Damage Analysis of Air Valves of Drinking Water Pipeline in the 2016 Kumamoto Earthquake

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ABSTRACT

This paper deals with the damage to air valves of drinking water pipelines in the 2016 Kumamoto earthquake. Not only damage to pipe body and joints but also valves were severely caused by the 2016 Kumamoto earthquake. Firstly, a questionnaire survey on the damage to air valves was conducted to waterworks bureaus in Kyushu region in order to clarify the causes of the damage. The results show that the damage to air valves was caused not only in areas near the epicenter but also in areas far from the epicenter. This suggests that the cause of the damage to air valves is not only strong seismic motion. Since many damages were occurred at floating valve body and float valve body of air valve, an abrupt increase of water pressure in air valves is seems to be one of causes of the damage to valve.

Next, a relation between the distribution of the peak ground velocity and the location of the damage to air valves are studied in Kumamoto City. The damages to air valves were occurred not only in the areas of large peak ground velocity but also in the areas of not so large peak ground velocity in Kumamoto City. About 50% of damage to valves in the areas of large peak ground velocity seems to be caused by abrupt increase of water pressure in air valve according to the damaged part of the air valve.

The result of this study shows that one of causes of damage to air valves is abrupt increase of water pressure and abrupt decrease of water flow just after the earthquake. The cause of the abnormal behavior of water supply system just after an earthquake must be clarified and countermeasure of valves should be developed in the near future.

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INTRODUCTION

The 2011 Tohoku earthquake of magnitude 9.0 occurred on 11th March 2011, off the Ojika peninsula of Miyagi prefecture. Even in areas where direct damage such as rupture of water pipes did not occur in this earthquake, abnormal behaviors of the water distribution system such as rapid flow rate increase and water pressure decrease occurred immediately after the earthquake, and cases where the water supply system remarkably deteriorated a lot of it was seen. Changes in the water distribution and water pressure at the western part of Saitama City during the 2011 Tohoku earthquake are shown in Figure 1. The red line shows the change in the water distribution, the blue line shows the change in the water pressure. The water distribution rapidly increases around 14:46 when the earthquake occurred, and the water pressure is decreasing. Such abnormal behaviors have been reported in Tokyo and Osaka so far. Also, in the 2011 Tohoku earthquake a lot of damage to the air valve was reported, causing many leakage damage. An air valve is a valve having a function of automatically sucking and exhausting the air accumulated in the pipe and is installed in places where air bubbles are likely to occur, such as a continuous downward slope of a water distribution pipe and a convex portion of a pipe. Also, it is said that it is desirable that a few are installed for 1 km of water distribution pipe, even if it is not a place where air bubbles are likely to occur. Such water cutoff caused by damage to air valve may cause secondary disasters such as hindrance to firefighting activities in a large scale earthquake that may cause a fire from houses or the like. Even in the 2016 Kumamoto earthquake that occurred in April 2016, similar damage to air valves and other valves was reported. Table 1 shows the number of damaged places and damage rates of pipes and valves in the 2016 Kumamoto earthquake. It is known that damage rate to valves such as air valves is not small compared with damage of water pipes in the 2016 Kumamoto earthquake. Therefore, in order to investigate the actual condition of the air valve damage and to investigate the cause, this research will be conducted from the viewpoint of the form of the air valve, the difference of the surrounding situation, the characteristics of the seismic motion and the ground property.

The purpose of this research is to investigate the ground characteristics and the characteristics of the earthquake ground motion at the point where the damage to air valves occurred, to clarify the influence of the magnitude of the shaking caused by the earthquake on the air valve, and to elucidate the cause of the air valve damage.

