


Analysis of Mixed-Flow Model Results to Detect Incorrect Air-Water Interaction Predictions

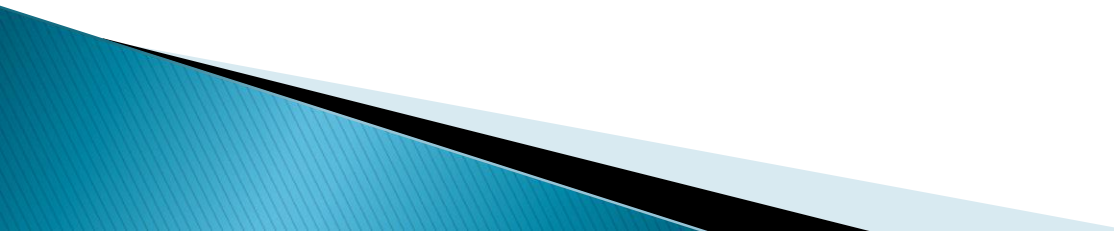
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STEVE WRIGHT

- ▶ BSE Agricultural Engrg. Wash. State Univ. 1971
 - ▶ MSE Hydraulic Engrg. Wash. State Univ. 1973
 - ▶ PhD Civil Engrg. Caltech 1977
 - ▶ Faculty CEE Univ. Michigan 1977–2018
 - ▶ Early research in stratified flows prepared me well for two phase flow research in sewers
 - ▶ Design consultant and technical review, various CSO storage tunnel projects including Toronto's Don River and Central Waterfront project
 - ▶ Attending these conferences since 1995
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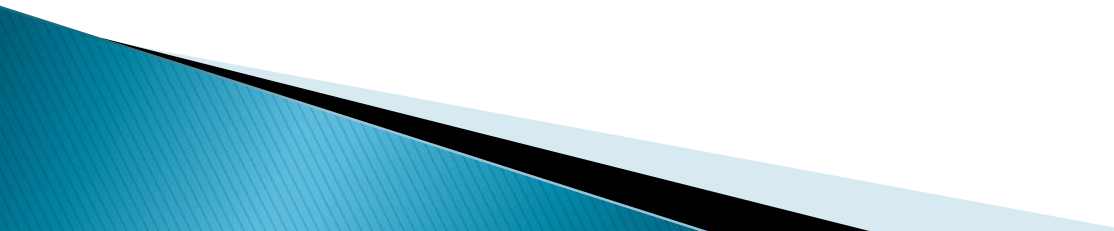
CONTEXT

- ▶ Many recent efforts formulating mixed-flow models to predict rapid filling in sewer systems
 - ▶ Various single-phase flow models that simulate combined free surface and pressurized flow
 - ▶ We have participated in model development and experimental studies that have been used by others for model validation
 - ▶ Learned much about limitations of such models
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LESSONS LEARNED

- ▶ Many models of the Preissmann Slot or Two-Component Pressure Approach type
 - These generally require specification of an acoustic wave speed for pressurized portion of flow
 - If air becomes entrapped in discrete pockets, numerical simulations and intuition show that value of wave speed is irrelevant to simulation since air compression is dominant influence
 - If model formulation only considers water phase (typical approach), simulations cannot model air compression in trapped air volumes and simulation results are not valid

