Dam Safety Practices in Turkey

Mutlu İlker Peker

The General Directorate of State Hydraulic Works of Turkey

TURKEY

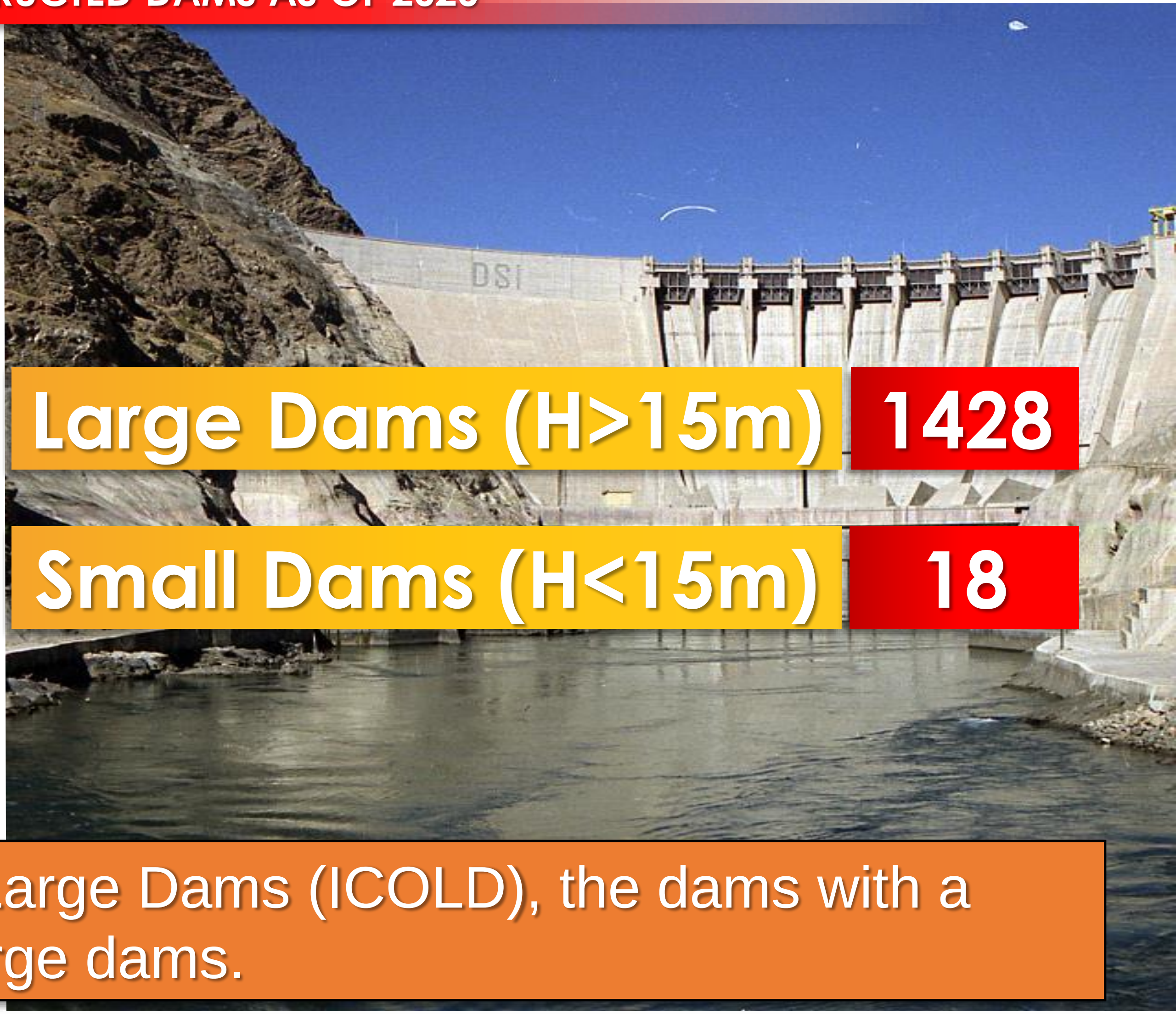
PRESENTATION OUTLINE

- Dams in Turkey
- Seismicity in Turkey
- Case studies across the world
- Dam design practices
- Instrumentation in dams
- Dam safety inspections
- Dam break analyses
- Results and evaluations

GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS
NUMBER OF CONSTRUCTED DAMS AS OF 2020

1446

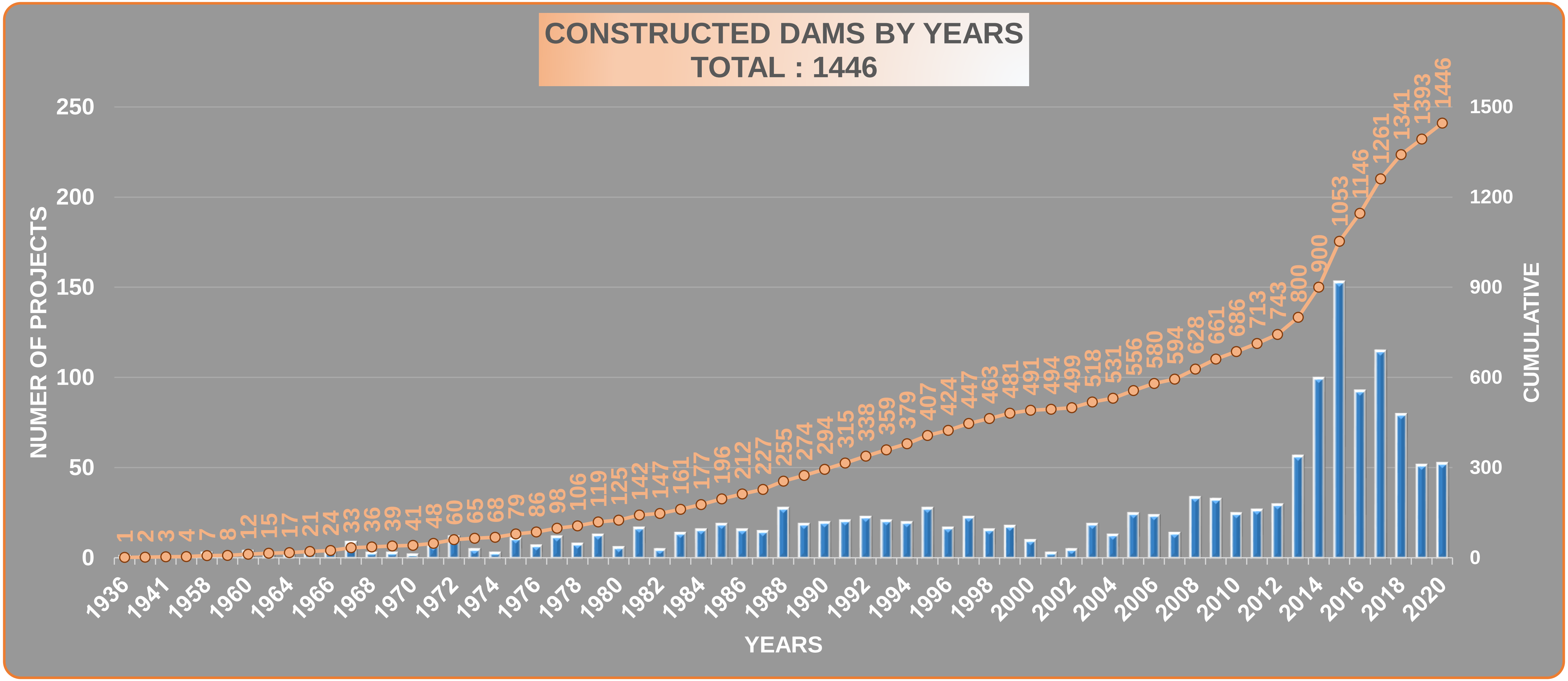
Dams in Total

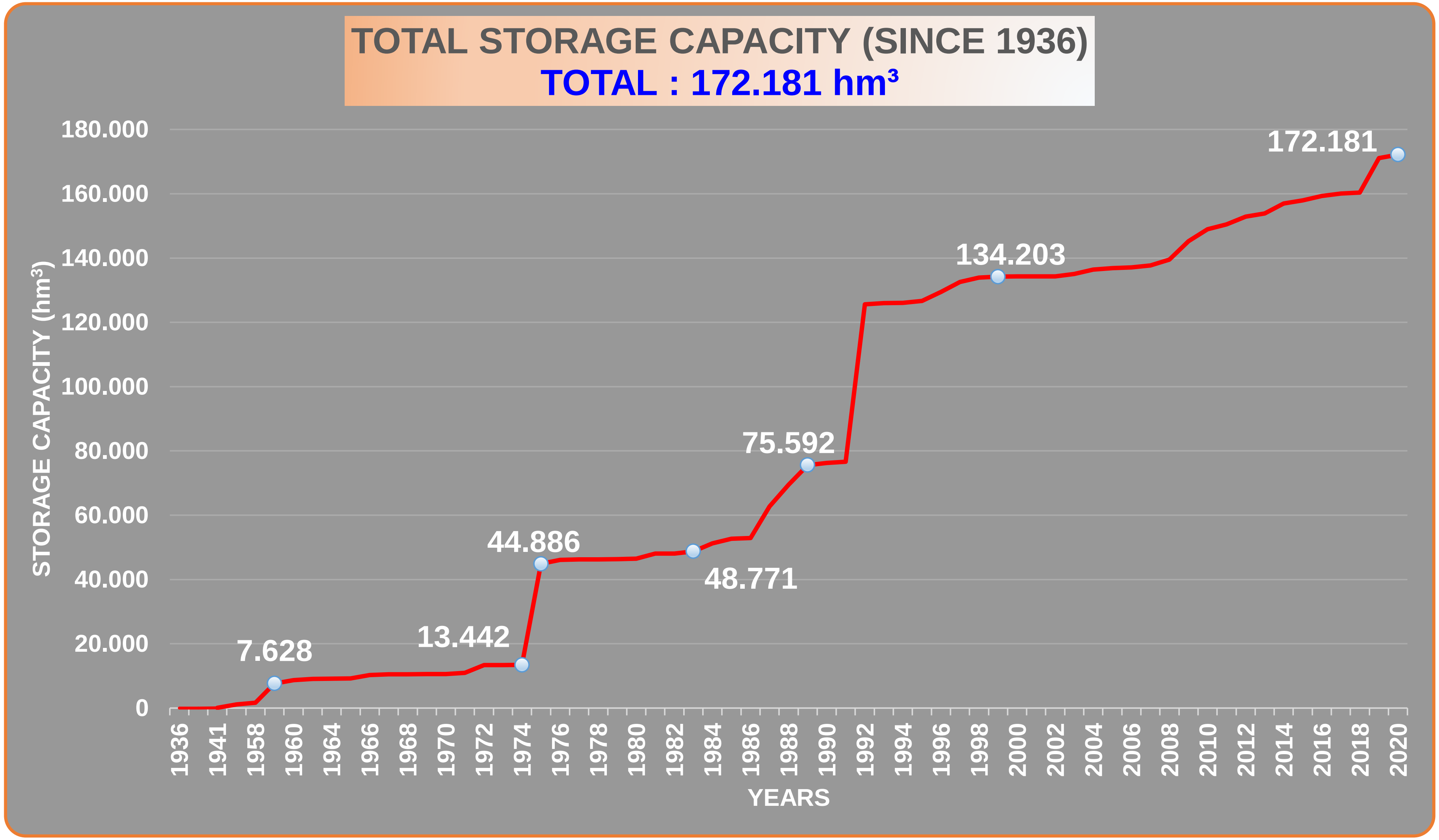


Large Dams (H>15m)	1428
Small Dams (H<15m)	18

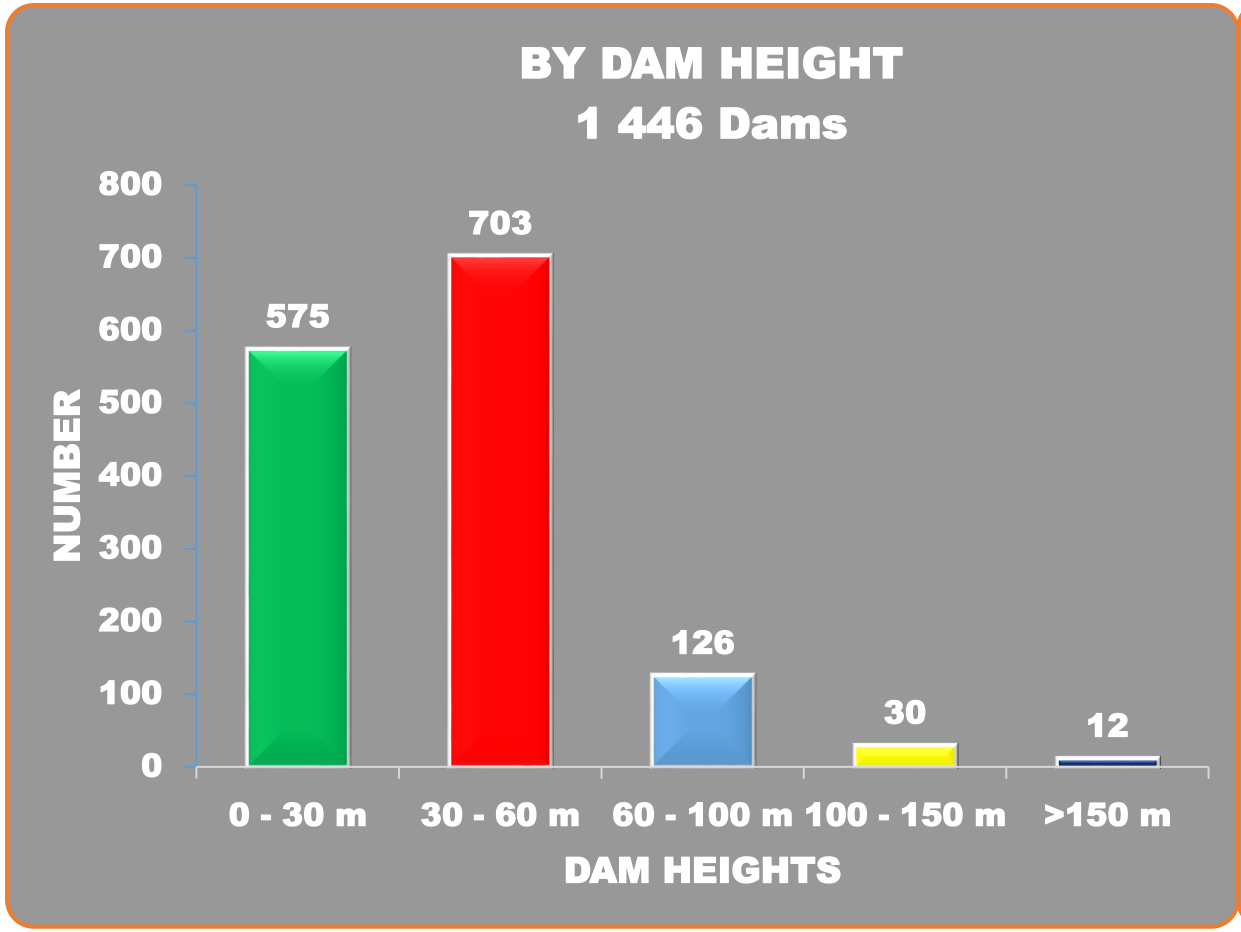
According to International Commission on Large Dams (ICOLD), the dams with a height of over 15 m are considered to be large dams.

