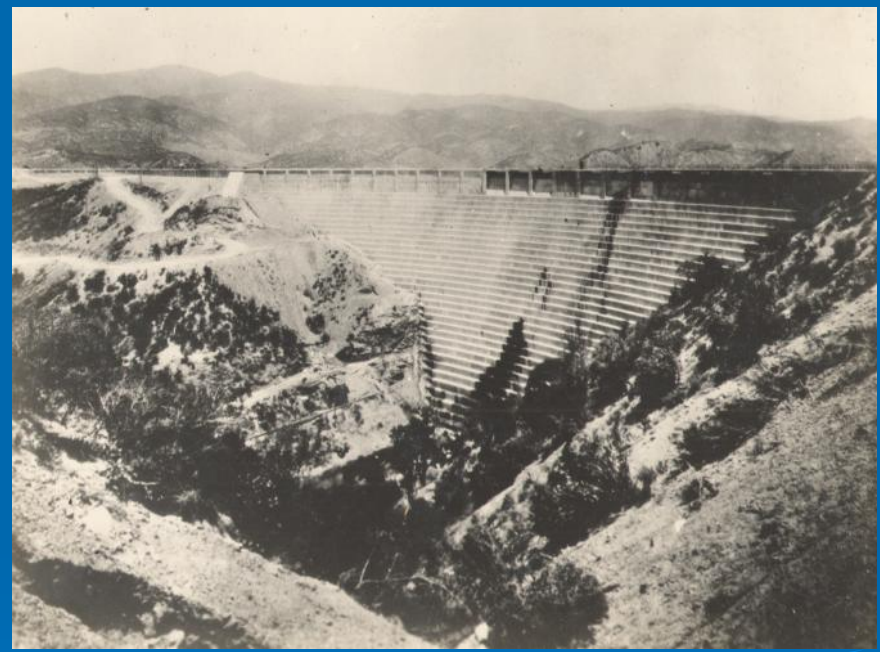
WHEN TECHNOLOGY FAILS

DAMS

PRESENTED BY AL TICE, P.E.

OUTLINE

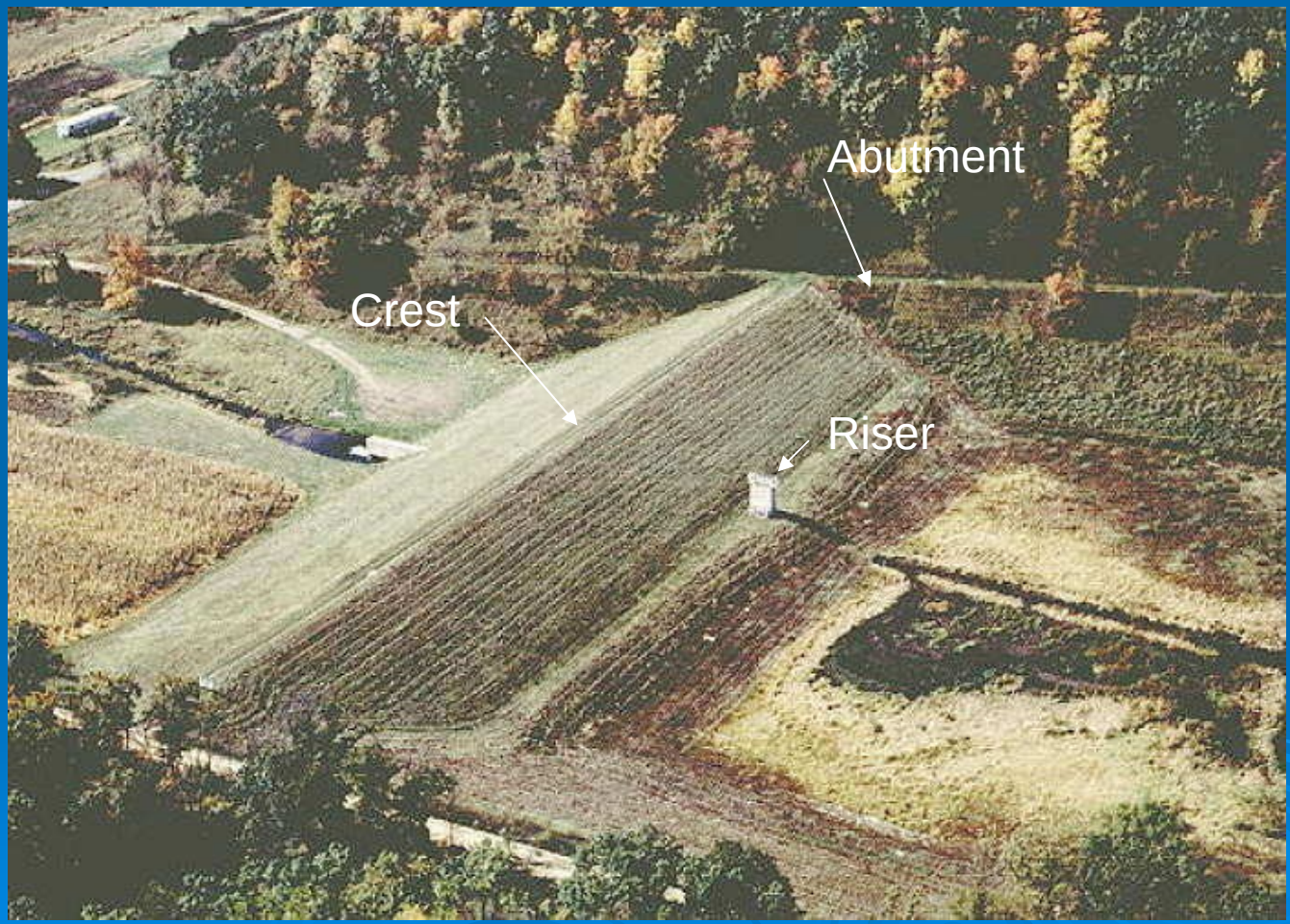
- DAMS IN GENERAL
- DAM TECHNOLOGY
- DAM FAILURE CAUSES
- NOTABLE FAILURES
- DAM SAFETY TODAY



