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DEVELOPMENT OF EMERGENCY POWER UNIT FOR GATES (*)

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1. INTRODUCTION

Because “outlet facilities” which are installed at dams for flood control and regular water supply are operated under high water pressure, they in many cases use hydraulic opening/closing equipment. Some dams have only one gate outlet facility. In preparation for the time when the gate becomes unusable at the time of flood, there is a need to establish measures in advance. The current measures are not good enough to cover all the possible problems.

(*) *Développement d’une centrale hydraulique de secours pour les vannes*.

After the 2011 off the Pacific coast of Tohoku Earthquake, the need to strengthen risk management measures for large-scale disaster is also ever increasing.

The characteristics of the unit we developed are: small, lightweight, require no electric power source, easy to handle, simple in structure, and inexpensive. Even in case of breakdown of a hydraulic unit, the unique hydraulic circuit of this device unit avoids the broken part by separating the part from the existing hydraulic circuit, which enables operation of a gate with the minimum system.

This paper reports the background of the development, design and examination process, and future development of the emergency hydraulic power unit. Fig.1 shows the overview image of the unit.

Fig.1
Overview image of the unit
Vue d'ensemble de la centrale

2. CURRENT RISK MANAGEMENT MEASURES

The power of electromotive gate is supplied by commercial power generation infrastructure or backup power generation facilities in case of power failure. However, in emergency cases, in addition to the measures to supply power from the Operation and Maintenance Office, it is necessary to take measures on the outlet facilities side. The existing risk management measures include power supply by auxiliary power generator on the outlet facilities or direct engine drive, etc. However, each measure has some disadvantages, and they are not completely meeting the needs to strengthen risk management. Furthermore, in case of breakdown of equipment including existing hydraulic units or pipes, they become inoperable. The current facilities also offer almost no measures against hydraulic pipe damage up to actuators. Table 1 shows the issues of the current risk management measures.

Table 1
Current Risk Management Measures

Measures	Contents	Issues
Auxiliary power generator on outlet facility	Ordinary operation is possible, if it can be installed.	Issues need to be addressed include installation space, measures against exhaust gas, installation cost, maintenance cost, and securing the path to bring in and take out the generator at the time of replacement.
Manual device	Operation by manual pump	The manual operation period is only about 10 minutes. It is not suitable for long-term operation such as drawdown operation during emergency.
Backup engine or motor	Operation by backup motor and pump	It does not work when power source is lost. It is necessary to improve reliability.
	Operation by backup engine and pump	There is a need to manually operate various valves of the existing hydraulic unit. Experiences and expertise are required.

3. BACKGROUND OF DEVELOPMENT

The authors felt the need of further risk management measures for breakdown of a hydraulic circuit for the conventional hydraulic opening/closing equipment. Significant damages caused by operational incapacity due to loss of power source and equipment breakdown caused by large-scale disaster during the 2011 Great East Japan Earthquake also taught us the importance of precautions. Strengthening risk management systems is an urgent task, and it is imperative to have the operation unit that is independent from the existing facility. Therefore, the authors decided to develop an emergency hydraulic unit.

The development process to materialize the concept in collaboration with a general hydraulic system manufacturer began in July, 2012. The basic design was completed by March, 2013, and the development of the device was completed in June, 2013.

4. DESIGN AND EXAMINATION

4.1. DESIGN PRINCIPLES

Our goal was to develop a unique system to overcome issues of the existing risk management measures. Ideas were examined based on the following basic conditions.

a) Require no power source.
b) Easy to operate and reliable.
c) Easy and minimum modification of existing facilities
d) Minimum use of existing opening/closing equipment
e) Inexpensive
f) Small and lightweight

Specifically, the unit should be engine driven as a precaution against power failure. The only work required on site should be to connect hoses and operate a switching lever to open the gate. Connecting hoses requires only partial modification of pipes, and the user should be able to choose either portable or fixed system. As for the operation oil, the unit would be too heavy, if a necessary amount of oil is added to the unit. Because the tank of the existing hydraulic unit will most likely be not damaged, the unit should use the operation oil kept in the tank of the existing hydraulic unit. This makes it possible to develop a small and light unit. The unit should also be independent from the operating panel on the outlet facility and hydraulic unit. Cost cut is achieved by using the general-purpose equipment. Furthermore, the unit must be excellent in long-term storage, because it will not be used on a regular basis. It must be easily maintained and must have a function of lighting, because it might be used at night or during blackout.

