Comparing the results of two simulating models of the Water Hammer phenomenon: Bentley Hammer V8i and Greek Legislation
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WATER HAMMER

• Hydraulic shock or water hammer is a temporary phenomenon that is regarded as the result of sudden changes in discharge of a liquid or gas in a closed piping system.

• Causes of Water Hammer
  o Rapid opening or sudden closure of control valves or pumps
  o Change in the continuity of the network
  o Change of boundary conditions

• Results of Water Shock
  o Cavitation, Suction, Leak, Downgrade water quality, Damage, Vibration

• Prevention techniques and protection devices
  o Techniques: Optimizing pipes’ diameter, route, elasticity
  o Devices: Pump bypass layout, protection devices (Air chambers, surge tanks and combined devices)
MATHEMATICAL MODEL

- Method of characteristics: The partial differential equations of motion (1) and continuity (2) into particular total differential equations (3) and (4).

\[
\frac{\partial p}{\partial t} + V \cdot \frac{\partial p}{\partial x} + \rho \cdot a^2 \cdot \frac{\partial V}{\partial x} = 0 \tag{1}
\]
\[
\frac{dV}{dt} = \frac{\partial V}{\partial t} + \frac{\partial V}{\partial x} \cdot \frac{dx}{dt} \tag{2}
\]
\[
\frac{dH}{dt} = \frac{\partial H}{\partial t} + \frac{\partial H}{\partial x} \cdot \frac{dx}{dt} \tag{3}
\]
\[
\frac{\partial V}{\partial t} + V \cdot \frac{\partial V}{\partial x} + \frac{1}{\rho} \cdot \frac{\partial p}{\partial x} = \frac{f \cdot V \cdot |V|}{2 \cdot D} + g \cdot \sin(a) \tag{4}
\]

- The equations can be intergraded to lead to the numerically handled finite difference equations (5) – (8).

\[
\frac{dV}{dt} + \frac{g}{a} \cdot \frac{dH}{dt} = - \frac{g \cdot V}{a} \cdot \sin(a) - \frac{f \cdot V \cdot |V|}{2 \cdot D} \tag{5}
\]
\[
\frac{dx}{dt} = V + a \tag{6}
\]
\[
\frac{dV}{dt} - \frac{g}{a} \cdot \frac{dH}{dt} = + \frac{g \cdot V}{a} \cdot \sin(a) - \frac{f \cdot V \cdot |V|}{2 \cdot D} \tag{7}
\]
\[
\frac{dx}{dt} = V - a \tag{8}
\]

- The Courant – Friedrichs – Lewy condition:

\[
\Delta t \leq \frac{\Delta x}{|V \pm a|} \tag{9}
\]
CASE STUDY: THE PRESSURIZED IRRIGATION NETWORK OF LIMNOCHORI

- One (1) main pipeline and ten secondary pipes with total length about 11 km
- Pipes are polyethylene PE, 12.5 PN and the installed nozzles are providing discharge of 7.5 l/sec
- Five (5) flow control valves on the main pipe
- One (1) tank that implements the operation of pumps
BENTLEY HAMMER V8i

- Software’s assumptions:
  - Fluid is homogeneous
  - Elasticity of pipeline and fluid follows linear pattern
  - The flow is unidimensional and fluid is incompressible
  - The pipe is full of the fluid
  - The average velocity is used
  - The head loss because of the viscosity is the same during the steady and the unsteady flow

- Input parameters in the software:

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Pipes Material</th>
<th>HDPE 3rd generation</th>
<th>–</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roughness Coefficient k</td>
<td>0.01</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Pipe’s Elasticity E</td>
<td>0.785</td>
<td>GPa</td>
</tr>
<tr>
<td></td>
<td>Factor Poisson μ</td>
<td>0.45</td>
<td>–</td>
</tr>
<tr>
<td>Fluid</td>
<td>Viscosity v</td>
<td>1.004·10^{-6}</td>
<td>m²/s</td>
</tr>
<tr>
<td></td>
<td>Acceleration of the gravity g</td>
<td>9.98</td>
<td>m/s²</td>
</tr>
<tr>
<td></td>
<td>Fluid’s Temperature T</td>
<td>20</td>
<td>oC</td>
</tr>
<tr>
<td></td>
<td>Fluid’s Elasticity factor K</td>
<td>2.188</td>
<td>GPa</td>
</tr>
<tr>
<td>Calculation Method</td>
<td>Calculation Time step Δt</td>
<td>0.025</td>
<td>sec</td>
</tr>
<tr>
<td></td>
<td>Vaporization pressure</td>
<td>Discrete Vapor Cavity</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Head loss (steady flow)</td>
<td>Darcy – Weisbach</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Head loss (transient flow)</td>
<td>Unsteady – Vitkovsky</td>
<td>–</td>
</tr>
</tbody>
</table>
GREEK LEGISLATION’S FORMULA

• The circular letter D.22.200/30 – 07 – 1977 that was published by the Ministry of Public Works suggests that formula to calculate the maximum transient pressure that is being developed during the phenomenon is the Joukowski formula.

\[ \Delta p = \frac{a \cdot \Delta V}{g} \]

• Calculated maximum pressure – sudden closure of the valve
• The calculation of the minimum pressures is not available
RESULTS – BENTLEY HAMMER V8i

• Implementation of five (5) different scenarios for each of (5) control valves:
  - Valve Close within 0 seconds
  - Valve Close within 30 seconds
  - Valve Close within 45 seconds
  - Valve Close within 60 seconds
  - Valve Close within 90 seconds

• The results of the pressures developed on main pipe during the sudden close of each valve

![Pressures (atm) chart]

- Min B Max B
- Min C Max C
- Min D Max D
- Min E Max E
- Min F Max F
- Min G Max G
- Min H Max H

Pressures (atm):
- 1.79
- 1.99
- 2.72
- 3.83
- 4.08
- 5.94
- 10.40
- 11.26
- 10.52
- 8.40
- 0.21
RESULTS – GREEK LEGISLATION

- Implementation the scenario of the sudden closure of a valve at each pipe
- The results of the pressures developed on main pipe during the sudden close of each valve
COMPARISON

Comments:

- The Joukowski formula is sufficient for the calculation of the maximum pressures through the main pipe.
- The maximum pressure calculated by Joukowski’s formula for specific secondary pipes is being exceeded by the calculated pressures using the software. The statistics of that case are:

<table>
<thead>
<tr>
<th></th>
<th>Greek Legislation</th>
<th>Software Bentley Hammer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump</td>
<td>Mean (atm)</td>
<td>Max (atm)</td>
</tr>
<tr>
<td>A</td>
<td>0.670</td>
<td>1.804</td>
</tr>
<tr>
<td>Β</td>
<td>0.56</td>
<td>1.68</td>
</tr>
<tr>
<td>C</td>
<td>0.86</td>
<td>1.60</td>
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<tr>
<td>D</td>
<td>0.93</td>
<td>1.80</td>
</tr>
<tr>
<td>E</td>
<td>0.89</td>
<td>1.09</td>
</tr>
<tr>
<td>F</td>
<td>0.72</td>
<td>1.44</td>
</tr>
<tr>
<td>G</td>
<td>1.51</td>
<td>1.91</td>
</tr>
<tr>
<td>H</td>
<td>0.64</td>
<td>1.11</td>
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<tr>
<td>Ι</td>
<td>1.17</td>
<td>1.77</td>
</tr>
<tr>
<td>D - Υ56</td>
<td>8.5</td>
<td></td>
</tr>
</tbody>
</table>

Pressures (atm)
REFERENCES

• Tzimopoulos, C., 1975. Μαθήματα υδραυλικού πλήγματος κριού, Θεωρία – Εφαρμογές [Water hammer phenomenon courses, Theory - Examples]. Thessaloniki: Department of Rural and Surveying Engineering.