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Managing Water in the West

Roller-compacted Concrete for Dam Safety Modifications

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Brazilian International RCC Symposium

U.S. Department of the Interior
Bureau of Reclamation

RCC for Dam Safety Modifications

- Introduction
- Risk assessment methodology for evaluating dam safety modifications
- RCC for dam safety modifications
- RCC mixtures
- Typical RCC modifications
- Case Histories
  - RCC dam and foundation stability modifications
  - RCC spillways
  - RCC overtopping protection

Introduction - Bureau of Reclamation (Reclamation)

- Celebrated its 100 th Anniversary in 2004
- 350 major concrete and embankment dams
- Canals, tunnels, pumping and power plants
- ~ 300 billion m^3 of water for irrigation, recreation, water conservation, and municipal needs
- Second largest hydropower producer in the USA
- 289 recreation sites and 90 million visitors

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Reclamation Dam Safety Program

- 50 percent of Reclamation dams more than 50 years old
- 90 percent of dams constructed before the currently used state-of-the-art design and construction practices
- Aging dams present dam safety challenges
- Reclamation inspects dams every 1 to 3 years
- Comprehensive facility review (CFR) every 6 years
- Risk assessment process for dam safety prioritization of $ funding

Bureau of Reclamation Risk Assessment Methodology

- **Bureau of Reclamation prioritizes all dam safety modifications based on the risk to loss of life**
- **Evaluate risk from the annual probability of events (static, hydrologic, seismic)**
- **Evaluate potential failure modes and likelihood of failure (given an event takes place)**
- **Evaluate downstream loss of life (LOL) consequences**
- **Compare to Reclamation *Annualized Loss of Life* criteria for individual and combined events**
- ***Take structural or non-structural actions to reduce risk***

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Reclamation Dam Safety Risk Criteria

- Estimated **Annualized Loss of Life** = (Annual Probability of Load) x (Probability of Failure Given the Load) x (Consequences Given the Failure [LOL])

- ALOL = P_{event} x $P_{failure}$ x LOL
- ALOL = (1/100) X 0.5 X 10 = 5 X 10^{-2}
- ALOL = (1/10,000) X 0.1 X 5000 = 5 X 10^{-2}

Allowable Annual Loss of Life (ALOL)

- 10^{-3} ALOL for any given failure mode
- 10^{-4} ALOL for sum of all potential failure modes

RCC for Dam Safety Modifications

- RCC is an accepted method for new dams and rehabilitation of existing dams
- RCC is both a material, a design procedure, and construction method
- Rapid construction favors RCC for dam safety modifications
  – Allowable time for reservoir operations impacts
  – Rapid RCC production promotes better quality
  – Cost of RCC is ~ 1 / 5 the cost of mass concrete

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RCC for Dam Safety Modifications

- RCC is versatile with many different possible configurations
- Often less RCC volume per lift than new dam construction
- Surface preparation depends on the quality of existing concrete
- May require no bond to allow for movement
- May have difficulty with access
- Space limitations may influence selection of construction equipment and materials

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Reclamation RCC Mixtures

- Vebe consistency (~ 20 – 30 seconds)

- 0 to 70 percent pozzolan (depending on design age)

- ASTM concrete sand and coarse aggregates

- Air-entrained (AEA) RCC for freeze-thaw durability

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RCC for Stability Buttress – Design Objectives

- Outlet works diversion
- Foundation excavation and cleaning
- De-watering / Un-watering plan
- Gallery design
- Seepage at interface and control measures
- Dam face surface preparation
- Bonding or de-bonding at surface contact
- Spillway design and overtopping protection
- Thermal stress analysis

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Case History - Santa Cruz Arch Dam - 1990

