Physical Modeling to Determine the Cause of Air-hammer in Sewer Pipes

B.X. Zhang, K.H. Wang, and T.G. Cleveland
Department of Civil and Environmental Engineering
University of Houston, Houston TX 77204-4791
Phone: 713-743-4277 E-mail: KHWang@uh.edu

Abstract

In this study, a physical model was constructed to examine the cause of air hammer in sewer pipelines. The air flow and pressure change under the surge condition were also investigated. A series of experimental measurements were conducted. The pressure increase inside the manhole was recorded. It was found the pressure was large enough to pop-off the manhole cover. The study also focused on exploring ways to mitigate the air hammer phenomenon. Test results considering the effects of valve closure time and air release holes are presented.

Introduction

Wastewater systems traditionally are intended to operate in a gravity flow mode. This method of operation requires changes in elevation to maintain gravity flow over long distances. Houston, along with other large cities, is departing from this tradition and exploring how to operate the wastewater system in a surcharged mode as a matter of routine during high flow periods. Occasionally the sewer system encounters some hydraulic related problems which affect the pipeline operations. One of the concerns is the identification of the cause and the quantification of the air pressure surge, called airhammer. Such surges of pressure are known to pop up manhole covers, creating a hazardous condition on the street for vehicles and pedestrians. When the flow is surcharged this problem will become even worse.

To study and quantify the pressure surges in pipelines, we first developed a mathematical model to simulate the hydraulic transients in sewer pipes. A physical model which consists of a main inlet line, a drop structure, and a man hole was constructed to examine the pressure surges and the occurrence of the manhole cover pop-off. The test results were used to form the basis for the verification and calibration of the mathematical model and to advance the understanding of the air-hammer formation.

Physical Model

A physical model was built with a 1:6 scale in the Hydraulics Laboratory of the University of Houston. The physical model consists of a main line, a drop structure and a re-circulating water supply system. The pipeline and drop structure system was built using four-inch-diameter, transparent pipes. The main line is about 40 ft long and an eight-inch-diameter manhole structure is situated in the middle of the main line. A sharp crested weir was installed in the downstream storage tank to measure the total flow rate. An ultrasonic doppler-shift flowmeter was also used to measure the flow rate along the pipeline. The pressure transducers were placed along the pipeline and on the manhole cover to measure the pressure changes under fluid transients.

As observed in the field, the possible cause for air-hammer to occur is due to the back up of flow before a lift station when the inflow is overcharged from infiltration during a rain storm. The back up of flow creates an upstream-propagating pressure surge. In the physical modeling study, the pressure surge induced by the closure of the downstream valve was recorded. The pressure changes along the pipeline were measured. In particular, the pressure increase inside the manhole was evaluated to determine the critical pressure for the manhole cover pop-off. Different surge conditions were examined. Tests with inflows from the drop structure were also conducted. The effects of air entrainments and induced surge flow for the cause of air hammer can be thoroughly investigated.

Results

The model tests considering the inline flow and downstream control was carried out to determine the cause of air hammer in a pipeline. A series of experimental measurements for different flow rates and surge conditions were conducted. The occurrence of manhole cover pop-off was observed in the model test. The numerically predicted pressure increase in an upstream-propagating surge compares fairly well with the measured data. The recorded air pressure inside the manhole shows substantially increase at the instant the manhole cover pops off. This critical pressure was used as a reference pressure to define the cases with manhole cover pop-off.

To explore ways to mitigate the air hammer phenomenon, model tests by considering the effects of valve closure time and air release holes were conducted. Three different closure times and air release scenarios were used in the tests. It was found that the pressure increase under the surcharged condition is much greater than the one under the flow condition without surcharge. The measured results indicated that the air release from the open holes on the manhole cover for unsurcharged flow does reduce the occurrence of the manhole cover pop-off. However, for surcharged flow, the propagation of the air flow and pressure increase is much faster than the function of air release (or pressure release). The manhole cover for most cases still popped off. The results collected for the tests with different valve closure time show that the longer closure time may delay the occurrence of manhole cover pop-off. Although the maximum pressure for a longer closure time decreases comparing to the pressure with instant valve closure, the phenomenon of manhole cover pop-off can still observe in the model tests.

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University of Houston, Department of Civil and Environmental Engineering4800 Calhoun, Houston, TX 77024
Phone 713-743-4278 Fax 743-4260