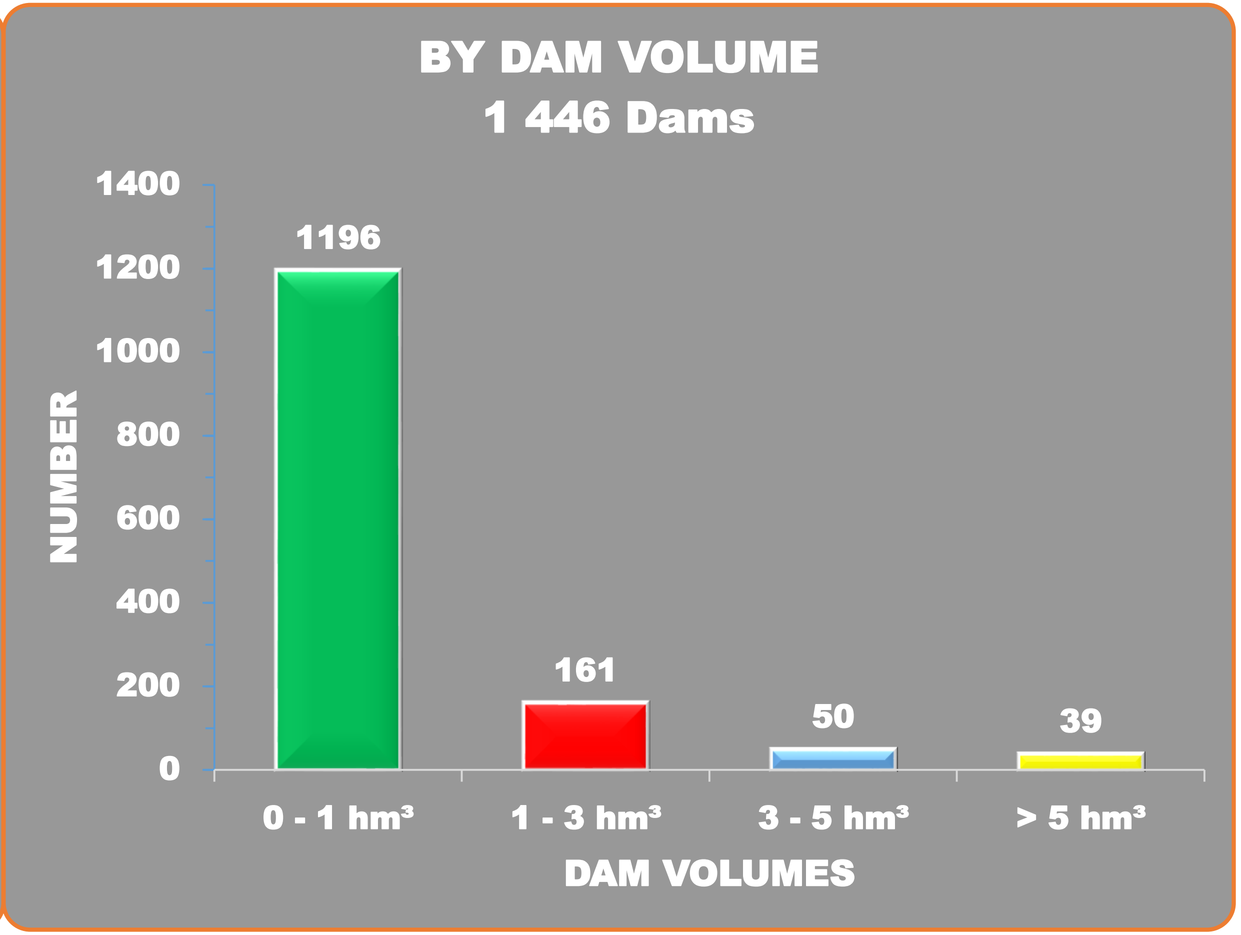
THE NUMBER OF CONSTRUCTED DAMS (1936 – 2020)



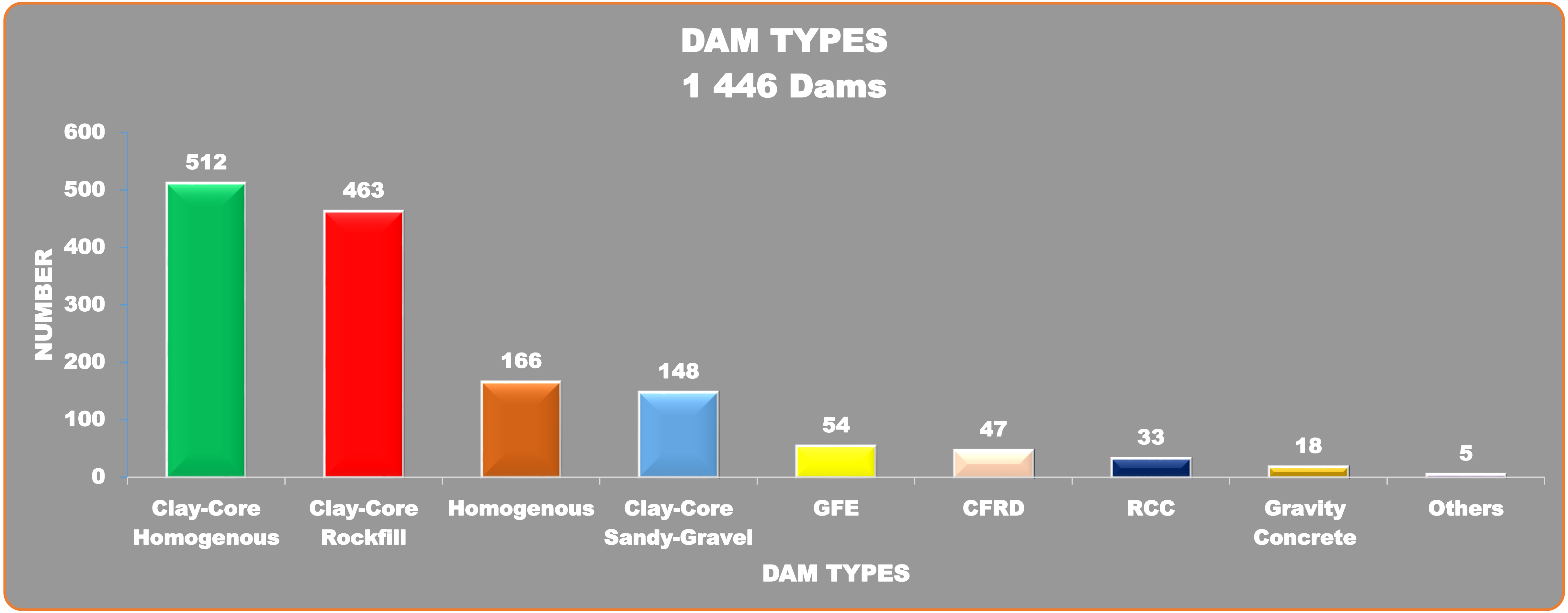

TOTAL STORAGE CAPACITY (SINCE 1936)
TOTAL : 172.181 hm³
STORAGE CAPACITY (hm³)
180.000
160.000
140.000
120.000
100.000
80.000
60.000
40.000
20.000
0
7.628
13.442
44.886
48.771
75.592
134.203
172.181
1936
1941
1958
1960
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
YEARS

CONSTRUCTED DAMS IN TURKEY (1936 – 2020)



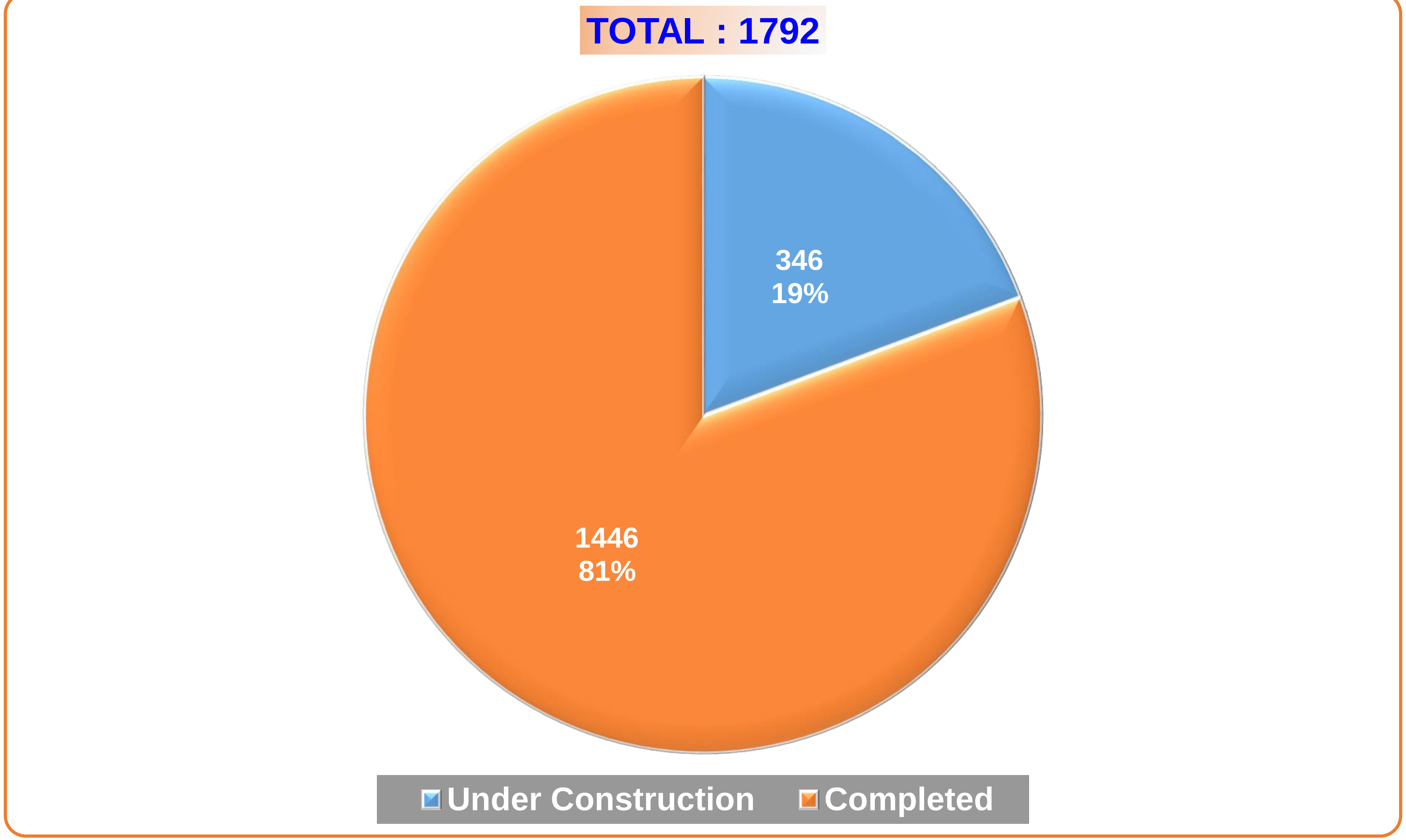


CONSTRUCTED DAMS BETWEEN 1936 – 2020

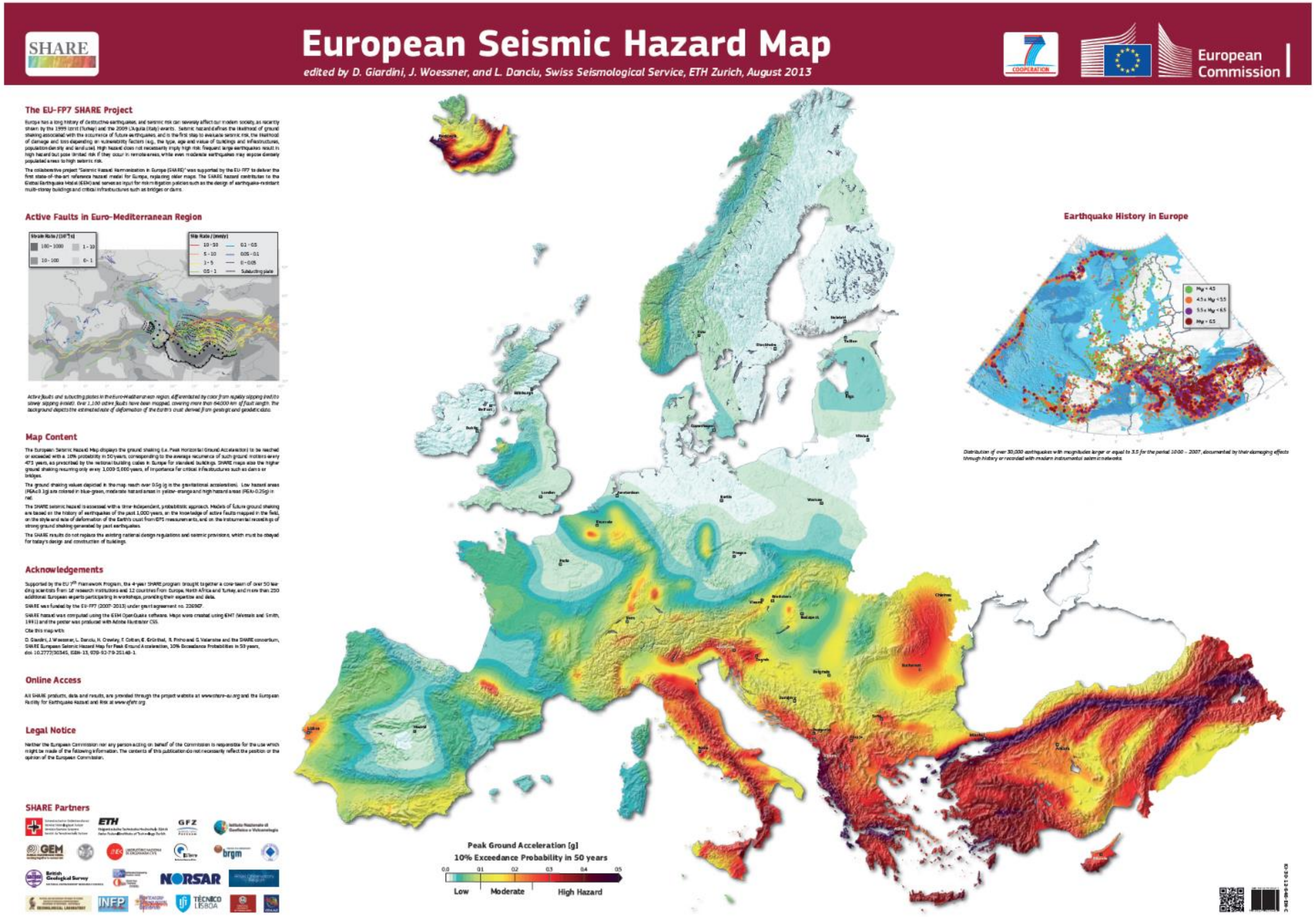


*GFE: Geomembrane Covered Embankments
*CFRD: Concrete-Faced Rockfill Dams
*RCC: Roller - Compacted Concrete Dams

