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Experimental study of water hammer-induced forces and deformations in dry pipe fire protection systems

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ABSTRACT

When designing a fire protection system, every effort should be taken to ensure its maximum operational safety. Therefore, correct identification of the dynamic load affecting the system during water hammer occurrence is essential to increase the operational reliability of such fire protection systems on their design stage. A test stand with a simple deluge system was designed for the experiments. The layout consisted of a distribution duct and one straight branch line (including three different diameter values) equipped with three fire nozzles. However, the main objective of this study is not to study the water hammer itself but, rather, to study the forces and displacements induced by the water hammer. The measurement results will be used to calibrate a mathematical model created using MATLAB software. The verified model will in turn enable numerical determination of the dynamic force values for larger systems. Furthermore, these force values will allow for pinpointing the critical sections, for which it is necessary to prevent displacements or transfer the acting forces to the building structure.

1. Introduction

Fire protection is one of the most important design issues encountered in the modern construction industry. This importance is particularly true when multiple lives or high-value properties are at stake.

When designing a fire protection system, every effort should be taken to ensure its maximum operational safety. However, designing such a system is not a simple task because its operational characteristics cannot handle instances of considerable overload. Sudden activation of a fire protection system by an alarm check valve creates conditions conducive to transient flow formation. When taken to the extreme, these conditions may take the form of a water hammer.

A water hammer is defined as a violent passing of a pressure wave, which is dangerous not only to the pumping plant supplying the system but also to the system itself [1]. A sudden increase in pressure may damage a duct, especially where the material is weaker than average [2,3]. The water-hammer phenomenon is also accompanied by oscillating motion emerging in the system ducts [4–7]. This motion in turn results in duct displacement, which, in extreme cases, may lead to fire protection system mounting damage. Therefore, correct identification of the dynamic load affecting the system during the occurrence of a water hammer is essential to increase the operational reliability of such fire protection systems on their design stage. The significance is even higher because such systems are not in continuous operation; thus, operational feedback is not likely to arrive ahead of time.

2. Nature of the phenomenon under study

The motivation for conducting this research study emerged from meeting with engineers who design and build fire protection systems. These engineers face a practical problem of determining dynamic forces acting in fire protection systems that result from unsteady flows. Foreseeing possible system displacements associated with the forces in question is also problematic, as is being able to target sections where such displacements are likely to be of largest magnitude. The magnitude of the water hammer present and the possible damage caused by this type of flow make it difficult to model the phenomenon on objects of similar scale to the real system dimensions. Furthermore, it is equally difficult to approximate the phenomenon using a model that would preserve similar numbers because this requires simulation of a water hammer occurring at the speed of sound at its maximum velocity. Thus, the idea emerged to conduct a preliminary study on a geometrically simplified model with small linear dimensions by attempting to induce a water hammer therein.

However, the main objective of this study is not to study the water hammer itself, rather, the objective is to study the forces and displacements induced by the water hammer. The measurement

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results will be used to calibrate a mathematical model created using MATLAB software. The verified model will in turn enable numerical determination of the dynamic force values for larger systems. Furthermore, these force values will allow for pinpointing the critical sections, for which it is necessary to prevent displacements or transfer the acting forces to the building structure.

3. Experiments conducted by the author

A test stand with a simple deluge system was designed for the experiments. The layout consisted of a distribution duct and one straight branch line (including three different diameter values) equipped with three fire nozzles [8] (Fig. 1)

The experimental system utilised a set of steel pipes with various external diameter values D_0 and wall thicknesses values e (Table 1). The experimental system was not filled with water [9,10]

The model was supplied with water from a pressure increasing station. Constant initial conditions were provided to obtain results that could be processed using statistical tools. Such constant flow conditions for the initial period were provided by using a hydro-pneumatic tank with capacity of 300 dm^3. Constant pressure conditions in the initial period were ensured through the use of a compressor, which could increase the pressure by up to 5.5 bars, connected to the setup.

The pressure distribution in the system was measured using strain gauge pressure transducers with operating ranges matching the pressure values occurring in the individual sections. The pressure sensors had linear operating characteristics with a correlation coefficient of 0.999. The sensor measuring ranges (1.2 and 2.0 MPa) were selected to match the steady flow stream speed v as well as the expected maximum pressure values at the points of measurement [11].

One of the pressure gauges was located before the point of water flow direction change (P1 – Figs. 2 and 3).

The measurements and analysis of the results regarded a simple water hammer, i.e., one for which the passing time of pressure wave T was always greater than the gate valve opening time, $t_z < T$ [12].

The experiment was performed at an average water temperature of 281 K.

The values of the forces impacting the system elements were assessed via two different methods and over the course of two stages.