DAMS IN GENERAL

- WHAT IS A DAM?
- TYPES OF DAM CONSTRUCTION
- EARTH FILL OR ROCK FILL

EARTH DAM

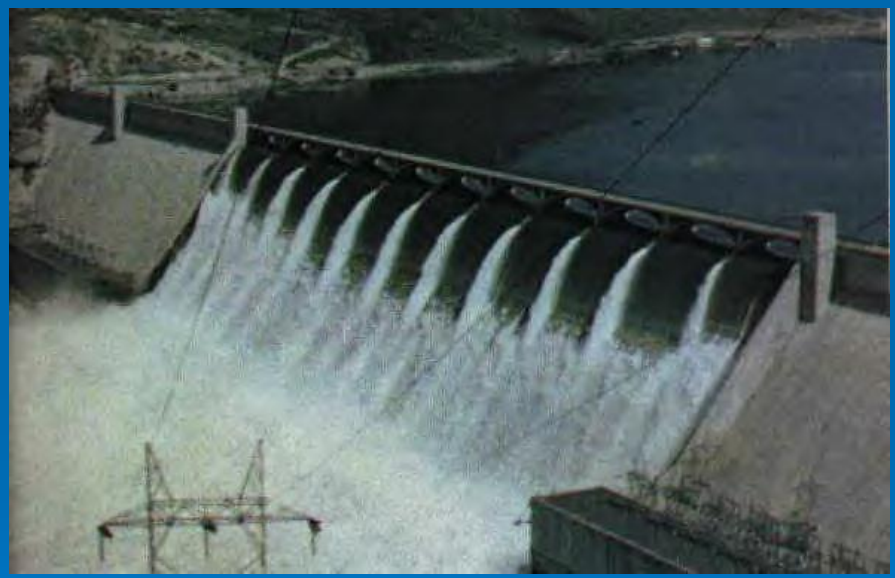


DAMS IN GENERAL

- WHAT IS A DAM?
- TYPES OF DAM CONSTRUCTION
- EARTH FILL
- **CONCRETE**

CONCRETE

GRAVITY



ARCH

DAM TECHNOLOGY

- HYDROLOGY – HOW MUCH WATER?

HYDROLOGY

- RAINFALL
- STREAM FLOW
- WHAT RAINFALL TO HANDLE
- AFTER LAKE IS FULL, WHAT COMES IN HAS TO GO OUT, EITHER THROUGH A SPILLWAY OR OVER THE DAM

DAM TECHNOLOGY

- HYDROLOGY – HOW MUCH WATER?
- **GEOLOGY**

GEOLOGY

- HOW DOES THE GROUND WORK WITH THE DAM?
  - FOUNDATION SUPPORT
  - LEAKAGE
  - LANDSLIDE POTENTIAL IN RESERVOIR
  - EARTHQUAKES

