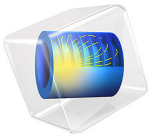

Resistor-Modulated Pipeline Cathodic Protection

Introduction

Highly alloyed stainless steel used in chlorinated seawater systems may be prone to internal corrosion under certain operating conditions. Conventional cathodic protection technique may be less suitable for stainless steel due to unacceptable anode consumption rates and propensity to hydrogen embrittlement at highly negative potentials.

In the present model, an alternative internal corrosion protection technique, based on resistor-modulated cathodic protection, is demonstrated using the Current Distribution, Pipe interface. The impact of different resistance values on the resulting level of corrosion protection offered is investigated. The effect of pipeline radius on the current demand required for corrosion protection is also demonstrated in the model.

The example is based on a paper by G.E. Nustad and others (Ref. 1).

Model Definition

The model geometry is shown in Figure 1.

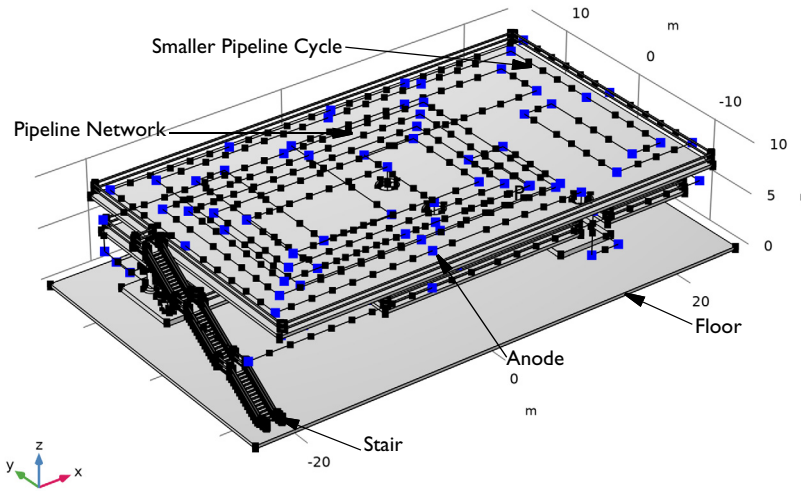

Figure 1: The model geometry consists of a pipeline network, several anodes as highlighted by bigger squares, stair and floor.

The model geometry consists of a complex pipeline network comprised of two pipeline cycles of different pipeline radii. For the first pipeline cycle the pipeline radius is 0.5 m and for the second pipeline cycle the pipeline radius is 0.2 m. The resistor-controlled sacrificial anodes are distributed across the pipeline network and are highlighted by the bigger squares in Figure 1. The stair, floor, and other process equipment are shown in the model geometry only for visualization purpose.

The pipeline network is represented by the edges, as shown in Figure 1. The Current Distribution, Pipe interface is used to solve for the electrolyte charge transport in the tangential direction along the pipeline network edges according to:

$$\mathbf{i}_l = -\sigma_l \nabla_T \phi_l$$
$$\nabla_T \cdot (A\mathbf{i}_l) = Q_l$$

where $\mathbf{i}_l$ (SI unit: A/m^2) is the electrolyte current density vector, σ_l (SI unit: S/m) is the electrolyte conductivity, which is 3 S/m for the chlorinated seawater, A (SI unit: m^2) is the pipeline cross-sectional area and Q_l (SI unit: A/m) is the electrolyte current source.

Different pipeline radii are specified by adding a separate Electrolyte edge feature for each pipeline radius.

The Pipe Electrode Surface edge feature is used to set the electrolyte current source across the pipeline network using the electrode kinetics described at the pipeline surface according to:

$$Q_l = i_{\text{loc}} \times 2\pi r_{\text{pipe}}$$
$$i_{\text{loc}} = f(\phi_l)$$

where r_{pipe} (SI unit: m) is the pipeline radius, i_{loc} (SI unit: A/m^2) is the local current density, $f(\phi_l)$ is an interpolation function obtained from the experimental polarization data (Ref. 1) available in the corrosion material library.

The Pipe Point Sacrificial Anode point feature is used to set the anode current according to:

$$I = \frac{\phi_{\text{s,pipe}} - E_{\text{eq}} - \phi_l}{R}$$
$$\sum_{\text{edges}} -\mathbf{t} \cdot (A\mathbf{i}_l) = I$$

where I (SI unit: A) is the anode current, $\phi_{s,pipe}$ (SI unit: V) is the electric potential at the pipeline surface, E_{eq} (SI unit: V) is the anode equilibrium potential, R (SI unit: Ω) is the coupling resistance between the anode and pipeline surface and $\mathbf{t}$ is the tangent vector at the location of the point, pointing outward from each adjacent edge.

Zinc sacrificial anode is used in the model for which the equilibrium potential is considered to be −1.03 V measured with respect to Ag/AgCl reference electrode. The coupling resistance parameter value is changed from 0.5 Ω to 2 Ω using a parametric sweep.

Results and Discussion

Figure 2 shows the electrode potential versus adjacent reference along the pipeline network for the coupling resistance of 2 Ω. It can be seen that the potential is more negative over a pipeline cycle with the smaller pipeline radius. The reason for this is that the current demand is lower for the pipeline cycle with the smaller radius due to a smaller internal area.

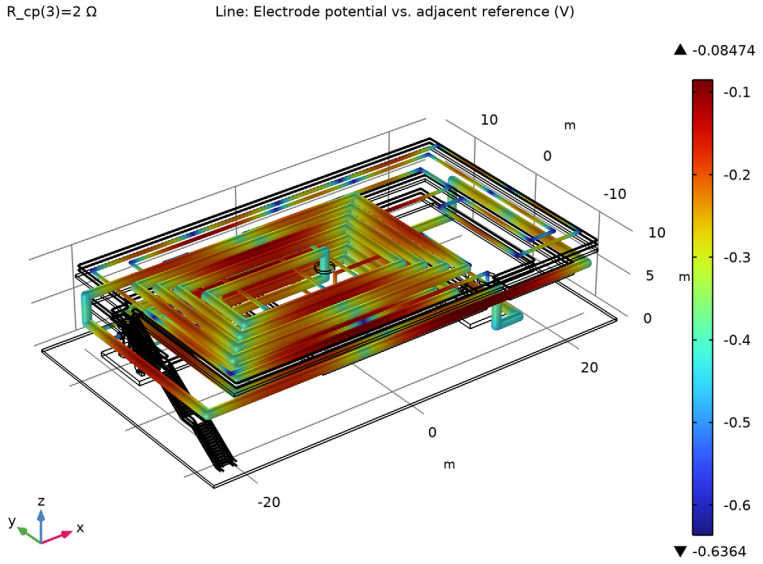

Figure 2: The electrode potential versus adjacent reference along the pipeline network for the coupling resistance value 2 Ω.

Figure 3 shows the electrode potential along the pipeline network for a coupling resistance of 0.5 Ω. It can be seen that the potential is more negative than that seen in Figure 2 for

the coupling resistance of 2 Ω. This is expected since the lower coupling resistance means the higher anode current leading to more corrosion protection of the pipeline network.

