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Published in:
Pipeline Systems : Proceedings of the International Conference on Pipeline Systems

Publication date:
1992

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Larsen, T., & Burrows, R. (1992). Measurements and Computations of Transients in Pumped Sewer Plastic Mains. In E. P. Evans, & B. Coulbeck (Eds.), *Pipeline Systems : Proceedings of the International Conference on Pipeline Systems: Manchester, UK, 24-26 March 1992* (pp. 117-123). Springer.

International Conference on Pipeline Systems
24 - 26 March 1992, Manchester, UK

Measurements and Computations of Transients in Pumped Sewer Plastic Mains

by

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ABSTRACT

Measurements of pressure and flow in a number of pumped plastic sewer mains have been carried out in order to compare the actual observed transients with computations. Primarily the situation following pump run-down has been studied. The investigation covered pipelines with steadily rising length profiles as well as pipelines with one or more high points. The comparisons emphasize the effects of cavitation and air pockets.

INTRODUCTION

The last decades urbanization and sanitation developments have resulted in larger and more centralized sewer systems, which have increased the need for distant transport of sewage. Accordingly a large number pumped sewer mains have been established. The new EC directive on municipal sewage discharges is expected to stimulate this trend further.

Plastic pipelines of uPVC (unplasticized polyvinycloride) for pumped sewer mains have recently become popular. The investigation mentioned here covers only pipelines of uPVC, but the principles described here are relevant to most other cases.

In contrast to traditional sewer pipeline practice, pumped plastic mains are often laid in length profiles directly following terrain without special attention to high points. In some cases manual or automatic air-valves are placed at the high point, in other cases not. The criterium for the choise of length profile and air valve equipment in this respect seems to be more or less based on individual experiences and judgement. The hydraulic design of such pipelines will, beside the basic problem of the hydraulic capacity, also include an analysis of transients and considerations on self cleaning of both sediments and air pockets.

The structural design of pumped sewer mains should consider the external soil pressure and the internal loads. Of interest here is the internal loads from the pressure of the fluid. The design practice differs slightly from country to country, but in relation to internal loads it is normal to design for a maximum static pressure. Furthermore, the expected pressure surges (from low peak to high peak) has to be restricted to a limited percentage of maximum allowed static pressure, e.g. 50 %, because of the risk of fatigue. Further details on fatigue can be found in [1]. The pipe supplier can often advice on these points as the design codes and other recommendations do not cover all details.

Below is described measurements and computations for 3 different pumped sewer mains, all of which are in service in North Jutland, Denmark. The investigation covered in total 6 pipelines and is described in detail in [2], but here only the 3 most typical examples are given.

NUMERICAL MODEL

The numerical model used in this investigation was based on standard procedures, which can be found in the literature. It is not the point of this paper to present new ideas in the numerical solutions of transient problems , so we refer to Wylie and Streeter, see [3], for all equations and other details. The following points summarise the major principles of the models used:

1. Standard method of characteristics, without interpolation, for single pipeline was applied for solution of the equations of motion of the fluid.
2. Cavitation (or water column separation) was included by assuming cavities to develop at the node points when the absolute pressure drops close to zero. Transient wave speed was not corrected for influence of cavitation.
3. Air pockets of pre selected sizes could be incorporated in chosen node points.
4. Pump inertia was included. Internal steel pipelines within the pumping station was not included, explicity except for the effect of friction.
5. An air chamber could be included at the first node point, where the pump was situated also (equations were solved by iteration).

The computer programme was written in Turbo Pascal. After the investigation a commercial version of the programme called *WHPS* was made available through direct contact with the authors [4].

BASIC RESULTS AND MODEL CALIBRATION

The method of characteristics is known to give accurate results in simple and well-defined situations. For each of the pumping mains tested some basic experiments were first completed to ensure that combined effects could be identified separately later. The basic experiences were as follows.

