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# **Preliminary Analysis of Underwater Maintenance Technology to the Water Cushion Pool of Xiluodu Hydropower Station**

by

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## **Report Outline**

- 1. Overview of Xiluodu Hydropower Station**
- 2. Introduction to the maintenance after the water cushion pool is drained**
- 3. Introduction to underwater maintenance technology for the water cushion pool**
- 4. Prospects for maintenance technology of hydraulic structures**



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## 1. Overview of Xiluodu Hydropower Station

The Xiluodu Hydropower Station is located at the lower reaches of the Jinsha River, which is a giant water conservancy and hydropower hub focusing on power generation and taking into account sand blocking, flood control and improving downstream channel conditions.



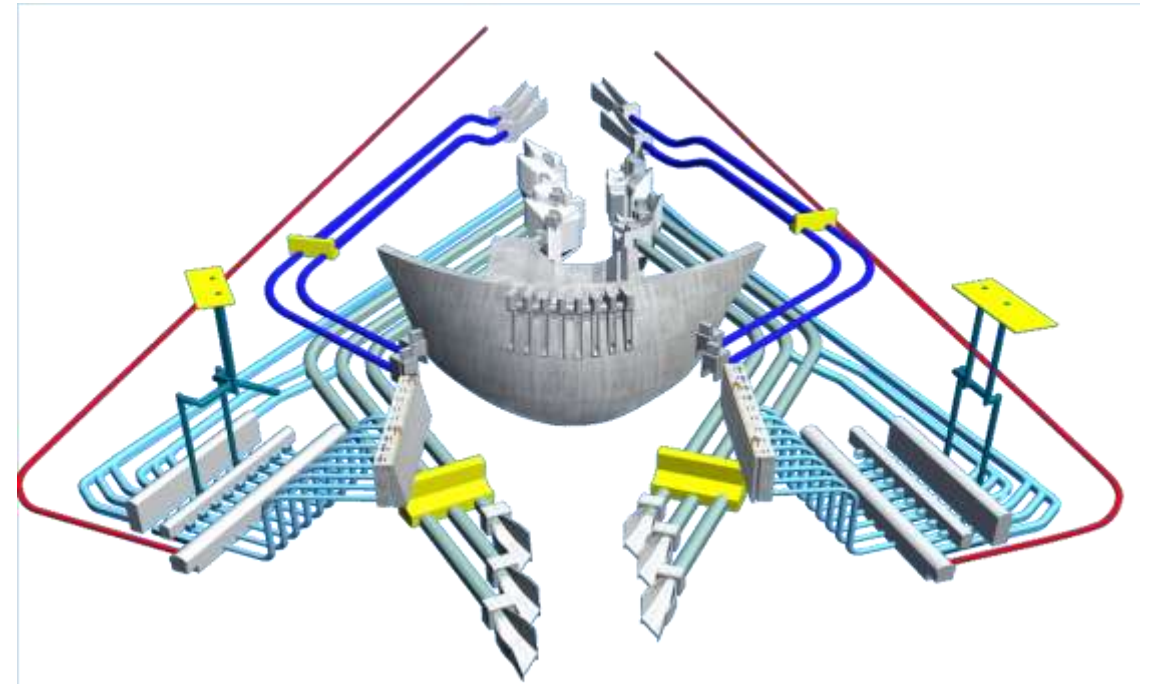


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## 1. Overview of Xiluodu Hydropower Station

The hydropower station is equipped with two underground powerhouses on the left and right banks, each installed with 9 hydropower generating units with a single unit capacity of 770MW, and the total capacity of 13,860MW.





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## 1. Overview of Xiluodu Hydropower Station

The hydropower station uses a concrete double-curved arch dam with a maximum height of 285.50m. The flood discharge and energy dissipation facilities consist of 7 surface holes and 8 middle holes in the dam body, and a water cushion pool behind the dam, which makes the flood discharge with the characteristic of “layered outflow, air collision, and energy dissipation in water cushion pool”.





