A Case Study on Renewal Strategies Concerning Lost Technologies in Construction of Rubber Gates

Tomoji Takatsu[1,a], Kohei Nagano[1,b], Shuji Takasu[1,c]
[1] Japan Dam Engineering Center, 2-9-7 Ikenohata, Taito-ku, Tokyo, JAPAN

[a] takatsu@jdec.or.jp, [b] nagano@jdec.or.jp, [c] takasu@jdec.or.jp

Abstract
Rubber gates, which have advantage over steel gates with hydraulic lifting when installing across rivers, have been installed in Japanese rivers since the end of 1960s. The number of rubber gates in Japan goes around 4,000. As many of them are over 20 years old, Japan needs to generate some plans to renew them despite appropriate maintenance of them. On the other hand, the number of installing rubber gates has been decreasing since the 1990s, this fact prevents handing down the know-how of production to younger generations. It is one of the main causes for technologies to be lost. We may call those the Lost Technologies. Therefore, the authors have conducted simulation studies for the repair/renewal of rubber gates, with the assumption that the technologies to produce them are lost, by decreasing the number of construction works of rubber gates. Although the results come from these simulation studies, the authors guess the study results shall be used as references for actual renewal works.
Keywords: renewal, rubber gate, lost technologies

1. INTRODUCTION

Rubber gates, which have advantages over steel gates with hydraulic lifting in installing across rivers and whose sample is shown in Figure 1, have been installed since the end of 1960s. Many of these are currently over 20 years old. In Japan, we have created several technical standards on construction, maintenance and renewal of rubber gates. Furthermore, Japan has been able to install gates across wide rivers using these standards developed in Japan, specifically for the construction of large gates. Over 4,000 rubber gates have installed by these standards. Rubber gates, which are raised up during ordinary times to maintain water level and lowered during floods to let the water flow, are essential for irrigation in Japan. Rubber gates need to be repaired and replaced due to deterioration of their material, even if they are maintained properly. In addition, there are examples when rubber gates have been repaired or replaced. This implies that Japan needs to prepare for repairing and replacing rubber gates. In Japan, we can repair and replace rubber gates using technologies of constructing new ones. That said, construction technologies are also required for repairing and replacing the damaged rubber gates.

On the other hand, the number of rubber gates construction works in Japan has been decreasing since the 1990s. This trend can be seen on Figure 1.

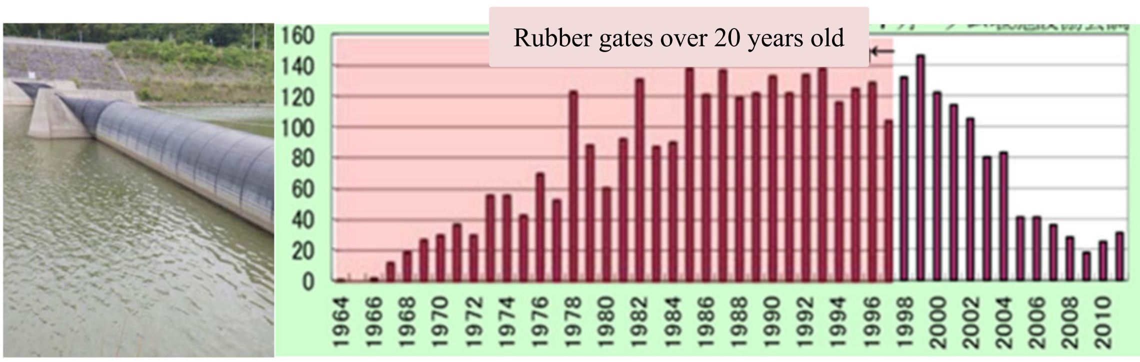


Photo of rubber gate — Change in the number of constructions

Figure 1. Change in the number of rubber gates constructed in Japan and a sample of rubber gate

This implies that rubber gates construction technologies are hardly handed down to future generations. It is natural that constructors withdraw from the business in case that demand has decreased. If the construction technologies were lost, Japan would not be able to construct nor maintain rubber gates. In Japan, we strongly need to keep construction technologies available. Furthermore, Japan needs to hand down these technologies to future generations. The reason why the authors generated this case study is because maintaining, repairing and replacing infrastructure all depend on the Public Accounting Law. The strategies for maintaining, repairing and replacing are as follows:

1) Repairing needs to be on/by same material
2) Replacing needs to be on/by same structure

In this paper, the authors assume that some technologies are lost, therefore not viable options for rubber gates.

