ASPECTS OF PRESSURE SEWERAGE SYSTEM DESIGN

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The article deals with some aspects and uncertainties of the design and operation of low pressure sewer systems. The most frequently used types of pumps are compared in the text with respect to the design parameters and impact to the hydraulic analysis of the pressure system. Also different methodologies of estimation of design flow are compared with the flow that was measured on the real low pressure sewer. The document describes the currently ongoing project of applied research, which focuses on optimizing the operation of pressure sewerage systems.

KEYWORDS

low pressure sewer, waste water, hydraulic analysis, research, back-flow valve, flow analysis, pressure measurement

1 INTRODUCTION

Low pressure sewer systems (LPSS) compared with conventional gravity sewerage systems have been used much less time and therefore there is less experience with their design and operation. Origins of pressure sewerage systems are dated back to 1965, when pressure drainage system was designed for 42 houses in Radcliff in the USA. The development of pressure sewer systems in the USA was sponsored by US EPA (Clean Water Act, 1977). Numerous pressure sewerage systems were also implemented on the territory of Canada, Hungary (PRESSKAN system) and Slovakia [Beranek 1998]. In the Czech Republic the pressure sewerage system has been spreading out since the first half of the nineties.

Within the studies of design problems, operation and actual behavior of LPSS the scientific research project of the Technology Agency of the Czech Republic titled "Smart pressure sewerage systems" is dealt with in the Institute of Municipal Water Management of the Faculty of Civil Engineering, Brno University of Technology (BUT). Current knowledge about the pressure sewerage system is gradually summarized and verified, its detailed overview is described in the following text.

1.1 Project TA04010023 - Smart pressure sewerage systems

It is an applied research project, which is being solved in cooperation with Faculty of Civil and Mechanical Engineering, BUT. The aim of the present project is to achieve an optimized operation and a proper, thus, a faultless functioning of pressure sewerage systems. This goal will be achieved by the development and practical implementation of three new technical tools, which enable an optimal design of new or additional optimization of functions of existing pressure sewerage systems. The software application for analysis of hydraulic load and the age of the water in the individual pipe sections of sewerage systems, intelligent control unit for controlling the function of individual pumps and automatic valve will form these tools. This approach follows a previous articles and work [Andrs 2014], [Hadas 2012], [Kovar 2014a] and [Kovar 2014b]. The necessity of these new tools is based on several years' monitoring and measuring in several existing pressure sewerage networks of various sizes. Within this observation basic operational and performance indicators were always evaluated, and typical defects of these systems were described. Most faults of pressure sewerage systems occur immediately or within two years since their start of the trial operation at the latest. Individual types of faults are described in details in the following text. Because of the current state of the technology, it is not possible to remove permanently one of these faults of pressure sewerage systems. The before-mentioned three new tools, which will create a comprehensive set of measures and will enable to optimize the function of pressure sewerage systems, help. These tools are tested within the development in current pressure sewerage systems, which are involved in the project through case studies.

2 TYPES OF PUMPS USED IN PRESSURE SEWERAGE SYSTEMS

In recent years the offer of pumps and complete domestic pumping stations designed specifically for pressure sewer systems has greatly spread out, see Fig. 2. Types of pumps are distinguished by the type of impeller, the presence or absence of the cutting mechanism and other parameters. Among pressure sewerage systems there are mostly two basic types: (1) hydrostatic screw pump, and (2) hydrodynamic centrifugal sludge pump. Centrifugal pumps have been used more frequently in recent years, and it brings some new aspects concerning the design of LPSS. The crucial difference is in pumping Q-H characteristics of both types of pumps. Hydrostatic screw pumps, which were used in pressure sewerage systems almost exclusively before, have a very steep dependence of flow and head, which is advantageous for hydraulic system design. There are several types of screw pumps available at the market of different manufacturers. For example, the pump Sigma EFRU 1 1/4" has Q-H pump characteristics defined by the manufacturer in the range from 0.91 l·s-1 with a pressure of 0.04 MPa up to 0.68 l·s-1 with a pressure of 0.80 MPa, see Fig. 1.

