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VARIETIES OF WATER LEVEL GAUGES TO PREVENT WATER-RELATED DISASTERS IN JAPAN

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ABSTRACT: In recent years, flood disasters are frequently occurring by typhoons and localized torrential rainfalls, which are heavily damaging people and materials in Japan. Therefore, the importance of water level observation has been re-acknowledged for flood warning and forecasting. Conventionally, water level observation stations have been installed mainly around large rivers which are managed by MLIT (Ministry Land, Infrastructure, Transport and Tourism) and each prefecture. In addition, recently to be prepared for floods caused by localized torrential rainfall, its target is also widening to small or medium rivers which are managed by local government to issue an adequate and prompt flood warning for local narrow area. In these stations, water level gauge is a fundamental equipment and is needed a high accuracy and a high durability. For this purpose, various types of gauges have been developed and improved in Japan.

Key Words: Water level gauge, Hydrology observation, Flood forecasting and warning system

1. INTRODUCTION

The land of Japan is vulnerable to flood disasters because of a relatively large annual precipitation (avg. 1,700mm) but there is a seasonal distribution, steep topography and rapid runoff, and population concentration to plain areas etc. Also these characteristics bring a difficulty of securing of stable available water. In recent years, the effect of water to the people has been more intensified and complicated due to changes of precipitation and flood features, social environment changes such as land development and so on. For promotion of flood control and water utilization, rainfall and water level data are important foundations to control water as structural/non-structural measures. As part of this water level monitoring with automatic gauge is done by river administrator, because it will be affected by natural factors(rainfall, topography, geology, channel changes etc.) and artificial factors (channel improvement, discharge changes by gate operation, intake and drainage etc.), and it cannot be predicted accurately. Observed water level data is used as statistical data for flood forecasting and warning, control of river facilities, future river planning etc., so water level data has direct effect on the people's lives and safety. Data error or data missing may cause a lot of problems which delay the issuing of the flood warning, erroneous discharge distribution in water uses, and over or under estimation of discharge in future river planning etc. Therefore, the roles of water level gauges are, very significant, and high reliability based on accuracy and durability are required. This paper introduces that types of water level gauges have been developed and improved in Japan for flood control and water utilization, application cases to river facility, and countermeasures for stable observation.

2. TYPES AND FEATURES OF WATER LEVEL GAUGES IN PRACTICAL USE

In Japan, unified water-level observation in rivers was started from about 1937. Initially, it was done by reading a staff gauge with eyes at two times a day. Then, automatic observation started in the 1960's, and in accordance with the development of Floating type, Reed-switch type water level gauges and dedicated data acquisition network using VHF radio, real-time remote monitoring started across the country. In the 1980's, Water pressure type and Ultrasonic type, and in the 1990's, Microwave and Optical fiber types were developed and widely used. In addition, applicability to rivers and dams has been enhanced by improvement of accuracy, stability, lightning protection, durability through the long time

usage in the severe natural environment. Such diversification in types and improvement in performance led to the wide range of options according to site conditions, required accuracy, and cost, etc. As the result, in the river observation stations in Japan, about 2,300 stations are operated by MLIT and about 4,200 stations by local governments, and observation data is utilized for flood forecasting and warning, and water resource management etc. This section overviews the types and characteristics of water gauges used in rivers and dams in Japan.

