



Introduction to the Capabilities of CANDE-2007

Input and Design Features

Tim McGrath

DESIGN

INVESTIGATE

REHABILITATE



CANDE 2007 – Design By AASHTO

- **ASD (Called service in the Tutorial)**
 - analysis for service loads
 - computes factors of safety for comparison with target values
- **LRFD**
 - AASHTO LRFRD Bridge Design Specifications, 4th Ed
 - Input load and resistance factors
 - Analysis for factored loads
 - Compares factored load to factored capacity

AAHSTO LRFD

- **Load Modifiers – Section 1**
 - ductility, **redundance**, importance
 - culverts – live load redundant, earth load is not
- **Load Factors – Section 3**
 - Earth, live, water
- **Resistance Factors – Section 12**
 - Vary by material and limit state

Corrugated Metal Design Criteria

Design Criterion (Strength limits)	Demand	Capacity
Thrust stress (psi)	$\sigma_{\max} = N_{\max} / A$	$f_y =$ yield strength
Global Buckling (psi)	$\sigma_{\max} = N_{\max} / A$	$f_b =$ buckling capacity
Seam strength (psi)	$\sigma_{\max} = N_{\max} / A$	$f_s =$ seam strength
Plastic Penetration %	pp = computed % plastic	failure = 100%
(Performance Limits) Allowable deflection %	$\Delta_{\max} =$ computed deflect %	Allowable = 5% (Long Spans = 2%)

Concrete Design Criteria

Design Criterion (Strength limits)	Demand	Capacity
Steel yielding (psi)	f_{\max} = max steel stress	f_y = yield strength
Concrete crushing (psi)	σ_{\max} = max compression	f'_c = compressive strength
Shear failure (lb/in)	V_{\max} = max shear force	V_{ult} = concrete shear capacity
Radial tension failure (psi)	t_{\max} = max radial stress	t_{ult} = ultimate radial strength
(Performance Limits) Allowable crack (in)	CW_{\max} = max crack width	CW_{Allow} = allowable CW (0.01 inch)

Thermoplastic Design Criteria

Design Criterion (Strength limits)	Demand	Capacity
Thrust stress (psi)	$\sigma_{\max} = N_{\max} / A$	f_u = ultimate strength
Global Buckling (psi)	$\sigma_{\max} = N_{\max} / A$	f_b = buckling capacity
Combined strain (in/in)	$\varepsilon_{\max} = \text{bending} + \text{thrust}$	ε_{ult} = ultimate strain
(Performance Limits)		
Allowable tensile strain	$\varepsilon_{t-\max}$ = max tensile strain	$\varepsilon_{t-\text{allow}}$ = allowable tensile strain
Allowable deflection %	Δ_{\max} = computed deflect %	Allowable = 5% (recommended)

16 Tutorial Problems

Example No.	Solution Level	Material Type	Structure Type	Installation Type	Execution Mode	Method of Analysis / Design
...						
7	2	R/C	Box	Embankment	Analysis	LRFD
8	2	Steel	Pipe	Embankment	Analysis	LRFD
9	2	Steel	Arch	Trench	Analysis	Service
10	2	R/C	Pipe	Embankment	Design	LRFD
11	2	Plastic	Pipe	Trench	Analysis	Service
12	3	R/C	Box	Embankment	Analysis	LRFD
...						

16 Tutorial Problems

Example No.	Design Features	CANDE Interface Features
...		
7	N/A	N/A
8	Uses slotted joints and Level 2 extended to add smaller construction steps above the crown of the pipe	N/A
9	Uses interface elements, Level 2 extended to apply live load, and large deformation / buckling analysis	Shows inputting interface angles using the graphic interface.
10	Includes soft backpacking soil around Pipe	Shows how to modify chart properties of graphs plotted using 'view/graphs.'
11	Profile analysis, includes interface elements, Level 2 extended to add soft haunches, long-term load duration, and global and local buckling calculations	Shows how to modify the input file using the text input including inputting a user defined soil material and how to compute interface angles for a pipe
12	Identical to Problem 7, except Level 3	Shows a user generated Level 3 mesh
...		

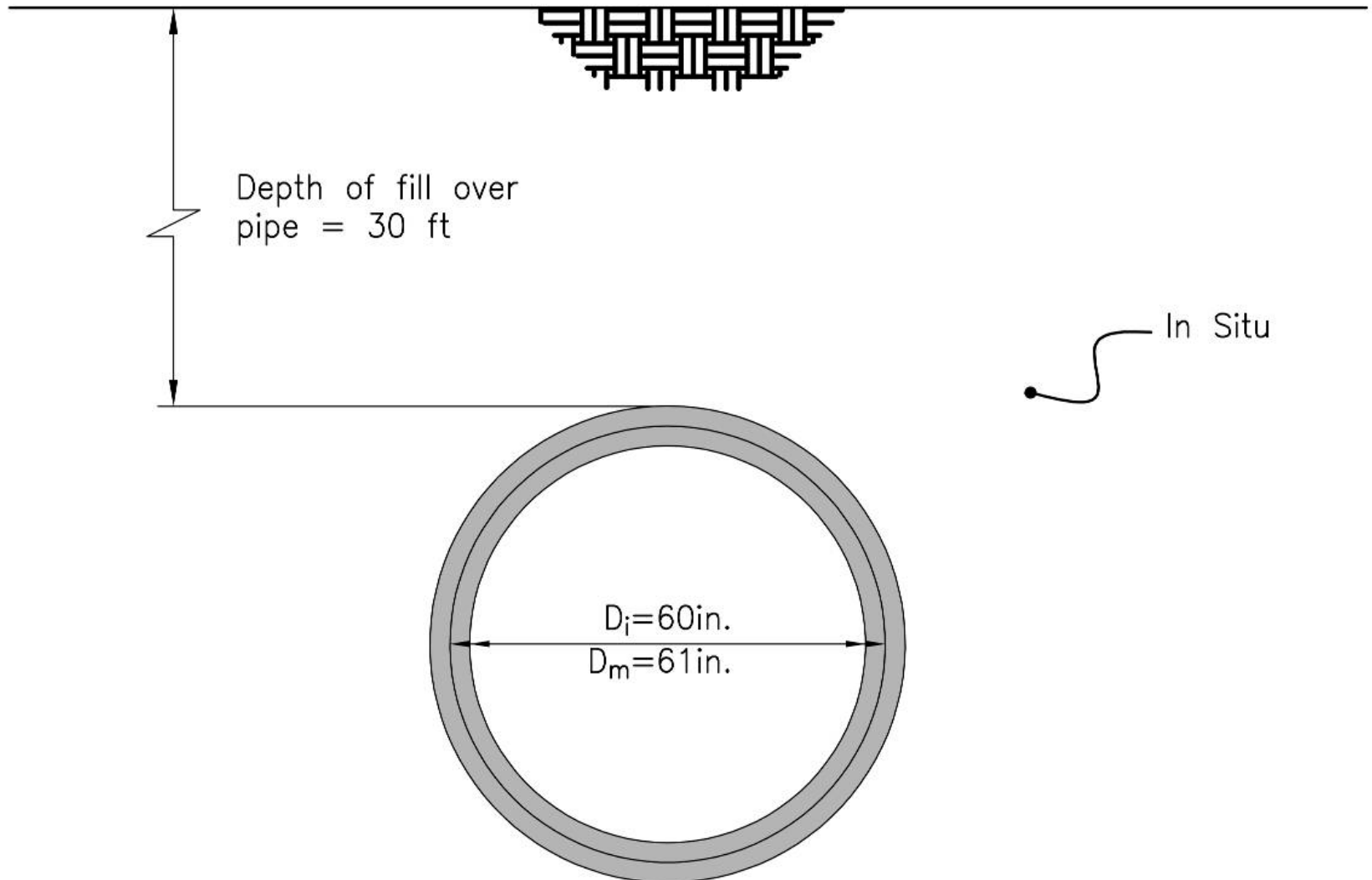
16 Tutorial Problems

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10	Includes Pipe	modify chart properties of graphs plotted using 'view/graphs.'
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16 Tutorial Problems

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...		

Problem 1 (P1) – Level 1, 60 in. CSP, Design



P1 – Selected Input Parameters

Method of analysis/design - Design - LRFD

Interface - Fully bonded (Slip is the other option)

Joint slip - No joint slip

Material behavior - Linear stress/strain

Analysis mode - Small deformation

Average diameter of pipe - Centroid of pipe wall = 61 in.

Number of load steps - Apply load in 10 equal load steps of 3 ft of soil.

LRFD load factor - 1.95

Load modifier - 1.05 (non-redundant for earth load)

Combined load factor = $1.95 \times 1.05 = 2.05$

P1 - Level 1 – Input Wizard, Screen 1

The screenshot shows the 'Main Input Control Parameters' dialog box for the CANDE 2007 Input Wizard. The window title is 'Main Input Control Parameters'. The main area is titled 'Control Information' and contains several sections of controls:

- Type of analysis:** Radio buttons for 'Analysis' and 'Design' (selected).
- Method of analysis/design:** Radio buttons for 'LRFD' (selected) and 'Service'.
- Solution level:** Radio buttons for 'Elasticity (Level 1)' (selected), 'FEM-auto mesh (Level 2)', and 'FEM-user mesh (Level 3)'. Below this is a checkbox 'Use the auto-generate option for the interface elements' which is unchecked.
- Level 2 Specific:** A sub-section containing:
 - Canned mesh type:** Radio buttons for 'Pipe mesh', 'Box mesh' (selected), and 'Arch mesh'.
 - Soil mesh pattern:** Radio buttons for 'Embankment' (selected), 'Trench', and 'Homogenous'.
 - Interface elements (pipe only):** Radio buttons for 'Pipe-soil' (selected), 'Trench-insitu', and 'None'.
 - A checked checkbox 'MOD:Make changes to the basic mesh' with three spinners below it:
 - Number of nodes to change: 0
 - Number of elements to change: 0
 - Number of new loading/boundary conditions: 0
- Number of pipe element groups (Level 3 only):** A spinner set to 1.
- Heading for output:** A text box containing '60. Corr. Steel - 30 ft Cover'.

At the bottom of the dialog are buttons for '<< Prev', 'Next >>', 'Finish', and 'Cancel'. A note says 'Press 'F1' for help'.

On the right side of the dialog, there is a large graphic with the text 'CANDE 2007 Input Wizard' and a scrollable text area containing the following text:

[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 model, method of analysis, etc.

As you change your input on this screen input will be enabled or disabled depending on the applicability for the model chosen.

P1 - Level 1 – Input Wizard, Screen 2

Main Input Control Parameters

Pipe Material 1

Pipe material type

Aluminum
 Basic
 Concrete
 Plastic
 Steel

Number of connected beam elements

Concrete specific input

Reinforcement shape

Standard
 Elliptical
 Arbitrary
 Boxes

Plastic specific input

Wall section type

Smooth (design and analysis)
 General (analysis only)
 Profile (analysis only)

Steel specific input

Joint slip

No
 Yes
 Yes, show trace

Vary joint travel length

Same lengths
 Different lengths

Number of joints

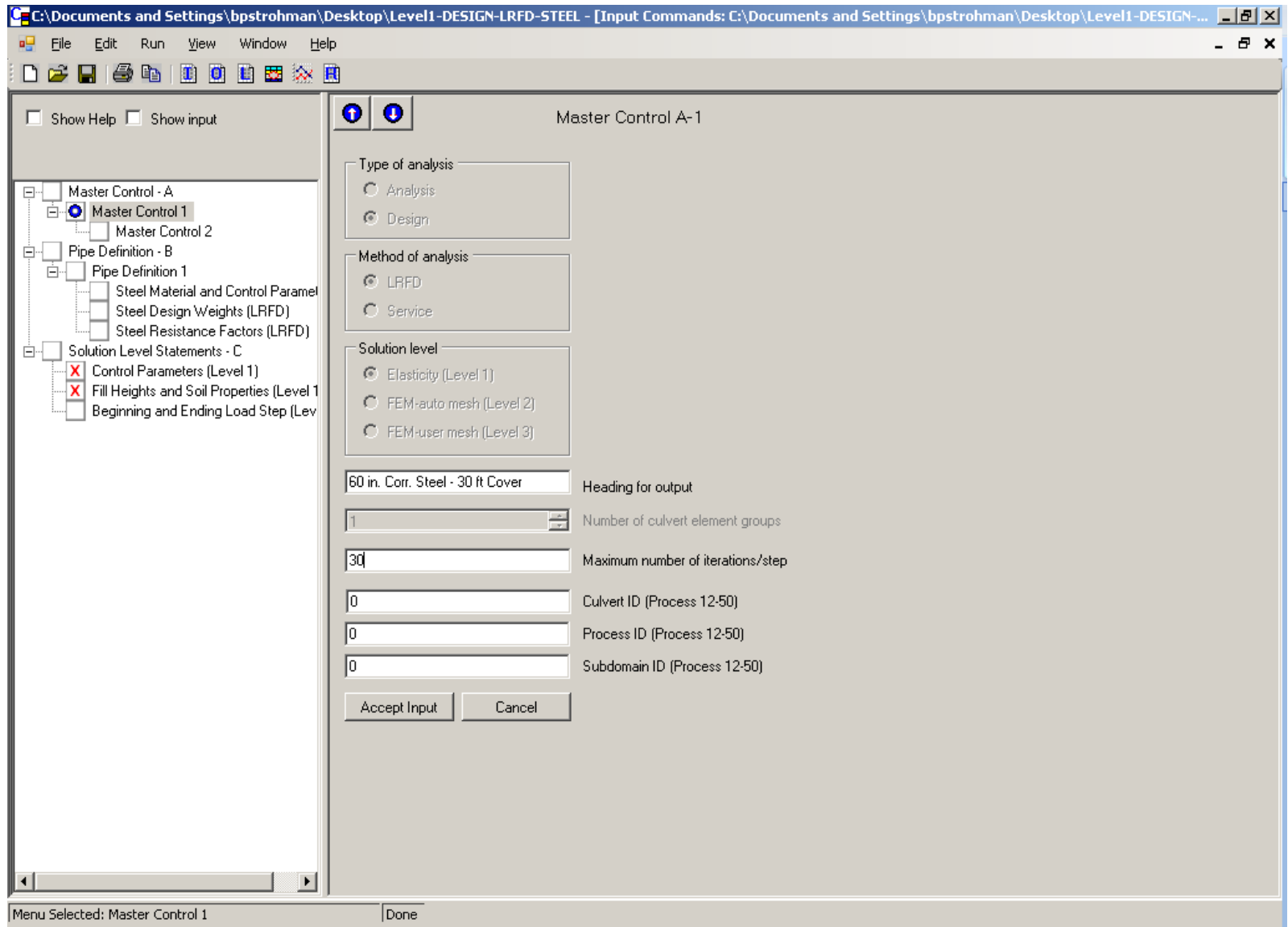
[Pipe Material Information](#)
Enter information on this screen related to the Pipe Material chosen. For Level 1 and 2 type models, only one pipe material is entered.

For Level 3 models, this screen will be repeated N times, where N is the "*Number of pipe element groups*" entered on the "Control Information" screen.

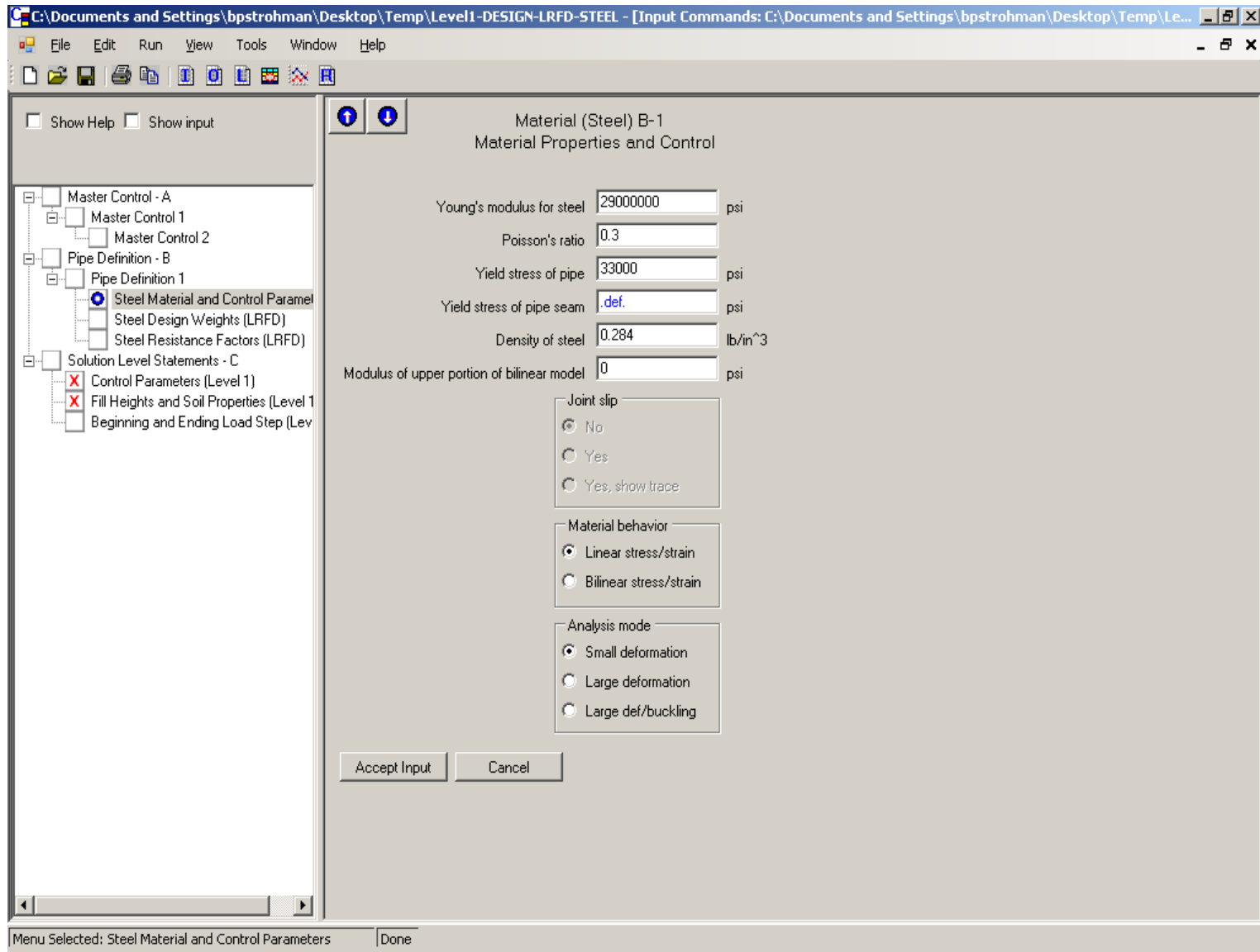
As you change your input on this screen input will be enabled or disabled depending on the applicability for the material chosen.