1. The wave speed of the transients seem only to vary within plus/minus 10 % of standard value calculated from the pipe specifications.
2. The use of the steady state friction factor combined with the computation of the friction at the old time step seems to be acceptable under the unsteady conditions to describe the damping of the first one or two reflections of the wave following the pump run-down. The peaks of the later reflections in the computations are overestimated, but this is less important.
3. Most uncertainty in the simple cases were related to the uncertainty of the initial flow conditions, especially the steady state flow before the pump run-down. Often the flow was lower than expected by up to 25 % of the nominal capacity.
4. The function of air chambers can be simulated rather accurately, so no further on this point will be discussed. The standard value of 1.2 for the polytropic exponent was used in the equation describing the relation between air pressure and air volume.

In the more complex cases described below the numerical model was first calibrated as well as possible against measurements to give the correct steady state flow and the wave velocity of simple (small) transients, where cavitation and effect of air pockets did not occur.

CAVITATION IN STEADILY RISING MAINS

It is often questioned what the real consequence of cavitaion is under different conditions. It is sometimes said that the calculation of cavitation is so uncertain that the uncertainty itself is argument enough to avoid it. In order to get some practical knowledge on this point it was decided to provoke cavitation in a simple case, which is a steadily rising pipeline without high points. The length profile and other data are seen in figure 1. It should be mentioned that cavitation was prevented under normal duty by an air chamber placed in the pumping station, but the air chamber was disconnected during the tests.

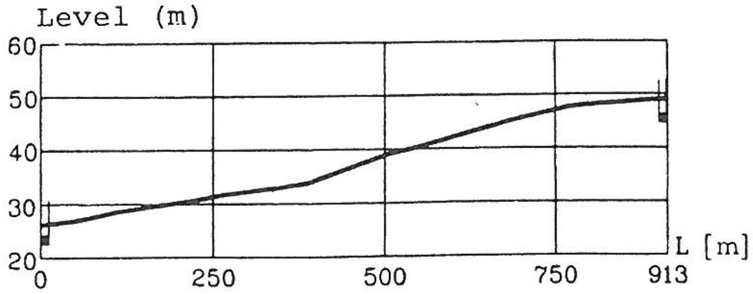

Figure 1. Length profile of sewer main in Voldsted, Denmark, 150 mm internal diameter, length 913 m, geometric lift 12.2 m, flow 15 l/sec, class 6 Bar uPVC.

Pressure measurements in the pumping station was now compared with computations on 3 levels as shown in figures 2a, 2b and 2c.

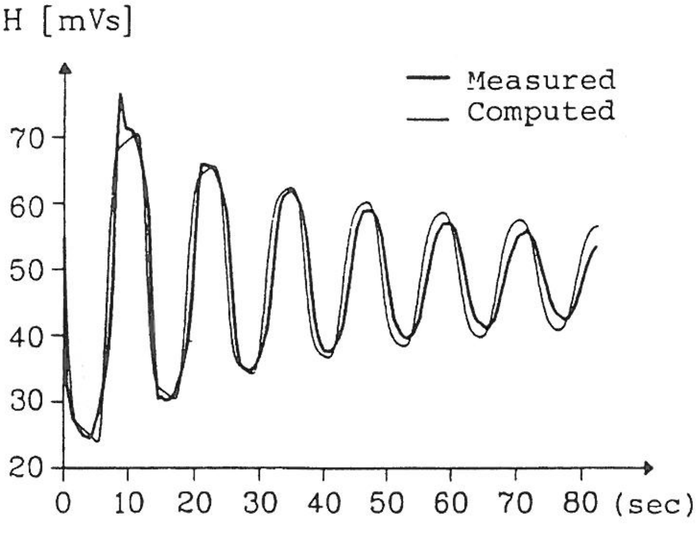

Figure 2a. Measurements against simple method of characteristics, without cavitation and without pump inertia. Computations underestimate the pressure peak.

