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EARTHQUAKE SAFETY OF EXISTING DAMS

Dr. Martin Wieland

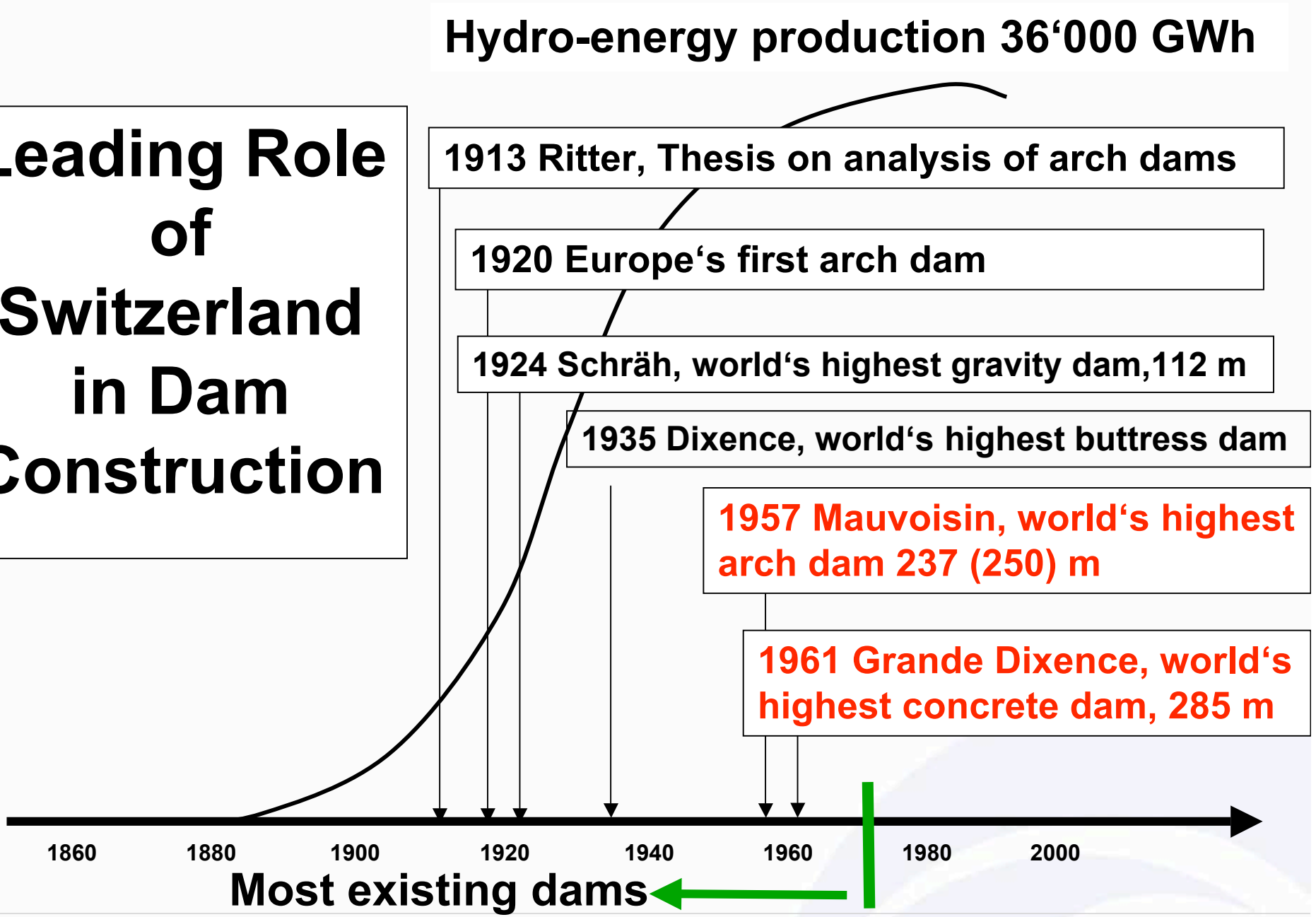
Chairman, ICOLD Committee on Seismic Aspects of Dam Design

Pöyry Energy Ltd., Zurich, Switzerland

Formerly Electrowatt-Ekono Ltd.

LARGE DAMS IN SWITZERLAND

Leading Role of Switzerland in Dam Construction



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Grande Dixence Gravity Dam, Switzerland

Highest concrete dam in world

Dam height: 285 m

Dam volume:
6 million m^3

Reservoir volume:
400 million m^3

Crest length: 695 m

Completion date: 1961

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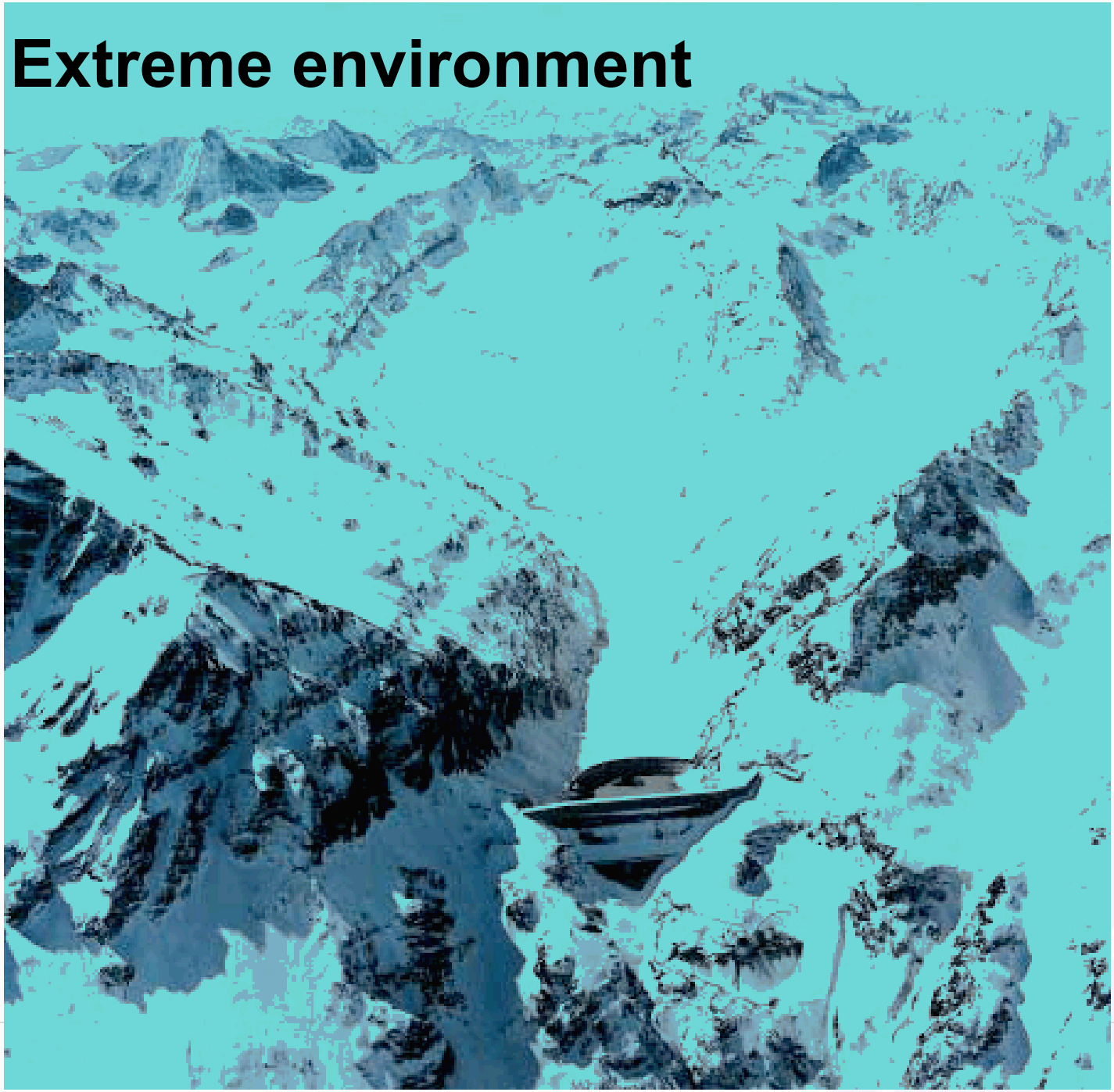
Extreme environment



Mauvoisin Arch Dam, 250 m Successful Operation for over 45 Years

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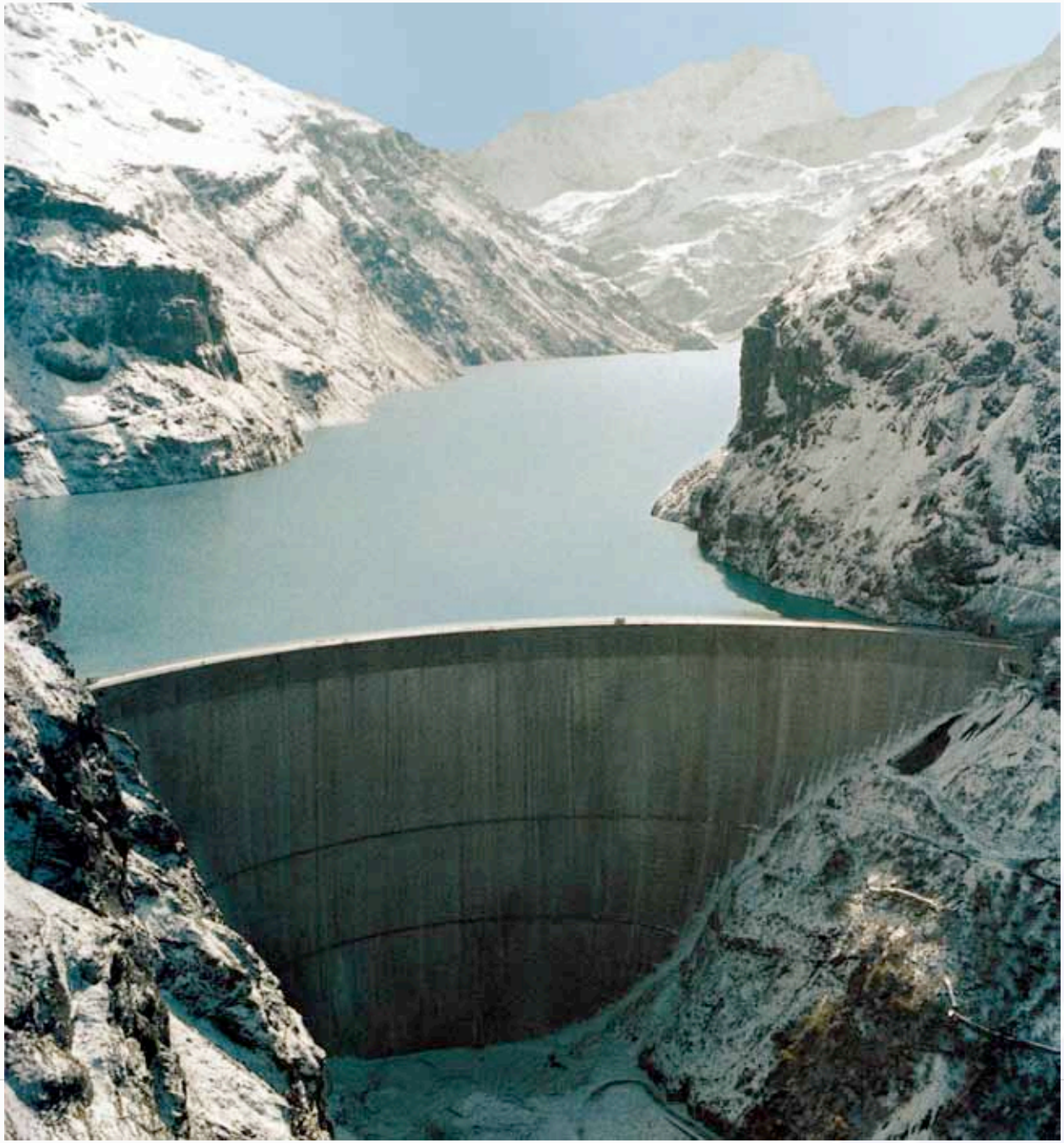