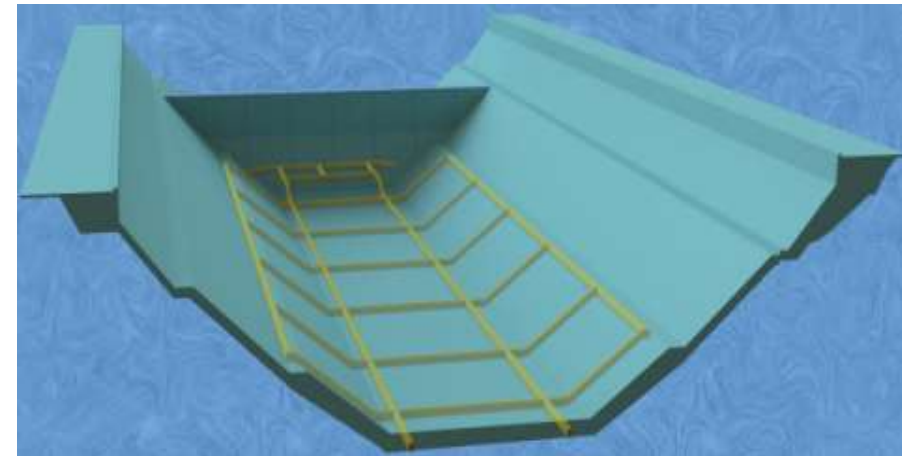
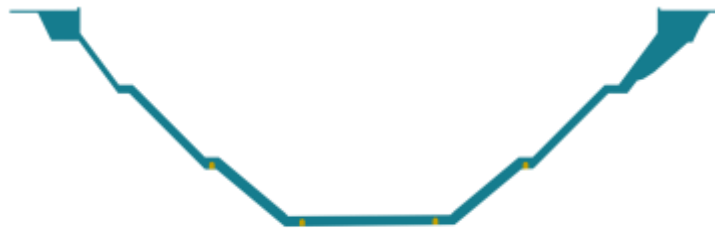
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## 1. Overview of Xiluodu Hydropower Station

There are three types of common defects in the operation of the water cushion pool:

- 1) Scour pits caused by the erosion of large-flow and high-speed sand-containing water;
- 2) Concrete cracks caused by temperature stress and structural stress;
- 3) The joint concrete is damaged by structural deformation and extrusion, and the filling material in the expansion joint is washed out.





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## 1. Overview of Xiluodu Hydropower Station

These three types of concrete defects should be treated at the initial stage of their occurrence to avoid operation of the water cushion pool with defects, which would lead to accelerated deterioration of the defects and structural damage.

Therefore, the Xiluodu Hydropower Plant will conduct a comprehensive inspection and maintenance of the water cushion pool after the flood season every year.



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## 1. Overview of Xiluodu Hydropower Station

It has experienced 8 flood seasons since the Xiluodu Water Cushion Pool was put into operation in June 2012. The post-flood maintenance can be divided into two stages:

- 1) From 2013 to 2017, the water cushion pool was checked and repaired after being drained.
- 2) Since 2018, underwater inspections and repairs have been carried out to the water cushion pool with the cooperation of underwater robots and divers.



Stage 1



Stage 2





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## 2. Introduction to the maintenance after the water cushion pool is drained

After the flood season from 2013 to 2017, the Xiluodu Water Cushion Pool underwent a total of 4 drainage inspections. The specific drainage time is as follows:

Order	Working condition	Date	Leakage of water cushion pool (L/min)	Change before and after maintenance (L/min)
The first time	Start pumping	2013-12-15	6346.26	-1264.2
	Drained	2014-1-18	4900.04	
	Start filling	2014-2-23	4786.01	
	Full	2014-3-29	5082.06	
The second time	Start pumping	2015-1-1	8429.48	-1127.31
	Drained	2015-2-20	8122.26	
	Start filling	2015-4-21	7522.22	
	Full	2015-8-30	7302.17	
The third time	Start pumping	2015-11-29	6870.23	-351.61
	Drained	2016-1-3	7013.00	
	Start filling	2016-6-27	6588.33	
	Full	2016-6-28	6518.62	
The fourth time	Start pumping	2017-3-25	7744.98	-442.81
	Drained	2017-5-12	5771.95	
	Start filling	2017-6-5	5640.19	
	Full	2017-6-26	7302.17	