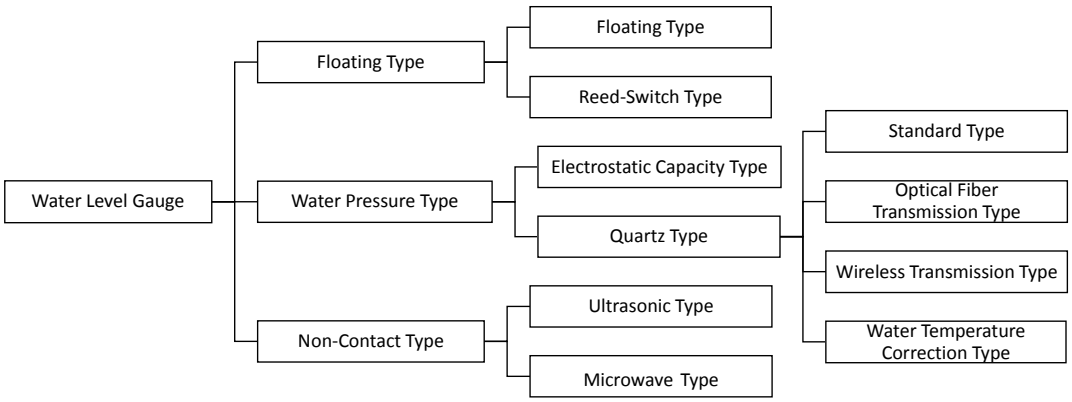

Figure 1: Types of Water Level Gauge

2.1 Floating Type water Level Gauge

2.1.1 Floating Type

This type measures rotation of pulley by balance of float and weight corresponding to the water level surface change. The measuring range is 0m to 100m Max. In Japan, since 1960's, high accuracy type with recording function and A/D converter for output signal has been developed. It has been used for monitoring the river and dam as a standard type. A Gauge is installed inside of the observation well and it is possible to obtain an average water level even when waving by damping effect of well. The features are, direct measurement of water surface, break-proof with mechanical architecture, and an easy operation and maintenance. This type still widely used today in dams, however in rivers, it is migrating to other types because the construction cost of observation well is expensive, and it may cause clog with sediment in the well, and may interfere with river current.

2.1.2 Reed-switch type

This type measures the water level by detecting the position of the float with a magnet by reed switch. Float and reed switch are put inside a small diameter pipe. The measuring range is 1.0m to 3.5m per one sensor. Usually it is used by a combination of some sensors depending on a needed measuring range. The features are, no need of an observation well, high accuracy +-1cm and no conversion/cumulative errors because of a direct output digital signal, a simple structure and a high durability. Until now, this type has been widely used as a standard gauge for rivers as much as traditional floating type. Moreover in the 1990s', radio transmission type which mounts a small radio transmitter and a solar panel was developed and was spread to resolve wire cutting troubles by driftwood and deformation of a riverbed.

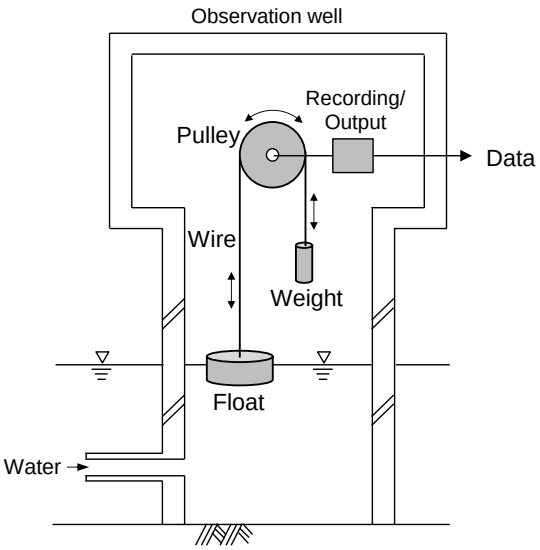

Figure 2: Floating Type

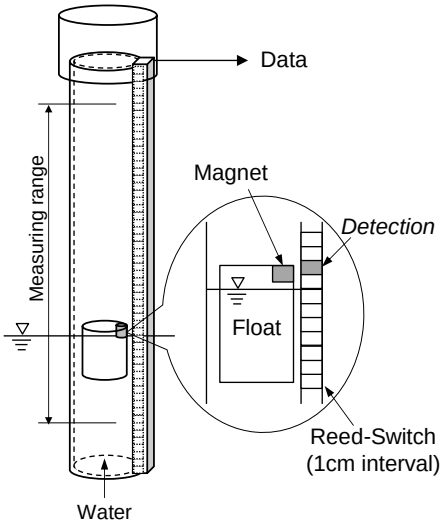

Figure 3: Reed-switch Type

2.2 Water Pressure Type Water Level Gauge

This type measures the water level by a water pressure sensor installed in the water. Due to its compact size, it is easy to install, and because high accuracy and wide measuring range, the use of this type is widespread in the rivers, dams and water gate. Pressure type is classified broadly into two kinds; Electrostatic capacity type, and Quartz type. The two differs by the configuration, accuracy, durability and cost of its sensitive part. Furthermore, Quartz type has three optional types. The first one is Optical fiber type with a higher durability against lightning. The second one is Wireless transmission type with no wire cutting troubles, and the third one is Water temperature correction type with accuracy.

2.2.1 Electrostatic capacity type

This type detects the change of electrostatic capacity corresponding to the impressed water pressure between electrodes. The features are accuracy of approximately 0.2%F.S, a small diameter body, and a low cost. The normal type of measuring range is up to 10m. This type is used extensively in the water facilities where they need many sensors such as water treatment plants or wells. It needs periodical calibration because its conversion characteristic might get affected by temperature, external impact and aging degradation.

