International Symposium
Qualification of dynamic analyses of dams and their equipments
and of probabilistic assessment seismic hazard in Europe
31th August – 2nd September 2016 – Saint-Malo

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Session 2: Performance of CFRD & AFRD

Performance and analysis of CFRD and AFRD during earthquake

Design earthquake & computation

Terminology of design earthquake motions

Performance criteria	Japan	Overseas
Mostly elastic limit	**Level 1**	Operating basis earthquake
No release of uncontrolled water	**Level 2**	Seismic design earthquake(SDE) MCE or SEE

Analysis and design methods in regulation and practice

Methods	Japan	Overseas
Seismic coefficient method (pseudo static)	Used for Level 1; Most dams designed by SC method have shown satisfactory performance so far, *except poorly compacted earthfill dams, appurtenant structures and dams in future	Obsolete, Not state-of-the arts
Modified seismic coefficient method	(Sometimes Used) Natural period and amplification are considered	(used in China)
Dynamic analysis, Time history or FEM or FDM	Used to evaluate the safety for Level 2 But, is it really reliable? Material properties are clear?	State-of-the arts

SUMMARY

1. Ishibuchi CFRD

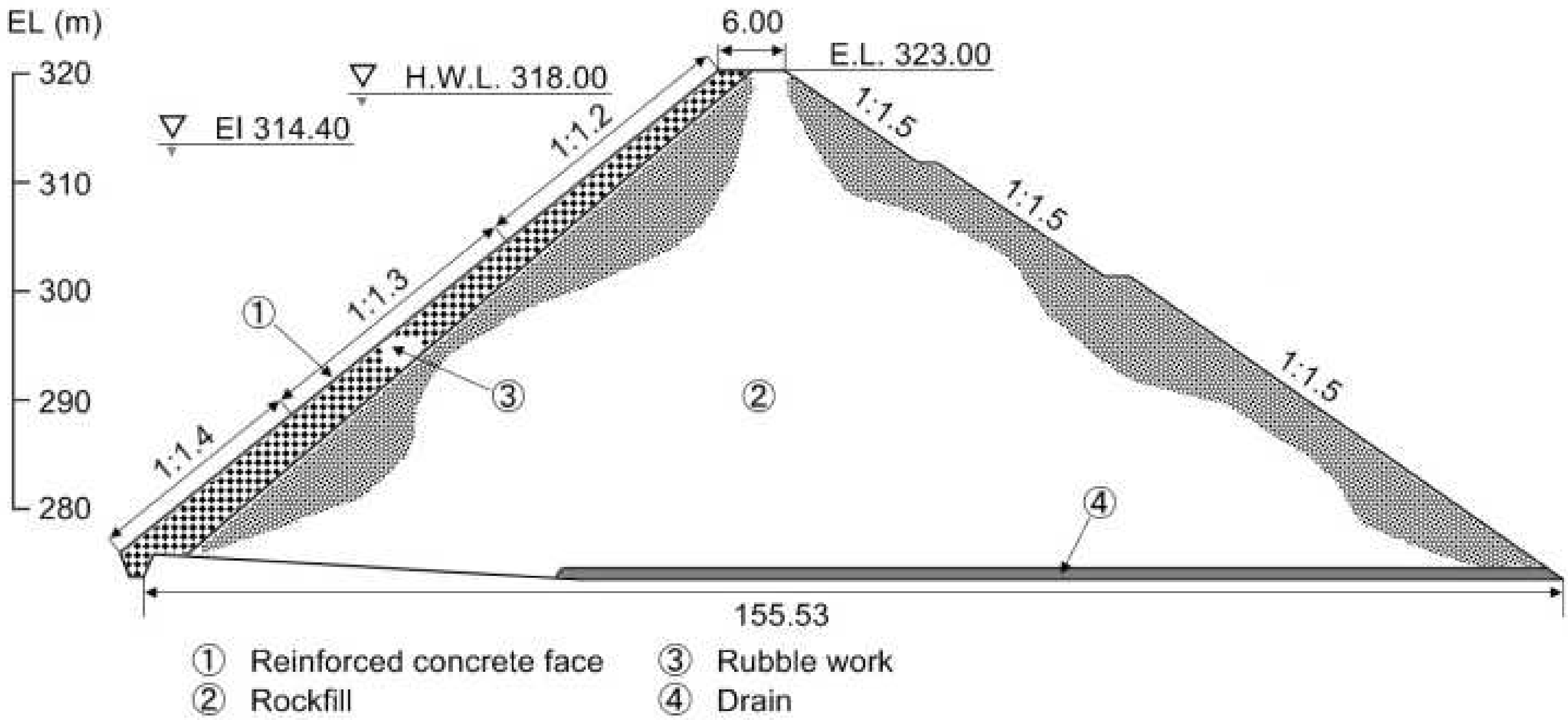
2. Yashio AFRD

3. Numappara AFRD

4. CONCLUSIONS

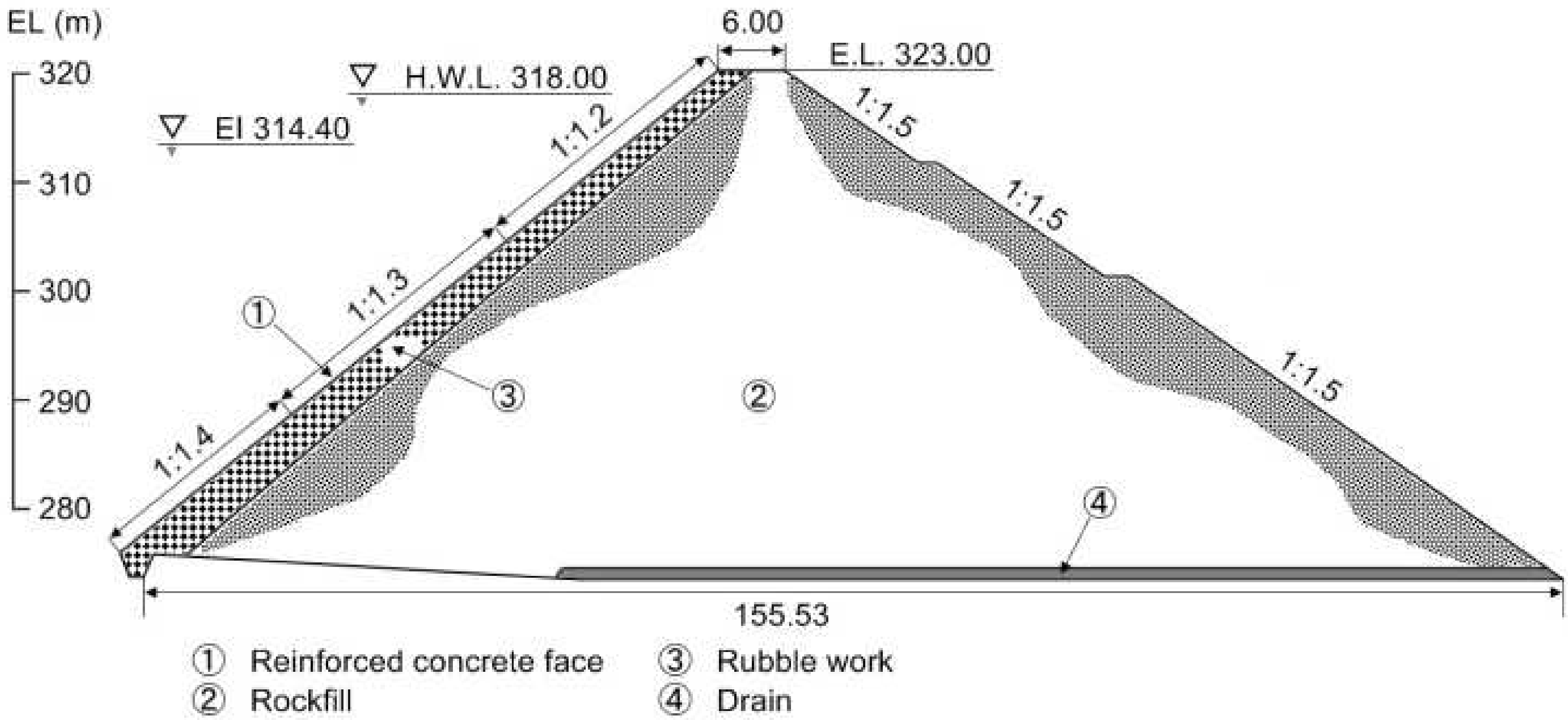
Ishibuchi Dam CFRD

Typical cross section



Ishibuchi Dam CFRD

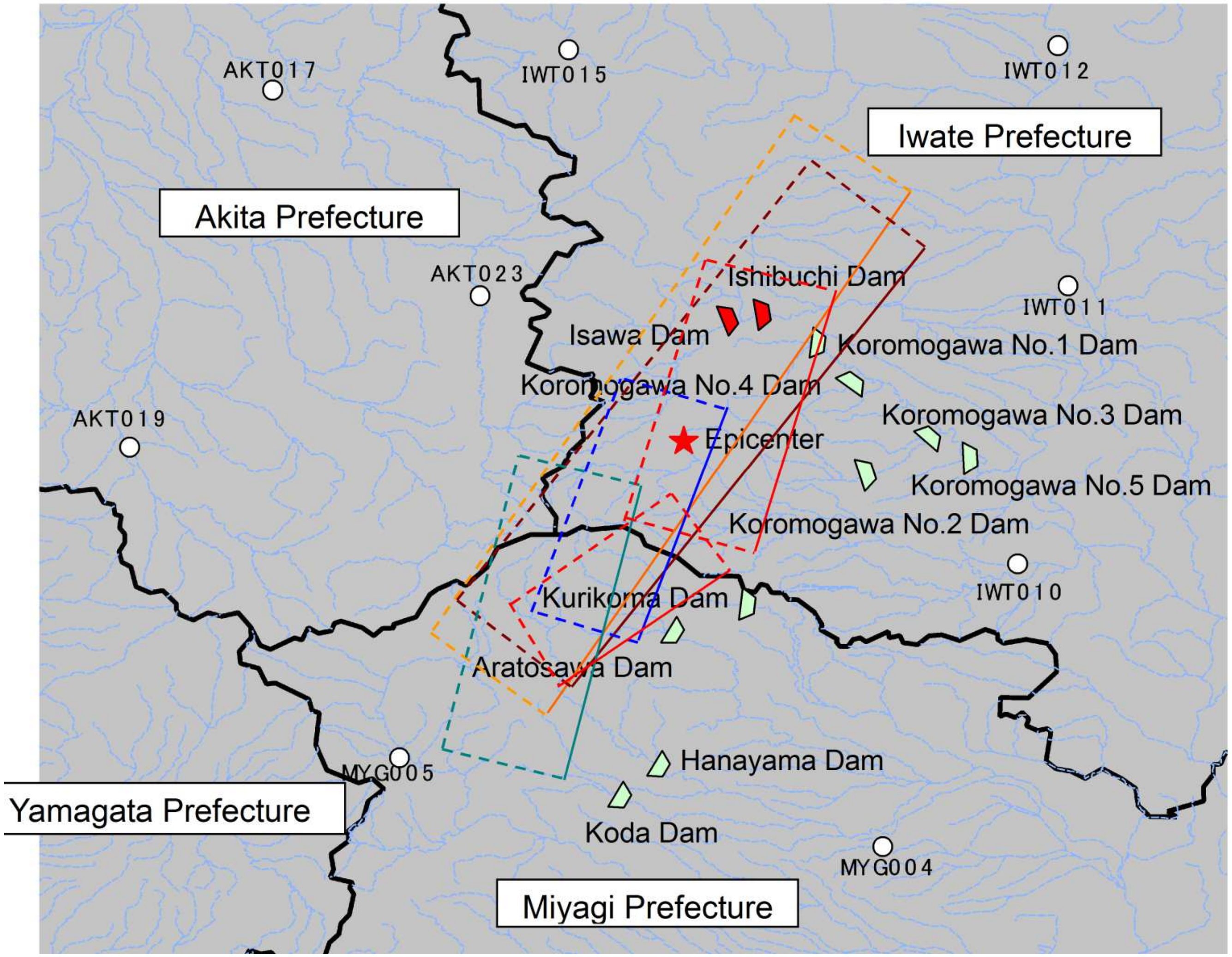
Typical cross section



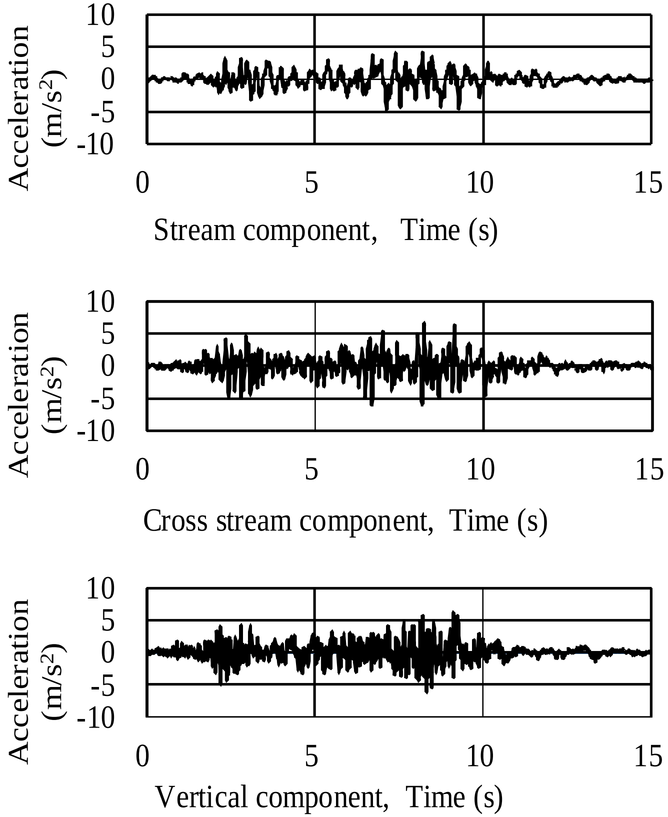
JDEC

Where the dam and fault were?

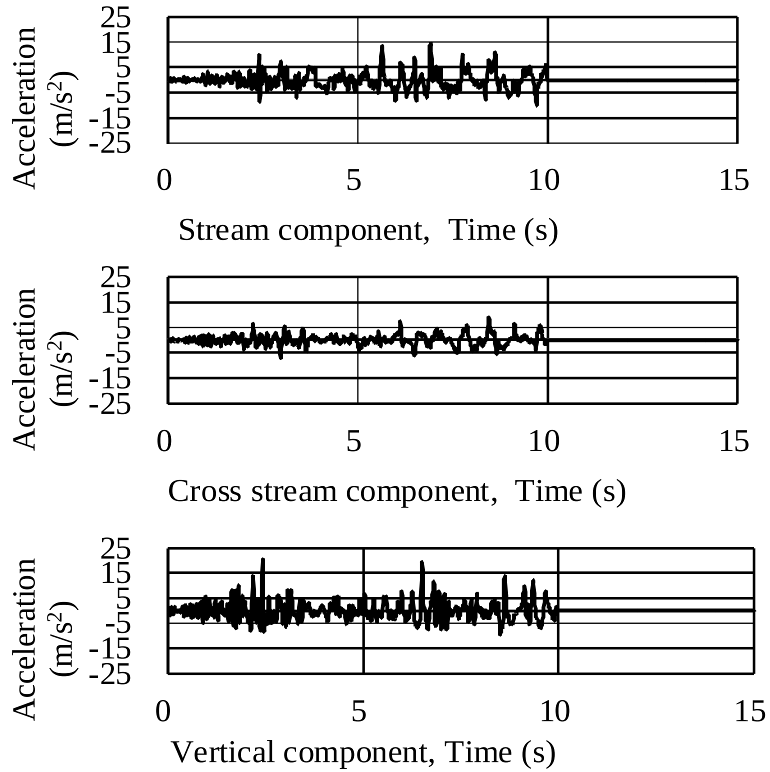
- **Ishibuchi dam**
- **Causative Fault**



Accelerograms



Foundation



Dam crest

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Concrete face just after the Quake

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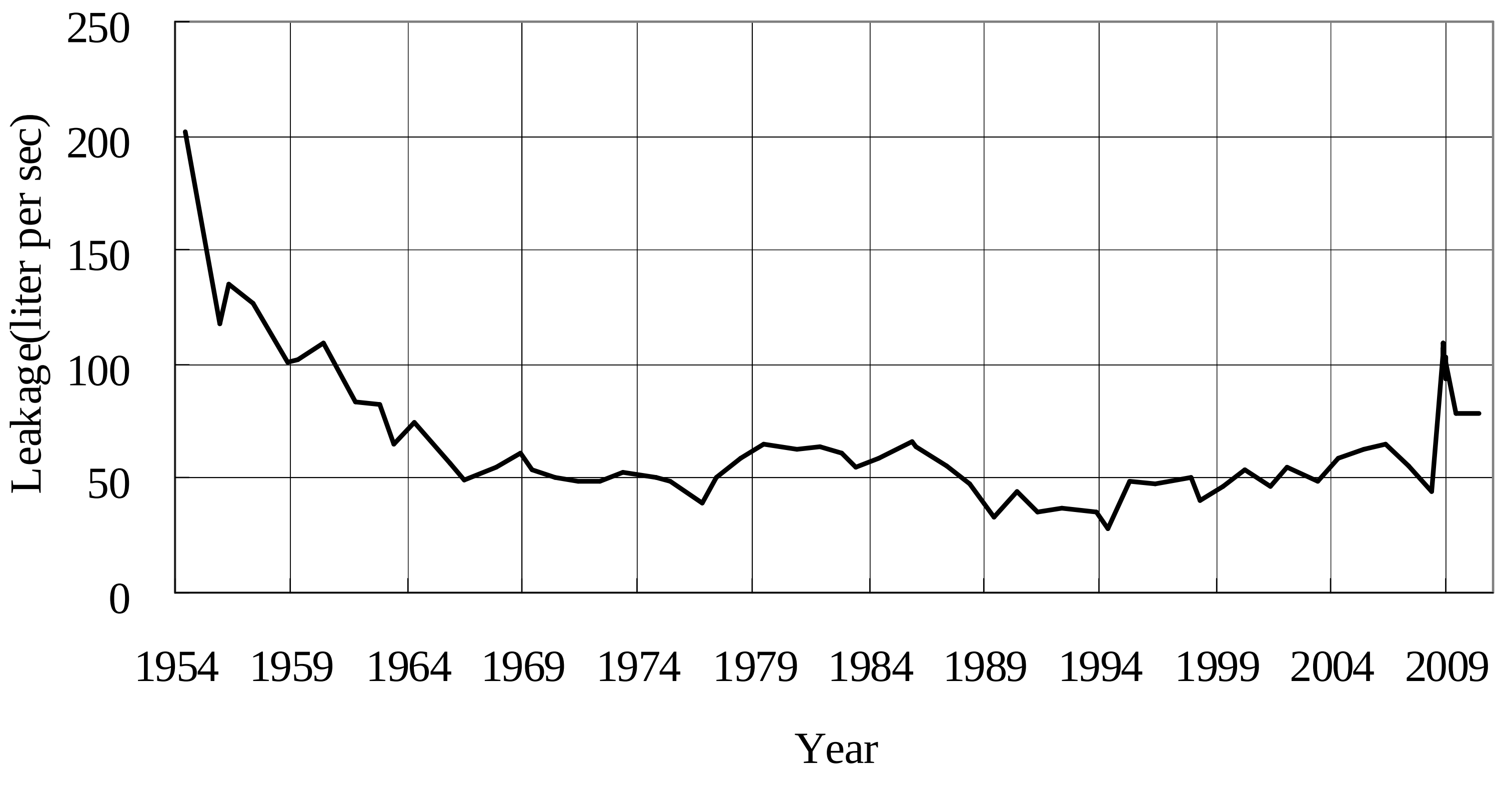
Leakage with time



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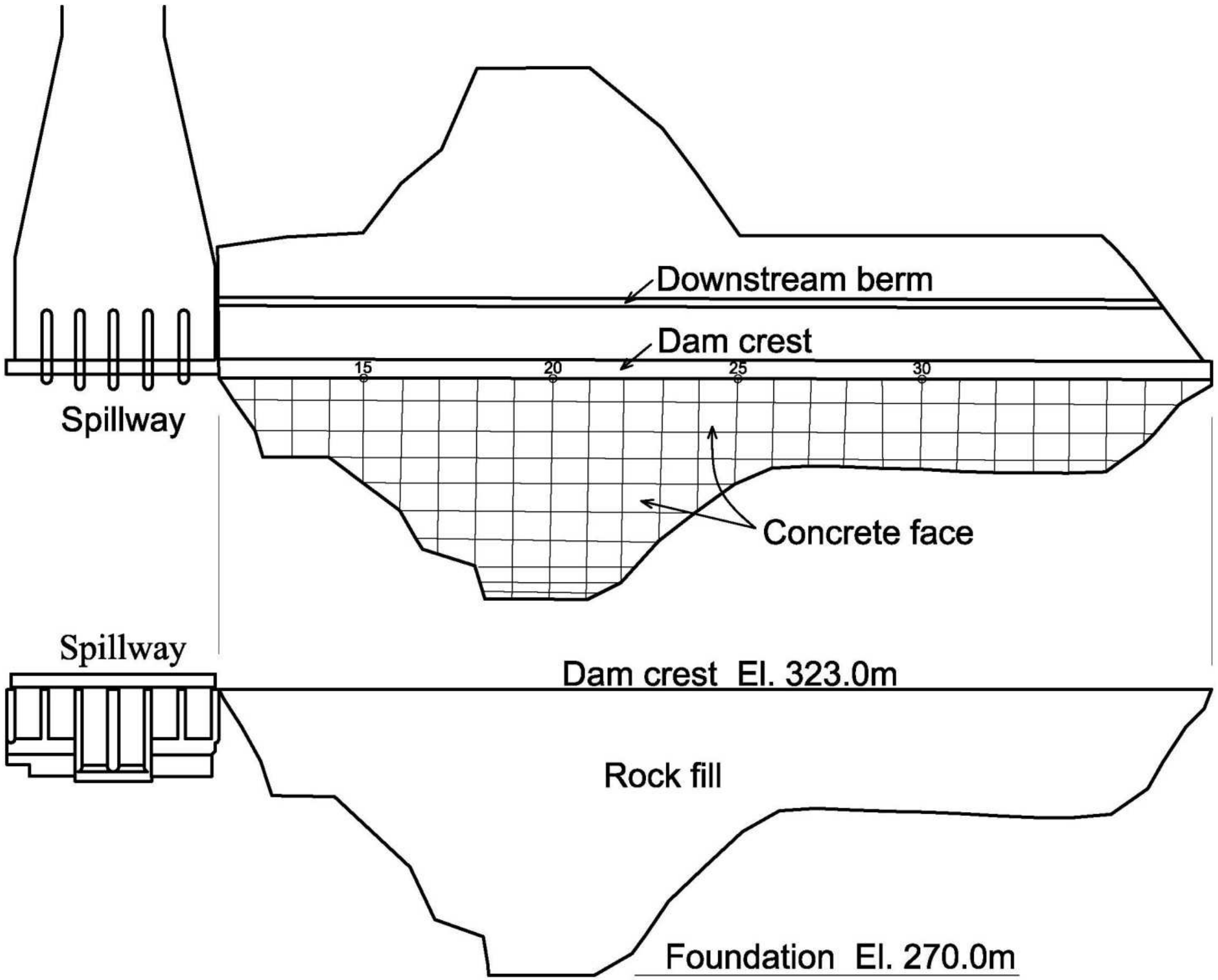
Plan and Elevation



