How to Define a Force in PIPENET Transient Module

1. Introduction:

The force calculator in PIPENET Transient Module is used to calculate hydraulic force acting on pipe wall and network components (such valves etc.). These forces will transfer to along the pipe line and finally load on pipeline anchors or system devices.

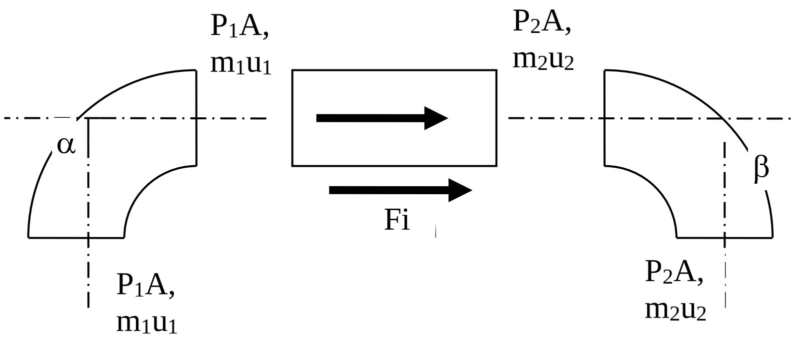
This document attempts to illuminate the theory principle behind the force calculator so that users can define force properly in PIPENET Transient Module.

2. Basic concepts and principles:

2.1 Control volume and control surface.

We cannot discuss hydraulic force without control volume and control surface. Abstractly, the **control volume** is a volume fixed in space and the surface enclosing the control volume is referred to as the **control surface**. Specifically in our study, the **control volume** is a part of network which is composed of physical elements (such as pipes and valves etc.) and the **control surface** usually is a break point for force transfer or a place at where flow changes direction.

The following figure depicts a simple example with a straight pipe and two elbows. The straight pipe is the control volume and the elbows are abstracted as the control surfaces. In fact, a control volume can enclose any number of network elements.



In the above example, the friction Fi between the pipe wall and fluid is the only force in the control volume. At the upstream elbow (control surface 1), the area of the pressure P_1 projects on the elbow wall is equal to the pipe area A and the flow changes direction with the momentum of m_1u_1. Therefore, the total force acting on the upstream elbow is $P_1A + \Delta m_1u_1 = P_1A + m_1u_1$. Similarly the downstream elbow bears $P_2A + m_2u_2$ force. The sum of the hydraulic force in the pipe and elbows is

$$\Sigma F = \left(P_2A + m_2u_2\right) - \left(P_1A + m_1u_1\right) + F_i$$

At steady state, $m_1=m_2$, $u_1=u_2$ and $Fi = (P_1-P_2)*A$. As the result, the total hydraulic force is zero at the steady state in a straight pipe and two elbows.

2.2 Rigid and elastic boundary.

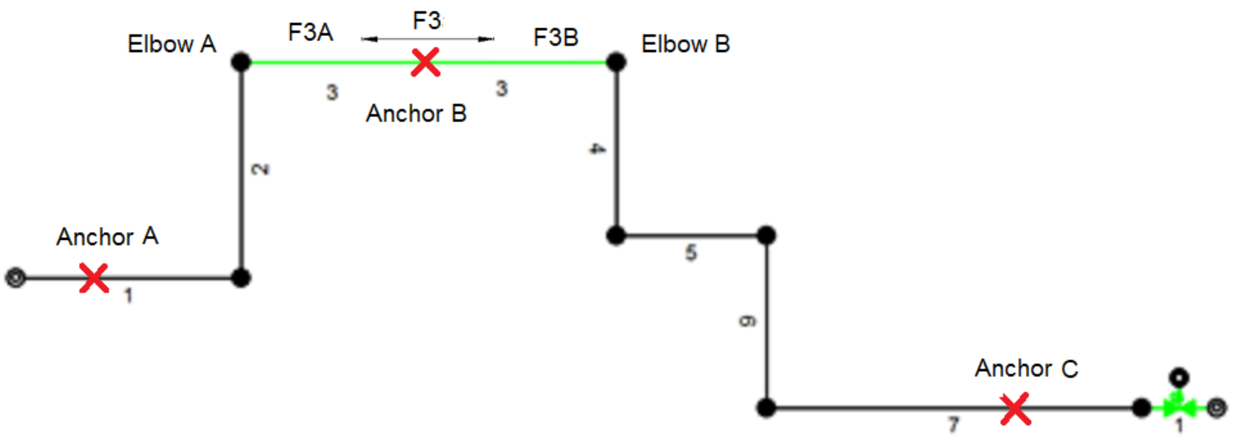
Rigid and elastic are used to describe the boundary condition of control surface. At a rigid boundary, fluid pressure and flow momentum produce hydraulic force PA + Δmu and act on the control surface. On the contrary, the control surface will not bear any hydraulic force PA + Δmu at an elastic boundary.

Now let us analyse some typical boundaries. The typical boundary conditions are summarized in Table1.

