International Journal of Engineering & Technology, 7 (3.33) (2018) 218-222

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Flow analysis using RDDA method with actual usage in water distribution network

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Abstract

In the analysis of the water pipeline network, the amount of demand applied is assumed based on the valve being open 24 hours, unlike cases where water is supplied when the valve is opened and blocked when it is closed. As a result, existing analysis results and actual survey data show a lot of differences in hydraulic pressure and flow rate. Also, problems such as faulty outflow, lack of pumping capacity, low reservoir height, and failure to operate decompression facilities have been confirmed. In this paper, a real demand driven analysis method is proposed to solve these problems. First, a virtual flow control facility, a virtual low water column, and a virtual node are applied to the analytical model. In the next step, as the existing demand amount is used at the virtual node, if the water in the reservoir is below a certain level water is supplied from the flow control facility and the flow is shut off when the water level exceeds a certain level. This is a method to analyze the water pipeline network by supplying the usage amount.

Keywords: *Water pipeline network, Real demand driven analysis, Actual survey data, Virtual flow control facility, Virtual node.*

1. Introduction

In the analysis of the water pipeline network, the inputs of the demands in the nodes are entered and analyzed as the continuous supply from opened valves or faucets for 24 hours based on the demand of the corresponding customers (e.g., large customers, ordinary customers) as shown in the bold solid line in Fig. 1. In reality, however, actual customers use water by opening/closing the valves according to their purpose of use (e.g., replenishing water in a large water tank for large customers, dish washing or toilet usage for ordinary consumers) as shown by the thin line in Fig. 1; the valve remains open for about an hour during a day for ordinary customers (entry diameter: 15 mm) and more or less is the same for large customers. In other words, tens of times of the demand is supplied during the supply time to the customer. In both methods, the sum of the water consumption for a day is the same. Meanwhile, the time that each customer uses water is not in the same time range - they may overlap with each other or use water in a totally different time range, resulting in a complicated form of supply. In the current analysis of demands, the demands assumed to be supplied with the valve opened for 24 hours are analyzed by entering one-tenth of the supply amount at which the valve is opened, which is considerably different from the actual flow. In a region where a large customer with a water tank are included, there is a problem in that, in the case where a large customer is supplied with water in a water tank or where the respective customers open a faucet at the same time, the city water supply fails to reach the ordinary customers.