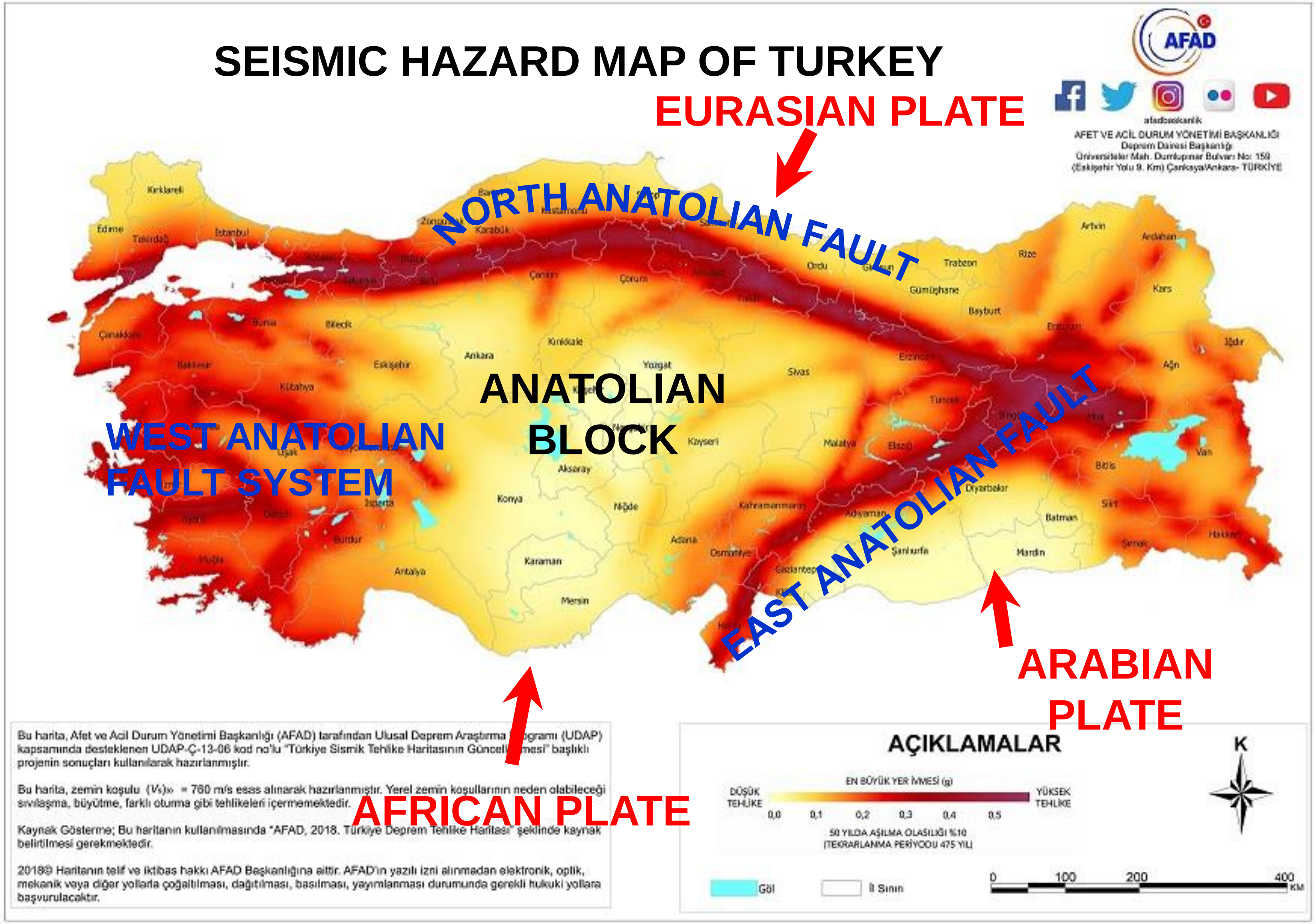
DAMS IN OPERATION AND UNDERCONSTRUCTION SINCE 1936



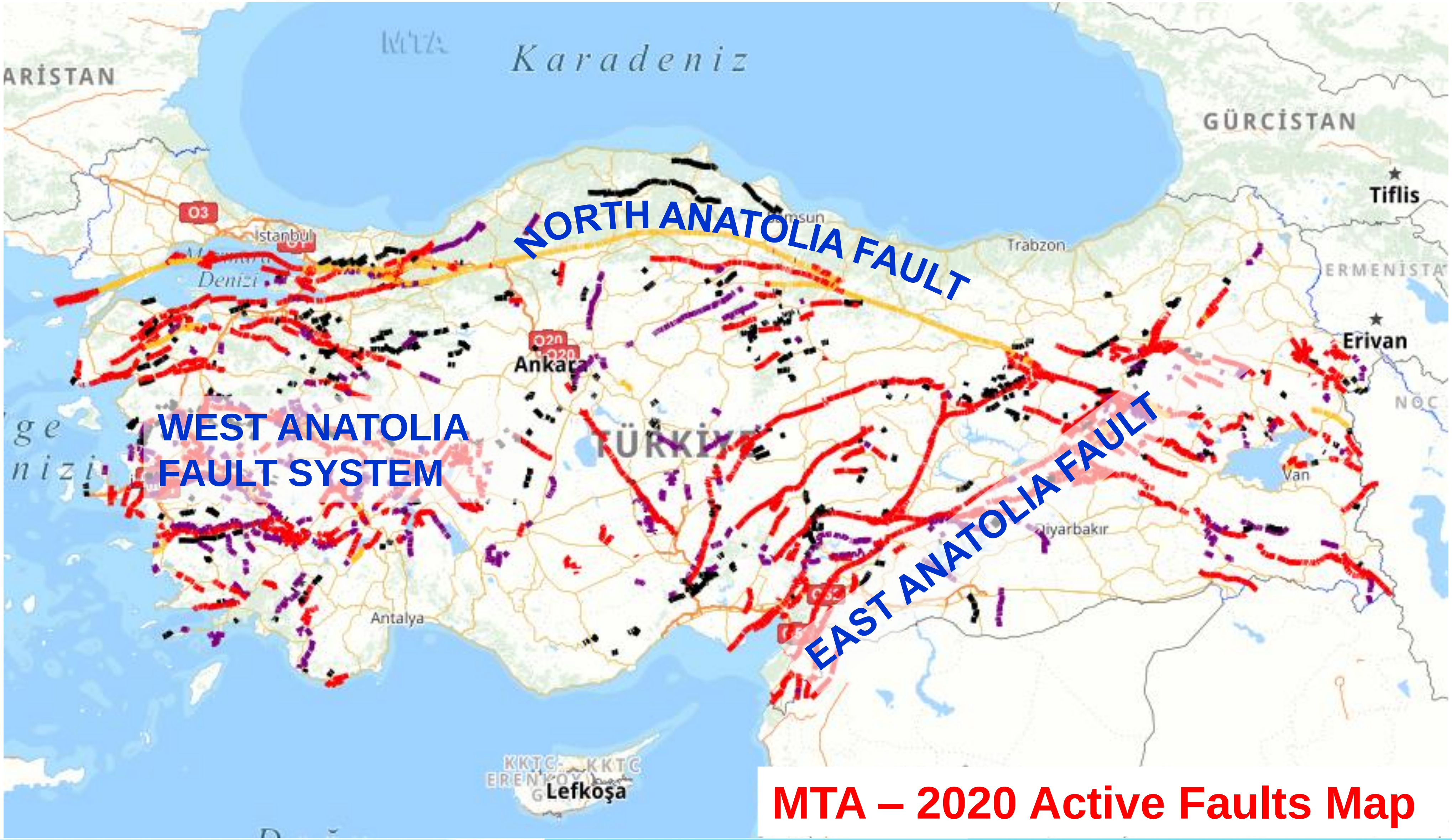
EUROPEAN SEISMIC HAZARD MAP



SEISMIC HAZARD MAP OF TURKEY



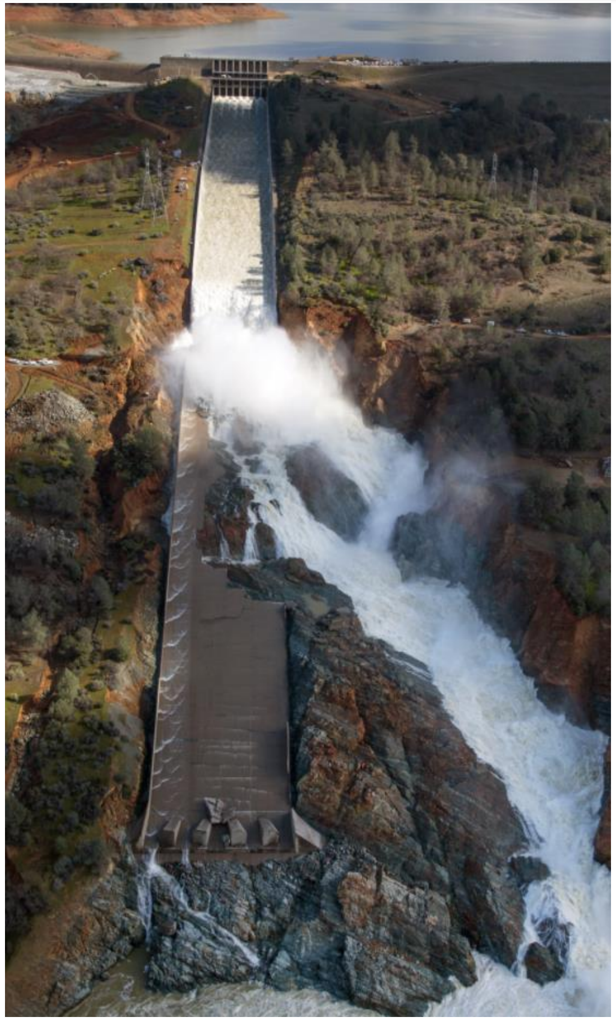
ACTIVE FAULTS IN TURKEY



MTA – 2020 Active Faults Map

CASE STUDIES OF DAMAGED OR COLLAPSED DAMS AROUND THE WORLD

CASE STUDIES: Oroville Dam



Oroville Dam (235 m), CA-USA

In 2017, the tallest dam in the USA has suffered from spillway failure, which was followed by rapid erosion of foundation.

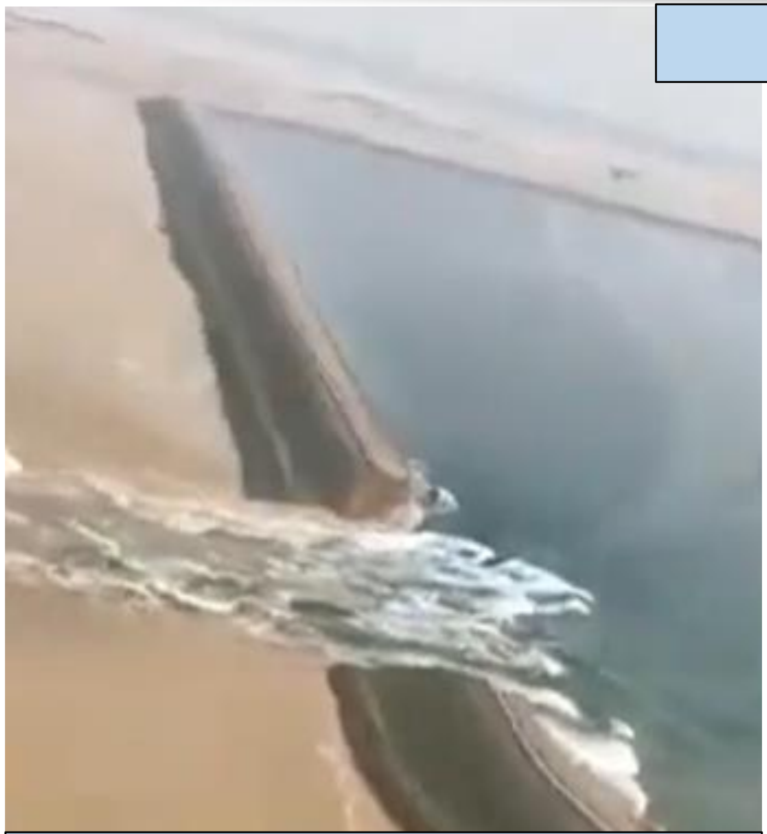
To control the damage, the flow rate was decreased, which resulted in overtopping of emergency spillway.
Overtopping or sliding instabilities of ogee weir structure emerged.
180.000 evacuated.
Repair cost 1.1 Billion $.
(damfailures.org)

CASE STUDIES: Oroville Dam

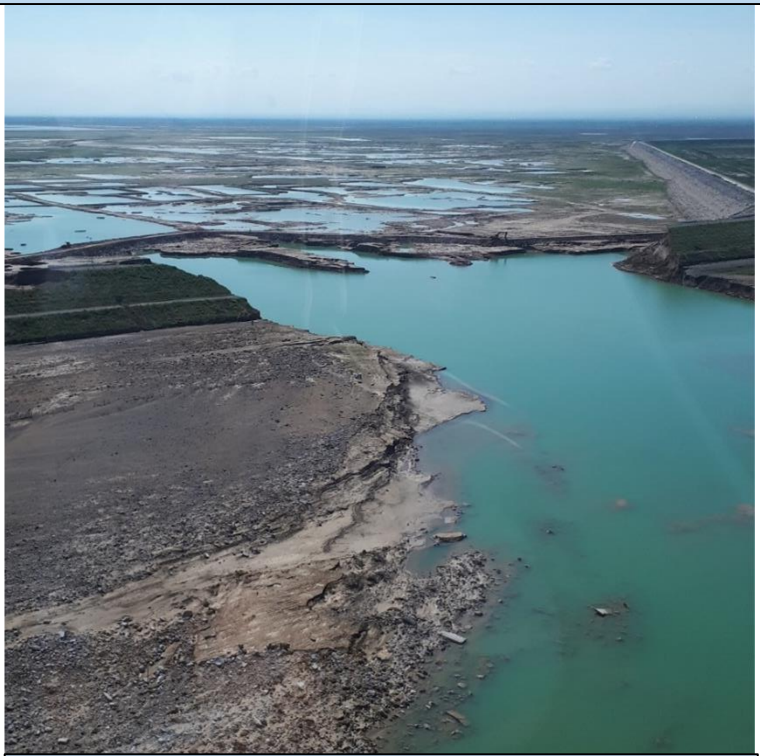
The damage was repaired, and the dam became operational again.

CASE STUDIES: Sardoba Dam

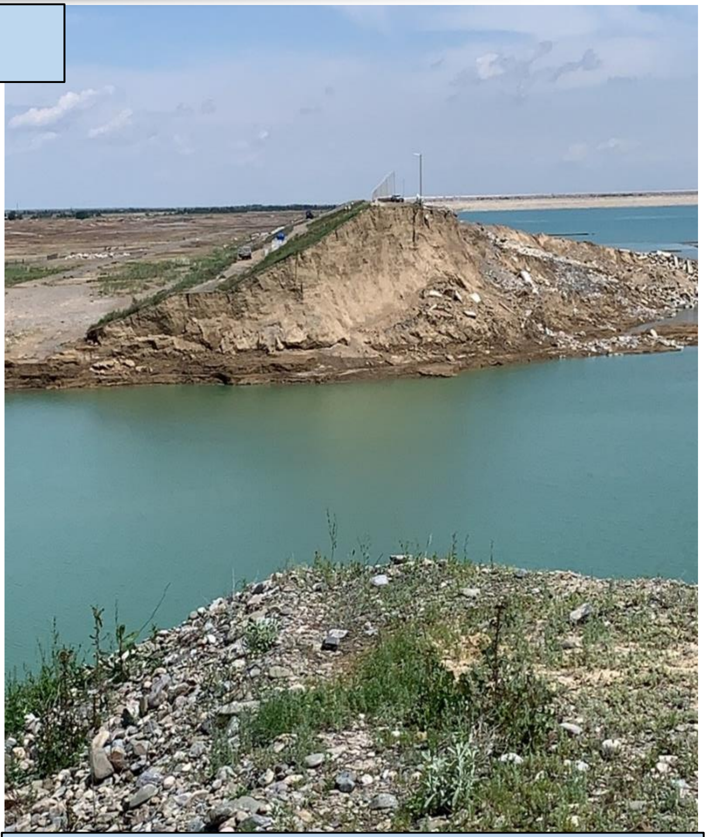
Sardoba Dam (29 m), Uzbekistan



In May 2020, the Sardoba Dam failed, causing 8 deaths and 70.000 evacuation. Estimated repair and damage cost is 500 Million $.



An expert team by DSI visited Sardoba Dam between 18.05.2020 and 21.05.2020 to investigate the failure mechanism.