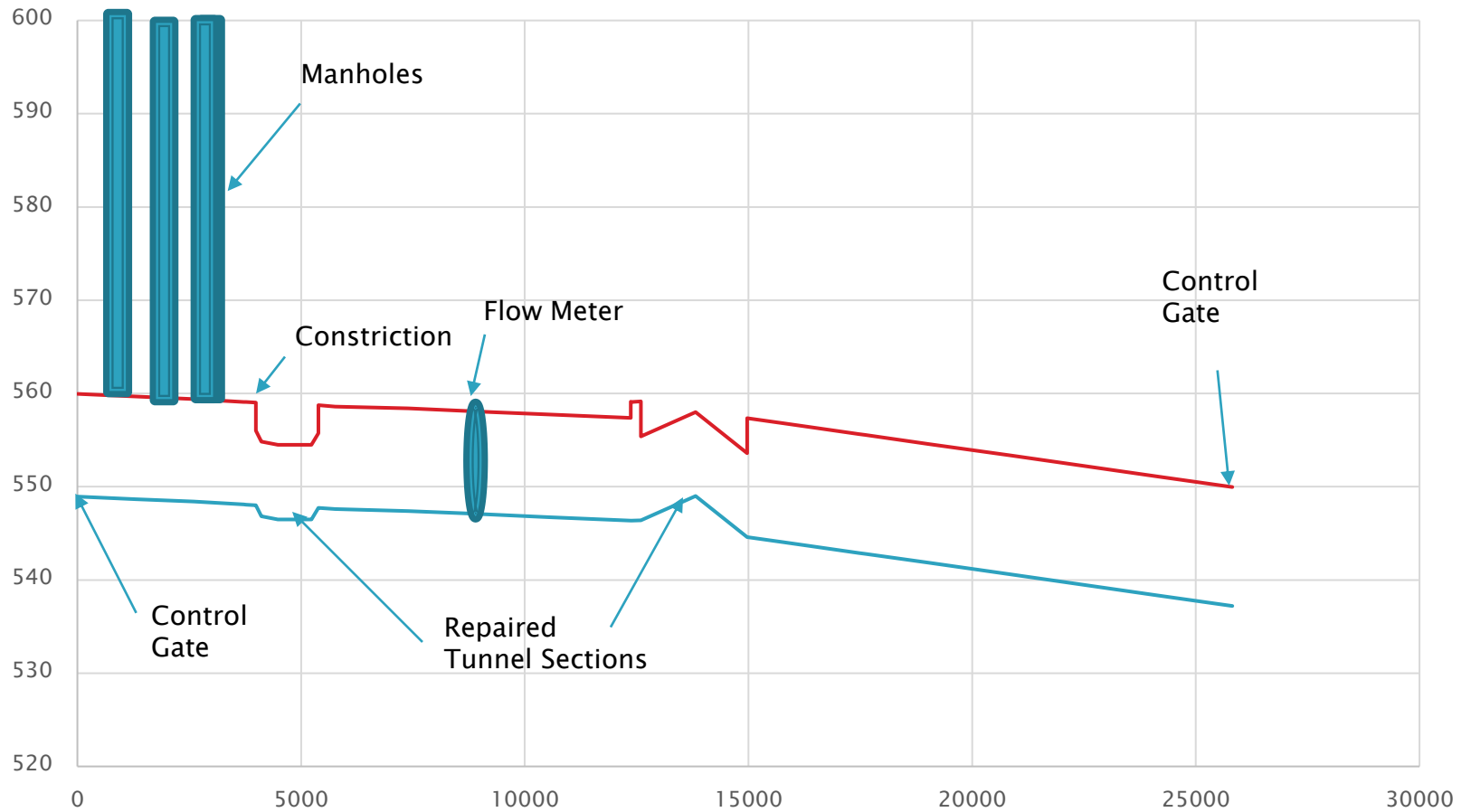
HOW TO DETERMINE IF MODEL RESULTS ARE VALID

- ▶ Simulations of typical systems involve complex geometries, large amount of output
 - ▶ Looking for only a maximum pressure and location may not inform whether simulation is valid or not, need to examine output in detail
- Present a case study to analyze model output in more detail that demonstrates the value of a consistency check
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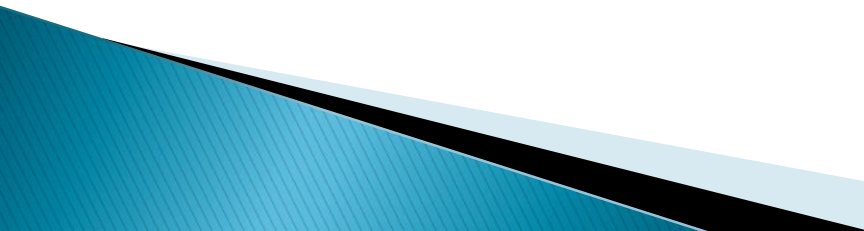
CASE STUDY

- ▶ Involved an application in a deep combined-sewer interceptor
 - Study reach is about 7.9 km long, with an upstream section about 1.2 km long and 3.4 m diameter where analyses of transient effects were focused
 - Interceptor collapse: failed due to soil piping condition and subsequent loss of support
 - Alleged that the control gate operation resulted in water hammer that developed cracks in tunnel wall, allowing the initiation of piping
 - Numerical simulation predicted development of modest water hammer pressures
 - Could water hammer occur in this system?

