# Experimental Study on Flow Capacity of Sewer Pipe with a Cylindrical Obstacle

Zhi Yang[1], Tianci Wang[1], Biao Huang[1,*] & David Z. Zhu[1,2]

[1]*College of Civil and Environmental Engineering, Ningbo University, China*

[2]*Department of Civil and Environmental Engineering, University of Alberta, Canada*

**Corresponding author email: huangbiao@nbu.edu.cn*

## Highlights

- Obstacles have varying degrees of influence on flow regimes.
- Obstacles may cause significant reduction of flow capacity.

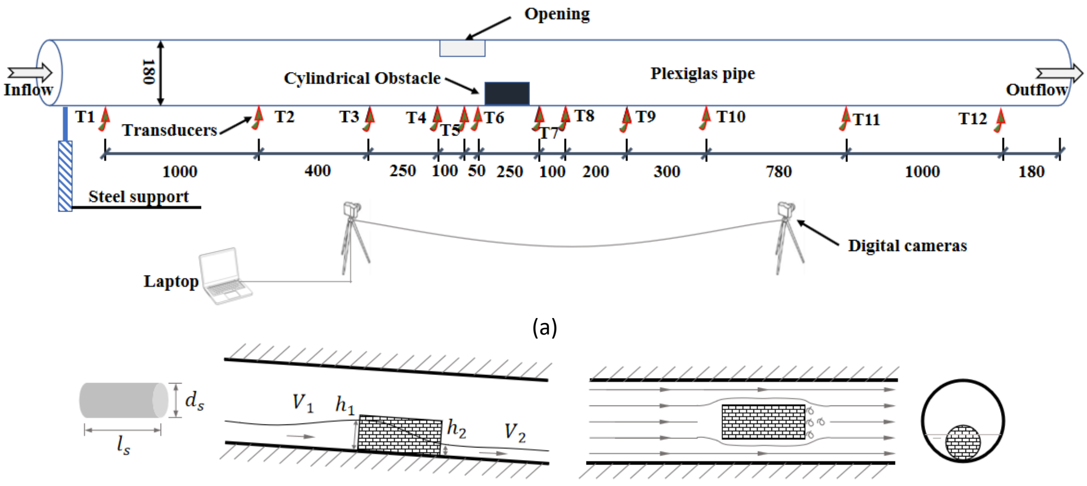
## Introduction

The flow capacity of sewer pipes can be significantly reduced by obstacles, such as discrete solids, fats, oils and grease (Figure 1), causing backup in homes and overflow into public streets. This study focuses on cylindrical discrete solids under steady flow, intended to investigate hydraulic behaviors of pipe flow with fixed obstacle.

**Figure 1.** Solid obstacles in sewer pipe from CCTV inspection

## Methodology

In order to investigate the hydraulic behaviors of partially blocked pipes, a series of experiments were conducted with a circular pipe of diameter 180 mm and length 8 m, and a steep slope 1%, in which a cylindrical obstacle was positioned along the direction parallel to the center axis. The flow regimes and longitudinal distribution of pressure were recorded by digital cameras and pressure transducers, respectively (Figure 2). The sizes of the cylindrical solid used in the experiments are given in Table 1.




(b)

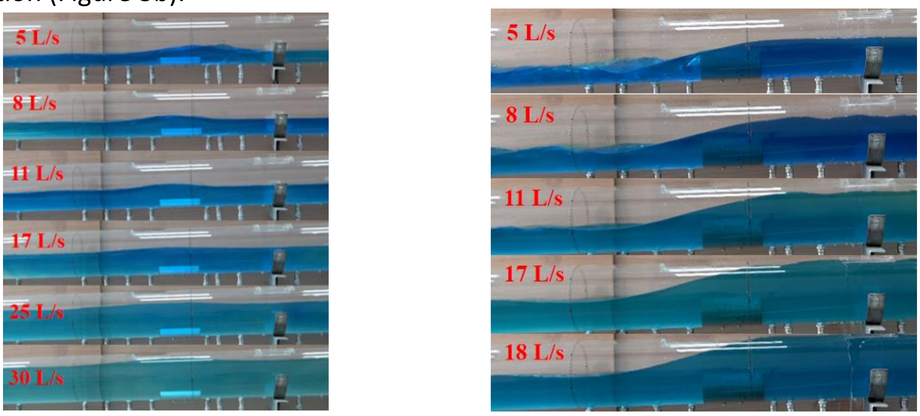
**Figure 2.** Experimental setup: (a) test rig and measurement facilities; (b) obstacle placement