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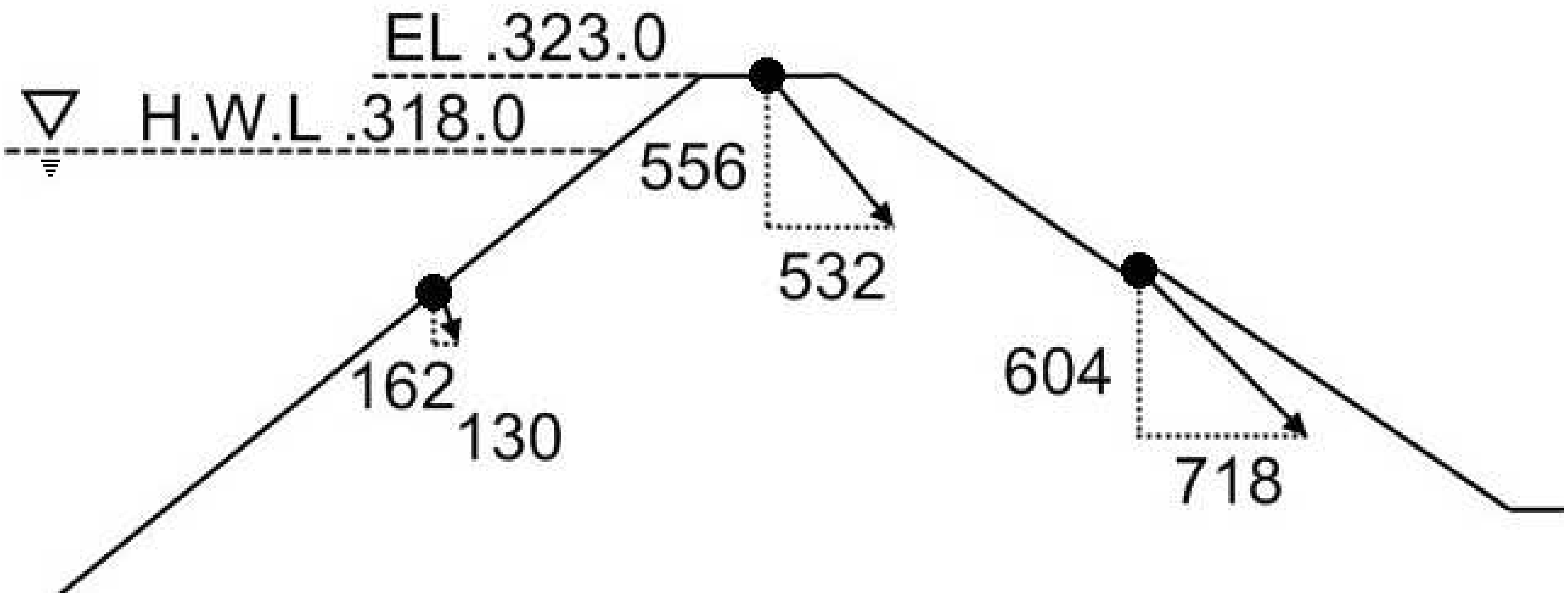
Deformation due to the quakae



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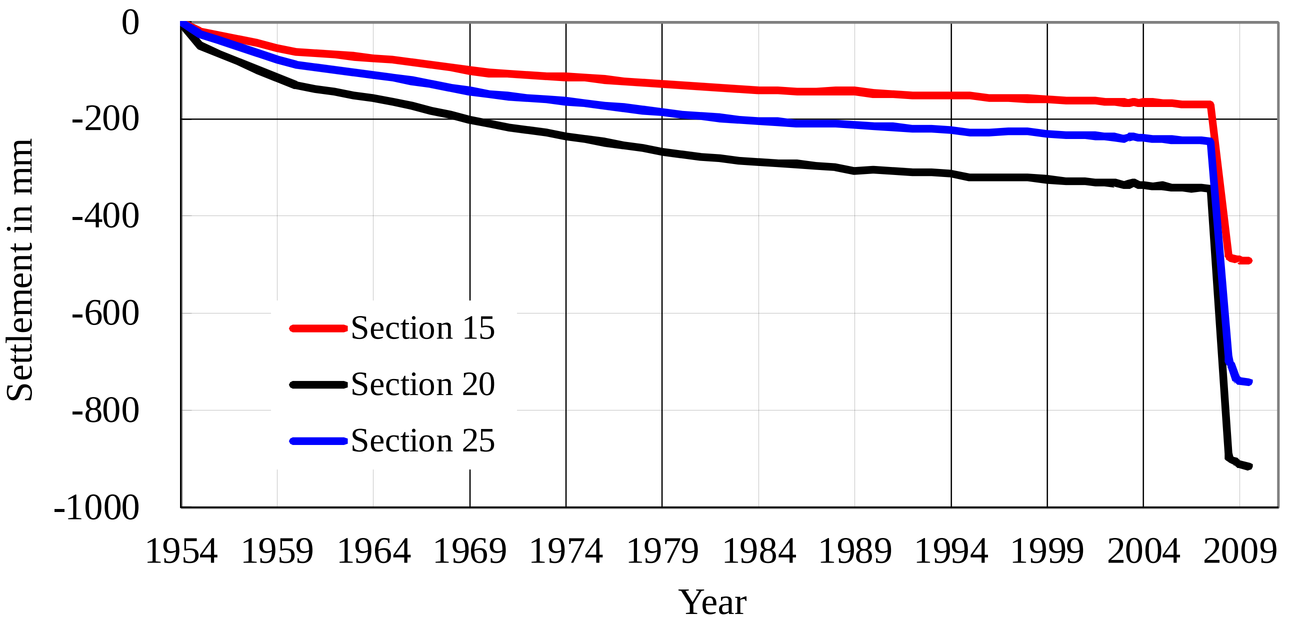
TITLE OF THE SLIDE



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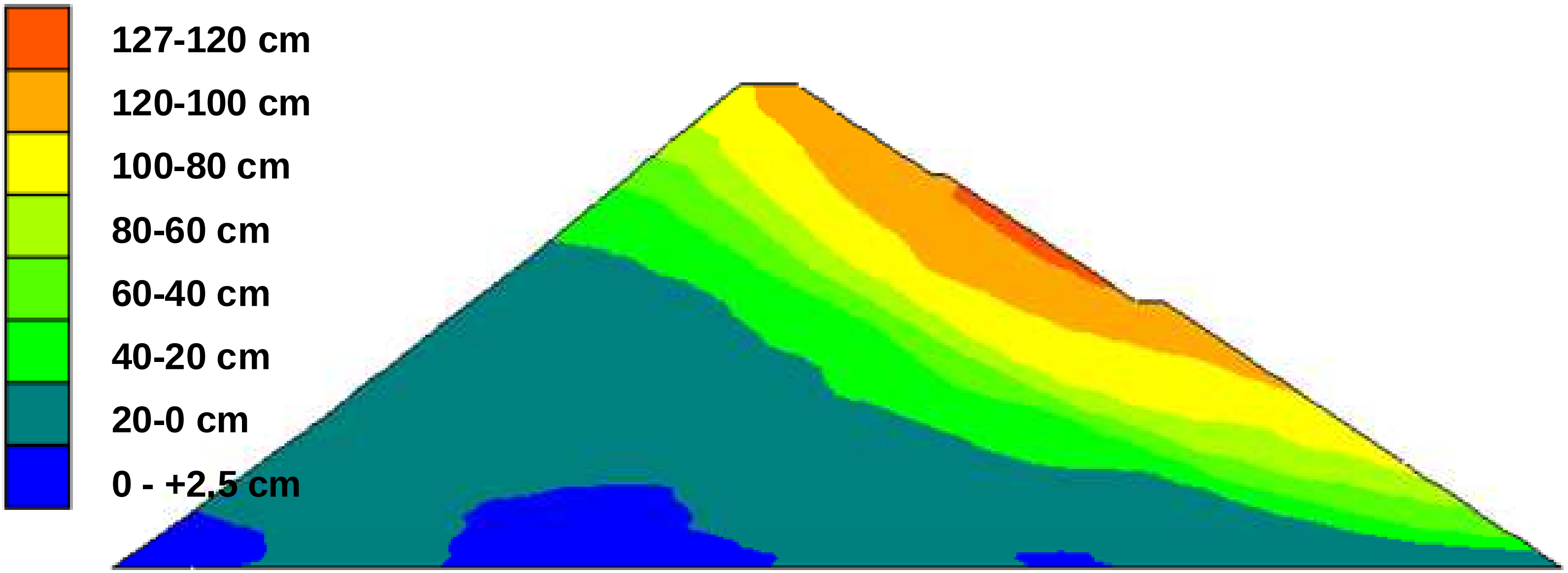
Strength parameters for rockfill

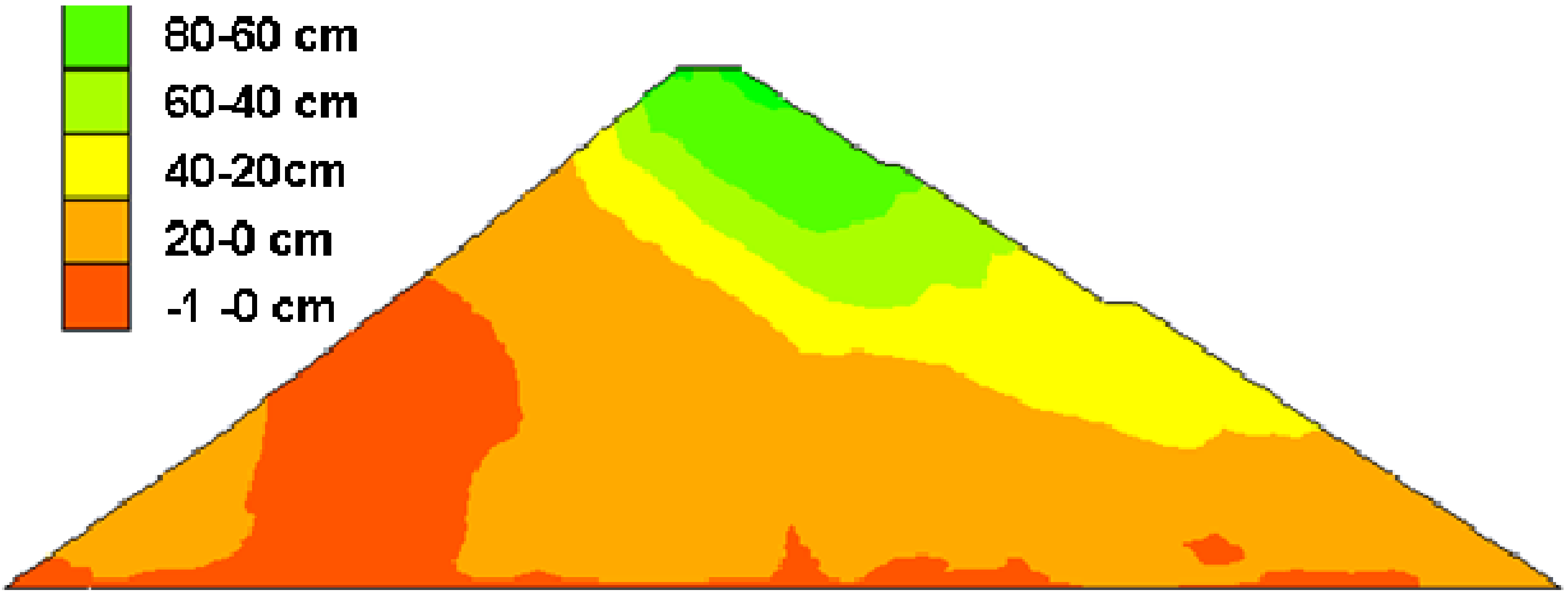
- $\phi_0 = \phi_{max} - 10.9\log(\sigma_n/50)$
- here,
- $\phi_{max} = 52.1^\circ$ for rockfill
- $\phi_{max} = 60.0^\circ$ for rubble work
- σ_n = mean confining pressure in kPa