- **Anchor**

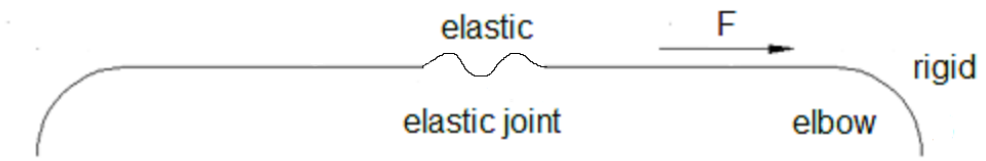
Anchor is installed at the middle point of straight pipe. The projected area of pressure on pipe wall is zero along the pipe axis, i.e. PA = 0. Also, the flow does not change direction at the middle point of the straight pipe, i.e. Δmu = 0. Therefore, the hydraulic force due to pressure projection and flow momentum change is zero. **Anchor is elastic boundary.**

In theory, anchor is a break point for force transfer and it should be set as an elastic control surface. However, it can be included in a control volume rather than to be a control surface in most cases and we recommend this simple processing method, please see the example in the figure below. If Anchor A & C is far away from Pipe 3, most hydraulic force produced at Elbow A & B will transfer to and cancel at Anchor B. In this case, the Anchor B can be included in the control volume for Force F3 and the control surfaces can be the Elbow A and B. On the other side, if the Anchor A & C is near to the Pipe 3, then the hydraulic force produced at the Elbow A & B will share among the three anchors. In this case, the Pipe 3 must be divided into two control volumes to calculate two forces: F3A and F3B. The anchor B becomes an elastic control surface.



- **Elastic boundary**

Similarly elastic joint is elastic boundary too. The reason is same as anchor.



- **Jet exit**

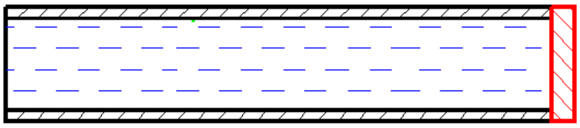
Jet exit is installed at pipe end. The projected area of pressure is zero. The flow does not change direction at the exit. Therefore, the hydraulic force is zero. **Jet exit is elastic boundary.**

- **Elbow**

Elbow changes flow direction and the projected area of pressure on the wall is equal to the pipe area. Therefore, the hydraulic force acting on an elbow is PA + Δmu. **Elbow is rigid boundary.**

- **Dead end**

At a dead end, the projected area of pressure is pipe area and the flow velocity and momentum is constantly zero. Therefore, the hydraulic force acting on a dead end can be calculated by PA + Δmu = PA, i.e. **Dead end can be treated as rigid boundary.**



- **Tank**

Tank can be regarded as an enlarged dead end. Therefore, **tank is rigid boundary.**

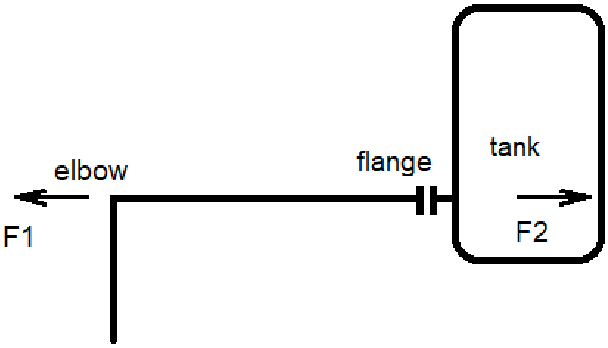
Table 1: Typical Control Surface in Force Calculation

Interruption	End Point
Control surface for local stress analysis	Elastic
Anchor (Axis restriction)	Elastic
Elastic boundary (Elastic joint, hose)	Elastic
Jet Exit (Nozzle, monitor etc.)	Elastic
Elbow (Angle valve)	Rigid
Dead end	Rigid
Tank (Tank, reservoir, pressure vessel etc.)	Rigid

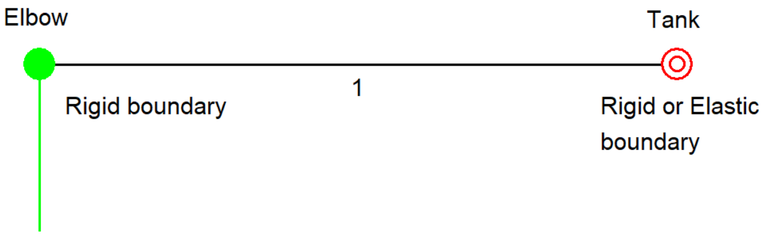
- **Conclusions**

Whether a boundary is rigid or elastic depends on exactly what the user wants to do. The same point in the network can be elastic or rigid, depending on what the user wants to do. In some cases it is always rigid (elbow) and in some cases it is always elastic (bellows with no tie rods). In other cases it can be rigid or elastic depending on what the user wants to do.

Take a pipe and a tank as an example, see the figure below.



In PIPENET, some tanks are usually abstracted as a constant pressure specification, see the figure below.



The force definition in the above example strongly depends on the purpose of the calculation.

- If the force is used to design the anchor system or do the stress analysis for the whole network, the control volume should include both pipe 1 and tank. The control surface at the tank's side should be rigid.
- If the force is used to size the bolts on the flange or calculate the stress on the bolts, the control volume should include pipe 1 only, the control surface at the flange should be elastic because it is for local stress analysis, see Table 1.

3. Force Definition in PIPENET

Based on the above discussion, we understand that hydraulic force produces at different parts of network and they can transfer, superpose and cancel freely in a control volume. Therefore, the control volume must not have any break points for force transfer, such as elastic joint etc. Anchor is a special case which can be included in control volume in most cases, see Section 2.2. Simple force is a one-dimension force which requires all elements in the control volume to be along the same axis. Therefore, the control volume of the simple force cannot have elbow or angle valve etc.

Table 2: Network Elements not allowed in Control Volume

Simple Force	Simple Force	Complex Force
Break point for force transfer	Anchor *	Anchor *
	Elastic joint	Elastic joint
	Hose	Hose
Flow change direction	Elbow	
	Angle valve	

Note *: Anchor can be included in the control volume if it bears most forces from upstream and downstream control volumes and surfaces.