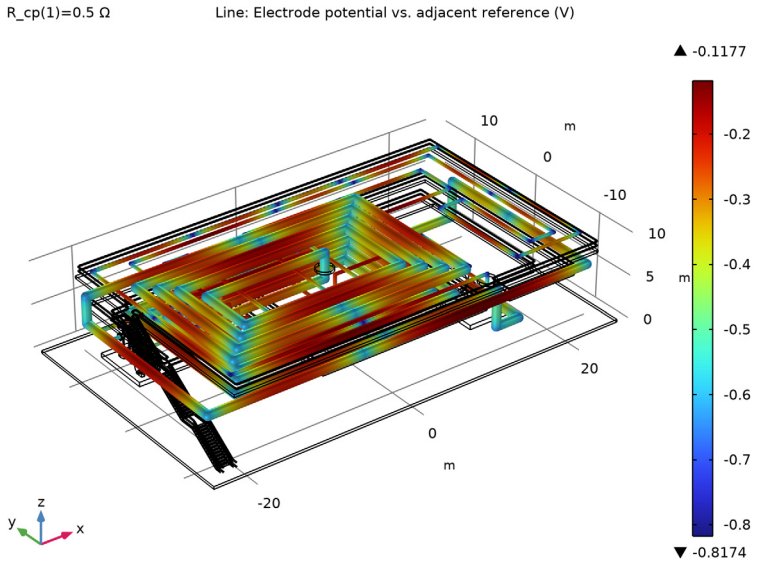

Figure 3: Electrode potential versus adjacent reference along the pipeline network for a coupling resistance value 0.5 Ω.

Figure 4 shows the total interface current density along the pipeline network for a coupling resistance of 2 Ω. The more negative total interface current density is observed

over the pipeline cycle with the smaller pipeline radius, a trend similar to the electrode potential seen in Figure 2.

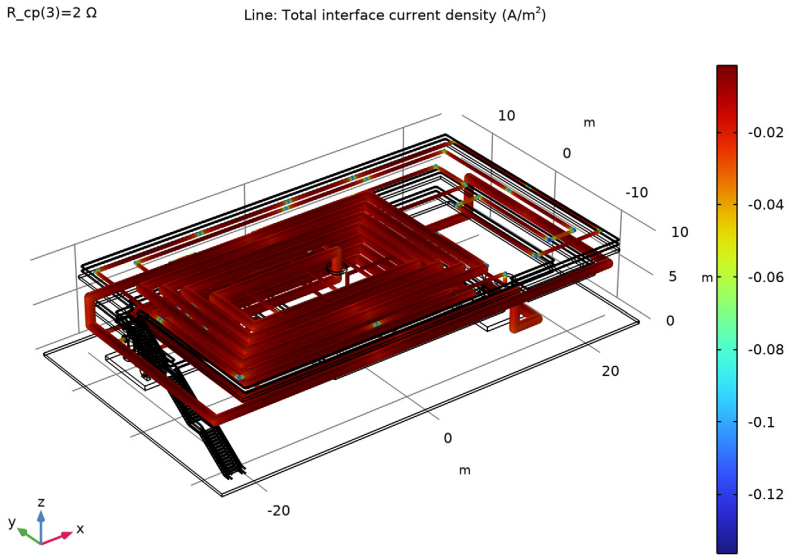

Figure 4: The total interface current density along the pipeline network for the coupling resistance value 2 Ω.

Figure 5 shows the total interface current density along the pipeline network for the coupling resistance of 0.5 Ω. The total interface current density is expectedly more

negative for the coupling resistance of 0.5 Ω than that for the coupling resistance of 2 Ω, seen in Figure 4.

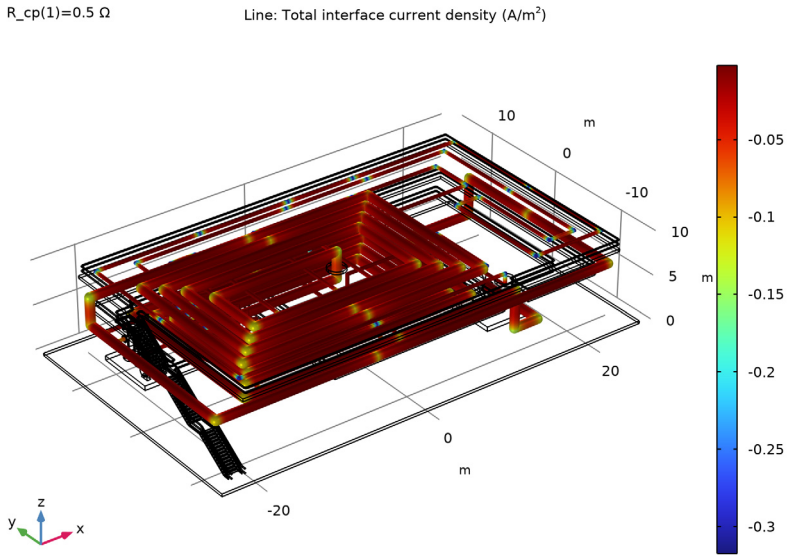

Figure 5: The total interface current density along the pipeline network for the coupling resistance value 1 Ω.

Finally, one can identify the regions along the pipeline network which may not be adequately protected for corrosion by applying a filter with an expression "Electrode potential versus adjacent reference > Pipeline protection potential". This filter expression would highlight regions along the pipeline network which do not fulfill the corrosion protection criterion. Here, the pipeline protection potential is considered to be –100 mV (Ref. 1).

Figure 6 to Figure 8 show the regions not fulfilling the corrosion protection criterion along the pipeline network for the coupling resistance of 0.5 Ω, 1 Ω, and 2 Ω, respectively. It can be seen in Figure 6 and Figure 7 that no region is highlighted along the pipeline

network, indicating that the coupling resistances of 0.5 Ω and 1 Ω provide an adequate corrosion protection throughout the pipeline network.

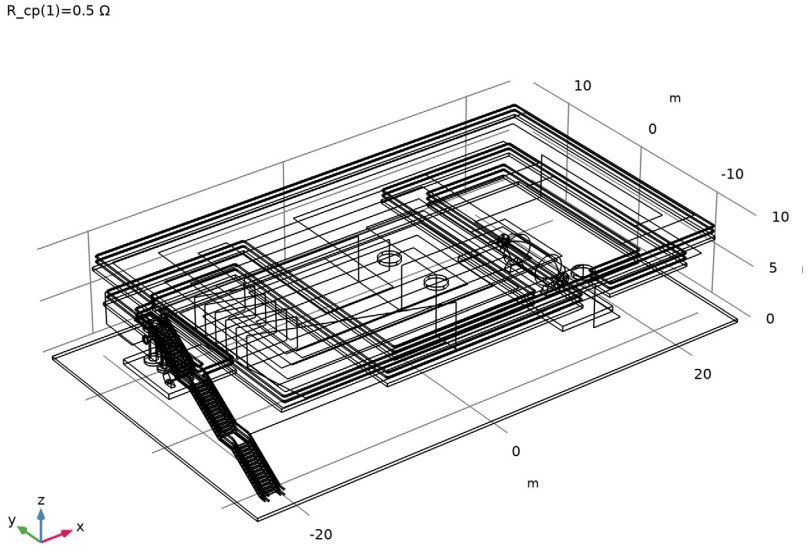

Figure 6: The corrosion protected region along the pipeline network for the coupling resistance value 0.5 Ω.