2.2.2 Quartz type

The most strong point of this type is having a very high accuracy by using a quartz oscillator for water pressure detection. Because the change of its output frequency in reaction to impressed water pressure is so large, and it has high linearity, high resolution, and high temperature character. The accuracy is only 0.05%F.S. and measuring range is up to 70m. It is suitable for not only in rivers but also in large dams. Furthermore, durability for long time usage is consisted of a robust body, high lightning protection by mounting arresters, and indirect pressure impress structure (through oil tube is filled with silicon oil). These features made Quartz type widely used in rivers and dams with reliability as a standard type in Japan. Following Wireless transmission type, Optical fiber transmission type, and Water temperature correction type are also available as an option. These are enhanced durability and accuracy to adapt to the various site conditions.

Standard type: It uses a metal cable for data transmission from sensor to signal coder, and arresters are mounted on the sensor and junction box to prevent an intrusion of lightening surge.

- Optical fiber transmission type: It uses an optical fiber cable for data transmission from the sensor and signal coder to protect the equipment from lightning fundamentally. The required power source to activate a sensor is light. It is converted from optical to electric power by using a very small O/E converter in the sensor. This type has been developing recently, and promoting as a countermeasure against missing data in the rivers and dams where lightning damages are frequently occurring.

- Wireless transmission type: A specified low power radio is used to transmit signal from the sensor to signal converter. Because of its less power consumption, power source for transmitter of sensor is supplied only by small solar panel and battery. The maximum transmission distance between a transmitter and a receiver is up to 1km. This type is used in the rivers where the sensor cable is likely to be cut by driftwood or by deformation of a riverbed.

- Water temperature correction type: Up to six water temperature gauges are mounted in the sensor cable to offset the change of water density corresponding to the water temperature. It is possible to do water level correction effectively even when vertical stratification of water temperature occurs. This type is useful especially for large dams that need accurate calculation of storage capacity and inflow.

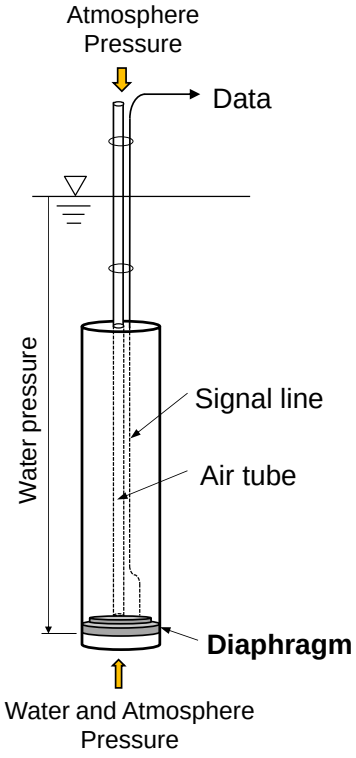

Figure 4: Electrostatic capacity Type

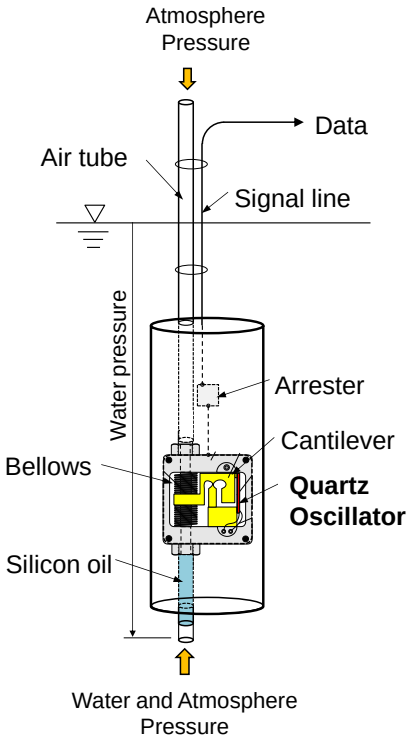

Figure 5: Quartz Type

2.3 Non-Contact Type Water Gauge

This type measures water level by propagation time of emitting pulse of ultrasonic or microwave from the sensor to the water surface. By non-contact measurement, it is not affected by driftwood and garbage, water quality, water temperature, and flow velocity. A sensor is installed on the bridge or extended arm from the river side, installation and maintenance work are easy. On the other hand, it is need to pay attention to the errors that may be caused by floating garbage under the sensor. In Japan, Ultrasonic type has been becoming popular from 1980s'. Microwave type has been becoming common from 2000s' since its measurement accuracy is not affected by the weather condition. The both types are mainly used in the rivers with heavy driftwood and in the small dams.

2.3.1 Ultrasonic Type

This type uses ultrasonic pulse of approximately 25 kHz. The measuring range is 0.6m to 15m, and the accuracy is +-1cm when it is no wind and flat water. A temperature gauge is attached for correction of the propagation time corresponding to the air temperature.