4.2. SPECIFIC EXAMINATIONS

4.2.1. Design conditions

Dam and Weir Facilities Technology Standard (draft) [1] regulates that the opening/closing speed of a standby engine drive unit should be 1/2 to 1/3 of the regular speed (0.3 m/min). The authors investigated and compared the opening/closing speed, working pressure, and hydraulic pump capacity of main outlet facilities of all the dams managed by Japan Water Agency and established criteria of design conditions for the device as shown in Table 2. Based on the design flow rate (discharge amount), the specifications of engines and hydraulic pumps were examined.

Table 2
Criteria for Design Condition

Design pressure	6.9 MPa	13.7 MPa
Design flow rate	27 l/min	19l/min

4.2.2. Major components

Major components of this unit include an engine (including a fuel tank), a hydraulic pump, various control valves, and connecting hoses. These are unitized. Specifications of key devices are determined based on integral examination of maintenance, cost, weight, and operability.

(a) Engine and hydraulic pump

A diesel engine was chosen, because it would be operable even after long-term storage. Engine output was examined in the range of 5.5 to 7.5PS, taking into account start-up performance and operability.

For the hydraulic pump, a gear pump was adopted, because of its simple structure as well as high reliability and durability. It is also excellent in long-term storage.

For selecting an engine and a hydraulic pump, the torque of engines and pumps were compared based on the above-mentioned design conditions and the ones of which the discharge flow rate best matched with the design conditions were chosen. Table 3 shows the examination results.

Table 3
Examination results of engine and hydraulic pump

	For 6.9 MPa		For 13.7 MPa	
	Engine	Pump	Engine	Pump
Revolutions	3600 min^{-1}	---	3600 min^{-1}	---
Theoretical discharge amount	---	6.16 ml/ revolution	---	6.16 ml/ revolution
Torque	11.4 Nm	7.3 Nm	16.4 Nm	14.3 Nm
Discharge flow rate	---	21.7 l/min	---	21.2 l/min

(b) Control valve

As for various control valves that constitute a hydraulic circuit, the minimum required functions were included to achieve a lightweight and simple structure. Table 4 shows the basic functions of the unit.

Table 4
Basic Functions

Function	Content	Used device
Pressure adjustment function	This is a safety valve that brings back operation oil to the tank when pressure goes beyond the set point in order to keep the pressure in the circuit stable as well as to protect equipment from abnormal pressure. The closing side prevents buckling of piston rod.	Relief valve
Opening hold function	By preventing backward flow of operation oil, the opening degree can be maintained if it stops at intermediate opening position.	Pilot check valve
Dead weight fall prevention function	When the pressure goes beyond the set pressure, operation oil begins to flow. The operation oil flows while maintaining the balance with operation pressure, which prevents fall of the unit due to weight of gate body at the time of closing operation.	Counter balance valve
Gate operation function	Opening and closing of gate is operated by a lever.	Manual switching valve
Backflow prevention function	Damage of pump/engine can be avoided by preventing backward flow of operation oil.	In-line check valve

Although the design pressure (6.9 MPa, 13.7 MPa) is set with relief valve, it can be freely adjusted within the design pressure. Opening/closing speed (equal to discharge flow rate) can be changed by adjusting engine revolution within pump's capacity.

