TRACE Modeling Issues

Information Systems Laboratories, Inc.

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TRACE/SNAP User Workshop
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Objective

Discuss and illustrate modeling issues affecting development of acceptable TRACE plant system models.

Outline

Key plant modeling guidelines (see TRACE User Manual, Volume 2, Page 7 for top-level guidelines and Page 249 for detailed guidelines)

- L/D considerations for modeling one-dimensional flow paths
- Loop seal nodalization
- Reactor vessel nodalization

Modeling frictional pressure drops and connections

- Example exercise

Loop elevation closure

- Example exercise

L/D Considerations for Modeling One-Dimensional Flow Paths

Example applications:

- PWR hot and cold legs,
- PWR and BWR steam lines

Use of longer cells increases Courant time step limit, allowing for improved running times.

- detail in the solution along the flow path is reduced.

Use of shorter cells increases the running time.

- provides more solution detail.

L/D Considerations for Modeling One-Dimensional Flow Paths

Use of very short cells (L/D < 1) violates the basic assumption of one-dimensional modeling that the changes in conditions in the direction of flow are much greater than the changes in conditions transverse (i.e., perpendicular) to the direction of flow.

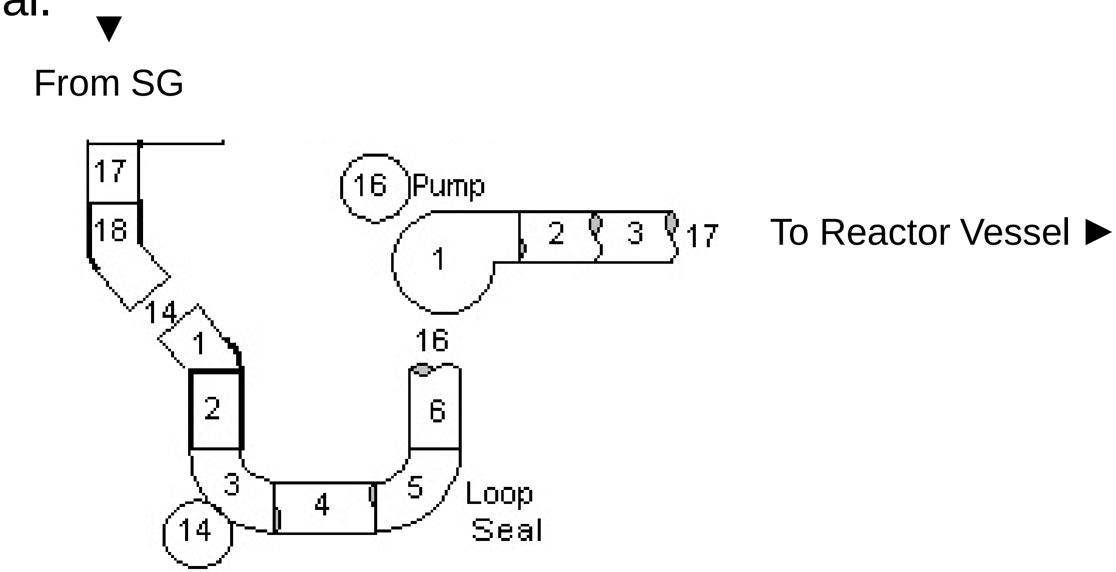
Current recommended convention for plant system models is a cell length-to-diameter ratio (L/D) goal of between 4 to 5 for one-dimensional components.

Compromises using L/D < 4 may be needed to adequately model the physical flow and/or thermal behavior

Example: PWR steam generator secondary boiler regions, with axial noding selected to correspond to SG tube primary axial noding.