2.3.2 Microwave Type

This type uses microwave pulse of approximately 5.8GHz. The measuring range is 0.5m to 15m, and the accuracy is +-1cm. It realizes stable measurement because propagation time of microwave does not gets affected by air temperature, wind, and raindrops. In Japan, it can be used regardless of the radio law and it doesn't affect the human body because it uses weak microwave.

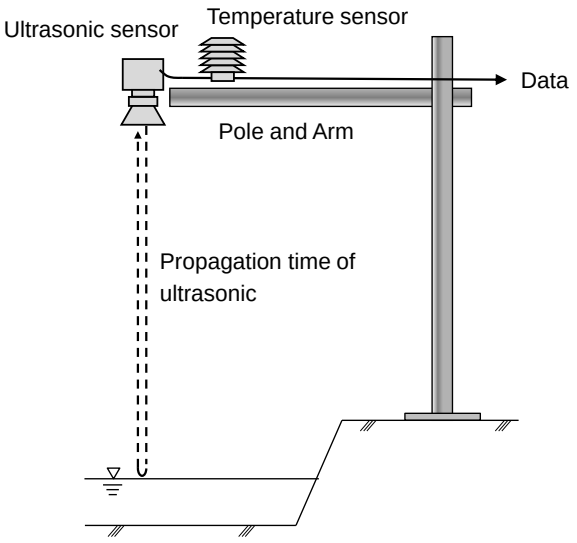

Figure 6: Ultrasonic Type

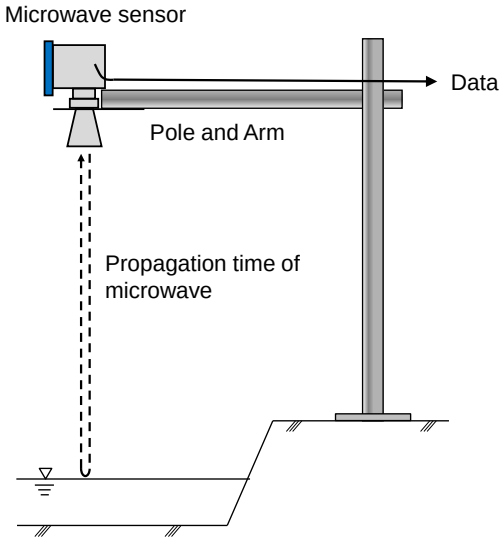

Figure 7: Microwave Type

3. APPLICATION CASES OF WATER LEVEL GAUGE TO RIVER FACILITIES IN JAPAN

In this chapter, it will show representative application cases of water level gauges to hydrology observation and river facilities management in Japan. Using type and system are selected depending on the related regulation, using purpose, importance of facilities, and site conditions (hydrological and hydraulic condition, installation condition, and maintainability etc.). In fact, Quartz type and Microwave type are frequently selected by these high accuracy, stability and wide measuring range.

Table.1. Application cases of water level gauge in Japan

Objects	Purposes	Measured point	Needed capability	Frequent type
River (Hydrology observation)	- Flood prediction - Flood warning and forecasting - Discharge calculation	- Main stream - Tributary	- High accuracy - Resistance to lightning - Resistance to flow and bed change, sedimentation	- Quartz type - Reed-switch type - Microwave type - Ultrasonic type
Dam	- Volume of inflow, outflow, storage measurement - Dam gate control - Issue of discharge warning	- Reservoir - Upstream - Downstream	- Wide measuring range - High accuracy - Resistance to lightning - Resistance to sedimentation	- Floating type - Quartz type
Retarding basin	- Flood adjustment - Issue of evacuation warning - Drainage gate operation	- Main stream - Overflow levee - Reservoir pond - Drainage gate	- Resistance to dry condition - Resistance to lightning - High accuracy	- Microwave type - Quartz type - Reed-switch type
Water gate, Weir	- Diversion adjustment in flood - Water level adjustment - Prevention of high tide, tsunami - Prevention of backflow to tributary - Lock operation	- Upstream of gate - Downstream of gate	- High accuracy - Resistance to lightning - Resistance to sedimentation	- Quartz type - Electrostatic capacity type - Reed-switch type - Floating type
Pumping station	- Pump operation	- Mainstream side - Tributary side	- Resistance to dry condition - Resistance to lightning - High accuracy	- Quartz type - Reed-switch type - Floating type
Irrigation system	- Storage monitoring - Discharge distribution	- Reservoir - Water intake gate - Pumping station - Channel	- High accuracy - Resistance to dry condition	- Quartz type - Microwave type
Tsunami/tide	- Issue of evacuation warning - Coastal and port management - Land elevation survey	- Estuary area - Port	- Non contact measurement - Very wide measuring range - Resistance to salt	- Ultrasonic type - Microwave type
Inland flood	- Issue of evacuation warning - Traffic regulation	-Roads in urban area	- Resistance to long term dry condition	-Microwave type