(c) Pipe

High-pressure rubber hoses were chosen for its workability. The operation oil in the existing hydraulic unit would be used as the operation oil for the unit. In consideration of workability, a suction/return hose was inserted to the oil filler hole of the existing hydraulic unit. Because of the possibility that the suction part might be adhered to the bottom of the tank and would decrease suction power, we attached a steel pipe on the edge of the hose and cut it in U-shape to prevent it from adhering to the bottom of the tank. The motor side hose which would be attached to the exterior of existing hydraulic unit or hydraulic cylinder pipe was attached via "one-touch coupler and connection port" to make attachment safe and easy. The connection port (e.g. multi-functional valve) needs to be attached to the existing equipment in advance. On the A (Open) and B (Close) line on the motor side hose, the female and male parts of a one-touch coupler were reversed and painted in different colors to prevent a connection mistake. A hose tray was made at the top of the device to make the unit compact at the time of storage.

4.2.3. Pressure loss within the unit

There is a need to calculate pressure loss of all constituting devices in order to determine the specifications of each control valve and connection hose. For calculation, we used the large flow rate of 21.7 L/min for 6.9MPa and area ratio of a generally used hydraulic cylinder for a gate. According to the “Opening/Closing Device for Gate (Hydraulic) Design Manual (Draft)”[2],the total pressure loss within the equipment shall be less than 2.5 to 3.0MPa in general. However, in the case of this unit, we used 2.0MPa as a target value because of uncertainty of the load of the device. Our examination revealed that we managed to keep the total loss at 1.8MPa.

By clearly defining the pressure after deducting the pressure loss of the equipment from the design pressure as “valid working pressure” to actually operate the gate, we succeeded in confirming the pressure at the time of installation of the unit. Tables 5 and Table 6 show the total pressure loss image and calculation results of valid working pressure.

Table 5
Total Pressure Loss Image

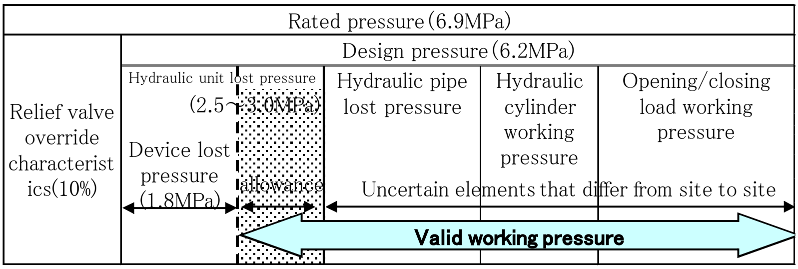

Table 6
Valid Working Pressure

Design pressure	For 6.9 MPa	For 13.7 MPa
Valid working pressure	4.4 MPa	10.5 MPa

4.2.4. Other examined items

(a) Fixed and portable system

When there are several gates or when a facility is away from the place where the unit is stored, a portable type unit is more usable. Therefore, we attached tires to the unit. In consideration for emergency situation, we adopted non-puncture tires. In some cases, the device should be fixed at the time of installation. Therefore, we designed the unit in such a way that it can be fixed by removing the tires. Because it has to be lightweight for transportation, its structure was made simple to the extent possible and its frame was made of aluminum. As a result, the unit weighted about 100 kg for both 6.9 MPa and 13.7 MPa. We confirmed that this could be lifted by two adults. Because of its lightweight and small structure, it can be loaded onto a station wagon. This has made it easy to transport the unit and made it possible to quickly respond in case of emergency.

(b) Opening/closing operation

In general, hydraulic opening/closing device uses a unique switching valve called solenoid valve (electromagnetic multidirectional switching valve). However, it is difficult to grasp the operation method because it is often hard to figure out the switching direction of operation oil from the outside of equipment. Therefore, we adopted the “manual switching lever” for easy operation. The operator turns the lever towards “Open” or “Close” from the middle position of suspension status. For safety, the operation lever has a spring so that it automatically returns to the middle position when the operator releases his/her hand from the lever. A cover plate with manual opening/closing style was also attached to prevent mishandling of the lever.

(c) Lighting

Assuming the situation where the actual operation is at night or during blackout, we attached a lamp to the unit. The lamp is detachable and a 5 m-extension cable is attached for the wide range of use.

(d) Attachments

In consideration for various conditions on site, the authors also prepared necessary attachments. Table 7 shows the list of attachments.

