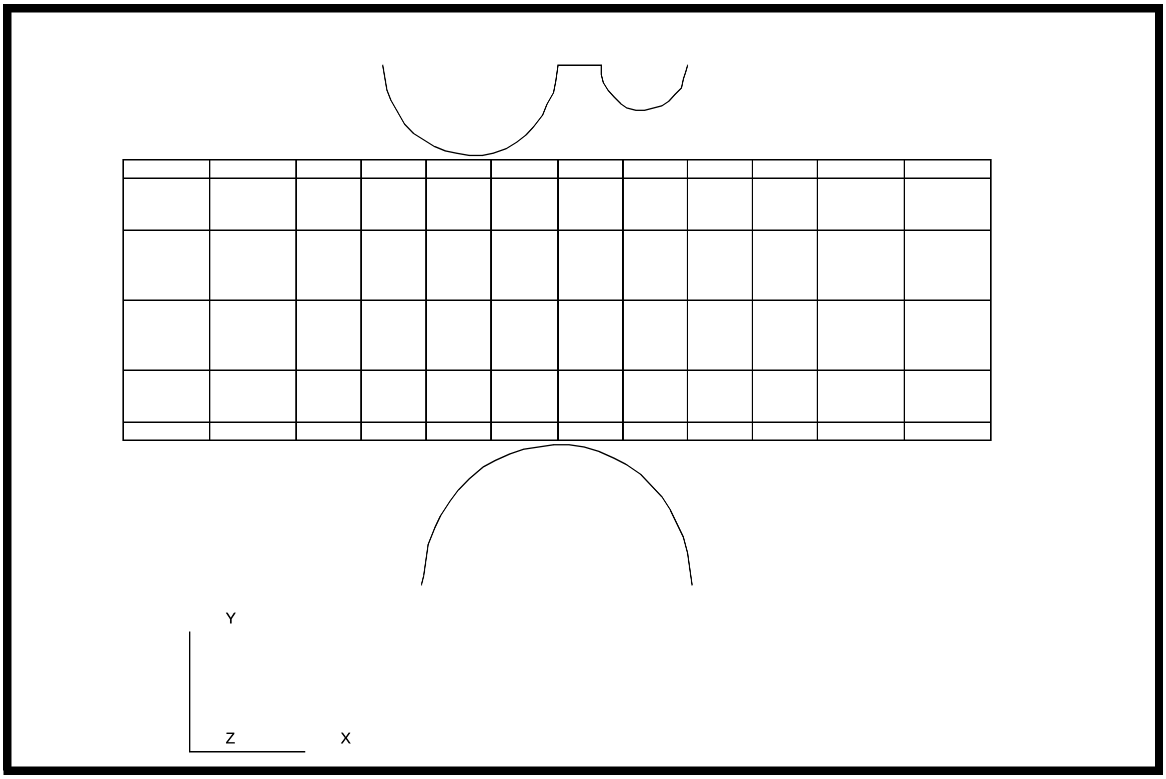
APPENDIX 3

Crushed Pipe II



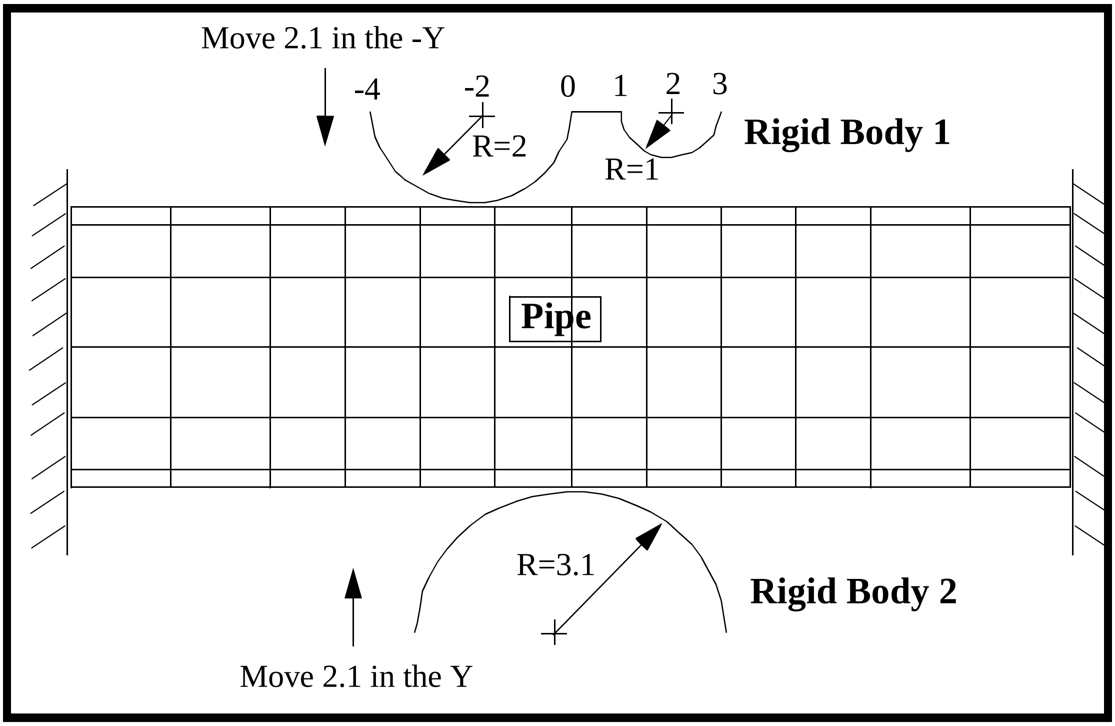
Objectives:

- Large displacement analysis.
- Rigid contact analysis using analytic rigid surfaces.
- Plasticity modeled with perfectly plastic material.

Model Description:

In this exercise, a symmetrical model of a cylindrical pipe is modeled as being crushed between two rigid bodies.

The model is created using 2D thin shell elements to model the pipe and Rigid Surface (Cylinder) elements to model the crushing rigid bodies. The pipe model will be covered with 2D Interface elements in order to model the contact between the pipe and the rigid bodies.



Data for Exercise:

Pipe Dimensions:	**D = 6.2** **Length = 20** **Thickness = 0.4**
Pipe Material:	**Steel, E = 30E6** **nu = 0.3** **Yield Stress = 45,000**
Mesh-	Rigid Body 1 and 2: 3D analytical **Pipe: S4R elements with IRS4 elements to contact rigid bodies**

Exercise Procedure:

1. Open a new database. Name it **crush2.db**.

File/New ...

Database Name: **crush2.db**

OK

Change the *Analysis Preference* to **MSC/ADVANCED_FEA**.

Analysis Code: **MSC/ADVANCED_FEA**

OK

2. Create a new group **geo_rigid**.

Group/Create ...

New Group Name: **geo_rigid**

■ **Make Current**

Group Contents: **Add Entity Selection**

Apply

Cancel

3. Create the model geometry.

◆ **Geometry**

Action: **Create**

Object: **Point**

Method: **XYZ**

Points Coordinates List: **[0, -6.3, 0]**

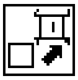
Apply

Create a second point by changing the *Point Coordinates List* to **[3.1, -6.3, 0]**.

Apply

4. Sweep point to make a curve for the lower rigid surface.

First, turn on the entity labels using the following toolbar icon:

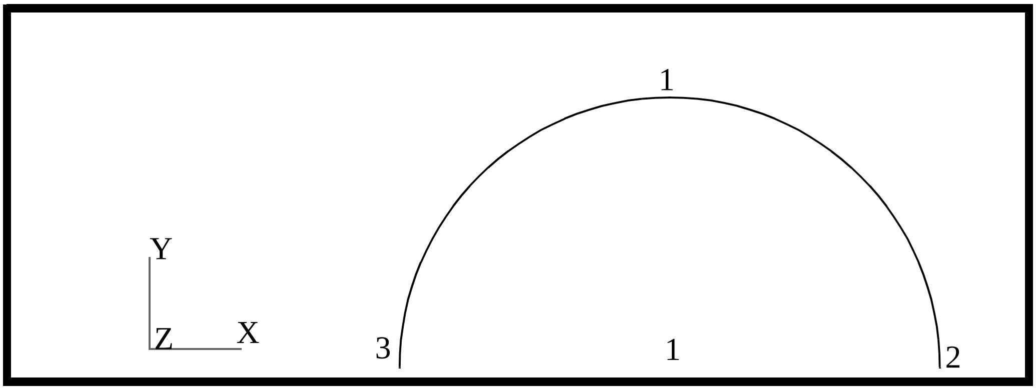

Show Labels

Action:	**Create**
Object:	**Curve**
Method:	**Revolve**
Axis:	**{Point 1[X1, Y1, 1.0]}**
Total Angle:	**180**
Point List:	**Point 2**

Apply

The screen should now display the points and curves as shown in Figure A2.1:

Figure A2.1 - Lower rigid surface



5. Create the geometric points for the upper rigid surface

◆ **Geometry**

Action:	**Create**
Object:	**Point**
Method:	**XYZ**
Points Coordinates List:	**[0, 5.2, 0]**

Apply

This will create **Point 4**

In a similar manner, create points 5, 6 and 7 using the **Create, Point, XYZ** option. The data for the transformations is given below.

Table 1: List of Points to Create

New Point	Point Coordinate List
5	**[-2.0, 5.2, 0]**
6	**[1.0, 5.2, 0]**
7	**[2.0, 5.2, 0]**

6. Create the curves for the upper rigid surface

Sweep Point 4 into an arc using:

Action:	**Create**
Object:	**Curve**
Method:	**Revolve**
Axis:	**{Point 5[X5, Y5, 1]}**
Total Angle:	**-180**
Point List:	**Point 4**

Apply

In a similar manner create a curve from **Point 6** using an *Axis* definition of **{Point 7[X7, Y7, 1]}**, a *Total Angle* of **180** and the *Point List* set to **Point 6**.

