SIMPSON GUMPERTZ & HEGER

Engineering of Structures
and Building Enclosures

Introduction to the Capabilities of CANDE-2007

Input and Design Features

Tim McGrath

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 LRRFD 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 %	Δ_{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)	ε_{max} = bending + thrust	ε_{ult} = ultimate strain
(Performance Limits)		
Allowable tensile strain	$\varepsilon_{t\text{-}max}$ = 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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9	Uses in… extend… deform…	…terface angles …nterface.
10	Include… Pipe	…dify chart properties of graphs plotted using 'view/graphs.'
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Uses interface elements, Level 2 extended to apply live load, and large deformation / buckling analysis

16 Tutorial Problems

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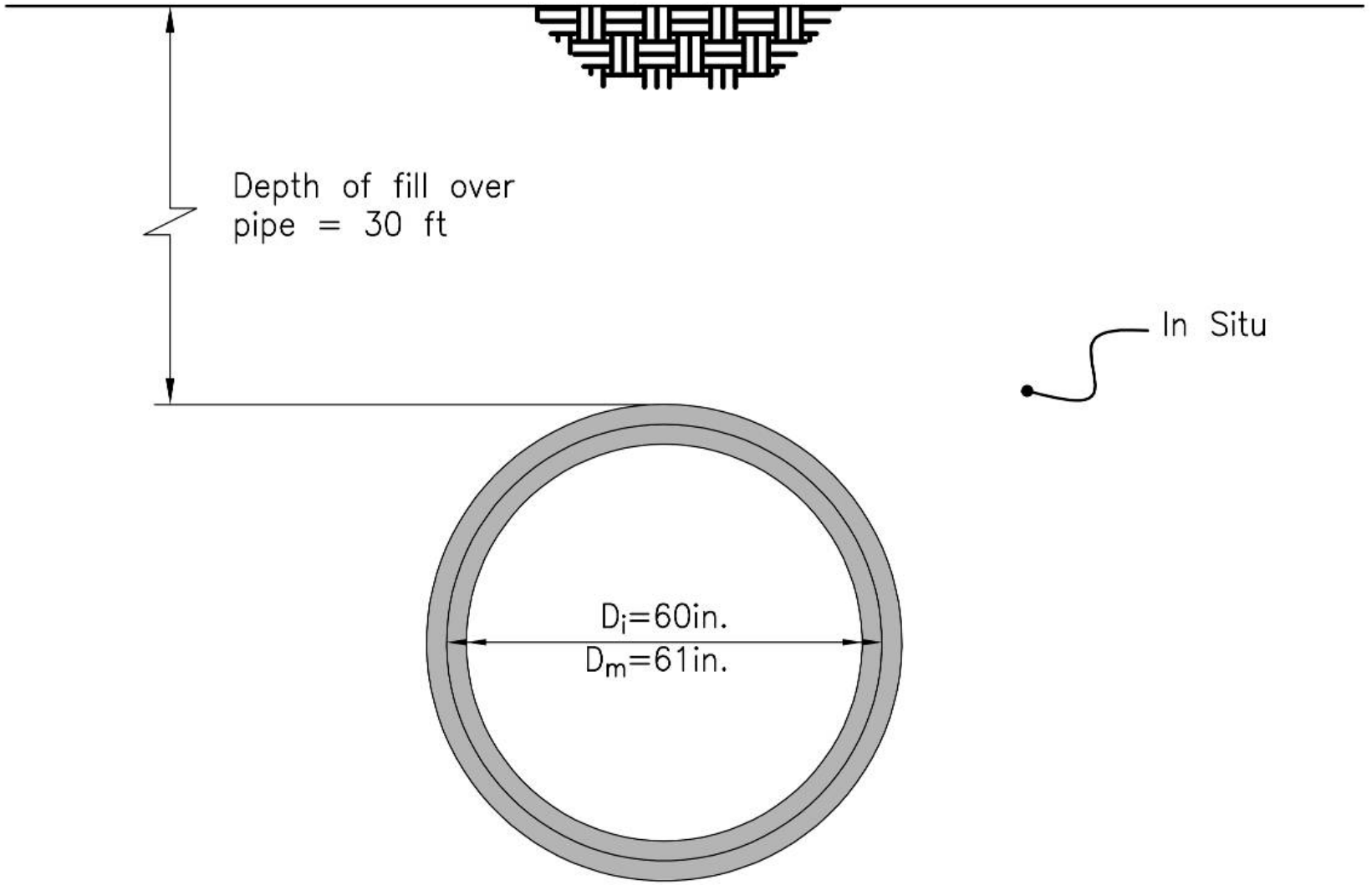
…		

Shows inputting interface angles using the graphic interface.

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.

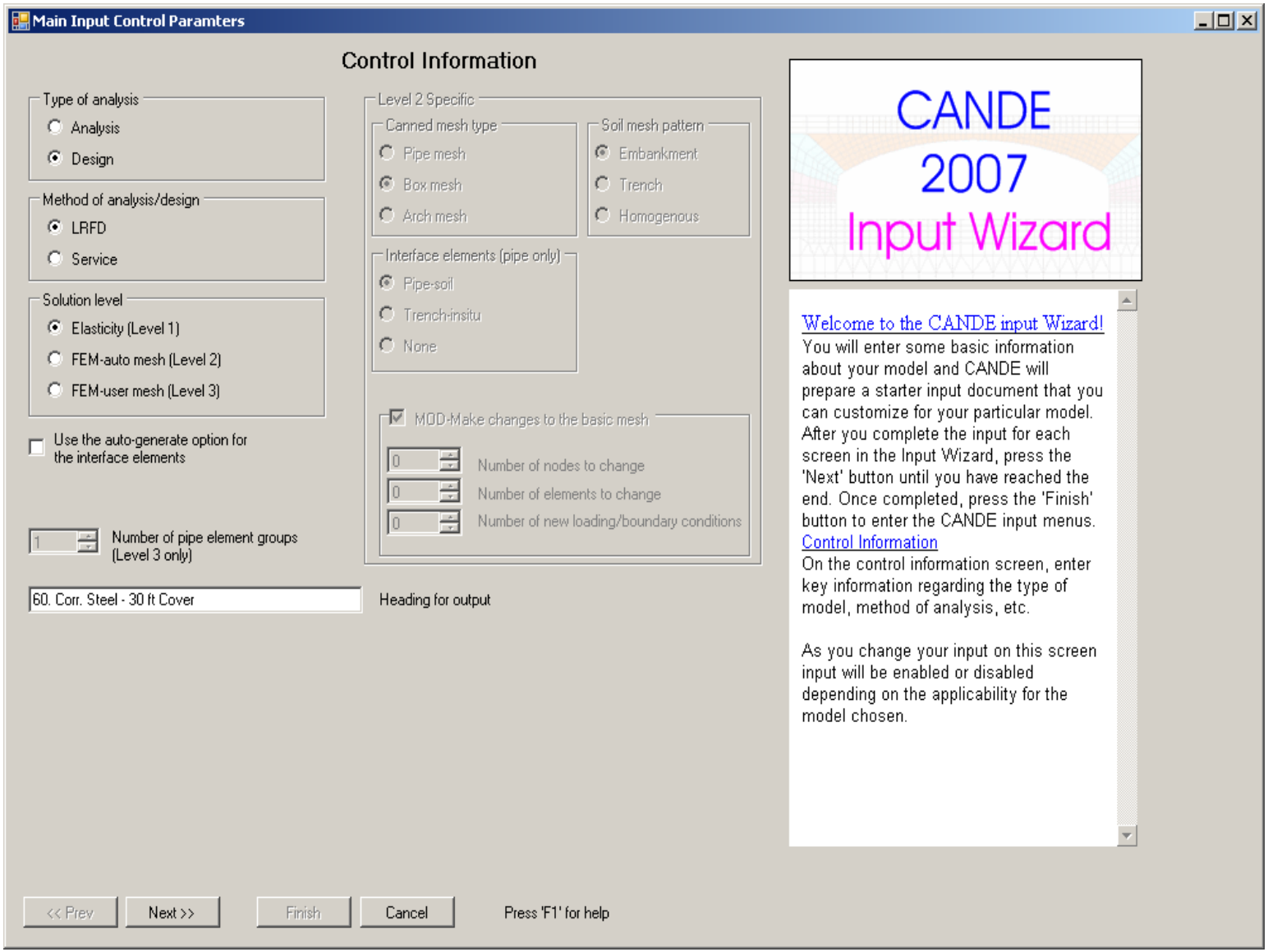
Number of load steps - Apply load in 10 equal load steps of 3 ft of soil.

LRFD load factor - 1.95

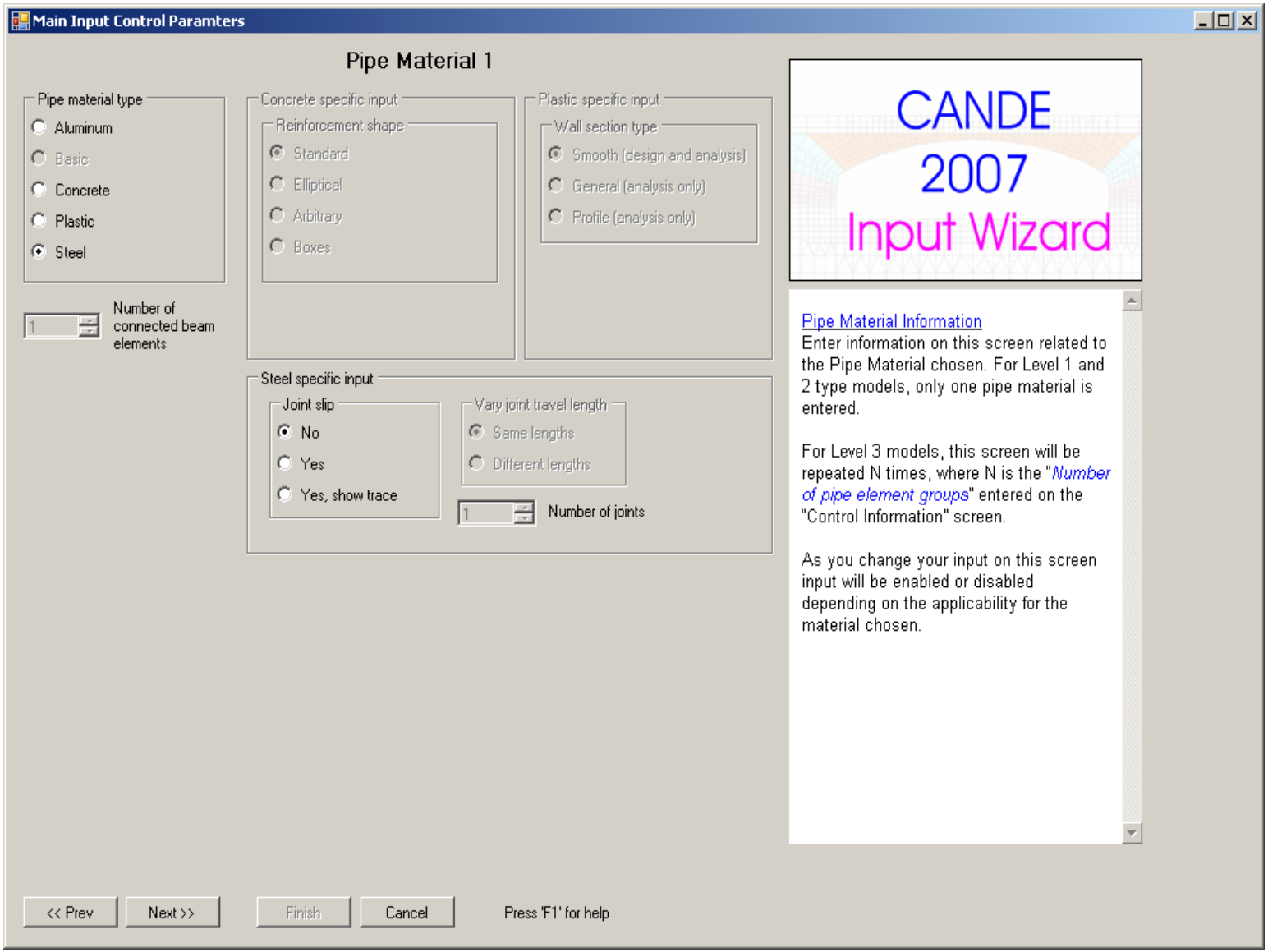
Load modifier - 1.05 (non-redundant for earth load)

