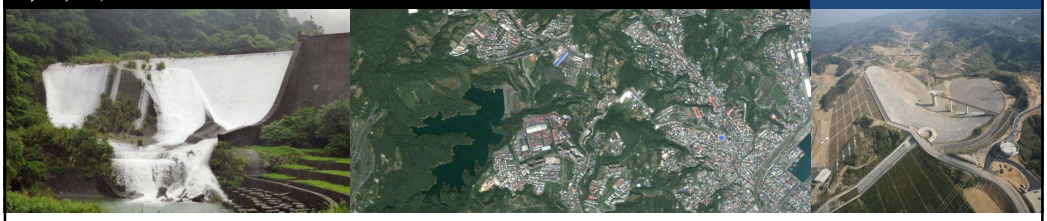
Dam Safety and Risk Management in Taiwan

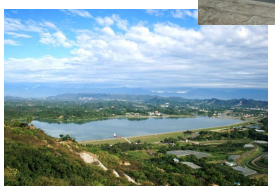


Sinotech Engineering Consultants

Hsien-Chang Kao

Sep. 2023

Self Introduction



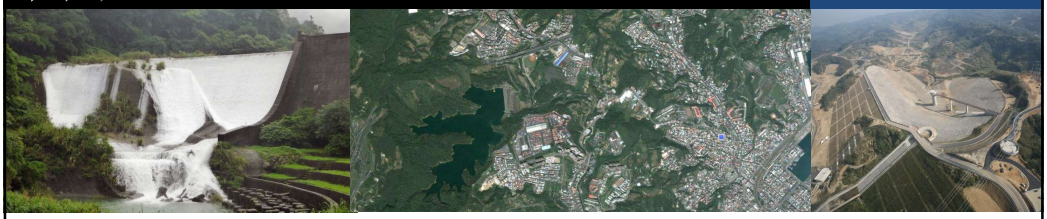
- Ph.D. Candidate, Institute of Civil Engineering, Taiwan University
- Registered in Professional Engineer of Geotechnical Engineering
- Dam safety Experiences
  - Nanhua Dam
  - Mudan Dam
  - Batutegi Dam(in Indonesia)
  - Baoshan II Dam
  - Xinshan Dam
  - Hushan Dam
  - Tsengwen Dam (Largest dam)
  - Feitsui Dam(Arch dam)
  - ……..

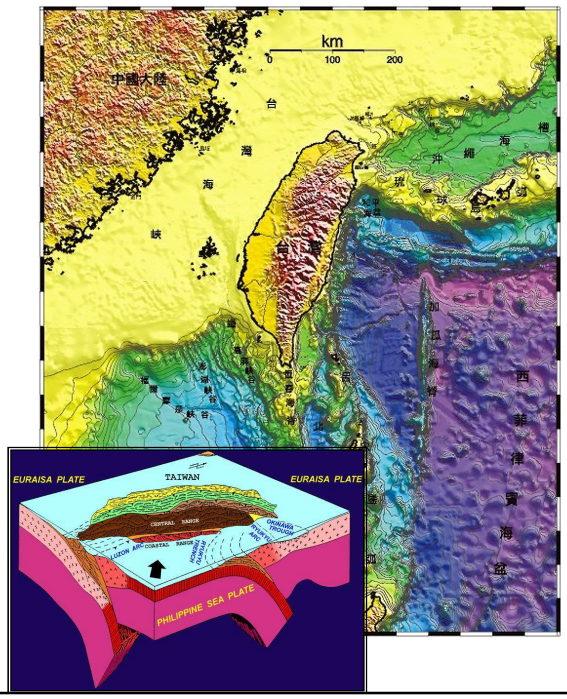
Contents

1. Dam Safety Management in Taiwan
2. Evolution of Dam Safety Management
3. Case Study：Xinshan dam
4. Conclusion

SINOTECH

Dams in Taiwan

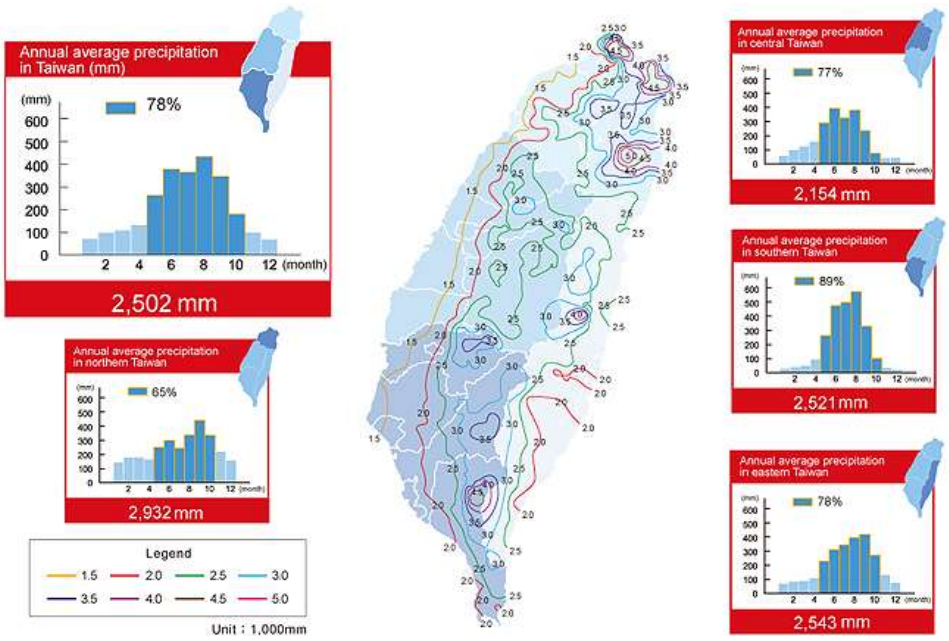




- Taiwan lies on western rim of circum-pacific seismic zone
- Located on convergent and compressive boundary between Eurasian and Philippine Sea Plates
- The rock formations are young and weak

