SUPPLEMENTARY MATERIAL

# Diagnosis of a transmission main by means of transients caused by the pump switch off.

M. Ferrante[a]

[a]Dipartimento di Ingegneria Civile ed Ambientale, University of Perugia, Via G.Duranti 93, 06125 Perugia, Italy

**ARTICLE HISTORY**

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## Appendix A. Calibration of Model 1

In the first calibration (Calibration 1), $a$ and $q_0$ are varied, since the pressure decrease due to the pump stop is linked both to the wave speed and to the initial discharge. The hypothesis $L_T = 995$ m, i.e. that the total length of the pipe corresponds to the value explicitly reported on the design drawing, yields a calibrated value of the wave speed $a$ =1534 m/s. Even if the pipe material is considered as perfectly rigid, this value should correspond to a water temperature of about 45°C (Pearsall 1965) while the water temperature was close to the normal conditions during the tests. On the contrary, the hypothesis $L_T = 840$ m, i.e. that the value obtained by the cadastral map is correct, yields a calibrated value $a$ =1290 m/s (Calibration 2), which is in a very good agreement with the value estimated considering the pipe thickness, diameter and material, with water in normal conditions. Hence, a first outcome of the transient test analysis is that the hypothesis that the actual total pipe length, $L_T$, is lower with respect to that reported on the design drawings and is equal to that evaluated on the cadastral map, is tested and verified.

Even under the considered hypotheses about the pipe length and wave speed, the shown

CONTACT M. Ferrante. Email: marco.ferrante@unipg.it

results of Model 1 are unsatisfactory on the short and on the long durations. On the long duration, the pressure head oscillation damping is not properly simulated even if the unsteady friction effects are considered. On the short duration it can be seen that the simulation obtained by the model does not explain the pressure head variations between the pump switch off and the reservoir reflected wave arrival time.

As a first improvement, to understand if the damping can be explained by the unsteady-friction effects, in Calibration 3 the $k_B$ parameter is also calibrated. The signal simulated by the model using the obtained values of $a$=1416 m/s and $k_B$=0.38, is shown in Fig 2. Both the values of $a$ and $k_B$ have no physical meaning. Once more, the high value of the wave speed cannot be justified by the water temperature and the pipe material, and the value of $k_B$ able to explain the pressure head damping is extremely high. In fact, the value of $k_B \simeq$0.025, given by the diagrams in (Pezzinga 2000) with reference to the considered initial conditions, is lower by an order of magnitude. The calibration of $a$ and $q_0$ with $K_B$=0.025 (Calibration 4) provides the values $a$=1298 m/s and $q_0$=0.57 l/s. The initial discharge estimate agrees with the value measured at the Venturi flow meter, considering the resolution of the instrument. The pressure signal simulated with the obtained values of the parameters, is also shown in Fig. 2.

## Appendix B. The variation of $\sigma^2$

### *Appendix B.1. Leak - Model 2*

The dependence of $\sigma_1^2$ and $\sigma_2^2$ on the two parameters of Model 2, $L_1$ and $Z_L$, is shown in Figures B1a and B1b, respectively. The numerical pressure signal corresponding to the minimum of $\sigma_2^2$, with $L_1$= 565 m and $Z_L$= 1.0 $10^5$ (dashed line in Fig. B2) is able to reproduce the damping of the peaks in time.

### *Appendix B.2. Illegal connection - Model 3*

The numerical signal corresponding to the minima of $\sigma_2^2$, with an open valve at the end of the illegal connection and with $L_1 = 365$ m, $L_2 = 550$ m and $D_2 = 0.095$ m are shown in Fig. B5 (dash dotted lines).