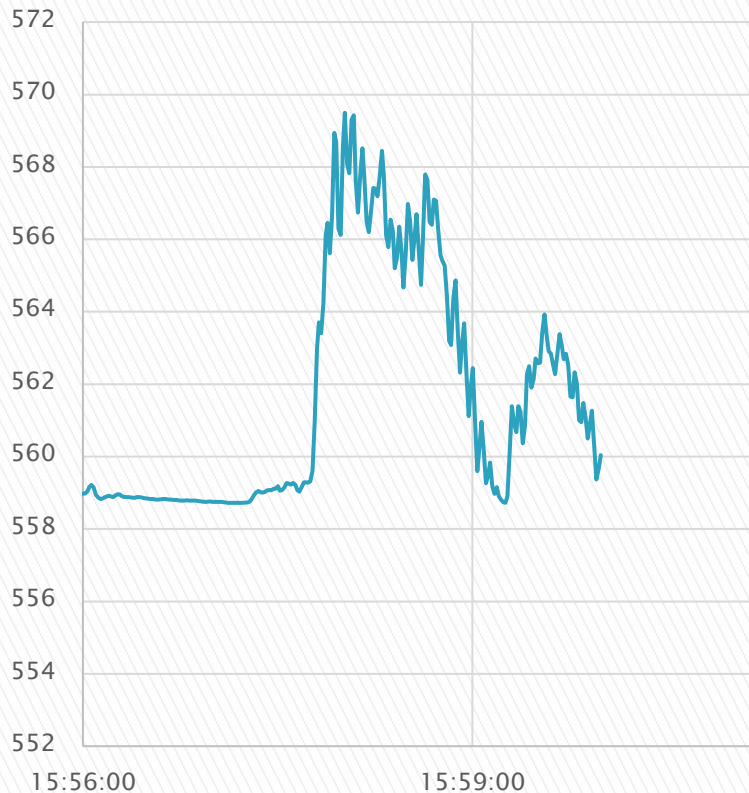
SYSTEM SCHEMATIC



EVENT SCENARIO

- ▶ Focus on one particular event because vent doors at upstream gate access shaft were forced open and a manhole slab lifted at location 1 km downstream
 - ▶ Control gates were closed in early morning to allow access downstream of study reach
 - ▶ Rainfall during day resulted in backup behind upstream gates and water began overflowing over emergency weir around mid-day, slowly filling the study reach
 - ▶ Overflow detected and upstream gates opened over a 7–8 minute interval
 - ▶ Rush of water from gate opening hypothesized as cause of water hammer that ultimately led to tunnel failure
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MODEL APPLICATION



- ▶ Tunnel failure due to crown collapse originated somewhere near to this location
- ▶ Model prediction predicted maximum peak pressure about 250 m upstream
- ▶ Why would water hammer initiate somewhere away from boundaries?

