International Symposium
Qualification of dynamic analyses of dams and their equipments
and of probabilistic assessment seismic hazard in Europe
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Session 2: Performance of AFRD & ACRD

TITLE

Evaluation of Earthquake Resistance on Asphalt Facing

OBJECTIVES

- Seismic response behaviors are studied on an AFED, which was severely damaged by cracking during a medium-scale earthquake.
- Two methods of safety evaluation are proposed and compared to confirm their applicability in practice.
- Safety evaluation is made by Introducing safety factors through the limit state design method, in order to prove their use as a practical design method of earthquake resistance.

1.The Damege of AFED

1.1 Intoroduction of Higashi-fuji dam

1.2 Earthquake damage and necessary of improved asphalt mixture.

2.DAMAGE EVALUATION OF IMPERVIOUS ZONE DURING E.Q

2.1 Seismic Response Analysis of Higashi-Fuji Dam

2.2 Evaluation in terms of Axial Failure Strain

2.3 Evaluation in terms of Accumulated Damage

3.DAMAGE EVALUATION OF IMPERVIOUS ZONE AT L1, L2 E.Q Motion

3.1 Definition of Safety Factors

3.2 Damage Evaluation by use of Safety Factor

3.3 Damage Evaluation for L1 earthquake (αB=200gal)

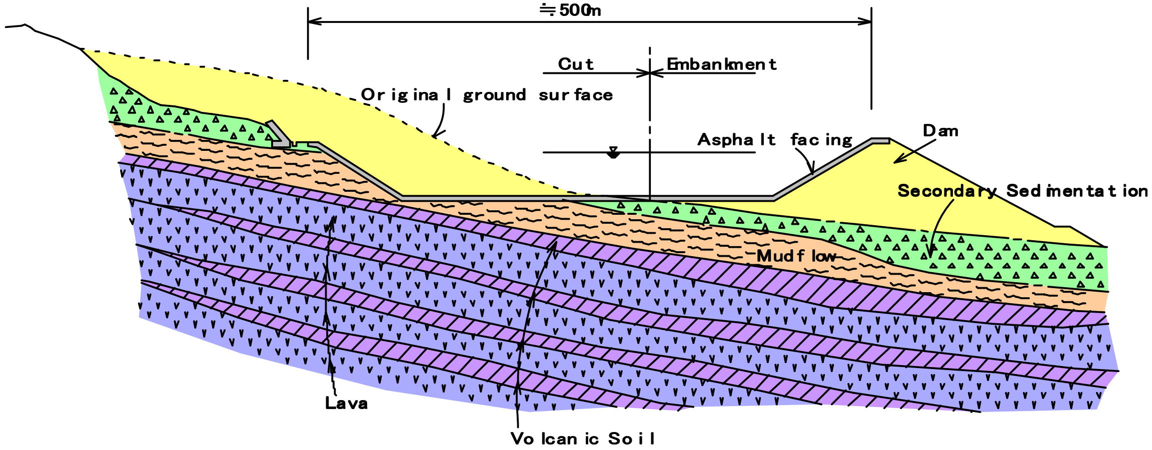
3.4 Damage Evaluation for L2 earthquake (αB =350gal)

4.CONCLUSIONS

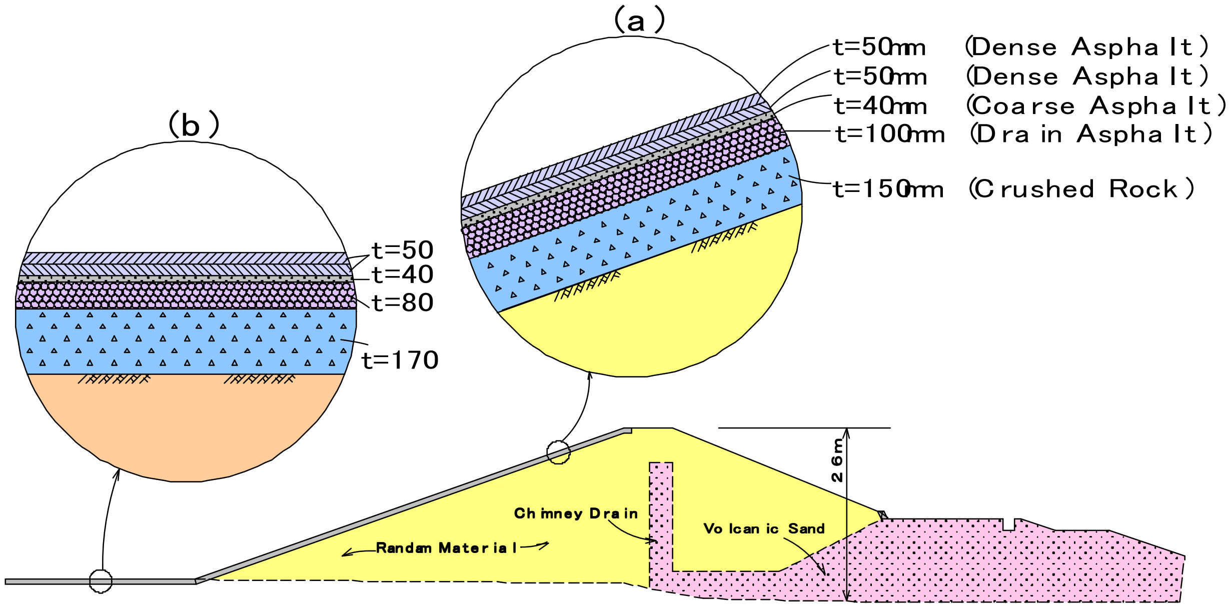
Introduction of Higashi-Fuji Dam

Higashi-Fuji Dam
(Asphalt faced Dam)

