*The Sixth Taiwan-US-Japan Workshop on Water System Seismic Practices*

# Recent Topics related to Seismic Safety of Dams

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Tatsuo OHMACHI
Professor, Tokyo Institute of Technology

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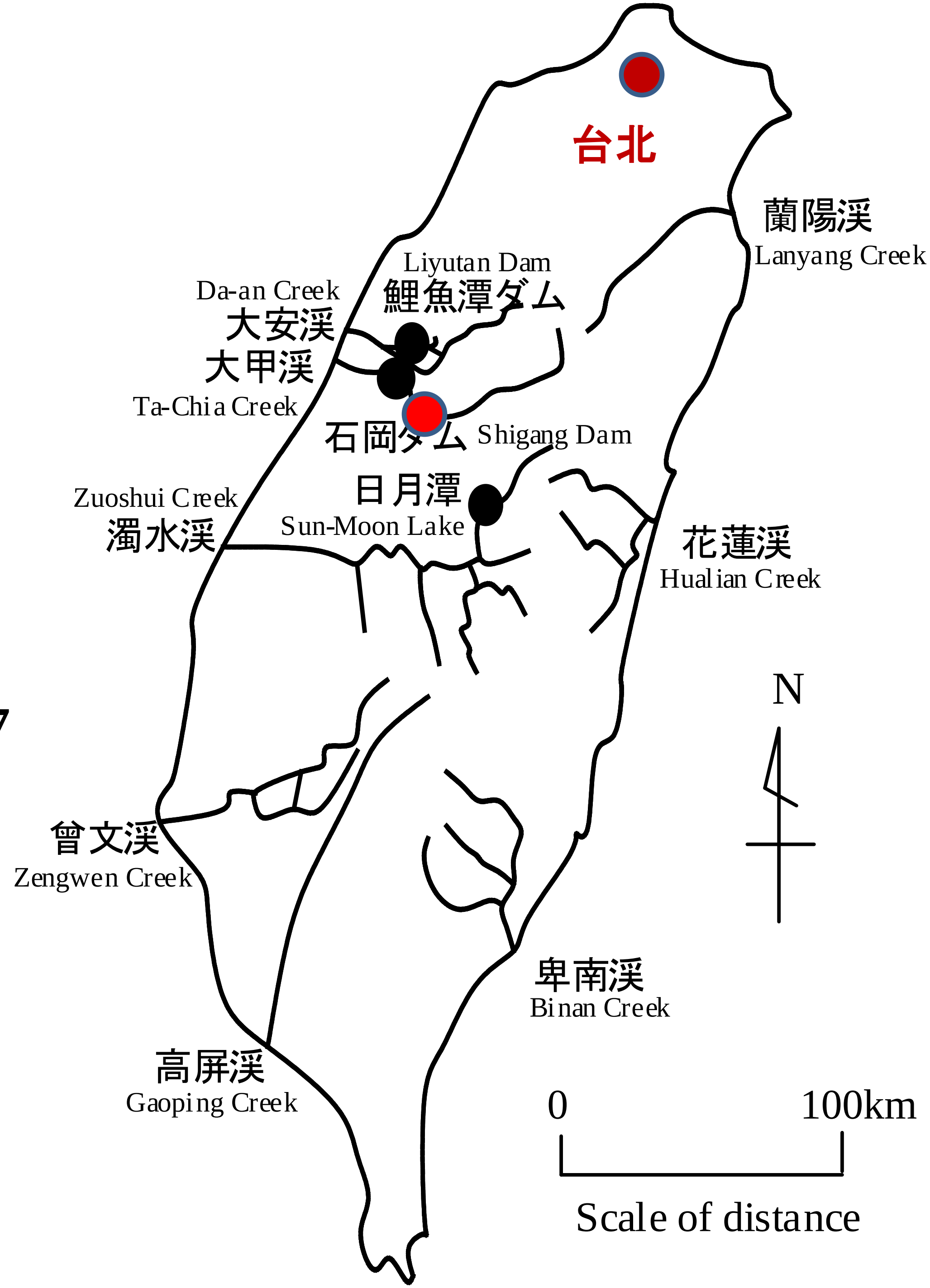
1. Recent earthquake damage to dams and lessons learnt
   1999 Chi-chi, Taiwan,   2004 Niigata-chuetsu, Japan
   2008 Iwate-Miyagi inland, Japan,  and 2008 Wenchuan, China
2. “Guidelines for seismic safety evaluation of dams(draft)”(2005)

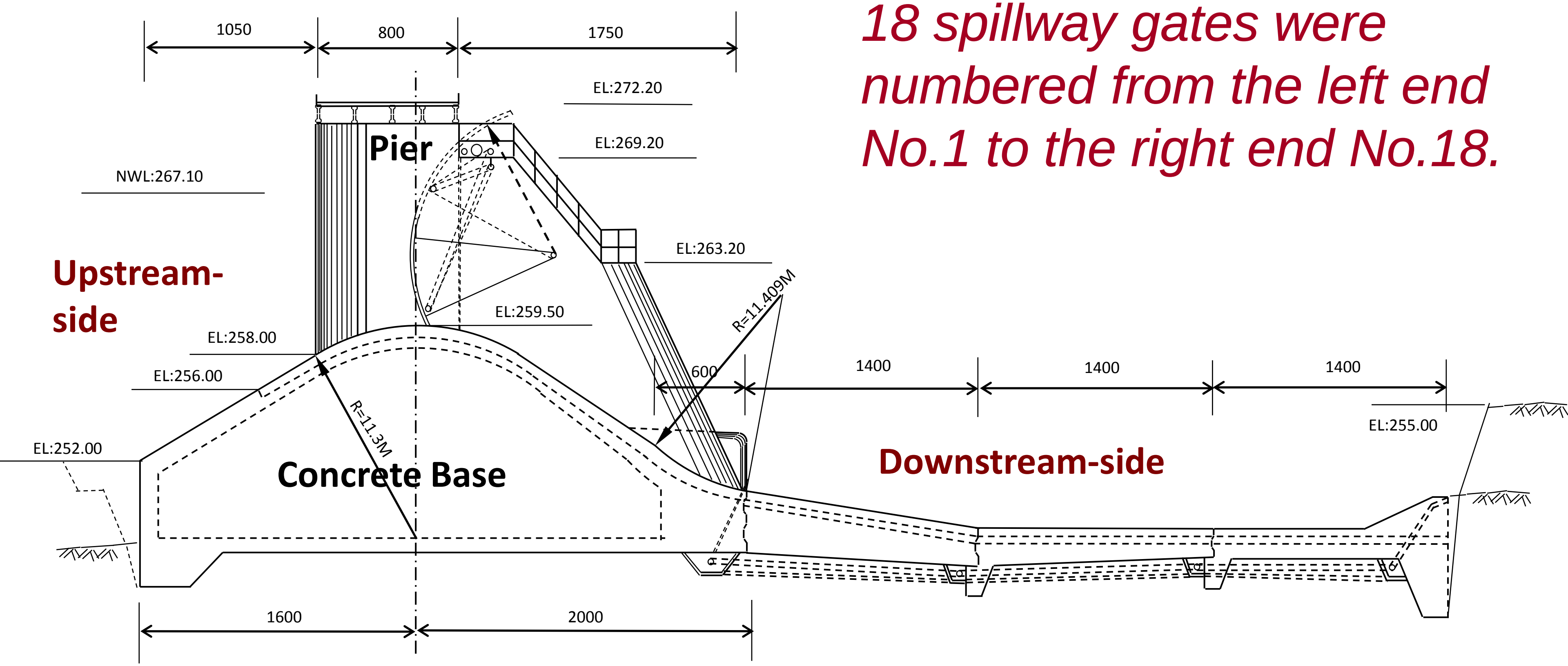
# The Chi-chi Earthquake (M7.7)

- The Earthquake struck Taiwan at 1:47 a.m. (local time ) on Sept. 21,1999, causing the collapse of Shih-Kang Dam constructed in 1977.



