SECTION 14A
CULVERTS

14A.1 INTRODUCTION TO RATING CULVERTS

This section covers the load rating of culverts, flexible and rigid other than concrete box culverts. Culverts include, but are not limited to: metal pipe, metal plate pipe, pipe arch, long span plate structure, thermoplastic pipe, steel reinforced thermoplastic pipe, and fiberglass pipe. This section also covers rigid pipes such as concrete pipes. Culverts are to be rated using the policies and guidelines of the Bridge Rating Manual, Section 1 and Subsections 14A.2 and 14A.3.
The load rating of concrete box culverts is covered in section 14.

When there are no plans available for the culverts, the requirements in Subsection 1.5 of CDOT Bridge Rating Manual, CDOT M&S Standards, or AASHTO Specifications may be used if proven to be representative of the culvert. Field measurements may also be used.

The types of flexible culverts covered by this section are:
AAC - Aluminum Arch Culvert
CMP - Corrugated Metal Pipe (Steel/Aluminum)
CPP - Corrugated Plastic Pipe
SAC - Steel Arch Culvert/Multiplate Arch Culvert
SPP - Smooth Plastic Pipe

The other types of rigid culverts also covered by this section are:
RCPC - Reinforced Concrete Pipe Culvert
CAC - Concrete Arch Culvert

14A.2 POLICIES AND GUIDELINES FOR RATING CULVERTS

14A.2.1 General

A) A culvert shall be rated or re-rated based on AASHTO Load and Resistance Factor Rating (LRFR) using latest version on CANDE (Culvert Analysis and Design) software. Programs other than CANDE must be approved in advance by the CDOT Bridge Rating Engineer.

B) A major culvert is defined as a culvert or a group of culverts that have a span length of greater than 20 feet measured parallel to the centerline of roadway from outside of the first pipe to the outside of the last pipe. A group of culverts are culverts with distance between them of less than or equal to the radius of the smallest culvert in the group.

C) A minor culvert is defined as a culvert or a group of culverts that have a span length of less than or equal 20 feet but greater than or equal to 4 feet measured parallel to the centerline of roadway from outside of the first pipe to the outside of the last pipe.

D) Inventory and operating ratings shall be performed for HL-93 as applicable. Additionally, an operating rating shall be performed for appropriate Legal Loads (Colorado or Interstate Type 3, 3-2, and 3S2), NRL, EVs, Colorado Permit Vehicle, and Modified Tandem. Rating for SHVs shall be performed if the rating factor (RF) for the NRL vehicle is less than 1.0. Truck configurations for the legal loads, NRL, SHVs, EVs, Colorado Permit Vehicle, and Modified Tandem can be obtained from Chapter 1 of the CDOT Rating Manual.

E) For live loads and impact factors refer to AASHTO Specifications, AASHTO Manual for Bridge Evaluation, and CDOT Bridge Rating Manual Section 1.

F) “For single-span culverts, the effects of live load may be neglected where the depth of fill is more than 8.0 ft. and exceeds the span length. For multiple span culverts, the effects may be neglected where the depth of fill exceeds the distance between inside faces of end walls.” AASHTO LRFD 8th edition, section 3.6.1.2.6. When these conditions are met, the capacity adequacy shall be verified for dead load and other superimposed loads. The rater shall also verify and document that the fill height meets CDOT M&S Standard fill height limitations.

G) The structure Inspection and appraisal report shall be investigated for the culvert condition. Reducing section properties due to loss of cross section or damage shall be investigated and accounted for by a professional engineer. Findings and recommendation shall be discussed with the Staff Bridge contact and the Bridge Rating engineer prior to finalizing the rating. If approved, the findings and recommendation shall be clearly documented in the rating package.

H) Refined analysis and/or soil interaction analysis may be used if rating shows that posting or color coding per section 1.15 or 1.16 is required. Geotechnical engineering may be required to provide soil interaction properties.

I) For multiple lines of buried pipe structure that meets the minimum spacing between pipes per AASHTO LRFD, Section 12.6.7, a single pipe instead of multi-pipe may be modeled for load rating analysis.

14A.2.2 Calculations

A) A set of calculations, separate from computer output, shall be submitted with each rating package. These calculations shall include derivations for dead loads, derivation of live load, and any other calculations or assumptions used for the rating.

B) Dead Loads

1. The final sum of all the individual weight components for dead load calculations may be rounded up to the next 5 pounds.

2. Dead loads shall include fill, pavement, curbs, sidewalks, railing, etc.

3. Fill Dead loads shall be calculated based on 125 lb/ft^3.

C) Use the minimum design yield strength value F_y from plans or AASHTO Specifications.

14A.3 RATING REPORTING AND PACKAGING REQUIREMENTS

14A.3.1 Rating Reporting/Package Requirements

A) A copy of the schematic drawing or sketch showing the elevation and applied loads shall be included with the rating package. Rating procedure shall be per section 1.11 or 1.12 as applicable.

B) The rater and checker shall complete the rating documentation as described in Section 1 of the Bridge Rating Manual. Any variation from the original design assumptions shall be added to the Rating Summary Sheet as applicable. The rating package requirements shall be per Section 1.13 and Section 1.14 of the Bridge Rating Manual and as amended herein.

14A.3.2 Consultant Submittal Requirements

A) Consultant designed/rated culverts: Before finalizing the rating package and when a computer program is used as the analysis tool, the rater shall verify with Staff Bridge that the program being used is acceptable to CDOT. Unapproved program data files may be rejected.

B) When the rating is finalized, the rater shall save the input and output files. The files name shall include the structure number of the rated culvert. The rating package including the program input and output files, the rating summary sheet, and necessary computations shall be transmitted electronically (.xlsx, .xml, etc.) and in PDF format to Staff Bridge for review and archiving.

14A.4 INTRODUCTION TO CANDE SOFTWARE

CANDE is a public domain 2D finite element software for analysis and design of culverts and buried structures (corrugated metal, reinforced concrete, and thermoplastics). CANDE can rate or design buried structures by Load Resistance Factor Design (LRFD) or Allowable Stress Design (ASD) methodologies.

There are three levels for analysis: Level 1, 2 and 3 as shown in Fig 14A-1. CANDE will generate a mesh automatically for half of the culvert then by using the Tool Box application can convert to a level 3 mesh (full culvert).

CANDE analyzes different types of culverts (steel, concrete, and plastic) for various design criteria as shown in Table 14A-1.

Culvert properties such as: (culvert type, soil types, culvert wall thickness, fill materials density, thickness, etc.) must be defined in CANDE but to receive a rating for the culvert, the user must use the Tool Box attached to CANDE software.

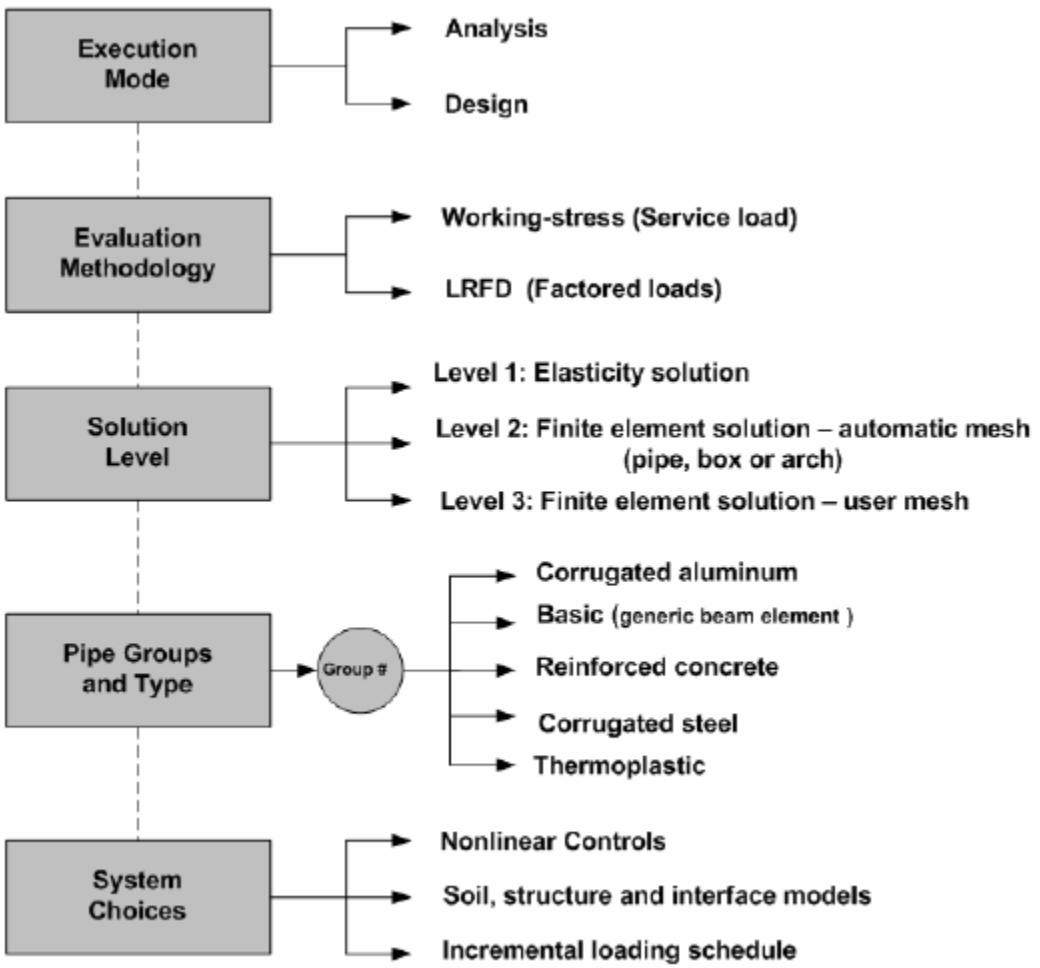
14A.5 INTRODUCTION TO CANDE TOOL BOX SOFTWARE

The CANDE Tool Box is an application that supplements the CANDE software to rate culverts. It has the ability to define wearing surface thickness, convert analysis level, define design, legal and permit trucks with varies load factors, and to obtaining rating factors.

Table 14A-1: Design/Analysis CANDE criteria

Buried structure Type	Analysis/Design Criteria
Corrugated Metal	• Thrust Yielding • Buckling • Seam Failure • Plastic hinging
Reinforced Concrete	• Steel Yielding • Concrete Crush • Shear failure • Radial Tension
Plastic	• Thrust Yielding • Bucking • Combined Strain • Tension Strain

Figure 14A-1 CANDE Analysis/Design procedure (as outlined in tha CANDE-2019 Manual)



The following information was obtained from CDOT standards and AASHTO Standard Specification Section 12:

Table 14A-2: Materials Specifications

Pavement Unit weight	146.67	pcf
Soil Unit Weight	125	pcf
Soil Stiffness factor K	0.22	
Steel Pipe material Modulus of Elasticity, E_m	29,000,000	psi
Pipe material Min. Tensile Strength, f_u	45,000	psi
Pipe material Min. Yield Point, F_y	33,000	psi
Capacity Modification Factor for Wall Area and Buckling, Φ_b	1.0	
Capacity Modification Factor for Seam Strength, Φ_s	0.67	
Elastic Young modulus for steel	29,000,000	psi
Poisson's ratio for steel	0.3	
Yield stress for steel	33,000	psi
Steel Density	490	pcf
Elastic Young modulus for aluminum	10,000,000	psi
Poisson's ratio for Aluminum	0.33	
Yield stress for Aluminum	24,000	psi
Aluminum Density	170	pcf
Compressive Strength of Concrete, $f'c$	Based on the actual grade	ksi
Concrete Density	150	pcf
Poisson's ratio for concrete	0.17	
Elastic Young modulus for concrete	$120 * (Density)^2$	psi
Plastic Elastic Young modulus for short-term loading	See attached table	
Plastic Ultimate stress limit for short-term loading	See attached table	
Plastic Elastic Young modulus for long-term loading	See attached table	
Plastic Ultimate stress limit for long-term loading	See attached table	
Poisson's ratio for plastic	0.3	

Table 14A-3: Plastic Materials Specifications

Type of plastic	Effective Young's Modulus (PE)		Ultimate strength (PU)	
	Short-Term (ksi)	Long-term (ksi)	Short-Term (ksi)	Long-term (ksi)
HDPE –High Density Polyethylene	110	22	3	0.9
PVC –Polyvinyl Chloride	400	140	6	2.6
PP –Polypropylene	135	31	3.1	1

Table 14A-4: Section Properties for Standard Steel Corrugation Sizes

Corrugation Profile	Section Properties	Corrugation thickness (in)						
		0.040	0.052	0.064	0.079	0.109	0.138	0.168
1-1/2 x 1/4	$PA\ in^2/in$	0.03800	0.05070	0.06340	0.07920	0.11090	0.14270	0.17480
	$PI\ in^4/in$	0.00025	0.00034	0.00044	0.00057	0.00086	0.00121	0.00164
	$PS\ in^3/in$	0.00172	0.00225	0.00280	0.00347	0.00479	0.00624	0.00785
2-2/3 x 1/2	$PA\ in^2/in$	0.03880	0.05160	0.06460	0.08070	0.11300	0.14530	0.17780
	$PI\ in^4/in$	0.00112	0.00150	0.00189	0.00239	0.00342	0.00453	0.00573
	$PS\ in^3/in$	0.00415	0.00543	0.00670	0.00826	0.01123	0.01420	0.01716
3 x 1	$PA\ in^2/in$	0.04450	0.05930	0.07420	0.09280	0.13000	0.16730	0.20480
	$PI\ in^4/in$	0.00515	0.00689	0.00866	0.01088	0.01546	0.02018	0.02509
	$PS\ in^3/in$	0.00990	0.01310	0.01628	0.02017	0.02788	0.03547	0.04296
5 x 1	$PA\ in^2/in$	0.00000	0.00000	0.06620	0.82670	0.11580	0.14900	0.18220
	$PI\ in^4/in$	0.00000	0.00000	0.00885	0.01109	0.01565	0.02032	0.02509
	$PS\ in^3/in$	0.00000	0.00000	0.01664	0.02056	0.02822	0.03571	0.04296

Corrugation Profile	Section Properties	Corrugation thickness (in)						
		0.110	0.140	0.170	0.188	0.218	0.249	0.280
6 x 2	$PA\ in^2/in$	0.12970	0.16690	0.20410	0.22830	0.26660	0.30420	0.34330
	$PI\ in^4/in$	0.06041	0.07816	0.09616	0.10800	0.12691	0.14616	0.16583
	$PS\ in^3/in$	0.05726	0.07305	0.08863	0.09872	0.11444	0.12998	0.14546

Corrugation Profile	Section Properties	Corrugation thickness (in)	
		0.318	0.380
6 x 2	$PA\ in^2/in$	0.38930	0.46780
	$PI\ in^4/in$	0.19000	0.23200
	$PS\ in^3/in$	0.16393	0.19496

Table 14A-5: Section Properties for Standard Aluminum Corrugation Sizes

Corrugation Profile	Section Properties	Corrugation thickness (in)					
		0.048	0.060	0.075	0.105	0.135	0.164
1-1/2 x 1/4	$PA\ \ in^2/in$	0.05070	0.06342	0	0	0	0
	$PI\ \ in^4/in$	0.00034	0.00035	0	0	0	0
	$PS\ \ in^3/in$	0.00228	0.00226	0	0	0	0
2-2/3 x 1/2	$PA\ \ in^2/in$	0	0.06458	0.08067	0.11300	0.14533	0.17775
	$PI\ \ in^4/in$	0	0.00189	0.00239	0.00342	0.00453	0.00573
	$PS\ \ in^3/in$	0	0.00675	0.00831	0.01131	0.01427	0.01726
3 x 1	$PA\ \ in^2/in$	0	0.07416	0.09317	0.1300	0.17400	0.20483
	$PI\ \ in^4/in$	0	0.00866	0.01088	0.01545	0.02017	0.02508
	$PS\ \ in^3/in$	0	0.01634	0.02024	0.02796	0.03554	0.04309
6 x 1	$PA\ \ in^2/in$	0	0.0646	0.08067	0.11300	0.14533	0.17775
	$PI\ \ in^4/in$	0	0.00850	0.01060	0.01490	0.01910	0.02340
	$PS\ \ in^3/in$	0	0.01604	0.01972	0.02697	0.03366	0.04021

Corrugation Profile	Section Properties	Corrugation thickness (in)					
		0.100	0.125	0.150	0.175	0.200	0.225
9 x 2 ½	$PA\ \ in^2/in$	0.11700	0.14583	0.17500	0.20408	0.23325	0.26242
	$PI\ \ in^4/in$	0.08310	0.10400	0.12490	0.14590	0.16700	0.18820
	$PS\ \ in^3/in$	0.06392	0.07924	0.09426	0.10908	0.12370	0.13813

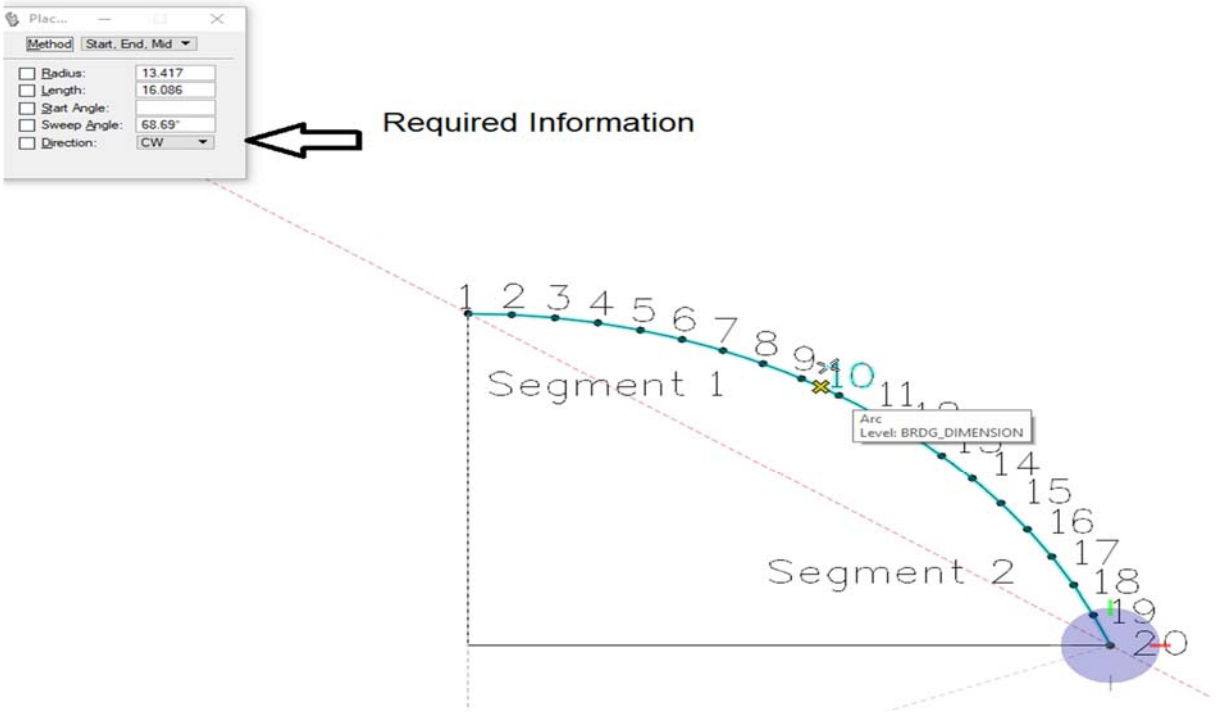
Corrugation Profile	Section Properties	Corrugation thickness (in)
		0.250
9 x 2 ½	$PA\ \ in^2/in$	0.29175
	$PI\ \ in^4/in$	0.20940
	$PS\ \ in^3/in$	0.15229

14A.6 ARCH GEOMETRIC DATA DEFINITION PROCEDURE IN CANDE

14A.6-1: Two Segment Arch Definition

1. Draw a horizontal line in MicroStation with length S (Pipe Span Length) as detailed in the Culvert Field Measurement Form
2. From the center of that line, draw a vertical line with length R (Pipe Rise)
3. Create an arc using the “Start, End, Mid” method and make sure the arc’s radius centers on the drew vertical line.
4. Record the radius and sweep angle from the “Place arc” command box
5. In the “Arch Segments and Angles” section of CANDE, input the value of the radius previously recorded in the “R1” and “R2” fields. Divide the sweeping angle by 2 and record those values in “Angle for R1 segment” and “Angle for R2 segment”.
6. Go to Material Definition 4 (Interface 1) and input 90° and change the coefficient of friction to 0.3 (the minimum value)
7. Go to Material Definition 5 (Interface 2) under the Material Control Parameters change the Material Name to “Interface #19” and change the Material ID to 19. This is the last interface of the nodes generated by CANDE. The program will calculate all the interface angles in between. Using the equation $\theta(i) = 90 - (i-1) * \frac{\Delta}{m-1}$ where i = 1, 2, …, m and m= total number of nodes (should always be 20 for a two-segmented arch) and delta = sweep angle, calculate the interface angle at the 20th node. Input this value into the “Angle from x-axis to normal interface” field of Material Definition 5 and change the coefficient of friction to 0.3.

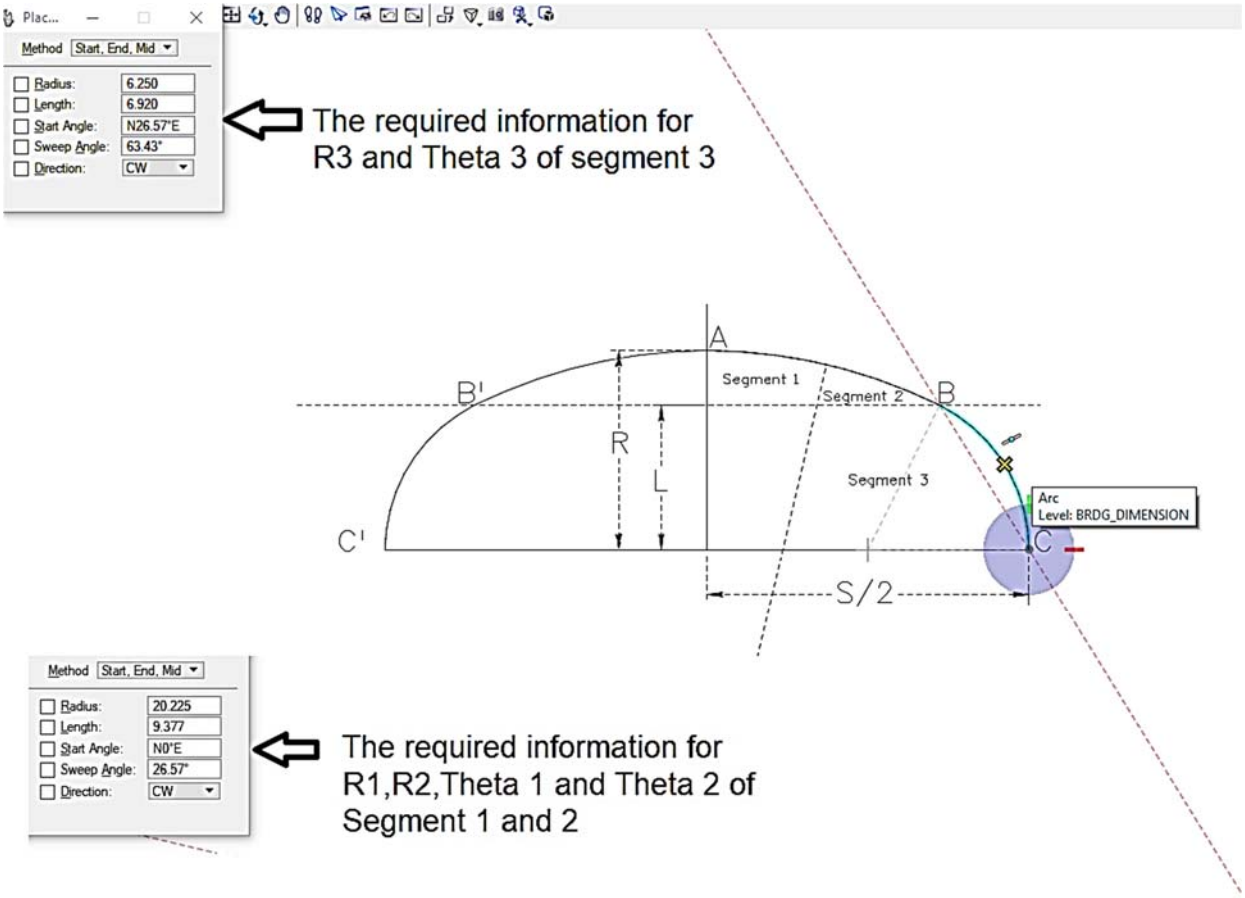
Figure 14A-2: Two Segmented Arch



14A.6-2: Three Segment Arch Definition

1. Draw a horizontal line in MicroStation with length S (Pipe Span Length) as detailed in the Culvert Field Measurement Form
2. From the center of that line, draw a vertical line with length R (Pipe Rise)
3. From the center of that line, draw another vertical line with length L (Vertical rise of side segment)
4. Create an arc for segment 1 and 2 using the “Start, End, Mid” method and make sure the arc’s start from B’ to B point (as shown in the attached drawing).
5. Record the radius and sweep angle from the “Place arc” command box for Arch of segment 1 and 2
6. In the “Arch Segments and Angles” section of CANDE, input the value of the radius previously recorded in the “R1” and “R2” fields. Divide the sweeping angle by 2 and record those values in “Angle for R1 segment” and “Angle for R2 segment”.
7. Create an arc using the “Start, End, Mid” method and make sure the arcs from point B to point C.
8. Record the radius and sweep angle from the “Place arc” command box.
9. In the “Arch Segments and Angles” section of CANDE, input the value of the radius previously recorded in the “R3” and sweeping angle. Record those values in “Angle for R3 segment” and “Angle for R3 segment”.
10. To activate R3 and Theta 3 values define “vertical rise of side segment” in “Arch and footing dimension definition” equal to “L” length.
11. Go to Material Definition 4 (Interface 1) and input 90° and change the coefficient of friction to 0.3 (the minimum value)
12. Go to Material Definition 5 (Interface 2) under the Material Control Parameters change the Material Name to “Interface #19” and change the Material ID to 19. This is the last interface of the nodes generated by CANDE. The program will calculate all the interface angles in between. Using the equation where i = 1, 2, …, m and m= total number of nodes (should always be 20 for a two-segmented arch) and delta = sweep angle, calculate the interface angle at the 20th node. Input this value into the “Angle from the x-axis to normal interface” field of Material Definition 5 and change the coefficient of friction to 0.3.