Mt.Fuji

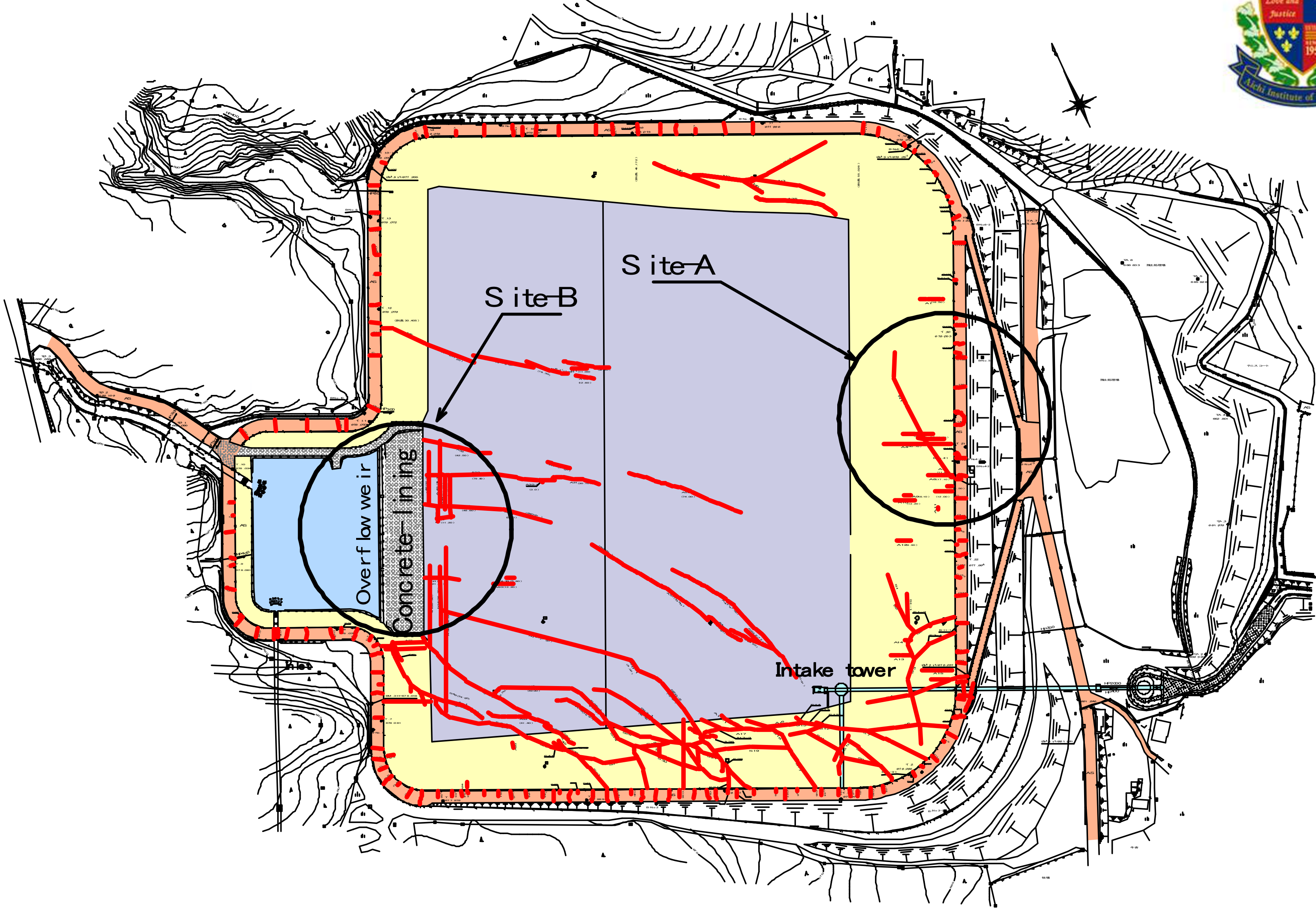


Schematic Cross Section of Dam

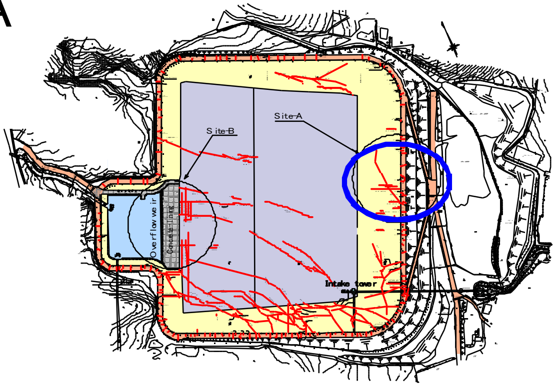


Standard Cross Section of Dam and Structure of Facing

Plan view of resiervoir & cracks

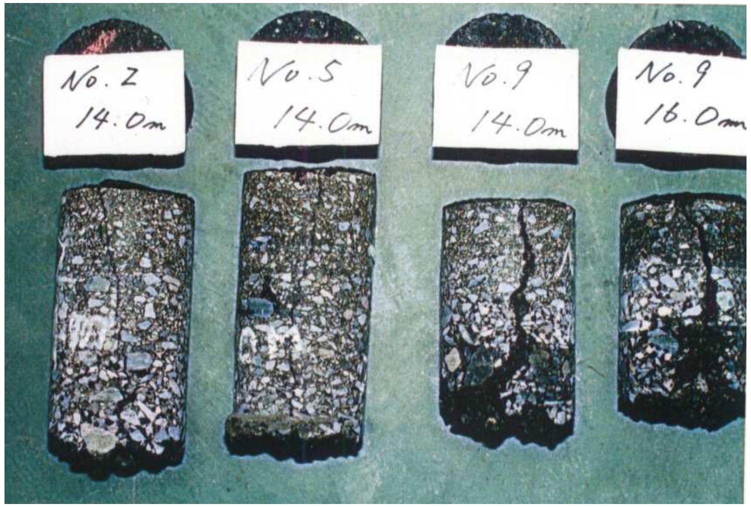


Site-A

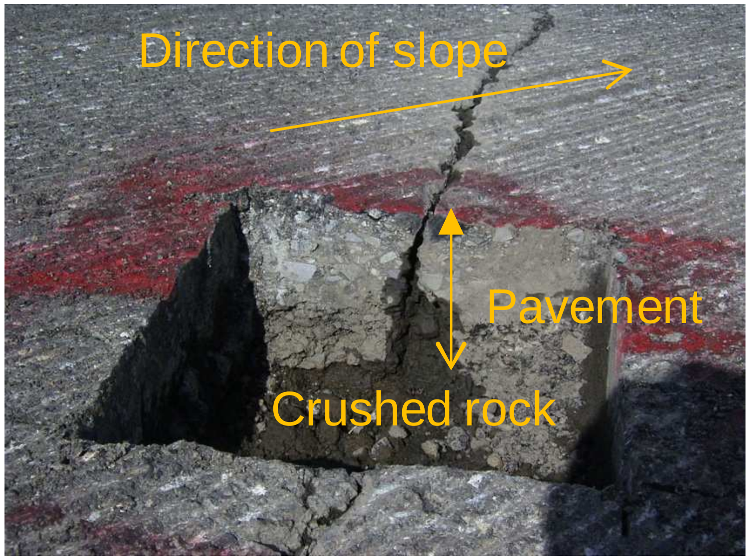


Cracks of Asphalt-facing discovered

just after the earthquake（1996/3/8）

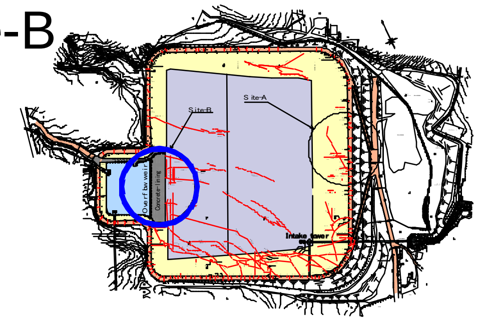


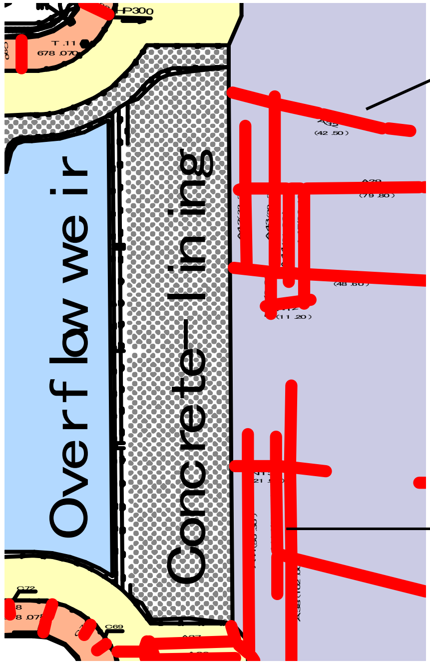
Cracks in Asphalt Facing with boring core