Loop Seal Nodalization

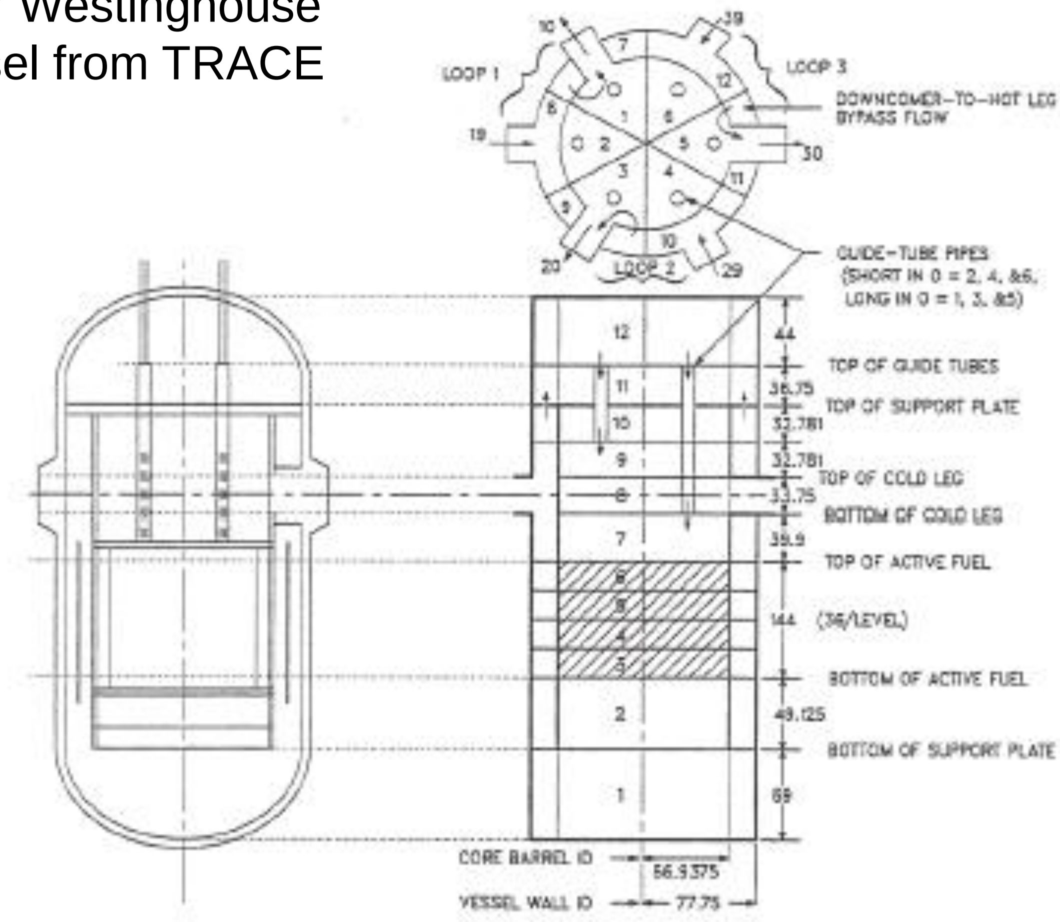
- Loop seal behavior is key for prediction of PWR SBLOCAs
- Nodalization should be set up to permit horizontal flow regimes near the bottom of the loop seal
- Allows simulation of steam escaping over liquid, providing capability for the loop seal to remain partially filled following “loop seal clearing”
- Flow resistance through a partially-filled loop seal can be much greater than through an empty loop seal.



Reactor Vessel Modeling Summary

Example diagrams shown for Westinghouse three-loop PWR reactor vessel from TRACE User's Manual Volume 2.

Practical, updated reactor vessel modeling guidelines based on recent TRACE plant model development experiences are discussed here.



Reactor Vessel Hydrodynamic Nodalization Considerations

Selection of axial levels, radial rings and azimuth sectors should be based on the plant configuration and on the physical behavior at steady state and during transients.

A generally-useful model is desirable and can be created, but the compromises included need to be considered for specific analyses.

Reactor Vessel Hydrodynamic Nodalization Considerations

A successful and economical general reactor vessel modeling approach is summarized as follows:

Axial Levels: ~20, typically

- ~3 in lower plenum,
- ~12 in core,
  - ➢ Use 2 cells between core grid spacers, no flow area reduction for the grid spacers and K losses adjusted accordingly.
  - ➢ Consider need for shorter levels at top of core for uncovery during SBLOCAs
- ~3 in upper plenum, and
- ~2 in upper head

Reactor Vessel Hydrodynamic Nodalization Considerations

Radial Rings: ~3, typically

- 2 for the core and
- 1 for the downcomer

Azimuth Sectors: selected based on major reactor vessel piping connections (hot legs, cold legs, direct vessel injection lines).