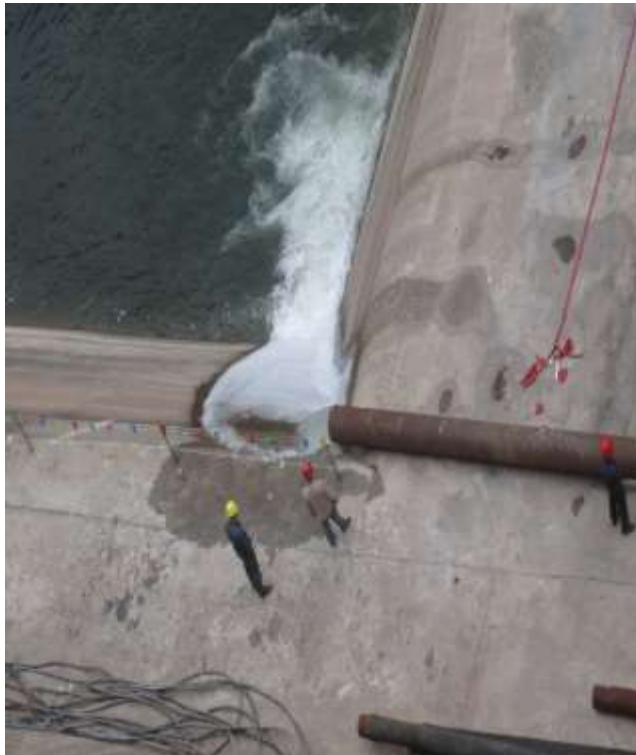


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## 2. Introduction to the maintenance after the water cushion pool is drained

Photos of drainage of water cushion pool





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## 2. Introduction to the maintenance after the water cushion pool is drained

Photos of cleaning and inspection after the water cushion pool has been drained





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## 2. Introduction to the maintenance after the water cushion pool is drained

### Typical defects and repair principles

#### 1) Concrete wear and scour

According to the different damage depths, and according to the principle of "smooth surface", epoxy cement, epoxy mortar and pre-shrink mortar are used for repair.





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## 2. Introduction to the maintenance after the water cushion pool is drained

### Typical defects and repair principles

#### 2) Concrete cracks and water seepage

On the premise of not damaging the main concrete, the concrete cracks are cleaned up, and then filled with epoxy cement or epoxy mortar; for the seepage cracks, elastic material grouting is used to stop the seepage, and then filled.





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## 2. Introduction to the maintenance after the water cushion pool is drained

### Typical defects and repair principles

3) The polyurea damage on the surface of the expansion joint and the internal polysulfide sealant fall off

The damaged polysulfide sealant in the expansion joint is cleaned and refilled, and the surface is sealed with polyurea.





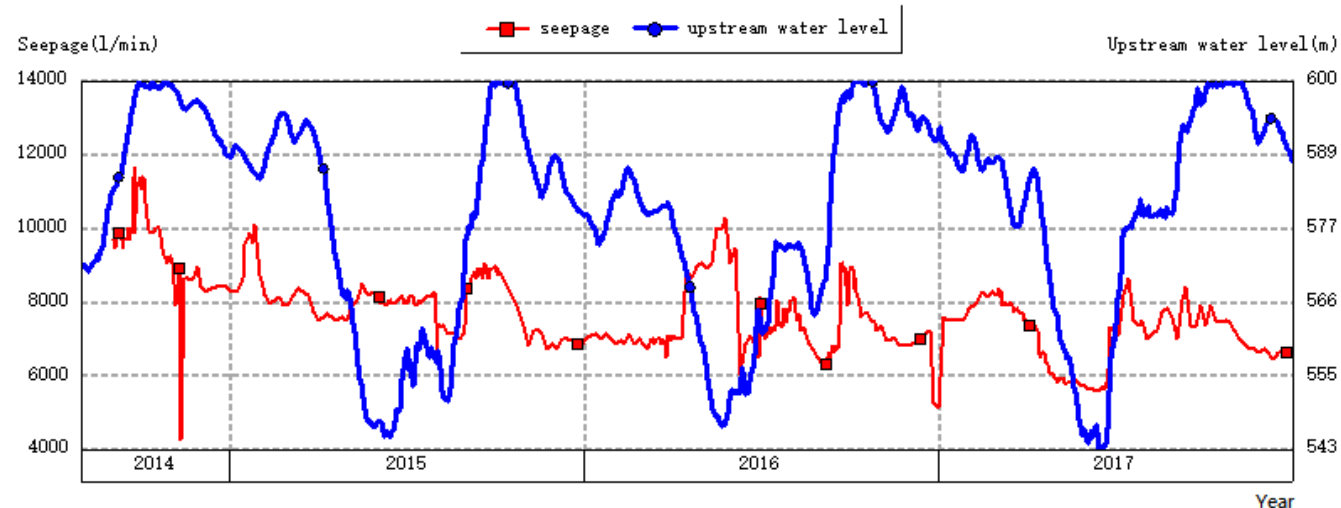
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## 2. Introduction to the maintenance after the water cushion pool is drained