Santa Cruz Arch Dam - 1990

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Santa Cruz Arch Dam - 1990

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Santa Cruz Arch Dam - 1990

- 0.6 m stepped spillway
- Conventional concrete for FT durability

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Santa Cruz Arch Dam - 1990

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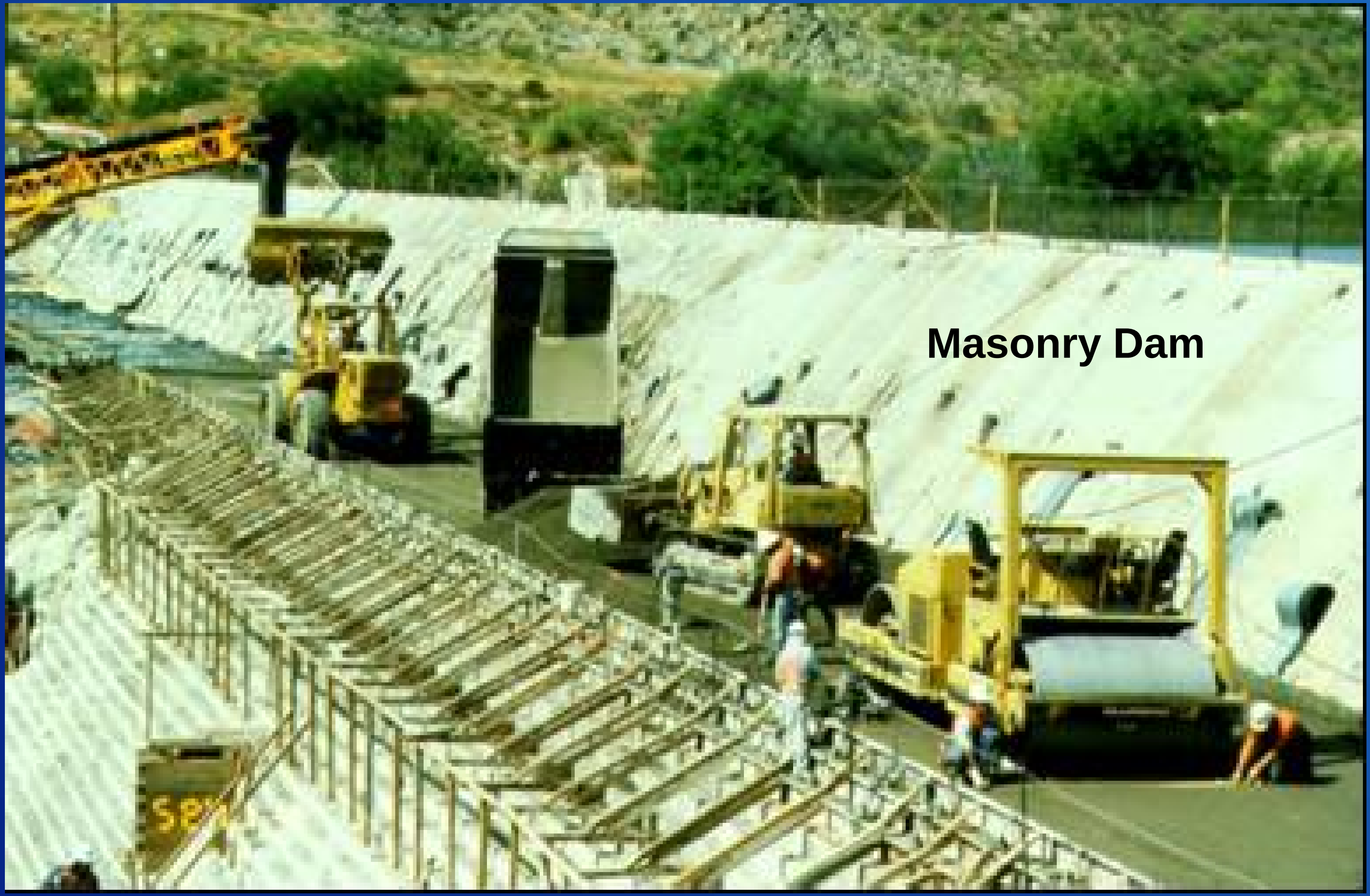
Camp Dyer Dam Buttress - 1992



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Camp Dyer Dam Buttress - 1992

- Flat drains for seepage

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Camp Dyer Dam Buttress - 1992