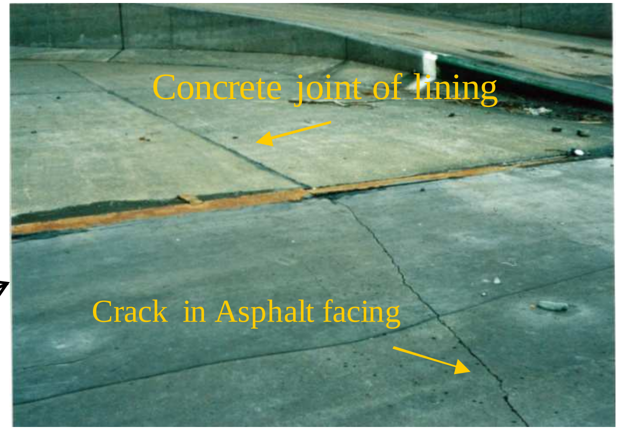


Cracks in Asphalt Facing with opencut on repair work

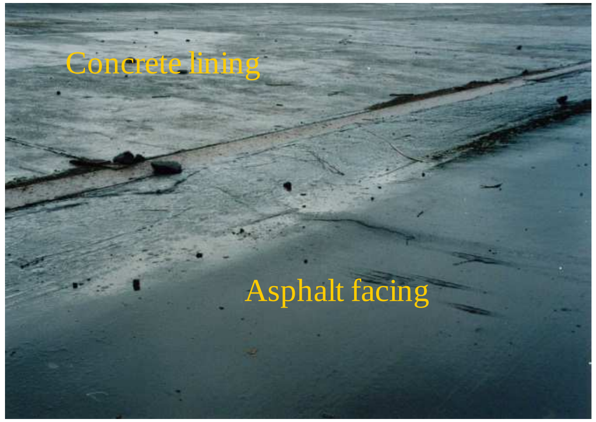
Site-B



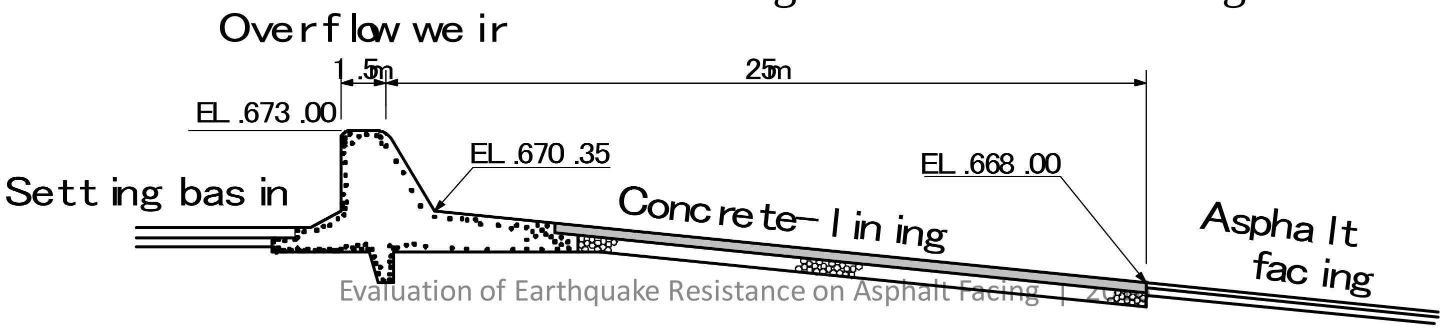




Cracking due to concrete joint of lining



Cracking due to difference in rigidities



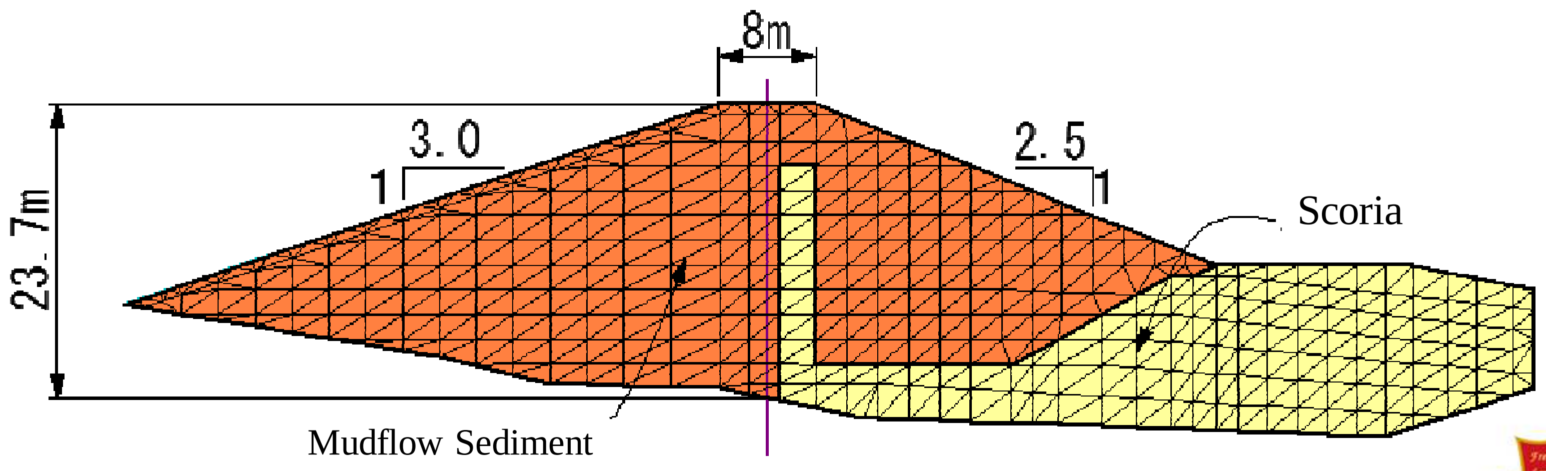
2. DAMAGE EVALUATION OF IMPERVIOUS ZONE DURING EARTHQUAKE

2.1Seismic Response Analysis of Higashi-Fuji Dam

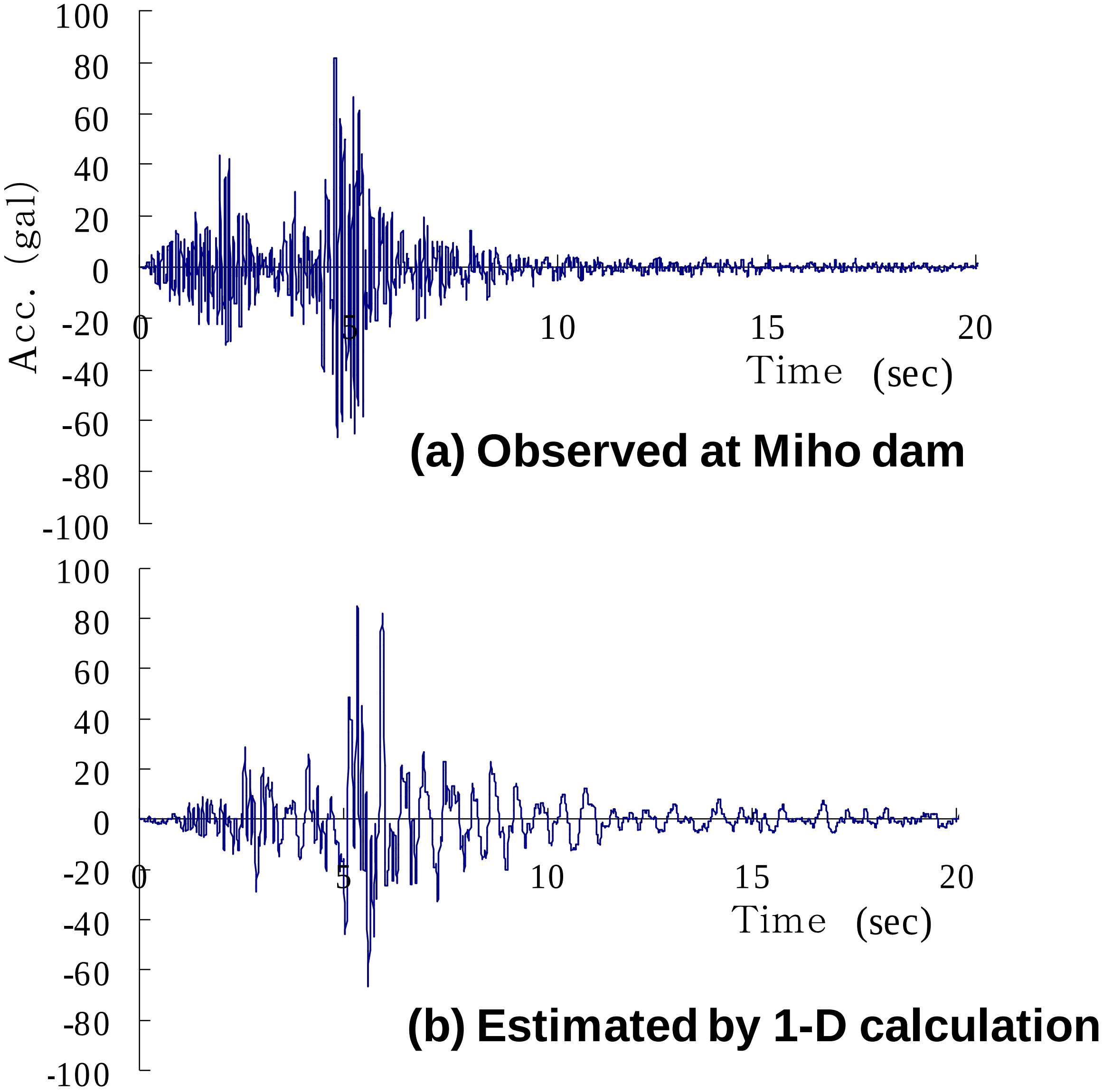
Seismic response Analysis described in the second report (Nakamura, etal.2010b)