<< Prev Next >> Finish Cancel Press 'F1' for help

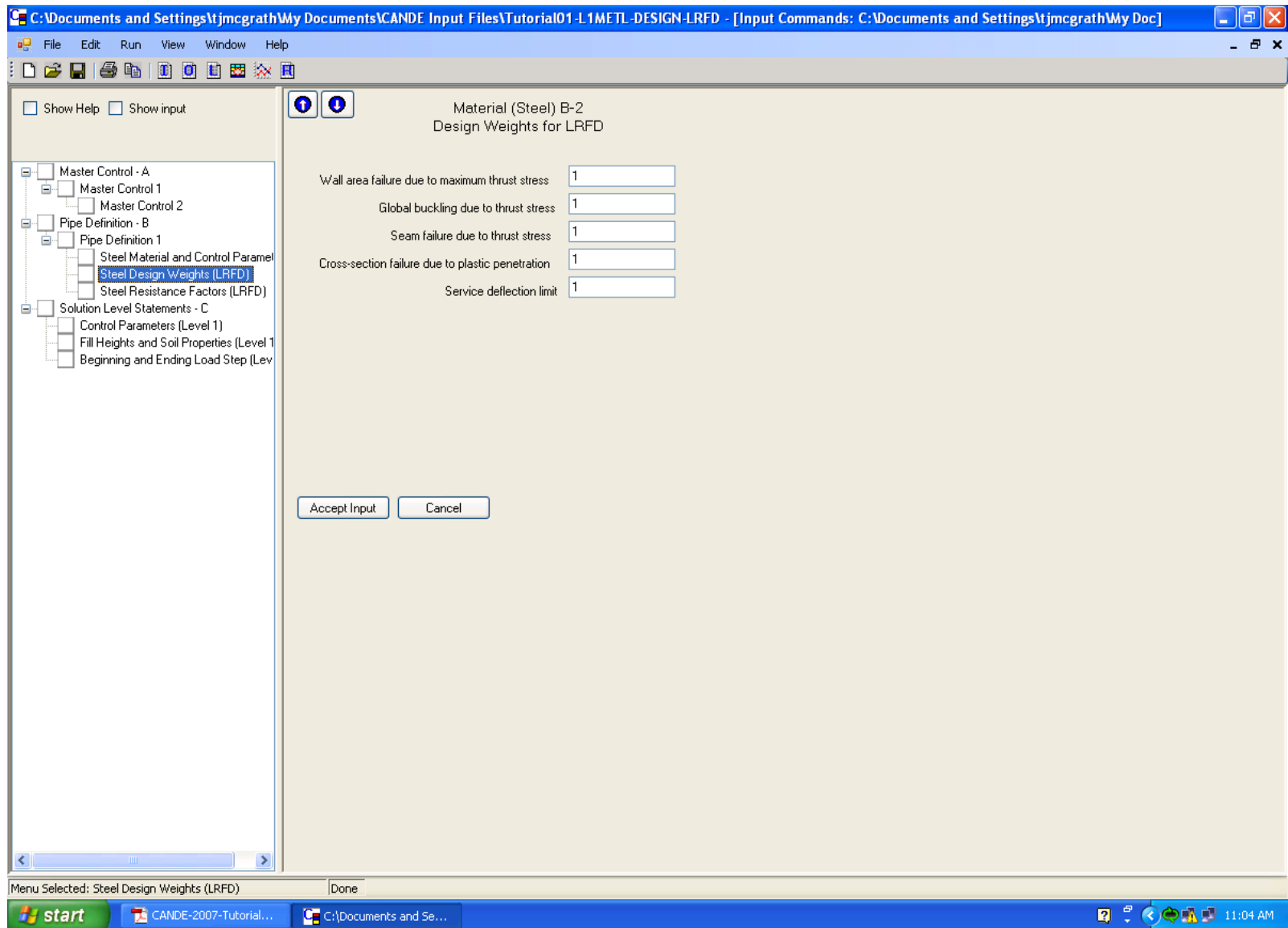
P1 - Master Control Screen



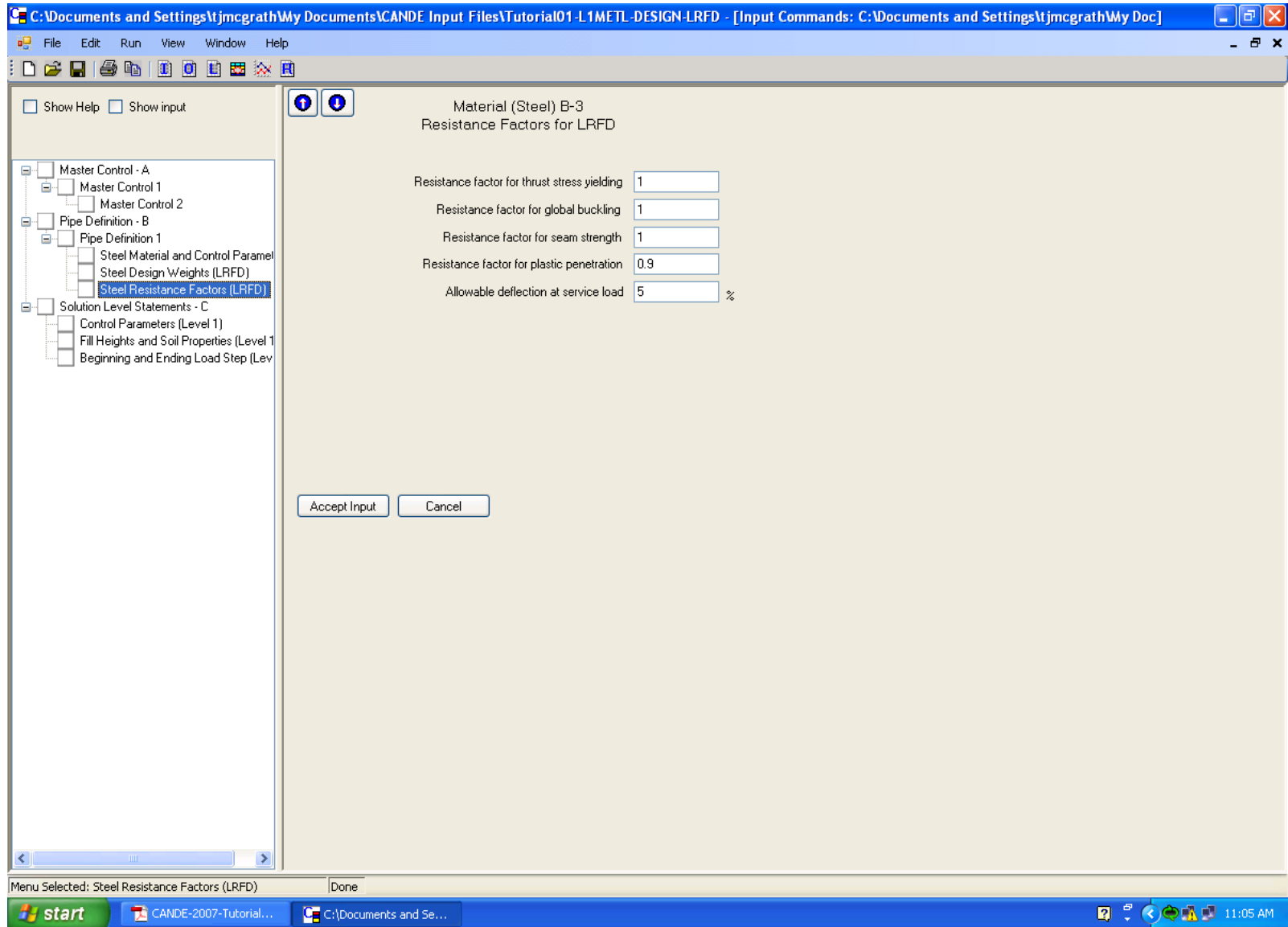
P1 - Screen B-1 - Material Properties



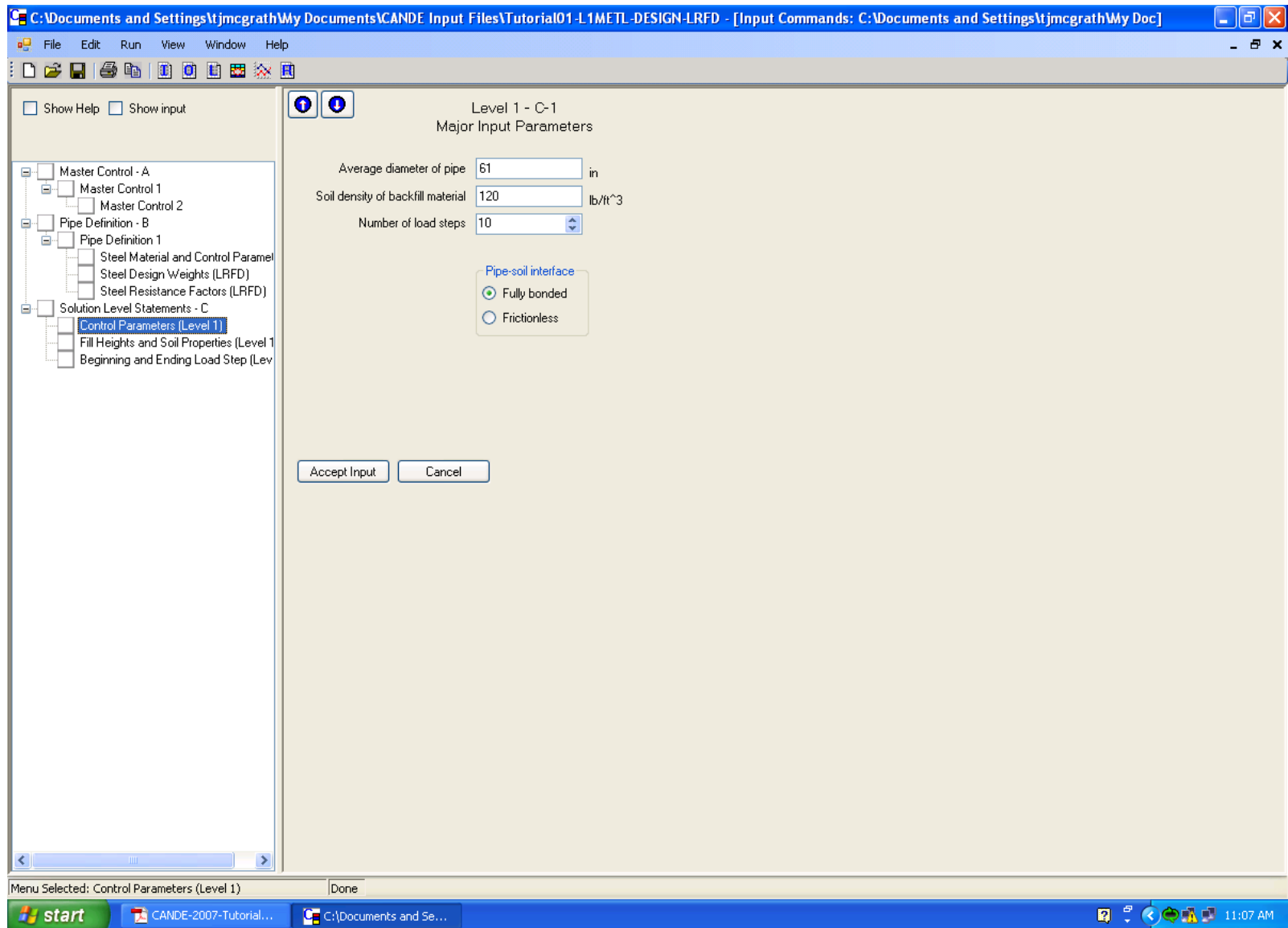
P1 - Screen B-2 - Design Weights



P1 - Screen B-3 - Resistance Factors



P1 - Screen C-1 - Major Input Parameters



P1 - Screen C-2 - Fill Height, Soil Parameters

Level 1 - C-2
Fill Heights and Soil Parameters

	Soil Height (ft)	Young's Modulus (lb/in ²)	Poisson's ratio
▶ 1	3	1000	0.25
2	6	1000	0.25
3	9	1000	0.25
4	12	1000	0.25
5	15	1000	0.25
6	18	1000	0.25
7	21	1000	0.25
8	24	1000	0.25
9	27	1000	0.25
10	30	1000	0.25

Accept Input Cancel Tab-Move to next cell F2(or keystroke)-Edit Cell
Shift-Tab-Move back a cell Ctrl-Alt-Tab-Exit data grid

Menu Selected: Fill Heights and Soil Properties (Level 1) Done

P1 - Screen C-3 – LRFD Load Factors

The screenshot shows a software window titled "C:\Documents and Settings\tjmcgrath\My Documents\CANDE Input Files\Tutorial01-L1METL-DESIGN-LRFD - [Input Commands: C:\Documents and Settings\tjmcgrath\My Doc]". The window displays the "Level 1 - C-3 Load Factors for LRFD" screen. On the left is a tree view with the following structure:

- Master Control - A
 - Master Control 1
 - Master Control 2
- Pipe Definition - B
 - Pipe Definition 1
 - Steel Material and Control Paramel
 - Steel Design Weights (LRFD)
 - Steel Resistance Factors (LRFD)
- Solution Level Statements - C
 - Control Parameters (Level 1)
 - Fill Heights and Soil Properties (Level 1)
 - Beginning and Ending Load Step (Level 1)

The main area contains a table with the following data:

Starting Load Step	Ending Load Step	LRFD Load Factor	Comment
1	1	2.05	Load increment #1 ...
2	2	2.05	Factor for load step #2 ...
3	3	2.05	Factor for load step #3 ...
4	4	2.05	Factor for load step #4 ...
5	5	2.05	Factor for load step #5 ...
6	6	2.05	Factor for load step #6 ...
7	7	2.05	Factor for load step #7 ...
8	8	2.05	Factor for load step #8 ...
9	9	2.05	Factor for load step #9 ...
10	10	2.05	Factor for load step #10 ...

Below the table is a large grey box with the text: "Note: Load factor includes load modifier". At the bottom of the window, there are buttons for "Accept Input" and "Cancel", and a keyboard shortcut legend: "Tab-Move to next cell", "F2(or keystroke)-Edit Cell", "Shift-Tab-Move back a cell", "Ctrl-Alt-Tab-Exit data grid". The status bar at the bottom shows "Menu Selected: Beginning and Ending Load Step (Level 1) Done".

P1 – Design Solution

Row, Col = (153,3)

DESIGN SOLUTION

DESIGN SOLUTION FOR STEEL GROUP # 1, DESIGN CYCLES = 3

*** REQUIRED THRUST AREA (IN**2/IN)..... 0.06587

*** REQUIRED MOM. OR INERTIA (IN**4/IN) 0.00298

*** REQUIRED SECTION MODULUS (IN**3/IN) 0.00887

THE FOLLOWING STEEL CORRUGATED SECTIONS MEET THE ABOVE REQUIREMENTS WITH MINIMUM AREA

CORRUGATION	THICKNESS	THRUST AREA	MOM. INERTIA
1-1/2 X 1/4	(NO ADEQUATE SECTION)		
2-2/3 X 1/2	0.109	0.11300	0.00342
3 X 1	0.064	0.07420	0.00866
5 X 1	0.064	0.06620	0.00885
6 X 2	0.110	0.12970	0.06041

THE CORRUGATION SIZE WITH MINIMUM AREA AND' MOMENT OF INERTIA IS 2-2/3 X 1/2 WITH THICKNESS 0.109 INCH.

AN ANALYSIS OF THIS CORRUGATION FOLLOWS.