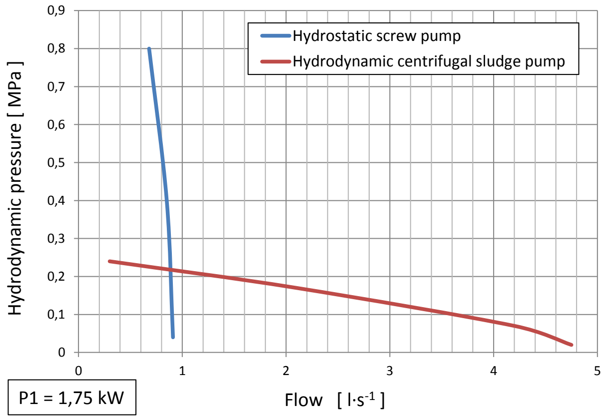

Figure 1. Comparison of pumping characteristics of hydrostatic and hydrodynamic pumps

Practically, this means that the pumping flow rate depends relatively a little bit on the head, respectively, on the current water pressure in the pipe, into which it is pumped, and varies only in the range of 0.23 l·s-1. Therefore during the hydraulic calculation the variable value of the pumped quantity is replaced by a constant one for volume screw pumps. The water flow through profile closure is obtained simply by multiplying the number of running pumps in the network and the pumping rate constant value. The entire hydraulic calculation is thus greatly simplified. For the dimension and design of pressure sewerage systems with hydrostatic pumps, it is possible to make a hydraulic design in a simplified form, for example, in a spreadsheet. Conversely, centrifugal pumps react very flexibly to the current value of the pressure in the extrusion pipe, into which it is pumped. The working pressure range of hydrodynamic pumps is much narrower than that of screw pumps; therefore they must be designed precisely. The working point of each centrifugal pump in the pressure sewer system varies depending on the current pipe pressure, and thus depending on the number of concurrently running pumps in the network. Individual pumps in the system interact. Pressure sewerage systems with centrifugal pumps need therefore to be dimensioned using methods of mathematical modelling and computer simulation of hydraulic parameters. For illustration, see Fig. 1, which shows the comparison of the pump characteristics of the hydrostatic and hydrodynamic pump. This difference has a crucial influence on the design and method of the system operation. The hydraulic analysis of LPSS with centrifugal pumps is more challenging than with the screw pumps and the design of such LPSS needs careful attention. Figure 3 shows a record of pressure measurements with time steps of 1 second in real LPSS, where centrifugal pumps are fitted. From the record of pressures a wide range of hydraulic phenomena is evident, which occurs in the pressure sewerage system. These include e.g. the transition from the pressure mode to free surface flow, the origin of underpressure, the origin and process of pressure surges during the start-up and switching off the pump, the pressure process during the start-up of the pumps with the same performance on different locations, etc.

Figure 2. Domestic sump pump with centrifugal submersible pump

3 DIMENSIONING AND ANALYSIS OF HYDRAULIC PRESSURE SEWERAGE SYSTEM

Specific procedures for dimensioning of LPSS on the Czech Republic conditions is stated e.g. in the Czech technical standard ČSN EN 1671. The task of dimensioning is a common design of the parameters of individual pumps and profiles of individual pipe sections. These parameters must be designed in balance. In LPSS not only underdimensioned, but also overdimensioned profiles of piping or pumps may cause unpleasant operating consequences. The design of centrifugal pumps with insufficient power has resulted in a lack of minimum driving speed, in extreme cases, even the inability of the pump to overcome the pressure in the pipeline and to pump water into the system. Conversely, overdimensioned pipe lines leads to an increased time of water hold-up in the pipe and may cause deterioration of the cleanability on the waste water treatment plant (WWTP), or odour problems, or clogging of piping sediment from the waste water.

For the hydraulic analysis of LPSS with centrifugal pumps methods of mathematical modelling and computer simulation are used. The analysis and simulation of various scenarios of hydraulic system load are performed. It is a combination of a precisely defined number of pumps at precisely defined points of the system, so as to achieve the desired hydraulic system load, which is determined by the probability of occurrence of this load case, respectively, by the flow of wastewater in the considered profile.

Load scenarios, which are analyzed for designed LPSS are as follows: (1) normal operation; (2) assessment of minimum flushing speed; (3) maximum hydraulic load of the system after the start of pumping after a power failure; and (4) assessment of the underpressure occurrence.