Combined load factor = 1.95 x 1.05 = 2.05

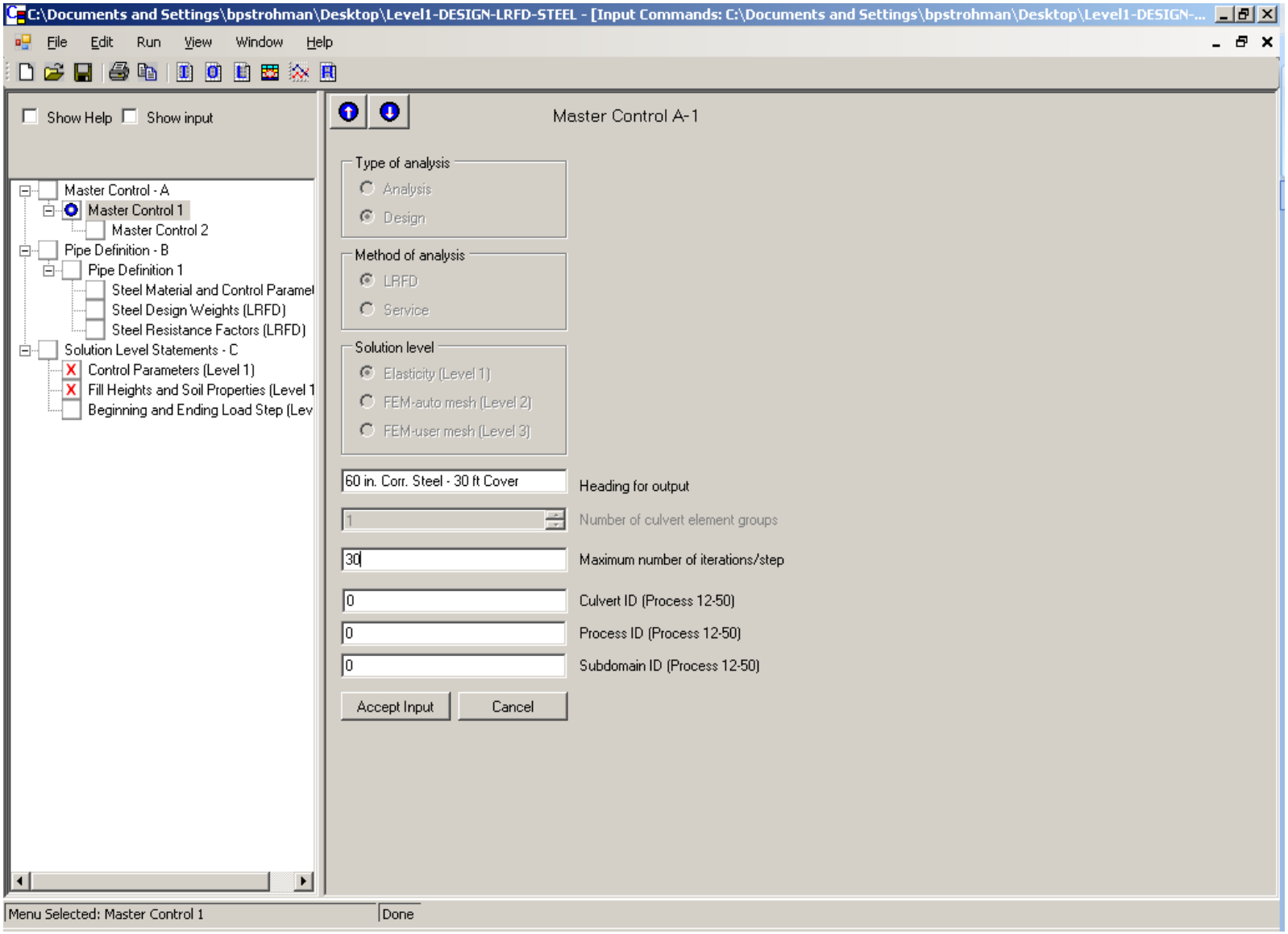
P1 - Level 1 – Input Wizard, Screen 1



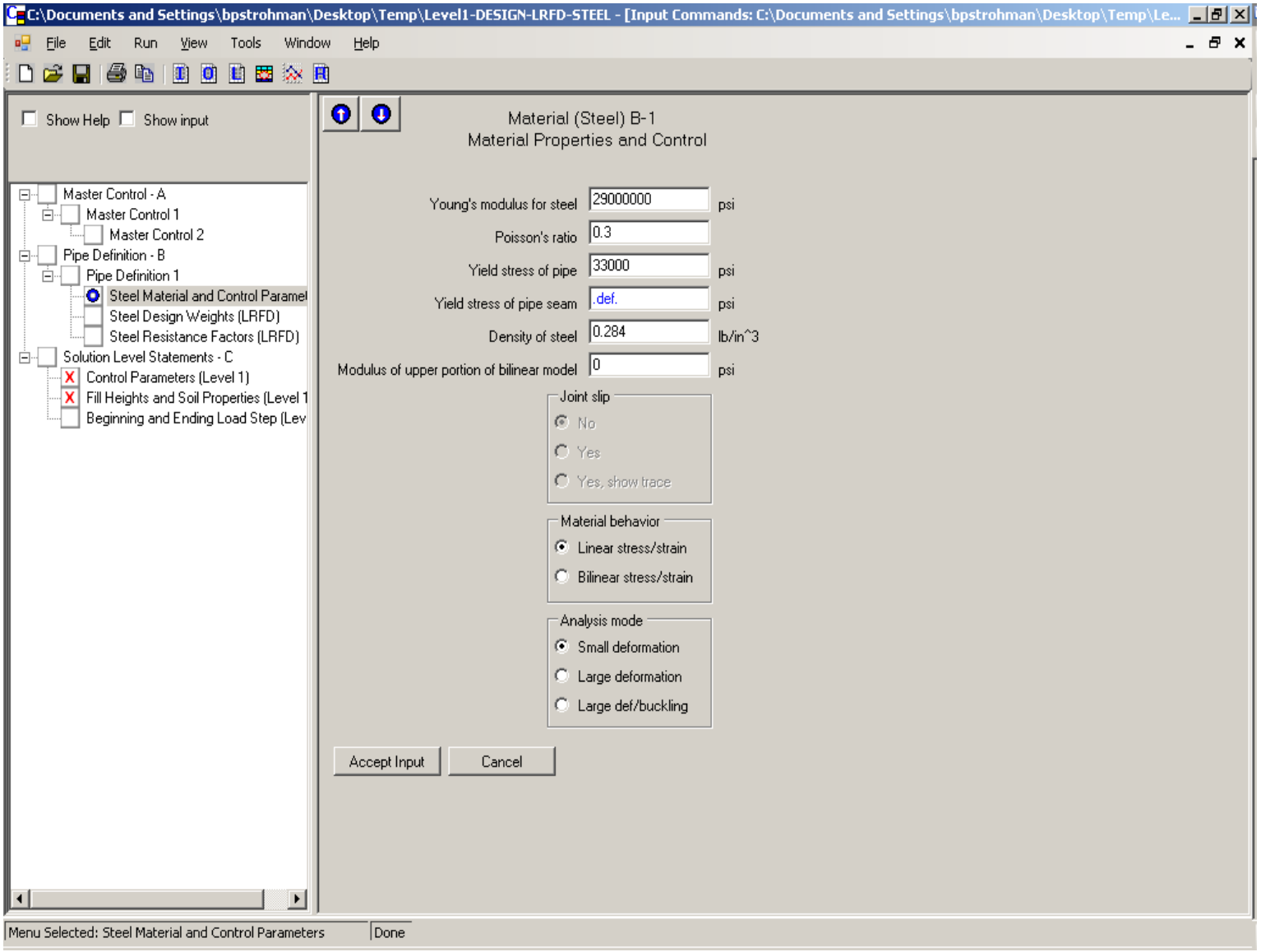
P1 - Level 1 – Input Wizard, Screen 2



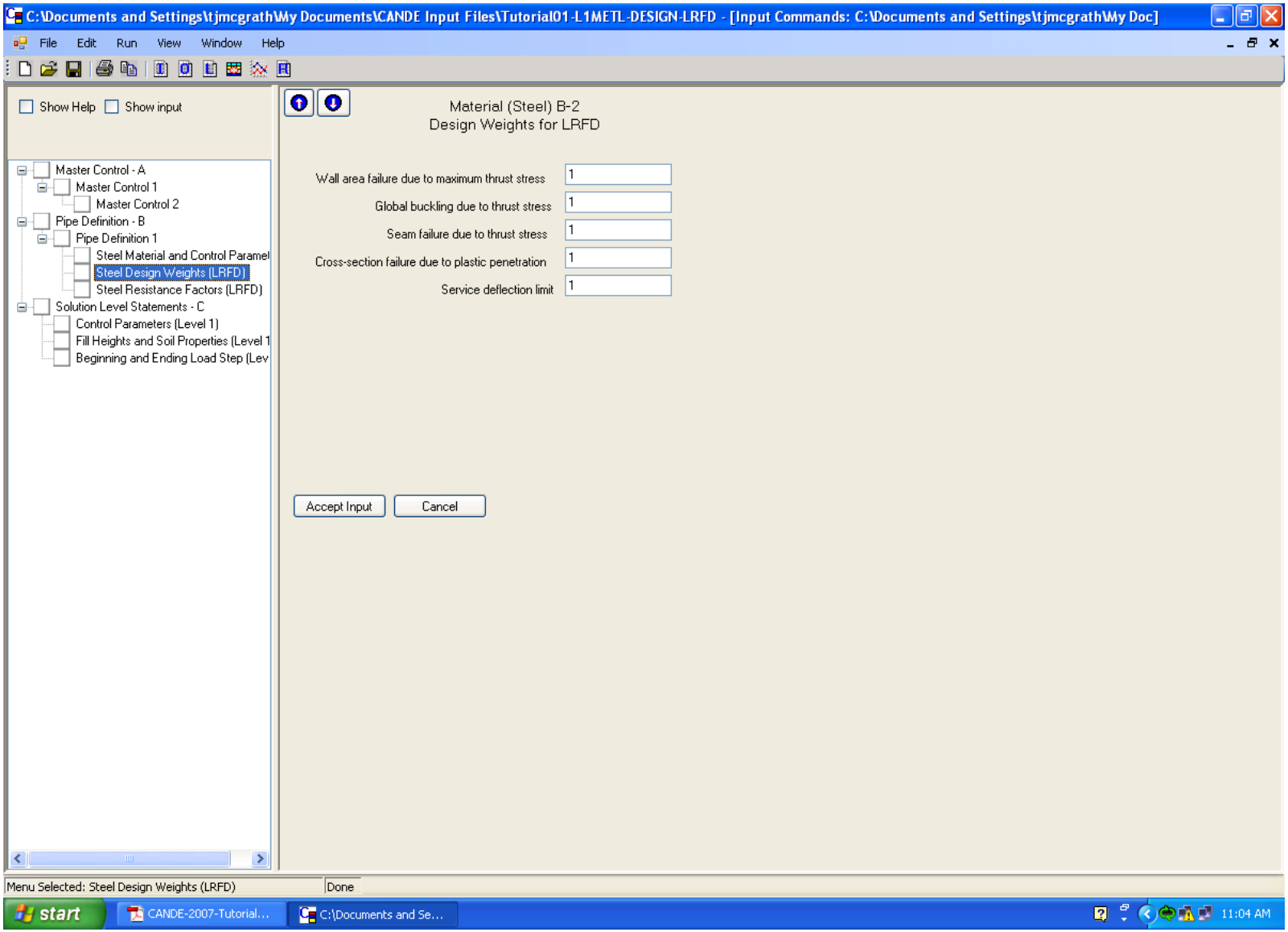
P1 - Master Control Screen



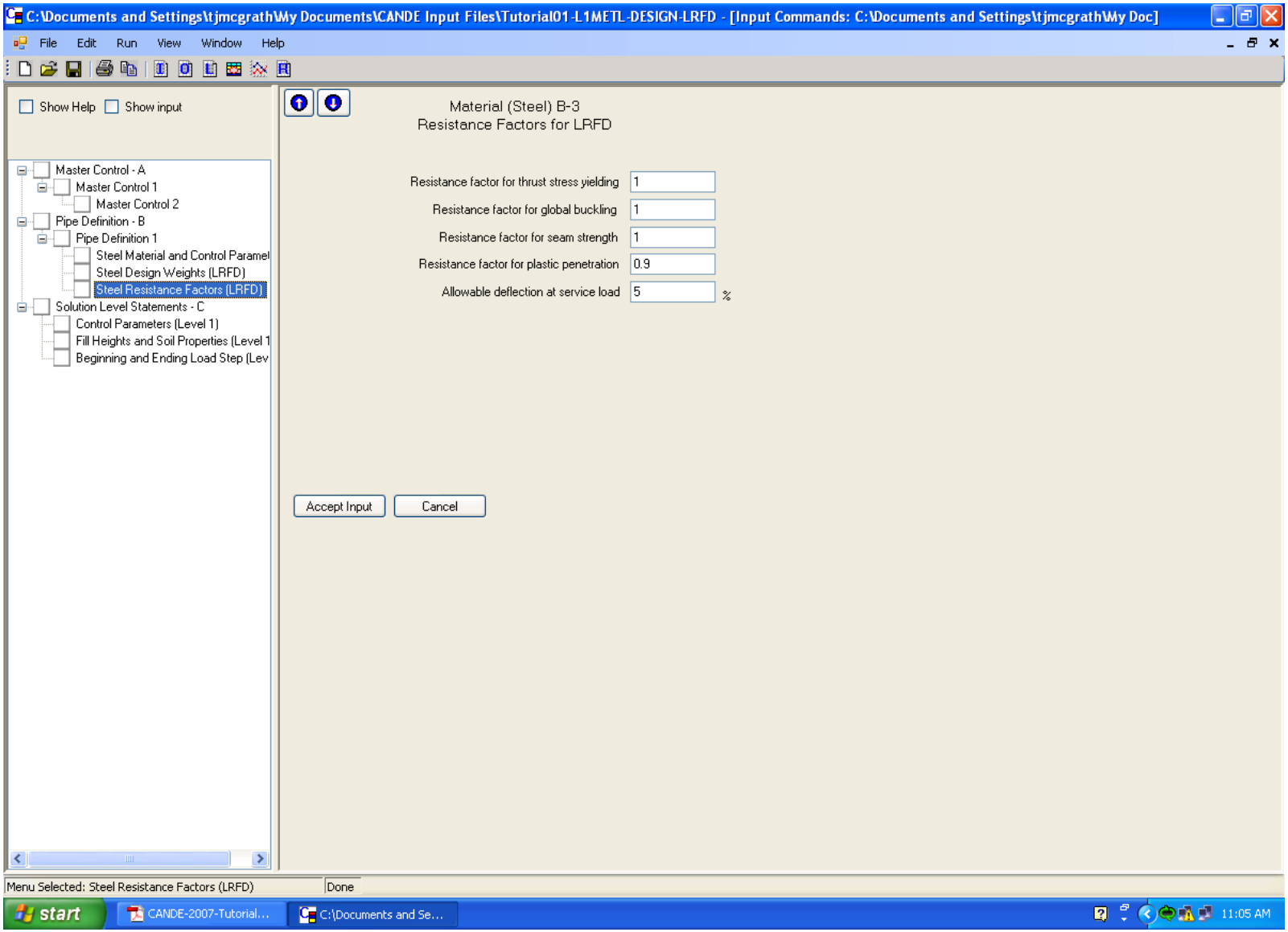
P1 - Screen B-1 - Material Properties



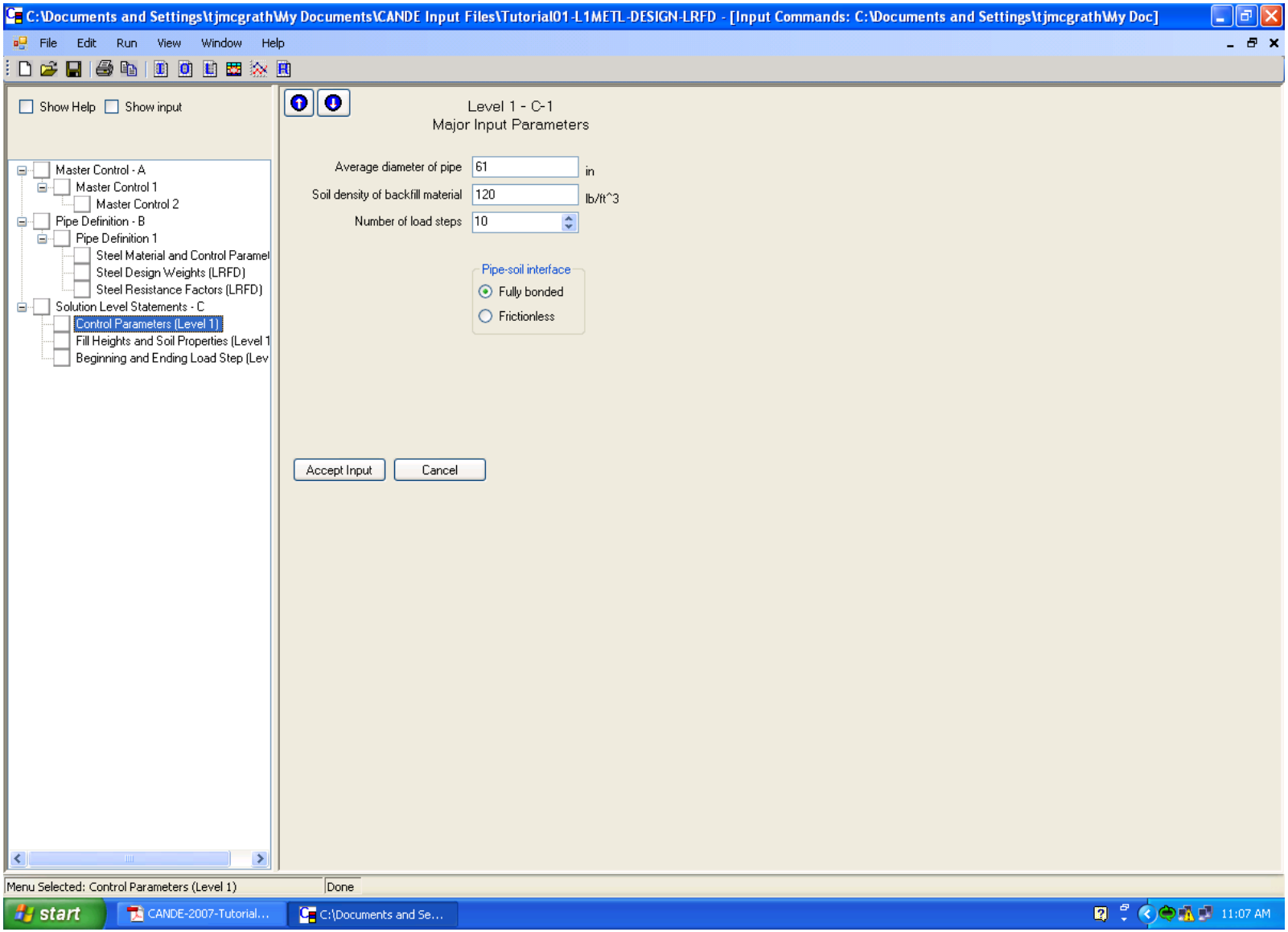
P1 - Screen B-2 - Design Weights



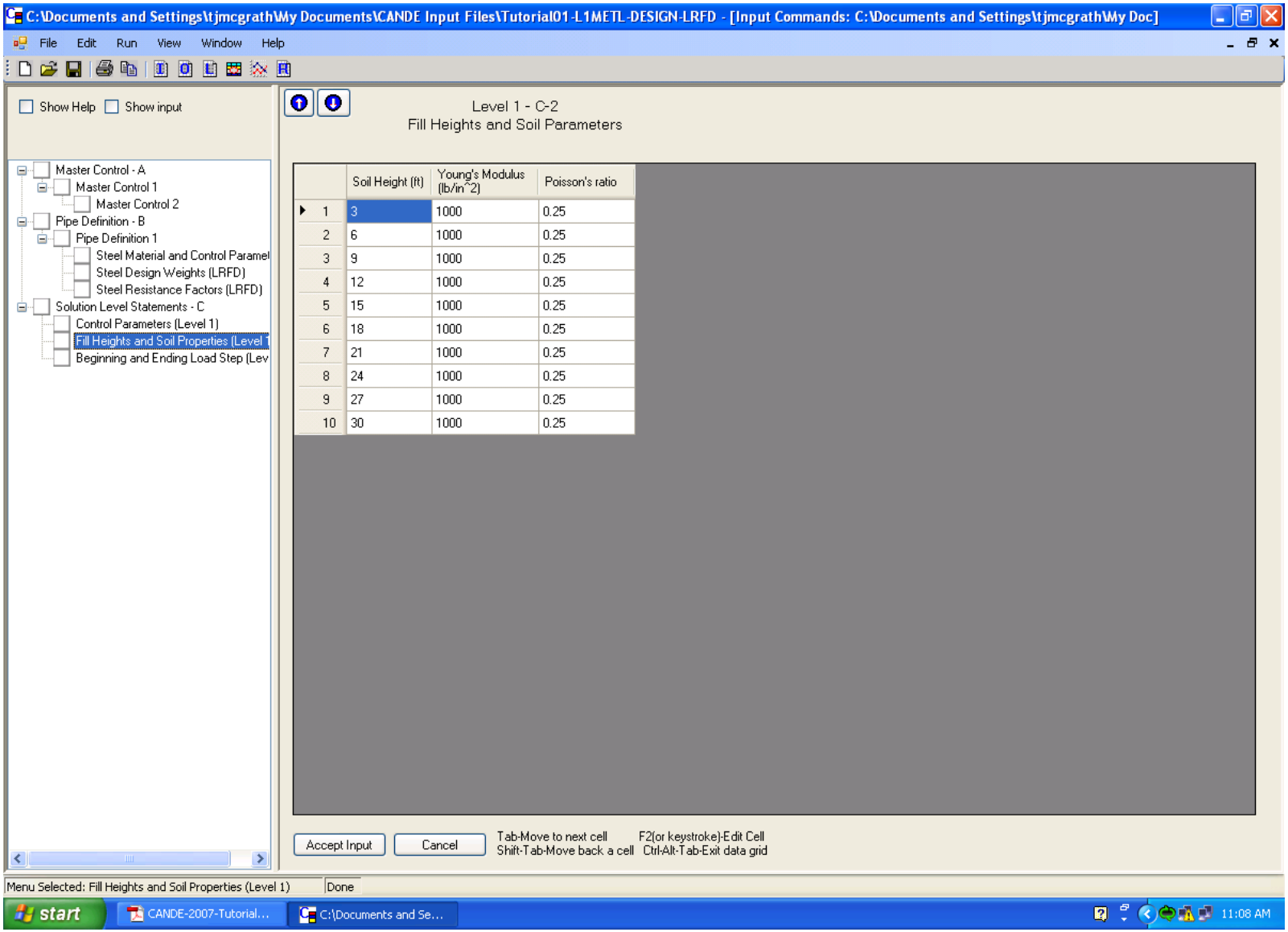
P1 - Screen B-3 - Resistance Factors



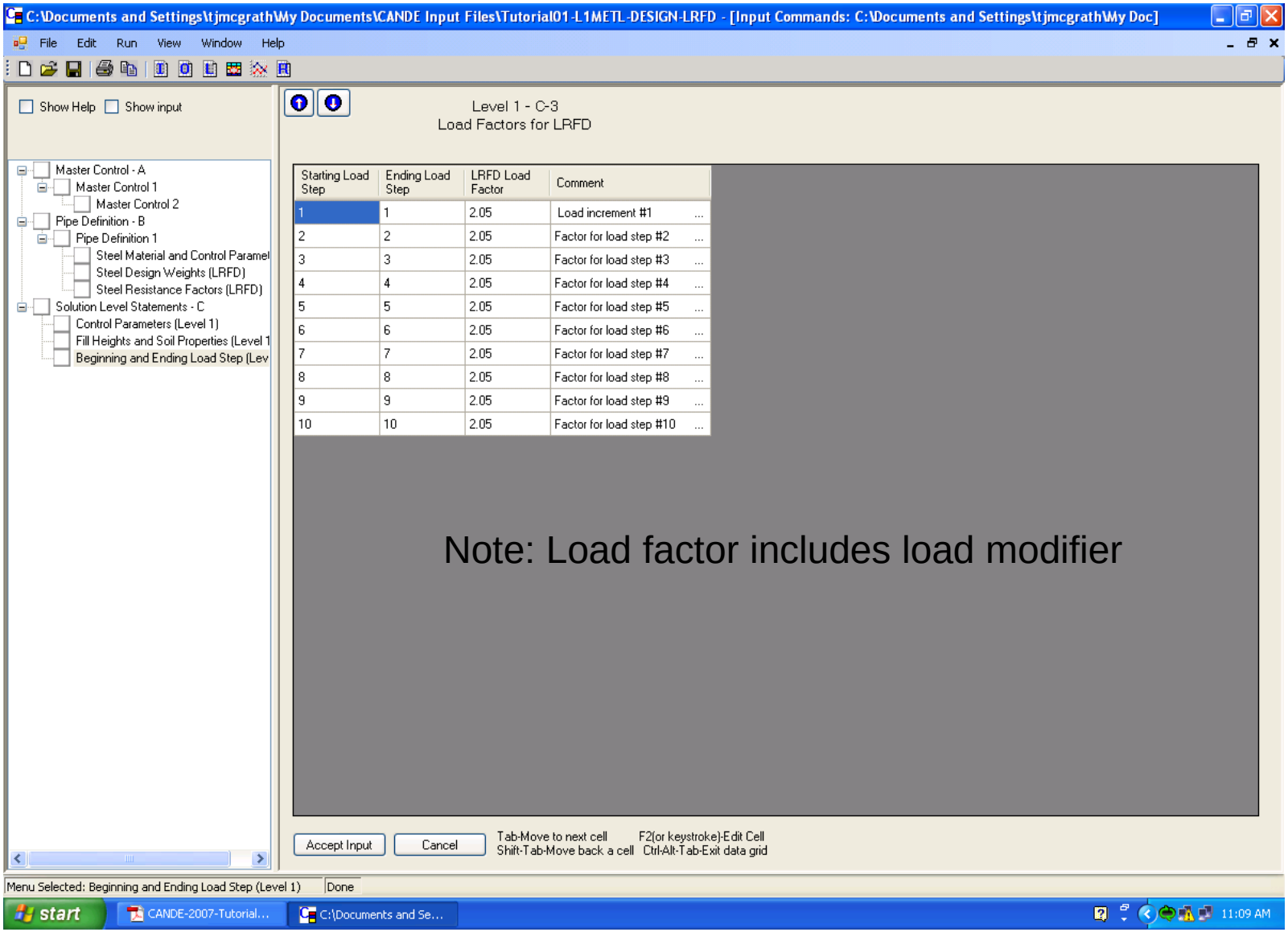
P1 - Screen C-1 - Major Input Parameters