DAM TECHNOLOGY

- HYDROLOGY – HOW MUCH WATER?
- GEOLOGY
- **GEOTECHNICAL ENGINEERING**

GEOTECHNICAL ENGINEERING

- STUDIES STRENGTH AND PERMEABILITY OF GROUND
- CHECKS MATERIALS FOR EARTH DAMS
- ANALYZE STABILITY OF GROUND AND EARTH SLOPES
- ANALYZE SEEPAGE THROUGH AND UNDER

DAM TECHNOLOGY

- HYDROLOGY – HOW MUCH WATER?
- GEOLOGY
- GEOTECHNICAL ENGINEERING
- **HYDRAULIC ENGINEERING**

HYDRAULIC ENGINEERING

- DESIGNS SPILLWAYS AND PIPES TO MOVE WATER SAFELY THROUGH THE DAM.
- CONCERNED ABOUT VELOCITY OF FLOWS.

DAM TECHNOLOGY

- HYDROLOGY – HOW MUCH WATER?
- GEOLOGY
- GEOTECHNICAL ENGINEERING
- HYDRAULIC ENGINEERING
- **MATERIALS ENGINEERING**

MATERIALS ENGINEERING

- MAINLY IN CONCRETE DAMS
- DESIGN CONCRETE FOR EXPECTED STRESSES.
- HEAT BUILD UP A CONCERN

DAM TECHNOLOGY

- HYDROLOGY – HOW MUCH WATER?
- GEOLOGY
- GEOTECHNICAL ENGINEERING
- HYDRAULIC ENGINEERING
- MATERIALS ENGINEERING
- **ENVIRONMENTAL SCIENCES**

ENVIRONMENTAL SCIENCES

- A MORE RECENT CONCERN
- WETLANDS ISSUES
- FISH HABITAT IMPACTS
- MINIMUM STREAM FLOWS

ENGINEERED vs NON-ENGINEERED DAMS

- LOTS OF DAMS “JUST BUILT”
- NON-ENGINEERED DAMS TEND TO BE OF EARTH
- USUALLY SPILLWAY NOT ADEQUATE
- MANY SERVE OK
- MANY FAIL OR NEED LOTS OF REPAIR TO MAKE SAFE

WHY DO DAMS FAIL?

- POOR UNDERSTANDING OF GEOLOGY
- POOR CHOICES OF MATERIALS
- POOR CONSTRUCTION
- NO DESIGN
- TOO MUCH WATER

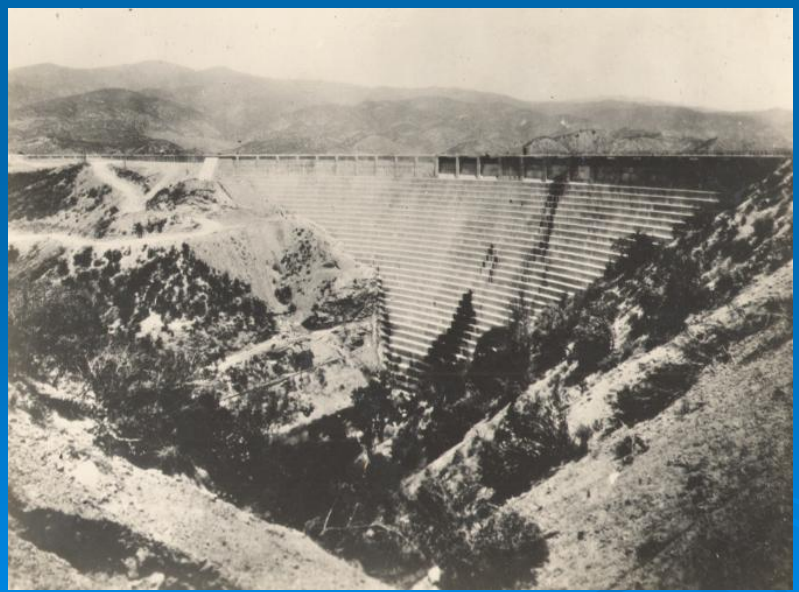
FAILURE EXAMPLES

AUSTIN DAM - 1911

- Concrete gravity dam on layered rock.
- Dam cracked and moved during filling, but filling continued.
- Dam failed by sliding on shale in foundation and from uplift forces.
- 87 Fatalities and much damage to town.
- Led to demands for state and federal legislation to regulate design, operation and maintenance.
- But laws rarely funded and minimal real impact on design.
- California designers felt demeaning to submit designs and lobbied for exemption from their state law.

ST. FRANCIS DAM – 1928

- Concrete gravity/arch built in 1926.
- ROLL TAPE!