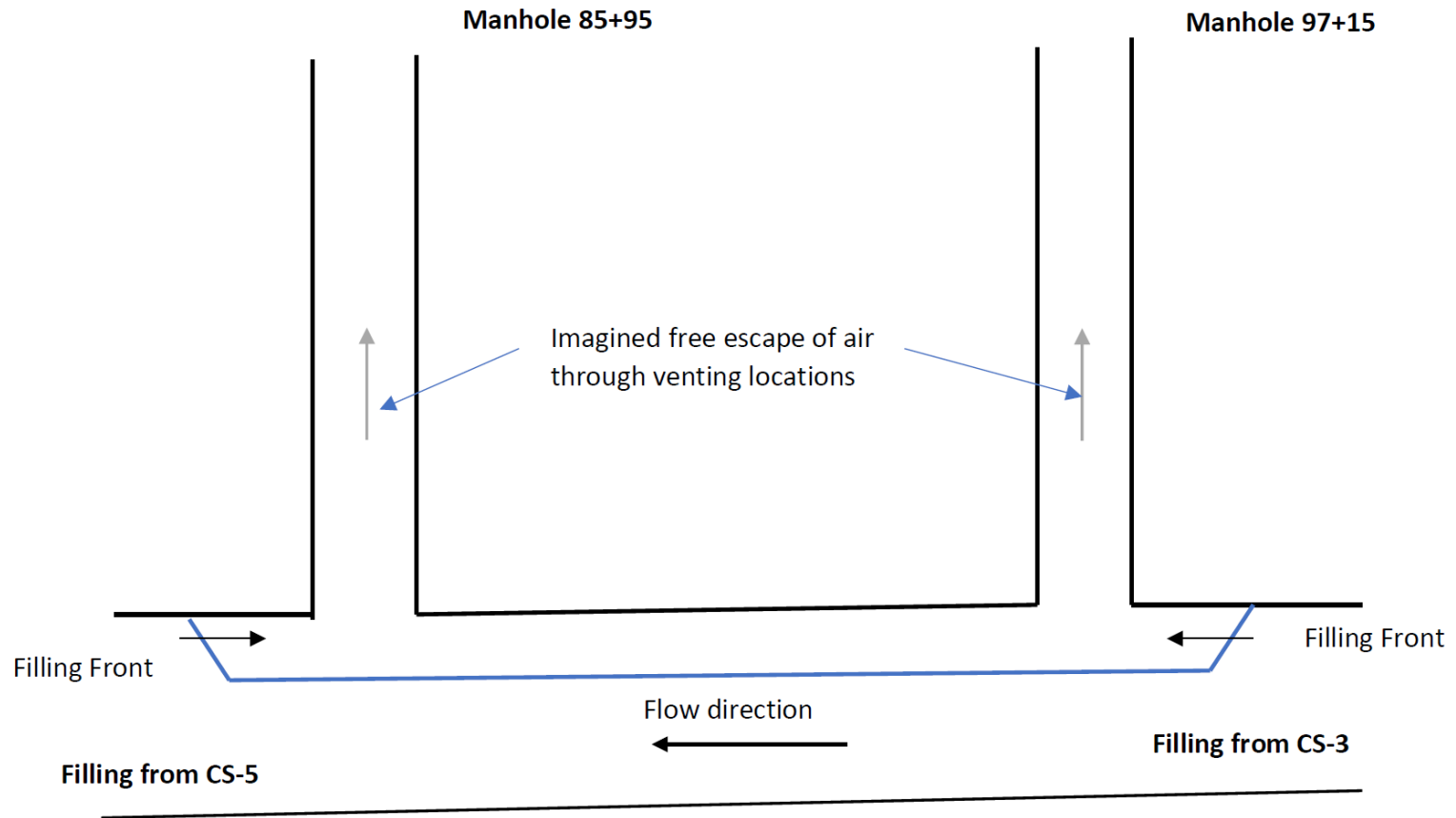
Pressure predicted at Constriction,
looks like waterhammer