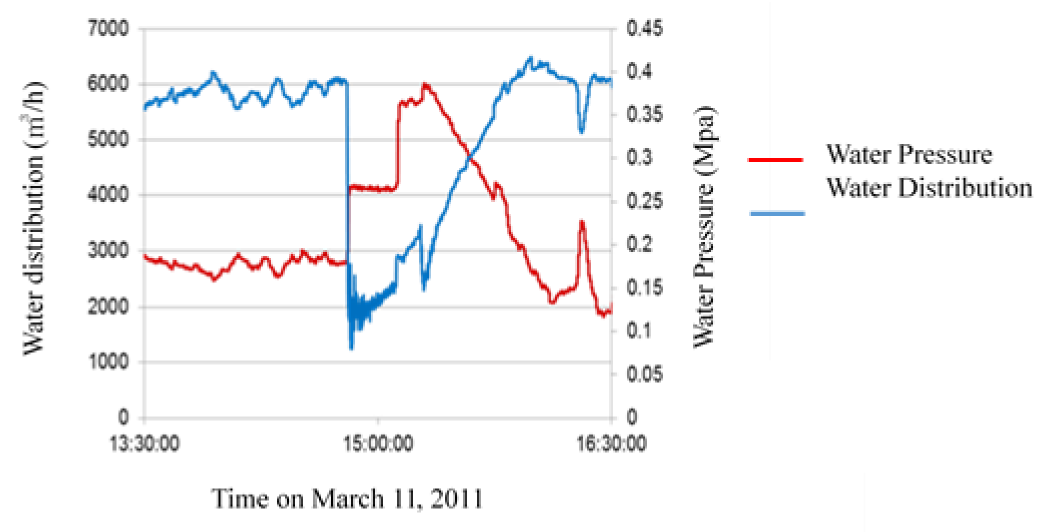

Figure 1. Changes in water distribution and water pressure at the western part of Saitama City during the 2011 Tohoku earthquake [1]

TABLE I. DAMAGES TO PIPELINES AND VALVES IN THE 2016 KUMAMOTO EARTHQUAKE[2]

	Number of damage points	Damage rate(point/km)
Pipes	**296**	**0.087**
Valves	**144**	**0.042**

A QUESTIONNAIRE SURVEY ON DAMAGE TO AIR VALVE OF WATER SUPPLY SYSTEM IN THE 2016 KUMAMOTO EARTHQUAKE

The purpose of the questionnaire survey was to investigate the actual condition and cause of the damage, such as the form of the damaged air valve in the 2016 Kumamoto earthquake, the difference in damage due to the surrounding situation such as installation location and downstream piping form.

The target area shall be the entire Kyushu region so that data can be obtained from the area where the seismic intensity is large to the small area. Also, the number of target water utility is 209 in seven prefectures excluding Okinawa Prefecture in the Kyushu district.

The number of damage to air valves in each prefecture in the 2016 Kumamoto earthquake is shown in Figure 2. According to Figure 2, it is understood that the damage was concentrated in Kumamoto Prefecture and Oita Prefecture where the epicenter is located. On the other hand, air valve damage has also occurred in areas relatively far from the epicenter such as Saga City in Saga Prefecture and Nobeoka City in Miyazaki Prefecture.

Figure 3 shows the structure of the air valve, and Figures 4 and 5 show the broken part and factor of the air valve, respectively. Concerning on the damaged part, the floating valve body (Photo 1) had the most damage and then the float valve body (Photo 2). The floating valve body / float valve body is a part for efficiently exhausting the air contained in the water in the pipeline. As mechanism, when the air contained in the water in the pipeline accumulates in the air valve, as the water level drops, the floating valve body / float valve body descends, the air hole valve seat is opened, and the air is exhausted. When the exhaust is completed, the float valve body rises and the air hole closes. This movement is automatically repeated to discharge the air in the pipeline. In addition, the float valve body guide / cover are also a part susceptible to the influence of water pressure fluctuation, and it is thought that it was influenced this time as well. On the other hand, the flange joint part (Photo 3), which was damaged next to the floating valve body and the float valve body, is in contact with the outside at the part which plays a role of connecting the water pipe and the air valve, and is not affected by the water pressure fluctuation. Therefore, this damage is considered to be caused by aged deterioration and direct external force caused by earthquake vibration. According to Figure 6, the damage of the flange joint portion occupies about 15% of the whole and is the third most damaged portion.