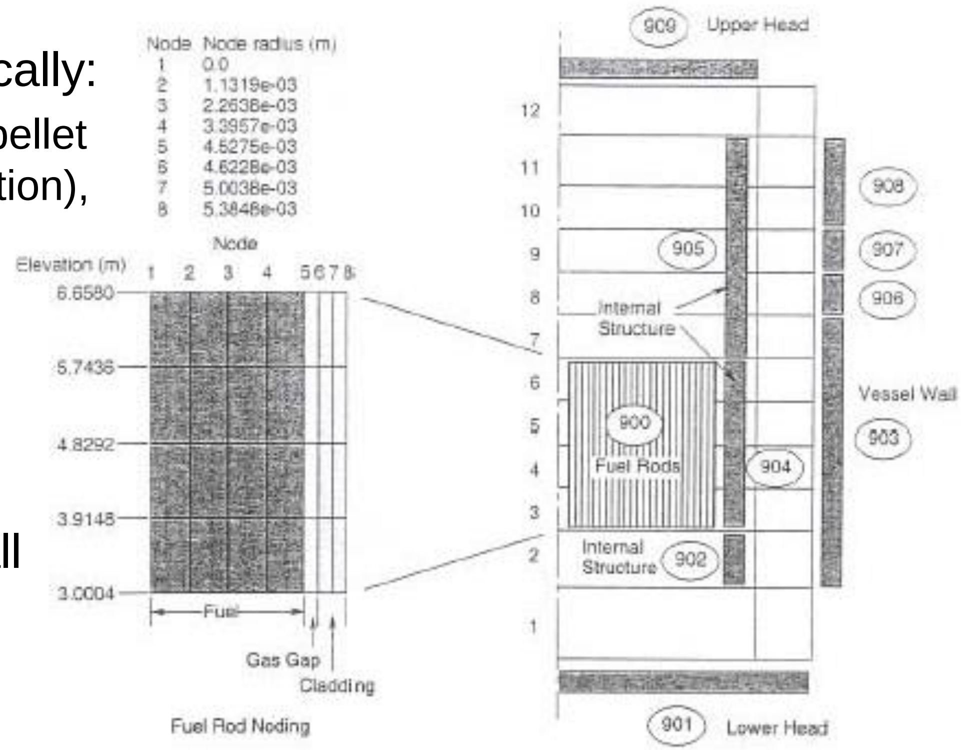
- 6 sectors for three loop and “2x4” loop plants,
- 8 sectors for four loop plants, (consider need for downcomer channels dedicated to direct vessel injection in advanced plants.)

Model lower core bypass (guide tubes and/or barrel baffle region) and upper plenum to upper head cooling flow (guide tubes) using one-dimensional PIPEs.

Reactor Vessel Heat Structure Considerations

~8 total fuel rod radial nodes, typically:

- 5 for UO2 (more if radial profile in pellet is important for a particular application),
- 1 for gap, and
- 2 for cladding.



VESSEL component has built-in wall heat structure feature (incompatible with SNAP).

Recommend using separate HTSTR components for the vessel wall and internal structures (vessel cylindrical wall and heads, core barrel, support columns and plates, guide tubes).

Modeling Frictional Pressure Drops and Connections

Frictional pressure loss modeling is a frequent source of errors.

TRACE allows constant user-input flow friction data to be entered in two formats, friction factors (FRIC, FRICR) and flow loss coefficients (K, KR), where:

K = FRIC (L/D)

The format selection is made with NAMELIST Variable IKFAC:

IKFAC = 0, enter FRICs (TRACE default)

IKFAC = 1, enter Ks (SNAP default)

Traditional TRAC modeling was based on FRIC, but other code and experimental applications typically used K. Use of K in TRACE applications is currently recommended to avoid confusion when comparing with other applications.

Modeling Frictional Pressure Drops and Connections

TRACE also allows for Reynolds dependent flow loss factors for forward and reverse directions.

The input for this form of flow loss input is activated when NAMELIST variable FLOWDEPK = .TRUE. The Reynolds dependent flow loss factor take on the form of:

K (or FRIC) = $\boldsymbol{B/Re^{C}}$

Where:

Re = the Reynolds Number,

B = input variable FRICBFORRE for forward flow or FRICBREVRE for reverse flow, and

C = input variable FRICCFORRE for forward flow or FRICCREVRE for reverse flow

Question: Under what circumstances might the Reynolds Dependent Flow Loss factor be important to consider?