Details

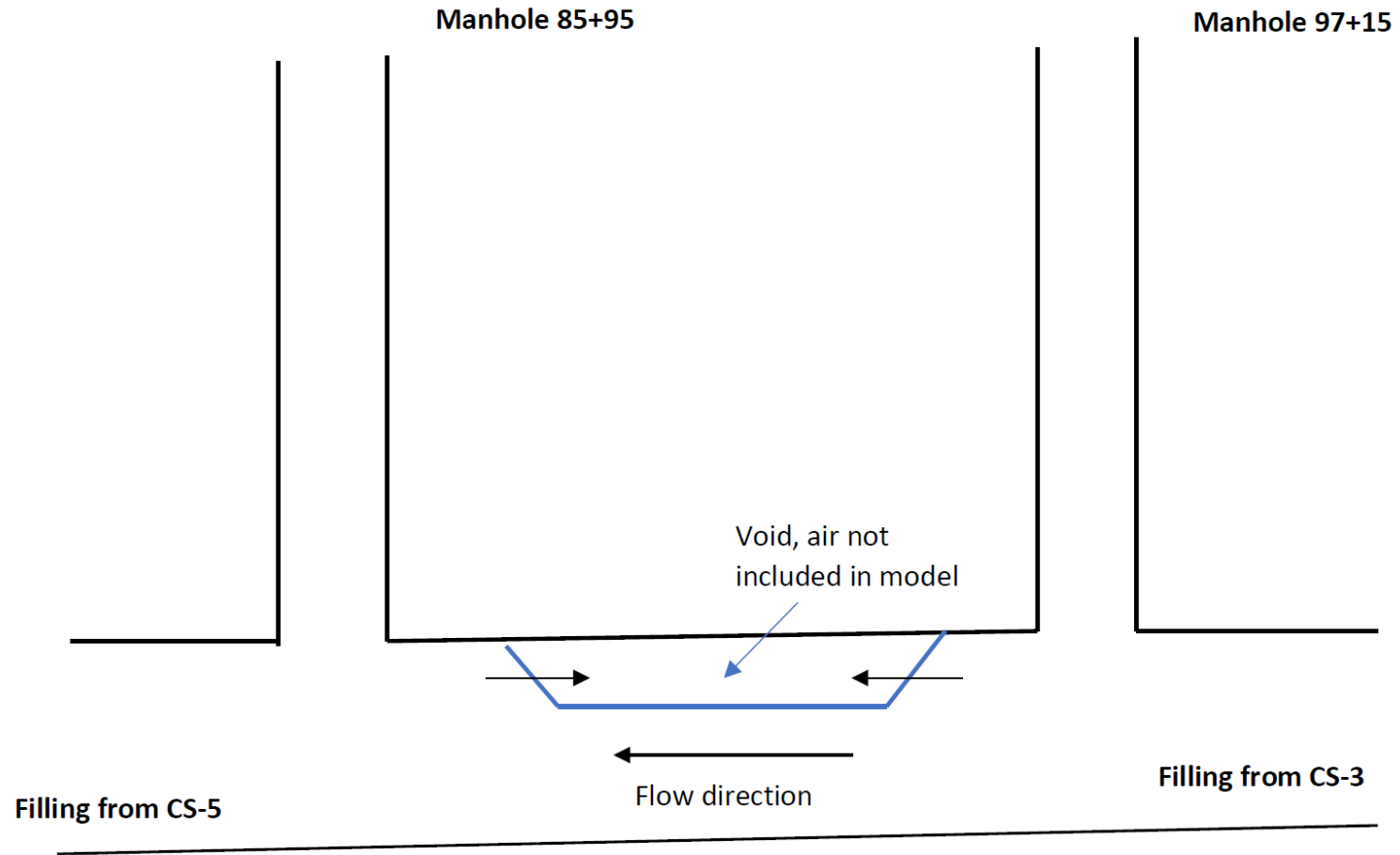
CONSIDERATIONS

- ▶ From SCADA data from other locations, the water level in the 2.4 m diameter section would have reached the crown either just before the gates started opening or very shortly afterwards due to filling behind the closed downstream gates and air could also not escape upstream due to the block at upstream gates. Nowhere for it to go within tunnel
- ▶ An air volume estimated at about 4500 m³ could only escape from four manholes with limited venting area; would have taken more than a day to vent
- ▶ Predicted peak transient occurred about 35 minutes after the upstream gates started opening, long after the wave from initial discharge from gate opening would have reached the constriction, but perhaps a time consistent with the simulated void to disappear