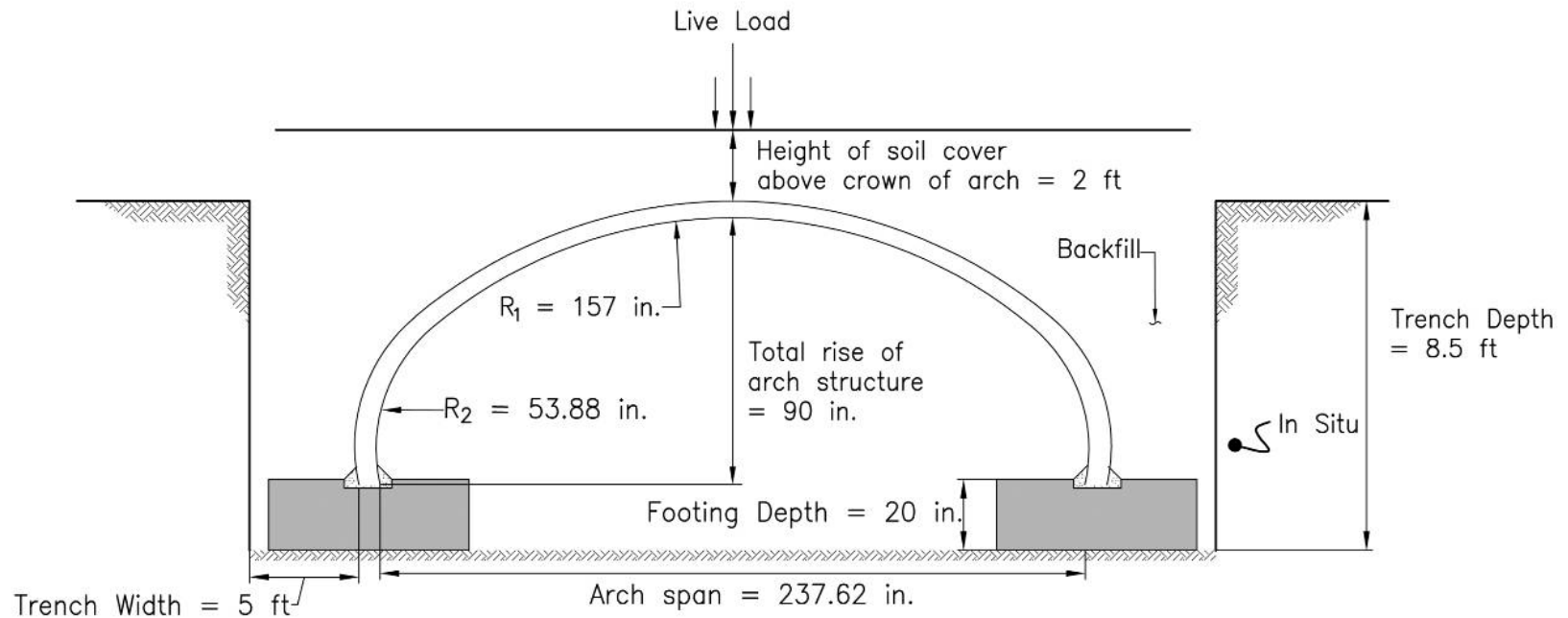
+++++

SOLUTION OUTPUT RESULTS

+++++

Menu Selected: Beginning and Ending Load Step (Level 1) Resetting menus

Problem 6 (P6) – Concrete Arch, Level 2



P6 – Input Wizard - Screen 1

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)

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

WELCOME TO THE 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 model, method of analysis, etc.

<< Prev Next >> Finish Cancel Press 'F1' for help

P6 – Input Wizard - Screen 3

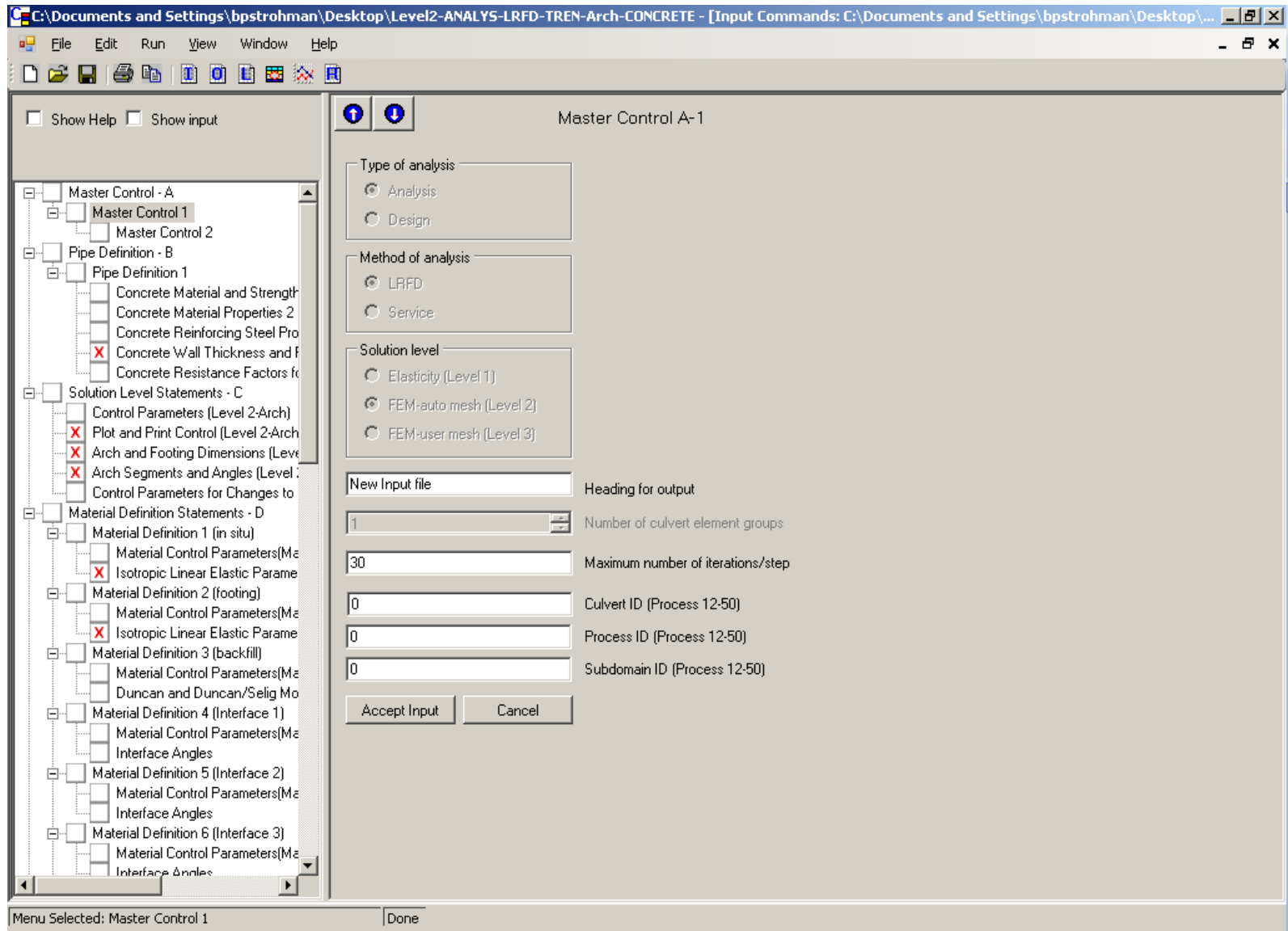
	Soil Material Model	Select 'canned' or 'User' soil parameters (Soil models 3, 4, and 5 only)
Soil 1-in situ	1-Isotropic-Linear Elastic	Canned
Soil 2-footing	1-Isotropic-Linear Elastic	Canned
Soil 3-backfill	3-Duncan/Selig	Canned

**CANDE
2007
Input Wizard**

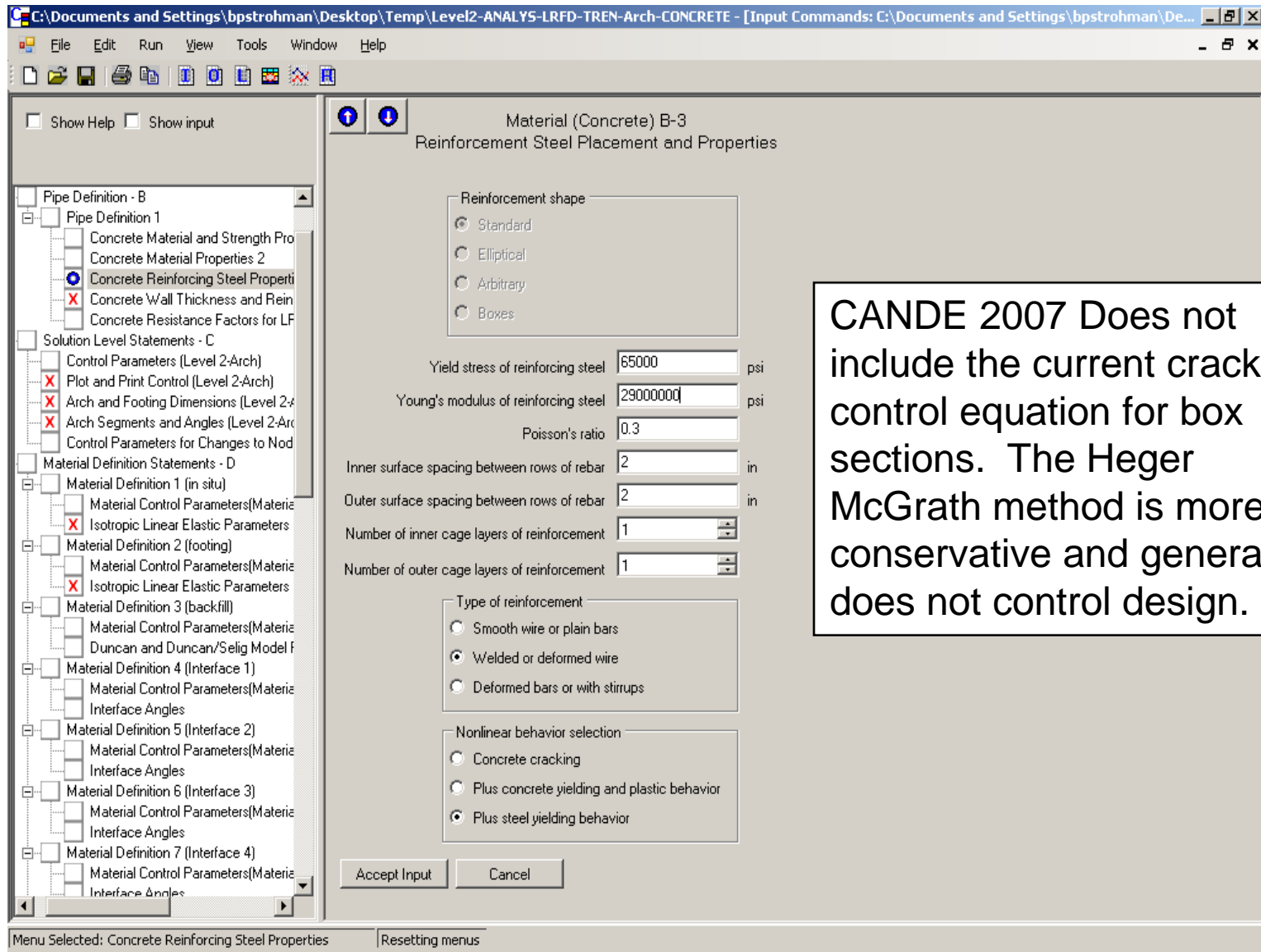
Soil Properties Information
Enter information on this screen related to the Soil Properties. This screen is only applicable for Levels 2 and 3. For Level 2 models, the number of soil models is predetermined by CANDE. For Level 3 models, the number of soil models is input on the "Level 3 Information" screen. Set the Soil Material Model type along with information related to the type chosen. Specific soil names and properties will input on the main CANDE input screens once the input wizard has completed the initial generation of the

<< Prev Next >> Finish Cancel Press 'F1' for help

P6 - Master Control A-1



P6 – Screen B-3 - Reinforcement



CANDE 2007 Does not include the current crack control equation for box sections. The Heger McGrath method is more conservative and generally does not control design.

P6 – Screen CX-4 – Boundary Conditions (LL)

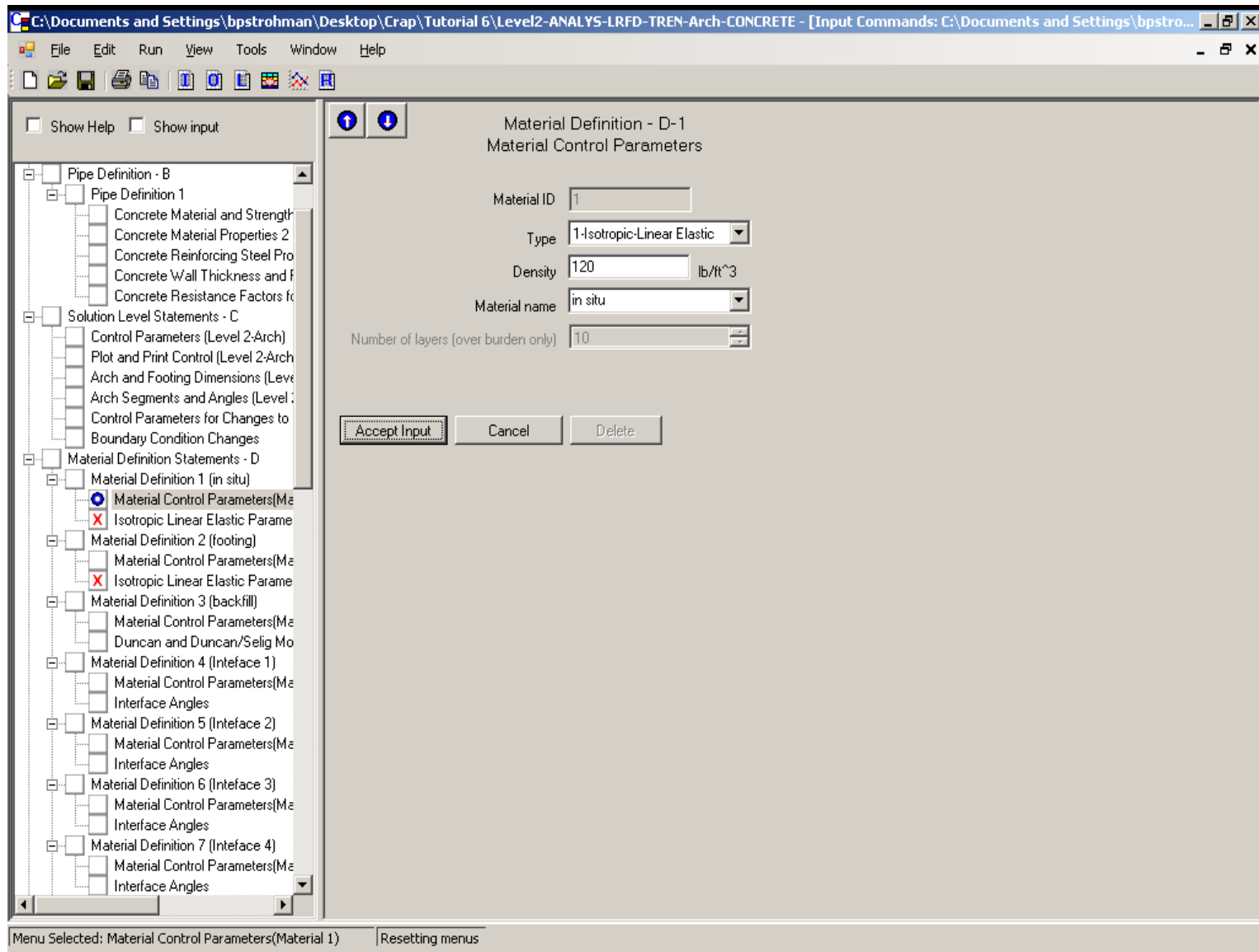
Level 2 - CX-4
Nodal Loads and/or Displacements to be Applied
Extended

	Node	X Cond.	X Value	Y Cond.	Y Value	Angle for Skewed Bound Input	Const. Step
1	224	0-Force	0	0-Force	-24.05	0	9
2	224	0-Force	0	0-Force	-24.05	0	10
3	224	0-Force	0	0-Force	-24.05	0	11
4	224	0-Force	0	0-Force	-24.05	0	12
5	225	0-Force	0	0-Force	-24.05	0	9
6	225	0-Force	0	0-Force	-24.05	0	10
7	225	0-Force	0	0-Force	-24.05	0	11
▶ 8	225	0-Force	0	0-Force	-24.05	0	12

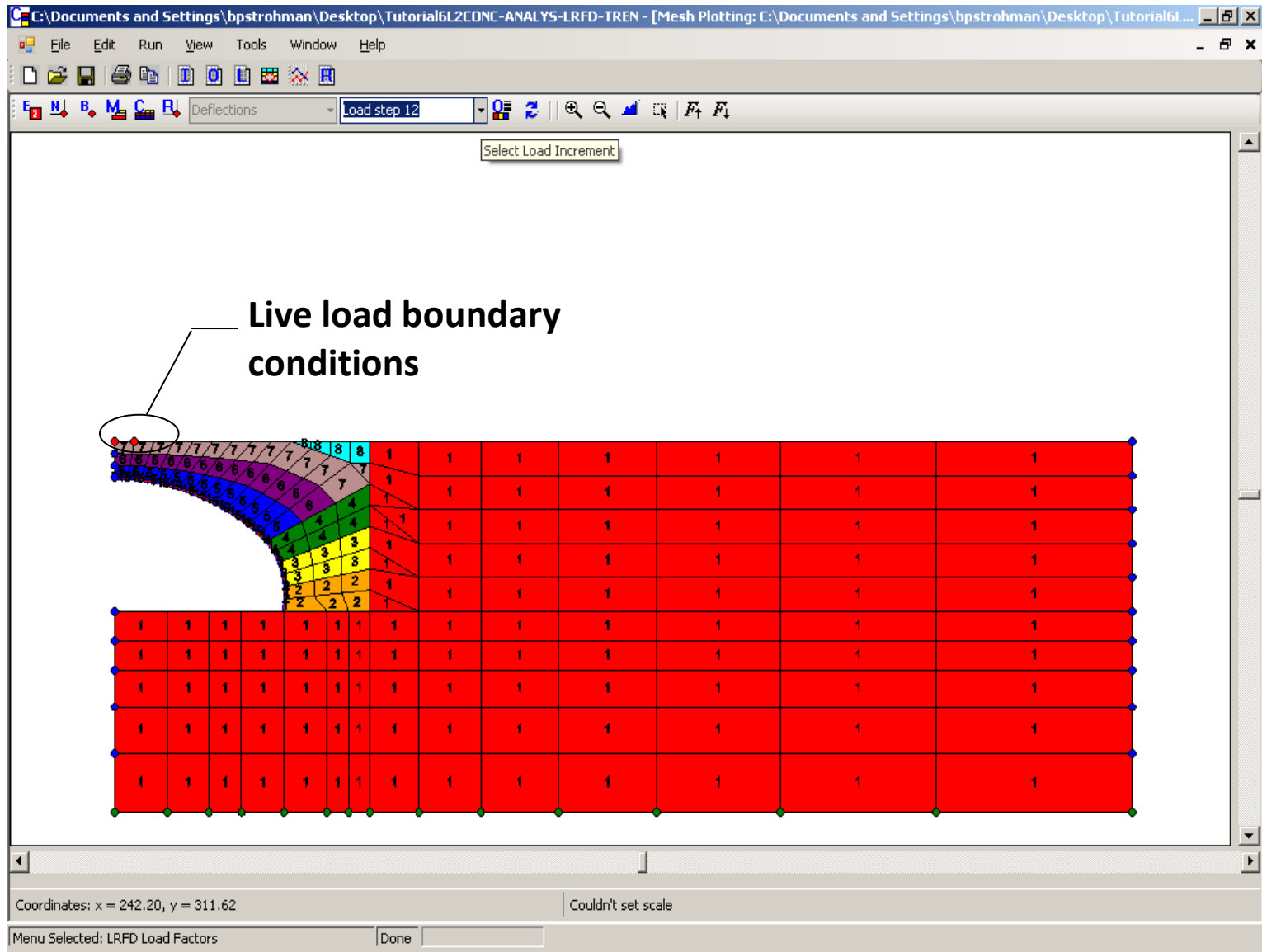
Accept Input Cancel Tab-Move to next cell F2(or keystroke)-Edit Cell
Shift-Tab-Move back a cell Ctrl-Alt-Tab-Exit data grid