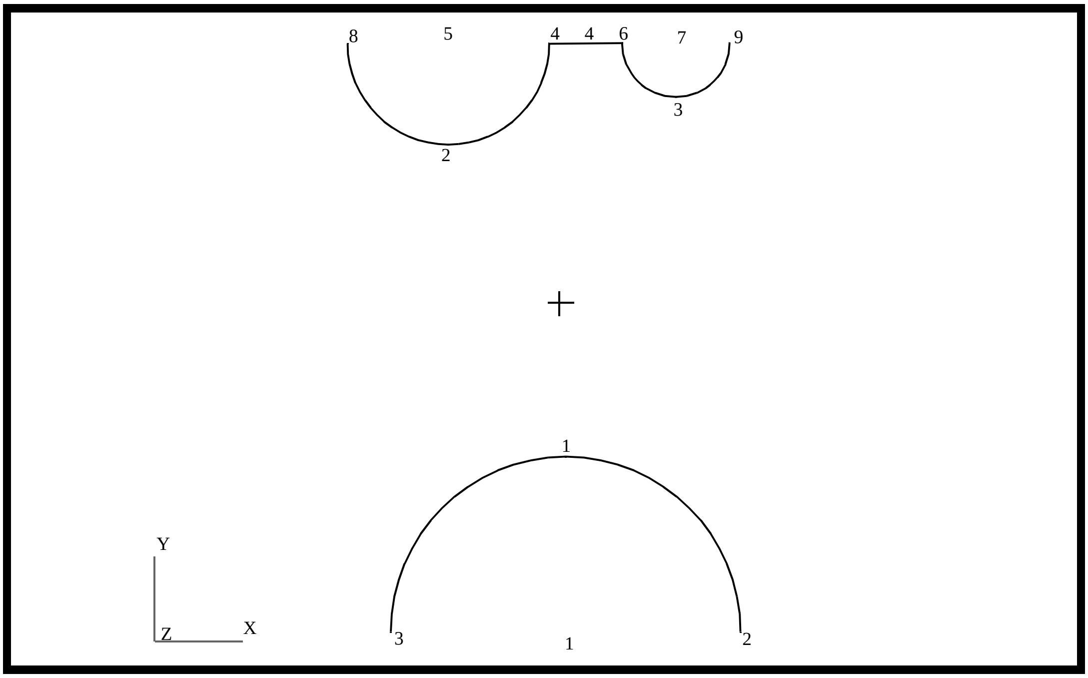
Connect the two half circles with a straight line by using

Action:	**Create**
Object:	**Curve**
Method:	**Point**
Options:	**2 Point**
Starting Point List:	**Point 4**
Ending Point List:	**Point 6**

Apply

This ends the definition of the geometry of the upper and lower rigid bodies. The screen should now show the points and curves displayed in Figure A2.2:

Figure A2.2 - Upper and lower rigid bodies



7. Create a new group **geo_pipe**.

Group/Create ...

New Group Name: **geo_pipe**

■ **Make Current**

Group Contents: **Add Entity Selection**

Apply

Cancel

8. Create the geometric points for the Pipe model.

◆ **Geometry**

Action: **Create**

Object: **Point**

Method: **XYZ**

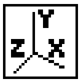
Points Coordinates List: **[-10, 0, 0]**

Apply

In a similar manner, using the **Create, Point, XYZ** method to create Point 11 by changing the *Point Coordinates List* to **[-10, 3.1, 0]**.

9. Create the surfaces for the pipe model

First, change to the isometric view by clicking on the following icon in the toolbar.



Iso 1 View

Sweep **Point 11** into two arcs

Action: **Create**

Object: **Curve**

Method: **Revolve**

■ **Patran 2 Convention**

Axis: **{Point 10[1, Y10, Z10]}**

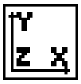
Total Angle: **180**

Curves per Point: **2**

Point List: **Point 11**

Apply

Change the viewport to **Front View**, using the following toolbar icon:



Front View

Sweep **Curves 5** and **6** into two surfaces

Action: **Create**

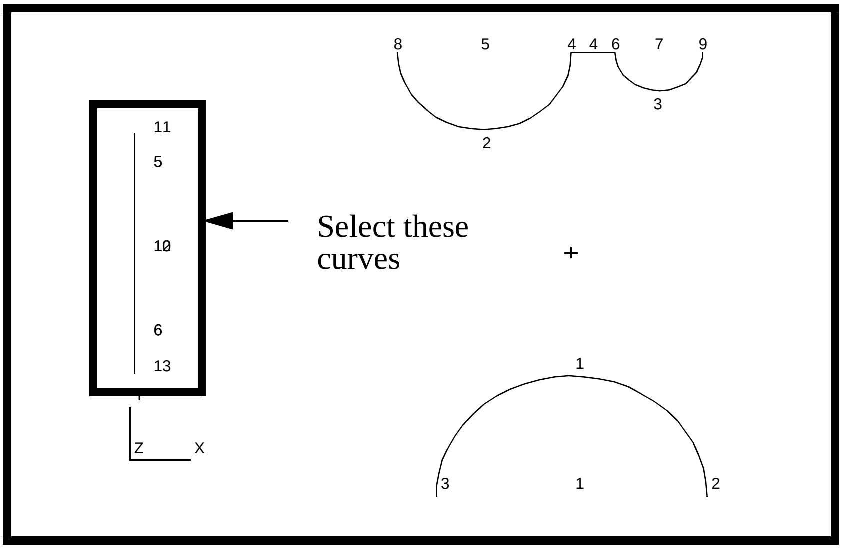
Object: **Surface**

Method: **Extrude**

Translation Vector:	**<4, 0, 0>**
Curve List:	see Figure A2.3

Apply

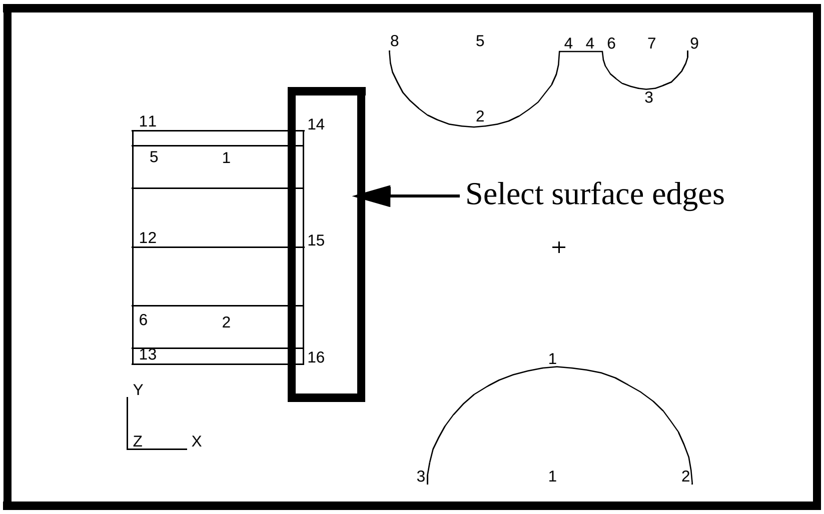
Figure A2.3 - Curves to sweep into pipe surface



In a similar manner, create two more surfaces from the right edges of Surfaces 1 and 2 using a *Translation Vector* of **<12, 0, 0>**.

Select the surface edges as shown in Figure A2.4:

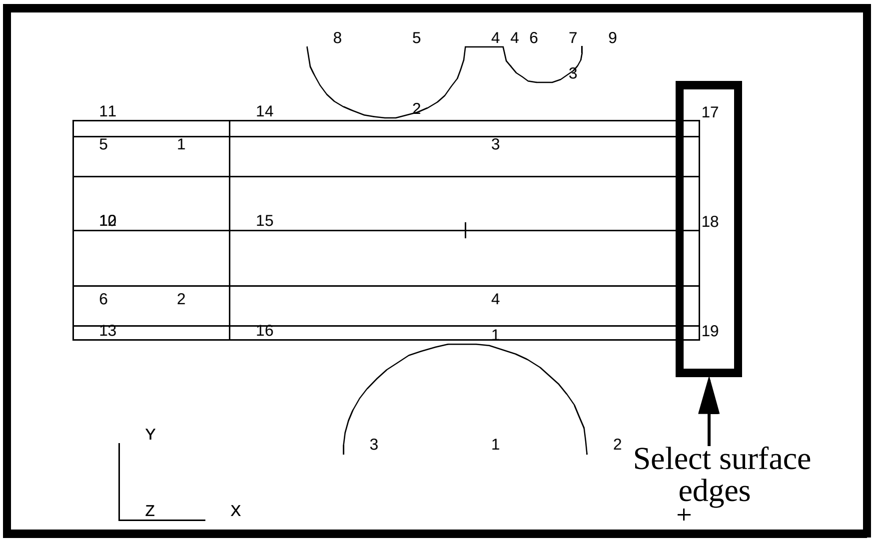
Figure A2.4 - Surface edges to sweep into pipe surface



The *Curve List* should be **Surface 1.2 2.2**

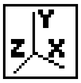
Finally create the last two surfaces using a *Translation Vector* of **<4, 0, 0>**.

