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Research papers

Assessing the effectiveness of an airshaft for dropshaft air re-circulation and depressurization

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ABSTRACT

Dropshafts are commonly used to convey water to deep tunnels. Plunging flow dropshafts have been reported to cause downstream air pressurization and subsequent sewer odor issues. A retrofit by connecting the dropshaft to an airshaft with several horizontal pipes for air re-circulation has been implemented in Edmonton, Canada. Tools for predicting the performance of this retrofit are needed. In the current work, physical model study and prediction were conducted to assess the effectiveness of the retrofit. Experiments were run with the dropshaft connected to the airshaft with different numbers of horizontal pipes. Predictions of air pressure and air entrainment of the retrofitted dropshaft were in good agreement with the experimental data. The effect of the airshaft became more important under a pressurized downstream condition with a larger sized airshaft. The prediction was also applied to simulate the performance of the retrofitted prototype dropshaft in Edmonton, regarding the bottom air pressure and the air flow rates in horizontal pipes. The prediction compared well with the field monitoring results, and the airshaft was found to be effective in depressurizing the downstream sewers, which helped to reduce the downstream pressure by about 60%.

1. Introduction

Dropshafts have been used widely to transfer water from shallow sewers to deep tunnels in urban drainage systems in the cities like Chicago (Anderson and Dahlin 1975) and Edmonton, Canada (Zhang et al. 2015). The drop height of dropshafts can reach dozens of meters and a large amount of air can be induced into dropshafts. The relative air demand (β), defined as the ratio of air flow rate induced into the dropshaft to the corresponding water flow rate, was found as high as 40 for a dropshaft with a drop height of 7.72 m in Camino et al. (2015) and 160 ± 78 for a prototype dropshaft with a drop height of about 25 m in Zhang et al. (2015). Ma et al. (2016a) recently reported that water could disintegrate into small drops after a certain falling distance in dropshafts. The momentum transfer from water drops to the air phase was believed to be the main reason causing the large air demand and downstream pressurization of the dropshaft.

In existing studies, the air demand of a dropshaft was usually estimated based on some empirical equations. Camino et al. (2015) developed an empirical relationship between the relative air demand β and the dimensionless water flow rate $Q^* = Q_w/(gD^5)^{0.5}$ (Q_w is the water flow rate and D is the dropshaft diameter) in the form of $\beta = aQ^{*b}$ (where a, b are fitting parameters). Granata et al. (2015) proposed an empirical equation to estimate the peak air demand of a drop manhole, which correlated the air demand with the Froude number of the approaching flow, filling ratio, pool depth in the drop manhole and the dimensions of the drop manhole (drop height, drop manhole diameter and outlet pipe diameter, etc.). However, the fitted equations about air entrainment of the dropshaft were derived from some specific configurations and they are not necessarily suitable for other dropshafts with different geometries. Also, there is a lack of similitude criterion for air entrainment of dropshaft (Gualtieri and Chanson, 2013). The laboratory results cannot be directly applied to the prototype situation because small scale model studies usually underestimate the air entrainment significantly (Stephenson and Metcalf, 1991; Chanson, 2009).

Due to the significant air entrainment, dropshafts have been considered as an important element causing downstream pressurization and subsequent sewer odor issue (Edwini-Bonsu and Steffler 2006; Zhang et al. 2015). Several efforts have been made to improve the performance of dropshaft regarding the air entrainment, like the introduction of vortex dropshafts (Jain 1988), stacked drop manhole (Camino et al. 2010) and baffle drop structure (Odgaard et al. 2013). However, due to the complexity of construction and high cost, there are

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Notation

A	cross-section area of dropshaft
C_d	drag coefficient
d	water drop diameter
D_e	diameter of outlet pipe
D_i	diameter of inlet pipe
D	diameter of dropshaft
f	friction loss coefficient
g	gravity acceleration
H	drop height
K	head loss coefficient
L	distance along the airshaft
P	average air pressure
Q_a	air flow rate
Q_w	water flow rate
V	water drop velocity
V_a	average air velocity in the dropshaft
z	falling distance from the invert of the inlet pipe
α	coefficient of induced air flow rate
β	relative air demand
ρ_a	air density

Subscripts and superscripts

c1	horizontal circulation pipe c1
c2	horizontal circulation pipe c2
h	horizontal pipes in prototype dropshaft
I	air inlet
s	airshaft

still some concerns to apply these innovated dropshafts widely in practice. Also, these new designs do not address the problem of existing dropshafts and effective retrofits to the existing ones are still needed.

The City of Edmonton successively retrofitted two of the existing dropshafts in 2006 and 2010 by connecting them to an airshaft via several horizontal pipes, with which air circulation was formed inside the dropshaft (Zhang et al. 2015). The two dropshafts had a diameter of 1.2 m and their drop heights were 24.8 m and 11.4 m, respectively. Both of the airshafts were 1.2 m diameter and a number of horizontal pipes were installed with a spacing of about 4.0 m. A field monitoring program of these two retrofitted dropshafts was conducted from 2006 to 2011. This retrofit was found to be effective in depressurizing the downstream sewer pipe of the dropshaft. However, no design guideline for selecting design parameters such as the size of the airshaft and the number and locations of the circulation pipes has been proposed. There is a need to develop tools for predicting the performance of this type of retrofit.