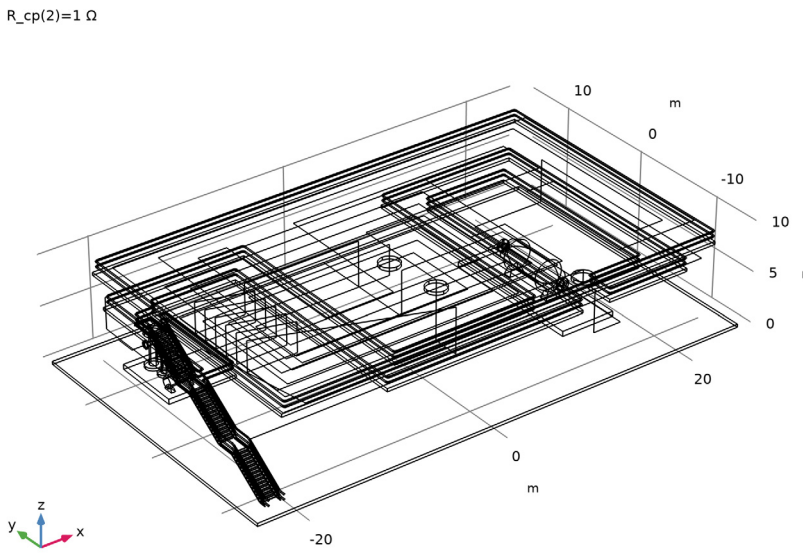

Figure 7: The corrosion protected region along the pipeline network for a coupling resistance value 1 Ω.

Figure 8 shows that there are some regions along the pipeline network that do not fulfill the corrosion protection criterion for the coupling resistance of 2 Ω. This indicates that

the coupling resistance of 2 Ω is not able to provide the adequate corrosion protection for the entire pipeline network.

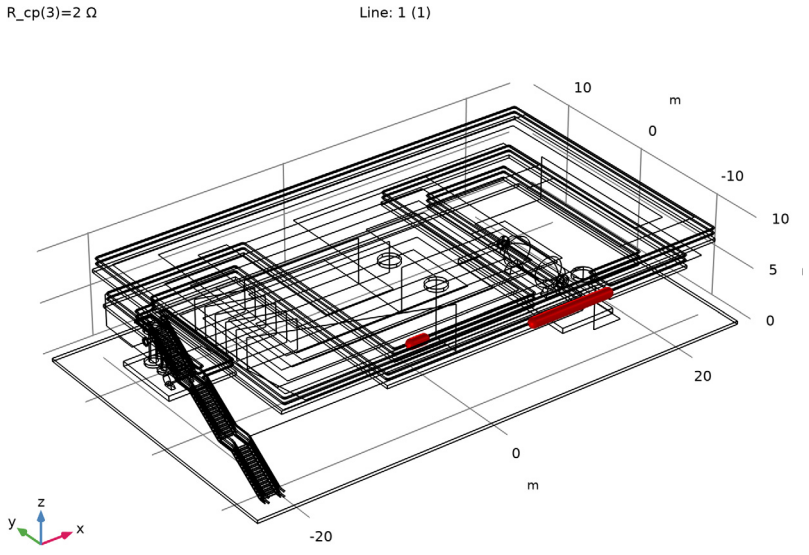

Figure 8: The corrosion protected region along the pipeline network for the coupling resistance value 2 Ω.

The model thus demonstrates identification of corrosion protected regions along the pipeline network for different pipeline radii and coupling resistances. The model can also be used to identify the optimum anode spacing along the pipeline network to provide the adequate corrosion protection.

Notes About the COMSOL Implementation

The model is implemented using the Current Distribution, Pipe interface. Note that the interface is applicable only for the edge domains that represent the electrolyte tube of a given radius. The Current Distribution, Pipe interface can typically be used for modeling internal pipeline corrosion and its protection.

Reference

1. G.E. Nustad, T. Solem, R. Johnsen, H. Osvoll, P.O. Gartland, M. Brameld, and G. Clapp, "Resistor controlled cathodic protection for stainless steels in chlorinated seawater: A review after 8 years in service," *NACE Corrosion*, Paper number 03082, 2003.

Application Library path: `Corrosion_Module/Cathodic_Protection/resistor_modulated_pipeline_cathodic_protection`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Electrochemistry>Primary and Secondary Current Distribution>Current Distribution, Pipe (cdpipe)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Stationary**.

6 Click **Done**.

GEOMETRY 1

The model geometry is available as a geometry sequence in a separate MPH-file. If you want to build it from scratch, follow the instructions in the section Appendix — Geometry Modeling Instructions. Otherwise load it from file with the following steps.

1 In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.

2 Browse to the model's Application Libraries folder and double-click the file `resistor_modulated_pipeline_cathodic_protection_geom_sequence.mph`.

3 In the **Insert Sequence** dialog box, click **OK**.

4 In the **Geometry** toolbar, click **Build All**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

GLOBAL DEFINITIONS

Parameters 1

Load the model parameter from a text file.

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `resistor_modulated_pipeline_cathodic_protection_parameters.txt`.

MATERIALS

Use the Corrosion Material Library to set up the material properties for the electrode kinetics at the stainless steel electrode surface.

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Corrosion>Iron Alloys (Steels)> UNS S31254 (stainless steel) in chlorinated seawater solution (Cathodic)**.

4 Click **Add to Component** in the window toolbar.

5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

CURRENT DISTRIBUTION, PIPE (CDPIPE)

Now, start setting up the physics. Note that the governing equations are solved only over pipeline network. Hence, first set the interface selection to the pipeline network. Also, set the reference electrode potential to 0.241 V (SCE vs. SHE). Then, set different pipeline radii using separate **Electrolyte** node for each pipe radius.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Current Distribution, Pipe (cdpipe)**.

2 In the **Settings** window for **Current Distribution, Pipe**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **Pipeline Network**.

4 Click to expand the **Physics vs. Materials Reference Electrode Potential** section. From the list, choose **0.241 V (SCE vs. SHE)**.

Electrolyte 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Current Distribution, Pipe (cdpipe)** click **Electrolyte 1**.

2 In the **Settings** window for **Electrolyte**, locate the **Electrolyte** section.

3 In the r_{pipe} text field, type `r_pipe`.

4 From the σ_l list, choose **User defined**. In the associated text field, type `sigma_l`.

Electrolyte 2

1 In the **Physics** toolbar, click **Edges** and choose **Electrolyte**.

2 In the **Settings** window for **Electrolyte**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **piping_02 (Piping Cycle 2)**.

4 Locate the **Electrolyte** section. In the r_{pipe} text field, type `r_pipe_smaller`.

5 From the σ_l list, choose **User defined**. In the associated text field, type `sigma_l`.

Pipe Electrode Surface 1

Now, set up the electrode kinetics using the Pipe Electrode Surface feature.

1 In the **Physics** toolbar, click **Edges** and choose **Pipe Electrode Surface**.

2 In the **Settings** window for **Pipe Electrode Surface**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **Pipeline Network**.

Electrode Reaction 1

1 In the **Model Builder** window, click **Electrode Reaction 1**.

2 In the **Settings** window for **Electrode Reaction**, locate the **Electrode Kinetics** section.

3 From the $i_{\text{loc,expr}}$ list, choose **From material**.

Pipe Point Sacrificial Anode 1

Finally, set up the sacrificial anode by specifying the anode equilibrium potential and coupling resistance.

1 In the **Physics** toolbar, click **Points** and choose **Pipe Point Sacrificial Anode**.

2 In the **Settings** window for **Pipe Point Sacrificial Anode**, locate the **Point Selection** section.

3 From the **Selection** list, choose **Point Sacrificial Anodes**.

4 Locate the **Equilibrium Potential** section. In the E_{eq} text field, type `Eeq_Zn`.

5 Locate the **Connection** section. In the R text field, type `R_cp`.

MESH 1

Set the extremely fine mesh for all edges.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Extremely fine**.

4 Locate the **Sequence Type** section. From the list, choose **User-controlled mesh**.

Edge 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Mesh 1** click **Edge 1**.