Figure A2.5 - Surface edges to sweep into pipe surface



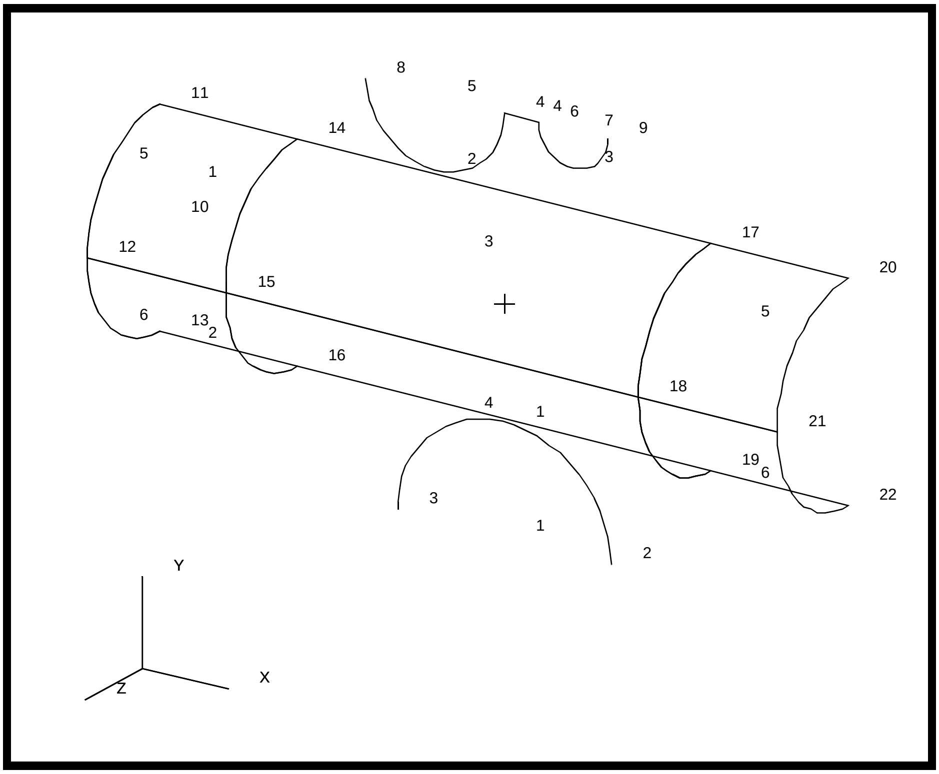
The *Curve List* should be **Surface 3.2 4.2**.

Change the display of the model.Click on the following icon to change to isometric view:

 **Iso 1 View**

Your model should look like the one shown in Figure A2.6:

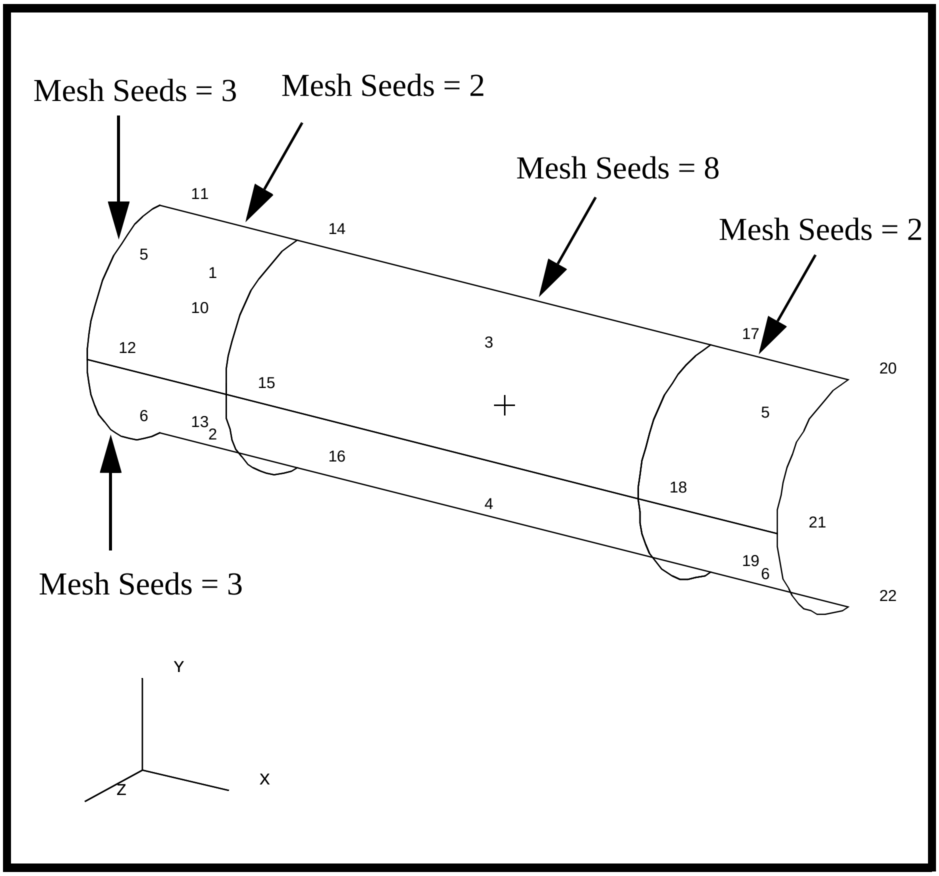
Figure A2.6 - Isometric view of pipe surface and rigid bodies



10. Create the mesh seeds for the finite element mesh.

First, we will define the mesh seed for the body of the pipe. You will define the mesh seeds as shown in Figure A2.7:

Figure A2.7 - Mesh seed locations



◆ **Finite Elements**

Action:	**Create**
Object:	**Mesh Seed**
Method:	**Uniform**

◆ **Number of Elements**

Number:	**2**
Curve List:	**Surface 1.1 5.1**

NOTE: To select multiple entries, click in the *Curve List* databox and screen select the top edge of Surface 1 (**Surface 1.1**) and the top edge (while holding down the shift key) of Surface 5 (**Surface 5.1**).

In a similar manner set *Number* = **3** and a *Curve List* of **Curve 5 6** (the left edge of Surface 1 and Surface 2).

Again, set *Number* = **8** and a *Curve List* of **Surface 3.1** (the top of Surface3).

11. Create a new group **fem_pipe**.

Group/Create ...

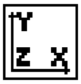
New Group Name:	**fem_pipe**
■ **Make Current**	
Group Contents:	**Add Entity Selection**

Apply

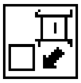
Cancel

12. Create the mesh for the pipe body.

Change the view to a front view by using the following toolbar icon:


Front View

Click the following icon in the quickpick menu to turn off all the entity labels.

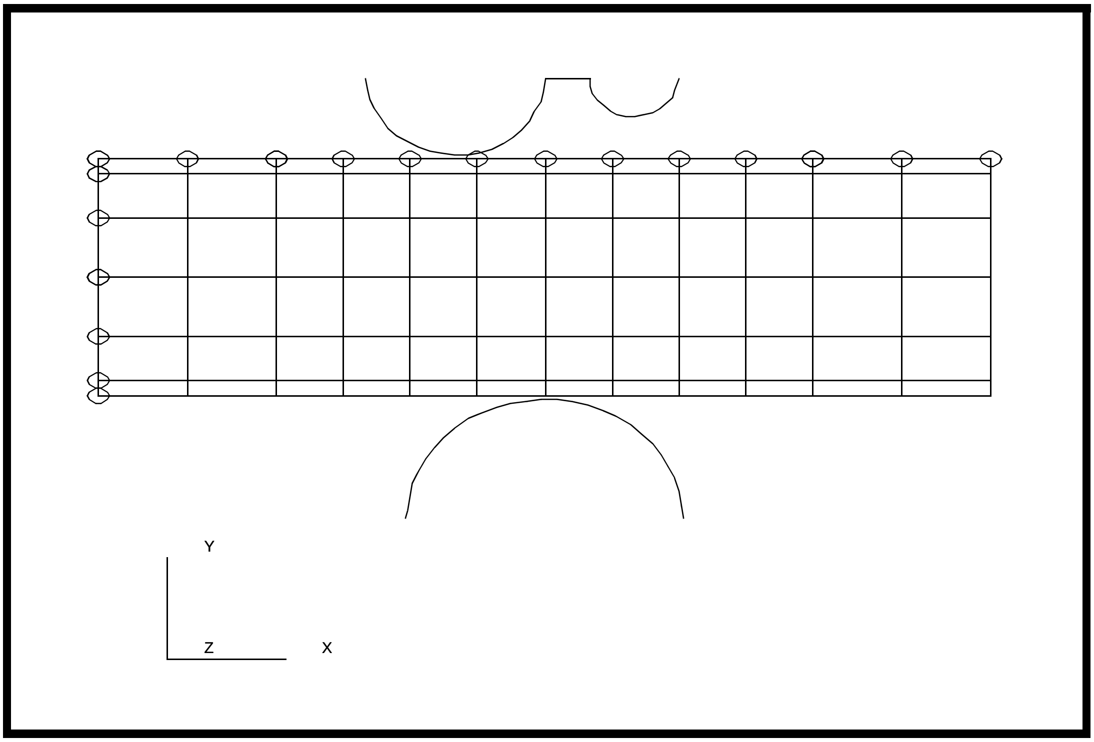

Hide Labels

Action:	**Create**
Object:	**Mesh**
Type:	**Surface**
Global Edge Length:	**1**
Element Topology:	**Quad4**
Surface List:	select all surfaces in model

Apply

Your model should look like the one shown in Figure A2.8:

Figure A2.8 - Meshed pipe surface



13. Create a new group **fem_irs_top**.

Group/Create ...

New Group Name:	**fem_irs_top**
■ **Make Current**	
Group Contents:	**Add Entity Selection**

Apply

Cancel

14. Create IRS elements for the top surface.

Next, we need to create a series of duplicate **Quad4** elements lying on top of the elements that make up the upper, central portion of the pipe model. These elements will be used to define our contact surfaces.