2. Rubber Gates in Japan

In Japan, rubber gates have been installed in severe environmental conditions. For example, rivers have high velocity water flow, massive rolling stones, flood/drift woods and so on. Moreover, they are destructive attackers. These come from the followings:

1) Rivers have steep incline: as Japan has lots of mountains despite its narrow land, the rivers need to carry water from high to low through a short distance.
2) Mountains with massive trees and rocks: since Japan's mountains are steep and covered with lots of trees, river water goes down to its estuary with flood/drift woods and rocks.

The sample photos in Figure 2 show rolling stones (on the left) and flood/drift woods (on the right). The diameters of rolling stones with sharp edges are over 20 cm. The length of flood/drift woods is over 5 m. So they have enough potential to damage rubber gates.

Samples of rolling stones

Samples of flood/drift woods

Figure 2. Samples of flood/drift woods on rivers

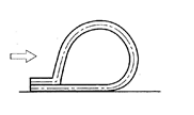
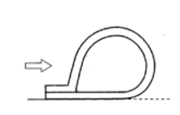
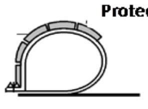
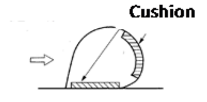
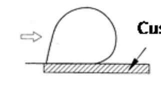
Let us return to the original issue. As the above damaging objects seriously endanger the rubber gates installed across rivers, they need to be protected from them. The representative techniques for rubber gate protection are as follows:

1) Outer protection layer with ceramics chips: since ceramics are abrasion proof, damages hardly reach the rubber layers.
2) Thick rubber (more than twice as thick as ordinary rubber): this gains time for damage to reach inner layers.
3) Outer protector by harder material: since ceramics are abrasion proof, damages hardly reach the rubber layers.
4) Cushioning material in bag for impact: cushions are able to absorb energy that could damage the rubber.
5) Cushioning material on river bed: cushions are able to absorb energy that could damage the rubber.

Technologies applied with ceramics are easily lost due to their peculiarity. This is because very few suppliers have the ability to apply technologies with ceramics. Two types of technologies are needed to use this material. One is to manufacture chips with small diameter. The other is to rub chips. Since the need for thick rubber is decreasing due to a decrease in the number of installing rubber gates, the technology for manufacturing these is also easily lost. Outer protectors cannot protect the entire surface of rubber gates, so their effect is not enough. The comparison of these protection techniques is given in Table 1.

In this paper, the authors focus on the technique of protecting rubber bags from damaging objects on the outer protection layer with ceramics chips. The reason is that we have a sample case of a 35 m long and 4 m high renewal rubber gate with ceramics chips layer. Figure 3 shows the surface of outer protection layer within the ceramics chips. The rectangular shapes that can be recognized on the photo are the exposed ceramic chips. The chips have a diameter of 1 mm and a length of 5 mm. Rubber bags are protected by these ceramic chips that contact the damaging objects in the river water. This depends on the abrasion resistance of ceramics. This protection technique has the advantage that the rubber bag thickness does not increase much. The rubber with ceramics chips is manufactured as shown in Figure 4.

Table 1. Comparison of Countermeasure/Protection Options

Option	1	2	3	4	5
Countermeasure Options	Outer Protection Layer with Ceramics Chips	Thicker Rubber as Twice and thicker than ordinary rubber	Outer Protector by harder rubber material	Cushioning Material in Bag for impact	Cushioning Material on River Bed
Illustration					
Effect	O	O	△	O	△
Procurement	×	×	O	×	O