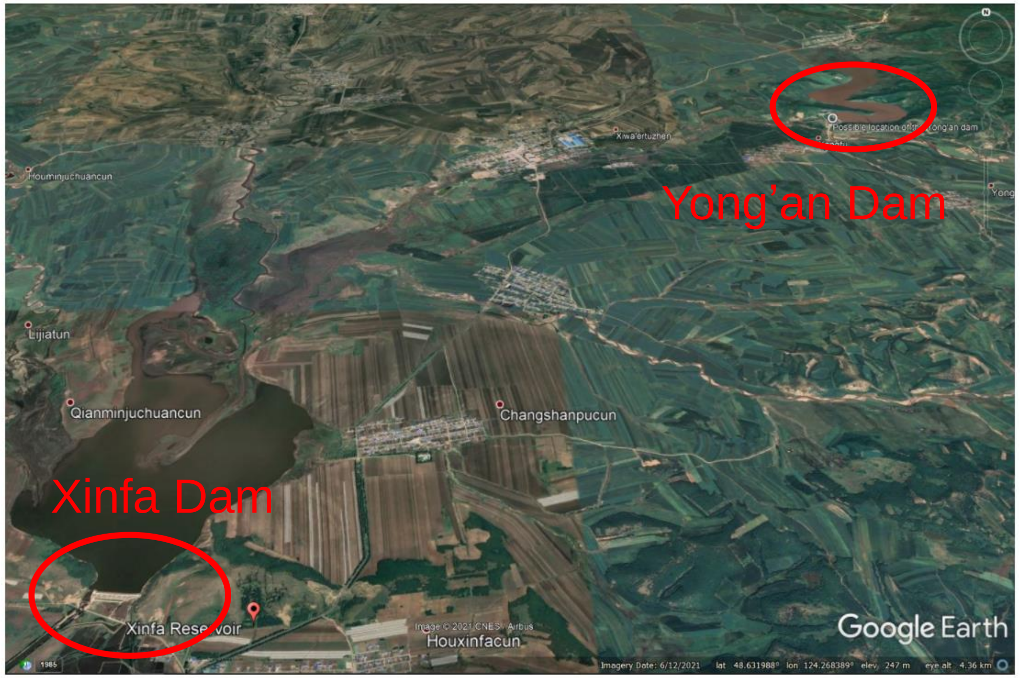


DSI team prepared a preliminary report investigating potential reasons that might trigger the collapse.

CASE STUDIES: Sardoba Dam

Sardoba Dam Failure (29 m), Uzbekistan
(2017 – 2020)

CASE STUDIES: Xinfa and Yong'an Dams




Collapse of Xinfa Dam


Collapse of Yong'an Dam

On 18th July 2021, two earthen dams in China were totally collapsed due to heavy rainfalls.

46 million m^3 water was released, causing massive flooding in residential areas.

No casulties reported.
16 000 people were affected.
Bridges and trasport infrastructure were destroyed in the downstream.

CASE STUDIES: Edenville and Sanford Dam

Edenville Dam, USA

Sanford Dam, USA

In May 2020, two dams were failed due to heavy rainfalls in Michigan State, USA.

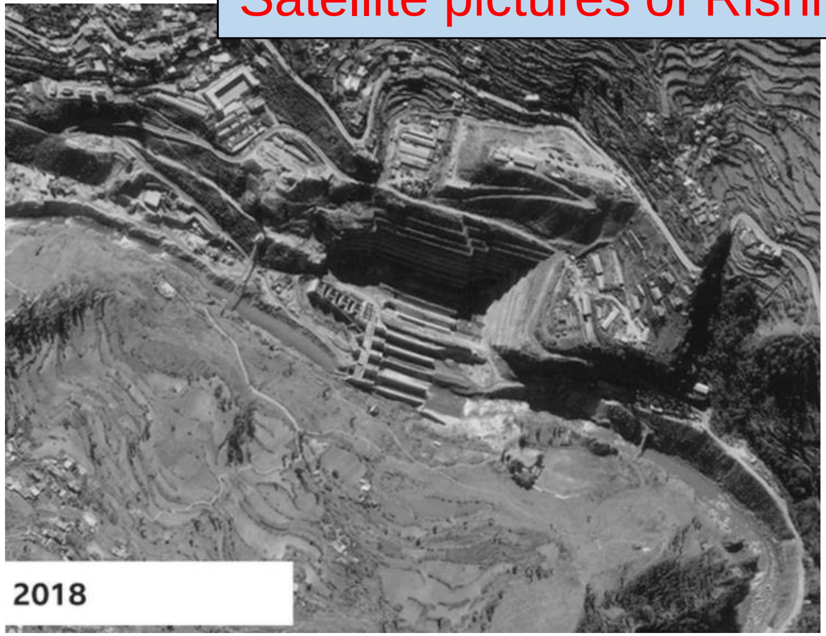
The uncontrolled water released from Edenville Dam overtopped the Sanford Dam and eventually collapsed it.

CASE STUDIES: Edenville and Sanford Dam

Edenville Dam, USA
(1925 – 2020)

CASE STUDIES: Rishi Ganga Hydropower Plant

Satellite pictures of Rishi Ganga Hydropower Plant



Uttarakhand, India

On 7th February 2021, the devastating flood washed away two (2) Hydropower Plants.

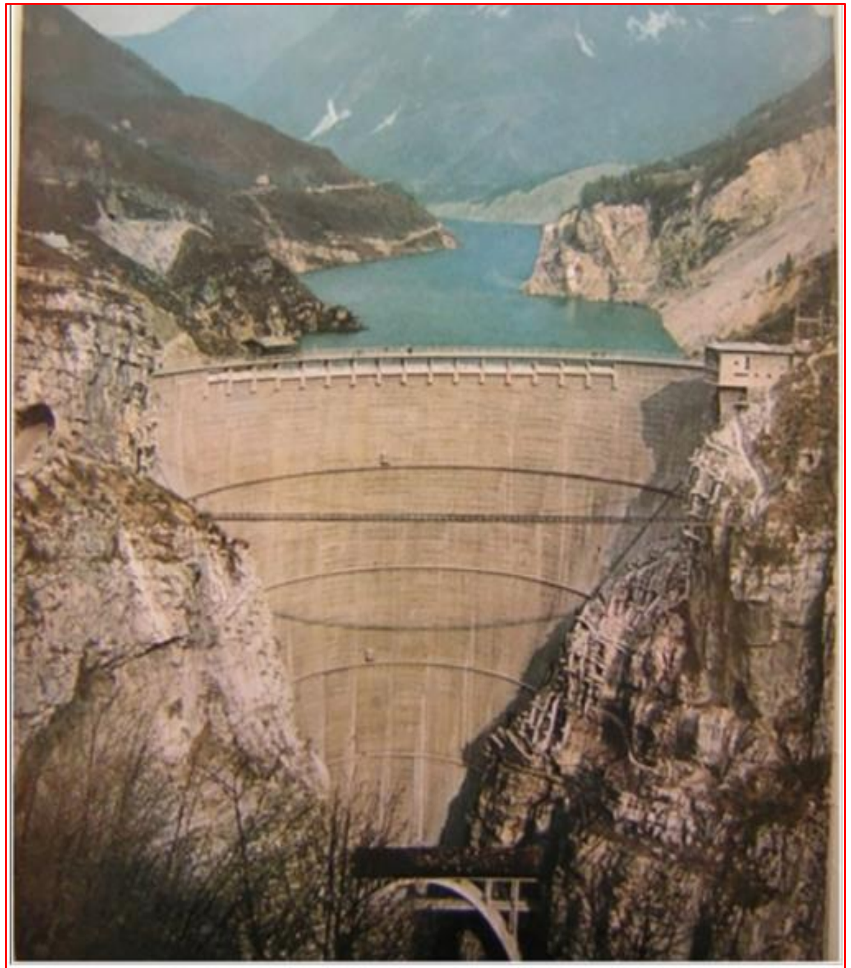
Glacier outbursts caused the flood.
At least 70 people dead, more than 150 people still missing.

CASE STUDIES: Teton Dam

Teton Dam (93 m), USA

In 1976, during the first filling, the dam completely collapsed due to piping.
11 deaths, 400M $ property damage.

CASE STUDIES: Vajont Dam



Vajont Dam, Magazine Cover. (Photo Source: Life Magazine, 1963)

Vajont Dam (262 m), İtaly

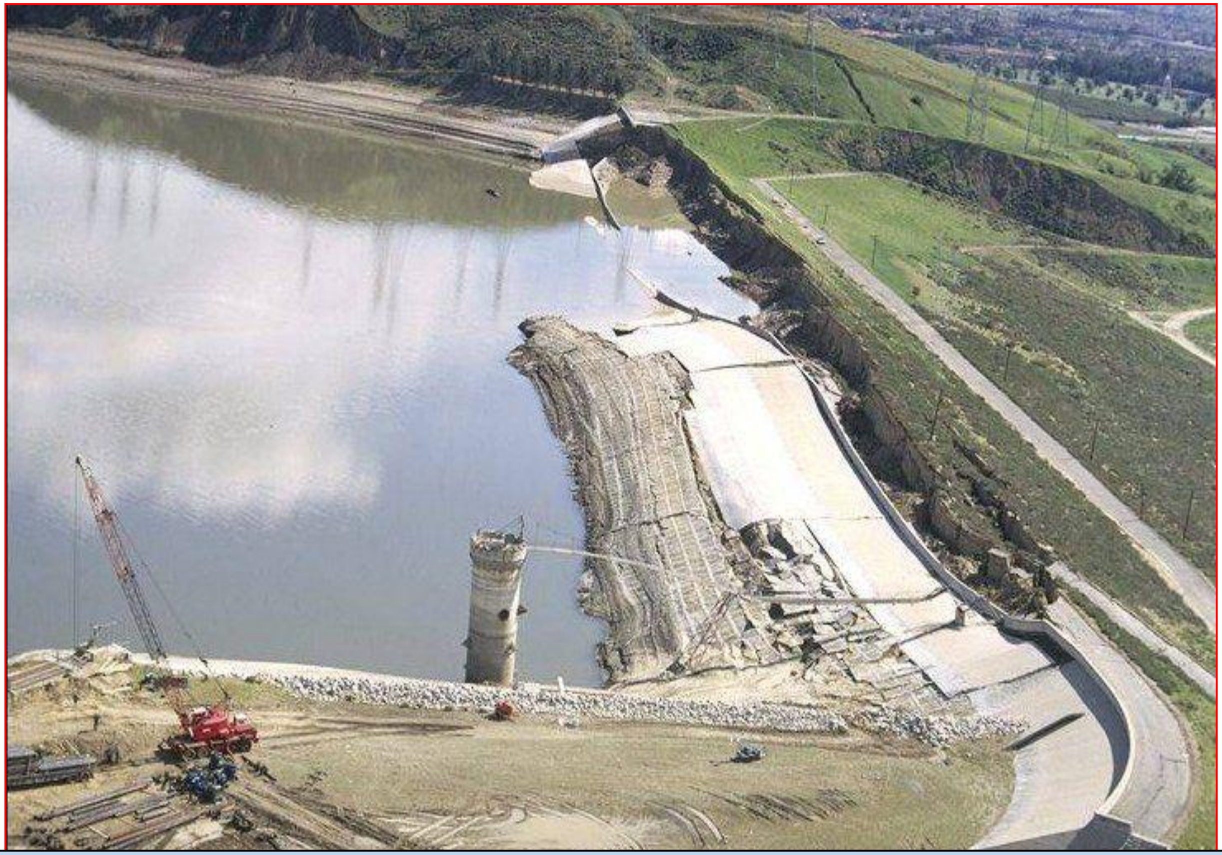
In 1963, a massive rockslide occurred in the valley basin.
The volume of rockslide (267 Million m^3) was about twice the reservoir water.

The water overtopped the dam, causing 2056 deaths.
The dam body sustained very little damage and still remains in place today with no water holding behind.(*damfailures.org*)

CASE STUDIES: Vajont Dam

Failure mechanism of Vajont Dam

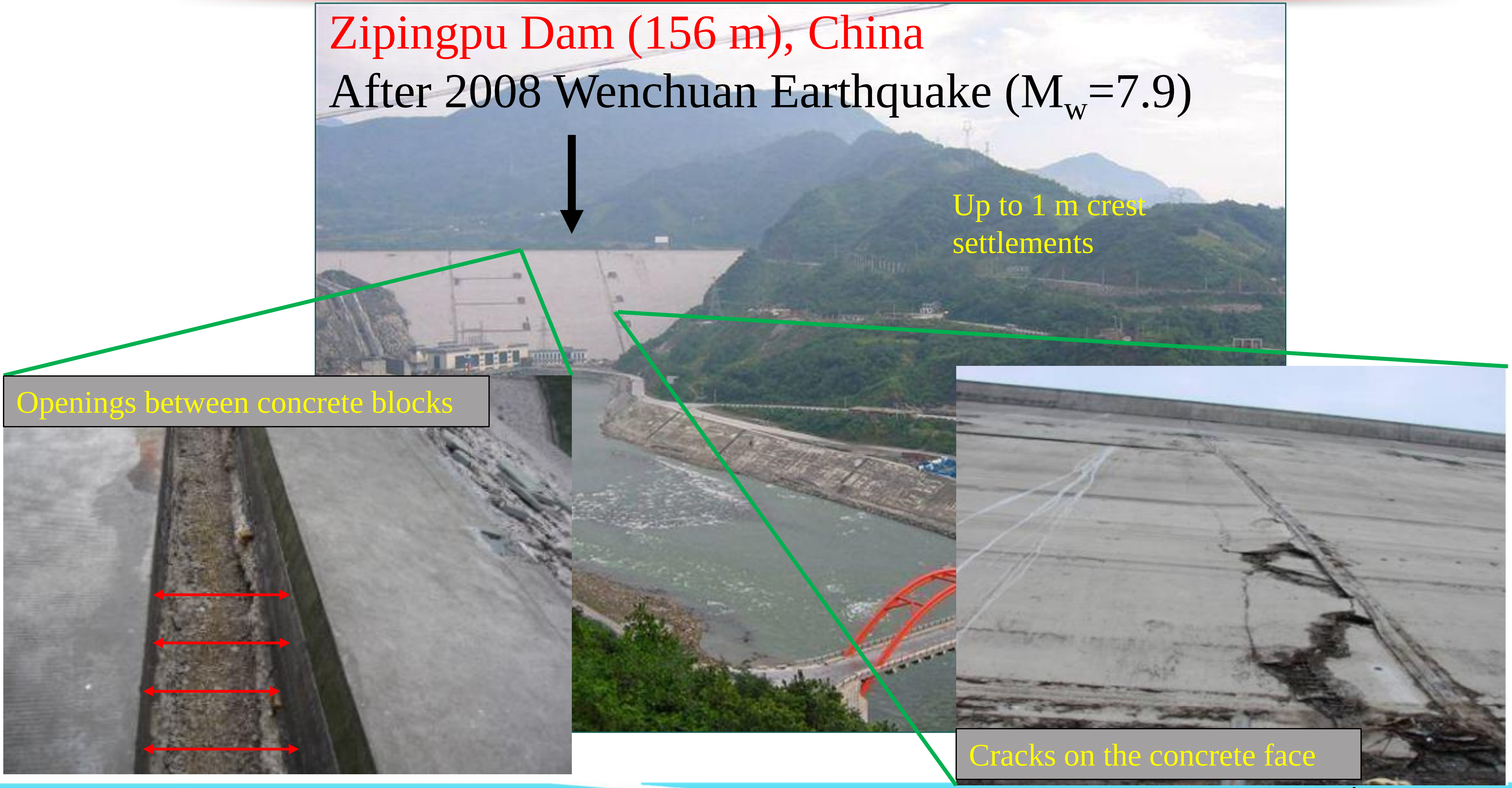
CASE STUDIES: Lower San Fernando Dam



Lower San Fernando Dam (43 m), USA

After San Fernando Earthquake in 1971 (M_w = 6.6)

The dam crest remained above the reservoir water level after earthquake-induced settlements, which prevented a total collapse.