3.1 Hydrology Observation in River Basin

Hydrology observation is conducted for the purpose of collecting the rainfall and water level data concerning river plan and management in the main rivers under the control of MLIT (the Ministry of Land, Infrastructure, Transport and Tourism) and local government. The observed data is utilized variously for flood forecasting and warning, flow management, facility operation, and long-term accumulative statistics etc. Water level observation stations are located 10-20km interval each according to split flow/confluence and the river characteristics. Facility of station composes of a water level gauge, a data transmission device, a power source and an observation house. The frequently-used water level gauges there are, Quartz type, Reed-switch type, Microwave type, and Ultrasonic type. It is selected for each station depending on the required accuracy, existence structure to install such as concrete bank or bridge, and flow condition. In the important observation stations, ‘unit duplexing’ is implemented for a countermeasure against missing data. In this case, different type is installed to prevent trouble of equipment by identical factor. The observed data is transmitted by VHF radio transmitter (70MHz or 400MHz) which is standardized by MLIT. In recent years, transmitting by optical fiber laying along the river has been improving. Power source for each device is by commercial power supply. In addition, in preparation for power failure, large capacity battery is also installed. The data transmitted from each station is collected

into river information system of the river office. That is utilized for real time observation of entire basin, flood forecasting and warning, and disaster prevention information to the related organization and residence. Additionally, the data is opened to the public over the internet. In order to confirm the data reliability, the outlier and the missing data are extracted by AQC (Automatic Quality Check) and MQC (Manual Quality Check), and then the checked data is utilized as definite value for analysis data and statistical data.

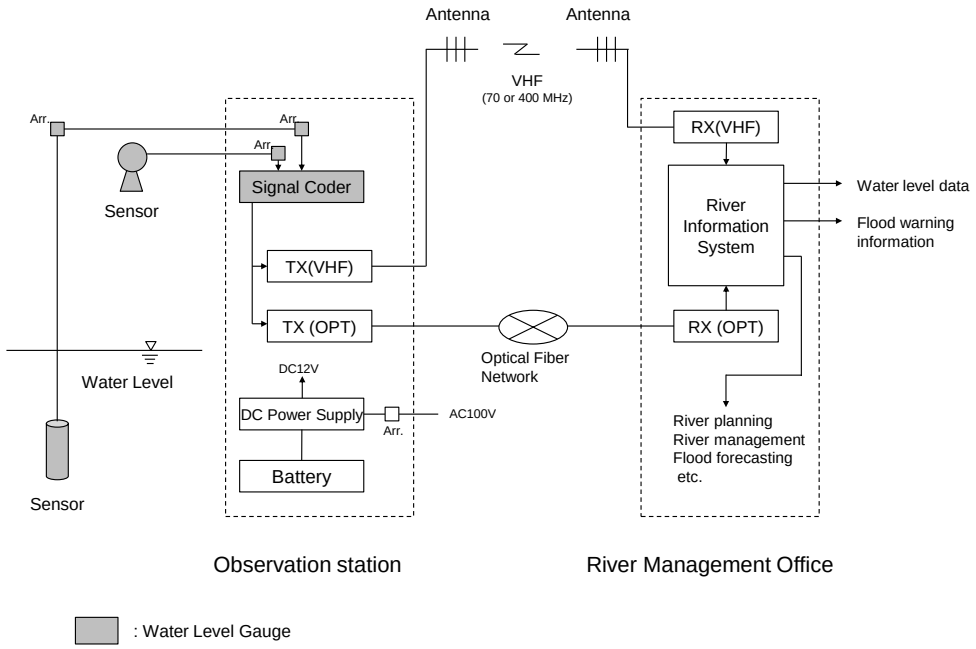

Figure 8: Application case in Hydrology Observation in River Basin

3.2 Dam

Water level gauge is installed to measure reservoir water level that is to be basic data for the dam management. Floating type and Quartz type are mostly in used. Usually two sets of gauges are installed in preparation for breakdown. The observed data is input in real time to the dam control device together with the gate opening data, and the data is utilized to calculation of inflow, storage, and quantity of intake, discharge and the judgment of gate operation. The required features are high accuracy, wide measuring range and high durability. The required accuracy of reservoir water revel is +-1cm because more measurement error causes considerable differences to storage volume. For measuring an average water level of surface wave by wind and seiche, damper effect of observation well and smoothing processing are important. According to circumstances, measurement per mm is sometime necessary to know the tiny variation of increase and decrease of water level. Needed measurement range is from the lowest level to the surcharge level in a flood. For securement of durability, lightning arresters should be installed in power and signal line. In recent years, Optical fiber type of Quartz type water level gauge is frequently introduced in order to resolve the equipment damage by lightning surge fundamentally.

