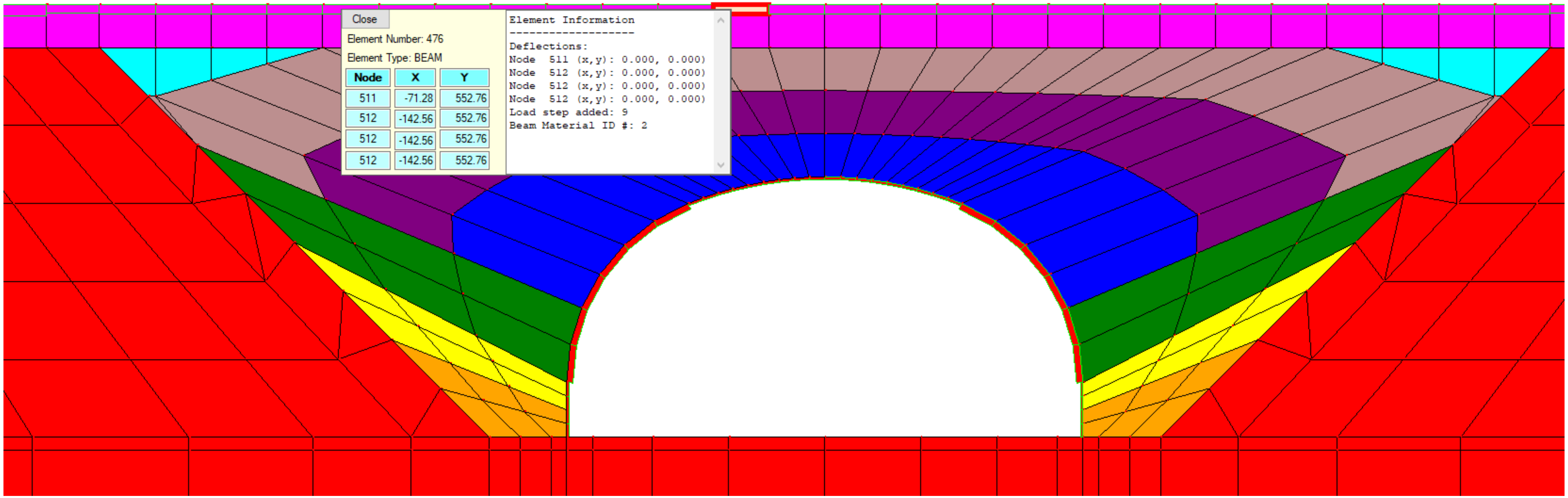
- Select Option 2 – Insert Pavement on Mesh-Surface of Full-Mesh Level-3 File

```
 Enter the menu number below:
2
 Menu number =  2


 MENU OPTION #2: ADD ELASTIC PAVING LAYER OVER SOIL SURFACE,
 AND/OR CHANGE TOP SOIL LAYER TO AN ELASTIC WEARING COURSE.
 Using the following browser screen, select the Level 3 cid
 file to be modified to include elastic surface treatment.

 Press enter to see browser screen.



 Selected CID File Name = Full-Level2-ANALYS-LRFD-TREN-Arch-CONCRETE.cid



 Good Start! First input line A-1 reads:
 Heading = Str.006-46-01374



 Select treatment for soil-surface suboptions:
 Enter 1 - to add pavement layer over surface elements. Generally recommeded for all load rating. (DEFAULT)
 Enter 2 - to replace top soil layer with elastic wearing course. Recommended to avoid failure of nonlinear models.
 Enter 3 - to perform both options: Add pavement layer plus change top soil layer to an elastic wearing course.
1
 Suboption selection =    1
```

Add any additional Dead Here as Pavement Unit Weight
(Adjust for Load Factors)

Step 3b. CANDE Level 3 Full Mesh File Pavement – CANDE

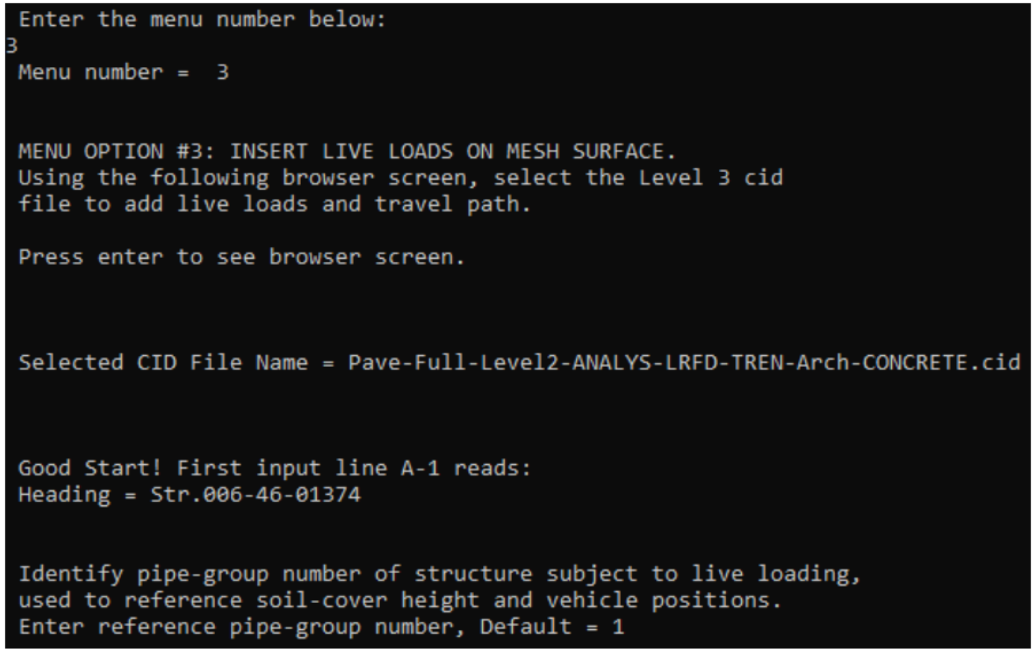
- Open Updated "Pave-Full - " .cid File in CANDE and Run