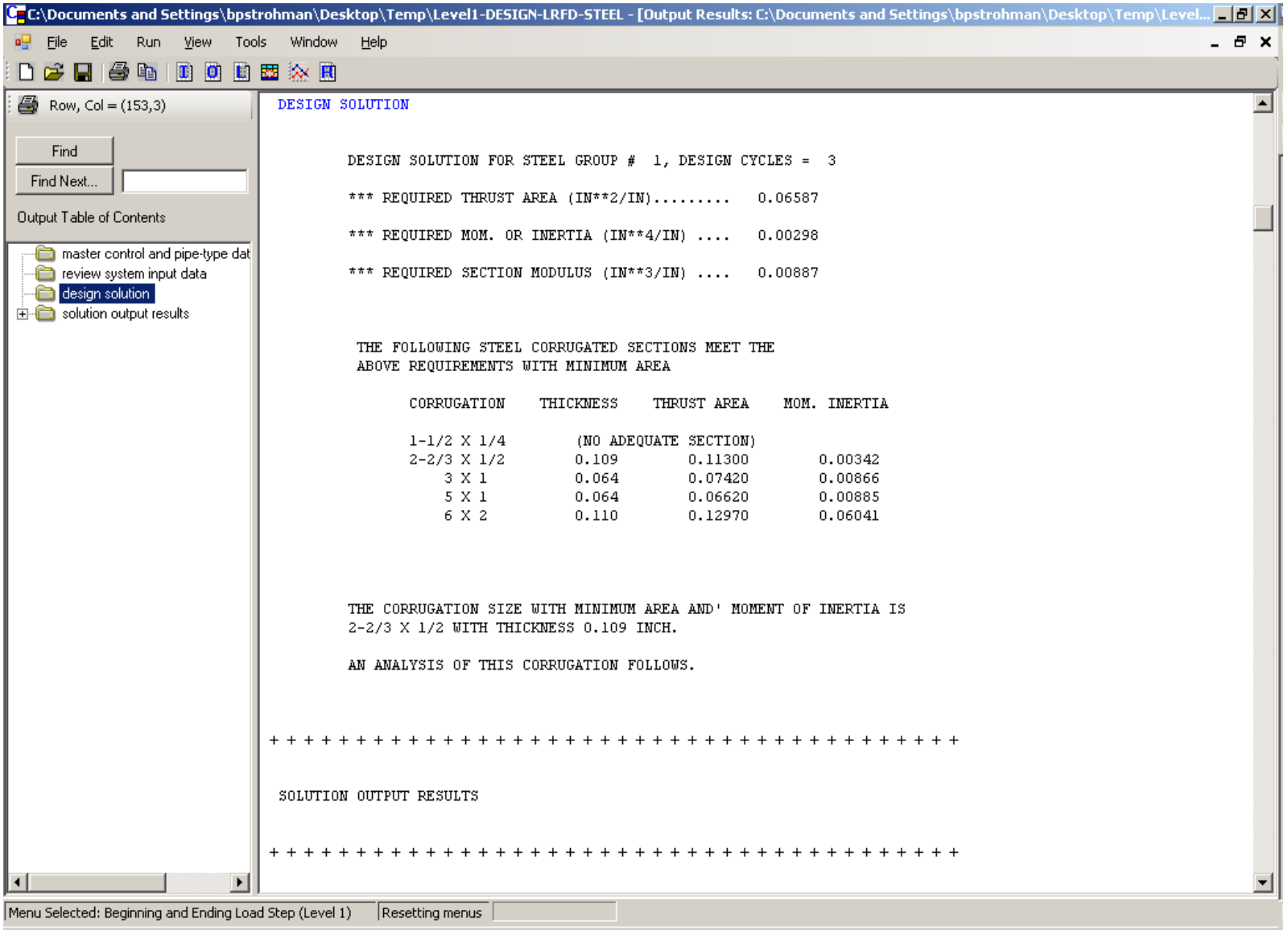
P1 - Screen C-2 - Fill Height, Soil Parameters