Modeling Frictional Pressure Drops and Connections

NAMELIST Variables NFRC1 and NFRC3 are used to define whether the K or FRIC may be input using different values for the forward and reverse directions.

- For one-dimensional components:
  - NFRC1 = 1, enter one flow loss at each face, applied in forward and reverse directions
  - NFRC1 = 2, enter two flow losses at each face, one for the forward direction and one for the reverse direction
  - TRACE and SNAP defaults are NFRC1 = 1

- For three-dimensional VESSEL components:
  - NFRC3 = 1, enter one flow loss at each face, applied in forward and reverse directions
  - NFRC3 = 2, enter two flow losses at each face, one for the forward direction and one for the reverse direction
  - TRACE and SNAP defaults are NFRC3 = 1

Modeling Frictional Pressure Drops and Connections

The user may also elect to allow the TRACE code to internally calculate additional FRIC and FRICR friction data based on an abrupt area change model.

The abrupt area change flow loss is based upon the flow areas at the cell face and in the adjacent upstream and downstream cells, and upon the flow rate.

For one-dimensional components:

- an abrupt area change flow loss is requested with array-input parameter NFF = -1 or -100 at a cell face.
- TRACE NFF default: None, user must enter NFF
- SNAP NFF default: 1 [(homogeneous flow friction factor)(L/D) + K]

For three-dimensional VESSEL components:

- an abrupt area change flow loss is requested by entering a negative value for the flow loss coefficient, for example “CFZLYT”, at a cell face.
- TRACE calculates an abrupt area change flow loss and adds it to a constant user-input flow loss with the absolute value of the data entry.

Modeling Frictional Pressure Drops and Connections

The total frictional flow loss at a cell face is the sum of:

(1) the constant user-input FRIC or K flow loss,

(2) the TRACE-calculated abrupt area change FRIC flow loss, if requested, and

(3) the TRACE-calculated wall friction flow loss, where f_{wall} is the homogeneous-flow friction factor that TRACE calculates as a function of hydraulic diameter, wall surface roughness and flow rate.

When entering FRIC data, the total frictional pressure drop is:

$$\Delta P = [\, FRIC_{Constant} + FRIC_{Abrupt} + f_{wall} \,] * [\, L / D \,] * [\, \rho * V^2 / 2 \,]$$

When entering K data, the total frictional pressure drop is:

$$\Delta P = [\, K_{constant} + (FRIC_{Abrupt} * L / D) + (f_{wall} * L / D) \,] * [\, \rho * V^2 / 2 \,]$$

Where:

L = the sum of the half-cell lengths on each side of the cell face,

D = the hydraulic diameter of the cell face, and

V (velocity) is based on the flow area of the cell face.

Note: See User Guide Volume 2 for the D that is applicable at cell faces where the abrupt area change loss model is active. The SNAP “calculate hydraulic diameter” option only applicable for situations where parallel flow paths are not lumped together (for example, as is done when modeling all steam generator tubes using a single TRACE PIPE component).

Calibration of System Model Pressure Drops

After a system model has been developed and checked for loop elevation closure, it may be run with pumps and heat sources powered, so as to initialize the fluid and heat structures at the desired set of conditions. (A discussion and exercise on loop elevation closure methods is provided later in this presentation).

When the desired loop flow rates have been achieved, the analyst should compare the calculated differential pressures with the available data from the prototype facility. For PWRs, prototype data is often available for the differential pressures across the core, reactor vessel, steam generators and reactor coolant pumps. For valid comparisons, the analyst needs to be aware of the basis of the prototype data (especially flow and elevation effects).

For PWRs, the pressure gained at the reactor coolant pump is that required to drive the loop flow at the desired rate through the reactor vessel, hot leg piping, steam generators and cold leg piping.

Adjustments are typically required in the FRIC or K input in order for an adequate match to be achieved between all of the TRACE and prototype differential pressures. Best to make these adjustments at locations where the geometry and flow behavior is particularly complex and uncertainty in the flow loss is the greatest (for example, turning and cross-flow through internals in reactor vessel lower plenum).