Figures 6 and 7 show the breakage points for each damage factor. Figure 6 indicates that the damages to the floating valve body and the float valve body account for 70% or more of the total in the case of breakage due to water pressure fluctuation in the pipe. In addition, Figure 7 explains that the breakage of the flange joint portion accounts for 70% by the damage due to external force to the valve body. As a result, measures against sudden changes in water pressure to the floating valve body and the float valve body are of utmost importance as countermeasures against earthquakes. On the other hand, countermeasures against earthquake shaking are, however, indispensable for the part in contact with the outside such as the flange joint part.

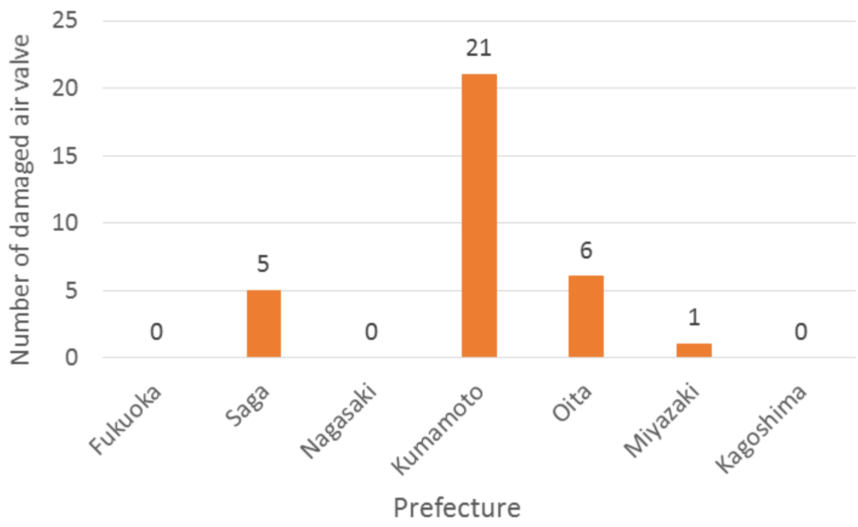

Figure 2. Number of damage to air valve in each prefecture

TABLE II. SURVEY COLLECTION RATE

Prefecture	Number of distibution	Collected number	Collected rate(%)
Fukuoka	62	40	64.5
Saga	20	13	65.0
Nagasaki	21	18	85.7
Kumamoto	29	19	65.5
Oita	16	11	68.8
Miyazaki	23	17	73.9
Kagoshima	38	18	47.4
Overall	209	136	65.1

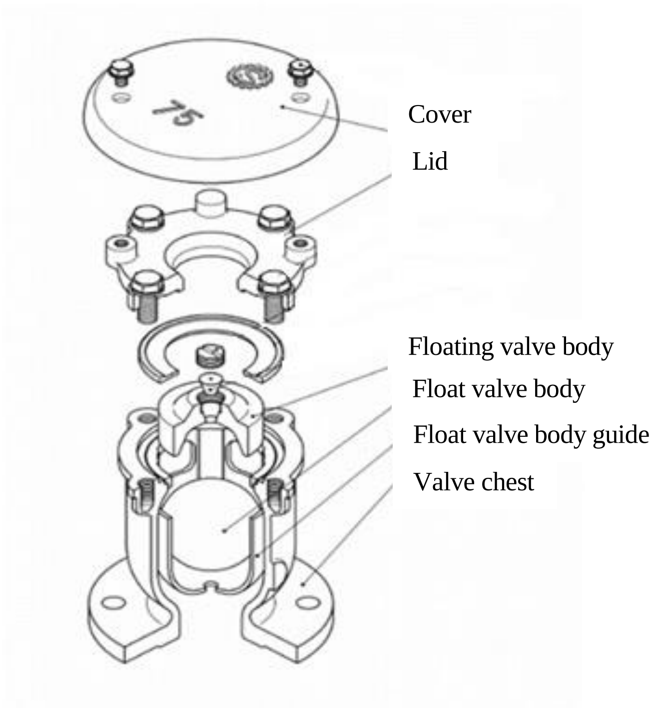

Figure 3. The structure of air valve [3]