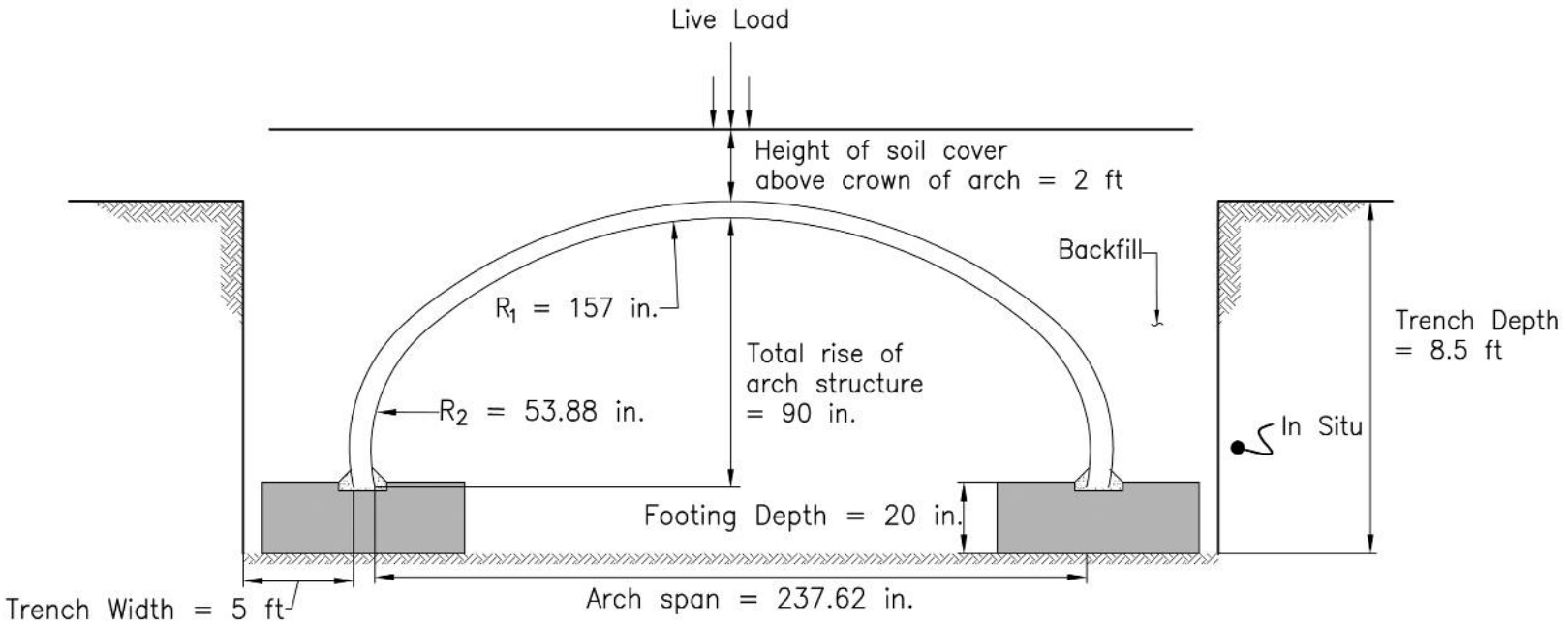
P1 - Screen C-3 – LRFD Load Factors



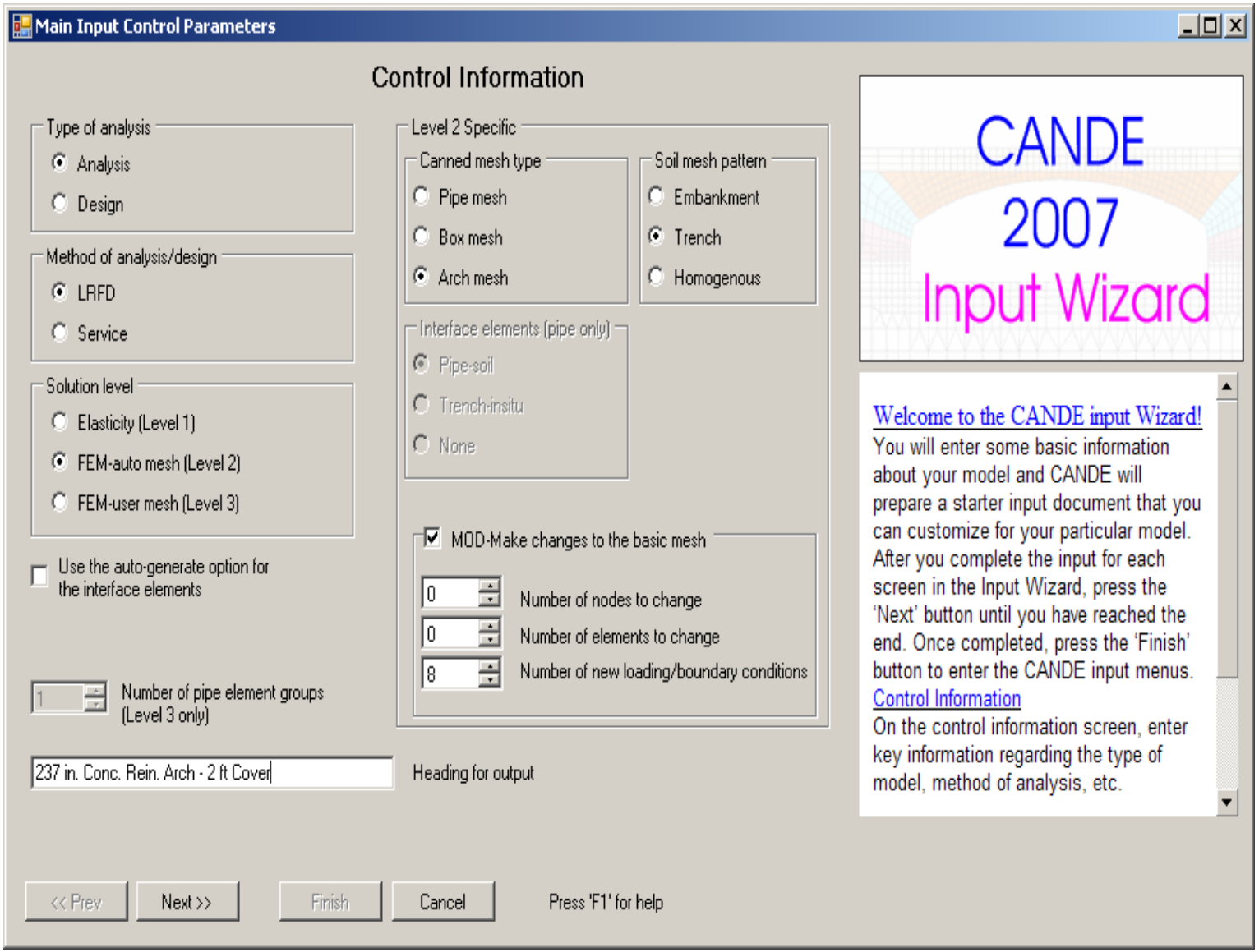
P1 – Design Solution



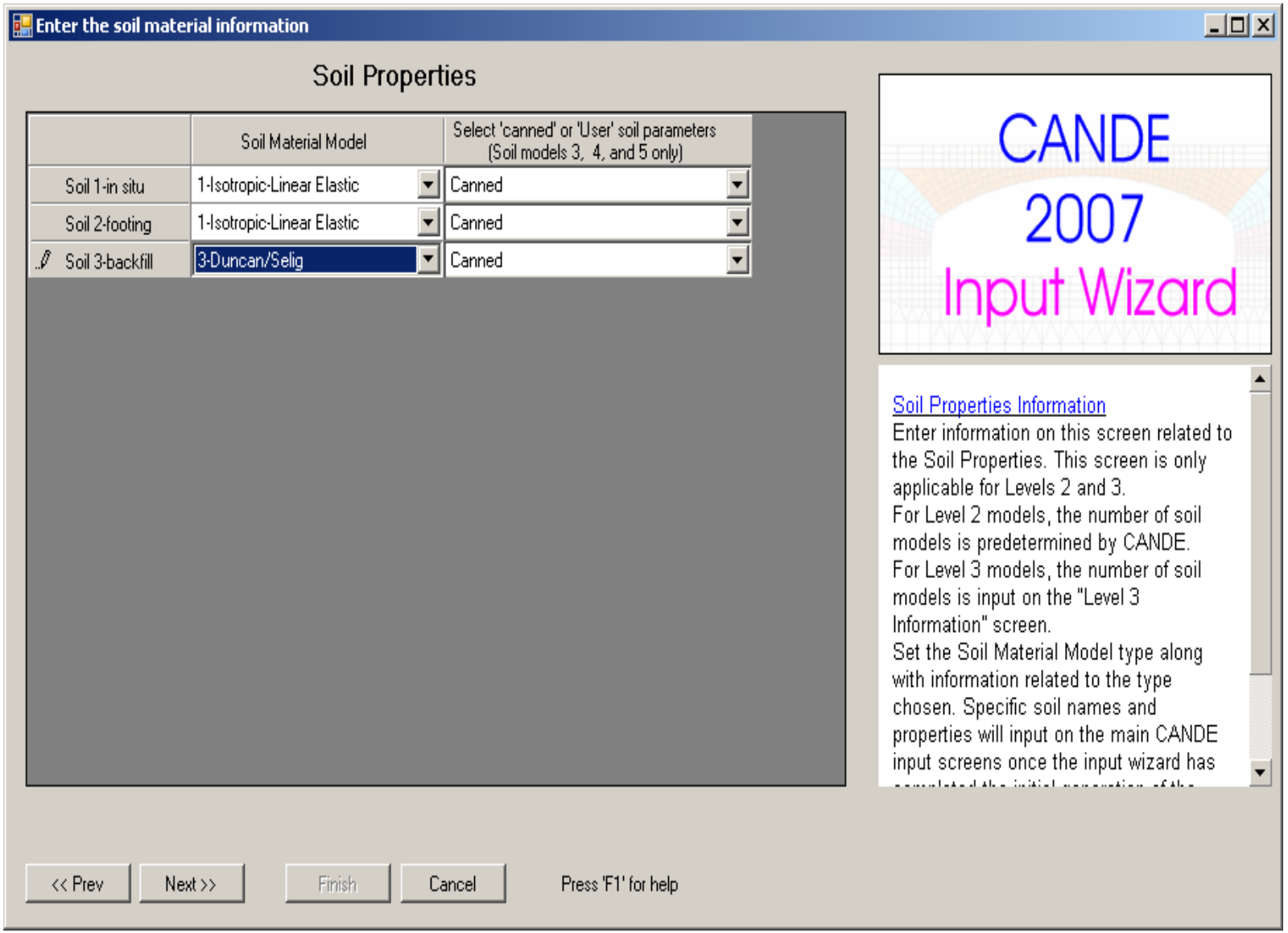
Problem 6 (P6) – Concrete Arch, Level 2



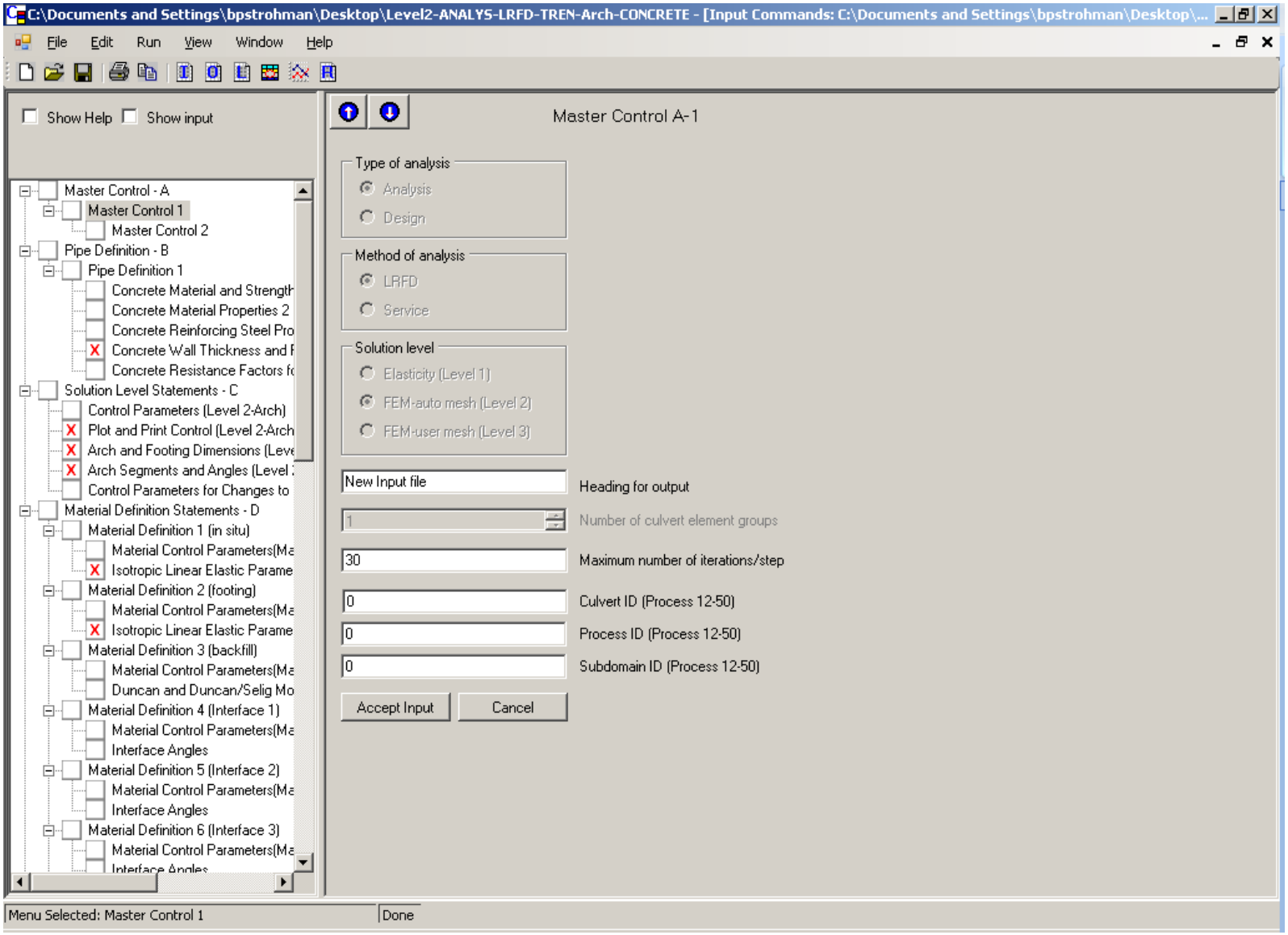
P6 – Input Wizard - Screen 1



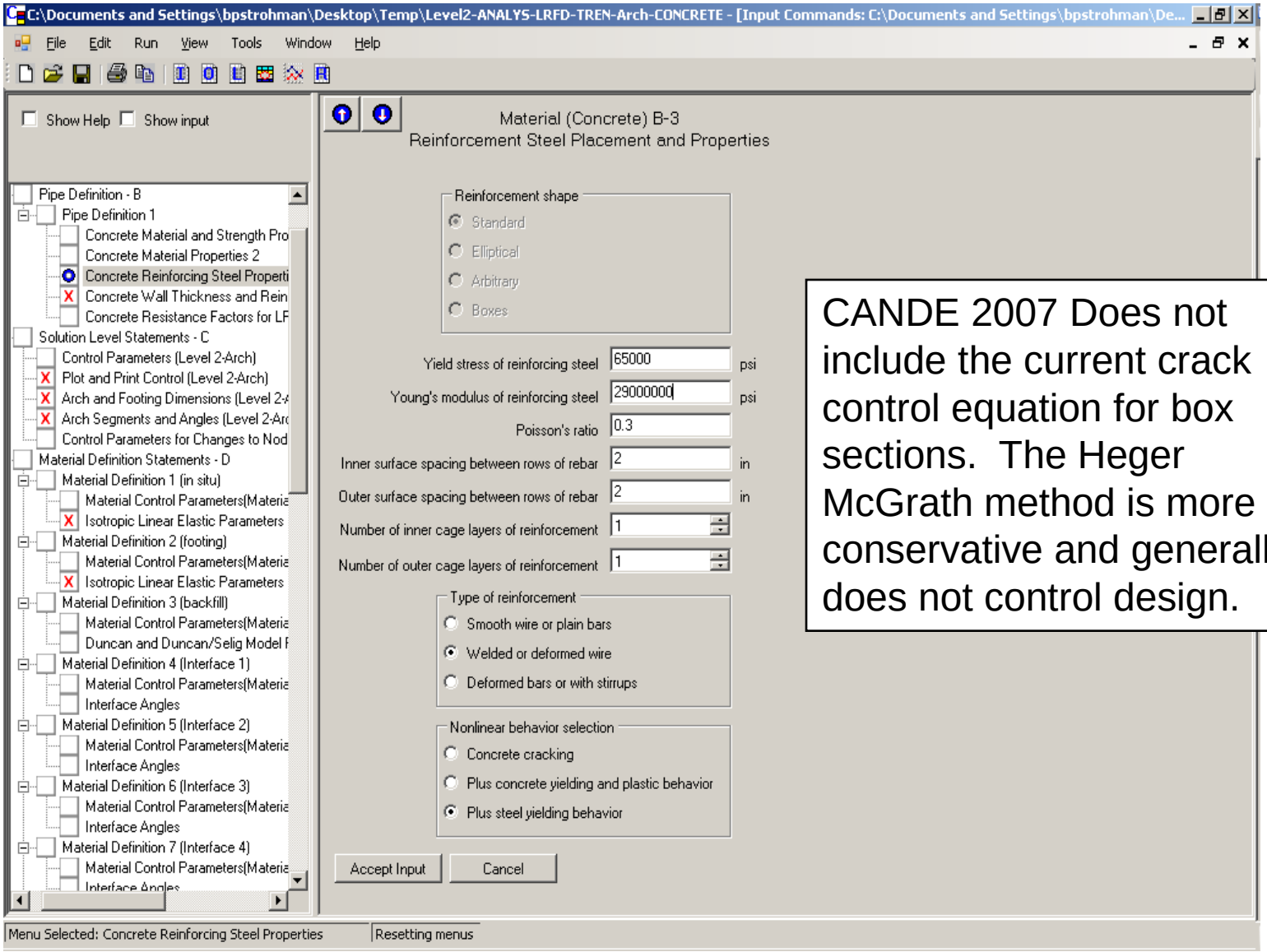
P6 – Input Wizard - Screen 3



P6 - Master Control A-1

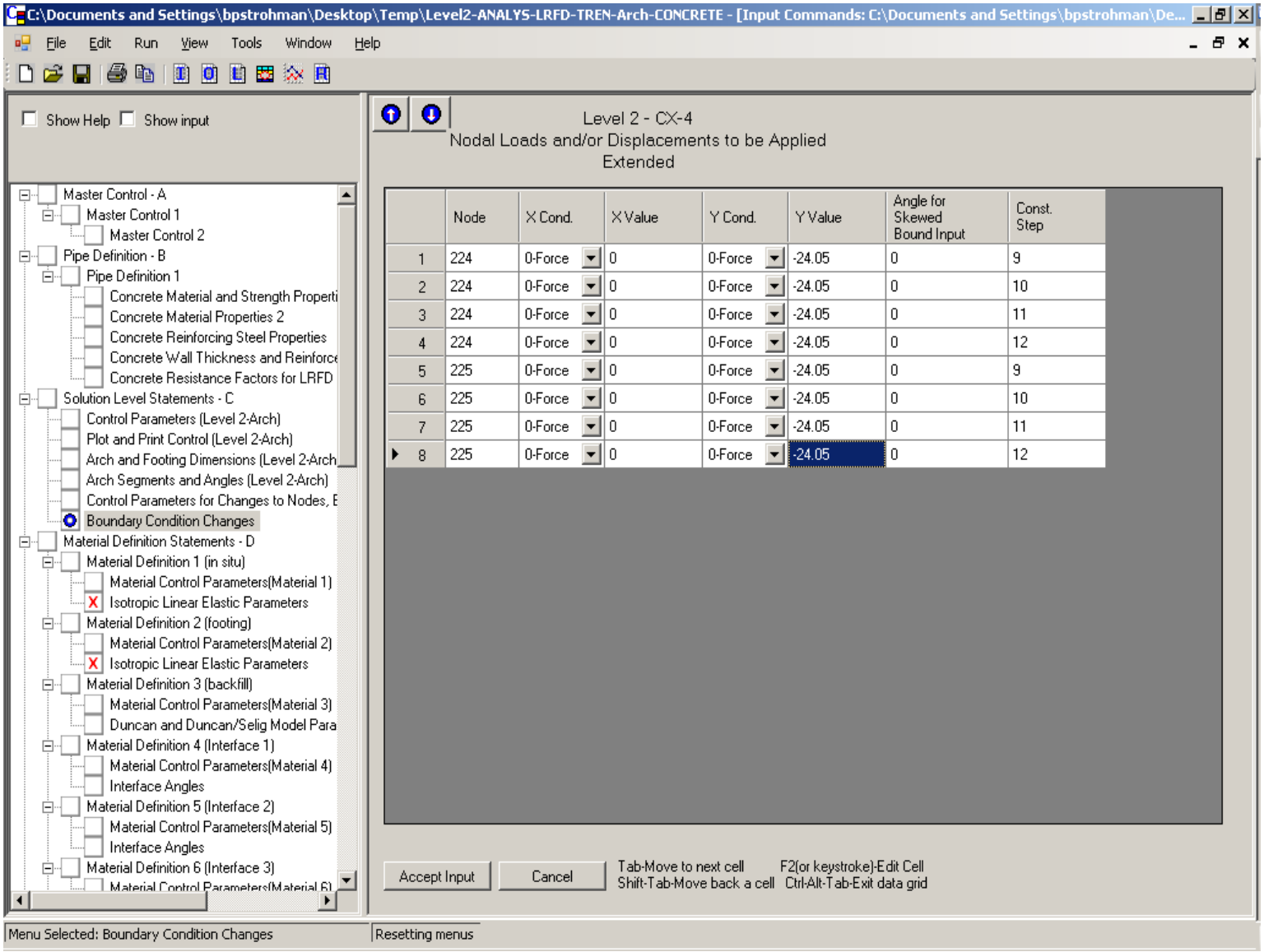


P6 – Screen B-3 - Reinforcement

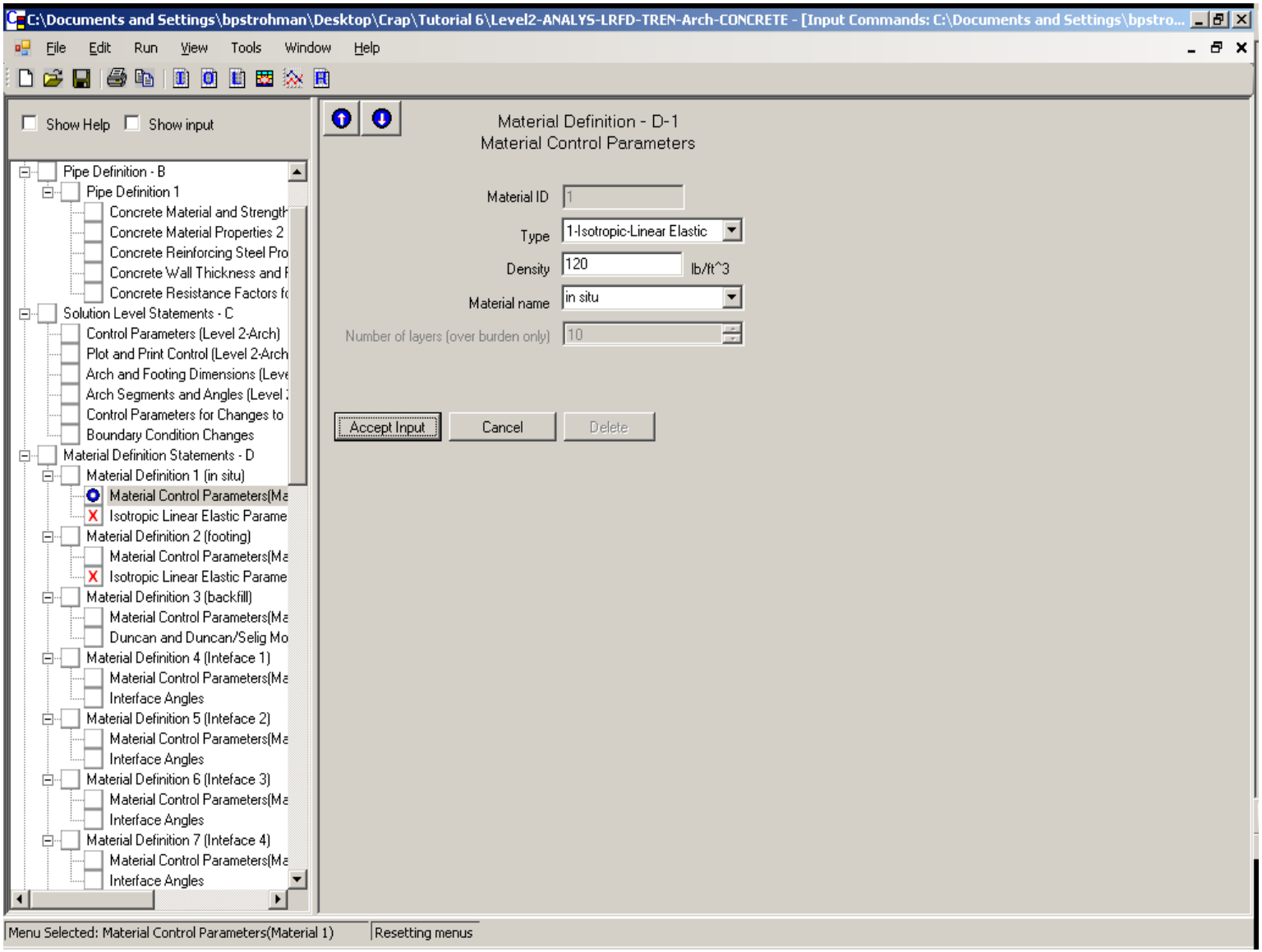


CANDE 2007 Does not include the current crack control equation for box sections. The Heger McGrath method is more conservative and generally does not control design.

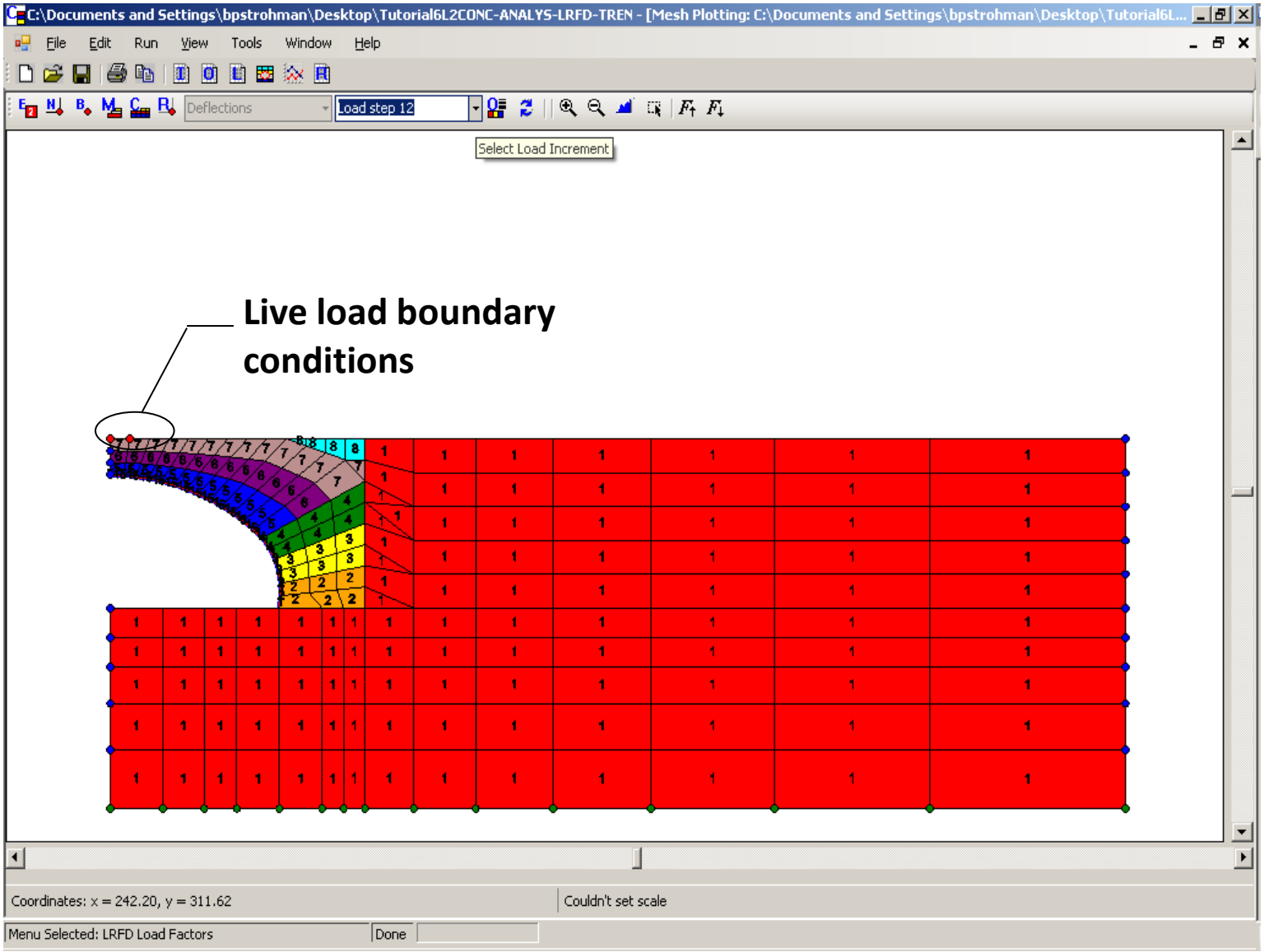
P6 – Screen CX-4 – Boundary Conditions (LL)



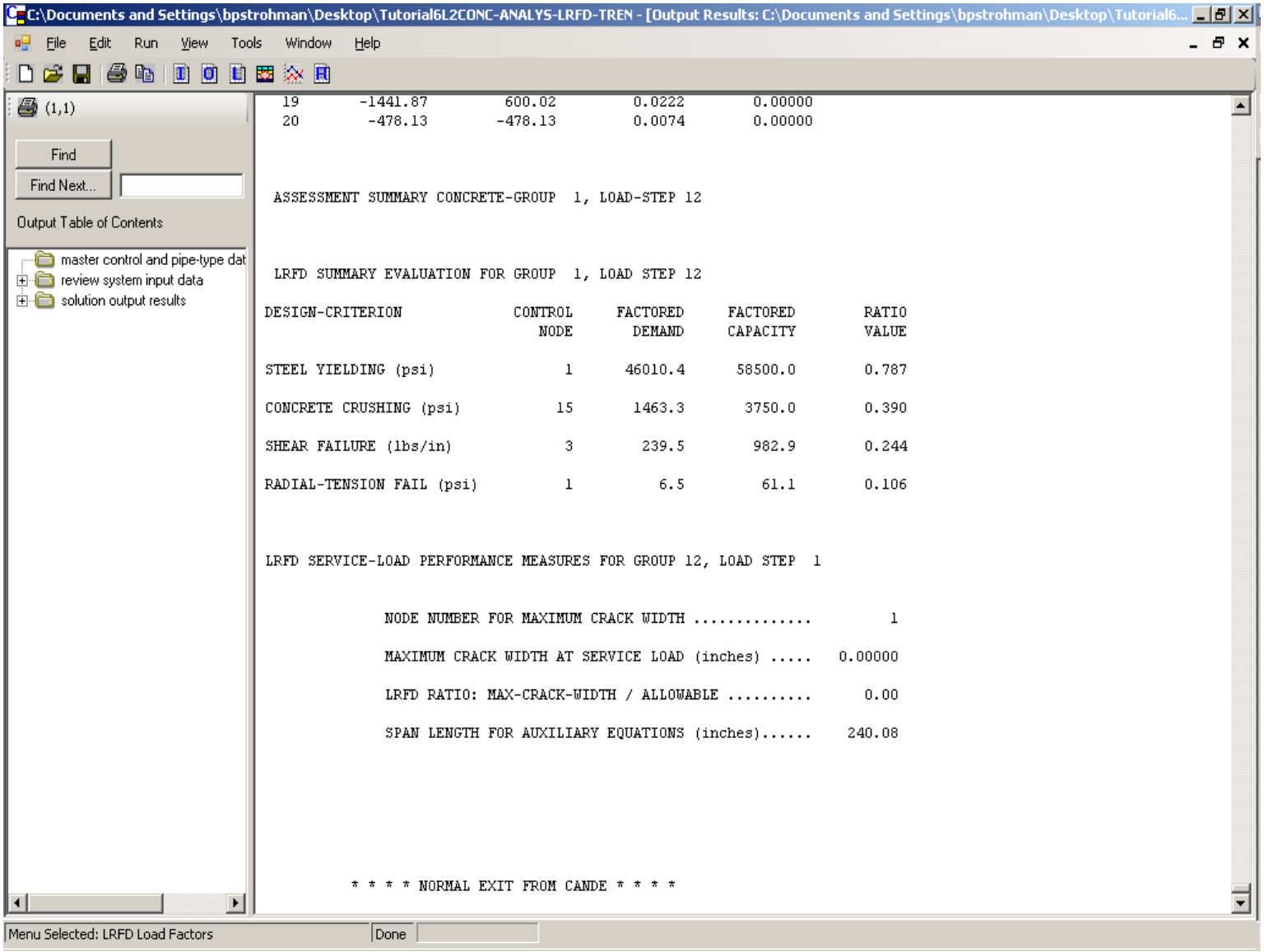
P6 – Screen D-1 – Soil Definition



P6 – Mesh, Soil Zones, and Load Increments



P6 – Output Design Assesment



Up Next –

Tim Toliver

CANDE 2007

(Culvert ANalysis and DEsign)

TRB Webinar

CANDE Overview

August 5, 2009

Presented by

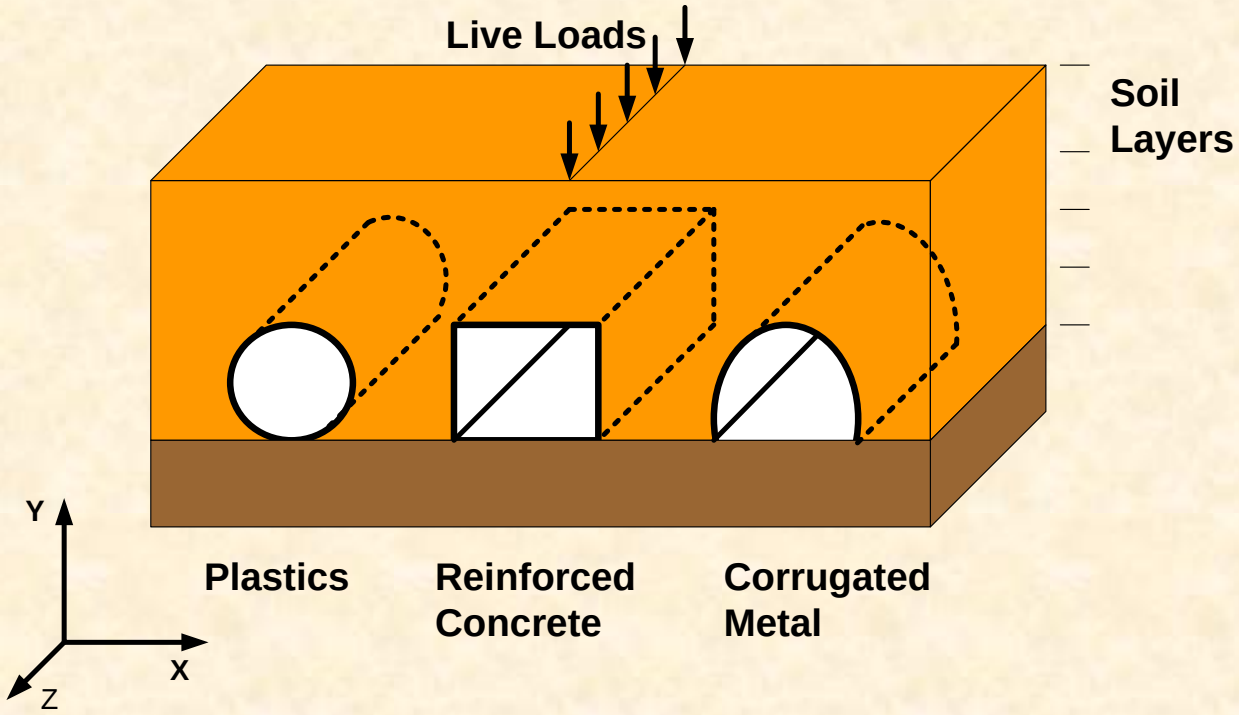
Mike Katona

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	• First release to culvert community • Mainframe computer required	FHWA
1980	• Incorporate Duncan Soil model • Improve r/concrete model • Add slotted joints for corrugated steel	FHWA
1989	• Develop PC version • Add Level 2 Arch • Improve Duncan/Selig soil model	FHWA
2007	• Graphical user interface for input/output • Large deformation and buckling prediction • Multiple pipe type capability (groups) • LRFD design criteria and methodology • Bandwidth minimizer	AASHTO • 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

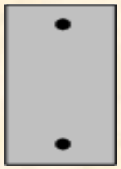
* Interpret experimental data from field and laboratory
* Test bed for new theoretical soil and pipe models

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
Corrugated Metal 	• **Thrust yielding** • **Buckling** • **Seam failure** • **Plastic hinging** • **Deflection limit**	Evaluate safety	Specify safety. Find corrugation size and gage
Reinforced Concrete 	• **Steel yielding** • **Concrete crush** • **Shear failure** • **Radial tension** • **Crack width**	Evaluate safety	Specify safety. Find steel areas.
Plastic 	• **Thrust yielding** • **Buckling** • **Combined strain** • **Tensile strain** • **Deflection**	Evaluate safety	Specify safety. Find thickness.