ST. FRANCIS DAM

Why did it fail?

- Poor foundation not recognized.
- Seepage under dam ignored

- Slide in abutment over stressed concrete section
- Original study named fault movement as cause, but more recent studies have discounted this.

ST. FRANCIS DAM

- EFFECTS
  - Estimated 450 fatalities
  - 1200 buildings destroyed or damaged
  - 24,000 acres of agricultural land destroyed
- IMPACTS
  - Led to founding of engineering geology as a branch of geology.
  - Increased pressures for dam safety regulation

MALPASSET DAM -1959

- 197’ Arch Dam in France built 1952-55
- Reached full pool in 1959.
- Seepage seen downstream before failure and dismissed as not important.
- Explosive failure threw 300-ton blocks a mile downstream.
- 421 fatalities.
- Cause was existing joint planes in abutment that allowed abutment to fail under water pressure. Pushed into dam and overstressed concrete.
- Inadequate foundation studies done.

MALPASSET DAM

- IMPACTS
  - Designers charged with negligence, but ultimately acquitted.
  - Led to changes in US design practices to focus more investigation on rock in abutments for arch dams using drilling and in-situ testing.

VAIONT DAM - 1963

- Double arch concrete dam 869’ high.
- Dam did not fail; a landslide of over 300 million tons of rock into reservoir caused water to overtop the dam and flood area below. Wall of water over 330 feet high over dam.
- 3000 fatalities
- Resulted in greater attention to characteristics of reservoir slopes.

BALDWIN HILLS - 1963

- Failure of a dam after long in-service life.
- Dam over known faults and soft rock.
- Dam was considered well-designed.
- Earth dam with extensive drains and an asphalt liner.
- Dam was well maintained and inspected.
- ROLL TAPE

BALDWIN HILLS

- Effects
  - Only 5 deaths due to warnings and evacuations.
  - $50 million damage.
- Why did it fail?
  - Land subsidence along fault cased by oil extraction.
  - Movement cracked liners and drains allowing water to erode soils below liner.

BALDWIN HILLS

- IMPACTS
  - California legislation to restrict dam construction near faults and require warning systems.

TETON DAM - 1976

- 300'+ Earth Dam
- Design and construction by US Bureau of Reclamation – highly respected agency
- ROLL TAPE!
  - 2 SEGMENTS ON TAPE

TETON DAM

- Effects
  - 11 deaths, 25,000 left homeless
  - 2 towns destroyed
  - 20,000 head of cattle killed
  - Power plant at dam destroyed
  - $1 Billion cleanup over several years
  - Dam never rebuilt

TETON DAM

- Why did it fail
  - Poor design for tough site; not enough attention to rock porosity.
  - Ignoring warning signs during construction.
  - Filled too fast.
  - Ignored implications of seepage seen.
  - A case of over-confidence.

TETON DAM

- Impacts
  - USBR design approach changed – more outside reviews of designs.
  - Final impetus for dam design regulation.
  - Led (along with Kelly Barnes Dam failure) directly to national dam inspection program by Corps of Engineers.

OTHER SIGNIFICANT FAILURES in 1970's

- Buffalo Creek Tailings Dam (W Va)
  - Not an engineered dam, more just a pile of material.
  - 125 killed
- Kelly Barnes Dam (GA)
  - Only 40 feet high; killed 39.
  - Last straw for many states
- Bearwallow Gap Dam (NC)
  - Small "dam" perched up high on hill
  - Failure led to funding for NC Dam Safety Program.

DAM SAFETY TODAY

- Practically all states have regulations on dams. Permits required to build dams.
  - Small dams (<15 to 25 ‘) exempt
  - Designs have to be by P. E.
- North Carolina Dam Safety Law of 1967
  - Regulations first issued in 1978
  - Under DENR, Div of Land Resources

KEY REGULATION FEATURES

- Dams classified by hazard posed
- Dams have to store or pass floods related to rainfall and hazard.
  - 100-year to PMF
- Geotechnical studies required for most
- Bottom drains required
- Limits on types of pipes

INSPECTIONS

- State has inventory of dams
  - ~5100 dams in inventory,
  - ~1100 considered high hazard
- Inspections once a year or two
  - Staff limitations impact frequency
- Can require owners to hire engineer for further inspection, testing or repair designs
  - Repairs subject to review and permitting

SUMMARY

- Dams will continue to fail; example Hope Mills.
- Many old dams that have outlived their functionality are at risk of failure.
- New dams less likely to fail, but still can have problems.

HOPE MILLS