Mauvoisin dam heightening by 13.5 m to 250 m, completed 1991

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LARGE DAMS IN HIGHLY SEISMIC REGIONS

Usoy landslide dam, Lake Sarez, Tajikistan, Height: ca. 650 m, Landslide triggered by 1911 M = 7.3 earthquake, region of very high seismicity

‘Lake Sarez‘ Dam, unstable rock mass in reservoir of over 0.5 billion m^3

Nurek Dam, Tajikistan, 300 m

Enguri Arch Dam, 272 m

Rogun Dam, planned highest dam, 335 m

EXAMPLES OF MAJOR DAMS UNDER DESIGN AND/OR CONSTRUCTION IN SEISMIC AREAS

Bakhtyari arch dam, Iran, Height: 315 m, Zagros mountains

Bakhtyari arch dam, Iran, 315 m

Left abutment

Dibang gravity dam, India, 288 m foothills of Himalayas

Dibang Dam Project, India, 288 m

Mishmi Fault near Dibang Dam Site, India

Deriner arch dam, 250 m, Turkey


18.08.2006

Ghir arch-gravity dam, Iran, 128 m

Shear Keys at Contraction Joints

SEISMIC HAZARD

July 26, 2003 Miyagi Earthquake, Japan

Location	NS	EW	Vertical	Distance (km)
Magnitude 5. 5 Shock				
Yamoto	366	476	360 cm/s^2	4.1
Naruse	**603**	**2005**	**584**	3.9
Kasimadai	**516**	**489**	183	7.6
Nanngou	268	229	226	6.5
Magnitude 6.2 Main shock				
Yamoto	**667**	**850**	**1242**	4.2
Nangou	366	**491**	193	9.9
Naruse	**636**	**756**	**923**	1.0
Kasimadai	**1606**	**910**	**492**	10.5
Magnitude 5.3 Shock				
Kanan	**649**	356	**499**	1.1
Nangou	276	166	126	4.9
Wakutani	255	342	130	6.9

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Tokachi-Oki earthquake, Sept. 26, 2003
Effects on dams

Name of Dam	Height in meters	Type	Peak acc. at foundation in gals	Peak acc. at the crest in gals
Makubetsu	27	Earthfill	132	261
Bisei	47	Composite	NA	NA
Sahoro	47	Gravity	82	364
Kuttari	28	Rockfill	NA	NA
Iwamatsu	37	Gravity	NA	NA
Tokachi	84	Rockfill	43	155
Satsunai	114	Gravity	51	677
Urakawa	42	Gravity	102	124
Samani	44	Gravity	153	NA
Takami	120	Rockfill	54	325
Niikappu	103	Rockfill	156	276

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Seismic hazard at dam site in Australia

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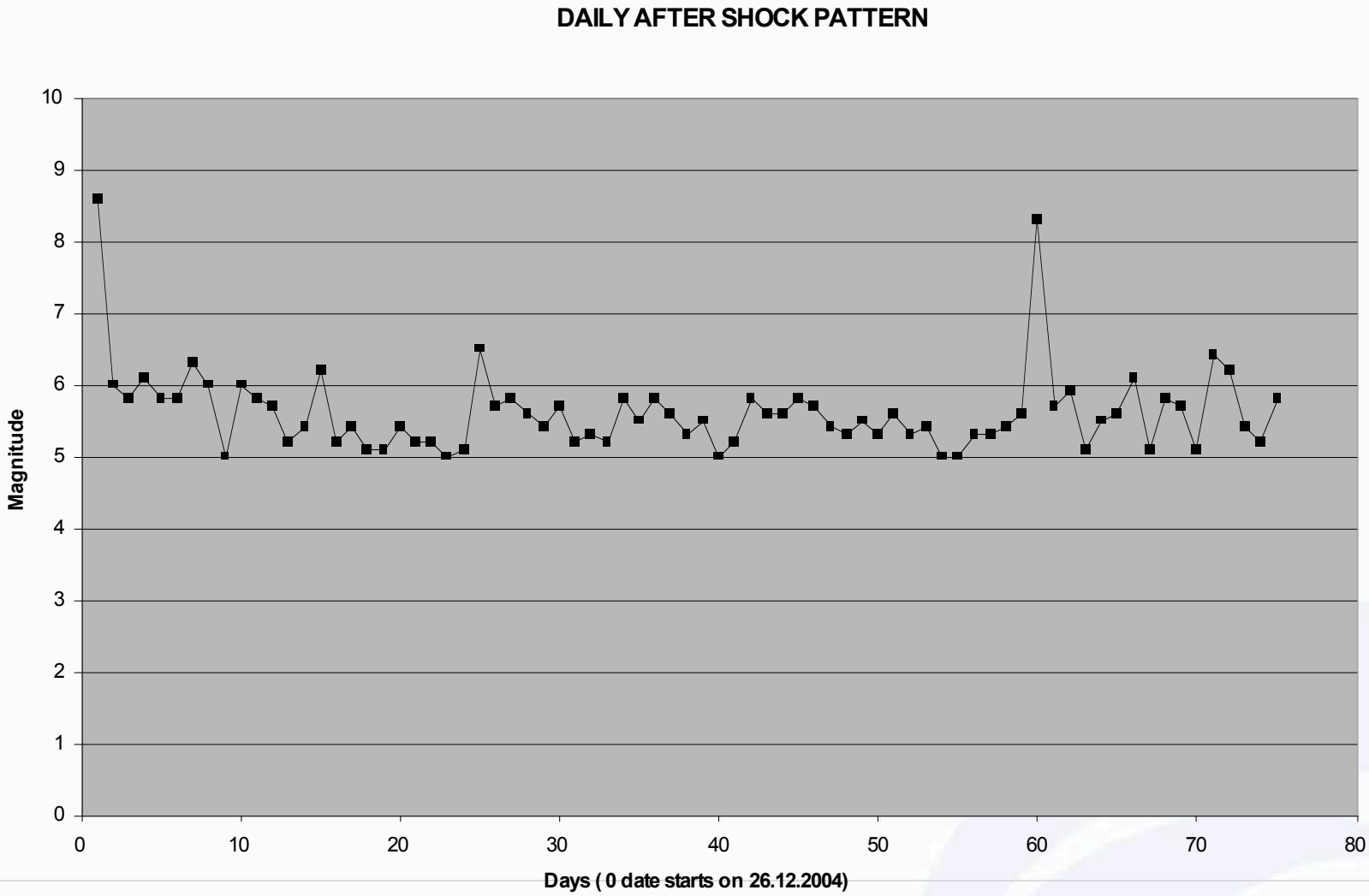
Seismicity in Andaman Sea after M = 9.1 earthquake of 26.12.2004



Kalpong rockfill dam, Andaman Islands, 2004

SEISMIC SAFETY OF EXISTING DAMS

EARTHQUAKE BEHAVIOUR AND DAMAGE OF LARGE CONCRETE DAMS

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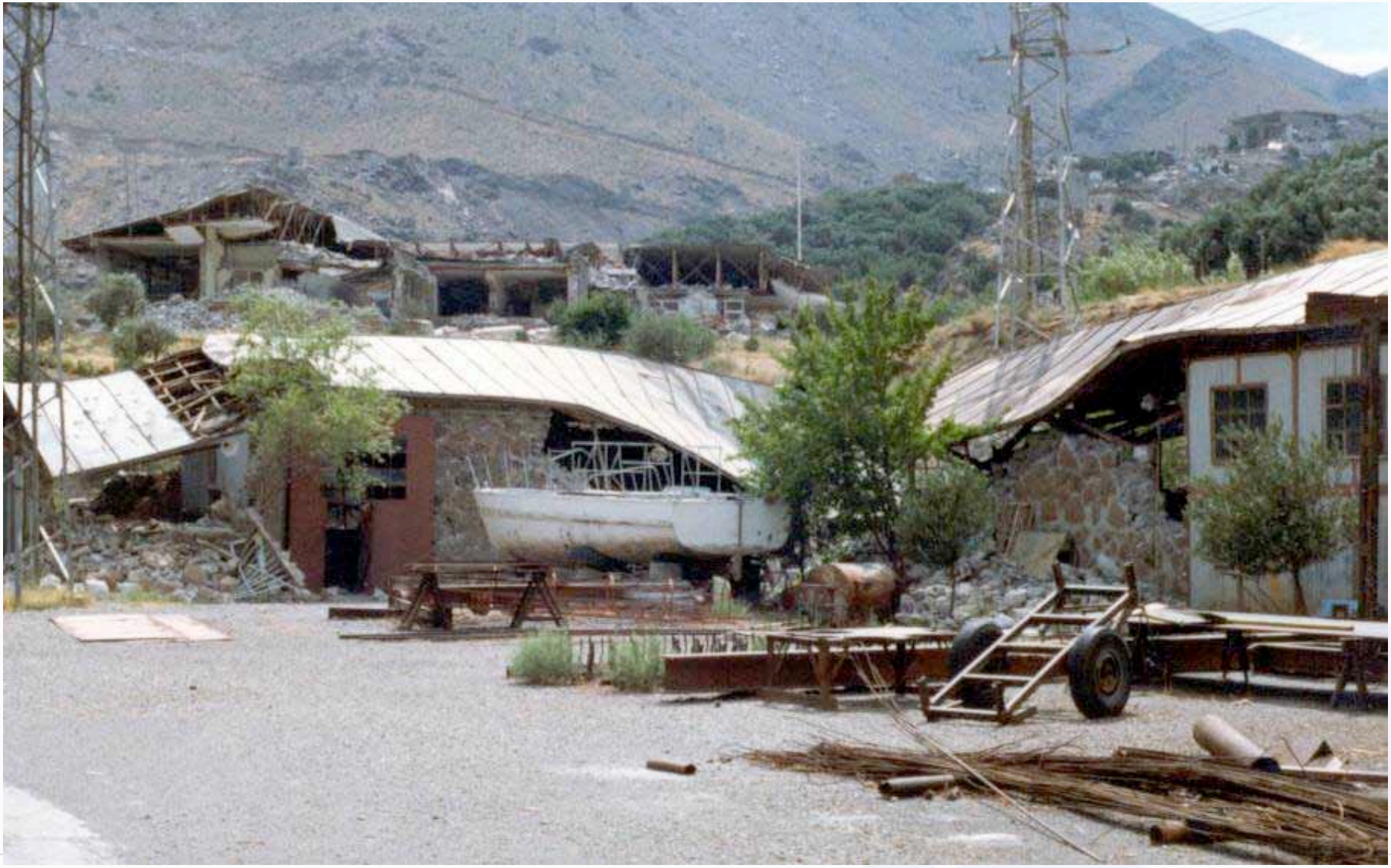
Manjil earthquake 1990, Sefid Rud Buttress Dam