# Shih-kang Dam

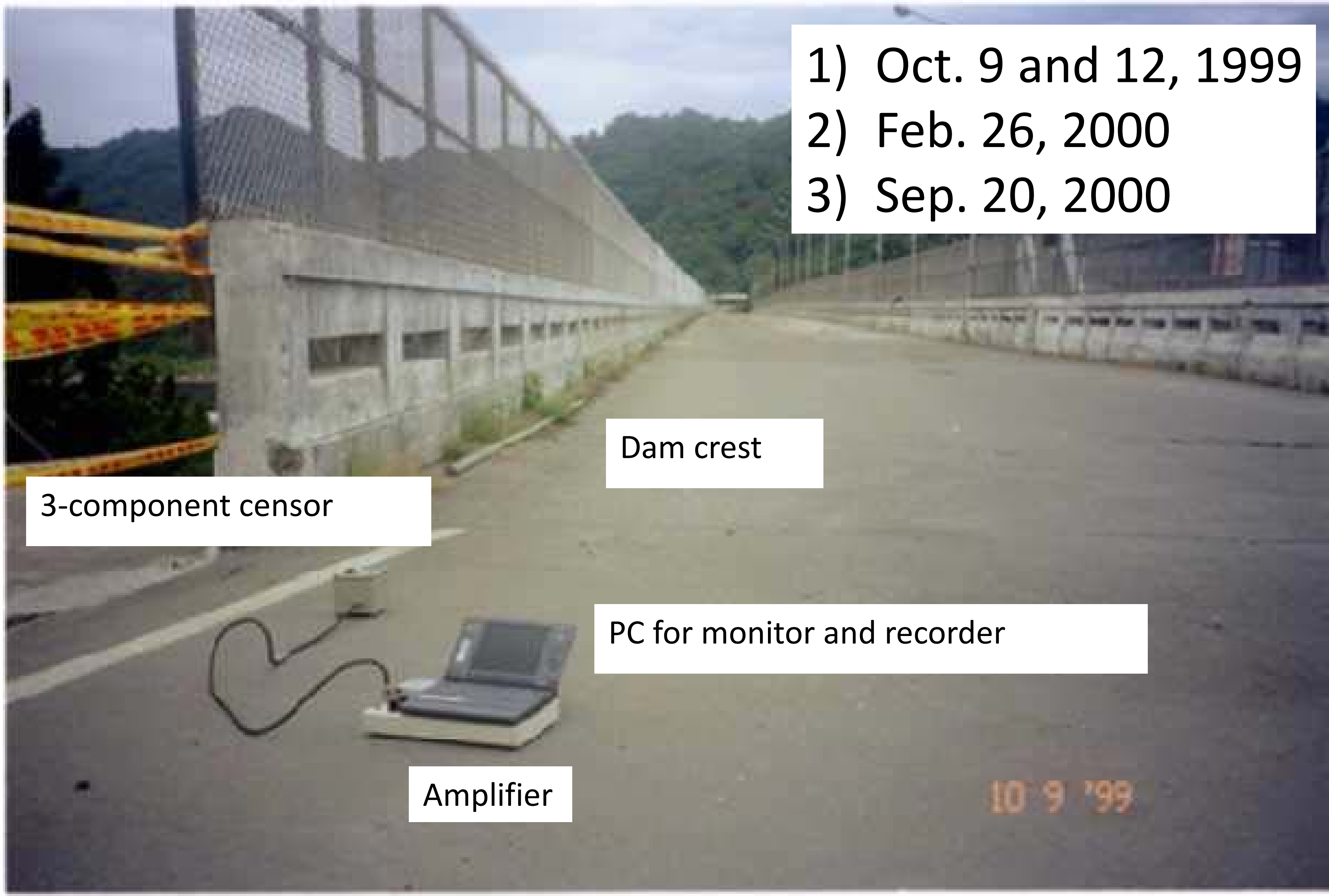
- The dam was a 357 m long concrete gravity dam, equipped with 18 spillway gates and 2 sediment flushing gates.
- Mainly due to seismic faulting crossing the dam foundation, the right half of the dam was crushed to pieces, and offset about 8.5m
- No casualty was reported, as a result of the dam break.




18 spillway gates were numbered from the left end No.1 to the right end No.18.

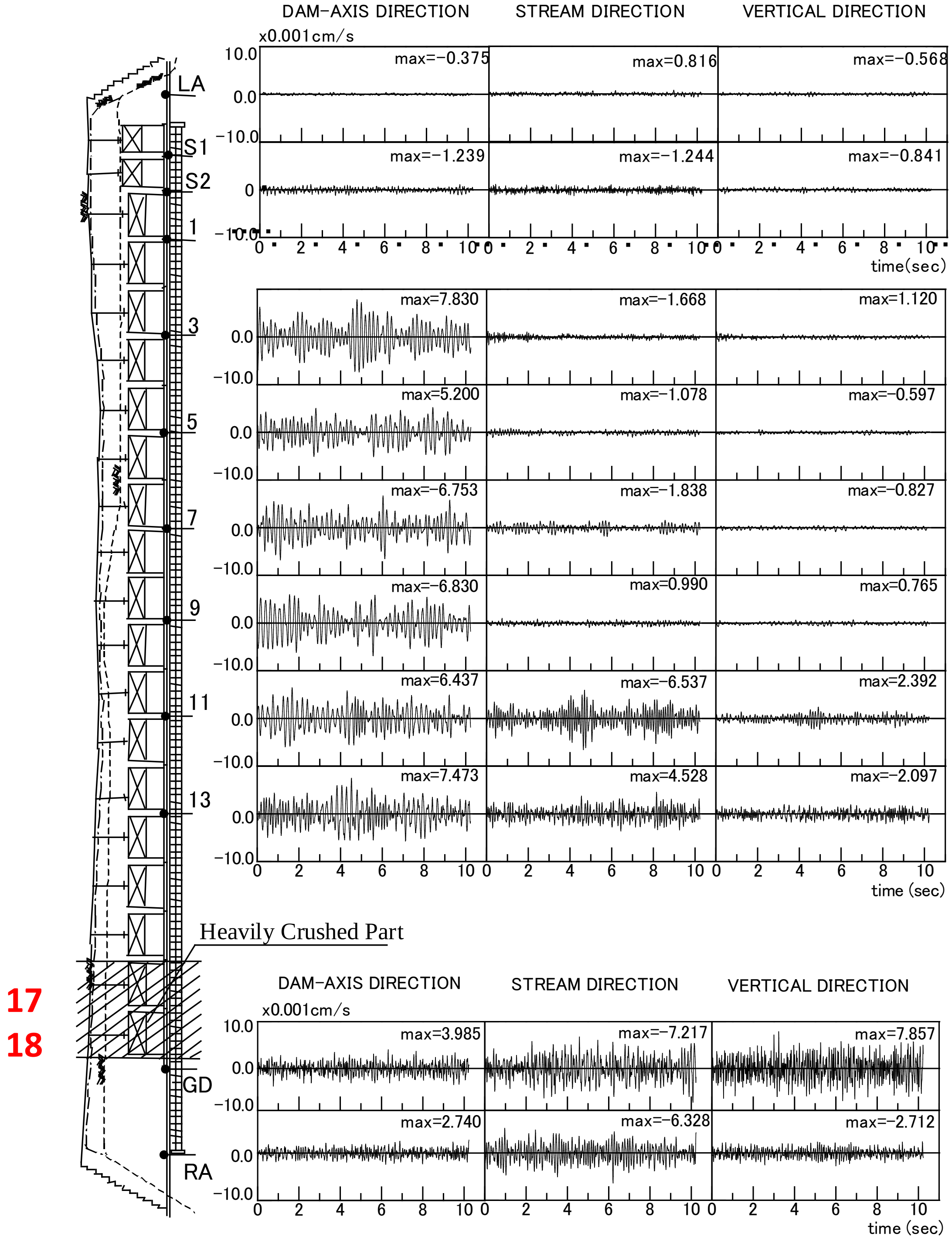
*Vertical and horizontal cracks were found ,here and there, on the surface of concrete base and piers.*

