Preventing Manholes from Rising due to Air Compression

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INTRODUCTION

In recent years, scattering manhole covers, rising pavement, and water spewing from manholes (Photo 1) due to concentrated torrential rains have become a problem in some cities in Japan, and similar cases have been seen within Yokohama. These case are thought to arise when an influx of rainwater exceeding the capacity of sewers suddenly occurs, compressing air which then causes the rainwater to spew from manholes and manhole perimeters surrounded by pavement. In regards to manhole rising caused by compressed air, etc., one can easily calculate the impact that compressed air might have by referencing the Guideline for Safety of Sewer Manhole (draft) (published by Japan Sewage Works Agency in 1999). However, this simple calculation method is not adequate for manholes where multiple conduits intricately connect, as complex hydraulic situations can be anticipated such as the mixing, wavy flows, and head flows of water. Methods for analyzing such flows have yet to be established. This paper will introduce a measure implemented to counteract this, in which a three-dimensional simulation was used to recreate the manholes that rose during torrential rains in Yokohama in 2013, utilizing computational fluid dynamics (CFD).

Photo 1

Photo 2

Due to the rapid development of a low-pressure in April 2013, rainfall of 50 mm/hr was recorded within Kanagawa Prefecture, and this torrential rain caused the upper part of manholes to rise, damaging and disfiguring pavement around the manholes. (Photo 2) As no overspill was observed in the areas where the manholes rose, it is thought that the damage was occurred by compressed air inside sewer. Additionally, it was revealed that water-levels reached 5 m below ground in manholes that are 16 m deep, through a manhole survey conducted following the torrential rain. Furthermore, as the manhole covers were not scattered, it is thought that the compressed air was either relatively weak, or that the pressure was released through seams in the asphalt pavement on sidewalks.

METHODS

In conducting the three-dimensional analysis, calculations were conducted through a runoff analysis model in order to gather information from sections where air compression occurred within the targeted sewer. Upon analysis, it was found that an air blockage space was created in the storage sewer's most upstream section on the upstream side of the manholes where rising occurred, and it was assumed that the air remaining in this space was compressed. A three-dimensional geometric model was created for the above area, and a calculation mesh was formulated as shown in Figure 2. In this space, there is a φ4000, 327 m long storage sewer connected to the manholes that rose, the adjacent manholes, and on the upstream side of the manholes. A diagram of the three-dimensional model created of this facility is shown in Figure 1. For inflow conditions, the input value was set as the conversion of speed from the quantity of inflow determined by the runoff analysis model when inflow into MH-1 at Q1 was in the peak time period for the three locations from Q1 to Q3. For CFD, the turbulence model was used as the mixed-length model while the free surface model was modeled into a two-phased flow of water and air utilizing the volume of fluid (VOF) method.

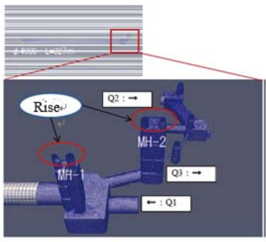

Figure1 3-Dimensional Model

RESULTS1

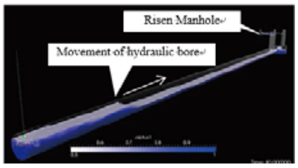

Figure 2 Flow inside

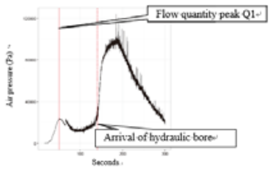

Figure 3 Analysis Result of Air

As a result of the analysis, it was found that wavy flows of water formed towards the upstream when the quantity of waterflow increased. This flow would then bounce off the wall of the storage sewer's most upstream section, creating a hydraulic bore as shown in Figure 2. This hydraulic bore would then travel downstream and arrive at the manholes that rose in approximately 70 seconds. Figure 3 shows the analysis results air pressure inside the manhole . These results show that the pressure rose to around 20,000 Pa at around 60 seconds from the start of calculations, and decreased afterwards. This rise was seen when the quantity of flow peaked for Q1, and it is thought that the air pressure increased because the water levels rose with the increase in the quantity of waterflow. The pressure rapidly increases again from about 140 seconds after the start of calculations. At this time, the hydraulic bore had reached the rising manholes, causing the water levels rose. As air inside strage sewer could not discharge to outside,it is thought that this caused a rapid increase in air pressure.