Figure 14A-3: Three Segmented Arch



14A.7 CULVERT RATING EXAMPLES

14A.7.1 Example 1: Corrugated Metal Pipe (CMP)

The example presented in this section is based on LRFR method. The rating is for Structure P-11-C, 2-Cells Corrugated Metal Pipe (CMP) pictured below.

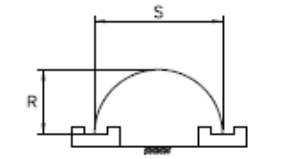
CANDE has two options for pipe rating, first option pipe only and second option pipe with soil interface. It is recommend to rate pipe without soil interface being more conservative.

The following information is provided by the inspector:

COLORADO DEPARTMENT OF TRANSPORTATION
STAFF BRIDGE
CORRUGATED METAL CULVERT FIELD MEASUREMENT FORM

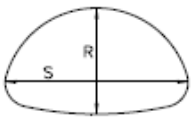
STRUCTURE # P-11-C

Material Type (Steel, aluminum, etc.)		STEEL
Galvanized (Yes or No)		YES
Number of Cells		2
Are all cells the same size and shape? (Yes or No)		YES
Document any differences:		
Top Wall Thickness - t_1 (in) = (See Detail B)		1/4"
Bottom Wall Thickness - t_2 (in) = (See detail B)		1/4"
Minimum Wall Thickness (in) =		1/4"
Corrugations Pitch - c (in) = (See Detail B)		6"
Corrugations Depth - d (in) = (See Detail B)		2"
Number of Bolts per longitudinal foot of splice ? Is it double or single row ?		5
Bolt Diameter (in)		3/4"
Pipe Span length - S (in) = See Section A-A for appropriate type		10'-10"
Pipe Rise - R (in) = See Section A-A for appropriate type		7'-8"
Maximum Normal Curvature top radius (Rt) dimensions (See Detail D)		M= (in) P= 36 (in)
Pavement Thickness (in) =		
Fill Height (in) =		102"
Is there noticeable settlement in the roadway over the culvert? Yes or No		NO
Is there noticeable differential settlement or rotation in the the culvert? Yes or No (Detail C)		NO
Is there noticeable sag or damage inside the culvert? Yes or No (If yes, take a photo)		NO
Noticeable Sag Dimensions (See Detail D)	Location =	M= (in) P= (in)
Inspector Initials :	Date:	

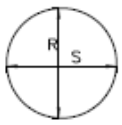


No t_2 values exist for this section

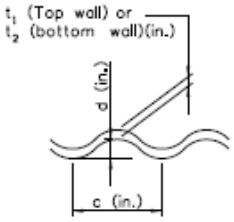
SECTION A-A
(ARCH)



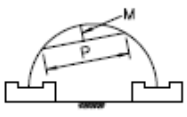
SECTION A-A
(PIPE ARCH)



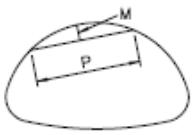
SECTION A-A
(CIRCULAR)



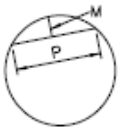
DETAIL B
(METAL CORRUGATION & GAGE INFORMATION)



(ARCH)



(PIPE ARCH)

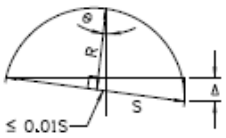


(CIRCULAR)

$R_t = \frac{M}{2} + \frac{P^2}{8M}$

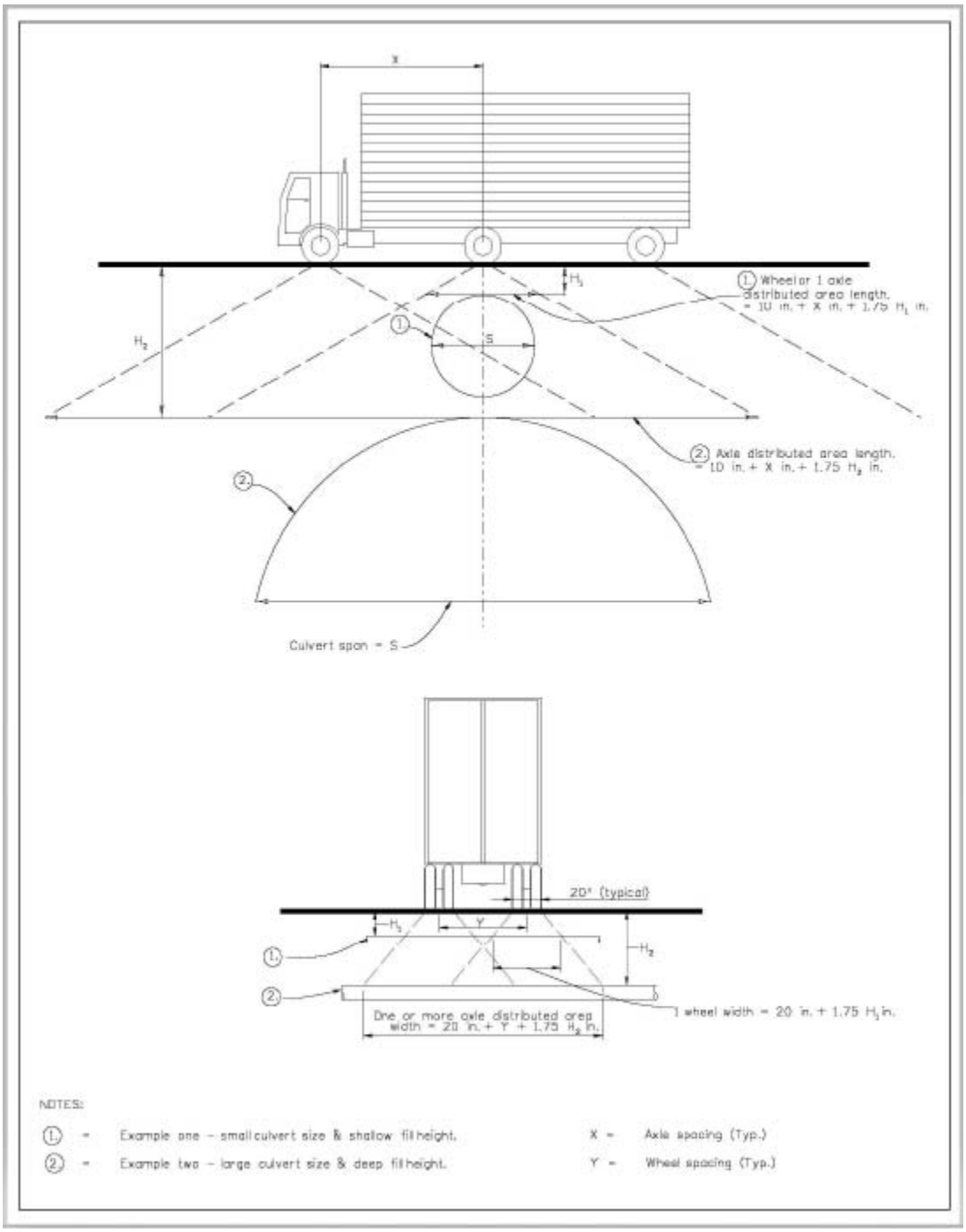
Calculate maximum existing normal curvature top radius (R_t) by taking measurments around the upper periphery of the culvert using a ruler of length "P" to obtain value of "M". This should be done at selected stations along length of culvert (particularly at locations with normal curvature and at location with noticeable sag)

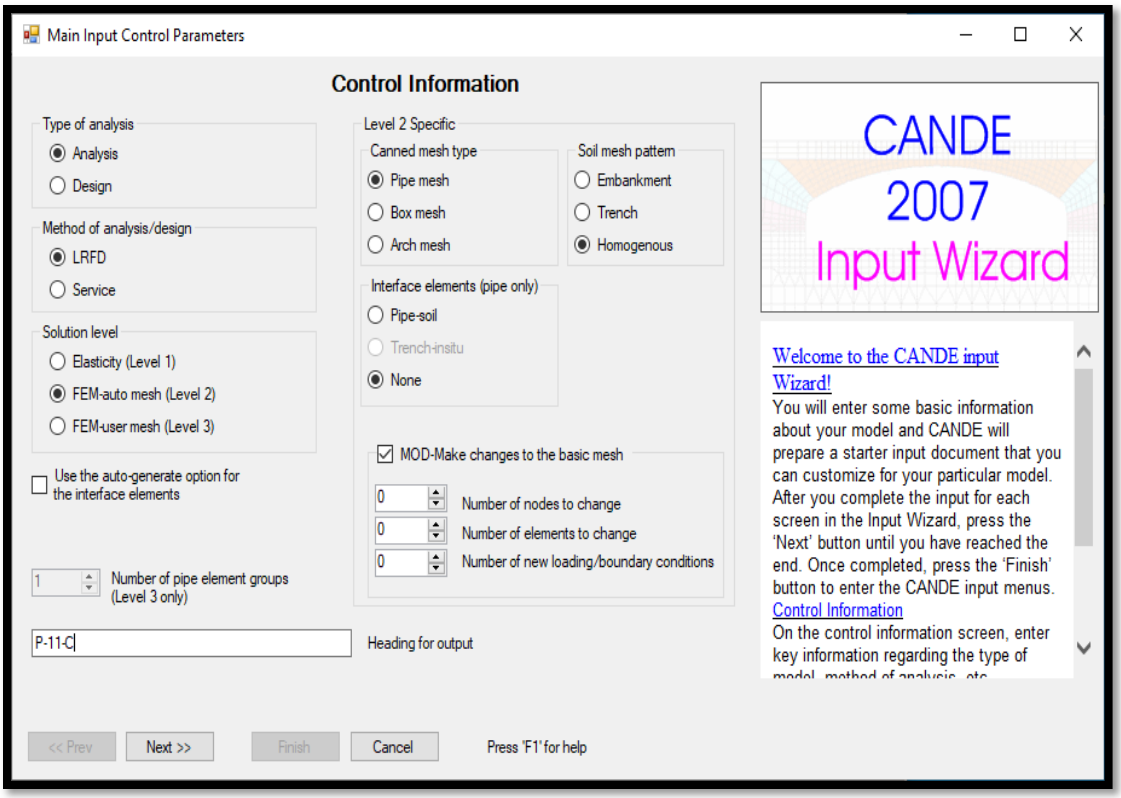
DETAIL D
Top Radius Rt



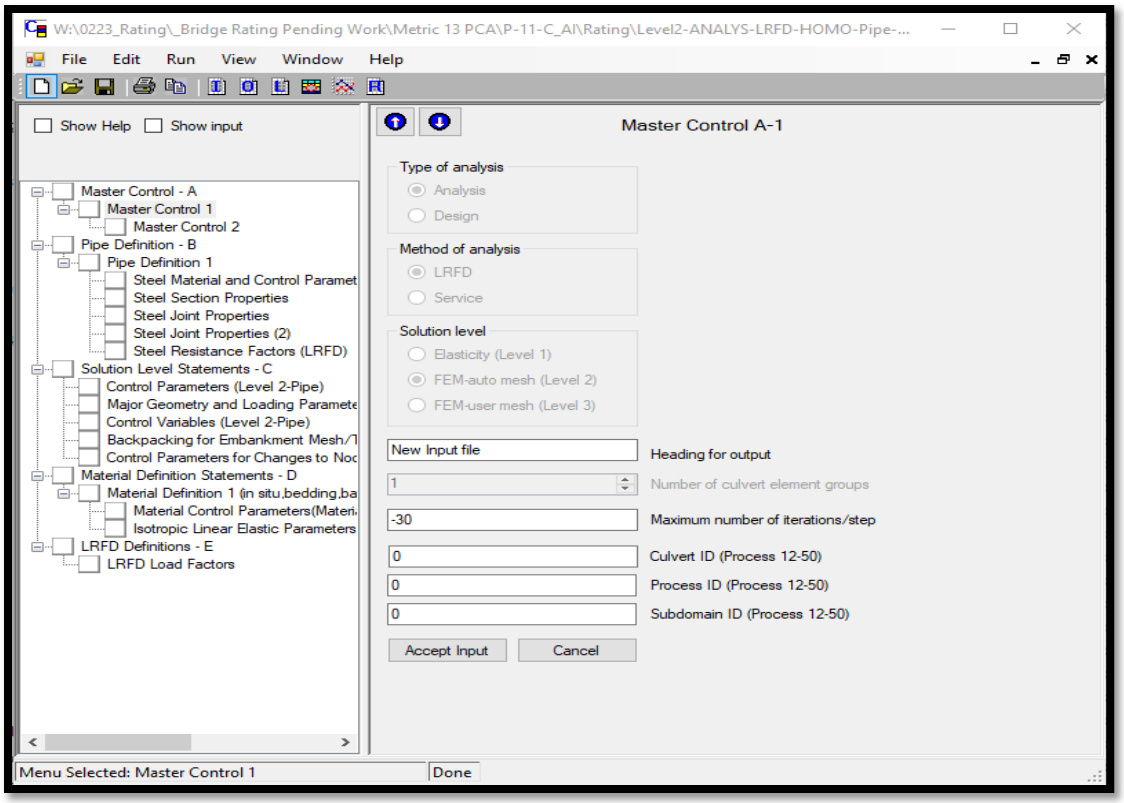
The rotation of the structure, θ, may be determined as: $\theta = \tan^{-1}\left(\frac{\Delta}{S}\right)$

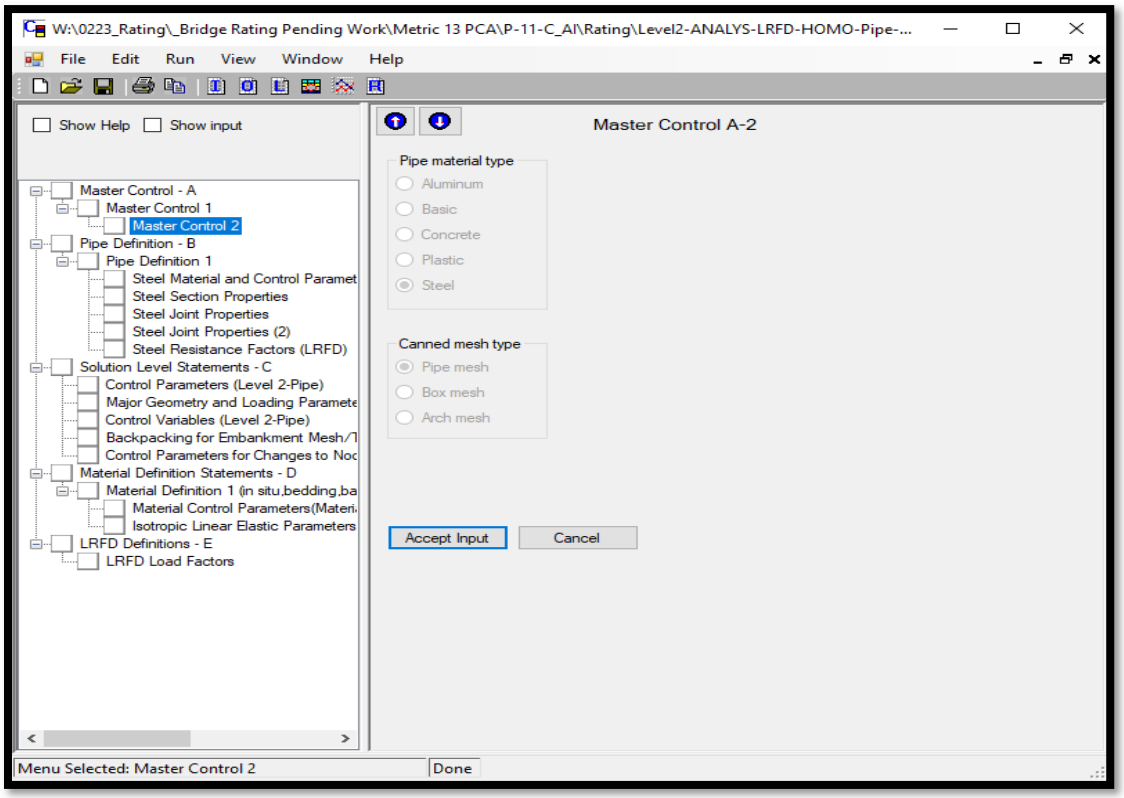
DETAIL C
DIFFERENTIAL SETTLEMENT

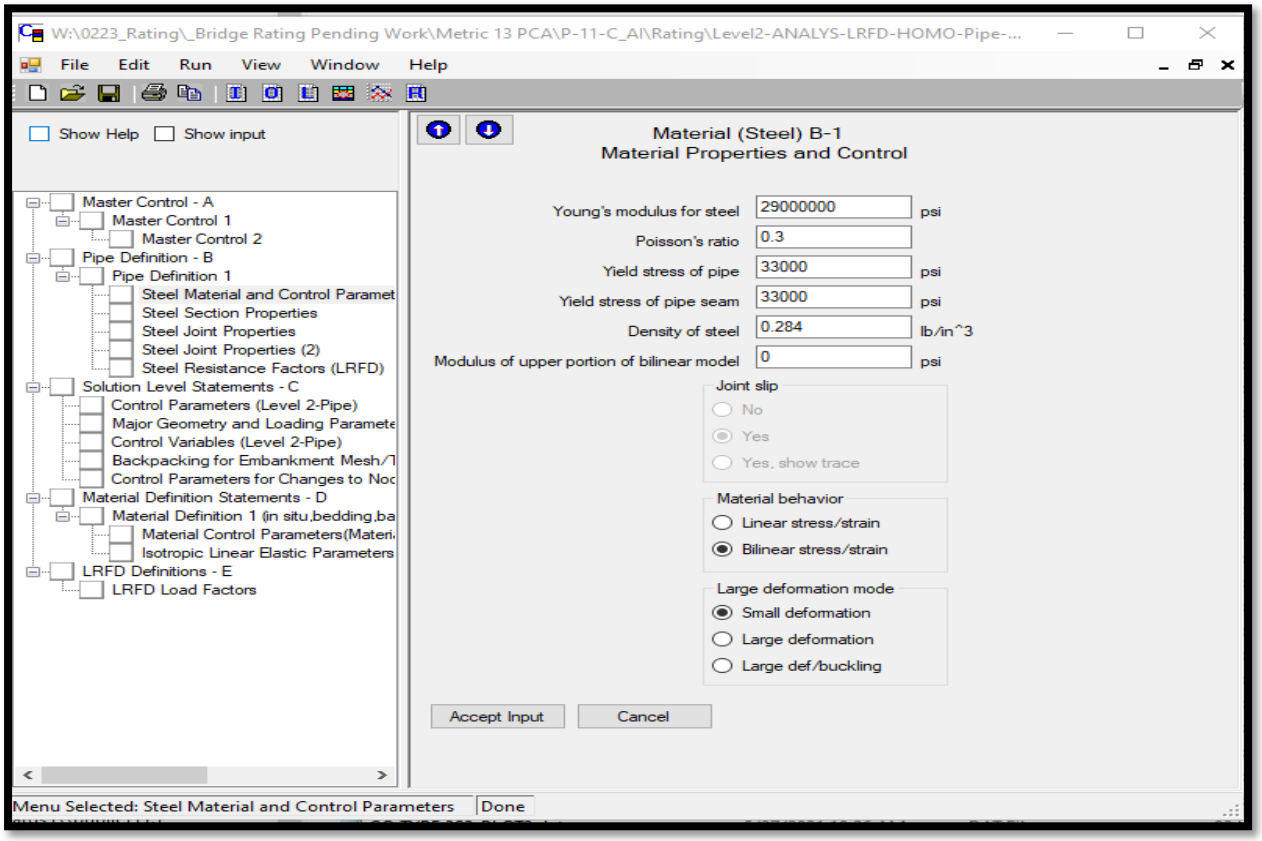

X
H1
H2
1. Wheel or 1 axle distributed area length. = 10 in. + X in. + 1.75 H1 in.
1.
S
2. Axle distributed area length. = 10 in. + X in. + 1.75 H2 in.
2.
Culvert span = S
20° (typical)
H1
Y
H2
1.
2.
1 wheel width = 20 in. + 1.75 H1 in.
One or more axle distributed area width = 20 in. + Y + 1.75 H2 in.
NOTES:
1. = Example one – small culvert size & shallow fill height.
2. = Example two – large culvert size & deep fill height.
X = Axle spacing (Typ.)
Y = Wheel spacing (Typ.)



- In Main input control parameter: Interface element “None” soil interface neglected, if soil information available rater may use “pipe-soil” option.
- Solution level used “level 2” and converted to “level 3” by Tool Box.
- LRFD analysis type used per section 1.6-B.