In the current study, the performance of a dropshaft connected with an airshaft was investigated. Laboratory model study and prediction for the air pressure and air demand of the retrofitted dropshaft were conducted. Additional experiments were run to explore the performance of the retrofitted dropshaft under a pressurized downstream condition similar to that in actual sewer systems. The effect of airshaft size on the air entrainment of the dropshaft was also investigated. Prediction was applied to simulate the performance of an existing retrofitted prototype dropshaft in Edmonton. The effectiveness of the airshaft on reducing air entrainment and downstream pressurization were assessed based on the lab modeling and field data.

2. Experiments

The model of dropshaft connected with an airshaft is shown in Fig. 1. The dropshaft model had a drop height of $H = 7.72$ m and a diameter of $D = 0.38$ m. The diameter of the water inlet pipe was $D_i = 0.19$ m. The outlet pipe had the same diameter as the dropshaft with a length of about 1.5 m and open to the atmosphere. The top of the dropshaft was sealed and the ambient air was only allowed to enter the dropshaft through a circular air inlet opened near the top, which was 10 cm diameter and located about 20 cm below the top. An airshaft with a diameter of $D^s = 0.15$ m was installed about 1 m downstream the dropshaft, connecting the outlet pipe to the top of the dropshaft. In addition, two horizontal pipes c1 and c2 with a diameter of $D^h = 0.1$ m and a length of 1.0 m were installed between the dropshaft and airshaft, at the height of $z = 3.32$ m (c1) and 4.82 m (c2). Here z is the falling distance from the invert of the inlet pipe, as labeled in Fig. 1. A valve was installed in the horizontal pipes to open or close the air flow. The horizontal pipes had an upward slope of about 2.5% to prevent water flowing into the airshaft.

In the experiment, air pressure in the dropshaft was measured by the pressure transducers (Model 264 Differential Pressure Transducer from Setra Systems Inc.). Each transducer was connected to a hollow metal tube inserted into the dropshaft with a downward hole of about 3 mm diameter on its surface for pressure reception. The air pressure was measured at six locations along the dropshaft of $z = 0.72$, 2.72, 4.72, 5.72, 6.72 and 7.42 m, labeled as P1 to P6, respectively, in Fig. 1. Air pressure was measured at two positions in each horizontal circulation pipe, one about 5 cm away from the wall of the dropshaft (denoted as P_{h1} in c1 and P_{h3} in c2) and the other in the middle of the pipe (denoted as P_{h2} in c1 and P_{h4} in c2). The sampling frequency of the

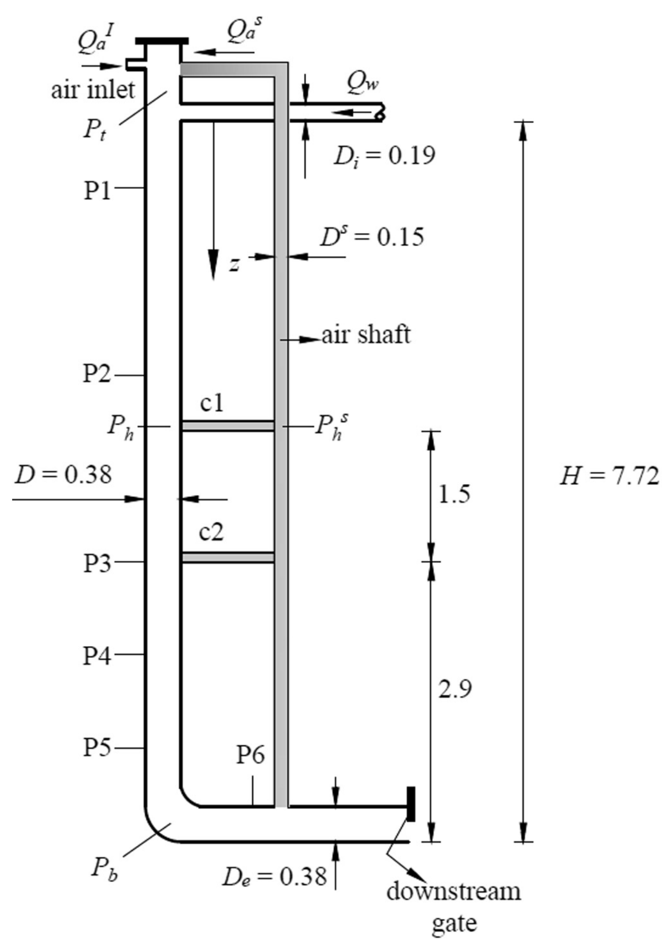

Fig. 1. Schematic of dropshaft connected with the airshaft and horizontal circulation pipes c1 and c2. P1 to P6 are for air pressure measurement in the dropshaft, located at $z = 0.72$, 2.72, 4.72, 5.72, 6.72 and 7.42 m, respectively. All dimensions are in meters.