# Transverse Cross Section of Shih-kang Dam (Spillway section)




**Shih-kang Dam was restored and has been in use still now.**

**Micro-tremor measurement was conducted three times along the dam crest.**

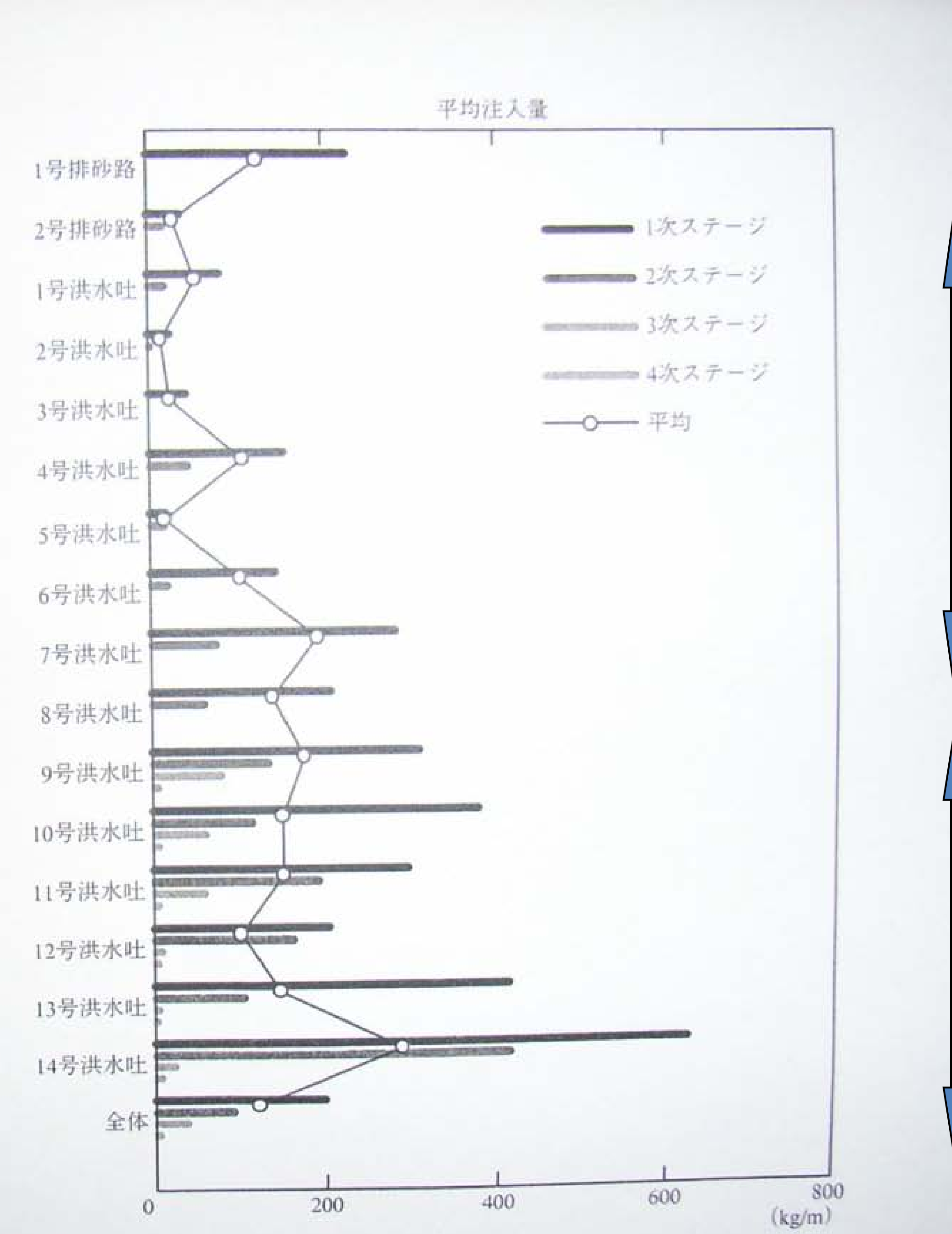


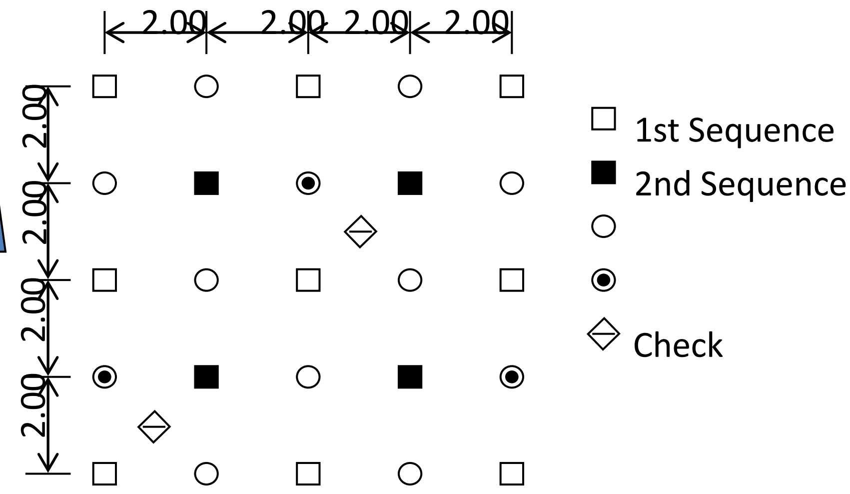

LA:Left Abutment
S1+S2: Sluice
(sediment flushing gates)

No.1 ～ No.18
Spillway gates

**Micro-tremors Observed after the 1999 Earthquake (1st Measurement)**
(max=1 is **10μm**)

RA: Right Abutment

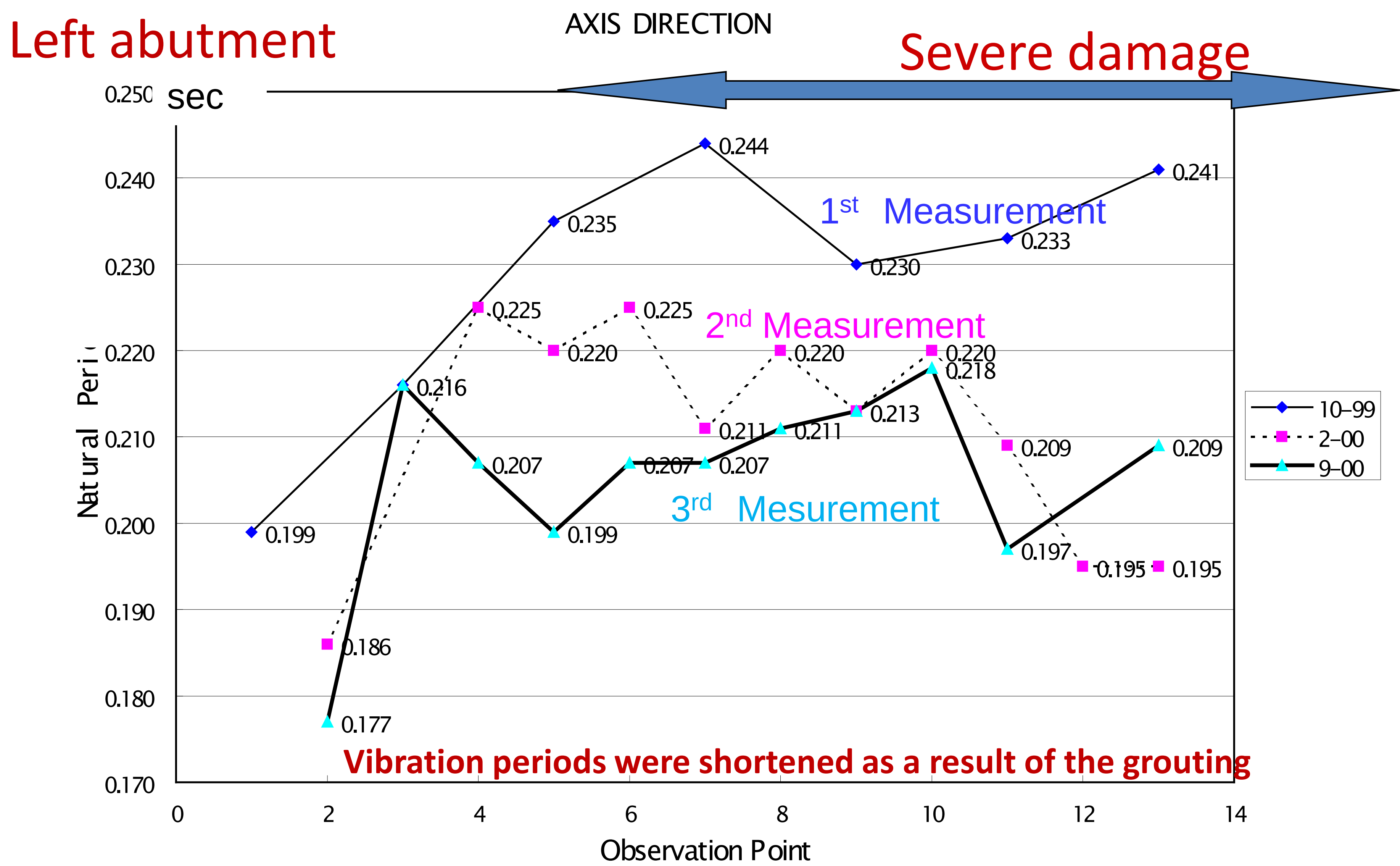



$1^{st} + 2^{nd}$ Sequences

$1^{st} + 2^{nd} + 3^{rd}$ and $4^{th}$ Sequences

# Grout Takes in the Restoration of Shih-kang Dam




# Vibration period distribution along the dam axis

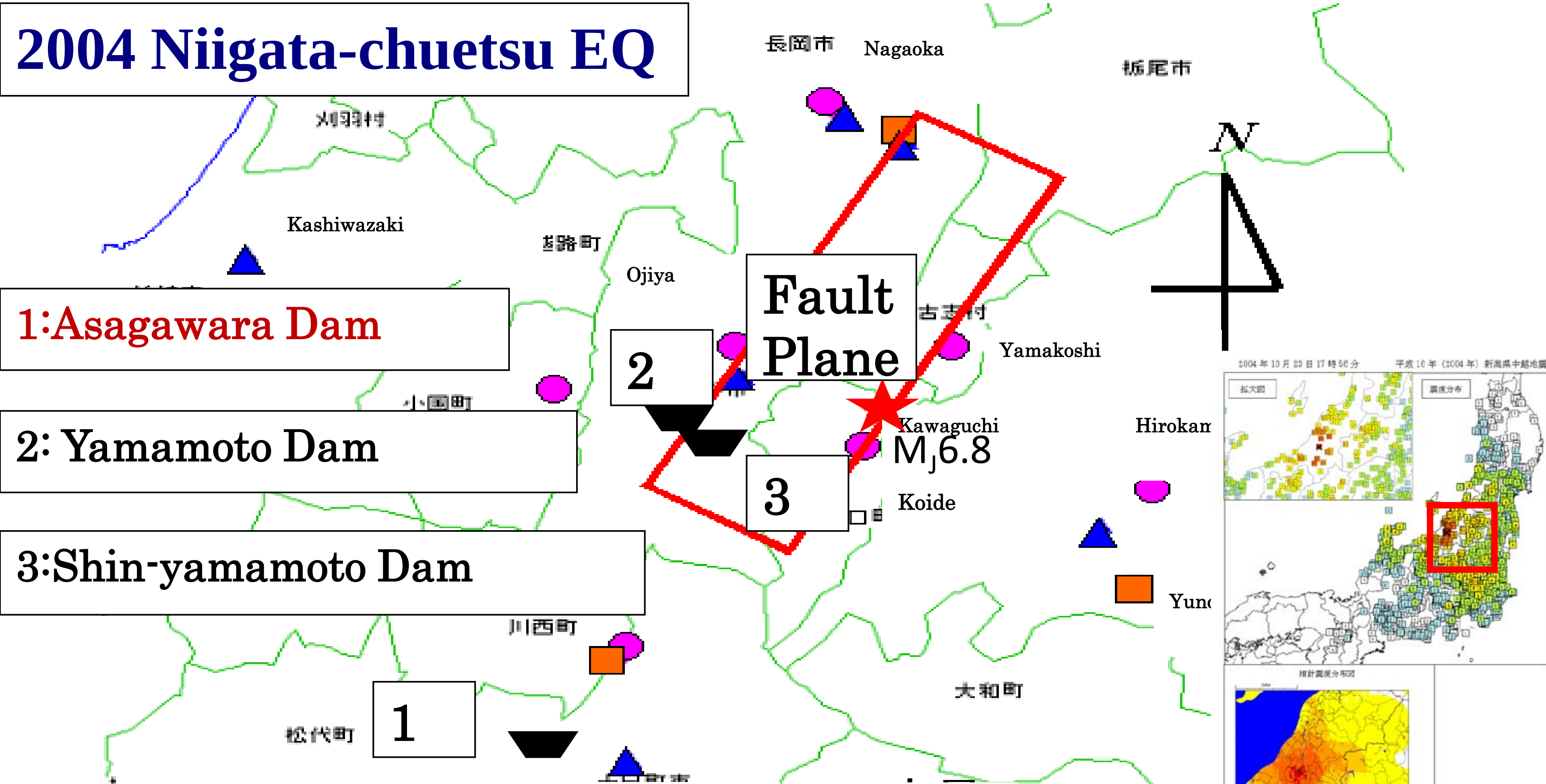
# Lessons from the 1999 Chi-chi Earthquake