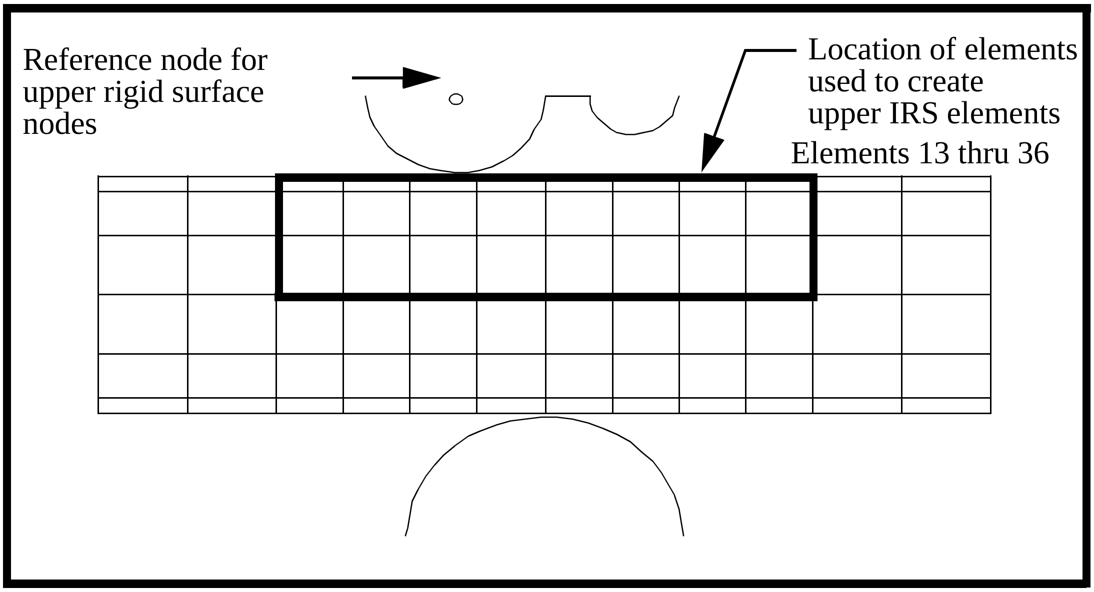
◆ **Finite Elements**

Action:	**Transform**
Object:	**Element**

Method:	**Translate**
Translation Vector:	**<0, 0, 0>**
Element List:	see Figure A2.9

Apply

Figure A2.9 - Elements used for upper contact



15. Define the reference nodes for the upper rigid surface.

Add a “reference” node to the upper and lower rigid bodies. This node will be used to control the motion of the rigid bodies.

Action:	**Create**
Object:	**Node**
Method:	**Edit**
Node ID List:	**999**
Node Location List:	see Figure A2.9

Apply

16. Create a new group **fem_irs_bottom**.

Group/Create...

New Group Name: **fem_irs_bottom**

■ **Make Current**

Group Contents: **Add Entity Selection**

Apply

Cancel

17. Define the reference nodes for the lower rigid surface.

Action: **Create**

Object: **Node**

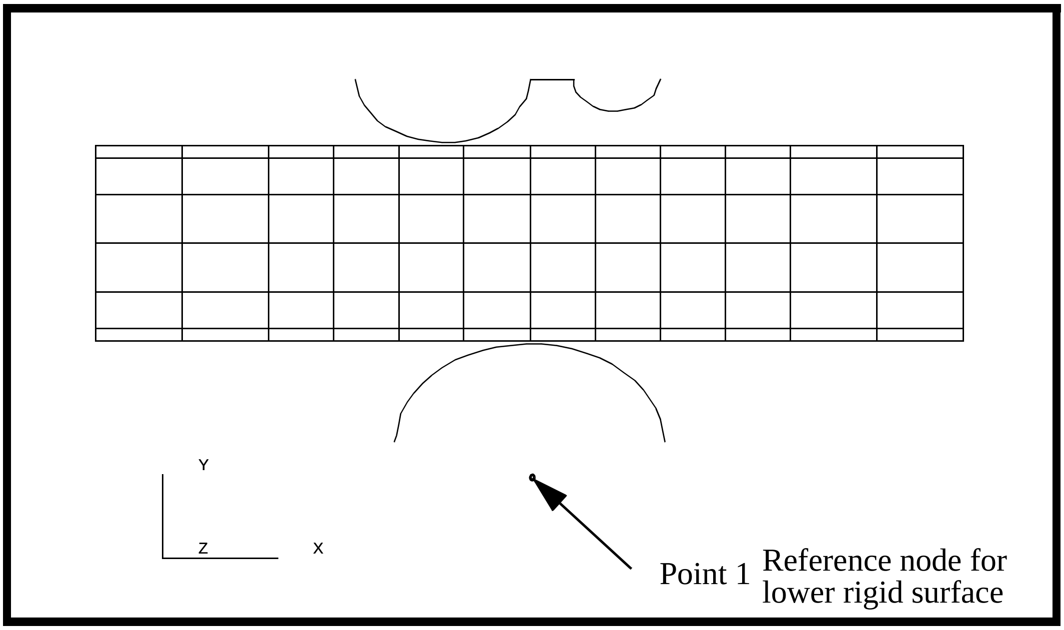
Method: **Edit**

Node ID List: **1000**

Node Location List: see Figure A2.10

Apply

Figure A2.10 - Location of lower rigid surface reference node



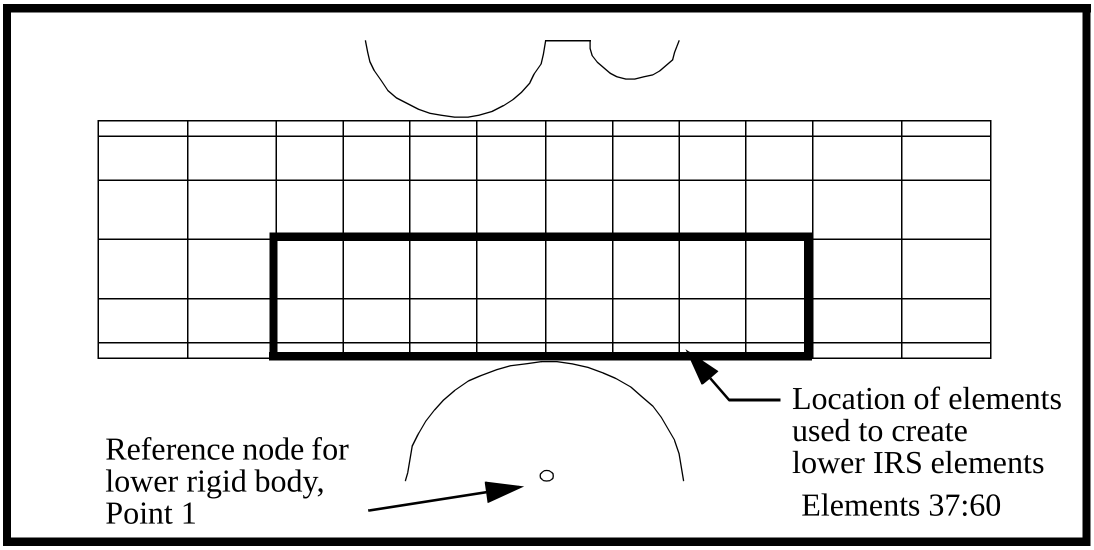
18. Create the lower irs elements.

In a similar manner, define a series of duplicate elements for the lower, central portion of the pipe model.

Action:	**Transform**
Object:	**Element**
Method:	**Translate**
Translation Vector:	**<0, 0, 0>**
Element List:	select the elements as shown in Figure A2.11

Apply

Figure A2.11 - Elements used for lower contact



19. Create a new group **fem_rigid_top**.

Group/Create

New Group Name:	**fem_rigid_top**
■ **Make Current**	
Group Contents:	**Add Entity Selection**

Apply

Cancel

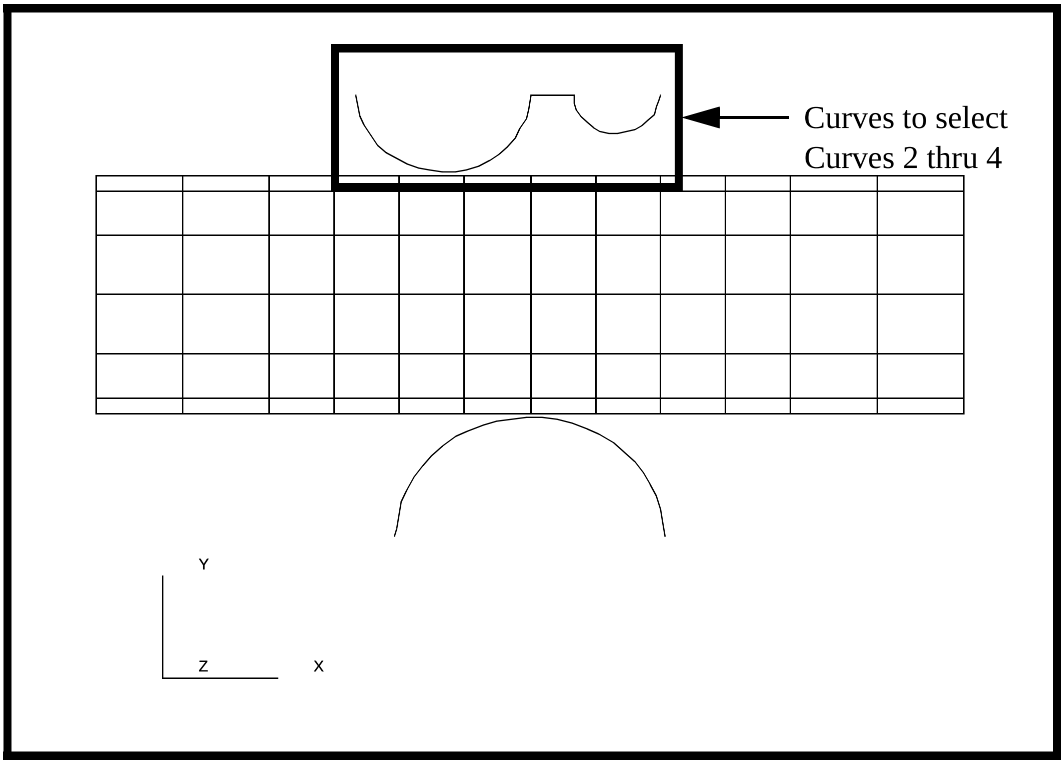
20. Create the upper rigid surface elements.

Next, create a beam mesh on the upper rigid bodies.