Hydraulic pressure pipe network analysis is a technical discipline, which is well known and standardly used e.g. in simulations of water networks. In technical practice a range of software tools is used, which mostly use the calculation core EPANET 2.0. LPSS hydraulic analysis can be performed in EPANET only on some selected operating conditions of the network. Not only waste water flows in the pipe of LPSS, but also a significant amount of gases in the form of bubbles, which cause significant hydraulic transformation of flows in the system in the direction from the pump to the closure profile.

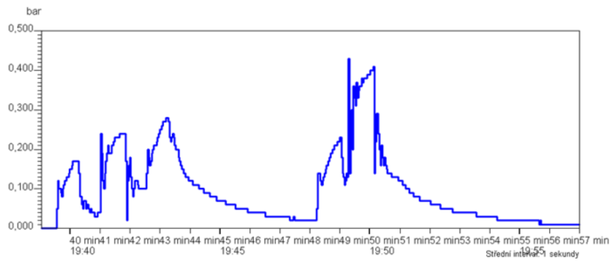

Figure 3. Water drainage from LPSS to the WWTP - evening peak flow

Therefore the design of pressure sewer is still loaded with great uncertainty, which enters the calculations and decision-making processes. The cause is the imperfect knowledge of the behaviour of these systems. There are basically two largest sources of uncertainty: (1) uncertainty in determining the design flow, and (2) uncertainty in the calculation methods used in the hydraulic analysis of pressure sewerage system.

There is a lack of current literature on this issue. Concerning the technical standards ČSN EN 1671 - Pressure sewerage systems outside buildings is available, which gives only the basic framework for the design of technical solutions. Some additional information can also be obtained in the ČSN EN 752 and ČSN 75 6101, respectively, ATV - A 163E.

The basic questions, which a designer solves during the LPSS design with respect to the required pump performance and optimal pipe dimensions are the following: (1) how many pumps in the system will start up simultaneously on "normal conditions" within the meaning of ČSN EN 1671; (2) what is the design flow of the pipeline section; (3) what are the appropriate hydrodynamic pressures on individual locations of pressure sewerage system.

All three issues are linked. The calculation of hydrodynamic pressures is the subject of hydraulic analyses of LPSS. The following text responds to the first and second question.

4 DESIGN FLOW DETERMINATION

The subject of the design of pressure sewerage system is, among others, the determining of the parameters of individual pumps and design of optimal dimensions of individual pipe sections. The initial task is to determine, however, the design flow rate for each LPSS section. According to the generally accepted conventions this flow is not considered to be inviolable. LPSS has to be optimally designed so that each section of pipe is flushed at a speed of 0.7 m·s-1 at least once per 24 hours, in order to avoid the clogging of the pipe with sediment from the waste water. The speed limit during normal operation should not exceed 2.5 m·s-1 with regard to operating costs for pumping. The network must also enable simultaneous operation of a precise number of pumps under normal conditions. A method of determining the design flow rate, respectively, the design of concurrently running pumps in ČSN EN 1671 is not explicitly defined.

In technical practice to solve this task some of the following methods are used: (1) the method of proportional flow known as "PRESSKAN" method [Beranek 1998]; (2) The process according to ATV - A 163E (standard ATV-A 116E, 1992); (3) Algorithm EPA [US EPA 2002]; (4) Environment One [Environment One Corporation, 2008]. A list of the methods used is not exhaustive. Some of them are the result of the previous research, or they are standardized technical norms. Some procedures are merely technical recommendations by manufacturer of technology; however, they are used and are also considered to be a standard.

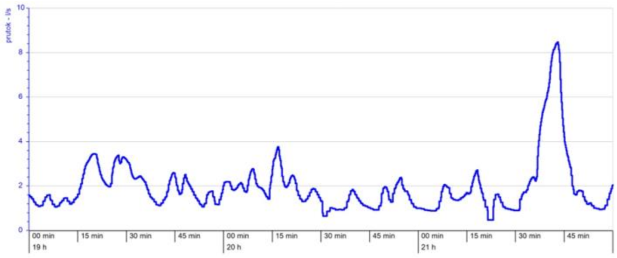

Figure 4. Water drainage from LPSS to the WWTP - evening peak flow

In the framework of the present study concerning this issue we dealt with an estimate accuracy of unknown design flow, which is offered by various methods. Therefore, long-term flow measurements were done in several existing pressure sewer systems, which lasted for several months. The obtained flows' time series was then statistically processed and evaluated. For a given sewer system a theoretical calculation of the design flow was then also carried out according to the above-mentioned methods. The results of the theoretical calculation were compared with the actually measured flow rates, respectively, with the results of the analysis of the flows' time series.