Seismic Cracks in Sefid Rud Buttress Dam

Transmission tower failure due to rockfall

Buildings at dam site , Sefid Rud dam

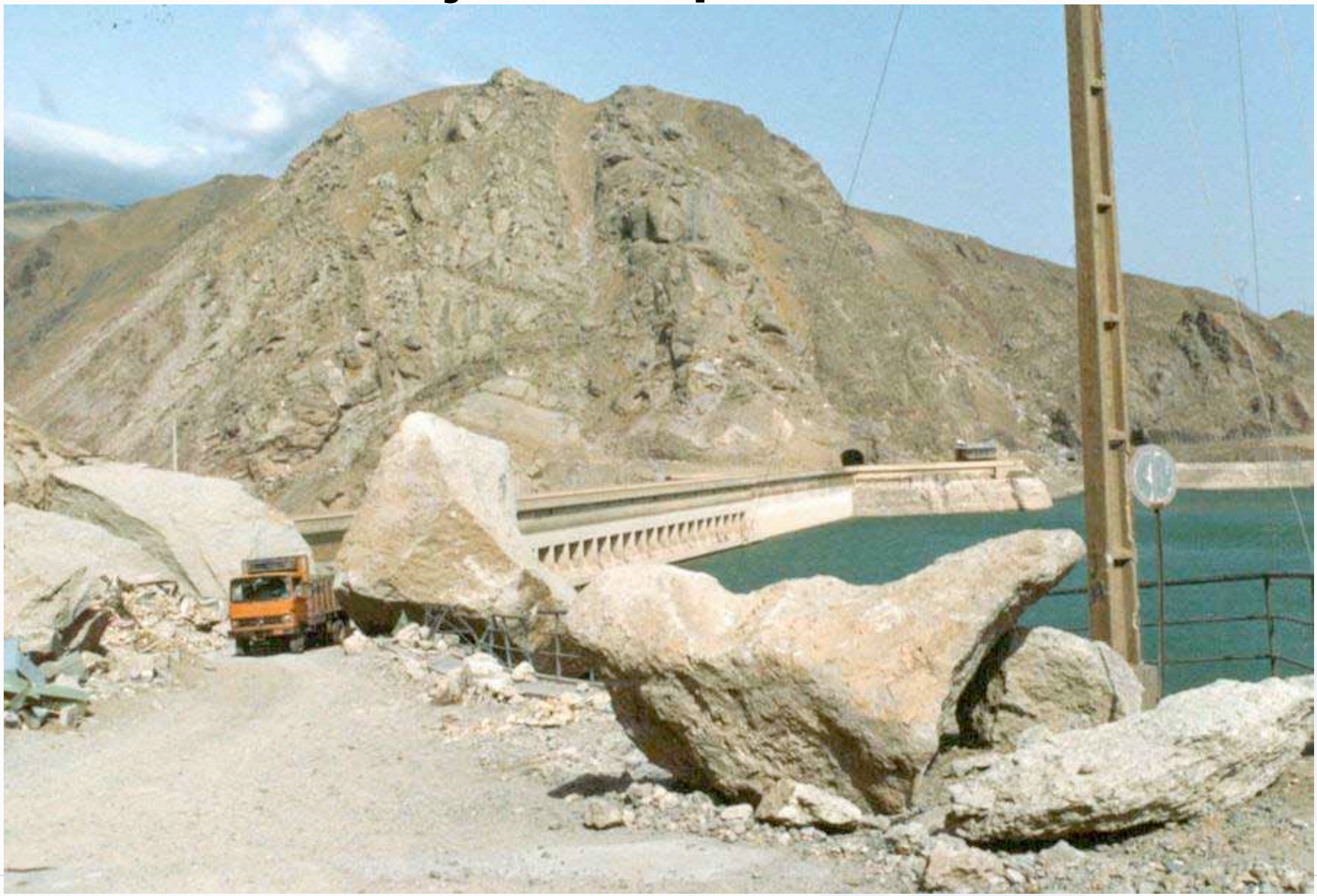


Manjil earthquake 1990

Manjil earthquake 1990

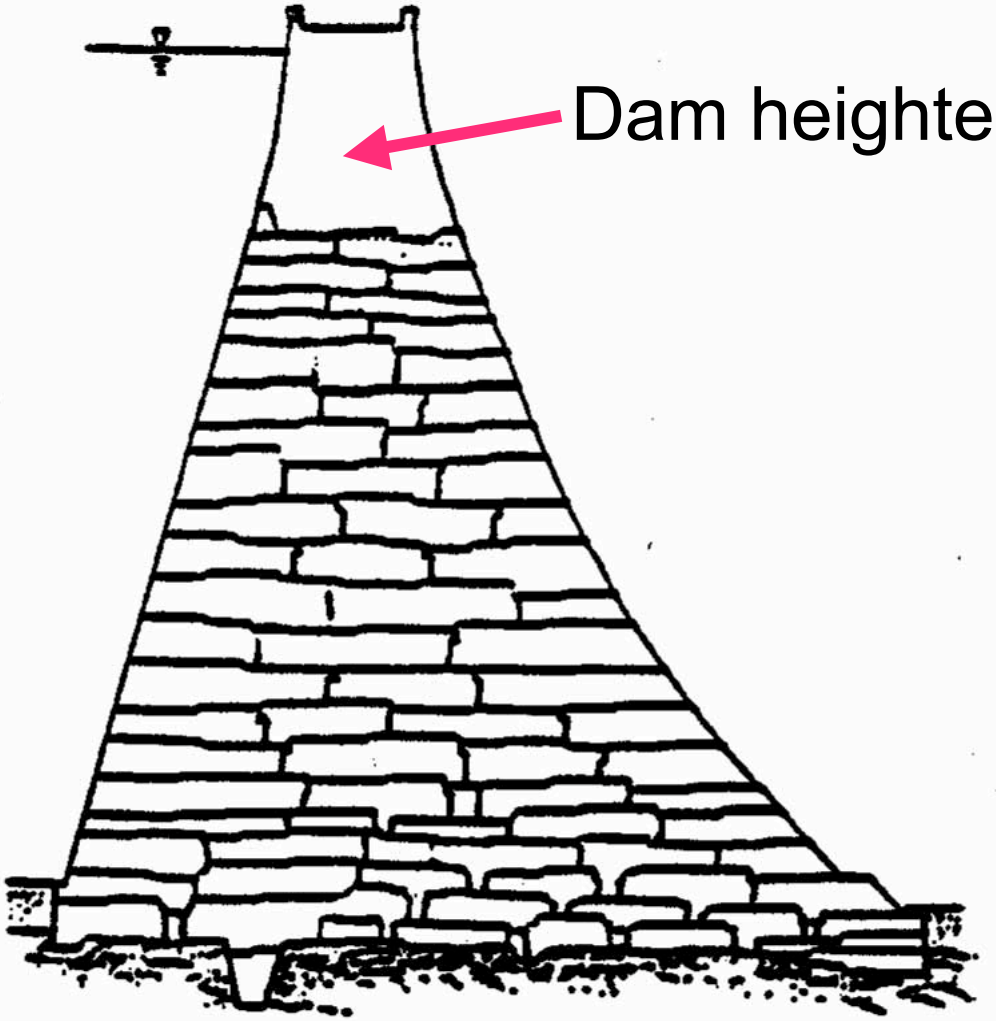
Rockfalls, Manjil earthquake

Manjil earthquake 1990

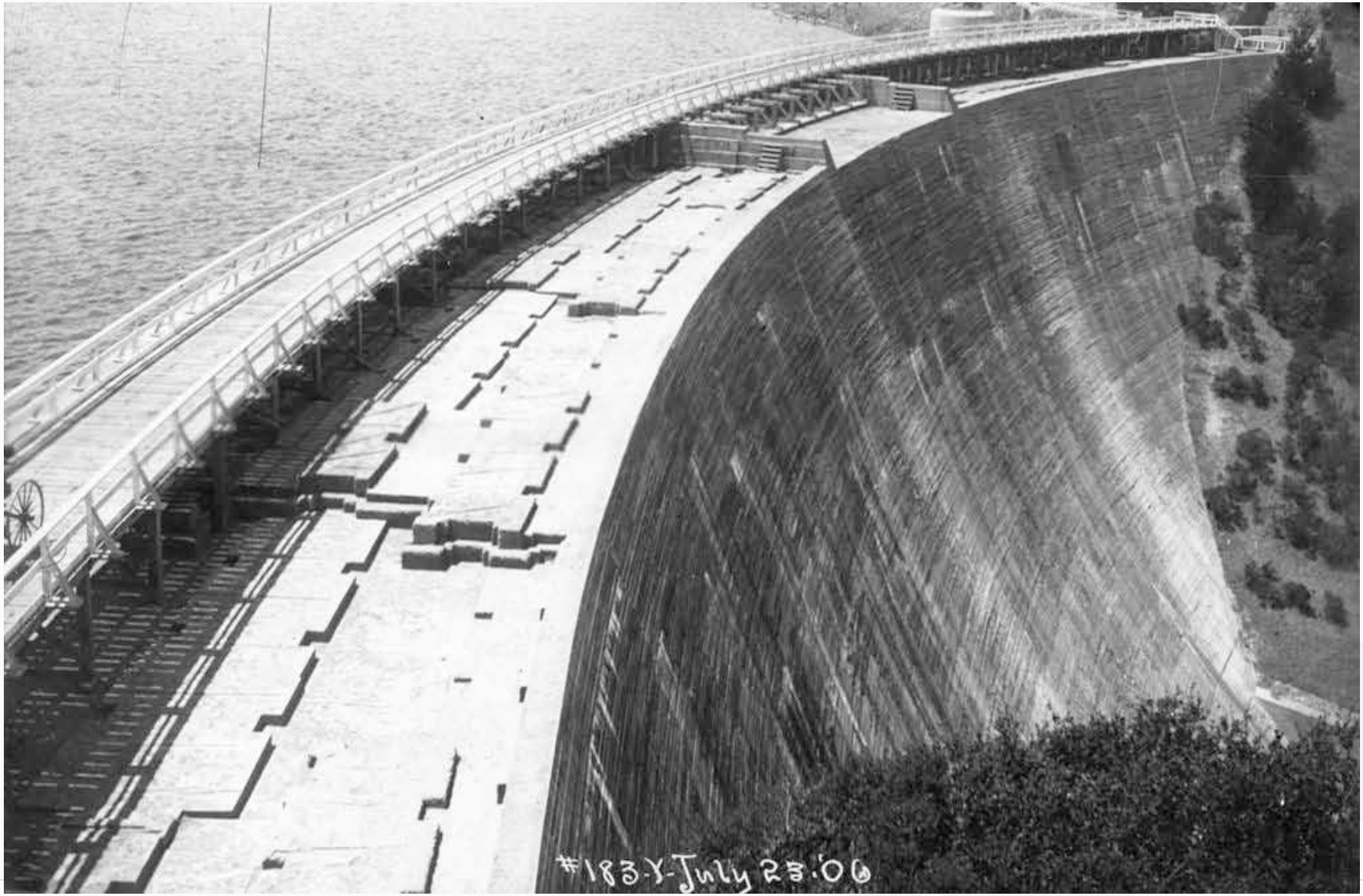


Manjil earthquake 1990

Lower Crystal Springs Gravity Dam survived 1906 San Francisco EQ undamaged

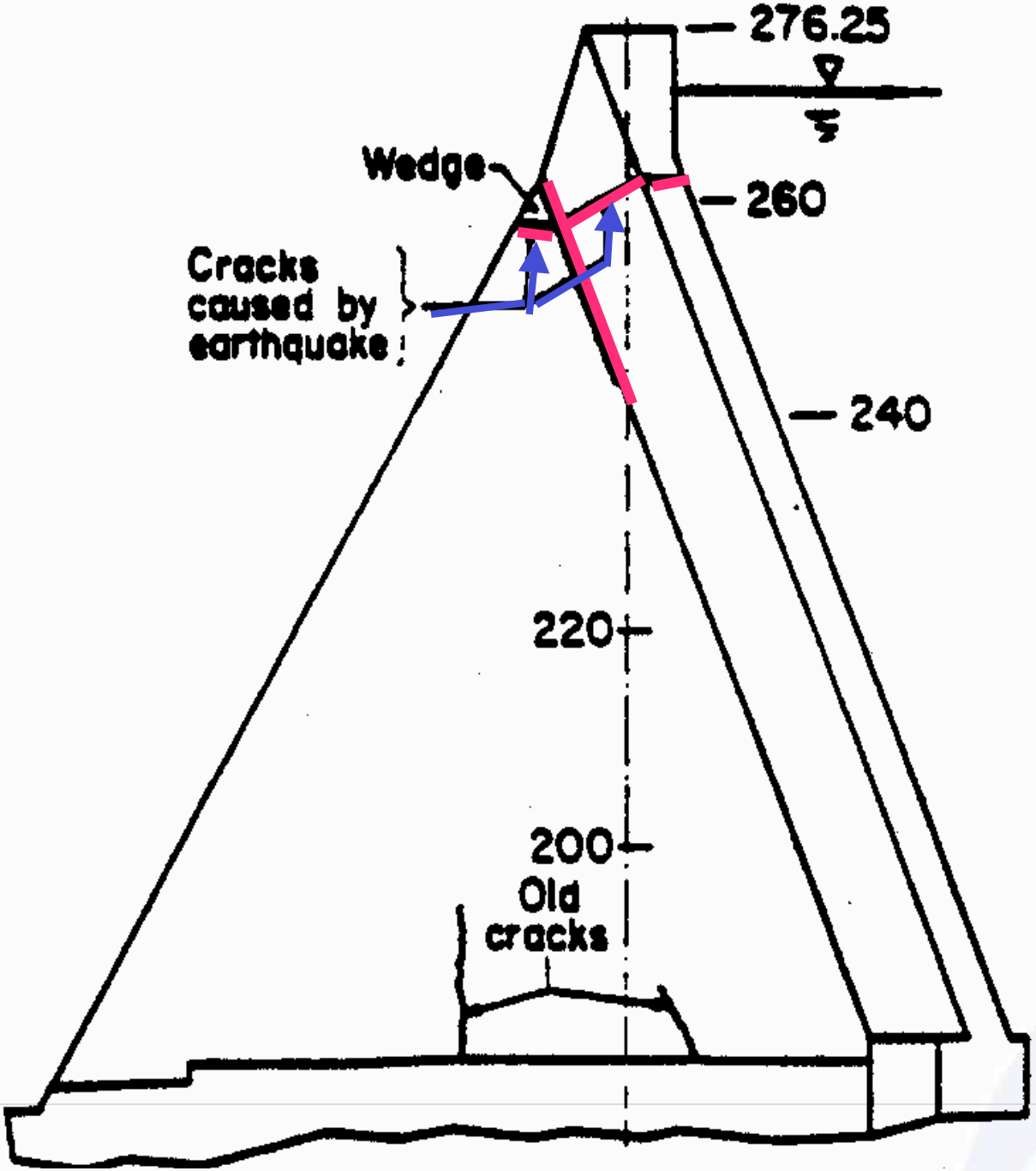


Lower Crystal Springs dam