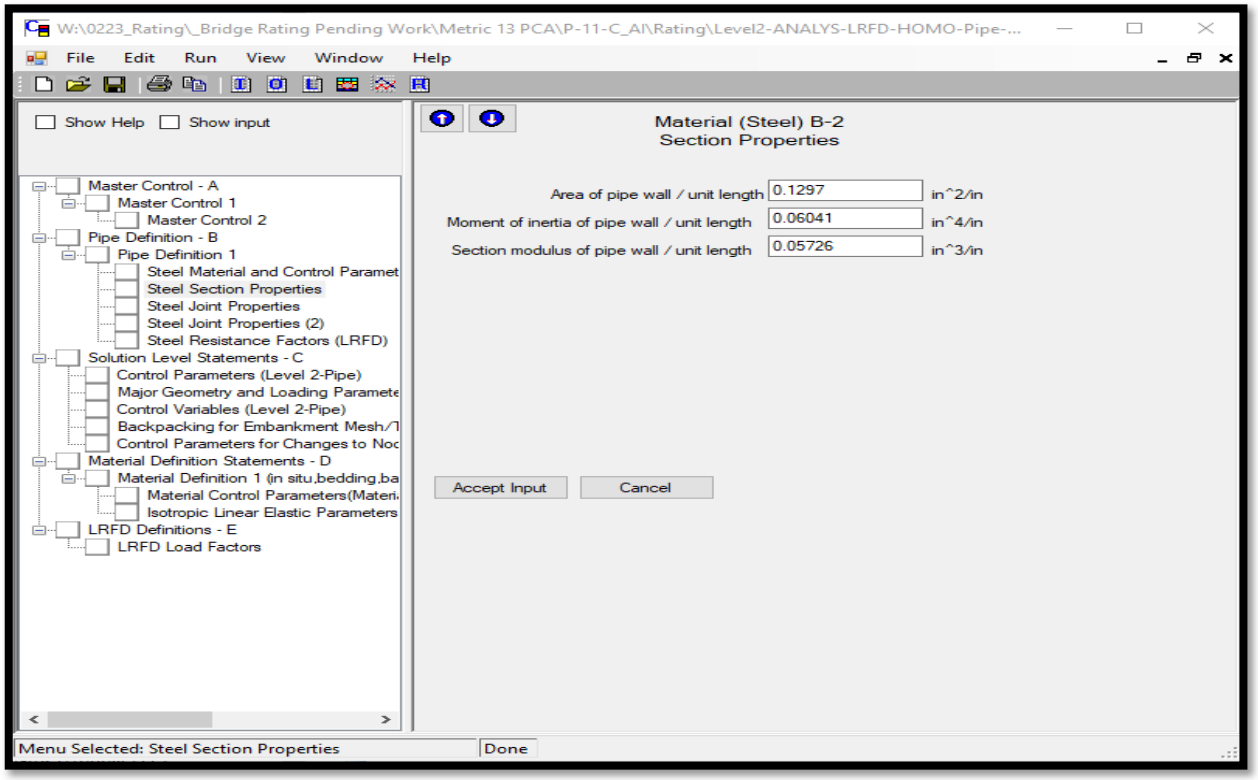

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_Al\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Master Control A-1
Type of analysis
Analysis
Design
Method of analysis
LRFD
Service
Solution level
Elasticity (Level 1)
FEM-auto mesh (Level 2)
FEM-user mesh (Level 3)
New Input file
Heading for output
1
Number of culvert element groups
-30
Maximum number of iterations/step
0
Culvert ID (Process 12-50)
0
Process ID (Process 12-50)
0
Subdomain ID (Process 12-50)
Accept Input
Cancel
Menu Selected: Master Control 1
Done


W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_Al\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Master Control A-2
Pipe material type
Aluminum
Basic
Concrete
Plastic
Steel
Canned mesh type
Pipe mesh
Box mesh
Arch mesh
Accept Input
Cancel
Menu Selected: Master Control 2
Done

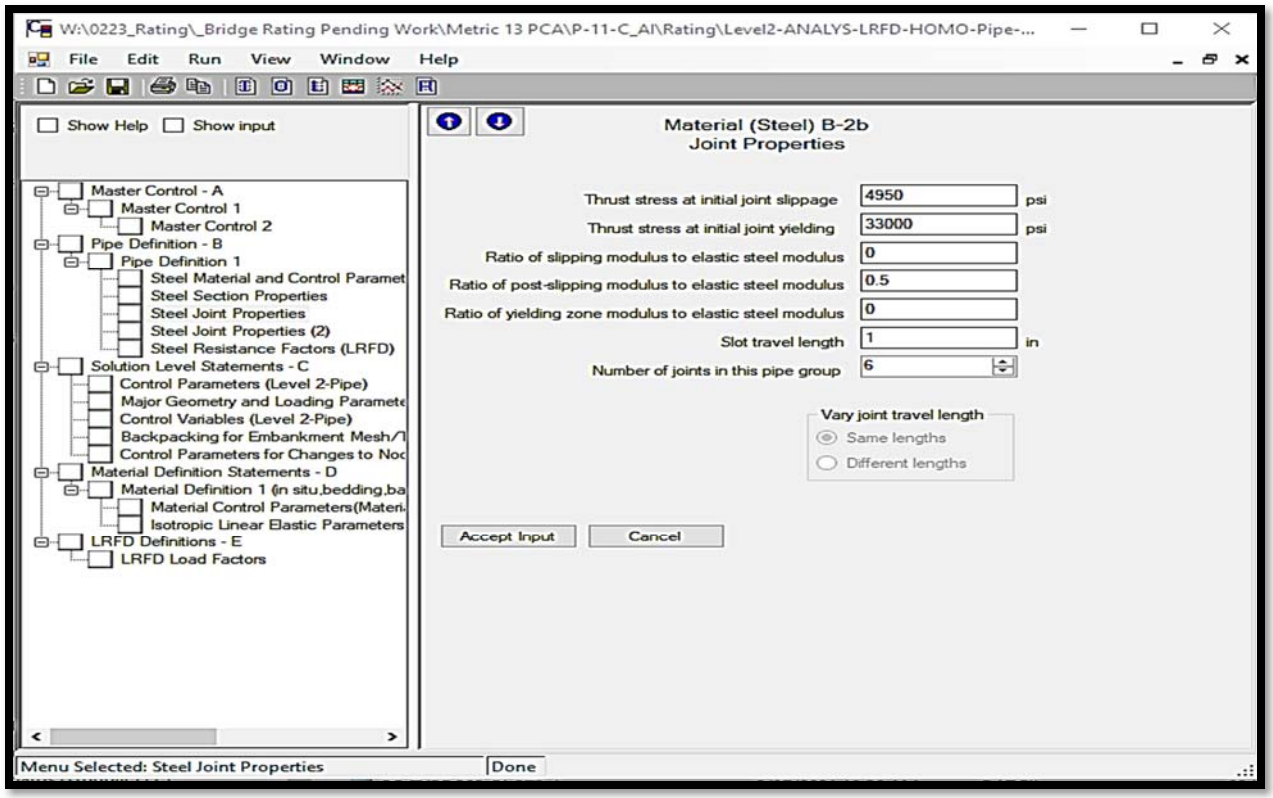


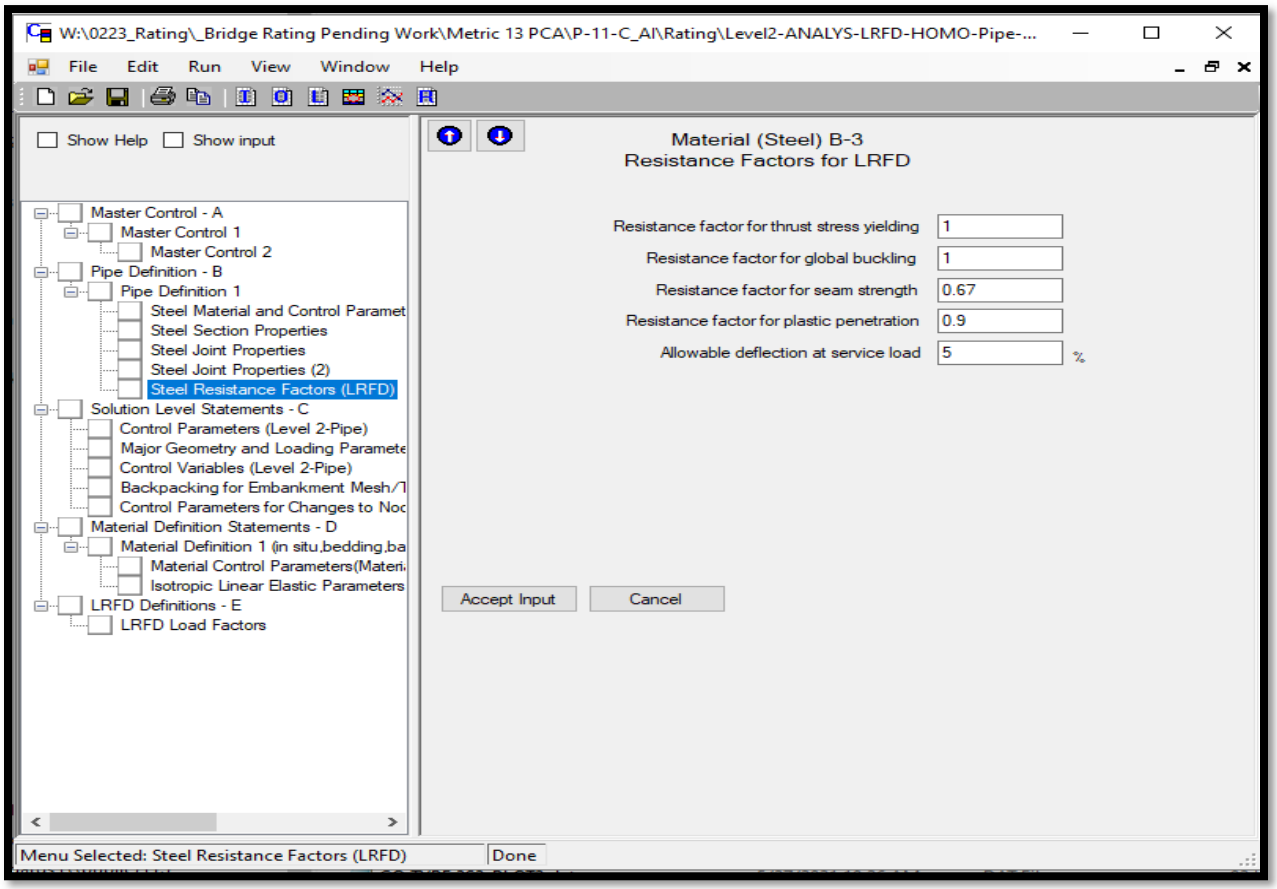
Material properties (Young Modulus, passion ratio, yield stress and steam stress of pipe) values exist by default in CANDE software help menu, rater may modify these inputs.

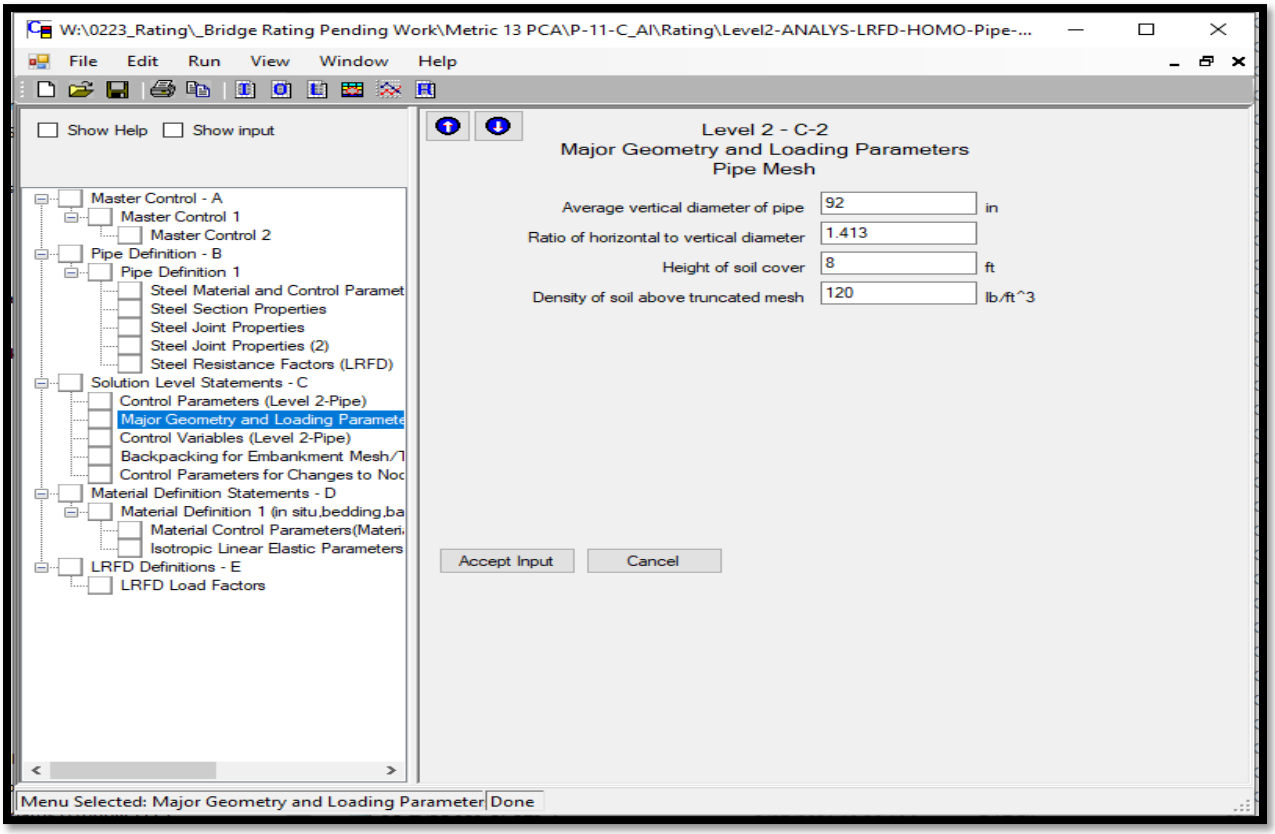
Detail of deformation modes available in “CANDE solution methods” for this example “small deformation mode” has been used.

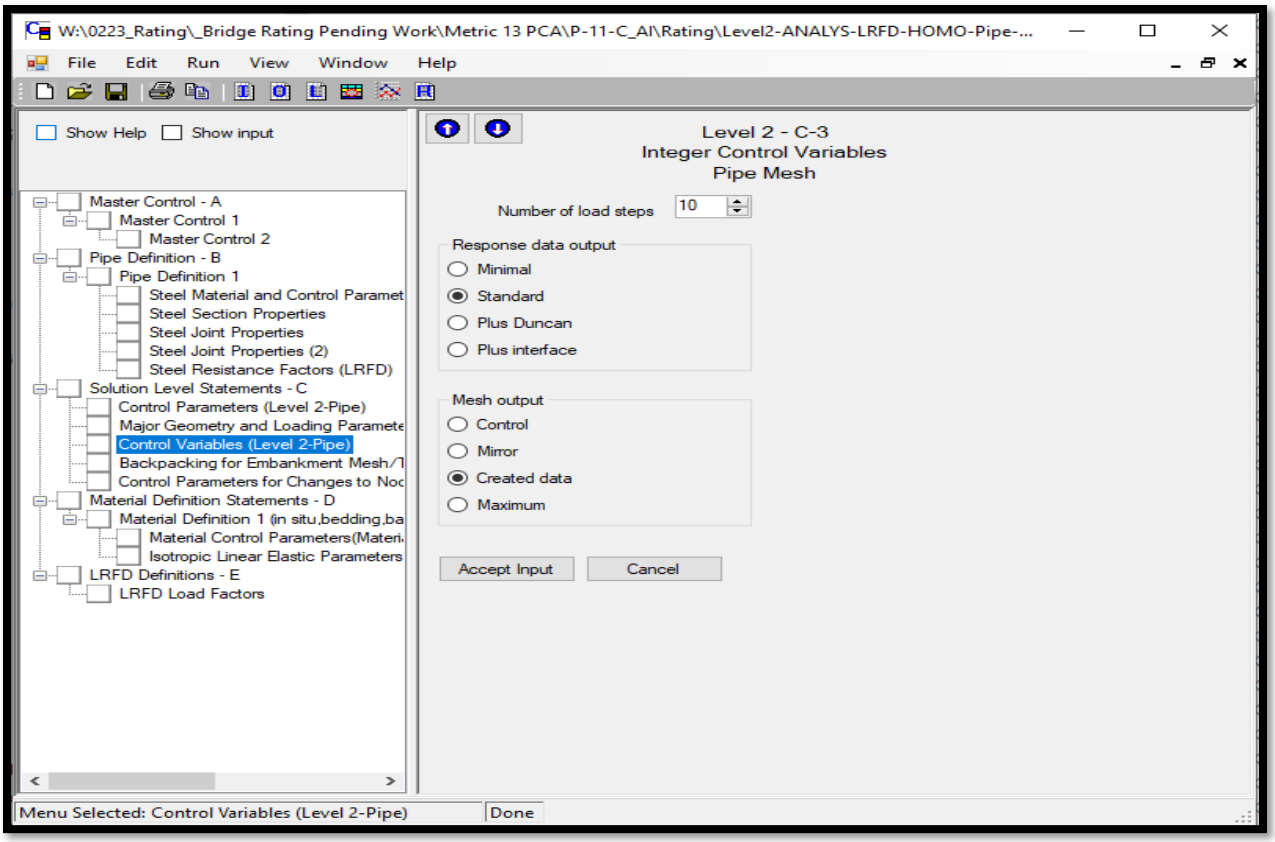


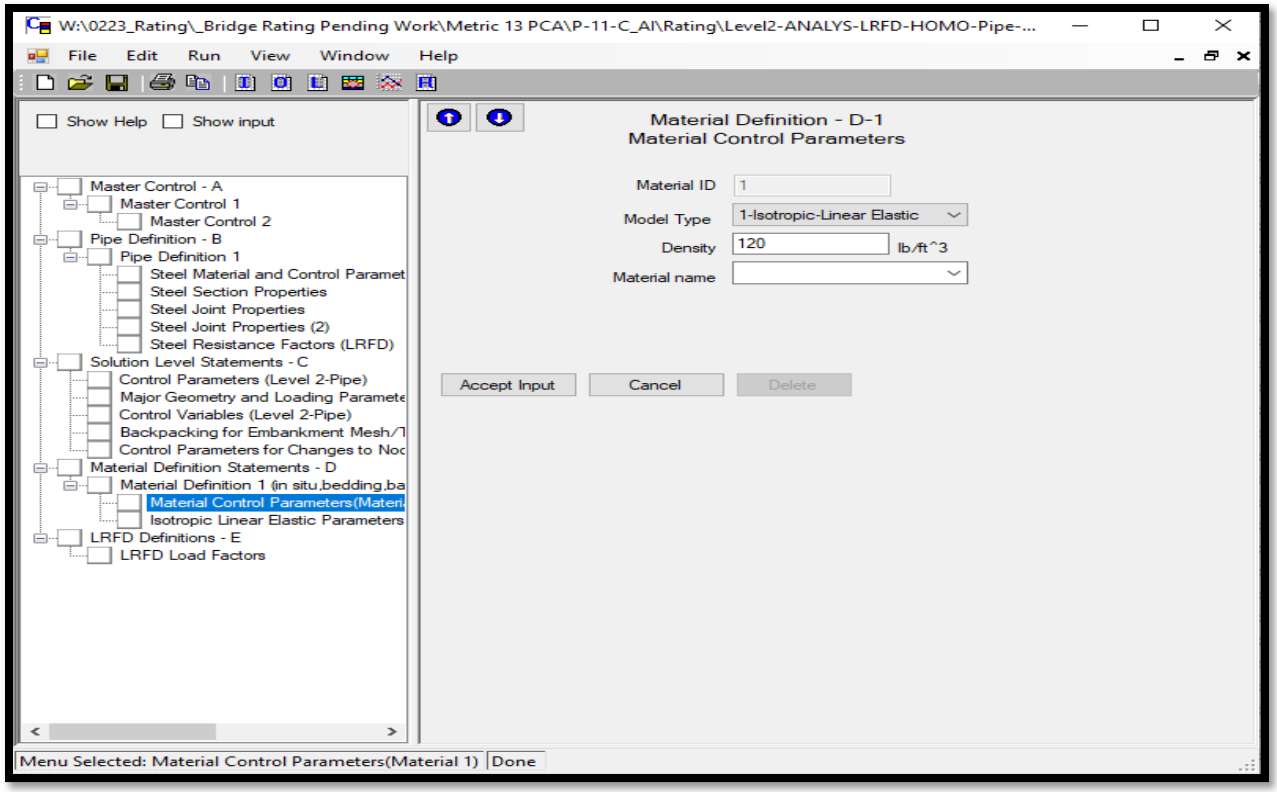
Area of Pipe wall, Moment of Inertia and section modulus inputs available in help menu (Table 14A-5).Based on material types (Steel or Aluminum) and pipe Corrugation pitch and depth from field measurement form.

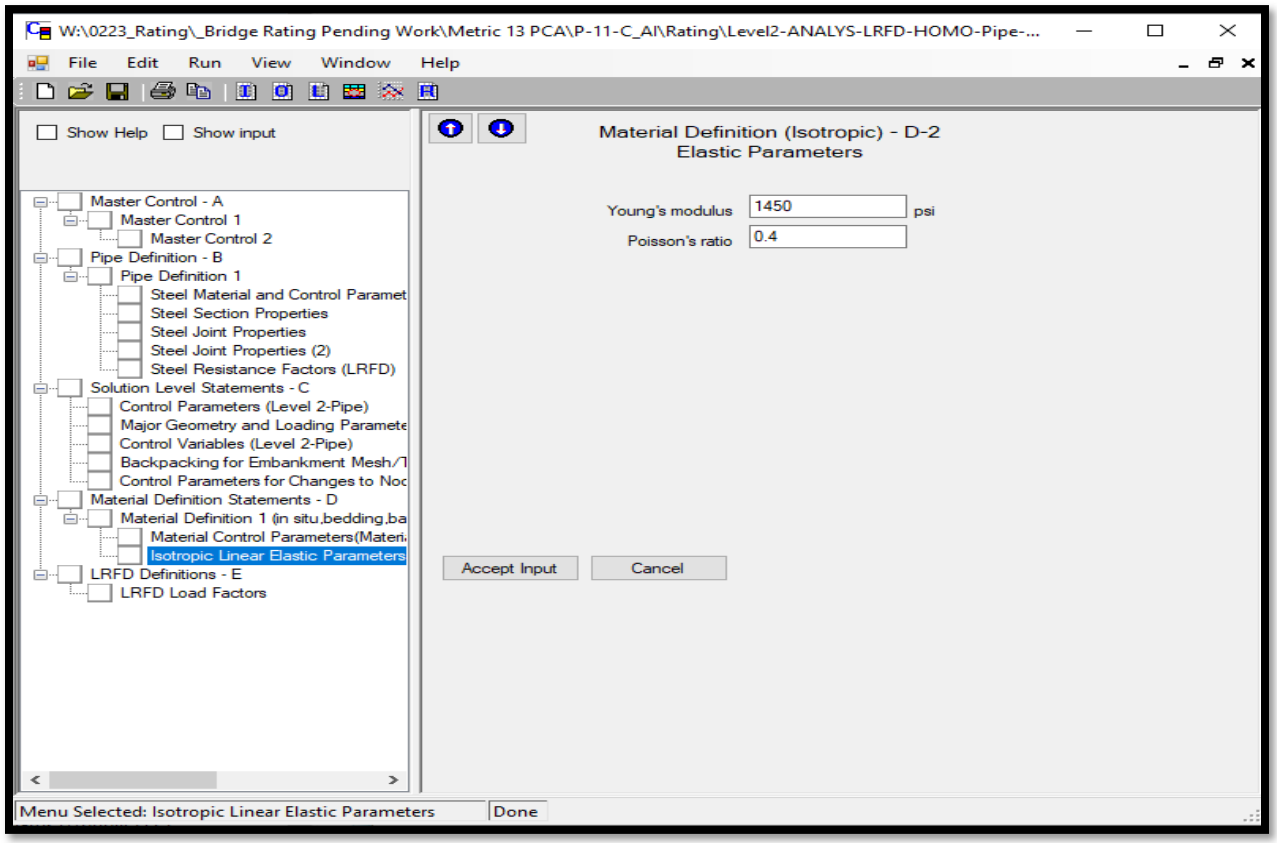

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Material (Steel) B-2b
Joint Properties
Thrust stress at initial joint slippage 4950 psi
Thrust stress at initial joint yielding 33000 psi
Ratio of slipping modulus to elastic steel modulus 0
Ratio of post-slipping modulus to elastic steel modulus 0.5
Ratio of yielding zone modulus to elastic steel modulus 0
Slot travel length 1 in
Number of joints in this pipe group 6
Vary joint travel length
Same lengths
Different lengths
Accept Input
Cancel
Menu Selected: Steel Joint Properties
Done

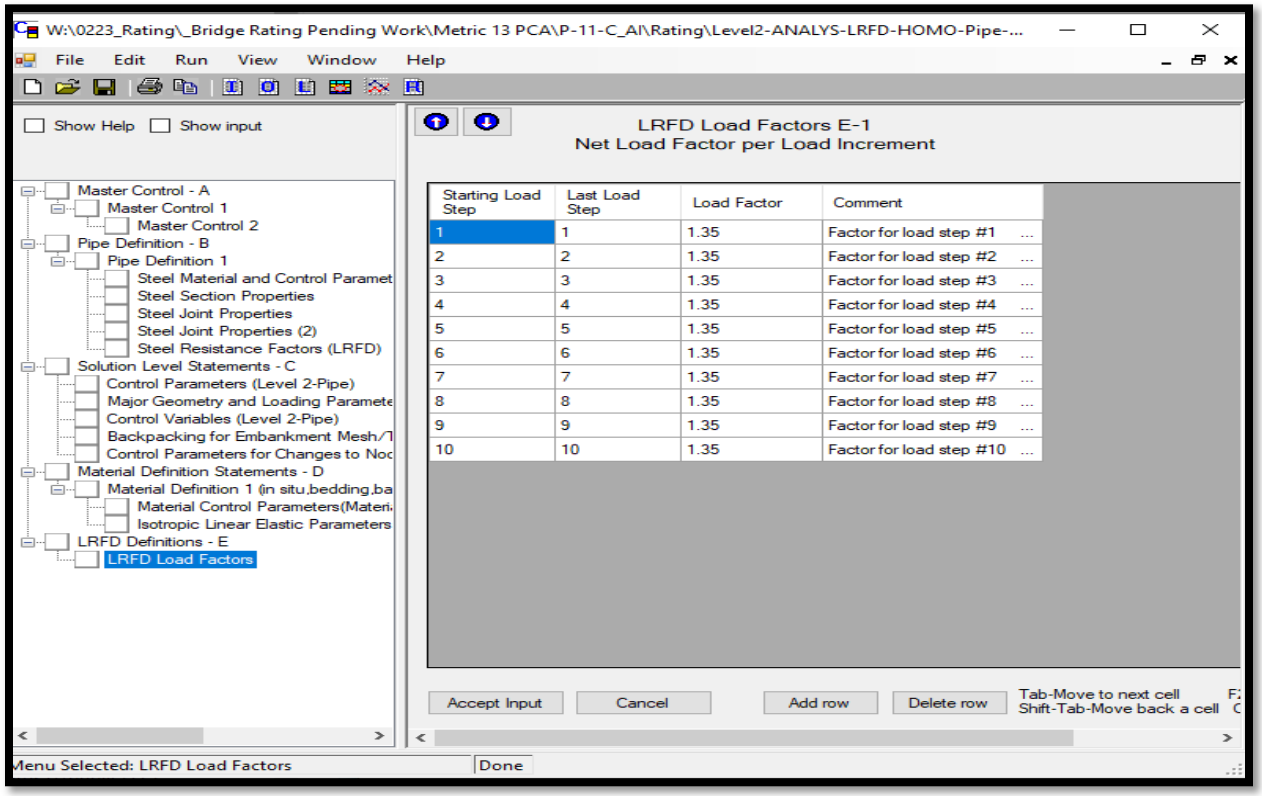

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Material (Steel) B-3
Resistance Factors for LRFD
Resistance factor for thrust stress yielding 1
Resistance factor for global buckling 1
Resistance factor for seam strength 0.67
Resistance factor for plastic penetration 0.9
Allowable deflection at service load 5 %
Accept Input
Cancel
Menu Selected: Steel Resistance Factors (LRFD)
Done