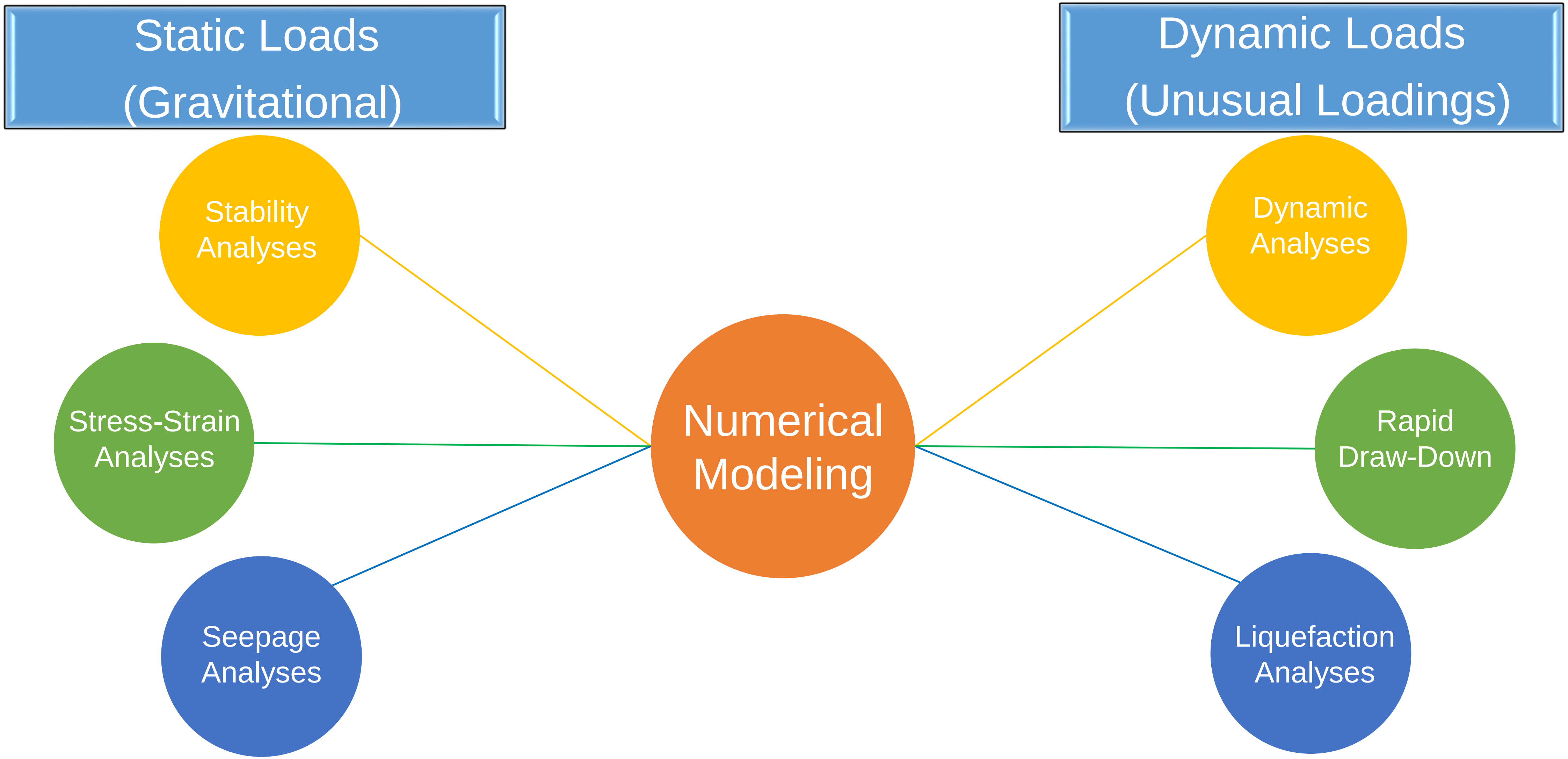

Zipingpu Dam (156 m), China
After 2008 Wenchuan Earthquake (M_w=7.9)
Up to 1 m crest settlements
Openings between concrete blocks
Cracks on the concrete face

DESIGN OF DAMS

TECHNICAL WORKS FROM PLANNING TO OPERATING

- TECHNICAL WORKS
  - Planning and Designing Phase
    - Hydrology
      - Criteria for dimensions
        - Dam design
    - Geotechnical and Geological
      - Seismic analyses
  - Construction Phase
    - Contract
      - Modifications in design
        - Field inspections
    - Instrumentation and monitoring
      - Constructional works
  - Operation and Maintenance Phase
    - Monitoring of water level
      - Modernization of Instrumentation
        - Sedimentation control
    - Operational works
      - Repair and maintenance
        - Field inspections
    - Evaluation of dam safety
      - Planning for flood events
        - Emergency action plans

MODELING PHASES IN DAM DESIGNS



RISK CLASSIFICATION OF DAMS

Risk Factor	Highest	High	Average	Low	Score
Reservoir Capacity (hm^3)	>120 **(6)**	120 - 1 **(4)**	1 - 0.1 **(2)**	<0.1 **(0)**	
Dam Height (m)	>60 **(6)**	60 - 30 **(4)**	29 - 15 **(2)**	<15 **(0)**	
Potential Evacuation Number	>1000 **(12)**	1000 - 100 **(8)**	99 - 1 **(4)**	0 **(0)**	
Potential Downstream Damage	High **(12)**	Average **(8)**	Low **(4)**	None **(0)**	
				Total	

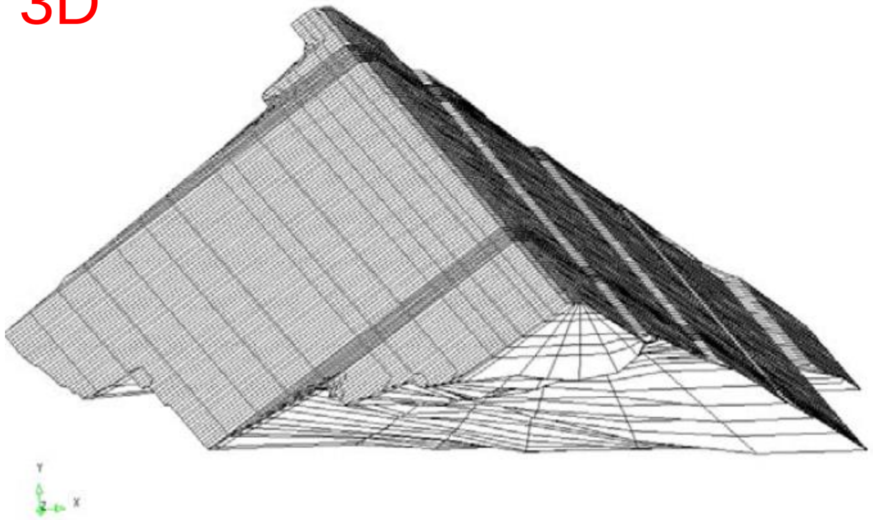
Total Risk Score	Risk Classification	
0 – 6	I	Low Risk
7 – 18	II	Moderate Risk
19 – 30	III	Substantial Risk
31 – 36	IV	High Risk

There are 4 different risk classifications. (ICOLD, Bulletin 72)

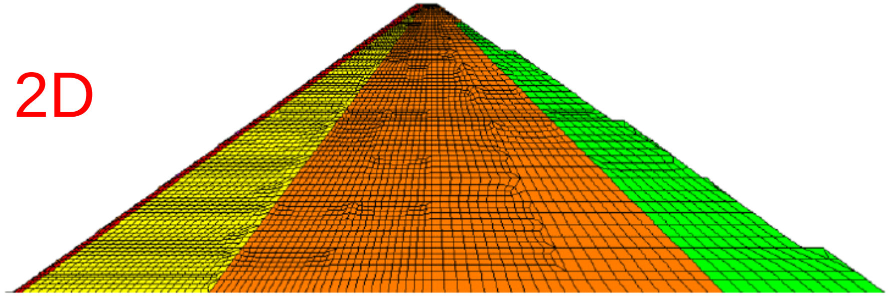
EXAMPLE FOR DYNAMIC ANALYSES

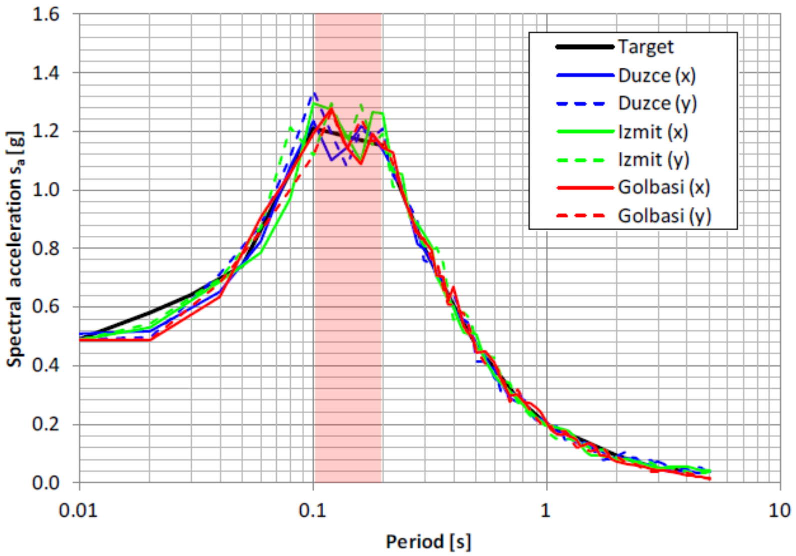
Ilısu Prof. Dr. Veysel Eroğlu Dam (Mardin)
CFRD, (131 m)

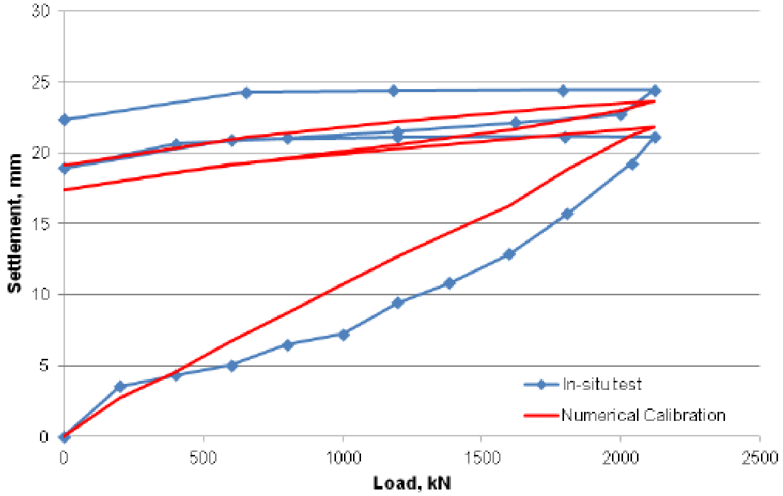
3D

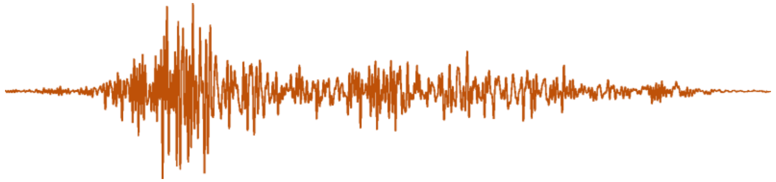


2D









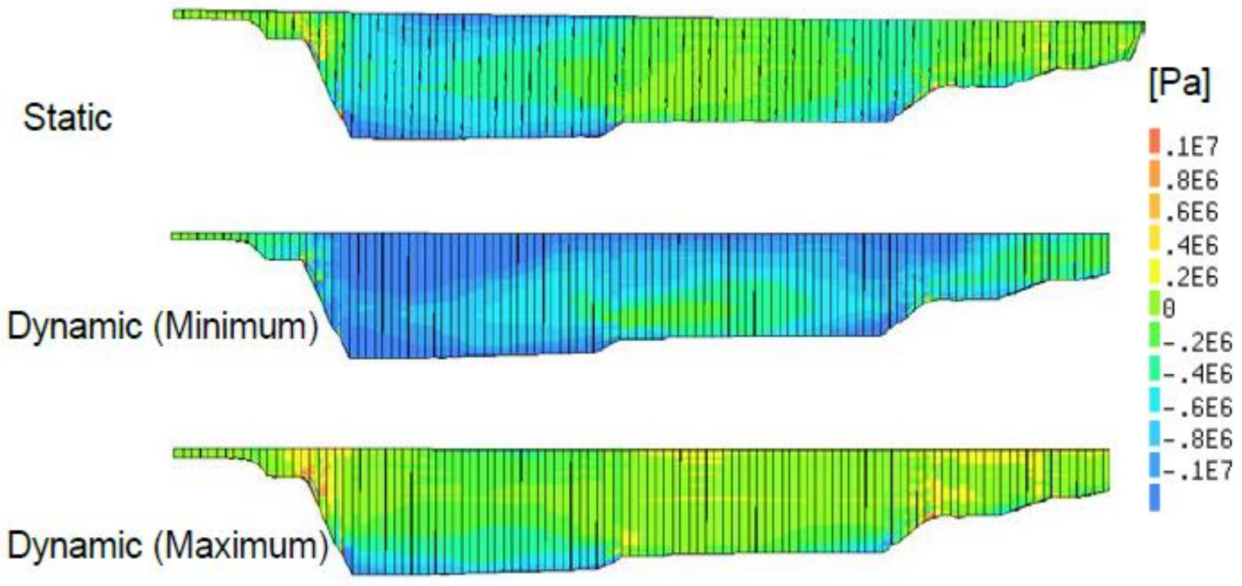
After design spectra is defined, the ground motions with similar characteristics are selected for dynamic analyses.

In-situ experiments conducted on rockfill material are compared with numerical results for calibration.

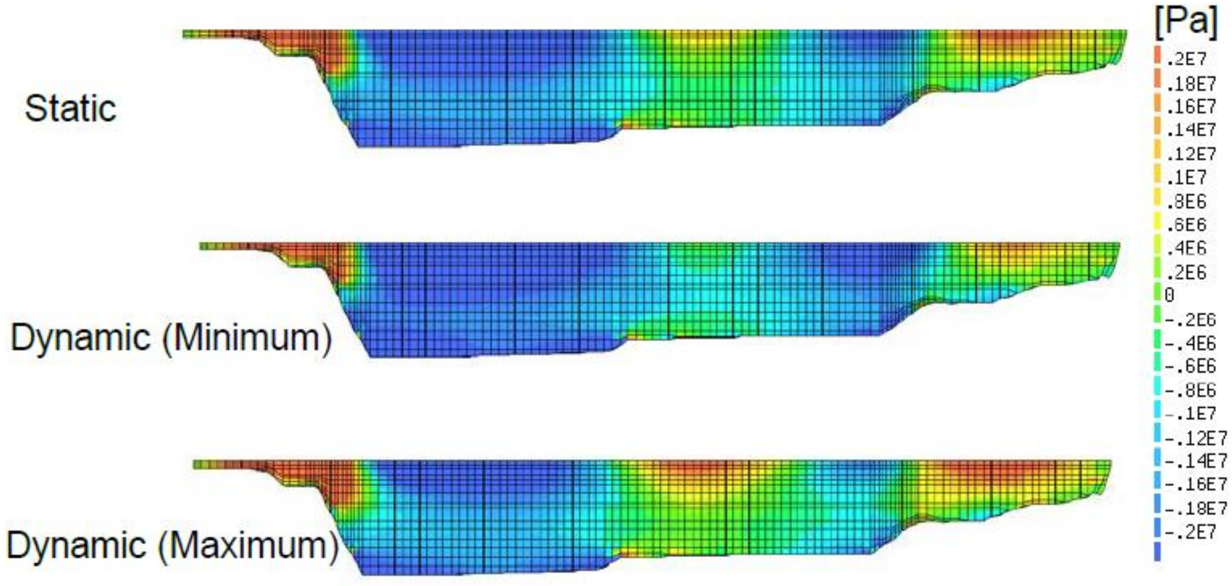
EXAMPLE FOR DYNAMIC ANALYSES

Ilısu Prof. Dr. Veysel Eroğlu Dam (Mardin)
CFRD, (131 m)

Estimated stresses in the concrete face when compressible joined are modelled.