2 In the **Settings** window for **Edge**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **All edges**.

Size 1

1 Right-click **Edge 1** and choose **Size**.

2 In the **Settings** window for **Size**, click to expand the **Element Size Parameters** section.

3 Locate the **Element Size** section. Click the **Custom** button.

4 Locate the **Element Size Parameters** section.

5 Select the **Maximum element size** check box. In the associated text field, type `0.5`.

6 Click **Build All**.

STUDY 1

Now, set the parametric sweep for the coupling resistance.

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
R_cp (Coupling resistance)	`0.5 1 2`	Ω

The model is now ready to be solved.

5 In the **Study** toolbar, click **Compute**.

RESULTS

Update the default plots for the electrode potential versus adjacent reference and total interface current density to compare the results for different coupling resistance values.

Electrode Potential vs. Adjacent Reference (cdpipe)

1 In the **Model Builder** window, under **Results** click **Electrode Potential vs. Adjacent Reference (cdpipe)**.

2 In the **Settings** window for **3D Plot Group**, locate the **Color Legend** section.

3 Select the **Show maximum and minimum values** check box.

4 Click to expand the **Number Format** section. Select the **Manual color legend settings** check box.

5 In the **Precision** text field, type 4.

6 In the **Electrode Potential vs. Adjacent Reference (cdpipe)** toolbar, click **Plot**.

The **Electrode Potential vs. Adjacent** reference plot for coupling resistance of 2 Ω should look like Figure 2.

Now, change the coupling resistance parameter value to 0.5 Ω and the plot should look like Figure 3.

7 Locate the **Data** section. From the **Parameter value (R_cp (Ω))** list, choose **0.5**.

8 In the **Electrode Potential vs. Adjacent Reference (cdpipe)** toolbar, click **Plot**.

Total Interface Current Density (cdpipe)

The total interface current density plot for the coupling resistance of 2 Ω should look like Figure 4.

Now, change the coupling resistance parameter value to 0.5 Ω and the plot should look like Figure 5.

1 In the **Model Builder** window, click **Total Interface Current Density (cdpipe)**.

2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

3 From the **Parameter value (R_cp (Ω))** list, choose **0.5**.

4 In the **Total Interface Current Density (cdpipe)** toolbar, click **Plot**.

Electrode Potential vs. Adjacent Reference (cdpipe)

Finally, plot the regions of corrosion protection with respect to the pipeline protection potential of -100 mV versus Ag/AgCl reference electrode for different coupling resistance values. This will reproduce Figure 6 to Figure 8.

In the **Model Builder** window, right-click **Electrode Potential vs. Adjacent Reference (cdpipe)** and choose **Duplicate**.

Pipe Regions not Fulfilling Protection Criterion

1 In the **Model Builder** window, under **Results** click **Electrode Potential vs. Adjacent Reference (cdpipe) 1**.

2 In the **Settings** window for **3D Plot Group**, type `Pipe Regions not Fulfilling Protection Criterion` in the **Label** text field.

Line 1

1 In the **Model Builder** window, expand the **Pipe Regions not Fulfilling Protection Criterion** node, then click **Line 1**.

2 In the **Settings** window for **Line**, locate the **Expression** section.

3 In the **Expression** text field, type `1`.

4 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

Filter 1

1 In the **Pipe Regions not Fulfilling Protection Criterion** toolbar, click **Filter**.

2 In the **Settings** window for **Filter**, locate the **Element Selection** section.

3 In the **Logical expression for inclusion** text field, type `cdpipe.Evsref>-0.1`.

4 In the **Pipe Regions not Fulfilling Protection Criterion** toolbar, click **Plot**.

Pipe Regions not Fulfilling Protection Criterion

1 In the **Model Builder** window, under **Results** click **Pipe Regions not Fulfilling Protection Criterion**.

2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

3 From the **Parameter value (R_cp (Ω))** list, choose **1**.

4 In the **Pipe Regions not Fulfilling Protection Criterion** toolbar, click **Plot**.

5 From the **Parameter value (R_cp (Ω))** list, choose **2**.

6 In the **Pipe Regions not Fulfilling Protection Criterion** toolbar, click **Plot**.

Appendix — Geometry Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 Click **Done**.

FLOORS

1 In the **Model Builder** window, right-click **Global Definitions** and choose **Geometry Parts> 3D Part**.

2 In the **Settings** window for **Part**, type `Floors` in the **Label** text field.

Block 1 (blk1)

1 In the **Geometry** toolbar, click  **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `50`.

4 In the **Depth** text field, type `30`.

5 In the **Height** text field, type `0.3`.

6 Locate the **Position** section. In the **x** text field, type `-25`.

7 In the **y** text field, type `-15`.

Block 2 (blk2)

1 In the **Geometry** toolbar, click  **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `44.75`.

4 In the **Depth** text field, type `27.15`.

5 In the **Height** text field, type `0.3`.

6 Locate the **Position** section. In the **x** text field, type `-21.5`.

7 In the **y** text field, type `-13.55`.

8 In the **z** text field, type `8.1`.

Block 3 (blk3)

1 In the **Geometry** toolbar, click  **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `1.5`.

4 In the **Depth** text field, type `0.27`.

5 In the **Height** text field, type `0.05`.

6 Locate the **Position** section. In the **x** text field, type `-23.2`.

7 In the **y** text field, type `-13`.

8 In the **z** text field, type `0.43`.

Array 1 (arr1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Array**.

2 Select the object **blk3** only.

3 In the **Settings** window for **Array**, locate the **Size** section.

4 In the **y size** text field, type `15`.

5 In the **z size** text field, type `15`.

6 Locate the **Displacement** section. In the **y** text field, type `0.27`.

7 In the **z** text field, type `0.18`.

Delete Entities 1 (del1)