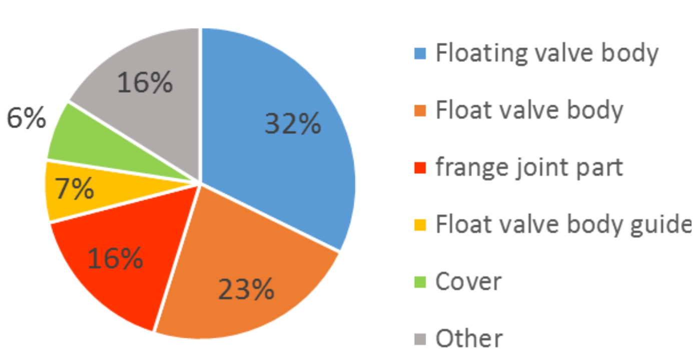

Figure 4. Broken part of air valve

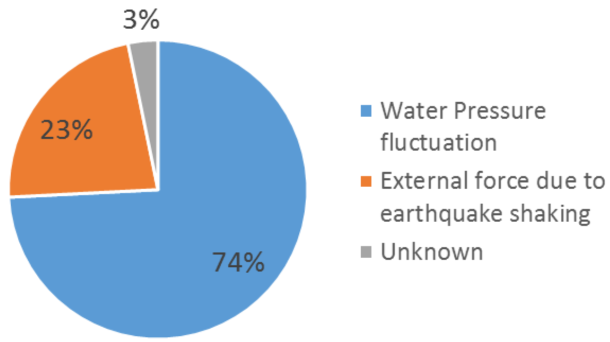

Figure 5. Factor of damage to air valve

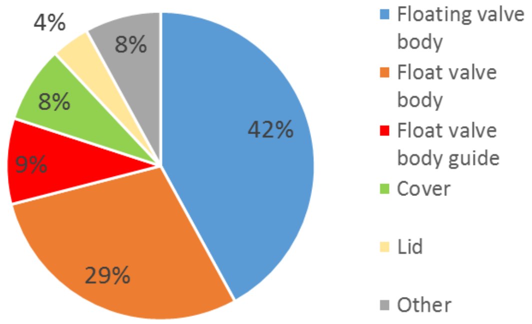

Figure 6. Damage parts due to water pressure variation in pipe

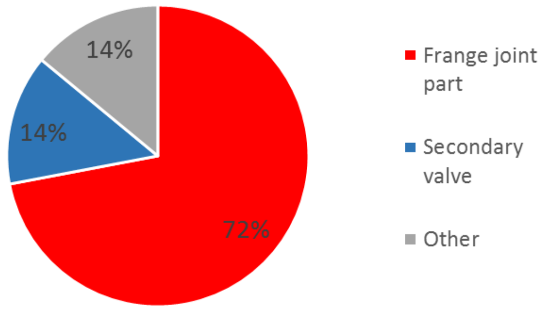

Figure 7. Damage parts due to external force applied to the valve body

Photo 1. Damaged floating valve body

Photo 2. Damaged float valve body

Photo 3. Leakage from flange joint

RELATION BETWEEN LEAKAGE FROM AIR VALVE AND THE PEAK GROUND VELOCITY

Figure 8 shows the distribution of the peak ground velocity (PGV) in the 2016 Kumamoto Earthquake and damage to pipe fittings. The relation between PGV and the damage to pipe fittings is discussed here. The damage to pipe fittings occurred almost entirely around the central and eastern parts of Kumamoto City. This figure suggests that more than half of them occurred in the area where PGV was 80 cm / s or more, but some damage occurred even in the area of PGV of 40 cm / s to 80 cm / s where PGV was relatively small. Figure 9 shows the number of damage to pipe fittings in each PGV range. This figure also indicates that the damage to pipe fitting occurred in the area where PGV is more than 80 cm / s. These figures clarify that the damage to pipe fittings concentrated in the central and eastern parts of the city where the distribution pipeline is dense, and in the region where PGV was large. However, it was found that some damage to pipe fittings occurred even in the areas where PGV was relatively small. These areas are sparse distribution of pipelines in case of Kumamoto City. Therefore, it is the magnitude of the seismic vibration affects fittings damage, but it is possible that factors other than seismic vibration affect pipe fittings and cause damage and leakage even if the seismic vibration is small.