JDEC

Horizontal permanent deformation



Vertical permanent defomation



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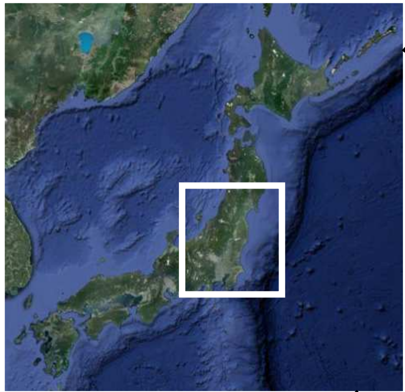
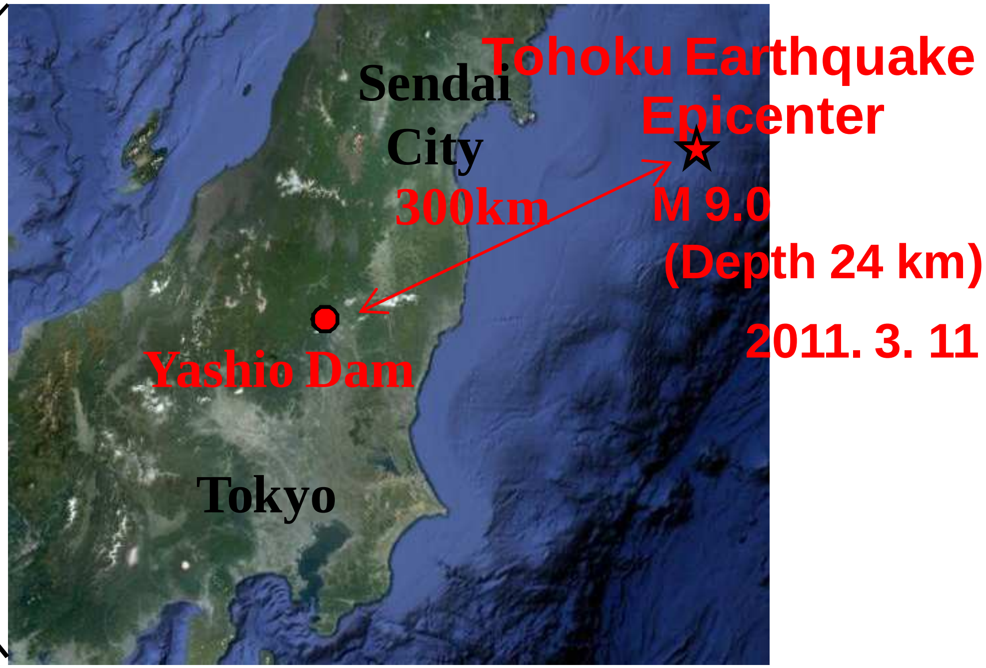
YASHIO AFRD

1. Introduction





2. Outline of the Yashio dam

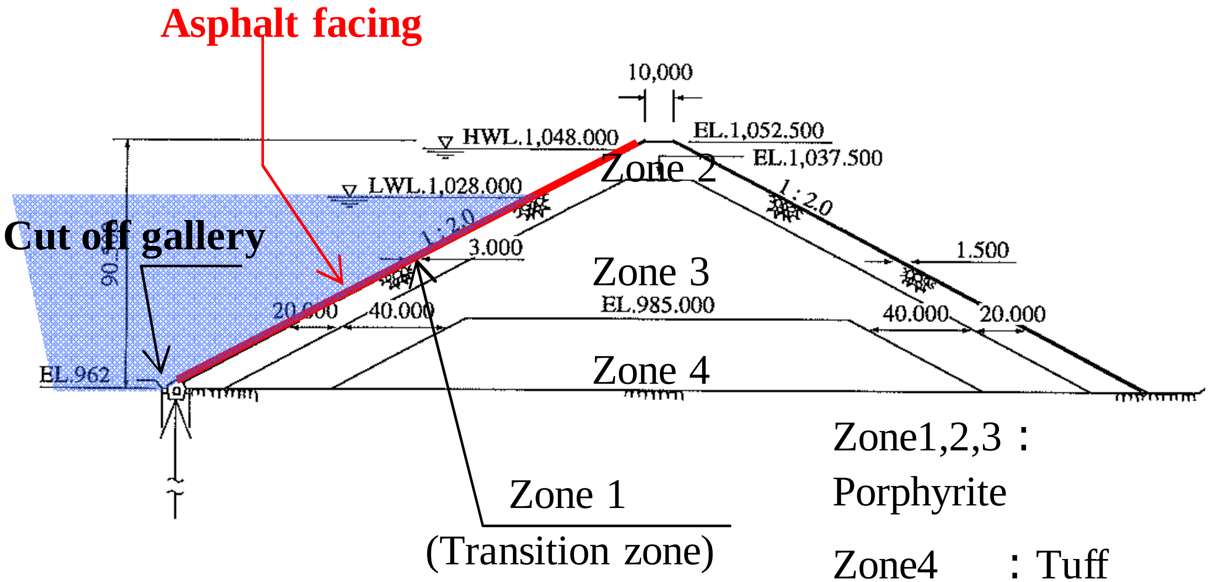
(a)Spesification
Shiobara power plant

Purpose	Hydropower（PSPP)
Capacity	900 MW
Completion	1995

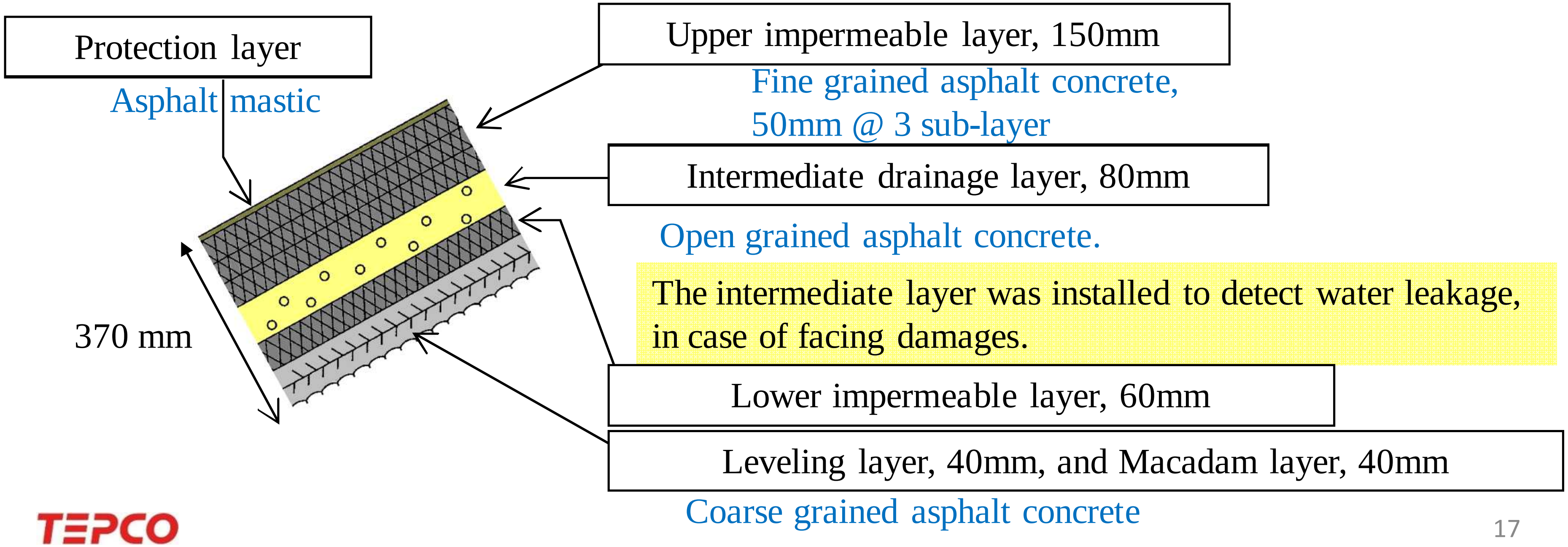
Yashio dam

Dam Type	AFRD
Dam height	90.5m
Crest length	263.0m
Dam volume	2.1 × k m^3
Reservoir capacity	11.9 × Mill. m^3

(b) Cross section of the Dam



(c) Structure of the asphalt facing

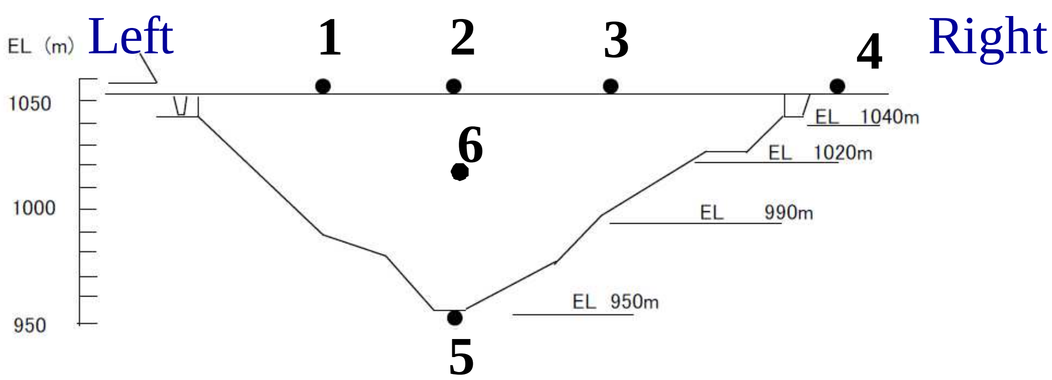


3. Observation during and after the earthquake

(a) Acceleration（gal)

Max. Acceleration at the crest and inner part of the Yashio dam

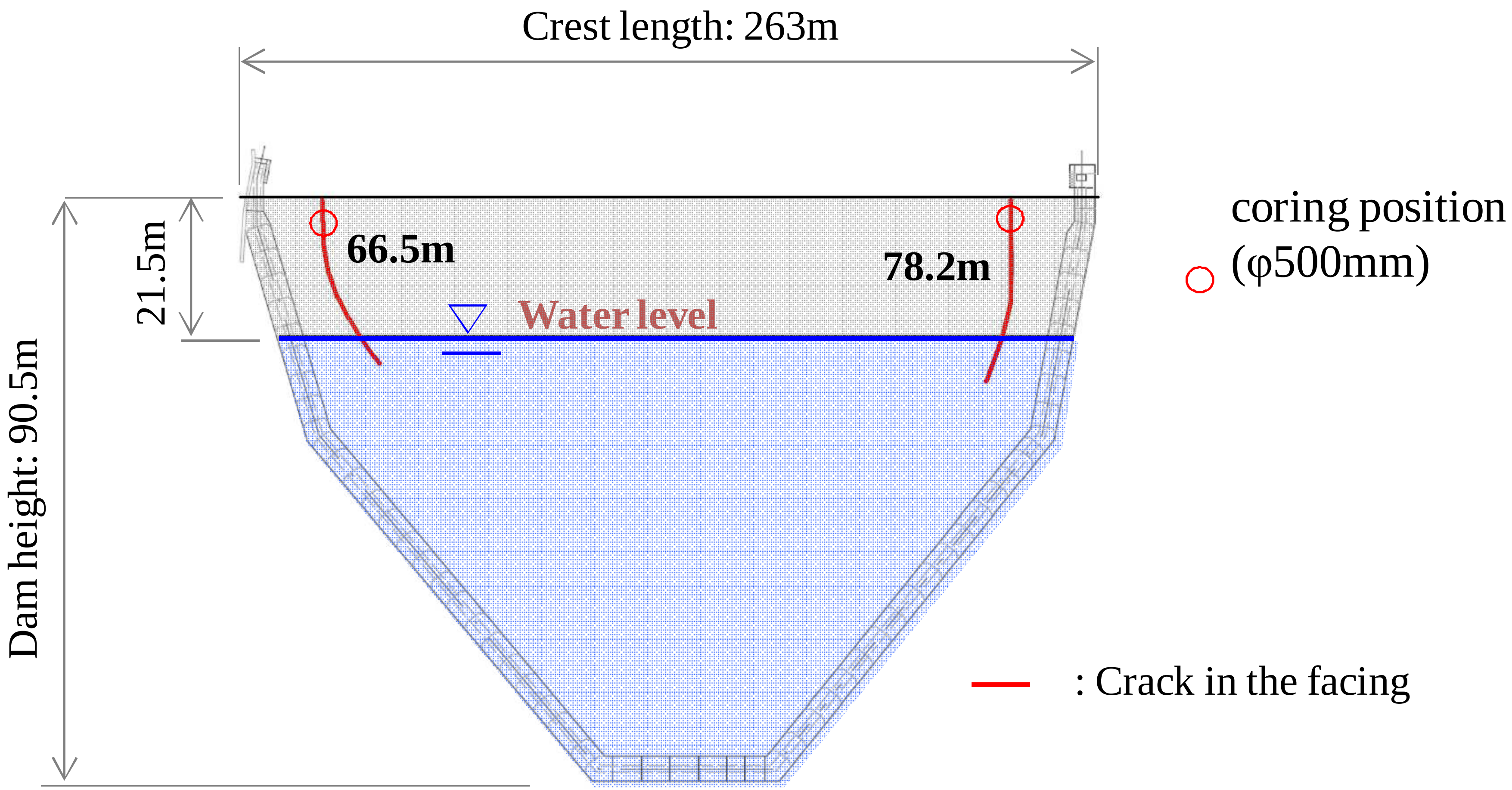
	1	2	3	4	6
Stream	174	253	252	66	125
Dam axis	157	185	104	66	132
Vertical	105	175	156	43	115