1. **Shih-kang Dam was totally collapsed by surface rupturing of the seismic fault crossing the dam body.**

2. **Despite the devastating damage to the dam body, followed by uncontrolled outflow discharge, no casualty was reported, which was very lucky.**

3. **Micro-tremor measurement applied to the dam has proved to be useful and effective not only for detecting the damage, but also finding effects of the restoration.**

# 2004 Niigata-chuetsu EQ




**Asagawara Dam (Built in 1945)**

Crest Length：291.80m

Dam Height：37m

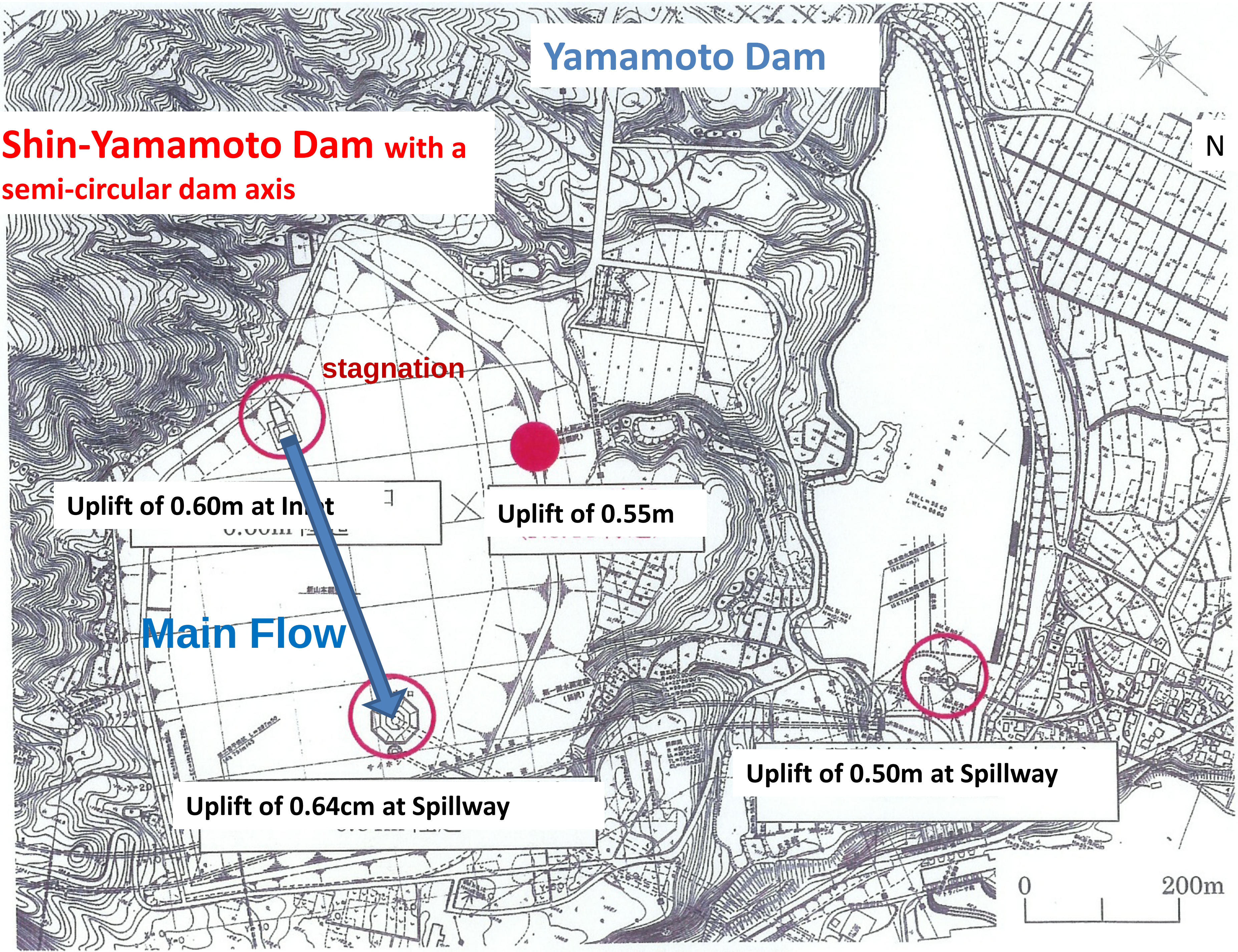
Volume：520,900$m^3$

Slopes：Upstream　1：2.8～3.0

Downstream　1：2.0～2.5

Cracks along the crest of Asagawara dam which is a 37m-high zoned fill-dam constructed in 1945.

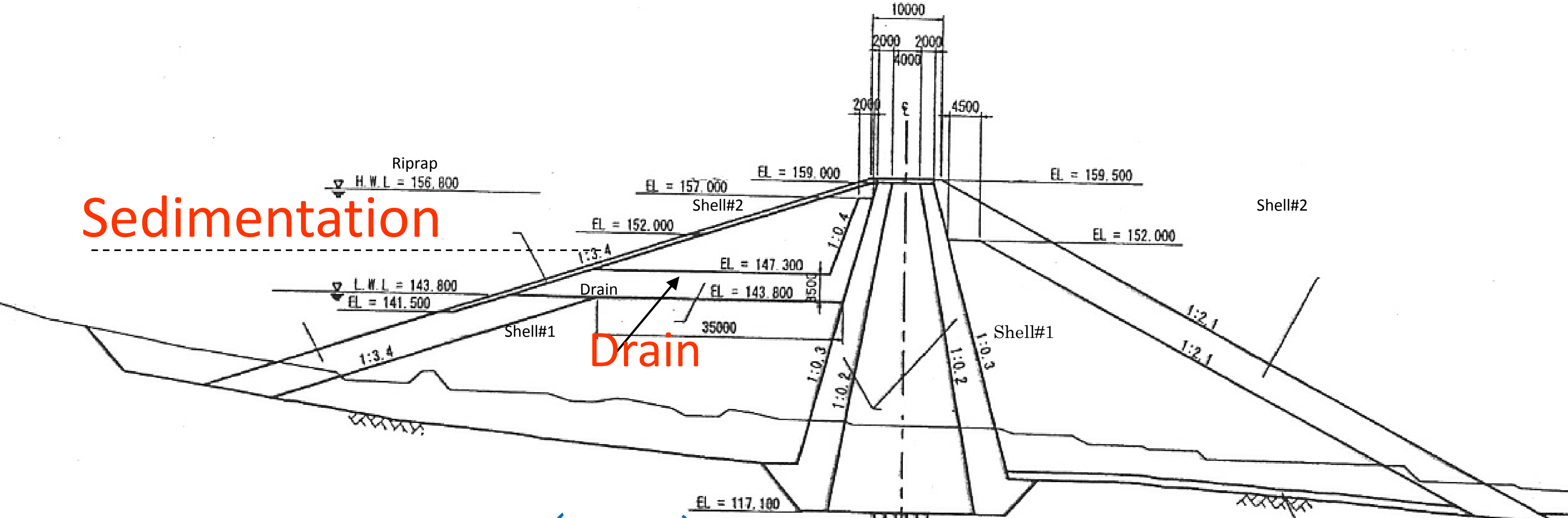

Downstream
Upstream
Trench Investigation at Asagawara Dam



Yamamoto Dam
Shin-Yamamoto Dam with a semi-circular dam axis
N
stagnation
Uplift of 0.60m at Inlet
Uplift of 0.55m
Main Flow
Uplift of 0.64cm at Spillway
Uplift of 0.50m at Spillway
0
200m


**Upstream View of Shin-Yamamoto Dam (Left-half Side)**

Boiled Sand indicating Liquefaction




## Shin-Yamamoto Dam(1990)

Crest Length : 1,360m

Dam Height : 42.4m

Volume : 2,300,000㎥

Slopes :

Upstream Side: 1 : 3.4

Downstream Side:1 : 2.1

**This dam was restored by removing loosened/liquefied portions followed by re-banking with good materials and careful compaction.**