For illustration we show the result of this comparison for a selected locality, where 437 residents are connected to LPSS through 148 petrol stations with screw pumps of PRESSKAN type. At the end of LPSS at its outcome into the gravity sewer manholes the inductive flowmeter is located. Flow measurement was carried out continuously for 6 months with a pulse value of 0.010 m3. The comparison results are shown in the following Table. 1.

Results shown in Tab. 1 indicate how large reserve the various methods bring to hydraulic calculations of networks already at a stage of design flow determination. By comparing actual measured values of the flows' time series, which was statistically analyzed with prediction results according to various procedures it is evident that the reserve ranges in the series of hundreds of percent compared with the measured value.

The method used	Designed flow [l·s-1]
The measured flow rate	1,20 *
PRESSKAN method	2,68
ATV – A 163E	3,28
Algorithm EPA	3,21
Environment One	6,70

Table 1. Comparison of the design flow according to individual methods with the actually measured value (Note: * non-exceeding probability of 95%)

Thus the consequences of exaggerated estimates of future flows were observed in some existing systems and it is possible to summarize them briefly as follows: (1) an overdimensioned pipe - higher investments, LPSS does not have a self-cleaning ability; (2) The overdimensioned flowmeter - inaccuracy in measuring the flow and volume, invoicing, poor quality data; (3) a long time of water hold-up in the pipe – the change of indicators of the waste water quality, the shift into the anaerobic condition, deterioration of cleanability, etc.

Figure 5. The material of the pressure sewer pipelines, which got clogged due to the influence of combination of underpressure and the lack of flushing speed

5 PRESSURE SEWERAGE SYSTEM FITTINGS

The following text describes two most common types of malfunctions, which were observed in the surveyed systems. In both cases these defects are caused by improper design, respectively, by the incorrect choice of fitting type. Here it should be stressed that the malfunctions which are described in the following text, occur mainly on pressure sewerage systems, which are equipped with centrifugal pumps. In certain aspects they have higher demands on the accuracy of the whole system design and fittings mounting.

5.1 Project TA04010023 - Smart pressure sewerage

A substantial amount of gases is normally present in the LPSS pipeline, which get there partially from the atmosphere during pumping, partially in the pipeline biological processes are formed. These gases form the so-called bags, which are held in the highest places of the pipeline.

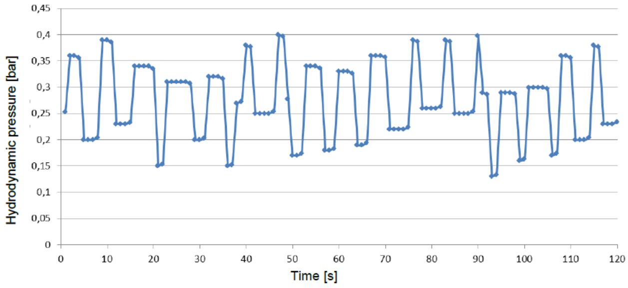

Figure 6. Hydrodynamic pressure pulsations with centrifugal pump by the venting pipe

Gas bags narrow the profile pipes and cause significant hydraulic losses. The bags are entrained and cause pressure pulsation by water flow in the pipeline. Due to unsuitable height arrangement of pipes and absence of sufficient quantities of automatic air valves (AAV), these gas bags can cause permanent operational problems. These include the pressure pulsation and unsteadiness of running pumps. These phenomena secondarily cause insufficient hydraulic capacity of the pipeline and shorten the life time of the pump, see Fig. 6. For the bleeding of the pipe fittings with fully automated function must be used.