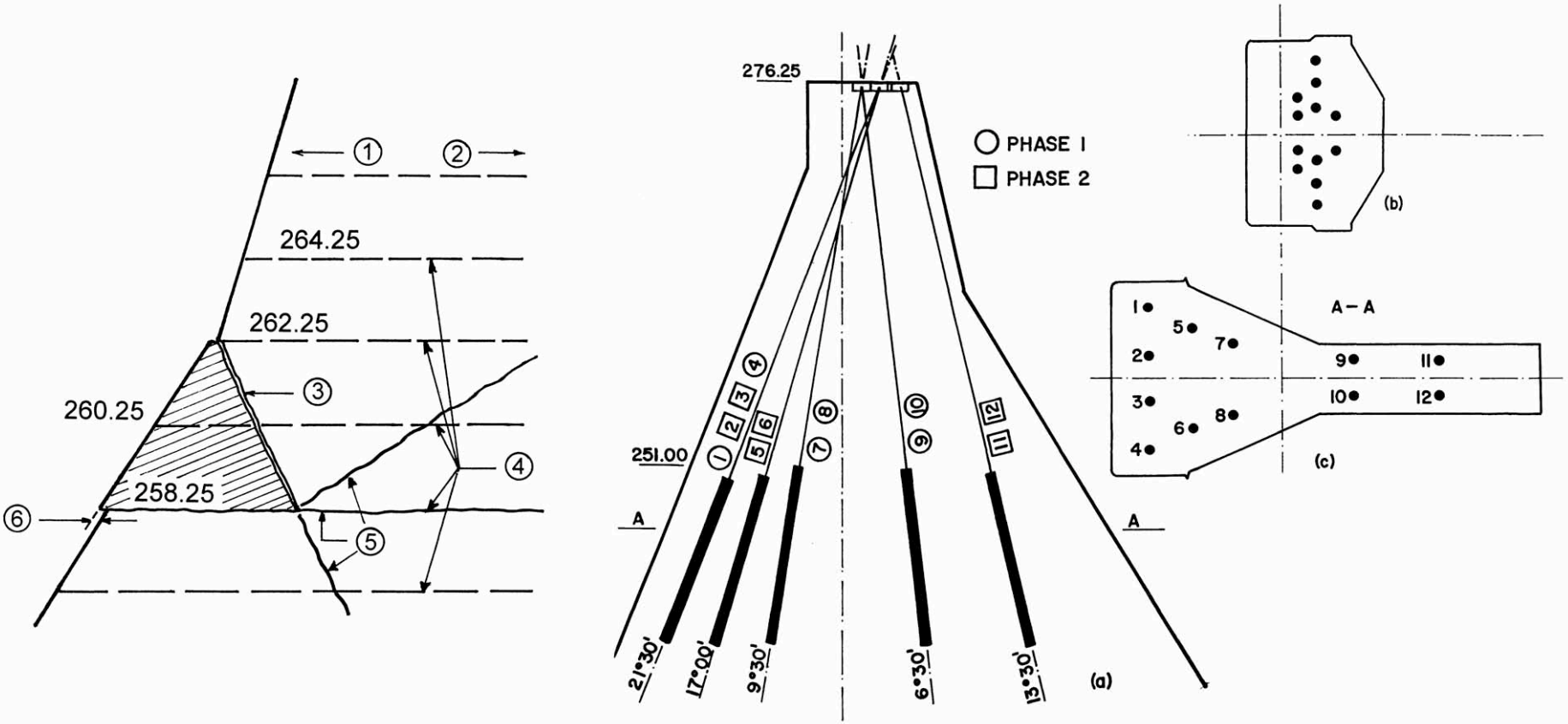


REPAIR OF DAMAGED CONCRETE DAMS

Cracks in Sefid Rud dam



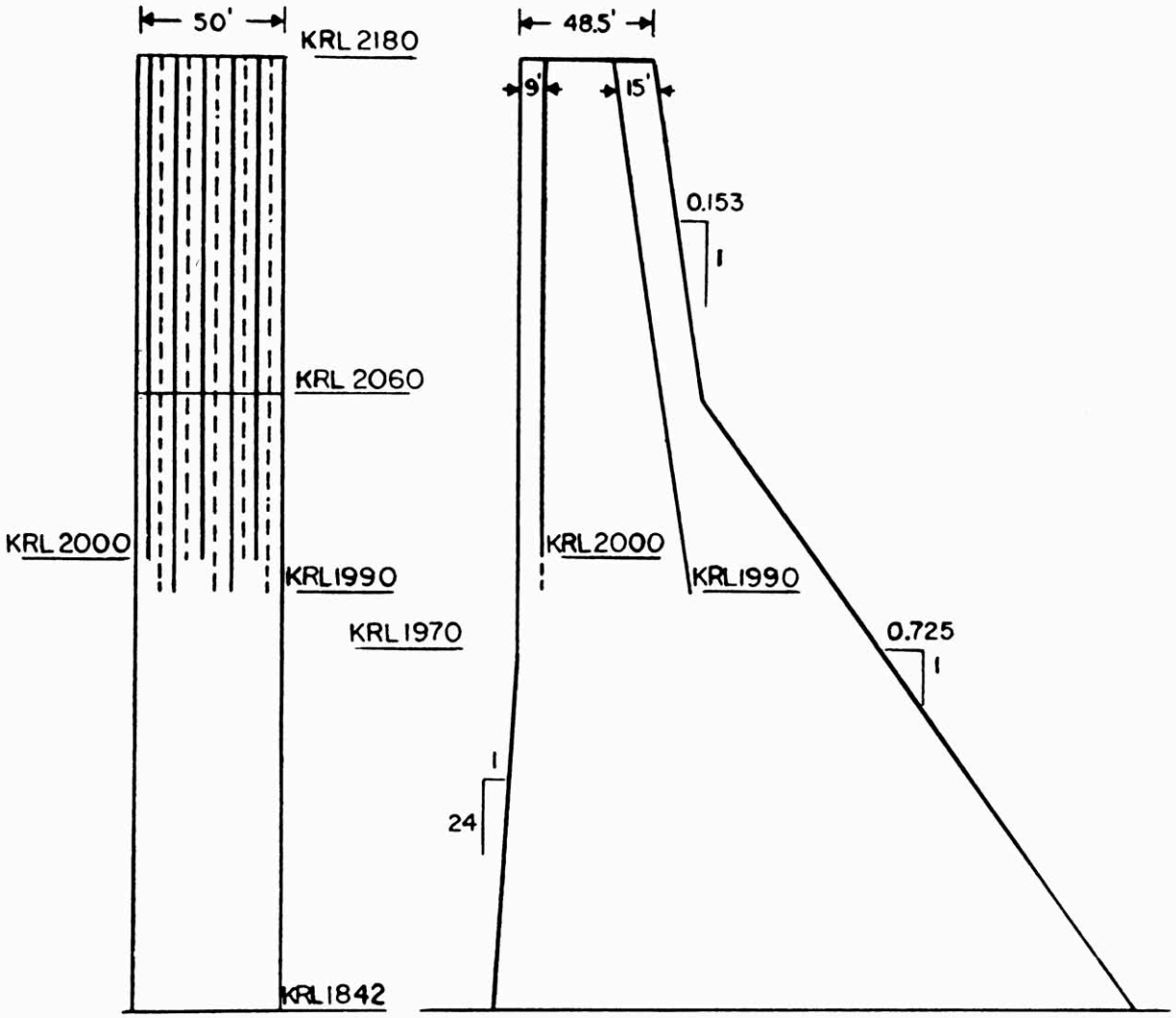
Repair of Sefid Rud dam, 1990
Anchoring force per block: 100 MN, 12 anchors



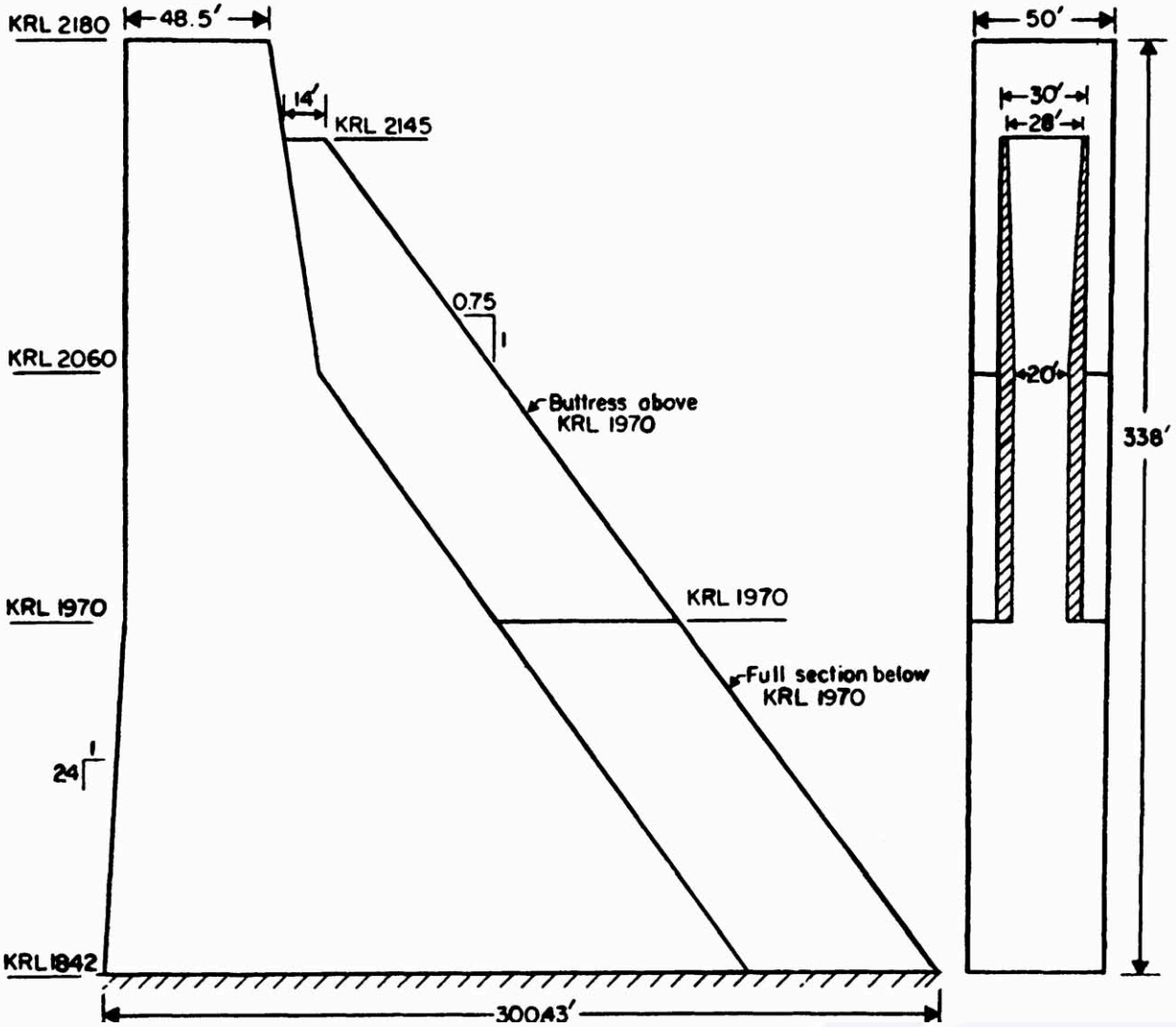
Manjil earthquake 1990, repair works

Manjil earthquake 1990, repair works

Repair of Koyna dam, India



Strengthening of Koyna dam, India



FAULTS IN DAM FOUNDATION

Manjil earthquake 1990, Sefid Rud dam
crack in bottom gallery, damaged grout curtain