Max Acceleration in the bed rock

	5
Stream	43
Dam axis	53
Vertical	45

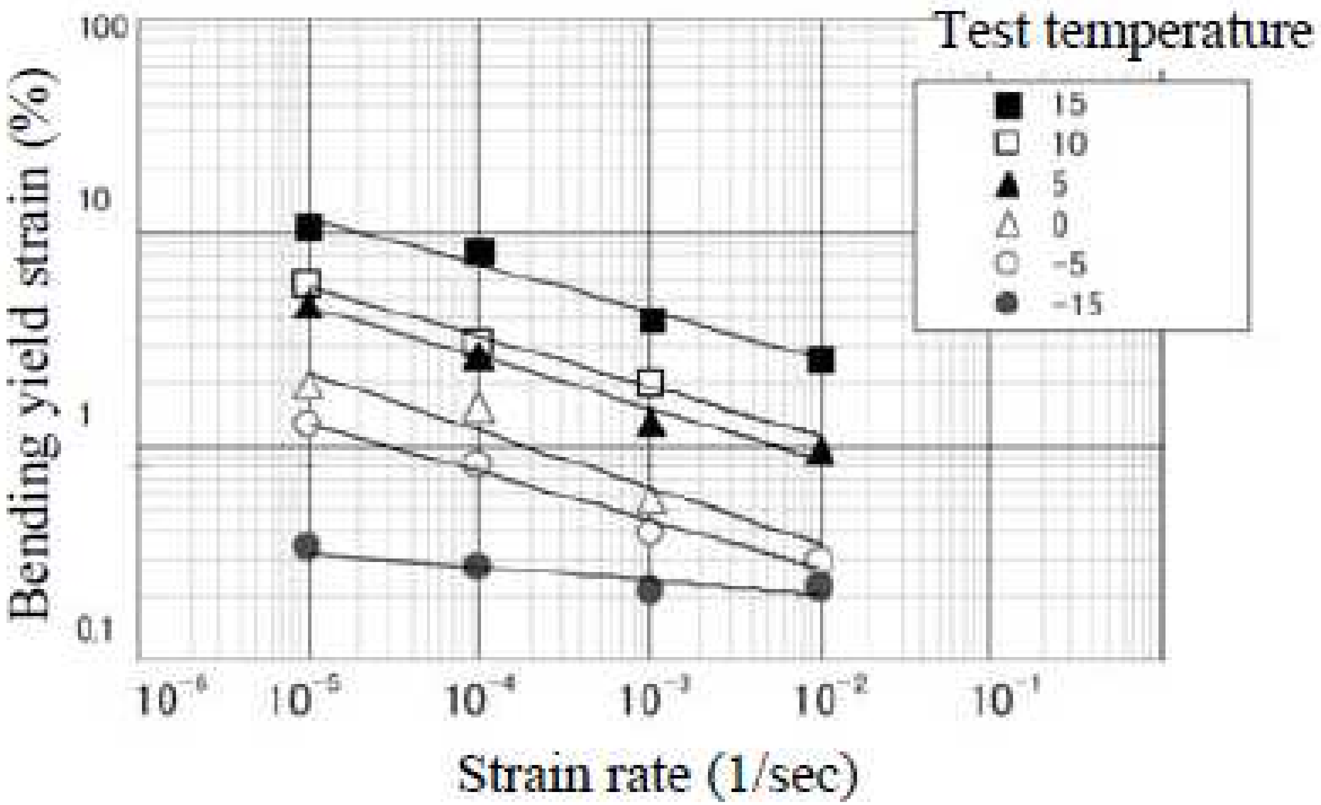
(b) Cracks in the Asphalt Facing



Maximum water leakage through the cracks of the upper impermeable layer was about 300 litter/ min.

Fig – Dam front view (asphalt facing)

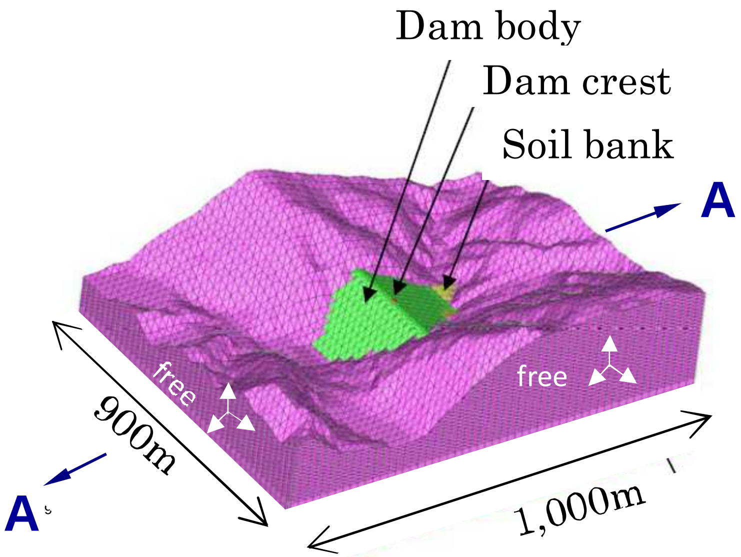
Tensile strain capacity of asphaltic concrete with strain rate and temperature



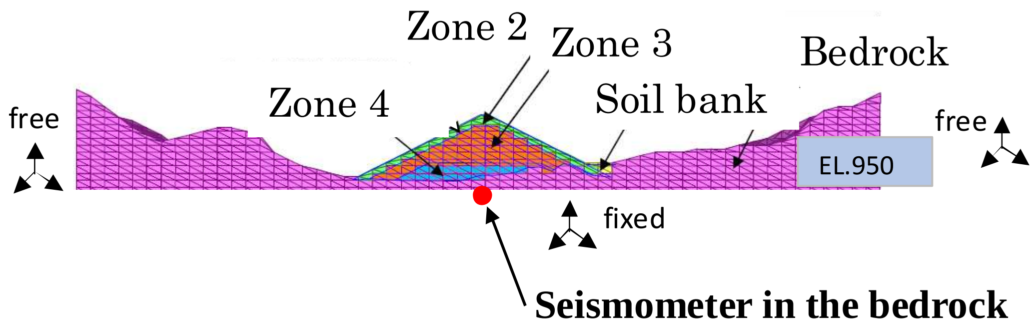
4. Study on the crack mechanism

i. Reproduction analysis

A reproduction analysis using a seismic wave record in the bedrock to pursue the crack mechanism:



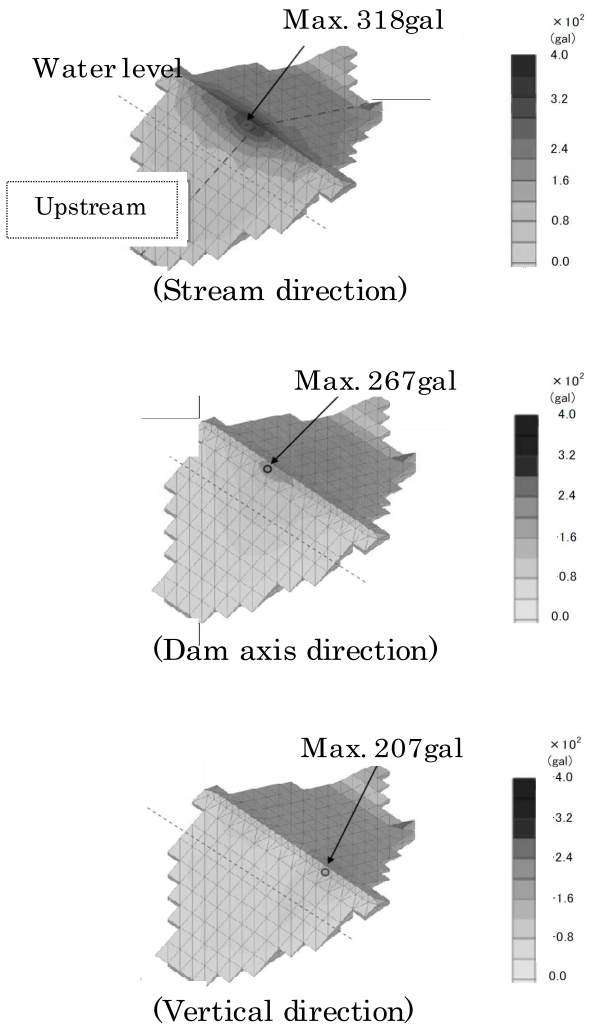
A – A cross section



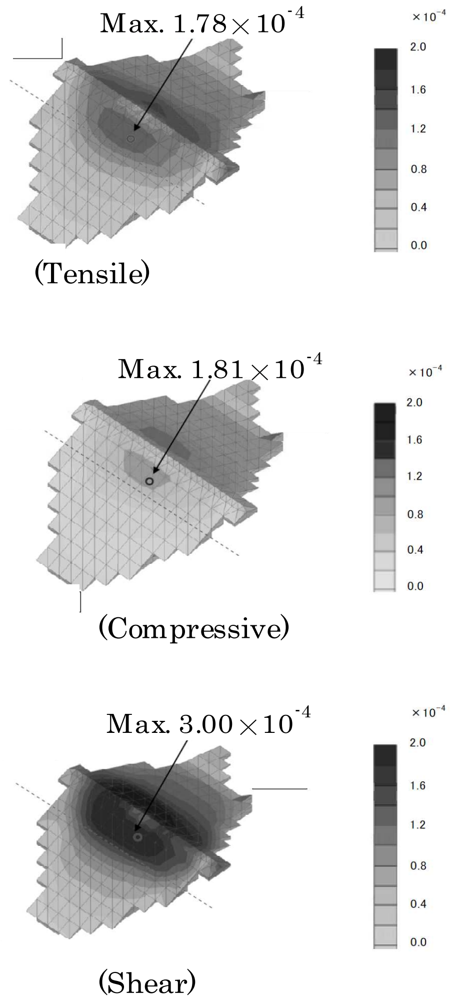
Boundary condition of this analysis

- Displacement of the base of the model was fixed.
- Displacement of the side of the model were not fixed.
- Hydrodynamic pressure ：Zanger's formula.