# Standard Cross Section of Shin-Yamamoto Dam

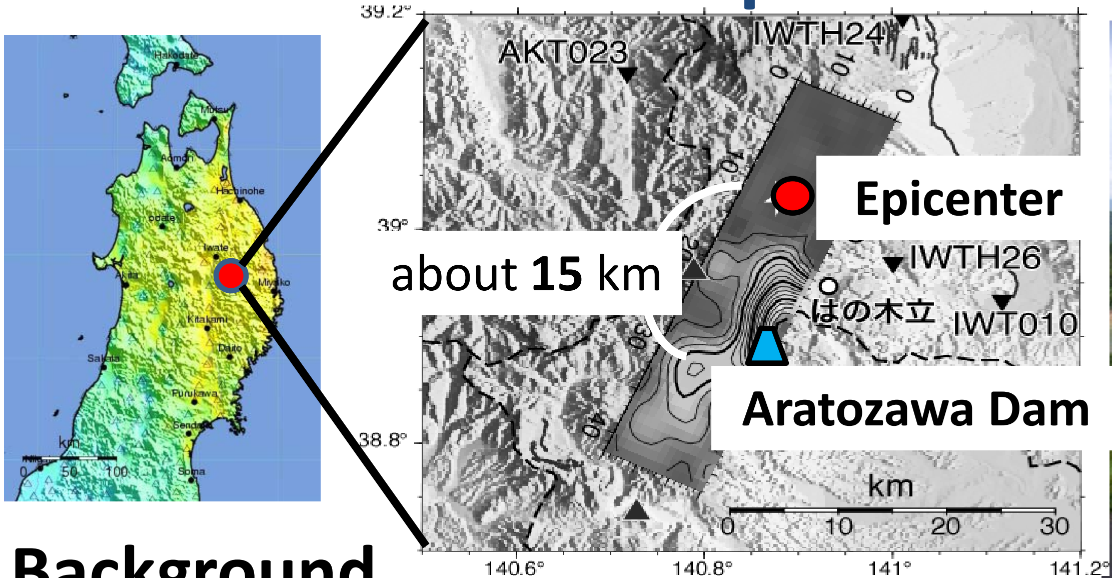
# Lessons from the 2004 Niigata-chuetsu Earthquake, Japan

1. Strong shaking due to near field earthquake motions causes damage to fill dams such as cracks, settlement, sliding and even liquefaction or sand boiling.

2. Such damage is not always fatal to dam safety, but requires prompt emergency management  such as dewatering the reservoir, warning to downstream areas, and investigation of causes and effects of the damage.

3. Sedimentation in a reservoir is sometimes harmful to a dam equipped with drain layers, because thick sedimentation leads to loss of the drain function.

# Outline of the earthquake and Aratozawa dam





## Background

**Iwate-Miyagi inland earthquake**

The earthquake(M7.2) occurred in 2008

The dead and missing were 23 people

**Aratozawa dam**

Constructed: 1994

Type: Center Clay-core Rock-fill Dam

Height: 74.4m

**Damage**

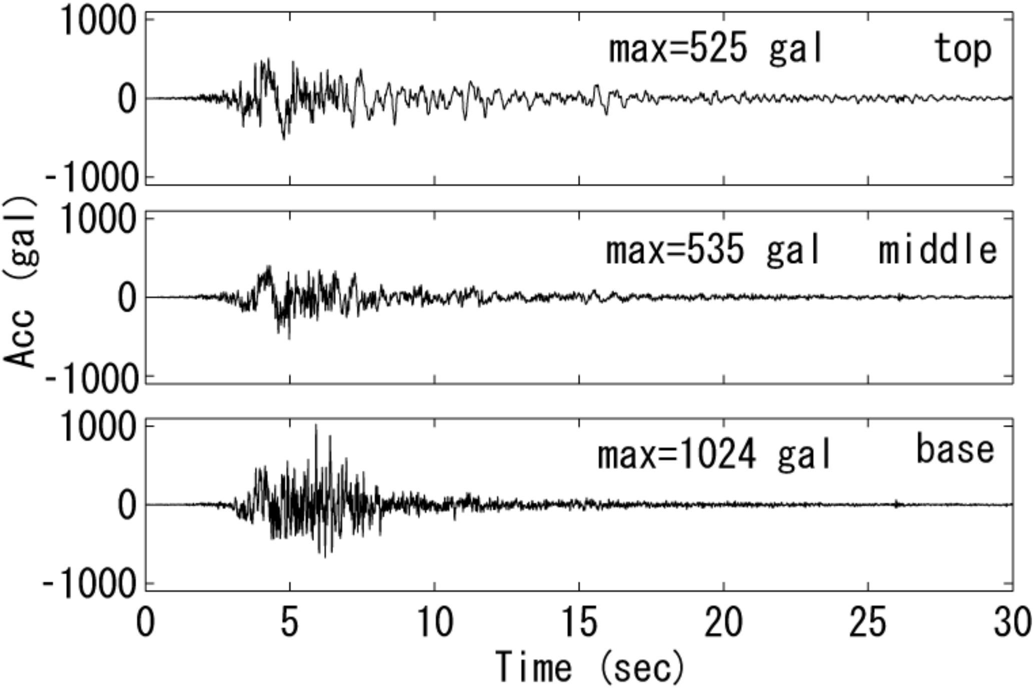
40cm settlement of the dam crest

Fortunately the dam escaped serious damage

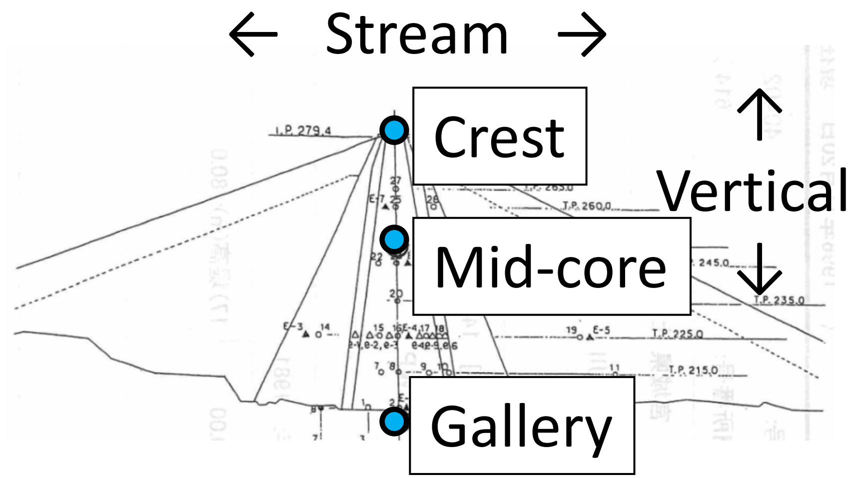
40cm Settlement

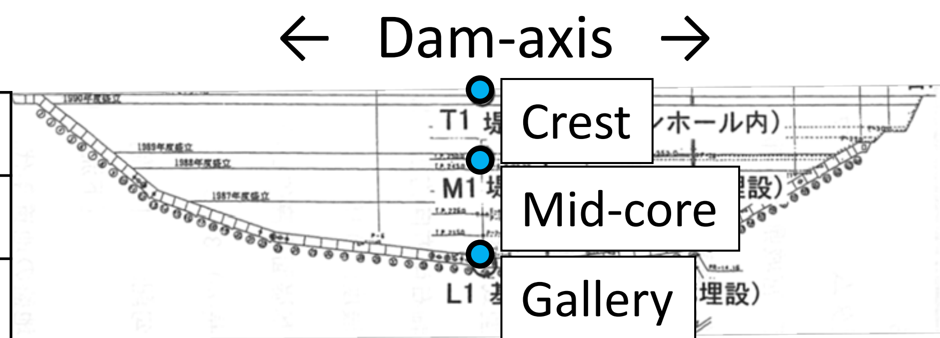
# Outline of strong motion records

*Acceleration time history (Stream)*




3 component Seismometers
(Sampling frequency 100Hz)



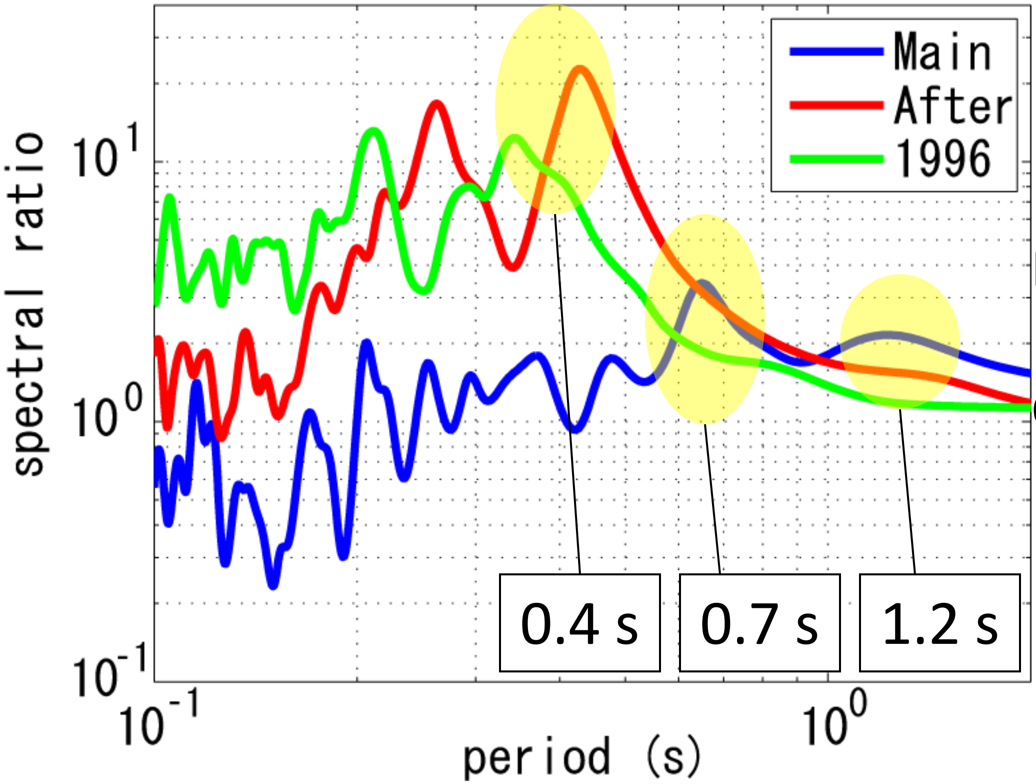




*Peak Accelerations(gal)*

| | **Stream** | **Dam-axis** | **Vertical** |
|---|---|---|---|
| Crest | 525 | 535 | 622 |
| Mid-core | 535 | 478 | 470 |
| Gallery | 1024 | 899 | 691 |

