A hydraulic model is a computer program configured to simulate flows for a hydraulic system. The system could be a sprinkler system, a firewater distribution system, or oil pipeline, etc. for either an existing network or one in development. The primary purpose for constructing and calibrating a hydraulic model is to create a tool that will provide a realistic representation of the hydraulic performance of the firewater system under study. A hydraulic model is a computer program that applies Hazen-Williams equations to simulate flow and pressure loss given a flow input such as a pump curve and an output demand. With a program such as KY Pipe and a reasonably accurate firewater map, the model can be easily created. However, the model needs crucial information about the pipe C-factors (Roughness Coefficient) for it to produce meaningful results.

Hydraulic modeling can be used for pre-incident planning purposes and/or for determining the effects of a particular impairment. For example, by simulating the flow and pressure at critical points, one would be able determine how to adequately respond to a particular incident. For example, the model could assist in identifying which hydrants to use and which pumps to turn on. A model can also predict the affects of a line being out of service in the event of a fire and then identify which other hydrants and pumps would be needed.

In fact, hydraulic modeling allows for infinite “what if” scenarios including:

- What if there is a fire and this line is impaired?
- What if there is a fire and this pump is impaired?
- What if a new pump was added or an old one replaced?
- What if this line is replaced with a new or larger pipe?
- What if a new line was installed here or there?
Hydraulic modeling can also be used to evaluate the fire water infrastructure. Using the model, infrastructure flaws such as bottlenecks in the system, lack of redundancy, pumping capacity and large pressure losses can be easily identified. From these findings, value engineering improvements can be determined and appropriately prioritized by simulating and examining the effects of proposed improvements.

Traditional Approaches for Determining the C-factor for Piping Systems

There are two traditional approaches for approximating the C-factors:

1. **Age-of-Pipe Approach**
   There are charts and tables approximating C-factor based on age of piping, but the information is of limited value and does not consider the actual site conditions.

2. **Isolated-Path Approach**
   Back calculate C-factors based on measured flow test pressure gradients along an isolated path of pipe with a measured flow at discharge point in the system.

Traditional Approach Limitations

There are known problems with each of these approaches. With the **Age-of-Pipe Approach**, the available data is largely limited to ductile iron but actual C-factors can vary based on region, installation, and other unknown factors. Underground drawings may also be incorrect. Pipes can vary in size, type and arrangement from what is detailed on drawings. This approach also does not account for obstructions, such as partially-closed valves, zebra mussels, etc.
The Isolated-Path Approach relies on a “key” assumption that the flow path is actually isolated. On older systems, truly isolated paths are difficult and sometimes impossible to achieve, and time consuming to confirm. If the path is not truly isolated, the test data will be invalid for calibration purposes.

A typical firewater system has multiple connections and multiple flow paths when delivering firewater to specific locations with firewater demands.

When using the Isolated-Path Approach, the intent is to close the isolation valves to isolate a particular path for the water to travel, measure the pressure gradient along the path, and measure the water discharging from the flowing points.

Note: The test data is only valid if the flow path is truly isolated.
Due to typical failure of completely closing isolation valves, the actual flow pattern is significantly different from the assumed flow path. Consequently, the resulting hydraulic model inherits fundamental deficiencies.

In addition to the isolation valve issue, undocumented demands could further skew the resulting hydraulic model and cause serious errors.

Each mechanical gauge along the path must be observed and documented by an observer, along with a pump operator and those at the flow points. Even if an isolated path can be achieved, each flow scenario will only calibrate a single path. Complex systems may require 20-100 flows scenarios. Isolating valves, setting up gauges, setting up the flow point, starting the pumps may permit only 2-4 scenarios a day, which may result in several months of flow testing which can become very expensive. Required path isolation may also be disruptive to operations and generally impractical.

Often, we may not be permitted to isolate a particular unit, street or process. When this occurs, it limits path isolation and is intrusive or disruptive. There is also a magnitude of parasitic demands to consider. Leaks and open valves cannot be determined if only measuring at a flow point challenging the validity of the data. In some cases, underground valves often will not close completely, will not fully open, may not be found, do not match the drawings, take excessive force/time to operate, and may break during operation making it impossible to confirm an isolated path.