During STAGE I, the assessment was performed by the measuring forces acting in the section of water flow direction change (detail A); the system was suspended using loop hangers only,

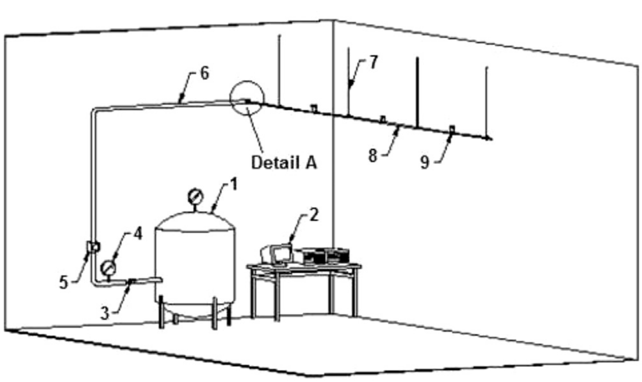

Fig. 1. Experimental setup layout: 1 – pressure increasing station; 2 – measurement station; 3 – flow-metre; 4 – pressure gauge; 5 – feed valve; 6 – distribution duct; diameter DN 50; 7 – loop hangers; 8 – branch line, diameters DN 40, DN 32 and DN 25; 9 – upright fire nozzles.

Table 1
Properties of the steel pipes used in the experiment.

No.	Nominal diameter DN [mm]	Outer diameter D_0 [mm]	Wall thickness e [mm]	Duct length L [m]
1	DN 50	60.3	3.65	14.5
2	DN 40	48.3	3.25	3.0
3	DN 32	42.4	3.25	3.0
4	DN 25	33.7	3.25	3.0

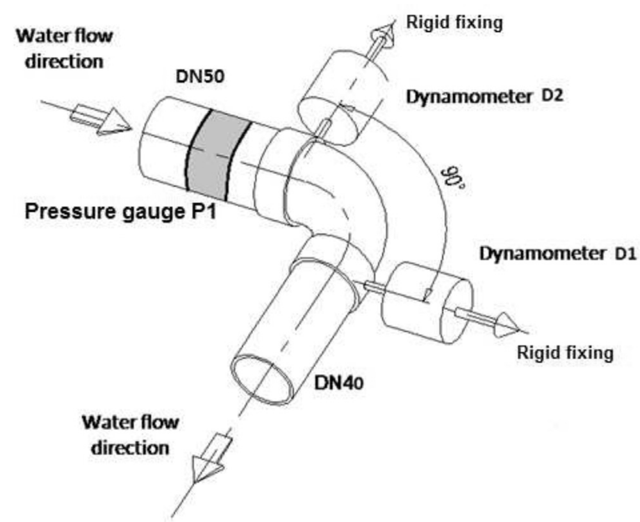

Fig. 2. Detail A from Fig. 1 – pressure gauge and dynamometer location in the control/gauging section.

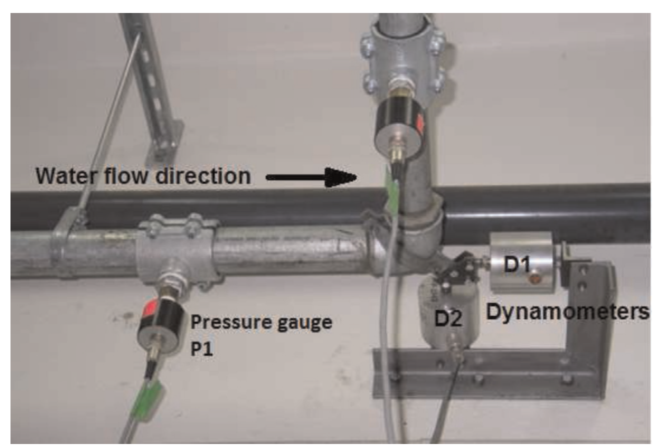

Fig. 3. Location of the pressure gauge and dynamometers used in STAGE I of the project.

allowing for the recording of the maximum forces occurring therein using strain gauge dynamometers (Figs. 2 and 3). The resulting characteristics enabled us to determine the type of force (compressive vs. tensile) and its value. Rigid connection of the dynamometers to the system was related to the tool structure, but it also enabled the recording of the maximum force values present in the model via dynamometer springs. To minimise the impact of system “jerking” resulting from sudden valve opening, an additional support was installed directly behind the valve.

During STAGE II, the assessment involved the deformation measurements for the system components. A Hilti fixed point support hung on a threaded pipe was selected for this purpose (Fig. 4). Such mounting prevented the free movement of the system, which guaranteed that the strain on the threaded pipe from