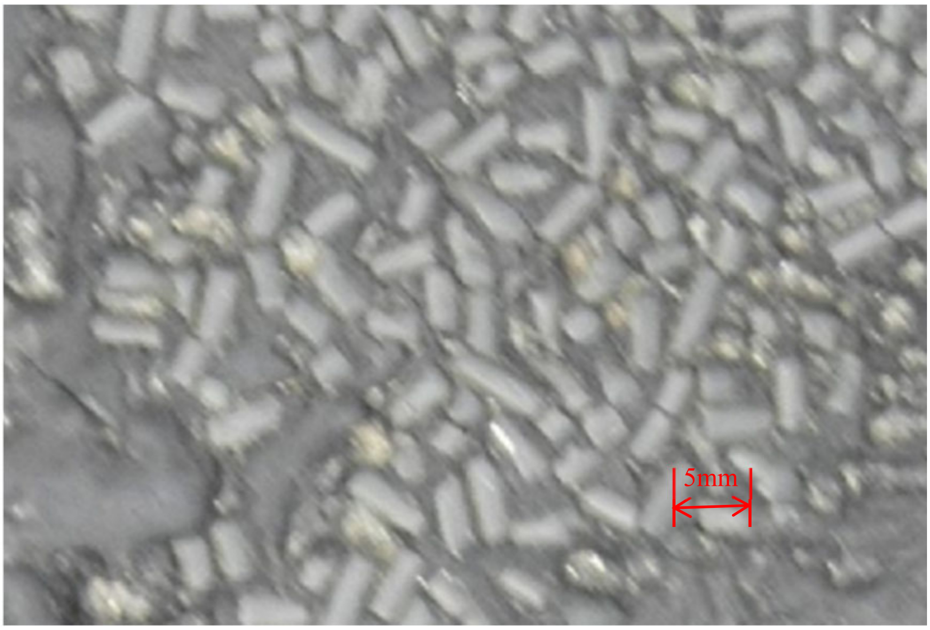


Figure 3. Surface of outer protection layer with ceramics chips

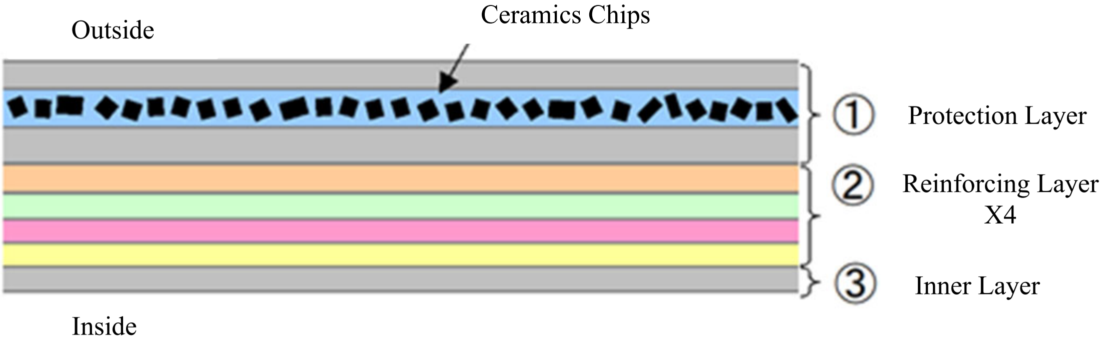


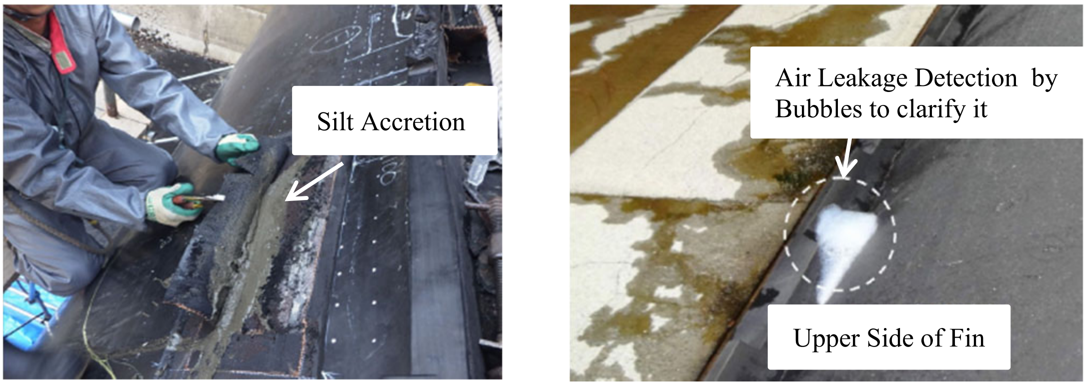
Figure 4. Structure of the rubber with ceramics chips

3. INSPECTIONS

Rubber gates need to be inspected with designated technical standards. Table 2 shows the inspection guideline given in one of them. Members are classified as rubber bag, Fixture and Aspect. Inspection intervals are classified as Annual, Monthly and Special Inspection. For special inspection, almost all functions of the rubber gates are stopped. This means the gates can be inspected in more detail than during a routine inspection. Overhauling the gates is a good time to perform special inspection. Visual inspection is mainly used as a routine inspection, yearly and/or monthly.