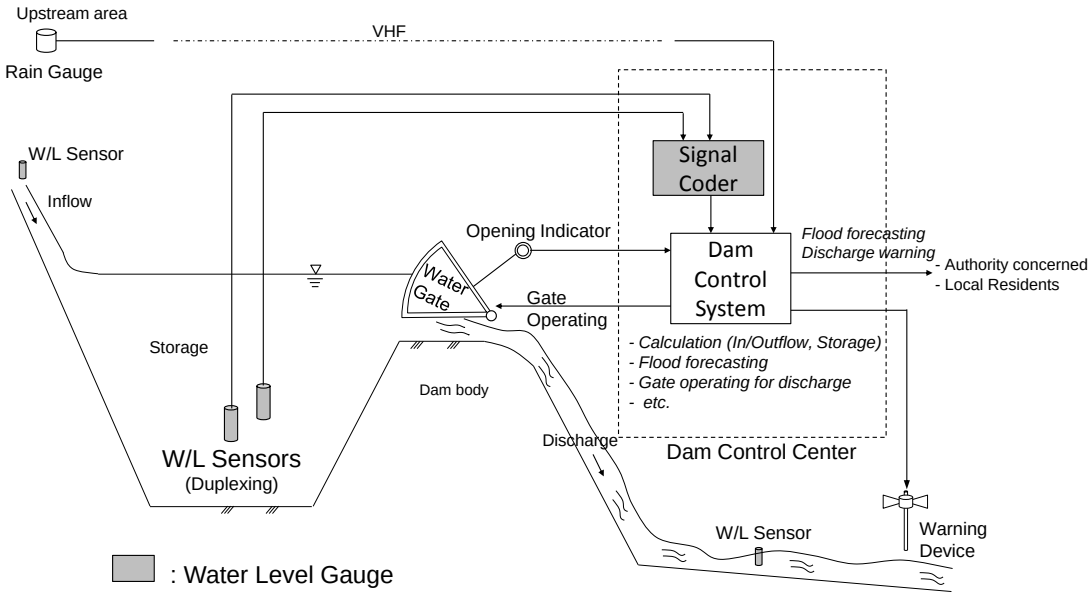

Figure 9: Application case in dam

3.3 Retarding Basin for Flood Control

In the retarding basin for controlling the flood discharge, water level gauges are installed for monitoring the water movement in a mainstream, overflow levee, reservoir pond, and drainage gate. The observed water level data is used for criteria of issuing flood warning information to local residents, management of inflow and storage volume, and for the operation of a drainage gate. Water level gauges are required to be able to resist in no flood and dry condition, and to have an accurate ability for calculating accurately inflow and storage volume and so on. A quartz type at main river and drainage gate, Microwave type and Reed-switch type at overflow levee and reservoir pond are used most frequently.