5

SINOTECH

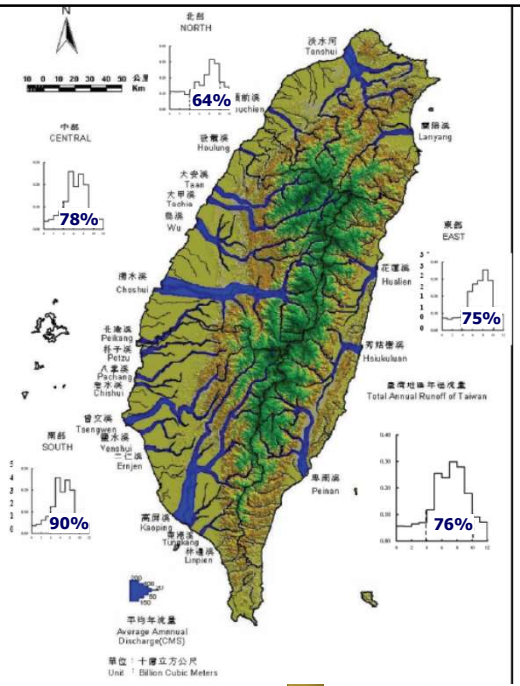


6

SINOTECH

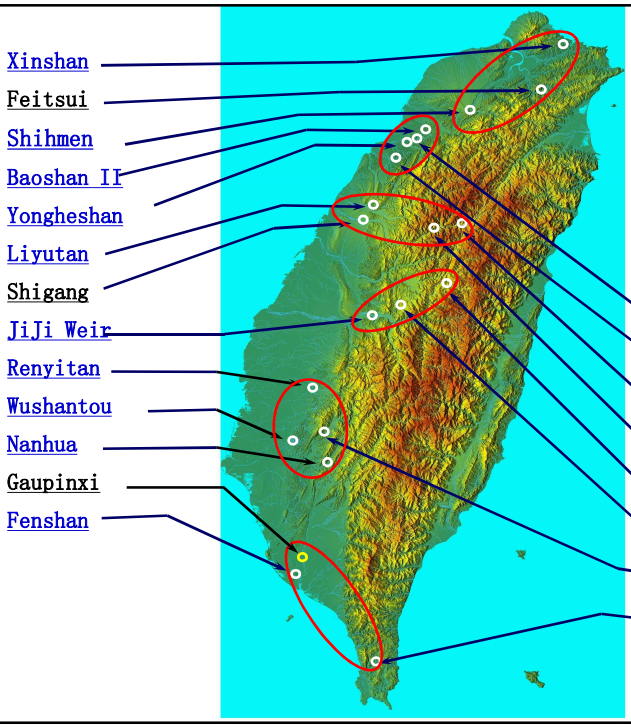
Average Annual Runoff in Taiwan (1949~2006)

Region	Percent of Runoff in Dry Season (Nov.~Apr.)
North	36%
Central	22%
South	10%
East	25%



7

SINOTECH



Major Dams in Taiwan

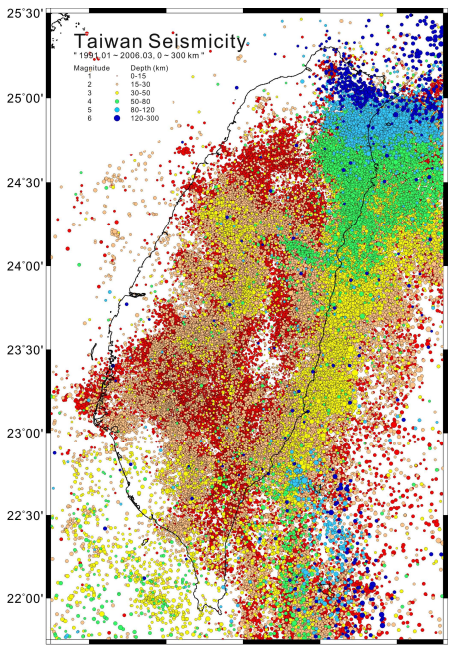
Xinshan
Feitsui
Shihmen
Baoshan II
Yongheshan
Liyutan
Shigang
JiJi Weir
Renyitan
Wushantou
Nanhua
Gaupinxi
Fenshan

Dapu
Minder
Guguan
Deji
Wushe
Sun Moon Lake
Tsengwen
Mudan

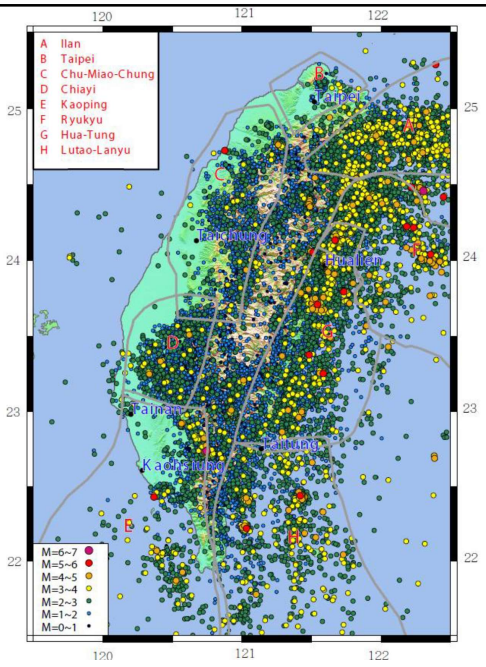
8

SINOTECH

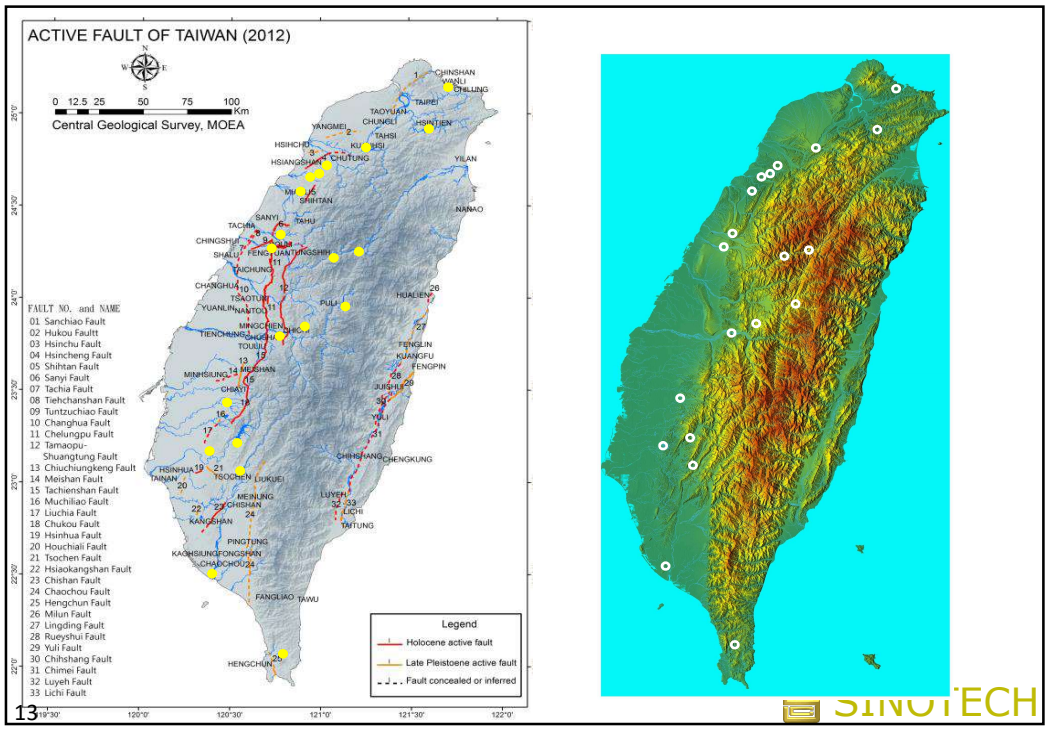
Name of Reservoir	Dam Type	Year of Completion	Gross Capacity of Reservoir $\times 10^8$ m^3
Wu-Shan-Tou	Earth Dam	1930	1.5
Sun Moon Lake	Earth Dam	1934	1.72
Wu-She	Gravity Dam	1959	1.48
Shih-Men	Earth Dam	1964	3.1
Pai-Ho	Earth Dam	1965	0.25
Tseng-Wen	Earth Dam	1973	7.1
Te-Chi	Arch Dam	1974	2.3
Jong-Hua	Arch Dam	1984	0.12
Ming-Hu	Gravity Dam	1985	0.08
Fei-Tsui	Arch Dam	1987	4.06
Li-Yu-Tan	Earth Dam	1992	1.26
Nan-Hua	Earth Dam	1993	1.58
Mu-Dan	Earth Dam	1995	0.31
Ming-Tan	Gravity Dam	1995	0.12
Bao-Shan Ⅱ	Earth Dam	2006	0.32
Husan	Earth Dam	2016	0.50