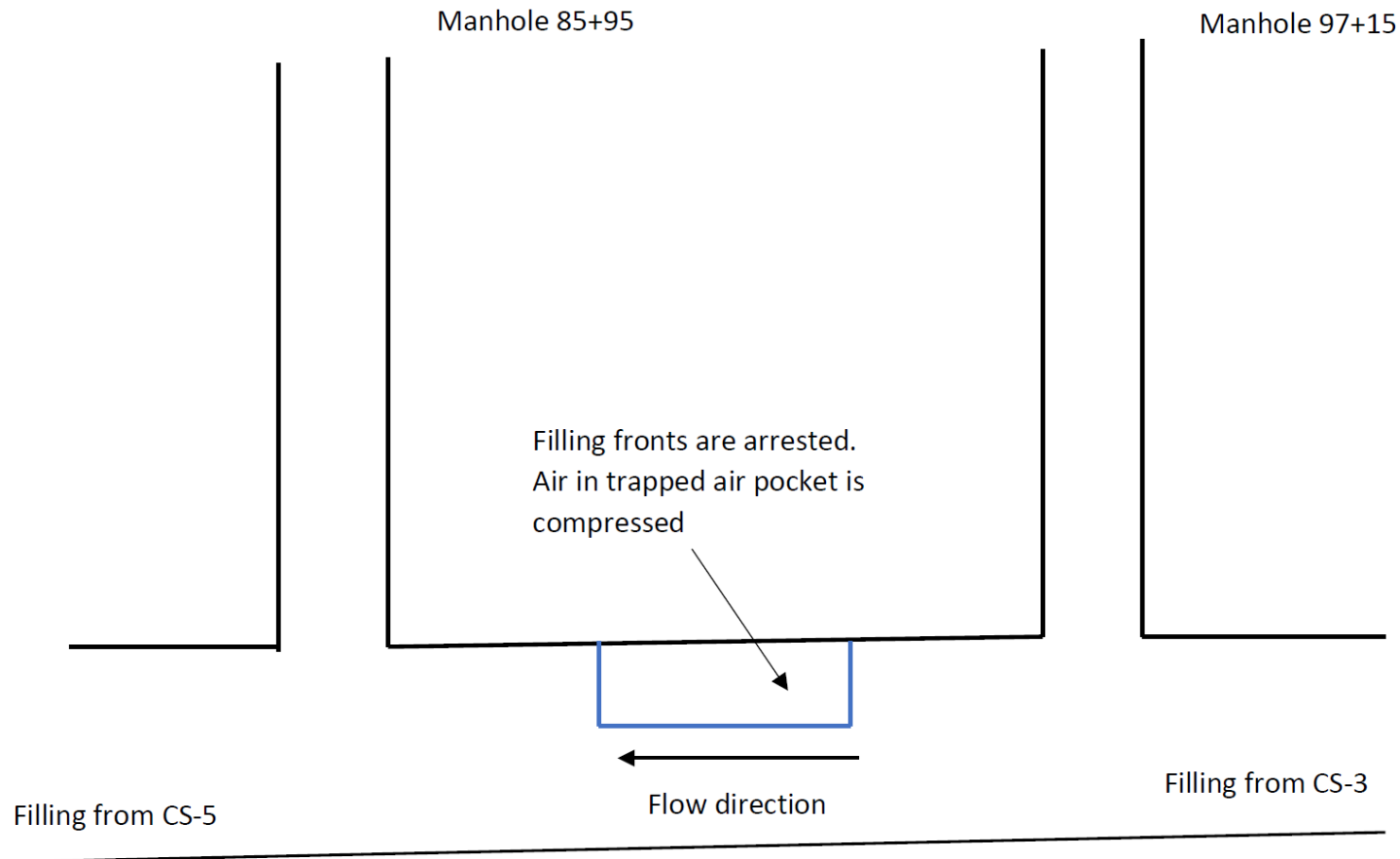
POSSIBLE MECHANISM FOR PREDICTED TRANSIENT, NO AIR MODELED