Chi-Chi earthquake 1999, Shih-Kang Dam

Damage in intake structure and water tunnel of Shih-Kang dam caused by fault movements during 1999 Chi-Chi earthquake, Taiwan

OBSERVED EARTHQUAKE EFFECTS ON EMBANKMENT DAMS

Bhuj earthquake 2001, Irrigation dams

Bhuj earthquake 2001

Bhuj earthquake 2001

Bhuj earthquake 2001

Bhuj earthquake 2001

Bhuj earthquake 2001

San Fernando earthquake 1971

San Fernando earthquake 1971

Slide in Kitayama Dam, Kobe Earthquake 1995

Observed Earthquake Performance of Embankment Dams

- Modern well-built embankment dams have performed well
- Compacted clay dams have performed well
- Rockfill and concrete-faced rockfill dams have performed well (very limited exposure to strong ground shaking)
- Insufficiently compacted sand or silt dams and tailings and hydraulic fill dams have performed poorly

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SEISMIC REHABILITATION OF EXISTING DAMS

Seismic improvements of 116 dams California

36 Temporary storage restrictions

34 Buttresses added or slopes flattened on earth dams

27 Freeboard increased

21 Outlet works rehabilitations

12 Permanent storage restrictions

11 Foundation and/or embankment materials removed and replaced

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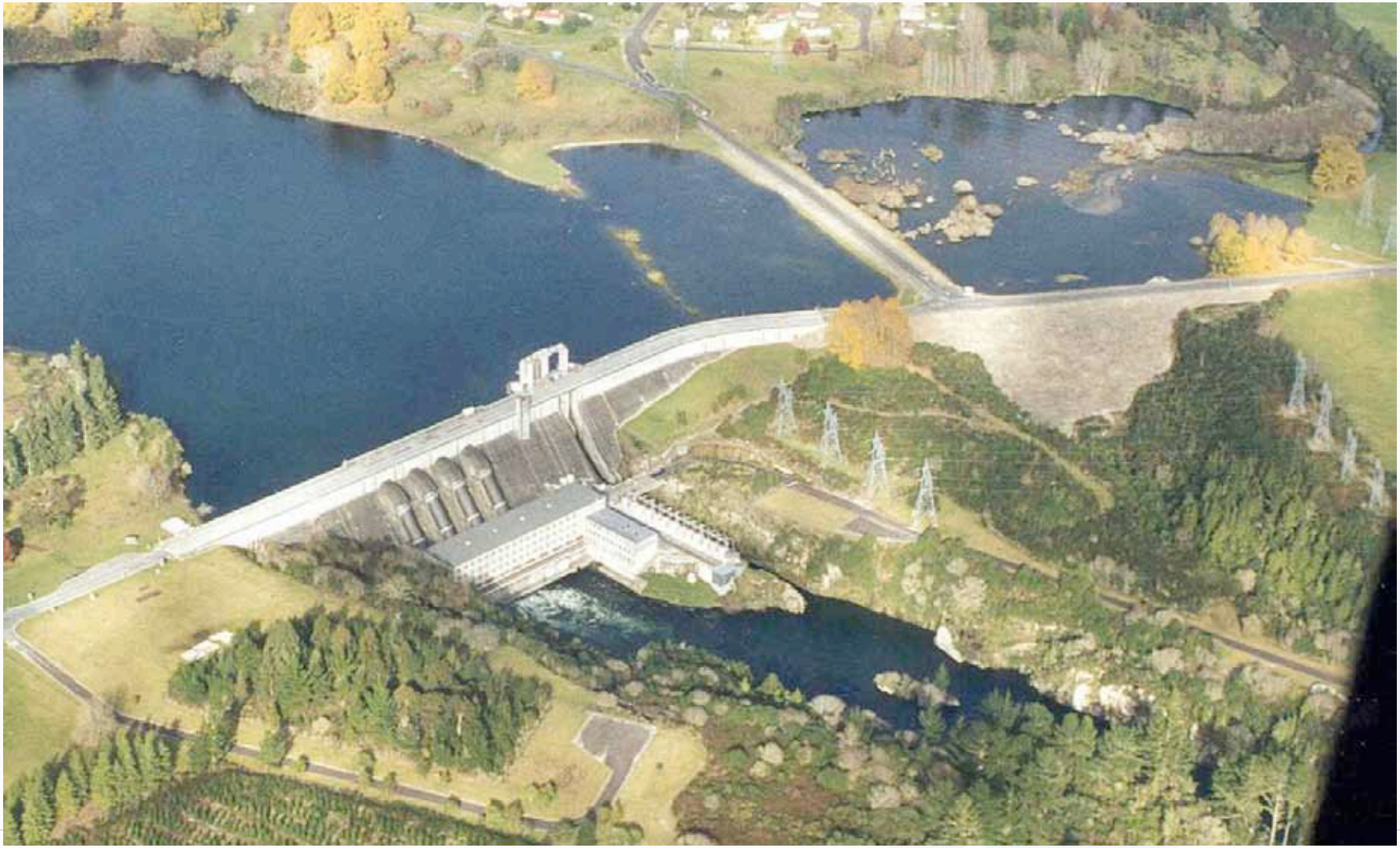
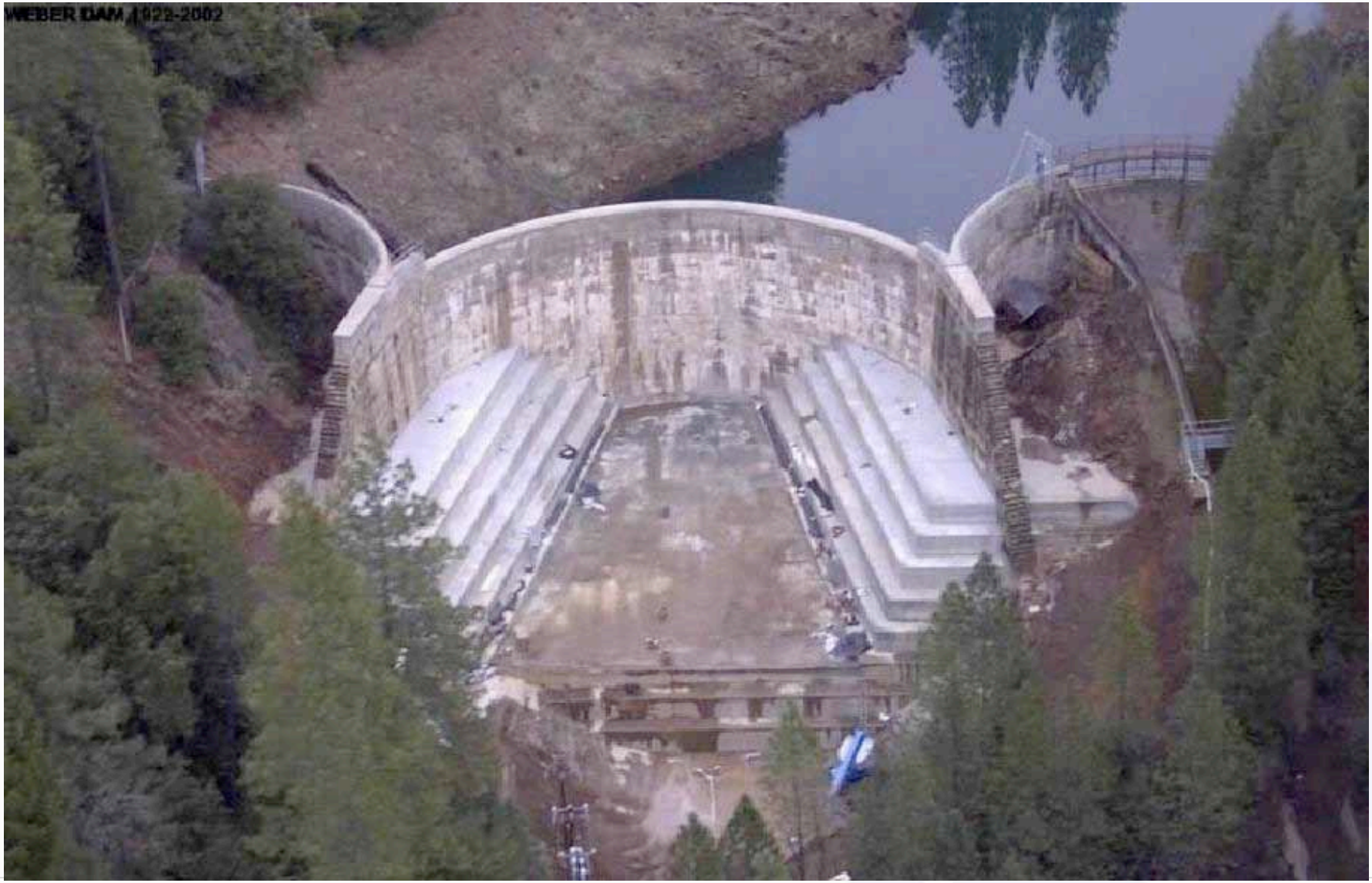
Seismic rehabilitation of spillway on crest of Whakamaru gravity dam, New Zealand