1 In the **Model Builder** window, right-click **Floors** and choose **Delete Entities**.

2 In the **Settings** window for **Delete Entities**, locate the **Entities or Objects to Delete** section.

3 From the **Geometric entity level** list, choose **Object**.

4 Select the objects **arr1(1,1,10)**, **arr1(1,1,11)**, **arr1(1,1,12)**, **arr1(1,1,13)**, **arr1(1,1,14)**, **arr1(1,1,15)**, **arr1(1,1,2)**, **arr1(1,1,3)**, **arr1(1,1,4)**, **arr1(1,1,5)**, **arr1(1,1,6)**, **arr1(1,1,7)**, **arr1(1,1,8)**, **arr1(1,1,9)**, **arr1(1,10,1)**, **arr1(1,10,11)**, **arr1(1,10,12)**, **arr1(1,10,13)**, **arr1(1,10,14)**, **arr1(1,10,15)**, **arr1(1,10,2)**, **arr1(1,10,3)**, **arr1(1,10,4)**, **arr1(1,10,5)**, **arr1(1,10,6)**, **arr1(1,10,7)**, **arr1(1,10,8)**, **arr1(1,10,9)**, **arr1(1,11,1)**, **arr1(1,11,10)**, **arr1(1,11,12)**, **arr1(1,11,13)**, **arr1(1,11,14)**, **arr1(1,11,15)**, **arr1(1,11,2)**, **arr1(1,11,3)**, **arr1(1,11,4)**, **arr1(1,11,5)**, **arr1(1,11,6)**, **arr1(1,11,7)**, **arr1(1,11,8)**, **arr1(1,11,9)**, **arr1(1,12,1)**, **arr1(1,12,10)**, **arr1(1,12,11)**, **arr1(1,12,13)**, **arr1(1,12,14)**, **arr1(1,12,15)**, **arr1(1,12,2)**, **arr1(1,12,3)**, **arr1(1,12,4)**, **arr1(1,12,5)**, **arr1(1,12,6)**, **arr1(1,12,7)**, **arr1(1,12,8)**, **arr1(1,12,9)**, **arr1(1,13,1)**, **arr1(1,13,10)**, **arr1(1,13,11)**, **arr1(1,13,12)**, **arr1(1,13,14)**, **arr1(1,13,15)**, **arr1(1,13,2)**, **arr1(1,13,3)**, **arr1(1,13,4)**, **arr1(1,13,5)**, **arr1(1,13,6)**, **arr1(1,13,7)**, **arr1(1,13,8)**, **arr1(1,13,9)**, **arr1(1,14,1)**, **arr1(1,14,10)**, **arr1(1,14,11)**, **arr1(1,14,12)**, **arr1(1,14,13)**, **arr1(1,14,15)**, **arr1(1,14,2)**, **arr1(1,14,3)**, **arr1(1,14,4)**, **arr1(1,14,5)**, **arr1(1,14,6)**, **arr1(1,14,7)**, **arr1(1,14,8)**, **arr1(1,14,9)**, **arr1(1,15,1)**, **arr1(1,15,10)**, **arr1(1,15,11)**, **arr1(1,15,12)**, **arr1(1,15,13)**, **arr1(1,15,14)**, **arr1(1,15,2)**, **arr1(1,15,3)**, **arr1(1,15,4)**, **arr1(1,15,5)**, **arr1(1,15,6)**, **arr1(1,15,7)**, **arr1(1,15,8)**, **arr1(1,15,9)**, **arr1(1,2,1)**, **arr1(1,2,10)**, **arr1(1,2,11)**, **arr1(1,2,12)**, **arr1(1,2,13)**, **arr1(1,2,14)**, **arr1(1,2,15)**, **arr1(1,2,3)**, **arr1(1,2,4)**, **arr1(1,2,5)**, **arr1(1,2,6)**, **arr1(1,2,7)**, **arr1(1,2,8)**, **arr1(1,2,9)**, **arr1(1,3,1)**, **arr1(1,3,10)**, **arr1(1,3,11)**, **arr1(1,3,12)**, **arr1(1,3,13)**, **arr1(1,3,14)**, **arr1(1,3,15)**, **arr1(1,3,2)**, **arr1(1,3,4)**, **arr1(1,3,5)**, **arr1(1,3,6)**, **arr1(1,3,7)**, **arr1(1,3,8)**, **arr1(1,3,9)**, **arr1(1,4,1)**, **arr1(1,4,10)**, **arr1(1,4,11)**, **arr1(1,4,12)**, **arr1(1,4,13)**, **arr1(1,4,14)**, **arr1(1,4,15)**, **arr1(1,4,2)**, **arr1(1,4,3)**, **arr1(1,4,5)**, **arr1(1,4,6)**, **arr1(1,4,7)**, **arr1(1,4,8)**, **arr1(1,4,9)**, **arr1(1,5,1)**, **arr1(1,5,10)**, **arr1(1,5,11)**, **arr1(1,5,12)**, **arr1(1,5,13)**, **arr1(1,5,14)**, **arr1(1,5,15)**, **arr1(1,5,2)**, **arr1(1,5,3)**, **arr1(1,5,4)**, **arr1(1,5,6)**, **arr1(1,5,7)**, **arr1(1,5,8)**, **arr1(1,5,9)**, **arr1(1,6,1)**, **arr1(1,6,10)**, **arr1(1,6,11)**, **arr1(1,6,12)**, **arr1(1,6,13)**, **arr1(1,6,14)**,

arr1(1,6,15), **arr1(1,6,2)**, **arr1(1,6,3)**, **arr1(1,6,4)**, **arr1(1,6,5)**, **arr1(1,6,7)**, **arr1(1,6,8)**, **arr1(1,6,9)**, **arr1(1,7,1)**, **arr1(1,7,10)**, **arr1(1,7,11)**, **arr1(1,7,12)**, **arr1(1,7,13)**, **arr1(1,7,14)**, **arr1(1,7,15)**, **arr1(1,7,2)**, **arr1(1,7,3)**, **arr1(1,7,4)**, **arr1(1,7,5)**, **arr1(1,7,6)**, **arr1(1,7,8)**, **arr1(1,7,9)**, **arr1(1,8,1)**, **arr1(1,8,10)**, **arr1(1,8,11)**, **arr1(1,8,12)**, **arr1(1,8,13)**, **arr1(1,8,14)**, **arr1(1,8,15)**, **arr1(1,8,2)**, **arr1(1,8,3)**, **arr1(1,8,4)**, **arr1(1,8,5)**, **arr1(1,8,6)**, **arr1(1,8,7)**, **arr1(1,8,9)**, **arr1(1,9,1)**, **arr1(1,9,10)**, **arr1(1,9,11)**, **arr1(1,9,12)**, **arr1(1,9,13)**, **arr1(1,9,14)**, **arr1(1,9,15)**, **arr1(1,9,2)**, **arr1(1,9,3)**, **arr1(1,9,4)**, **arr1(1,9,5)**, **arr1(1,9,6)**, **arr1(1,9,7)**, and **arr1(1,9,8)** only.

Block 4 (blk4)

1. In the **Geometry** toolbar, click  **Block**.
2. In the **Settings** window for **Block**, locate the **Size and Shape** section.
3. In the **Width** text field, type `1.5`.
4. In the **Depth** text field, type `1.8`.
5. In the **Height** text field, type `0.05`.
6. Locate the **Position** section. In the **x** text field, type `-23.2`.
7. In the **y** text field, type `-8.95`.
8. In the **z** text field, type `2.95`.

Move 1 (mov1)

1. In the **Geometry** toolbar, click  **Transforms** and choose **Move**.
2. Select the objects **arr1(1,1,1)**, **arr1(1,10,10)**, **arr1(1,11,11)**, **arr1(1,12,12)**, **arr1(1,13,13)**, **arr1(1,14,14)**, **arr1(1,15,15)**, **arr1(1,2,2)**, **arr1(1,3,3)**, **arr1(1,4,4)**, **arr1(1,5,5)**, **arr1(1,6,6)**, **arr1(1,7,7)**, **arr1(1,8,8)**, **arr1(1,9,9)**, and **blk4** only.
3. In the **Settings** window for **Move**, locate the **Input** section.
4. Select the **Keep input objects** check box.
5. Locate the **Displacement** section. In the **y** text field, type `5.85 11.7`.
6. In the **z** text field, type `2.7 5.4`.

Work Plane 1 (wp1)

1. In the **Geometry** toolbar, click  **Work Plane**.
2. In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
3. From the **Plane** list, choose **yz-plane**.
4. In the **x-coordinate** text field, type `-23.2`.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
-12.75	0.3
-8.92	2.85
-7.12	2.85
-3.07	5.55
-1.27	5.55
2.78	8.25
4.55	8.25
4.55	8.5
2.45	8.5
-1.6	5.8
-3.3	5.8
-7.45	3.1
-9.25	3.1
-13.45	0.3

Extrude 1 (ext1)

1 In the **Model Builder** window, under **Global Definitions>Geometry Parts>Floors** right-click **Work Plane 1 (wp1)** and choose **Extrude**.

2 In the **Settings** window for **Extrude**, locate the **Distances** section.

3 In the table, enter the following settings:

Distances (m)
0.05

Move 2 (mov2)

1 In the **Geometry** toolbar, click **Transforms** and choose **Move**.

2 Select the object **ext1** only.

3 In the **Settings** window for **Move**, locate the **Input** section.

4 Select the **Keep input objects** check box.

5 Locate the **Displacement** section. In the **x** text field, type 1.5.

Block 5 (blk5)

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `1.55`.