List of earthquakes in Taiwan
from 1991 to 2006



Earthquakes in Taiwan
from 2011/11 to 2012/10

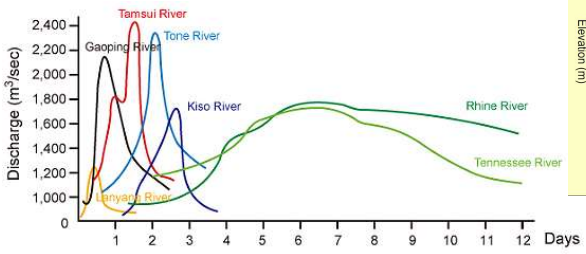


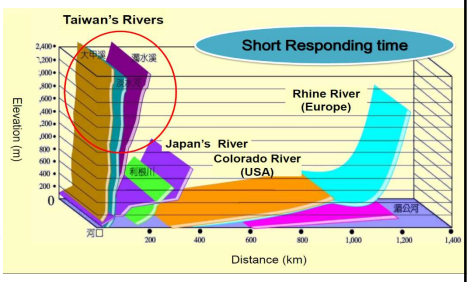
SINOTECH

13

Role and Challenge of Reservoir in Taiwan

- **The reservoir can be said the most important and reliable water resource in Taiwan**
- **High mountain, steep drainage slope, small reservoir volume**
  - ➡ **Young and weak geology, unstable slope**
  - ➡ **Most precipitations come from typhoons, with high rainfall intensity and large erosion**
  - ➡ **Threat of earthquakes**