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

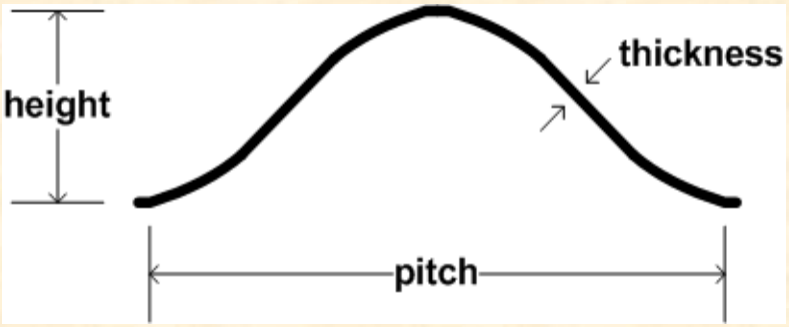
- **Corrugated Metal (Aluminum or Steel)**
- **Reinforced Concrete**
- **Thermoplastic**
- **Basic (generic)**

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 (in^2/inch)
PI = Moment inertia (in^4/inch)
PS = Section mod. (in^3/inch)

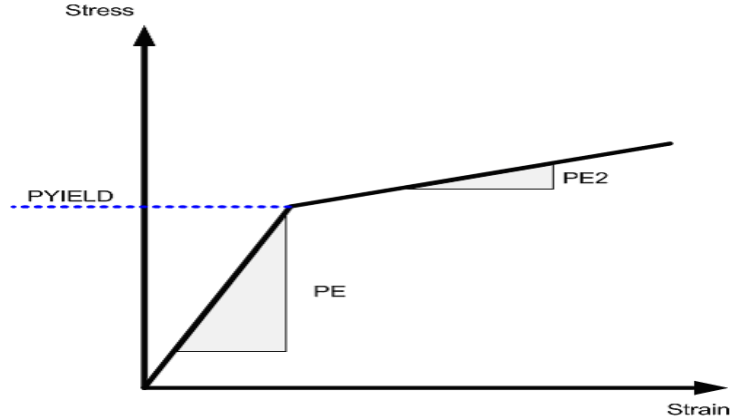
Standard corrugation sizes, pitch-x-height (inch-x-inch)

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

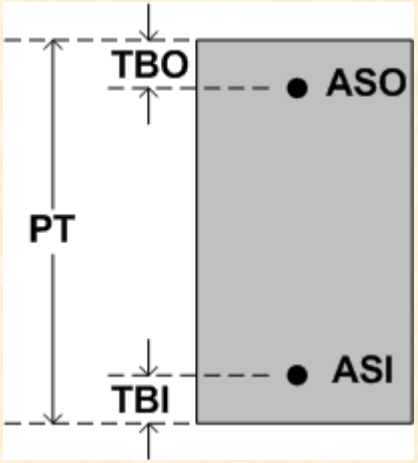
- **Bi-linear stress-strain response**
- **Elastic unloading from plastic**
- **Identical in compression/tension**



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 --



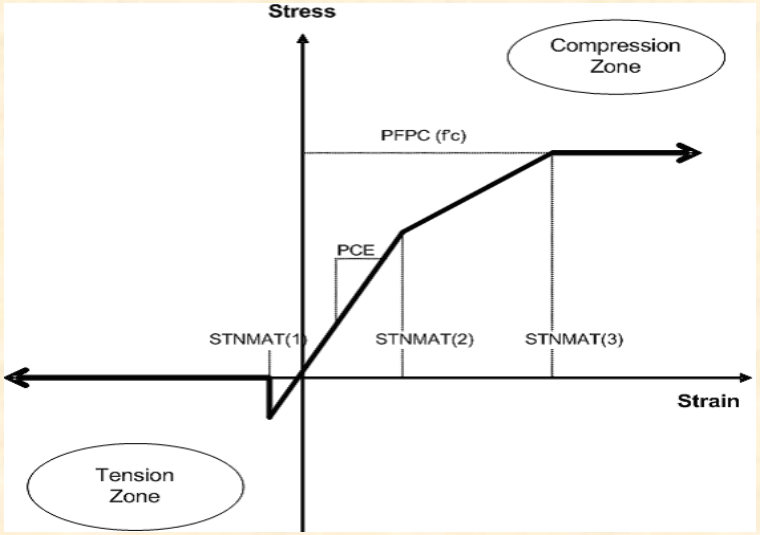
PT = Concrete wall thickness (inches)
ASI = Inner wall steel area (in^2/inch)
ASO = Outer wall steel area (in^2/inch)
TBI = Concrete cover to c.g. of ASI (inches)
TBO = Concrete cover to c.g. of ASO (inches)

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

-- CONCRETE MATERIAL --

Concrete stress-strain model

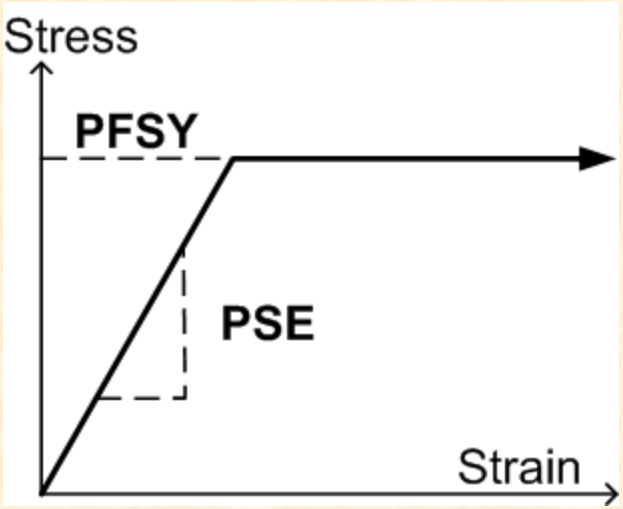
- **Abrupt tensile cracking with tensile stress release and no subsequent healing.**
- **Tri-linear compression curve becomes fully plastic at compressive strength limit.**
- **Elastic unloading from plastic zones.**



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

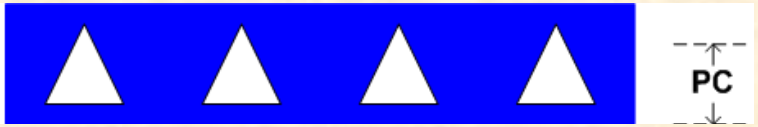
- **Elastic-perfectly-plastic model**
- **Identical in tension and compression**
- **PSE = Elastic modulus (29,000 ksi)**
- **PFSY = Yield strength (60 ksi)**

-- PLASTIC CROSS SECTIONS --

Solid Wall

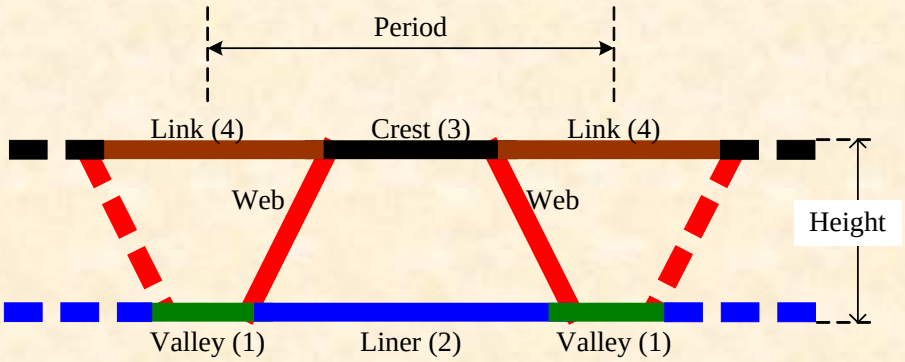
PT = Wall height (in)

General Wall



- **PT and PC = Wall height and centroid (in)**
- **PA = Area (in^2/inch)**
- **PI = Moment inertia (in^4/inch)**

Profile Wall



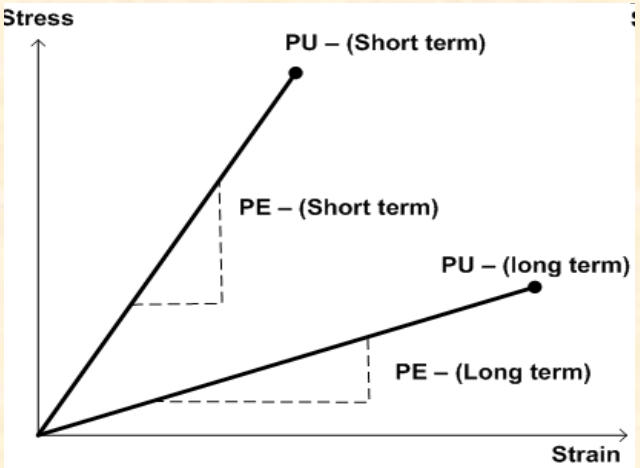
Profile Input Geometry

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**



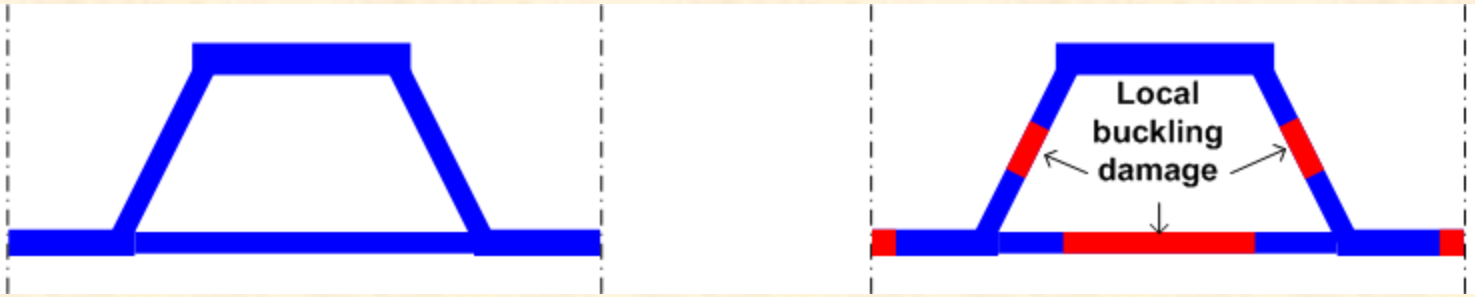
Default values for

- 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)

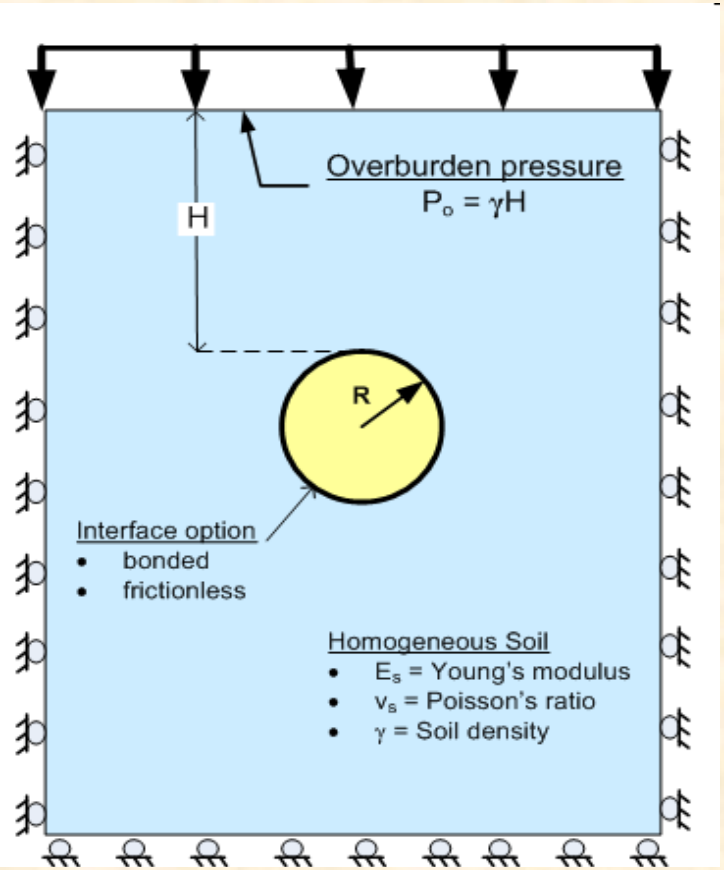
  Choices: (1) Pipe-mesh (2) Box-mesh (s) Arch-mesh

- **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:

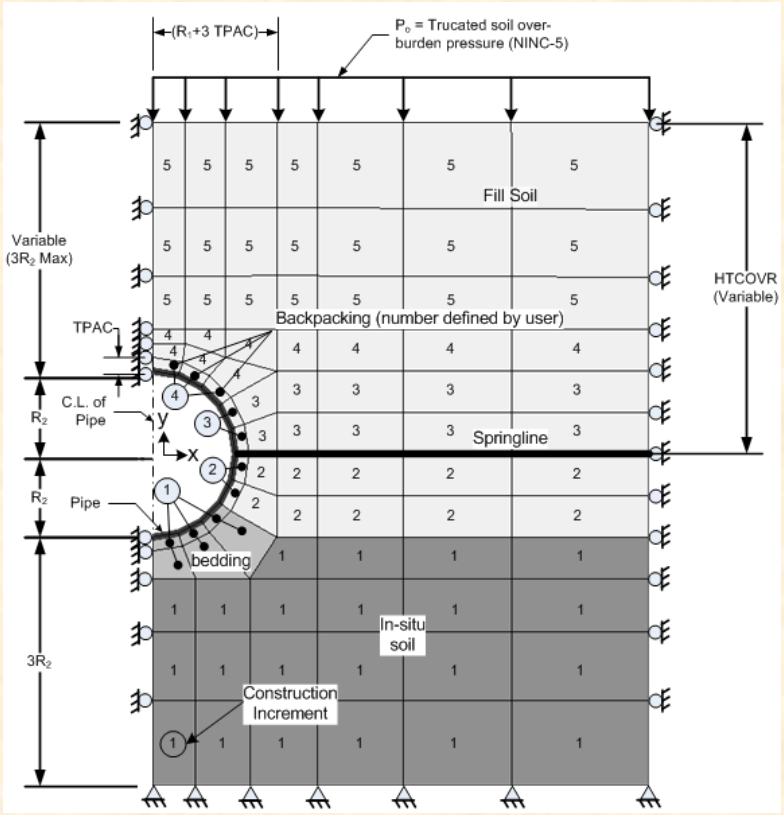
- **Pipe Mesh (circular or elliptical)**
- **Box Mesh (square or rectangular)**
- **Arch mesh (2-or-3 segments, curved or straight)**

Extended Level 2

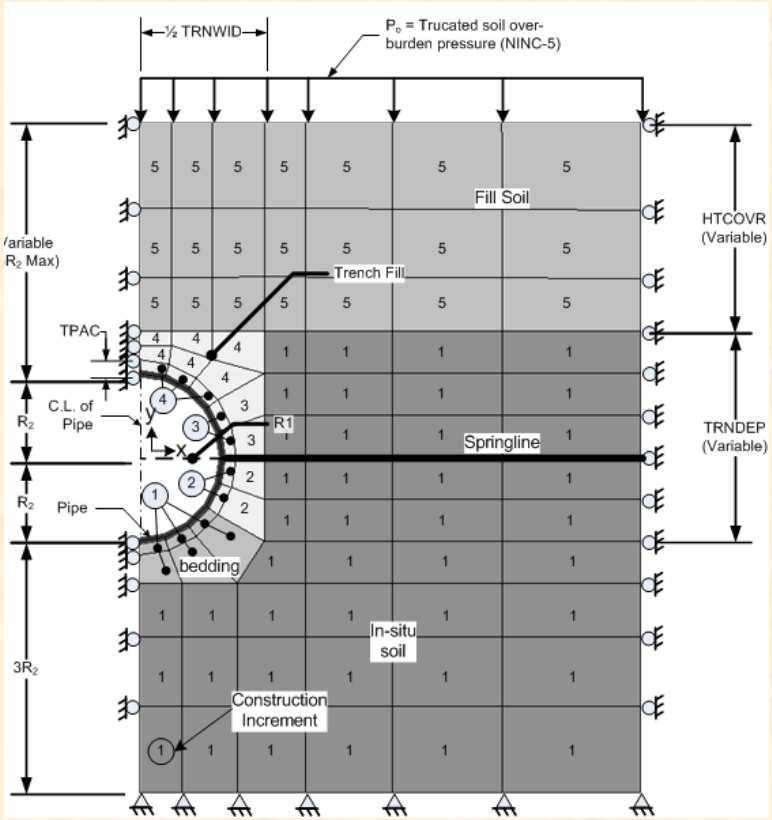
- **Adjust geometry**
- **Change material zones (e.g. create voids)**
- **Add live loads**