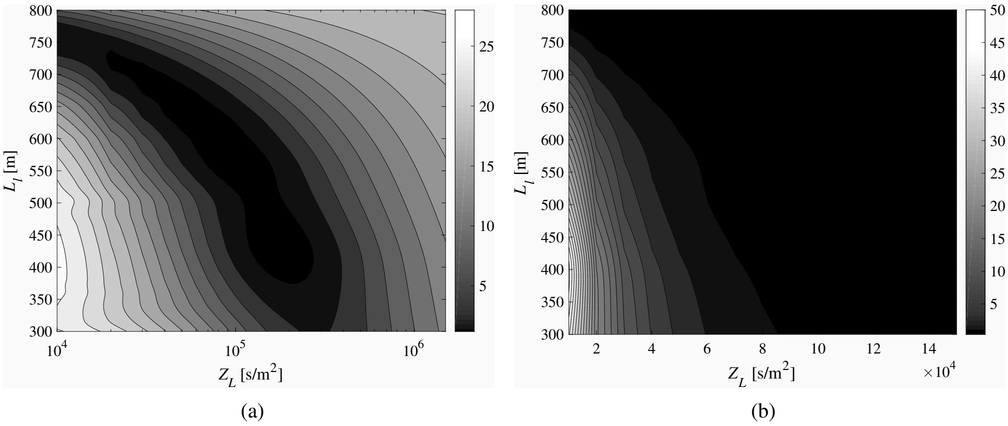



Figure B1.: Variation of (a) $\sigma_1^2$ and (b) $\sigma_2^2$ with the leak location, $L_1$, and impedance, $Z_L$, in Model 2 of Fig. 3.

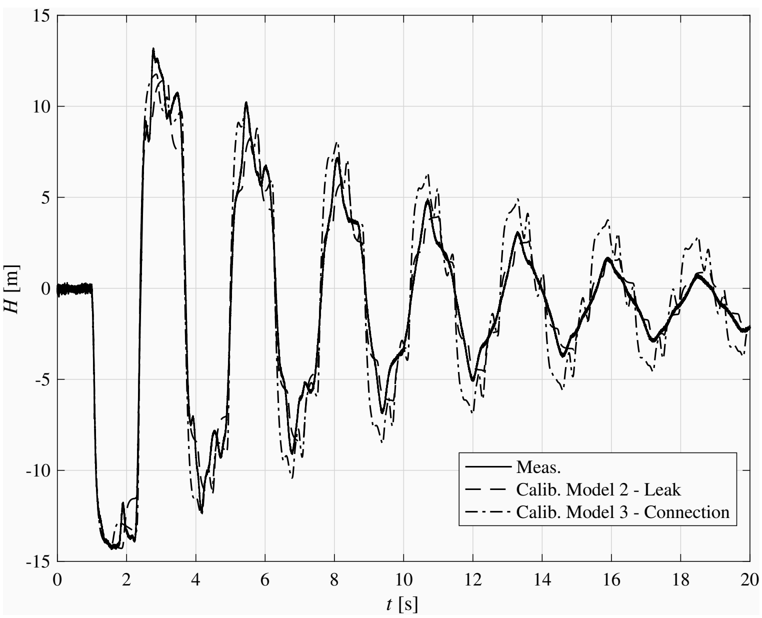
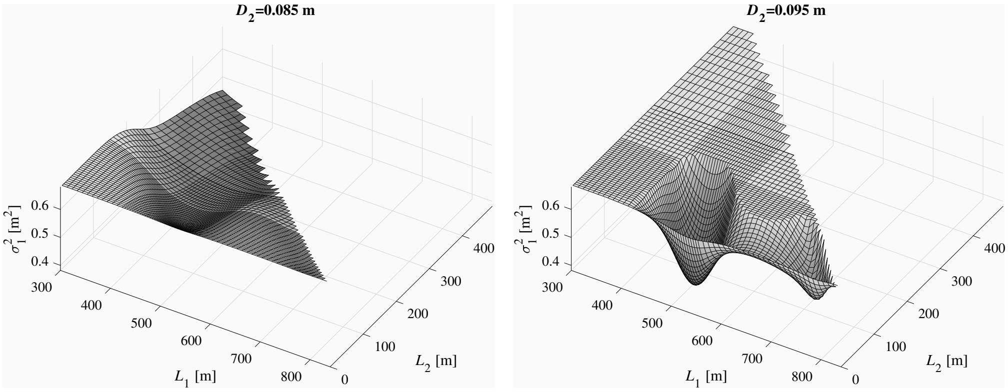