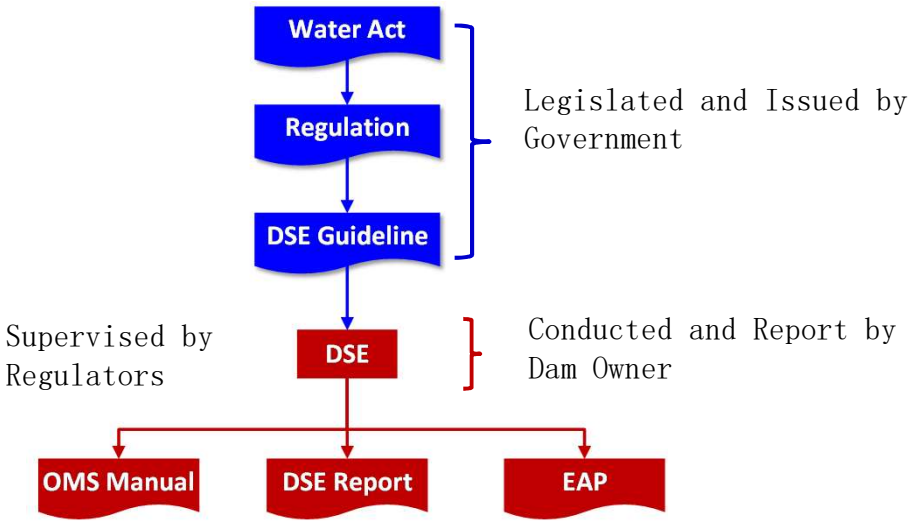




SINOTECH

14

Framework of DSM in Taiwan

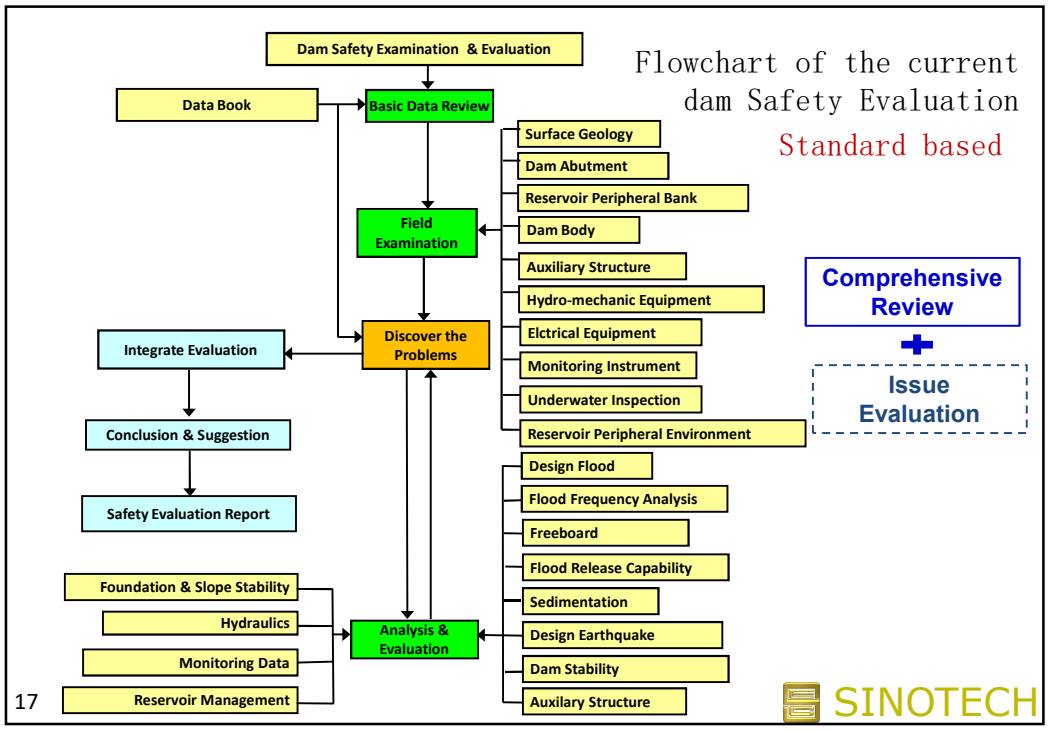


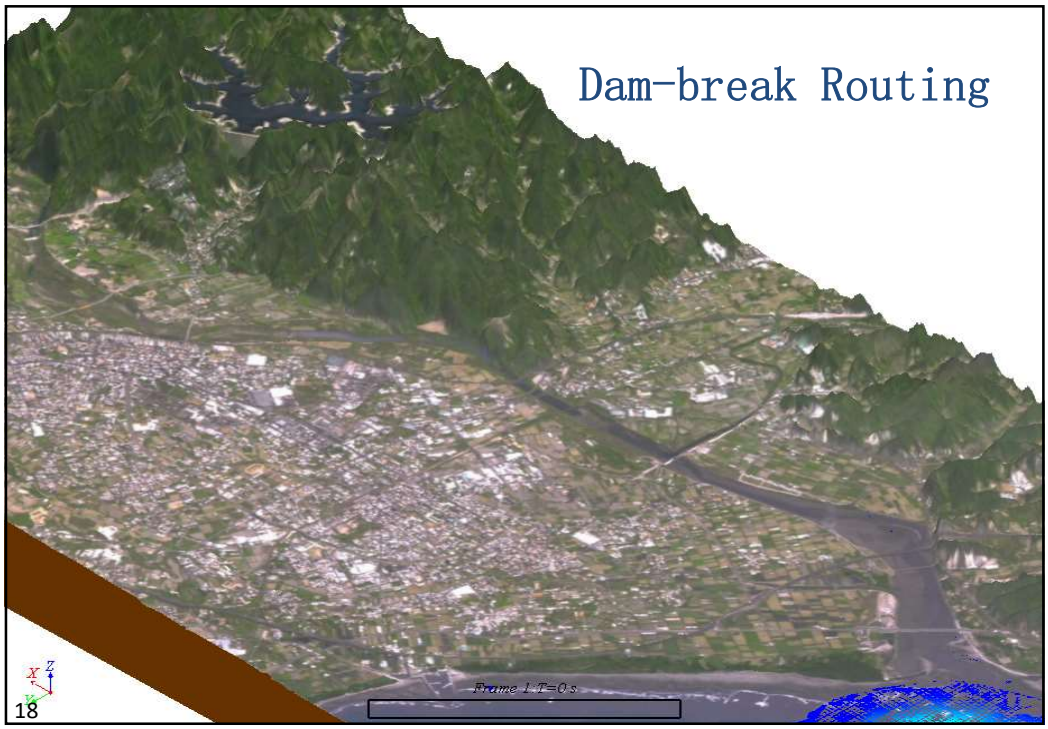
SINOTECH

Dam Safety Regulations

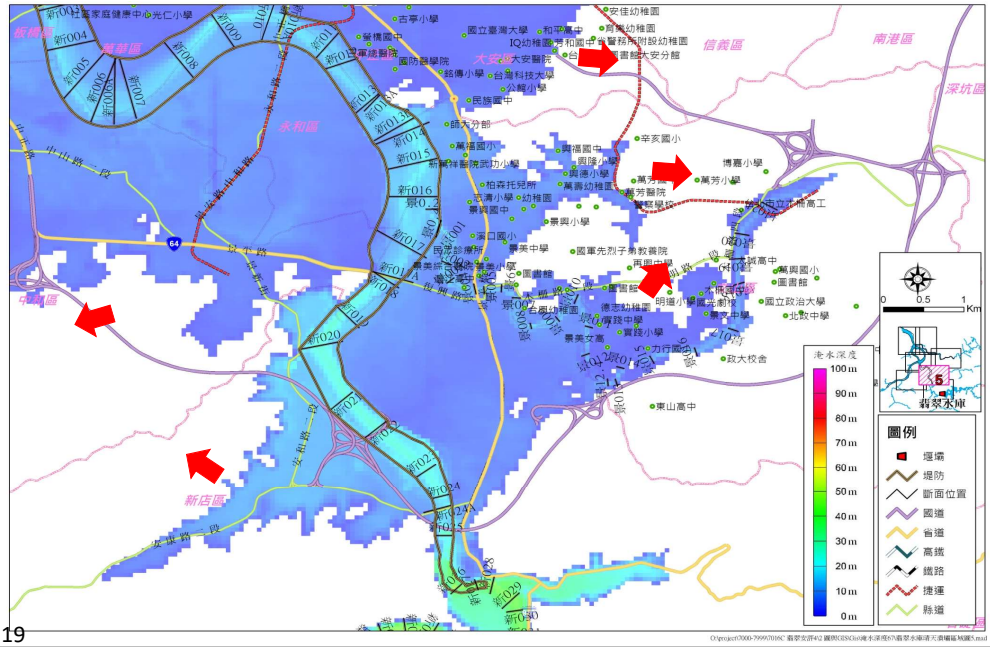
Item		Description
Inspection	Regular	Daily, Monthly, Quarterly. Yearly…….
	Irregular (Special)	After Strong Earthquake、 Flood、 Storm…
	Re-check	If Necessary
Evaluation	Before First Filling	Necessary
	After First Filling	Necessary
	Regular	Every 5- yr. Integral Evaluation (or Comprehensive Review)
	Special	After Irregular Inspection if Necessary (Issue Evaluation)