Pressure Drop Modeling Exercise

Refer to the "Friction" exercise instructions in the Workbook under Day-2 Morning

Background considerations related to this exercise:

- For every K, there is an associated reference flow area A
- Can modify K to provide the same pressure drop for the same flow through a different A using the formula $K_1/A_1^2 = K_2/A_2^2$
- TRACE input Ks are constants (typically fully-turbulent flow is assumed)
- TRACE-calculated wall friction and abrupt area change loss are functions of velocity
- Carefully consider the forms and conditions used for the upstream and downstream boundary conditions
- Hand calculation checks of TRACE-calculated pressure drops can be useful for confirming model performance and identifying modeling errors

Loop Elevation Closure

A few things need to be kept in mind relative to loop elevation closure when developing or using an existing input deck.

A. TRACE allows three formats for entering elevation data for 1-D components:

1. GRAV Terms (IELEV = 0)

$$GRAV = \Delta Z / (0.5*DX_1 + 0.5*DX_2)$$

2. Elevation Input (IELEV = 1)

Absolute elevation of the cell center relative to a reference component

3. Change in Elevation Input for individual cells (IELEV = 2)

Loop Elevation Closure

While all three elevation data input formats are valid, the bottom line is the user needs to pay attention to the SNAP loop checker output and the warning messages that are output by TRACE during input processing.

When using SNAP for model development, the recommended elevation data input format is the GRAV term. Since some of the closure models in TRACE use GRAV terms, the other input formats are converted to GRAV terms internally. Using the GRAV input reduces the potential for input errors and non-physical results. Refer to the TRACE User's Manual, Volume 2: Modeling Guidelines for use of the other input formats.

Loop Elevation Closure

B. PIPEs can be used to model flow paths through a VESSEL component, such as the guide tubes in the upper plenum and upper head.

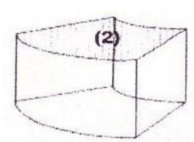
The following guidelines are helpful when connecting 1-D components to VESSELs to assure loop closure (GRAV input format is assumed and only axial connections are shown)

Consider the input nodalization:

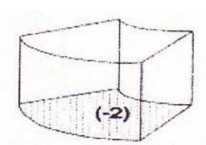
The change in elevation of the PIPE is the same as the change in elevation between the top of Level 15 and the bottom of Level 22 in the VESSEL

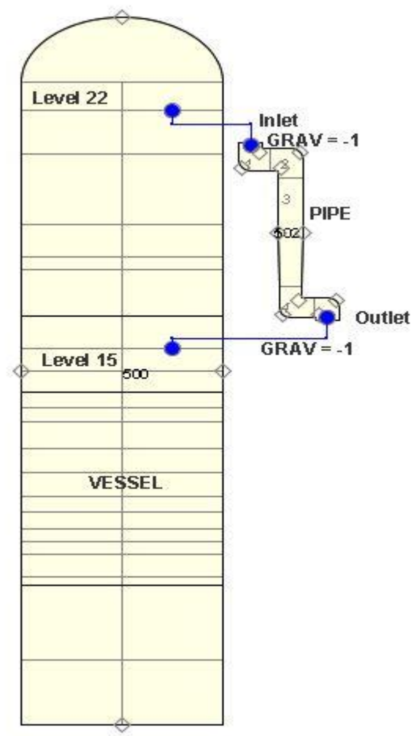
VESSEL axial cell face numbering:

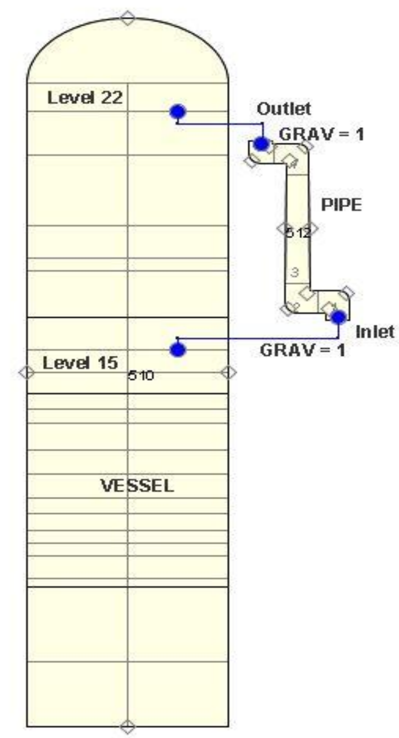
Outlet Face



Inlet Face







Loop Elevation Closure

Vessel cell face source connection considerations important for elevation closure:

1. If the inlet GRAV of a 1-D component is -1, then connect to the axial inlet face (LISRF = -2) of a VESSEL cell.

2. If the inlet GRAV of a 1-D component is 1, then connect to the axial outlet face (LISRF = +2) of a VESSEL cell.

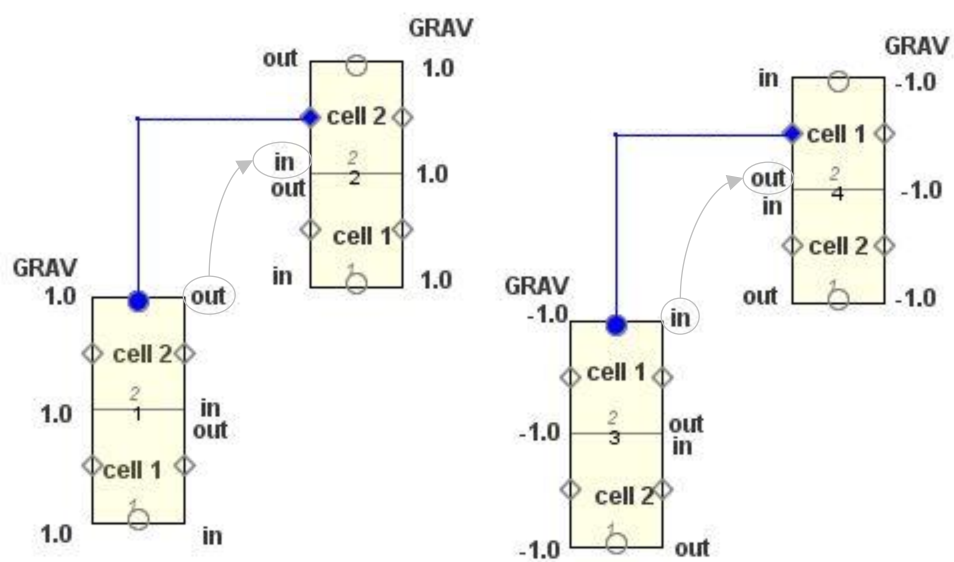
3. If the outlet GRAV of a 1-D component is -1, then connect to the axial outlet face (LISRF = +2) of a VESSEL cell.

4. If the outlet GRAV of a 1-D component is 1, then connect to the axial inlet face (LISRF = -2) of a VESSEL cell.

Loop Elevation Closure

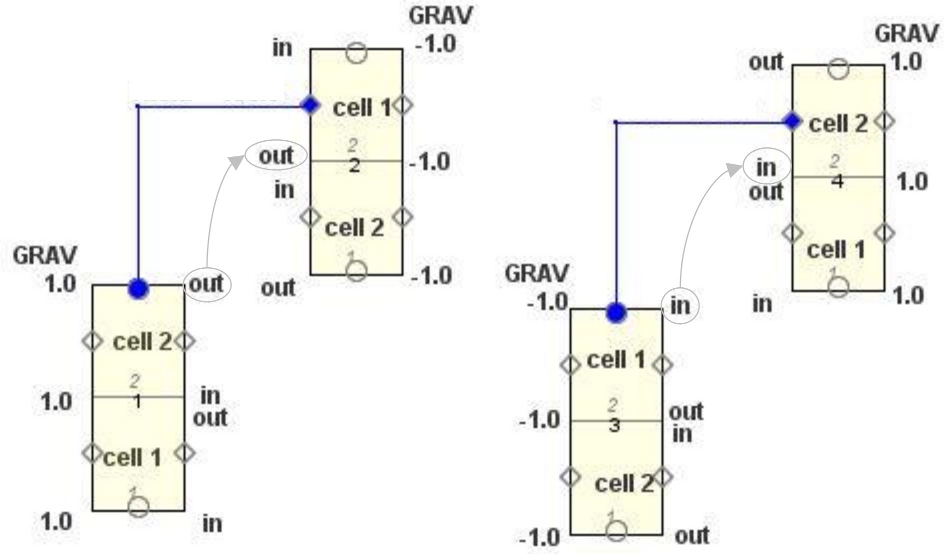
C. When connecting a PIPE to the side of another PIPE, four general rules are useful for achieving loop closure:

Rule 1: Outlet to Inlet Connection – Assume an upward oriented PIPE cell is connected to the side of another upward oriented PIPE cell, and vice versa, as shown below. The outlet face of the connecting PIPE cell is attached to the inlet face of the connected PIPE cell and vice versa.