Automatic venting function (vacuum breaker) is also extremely important. Except for precisely defined sections of pipe in pressure sewerage systems, the underpressure occurrence is an undesirable phenomenon and it is necessary to eliminate it. For this purpose automatic vacuum breakers (AVB) are used. During the underpressure in pressure sewer pipe the wastewater is sucked from domestic pump sumps without the start up of the pump. Water is sucked by a centrifugal pump wheel and takes away them also unpulverized solid particles of the waste water (rough filth and fibrous particles), which are subsequently deposited in the pipeline. Unpulverized solid particles of the waste water may reduce the tightness of back-flow valve which subsequently leaks. The high underpressure value can lead to the origin of surging, vibration and noise, mechanical damage of back-flow valve (tapping), untightness and leakage of waste water back in the pump sump.

Due to observation of existing systems, LPSS demonstrated the following: (1) in every highest point of the pipeline AAV / AVB (possibly bleeding / venting oven) should be equipped, exceptions may occur, but they require experience and hydraulic calculation; (2) the valve must actually be fully automatic, the replacement for ordinary hydrant has no meaning. It is also necessary to carry out regular maintenance, cleaning and controlling of valve functions; (3) with regard to the elimination of underpressure, the fitting of AVB only to a vertex of pipelines of main sewers is not sufficient. It appears that the ability of AVB to aerate the pipeline is locally limited to the nearest surroundings. In the rugged terrain and particularly on the downward parts of pressure sewers, it is necessary to aerate the pipeline on more locations, not only in peak quarries of the main sewer pipe.

5.2 Back-flow valves

Backflow valve is placed in the pump sump behind the pump but in front of the main valve at discharge into the system. The aim is to prevent the back-flow of water in the pump sump when the pump does not work. Besides the material performance, throughput, hydraulic resistance and wear resistance, also a minimum desired overpressure is another important design parameter, at which the valve will ensure the required tightness.

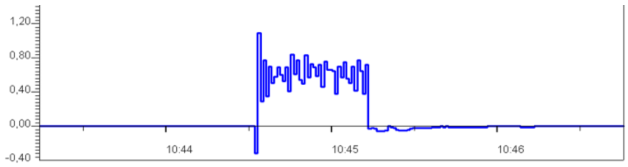

Figure 7. Measurement of pressure in the LPSS pipeline - low pressure values, sometimes underpressure

Pressure sewer system is dimensioned particular on load conditions, when the pumps pump and there are higher hydrodynamic pressures in the system. These load cases are usually accentuated in the design. The truth is that most of the days pressures in the pipes are usually very low and sometimes even on atmospheric pressure level, or even on a slight underpressure level, see Fig. 7. If the valve does not have the ability to tighten perfectly even at very low pressures of about 0.01 MPa, it may in specific cases lead to leakage of water from the system back into the pumping manholes, which cause cyclical pumping of water, a high number of motor-hours of pump and energy power consumption.

6 CONCLUSIONS

In the context of observations and measurements in several existing LPSS it was proved that the design of pressure sewerage system with centrifugal pump requires a very precise approach and experience. Centrifugal pumps operate with a much lower range of pressures and require a more accurate hydraulic design than hydrostatic pumps. For systems where tens or hundreds of hydrodynamic pumps are connected to a common pipeline, it is almost unthinkable to perform an optimal design of the pipeline dimensions and pump performance without the use of mathematical modelling and simulation of hydraulic conditions throughout the system. A significant uncertainty into the hydrotechnical calculation of these systems is brought by the introductory step; where for each calculated section of pipe the design flow is determined. For this process several different methods are used, but the results differ significantly from each other. In addition due to comparing with the actual measured flow rates on the existing pressure sewerage systems it was verified that at this stage there is an entry of significant reserves, which subsequently leads to overdimensioning the pipe with all the subsequent negative consequences.

Also, incorrect design or absence of certain fittings in the system can cause serious operational problems. Pressure sewer networks are relatively complex and technologically demanding systems and their use should be limited to absolutely necessary cases when the wastewater cannot be drained by gravity. Mistakes made in the design of the network are promoted to subsequent operational difficulties and their elimination is usually costly.

The article presents some aspects of the design of pressure sewerage systems, which is loaded by considerable uncertainties.

The ongoing applied research project TA04010023 of the Technology Agency of the Czech Republic titled "Smart pressure sewerage systems" deals with the solution of the problems of pressure sewerage systems.

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