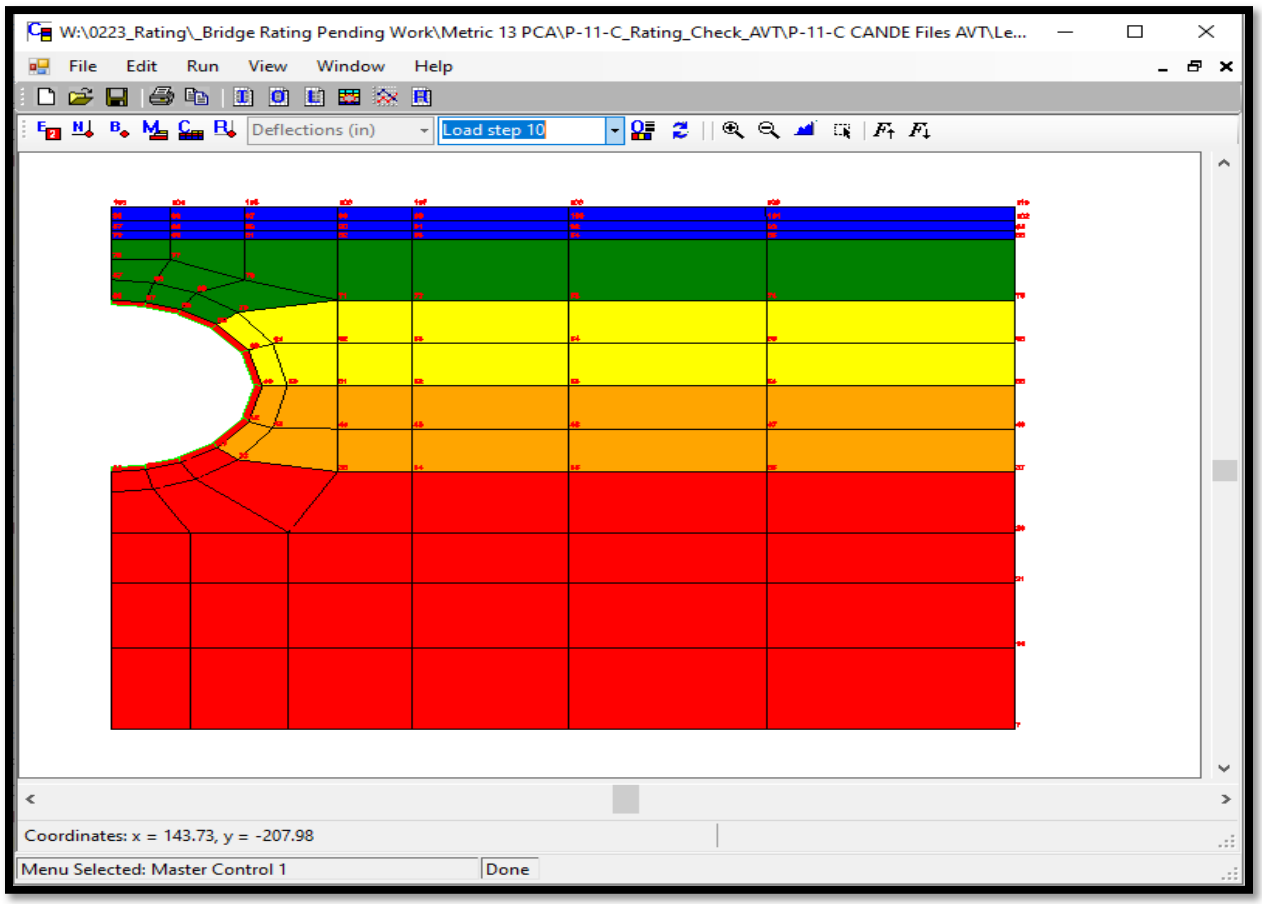

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Level 2 - C-2
Major Geometry and Loading Parameters
Pipe Mesh
Average vertical diameter of pipe 92 in
Ratio of horizontal to vertical diameter 1.413
Height of soil cover 8 ft
Density of soil above truncated mesh 120 lb/ft^3
Accept Input
Cancel
Menu Selected: Major Geometry and Loading Parameter
Done


W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Level 2 - C-3
Integer Control Variables
Pipe Mesh
Number of load steps 10
Response data output
Minimal
Standard
Plus Duncan
Plus interface
Mesh output
Control
Mirror
Created data
Maximum
Accept Input
Cancel
Menu Selected: Control Variables (Level 2-Pipe)
Done

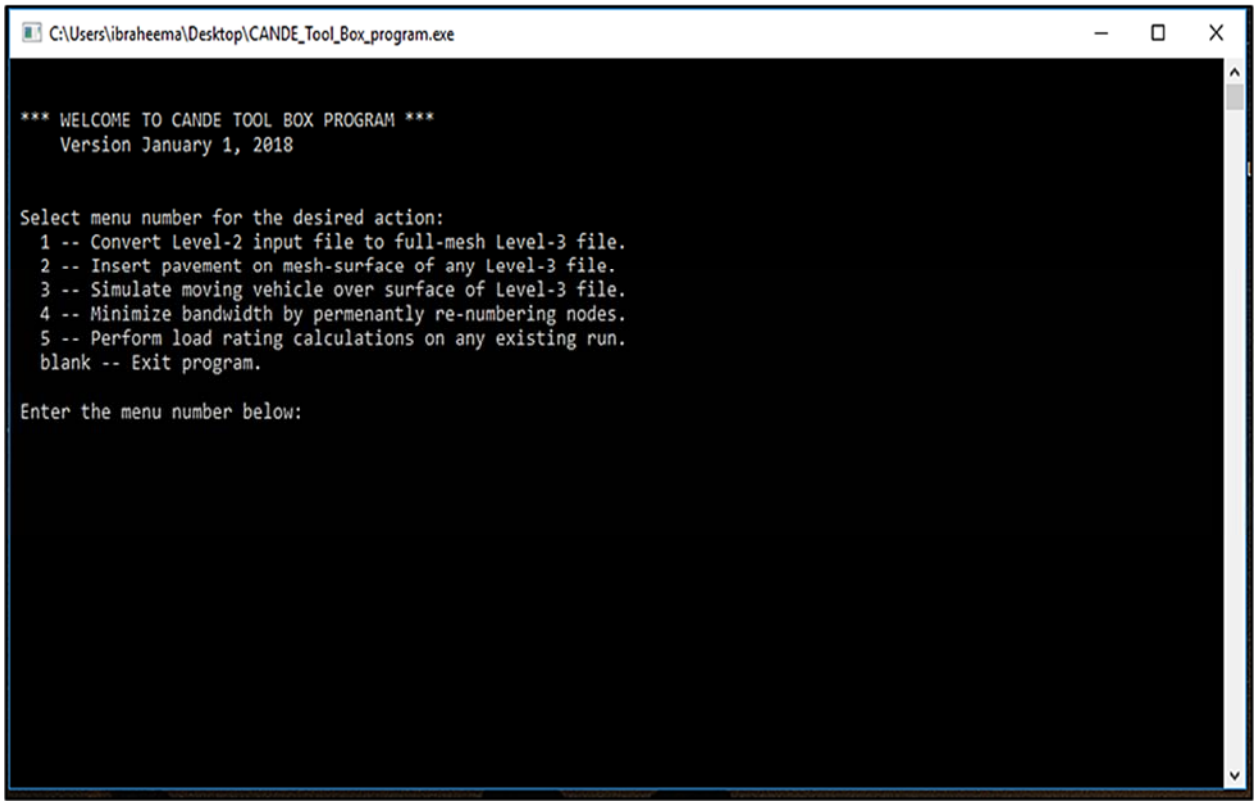

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Material Definition - D-1
Material Control Parameters
Material ID 1
Model Type 1-Isotropic-Linear Elastic
Density 120 lb/ft^3
Material name
Accept Input Cancel Delete
Menu Selected: Material Control Parameters(Material 1) Done


W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
Material Definition (Isotropic) - D-2
Elastic Parameters
Young's modulus 1450 psi
Poisson's ratio 0.4
Accept Input Cancel
Menu Selected: Isotropic Linear Elastic Parameters Done

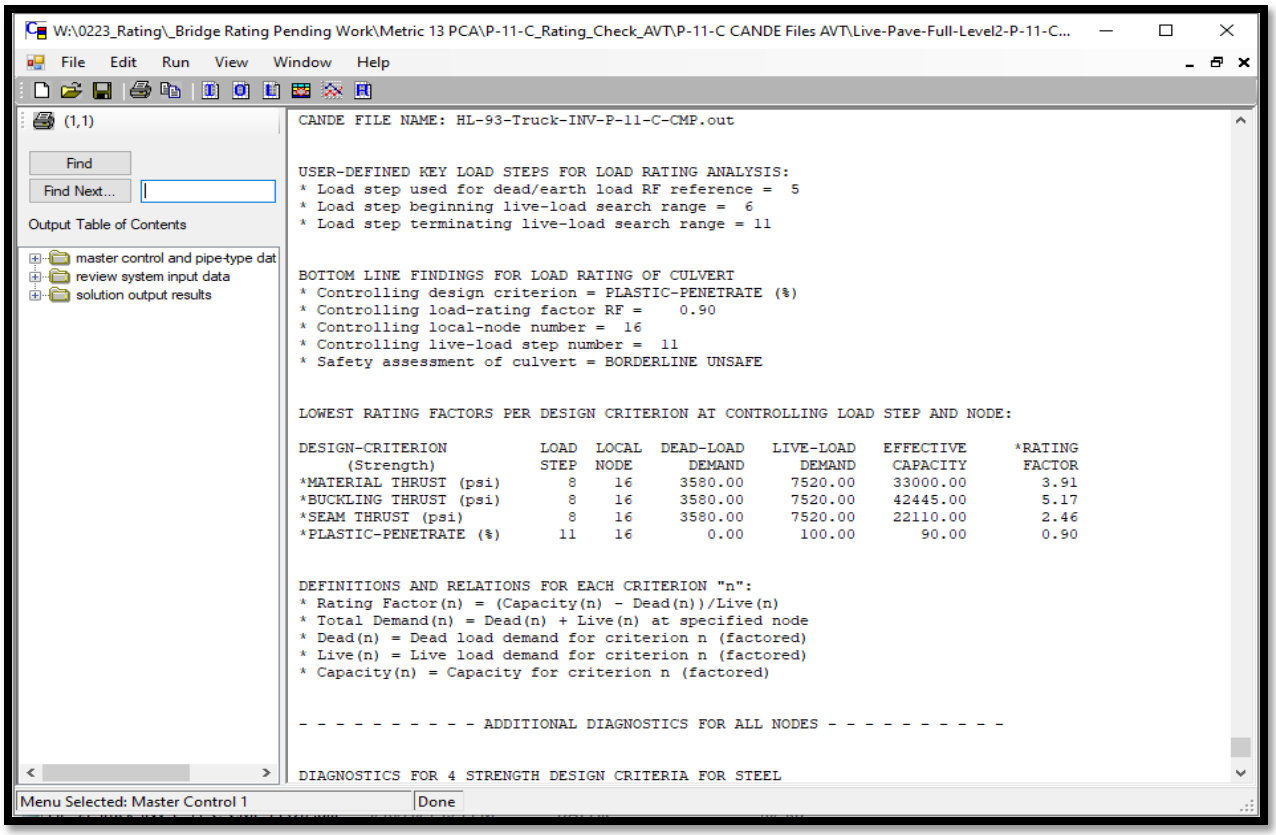

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_AI\Rating\Level2-ANALYS-LRFD-HOMO-Pipe-...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Paramet
Steel Section Properties
Steel Joint Properties
Steel Joint Properties (2)
Steel Resistance Factors (LRFD)
Solution Level Statements - C
Control Parameters (Level 2-Pipe)
Major Geometry and Loading Paramete
Control Variables (Level 2-Pipe)
Backpacking for Embankment Mesh/T
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ,bedding,ba
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
LRFD Definitions - E
LRFD Load Factors
LRFD Load Factors E-1
Net Load Factor per Load Increment
Starting Load Step | Last Load Step | Load Factor | Comment
1 | 1 | 1.35 | Factor for load step #1
2 | 2 | 1.35 | Factor for load step #2
3 | 3 | 1.35 | Factor for load step #3
4 | 4 | 1.35 | Factor for load step #4
5 | 5 | 1.35 | Factor for load step #5
6 | 6 | 1.35 | Factor for load step #6
7 | 7 | 1.35 | Factor for load step #7
8 | 8 | 1.35 | Factor for load step #8
9 | 9 | 1.35 | Factor for load step #9
10 | 10 | 1.35 | Factor for load step #10
Accept Input
Cancel
Add row
Delete row
Tab-Move to next cell
Shift-Tab-Move back a cell
Menu Selected: LRFD Load Factors
Done

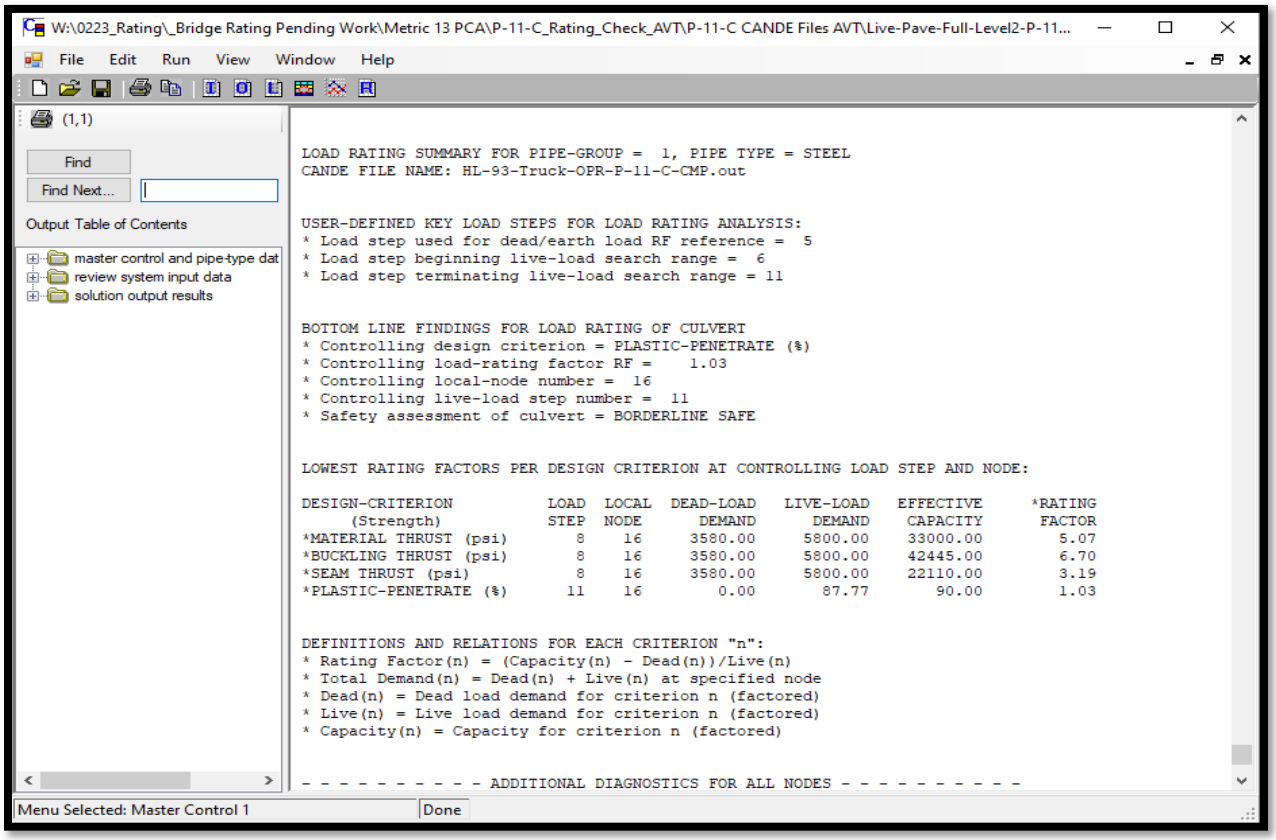

W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_Rating_Check_AVT\P-11-C CANDE Files AVT\Le...
File Edit Run View Window Help
Deflections (in)
Load step 10
Coordinates: x = 143.73, y = -207.98
Menu Selected: Master Control 1
Done

The CANDE Tool Box is used to convert mesh level 2 to level 3, update wearing surface thickness and unit weight, simulate various (design load, legal load, and permit load) and perform load rating calculations as shown below.
The rater must define each truck (legal and permit) configuration using option 3 in the Tool Box to get a rating for legal and permit trucks.
The rater must use live load factors specified in Section 1.3-M in CDOT Rating Manual 1.35 for design vehicle, 2.0 for legal load and 1.4 for permit load.
CANDE tool Box manual guide available in CANDE website:
https://www.candeforculverts.com/cande-tool-box.html



Below are rating results obtained from the CANDE output report for Inventory tandem design vehicle The process is slightly different for legal and permits trucks because the user must define the truck weight and axle spacing individually for each a truck.
For more pipe rating examples visit the CANDE website.


W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_Rating_Check_AVT\P-11-C CANDE Files AVT\Live-Pave-Full-Level2-P-11-C...
File Edit Run View Window Help
(1,1)
Find
Find Next...
Output Table of Contents
master control and pipe-type dat
review system input data
solution output results
CANDE FILE NAME: HL-93-Truck-INV-P-11-C-CMP.out
USER-DEFINED KEY LOAD STEPS FOR LOAD RATING ANALYSIS:
* Load step used for dead/earth load RF reference = 5
* Load step beginning live-load search range = 6
* Load step terminating live-load search range = 11
BOTTOM LINE FINDINGS FOR LOAD RATING OF CULVERT
* Controlling design criterion = PLASTIC-PENETRATE (%)
* Controlling load-rating factor RF = 0.90
* Controlling local-node number = 16
* Controlling live-load step number = 11
* Safety assessment of culvert = BORDERLINE UNSAFE
LOWEST RATING FACTORS PER DESIGN CRITERION AT CONTROLLING LOAD STEP AND NODE:
DESIGN-CRITERION (Strength) LOAD STEP LOCAL NODE DEAD-LOAD DEMAND LIVE-LOAD DEMAND EFFECTIVE CAPACITY *RATING FACTOR
*MATERIAL THRUST (psi) 8 16 3580.00 7520.00 33000.00 3.91
*BUCKLING THRUST (psi) 8 16 3580.00 7520.00 42445.00 5.17
*SEAM THRUST (psi) 8 16 3580.00 7520.00 22110.00 2.46
*PLASTIC-PENETRATE (%) 11 16 0.00 100.00 90.00 0.90
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)
- - - - - - - - - - ADDITIONAL DIAGNOSTICS FOR ALL NODES - - - - - - - - - -
DIAGNOSTICS FOR 4 STRENGTH DESIGN CRITERIA FOR STEEL
Menu Selected: Master Control 1
Done


W:\0223_Rating_Bridge Rating Pending Work\Metric 13 PCA\P-11-C_Rating_Check_AVT\P-11-C CANDE Files AVT\Live-Pave-Full-Level2-P-11...
File Edit Run View Window Help
(1,1)
Find
Find Next...
Output Table of Contents
master control and pipe-type dat
review system input data
solution output results
LOAD RATING SUMMARY FOR PIPE-GROUP = 1, PIPE TYPE = STEEL
CANDE FILE NAME: HL-93-Truck-OPR-P-11-C-CMP.out
USER-DEFINED KEY LOAD STEPS FOR LOAD RATING ANALYSIS:
* Load step used for dead/earth load RF reference = 5
* Load step beginning live-load search range = 6
* Load step terminating live-load search range = 11
BOTTOM LINE FINDINGS FOR LOAD RATING OF CULVERT
* Controlling design criterion = PLASTIC-PENETRATE (%)
* Controlling load-rating factor RF = 1.03
* Controlling local-node number = 16
* Controlling live-load step number = 11
* Safety assessment of culvert = BORDERLINE SAFE
LOWEST RATING FACTORS PER DESIGN CRITERION AT CONTROLLING LOAD STEP AND NODE:
DESIGN-CRITERION (Strength) LOAD STEP LOCAL NODE DEAD-LOAD DEMAND LIVE-LOAD DEMAND EFFECTIVE CAPACITY *RATING FACTOR
*MATERIAL THRUST (psi) 8 16 3580.00 5800.00 33000.00 5.07
*BUCKLING THRUST (psi) 8 16 3580.00 5800.00 42445.00 6.70
*SEAM THRUST (psi) 8 16 3580.00 5800.00 22110.00 3.19
*PLASTIC-PENETRATE (%) 11 16 0.00 87.77 90.00 1.03
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)
- - - - - - - - - - ADDITIONAL DIAGNOSTICS FOR ALL NODES - - - - - - - - - -
Menu Selected: Master Control 1
Done

COLORADO DEPARTMENT OF TRANSPORTATION
LOAD & RESISTANCE FACTOR RATING SUMMARY

Rated using:
Asphalt thickness: 6 in.
☑ Colorado legal loads ☐ Interstate legal loads
☐ Multi-lane for Legal & Permit Vehicles ☑ Single lane for Legal & Permit Vehicles

Structure #	P-11-C
State Highway #	017A
Batch I.D.	NA
Structure Type	CMP
Parallel Structure #	NA

Structural Member	CMP				
	Rating Factor				
Inventory	2.24				
Operating	2.90				
	Tons				
Type 3 truck	77.7				
Type 3S2 truck	120.2				
Type 3-2 truck	119.8				
Type SU4 truck (27T)	76.6				
Type SU5 truck (31T)	81.8				
Type SU6 truck (35T)	82.2				
Type SU7 truck (39T)	90.0				
NRL (40T)	89.2				
Lane-Type Legal					
EV2 (28.75T)	91.7				
EV3 (43T)	80.4				
Permit Truck (96T)	268.8				
Modified Tandem (50T)	148.0				

Comments:
- Rated using CANDE
- Fill Height=8.5 ft include 6 in asphalt thickness
- Operating Rating=104.4 ton
- Color Code= WHITE
-Rated based on CDOT BRM requirements.