Table 7
List of attachments

Attachments	Notes
Oil filler hole attachment	To be used if the oil filler hole of the existing hydraulic unit has smaller than the minimum size (φ65).
Additional fuel tank (10l)	For additional storage of fuel
Exhaust pipe attachment	To connect exhaust pipe

5. EXAMINATION RESULTS

5.1. MAJOR SPECIFICATIONS

Table 8 shows the major specifications of the design examination results of the device.

Table 8
Major specifications

Items		For 6.9 MPa	For 13.7 MPa
Main body	Dimension (W×D×H)	550 mm × 650 mm × 830 mm	550 mm × 650 mm × 830 mm
	Weight	90 kg	105 kg
Engine	Type	Air-cooled diesel engine	Air-cooled diesel engine
	Output	4.3 kW	6.2 kW
	Fuel consumption	270 g/kWh	275 g/kWh
	Tank capacity	3.3 l	5.4 l
Pump	Type	Gear pump	Gear pump
	Discharge amount	21.7 l/min	21.2 l/min
	Valid working pressure	4.4 MPa	10.5 MPa
Connecting hose		High pressure rubber hose	High pressure rubber hose

5.2. OPERATION METHOD

The operation method of the unit is simple, as follows. The work on site was minimized as much as possible.

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Remove the cap of an oil filler hole and insert a suction/return hose.

Fig. 2
Operation 1
Opération 1

Connect the hose on the motor side to the connecting port and completely close the stop valve.

Fig. 3
Operation 2
Opération 2

Start the engine and fix at the specified revolution.

Fig. 4
Operation 3
Opération 3

Operate the manual switching lever to turn to the “Open, Close, or Stop” position.

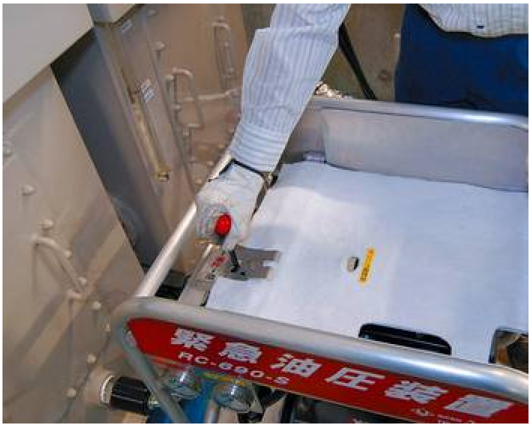
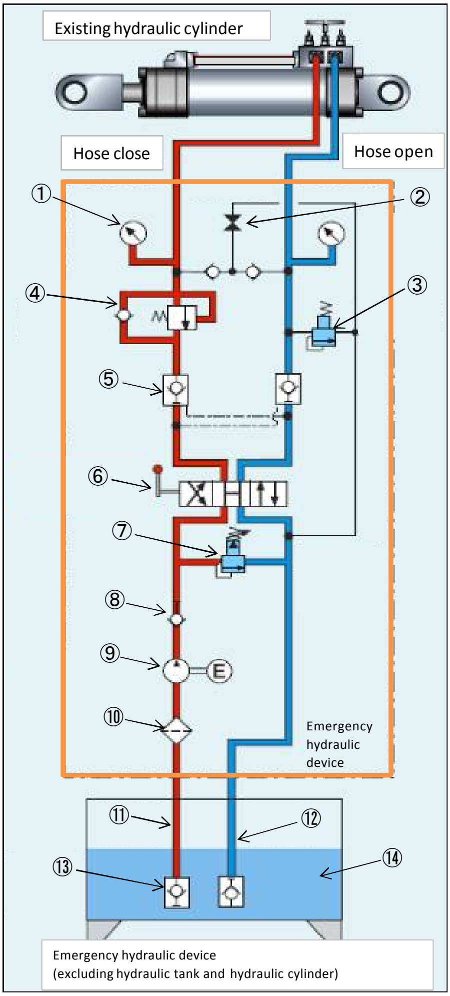


Fig. 5
Operation 4
Opération 4

At the time when the hose is connected to the unit and the stop valve of the connecting port is completely closed, the unit becomes independent from the existing circuit, and the unit operates on its own hydraulic circuit. This allows operation without being interrupted by the breakdown or some other trouble of existing equipment. In addition to a manual prepared for the device, an operational procedure sheet with pictures was also placed on the upper plate of the device to enable the users to confirm the procedure on site.