Action:	**Create**
Object:	**Mesh**
Type:	**Curve**
Global Edge Length:	**1**
Element Topology:	**Bar2**
Curve List:	see Figure A2.12

Apply

Figure A2.12 - Curves to select for upper rigid surface



21. Create a new group **fem_rigid_bottom**.

Group/Create ...

New Group Name:	**fem_rigid_bottom**

■ **Make Current**

Group Contents: **Add Entity Selection**

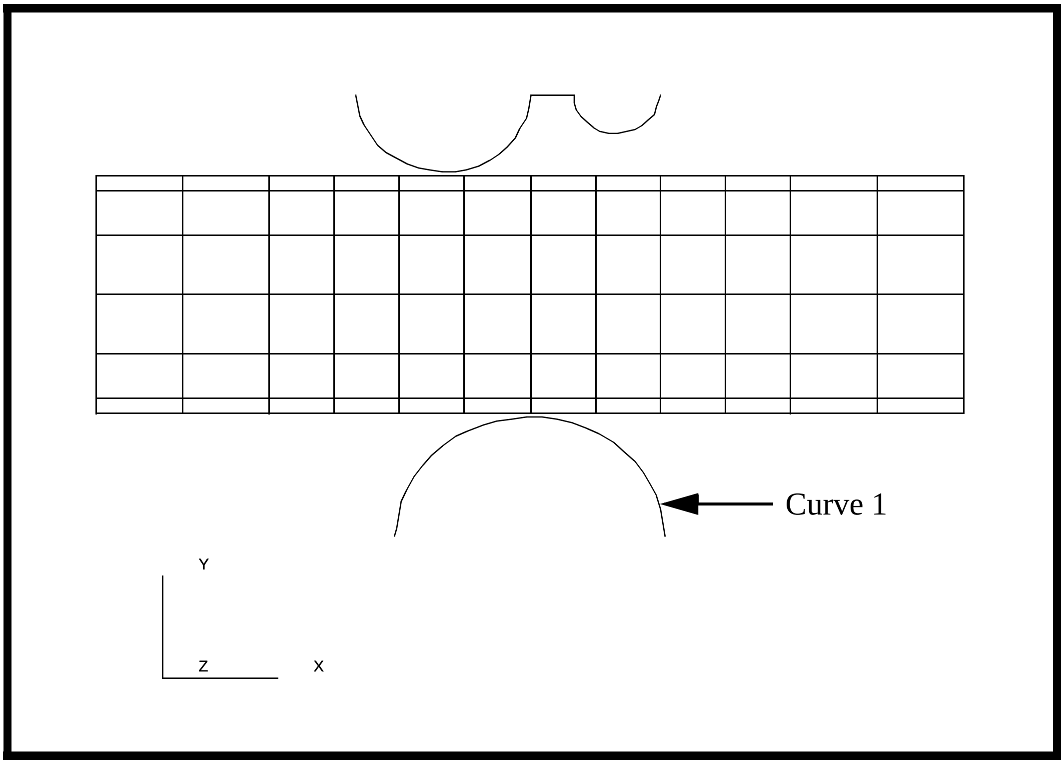
Apply

Cancel

22. Create the elements for the lower rigid surface.

In a similar manner, create a beam mesh on the lower rigid body. The *Global Edge Length* is = **1** and pick the curve shown in Figure A2.13:

Figure A2.13 - Curve to select for lower rigid surface



23. Equivalence the finite element nodes (eliminate any extra, overlapping nodes created by the mesher).

Action: **Equivalence**

Object: **All**

Type: **Tolerance Cube**

Apply

24. Create a new group called **fem_all**, which will be used for post processing later.

Group/Create ...

New Group Name:	**fem_all**
■ **Make Current**	
Group Contents:	**Add All FEM**
Apply	

25. Create a new group **all**, which will be used to apply LBCs onto.

New Group Name:	**all**
■ **Make Current**	
Group Contents:	**Add All Entities**
Apply	
Cancel	

26. Create the material properties for the pipe.

◆ **Materials**

Action:	**Create**
Object:	**Isotropic**
Method:	**Manual Input**
Material Name:	**steel**
Input Properties...	
Constitutive Model:	**Elastic**
Elastic Modulus:	**30E6**
Poisson's Ratio:	**0.30**
Apply	

The model will also experience yielding during the analysis, so a Plastic Constitutive Model needs to be defined.

Constitutive Model:	**Plastic**

Hardening Rule: **Perfect Plasticity**

Yield Stress: **45000**

Apply

Cancel

27. Post the group **fem_pipe** only.

Group/Post ...

Select Groups to Post: **fem_pipe**

Apply

Cancel

28. Now create the Element Properties for your model.

◆ **Properties**

Action: **Create**

Dimension: **2D**

Type: **Shell**

Property Set Name: **pipe**

Options: **Thin**

Homogeneous

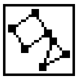
Input Properties...

Material Name: **steel**

Shell Thickness: **0.4**

OK

Click in the *Select Members* databox. Select the 2D element icon in the Select menu and then select ***all*** elements displayed.



2D Element

Select Members: select all elements

Add

Apply

29. Post the group **fem_irs_top** only.

Group/Post ...

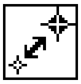
Select Groups to Post: **fem_irs_top**

Apply

Cancel

30. Create the element property for the top IRS elements.

Use the following toolbar icon to increase the node size to make picking easier:

 **Node Size**

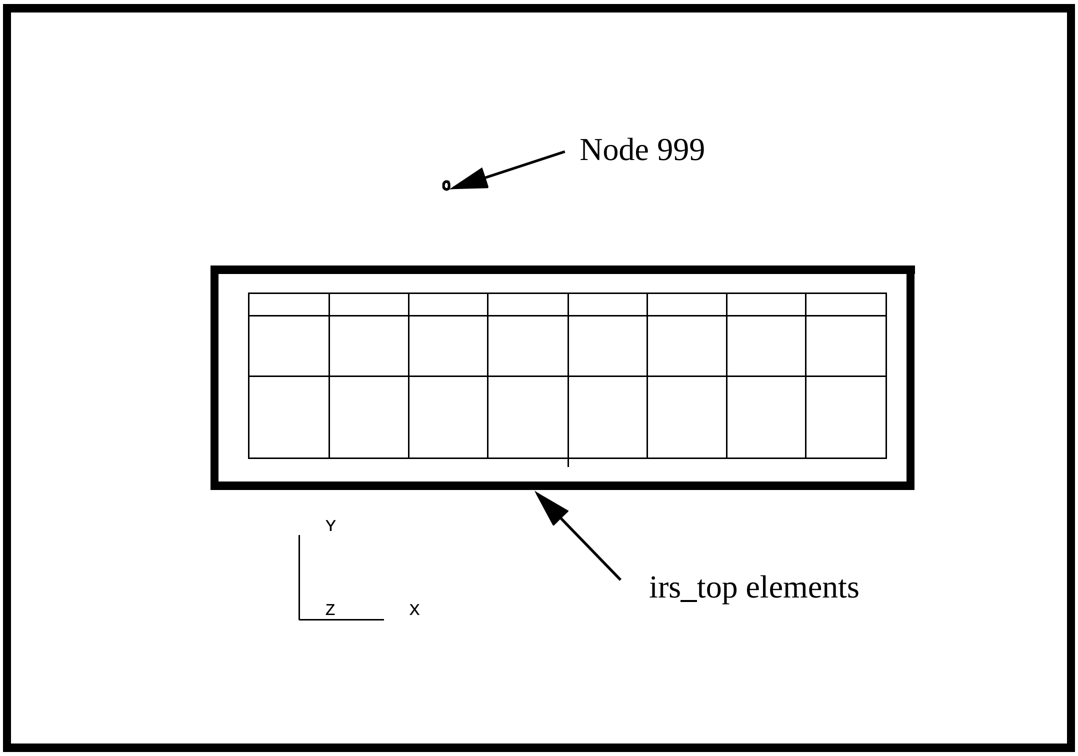
◆ **Properties**

Action:	**Create**
Dimension:	**2D**
Type:	**IRS (shell/solid)**
Property Set Name:	**irs_top**
Options:	**Elastic Slip Soft Contact**

Input Properties...

ELSET Name:	**top**
Reference Node:	see Figure A2.14

Figure A2.14 - Pipe elements/reference node for upper contact



OK

Click in the *Select Members* databox and screen select ***all*** members on the screen.

Add

Apply

31. Post the group **fem_irs_bottom** only.

Group/Post ...

Select Groups to Post: **fem_irs_bottom**

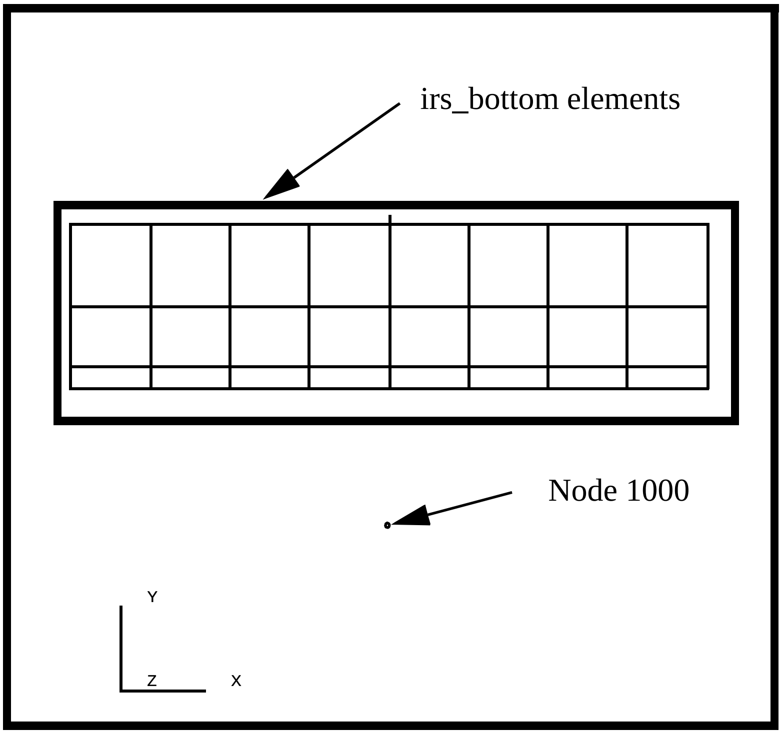
Apply

Cancel

32. In a similar manner, enter the information for the bottom IRS elements on the underside of the pipe.

Property Set Name:	**irs_bottom**
Options:	**Elastic Slip Soft Contact**
Input Properties...	
ELSET Name:	**bottom**
Reference Node:	see Figure A2.15

Figure A2.15 - Pipe elements/reference node for lower contact



OK

Click in the *Select Members* databox and screen select ***all*** members on the screen.