PE Seal

Rated by: (Print name and sign) Date:
Checked by: (Print name and sign) Date:

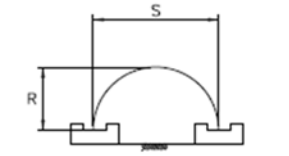
CDOT Staff Bridge • LRFR 02/2017

14A.7.2 Example 2: Steel Arch Rating (SAC)

COLORADO DEPARTMENT OF TRANSPORTATION
STAFF BRIDGE
CORRUGATED METAL CULVERT FIELD MEASUREMENT FORM

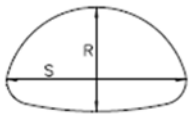
STRUCTURE # C-21-BG

Material Type (Steel, aluminum, etc.)	STEEL
Galvanized (Yes or No)	YES
Number of Cells	1
Are all cells the same size and shape? (Yes or No)	NA
Document any differences:	
Top Wall Thickness - t_1 (in) = (See Detail B)	1/4"
Bottom Wall Thickness - t_2 (in) = (See detail B)	1/4"
Minimum Wall Thickness (in) =	1/4"
Corrugations Pitch - c (in) = (See Detail B)	8"
Corrugations Depth - d (in) = (See Detail B)	1.5"
Number of Bolts per longitudinal foot of splice ? Is it double or single row ?	3
Bolt Diameter (in)	1.25"
Pipe Span length - S (in) = See Section A-A for appropriate type	35'-4.75"
Pipe Rise - R (in) = See Section A-A for appropriate type	10'-6.5"
Maximum Normal Curvature top radius (Rt) dimensions (See Detail D)	M=1.25 (in) P= 36 (in)
Pavement Thickness (in) =	2"
Fill Height (in) =	36"
Is there noticeable settlement in the roadway over the culvert? Yes or No	NO
Is there noticeable differential settlement or rotation in the the culvert? Yes or No (Detail C)	NO
Is there noticeable sag or damage inside the culvert? Yes or No (If yes, take a photo)	NO
Noticeable Sag Dimensions (See Detail D) Location =	M= (in) P= (in)
Inspector Initials : LM Date: 1/7/2019	



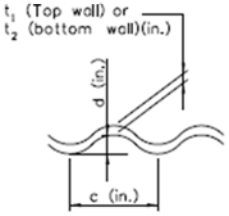
No t_2 values exist for this section

SECTION A-A
(ARCH)

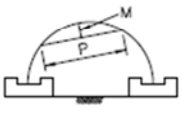


SECTION A-A
(PIPE ARCH)

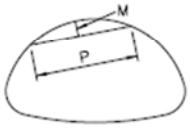
SECTION A-A
(CIRCULAR)



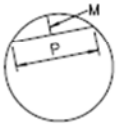
DETAIL B
(METAL CORRUGATION & GAGE INFORMATION)



(ARCH)



(PIPE ARCH)

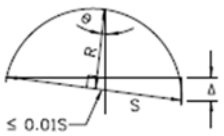


$R_t = \frac{M}{2} + \frac{P^2}{8M}$

(CIRCULAR)

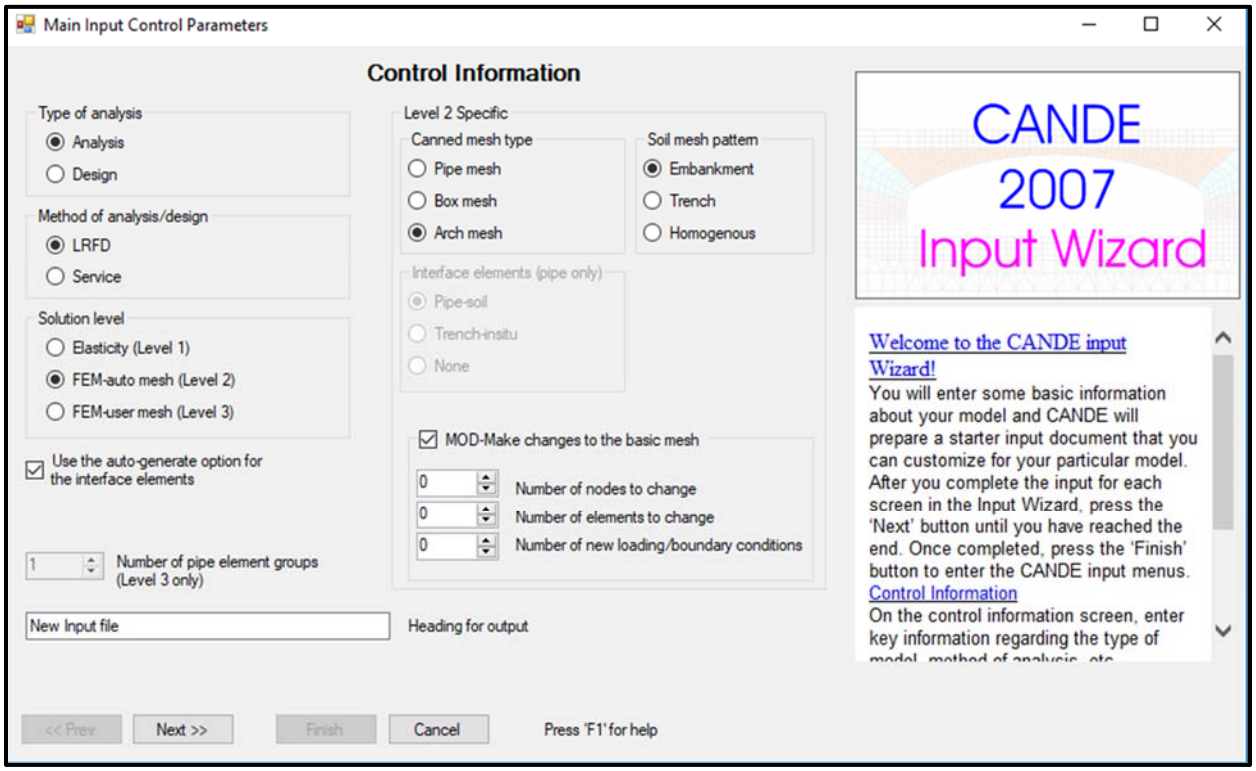
Calculate maximum existing normal curvature top radius (R_t) by taking measurments around the upper periphery of the culvert using a ruler of length "P" to obtain value of "M". This should be done at selected stations along length of culvert (particularly at locations with normal curvature and at location with noticeable sag)

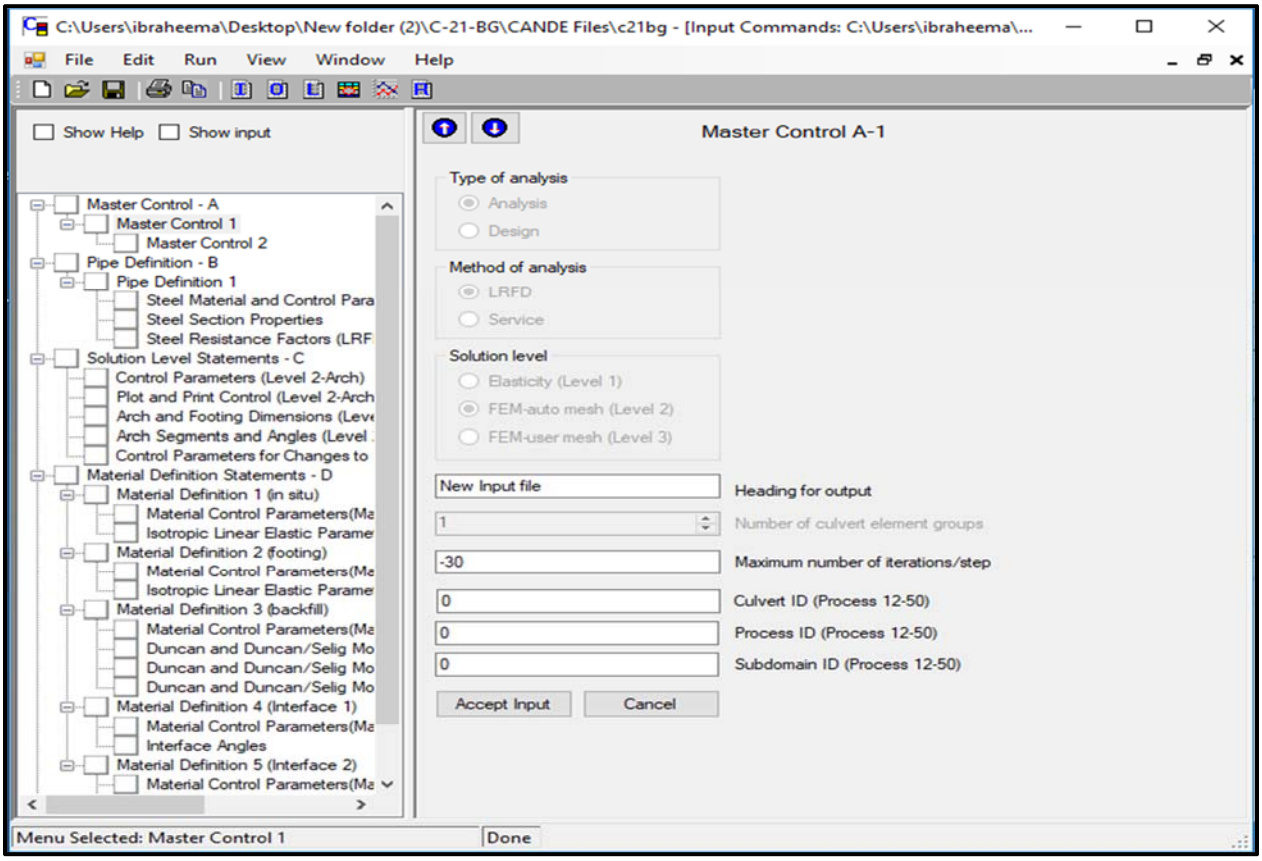
DETAIL D
Top Radius Rt

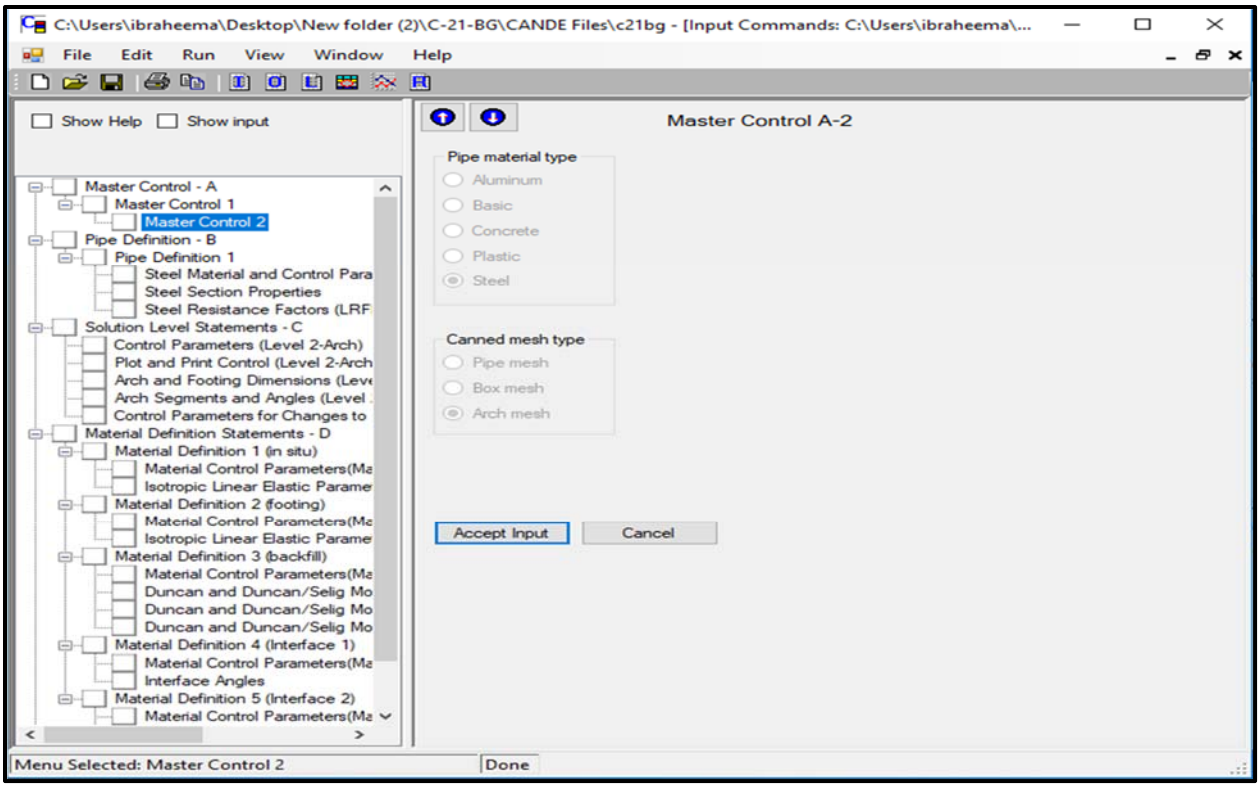


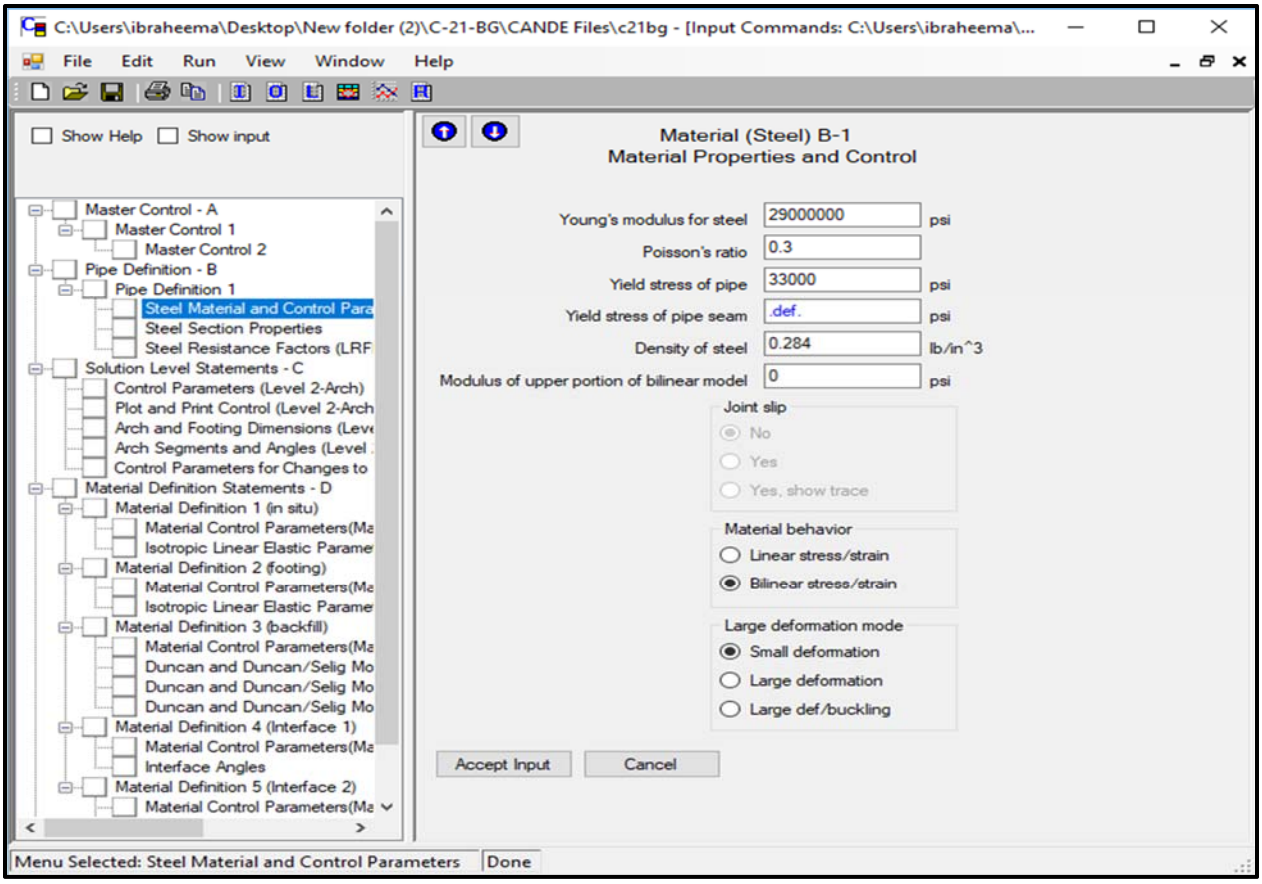
The rotation of the structure, θ, may be determined as: $\theta = \tan^{-1}\left(\frac{\Delta}{S}\right)$

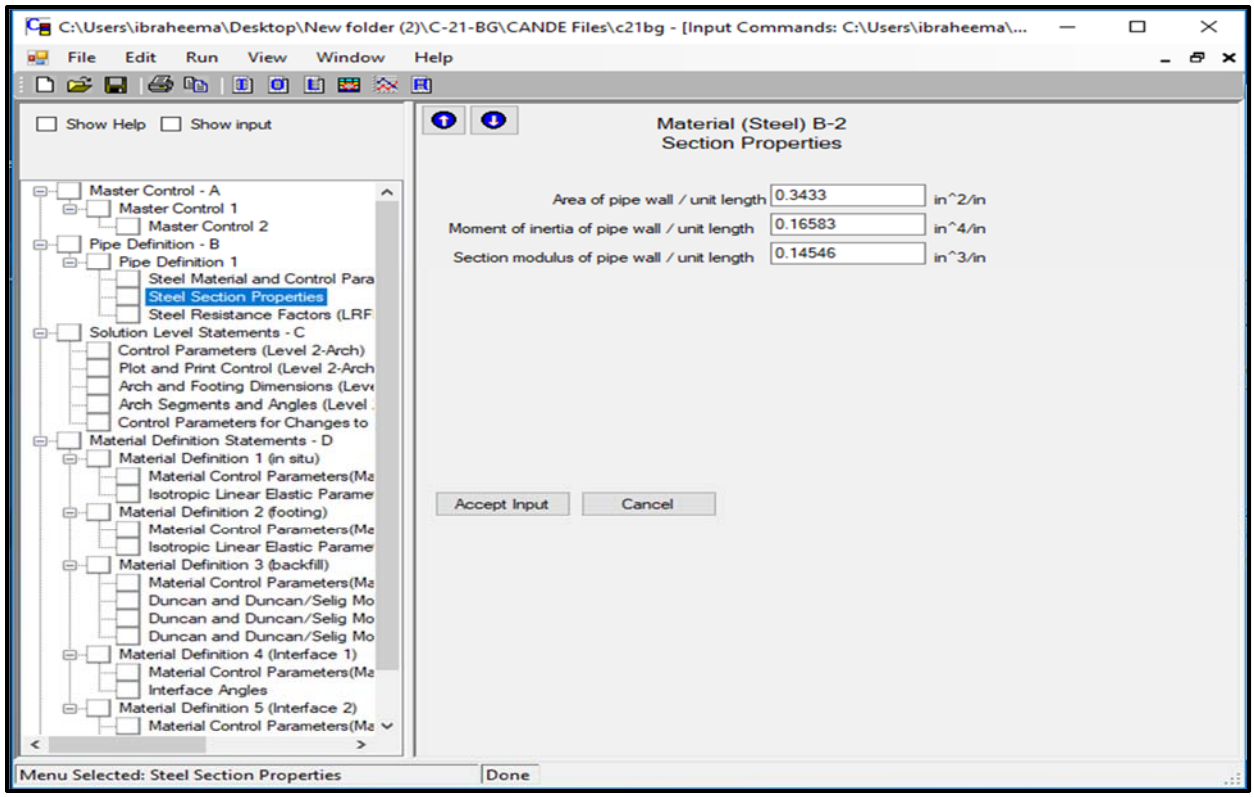
DETAIL C
DIFFERENTIAL SETTLEMENT

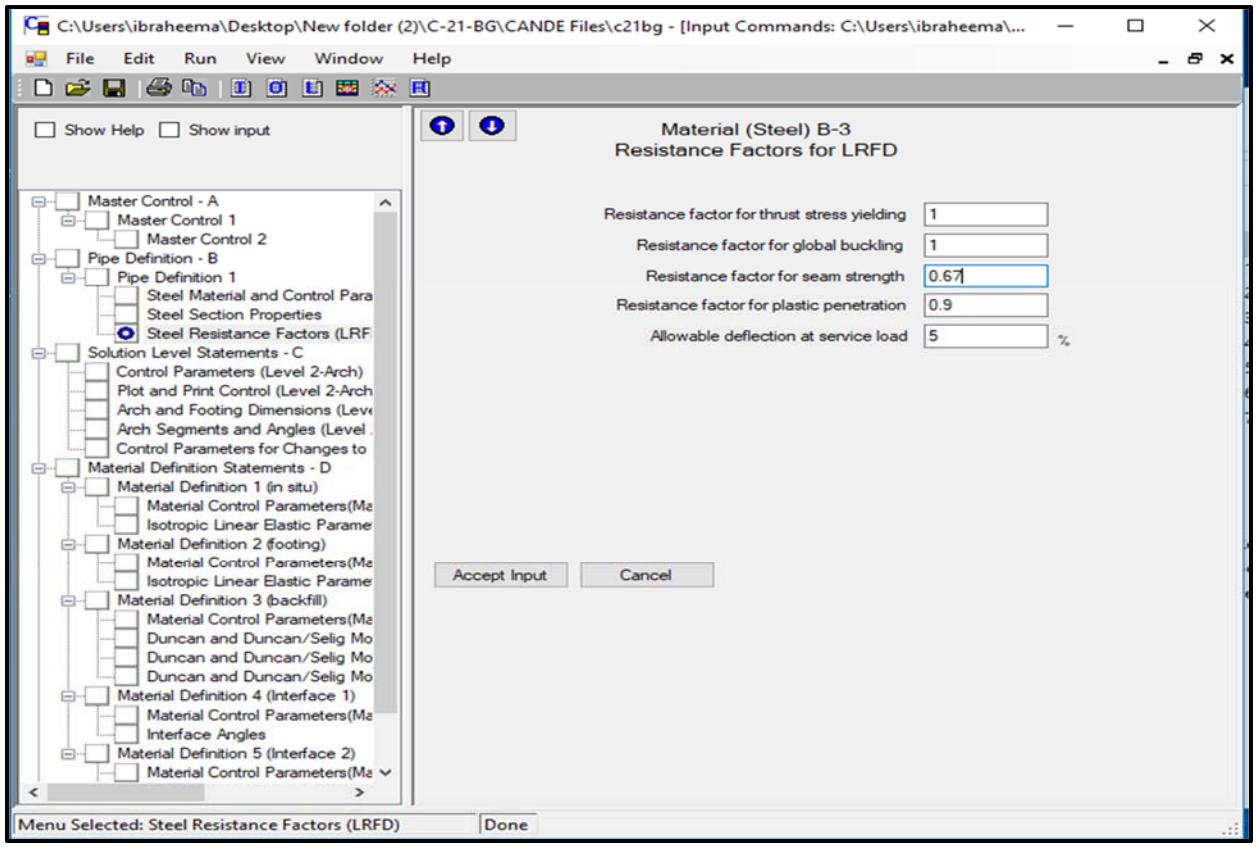

Main Input Control Parameters
Control Information
Type of analysis
Analysis
Design
Method of analysis/design
LRFD
Service
Solution level
Elasticity (Level 1)
FEM-auto mesh (Level 2)
FEM-user mesh (Level 3)
Use the auto-generate option for the interface elements
Number of pipe element groups (Level 3 only)
New Input file
Heading for output
Level 2 Specific
Canned mesh type
Pipe mesh
Box mesh
Arch mesh
Soil mesh pattern
Embankment
Trench
Homogenous
Interface elements (pipe only)
Pipe-soil
Trench-insitu
None
MOD-Make changes to the basic mesh
Number of nodes to change
Number of elements to change
Number of new loading/boundary conditions
CANDE 2007 Input Wizard
Welcome to the CANDE input Wizard!
You will enter some basic information about your model and CANDE will prepare a starter input document that you can customize for your particular model. After you complete the input for each screen in the Input Wizard, press the 'Next' button until you have reached the end. Once completed, press the 'Finish' button to enter the CANDE input menus.
Control Information
On the control information screen, enter key information regarding the type of
<< Prev
Next >>
Finish
Cancel
Press 'F1' for help

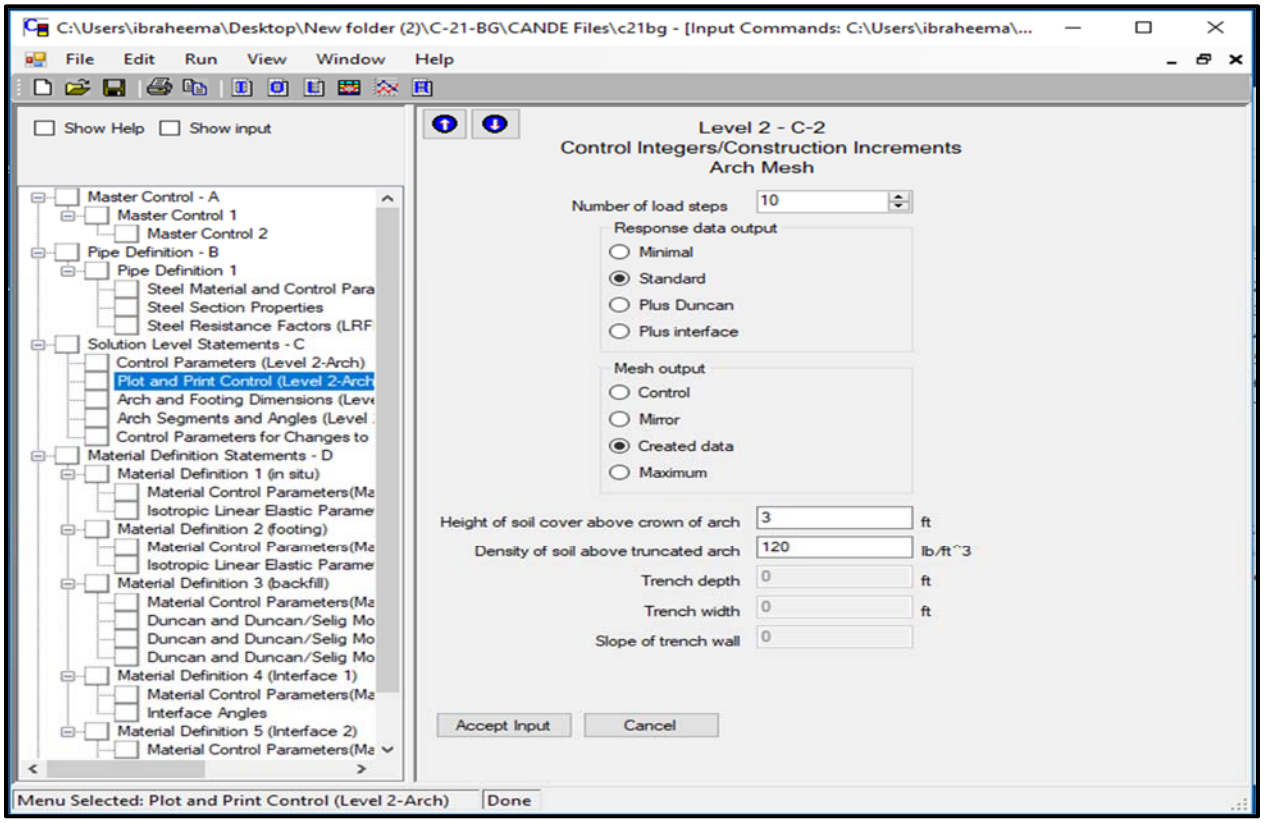

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Leve
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Master Control A-1
Type of analysis
Analysis
Design
Method of analysis
LRFD
Service
Solution level
Elasticity (Level 1)
FEM-auto mesh (Level 2)
FEM-user mesh (Level 3)
New Input file
Heading for output
1
Number of culvert element groups
-30
Maximum number of iterations/step
0
Culvert ID (Process 12-50)
0
Process ID (Process 12-50)
0
Subdomain ID (Process 12-50)
Accept Input
Cancel
Menu Selected: Master Control 1
Done