**Table 1.** Sizes of cylinder for different test cases

| Cylinder | Diameter (mm) | Length (mm) |
|---|---|---|
| C1 | 40 | 80 |
| C2 | 40 | 120 |
| C3 | 40 | 180 |
| C4 | 60 | 60 |
| C5 | 60 | 120 |
| C6 | 60 | 180 |
| C7 | 80 | 80 |
| C8 | 80 | 120 |
| C9 | 80 | 180 |
| C10 | 100 | 180 |
| C11 | 120 | 180 |

## Results and discussion

For the observed supercritical flows, the influence of smaller obstacles was quite limited, as expected. When the flow rate was 5 L/s, the obstacle C3, of which the diameter = 40 mm, was completely submerged. The water flow near the obstacle was disturbed, but the increase of water level did not extend further upstream. As the flow rate increased, the disturbance became weakened and the water surface tended to be smooth (Figure 3a). For a larger solid C9, the upstream flow changed significantly, compared with that without obstruction (Figure 3b).




(a) (b)

**Figure 3.** Water surface profile under different flow rates with (a) obstacle C3; (b) obstacle C9

As can be seen from Table 2, when the flow rate was 5 L/s, the increase in water depth reaches 59.8% due to local disturbance. While for other flow rates, the increase in water depth does not exceed 20%. The flow capacity of the pipe is approximate to 30 L/s when with obstacle C3, which is close to the full capacity for a clean pipe. Under the obstacle C3 condition, the upstream water depth was still less than the critical depth, and the flow pattern did not change much. Thus, for cases with a diameter ratio of obstacle and pipe smaller than 2/9, the influence on water flow due to obstruction can be neglected under large flow rates.

**Table 2.** Water depth upstream of obstacle C3 under different flow rates

| Water depth | Flow rate (Q) | | | | |
|---|---|---|---|---|---|
| | 5 L/s | 8 L/s | 11 L/s | 17 L/s | 25 L/s |
| $h_0(m)$ | 0.04058 | 0.04058 | 0.04058 | 0.04058 | 0.04058 |
| $h_3(m)$ | 0.06483 | 0.06650 | 0.07879 | 0.09962 | 0.12746 |
| $\Delta h / h_0$ | 59.8% | 20.0% | 17.9% | 15.9% | 15.4% |

Note: $h_0$ = water depth without obstacle and $h_3$ = water depth with obstacle for the case with C3

Figure 4 shows that as the obstacle diameter increases, the upstream water level runs up above the critical water depth. Hydraulic jump is generated upstream, and weir flow downstream of the obstacle. With the increase of obstacle diameter and flow rate, the upstream water depth continues to rise until free-surface-pressurized flow occurs. The flow is said to be chocked when there exists full pipe flow somewhere. The full capacity of the pipe is about 37.9 L/s, but it decreases to about 22L/s, 19L/s, 13L/s and 11L/s with obstacles

C6, C9, C10 and C11, respectively. It can be clearly seen from Fig. 4a that as the obstacle diameter increases, the flow capacity decreases significantly. For the obstacle C11 with diameter = 120 mm, it drops by more than 70%.

Water surface profiles with various size obstacles when the flow rate was 8 L/s are given in Figure 5. The backwater height and length in the upstream increases with the diameter of obstacles. The water level downstream of the obstacle gradually returns to normal water depth.