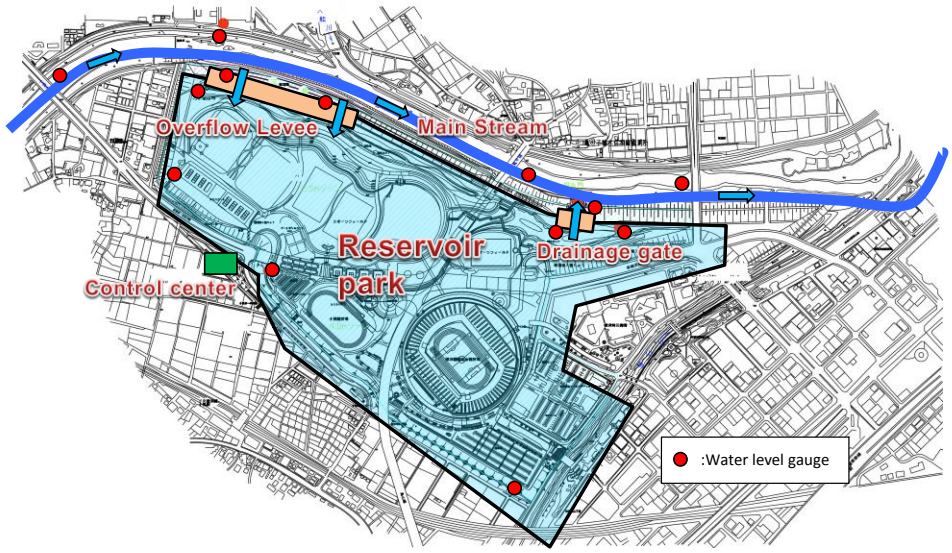

Figure 10: Application case in Retarding Basin

3.4 Water gate, Weir

Water level gauges are installed at upstream and downstream in a water gate and a weir for the operation of diversion, water level and discharge adjustment, water intake, tide prevention, flood regulating. The both of observed water level data and difference are input to a gate control panel and used for criteria of gate opening and closing. Also in the automatically-controlled gate, contact signal is input from signal coder to gate control panel when water level reaches to gate operational criteria. In flood regulating water gate, the operation is usually done based on the current direction which will be judged by difference of water level between upstream and downstream. However, when difference is small or tide is high, it is difficult to judge it accurately. In this case, current direction gauge (Ultrasonic type or Electromagnetic type) is also installed. As requirements for the water level gauge for a secure and stable water gate control, there must be a high accuracy, stability and durability. Also in saltwater, corrosion resistance is needed. Quartz type, Reed-switch type and Floating type are commonly used. In addition, periodical maintenance is necessary to keep good observational conditions. Main maintenance items are, check/adjustment of accuracy and output signal, cleanup of sensor and surrounding sediment and so on.

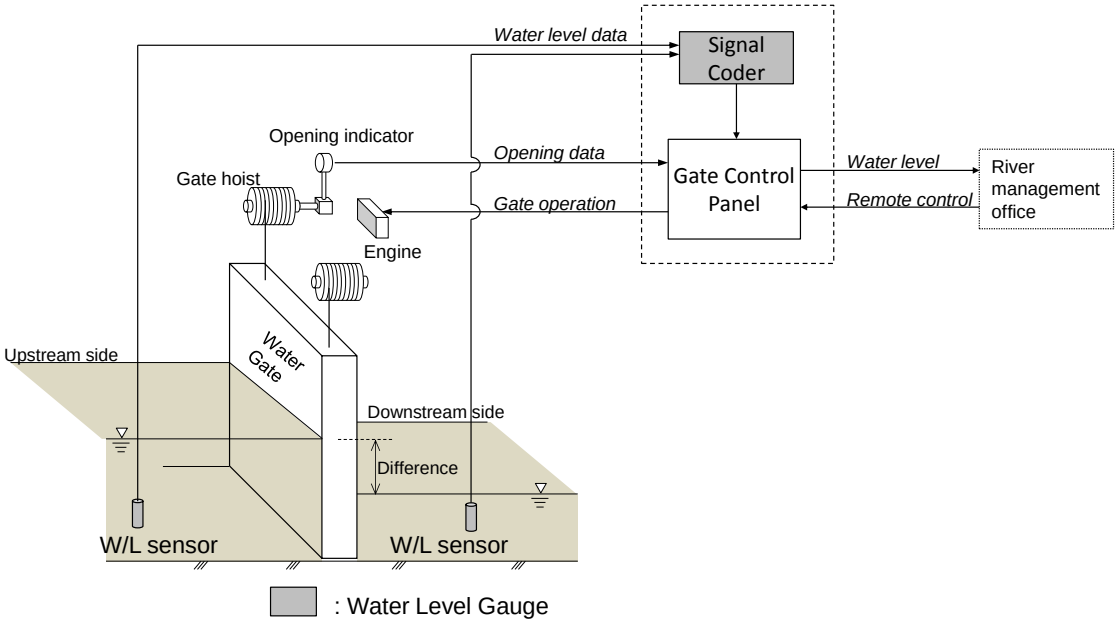

Figure 11: Application case in Water Gate/ Weir

3.5 Drainage Pumping Station

In a drainage pumping station attached to a flood regulating water gate, water level gauge is installed at mainstream side and tributary side for the pump operation. When water level of the mainstream is lower than the tributary, the water gate opens, and tributary flow drains naturally. When it is higher, the water gate closes and, tributary flow is forced to drain by pump. As requirements for the water level gauge for a secure and stable pump control, are a high accuracy, stability and durability. Water level data is crucial to sure pump operation because non-activation of pump will directly bring an inland flood. Commonly-used type of water level gauge in pumping station is Quartz type, Reed-switch type and Floating type. To keep a good condition, periodical maintenance is very important. It is to check/adjust the signal accurately, and to clean up the sediment surrounding the sensor.

3.6 Irrigation Facilities Monitoring

In Japan, irrigation facilities have widely constructed for rice producing. To supply water to the paddy field securely, it is necessary to manage water intake and discharge distribution by grasping storage in reservoir and discharge in channel and operating a water gate and a pump. For these purposes, water

level gauge is used. For measuring a discharge, there are mainly 3 methods. The first is H-Q relation curve, the second is weir formula or water gradient, and the third is measuring a flow velocity by using current meter. At any rate, water level data by gauge is needed. The requirements of the water level gauge for irrigation facilities are having high accuracy and durability (especially resistance to drying). Commonly-used types of water level gauges are, the Quartz type and the Microwave type.