# Transfer Functions of the dam

*Transfer function between the gallery and crest (crest/gallery)*




Iwate-Miyagi

- Main shock(2008 6/14 7.2)

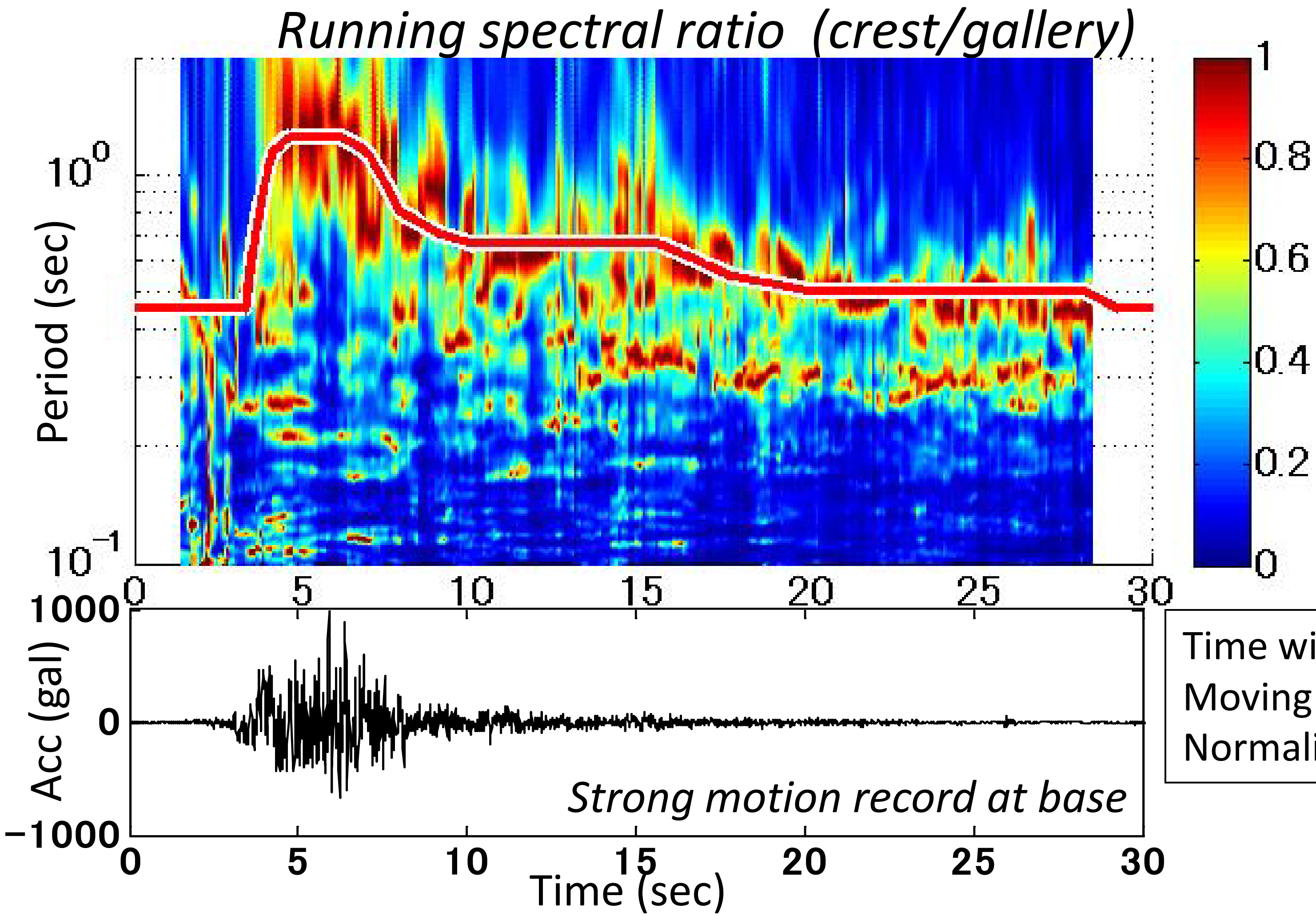
Others

- Aftershock(2008 6/14 M4.7)
- Earthquake (1996 M5.9)

The peak period of the dam was 0.7sec/1.2 sec during the main shock and about 0.4sec in other smaller earthquakes.

As the change in the period during the main shock was remarkable, detailed analysis was conducted using *running spectra.*

# Running spectra during the main shock



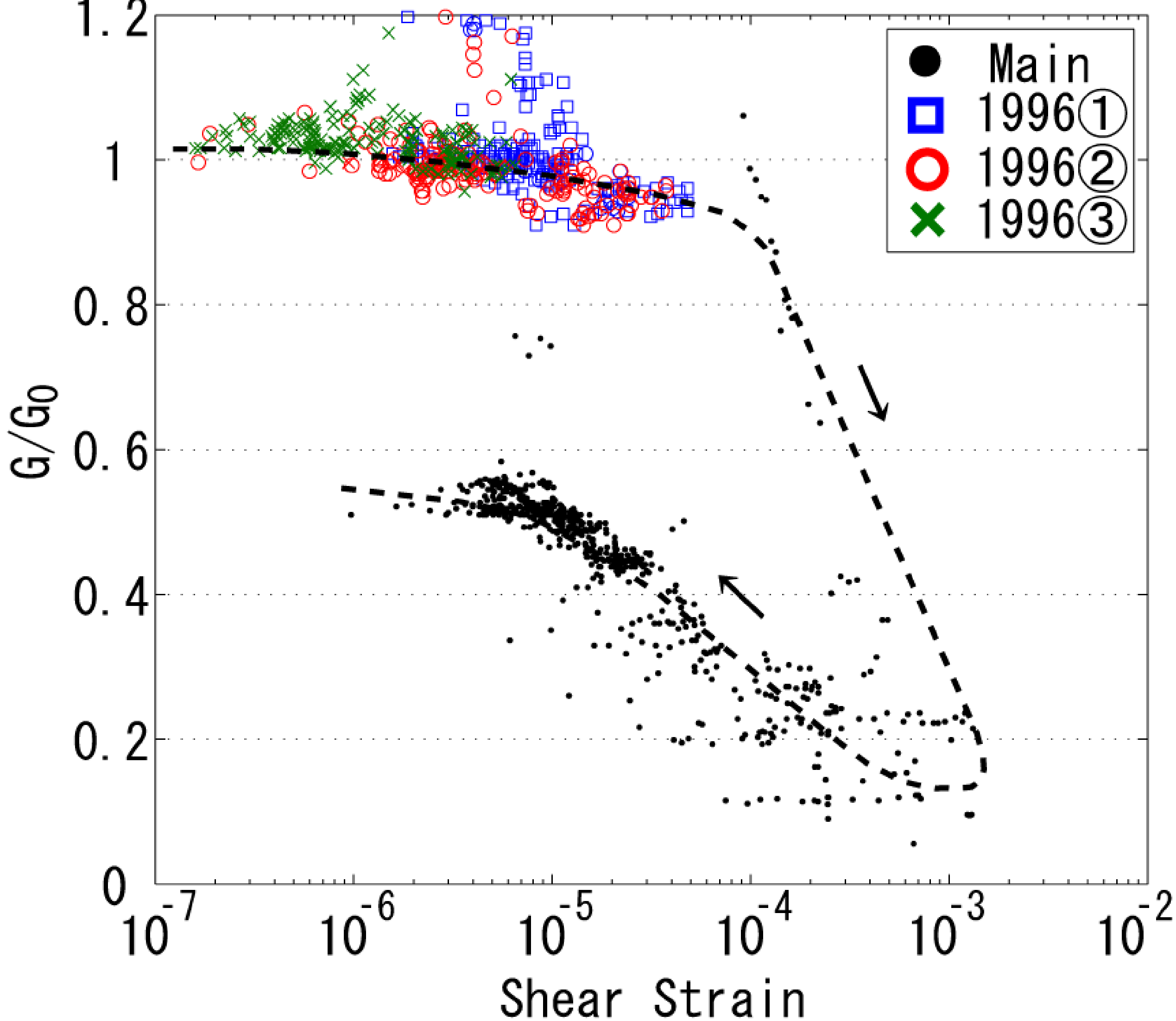

Time window : 2.56sec
Moving interval : 0.1sec
Normalized at each time

The peak period was first 0.4 sec and suddenly elongated to 1.2sec by strong shaking and later shortened again to 0.5sec.

This is evidently the nonlinear response of a rockfill dam.