RESULTS2

In order to decrease the air pressure inside the sewer, a comparative investigation was conducted between Case1 (current status), Case2 (countermeasure 1), and Case3 (countermeasure 2). For Case2, a short pipe was attached to the lower portion on the side of the manhole that rose, whereas for Case3, an air outlet was directly attached to the upper portion of the manhole that rose. This three-dimensional model is shown in Figure 4 and Figure 5. Figure 6 shows the analysis results of the air pressure of the manholes that rose. The pressure which reached about 100,000 Pa in Case1 was decreased to about 30,000Pa in Case2, while Case3 brought this figure down close to zero. However, as Figure 7 shows, in Case3 where air outlets are attached right above the manhole, it was found that there is the possibility that water will spill out above-ground. As such, the current manhole structure under consideration is to have a regular manhole cover with a lock directly above the manhole, and horizontally attaching a box culvert with an air outlet on the upper side in order to prevent air from being compressed and water from spilling out.

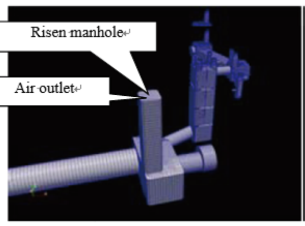

Figure4 Counter measure1(Case2):Horizontal Method

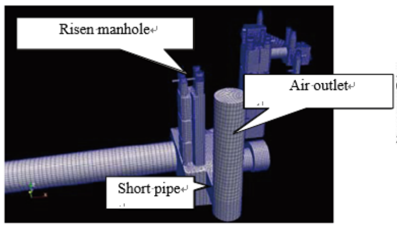

Figure 5 Countermeasure 2 (Case3): IntermediaryManholeAttachment

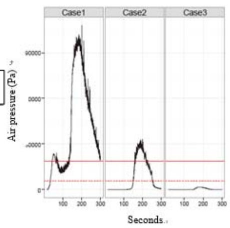

Figure 6 Analysis Result (Countermeasures)

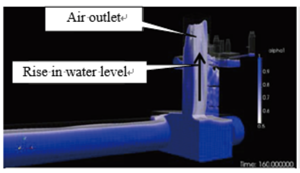

Figure 7 Analysis Result (Case3) at 160 160 Seconds

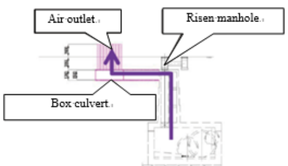

Figure 8 Countermeasure Idea (Considering Water Spill)

CONCLUSIONS

In the past, analyses of air pressure inside sewer have been conducted through simple models that assume water levels rise horizontally through simplifying the structure of sewer. In this case, by conducting CFD analysis, the flow of water was captured three-dimensionally, enabling analyses on air pressure which is interconnected with the complex water flows. As a result, it was found that cases exist where factors that cannot be grasped with the simple model play a role, such as the state of the water surface, and that structural changes are also important effective countermeasures. With the results of this case, selecting the appropriate analysis method that corresponds to the hydraulic situation of the sewer for air pressure countermeasures is important. We will reflect the result onto design and construction for other cases.

Kurose, H., & Nagashima, H. 2014 Survey Research on the Phenomena of Rising and Scattered Manholes and Pavement in Torrential Rains, Japan Annual Technical Conference on Sewerage, A Collection of Lectures. 51, 448-450.
Japan Sewage Works Agency, 1999 Guideline for Safety of Sewer Manhole (draft)
Sugi, S., Tsukada, S., Ishikawa, M., & Kouchiwa, H. 2013 Survey/investigation regarding analysis of hydraulic phenomena through CFD, Japan Institute of Wastewater Engineering and Technology Annual Report

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