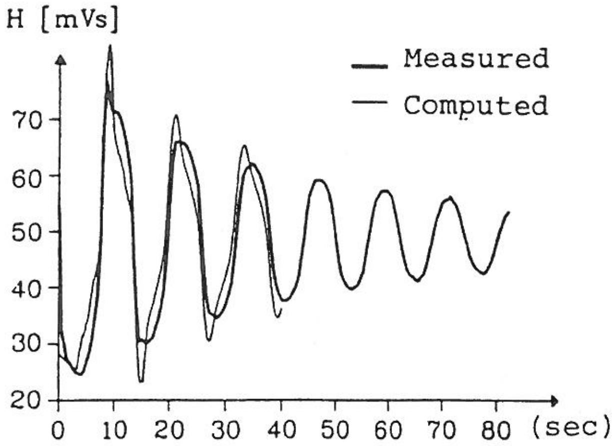

Figure 2b. Measurements against method of characteristics with cavitation included but without pump inertia. Better agreement than figure 2a is seen, but then the calculations overestimate the pressure.

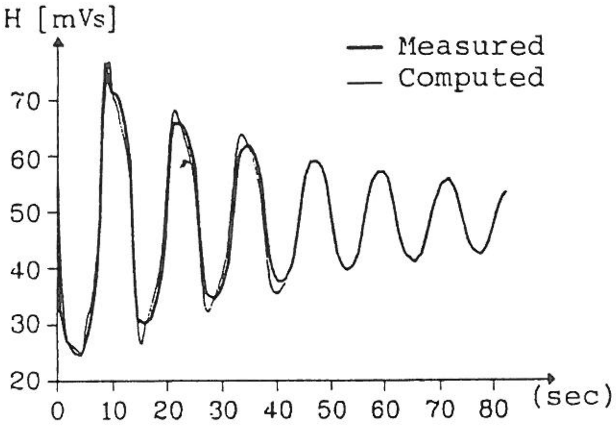

Figure 2c. Measurements against method of characteristics with cavitation and pump inertia included. An almost perfect agreement is seen.

The pump inertia itself has of course no direct effect on to the cavitation. But the pump inertia controls the pump run-down and thereby the shape of the low pressure wave moving from the pump out into the pipeline, so the pump inertia is affecting the location of the cavitaion in the pipeline. The conclusion is that the boundary conditions have to be modelled carefully. As cavitation in the calculation takes place at the node points it can also be concluded that a relatively high number of node points are preferable in order to locate the cavitation correctly.

RISING MAIN WITH ONE HIGH POINT

Figure 3 shows the length profile of the pumped sewer in Oue, North Jutland, Denmark.

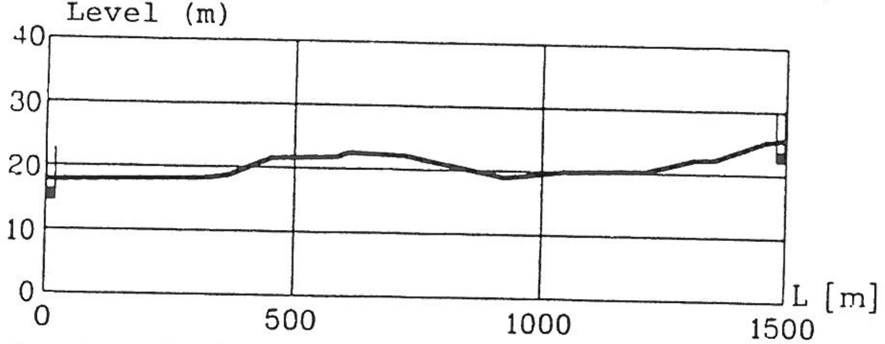

Figure 3. Length profile of sewer main in Oue, North Jutland, Denmark, 296 mm internal diameter, length 1500 m, geometric lift 12.2 m, flow 54 l/sec, class 6 Bar uPVC.