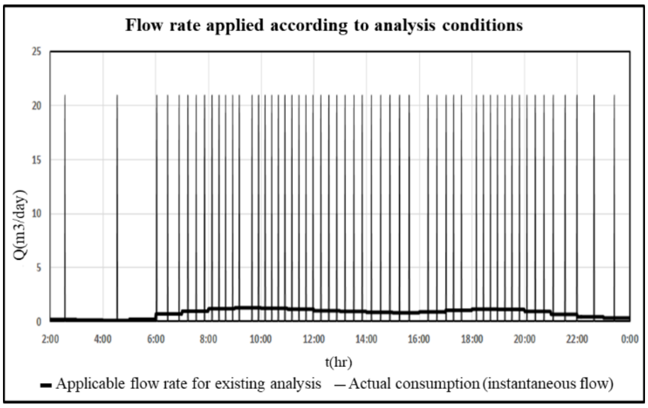


Fig. 1: Applied flow rate according to analysis conditions

2. Relevant Research

To alleviate the mismatch between the waterworks survey data and the pipe network analysis data, the water supply network using GIS (Geographic Information System) technology is interpreted and the technologies related to the management of the intelligent water pipeline network have been studied a lot [1] [2] [3] [4]. The existing methods assume that the valve at the nodal point is always opened, and the supply volume is one over several tenths of the actual consumption to analyze the water pipeline network according to 24-hour usage patterns. This kind of method to estimate demands is unable to analyze the flow rate and water pressure during water supply to the reservoir and instantaneous supply to ordinary customers due to frozen faucets. As for the Demand Driven Analysis (DDA) technique, which is the existing water pipeline network analysis technique, the Pressure Demand Analysis (PDA), and the Real Demand Driven Analysis (RDDA) which we propose in this thesis, the DDA technique is to calculate the head of the nodal points in the state where the supply amount of the nodal points is specified, which makes it suitable for the pipeline network analysis of normal flow with no changes in water pressure. Here, EPANET is mainly used. The water pressure at each node shall be calculated by using the continuity equation and the recurrence equation, provided that the flow rate demanded at the node can be fulfilled at any time. Abnormal conditions in which hydrological conditions change in the water pipeline network (e.g., interruption in the duct line, increase in head loss, abrupt increase in flow rate demands in the local area, etc.) may cause negative pressure at some nodes. However, from analytical results it can be deduced that the demand is maintained even if the water pressure drops close to zero. Moreover, there is another problem in that it is unable to analyze the instantaneous flow rate that occurs at the node (which is tens of times of the demand) as its analysis is based on the fact that the faucet is opened at the nodal point to supply water for 24 hours. Meanwhile, the Pressure Demand Analysis (PDA) technique is to calculate the supply amount according to the required head in the state where the head of the nodal point and supply amount are unknown. It is suitable for the pipeline network analysis of abnormal flow such as tube failures and low pressure status inside the pipe. It is possible to estimate the actual suppliable flow rate which cannot be simulated in the DDA. The relationship with the Head Outflow Relationship (HOR) should be identified based on the measured value of the nodes and the establishment of the monitoring system. Negative pressure does not occur during analysis by the PDA technique, but the numerical analysis results which are contrary to the theory can be derived according to the relations of HOR. However, this technique also has a problem in that it is unable to analyze the instantaneous flow rate that occurs at the node (which is tens of times of the demand) as its analysis is based on the fact that the faucet is opened at the nodal point to supply water for 24 hours. The Real Demand Driven Analysis (RDDA) technique proposed in this thesis aims to reduce the gap between the existing pipeline network analysis results and the actual survey results by ensuring the demand amount supplied at the nodes is similar to the actual amounts being used.

Table 1: Comparison of pipeline analysis methods

Classification	RDDA (Real Demand Driven Analysis)	DDA (Demand Driven Analysis)	PDA (Pressure Demand Analysis)
Analysis outline	Calculate the head of a nodal point by applying the instantaneous flow rate of the nodal point by pipe diameter only to the opening time of the valve.	Calculate the head of a nodal point with the supply amount by the nodal point specified.	Calculate the supply amount according to the head with the head of the nodal points and the supply amount unspecified.
Supply time	More or less an hour	24 hours	24 hours
Supply amount	Supply the actual consumption amount only during the supply time.	Supply the quantity demanded.	Supply quantity demanded according to water pressure.
Quantity demanded	Total quantity demanded per day is the same (the sum of instantaneous demand × 1 hour, and that of the daily maximum quantity demanded × 24 hours are the same)		
Issues	Analytical conditions must be assumed, it takes time to analyze and requires a professional analyst.	It is difficult to perform actual (instantaneous) supply analysis.	

3. Analysis method for water pipeline network based on actual usage(RDDA)

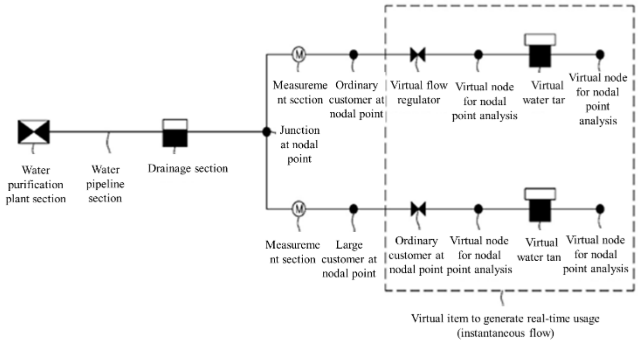


Fig. 2. Overview of pipeline analysis method

Fig. 2 shows a device for deriving the actual consumption, and the device within the dotted line is a virtual device applied to the pipeline network analysis model to derive the actual flow rate. Apply the virtual flow rate control facility, virtual reservoir, and virtual nodes to the model and enter the 24-hour quantity demanded, which was applied to the existing analysis method of Fig. 1, to the virtual nodes. As for the virtual water tank specifications, they should be similar to the size of a toilet water tank for home use at detached houses while they should be more or less like the size of an underground water tank for apartment homes. As for the water level of the initial virtual water tank, the high water level (HWL) should be entered. See the following configuration: when the water is used at the virtual node, the water level of the virtual water tank gradually drops down. When the water level exceeds a predetermined level, the virtual control facility should shut it down. Repeat this procedure to derive the instantaneous flow rate as shown with the thin line in Fig. 1. As for the initial flow rate of the virtual control facility, enter the maximum permissible water flow rate for each pipe diameter; if field survey data is available, the maximum value of the surveyed data should be applied.