- A finite element model used in maximum cross section
- The equivalent Linear analysis by applying H-D model

Analysis Model of Higashi-Fuji Dam

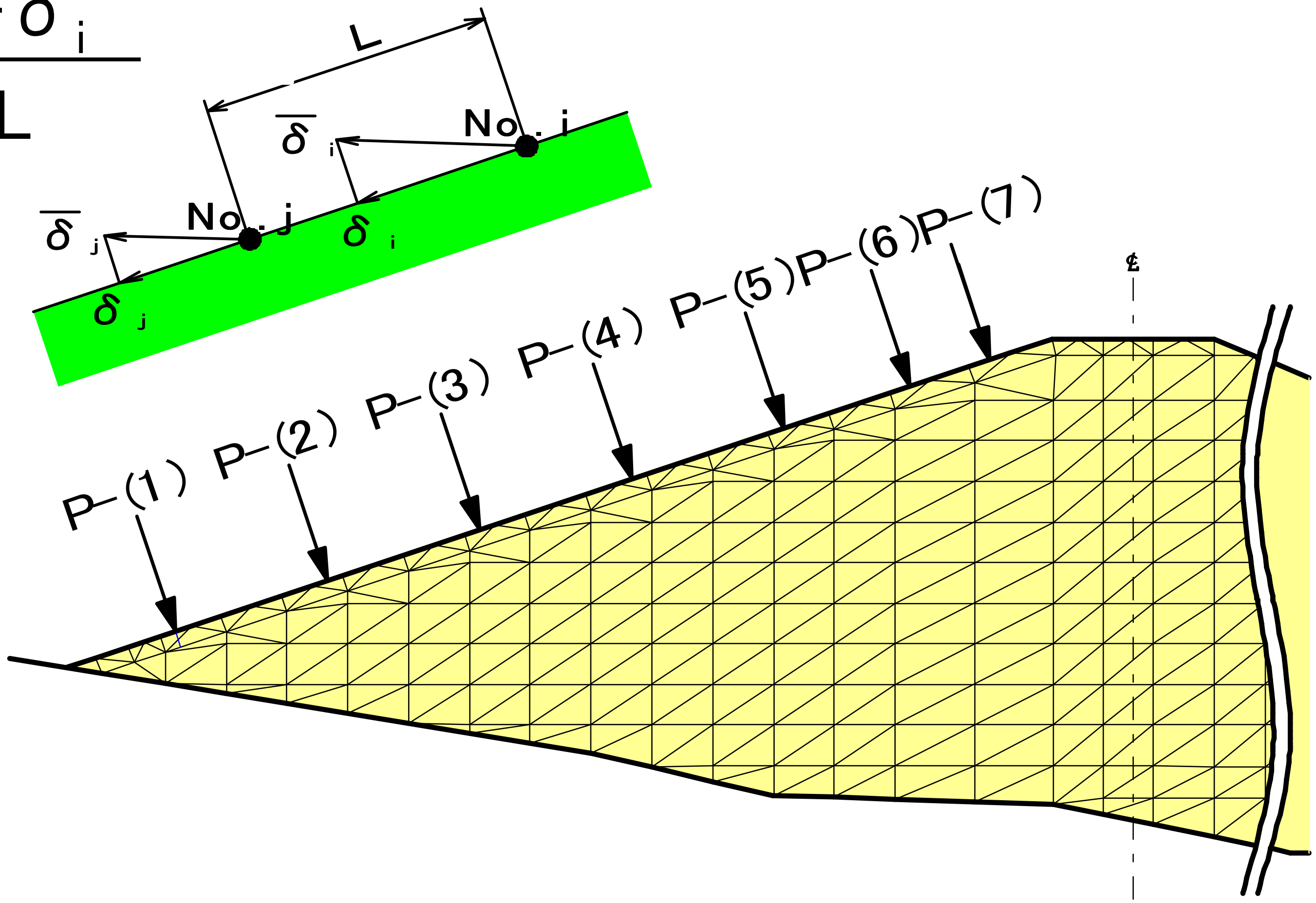


Input Acceleration Wave



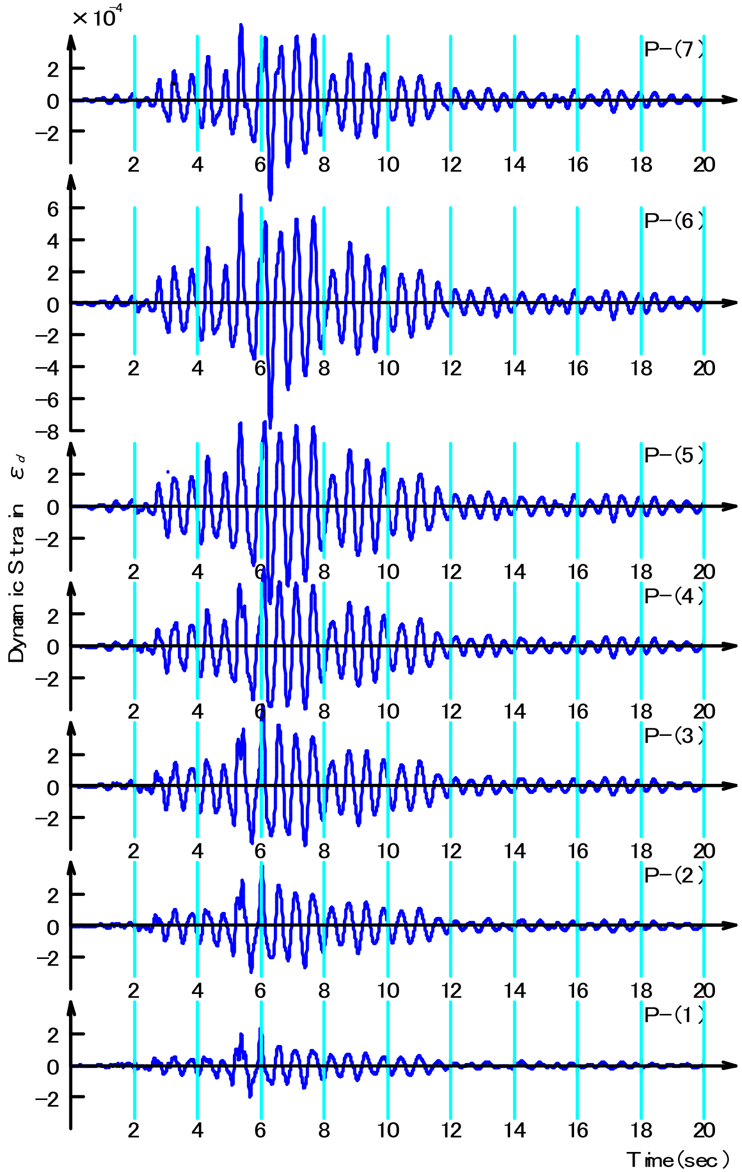
Definition of Dynamic Strain（along Sloping Surface）

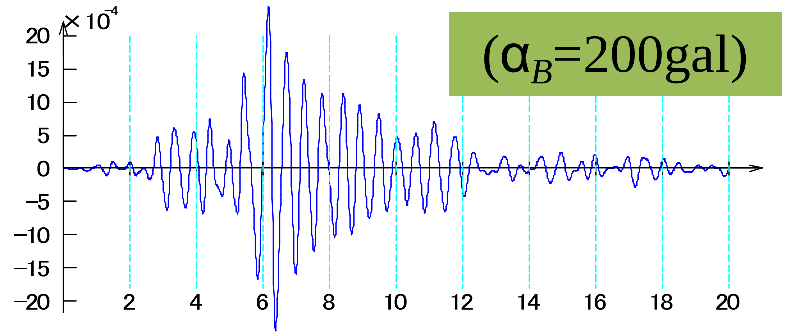
$$\varepsilon_d = \frac{\delta_j - \delta_i}{L}$$