In figures 4 and 5 are shown the pressure measurements and computations at a point within the pumping stations on two different days. Figure no 4 was recorded during a rain period where the pumps had run continously for hours. It can therefore be assumed that air pockets were washed out. Figure no 5 was taken in a normal dry period and a significant difference in the picture was observed. First it is obvious that the maximum peak was lower, but also a slow long period oscillation occurred. A reasonable agreement between computations was achieved in the first case, but in the second case agreement was first found after incorporating an air pocket as large as 1350 l at the high point.

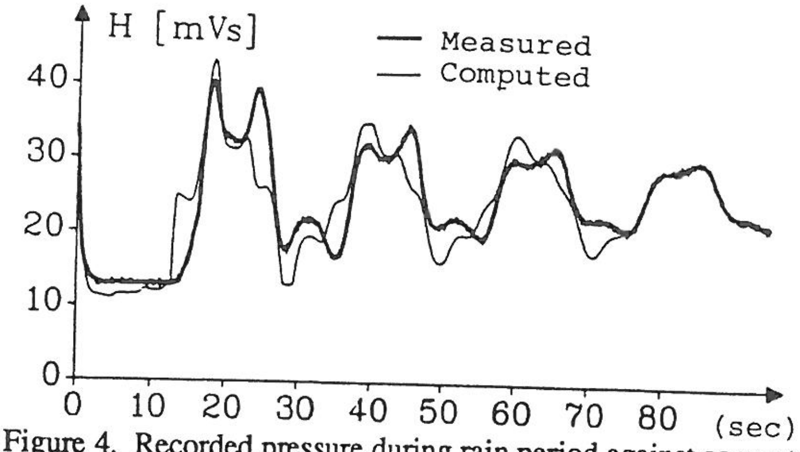

Figure 4. Recorded pressure during rain period against computed pressure.

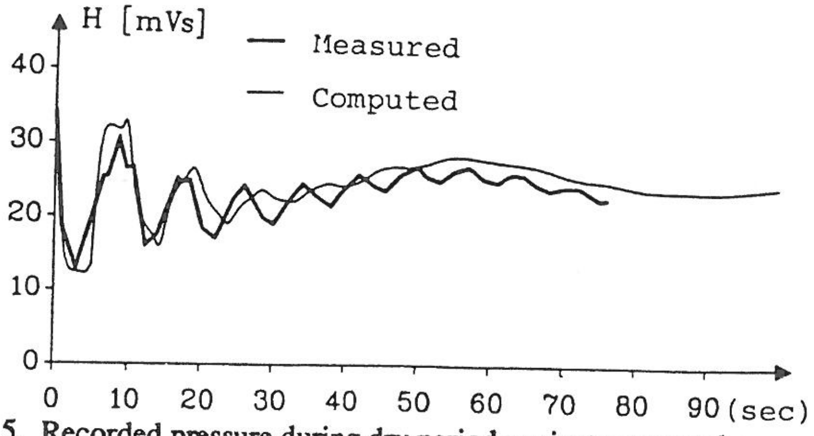

Figure 5. Recorded pressure during dry period against computed pressure where an air pocket of 1350 l was incorporated at the high point.

RISING MAIN WITH SEVERAL HIGH POINTS

The figure 6 shows the length profile of the pumped sewer in Støvring, North Jutland Denmark.

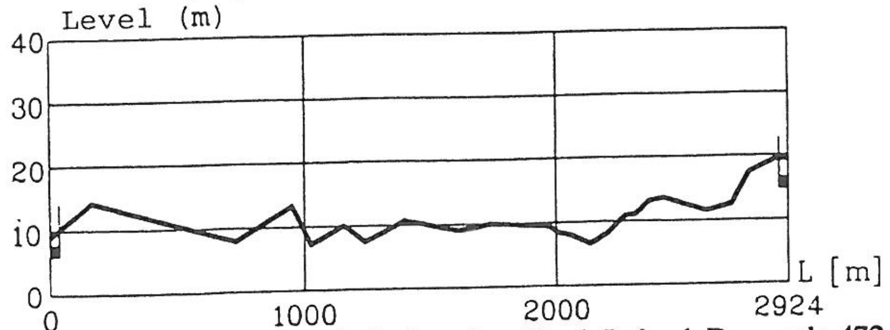

Figure 6. Length profile of sewer main in Støvring, North Jutland, Denmark, 472 mm internal diameter, length 2924 m, geometric lift 13.2 m, flow 150 l/sec, class 6 Bar uPVC.