-- LEVEL 2 PIPE MESH --

Embankment mesh

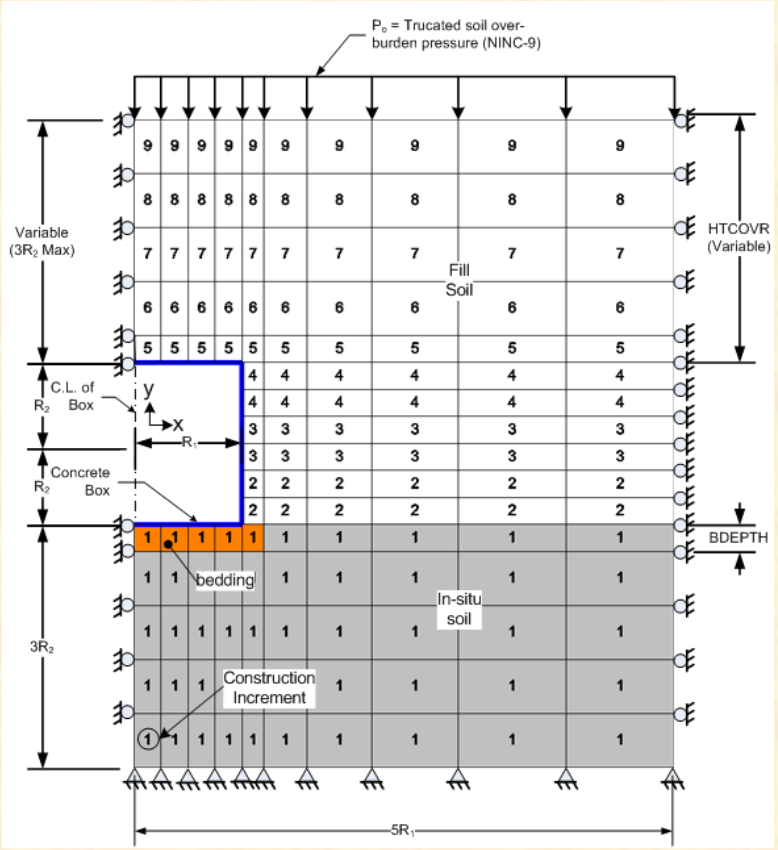


Trench mesh

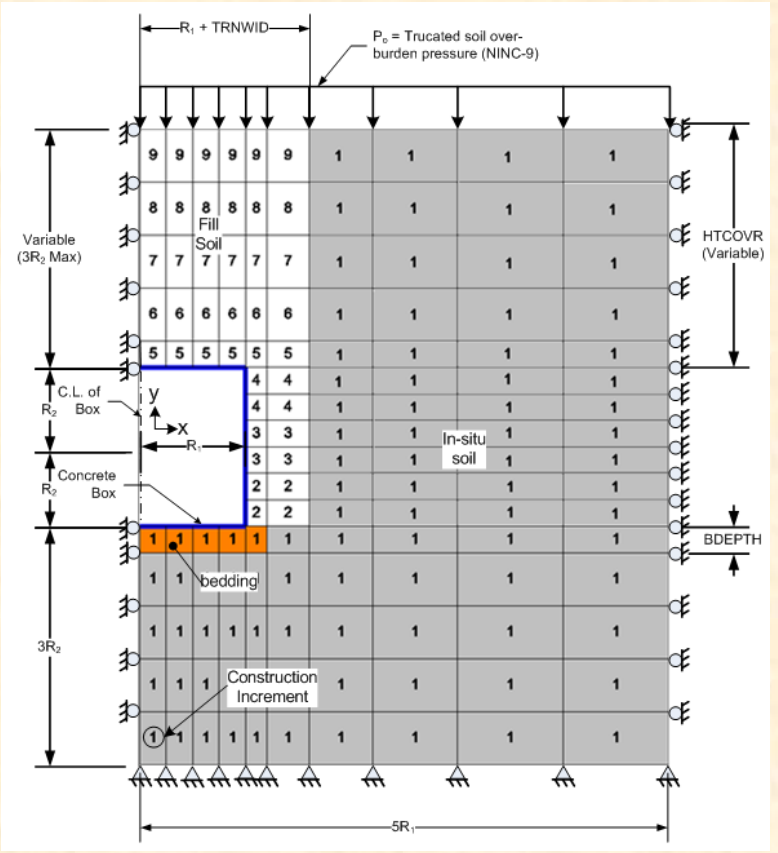


-- LEVEL 2 BOX MESH --

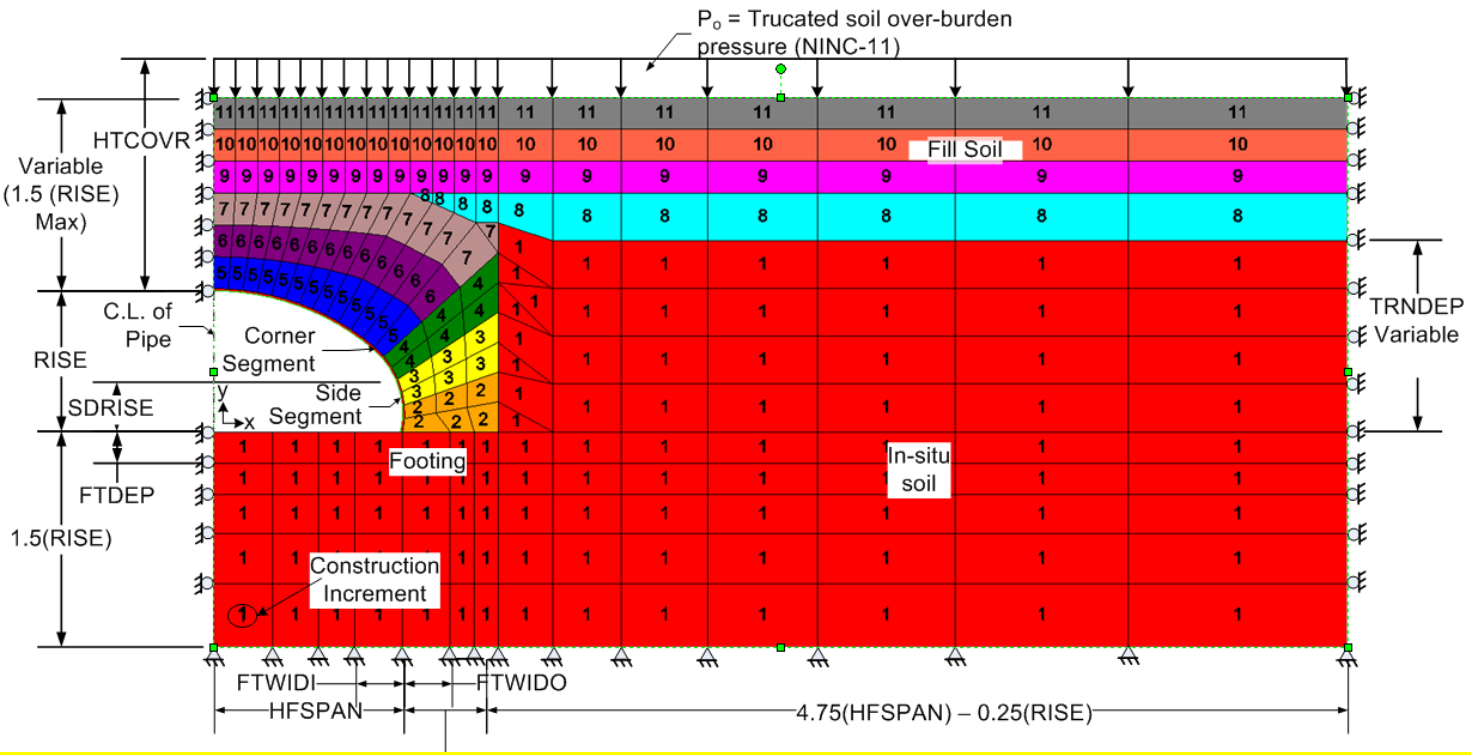
Embankment mesh



Trench mesh



-- LEVEL 2 ARCH MESH --



Choices: **(1) Embankment or trench installation**

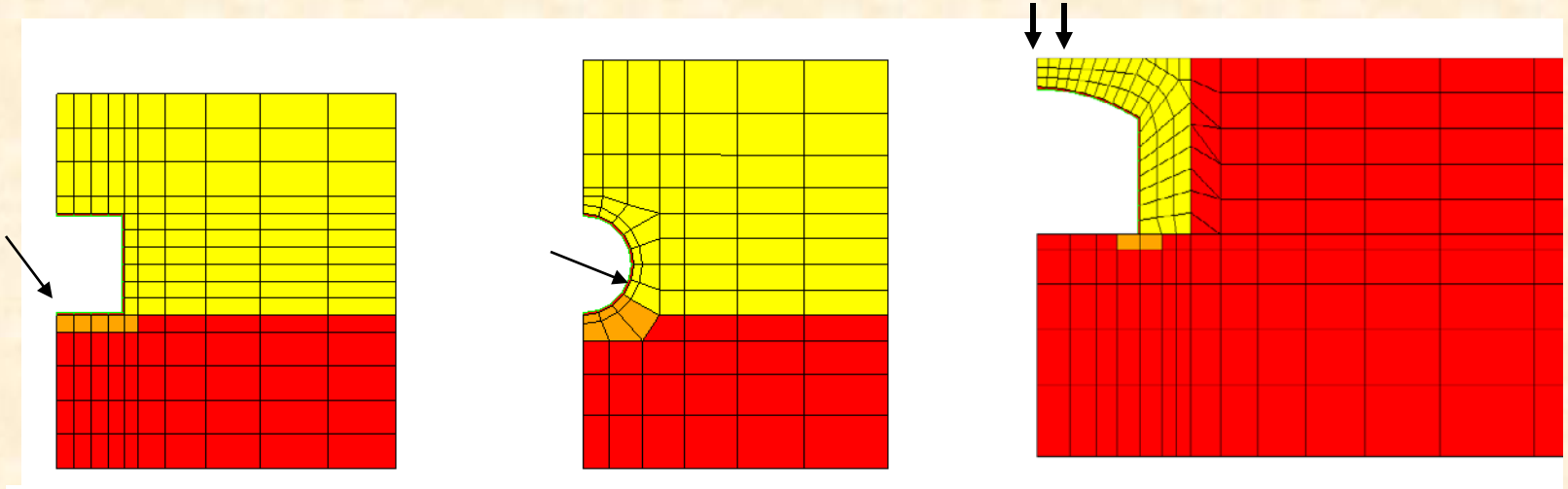
(2) Two segment or three segment arch shapes

(3) Straight or curved segments

-- LEVEL 2 EXTENDED --

For any Level 2 mesh configuration:

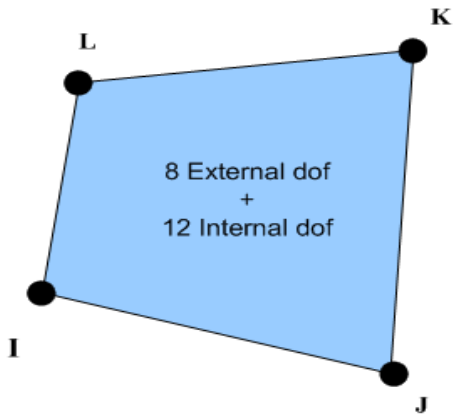
- **Change coordinates of nodes**
- **Change properties of elements**
- **Add or change boundary conditions**



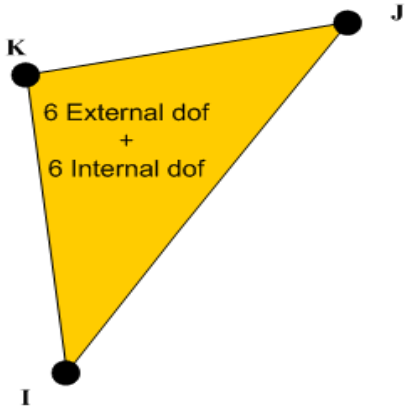
Change bedding shape **Change to soft void** **Add live load on surface**

-- LEVEL 3 BUILDING BLOCKS --

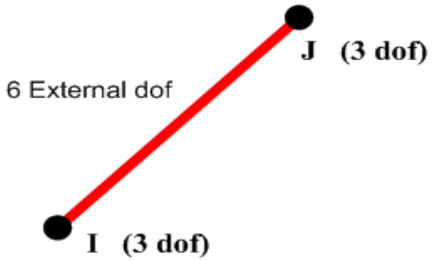
Quadrilateral



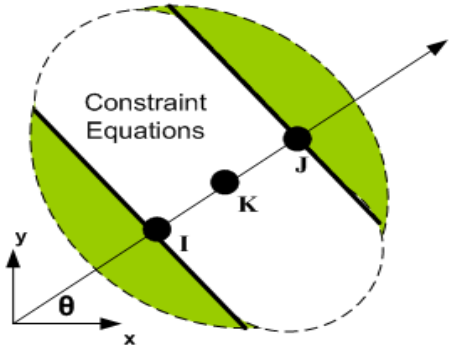
Triangle



Beam-Column



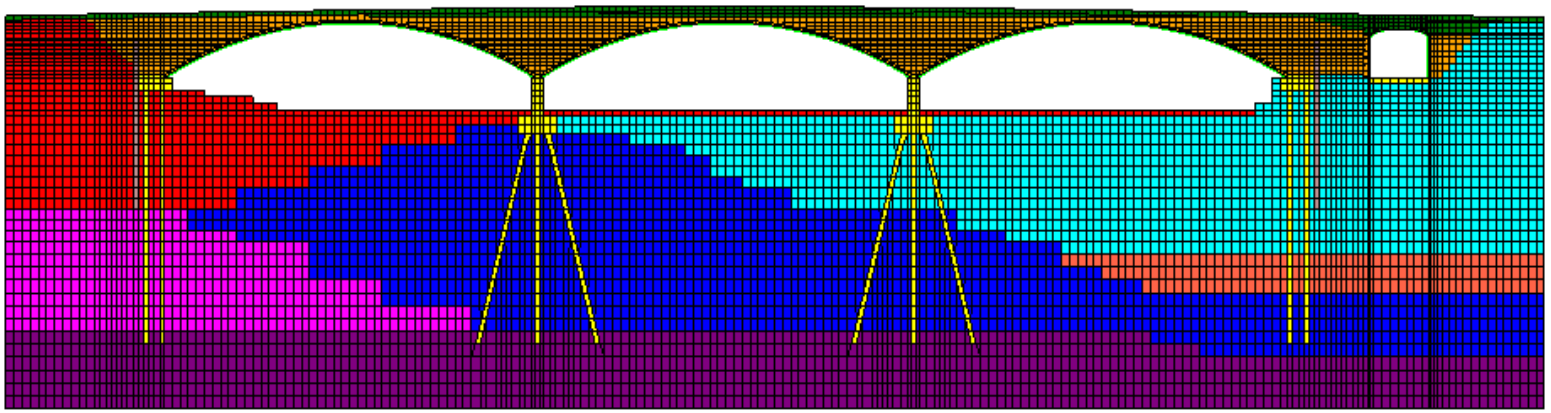
Interface



-- 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.

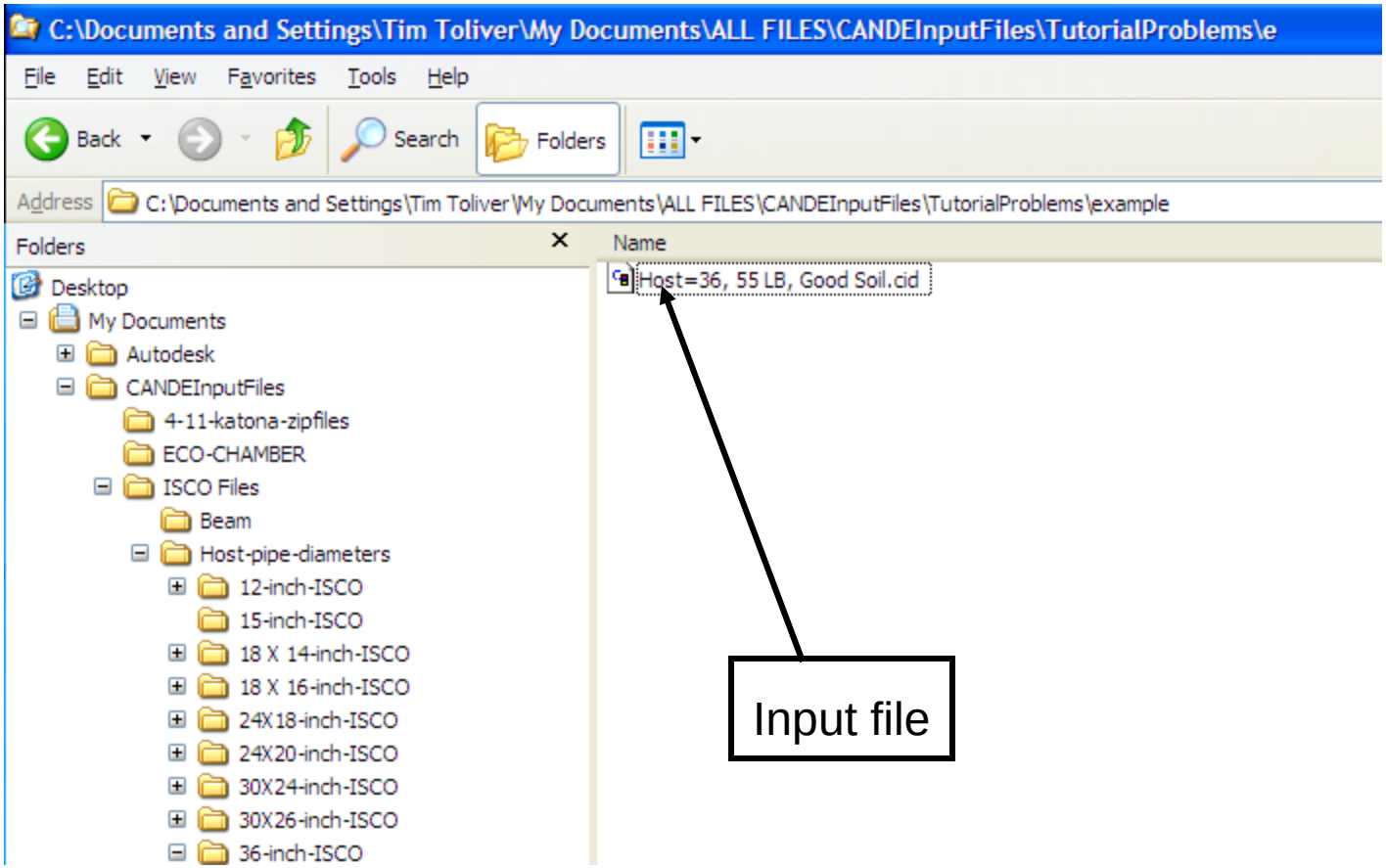
Six Cases Analyzed

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 + good grout	**Case 5** - Damaged host pipe + plastic liner + **good** grout
Case 3 - Damaged host pipe + plastic liner + **fair** grout	**Case 6** - Damaged host pipe + plastic liner + **fair** 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