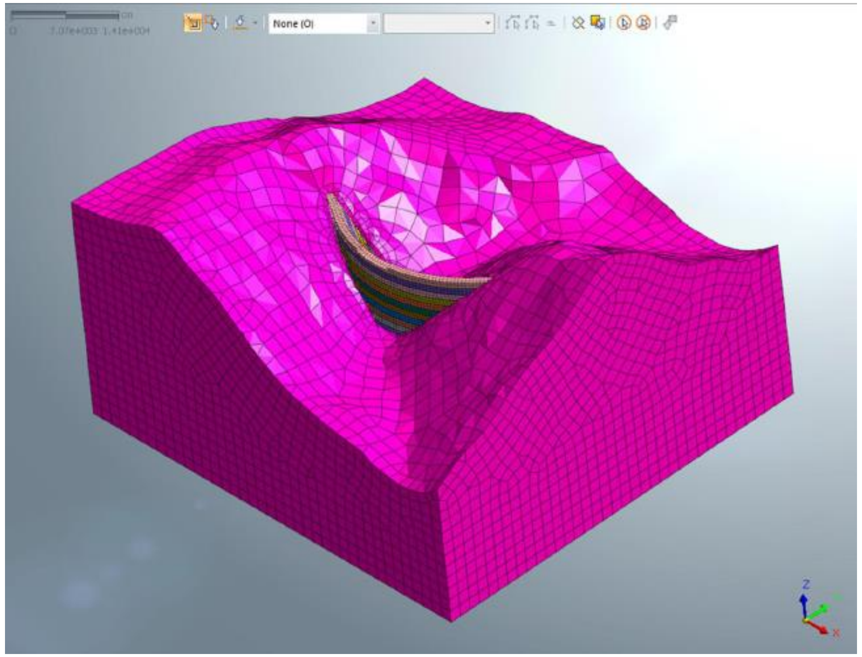
Estimated stresses in the concrete face when compressible joints are <u>not</u> modelled.

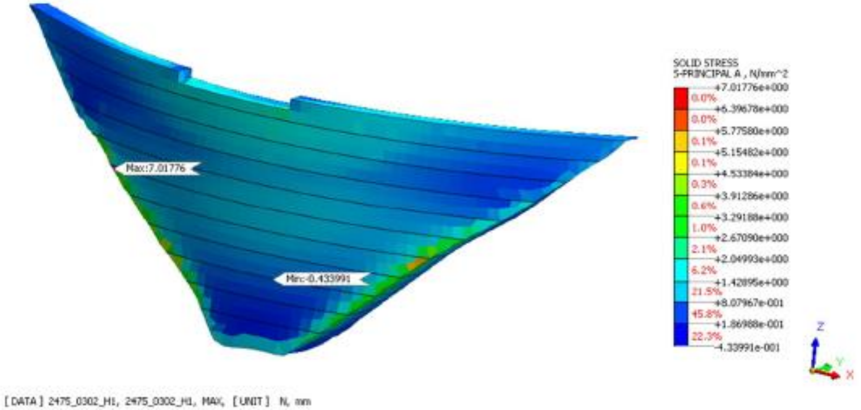


EXAMPLE FOR DYNAMIC ANALYSES

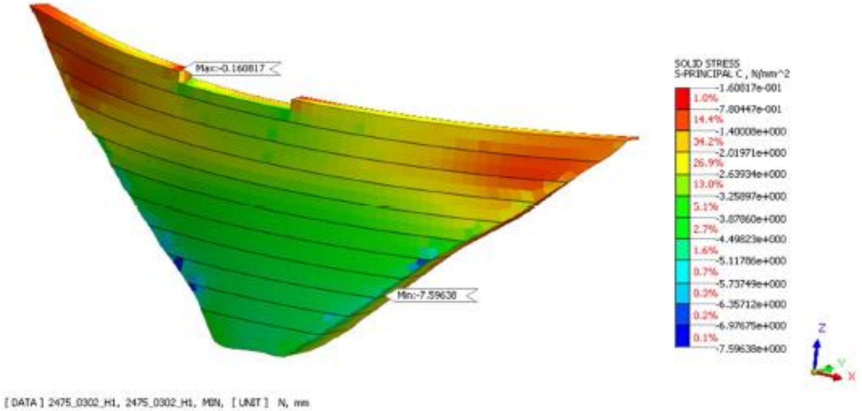
Söylemez Dam (Erzurum)
RCC + Arch (113 m)

In complex geometries, the topography and 3D modelling are involved in numerical modellings.





Şekil 3.79: EED_302_H1 (Irpinia, Italy-02) – Maksimum Asal Çekme Gerilmeleri



Şekil 3.80: EED_302_H1 (Irpinia, Italy-02) – Minimum Asal Basınç Gerilmeleri

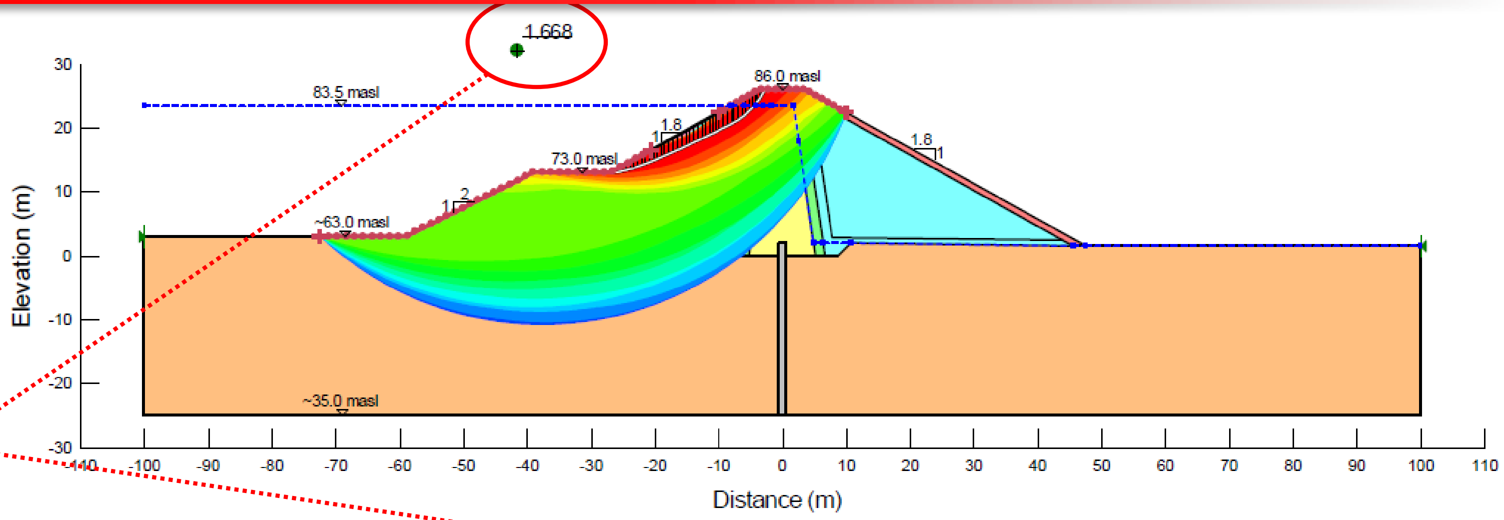
As result of seismic analyses using safety evaluation earthquakes, the seismic performance of the structure is evaluated in terms of dam safety criteria.

EXAMPLE FOR STATIC ANALYSES

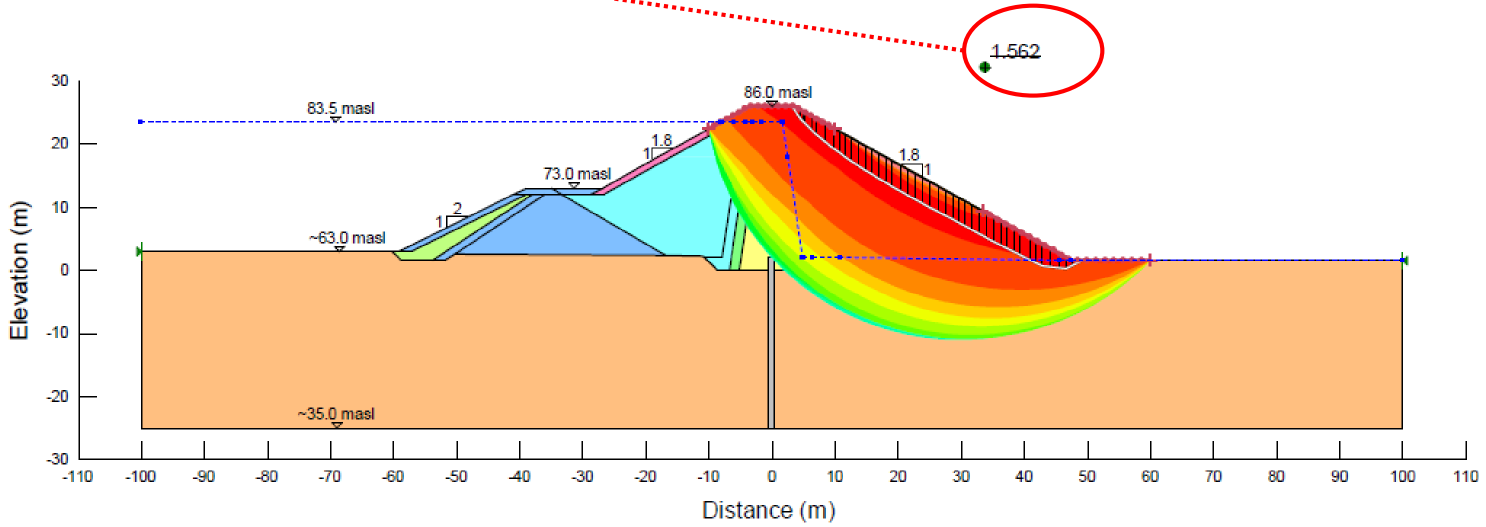
Bolaman Dam (Ordu)
Clay-Core Rockfill Dam
(28.5 m)

Factor of Safety for slopes stabilities is estimated as 1.68 and 1.56 (>1.5).

The safety factors on upstream and downstream slopes meet the required criteria.



Şekil 6-18: Memba Yamacı Stabilite Analizi. İşletim Durumu – Statik (FSL)



Şekil 6-19: Mansap Yamacı Stabilite Analizi. İşletim Durumu – Statik (FSL)

DAM CONSTRUCTION SPECİFİCATIONS

The construction contracts need to be as detailed as possible. One way to achieve this is through Technical Construction Specifications which are compatible with the criteria of International Large Dam Commissions.

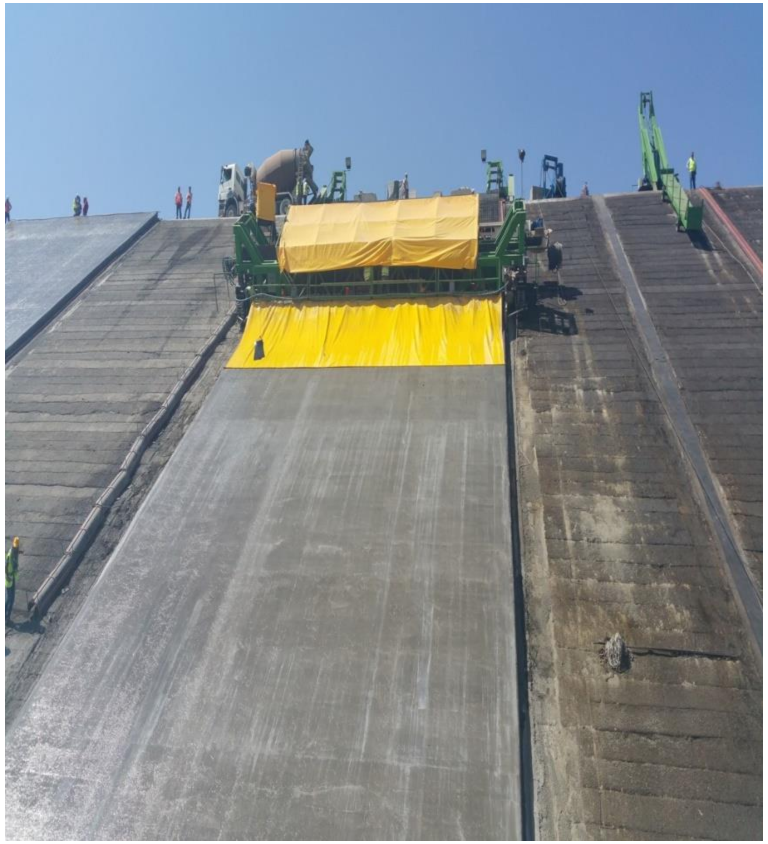
Some of the main DSI Technical Specifications;

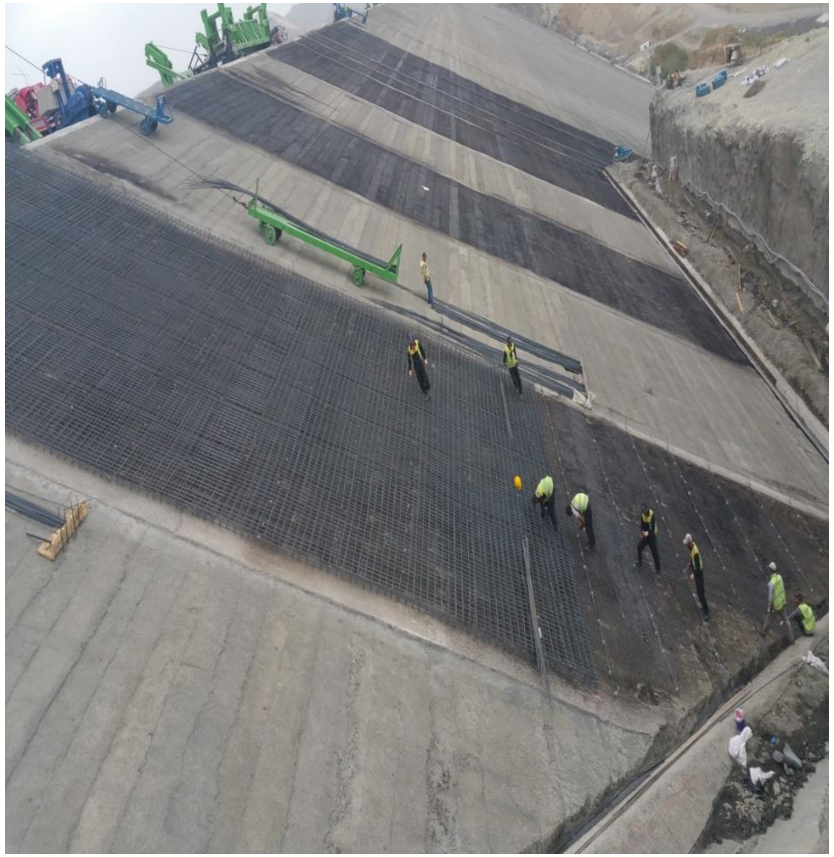
- Concrete Works Technical Specification
- Earth-fill Works Technical Specification
- Roller-Compacted Concrete Works Technical Specification
- Drilling and Grouting Technical Specification
- Drainage Works Technical Specification
- Excavation Works Technical Specification
- Geotextile – Geomembrane Technical Specification
- Instrumentation Technical Specification

WORK IN THE FIELD

WORK IN THE FIELD

WORK IN THE FIELD





INSTRUMENTATION AND VISUAL INSPECTIONS IN DAMS

INSTRUMENTATION AND MONITORING

During construction and after construction, the dams can be monitored via instruments placed in the bodies.