4. Case Analysis

4.1 Simple pipeline analysis

For the water pipeline network data used for the analysis, the net1.net in the Examples, an example for the EPANET water pipeline network analysis program by the United States Environmental Protection Agency, was used [5].

4.1.1. Analysis method

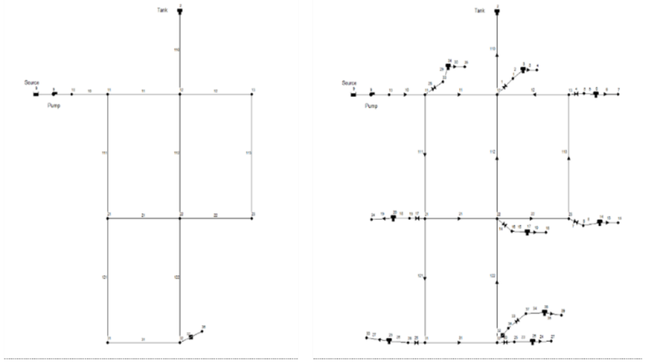
Existing analysis method (DDA). In the same way as in the example, the quantity demanded was entered on the assumption that it is continuously supplied through the valve opened according to a 24-hour pattern, and was analyzed in 1-minute intervals.

Real Demand Driven Analysis (RDDA). To realize the instantaneous flow rate in the pipeline network in the example, a virtual water tank node of the flow regulator applied only to the models having the demands by node was entered to include the device which allows the valve or the faucet to be opened and flow only during the supply time so that it can be analyzed in 1-minute intervals. Table 2 shows the data by nodes applied to the analysis.

Double the Real Demand Driven Analysis (RDDA-Double). The purpose of analysis based on actual usage (instantaneous flow) is to analyze problems in actual supply and solve problems accordingly. As a way to solve problems, what is proposed here is a method to limit the control flow of a large customer to double the amount of the quantity demanded. The input method was analyzed by entering the amount that passes the virtual water flow regulator twice the quantity demanded. It is not possible to regulate the water flow at detached houses where water is supplied simply by opening the faucet, thus, the control flow rate was set to the maximum discharge rate.

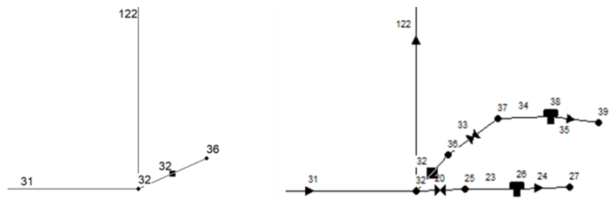
Table 2: Application data by simple pipe node point

By point	Daily maximum demand (gal/min)	Water tank spec			Flow regulator control flow	
		Diameter (ft)	Depth of water (ft)	Control level (ft)	Max. flow (gal/min)	Double flow (gal/min)
11	150	55.8	6.6	6.4~6.6	5161	300
12	150	55.8	6.6	6.4~6.6	5161	300
13	100	38.3	6.6	6.4~6.6	2422	200
21	150	55.8	6.6	6.4~6.6	5161	300
22	200	55.8	6.6	6.4~6.6	5161	400
23	150	55.8	6.6	6.4~6.6	5161	150
31	100	38.3	6.6	6.4~6.6	2422	100
32	100	38.3	6.6	6.4~6.6	2422	100
32 Single-use	0.13	0.8	0.8	0~0.8	4	4



a) Block diagram of existing analysis method b) Block diagram for analyzing with actual usage

Fig. 3. Diagram for simple pipe analysis



a) Block diagram of existing analysis method b) Block diagram for analyzing with actual usage

Fig. 4. Detail diagram for simple pipe analysis point

4.1.2. Analysis results by pipe branch

In Fig. 5, the upper part shows the water pressure in the m unit, while the lower part displays the flow rate in the m3/day unit to depict the results of the existing analysis, actual usage analysis, and double analysis for the quantity demanded on the same figure and table so as to show the difference in the results of each analysis method.