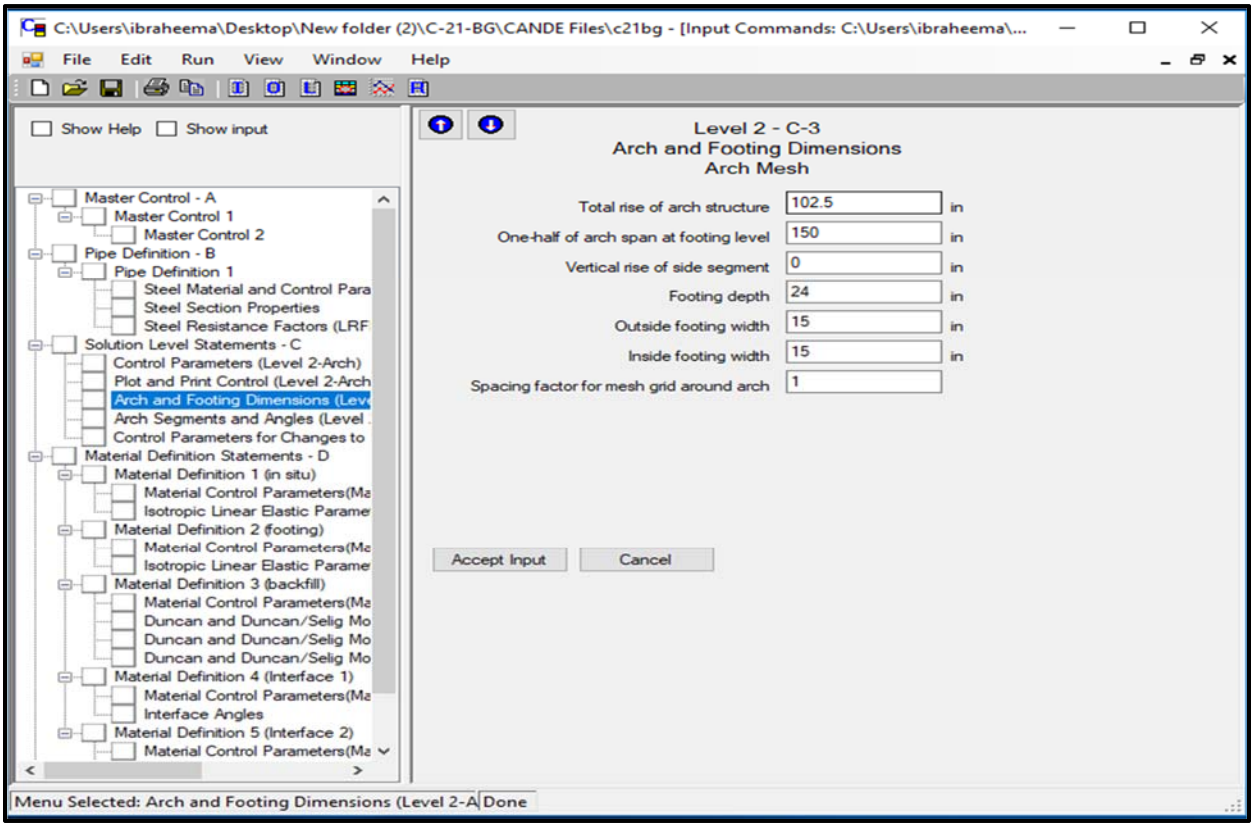

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Master Control A-2
Pipe material type
Aluminum
Basic
Concrete
Plastic
Steel
Canned mesh type
Pipe mesh
Box mesh
Arch mesh
Accept Input
Cancel
Menu Selected: Master Control 2
Done

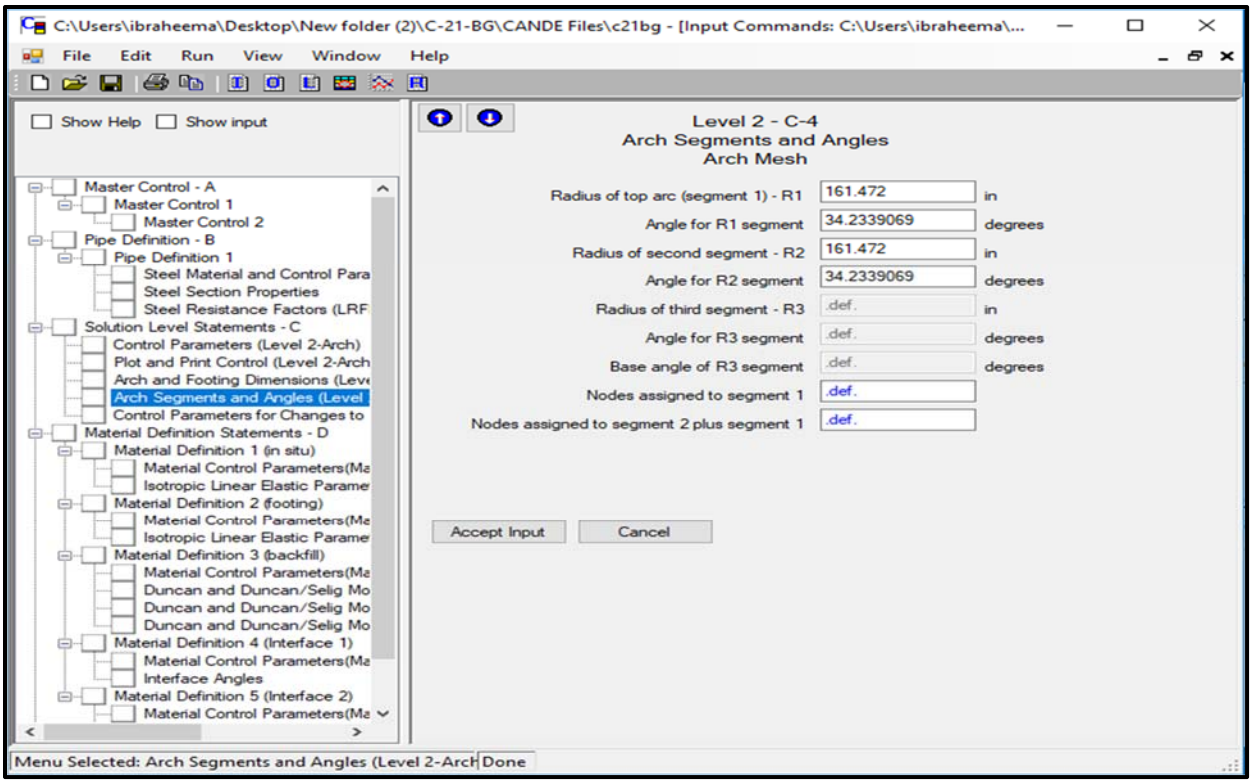

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Material (Steel) B-1
Material Properties and Control
Young's modulus for steel 29000000 psi
Poisson's ratio 0.3
Yield stress of pipe 33000 psi
Yield stress of pipe seam .def. psi
Density of steel 0.284 lb/in^3
Modulus of upper portion of bilinear model 0 psi
Joint slip
No
Yes
Yes, show trace
Material behavior
Linear stress/strain
Bilinear stress/strain
Large deformation mode
Small deformation
Large deformation
Large def/buckling
Accept Input
Cancel
Menu Selected: Steel Material and Control Parameters
Done

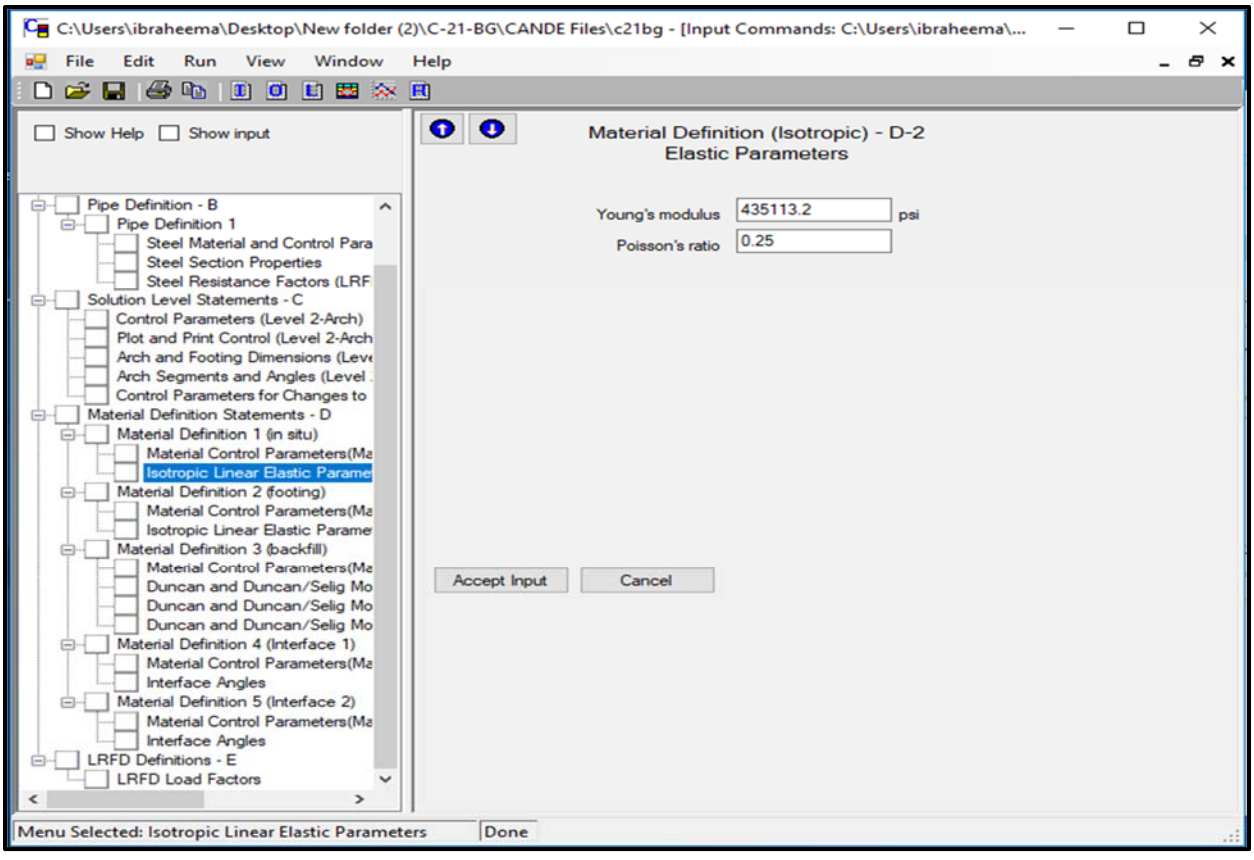

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Material (Steel) B-2
Section Properties
Area of pipe wall / unit length 0.3433 in^2/in
Moment of inertia of pipe wall / unit length 0.16583 in^4/in
Section modulus of pipe wall / unit length 0.14546 in^3/in
Accept Input
Cancel
Menu Selected: Steel Section Properties
Done

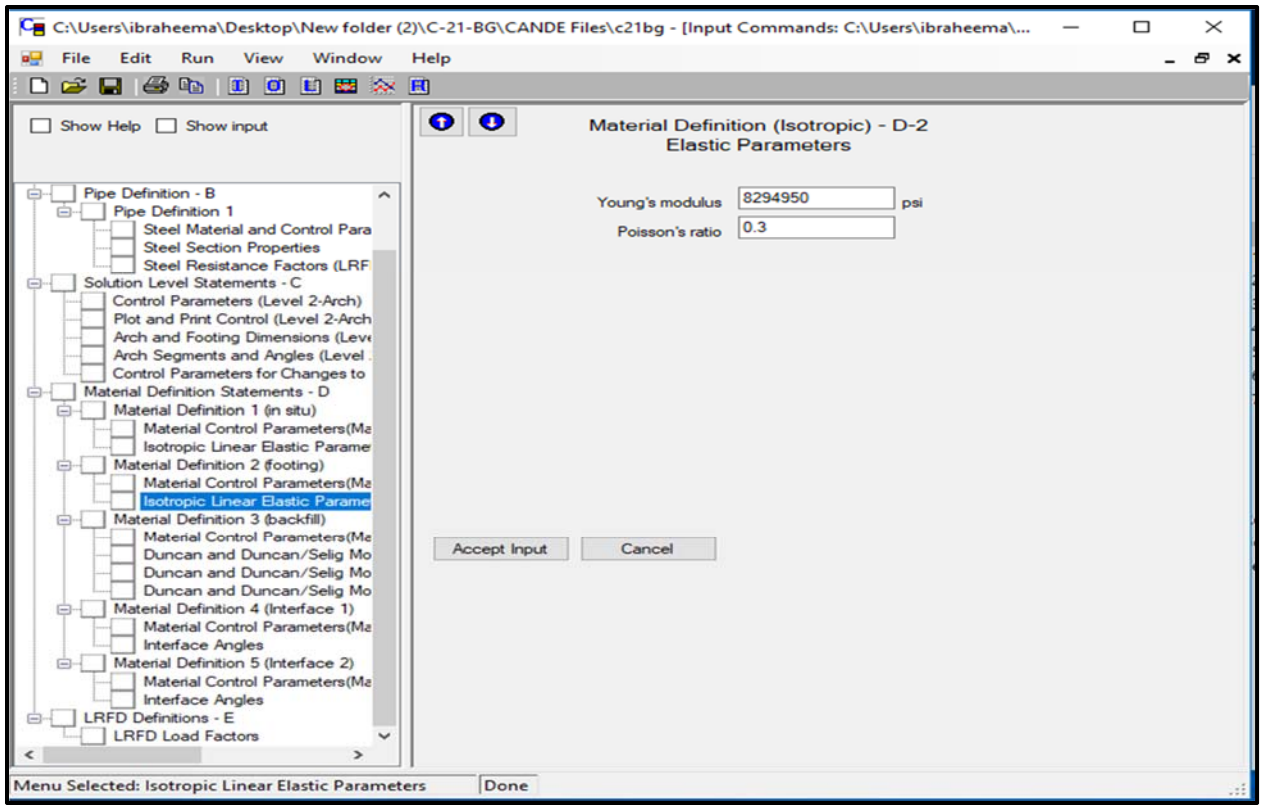

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Material (Steel) B-3
Resistance Factors for LRFD
Resistance factor for thrust stress yielding 1
Resistance factor for global buckling 1
Resistance factor for seam strength 0.67
Resistance factor for plastic penetration 0.9
Allowable deflection at service load 5 %
Accept Input
Cancel
Menu Selected: Steel Resistance Factors (LRFD)
Done

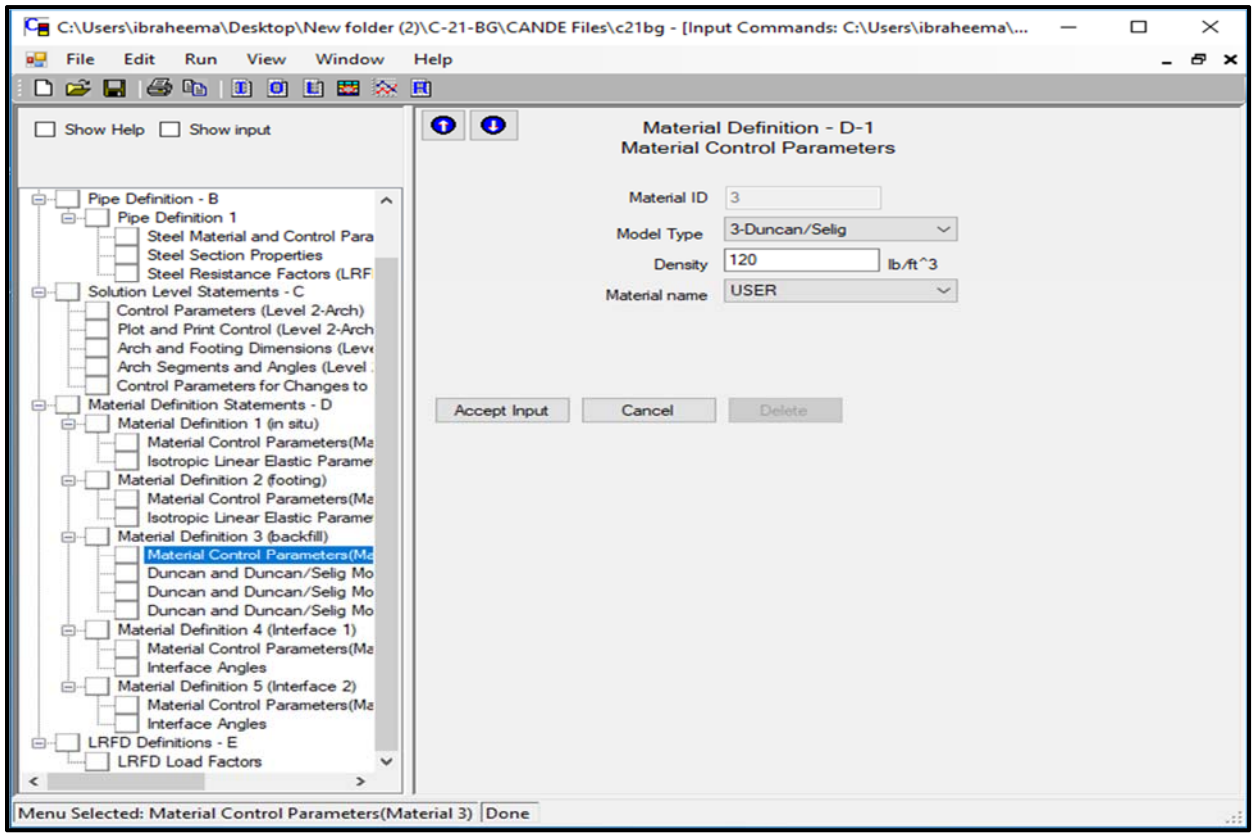

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Leve
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Level 2 - C-2
Control Integers/Construction Increments
Arch Mesh
Number of load steps 10
Response data output
Minimal
Standard
Plus Duncan
Plus interface
Mesh output
Control
Mirror
Created data
Maximum
Height of soil cover above crown of arch 3 ft
Density of soil above truncated arch 120 lb/ft^3
Trench depth 0 ft
Trench width 0 ft
Slope of trench wall 0
Accept Input
Cancel
Menu Selected: Plot and Print Control (Level 2-Arch)
Done

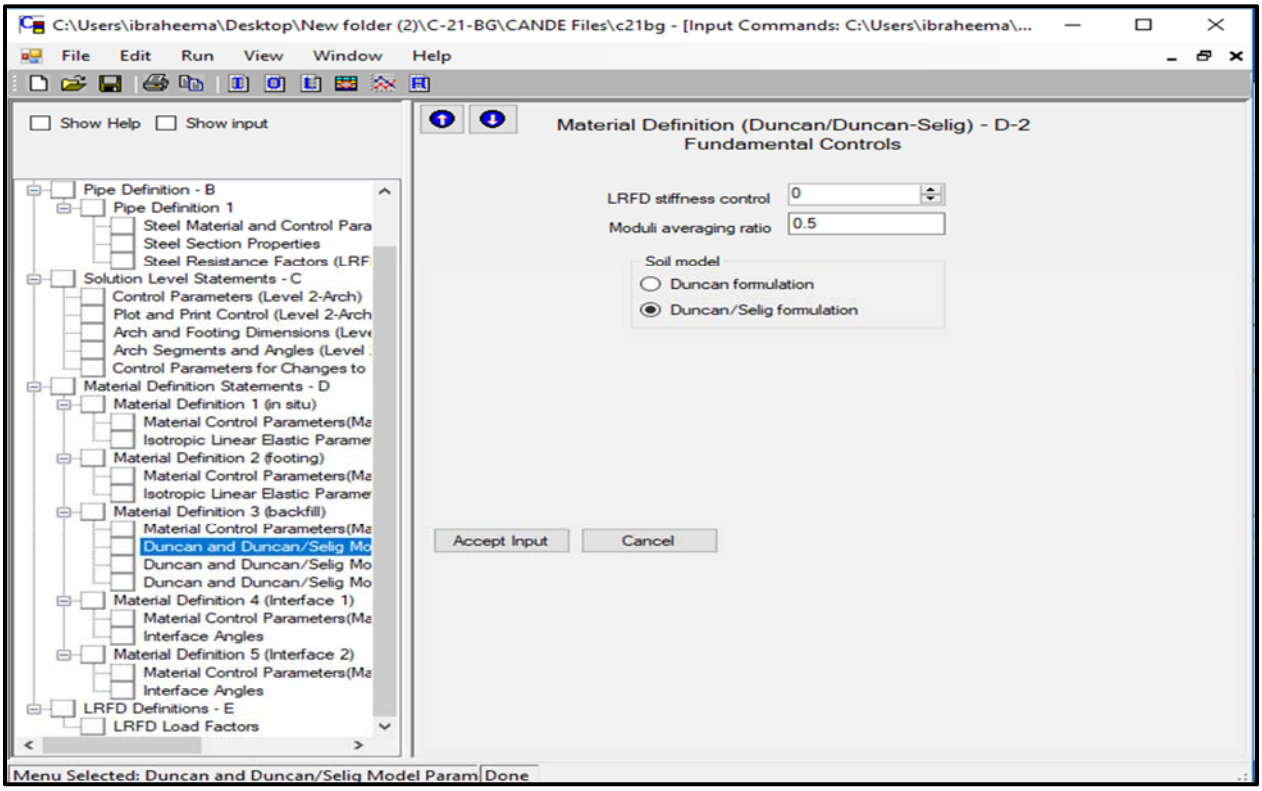

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Leve
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Level 2 - C-3
Arch and Footing Dimensions
Arch Mesh
Total rise of arch structure 102.5 in
One-half of arch span at footing level 150 in
Vertical rise of side segment 0 in
Footing depth 24 in
Outside footing width 15 in
Inside footing width 15 in
Spacing factor for mesh grid around arch 1
Accept Input
Cancel
Menu Selected: Arch and Footing Dimensions (Level 2-A
Done