◻ Result of reproduction analysis, acceleration



Max. Acc



Max. Strain

Table - Max. Acc in gal

	Analy.	Obser.
Stream	318	253
Axis	267	185
Vertical	207	175

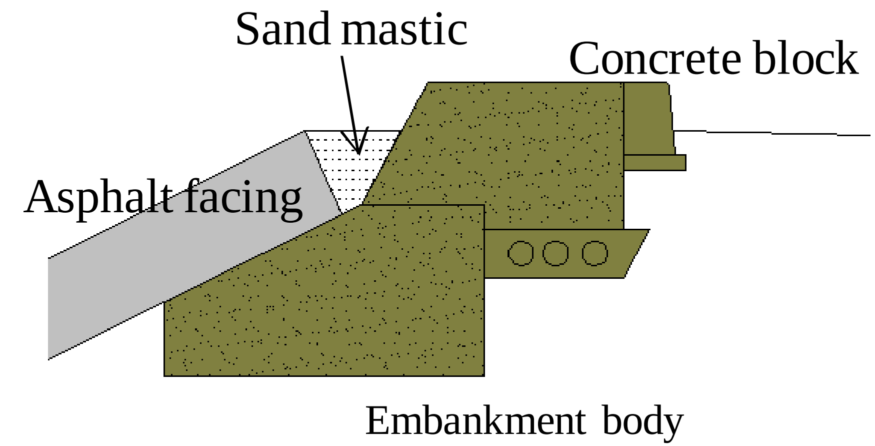
Acceleration was reproduced slightly bigger than the observed record.

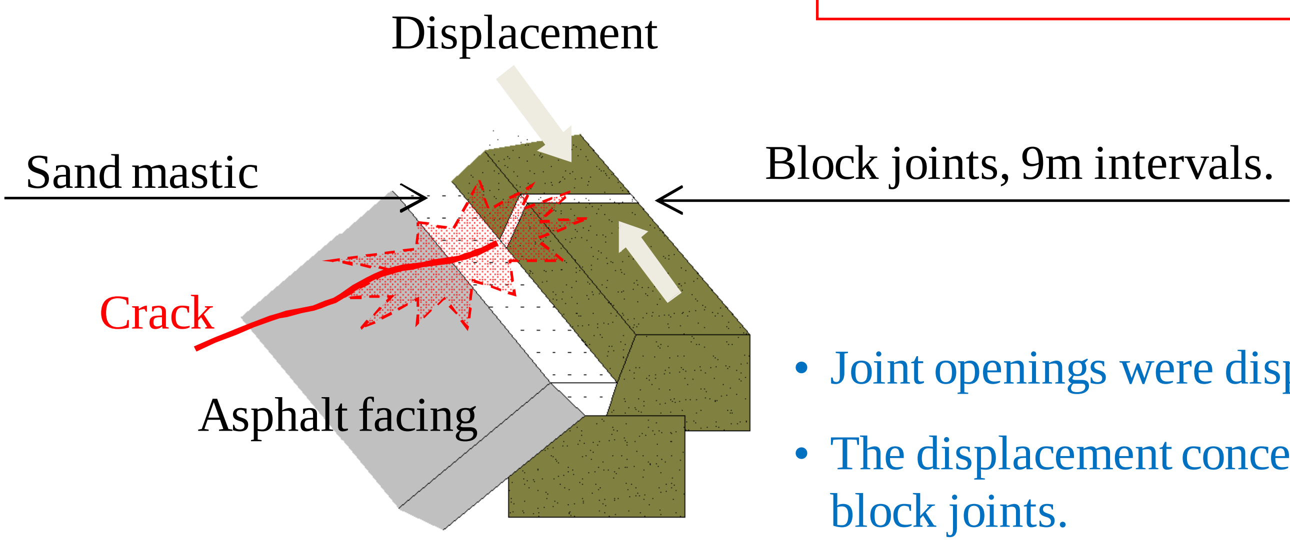
Table - Max. Strain by the analysis and failure strain (Unit: 10^{-3})

	Max. Strain	Failure strain
Compressive	0.2	12.0
Tensile	0.2	2.3
Shear	0.3	28.0

The calculated strain in the facing didn't exceed the failure strain of the asphalt concrete.

ii. Detail structure at the dam crest

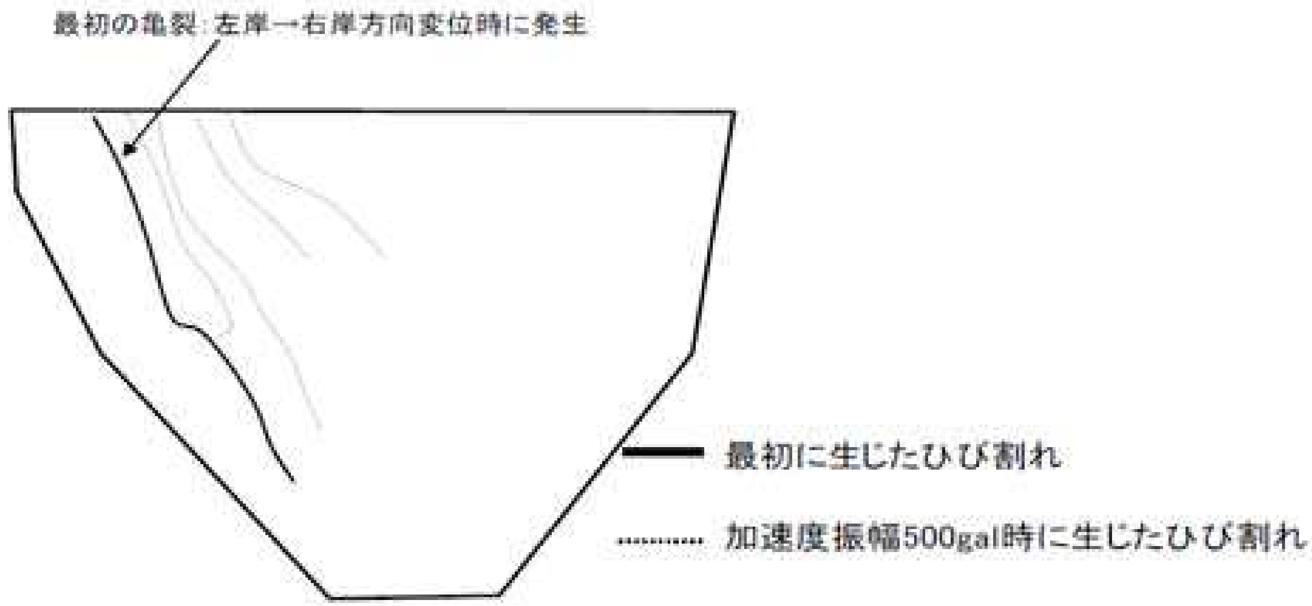




- Joint openings were displaced by the earthquake;
- The displacement concentrated strains near the block joints.

These things were confirmed by the result of the reproduction analysis.

Physical model test on shake table



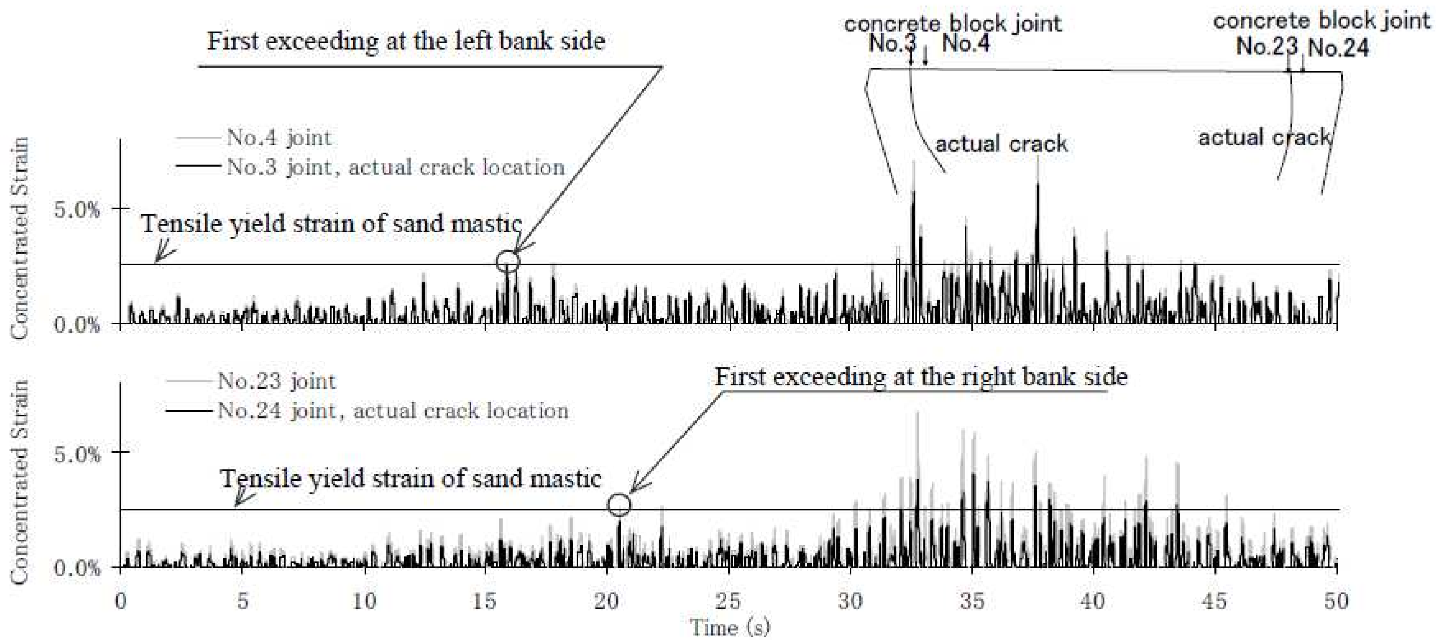
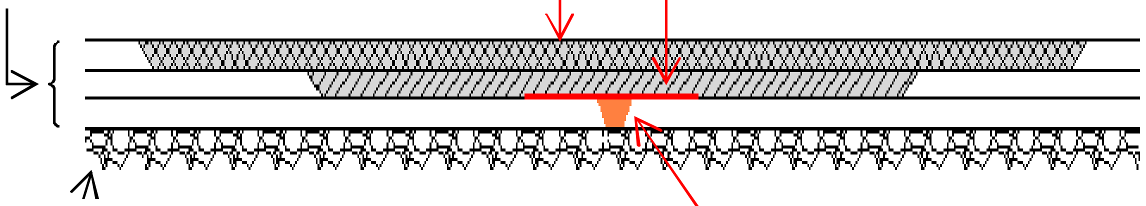


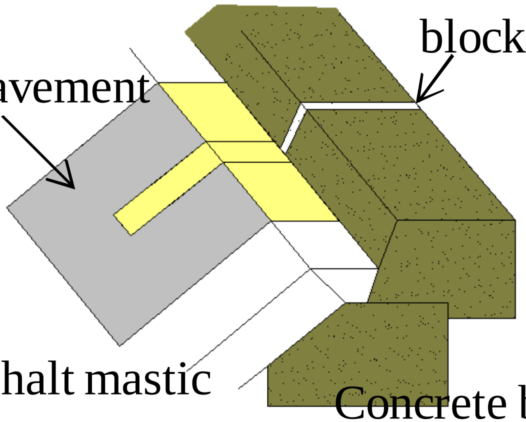
Figure 11. Concentrated strain by estimates at the actual crack location.