4 In the **Depth** text field, type `0.05`.

5 In the **Height** text field, type `0.25`.

6 Locate the **Position** section. In the **x** text field, type `-23.25`.

7 In the **y** text field, type `4.55`.

8 In the **z** text field, type `8.25`.

Work Plane 2 (wp2)

1 In the **Geometry** toolbar, click **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **z-coordinate** text field, type `5.7`.

Work Plane 2 (wp2)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 2 (wp2)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 In the table, enter the following settings:

xw (m)	yw (m)
-21.7	-3.1
-18.62	-3.1
-18.62	9.245
-10.14	9.245
-10.14	-12.125
10.14	-12.125
10.14	9.25
18.62	9.25
18.62	-9.25
13.02	-9.25
13.02	-12.125
21.5	-12.125

xw (m)	yw (m)
21.5	12.125
7.28	12.125
7.28	-9.25
-7.28	-9.25
-7.28	12.125
-21.5	12.125
-21.5	-1.3
-21.7	-1.3

Extrude 2 (ext2)

1 In the **Model Builder** window, under **Global Definitions>Geometry Parts>Floors** right-click **Work Plane 2 (wp2)** and choose **Extrude**.

2 In the **Settings** window for **Extrude**, locate the **Distances** section.

3 Select the **Reverse direction** check box.

4 In the table, enter the following settings:

Distances (m)
0.3

Block 6 (blk6)

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type 0.05.

4 In the **Depth** text field, type 1.7.

5 Locate the **Position** section. In the **x** text field, type -21.75.

6 In the **y** text field, type -3.1.

7 In the **z** text field, type 5.

Block 7 (blk7)

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type 0.05.

4 In the **Depth** text field, type 1.8.

5 Locate the **Position** section. In the **x** text field, type -21.75.

6 In the **y** text field, type 2.75.

7 In the **z** text field, type `8`.

Block 8 (blk8)

1 In the **Geometry** toolbar, click  **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.2`.

4 In the **Depth** text field, type `1.8`.

5 In the **Height** text field, type `0.3`.

6 Locate the **Position** section. In the **x** text field, type `-21.7`.

7 In the **y** text field, type `2.75`.

8 In the **z** text field, type `8.1`.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Height** text field, type `3`.

4 Locate the **Position** section. In the **x** text field, type `-0.75`.

5 In the **y** text field, type `0.155`.

6 In the **z** text field, type `8`.

Cylinder 2 (cyl2)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Height** text field, type `3`.

4 Locate the **Position** section. In the **x** text field, type `10.75`.

5 In the **y** text field, type `-11.3`.

6 In the **z** text field, type `8`.

Cylinder 3 (cyl3)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Height** text field, type `3`.

4 Locate the **Position** section. In the **y** text field, type `-5.3`.

5 In the **z** text field, type `8`.

Difference 1 (dif1)

1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Difference**.

2 Select the object **blk2** only.

3 In the **Settings** window for **Difference**, locate the **Difference** section.

4 Click to select the  **Activate Selection** toggle button for **Objects to subtract**.

5 Select the objects **cyl1**, **cyl2**, and **cyl3** only.

Difference 2 (dif2)

1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Difference**.

2 Select the object **mov2** only.

3 In the **Settings** window for **Difference**, locate the **Difference** section.

4 Click to select the  **Activate Selection** toggle button for **Objects to subtract**.

5 Select the objects **blk6** and **blk7** only.

Union 1 (uni1)

1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.

2 Click in the **Graphics** window and then press Ctrl+A to select all objects.

3 In the **Settings** window for **Union**, locate the **Union** section.

4 Clear the **Keep interior boundaries** check box.

Work Plane 3 (wp3)

1 In the **Geometry** toolbar, click  **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **yz-plane**.

4 In the **x-coordinate** text field, type `-23.22`.

Work Plane 3 (wp3)>Plane Geometry

1 In the **Model Builder** window, click **Plane Geometry**.

2 In the **Work Plane** toolbar, click  **Sketch** to toggle off sketch mode.

Work Plane 3 (wp3)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click  **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Object Type** section.

3 From the **Type** list, choose **Open curve**.

4 Locate the **Coordinates** section. In the table, enter the following settings:

xw (m)	yw (m)
4	9.4
2.45	9.4
-1.6	6.7
-3.3	6.7
-7.45	4
-9.25	4
-13.45	1.2
-14	1.2

Work Plane 3 (wp3)>Fillet 1 (fil1)

1 In the **Work Plane** toolbar, click  **Fillet**.

2 In the **Settings** window for **Fillet**, locate the **Radius** section.

3 In the **Radius** text field, type `0.5`.

4 On the object **pol1**, select Points 2–7 only.

Work Plane 4 (wp4)

1 In the **Model Builder** window, right-click **Floors** and choose **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **yz-plane**.

4 In the **x-coordinate** text field, type `-21.725`.

Work Plane 4 (wp4)>Plane Geometry

1 In the **Model Builder** window, click **Plane Geometry**.

2 In the **Work Plane** toolbar, click  **Sketch**.

Work Plane 4 (wp4)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click  **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Object Type** section.

3 From the **Type** list, choose **Open curve**.

4 Locate the **Coordinates** section. In the table, enter the following settings:

xw (m)	yw (m)
3	9.4
2.45	9.4

xw (m)	yw (m)
-1.6	6.7
-1.8	6.7

Work Plane 4 (wp4)>Polygon 2 (pol2)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Object Type** section.

3 From the **Type** list, choose **Open curve**.

4 Locate the **Coordinates** section. In the table, enter the following settings:

xw (m)	yw (m)
-3	6.7
-3.3	6.7
-7.45	4
-9.25	4
-13.45	1.2
-14	1.2

Work Plane 4 (wp4)>Fillet 1 (fil1)

1 In the **Work Plane** toolbar, click **Fillet**.

2 On the object **pol1**, select Points 2 and 3 only.

3 On the object **pol2**, select Points 2–5 only.

4 In the **Settings** window for **Fillet**, locate the **Radius** section.

5 In the **Radius** text field, type 0.5.

Work Plane 5 (wp5)

1 In the **Model Builder** window, right-click **Floors** and choose **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **z-coordinate** text field, type 9.4.

Work Plane 5 (wp5)>Plane Geometry

1 In the **Model Builder** window, click **Plane Geometry**.

2 In the **Work Plane** toolbar, click **Sketch**.

Work Plane 5 (wp5)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Object Type** section.

3 From the **Type** list, choose **Open curve**.

4 Locate the **Coordinates** section. In the table, enter the following settings:

xw (m)	yw (m)
-23.22	4
-23.22	4.5
-21.2	4.5
-21.2	13.55
23.2	13.55
23.2	-13.5
-21.2	-13.5
-21.2	3.2
-21.725	3.2
-21.725	3

Work Plane 5 (wp5)>Fillet 1 (fil1)

1 In the **Work Plane** toolbar, click **Fillet**.

2 In the **Settings** window for **Fillet**, locate the **Radius** section.

3 In the **Radius** text field, type `0.2`.

4 Locate the **Points** section. Click to clear the **Activate Selection** toggle button for **Vertices to fillet**.

5 On the object **pol1**, select Points 2 and 4–10 only.

6 Click to select the **Activate Selection** toggle button for **Vertices to fillet**.

7 On the object **pol1**, select Points 2 and 4–10 only.

Work Plane 6 (wp6)

1 In the **Model Builder** window, right-click **Floors** and choose **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 In the **z-coordinate** text field, type `6.7`.

Work Plane 6 (wp6)>Plane Geometry

1 In the **Model Builder** window, click **Plane Geometry**.

2 In the **Work Plane** toolbar, click **Sketch**.

Work Plane 6 (wp6)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Object Type** section.