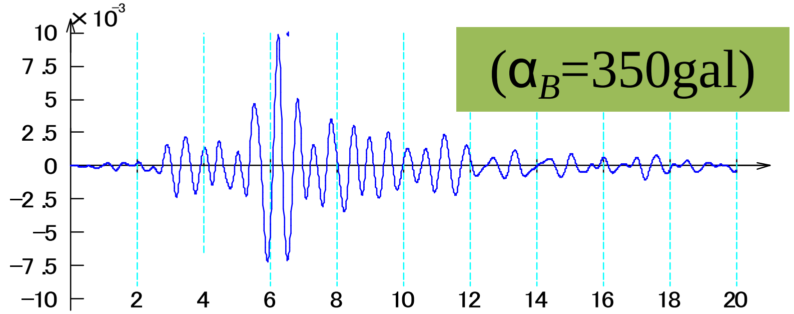


Dynamic Strain Evaluation

Time History of Dynamic Strain (α_B＝85gal)



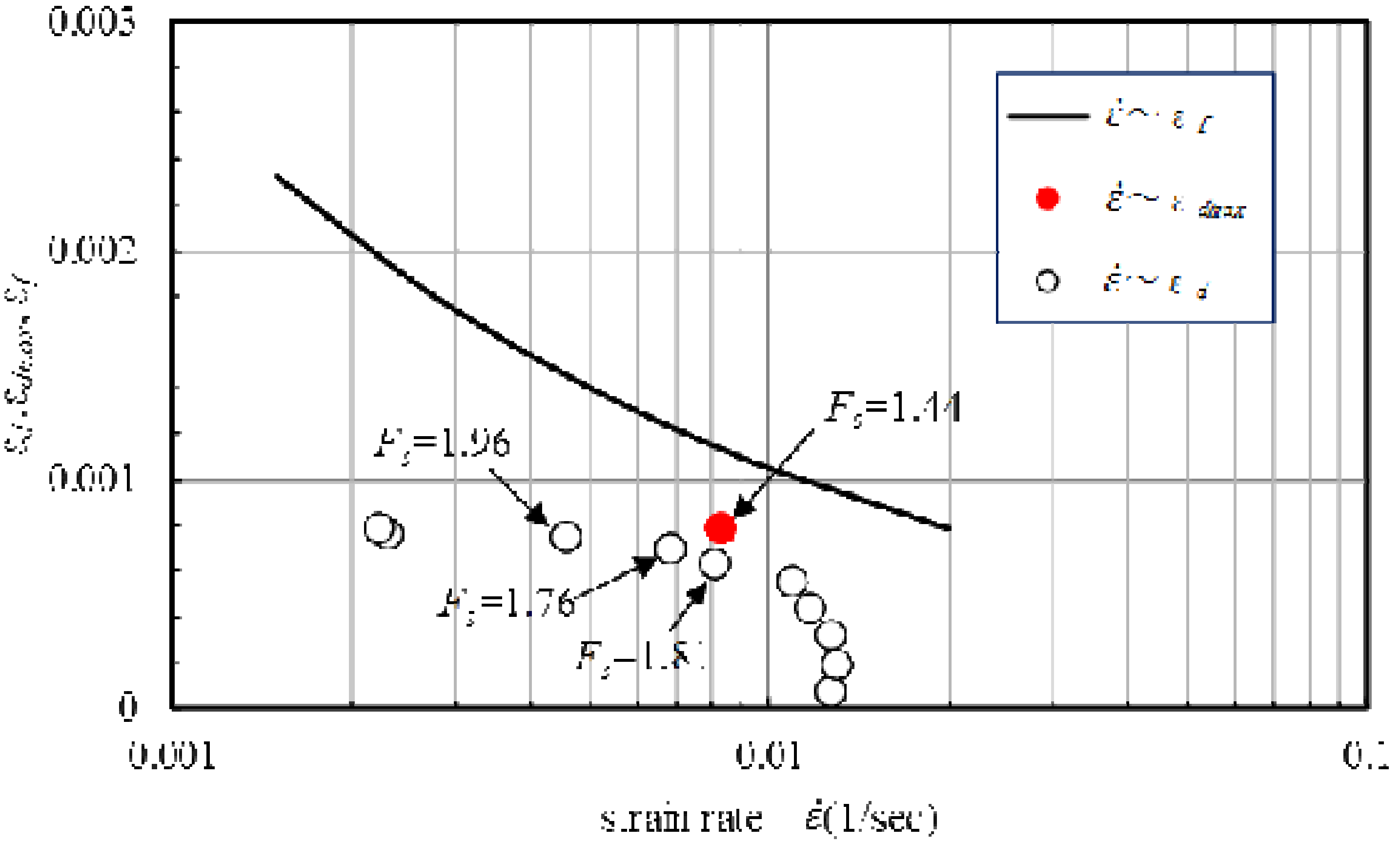




$\dot{\varepsilon}$

2.2 Evaluation in terms of Axial Failure Strain

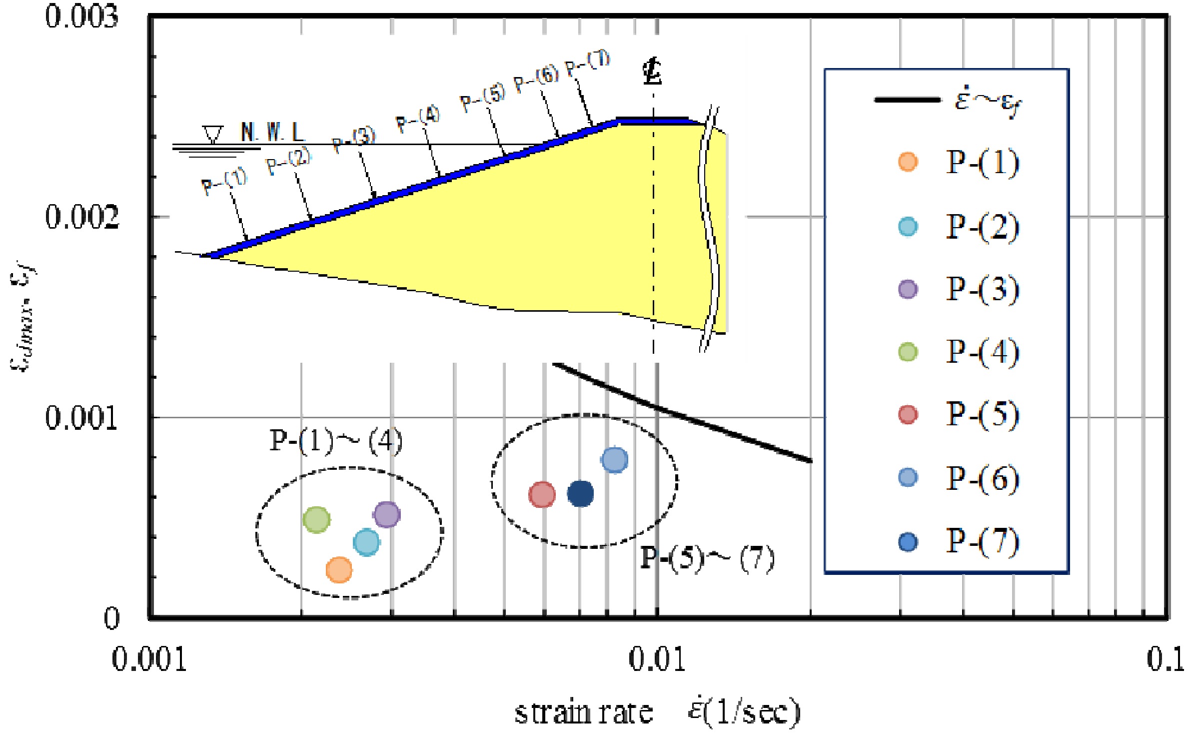
Dynamic Strain and Failure Strain in P-(6)



○ : the values of ε_d and $\dot{\varepsilon}$ in a time interval Δt=0.01sec

● : the value of $\dot{\varepsilon}$ is estimated on average as a quarter of period of wave at this peak can be read as Δt=0.0095sec.