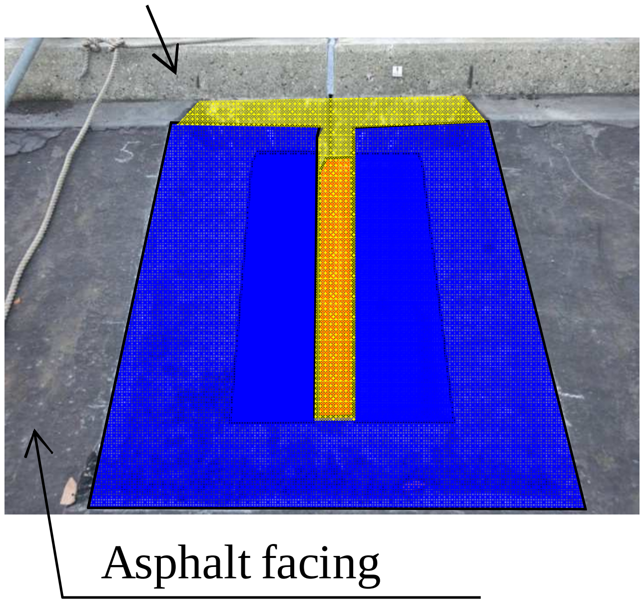
5. Repair works

(Durable measure in 1 month)

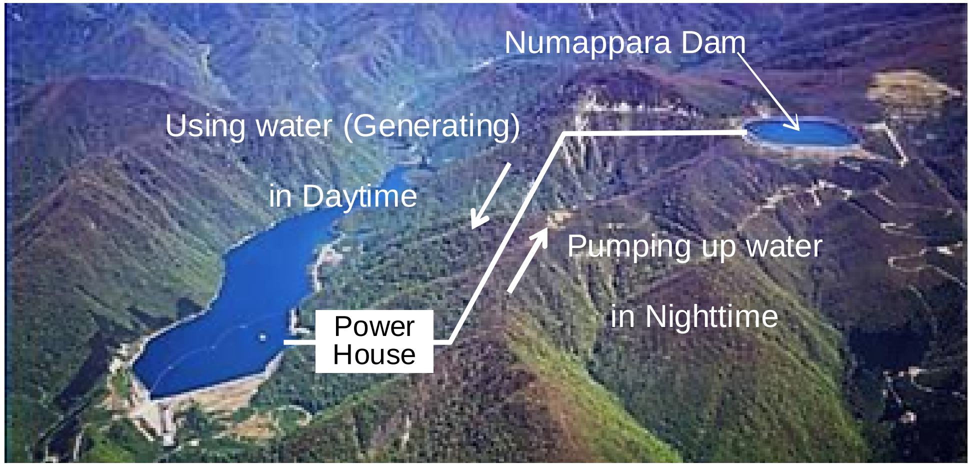


6. Reinforcement work at the crest

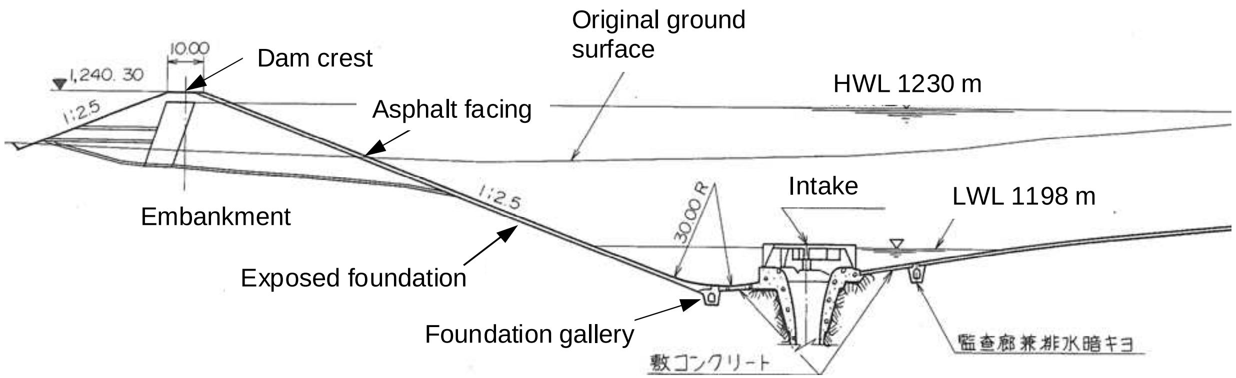


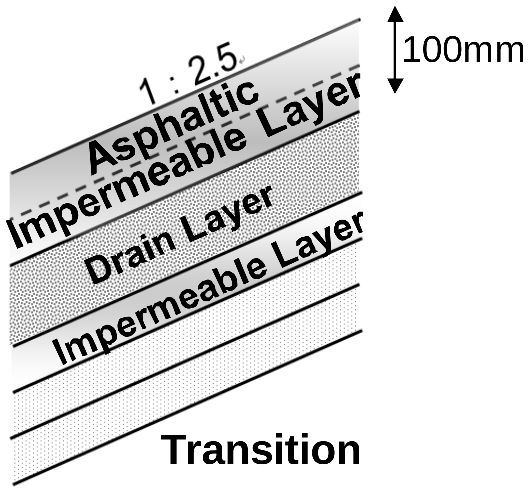


NUMAPPARA AFRD



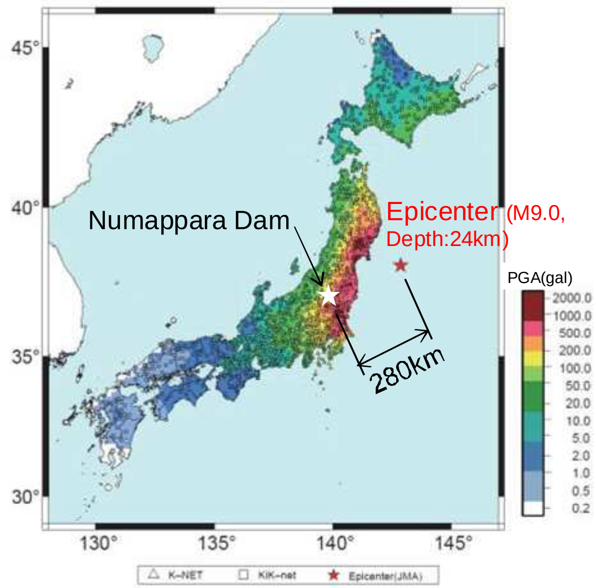
Layer	Thick
Protective Layer	2mm
Asphaltic Impermeable Layer	50mm × 2
Drain Layer	80mm
Asphaltic Impermeable Layer	40mm
Leveling Layer	40mm
Macadam Layer	40mm
Transition	600mm



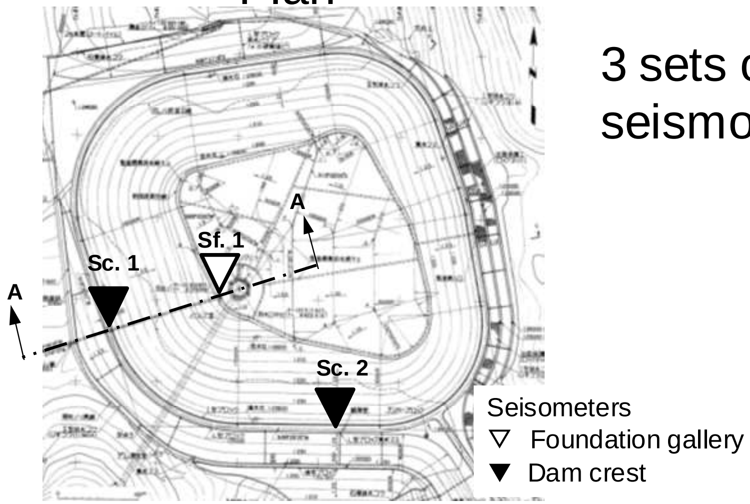


SESIMIC MONITORING

2011 Tohoku E.

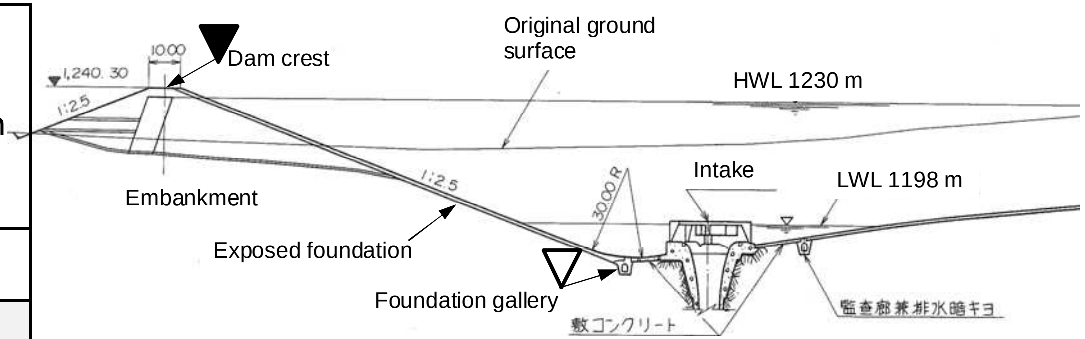


Plan



3 sets of 3-D seismometer

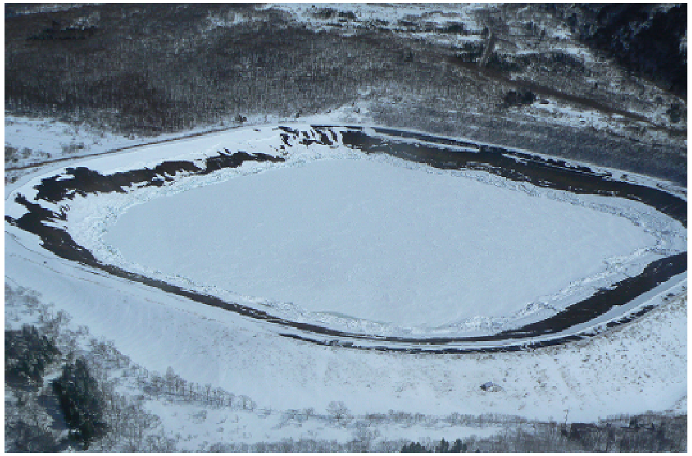
A-A secion



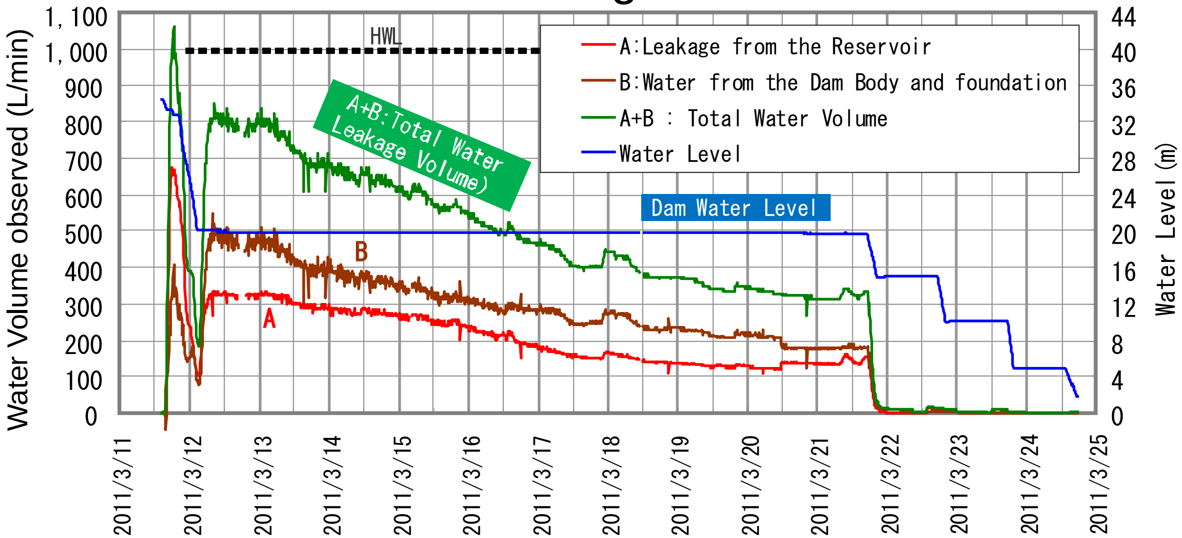
Uni : m/s^2

Location	Horizontal direction		Vertical direction
	Dam axis	Perpendicular to dam axis	
Sc. 1	3.16	3.82	1.95
Sf. 1	1.35	2.10	0.97
Sc. 2	3.16	3.47	1.68