Menu Selected: Boundary Condition Changes Resetting menus

P6 – Screen D-1 – Soil Definition



P6 – Mesh, Soil Zones, and Load Increments



P6 – Output Design Assessment

(1,1)
 19 -1441.87 600.02 0.0222 0.00000
 20 -478.13 -478.13 0.0074 0.00000

ASSESSMENT SUMMARY CONCRETE-GROUP 1, LOAD-STEP 12

LRFD SUMMARY EVALUATION FOR GROUP 1, LOAD STEP 12

DESIGN-CRITERION	CONTROL NODE	FACTORED DEMAND	FACTORED CAPACITY	RATIO VALUE
STEEL YIELDING (psi)	1	46010.4	58500.0	0.787
CONCRETE CRUSHING (psi)	15	1463.3	3750.0	0.390
SHEAR FAILURE (lbs/in)	3	239.5	982.9	0.244
RADIAL-TENSION FAIL (psi)	1	6.5	61.1	0.106

LRFD SERVICE-LOAD PERFORMANCE MEASURES FOR GROUP 12, LOAD STEP 1

NODE NUMBER FOR MAXIMUM CRACK WIDTH 1
 MAXIMUM CRACK WIDTH AT SERVICE LOAD (inches) 0.00000
 LRFD RATIO: MAX-CRACK-WIDTH / ALLOWABLE 0.00
 SPAN LENGTH FOR AUXILIARY EQUATIONS (inches)..... 240.08

* * * * NORMAL EXIT FROM CANDE * * * *

Menu Selected: LRFD Load Factors Done



Up Next –

Tim Toliver

CANDE 2007

(Culvert Analysis and Design)

TRB Webinar
CANDE Overview

August 5, 2009

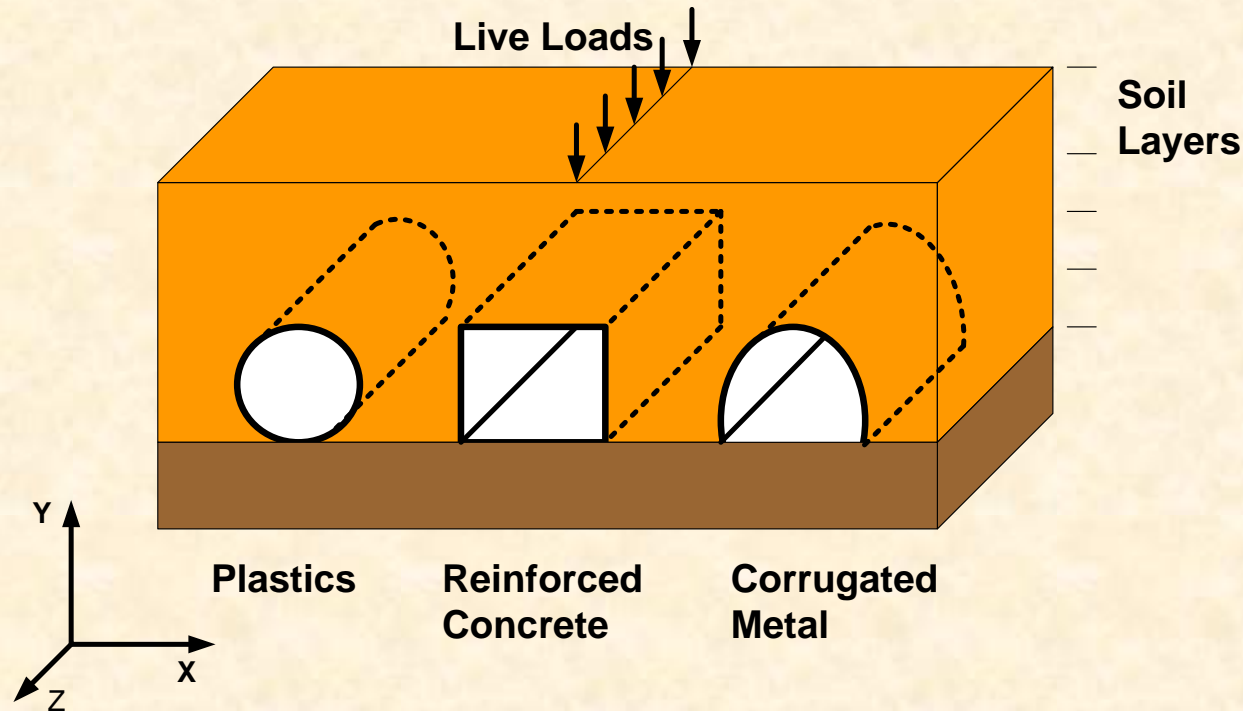
Presented by
Mike Katona

CANDE BACKGROUND

- CANDE Purpose
- CANDE History
- CANDE Users

- CANDE PURPOSE -

CANDE is a plane-strain structural analysis and design computer program for buried structures incorporating soil and structure.



- CANDE HISTORY -

DATE	COMMENTS	SPONSOR
1976	<ul style="list-style-type: none">• First release to culvert community• Mainframe computer required	FHWA
1980	<ul style="list-style-type: none">• Incorporate Duncan Soil model• Improve r/concrete model• Add slotted joints for corrugated steel	FHWA
1989	<ul style="list-style-type: none">• Develop PC version• Add Level 2 Arch• Improve Duncan/Selig soil model	FHWA
2007	<ul style="list-style-type: none">• Graphical user interface for input/output• Large deformation and buckling prediction• Multiple pipe type capability (groups)• LRFD design criteria and methodology• Bandwidth minimizer	AASHTO <ul style="list-style-type: none">• NCHRP 15-28• Report 619

-- CANDE-2007 DEVELOPERS -

Principal Investigators for CANDE-2007 (NCHRP 15-28)

- **Mark Mlynarski (Michael Baker Jr, Inc.)**

Responsible for graphical user interface input/output and oversight.

- **Tim McGrath (SGH)**

Responsible for LRFD interpretations and tutorial manual.

- **Mike Katona**

Responsible for CANDE Engine, new capabilities and models.

- CANDE USERS –

1. DOT Engineers and Consultants

- * Evaluate alternative new culvert designs**
- * Check safety of existing culverts and rehabilitation methods**

2. Culvert Manufacturers and Suppliers

- * Develop new culvert products and installation methods**
- * Design specific solutions for customers**

3. Researchers and Investigators


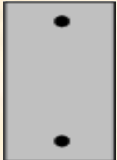
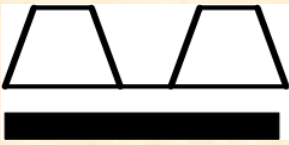
- * Interpret experimental data from field and laboratory**
- * Test bed for new theoretical soil and pipe models**

CANDE CAPABILITY OVERVIEW - 1

Major Input Selections (user choices)

- **Execution Mode – Analysis or Design**
- **Evaluation Method – Working stress or LRFD**
- **Pipe Type(s) – CMP, R/C and Plastic**
- **Solution Level – Level 1, 2 or 3**
- **System Choices – Soil models, interfaces, loading, etc.**

- EXECUTION MODE: DESIGN or ANALYSIS -

Pipe Type	Design Criteria	Analysis	Design Goal
<p>Corrugated Metal</p> 	<ul style="list-style-type: none"> • Thrust yielding • Buckling • Seam failure • Plastic hinging • Deflection limit 	<p>Evaluate safety</p>	<p>Specify safety. Find corrugation size and gage</p>
<p>Reinforced Concrete</p> 	<ul style="list-style-type: none"> • Steel yielding • Concrete crush • Shear failure • Radial tension • Crack width 	<p>Evaluate safety</p>	<p>Specify safety. Find steel areas.</p>
<p>Plastic</p> 	<ul style="list-style-type: none"> • Thrust yielding • Buckling • Combined strain • Tensile strain • Deflection 	<p>Evaluate safety</p>	<p>Specify safety. Find thickness.</p>

CANDE CAPABILITY OVERVIEW - 2

Major Input Selections (user choices)

- **Execution Mode – Analysis or Design**
- • **Evaluation Method – Working stress or LRFD**
- **Pipe Type(s) – CMP, R/C and Plastic**
- **Solution Level – Level 1, 2 or 3**
- **System Choices – Soil models, interfaces, loading, etc.**

- EVALUATION METHOD -

(1) Working Stress Method

- Input actual service loads for dead, earth and live loads
- Output evaluation given by safety factors = **capacity/demand**

(2) Load Resistance Factored Design (LRFD) Method

- Input actual service loads for dead, earth and live loads
 - Input load factors for dead, earth and live loads (load steps)
 - Input resistance factors for design-criteria capacities
- Output evaluation are ratios = **factored-demand/factored-capacity**

CANDE CAPABILITY OVERVIEW - 3

Major Input Selections (user choices)

- **Execution Mode – Analysis or Design**
- **Evaluation Method – Working stress or LRFD**
- • **Pipe Type(s) – CM, R/C and Plastic**
- **Solution Level – Level 1, 2 or 3**
- **System Choices – Soil models, interfaces, loading, etc.**

- PIPE TYPES -

Pipe type refers to material and cross-section geometry

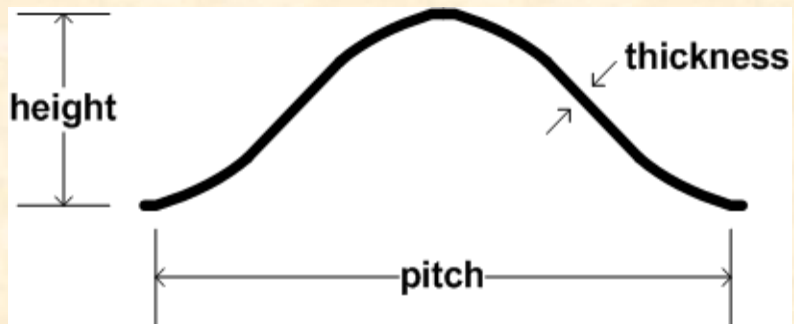
- **Corrugated Metal (Aluminum or Steel)**
- **Reinforced Concrete**
- **Thermoplastic**
- **Basic (generic)**

Each pipe type is described by input for:

- **Cross-section geometry**
- **Material stress-strain model parameters**
- **Design criteria (later)**

-- CORRUGATED METAL CROSS SECTION --

Aluminum and Steel Cross-section Properties



PA = Area (in²/inch)

PI = Moment inertia (in⁴/inch)

PS = Section mod. (in³/inch)

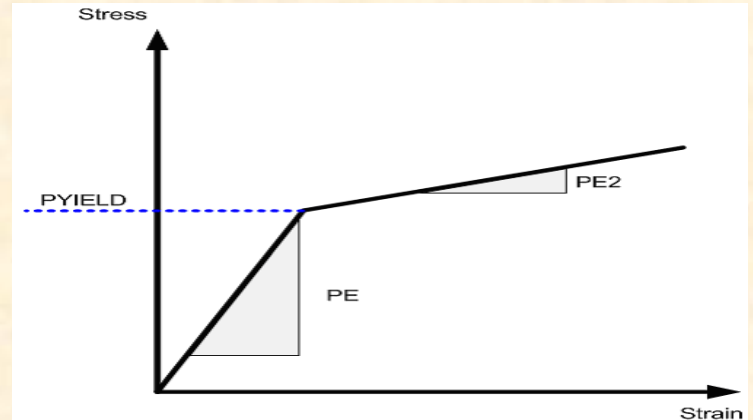
Standard corrugation sizes, pitch-x-height (inch-x-inch)

Aluminum (CANDE Table 5.4-1)	1.5-x-0.25, 2.67-x-0.50, 3.0-x-1.0 6.0-x-1.0, 9.0-x-2.5
Steel (CANDE Table 5.4-4)	1.5-x-0.25, 2.67-x-0.50, 3.0-x-1.0 5.0-x-1.0, 6.0-x-2.0

-- CORRUGATED METAL MATERIAL --

Aluminum and Steel Behavior

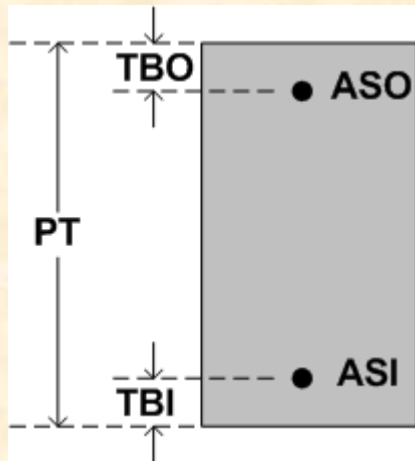
- Bi-linear stress-strain response
- Elastic unloading from plastic
- Identical in compression/tension



Aluminum and Steel Default Values

Model Parameter	Aluminum	Steel
PE (Elastic modulus) - ksi	10,000	29,000
PYIELD (Yield stress) - ksi	24	33
PE2 (Hardening modulus) - ksi	5% of PE	0.0
Poisson ratio	0.33	0.30

-- R/CONCRETE CROSS SECTION --



PT = Concrete wall thickness (inches)

ASI = Inner wall steel area (in²/inch)

ASO = Outer wall steel area (in²/inch)

TBI = Concrete cover to c.g. of ASI (inches)

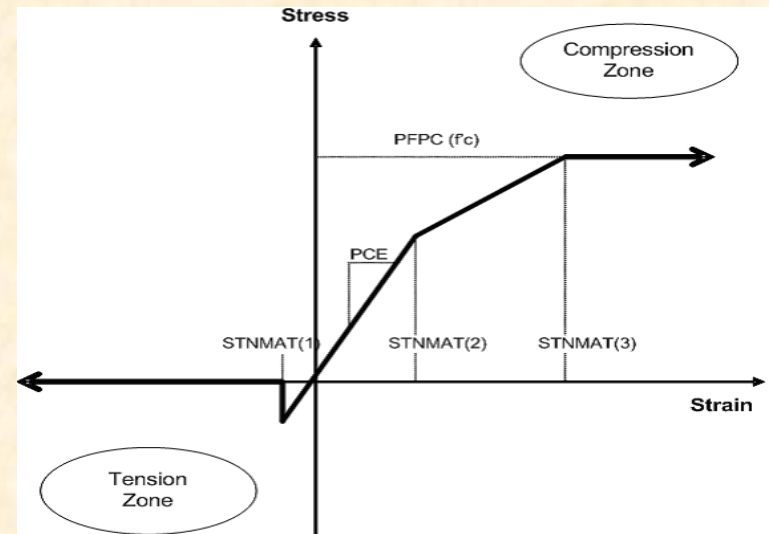
TBO = Concrete cover to c.g. of ASO (inches)

Other geometry parameters for steel cage details are used for crack width predictions.

-- CONCRETE MATERIAL --

Concrete stress-strain model

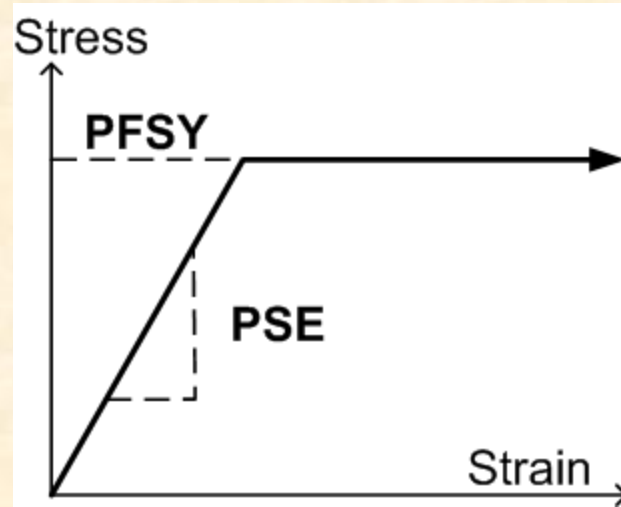
- **Abrupt tensile cracking with tensile stress release and no subsequent healing.**
- **Tri-linear compression curve becomes fully plastic at compressive strength limit.**
- **Elastic unloading from plastic zones.**



Key model parameters (default values).