File Generation

Typically begin with one input file

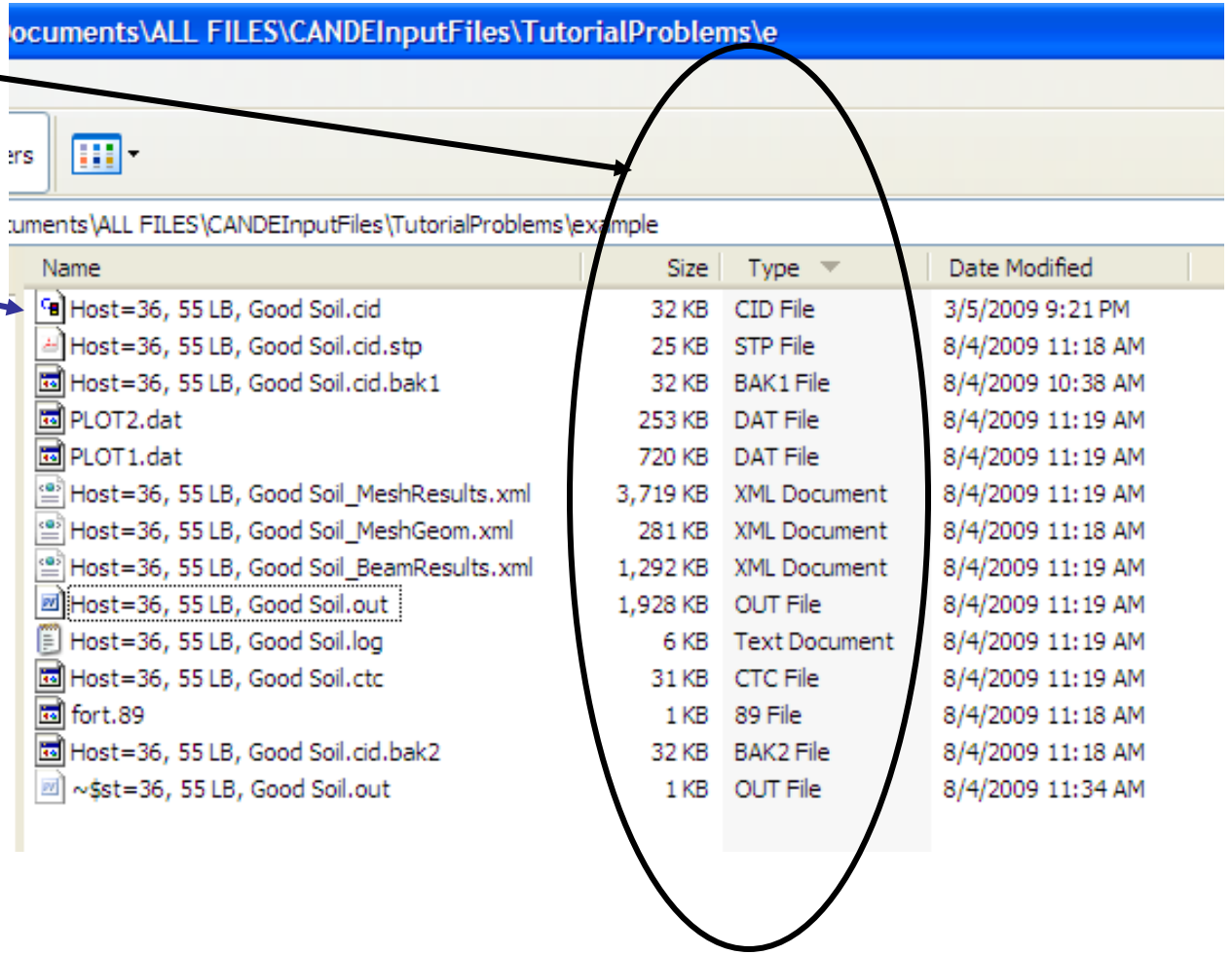


File Generation

New files after running input files

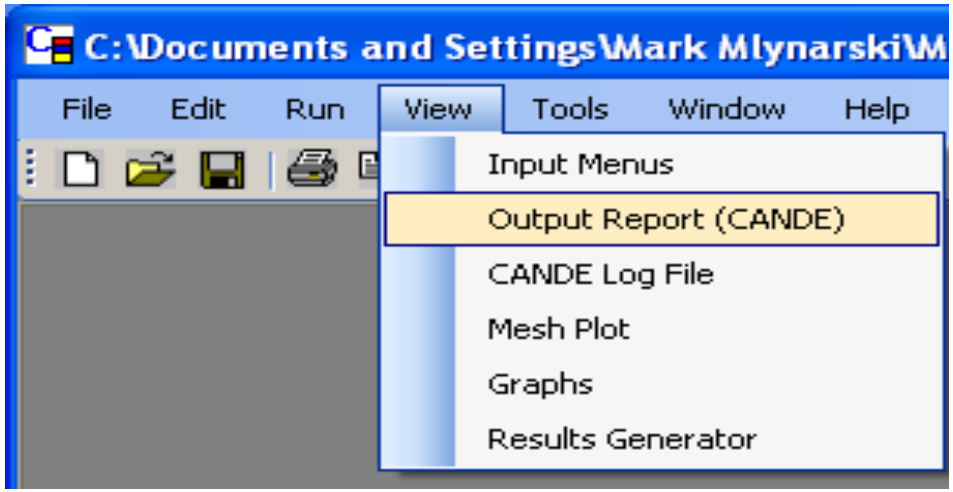
CID file is the input file and most critical.

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



OUTPUT AND GUI

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

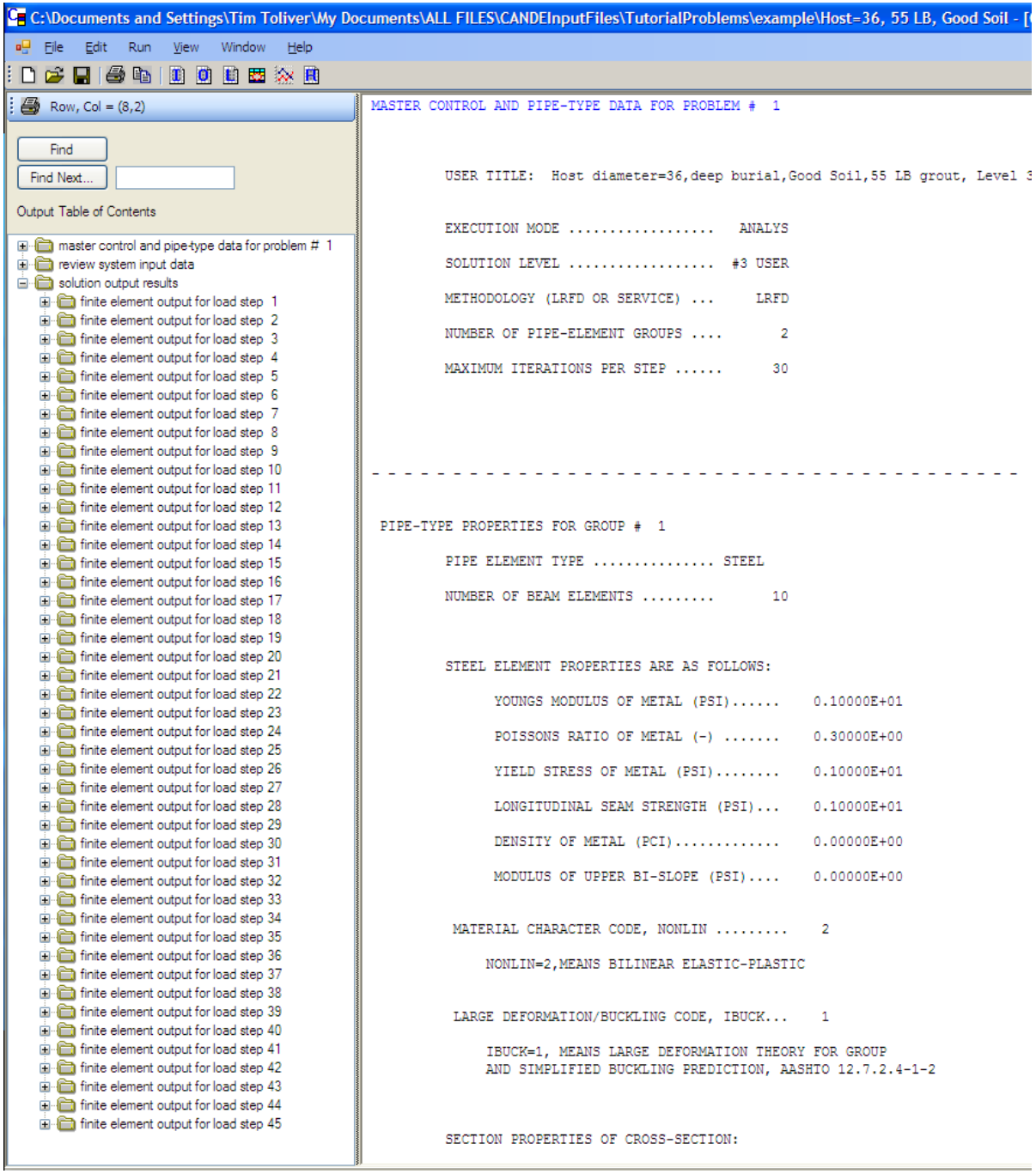


Key Selection Choices

- **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

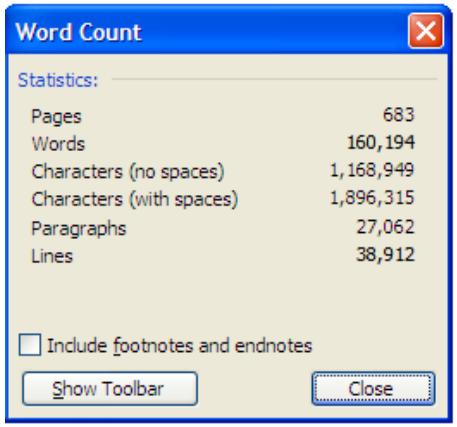
OUTPUT REPORT CANDE

- **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**



Output Report

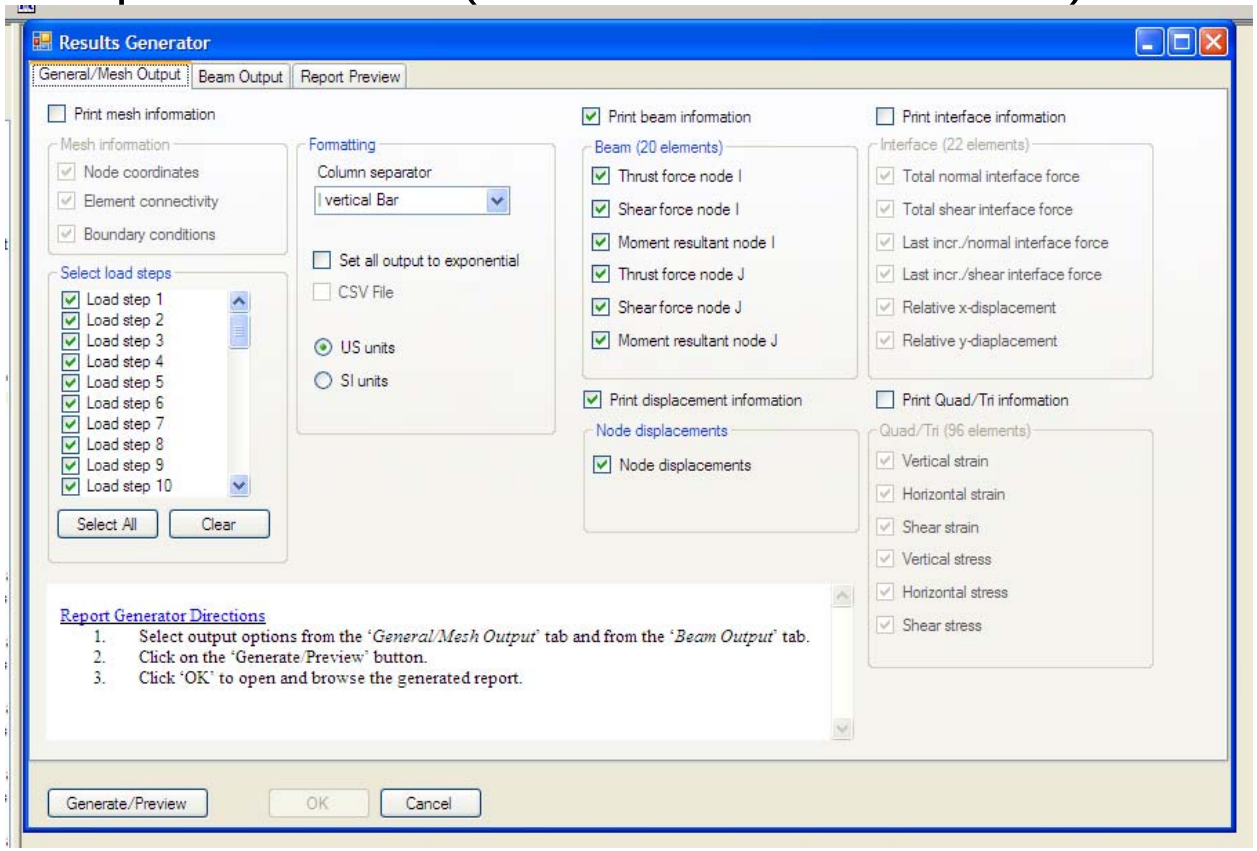
- The .OUTfile is a word compatible file.
- The .OUTfile can get very large
- The preceding example had:
  - 683 pages
  - 38,912 lines of text
  - 1,168,949 characters of text



- 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).



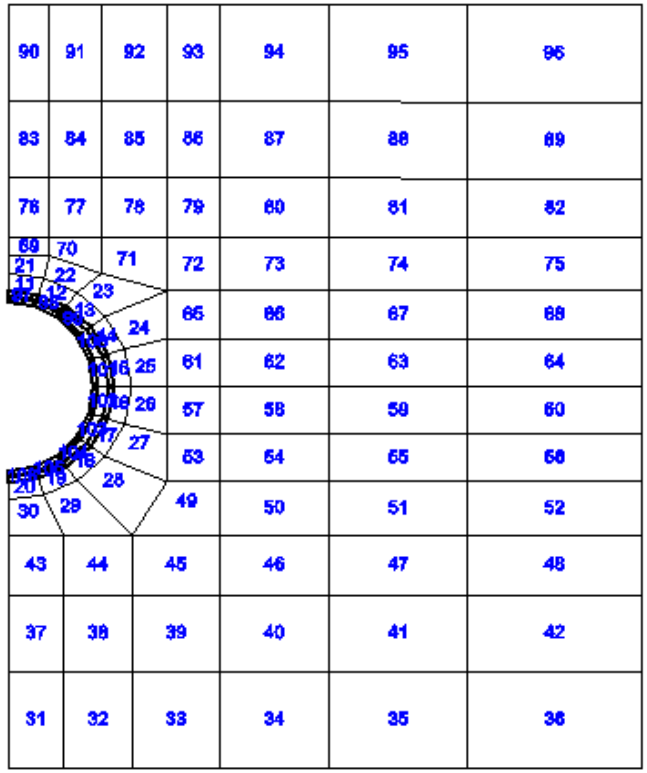
Customizing Report

- 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 -

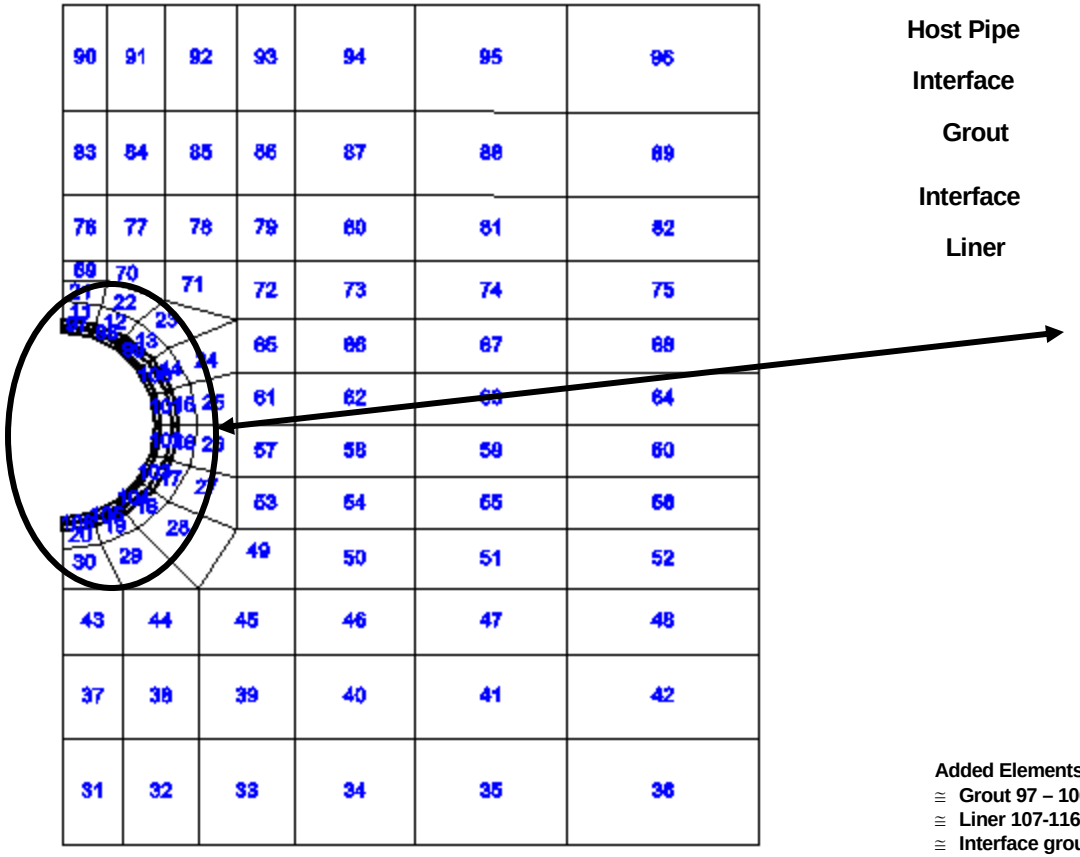
- **Plot nodes, elements, materials, construction increments, etc. can be plotted.**
  - Select View>Mesh Plot (from the CANDE Toolbar).

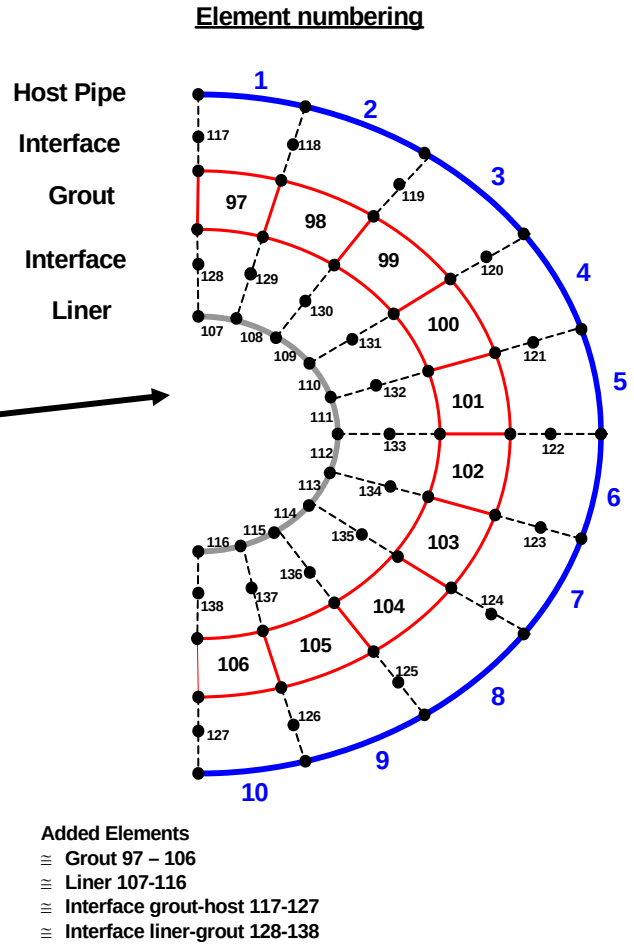
Element numbering



- 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.