In figures 7 and 8 are shown the same pressure measurements compared with computations first without and secondly with air pockets incorporated in the calculations.

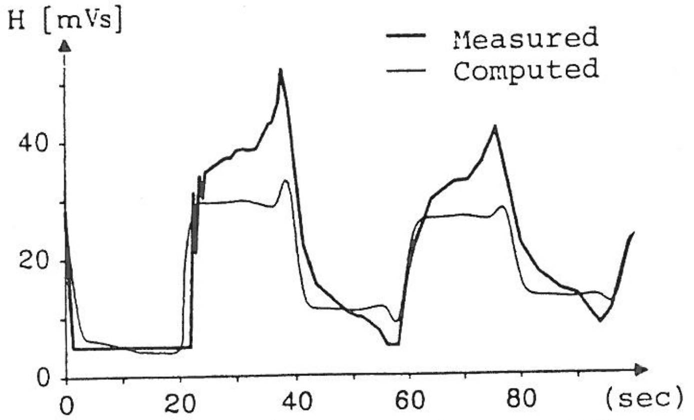

Figure 7. Measured pressure against computations.

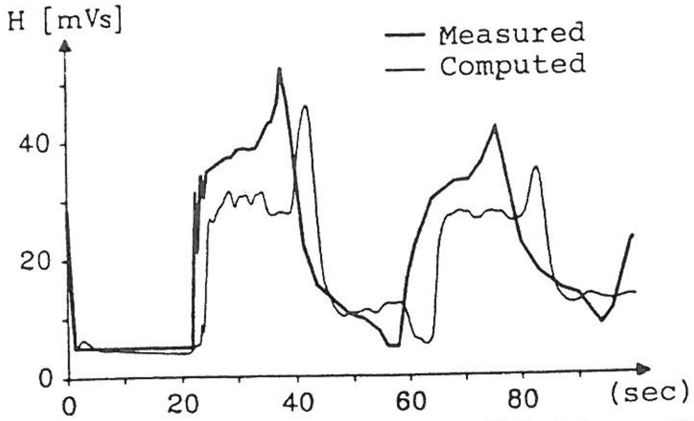

Figure 8. Measured pressure against computation where 50 l of air was distributed equally in the 5 high points.

It is remarkable from figure 7 that the measured pressure peak is significantly higher than the computed value. In other word in this case the air pocket (or pockets) have amplified the maximum peak. By trial and error in the computations assuming different sizes of air pockets it was concluded, as seen in figure no 8, that if totally 50 l of air was distributed equally in the

5 high points a reasonable agreement could be found. Although this was an uncertain determination of the air pockets, it is clear that the pockets here must have been much smaller than in the previous example from Oue (figures 4 to 6).

CONCLUSIONS

The results presented here do not pretend to give full scientific evidence on the general aspects of cavitation and air pockets in pipelines. The findings should be taken more as practical experiences. From this viewpoint the conclusions are

- The influence of cavitation seems to be computed acceptably by the simple assumption of cavities in node points in the case of a steady (monotonic) rising main. It seems acceptable to rely on such computation for the evaluation the effect of power failure and other rare and extreme cases.
- Air pockets seem more or less always to appear in pumped mains with high points during dry periods where the pumps only runs for a short part of the time.
- Air pockets can either damp or amplify the pressure peaks depending on their size and the character of the transients. Accordingly one can expect that air pockets in special cases can cause severe overload and even failure of the pipeline.

ACKNOWLEDGEMENTS

The former civil engineering students now practising engineers J. H. Christensen, J. Vollertsen and A. Bruun are sincerely acknowledged for their excellent field measurements and computational work during this study.

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