# Shear Modulus vs. Shear Strain

*Stream direction (from gallery to crest)*



# Lessons from the 2008 Iwate-Miyagi Inland Earthquake

1. During the main shock of the 2008 Iwate-Miyagi Inland earthquake, Aratozawa dam was severely shaken, nevertheless the dam escaped serious damage.

2. During the main shock, the acceleration exceeded 10 $m/s^2$ at the gallery, inducing large shear strains in excess of $10^{-3}$.

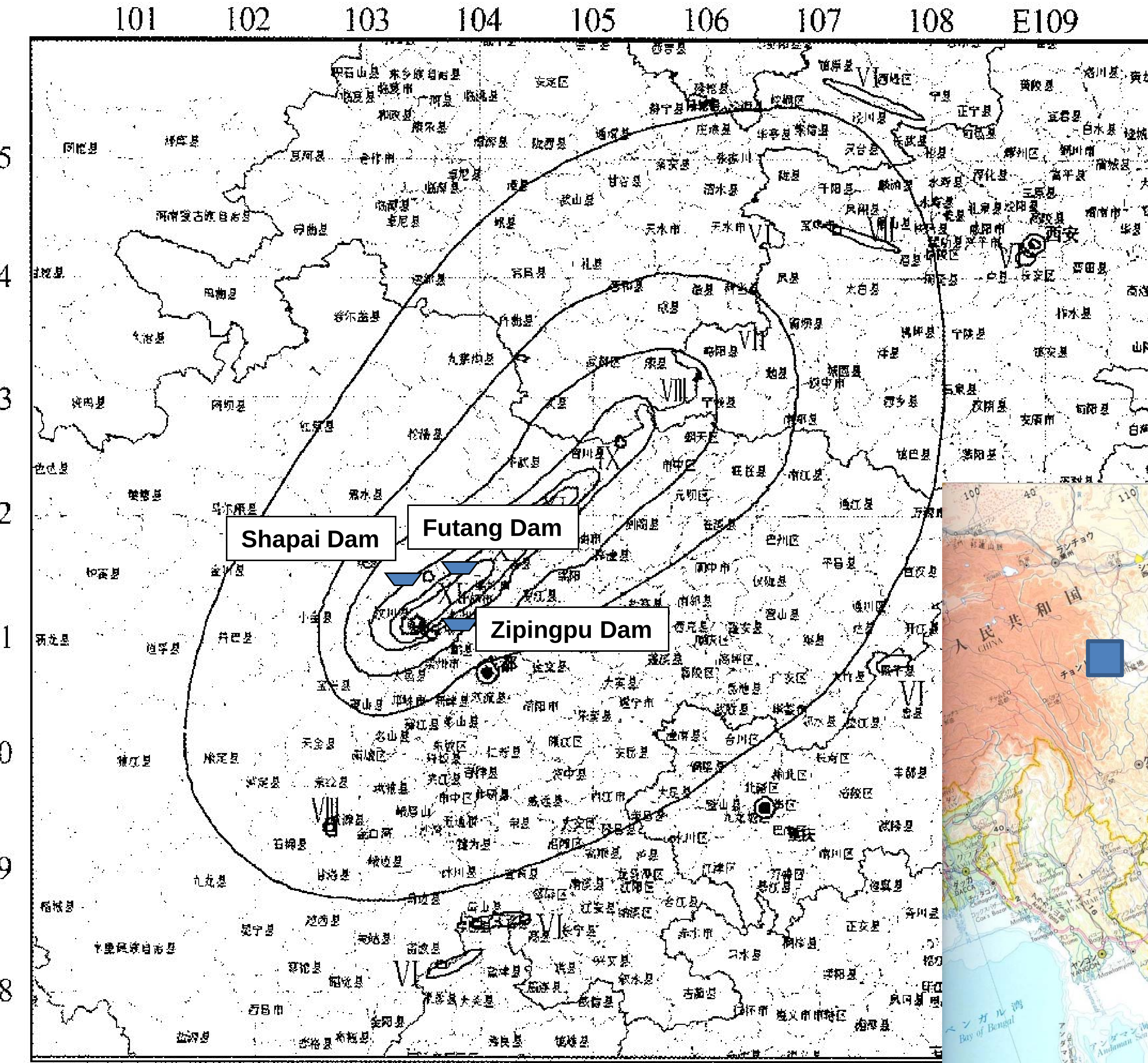
3. Due to the large strains, the shear modulus G showed a remarkable decrease from the initial shear modulus $G_0$. As a result of the decrease in G, wave velocity was reduced and the vibration period of the dam was elongated.

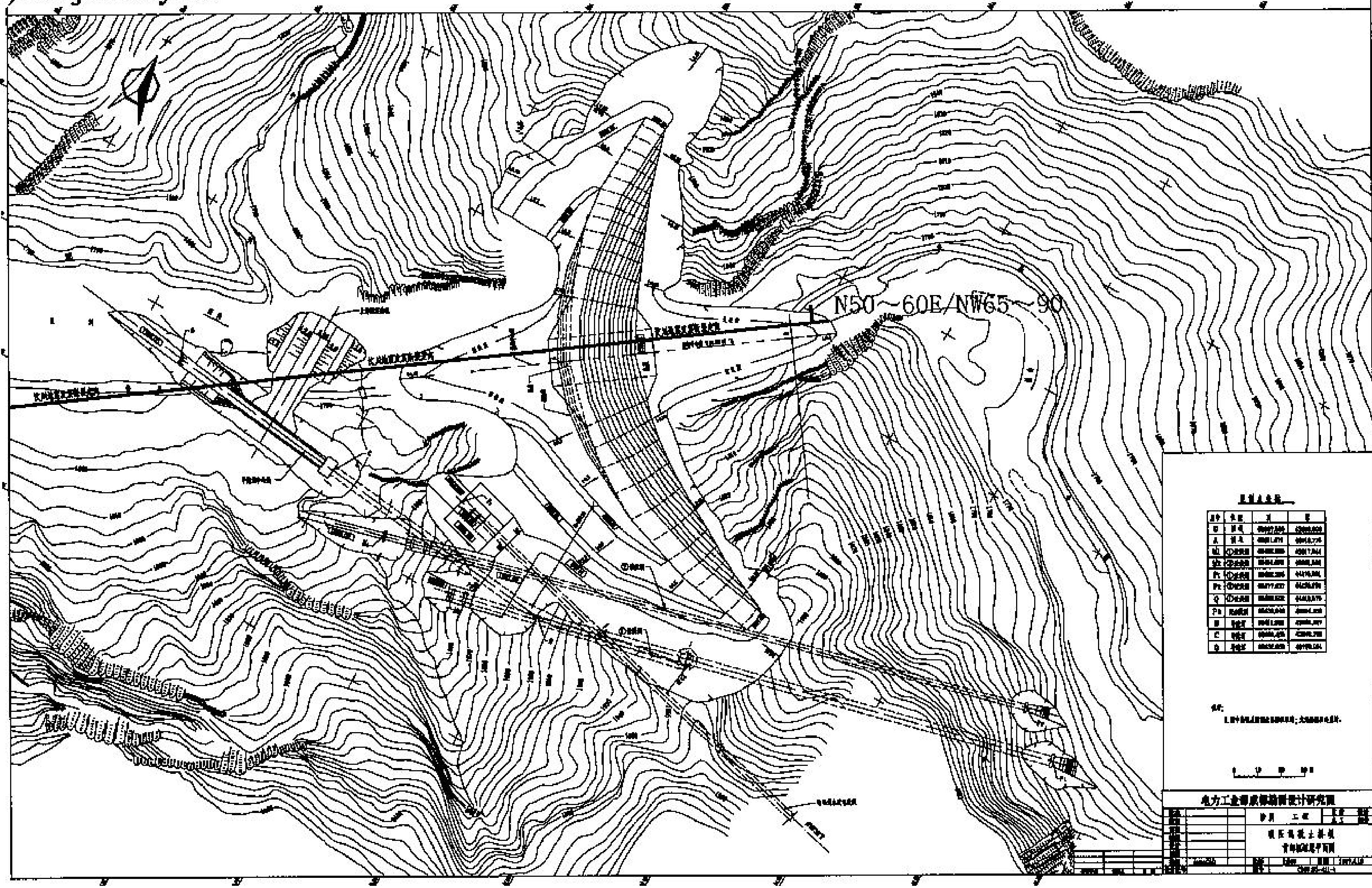
4. Towards the end of the main shock, the modulus G in the core showed a gradual increase, but remained below $G_0$.

# 中国四川省汶川地震 (Wenchuan EQ, M8.0)

May 12, 2008

竜門山断層（Longmenshan Fault, L ≒ 300km)




# Plan of Shapai(沙牌) Dam

Access road was closed until September, 2008, due to extensive landslides.