Add

Apply

33. Post the group **fem_rigid_top** and **fem_rigid_bottom**.

Group/Post ...

Select Groups to Post:	**fem_rigid_top** **fem_rigid_bottom**

Apply

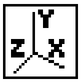
Cancel

A form will appear asking you to select a current group. Select **fem_rigid_top.**

OK

Cancel

Click on the following icon to change to isometric view:



Iso 1 View

34. Finally, create the element properties for the upper and lower rigid surfaces.

To do this, you will have to define the normal which should point away from the rigid body and to the contact IRS elements. To do this, we will need to define a surface generation vector.

The *Surface Generator Direction* and the *Start Node* are used to determine the “inside” and the “outside” of the rigid body. We want the “outside” of the rigid body to contact the pipe model. A more formal definition of these terms is:

The generator direction follows the right hand rule and is specified as:

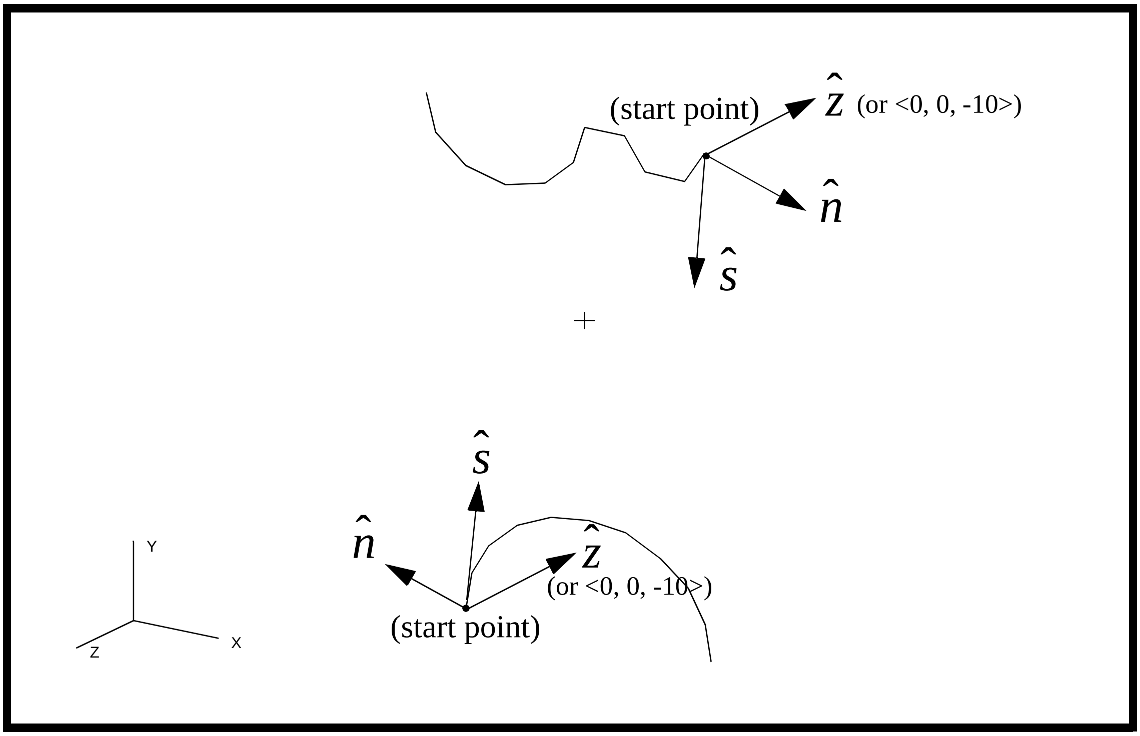
$$\hat{n} = \hat{s} \times \hat{z}$$

where

$\hat{n}$	is the unit normal direction.
$\hat{s}$	is the cord length direction.
$\hat{z}$	is the generator direction.

These vectors are shown for each of the rigid bodies in the sketch shown in Figure A2.16:

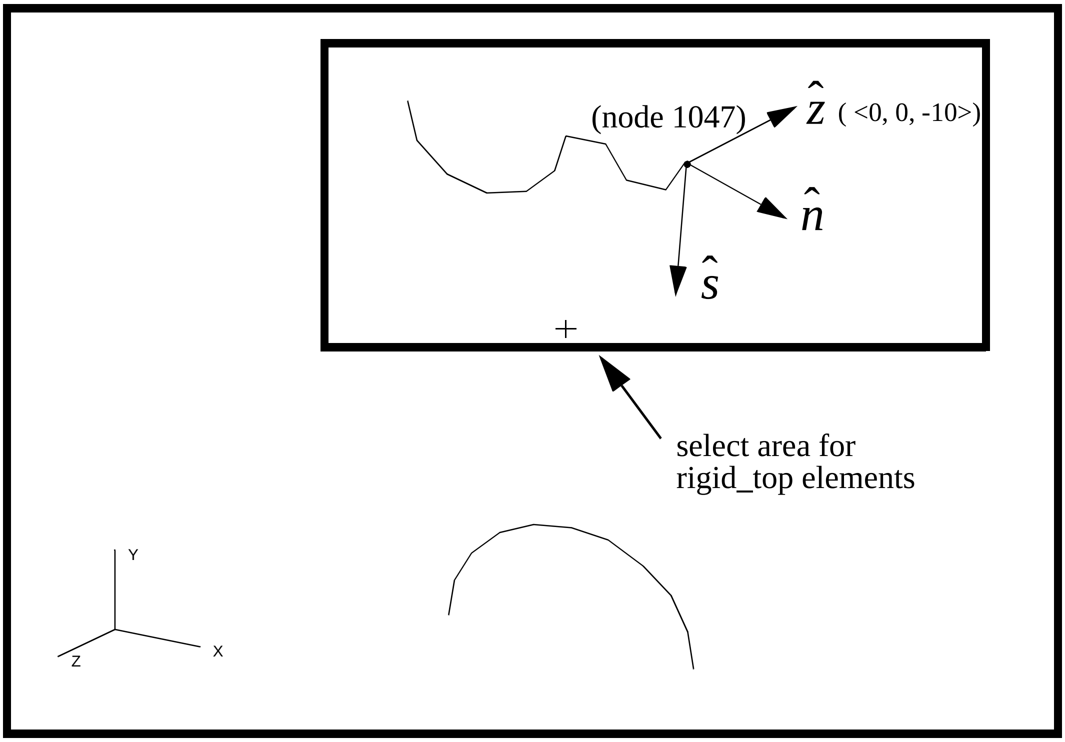
Figure A2.16 - Sketch of normal directions for rigid bodies



◆ **Properties**

Action:	**Create**
Dimension:	**1D**
Type:	**RigidSurf(Cyl)**
Property Set Name:	**rigid_top**
Input Properties...	
ELSET Name:	**top**
Surface Gen. Direction:	**< 0, 0, -10>**
Start Point (Node_id):	see Figure A2.17

Figure A2.17 - Normal definitions for upper rigid body



OK

Click on *Select Members* databox, then select the Beam Element icon in the Select Menu.

Beam Element

Now screen select the members shown in the figure above.

Add

Apply

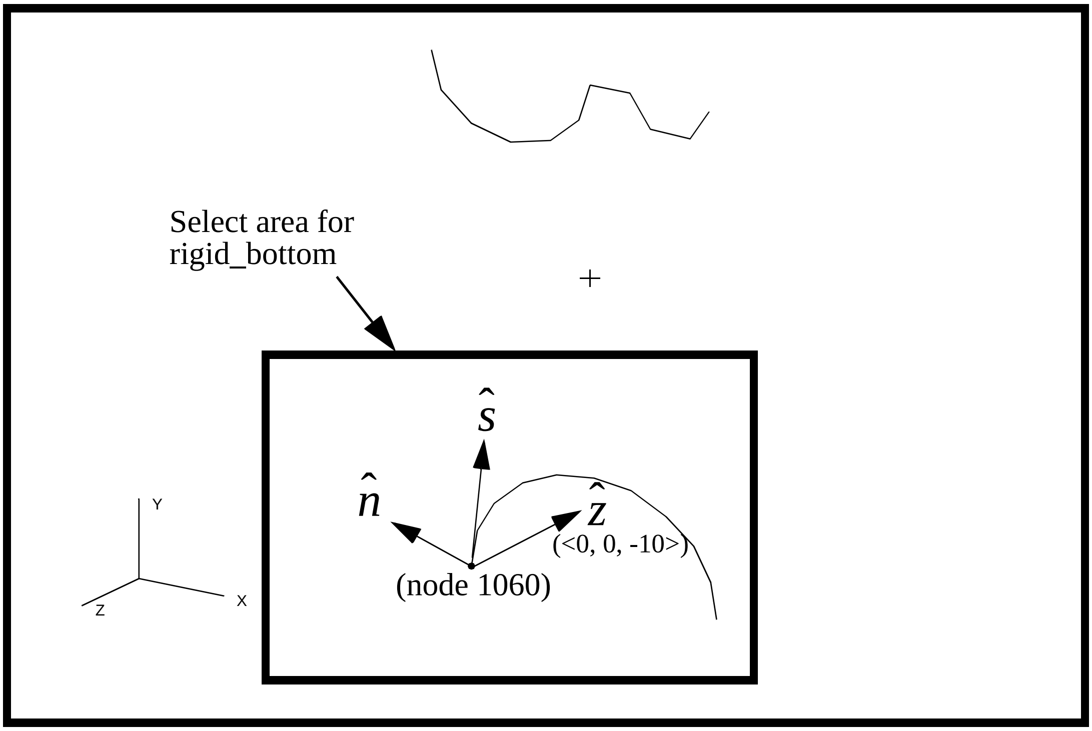
In a similar manner, enter the information for the Rigid Surface elements for the lower rigid surface.