SINOTECH

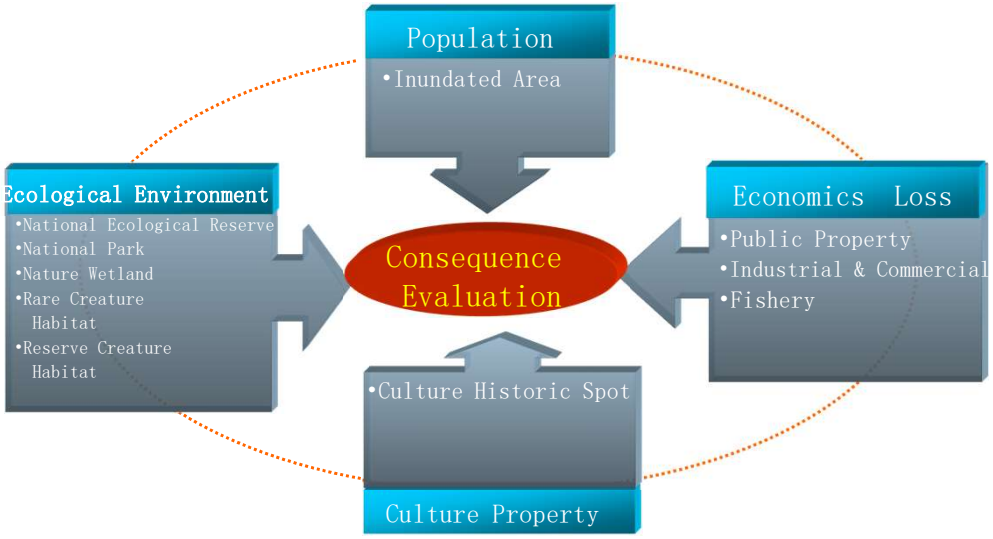

Dam Safety Examination & Evaluation
Data Book
Basic Data Review
Field Examination
Discover the Problems
Integrate Evaluation
Conclusion & Suggestion
Safety Evaluation Report
Surface Geology
Dam Abutment
Reservoir Peripheral Bank
Dam Body
Auxiliary Structure
Hydro-mechanic Equipment
Elctrical Equipment
Monitoring Instrument
Underwater Inspection
Reservoir Peripheral Environment
Design Flood
Flood Frequency Analysis
Freeboard
Flood Release Capability
Sedimentation
Design Earthquake
Dam Stability
Auxilary Structure
Foundation & Slope Stability
Hydraulics
Monitoring Data
Reservoir Management
Analysis & Evaluation
Flowchart of the current dam Safety Evaluation
Standard based
Comprehensive Review
Issue Evaluation
17
SINOTECH


Dam-break Routing
18

Inundated Area & Evacuation Route



Consequences Evaluation

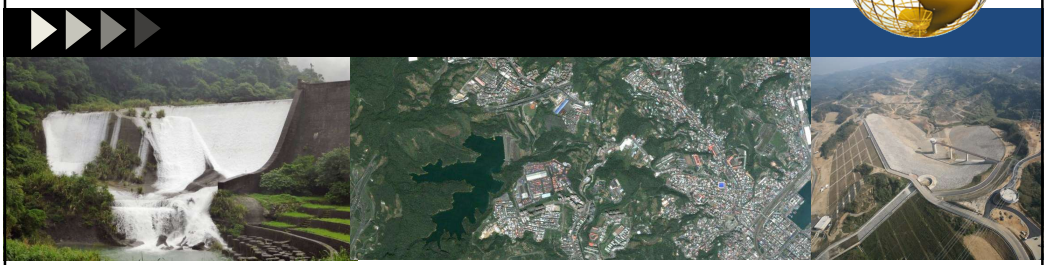


SINOTECH

Dam-break Emergency Action Plan

SINOTECH

Evolution of Dam Safety Management



Evolution of Dam Safety Management

- **Standard-Based**
- **Risk-Based**
- **Risk-Informed**
  - **PFMA**
  - **Some of the major dam owners in Taiwan have started using PFMA to identify the weak points of their dams.**

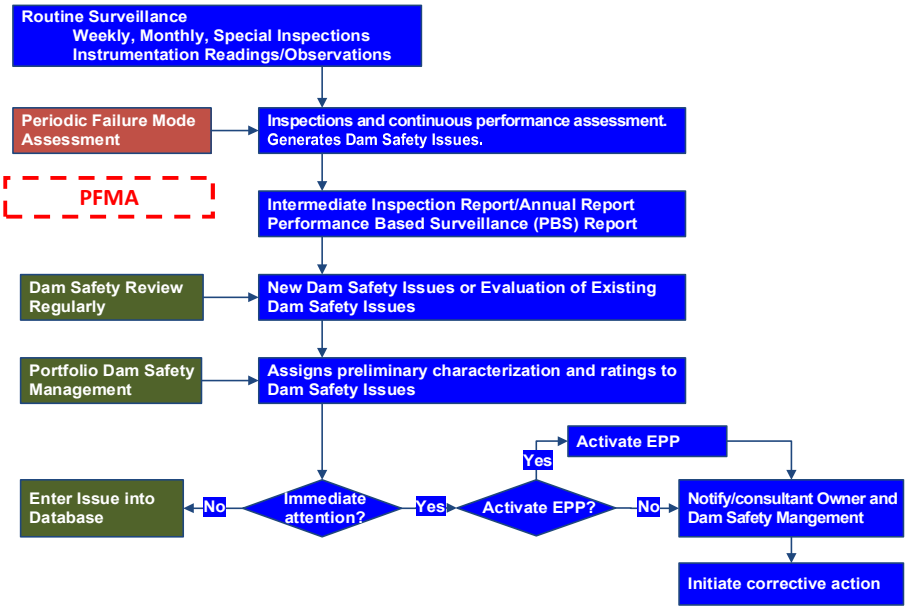
SINOTECH

Concept of Dam Risk Management

- **The dam owner should always asked himself**
  - **Why the dam may fail ?**
    - **Where the risks come from?**
  - **How it fail ?**
    - **What is the potential failure modes expected ?**
    - **Describe the failure process step by step**
  - **Where ?**
    - **Where the failure mode may initiate ?**
    - **Where we can find the evidences in the early stage when failure occurred?**
  - **When it may happen ?**
    - **What is the potential triggers for the failure modes?**
  - **Who should responds for it?**

SINOTECH

Risk-Informed Dam Safety Management

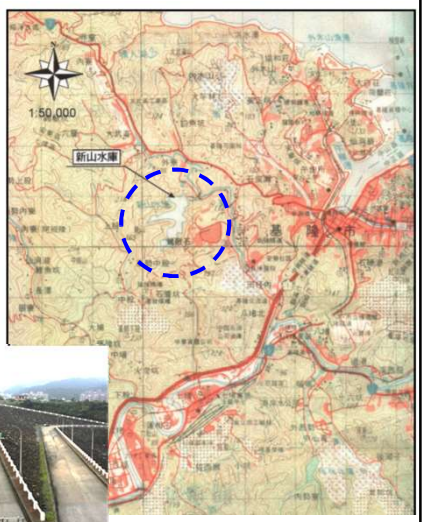


Case Study: Xinshan Dam

SINOTECH

Introduction

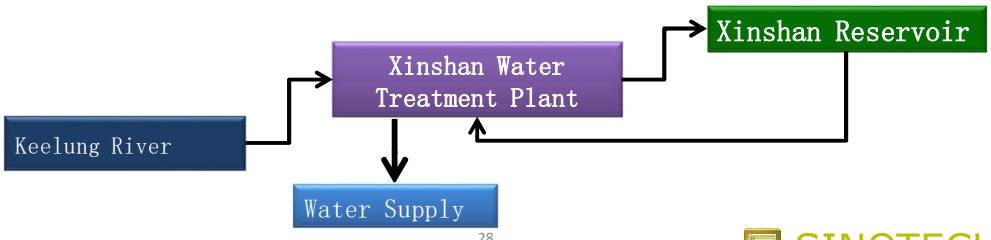
- Xinshan dam is an embankment located in northern Taiwan.
- The reservoir serves as an off-stream reservoir for the water supply of Keelung city.