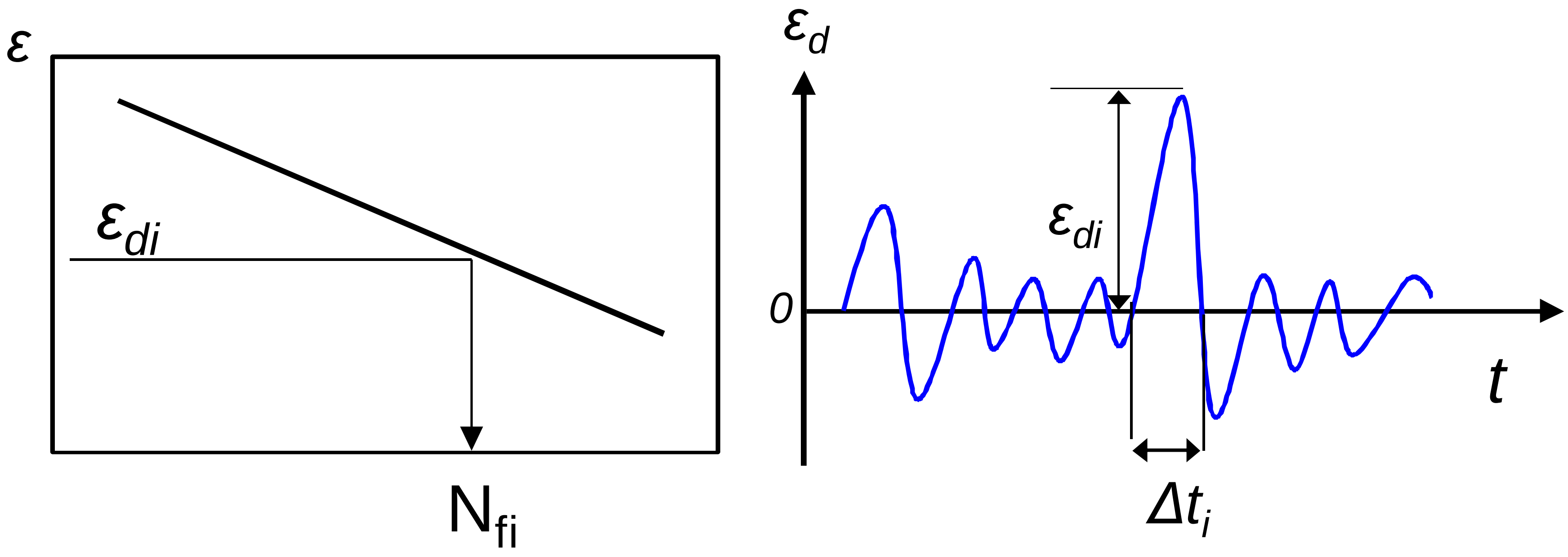
Failure Evaluation along slope (α_B =85gal, St60/80)



- In this type of safety evaluation, the condition F_s < 1.0 should be appropriate to recognize its critical state of the facing zone.
- Taking reduction in flexibility due to aging effects of more than 25years into account

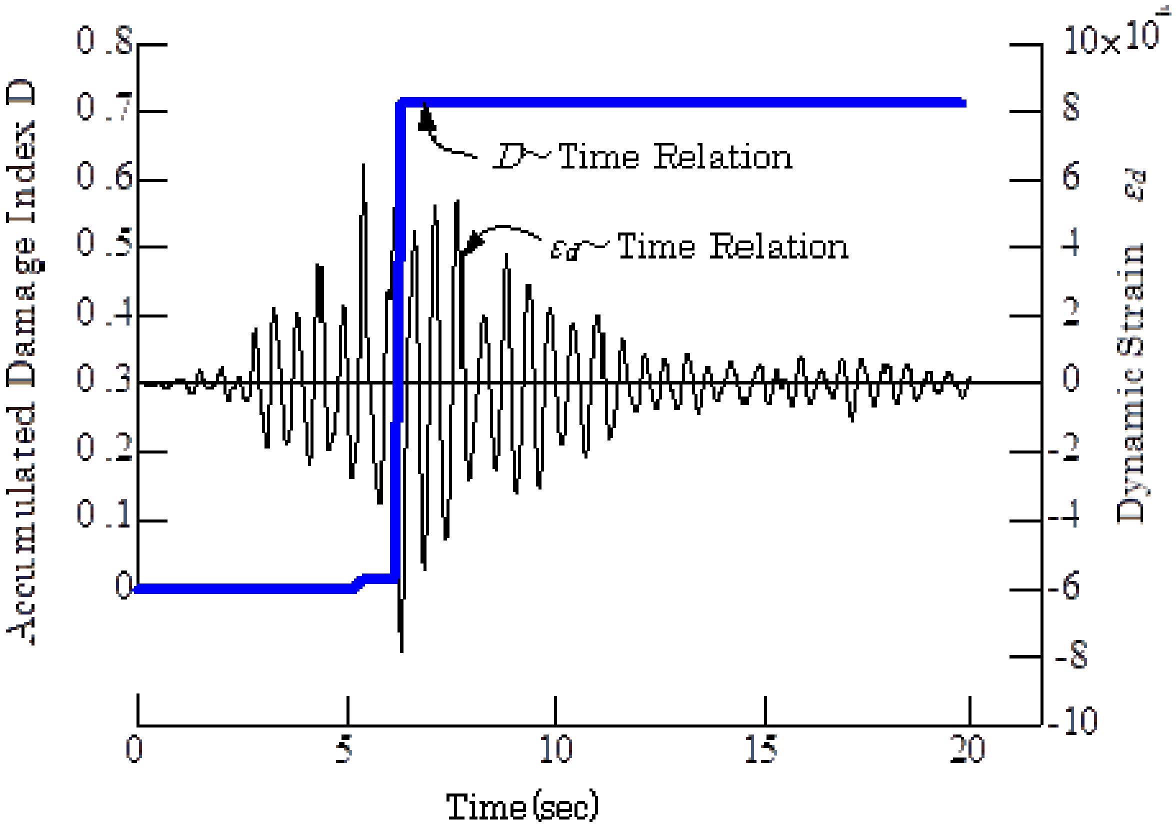
2.3 Evaluation in terms of Accumulated Damage

Concept of accumulated damage



$$D = \sum \frac{0.5}{N_{fi}}$$

Accumulated Damage Evaluation in P-(6)



3. DAMAGE EVALUATION OF IMPERVIOUS ZONE AT L1, L2 E.Q MOTION

Limit states of the structure are classified (JAEE, 2006)

1. No damage (seismic performance 1)

2. Functional soundness is retained but repair works are necessary (seismic performance 2),

3. Structural function is lost though not in collapsed or complete failure states (seismic performance 3),

4. Structure is collapsed or completely failed.

In the structural design of dam facilities, which are regarded as highly essential, it might be necessary to confirm that the seismic performance 2 should be satisfied against the L2 earthquake motion.