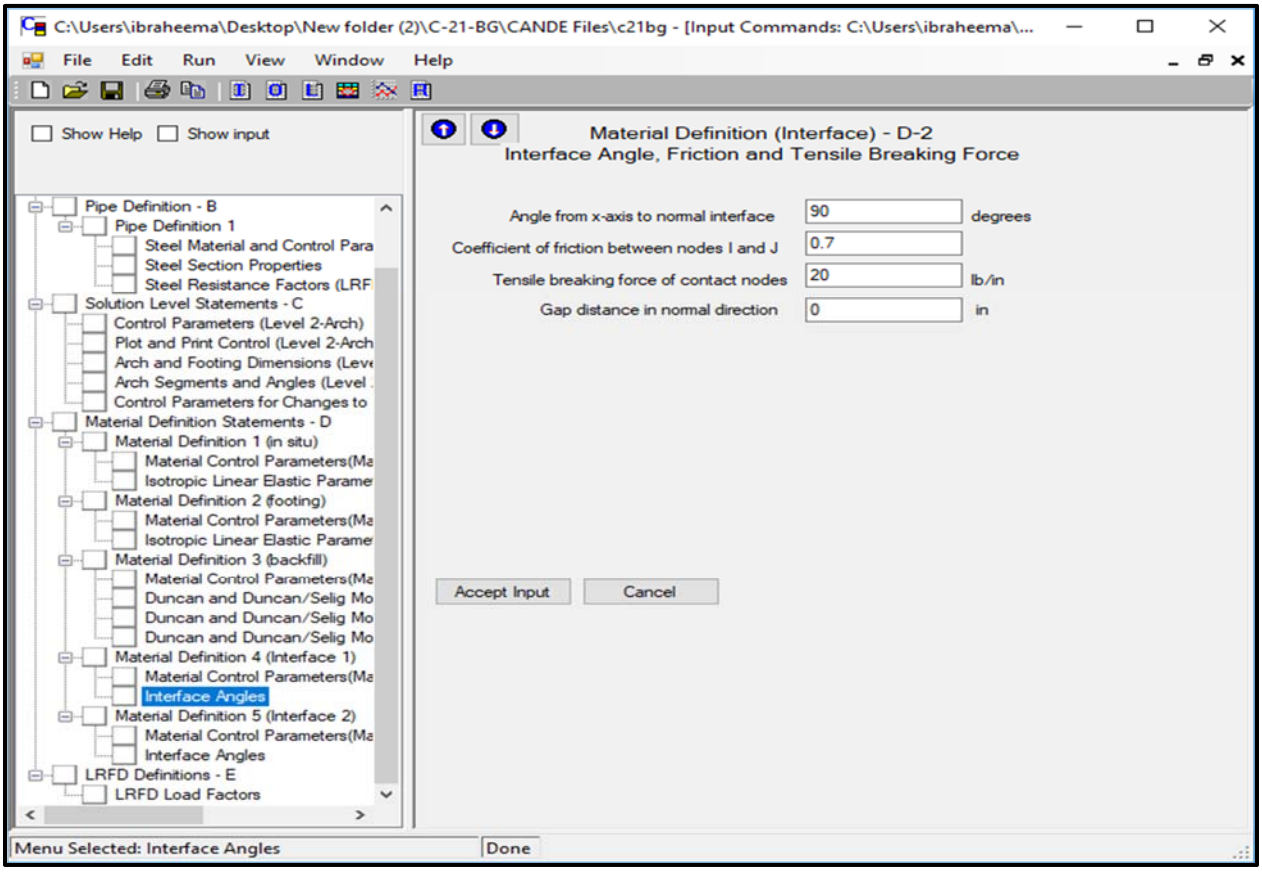

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Level 2 - C-4
Arch Segments and Angles
Arch Mesh
Radius of top arc (segment 1) - R1 161.472 in
Angle for R1 segment 34.2339069 degrees
Radius of second segment - R2 161.472 in
Angle for R2 segment 34.2339069 degrees
Radius of third segment - R3 .def. in
Angle for R3 segment .def. degrees
Base angle of R3 segment .def. degrees
Nodes assigned to segment 1 .def.
Nodes assigned to segment 2 plus segment 1 .def.
Accept Input Cancel
Menu Selected: Arch Segments and Angles (Level 2-Arch Done

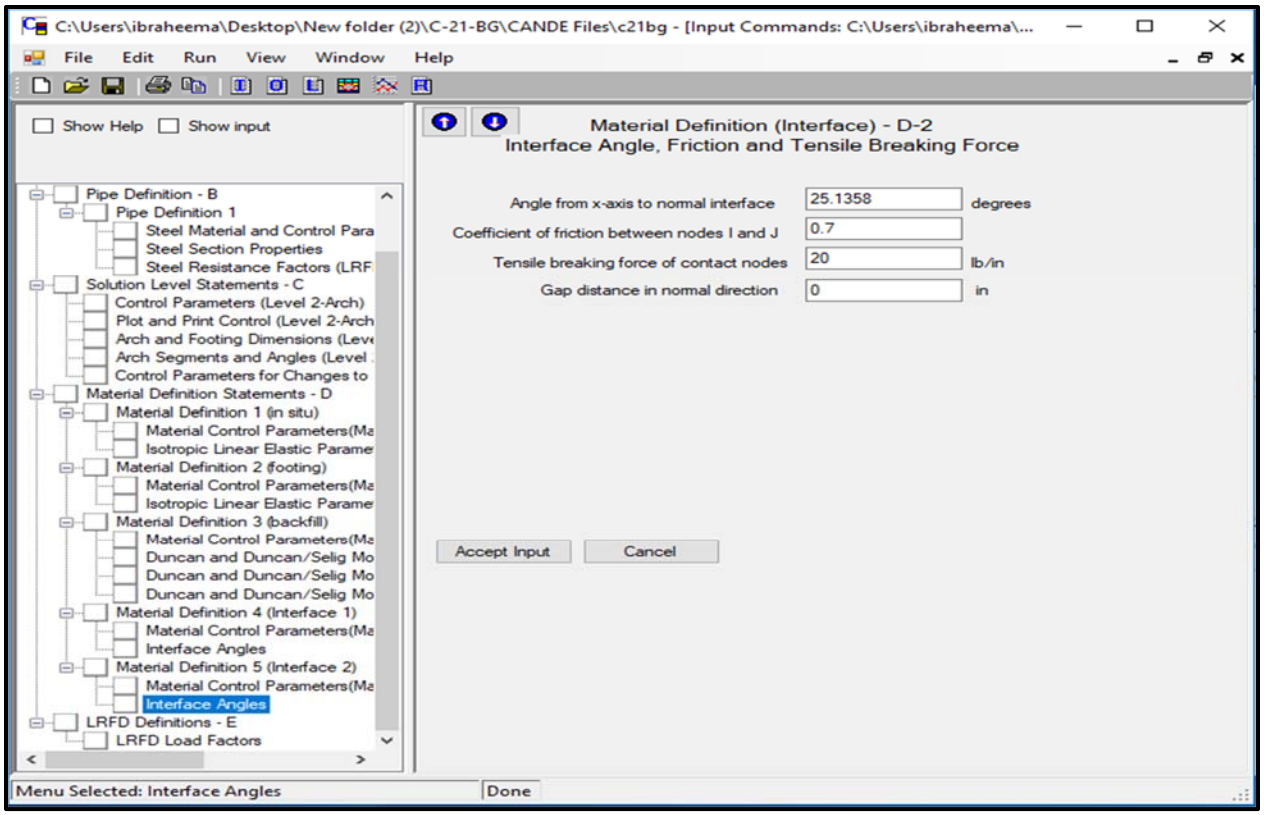

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Material Definition (Isotropic) - D-2
Elastic Parameters
Young's modulus 435113.2 psi
Poisson's ratio 0.25
Accept Input Cancel
Menu Selected: Isotropic Linear Elastic Parameters Done

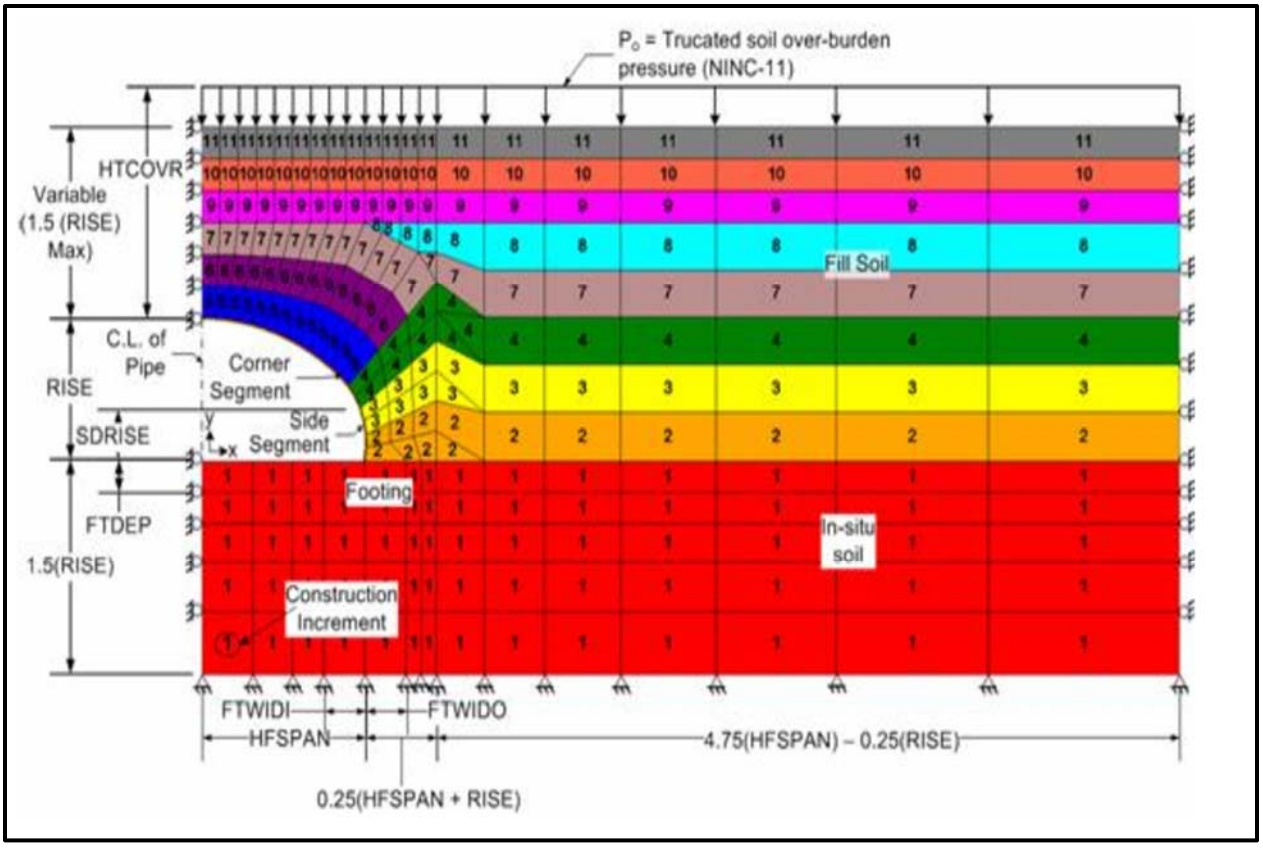

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Material Definition (Isotropic) - D-2
Elastic Parameters
Young's modulus 8294950 psi
Poisson's ratio 0.3
Accept Input Cancel
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Menu Selected: Isotropic Linear Elastic Parameters
Done


C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Material Definition - D-1
Material Control Parameters
Material ID 3
Model Type 3-Duncan/Selig
Density 120 lb/ft^3
Material name USER
Accept Input Cancel Delete
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Menu Selected: Material Control Parameters(Material 3)
Done

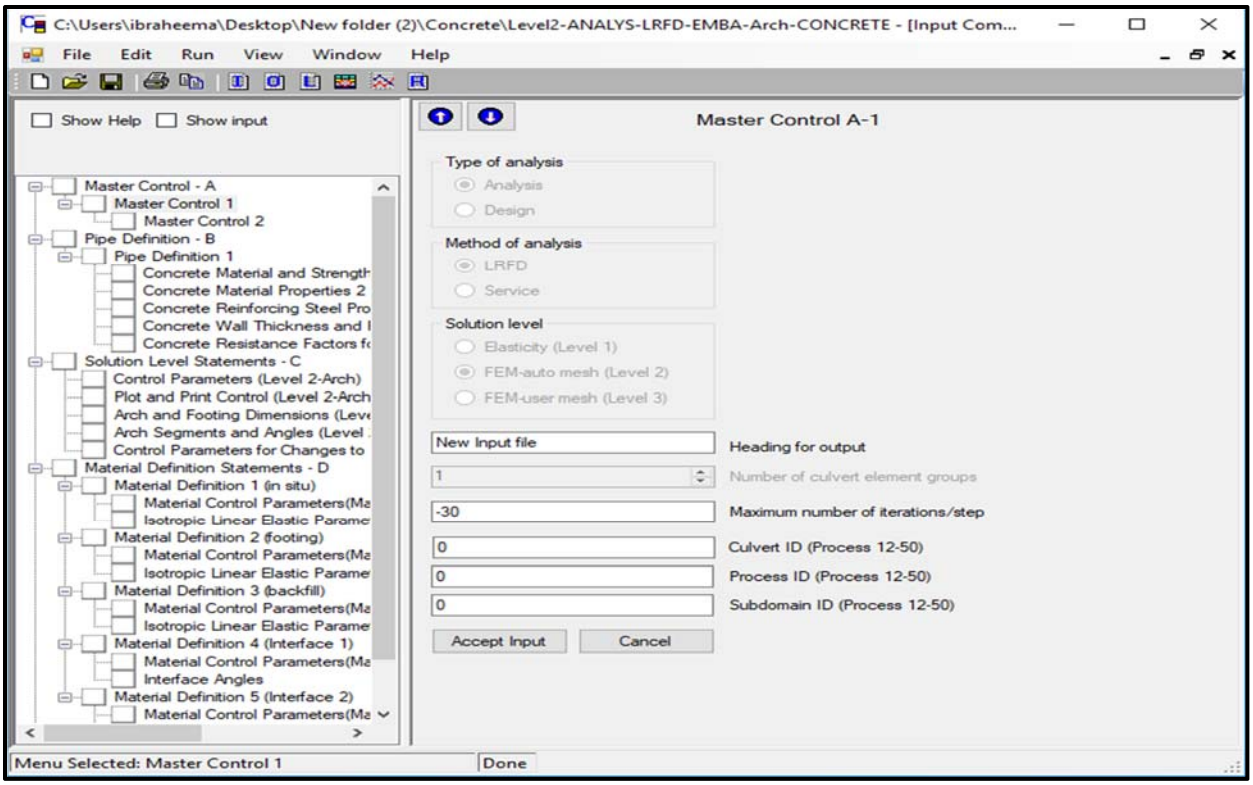

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Material Definition (Duncan/Duncan-Selig) - D-2
Fundamental Controls
LRFD stiffness control 0
Moduli averaging ratio 0.5
Soil model
Duncan formulation
Duncan/Selig formulation
Accept Input Cancel
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Leve
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Menu Selected: Duncan and Duncan/Selig Model Param
Done

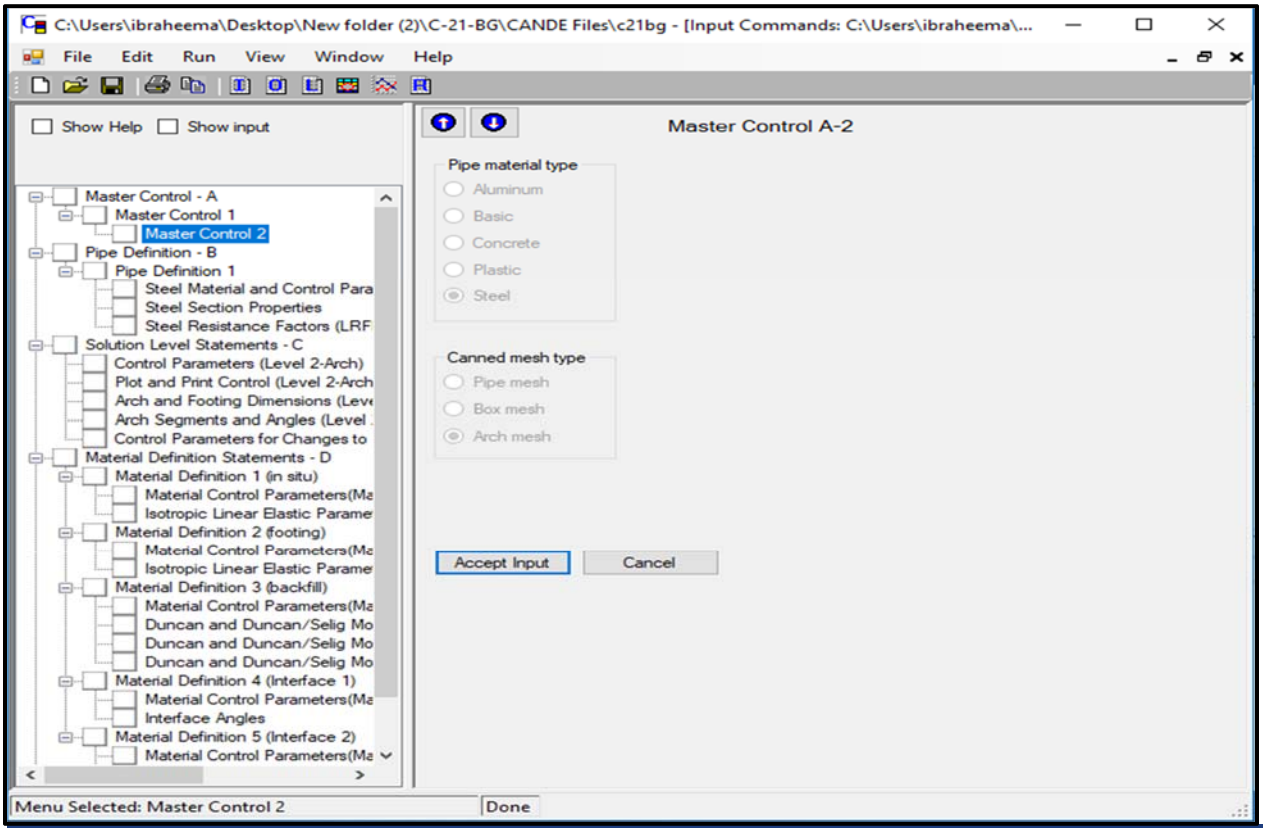

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Material Definition (Interface) - D-2
Interface Angle, Friction and Tensile Breaking Force
Angle from x-axis to normal interface 90 degrees
Coefficient of friction between nodes I and J 0.7
Tensile breaking force of contact nodes 20 lb/in
Gap distance in normal direction 0 in
Accept Input Cancel
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Leve
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Menu Selected: Interface Angles
Done

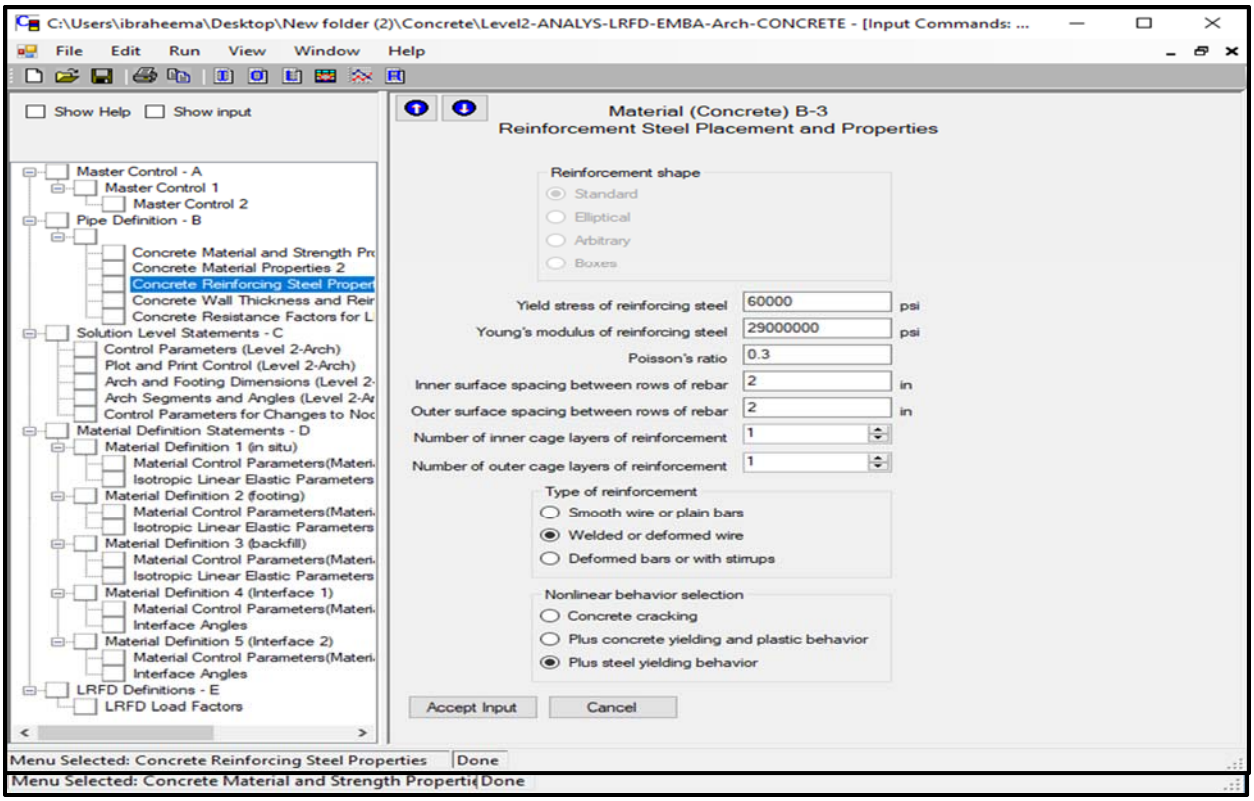

C:\Users\ibraheema\Desktop\New folder (2)\C-21-BG\CANDE Files\c21bg - [Input Commands: C:\Users\ibraheema\...
File Edit Run View Window Help
Show Help Show input
Pipe Definition - B
Pipe Definition 1
Steel Material and Control Para
Steel Section Properties
Steel Resistance Factors (LRF
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch
Arch and Footing Dimensions (Lev
Arch Segments and Angles (Level
Control Parameters for Changes to
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 2 (footing)
Material Control Parameters(Ma
Isotropic Linear Elastic Parame
Material Definition 3 (backfill)
Material Control Parameters(Ma
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Duncan and Duncan/Selig Mo
Material Definition 4 (Interface 1)
Material Control Parameters(Ma
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Ma
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Material Definition (Interface) - D-2
Interface Angle, Friction and Tensile Breaking Force
Angle from x-axis to normal interface 25.1358 degrees
Coefficient of friction between nodes I and J 0.7
Tensile breaking force of contact nodes 20 lb/in
Gap distance in normal direction 0 in
Accept Input
Cancel
Menu Selected: Interface Angles
Done

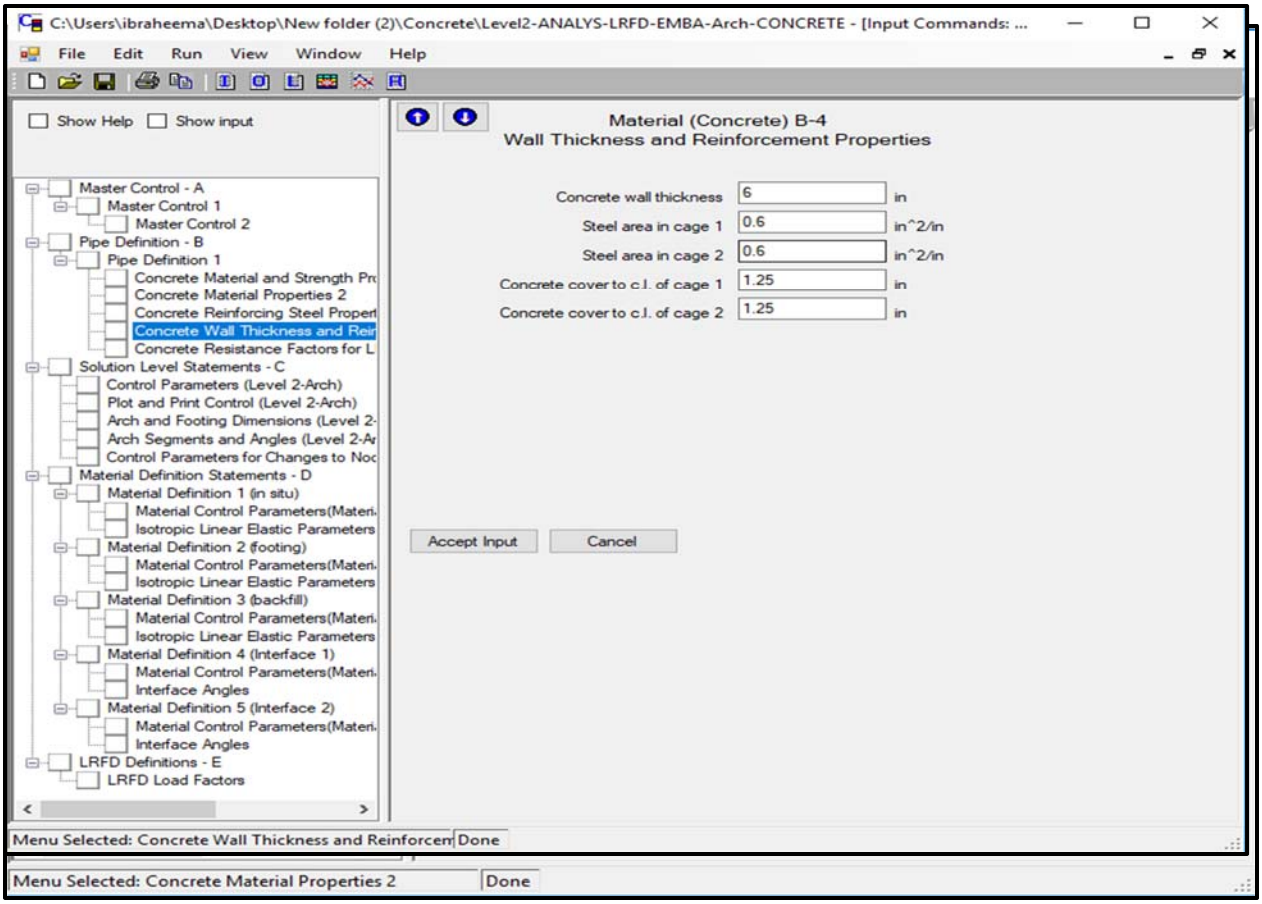

P0 = Trucated soil over-burden pressure (NINC-11)
HTCOVR
Variable (1.5 (RISE) Max)
C.L. of Pipe
RISE
SDRISE
FTDEP
1.5(RISE)
Corner Segment
Side Segment
Footing
Fill Soil
In-situ soil
Construction Increment
FTWIDI
FTWIDO
HFSPAN
4.75(HFSPAN) – 0.25(RISE)
0.25(HFSPAN + RISE)