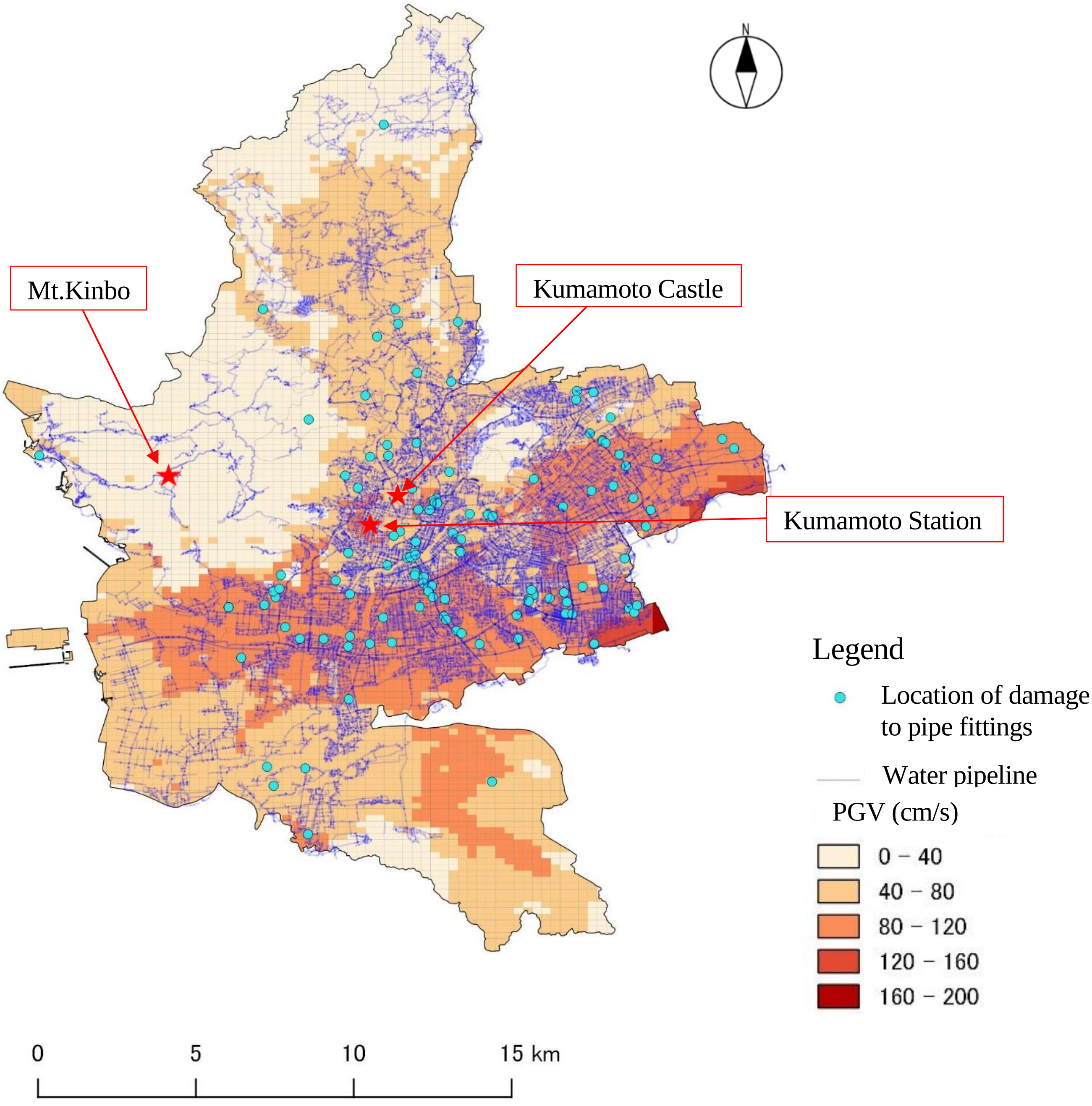

Figure 8. Distribution of PGV and damage to pipe fittings

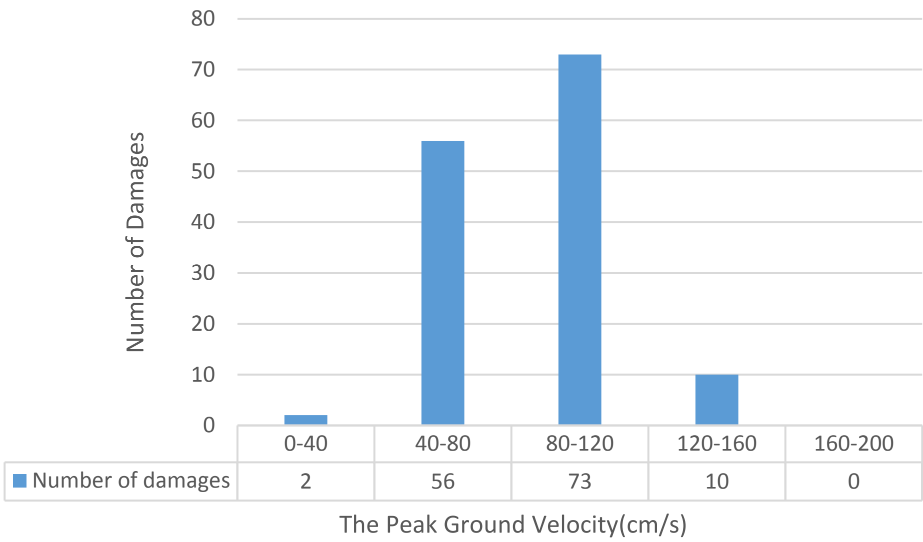

Figure 9. Number of damage to fitting in each PGV range

CONCLUSION

This paper studied the damage to air valves of drinking water pipelines in the 2016 Kumamoto Earthquake. The following results were obtained.

First, we investigated the breakage point of the air valve and the cause of the damage from a questionnaire. As a result, breakage of the floating valve body / float valve body accounted for a large proportion as the damaged part. Also, the damage of the flange joint portion occupies about 15% of the whole and is the third most damaged portion. Therefore, measures against sudden changes in water pressure to the floating valve body and the float valve body are of utmost importance as countermeasures against earthquakes. On the other hand, countermeasures against earthquake shaking are, however, indispensable for the part in contact with the outside such as the flange joint part.

Next, we focused on the distribution of PGV in the 2016 Kumamoto earthquake and the damage to pipe fittings. This study clarified that the damage to pipe fittings concentrated in the central and eastern parts of the city where the distribution of pipeline is dense, and in the region where PGV was large. However, it was found that some damage to pipe fittings occurred even in the areas where PGV was relatively small. Therefore, the magnitude of the seismic vibration affects damage to pipe fittings, but it is possible that factors other than seismic vibration affect pipe fittings and cause damage and leakage even if the seismic vibration is small.

REFERENCE

[1] Ishida, A. 2015. "Study on earthquake damage factor of air valve in water distribution network of water supply", Heisei 20th master thesis dissertation of Kanazawa University

[2] Kumamoto City Water Supply and Drink Bureau, 2017. "Status of pipeline damage"

[3] Shimizu Industry Co., Ltd., "Instruction manual name: SAJ type JWWAB 137 Rapid pneumatic valve nominal diameter for water supply 13 to 25, 75"