Seismic Performances and Limit States of Main Levee and Impervious Zone

	Seismic Performance 1	Seismic Performance 2	Seismic Performance 3
Seismic Performance	Level 1 Earthquake	Level 2 Earthquake	
	functional soundness is retained and ready in service without repair even after earthquake	functional restoration is attained in short duration after earthquake	whole structural system does not collapse due to earthquake
Limit State	Serviceability Limit State / retain functional soundness	Damage-Control Limit / keep in restricted damage	Survival Limit State / prevent fatal damage
Goal of Seismic Performance in Impervious Zone	・no cracking ・structural element doesn't fail	sequential cracks spreading whole region of impervious zone don't happen	—
Goal of Seismic Performance in Main Levee	・structural failure doesn't happen ・no sliding failure ・no residual settlement	structural restoration is feasible and storage and discharge functions are maintained in dam, even when its structural damage happens due to earthquake	dam doesn't collapse in short duration and its storage function is thoroughly maintained, even though heavy structural damage happens with slight defect in storage function

3.1 Definition of Safety Factors

- Mterial factor (γ_m)
  uncertainties in testing, specimen, time dependency

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$$\varepsilon_r = \varepsilon_f / \gamma_m \qquad (\gamma_m = 1.3)$$

ε_r: design value
ε_f : failure strain

- Structural analysis factor (γ_a)
  uncertainties in structural analysis

$$\varepsilon_a = \varepsilon_{dmax} \times \gamma_a \quad (\gamma_a = 1.1)$$

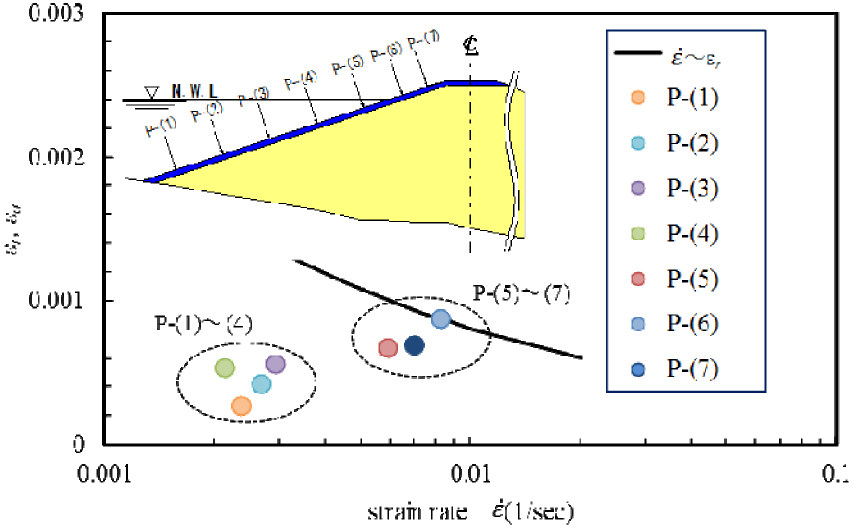
ε_a :response value
ε_{dmax}:max strain

- Evaluation of structural safety (γ_i)

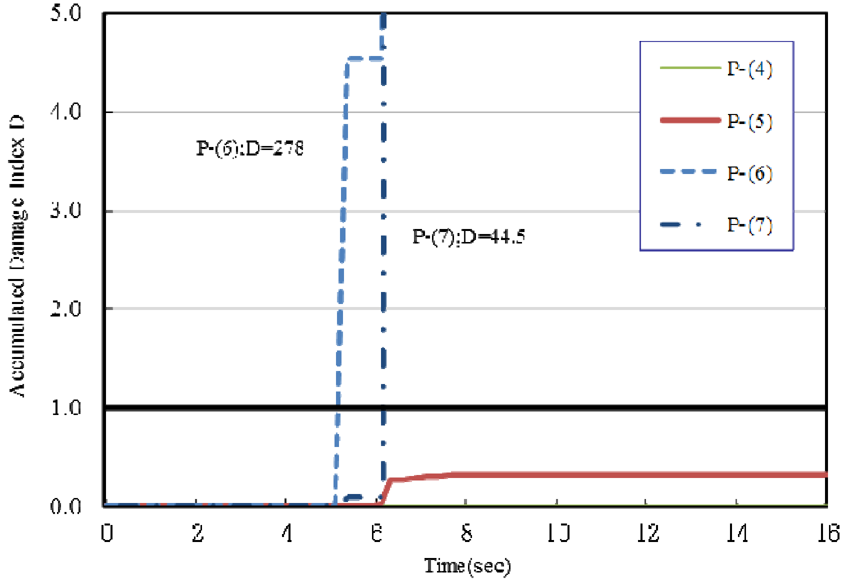
$$\gamma_i \times (\varepsilon_a / \varepsilon_r) \leqq 1.0 \qquad (\gamma_i = 1.0)$$

γ_i :structural factor

3.2 Damage Evaluation by use of Safety Factor

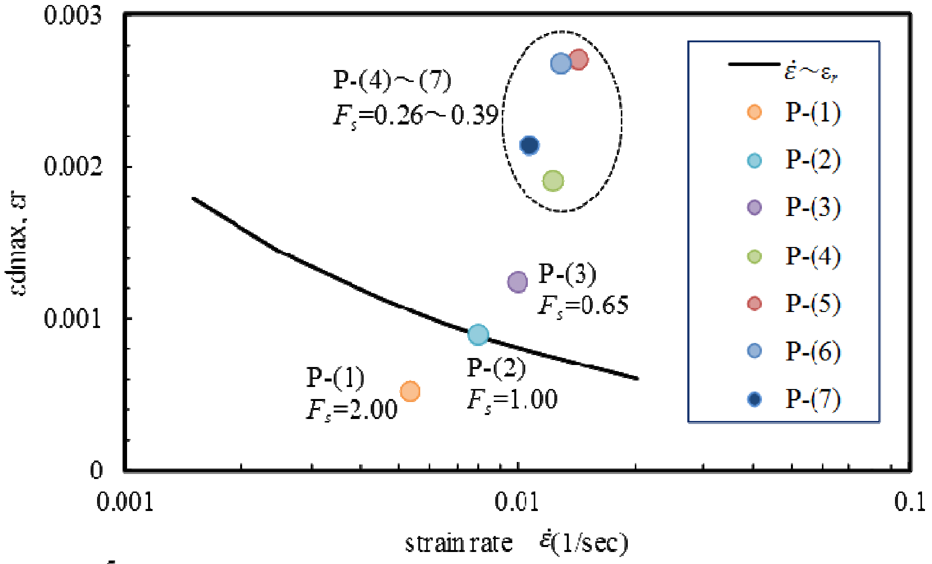


Safety Evaluation by Strain at Failure (α_B =85gal, St60/80)

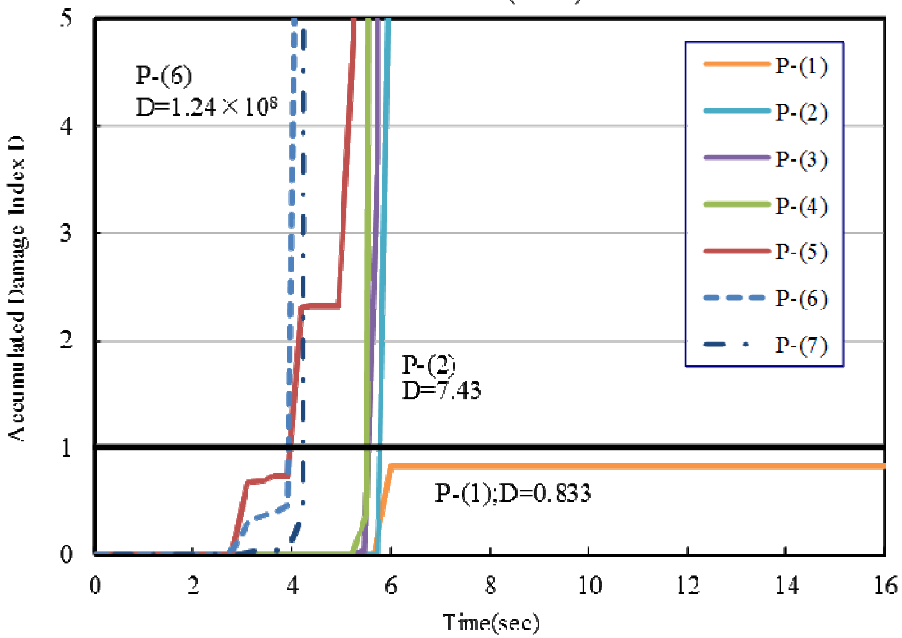


Safety Evaluation by Accumulated Damage (α_B =85gal, St60/80)