3.7 Tsunami, Tide

In coast area, water level gauge is used for monitoring tsunami and tide level. For tsunami monitoring, the Ultrasonic type is commonly used because of its wide measuring range and certainty. Responding to huge tsunami damage by Tohoku earthquake on 11th March 2011, this monitoring system has been rapidly spreading. Detected tsunami data is expected to be used for issuing an evacuation information and operating to tide gate automatically for preventing damages. For tide level monitoring, Floating type or the Microwave type is commonly used because of its high accuracy and stability. Especially in case the purpose is for survey of ground deformation, 1mm accuracy is needed.

3.8 Inundation Detection in Urban Area

Water level gauge is used for inundation detection in the low-lying area where inland flood may cause by localized torrential rainfall. Detected inundation information is delivered to authority concerned and local residents by Internet or e-mail, and can be used for evacuation warning and traffic regulation etc. For this purpose, water level gauge is needed a sure detection ability even when sudden and temporal inundation during long-term dry condition. Microwave type is suitable for this purpose.

4. COUNTERMEASURES AGAINST MISSING DATA

The countermeasures against data missing are taken place by means of unit duplexing, power source enhancement, and excess flood for the stable observation in the stations where an occasional data missing will seriously influence to flood warning and gate operation.

4.1 Unit Duplexing

Water level gauge: Two sets of gauges are installed to prevent data missing due to a breakage or failure of gauge by external cause such as clash of debris/driftwood or lightning surge. In this instance, different kinds of gauges are installed to avoid breakage by the same cause.

Transmission device: In addition to VHF radio transmitter as a standard, optical fiber transmitter is installed in preparation for transmission failure in case optical fiber is laid along the river.

4.2 Power Source Enhancement

For secure power supply, following is introduced; a lightning arrester for power line, a large capacity battery in preparation for long-term electric outage, and an auto reset breaker to energize after restoring power source.

4.3 Preparation for Excess Flood

In preparation for exceeding the designed water level, it is conducted extend upward the measuring range of gauge and leveling up the height of observation house to protect from inundation.

5. PERIODICAL MAINTENANCE

Observation environment in the river changes frequently subject to the influence of flow change, sedimentation and driftwood. These often may cause troubles to water level gauge. In addition,

electrical/mechanical characteristic features of gauge may change due to own deterioration. Therefore, periodical maintenance work to remove obstructive factor and check the gauge condition is very important to keep a stable observation. Maintenance frequency depends by the importance of observation and the environment conditions. In Japan, regular check is done once a month, and overall check including accuracy test is done once a year.

5.1 Frequent Troubles

As the factors which may affect to the observation, there are, drying up by flow change or sedimentation, destabilization of gauge by scouring, breakage by driftwood or lightning surge, error by gauge's own aging degradation, electric outage and so on.

5.2 Maintenance Items

Main items of maintenance are as follows;

- Data check: correspondence of gauge and staff gauge
- Surrounding environment check: flow change, sedimentation, drying up etc.
- Cleanup: removal of sediment, driftwood, trashes
- Operation check and adjustment: input/output signal, input voltage, records, parameters
- Accuracy test: correspondence between gauge data and artificial each water level

5.3 Requirement to Service Engineer

The person who is engaged in maintenance service, is required an ability as a hydrological observation engineer. It means not only electrical engineer who operates equipment, but also the person who has hydrological basic knowledge to maintain appropriately judging the conditions in a comprehensive perspective. More importantly, it is necessary to correctly assess the inherent characteristic and tendency such as change of river channel or trouble in the past of the river and the station based on the knowledge and an ability which are obtained through the experience.

6. CONCLUSIONS

In this paper, it is introduced varieties and application case of water level gauges, countermeasures against missing data, and maintenance to keep the stable observation. In Japan, various types of water level gauges have been developed and improved accuracy and durability through long time usage including flood experience. Furthermore, unit duplexing and periodical maintenance have been also implemented for stable observation. As a result, accurate and secure data acquisition is accomplishing. Meanwhile in recent years, serious flood damages are frequently occurring by local torrential rainfall in medium and small size rivers where flood warning system has not been introduced. For the countermeasure, new sensor and system with a low cost for the narrow and densely area observation are developing, for instance, the Optical fiber sensor which can measure the water level by own strain in multipoint, and the Ad hoc wireless observation system which can communicate each other and self-sustaining by using small devices. Such a diversification of gauge will make it possible to adapt to a lot of rivers and it is expected to realize more appropriate river management.

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