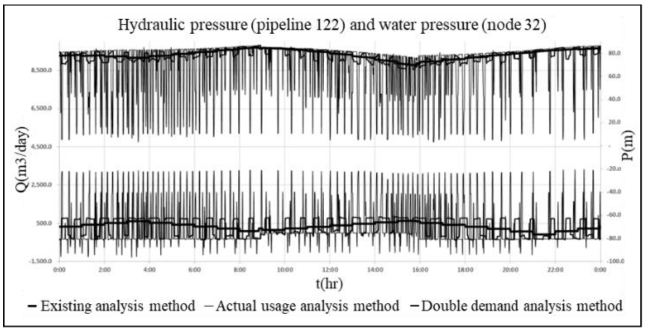
Existing analysis method (DDA). As shown in the bold lines in Table 3 and Fig. 5, the water pressure and the flow rate at nodal point 32 and pipeline 122 near the large supply area gradually changed according to the applied pattern of use, thus the water pressure change also seems moderate.

Real Demand Driven Analysis (RDDA) Method. It is the thinnest line shown in Table 3 and Fig. 5 and an analysis method designed to supply water when the valve is open and stop the water supply when the valve is closed was applied to a large supply area. As shown in Fig. 5, the analyzed water pressure and flow rate at node 32 and pipeline 122 demonstrate that a supply amount that is several tens of times more than the existing analysis method is repeated instantaneously, and the water pressure instantaneously drops to 5 m or less when water is supplied. Likewise, the water pressure instantaneously drops to under 5 m due to the influence of the large supply area and the instantaneous flow rate of the detached houses, making it difficult to supply water.

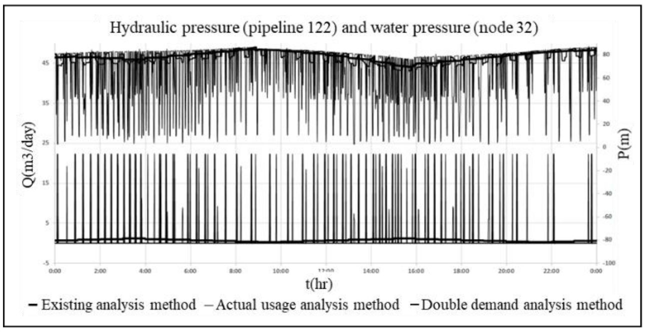
Double the Real Demand Driven Analysis (RDDA-Double). The method proposed in this thesis is to solve the problem by accurately analyzing the problems in the water pipeline network according to the real flow. This is to solve the problem with the supply by limiting the demand to twice the quantity demanded for large demand points. It is considered that limiting the supply to twice the quantity demanded shall result in a moderate change in the water pressure caused by the fluctuation of the flow rate so that the problem of supply can be addressed. It is not possible to regulate the water flow in the detached houses area where water is supplied simply by opening the faucet. At pipeline 32 and node 36 in the detached houses area in the case of instantaneous flow supply, the water pressure somewhat decreases due to the doubly limited demands in the large supply area, but it shows that it continues to maintain more than 15 m of pressure, which is enough for supply. The methods of limiting the supply to double the quantity demanded include the installation of bypass pipes in small diameter in the underground water tank, reduction in the main pipe and installation of a decompression device.

Table 3: Result by simple pipe analysis point

Analysis point	Existing analysis	Actual usage analysis	Double analysis of the quantity demanded	Remarks
Nodal point 32	85.2~69.6	87.0~3.1	86.9~66.1	Water pressure(m)
Pipeline 122	-80.4~638.2	3284~-1257	852~-368	Flow rate(m^3/d)
Nodal point 36	85.2~69.5	87.0~2.7	86.9~37.3	Water pressure(m)
Pipeline 32	0.3~1.2	2.7~87	0~22.3	Flow rate(m^3/d)



a) Water pressure and pipe flow: Large supply area



b) Water pressure and pipe flow: Detached house area

Fig. 5: Pressure and flow analysis result by simple pipe nodal point

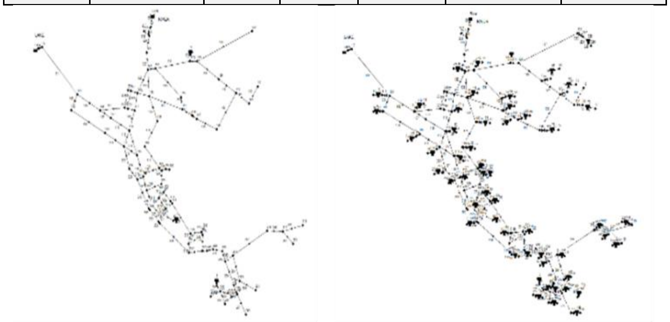
4.2 Application to complex pipelines

To ensure objectivity of the water pipeline network data used for the analysis, the net3.net in the Examples, an example for the EP-ANET water pipeline network analysis program by the United States Environmental Protection Agency, was used [5].