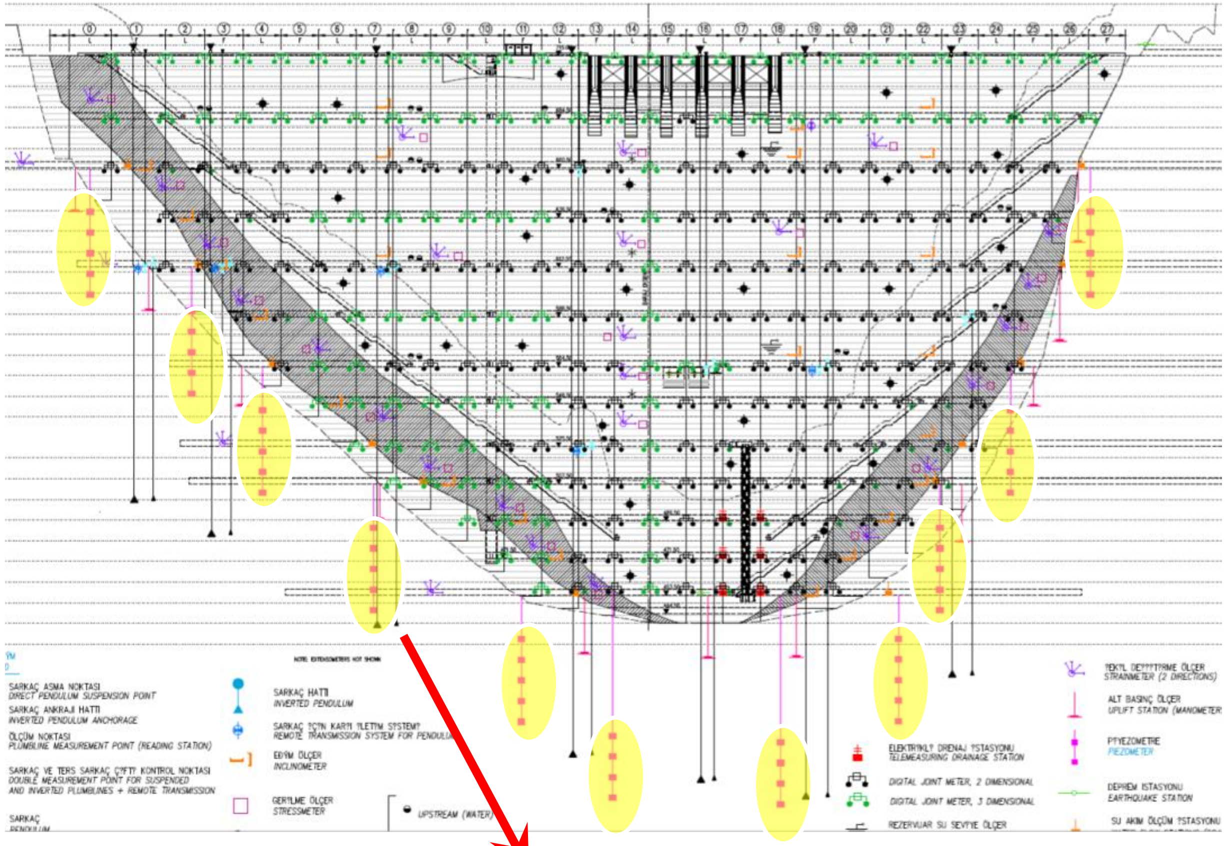
Importance of Instrumentation:

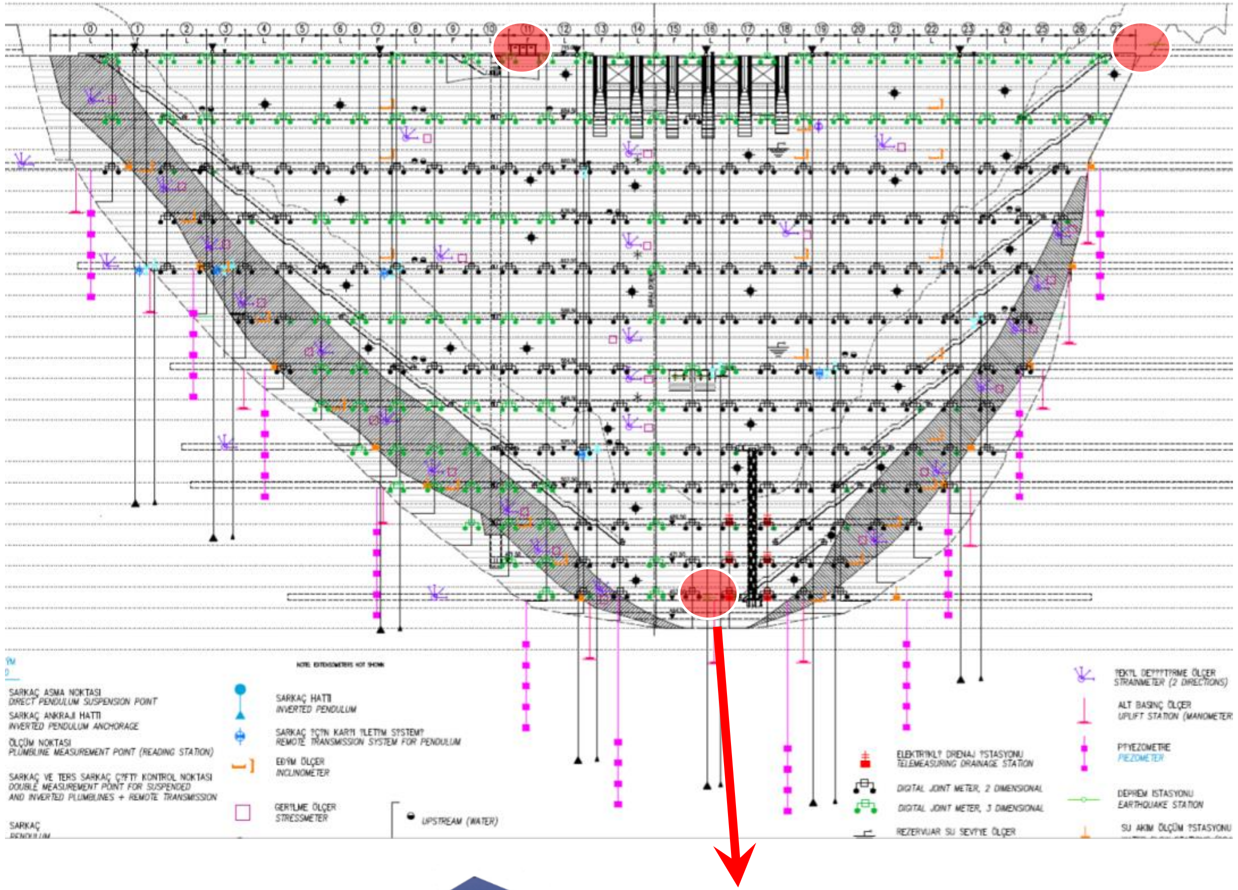
- Provides vital data with regards to dam safety measures during construction and after construction.
- Provides information about the performance of the dam.
- Provides an opportunity to check the estimated performance during design works.
- Provides feedback after repairs.
- Provides data for research and development.
- Useful for detecting unexpected behavior.

YUSUFELİ DAM and HEPP

Yusufeli Dam and HPP (275 m)
Double Curvature Concrete Arch Dam
540 MW (3 Units)

YUSUFELİ DAM and HEPP - INSTRUMENTATION





VW Piezometer

Accelerometer

YUSUFELİ DAM and HEPP- INSTRUMENTATION

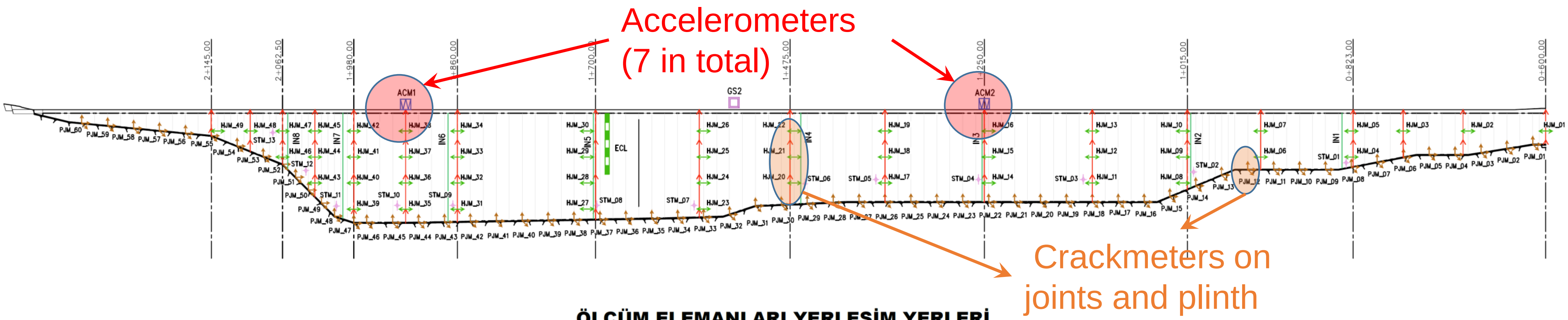
CİHAZ ADI	ADET
Eğim Ölçer / Tilt Meters	24
Çubuk Eksansiyometre (4 Çubuklu) / Rod Extensometers	25
Çubuk Eksansiyometre (1 Çubuklu) / Rod Extensometers	12
Elektronik Akım Ölçer İstasyonu / Electronic Flow Measurements	6
Birim Şekil Değiştirme Ölçer / Strain Gauges	29
Gerilme Ölçer / Stressmeters	30
Derz Ölçer (3 Boyutlu) / Joint Meters (Triaxial)	105
Derz Ölçer (1 Boyutlu) / Joint Meters (one dimentional)	152
Titreşen Telli Sıcaklık Ölçer / VW Temperature Measurement	20
Thermistör / Thermistors	3782
Termokapl / Thermocouples	150
Toplam Basınç Ölçer / Total Pressure Cells	32
Piyezometreler / Piezometers	48
Sızıntı Ölçüm İstasyonu / V Notches	12
İvmeölçer Cihazı / Accelerometers	3
Ters Sarkaç / Inverted Pendulum	7
Düz Sarkaç / Pendulum	7

Total
4441
Instruments

ILISU PROF. DR. VEYSEL EROĞLU DAM and HEPP

Ilısu Dam and HPP(135 m)
Concrete – Faced Rockfill Dam
1200 MW (6 Units)

ILISU PROF. DR. VEYSEL EROĞLU DAM and HEPP - INSTRUMENTATION



ÖLÇÜM ELEMANLARI YERLEŞİM YERLERİ
LOCATION OF INSTRUMENTATION
1 / 3'000

INSTRUMENTS	NO
Piezometers (foundation)	141
Lateral Extensometer	42
Pressure Cells	106
Hydraulic Settlement Cells	93
Magnetic Extensometers	4
Inclinometers	8
Crack Meters	163

INSTRUMENTS	NO
Accelerometers	7
Water Level Meter	1
Strain Gages	45
Fiber Optic Leakage Detector	1
Benchmarks	57
Pendulum	4
Inverted Pendulum	4

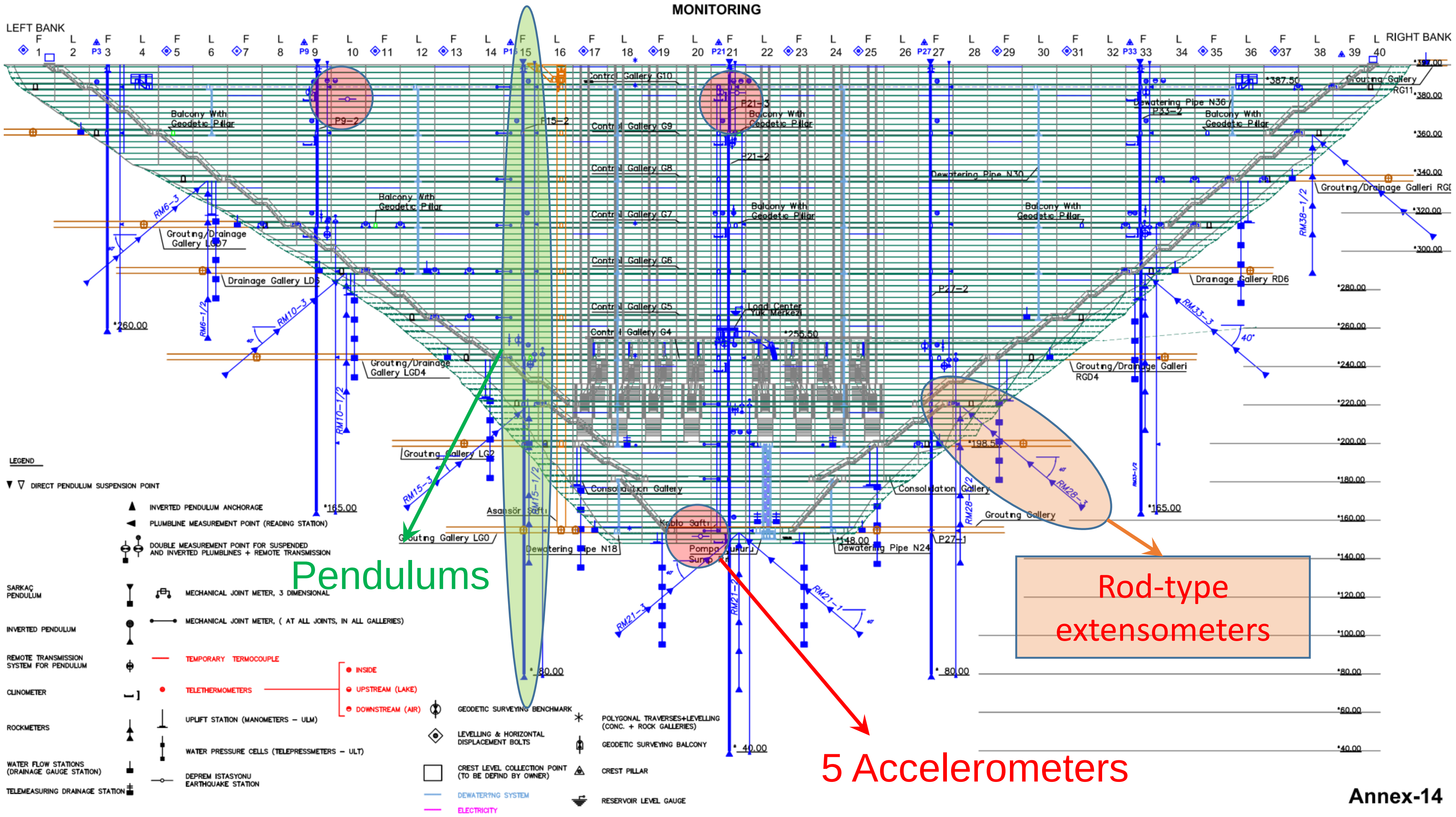
INSTRUMENTS	NO
Extensometers	16
Flow Meter	5
Temperature Sensors (short term)	39
Temperature Sensors (long term)	18
Strain Meters (with thermometers)	18
Water Temperature Sensor	1
Weather Station	1

Total 774

DERİNER DAM and HEPP

Deriner Dam and HPP (249 m)
Double Curvature Concrete Arch Dam
670 MW (4 Units)