PFPC	Concrete strength (4000 psi)
PCE	Elastic modulus (3,834 ksi)
Strain-1	Tensile cracking strain (0.0)
Strain-2	Initial yielding strain (0.0005 in/in)
Strain-3	Initial plastic strain (0.002 in/in)
PNU	Poisson ratio (0.17)

-- REINFORCING STEEL --



Reinforcement stress-strain behavior

- Elastic-perfectly-plastic model
- Identical in tension and compression
- PSE = Elastic modulus (29,000 ksi)
- PFSY = Yield strength (60 ksi)

-- PLASTIC CROSS SECTIONS --

Solid Wall



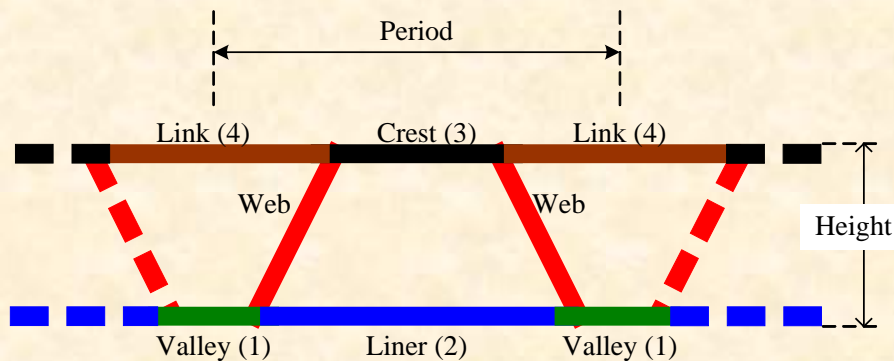
PT = Wall height (in)

General Wall



- PT and PC = Wall height and centroid (in)
- PA = Area (in²/inch)
- PI = Moment inertia (in⁴/inch)

Profile Wall



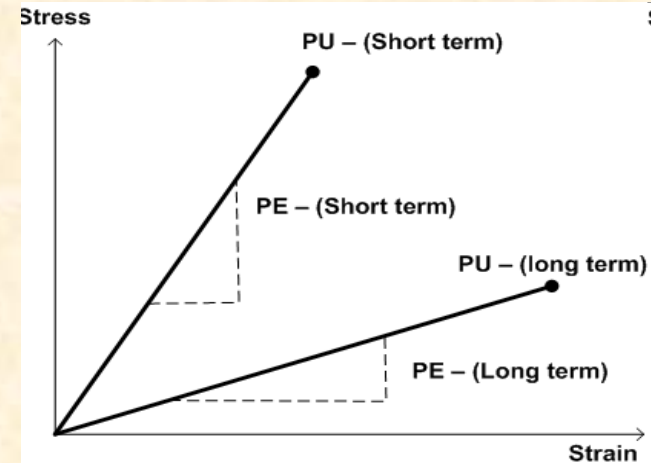
Profile Input Geometry

Profile	Period and height
Web	Angle, thickness, k-value
(1) Valley	Thickness, length, k-value
(2) Liner	Thickness, length, k-value
(3) Crest	Thickness, length, k-value
(4) Link	Thickness, length, k-value

-- PLASTIC MATERIALS --

Thermoplastic stress-strain

- Linear elastic representation
- Long-term and short-term properties
- Prescribed strength limits



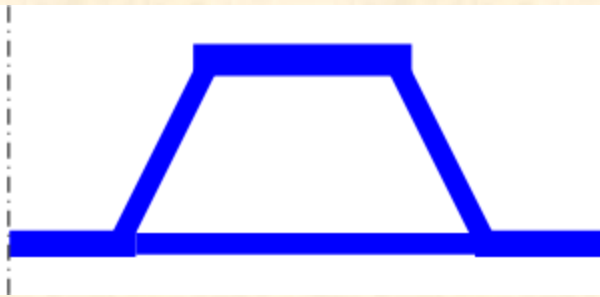
Default values for

- HDPE (high density polyethylene)
- PVC (polyvinyl chloride)
- PP (polypropylene)

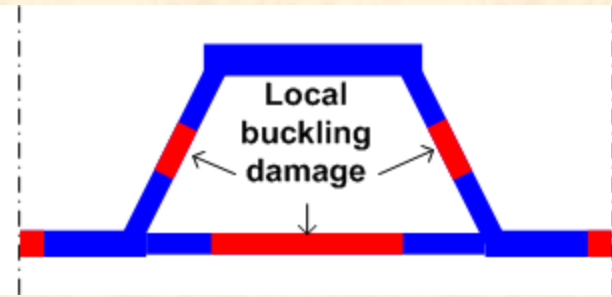
-- PROFILE LOCAL BUCKLING --

Compressive strains in profile elements cause interior wrinkling (buckles) that reduce cross-section effectiveness.

Unloaded profile



Loaded profile



CANDE damage analysis performed on each profile element at each node around pipe.**

** *Local damage based on AASHTO LRFD 12.12.3.5.3*

CANDE CAPABILITY OVERVIEW - 4

Major Input Selections (user choices)

- **Execution Mode – Analysis or Design**
- **Evaluation Method – Working stress or LRFD**
- **Pipe Type(s) – CMP, R/C and Plastic**
- • **Solution Level – Level 1, 2 or 3**
- **System Choices – Soil models, interfaces, loading, etc.**

- SOLUTION LEVELS -

- **Level 1 – Elasticity solution by Burns and Richard.**

Idealized model useful for insights and simple design

- **Level 2 – Finite element method with automated meshes.**

Realistic models for symmetric installations (work horse)

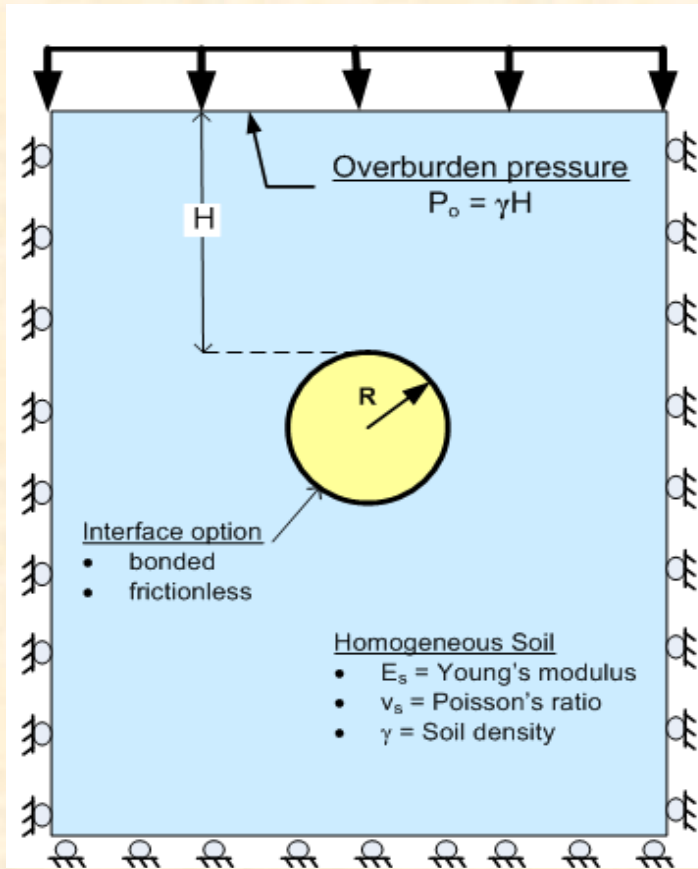
Choices: (1) Pipe-mesh (2) Box-mesh (s) Arch-mesh

- **Level 3 – Finite element method with user-defined mesh.**

Unlimited modeling fidelity within 2-D framework.

-- LEVEL 1 --

Conceptual model



Input parameters

- Pipe radius (R)
- Soil density (γ)
- Load steps
- Interface condition
- Soil properties, depth (E , ν , H)

Output around pipe

- Displacements
- Moment, Thrust and Shear
- Interface normal and shear stress
- Pipe-type dependent responses

-- LEVEL 2 CHOICES --

Automated Finite Element Meshes (symmetric) for:

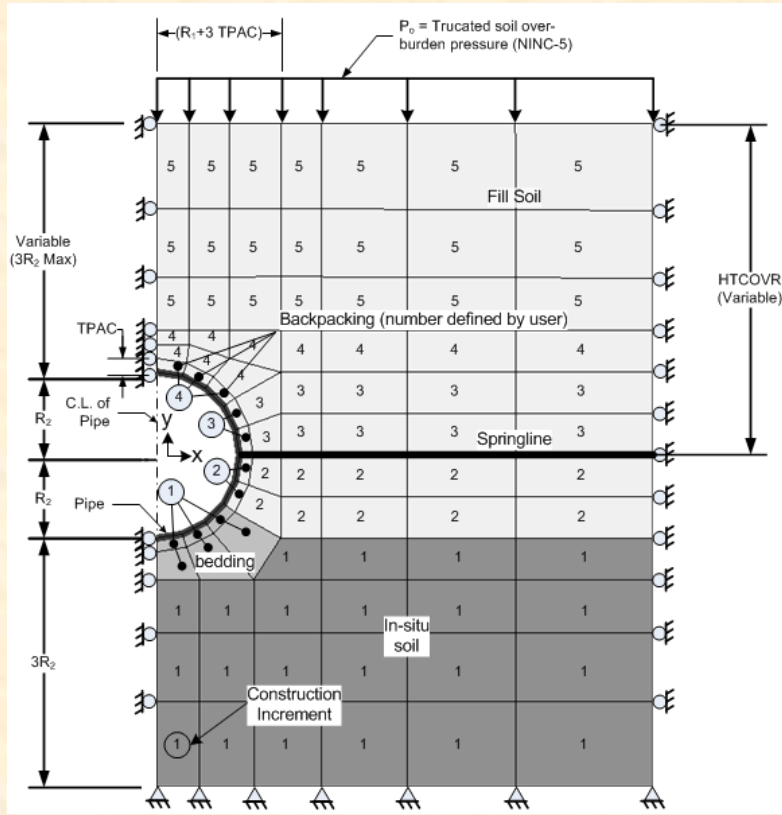
- **Pipe Mesh (circular or elliptical)**
- **Box Mesh (square or rectangular)**
- **Arch mesh (2-or-3 segments, curved or straight)**

Extended Level 2

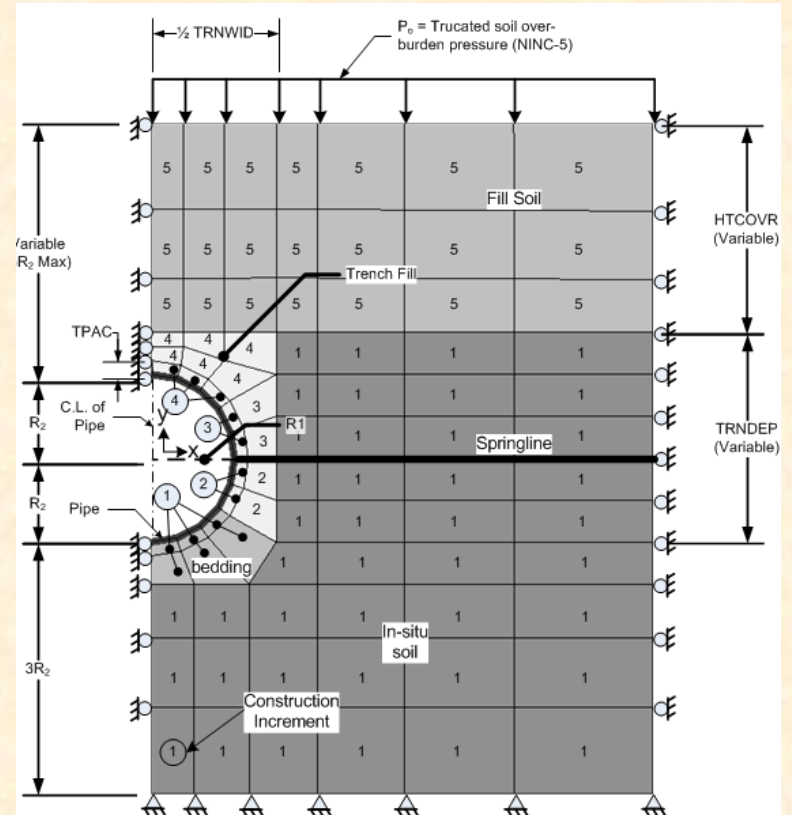
- **Adjust geometry**
- **Change material zones (e.g. create voids)**
- **Add live loads**