Table 2. Inspection Guideline

Member	Spot		Item/Measured Variable	Interval	Method
Rubber Bag	Outer Layer	Abrasion	Abrasion Loss compared with Planned Value	Annual	Visual inspection Measure
		Deterioration Damage	Separation and Crack related to exposed Texture in Outer Layer	Annual	Visual inspection Measure
	Joint		Separation and Crack Crease Convex Ballooning Separation by Hands	Annual	Visual inspection Measure Manipulate Hammering test
Fixture	Bolt Anchor Fastener		Air Leakage	Monthly	Visual inspection
			Deformation Corrosion Abrasion	Special Inspection	Visual inspection Hammring test
			Loose Bolt		



Silt Accretion Air Leakage

Figure 5. Representative damages near fins

A few representative damages are shown as follows. Firstly, Figure 5 shows silt accretion and air leakage, which appear near fins controlling gates' vibration. These damages come from cracks and/or separations of joints and/or layers. Mainly rolling stones in river water generate the cracks.

Secondly, convex ballooning is illustrated in Figure 6 that gives a sample of growth process on convex one for 4 months. The damages of convex one occur due to two causes. The first is penetrating water between the outer and inner layers. The second one is air leakage from crack on inner layer that is very much dangerous. The illustration of gap on embedding rubbers is shown in Figure 7. Table 3 lists up the damages and their estimated causes, and summarizes information from technical standards.

Finally, Figure 5 shows the flowchart and criteria of inspection, coming from technical standards. From inspection results, the engineers on site need to judge soundness, follow-up observation, emergency repair, permanent repair, and/or renewal. That is, the inspection results should serve as feedback for any next action. Moreover, inspection engineers need to have acquired judgment ability.

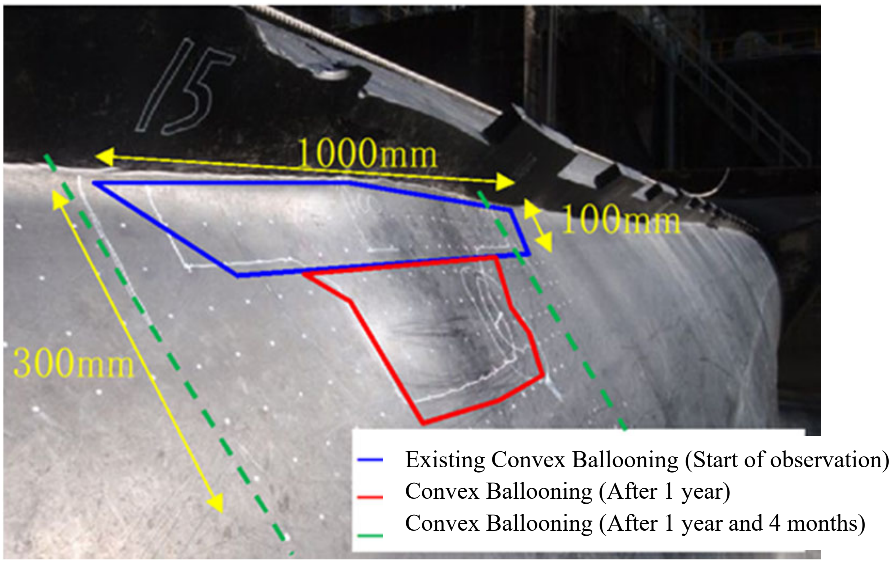
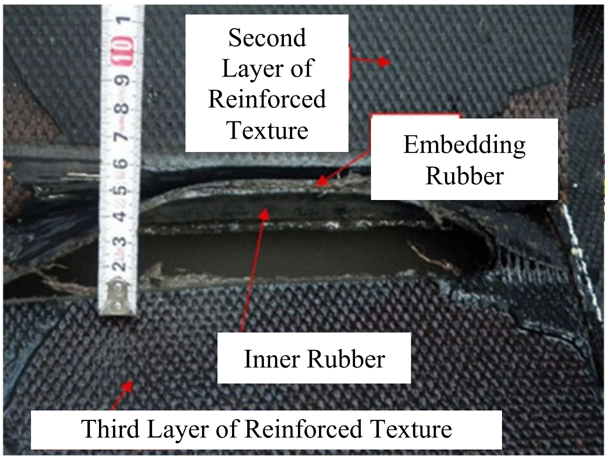