DERİNER DAM and HEPP– INSTRUMENTATION



DAM BREAK ANALYSES

DAM BREAK ANALYSES

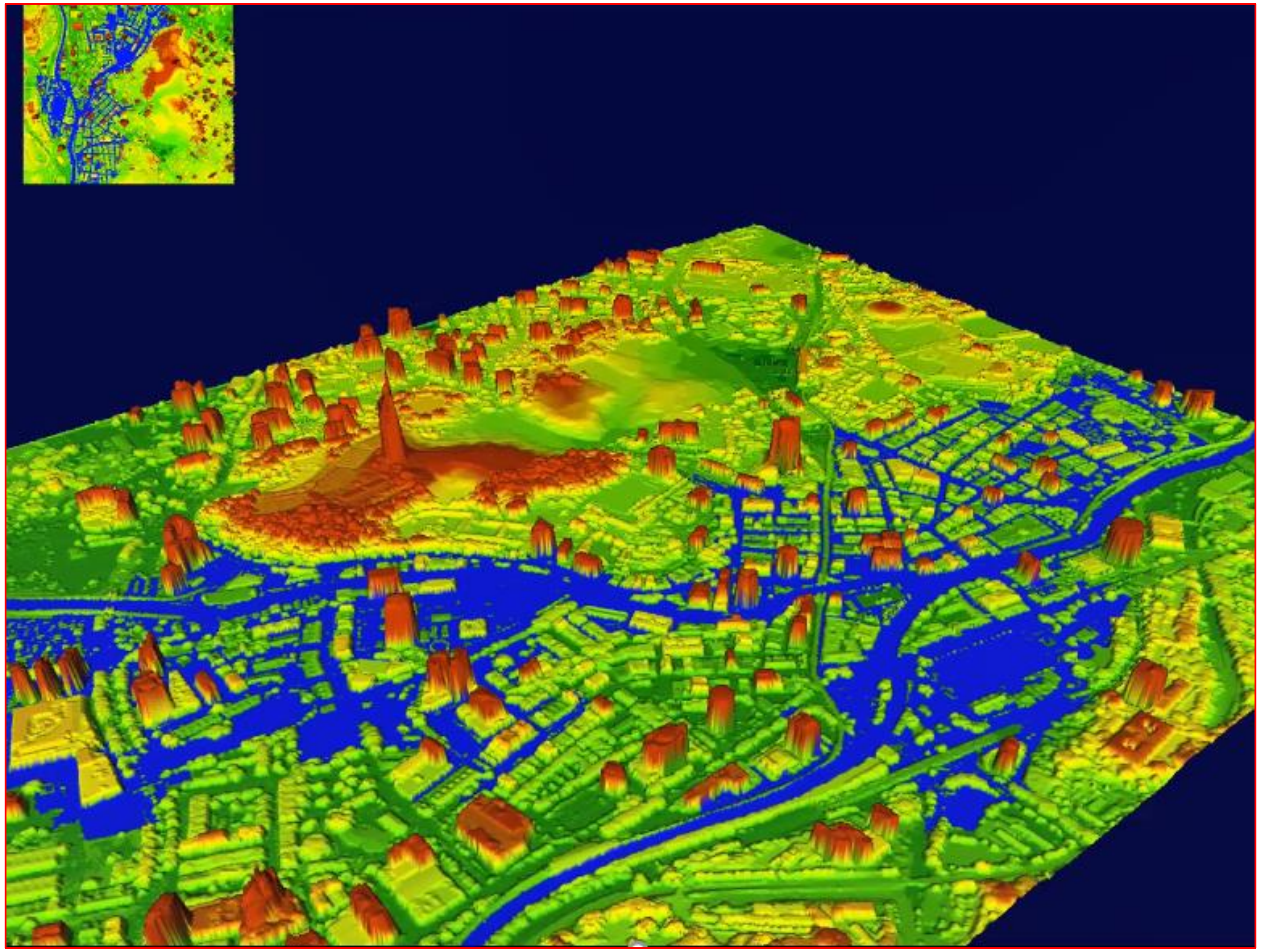
Dam Break Analyses are widely performed across the world, as the technological advances improve the capability of computers.

DSI performs dam break analyses within the scope of dam safety.

Primary purposes of dam break analyses:

- Estimate the amount of reservoir outflow with time
- Estimate the routing of the outflow
- Prepare emergency action plans afterwards

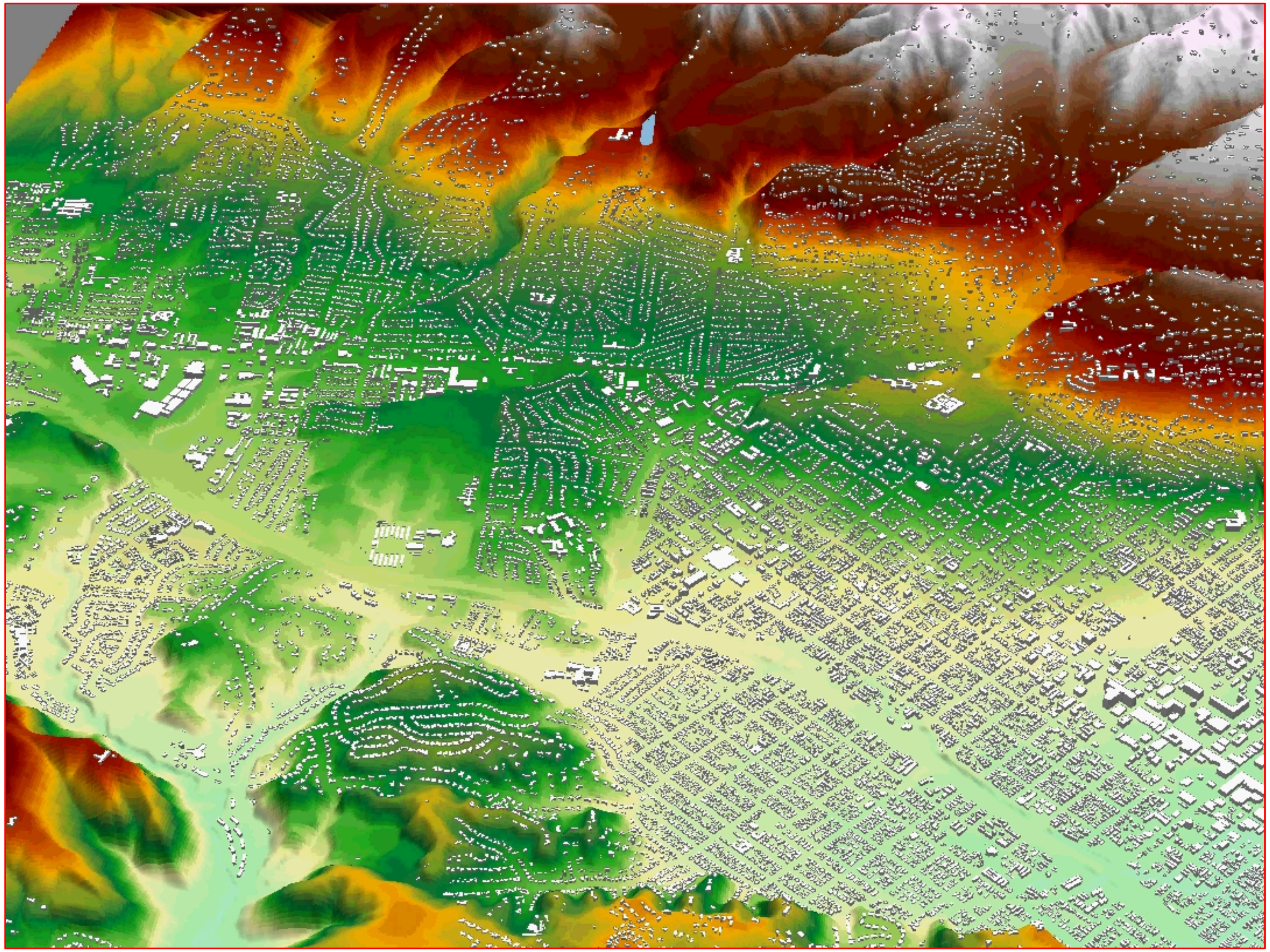
İZMİR ÜRKMEZ DAM - DAM BREAK ANALYSIS



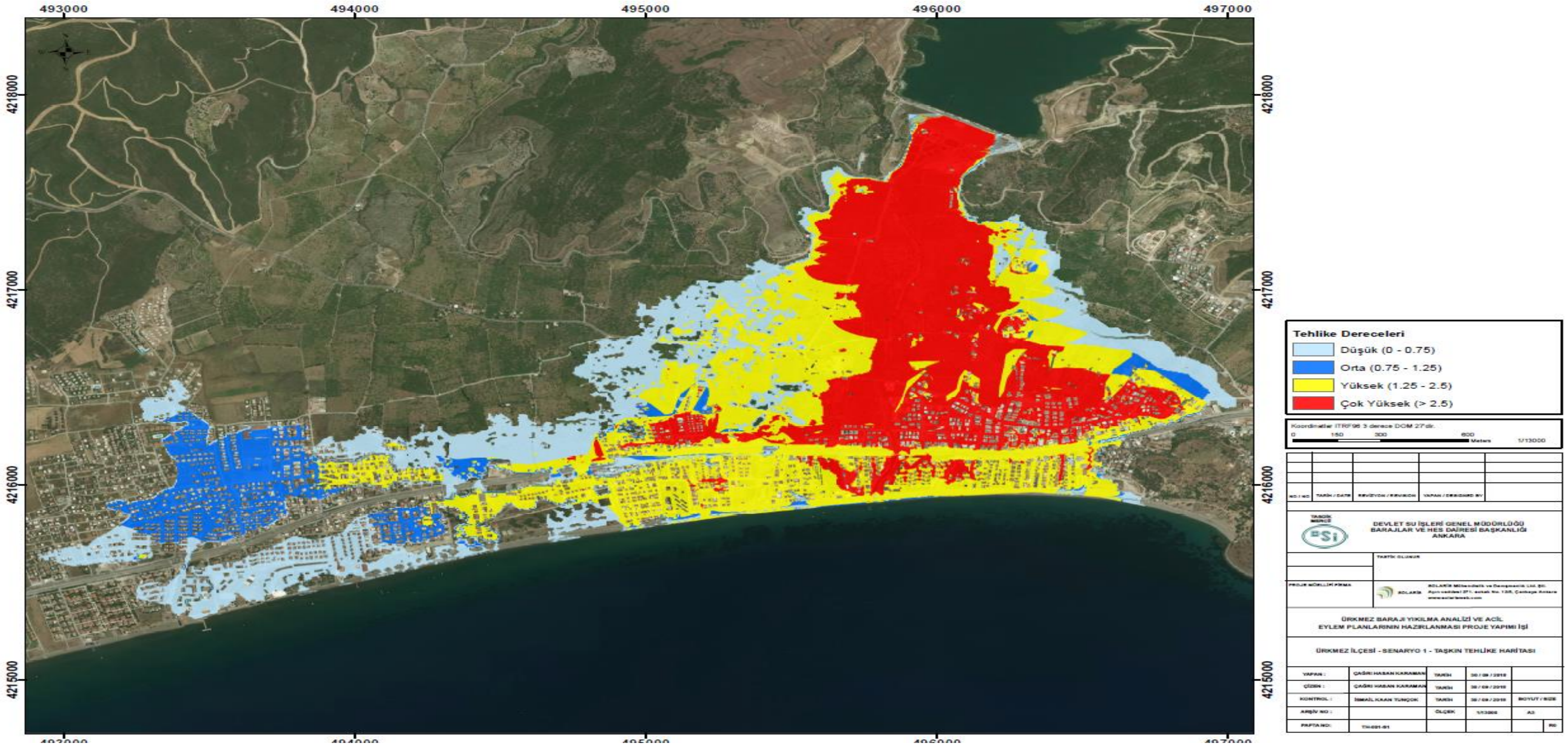
Dam break analysis of Urkmez Dam, located in city of Izmir, was performed.

The flood hazard maps are produced for emergency preparedness plan.

İZMİR ÜRKMEZ DAM - DAM BREAK ANALYSIS



İZMİR ÜRKMEZ DAM - DAM BREAK ANALYSIS

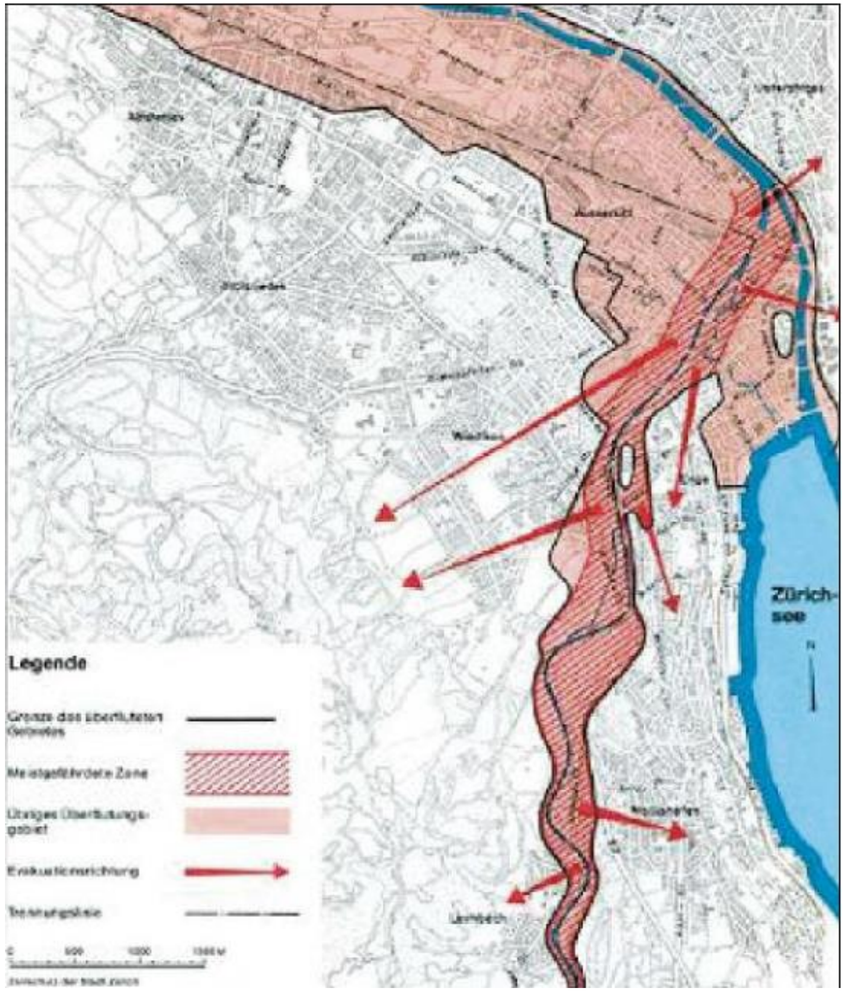


EARLY WARNING SYSTEMS

Tepekışla Dam ve HPP(Tokat)

After the flood hazard maps are produced, early warning systems are installed in downstream residential areas as part of emergency preparedness plans.

EARYLY WARNING SYSTEMS



Water alarm sirens(left) and general alarm sirens (right).

DAM SAFETY, CONSEQUENCES OF DAM FAILURE, AND MEASURES FOR RISK REDUCTION

RESULTS AND EVALUATIONS

- The number of constructed dams in Turkey is significantly high (currently 1446).
- Due to seismic activities in Turkey, special attention is given to design of dams accordingly.
- The experience in dam engineering gained since 1900s allowed the designs to be safely standardized. Thus, as long as the design criteria is followed accordingly, the potential risks are minimized.
- Inspections and monitoring are carried out visually and instrumentally.
- The dams are constantly being monitored during both construction and operation phases by the technical staff responsible for safety of dams .
- The flood hazard maps are produced via dam break analyses to set up emergency action plans (EAP).

Thank You.