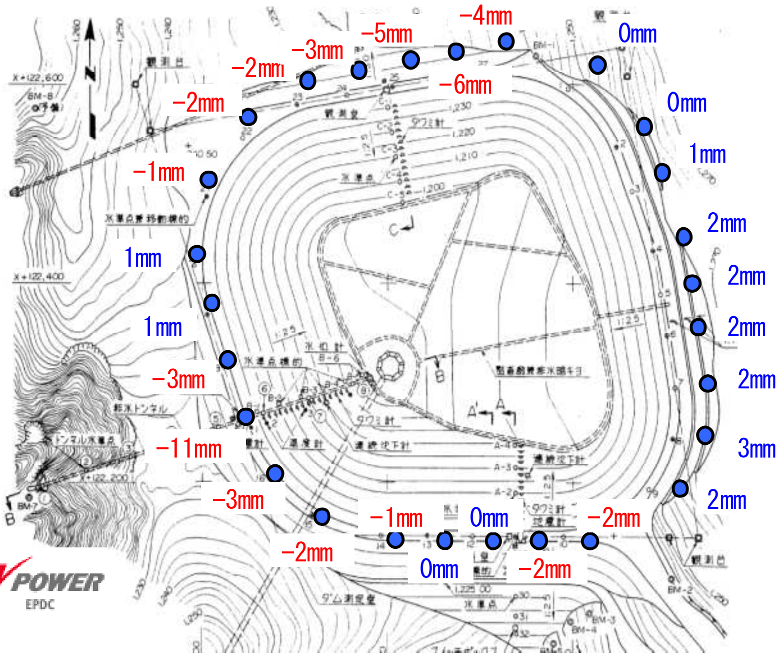
INDUCED INCIDENTS



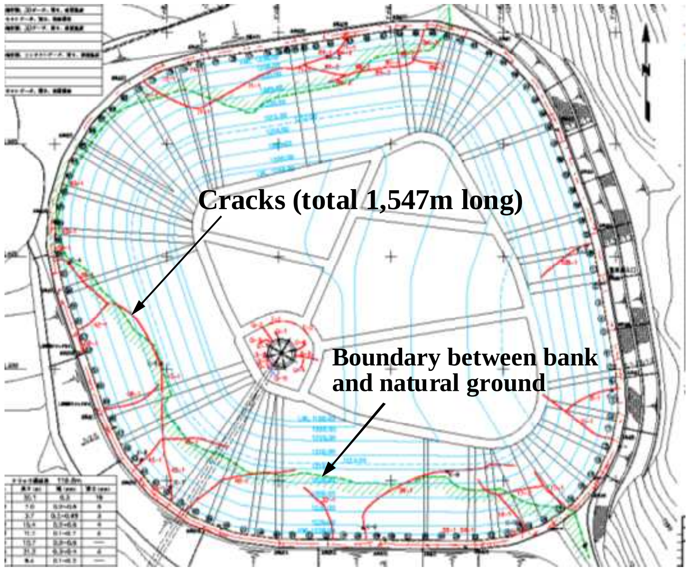
Leakage



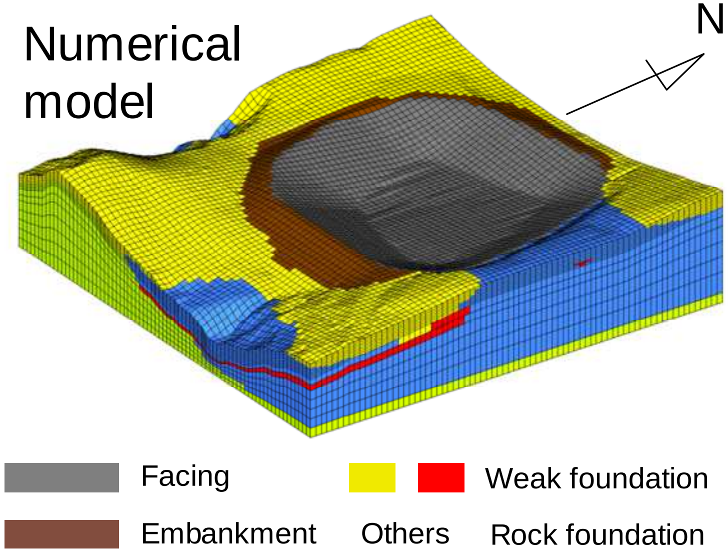
Settlement

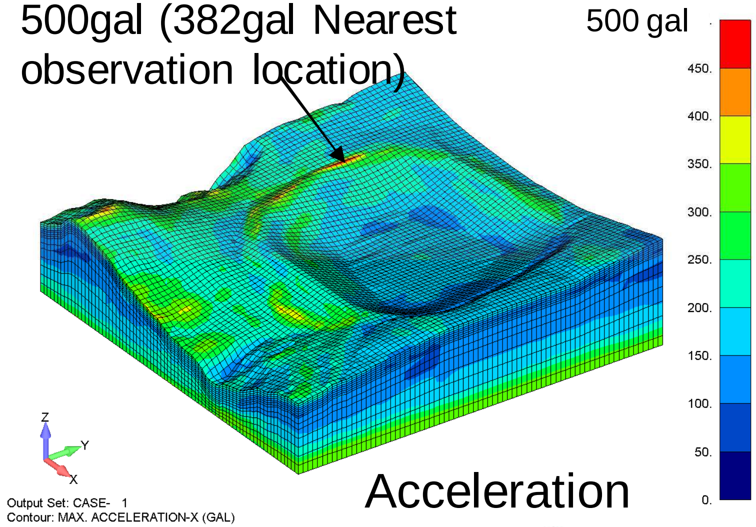


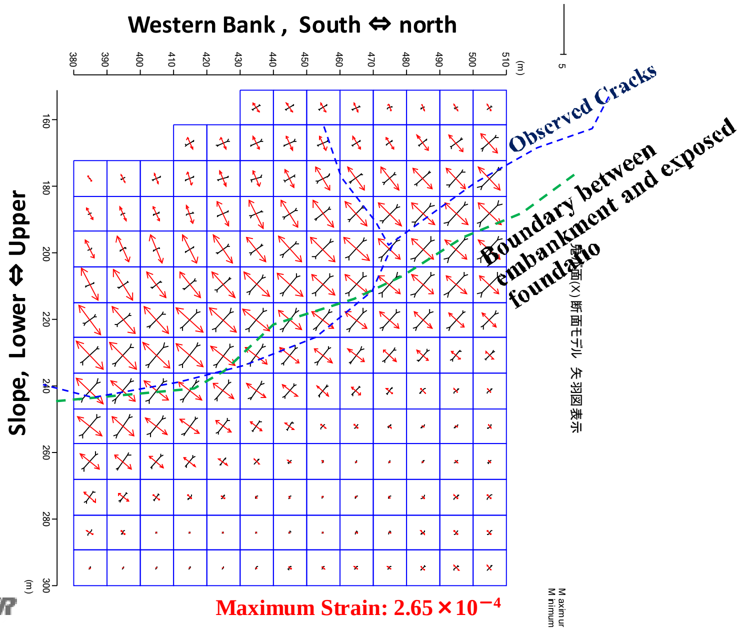
Cracks

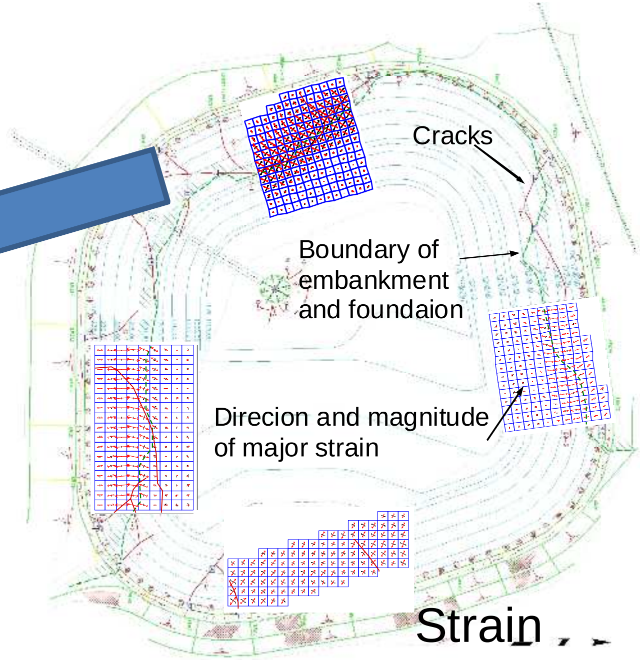


NUMERICAL SIMULATION









REMEDIAL WORKS

U-Shaped Cut, Removal of existing protection layer

↓

Filling of Rubberized Asphalt

↓

Laying of Reflection Crack Sheets

↓

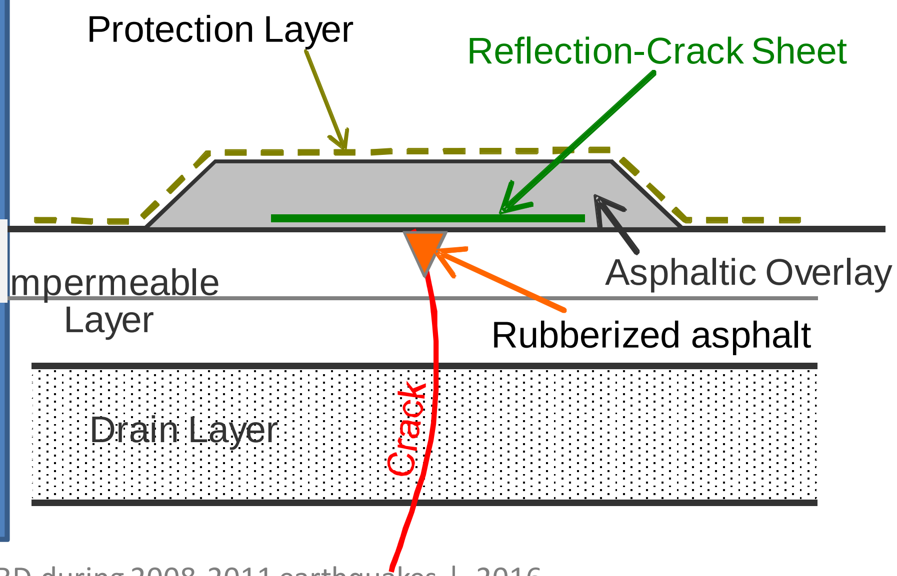
Preparation of laying of asphalt （heat and scratch surface）

↓

Paving of Asphalt (man-powered work)

↓

Coating the protection layer



CONCLUSIONS

- The face is rigid the fill is flexible. There has been a wide spectrum of views; the faced rockfill dams can resist strong earthquake motions? Three dams (Ishibuchi, Yashio and Numappara) showed the fundamentally satisfactory performance during strong earthquakes.

- The asphalt face of AFRD might be cracked under low ambient temperature condition when subjected to strong motions.

- The cracks of the asphalt facing emerged at local areas of the joints of curve of crest pavement road in Yashio AFRD and the boundary between the embankment and the excavated foundation in Numappara AFRD. The leakages from the cracks were not much to threat the safety of the dam and they were repaired successfully afterwards. The prudent design is necessary for the junction of concrete structures and the asphalt facing. The compaction of rockfill is most important to minimize deformation due to earthquakes. The adequate outlet structures can facilitate remedial works by prompt dewatering after earthquakes.


THANK YOU FOR
YOUR ATTENTION