Figure 6. Growth process on convex ballooning



Sample case of the gap on joint

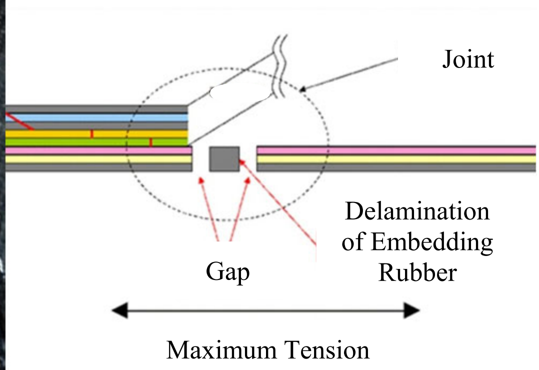
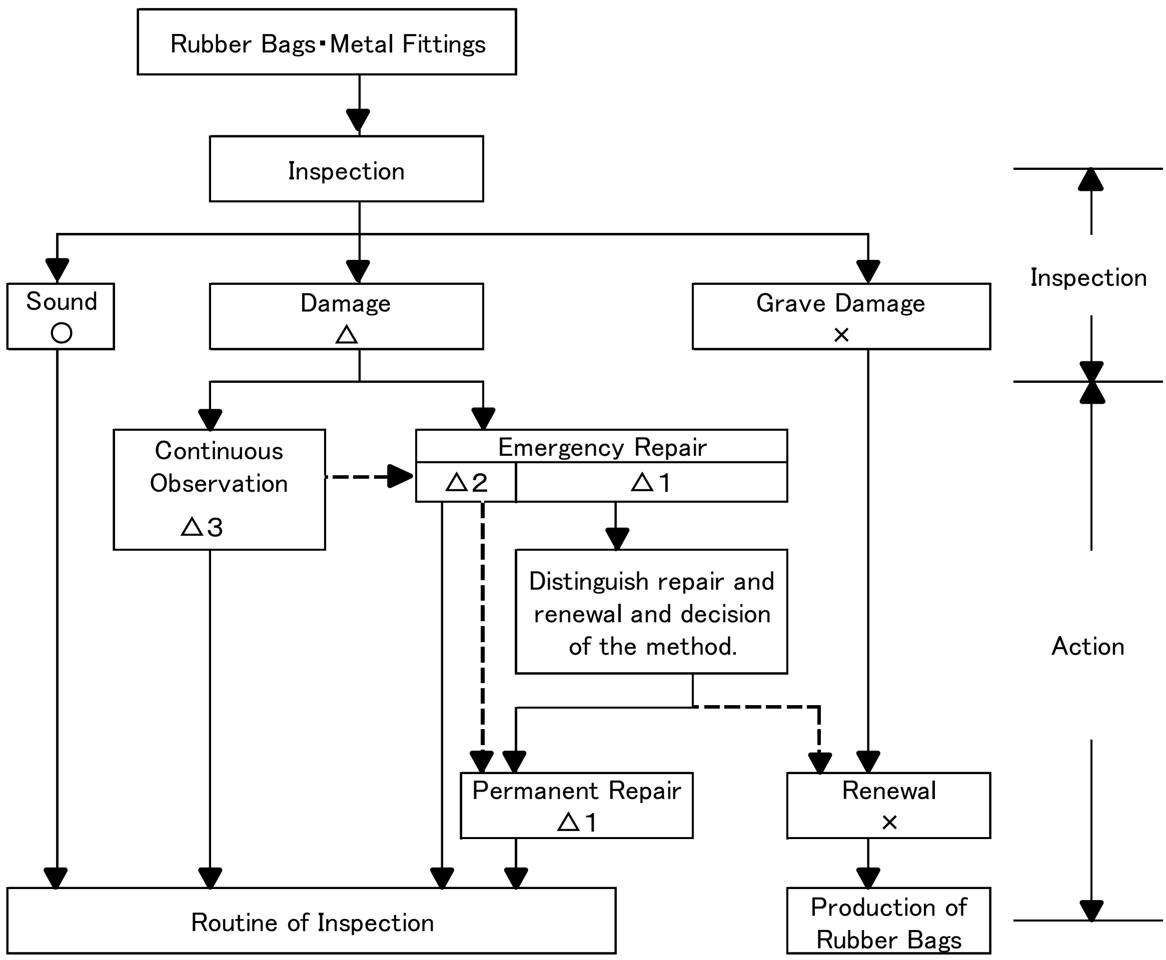