### Maintenance conclusions and recommendations

After drained and repaired, the concrete pits, damage and cracks were contained in time, the working condition of the expansion joint was effectively improved, and the leakage of the water cushion pool was significantly reduced.







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## 2. Introduction to the maintenance after the water cushion pool is drained

### Maintenance conclusions and recommendations

However, there are some shortcomings in draining the water cushion pool for maintenance, as follows:

- 1) Drainage is time-consuming and large investment;
- 2) The unloading rebound deformation of the water cushion pool slope and bottom plate caused by draining is not conducive to structural stability;
- 3) The water cushion pool was overhauled during the low temperature season, and the low temperature will aggravate the shrinkage and rebound deformation after being drained.



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## 2. Introduction to the maintenance after the water cushion pool is drained

### Maintenance conclusions and recommendations

According to the results of maintenance after draining over the years, the water cushion pool has fewer defects and slight damage. Frequent draining and unloading may cause secondary damage to the water cushion pool.

With the increasing maturity of underwater maintenance technology, it is recommended that the water cushion pool can be repaired underwater after the flood season.



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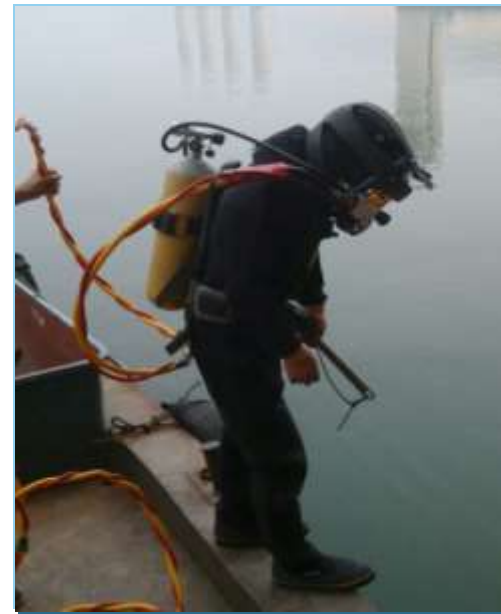
## 3. Introduction to underwater maintenance technology for the water cushion pool

### Diving job classification

Divided by equipment---Scuba diving, Heavy diving;

Divided according to different breathing gas---  
Air diving, Mixed gas diving;

Divided according to different air supply methods---surface air diving, self-contained diving





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## 3. Introduction to underwater maintenance technology for the water cushion pool

**Unmanned diving equipment**

Underwater television;

Underwater manipulator with camera;

Underwater maintenance robot;

Underwater sonar scanning.





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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Application prospects of underwater maintenance robots

#### 1) Limitations of diving operations, including:

- The working depth is very limited, generally 0 to 60 meters;
- Each working time is relatively short;
- Divers work less efficiently underwater;
- Threat to the life and health of divers.

#### 2) The rapid development of robotics and electronic information technology

#### 3) Encouragement of National Science and Technology Innovation

#### 4) The mature application of underwater robots in offshore oil and underwater salvage search and rescue





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## 3. Introduction to underwater maintenance technology for the water cushion pool

### The main functions of the underwater robot owned by Xiluodu

Crawling and swimming underwater;

Positioning underwater;

Camera observation underwater;

Sonar detection underwater;

Cleaning and sanding underwater;

Grabbing and cutting underwater.