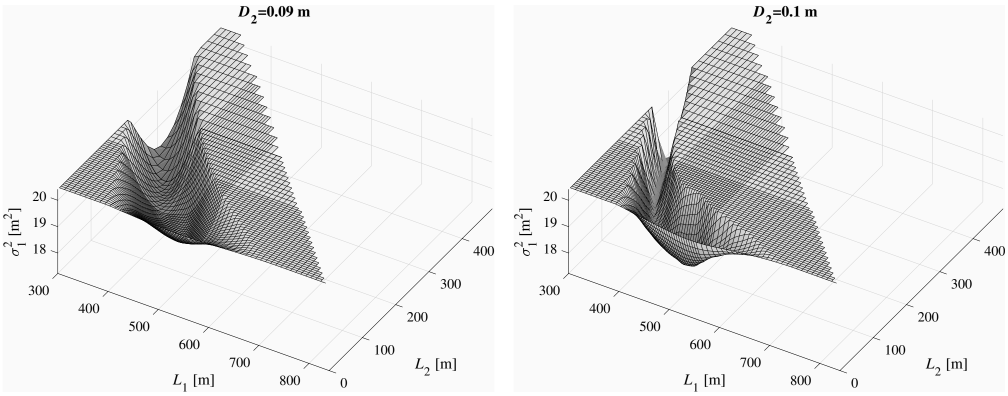

Figure B2.: Comparison of $H$ measured at the pressure transducer (Meas.) with results of the calibration of the models with a leak (dashed line, Model 2) or an illegal connection (dash dotted line, Model 3) in the system, corresponding to the minima of $\sigma_2^2$.

### *Appendix B.3. Trunk with a different diameter - Model 4*




(a) (b)

Figure B3.: Variation of $\sigma_1^2$ for a pipe with a different diameter, $D_2$, of length $L_2$ and at a distance $L_1$ from the upstream node (Model 4 of Fig. 3).




(a) (b)

Figure B4.: Variation of $\sigma_2^2$ with the pipe with a different diameter, $D_2$, of length, $L_2$ and at a distance $L_1$ from the upstream node (Model 4 of Fig. 3).

## References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Ferrante, M. and Capponi, C. (2017). Viscoelastic models for the simulation of transients in polymeric pipes. *Journal of Hydraulic Research, IAHR*, 0(0):1–14.

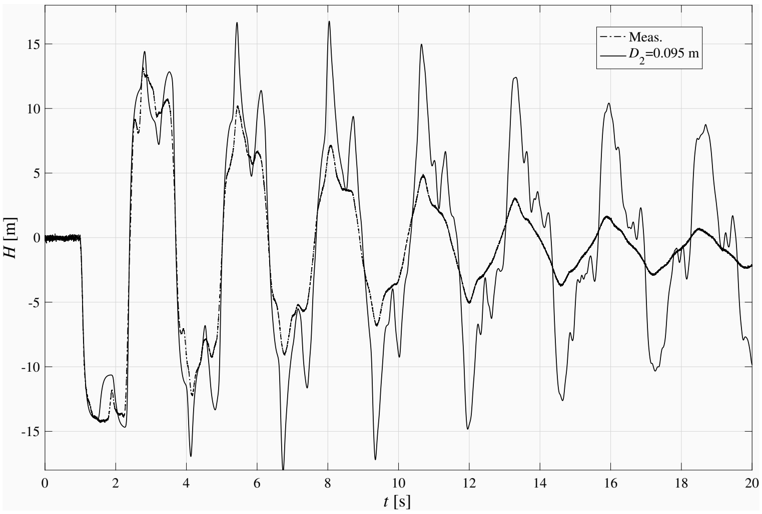


Figure B5.: Comparison of $H$ measured at the pressure transducer (Meas.) and obtained by the calibration of Model 4, with a trunk of diameter $D_2$ (dash dotted line), corresponding to the minima of $\sigma_2^2$.


Pearsall, I. S. (1965). Paper 2: The Velocity of Water Hammer Waves. *Proceedings of the Institution of Mechanical Engineers, Conference Proceedings*, 180(5):12–20.

Pezzinga, G. (2000). Evaluation of Unsteady Flow Resistances by Quasi-2D or 1D Models. *Journal of Hydraulic Engineering, ASCE*, 126(10):778–785.