-- LEVEL 2 PIPE MESH --

Embankment mesh

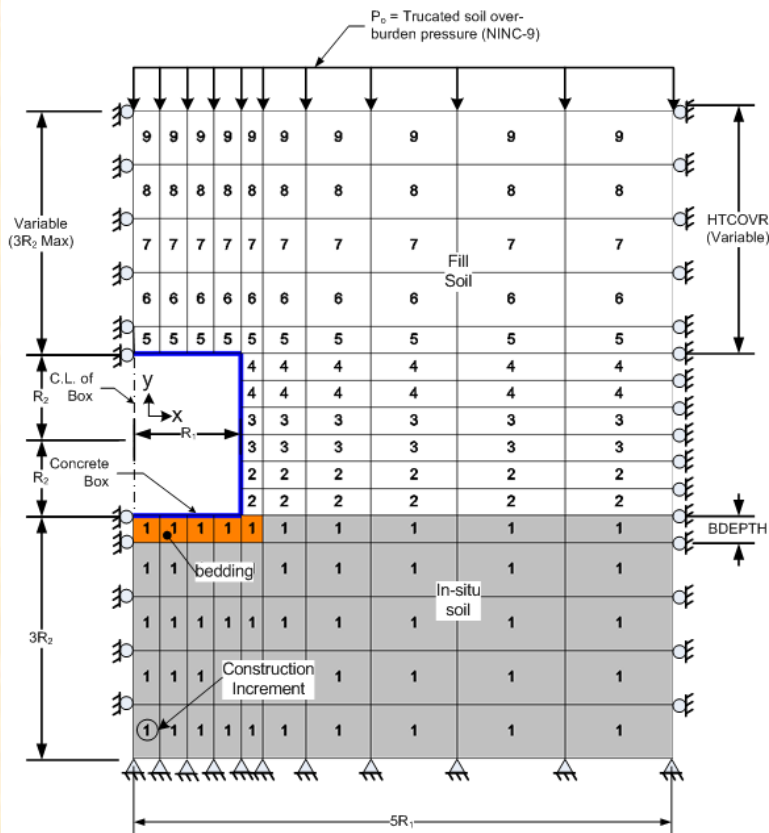


Trench mesh

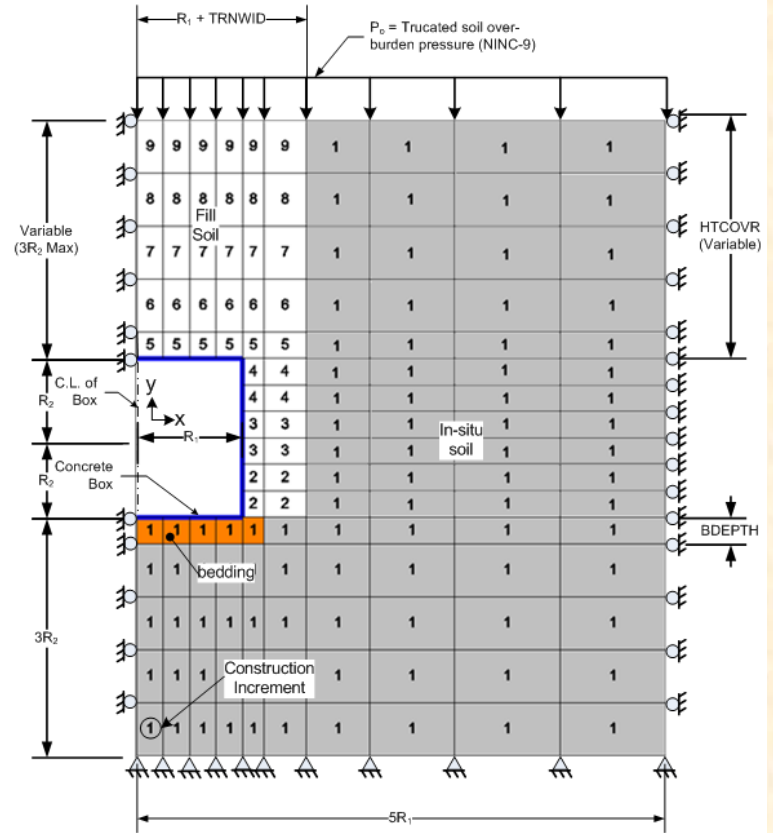


-- LEVEL 2 BOX MESH --

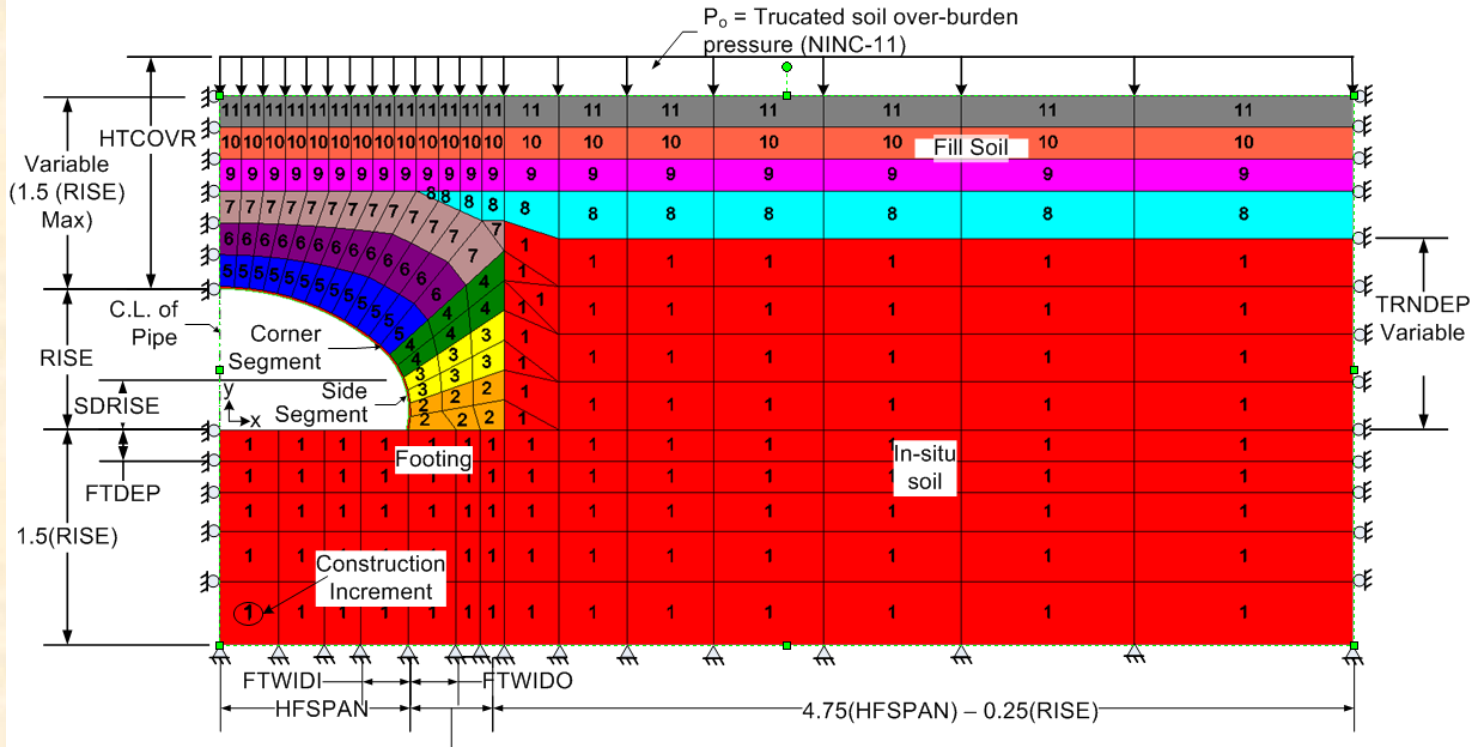
Embankment mesh



Trench mesh



-- LEVEL 2 ARCH MESH --

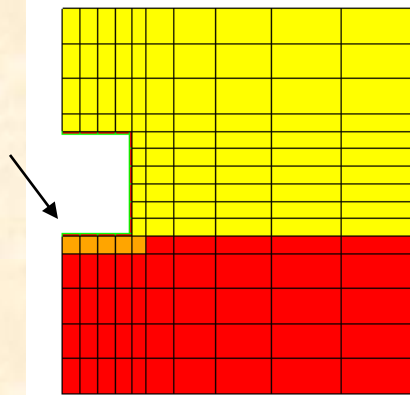


- Choices:**
- (1) Embankment or trench installation
 - (2) Two segment or three segment arch shapes
 - (3) Straight or curved segments

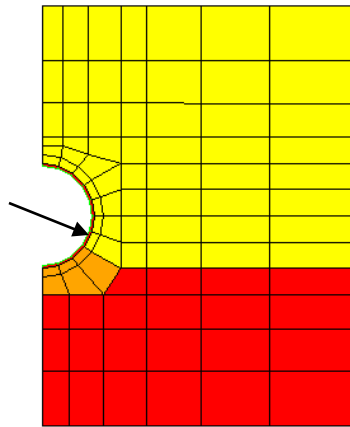
-- LEVEL 2 EXTENDED --

For any Level 2 mesh configuration:

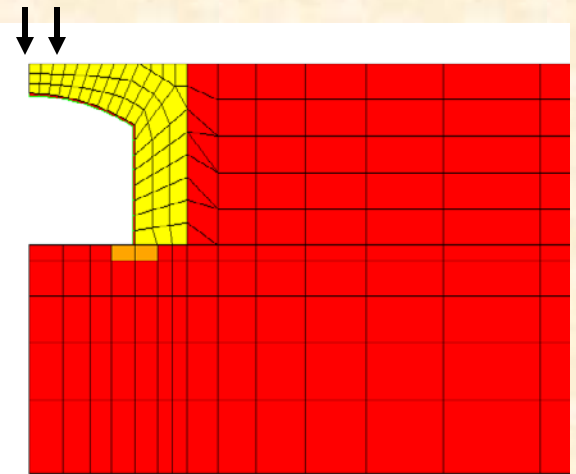
- **Change coordinates of nodes**
- **Change properties of elements**
- **Add or change boundary conditions**



Change bedding shape



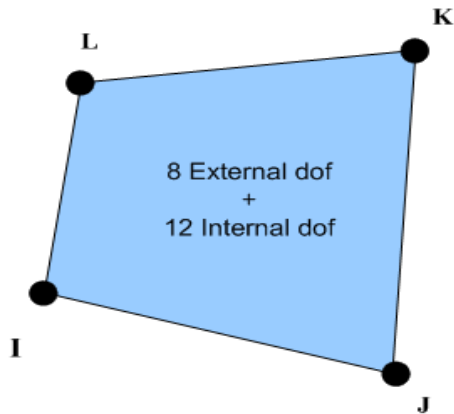
Change to soft void



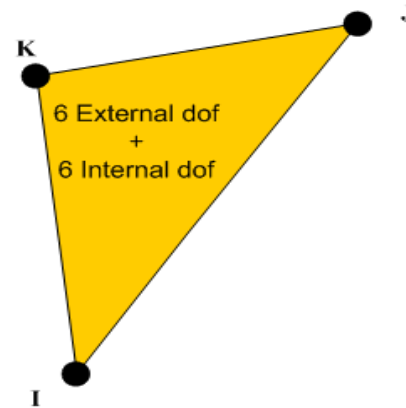
Add live load on surface

-- LEVEL 3 BUILDING BLOCKS --

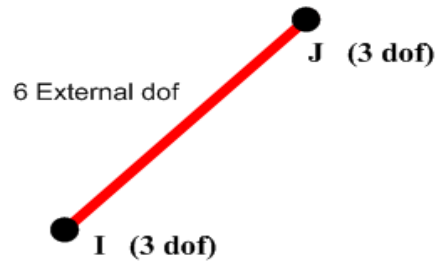
Quadrilateral



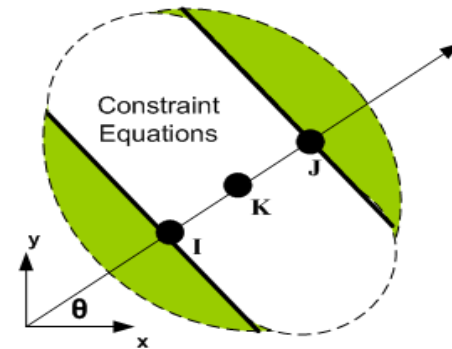
Triangle



Beam-Column



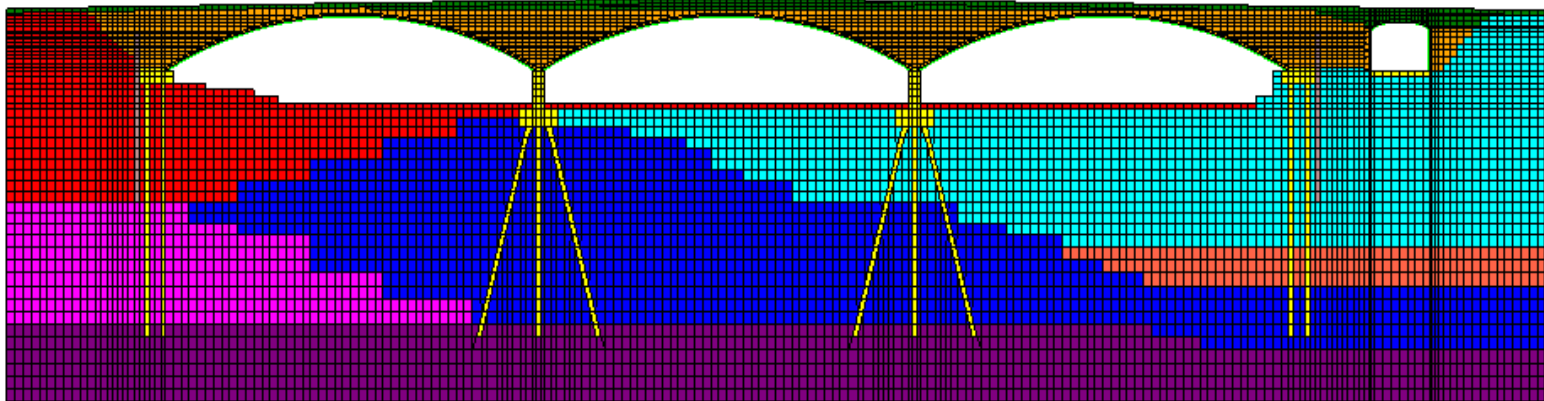
Interface



-- LEVEL 3 EXAMPLE MESH --

Three reinforced/concrete arches (92' span each)

- 8,586 elements total
- 4 pipe groups including side tunnel
- 10 soil material zones including pile supports
- 12 construction increments plus live load



CANDE CAPABILITY OVERVIEW - 5

Major Input Selections (user choices)

- **Execution Mode – Analysis or Design**
- **Evaluation Method – Working stress or LRFD**
- **Pipe Type(s) – CMP, R/C and Plastic**
- **Solution Level – Level 1, 2 or 3**
- • **System Choices – Soil models, interfaces, loading, etc.**

- SYSTEM CHOICES -

Other major choices include:

1. Soil model choices:

- **Linear elastic (isotropic and orthotropic)**
- **Overburden dependent (canned and user supplied)**
- **Duncan/Selig soil models (canned and user supplied)**
- **Extended Hardin soil model (canned and user supplied)**

2. Interface properties (angle, friction and tension)

3. Large deformation and buckling (on or off)

4. Nonlinear controls (iteration limit and bypass)

OVERVIEW COMPLETE

Next: LRFD Design Criteria and GUI Input

Then: GUI Output and Illustrations

Master

TRB Webinar

**INTRODUCTION TO
CAPABILITIES OF
CANDE-2007
(Culvert ANalysis and DEsign)**

August 5, 2009

Presented by:

Tim Toliver, P.E.

www.4pipe.com

Advanced Pipe Services 

Introduction

Output data and Viewing Options

- Graphical User Interface (GUI) output options
- Files generated by CANDE
- How to make a report based on FEA analysis results.
 - View output report
 - Mesh generation
 - Graphical outputs

Most of the examples are from a project Dr. Katona and I worked on.

Six Cases Analyzed

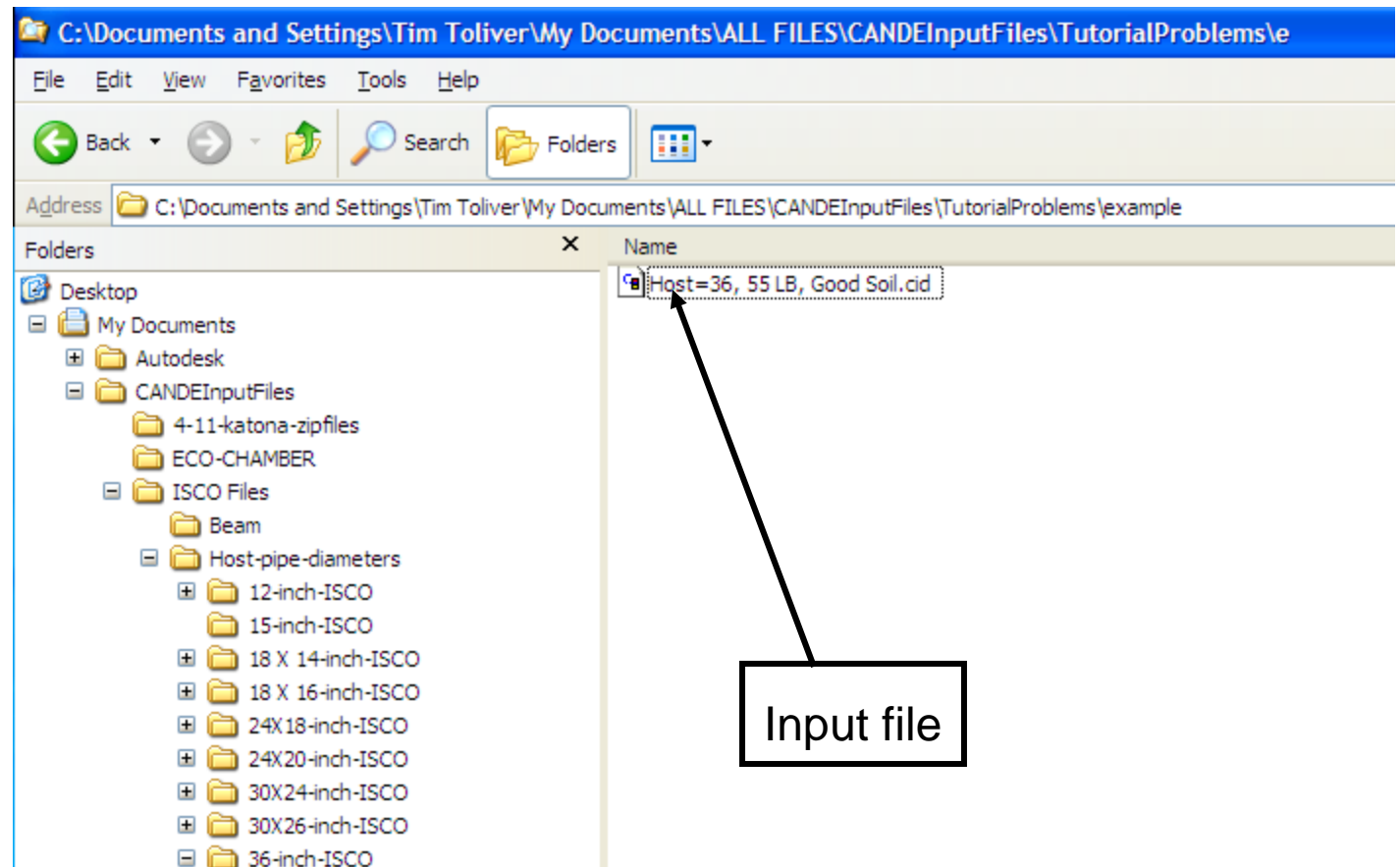
Good Soil Series	Poor Soil Series
Case 1 - Damaged host pipe only	Case 4 - Damaged host pipe only
Case 2 - Damaged host pipe + plastic liner + <u>good</u> grout	Case 5 - Damaged host pipe + plastic liner + <u>good</u> grout
Case 3 - Damaged host pipe + plastic liner + <u>fair</u> grout	Case 6 - Damaged host pipe + plastic liner + <u>fair</u> grout

- Diameters 18” to 72” (total of 10 diameter)
- Dead Load
- Live Load
- Good Soil – 3,000 psi Modulus (125 pcf)
- Poor Soil – 1,000 psi Modulus (120 pcf)
- Good Grout – 70 pcf; 211,000 psi Modulus; 770 psi Strength
- Fair Grout – 40 pcf; 69,000 psi Modulus; 200 psi Strength

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File Generation

Typically begin with one input file

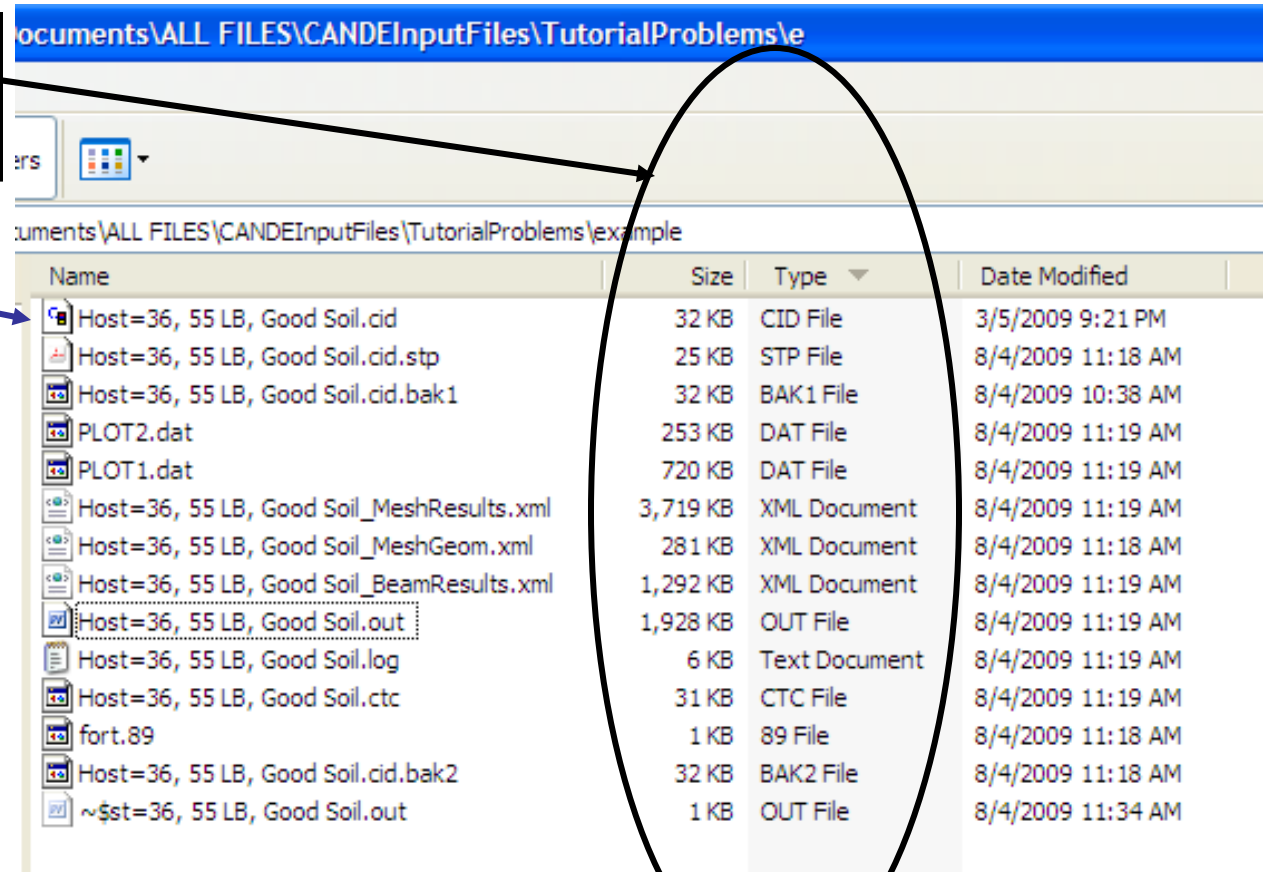


File Generation

New files after running input files

CID file is the input file and most critical.