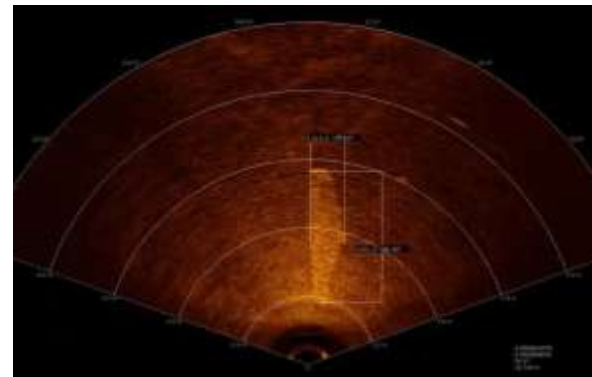
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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Inspection scheme underwater

The cooperation of underwater robots and divers was used in the inspection to the floor and slopes of water cushion pool, with multiple technologies such as underwater photography, underwater exploration, single-beam sonar, multi-beam sonar, ultra-short baseline positioning etc., which has the characteristics of "full coverage, quasi positioning and high accuracy".







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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Inspection results

Underwater inspection showed that the overall condition of the water cushion pool was good, and the types of defects existed mainly as follows:

- 1) The concrete of the floor and the slope is slightly damaged, where the damaged area mainly distributed near the water tongue area;
- 2) There are a few cracks in the concrete on the slope, some of which have water seepage;
- 3) The polyurea on the structural joint surface is partially peeled off and damaged.



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## 3. Introduction to underwater maintenance technology for the water cushion pool Repair Materials

The choice of repair materials is mainly considered from the mechanical properties of the material after curing and the convenience of construction. Corresponding repair materials are selected for different defects, and the main properties are shown in table below.

Material name	Applicable defect types	Main feature
"Xiamen Brand" Underwater Sealant	Leakage parts such as structural surfaces and construction joints	Superior plasticity High viscosity in water, short curing time, good sealing High bonding strength, good compression resistance, good abrasion and corrosion resistance Easy to operate underwater
HK-UW-1 epoxy mortar (concrete)	Damage of concrete flow surface	Can be cured under water, high compressive and flexural strength after curing Good shrinkage and strong adhesion Does not disperse underwater, self-leveling, self-compacting Good impact and abrasion resistance Easy to operate underwater
HK-969 Joint Filling Material	Damage of structural joints and construction joints	Strong ability to adapt to deformation Good adhesion to concrete High tensile strength, not sucked out and washed away by water during flood Easy to operate underwater



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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Construction process

The detected defects will be repaired underwater by the diver. Since underwater operations are far more difficult than conventional construction, the construction process is required to be as simple as possible. For the repair of different types of defects, the construction process is listed as follows:

#### 1) Damage of concrete surface

**Repair principle:** Damages less than 1cm in depth will not be repaired; Damages with a depth of 1cm to 3cm are repaired with epoxy mortar; Damages greater than 3cm in depth are repaired with epoxy concrete.

**Construction process:** Clean up the sediment and debris in the damaged area → Treating the base surface with a wire brush → Transport the mixed material to the area to be repaired → Fill material and scrape with spatula → Stable after about 30 minutes.



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## 3. Introduction to underwater maintenance technology for the water cushion pool Construction process

2) Defects such as concrete cracks, structural joint damage and leakage

*Repair principle: Water seepage cracks should be repaired with underwater sealant, which also has anti-seepage and structural reinforcement functions; Defects of impervious cracks are repaired with HK-969 Joint Filling Material; Defects of polyurea falling off and being broken need to be trimmed first.*

*Construction process: Clear loose debris in damaged areas → Use a high-pressure water gun to remove dust from structural seams → Transport the mixed material to the area to be repaired → Fill the repair material into the seam → Compact the material and smooth it with a spatula to ensure a smooth surface → Stable after about 30 minutes.*



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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Comparison before and after underwater repair