SINOTECH

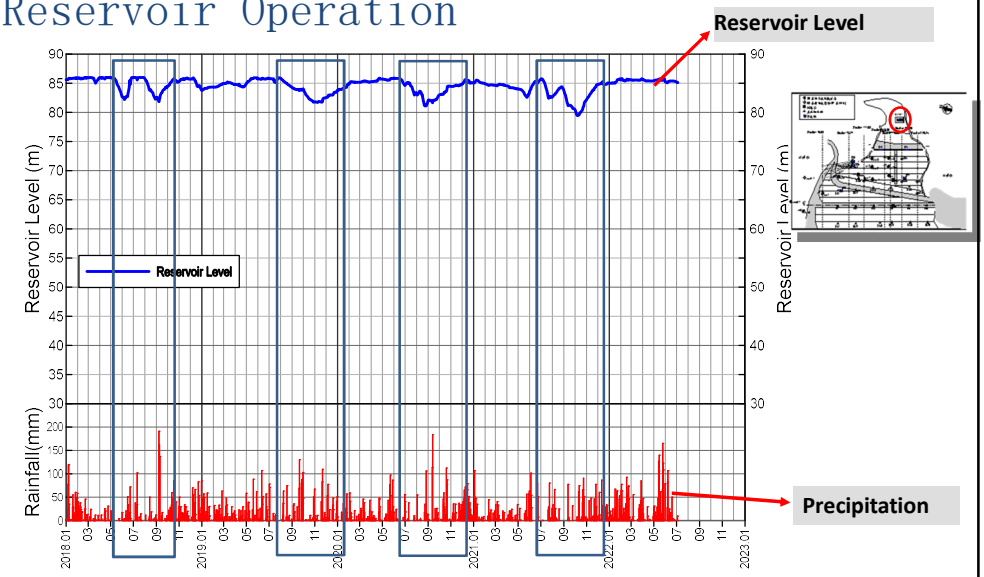
Introduction

- Normally, water is directly pumped from the Keelung River to the Xinshan Water Treatment Plant, and only excess water is pumped to the Xinshan Reservoir for storage.
  - ➡ The water level of the Xinshan Reservoir remains almost unchanged during the rainy season of this area from November to the following May.



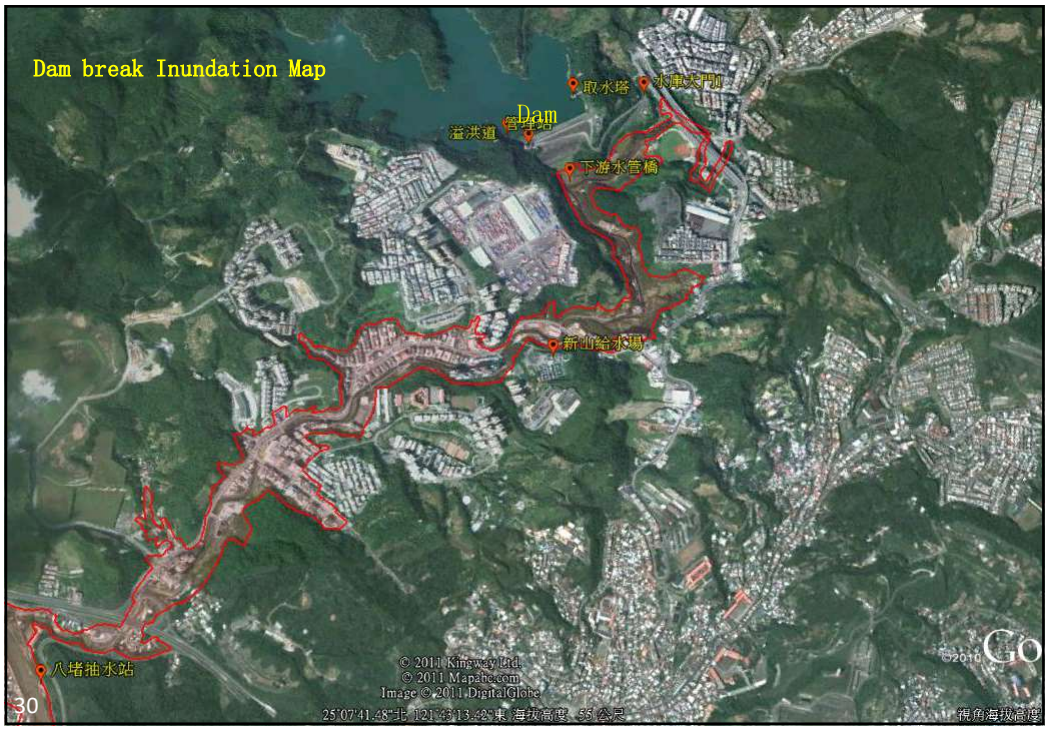
SINOTECH

Reservoir Operation



Reservoir operation is crucial for the water supply from June to December.

SINOTECH

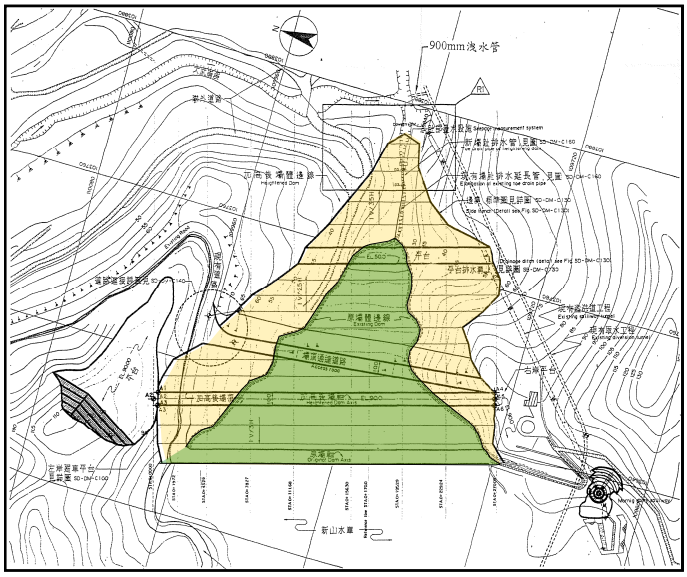


Introduction

- **Development of the reservoir was divided into two phases**
  - **At Phase I, a 51-meter-high embankment dam was constructed to elevation 75 meters in 1984.**
    - **The dam was designed as a zoned earth-fill dam with an inclined impervious clay core.**
    - **Due to the similarity of zoning materials, the dam's performance was considered more like that of a homogeneous dam than a zoned dam.**
  - **At Phase II, the dam was raised by 15 meters, and the reservoir capacity was increased from 4 million to 10 million cubic meters.**