In summary, the Isolated-Path approach is time consuming and very expensive. It requires a large team to isolate the flow path isolation and can be disruptive to operations and generally impractical. The resulting model typically will not be able to replicate the system performance at valve-open condition.
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Hydraulic Modeling and Dynamic Open Flow Calibration

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Dynamic Open Flow Calibration: Aon FPE's Approach

Dynamic Open Flow Calibration is an alternative approach developed by Phil Smith and Chen-Hsiang Su PE. of JENSEN HUGHES to address the issues with the traditional approaches and provide a reliable, cost-effective model with less intrusive/disruptive field flow testing. This alternative method used to calibrate the C-factors is well-established and is supported by the University of Kentucky, the developer of KY Pipe software.

Comparison

There are some notable differences between this method and the traditional approaches as shown in the chart below.

![Comparison Chart]

Open-Flow Approach

- No Closed Valves
  - The flow scenarios will be performed with system fully open to model the system as it exists
  - No time wasted opening and closing valves (Note: We request that the valves be checked to ensure they are open)
  - No “assuming” the path is isolated
  - Allows for less down time between flow scenarios
    - Typically, we can achieve 10-30 flow tests per day; whereas the traditional Isolated Path method would usually be limited to 2-4 flow tests per day
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Hydraulic Modeling and Dynamic Open Flow Calibration

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♦ Measure flow at the supply pumps and flow point(s)
  • Process water usage and leaks no longer have to be assumed or approximated, allowing for a more accurate hydraulic model
  • Flow into the system at the supply pumps is measured using an ultrasonic flow meter
    ○ The flow meter records the volume of water flowing into the system before, during and after each flow test, which means that the value of parasitic (process) water demands is measured between flow tests.
    ○ The flow is measured at the flowing point using traditional methods (hose monster, pitot, etc.)

Innovations in Measuring Pressure

♦ Pressure Recording Devices (typically 50-80 units used for a site)
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Hydraulic Modeling and Dynamic Open Flow Calibration

*continued*...

- Multiple pressure recording devices are affixed to hydrants throughout the site to simultaneously record the transient pressure changes before, during and after each flow test
- Removes the human element and human error; therefore, the testing could be more efficient, and provides more comprehensive data.

Data Integrity

- Measure flow at the supply pumps and flow point(s)
  - More flow scenarios, more data, greater accuracy

  The flow testing methodology is extremely streamlined with a small crew of people; thus, many more flow tests can be performed in a short period. Between 10-30 flows scenarios can be completed a day compared to 2-4 a day with the traditional method using isolated-path approach. The immense amount of data collected by the flow meter(s), pressure recorders, and hose monsters results in a higher degree of accuracy and reliability.
Objectives

♦ More water
  ▪ However, the ability to calculate the piping C-factors is still based on developing pressure gradients; therefore, we will flow the maximum amount of water the system can carry during each flow test
    ○ Typically, the duration of each flow test is a minimum of 5 -10 minutes.

Working with the Data

♦ Calculating the C-factors (basically)
  ▪ The underground system is broken down into groups of pipes that work as a system and then smaller groups within that and so on
  ▪ The flow test data is compressed to the basic elements of residual pressure and flow before, during and after each scenario
  ▪ The piping groups in the model are incrementally assigned C-factors until they can replicate a single flow scenario. Iteratively the C-factors are modified to replicate the next scenario and the one previous, until the model is able to replicate each flow scenario
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Hydraulic Modeling and Dynamic Open Flow Calibration

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Model Results
♦ The culmination of the dynamic open flow testing is a more reliable Hydraulic Model

The Fine Print
• There is a significant amount of data to process and analyze after flow testing; thus, it does take time to calibrate and deliver the model.
• The model represents hydraulic performance of the entire system, not each individual pipe.
• Measurement for individual pipes or sections of pipes is only appropriate for very simple piping systems.

Important Notes
• A low C-factor does not necessarily mean pipe is undersized, corroded, leaking, etc., although it could be.
• A low C-factor could be the result of a closed or partially closed valves, incorrect pipe size on the drawing, or acting in parallel with a pipe having a lower C-factor.
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Hydraulic Modeling and Dynamic Open Flow Calibration

continued...

C-Factor Investigation
KYPIPE C-Factor Calibration: Procedures (KY Pipe)
Hydraulic Modeling and Dynamic Open Flow Calibration

continued...

Advantages
- JENSEN HUGHES’ Hydraulic Model and Approach
  - Can be built more efficiently than traditional methods.
  - Is more reliable and accurate than other methods.
  - Is less intrusive/disruptive to the operation of the facility.
  - Is a powerful tool for pre-incident planning, development planning, system maintenance, and strategic system improvement.

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