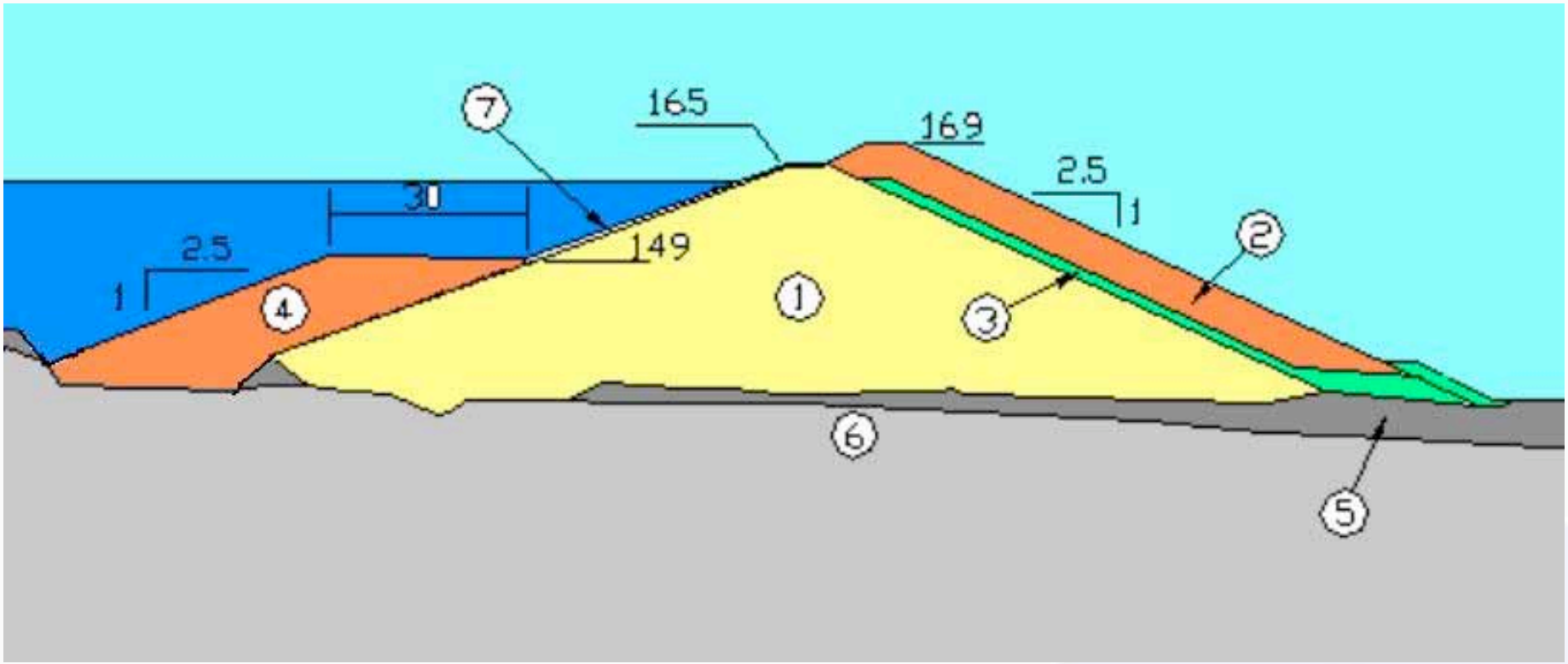
Rehabilitation of crest spillway

Design: 0.1 g, Rehabilitation: 1.8 g

Seismic rehabilitation of multiple arch dam



Seismic rehabilitation of embankment dam



Seismic rehabilitation of embankment dam

NEW TYPES OF DAMS: CONCRETE FACE ROCKFILL DAMS (CFRD)

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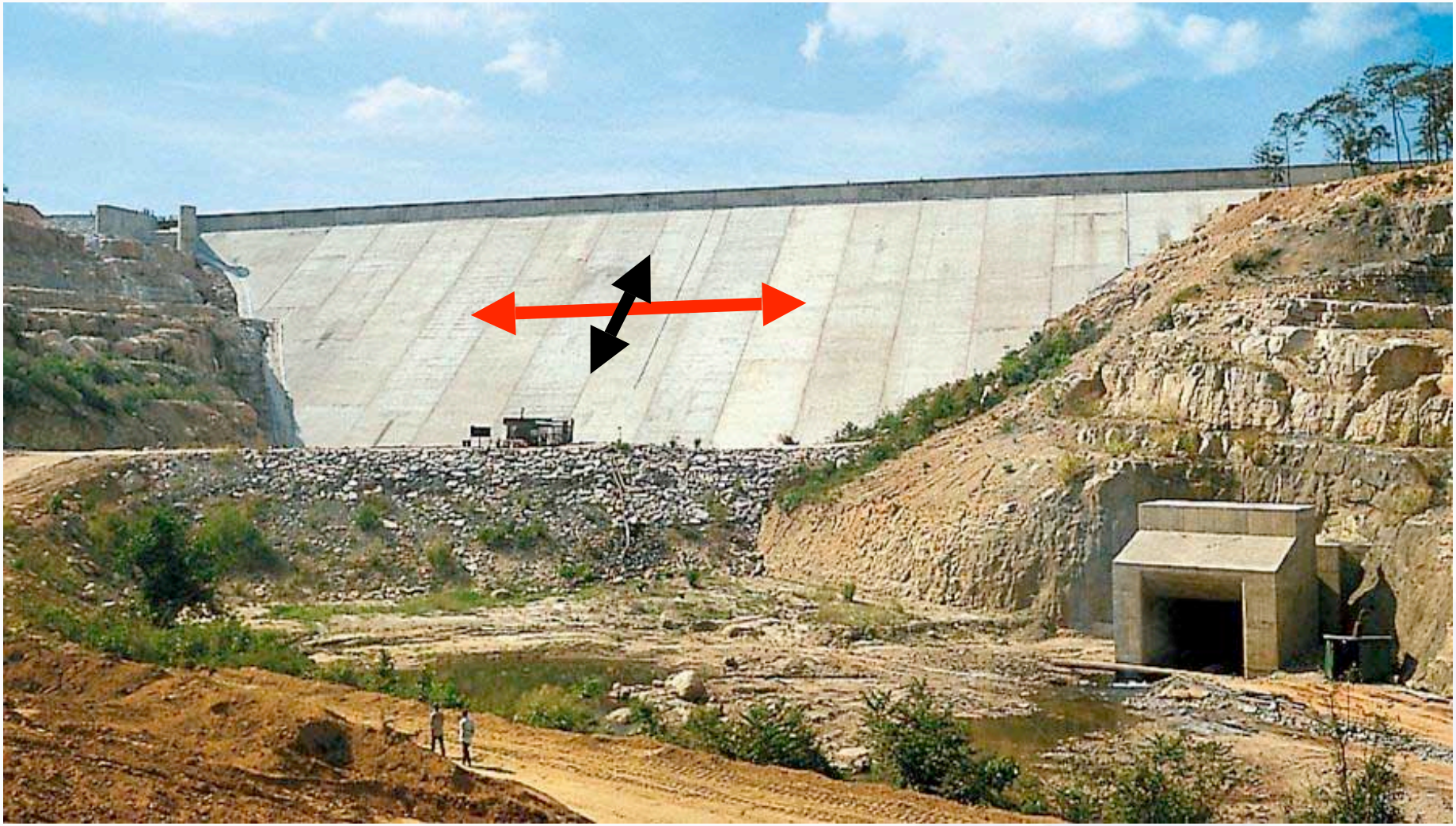
Problem of Concrete Face under Seismic Action



River embankment
Possible failure mode for top portion of CFRD

DAM SAFETY

Integral Dam Safety Concept

Structural Safety

Stiffness, Strength and Ductility
Deformations and Stability, etc.

Safety Monitoring

Seismic instrumentation, Visual observations
Data analysis and interpretation, etc.

Operational Safety

Rule curves, operation guidelines
Qualified staff, Maintenance, etc.

Emergency Planning

Water alarm, Flood plane mapping, Evacuation plans, **Engineering back-up**, etc.

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STRUCTURAL SAFETY: SEISMIC DESIGN CRITERIA

Overview on seismic design criteria

Dam and safety-relevant elements:

Operating basis earthquake, OBE (145 years)

Safety evaluation earthquake, SEE (ca.10,000 years)

Appurtenant structures:

Use of seismic building codes (ca. 475 years)

Temporary structures:

Use of seismic building codes (< 475 years)

Probability of exceedance of 10% during construction

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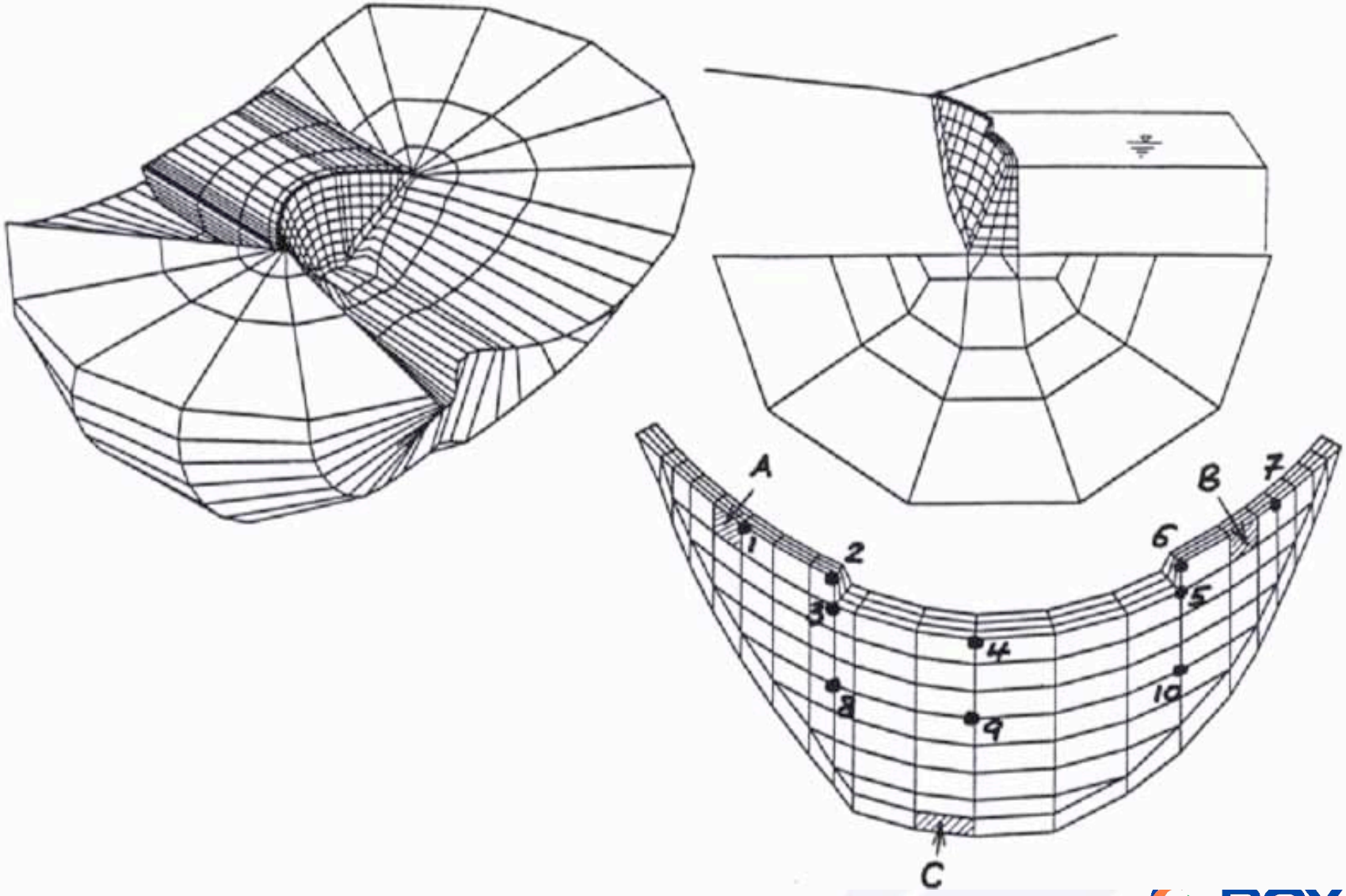
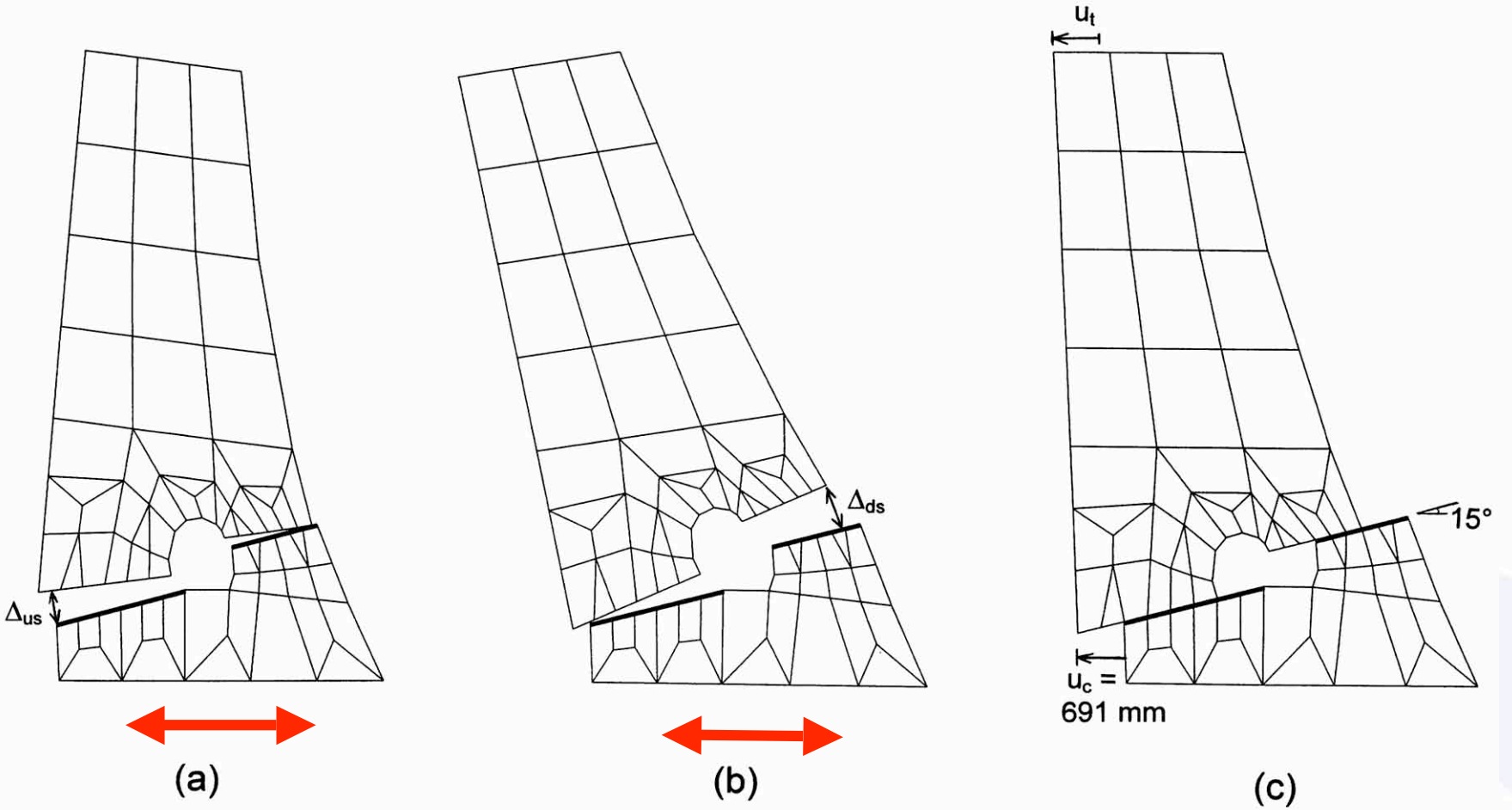
OBE: Linear seismic dam analysis