SINOTECH

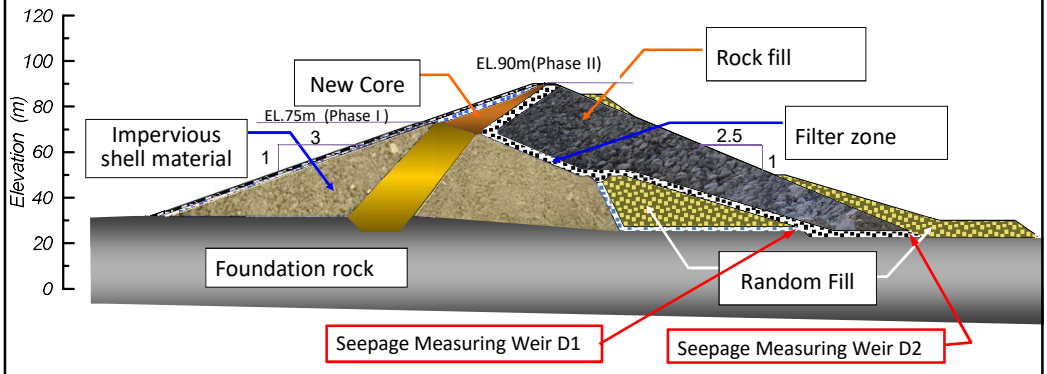
Schematic Layout of the Dam



SINOTECH

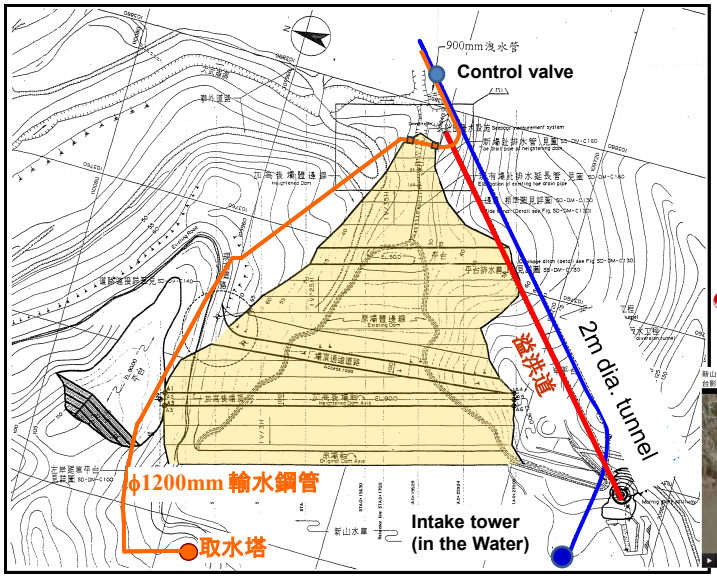
Schematic Profile of Dam

- **Construction for the 15-meter raise of the dam (Phase II) began in 1995 and was completed in February 1999.**
- **The total length of the dam embankment after the raise is 265 meters, with a maximum height of 66 meters.**



SINOTECH

Water Intake System (Phase I)



- **What we know**
  - ➡**The location of the intake tower.**
  - ➡**The location of the control valve downstream.**
  - ➡**A 0.9-meter diameter steel pipe is connected to a 2-meter diameter tunnel through a transition part in front of the control valve.**
  - ➡**Max water head in the pipe may be up to 50 m.**
- **What we don't know**
  - ➡**The details of the entire system.**

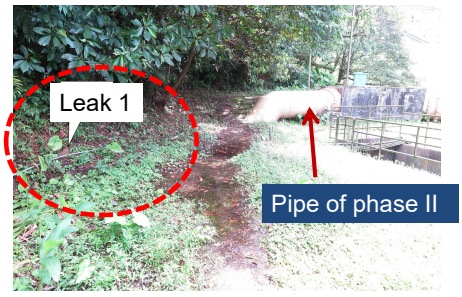
SINOTECH

Potential Failure Modes of the Dam

- Piping failure of the embankment core caused by concentrated seepage occurs
  - ➡ PFM1：along the cable trench in the new core
  - ➡ PFM2：along the contact of the new and old cores
  - ➡ PFM3：along the core/abutment contact
  - ➡ PFM4：along the settlement cracks in the thin inclined core
- PFM5：Internal erosion from embankment into the shear zone or open joints in the right abutment
- PFM6：Post-earthquake instability of downstream shell
- PFM7：Post-earthquake deformation and loss of freeboard
- PFM8：Damage to the phase I water intake tunnel or pipe

SINOTECH

Abnormal Leak Observed



- In June 2022, two leaks were observed at the weak points of Phase 1 intake tunnels/pipes.
- Based on the results of the PFMA, these leaks may indicate that pipe failure is occurring, which could eventually lead to uncontrolled but limited reservoir discharge. However, they do not pose a risk of dam failure.
- Subsequently, an investigation was conducted to identify the source of these leaks.

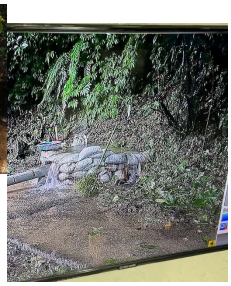
SINOTECH

Issues Raised

- Can we excavate to the damaged part to check?
  - ➡ No, it may burst since the pressure head in the pipe is up to 50 meters.
- Should we empty the reservoir right now?
  - ➡ No, since Taiwan is experiencing a severe drought, and people are worried about water shortage problems.
  - ➡ It is not a dam safety problem.
  - ➡ The situation is not conducive to making that decision.
- Ensuring the safety of downstream residents and minimizing the impact on water supply.

SINOTECH

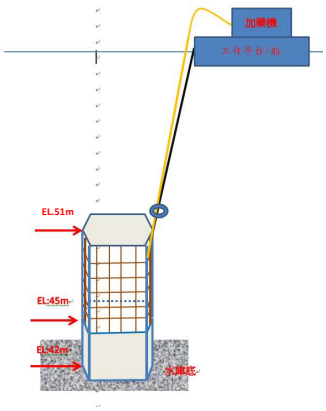
Countermeasures



- **Close Monitoring**
  - ➡ Observing seepage quantity
  - ➡ Installing cameras to monitor on-site changes
- **Identification of Seepage Source**
  - ➡ Conducting water quality analysis, including pH value, temperature, and conductivity, etc..
  - ➡ Performing tracer tests using food-grade dye.
- **Development of Emergency Response Strategies**
  - ➡ Assessing the time required to empty the reservoir (40 days).
  - ➡ Estimating the time needed to refill the reservoir to its full capacity (120 days).
  - ➡ Determining when to start draining out the reservoir (Sep. 1~Dec. 31)
  - ➡ Studying repair methods.