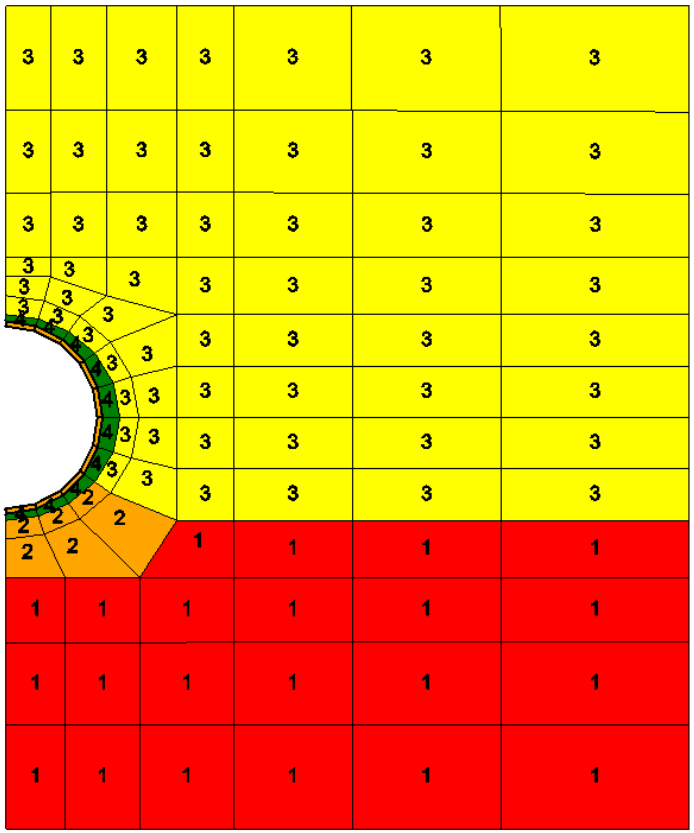
Added Elements

≅ **Grout 97 – 106**
≅ **Liner 107-116**
≅ **Interface grout-host 117-127**
≅ **Interface liner-grout 128-138**

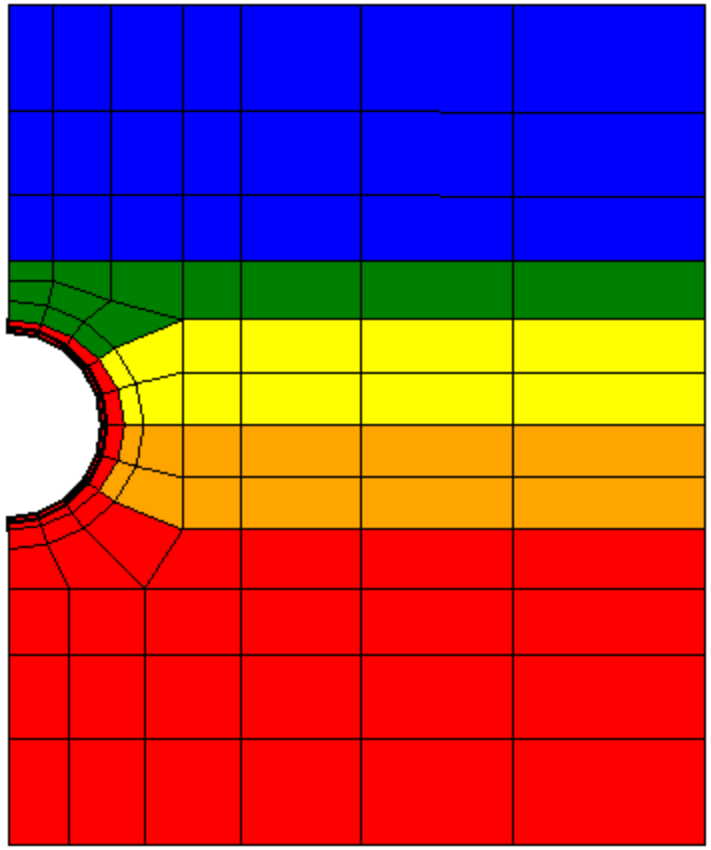
- MESH PLOT -

Other options include

Backfill Materials



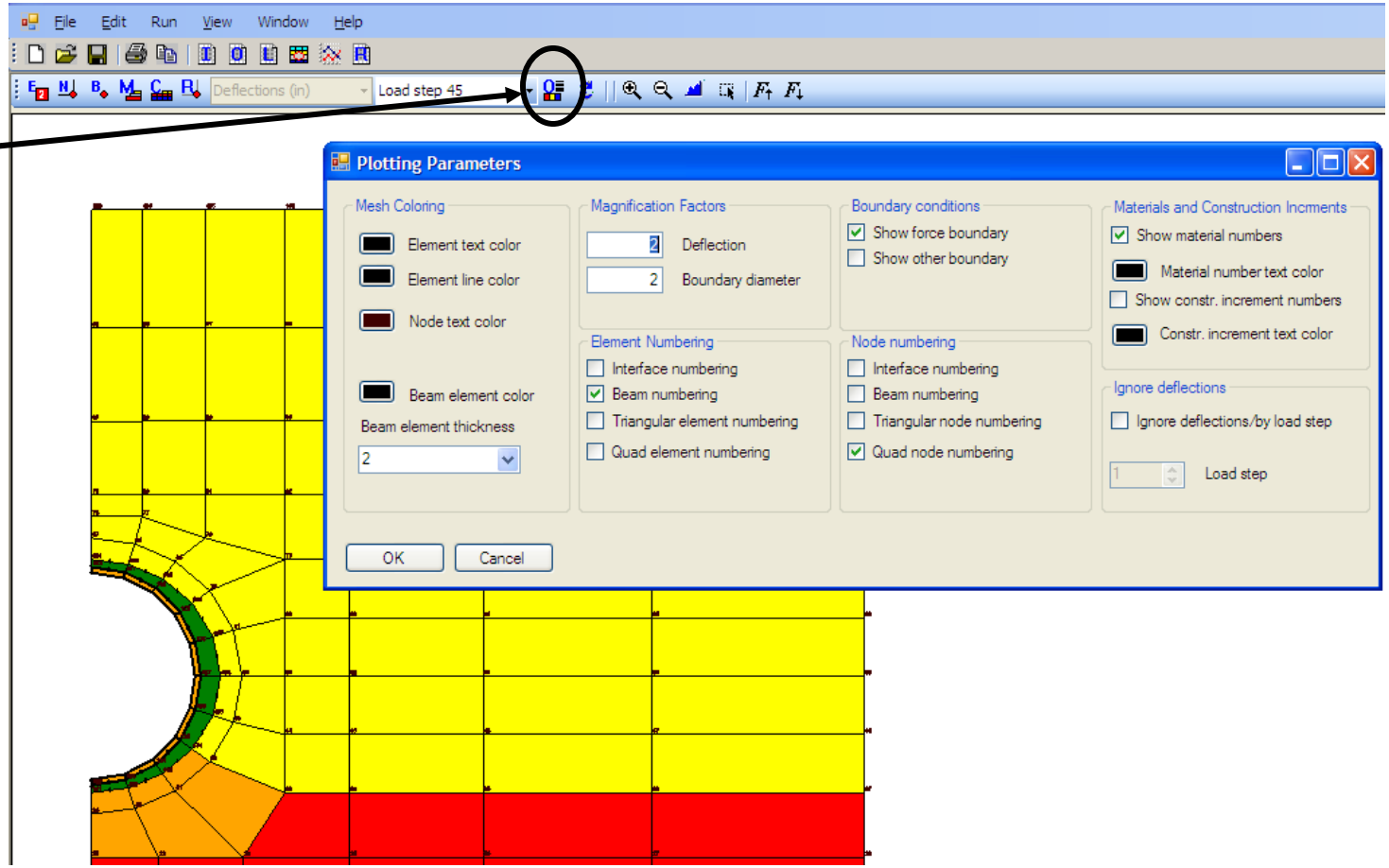
Construction Increments



Mesh Plot Output

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

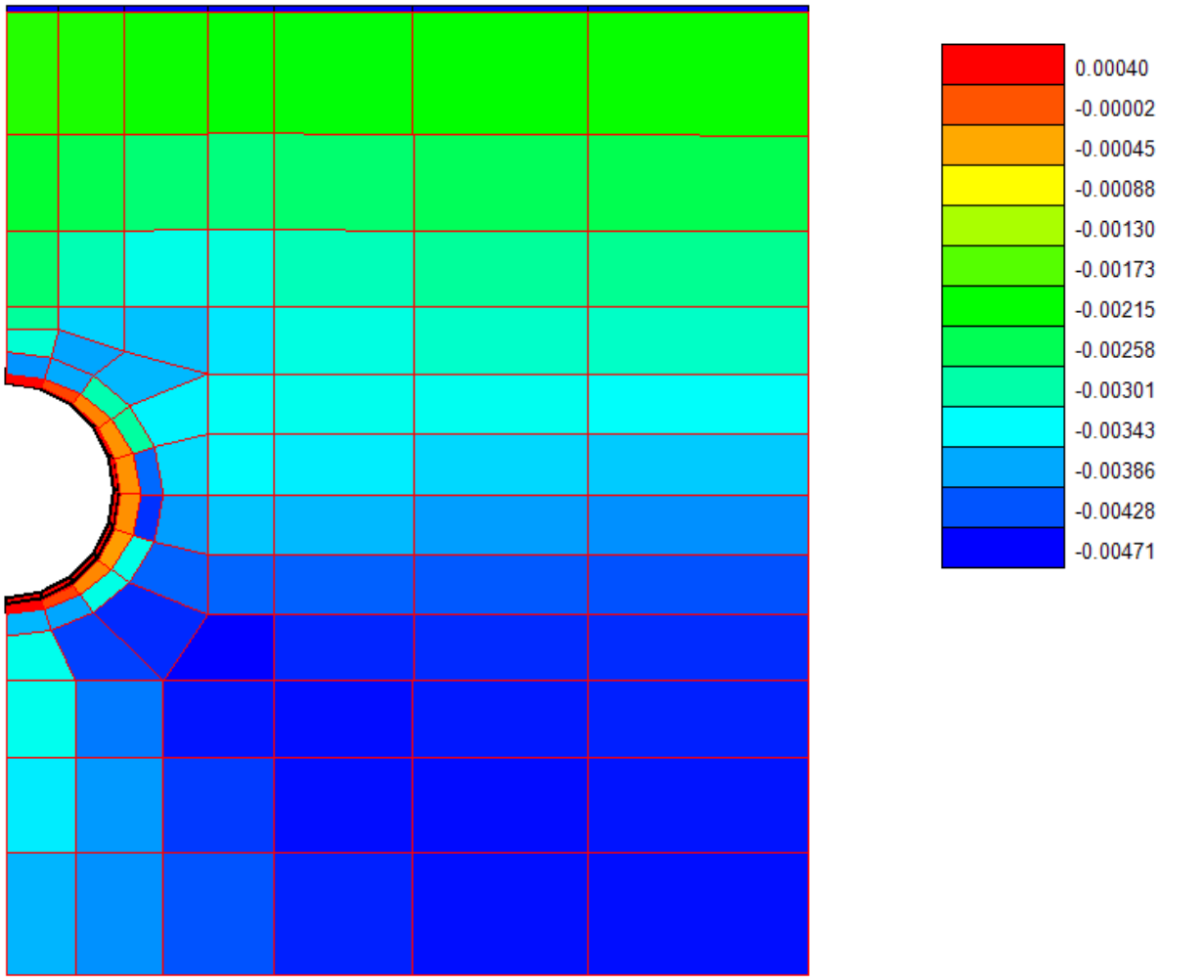
Mesh Viewer Options Button specifies plotting parameter



- MESH PLOT (output) -

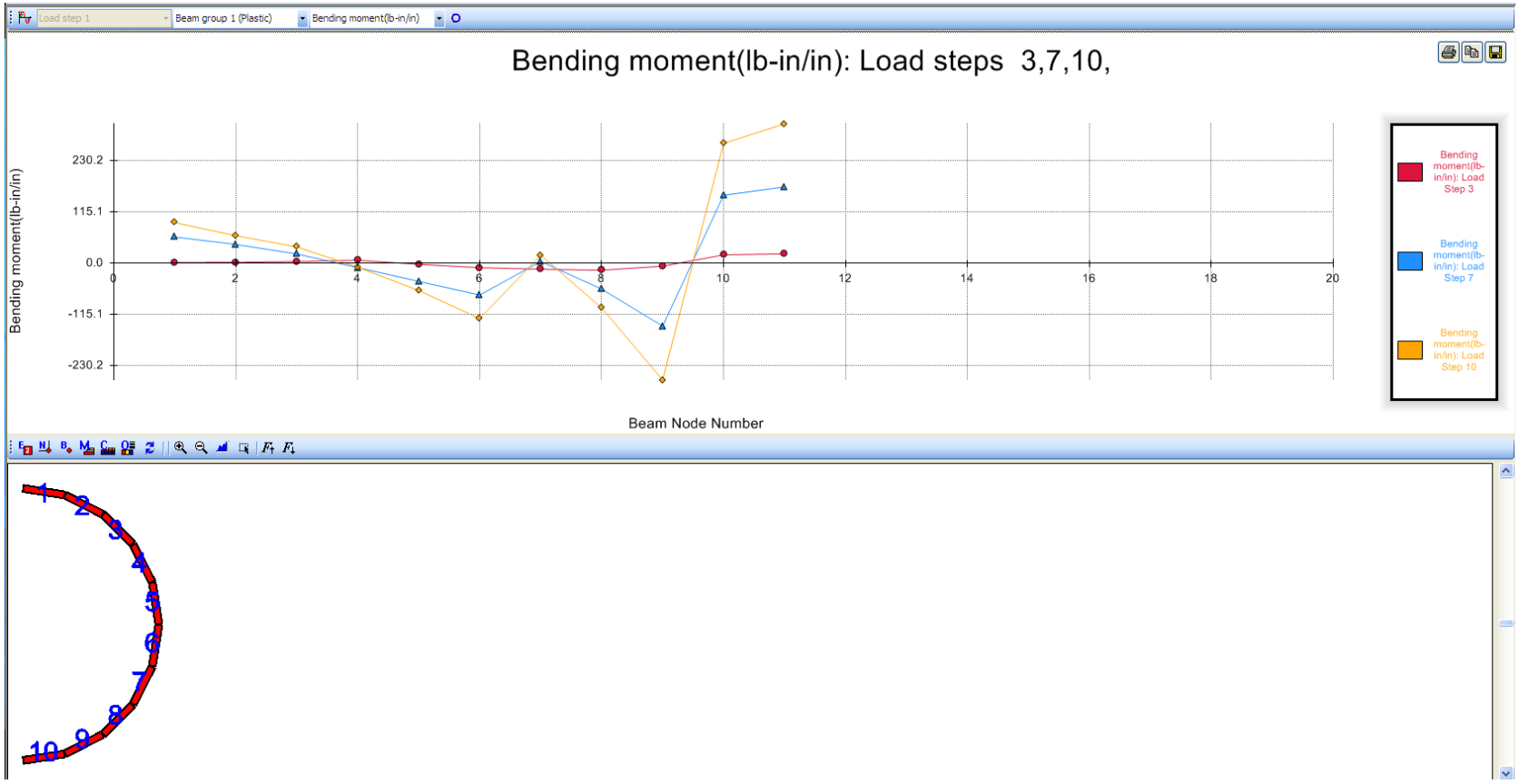
Plot stress/strain color contours (vertical, horizontal shear)

Vertical Strain

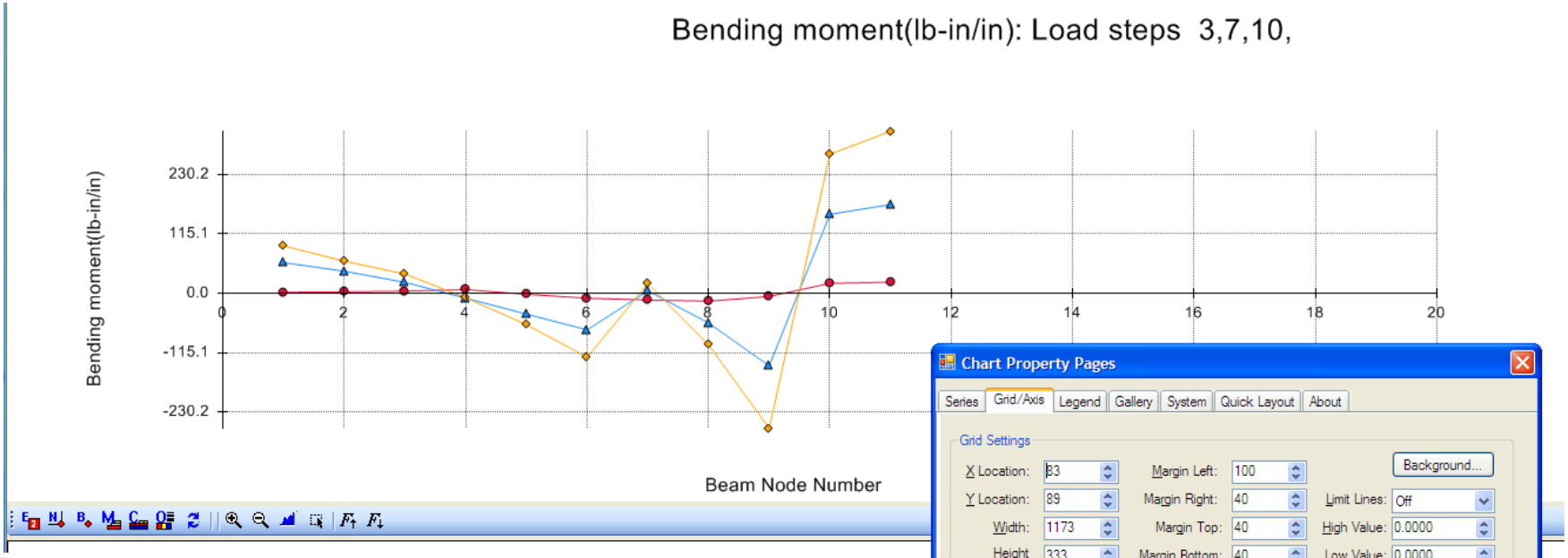


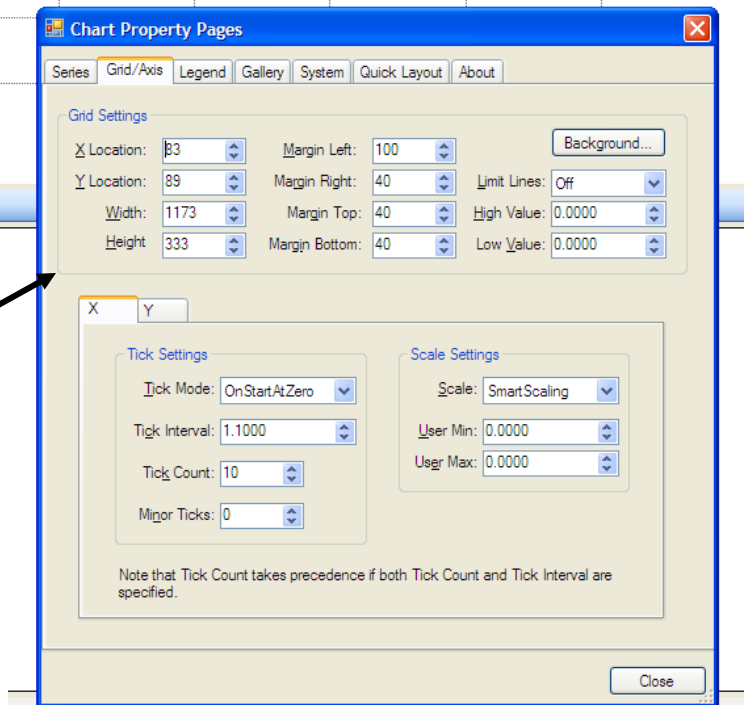
GRAPHS FOR PIPE GROUPS

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



Graph Properties Page





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.

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