Step 4a. CANDE Level 3 Moving Loads – CANDE Tool Box

- Select Option 3 – Simulate Moving Vehicle over Surface of Pave-Full Level-3 File

Must Be Completed for **ALL** Vehicles



Step 4b. CANDE Level 3 Moving Load File – Open " Live-Pave-Full-".cid in CANDE and Run

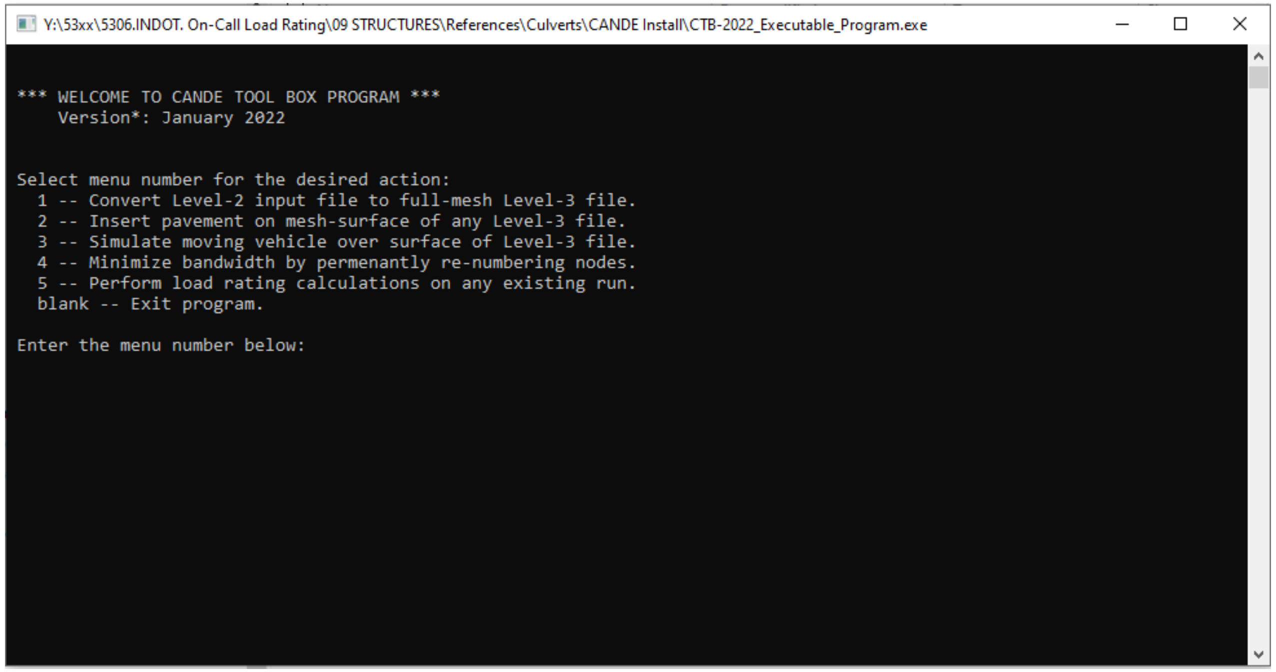
emcs

Load Rating Concrete Arches Under Fill

Step 5. CANDE Load Rating – CANDE Tool Box

- Selection Option 5 – Perform Load Rating Calculations on Moving Load File

Must be repeated for all Vehicles



Load Rating Concrete Arches Under Fill

CANDE Load Rating Results– CANDE Tool Box (HL-93 INV shown)

```
BOTTOM LINE FINDINGS FOR LOAD RATING OF CULVERT
* Controlling design criterion = CONCRETE CRUSHING (psi)
* Controlling load-rating factor RF =     1.54
* Controlling local-node number =   20
* Controlling live-load step number =  22
* Safety assessment of culvert = SAFE


LOWEST RATING FACTORS PER DESIGN CRITERION AT CONTROLLING LOAD STEP AND NODE:

DESIGN-CRITERION          LOAD  LOCAL  DEAD-LOAD   LIVE-LOAD   EFFECTIVE     *RATING
     (Strength)           STEP  NODE      DEMAND      DEMAND    CAPACITY      FACTOR
*STEEL YIELDING (psi)       15    17      161.19    15654.94    29700.00        1.89
*CONCRETE CRUSHING (psi)    22    20      321.53     1006.00     1875.00        1.54
*SHEAR FAILURE (lbs/in)     19    13        0.71       91.27      471.20        5.15
*RADIAL-TENSION FAIL (psi)  13    15        0.04        2.29       43.20       18.85


DEFINITIONS AND RELATIONS FOR EACH CRITERION "n":
* Rating Factor(n) = (Capacity(n) - Dead(n))/Live(n)
* Total Demand(n) = Dead(n) + Live(n) at specified node
* Dead(n) = Dead load demand for criterion n (factored)
* Live(n) = Live load demand for criterion n (factored)
* Capacity(n) = Capacity for criterion n (factored)
```

R.F > 1.0!

Questions?