Illustration of the gap

Figure 7. Illustration of gap on embedding rubbers

Table 3. Damages and their estimated causes

Damages	Estimated Causes
Air Leakage on Rubber Bag	Crack by Rolling Stones or Separation of Joint
Rubber Bag Burst	Crack, Over Pressure or Degradation on Joint
Air Leakage on Fixture	Failed Construction of Sealing, Packing and Fixture Bolt Degradation of Sealing Gap and/or Crack on Rubber Bag due to Vibration and/or Over Tension
Shallow Crack	Degradation of Rubber Bag
Deep Crack	Separation on ill-bonding part or Degradation of bonding
Convex Ballooning in Outer and/or Inner Layer	Air Leakage from crack on inner layer, this is very much dengerous
	Pooling water between outer layer and inner layer



Broken Line: Process with history of inspection

Inspection Result		Action	Criteria
×		Renewal	If repair is difficult, permanent repair cannot ensure original reliability, or economic advantage, renewal is selected.
△	△1	Emergency Repair and Permanent Repair	Emergency repair cannot ensure the original reliability. Permanent repair is selected, if it has economically advantage. Renewal is selected and it is determined ×, if the selection of renewal has economically advantage.
	△2	Emergency Repair	Emergency repair can ensure the original reliability. It is determined as △ 1 when the damage scale is large.
	△3	Follow-up Observation	Although there is damage and deterioration, reliability is maintained. Depending on the progress of the defect, it may be determined as △2.
○		Sound	No defects are found in the rubber bag and fixing bracket.

Figure 8. Flowchart and criteria of inspection

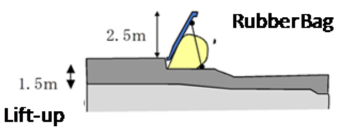
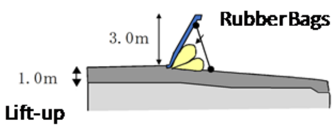
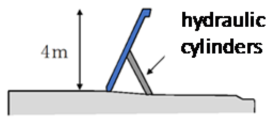
4. REPAIR AND RENEWAL

When the inspections in the previous section give results which are neither sound nor follow-up observations, those gates must be repaired or renewed. Firstly, let us consider the case of replacing. The authors assumed that protective layer rubber bag with the ceramics chips cannot be manufactured due to their peculiarity. In fact, the author recognizes the case that the manufacturer withdraws. Then, we must select an alternative technology from Table 1. Options 3 and 5 in Table 1 are not effective enough. Moreover, the authors assumed that Options 2 and 4 cannot be sufficiently procured. Only by making these assumptions were the authors able to negate all five options. Consequently, none of the five options has both abrasion resistance and availability. At this point, repairs are not possible due to unavailability of ceramics. Therefore, this is no longer repair, but renewal with a different type of gate. The candidates for gate types are steel flap gate with single/double rubber bladders and steel flap gate with hydraulic cylinders.

The authors then compared these three candidates. The allowed water level in target river caused the constraint of gate height to be 4 m. With this constraint, the height of riverbed becomes higher than the present height when selecting steel flap gate with single/double rubber bladders. This is the reason why steel flap gates with height more than 2.5 m for single rubber bladder, or 3 m for double ones, cannot be installed. Table 4 shows their comparison, while Figure 9 shows sample pictures of them. Since a lift-up is needed in case of a steel flap gate with single/double rubber bladders, more detailed planning is needed. Moreover, gate owners need to have a good relationship with the authorities in order to carry out this project. The necessary level of riverbed must be negotiated with the authorities. The reason is that the level is determined by technical standard and contracted between the authority and the gate keeper. In conclusion, detailed planning and negotiations are essential. The sample case which the authors have is redesigning now.

The above process is summarized in Figure 10.