14A.7.3 Example 3: Concrete Arch Culvert Rating (CAC)






C:\Users\ibraheema\Desktop\New folder (2)\Concrete\Level2-ANALYS-LRFD-EMBA-Arch-CONCRETE - [Input Commands: ...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Concrete Material and Strength Pr
Concrete Material Properties 2
Concrete Reinforcing Steel Proper
Concrete Wall Thickness and Rein
Concrete Resistance Factors for L
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch)
Arch and Footing Dimensions (Level 2-
Arch Segments and Angles (Level 2-A
Control Parameters for Changes to Noc
Material Definition Statements - D
Material Definition 1 (in situ)
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
Material Definition 2 (footing)
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
Material Definition 3 (backfill)
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
Material Definition 4 (Interface 1)
Material Control Parameters(Materi
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Materi
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Material (Concrete) B-3
Reinforcement Steel Placement and Properties
Reinforcement shape
Standard
Elliptical
Arbitrary
Boxes
Yield stress of reinforcing steel 60000 psi
Young's modulus of reinforcing steel 29000000 psi
Poisson's ratio 0.3
Inner surface spacing between rows of rebar 2 in
Outer surface spacing between rows of rebar 2 in
Number of inner cage layers of reinforcement 1
Number of outer cage layers of reinforcement 1
Type of reinforcement
Smooth wire or plain bars
Welded or deformed wire
Deformed bars or with stirups
Nonlinear behavior selection
Concrete cracking
Plus concrete yielding and plastic behavior
Plus steel yielding behavior
Accept Input
Cancel
Menu Selected: Concrete Reinforcing Steel Properties
Done
Menu Selected: Concrete Material and Strength Properti
Done


C:\Users\ibraheema\Desktop\New folder (2)\Concrete\Level2-ANALYS-LRFD-EMBA-Arch-CONCRETE - [Input Commands: ...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Concrete Material and Strength Pr
Concrete Material Properties 2
Concrete Reinforcing Steel Proper
Concrete Wall Thickness and Rei
Concrete Resistance Factors for L
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch)
Arch and Footing Dimensions (Level 2-
Arch Segments and Angles (Level 2-A
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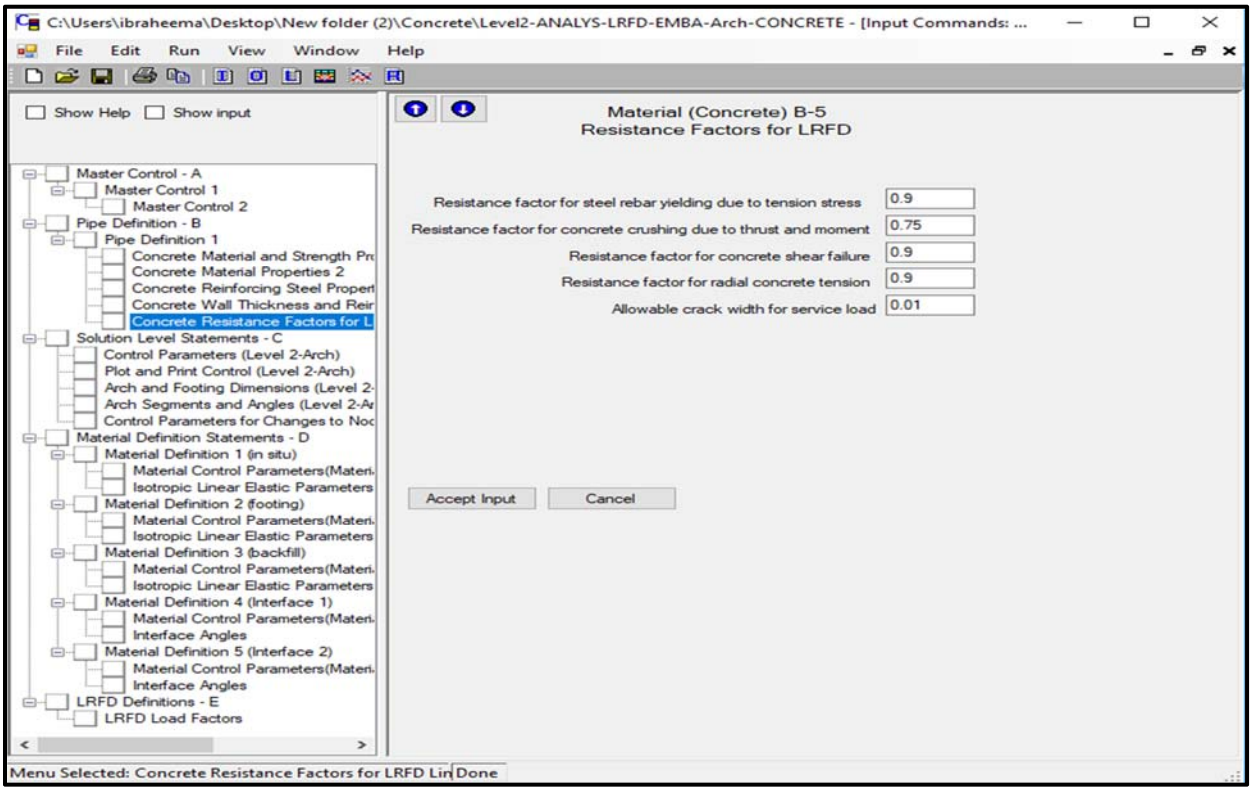
Isotropic Linear Elastic Parameters
Material Definition 3 (backfill)
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
Material Definition 4 (Interface 1)
Material Control Parameters(Materi
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Materi
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Material (Concrete) B-4
Wall Thickness and Reinforcement Properties
Concrete wall thickness 6 in
Steel area in cage 1 0.6 in^2/in
Steel area in cage 2 0.6 in^2/in
Concrete cover to c.l. of cage 1 1.25 in
Concrete cover to c.l. of cage 2 1.25 in
Accept Input
Cancel
Menu Selected: Concrete Wall Thickness and Reinforcen
Done
Menu Selected: Concrete Material Properties 2
Done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File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Concrete Material and Strength Pr
Concrete Material Properties 2
Concrete Reinforcing Steel Propert
Concrete Wall Thickness and Reir
Concrete Resistance Factors for L
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Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch)
Arch and Footing Dimensions (Level 2-
Arch Segments and Angles (Level 2-Ar
Control Parameters for Changes to Noc
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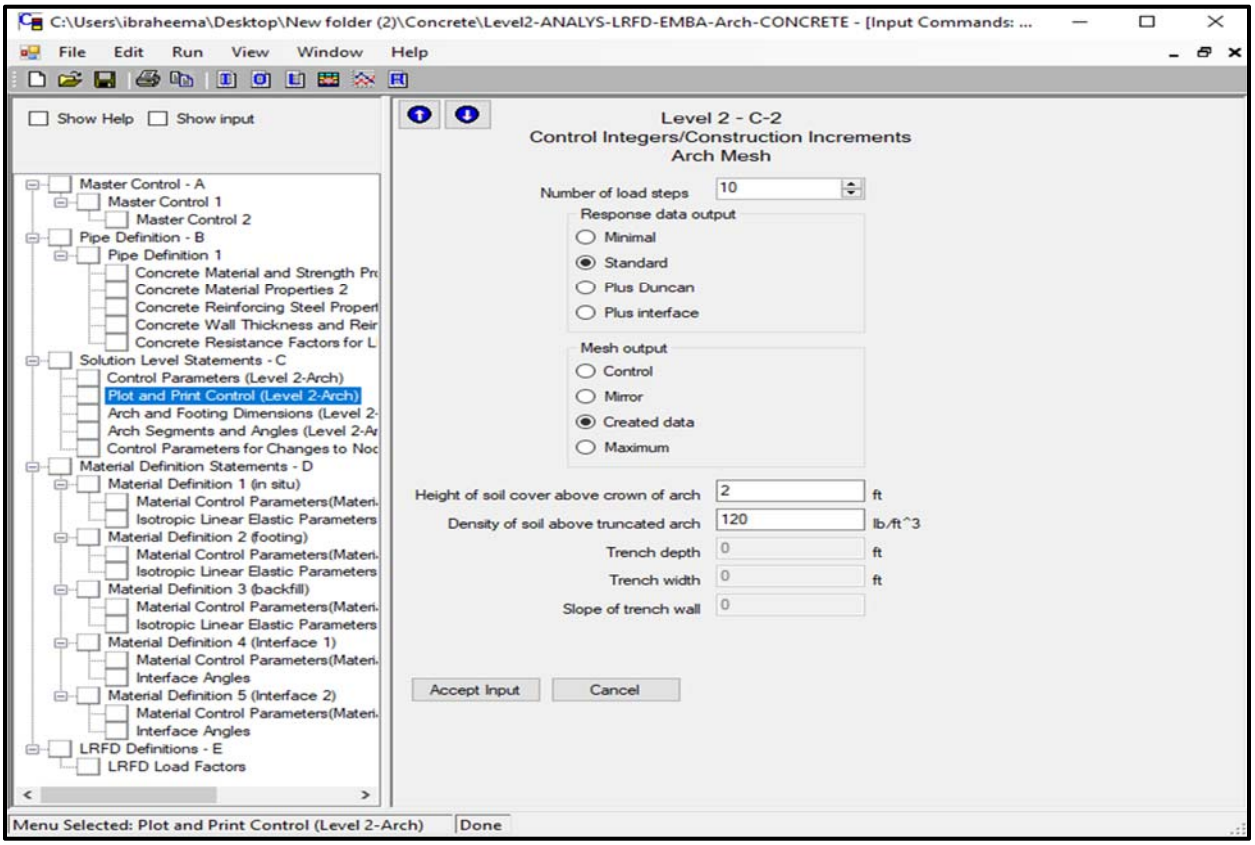
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
Material Definition 4 (Interface 1)
Material Control Parameters(Materi
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Materi
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Material (Concrete) B-5
Resistance Factors for LRFD
Resistance factor for steel rebar yielding due to tension stress 0.9
Resistance factor for concrete crushing due to thrust and moment 0.75
Resistance factor for concrete shear failure 0.9
Resistance factor for radial concrete tension 0.9
Allowable crack width for service load 0.01
Accept Input
Cancel
Menu Selected: Concrete Resistance Factors for LRFD Lin
Done


C:\Users\ibraheema\Desktop\New folder (2)\Concrete\Level2-ANALYS-LRFD-EMBA-Arch-CONCRETE - [Input Commands: ...
File Edit Run View Window Help
Show Help Show input
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Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Concrete Material and Strength Pr
Concrete Material Properties 2
Concrete Reinforcing Steel Propert
Concrete Wall Thickness and Reir
Concrete Resistance Factors for L
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Plot and Print Control (Level 2-Arch)
Arch and Footing Dimensions (Level 2-
Arch Segments and Angles (Level 2-Ar
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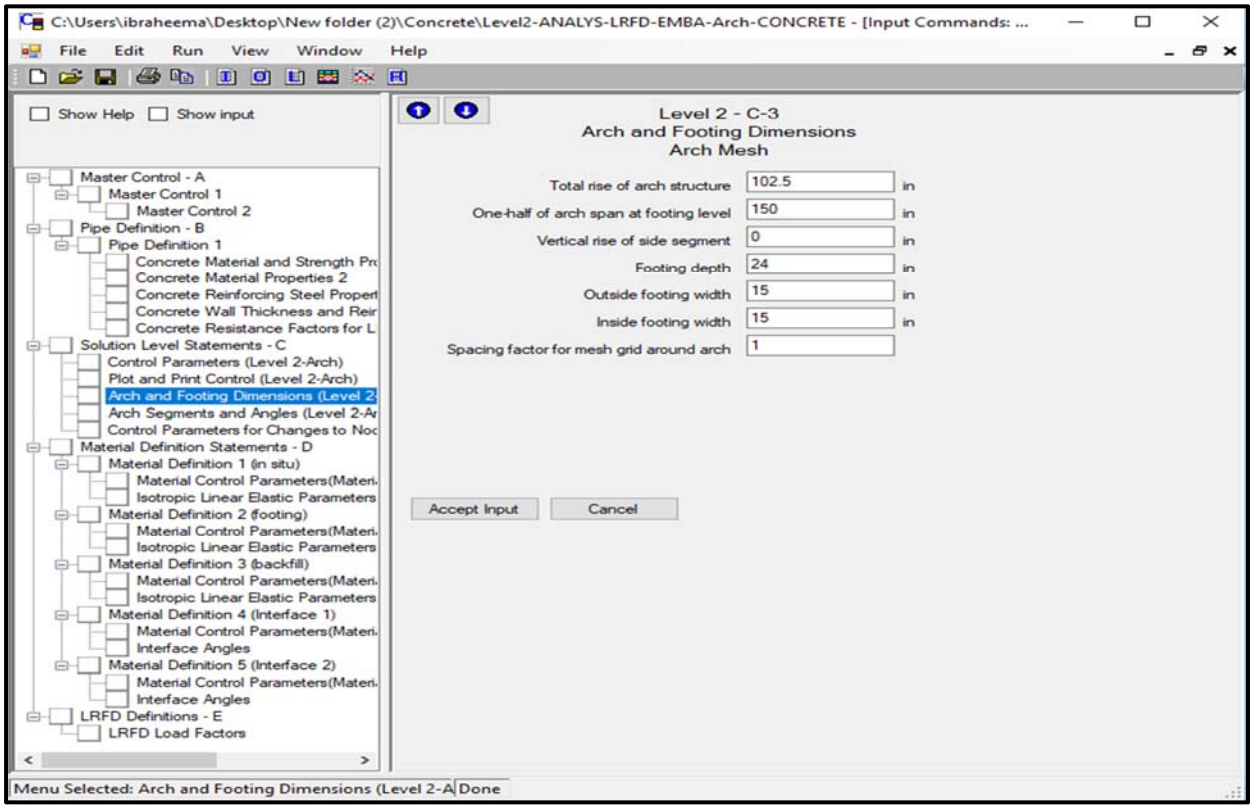
Material Control Parameters(Materi
Isotropic Linear Elastic Parameters
Material Definition 4 (Interface 1)
Material Control Parameters(Materi
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Materi
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Level 2 - C-2
Control Integers/Construction Increments
Arch Mesh
Number of load steps 10
Response data output
Minimal
Standard
Plus Duncan
Plus interface
Mesh output
Control
Mirror
Created data
Maximum
Height of soil cover above crown of arch 2 ft
Density of soil above truncated arch 120 lb/ft^3
Trench depth 0 ft
Trench width 0 ft
Slope of trench wall 0
Accept Input
Cancel
Menu Selected: Plot and Print Control (Level 2-Arch)
Done


C:\Users\ibraheema\Desktop\New folder (2)\Concrete\Level2-ANALYS-LRFD-EMBA-Arch-CONCRETE - [Input Commands: ...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Concrete Material and Strength Pr
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Arch Segments and Angles (Level 2-Ar
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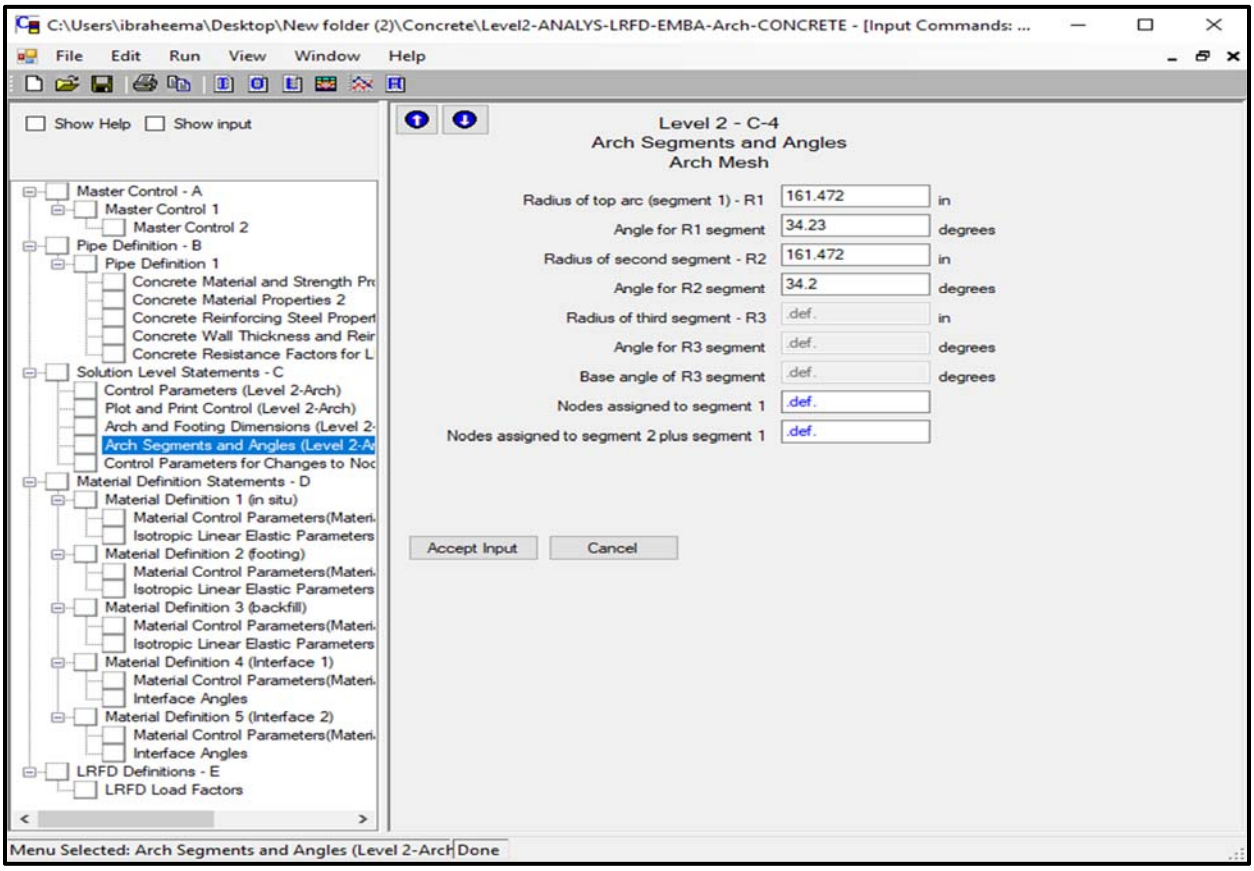
Material Definition 4 (Interface 1)
Material Control Parameters(Materi
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Materi
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Level 2 - C-3
Arch and Footing Dimensions
Arch Mesh
Total rise of arch structure 102.5 in
One-half of arch span at footing level 150 in
Vertical rise of side segment 0 in
Footing depth 24 in
Outside footing width 15 in
Inside footing width 15 in
Spacing factor for mesh grid around arch 1
Accept Input
Cancel
Menu Selected: Arch and Footing Dimensions (Level 2-A
Done


C:\Users\ibraheema\Desktop\New folder (2)\Concrete\Level2-ANALYS-LRFD-EMBA-Arch-CONCRETE - [Input Commands: ...
File Edit Run View Window Help
Show Help Show input
Master Control - A
Master Control 1
Master Control 2
Pipe Definition - B
Pipe Definition 1
Concrete Material and Strength Pr
Concrete Material Properties 2
Concrete Reinforcing Steel Propert
Concrete Wall Thickness and Reir
Concrete Resistance Factors for L
Solution Level Statements - C
Control Parameters (Level 2-Arch)
Plot and Print Control (Level 2-Arch)
Arch and Footing Dimensions (Level 2-
Arch Segments and Angles (Level 2-A
Control Parameters for Changes to Noc
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Isotropic Linear Elastic Parameters
Material Definition 4 (Interface 1)
Material Control Parameters(Materi
Interface Angles
Material Definition 5 (Interface 2)
Material Control Parameters(Materi
Interface Angles
LRFD Definitions - E
LRFD Load Factors
Level 2 - C-4
Arch Segments and Angles
Arch Mesh
Radius of top arch (segment 1) - R1 161.472 in
Angle for R1 segment 34.23 degrees
Radius of second segment - R2 161.472 in
Angle for R2 segment 34.2 degrees
Radius of third segment - R3 .def. in
Angle for R3 segment .def. degrees
Base angle of R3 segment .def. degrees
Nodes assigned to segment 1 .def.
Nodes assigned to segment 2 plus segment 1 .def.
Accept Input
Cancel
Menu Selected: Arch Segments and Angles (Level 2-Arch
Done

Steel arch rating results vs concrete arch

- Steel Arch

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

DESIGN-CRITERION (Strength)	LOAD STEP	LOCAL NODE	DEAD-LOAD DEMAND	LIVE-LOAD DEMAND	EFFECTIVE CAPACITY	*RATING FACTOR
*MATERIAL THRUST (psi)	24	39	2440.00	9560.00	33000.00	3.20
*BUCKLING THRUST (psi)	24	39	2440.00	9560.00	31881.00	3.08
*SEAM THRUST (psi)	24	39	2440.00	9560.00	33000.00	3.20
*PLASTIC-PENETRATE (%)	27	5	0.00	100.00	90.00	0.90

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)

- Concrete Arch

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

DESIGN-CRITERION (Strength)	LOAD STEP	LOCAL NODE	DEAD-LOAD DEMAND	LIVE-LOAD DEMAND	EFFECTIVE CAPACITY	*RATING FACTOR
*STEEL YIELDING (psi)	24	29	0.00	6820.09	54000.00	7.92
*CONCRETE CRUSHING (psi)	24	29	0.00	1236.16	3000.00	2.43
*SHEAR FAILURE (lbs/in)	21	27	0.00	405.95	754.70	1.86
*RADIAL-TENSION FAIL (psi)	19	20	0.00	27.32	54.60	2.00

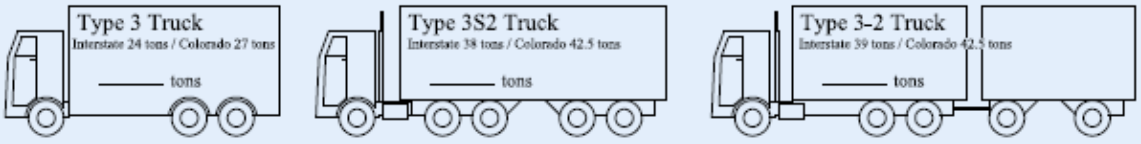
DEFINITIONS AND RELATIONS FOR EACH CRITERION "n":
* Rating Factor(n) = (Capacity(n) - Dead(n))/Live(n)
* Total Demand(n) = Dead(n) + Live(n) at specified node
* Dead(n) = Dead load demand for criterion n (factored)
* Live(n) = Live load demand for criterion n (factored)
* Capacity(n) = Capacity for criterion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

COLORADO DEPARTMENT OF TRANSPORTATION
LOAD & RESISTANCE FACTOR RATING SUMMARY

Rated using:
Asphalt thickness: 2 in.
☐ Colorado legal loads ☑ Multi-lane for Legal & Permit Vehicles
☑ Interstate legal loads ☐ Single lane for Legal & Permit Vehicles

Structure #	C-21-BG
State Highway #	I-76
Batch I.D.	CANDE
Structure Type	SAC
Parallel Structure #	

Structural Member	SAC				
	Rating Factor				
Inventory	3.08				
Operating	3.72				
	Tons				
Type 3 truck	78.7				
Type 3S2 truck	143.3				
Type 3-2 truck	131.8				
Type SU4 truck (27T)	84.2				
Type SU5 truck (31T)	92.1				
Type SU6 truck (35T)	100.5				
Type SU7 truck (39T)	113.1				
NRL (40T)	122.0				
Lane-Type Legal					
EV2 (28.75T)	103.2				
EV3 (43T)	89.9				
Permit Truck (96T)	383.0				
Modified Tandem (50T)	162.5				



Comments:
-Rated using CANDE
-In Situ soil modeled as isotropic soil
-Backfill modeled using Duncan/Selig model
-Color Code: WHITE
-Asphalt thickness taken per inspection

PE Seal

Rated by: (Print name and sign)	Date:	Checked by: (Print name and sign)	Date:

CDOT Staff Bridge - LRFR 02/2017