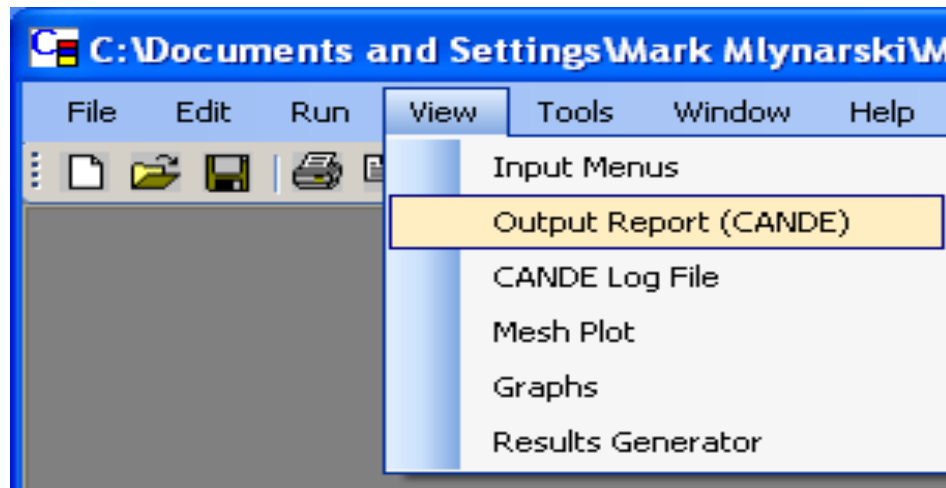
All others may be deleted, however if deleted to view an output report you will need to re-run the input file.



Name	Size	Type	Date Modified
Host=36, 55 LB, Good Soil.cid	32 KB	CID File	3/5/2009 9:21 PM
Host=36, 55 LB, Good Soil.cid.stp	25 KB	STP File	8/4/2009 11:18 AM
Host=36, 55 LB, Good Soil.cid.bak1	32 KB	BAK1 File	8/4/2009 10:38 AM
PLOT2.dat	253 KB	DAT File	8/4/2009 11:19 AM
PLOT1.dat	720 KB	DAT File	8/4/2009 11:19 AM
Host=36, 55 LB, Good Soil_MeshResults.xml	3,719 KB	XML Document	8/4/2009 11:19 AM
Host=36, 55 LB, Good Soil_MeshGeom.xml	281 KB	XML Document	8/4/2009 11:18 AM
Host=36, 55 LB, Good Soil_BeamResults.xml	1,292 KB	XML Document	8/4/2009 11:19 AM
Host=36, 55 LB, Good Soil.out	1,928 KB	OUT File	8/4/2009 11:19 AM
Host=36, 55 LB, Good Soil.log	6 KB	Text Document	8/4/2009 11:19 AM
Host=36, 55 LB, Good Soil.ctc	31 KB	CTC File	8/4/2009 11:19 AM
fort.89	1 KB	89 File	8/4/2009 11:18 AM
Host=36, 55 LB, Good Soil.cid.bak2	32 KB	BAK2 File	8/4/2009 11:18 AM
~\$st=36, 55 LB, Good Soil.out	1 KB	OUT File	8/4/2009 11:34 AM

OUTPUT AND GUI

After running input file, open “View” tab shown below.



Key Selection Choices

- **Output Report (CANDE)** – most comprehensive source of information
- **Mesh plot** – finite element mesh topology and stress/stain contours
- **Graphs** – Pipe-group plots of structural responses like moment diagrams

OUTPUT REPORT CANDE

- Output report can be quite large depending upon mesh complexity and number of load steps.
- Interactive table contents locates data of interest and is divided into three parts:
 - Master Control
 - Input Data
 - Output Data

8/6/2009

Row, Col = (8,2)

Find
Find Next...

Output Table of Contents

- master control and pipe-type data for problem # 1
- review system input data
- solution output results
 - finite element output for load step 1
 - finite element output for load step 2
 - finite element output for load step 3
 - finite element output for load step 4
 - finite element output for load step 5
 - finite element output for load step 6
 - finite element output for load step 7
 - finite element output for load step 8
 - finite element output for load step 9
 - finite element output for load step 10
 - finite element output for load step 11
 - finite element output for load step 12
 - finite element output for load step 13
 - finite element output for load step 14
 - finite element output for load step 15
 - finite element output for load step 16
 - finite element output for load step 17
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 - finite element output for load step 37
 - finite element output for load step 38
 - finite element output for load step 39
 - finite element output for load step 40
 - finite element output for load step 41
 - finite element output for load step 42
 - finite element output for load step 43
 - finite element output for load step 44
 - finite element output for load step 45

MASTER CONTROL AND PIPE-TYPE DATA FOR PROBLEM # 1

USER TITLE: Host diameter=36,deep burial,Good Soil,55 LB grout, Level 3

EXECUTION MODE ANALYS

SOLUTION LEVEL #3 USER

METHODOLOGY (LRFD OR SERVICE) ... LRFD

NUMBER OF PIPE-ELEMENT GROUPS 2

MAXIMUM ITERATIONS PER STEP 30

PIPE-TYPE PROPERTIES FOR GROUP # 1

PIPE ELEMENT TYPE STEEL

NUMBER OF BEAM ELEMENTS 10

STEEL ELEMENT PROPERTIES ARE AS FOLLOWS:

YOUNGS MODULUS OF METAL (PSI)..... 0.10000E+01

POISSONS RATIO OF METAL (-) 0.30000E+00

YIELD STRESS OF METAL (PSI)..... 0.10000E+01

LONGITUDINAL SEAM STRENGTH (PSI)... 0.10000E+01

DENSITY OF METAL (PCI)..... 0.00000E+00

MODULUS OF UPPER BI-SLOPE (PSI).... 0.00000E+00

MATERIAL CHARACTER CODE, NONLIN 2

NONLIN=2,MEANS BILINEAR ELASTIC-PLASTIC

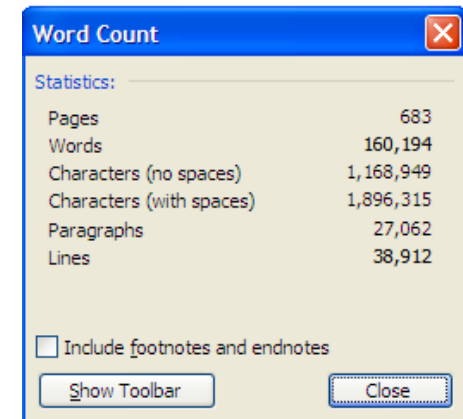
LARGE DEFORMATION/BUCKLING CODE, IBUCK... 1

IBUCK=1, MEANS LARGE DEFORMATION THEORY FOR GROUP AND SIMPLIFIED BUCKLING PREDICTION, AASHTO 12.7.2.4-1-2

SECTION PROPERTIES OF CROSS-SECTION:

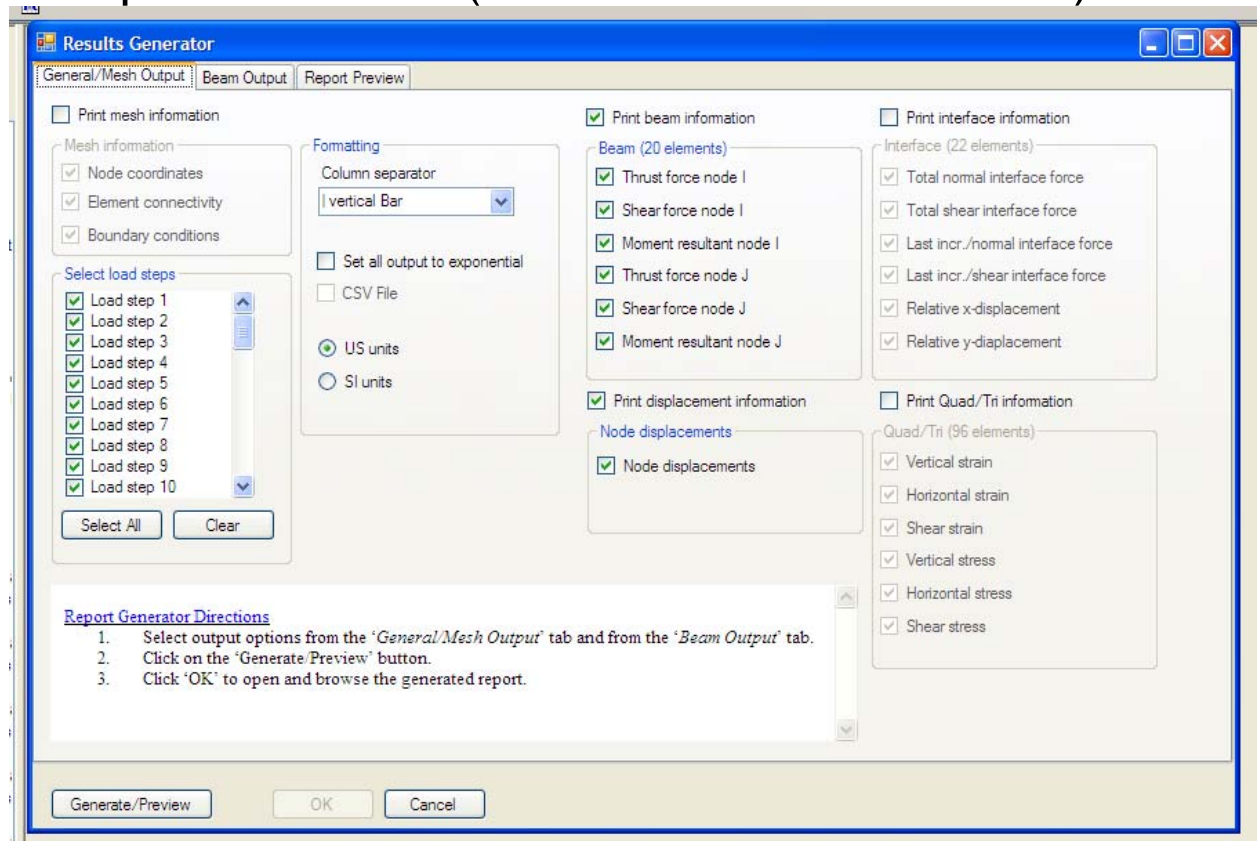
Output Report

- The .OUTfile is a word compatible file.
- The .OUTfile can get very large
- The preceding example had:
 - 683 pages
 - 38,912 lines of text
 - 1,168,949 characters of text
- Minimizing the report and summarizing the results is important.



Presenting Data

- Rather than using the “.OUTfile”, you can customize the report by using the results generator.
 - To start the results generator
 - Select View>Output Generator (from the CANDE Toolbar).



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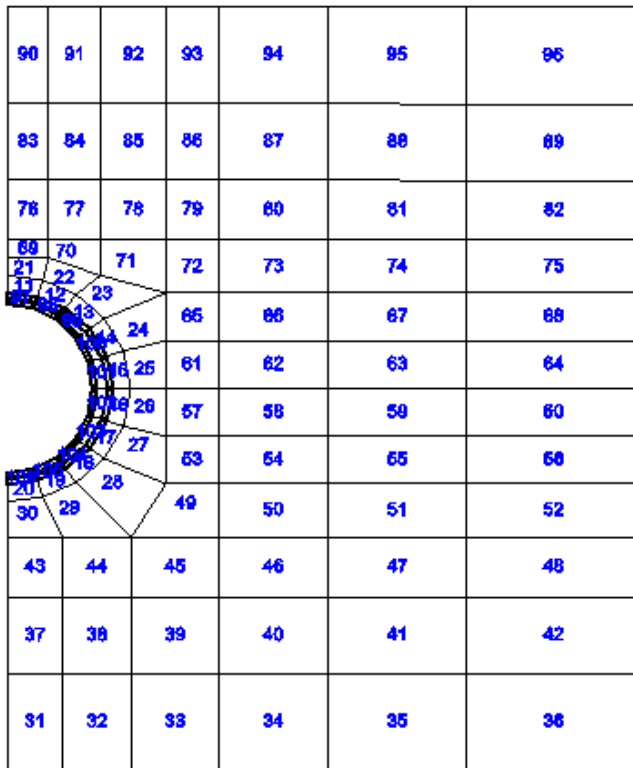
Customizing Report

- To further customize your report you can accomplished by cutting and pasting portions of the report.
- One easy way to do this is to use the interactive table of content to go directly to the are of interest in the report.
- Copy using the <control><C> command
- Then insert text directly into a word document.

- MESH PLOT -

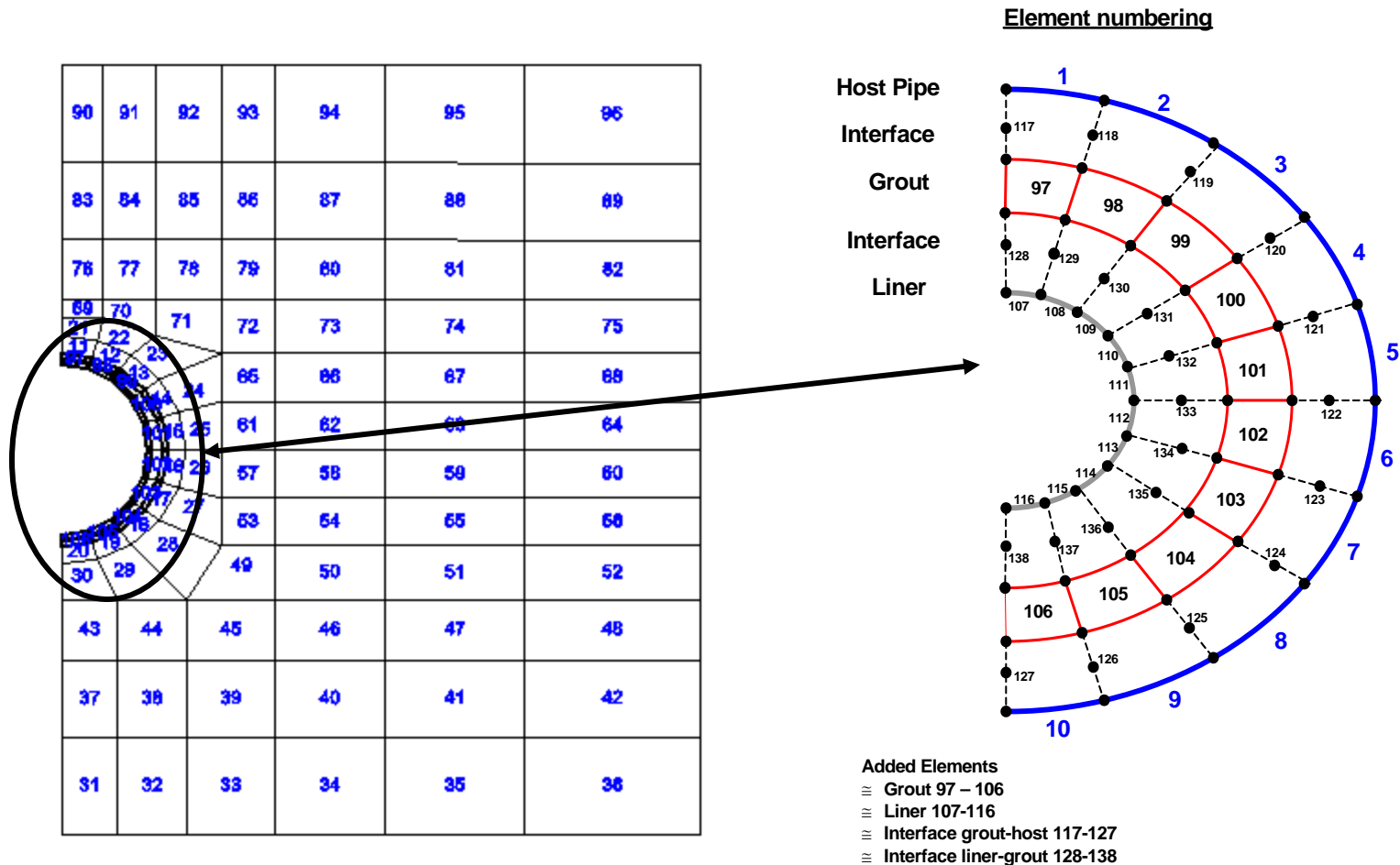
- Plot nodes, elements, materials, construction increments, etc. can be plotted.
 - Select View>Mesh Plot (from the CANDE Toolbar).