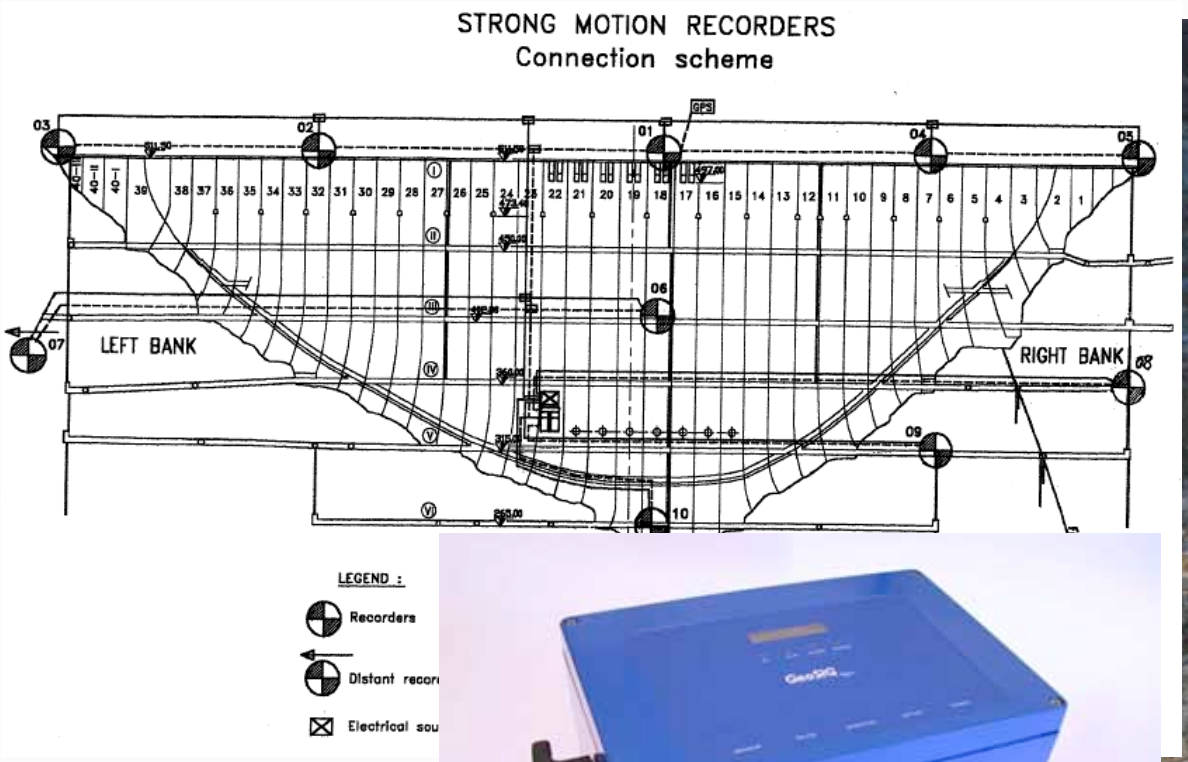


SEE: Rigid body analysis of concrete blocks



DAM SAFETY MONITORING
Strong Motion Instrumentation

Strong motion instrumentation of dams



Strong motion instruments in dam

Minimum System

Dam crest

Dam base

Free field

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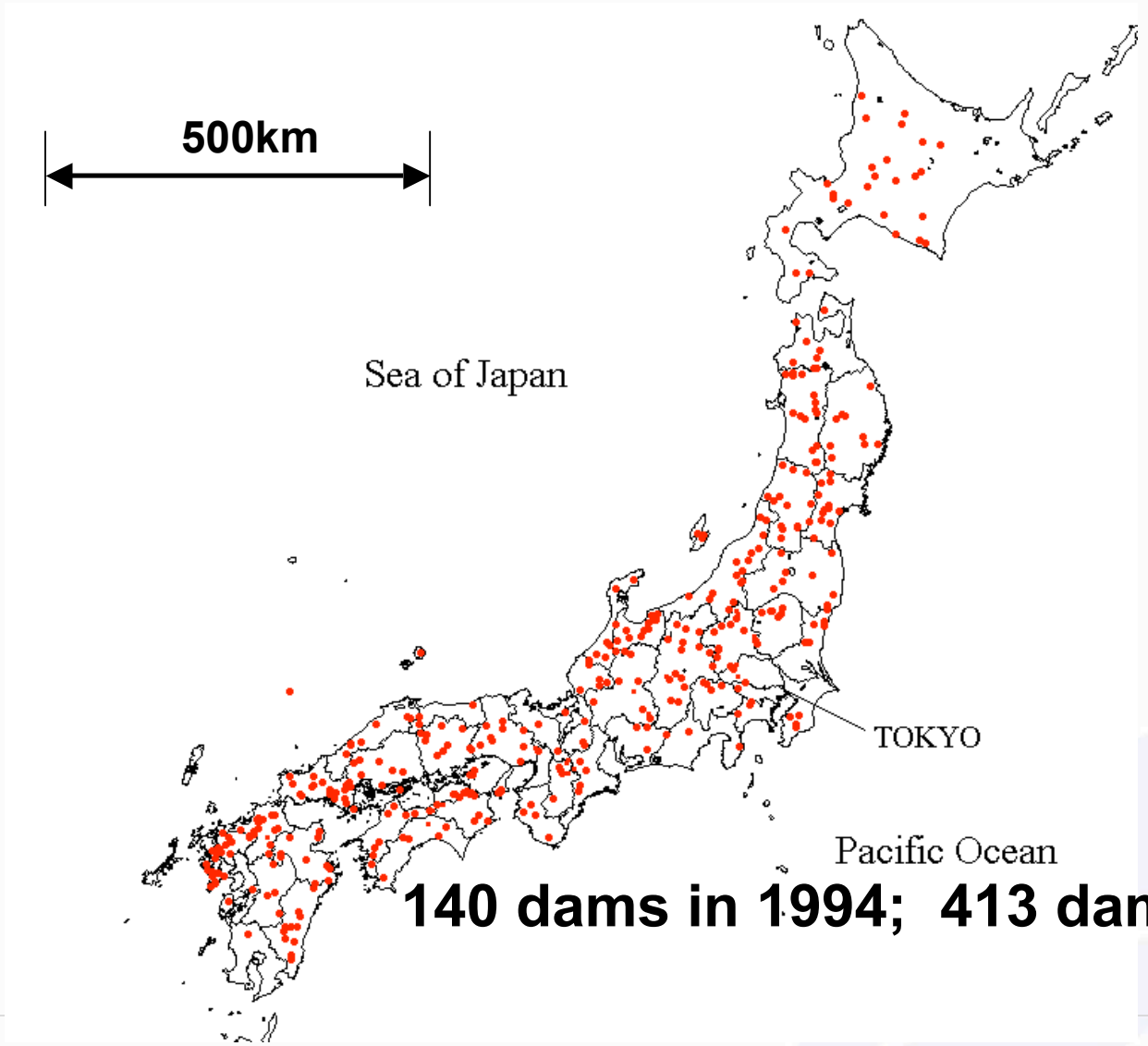
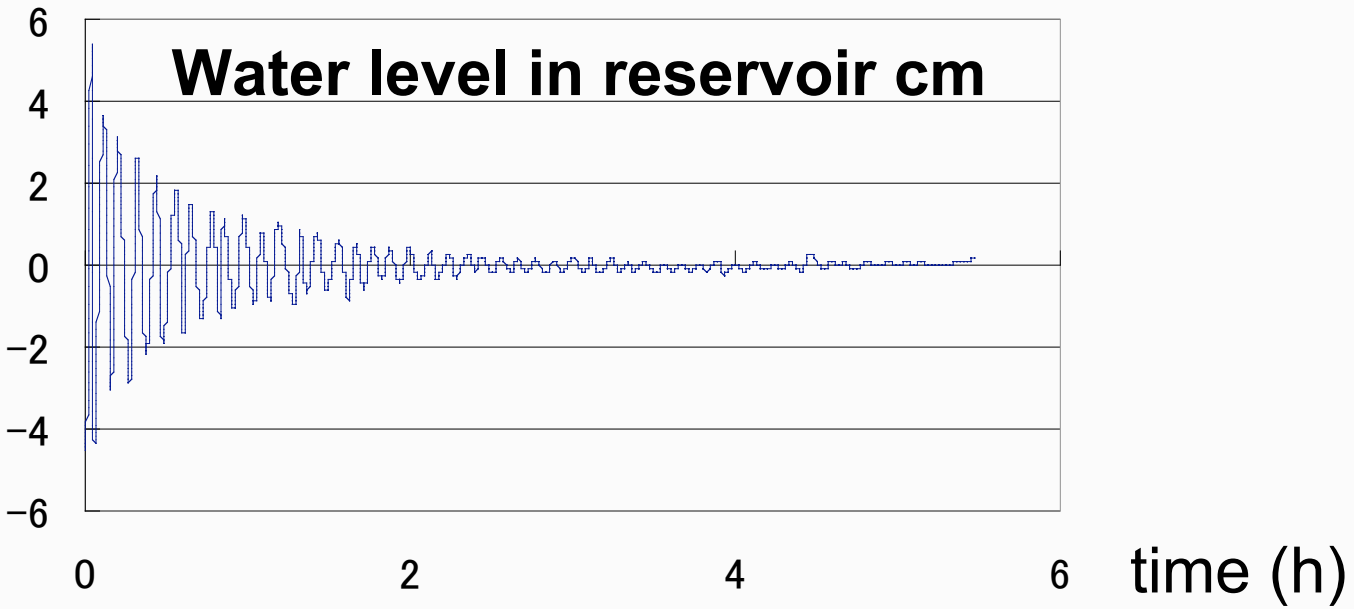
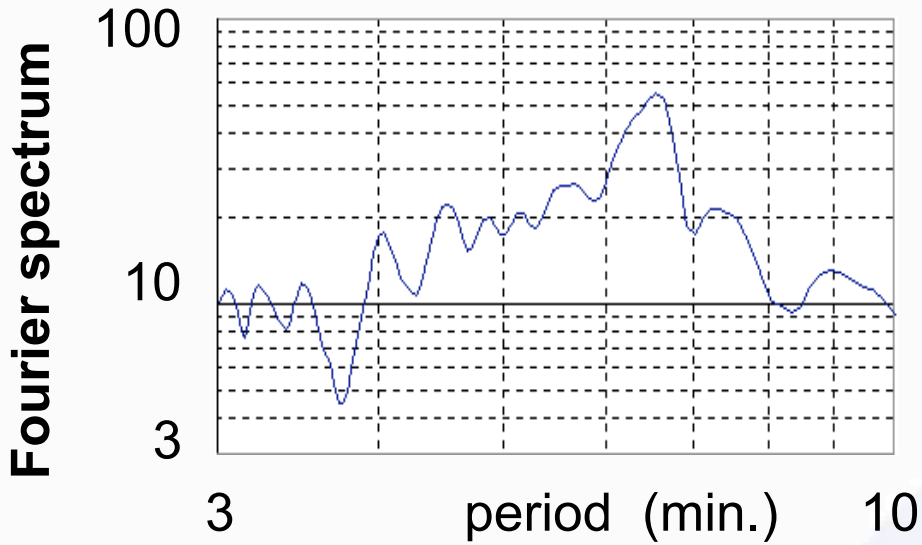
Distribution of dams with seismographs, Japan
(Ministry of Land, Infrastructure and Transport)