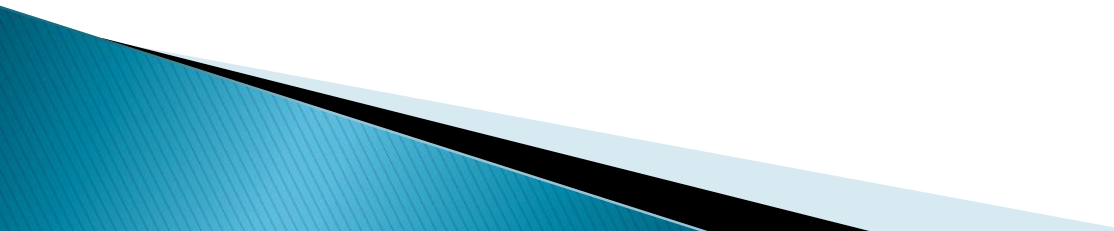
Simulation Ignoring Air



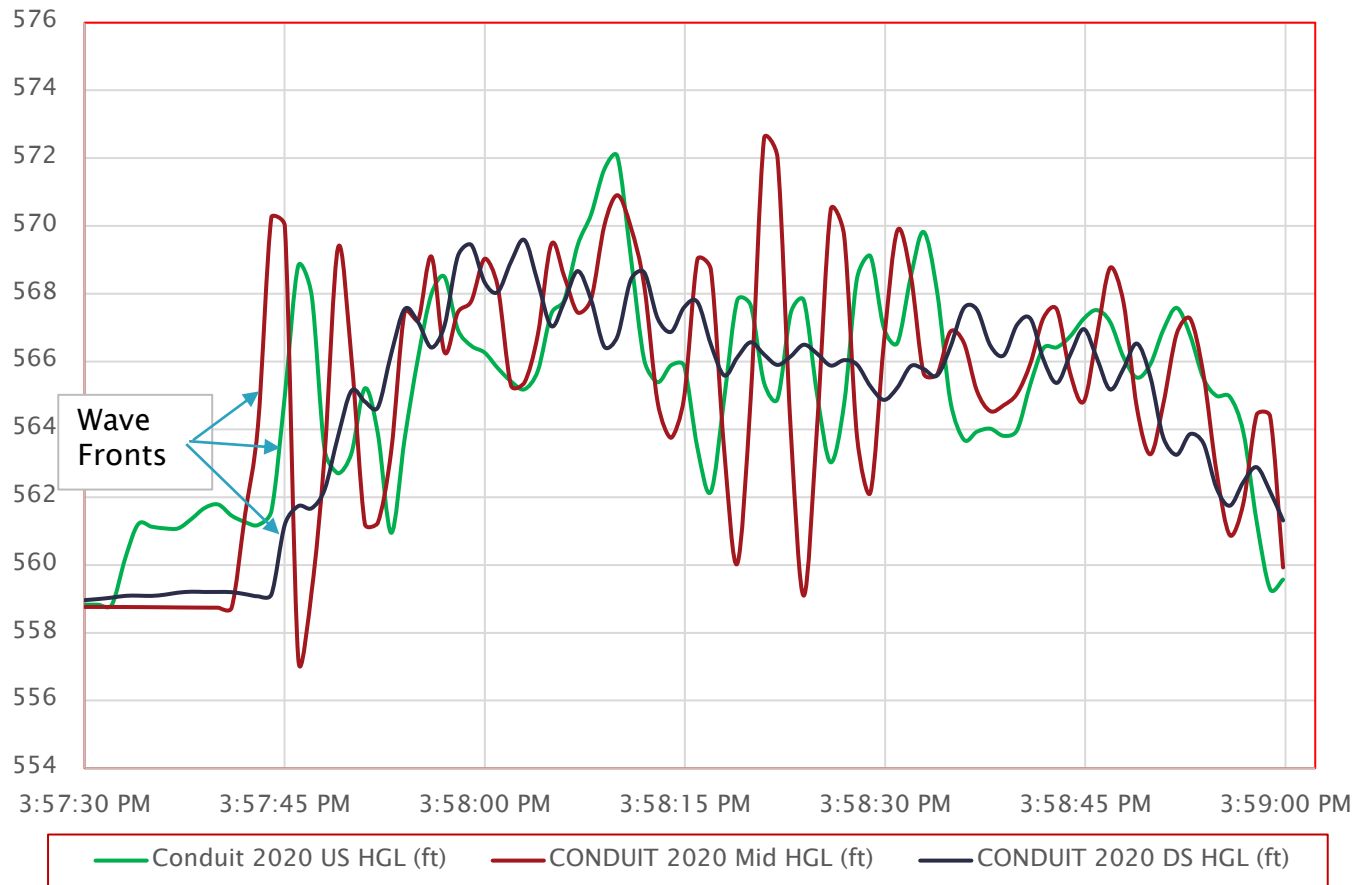
What Really Happens with Trapped Air between the Two Manholes