SINOTECH

Tracer Testing



SINOTECH

Observation of Leakage

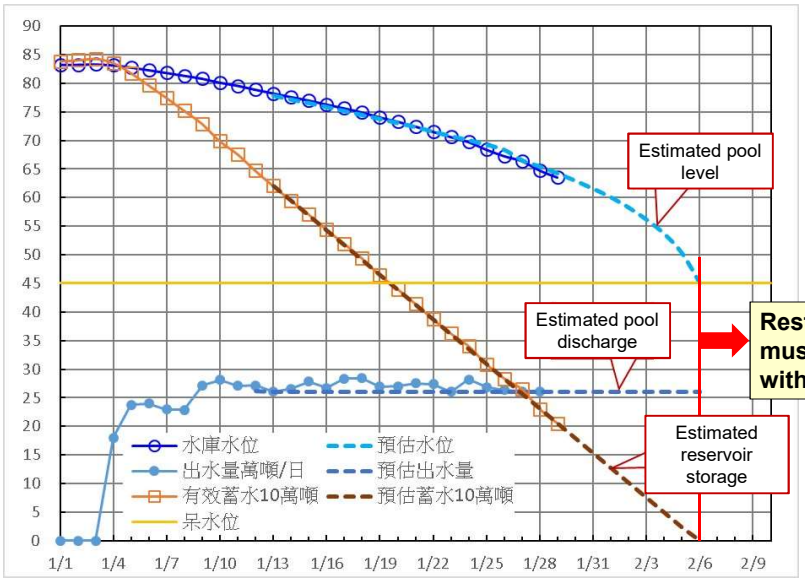
SINOTECH

41

Rapid drawdown

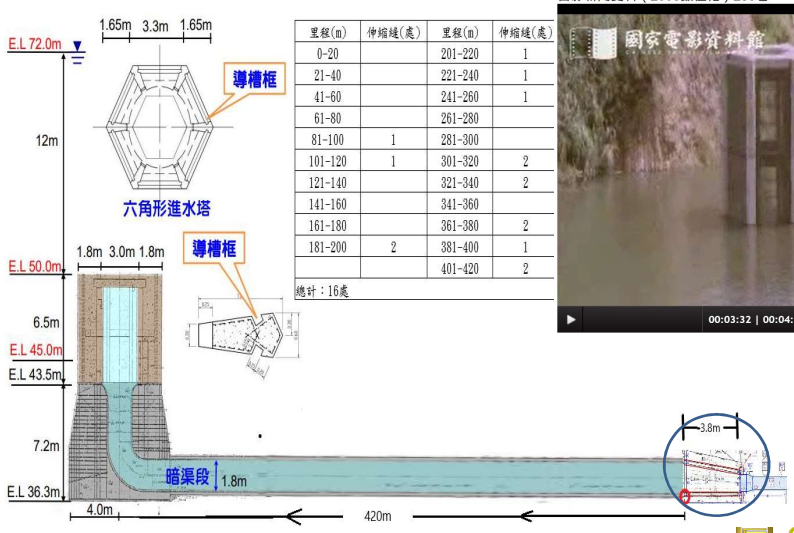
SINOTECH

42



SINOTECH

PFM8: Damage to Phase I Water Intake Pipe and Tunnel Connection During Normal Reservoir Operation



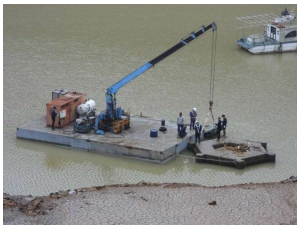
里程(m)	伸縮縫(處)	里程(m)	伸縮縫(處)
0-20		201-220	1
21-40		221-240	1
41-60		241-260	1
61-80		261-280	
81-100	1	281-300	
101-120	1	301-320	2
121-140		321-340	2
141-160		341-360	
161-180		361-380	2
181-200	2	381-400	1
		401-420	2

總計：16處

新山水庫大壩竣工
台影新聞史料（2008數位化）285卷

SINOTECH

Replacement of the trash racks (1/2)

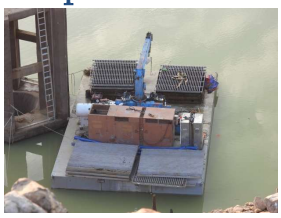





45

SINOTECH

Replacement of the trash racks (2/2)



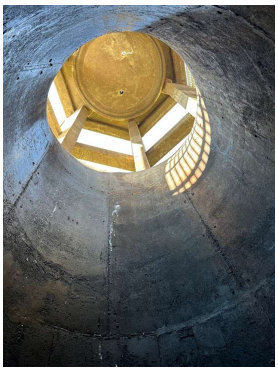


46

SINOTECH

Tunnel Inspection



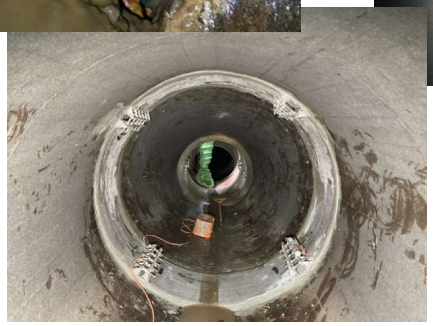




47

SINOTECH

Repair of the Broken Area in the Tunnel



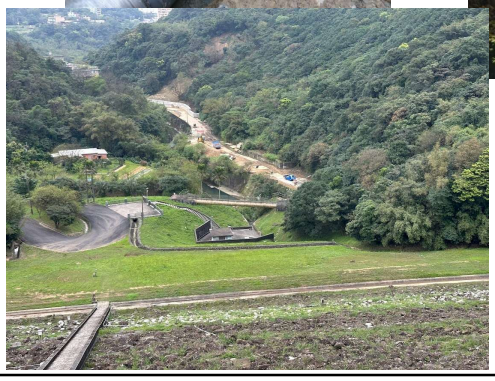


48

SINOTECH

Install the new Pipe & Control Valves






49

SINOTECH

Recharge of the Reservoir

- All the restoration works were completed within 3 weeks.(End of Feb)
- The reservoir filled to its full capacity in June 2023 and did not cause any impact on the water supply.

50

SINOTECH

Conclusions

- **Lessons learned from Xinshan dam incident**
  - **This is the first case in Taiwan where PFMA (Potential Failure Mode Analysis) is being used to prevent uncontrolled water release incident from reservoir.**
  - **The PFMA technique can be helpful in identifying weak points in the dam, even when the information is incomplete.**
  - **This approach allows us to maintain a balance between water supply and public safety, as potential failure modes can be identified and addressed early.**

SINOTECH

Thanks for Your Attention