Downstream face


Upstream face

Tunnel spillway

**Shapai(沙牌) Dam:**

RCC Arch dam
H=130m、L=250m
Constructed in 2003
Epicentral Dist. 30km

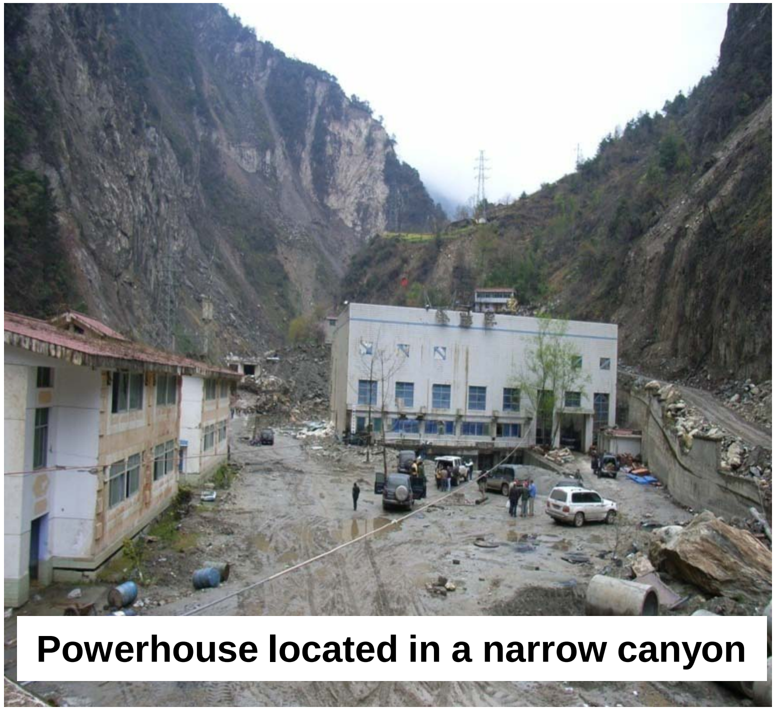
**Earthquake Damage:**

No damage to dam body, but some damage to spillway, elevator tower, plumb line, etc. Moreover,


Elevator tower

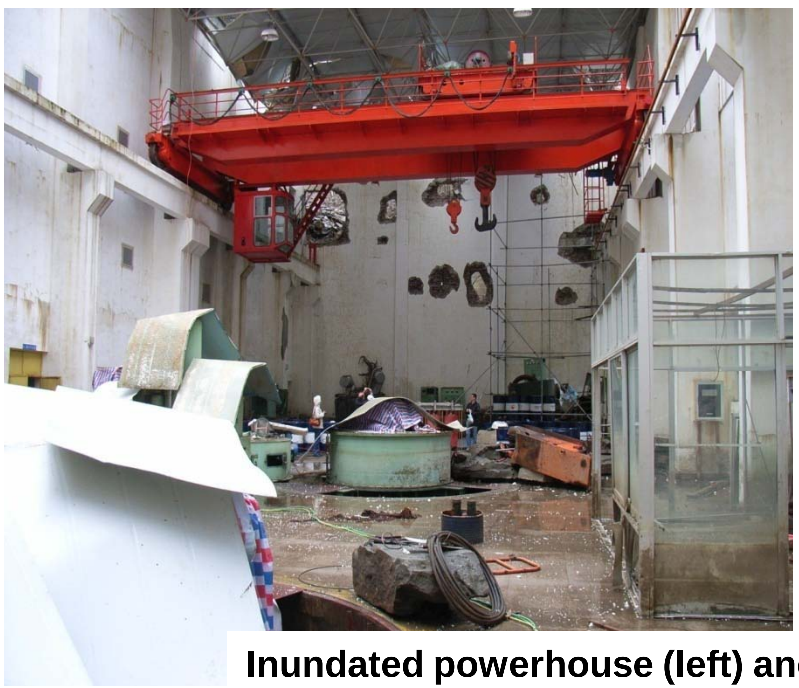

Plumb line

# Shapai powerhouse was severely damaged mainly due to landslides.



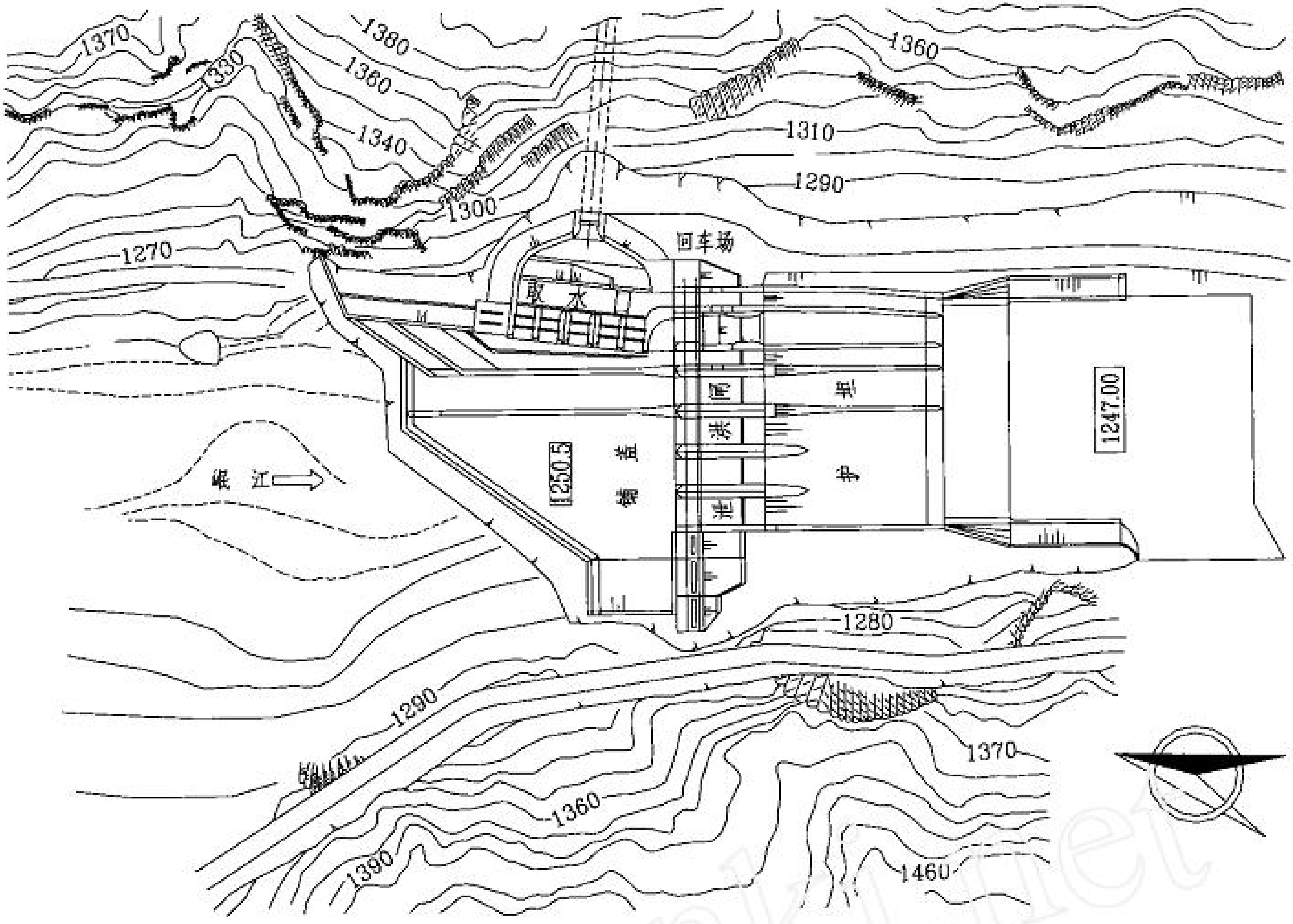
Powerhouse located in a narrow canyon

Penstock was broken by rock falls, inundating the canyon with water.



Inundated powerhouse (left) and switchyard (right)

**Power Capacity: 36MW**




# Plan of Futang Dam (H=31m, L=189.5m)

Futang Dam and Landslide in its Neighborhood

# Lessons from the 2008 Wenchuan Earthquake

1. A fault rupture over an extended length should be considered in the seismic hazard modeling of a dam; which is quite different from a point source modeling traditionally considered.

2. Reliable post-earthquake functionality of flow control equipment, e.g., gates, valves, controls, etc., is essential for dam safety and is necessary for the safe regulation of downstream flows.

3. Landslides and rock fall can have a high impact on powerhouses, power conduits, and appurtenant structures. Under some circumstances, it is advisable to have a powerhouse located underground rather than on the ground surface or to provide barriers for protection against potential rock fall.

4. Dam and reservoir monitoring instrumentation should have sufficient seismic resistance to survive extreme events and to record and transmit data during and after a big earthquake.

# JSCE Proposal on Earthquake Resistance of C. E. Structures

- Following the 1995 Kobe earthquake, the Japan Society of Civil Engineers (JSCE) issued three times the Proposal.
- The first in May,1995, the second in January, 1996, and the third in June 2002 .
- The Proposal covers a wide range from review and upgrading of seismic codes, seismic diagnosis and reinforcement to seismic safety planning.
- One of the main targets of the Proposal was to revise seismic codes, especially those of earthquake motions.

# Earthquake motions to be considered in seismic design, proposed by JSCE

1) Two types of earthquake motions should be considered in seismic design of civil engineering structures; Level 1 and 2 motions.
2) Level 1 (L1) motion covers motions of moderately high intensity, while Level 2 (L2) motion addresses strong motion of extremely high intensity of the nature experienced in Kobe city during the 1995 earthquake.
3) For the L2 motion, structures are allowed to undergo some damage as long as collapse and loss of life are prevented.

# Safety Requirements of Dams Subjected to Level 2 Motions

**Guidelines for Seismic Safety Evaluation (Draft), issued by MLIT in 2005**

- Irrespective of dam type, a dam subjected to the L2 motion is required *;*

*(1) to maintain its capability of water storage during and after the earthquake, and*

*(2) to remain within repairable damage even if it suffers earthquake-induced damage.*

- The statement (1) is paraphrased into

*(3) not to release uncontrolled outflow discharge from reservoir.*

**Thank you for your attention**