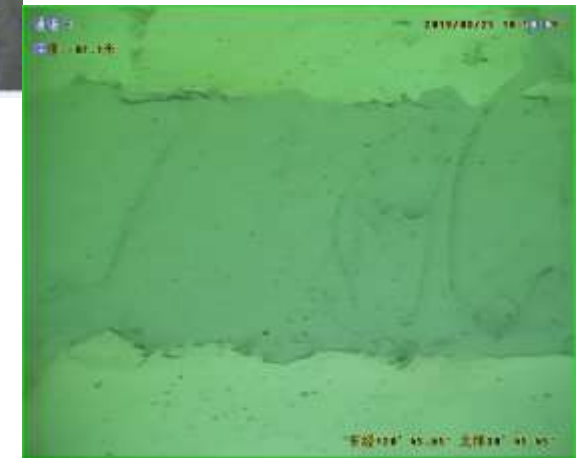
Before repairment



After repairment



Before repairment



After repairment



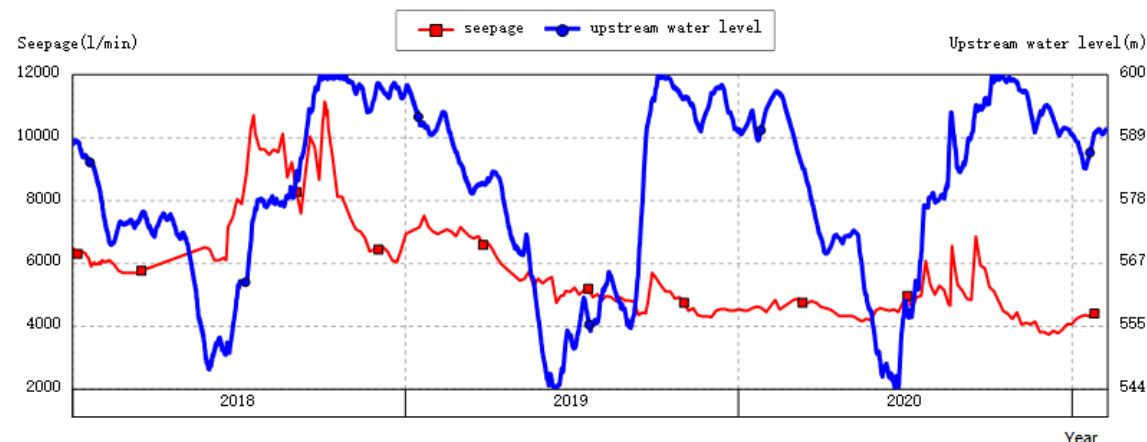
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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Maintenance conclusion

Underwater inspection and repair of the water cushion pool not only saves construction period and cost, but also benefits the structural stability of the water cushion pool. After the maintenance, the concrete damage and cracks have been well improved, the repair effect is better, and the leakage of the water cushion pool is also significantly reduced.





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## 3. Introduction to underwater maintenance technology for the water cushion pool

### Maintenance conclusion

The inspection results proved the reliability of the underwater inspection and revealed the damage type and distribution law of the water cushion pool during flood discharge. It should be taken as the focus of attention in the future and can also provide reference significance for related projects.

With the promotion of underwater maintenance technology, higher requirements will be imposed on concrete underwater repair materials and processes, which can promote the development of maintenance technology for hydraulic structures.



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## 4. Prospects for maintenance technology of hydraulic structures

### Improvement of underwater robots

- 1) Add the function of "clean water replacement" ,which can overcome the interference of silt coverage and muddy environment on data collection, and achieve high-definition data acquisition on underwater concrete surfaces;
- 2) Strengthen the research of small and flexible underwater robots, which can inspect and repair irregular and narrow underwater area, so as to achieve no dead spots.



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## 4. Prospects for maintenance technology of hydraulic structures

### Improvement of underwater robots

- 3) Multi-technology integration inspection to achieve higher precision positioning, higher definition imaging, and more obvious detail capture;
- 4) A comprehensive robot that can integrate underwater inspection and multiple repair skills to achieve the goal of underwater unmanned inspection and repair.



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## 4. Prospects for maintenance technology of hydraulic structures

### Prospects for other maintenance technologies

- 1) Research of intelligent inspection system of special drones for different scenarios, which can realize intelligent inspection of areas such as high dam surfaces, overflow surfaces, and high slopes;
- 2) Innovatively research on robot technology suitable for inspections of different hydraulic structures, such as main and auxiliary robots, orbital robots, to improve the level of digital and intelligent hydraulic inspections.
- 3) Relying on new technologies such as big data, cloud computing, and artificial intelligence, the intelligent maintenance systems for hydropower stations that integrate intelligent inspection, intelligent diagnosis, independent evaluation, decision-making support, and unmanned inspection and repair will be proposed, which can further explore the construction of intelligent water conservancy.



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**The End**  
**Thank you!**