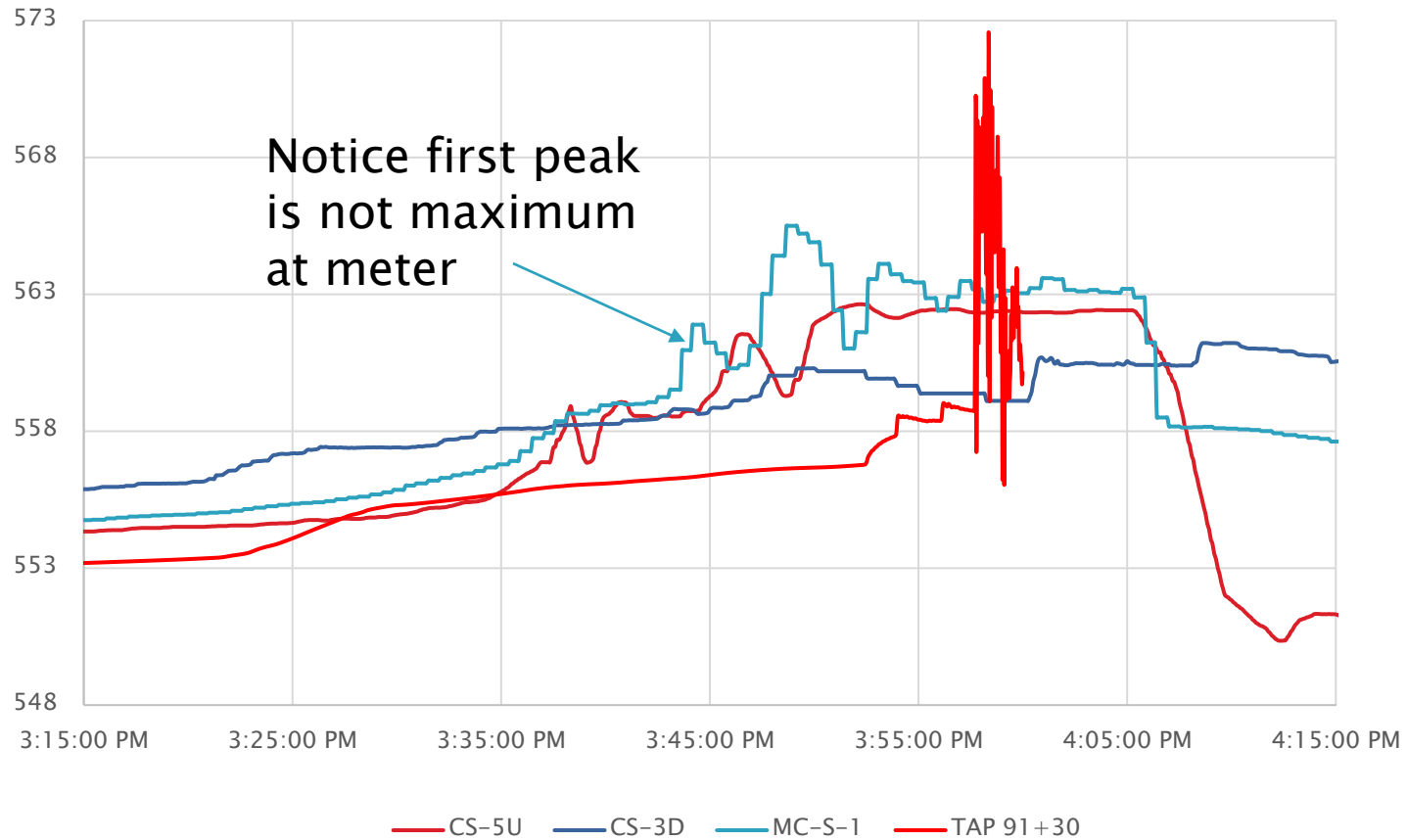
WHAT INVALID RESULTS FROM AN SIMULATION WOULD SHOW

- ▶ Evidence of filling fronts passing potential vent locations just before the pressure peak
 - ▶ Peak pressure at the location where the filling fronts “collide”
 - ▶ Water hammer waves propagating upstream and downstream from that location with decreasing pressure magnitude with distance
 - ▶ Peak pressure should increase in magnitude if acoustic wave speed is increased (this occurs).
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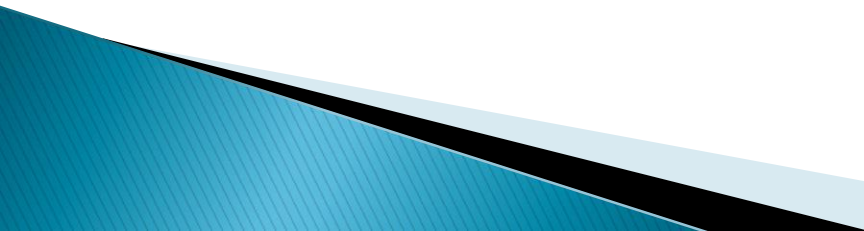
PREDICTION RESULTS IN CONDUIT BETWEEN MANHOLES



LIMITED MONITORING DATA



OBERVATIONS

- ▶ Examination of model output verifies that water hammer associated with “collapse” of void is predicted as anticipated
 - ▶ Presence of trapped air between filling fronts would have substantially altered the dynamics
 - ▶ Note that these predictions could only happen in a system that is perfectly vented at manholes, which this system is apparently not. Trapping of a large volume of air at crown along reach would alter the dynamics further and change the magnitude and timing of the peak pressure occurrence
 - ▶ Model cannot be used for intended purpose
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CONCLUSIONS

- ▶ If a system is well-ventilated at discrete ventilation points, it is possible to use a properly formulated single-phase numerical model to simulate where air pockets form and then assess whether there is a possibility of air compression influencing the transient
- ▶ If the issue is related to poor system ventilation and air must be compressed significantly to vent the system, a model must contain this capability
- ▶ Do not assume that if an incomplete model can solve one filling scenario, it can also solve other related problems. Examine the model output to know exactly what is being predicted!



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Thank You