3 From the **Type** list, choose **Open curve**.

4 Locate the **Coordinates** section. In the table, enter the following settings:

xw (m)	yw (m)
-21.725	-1.8
-21.725	-2.2
-21.2	-2.2
-21.2	12.075
-7.32	12.075
-7.32	-9.3
7.32	-9.3
7.32	12.075
21.45	12.075
21.45	-12.075
13.07	-12.075
13.07	-9.3
18.67	-9.3
18.67	9.3
10.09	9.3
10.09	-12.075
-10.09	-12.075
-10.09	9.3
-18.67	9.3
-18.67	-2.8
-21.725	-2.8
-21.725	-3

Work Plane 6 (wp6)>Fillet 1 (fil1)

1 In the **Work Plane** toolbar, click **Fillet**.

2 In the **Settings** window for **Fillet**, locate the **Radius** section.

3 In the **Radius** text field, type `0.2`.

4 Locate the **Points** section. Click to clear the **Activate Selection** toggle button for **Vertices to fillet**.

5 On the object **pol1**, select Points 3–6, 8, 10, and 12 only.

6 Click to select the **Activate Selection** toggle button for **Vertices to fillet**.

7 On the object **pol1**, select Points 2, 3, and 5–22 only.

Work Plane 7 (wp7)

1 In the **Model Builder** window, right-click **Floors** and choose **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **zx-plane**.

4 In the **y-coordinate** text field, type `-14`.

Work Plane 7 (wp7)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 7 (wp7)>Circle 1 (c1)

1 In the **Work Plane** toolbar, click **Circle**.

2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.08`.

4 Locate the **Position** section. In the **xw** text field, type `1.2`.

5 In the **yw** text field, type `-23.22`.

Sweep 1 (swe1)

1 In the **Model Builder** window, right-click **Floors** and choose **Sweep**.

2 In the **Settings** window for **Sweep**, locate the **Spine Curve** section.

3 Select the **Manual control of sweep direction** check box.

4 Select the **Reverse direction** check box.

5 On the object **wp7**, select Boundary 1 only.

6 Click to select the **Activate Selection** toggle button for **Edges to follow**.

7 On the object **wp3**, select Edges 1–13 only.

8 On the object **wp4**, select Edges 1–14 only.

9 On the object **wp5**, select Edges 1–16 only.

10 On the object **wp6**, select Edges 1–40 only.

11 Locate the **Keep Input** section. Clear the **Keep input objects** check box.

Move 3 (mov3)

1 In the **Geometry** toolbar, click **Transforms** and choose **Move**.

2 Select the object **swe1** only.

3 In the **Settings** window for **Move**, locate the **Input** section.

4 Select the **Keep input objects** check box.

5 Locate the **Displacement** section. In the **z** text field, type `-0.5`.

PIPING_01

1 In the **Model Builder** window, under **Global Definitions** right-click **Geometry Parts** and choose **3D Part**.

2 In the **Settings** window for **Part**, type `Piping_01` in the **Label** text field.

Block 1 (blk1)

1 In the **Geometry** toolbar, click  **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `5.5`.

4 In the **Depth** text field, type `14.5`.

5 In the **Height** text field, type `0.5`.

6 Locate the **Position** section. In the **x** text field, type `11.8`.

7 In the **y** text field, type `-7.6`.

8 In the **z** text field, type `0.3`.

Work Plane 1 (wp1)

1 In the **Geometry** toolbar, click  **Work Plane**.

2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.

3 From the **Plane** list, choose **yz-plane**.

4 In the **x-coordinate** text field, type `14.55`.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1)>Rectangle 1 (r1)

1 In the **Work Plane** toolbar, click  **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `4.3`.

4 In the **Height** text field, type `1.45`.

5 Locate the **Position** section. In the **xw** text field, type `-2.15`.

6 In the **yw** text field, type `2.8`.

Work Plane 1 (wp1)>Circle 1 (c1)

1 In the **Work Plane** toolbar, click  **Circle**.

2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `1.45`.

4 In the **Sector angle** text field, type `90`.

5 Locate the **Position** section. In the **xw** text field, type `2.15`.

6 In the **yw** text field, type `2.8`.

Work Plane 1 (wp1)>Rectangle 2 (r2)

1 In the **Work Plane** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.78`.

4 In the **Height** text field, type `0.3`.

5 Locate the **Position** section. In the **xw** text field, type `3.22`.

6 In the **yw** text field, type `2.8`.

Work Plane 1 (wp1)>Rectangle 3 (r3)

1 In the **Work Plane** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.2`.

4 In the **Height** text field, type `0.6`.

5 Locate the **Position** section. In the **xw** text field, type `4`.

6 In the **yw** text field, type `2.8`.

Work Plane 1 (wp1)>Mirror 1 (mir1)

1 In the **Work Plane** toolbar, click **Transforms** and choose **Mirror**.

2 Select the objects **c1**, **r2**, and **r3** only.

3 In the **Settings** window for **Mirror**, locate the **Input** section.

4 Select the **Keep input objects** check box.

Work Plane 1 (wp1)>Union 1 (uni1)

1 In the **Work Plane** toolbar, click **Booleans and Partitions** and choose **Union**.

2 In the **Settings** window for **Union**, locate the **Union** section.

3 Clear the **Keep interior boundaries** check box.

4 Click in the **Graphics** window and then press Ctrl+A to select all objects.

Revolve 1 (rev1)

1 In the **Model Builder** window, under **Global Definitions>Geometry Parts>Piping_01** right-click **Work Plane 1 (wp1)** and choose **Revolve**.

2 In the **Settings** window for **Revolve**, locate the **Revolution Axis** section.

3 Find the **Point on the revolution axis** subsection. In the **yw** text field, type `2.8`.

4 Find the **Direction of revolution axis** subsection. In the **xw** text field, type `1`.

5 In the **yw** text field, type `0`.

Pyramid 1 (pyr1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Pyramid**.

2 In the **Settings** window for **Pyramid**, locate the **Size and Shape** section.

3 In the **Base length 1** text field, type `1.56`.

4 In the **Base length 2** text field, type `0.8`.

5 In the **Height** text field, type `0.95`.

6 Locate the **Position** section. In the **x** text field, type `14.55`.

7 In the **y** text field, type `2.5`.

8 In the **z** text field, type `0.8`.

Pyramid 2 (pyr2)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Pyramid**.

2 In the **Settings** window for **Pyramid**, locate the **Size and Shape** section.

3 In the **Base length 1** text field, type `1.56`.

4 In the **Base length 2** text field, type `0.8`.

5 In the **Height** text field, type `0.95`.

6 Locate the **Position** section. In the **x** text field, type `14.55`.

7 In the **y** text field, type `-2.5`.

8 In the **z** text field, type `0.8`.

Union 1 (uni1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 Click in the **Graphics** window and then press Ctrl+A to select all objects.

3 In the **Settings** window for **Union**, locate the **Union** section.

4 Clear the **Keep interior boundaries** check box.

Polygon 1 (pol1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `resistor_modulated_pipeline_cathodic_protection_geometry_piping1_polygon1.txt`.

5 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

6 In the **New Cumulative Selection** dialog box, type `piping_01` in the **Name** text field.

7 Click **OK**.

8 In the **Settings** window for **Polygon**, click **Build Selected**.

PIPING_02

1 In the **Model Builder** window, under **Global Definitions** right-click **Geometry Parts** and choose **3D Part**.

2 In the **Settings** window for **Part**, type `Piping_02` in the **Label** text field.

Block 1 (blk1)

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `3.75`.