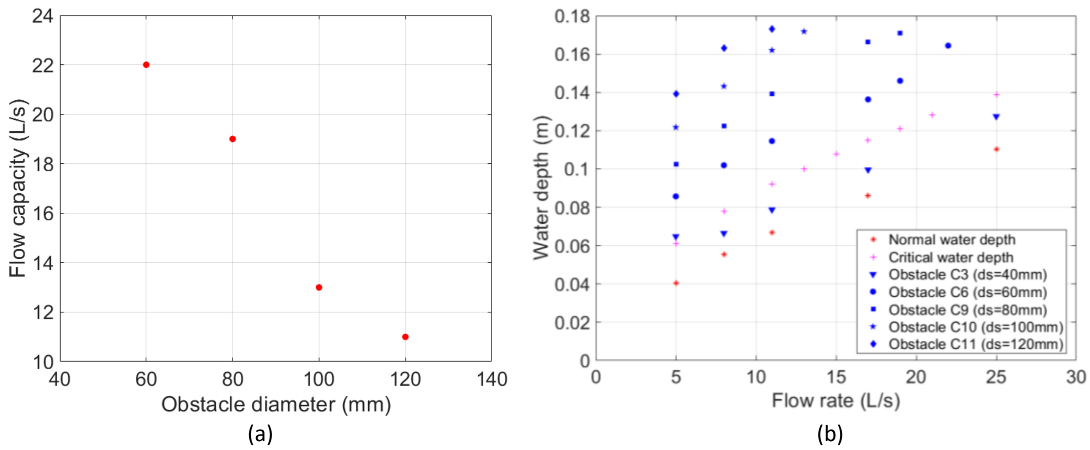



**Figure 4.** The relationship between (a) flow capacity and obstacle diameter; (b) upstream water depth and flow rate ( $l_s$ = 180 mm)

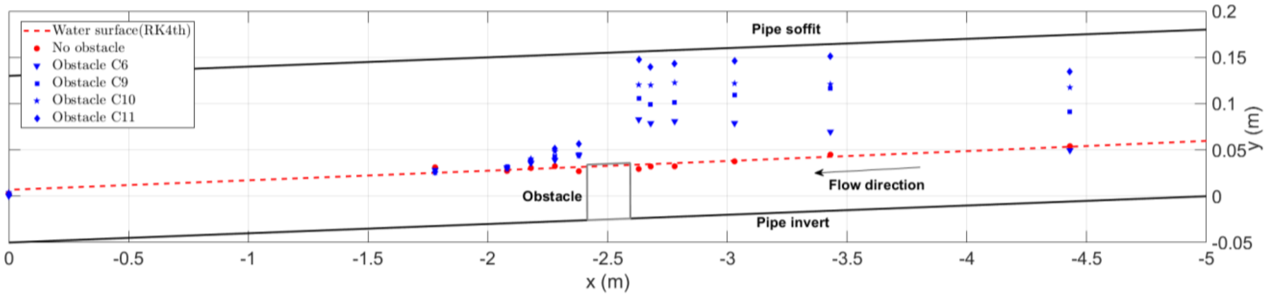



**Figure 5.** Water surface profiles with different obstacles ($Q$ = 8 L/s)

# Conclusions and future work

This study investigates the effect of a fixed obstacle on the flow capacity of sewer pipe under steady flow conditions. For supercritical flows, small obstacles (diameter ratio of obstacle and pipe < 2/9) only have a slight disturbance to the flow, and little effect on the flow capacity of the pipe. As the diameter ratio increases, the influence on the flow capacity gradually increases. The water level at the upstream of the obstacle increases and develops into a portion of subcritical flow, possibly causing pipe chocked.

Preliminary results indicate that the diameter (or height) of the obstacle is the critical parameter in terms of flow capacity reduction. The flow should be analyzed in detail in future work, and a semi-empirical equation will be given as a result, which can be used a reference for practical engineering.

# References

Mahajan, B. M. (1981). Experimental investigation of transport of finite solids in a 76 mm diameter partially filled pipe. Nall. Bur. Stand. (U.S.) NBSIR 81-2266.

Mahajan, B M. (1983). Analysis of liquid flow-induced motion of a discrete solid in a partially filled pipe. Journal of Research of the National Bureau of Standards, 88(4), 261-288.

Butler D., Littlewood K., Orman N. (2005). A model for the movement of large solids in small sewers. Water science and technology, 52(5), 69-76.

Walski, T., Edwards, B., Helfer, E., & Whitman, B. E. (2009). Transport of large solids in sewer pipes. Water environment research, 81(7), 709-714.