140 dams in 1994; 413 dams in 2003





Natural period
T= 6.5 min

Damping ratio
0.02

Free vibration of reservoir

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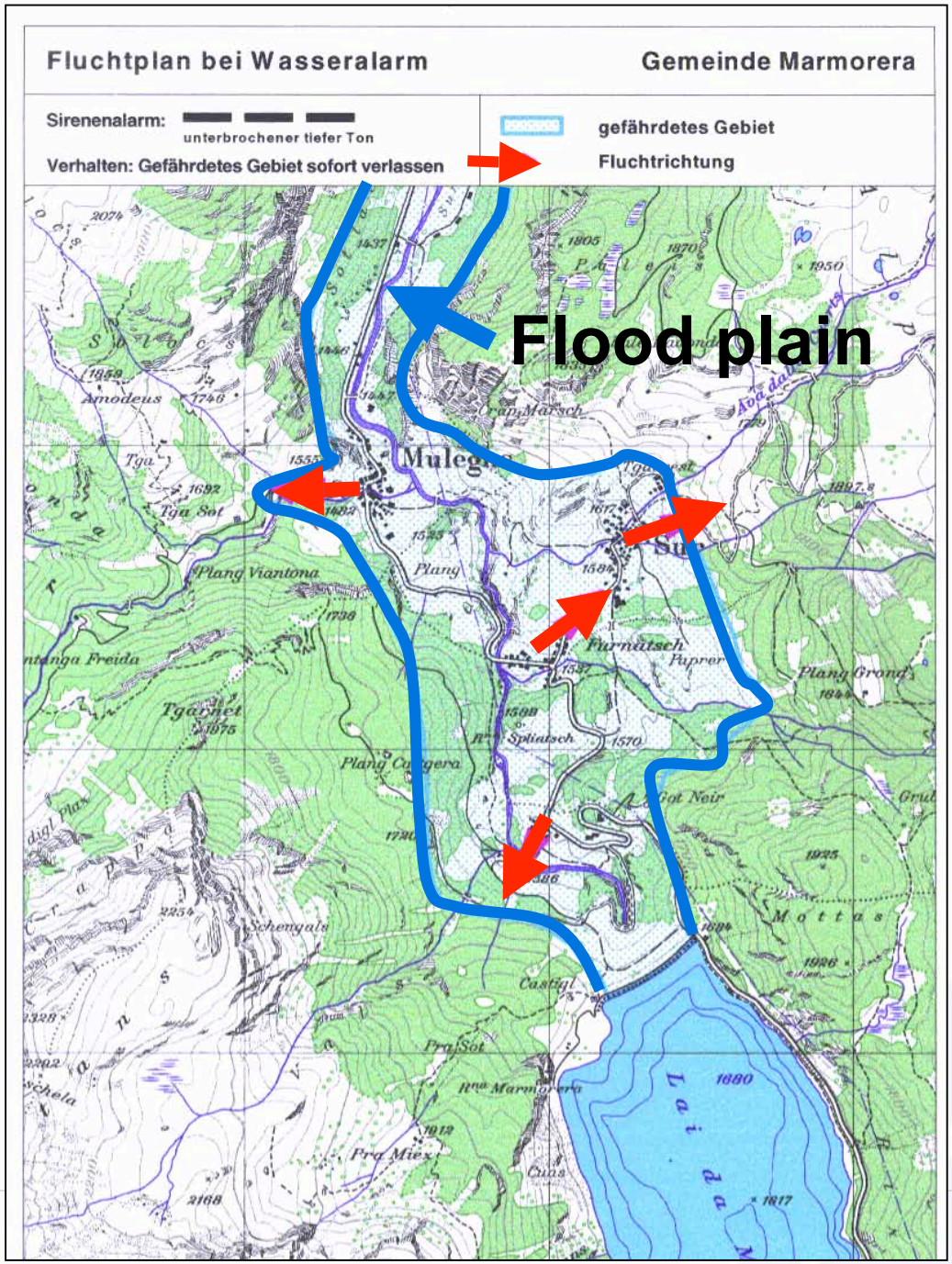
OPERATIONAL SAFETY OF DAMS

Taum Sauk CFRD dam failure, USA, 14.12.2005

Pump Storage Reservoir, overtopping due to uncontrolled pumping

EMERGENCY PLANNING: WATER ALARM SYSTEMS FOR LARGE DAMS



Evacuation Map: Water Alarm

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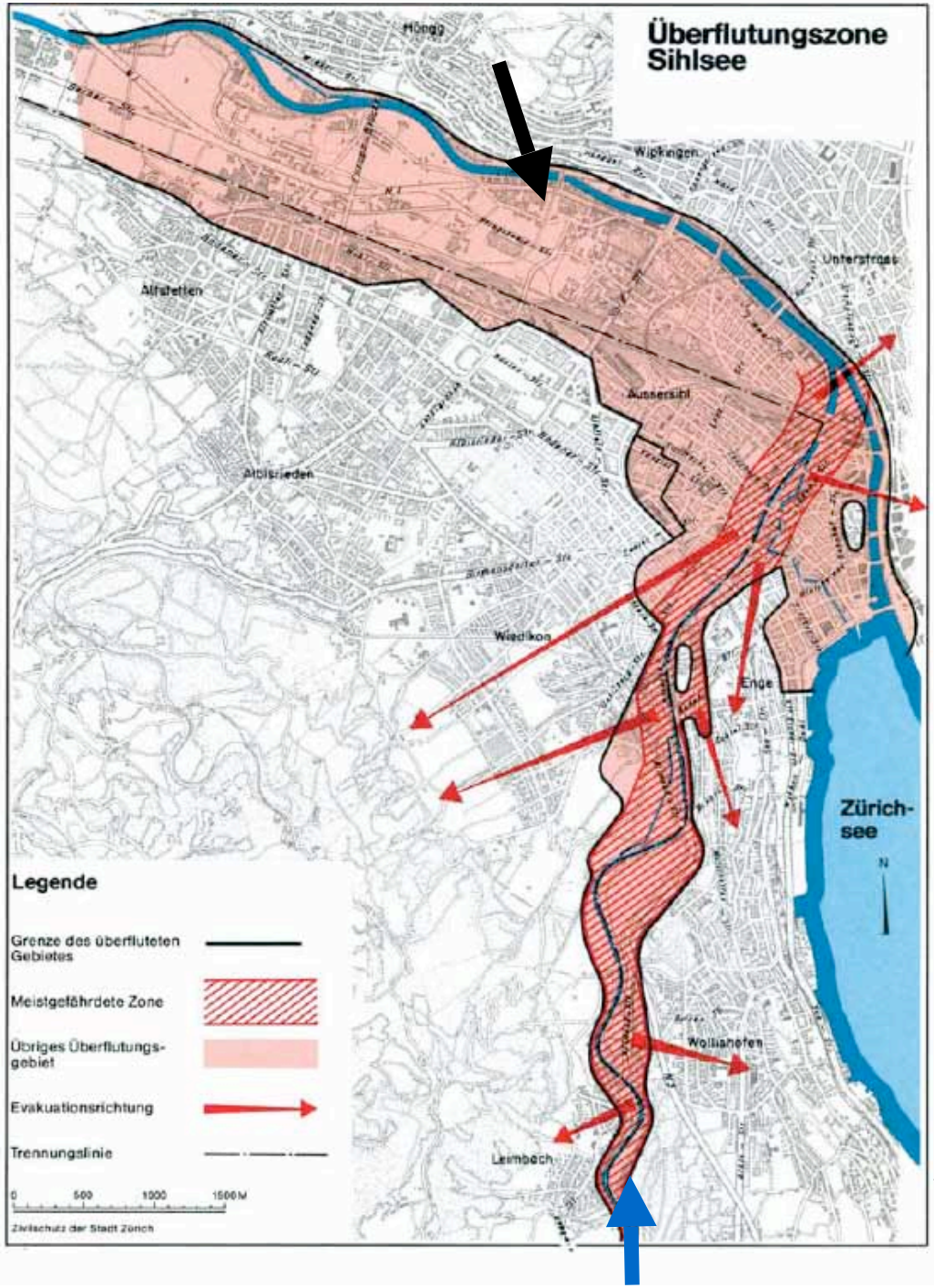

Evacuation map of Zurich: Water Alarm Dam Break

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ACTIVITIES OF COMMITTEE ON SEISMIC ASPECTS OF DAM DESIGN OF INTERNATIONAL COMMISSION ON LARGE DAMS (ICOLD)

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ICOLD BULLETINS

- Bulletin 52 (1986), Earthquake analysis procedures for dams – State of the Art (**Zienkiewicz, Clough, Seed**)
- Bulletin 72 (1989): **Selecting seismic parameters for large dams (under revision)**
- Bulletin 112 (1998): Neotectonics and dams
- Bulletin 120 (2001): Design features of dams to effectively resist seismic ground motion
- Bulletin 123 (2002): Earthquake design and evaluation of structures appurtenant to dams
- Bulletin (2007) **Reservoirs and Seismicity**

Terms of Reference, May 2005-2009

- **Revision of existing seismic bulletins**
- **Seismic safety of existing dams**
- **Seismic instrumentation of dams**
- **Seismic risk aspects of dams (seismic hazard and seismic vulnerability)**
- (Seismic analysis of dams)

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Conclusions

- Dams are not inherently safe against earthquakes.
- Technology for building dams that can safely resist strong ground shaking is available.
- New safety concepts are still needed for

  (i) very large dams in highly seismic regions,

  (ii) new types of dams such as CFRD and RCC dams,

  (iii) dams at difficult sites.

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Conclusions

- In regions of low to moderate seismicity where strong earthquakes occur very rarely, it is sometimes believed

  (i) that too much emphasis is put on earthquake safety,

  (ii) that dams designed for a seismic coefficient of 0.1 are safe against earthquakes.

- These assumptions are incorrect!

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Conclusions

- Emergency planning and the installation of water alarm systems in the downstream region of large dams is a must. Even if a dam is structurally safe, there are natural or man-made events that could cause failure.

Conclusions

- For emergency planning to be effective, the population affected must be involved and informed about what to do in an emergency.
- The first water alarm systems for dams were installed in Switzerland some 50 years ago and Swiss engineers have been at the forefront of emergency planning ever since.

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Fifth International Conference on Dam Engineering (DM07), Lisbon, Portugal

February 14 -16, 2007

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