Fig.6 and 7 show the circuit structure of the device and usage image, respectively.



1. Pressure meter
2. Depressurizing valve
3. Relief valve
4. Counter valance valve
5. Pilot check valve
6. Manual switch valve
7. Relief valve
8. Inline check valve
9. Pump&Engine
10. Y-shaped strainer
11. Return hose
12. Suction hose
13. Inline check valve
14. Existing hydraulic tank

1. Appareil de mesure de pression
2. Soupape de limitation de pression
3. Soupape de décharge
4. Vanne d'équilibrage
5. Clapet anti-retour pilote
6. Soupape de commutation manuelle
7. Soupape de décharge
8. Clapet anti-retour en ligne
9. Pompe & moteur
10. Crépine en Y
11. Tuyau de retour
12. Tuyau d'aspiration
13. Clapet anti-retour en ligne
14. Réservoir hydraulique existant

Fig. 6
Circuit Structure
Composition des circuits

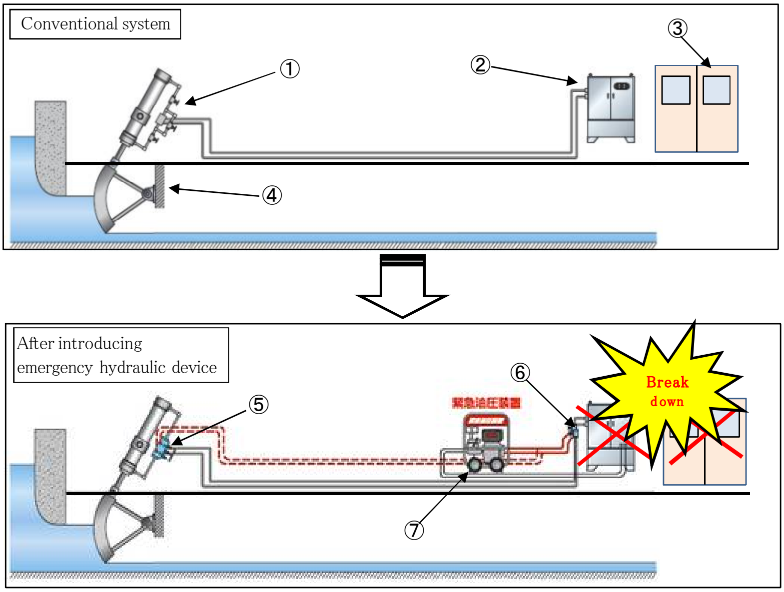


Fig. 7
Usage Image
Schéma supposé lors de l'utilisation

1. Hydraulic cylinder
2. Hydraulic unit
3. Control unit on the motor side
4. Main dam discharge facility (Secure operation is required at the time of water discharge)
5. Connecting port(Pattern A)
6. Connecting port(Pattern B)
7. When equipment is breakdown operation can continue by switching to emergency hydraulic device (Connect motor hose to pattern A or pattern B)

1. Vérin hydraulique
2. Centrale hydraulique
3. Tableau de commande côté moteur
4. Evacuateur principal du barrage (fonctionnement fiable impératif pour les évacuations)
5. Port de connexion (modèle A)
6. Port de connexion (modèle B)
7. En cas de panne, l'exploitation peut continuer en branchant la centrale de secours (connexion du tuyau de moteur au modèle A ou B)

6. ACTUAL OPERATION TEST

After completion of the unit, the authors conducted an actual operation test at the Nunome Dam and checked various aspects of performance. The time from “full closing” to “full opening” of the gate by existing equipment was 10 minutes 52 seconds, while the unit took 26 minutes 12 seconds. This result has met our initial goal that the opening/closing speed of the device should be 1/2 to 1/3 of the regular speed. There was no abnormal rise of operation oil temperature at the time of operation. The fuel consumption was 0.43L during the operation from full closing to full opening, which was the appropriate amount for actual operation.