Loop Elevation Closure

Rule 2: Outlet to Outlet or Inlet to Inlet Connection – Assume an upward oriented PIPE cell is connected to the side of a downward oriented PIPE cell, and vice versa, as shown below. The outlet face of the connecting PIPE cell is attached to the outlet face of the connected PIPE cell and vice versa.

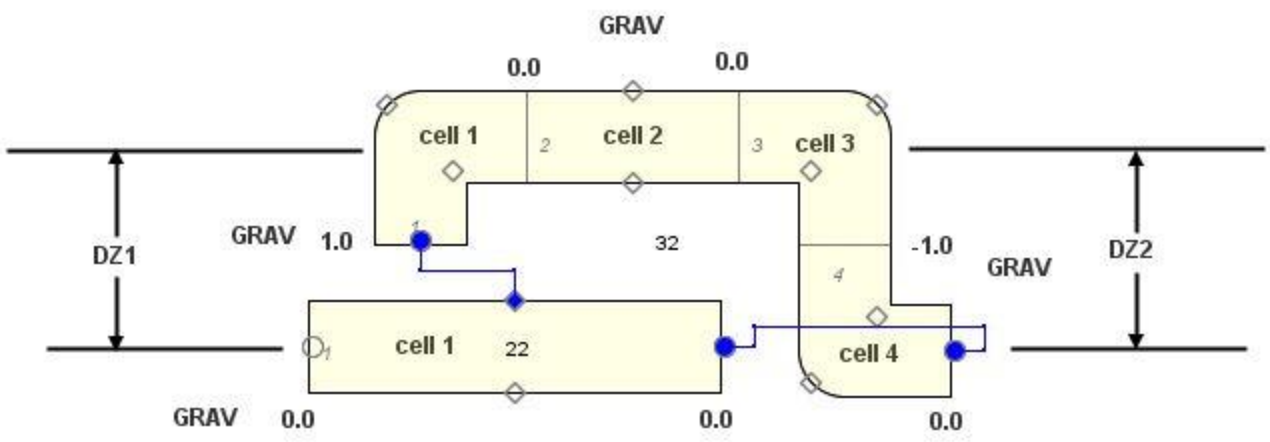


Loop Elevation Closure

Rule 3: Horizontal to Vertical PIPE Connection – Consider loops that include vertically oriented PIPE cells connected to horizontal PIPE cells as shown below. For loop closure, DZ_1 must equal DZ_2. The vertical PIPE cell is connected to the edge of the horizontal PIPE cell, thus:

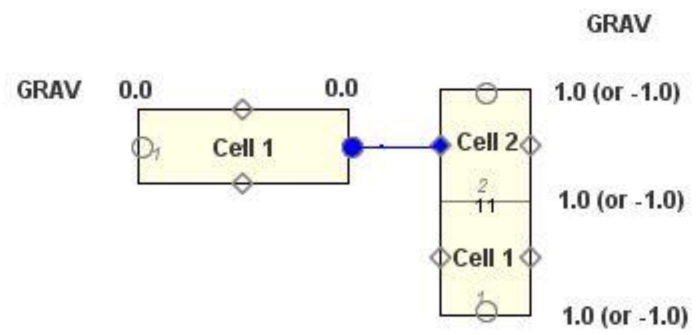
DZ_1 = ½ HD of horizontal PIPE cell + ½ DX_{cell-1}

DZ_2 = ½ DX_{cell-3} + ½ DX_{cell-4}



Loop Elevation Closure

Rule 4: Horizontal to Vertical Side Connection – Consider loops that include a horizontally oriented cell (GRAV = 0.0) connected to the side of a vertically oriented cell as shown below. The horizontal cell is connected to the center of the vertical cell.



Loop Elevation Closure Exercise

Start with the PWR-SS.med file found in the

Day-2/Morning/Loop-Elevation-Closure folder.

1. Check the model for loop closure using the SNAP loop check option.
2. Correct any loop closure errors uncovered.
3. Run a 1000 s, static-check steady-state (steady-state calculation indicator – STDYST 5) to assure that no unphysical flow behavior occurs.
4. Refer to Day-2/Afternoon/Loop-Elevation-Closure folder for the detailed exercise instructions.

Questions?

Any questions on before moving on?