4.2.1. Analysis method

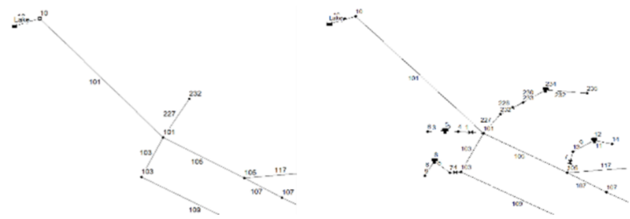
Table 4: Application data by complex pipe nodal point

By point	Quantity demanded (gal/min)	Water tank spec			Flow regulator control flow	
		Dia Meter (ft)	Depth of water (ft)	Control level (ft)	Maximum Flow rate (gal/min)	Double Flow rate (gal/min)
101	189.95	55.8	6.6	4.6~6.6	5161	379.9
103	133.2	55.8	6.6	4.6~6.6	5161	266.4
105	135.37	55.8	6.6	4.6~6.6	5161	270.74
109	231.4	74.9	6.6	4.6~6.6	9290	462.8
111	141.94	55.8	6.6	4.6~6.6	5161	283.88
115	52.1	30.1	6.6	4.6~6.6	1501	104.2
117	117.71	55.8	6.6	4.6~6.6	5161	235.42
121	41.63	30.1	6.6	4.6~6.6	1501	83.26
101 Single-use	0.13	0.8	0.8	0-0.8	4	4



a) Block diagram of existing analysis method b) Block diagram for analyzing with actual usage

Fig. 6: Diagram for complex pipe analysis



a) Block diagram of existing analysis method b) Block diagram for analyzing with actual usage

Fig. 7: Detail diagram for complex pipe analysis point

Existing analysis method (DDA). In the same way as the example, the quantity demanded was entered on the assumption that it is continuously supplied through the valve opened according to a 24-hour pattern, and was analyzed in 1-minute intervals.

Real Demand Driven Analysis (RDDA) Method. To realize the instantaneous flow rate in the pipeline network in the example, a virtual flow regulator water tank node applied only to the models for each node was entered to include a device which allows the valve or the faucet to be opened and flow only during the supply time so that it can be analyzed in 1-minute intervals. The data by nodes applied to the analysis are shown Table 4. Of the total 53 nodal points, only the nine points near the analysis point shown in the figure are indicated.

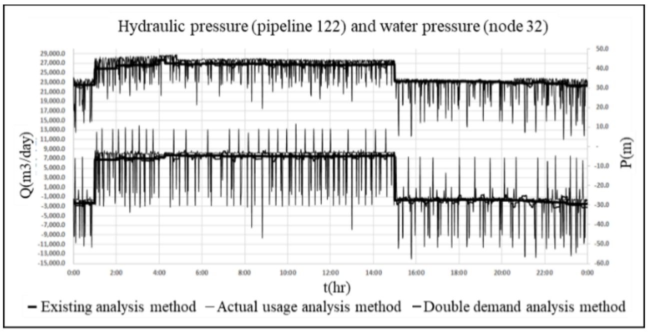
Double the Real Demand Driven Analysis (RDDA-Double). The purpose of analysis based on actual usage (instantaneous flow) is to analyze problems in actual supply and solve problems accordingly. As a way to solve problems, what is proposed here is a method to limit the control flow of a large customer to double the amount of the quantity demanded. The input method was analyzed by entering the amount that passes the virtual water flow regulator twice the quantity demanded. It is not possible to regulate the water flow at detached houses where water is supplied simply by opening the faucet, thus, the control flow rate was set to the maximum discharge rate.