It took about 25 minutes for two staff members to move the device from the storage place on the dam body to the designated place and install it. The length of time can be shortened by training.

7. CONCLUSION

Although our attempt to develop a backup hydraulic opening/closing unit was unprecedented, the development completed within an extremely short period of approximately 1 year. The patent application was submitted together with collaborative developers in March, 2013. Academic experts who had seen the actual operation test and demonstration of the actual device gave us high evaluation: “It is great that the system is simple and its operation is easy” and “It is a highly necessary system to add to the existing one”.

Although Japan Water Agency considered that the system we developed this time was targeting the gate facilities, we are receiving offers for purchase from other organizations. The need for this equipment is extremely high, and it is versatile in a wide range of use. Because it does not require power source and is unique, small, lightweight, and easy to handle, it can be used not only for dam gates but also for various types of hydraulic opening/closing unit regardless of time, place and operator. It is also applicable to a wire-rope type opening/closing unit by adding a hydraulic motor as an actuator. Furthermore, by adding a remote control function to the unit, it can also be used in the place where operators cannot get close to the unit. These possibilities help us strengthen risk management measures.

With development of this unit, reliability of facility operation at the time of emergency has drastically improved.

REFERENCES

[1] JAPAN ASSOCIACION OF DAM & WEIR EQUIPMENT ENGINEERING. Dam and Weir Facilities Technology Standard (draft) , 2013(in Japanese)

[2] JAPAN ASSOCIACION OF DAM & WEIR EQUIPMENT ENGINEERING. Opening/Closing Device for Gate (Hydraulic) Design Manual (draft) , 2000 (in Japanese)

SUMMARY

In case of power failure or equipment breakdown at dam outlet facilities caused by large-scale disaster, it is anticipated that the dam function might be lost due to inoperability of gates, and that might bring significant damage to downstream areas. Many of the current dam outlet facilities use hydraulic opening/closing equipment, and current measures that are taken against disasters include duplication of power source and hydraulic circuit as well as installation of backup power generator unit. However, power failure, damage of hydraulic pipes up to actuators such as hydraulic cylinders, or breakdown of hydraulic control equipment can incapacitate the operation of the facilities. Furthermore, operation by backup engine requires knowledge of hydraulic circuits in order to carry out manual operation of various valves in the hydraulic units. The calm and reliable operation is difficult in the so-called “panic state”.

The authors developed an emergency hydraulic power unit that can address current risk management issues, aiming at installing the “small, lightweight, easy-to-operate and reliable emergency hydraulic unit” on site.

RÉSUMÉ

Lors d’une catastrophe provoquant une panne d’alimentation électrique ou une panne des équipements au niveau du déversoir du barrage, il est envisageable qu’il soit impossible d’actionner les vannes, et que des dégâts se produisent alors en aval. La plupart des déversoirs actuels sont munis d’équipements hydrauliques pour ouvrir et fermer les vannes et des mesures, comme l’installation d’alimentations électriques et circuits hydrauliques redondants ou encore de machines motrices de réserve, etc., sont généralement prises. Toutefois, en cas de panne électrique, de rupture de tuyauterie hydraulique menant aux actionneurs, notamment vérins hydrauliques, ou encore de panne de l’installation de commande hydraulique, il peut arriver que tout le système soit hors de contrôle. En outre, le fonctionnement des moteurs, comme

source d'alimentation de réserve, nécessite des connaissances particulières quant aux circuits hydrauliques afin d'actionner manuellement chaque vanne installée au sein de l'unité hydraulique. Une manipulation correcte et réfléchie s'avère difficile dans un « état de panique ».

Dans ce contexte, nous avons développé une centrale hydraulique de secours afin de résoudre de tels problèmes de gestion des risques et mis en place une « centrale hydraulique compacte, légère, facile et sûre à manipuler pour les cas d'urgence » sur les lieux. Dans le présent document, nous présentons le contexte et l'historique du développement, le concept étudié et mis en œuvre, ainsi que les perspectives futures.