3.3 Damage Evaluation for L1 earthquake (αB=200gal)

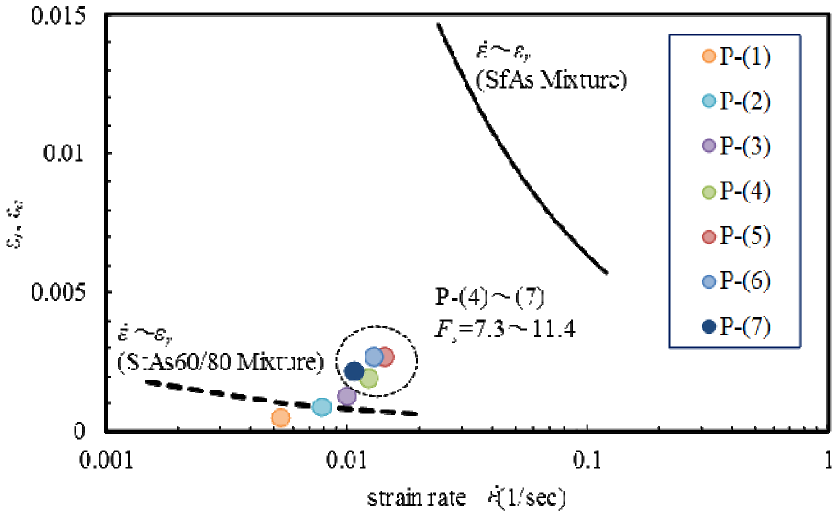


Safety Evaluation by Strain at Failure (α_B =200gal, St60/80)

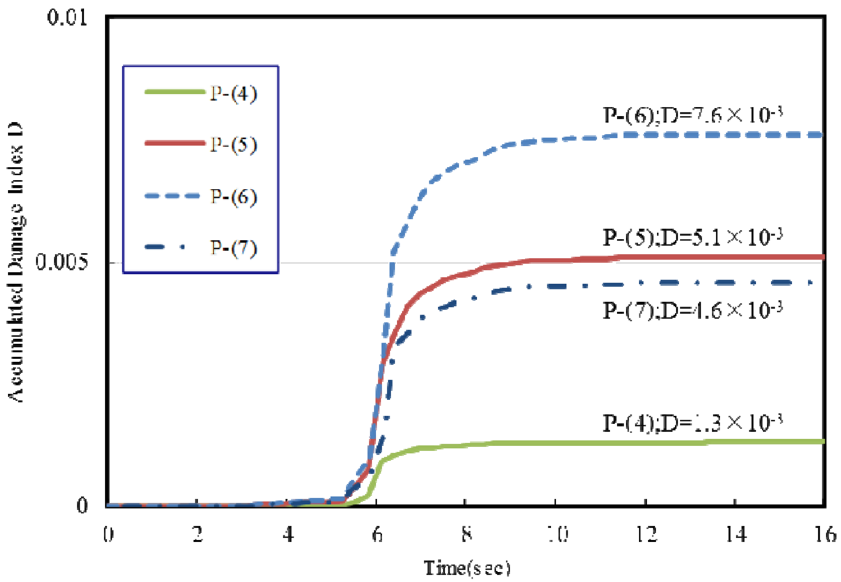


Safety Evaluation by Accumulated Damage (α_B =200gal, St60/80)

3.3 Damage Evaluation for L1 earthquake (αB=200gal)

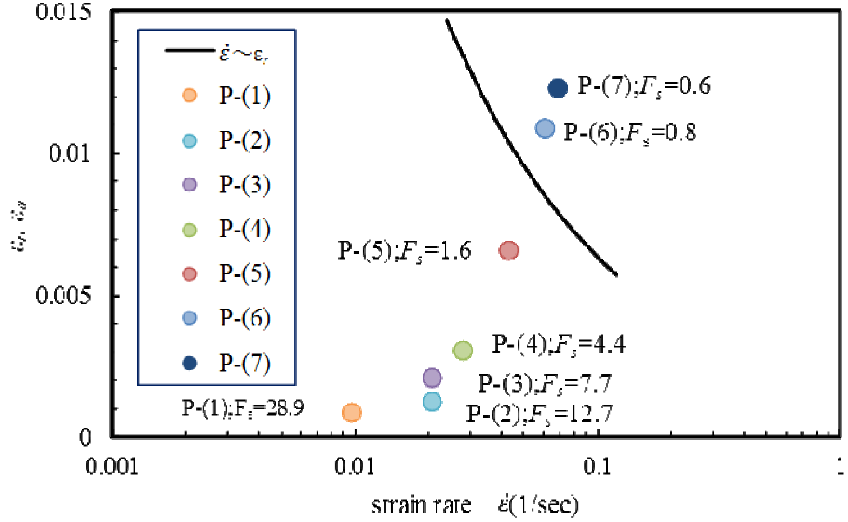


Safety Evaluation by Strain at Failure (α_B =200gal, SfAs)

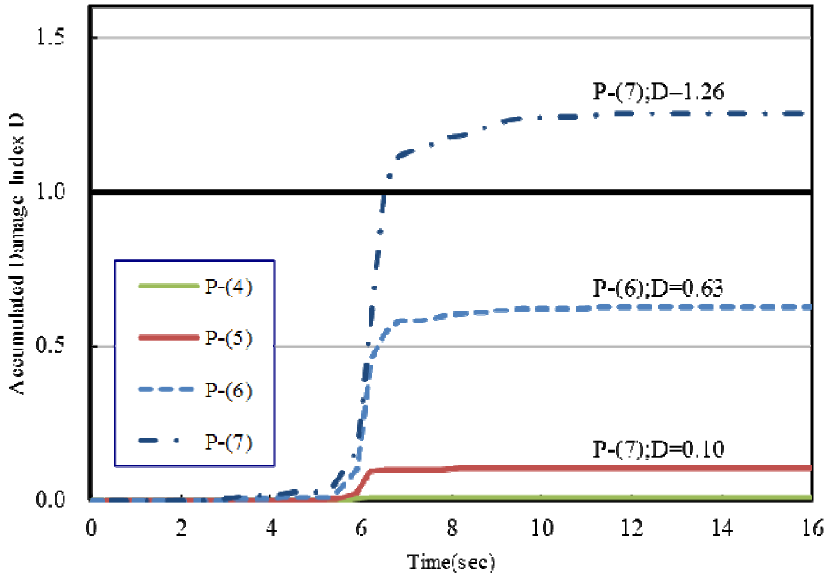


Safety Evaluation by Accumulated Damage (α_B =200gal, SfAs)

3.4 Damage Evaluation for L2 earthquake (αB =350gal)



Safety Evaluation by Strain at Failure (α_B =350gal, SfAs)



Safety Evaluation by Accumulated Damage (α_B =350gal, SfAs)

CONCLUSIONS-1

◆Two different ways of failure evaluation are proposed. Both procedures, by taking strain rate dependency of materials into account, indicated relatively consistent results. Evaluation for the earthquake causing real damage also revealed formation of devastated area in the impervious zone near the crest, which supports actual suffering states.

◆In applying the proposed procedures for a practical design, it should be necessary to consider the safety factors defined in the limit state design method. The values of the safety factors are given as the material factor $\gamma m=1.3$ and the structural analysis factor $\gamma a=1.1$, which suggests that application of the concept of the safety factor is fully satisfactory for the earthquake resistant design of the asphalt mixture impervious facing zone.

CONCLUSIONS-2

◆ It is recognized that the impervious zone composed of the improved asphalt mixture SfAs gives sufficiently safe side value in damage evaluation for the L1-level earthquake. In the L2-level earthquake, though some cracking failures are anticipated to occur near the dam crest, such damages of the impervious zone as involving severe leakage of the reservoir water are not probable because much less probability of failure is proved in the analysis in the lower part of the dam below the high water level.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