Element numbering



- MESH PLOT -

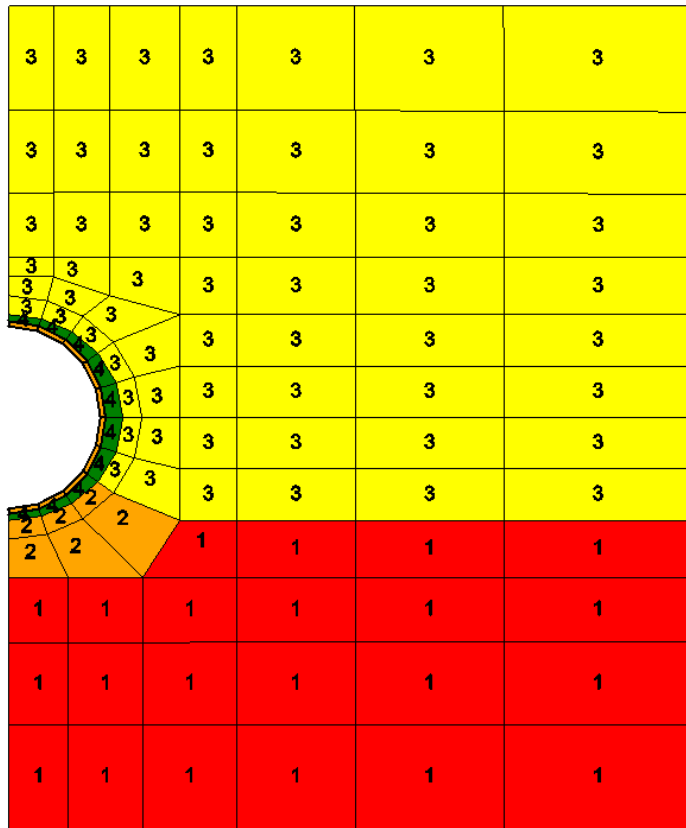
- At times the element numbering may be too close together or on top of each other in the case of interface elements.
- In the case of interface elements may be necessary to generate a second diagram to illustrate the element layout.



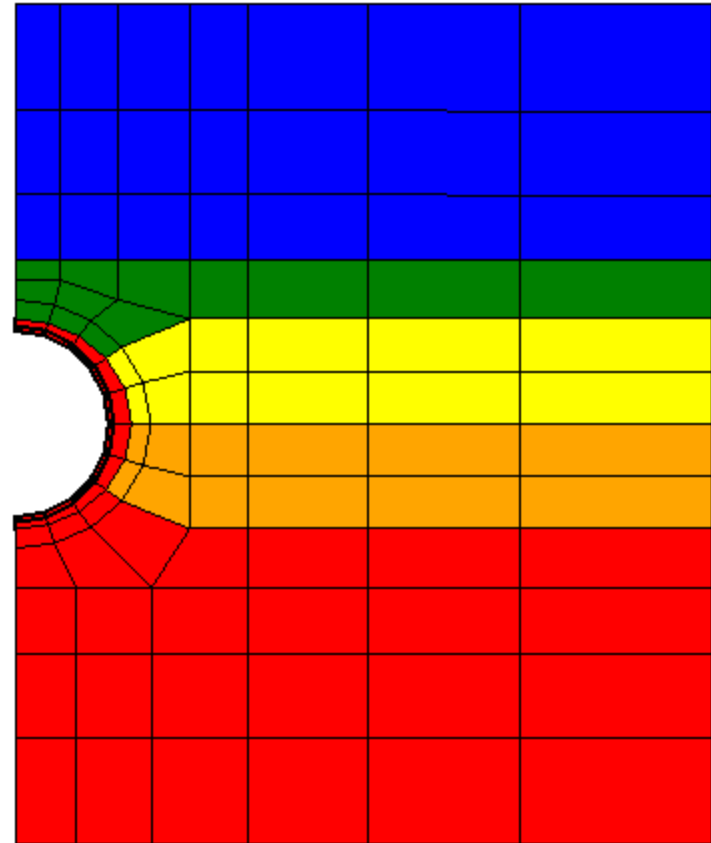
- MESH PLOT -

Other options include

Backfill Materials



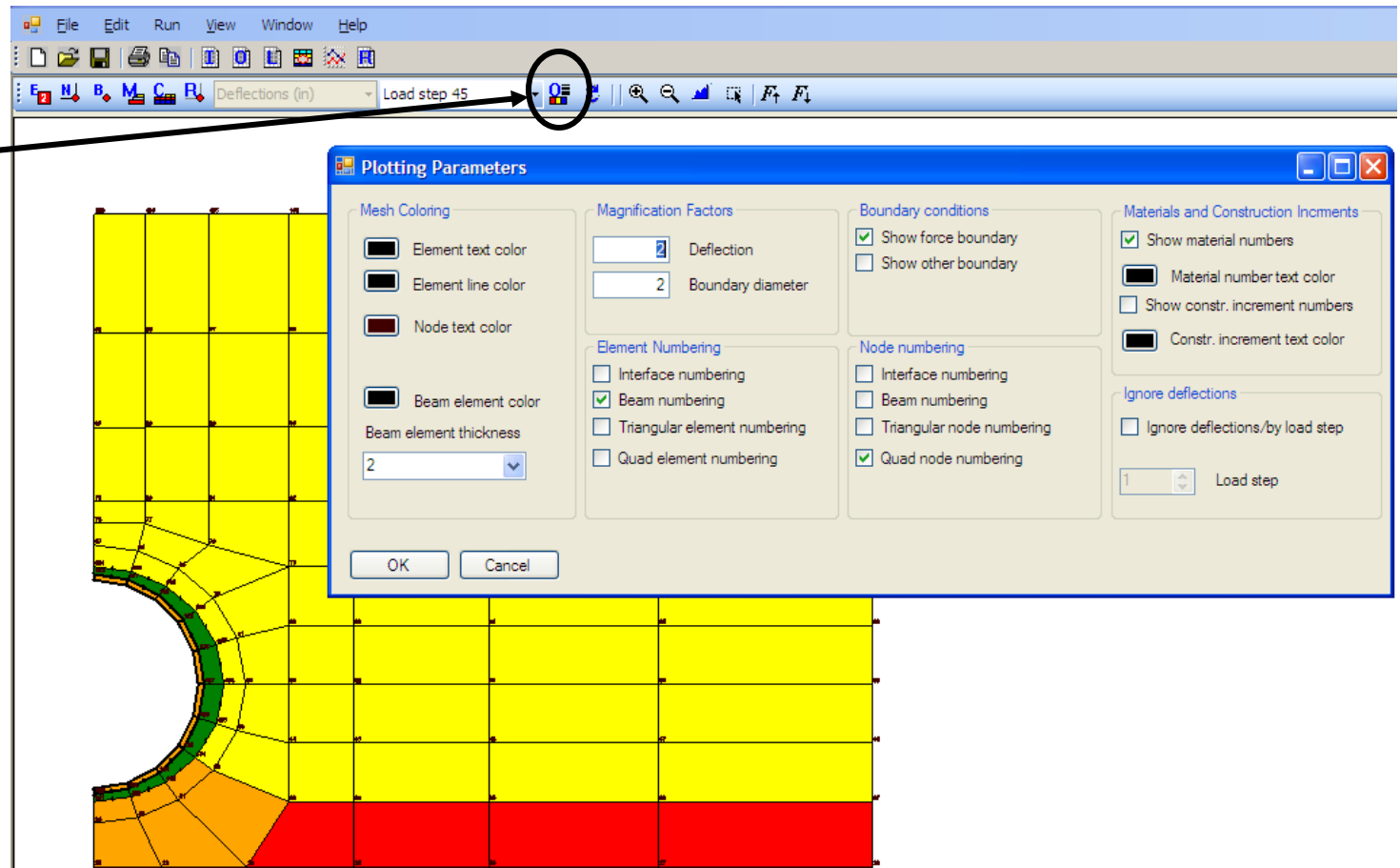
Construction Increments



Mesh Plot Output

- Plot can be customized using the Mesh viewer options feature.

Mesh Viewer
Options
Button
specifies
plotting
parameter



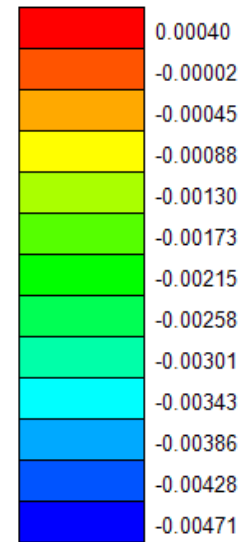
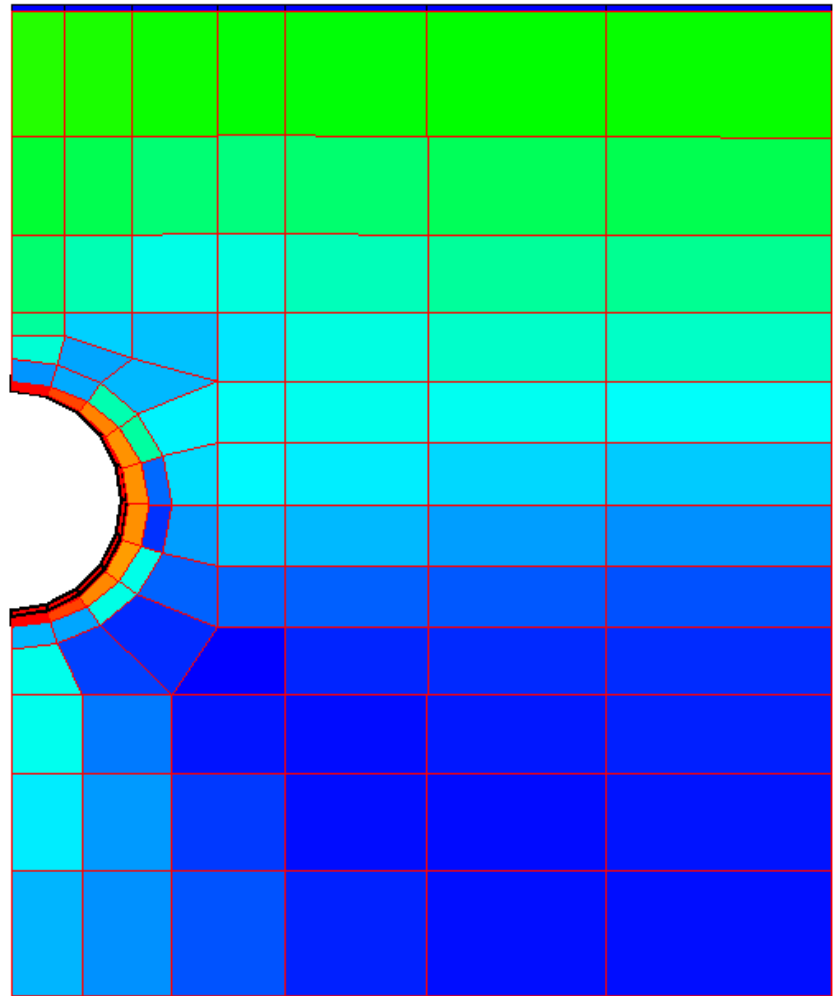
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- MESH PLOT (output) -

Plot stress/strain color contours (vertical, horizontal shear)

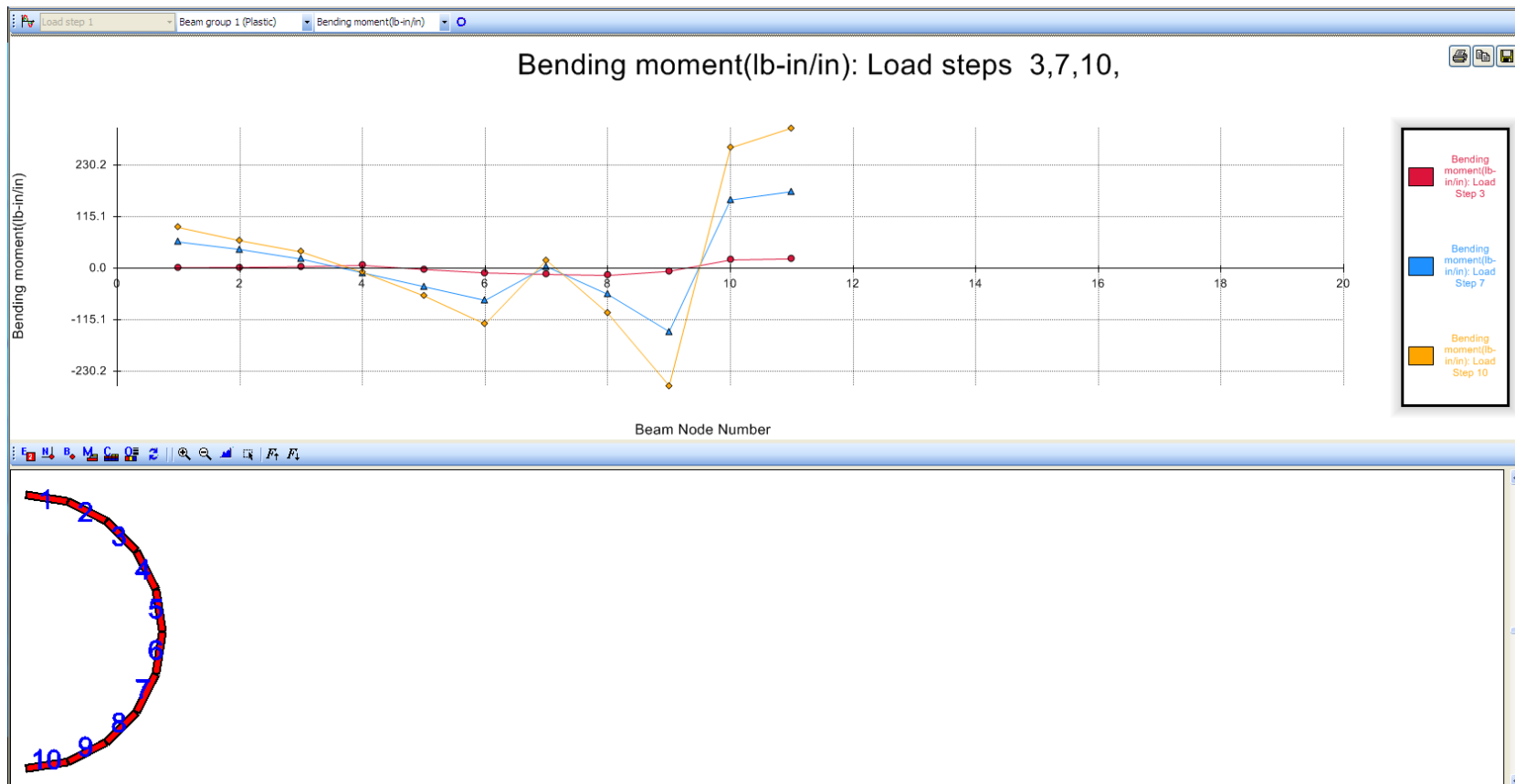
Vertical Strain

Scale for Vertical Strain (in/in)
Defl. Magnif. = 2.00



GRAPHS FOR PIPE GROUPS

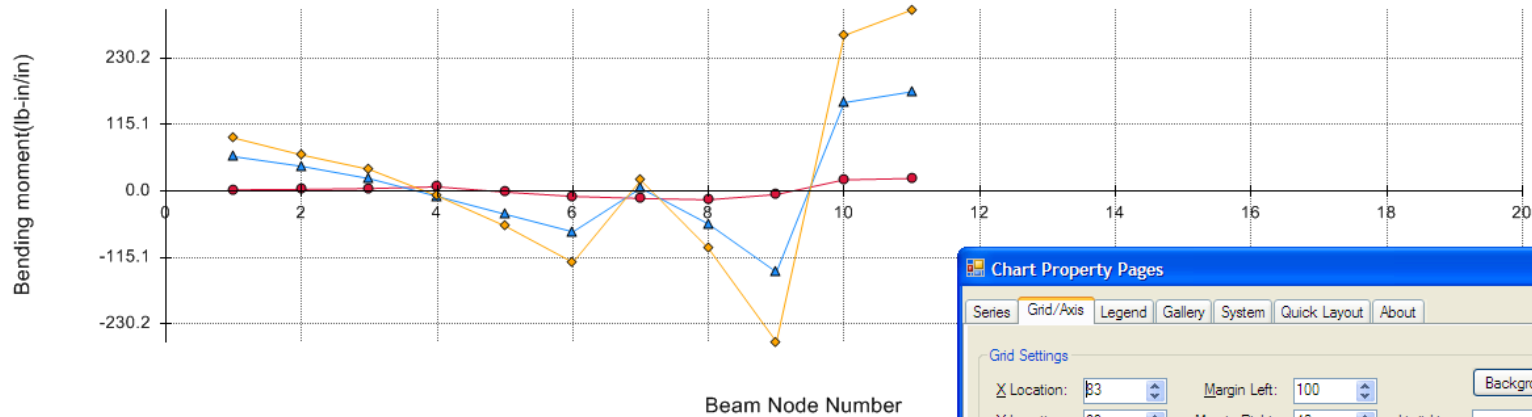
Plot diagrams for moments, thrust, shears and many key responses



8/6/2009

Graph Properties Page

Bending moment(lb-in/in): Load steps 3,7,10,



The screenshot shows the 'Chart Property Pages' dialog box with the 'Grid/Axis' tab selected. The 'Grid Settings' section includes fields for X Location (B3), Y Location (89), Width (1173), Height (333), Margin Left (100), Margin Right (40), Margin Top (40), Margin Bottom (40), Limit Lines (Off), High Value (0.0000), and Low Value (0.0000). The 'Tick Settings' section includes Tick Mode (OnStartAtZero), Tick Interval (1.1000), Tick Count (10), and Minor Ticks (0). The 'Scale Settings' section includes Scale (SmartScaling), User Min (0.0000), and User Max (0.0000). A note at the bottom states: 'Note that Tick Count takes precedence if both Tick Count and Tick Interval are specified.' A 'Close' button is located at the bottom right.

Graph properties page (right click on graph) can format you graphical presentation of the data.

Thank you
for Attending the TRB Webinar
INTRODUCTION TO CAPABILITIES OF
CANDE-2007
(Culvert Analysis and Design)

Presented by:

Tim Toliver, P.E.

www.4pipe.com

E-mail contact: tim@4pipe.com

Advanced Pipe Services 