4 In the **Depth** text field, type `6.8`.

5 In the **Height** text field, type `0.5`.

6 Locate the **Position** section. In the **x** text field, type `-20.9`.

7 In the **y** text field, type `3.55`.

8 In the **z** text field, type `0.3`.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.6`.

4 In the **Height** text field, type `0.25`.

5 Locate the **Position** section. In the **x** text field, type `-19.025`.

6 In the **y** text field, type `7`.

7 In the **z** text field, type `0.8`.

Cylinder 2 (cyl2)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.3`.

4 In the **Height** text field, type `1.5`.

5 Locate the **Position** section. In the **x** text field, type `-19.025`.

6 In the **y** text field, type `7`.

7 In the **z** text field, type `1.05`.

Cylinder 3 (cyl3)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.6`.

4 In the **Height** text field, type `0.25`.

5 Locate the **Position** section. In the **x** text field, type `-19.025`.

6 In the **y** text field, type `7`.

7 In the **z** text field, type `2.55`.

Cylinder 4 (cyl4)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.8`.

4 In the **Height** text field, type `0.25`.

5 Locate the **Position** section. In the **x** text field, type `-19.025`.

6 In the **y** text field, type `8.6`.

7 In the **z** text field, type `0.8`.

Cylinder 5 (cyl5)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.4`.

4 In the **Height** text field, type `3`.

5 Locate the **Position** section. In the **x** text field, type `-19.025`.

6 In the **y** text field, type `8.6`.

7 In the **z** text field, type `1.05`.

Cylinder 6 (cyl6)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.8`.

4 In the **Height** text field, type `0.25`.

5 Locate the **Position** section. In the **x** text field, type `-19.025`.

6 In the **y** text field, type `8.6`.

7 In the **z** text field, type `4.05`.

Cylinder 7 (cyl7)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.38`.

4 In the **Height** text field, type `0.1`.

5 Locate the **Position** section. In the **x** text field, type `-19.8`.

6 In the **y** text field, type `8.6`.

7 In the **z** text field, type `3.15`.

8 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

Cylinder 8 (cyl8)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.25`.

4 In the **Height** text field, type `0.4`.

5 Locate the **Position** section. In the **x** text field, type `-19.7`.

6 In the **y** text field, type `8.6`.

7 In the **z** text field, type `3.15`.

8 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

Cylinder 9 (cyl9)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.35`.

4 In the **Height** text field, type `0.1`.

5 Locate the **Position** section. In the **x** text field, type `-18.55`.

6 In the **y** text field, type `7`.

7 In the **z** text field, type `1.85`.

8 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

Cylinder 10 (cyl10)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.175`.

4 In the **Height** text field, type `0.25`.

5 Locate the **Position** section. In the **x** text field, type `-18.8`.

6 In the **y** text field, type `7`.

7 In the **z** text field, type `1.85`.

8 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

Cylinder 11 (cyl11)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `0.55`.

4 In the **Height** text field, type `2.5`.

5 Locate the **Position** section. In the **x** text field, type `-20.29`.

6 In the **y** text field, type `4.7`.

7 In the **z** text field, type `1.6`.

8 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

Pyramid 1 (pyr1)

1 In the **Geometry** toolbar, click  **More Primitives** and choose **Pyramid**.

2 In the **Settings** window for **Pyramid**, locate the **Size and Shape** section.

3 In the **Base length 1** text field, type `0.4`.

4 In the **Height** text field, type `0.5`.

5 Locate the **Position** section. In the **x** text field, type `-20`.

6 In the **y** text field, type `4.7`.

7 In the **z** text field, type `0.8`.

Pyramid 2 (pyr2)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Pyramid**.

2 In the **Settings** window for **Pyramid**, locate the **Size and Shape** section.

3 In the **Base length 1** text field, type `0.4`.

4 In the **Height** text field, type `0.5`.

5 Locate the **Position** section. In the **x** text field, type `-18.15`.

6 In the **y** text field, type `4.7`.

7 In the **z** text field, type `0.8`.

Union 1 (uni1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 Click in the **Graphics** window and then press Ctrl+A to select all objects.

3 In the **Settings** window for **Union**, locate the **Union** section.

4 Clear the **Keep interior boundaries** check box.

Polygon 1 (pol1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `resistor_modulated_pipeline_cathodic_protection_geometry_piping2_polygon1.txt`.

5 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

6 In the **New Cumulative Selection** dialog box, type `piping_02` in the **Name** text field.

7 Click **OK**.

Polygon 2 (pol2)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `resistor_modulated_pipeline_cathodic_protection_geometry_piping2_polygon2.txt`.

5 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. From the **Contribute to** list, choose **piping_02**.

GEOMETRY 1

Floors

1 In the **Geometry** toolbar, click **Part Instance** and choose **Floors**.

2 In the **Settings** window for **Part Instance**, type `Floors` in the **Label** text field.

Piping Cycle 1

1 In the **Geometry** toolbar, click **Part Instance** and choose **Piping_01**.

2 In the **Settings** window for **Part Instance**, type `Piping Cycle 1` in the **Label** text field.

3 Click to expand the **Edge Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
piping_01	√	√	None

Piping Cycle 2

1 In the **Geometry** toolbar, click **Part Instance** and choose **Piping_02**.

2 In the **Settings** window for **Part Instance**, type `Piping Cycle 2` in the **Label** text field.

3 Locate the **Edge Selections** section. In the table, enter the following settings:

Name	Keep	Physics	Contribute to
piping_02	√	√	None

Pipeline Network

1 In the **Geometry** toolbar, click **Selections** and choose **Union Selection**.

2 In the **Settings** window for **Union Selection**, type `Pipeline Network` in the **Label** text field.

3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Edge**.

4 Locate the **Input Entities** section. Click **Add**.

5 In the **Add** dialog box, in the **Selections to add** list, choose **piping_01 (Piping Cycle 1)** and **piping_02 (Piping Cycle 2)**.

6 Click **OK**.

Point Sacrificial Anodes

1 In the **Geometry** toolbar, click **Selections** and choose **Explicit Selection**.

2 In the **Settings** window for **Explicit Selection**, locate the **Entities to Select** section.

3 From the **Geometric entity level** list, choose **Point**.

4 In the **Label** text field, type `Point Sacrificial Anodes`.

5 Locate the **Entities to Select** section. Click the  **Paste Selection** button for **Entities to select**.

6 In the **Paste Selection** dialog box, type `pi3(2): 1-3, 9, 15, 24, 29, 34, 36, 45, 48, 56, 66, 73, 80, 84, 85, 97, 101, 106, 111, 115, 121, 124, 130, 135, 139, 143, 162, 166, 170, 178, 182, 183, 186, 192, 193, 201, 207, 215, 219, 221, 224, 227, 231, 236, 239, 244, 250 pi2(2): 1, 11, 13, 18, 27, 28, 36, 38, 46, 51, 58, 60, 66, 72, 77, 82, 86, 91, 94, 100, 103, 186, 187, 189, 190, 193, 198, 220, 238, 240, 271, 274, 280, 284, 290, 295, 298, 303, 307, 313, 317, 324, 327, 335, 337, 346, 349, 351, 355, 362, 369, 375, 379, 381 pi1(1): 657 pi3(3): 1, 6, 7, 12, 13, 15, 16, 46, 52, 58, 62, 73, 74, 77 pi2(1): 11` in the **Selection** text field.

7 Click **OK**.

Form Union (fin)

1 In the **Model Builder** window, click **Form Union (fin)**.

2 In the **Settings** window for **Form Union/Assembly**, click  **Build Selected**.