◆ **Properties**

Action: **Create**

Dimension:	**1D**
Type:	**RigidSurf (Cyl)**
Property Set Name:	**rigid_bottom**
Input Properties...	
ELSET Name:	**bottom**
Surface Gen. Direction:	**< 0, 0, -10>**
Start Point (Node_id):	select the start node shown in Figure A2.18
OK	
Select Members:	shown in Figure A2.18
Add	
Apply	

Figure A2.18 - Normal definitions for lower rigid body



35. Post the group “**all**” only. We will define the loads and boundary conditions.

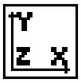
Group/Post ...

Select Groups to Post: **all**

Apply

Cancel

Select the following toolbar front view icon to change the display.



Front View

36. Now apply the loads and boundary conditions to the end of the pipe.

The ends of the pipe are to be fixed in all translations. The upper rigid surface will then be forced down into the pipe and lower rigid surface forced up into the pipe.

◆ **Loads/BCs**

Action: **Create**

Object: **Displacement**

Method: **Nodal**

New Set Name: **end_disp**

Input Data...

Translations <T1,T2,T3>: **< 0, 0, 0 >**

Rotations <R1,R2,R3>: **< 0, 0, 0 >**

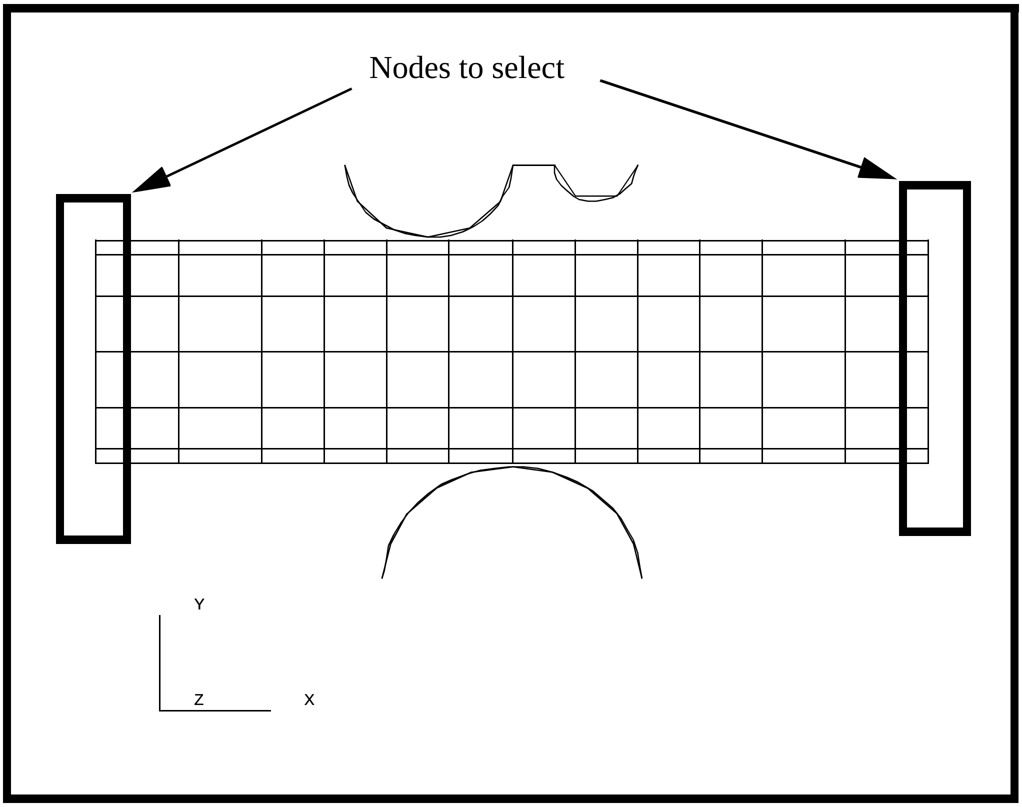
OK

Select Application Region...

Geometry Filter: ◆ **FEM**

Click in the *Select Nodes* databox, and screen select the nodes at both ends of the pipe as shown in Figure A2.19:

Figure A2.19 - Fixed ends of pipe



Add

OK

Apply

37. Next create the symmetrical edge constraints for the top and bottom edges of the pipe model.

Action:	**Create**
Object:	**Displacement**
Type:	**Nodal**
New Set Name:	**symmetry**

Input Data...

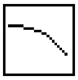
Translations <T1,T2,T3>:	**< , , 0>**
Rotations <R1,R2,R3>:	**< 0, 0, >**

OK

Select Application Region...

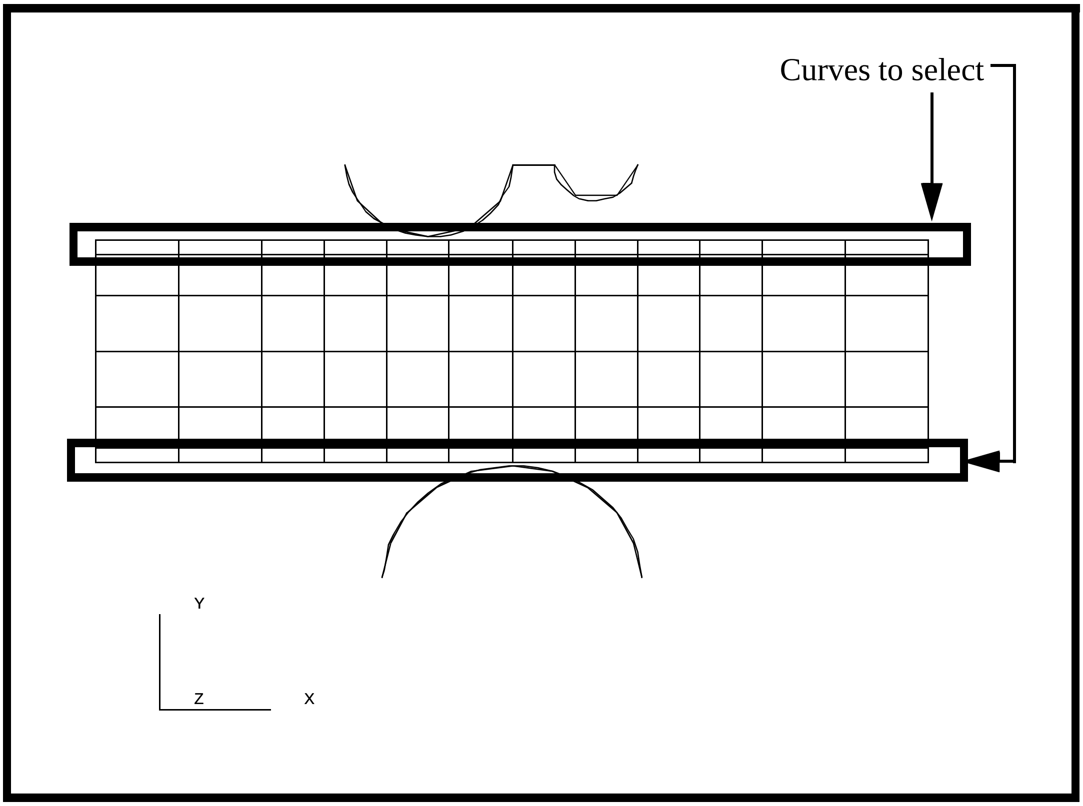
Geometry Filter: ◆ **Geometry**

Click in the *Select Geometry Entities* databox, change the select menu icon at the bottom to *Select a Curve,*

 **Curve**

Screen select the surface edges at both ends of the pipe as shown in Figure A2.20:

Figure A2.20 - Locations for symmetry BCs



Add

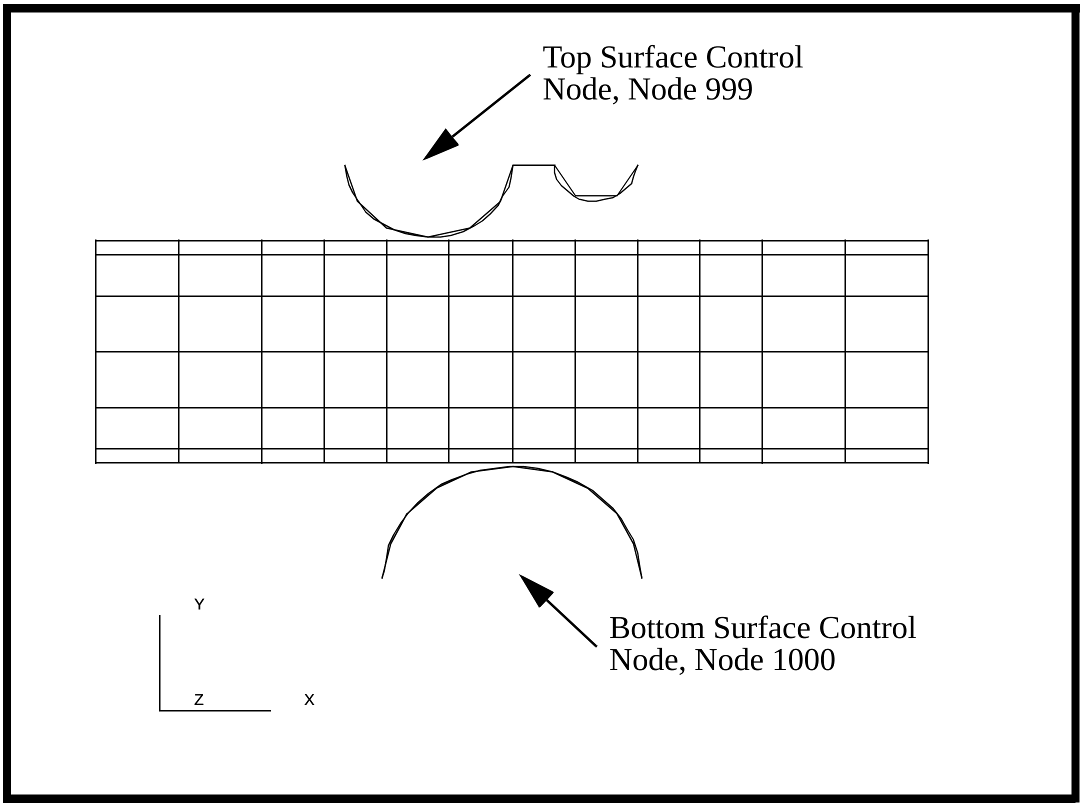
OK

Apply

38. Next, you will create the enforced displacement on the upper rigid body.

New Set Name:	**top_rigid_down**
Input Data...	
Translations <T1,T2,T3>:	**< 0, -2.2, 0>**
Rotations <R1,R2,R3>:	**< 0, 0, 0 >**
OK	
Select Application Region...	
Geometry Filter:	◆ **FEM**
Select Nodes:	**Node 999**
Add	
OK	
Apply	

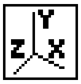
Figure A2.21 - Reference nodes for rigid bodies



39. The last boundary condition is the enforced displacement on the lower rigid body.

New Set Name:	**bot_rigid_up**
Input Data...	
Translations <T1,T2,T3>:	**< 0, 2.2, 0>**
Rotations <R1,R2,R3>:	**< 0, 0, 0 >**
OK	
Select Application Region...	
Geometry Filter:	◆ **FEM**
Select Nodes:	**Node 1000**
Add	
OK	
Apply	

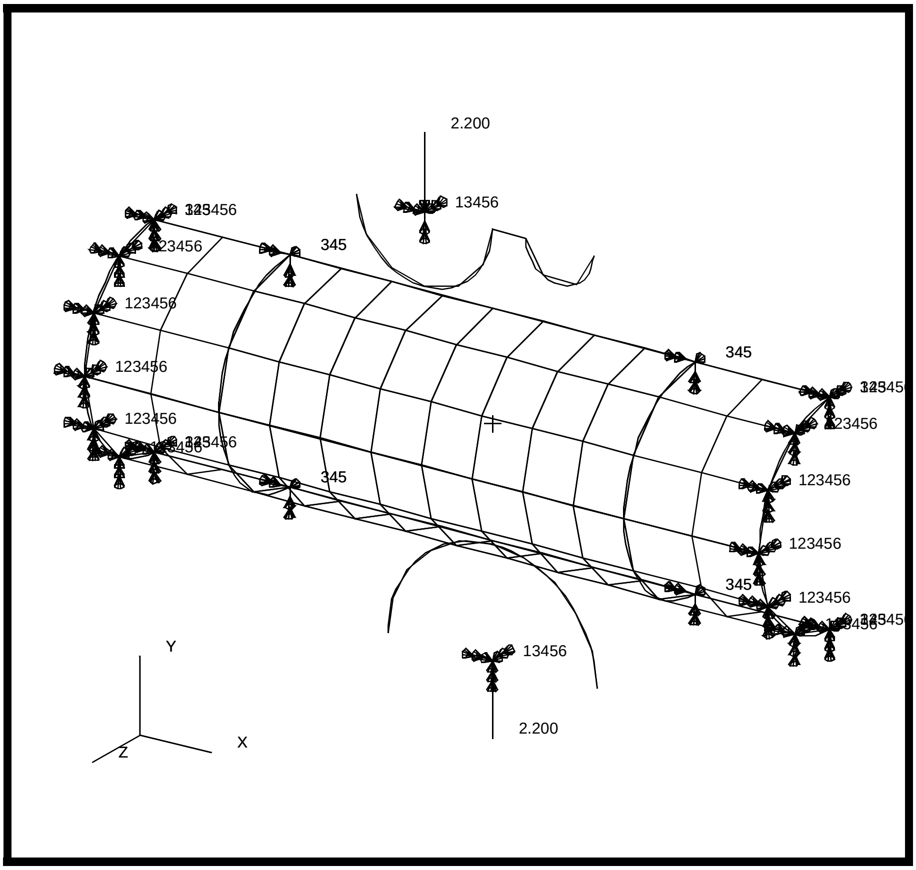
Change the display of the model using the isometric view icon.



Iso 1 View

Your model should now look like the picture shown in Figure A2.22:

Figure A2.22 - Model with all Loads/BCs applied



40. Your model is now ready for analysis.

◆ **Analysis**

Action:	**Analyze**
Object:	**Entire Model**
Method:	**Full Run**
Job Name:	**crush2**
Step Creation...	
Job Step Name:	**pipe_crush**
Solution Type:	**Nonlinear Static**
Solution Parameters...	
Large Deflections/Strains:	**ON**
Max No. of Increments Allowed:	**100**

RIKS Method: **OFF** ▭

Automatic Load Increments: **ON** ▭

OK

Apply

Cancel

Note: The default load case contains all the loads required to run this step and is selected by default.

Step Selection...

Selected Job Steps: **pipe_crush**

Apply

Apply

The non-linear analysis job **crush2** will then be submitted for analysis to the workstation designated in the Submit Script (usually your local workstation).

The analysis job will take (on average) 5 to 10 minutes to run. When the job is done there will be a results file titled **crush2.fil** in the same directory you started MSC/PATRAN in and the **crush2.023** file will disappear.

Again, you can monitor the progression of the job by looking at **crush2.msg** and **crush2.sta** as well as using the UNIX command **ps -a** and **tail crush2.msg**.

41. Read in the results.

◆ **Analysis**

Action: **Read Results**

Select Results File...

Selected Results File: **crush2.fil**

OK

Apply

42. Post the group **fem_all** only for post processing.

Group/Post ...

Select Groups to Post:	**fem_all**

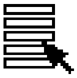
Apply

Cancel

43. Use Results to post process your results of the analysis.

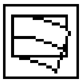
◆ **Results**

Click on the **Select Results** icon



Action:	**Create**
Object:	**Quick Plot**
Select Result Cases:	select the last increment
Select Deformation Result:	**Deformation, Displacements**

Change the Display Properties for results



Display/Results ...

Scale Factor:	**1.0**

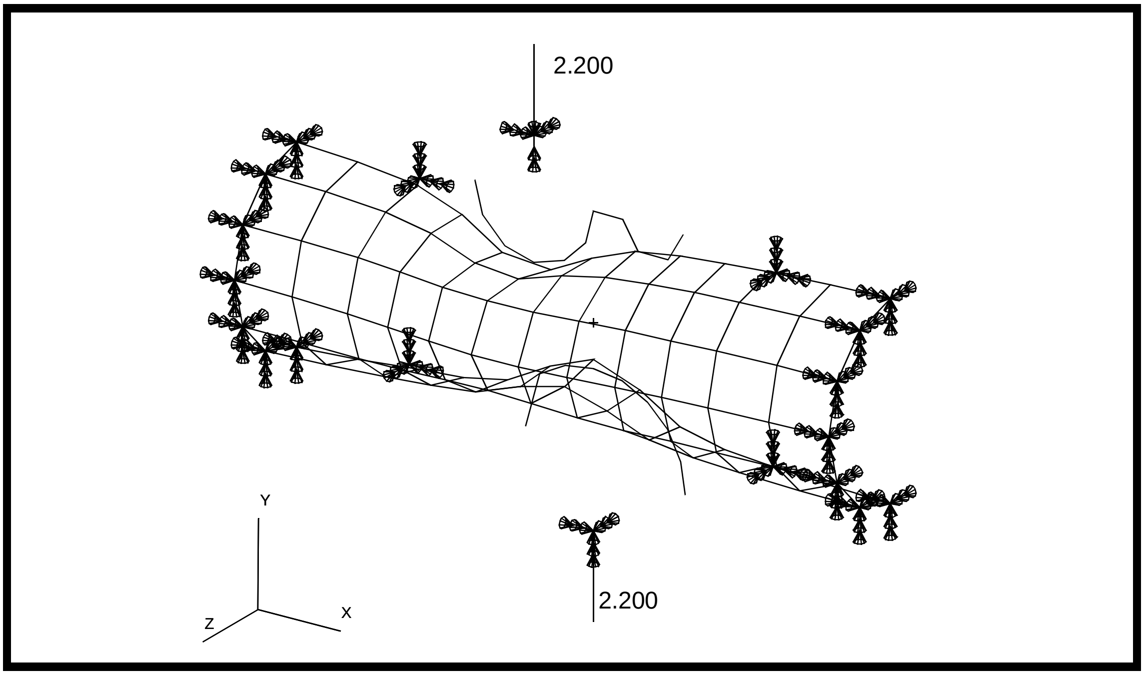
◆ **True Scale**

❐ **Show Undeformed Entities**

Apply

Your model should appear as shown in Figure A2.23:

Figure A2.23 - Deformed pipe model

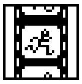


44. Create an animation of the deformation and Von Mises stresses using:

Action:	**Create**
Object:	**Quick Plot**
Select Result Type:	select the last increment
Select Fringe Result:	**Stress, Components**
Result Quantity:	**Von Mises**
Select Deformation:	**Deformation, Displacement**

■ **Animate**

Bring up the Animation Options form



■ **Animate Fringe**

■ **Animate Deformation**

Animation Method:	◆ **Ramped**
Animation Graphics:	◆ **2D**
Number of Frames:	**10**

OK

Apply

When done, quit PATRAN.

This concludes the exercise.