4.2.2. Analysis results by pipe branch

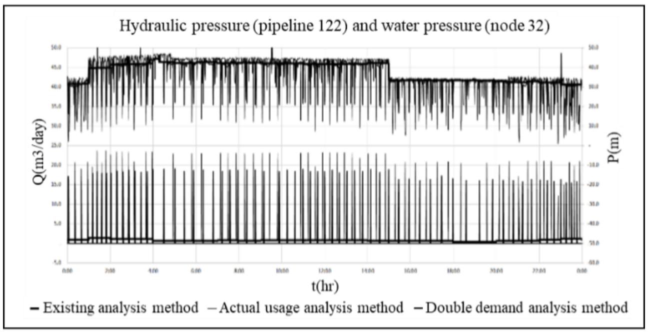
In Fig. 8, the upper part shows the water pressure in the m unit, while the lower part displays the flow rate in the m3/day unit to depict the results of the existing analysis, actual usage analysis, and double analysis for the quantity demanded on the same figure and table so as to show the difference in the results of each analysis method.

Table 5: Results by complex pipe analysis point

Analysis point	Existing analysis	Real flow analysis	Double limit analysis	Remarks
Nodal point 101	44.5~31.2	47~4.2	46.3~30.0	Water pressure(m)
Pipeline 105	7730~-2486	13971~-13971	8672~-3307	Flow rate(m^3/d)
Nodal point 232	44.4~31.1	53~1.0	61.8~15.1	Water pressure(m)
Pipeline 227	0.4~1.4	0.4~23.7	0~19.1	Flow rate(m^3/d)



a) Water pressure and pipe flow: Large supply area



b) Water pressure and pipe flow: Detached house area

Fig. 8: Pressure and flow analysis results by complex pipe nodal point

Existing analysis method (DDA). As shown in the bold lines in Table 5 and Fig. 8, the water pressure and the flow rate at nodal point 101 and pipeline 105 near the large supply area gradually changed according to the applied pattern of use, thus the water pressure change also seems moderate.

Real Demand Driven Analysis (RDDA) Method. It is the thinnest line shown in Table 5 and Fig. 8 and an analysis method designed to supply water when the valve is open and stop the supply when the valve is closed was applied to a large supply area. As shown in Fig. 8, the analyzed water pressure and flow rate at node 101 and pipeline 105 demonstrate that a supply amount that is several tens of times more than the existing analysis method is repeated instantaneously, and the water pressure instantaneously drops to 5 m or less when water is supplied. Likewise, the water pressure at pipeline 227 and node 232 in the detached house area instantaneously drop to under 5 m due to the influence of the large supply area and the instantaneous flow rate of the detached houses, making it difficult to supply water.

Double the Real Demand Driven Analysis (RDDA-Double). The method proposed in this thesis is to solve the problem by accurately analyzing the problems in the water pipeline network according to real flow. This is to solve the problem with the supply by limiting the demand to twice the quantity demanded for large demand points. It is considered that limiting the supply to twice the quantity demanded shall result in a moderate change in the water pressure caused by the fluctuation of the flow rate so that the problem of supply can be addressed. It is not possible to regulate the water flow in the detached houses area where water is supplied simply by opening the faucet. At pipeline 227 and node 232 in the detached houses area in the case of instantaneous flow supply, the water pressure somewhat decreases due to the doubly limited demands in the large supply area, but it shows that it continues to maintain more than 15 m of pressure, which is enough for supply. The methods of limiting the supply to double the quantity demanded include the installation of bypass pipes in small diameter in the underground water tank, reduction in the main pipe and installation of a decompression device.

5. Conclusion

As only about 1/24 of the actual usage is entered as the quantity demanded to be applied to the existing water pipeline network analysis method, it is difficult to analyze the poor water outflow and the drop in the water pressure of an ordinary customer while a large customer uses water. In order to address the problems with water supply such as poor water outflow, therefore, it is necessary to enter the actual usage on a per-minute basis, which is similar to the current supply status.

In the pipeline network modeling, a virtual flow regulator, a virtual water tank, and a virtual node were entered to derive the actual usage, and a flow rate similar to the actual usage (instantaneous flow) every minute could be derived according to the water level control condition. In addition, analysis using the derived actual usage every minute led to similar results to the real flow and water pressure.

Based on the results of this study, it has been confirmed that a value more similar to the real value can be derived by applying the flow rate surveyed in the field survey to the flow regulator. By applying the instantaneous flow rate, the consumption amount of large customers limited to twice the quantity demanded was analyzed and, the results confirmed that the supply of water is stable.

Acknowledgement

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Guideline of non-destructive precision inspection and system improvement plan)

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