Table 4. Comparison of rubber bladders and hydraulic cylinders

	Steel Flap Gate with single Rubber Bladder	Steel Flap Gate with double Rubber Bladders	Steel Flap Gate with hydraulic cylinders
Illustration			
Height of Gate (m)	2.5	3	4
Anti-inundation measure	Need	Need	Not Need
Cost for superstructure (conparison)	0.6~0.7	0.7~0.8	1
Consultation	Need	Need	Not Need
Comments	Need to lift up	Need to lift up	No lift-up

Rubber Gate | Steel Flap Gate with Rubber Bladders | Steel Flap Gate with Hydraulic Cylinders

Figure 9. Samples of rubber gate and steel flap gate with rubber bladders and hydraulic cylinders

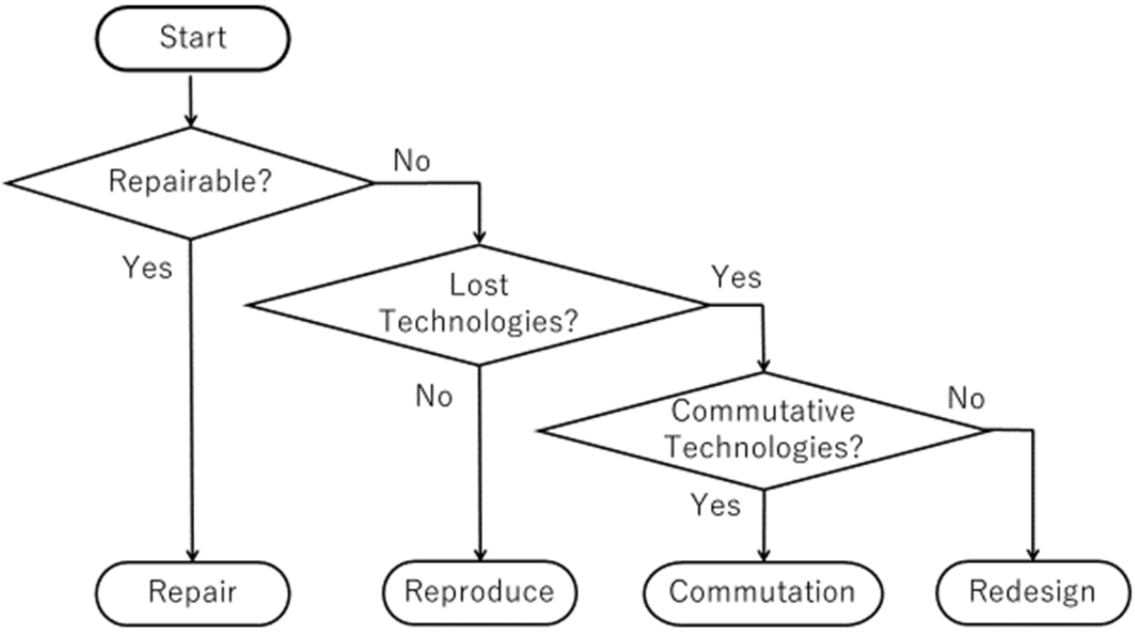


Figure 10. Flowchart for maintenance of rubber gates with lost technologies

5. CONCLUSIONS

Japan has created several original engineering standards for rubber gates in severe conditions. These standards have been established not only for the construction of rubber gates, but also for their maintenance and renewal. Moreover, no major accidents have occurred on rubber gates constructed on the basis of the established standards. Finally, all of these have realized the construction of large scale rubber gates instead of steel flap gates. This implies that Japanese civil engineers have improved rubber gates to fit the Japanese environment. Moreover, rubber gates have taken essential role in river management of Japan.

Based on the above achievements in the field of rubber gates, the authors have reached the following conclusions in their case study:

1) Necessity keeps technologies sound: this generally implies that construction works help handing down to future generations technologies to build infrastructure.
2) Alternative elemental technologies are not always available: some key technologies for repair and/or renewal of infrastructure have not been handed down to future generations.
3) Gate type has to be changed under certain circumstances: some technologies to construct a particular structure have become lost technologies, e.g. the technology to build the Great Buddha of Todaiji Temple in Japan.

Though the authors have obtained valuable results for the renewal of rubber gates, further investigations must still be done on actual rubber gates. Therefore, the remaining issues are as follows:

1) We must collect more renewal examples: the number of construction examples owned by authors is currently too small.
2) We must generate standards for renewal of rubber gates: we are not able to apply/share the stored knowledge if it is not standardized.
3) We must renew more rubber gates using the standard: it is necessary to improve the standard when we find some improvement points.

REFERENCE

S. Takasu, T. Takatsu and K. Nagano (2019),"Examination on Renewal Plan of Rubber Gate," Annual Report 2019 of Dam Engineering Research Institute, Japan Dam Engineering Center, pp. 4-19 – 4-27 (in Japanese).