Camp Dyer Dam Buttress – 1992

RCC Facing compaction

Camp Dyer Dam Buttress - 1992

Camp Dyer Dam Buttress - 1993

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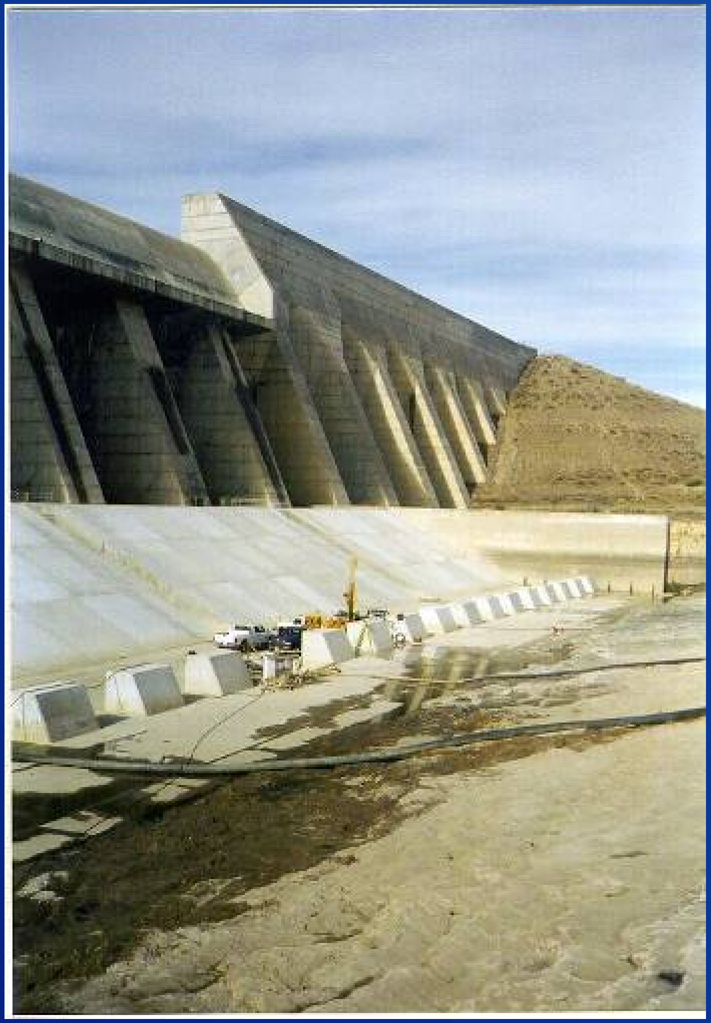
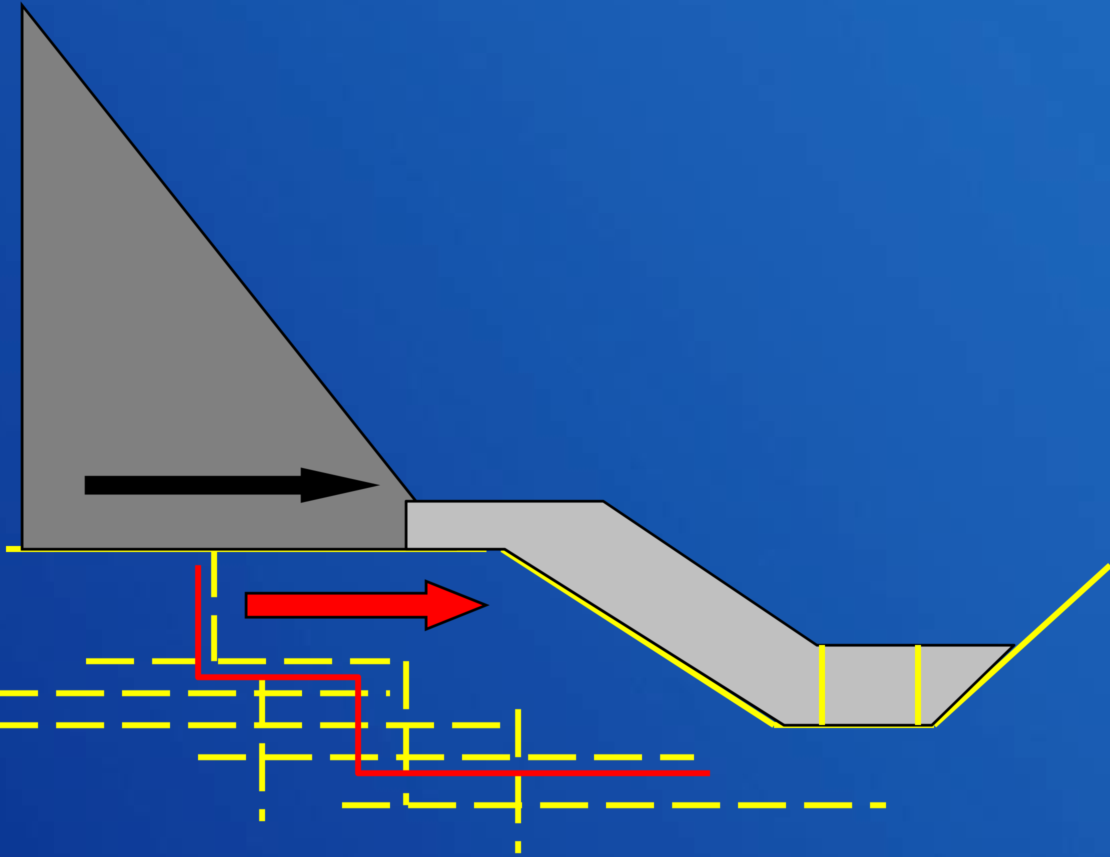
Pueblo Dam Spillway and Foundation Buttress – 1999





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Pueblo Dam Spillway and Foundation Buttress – 1999

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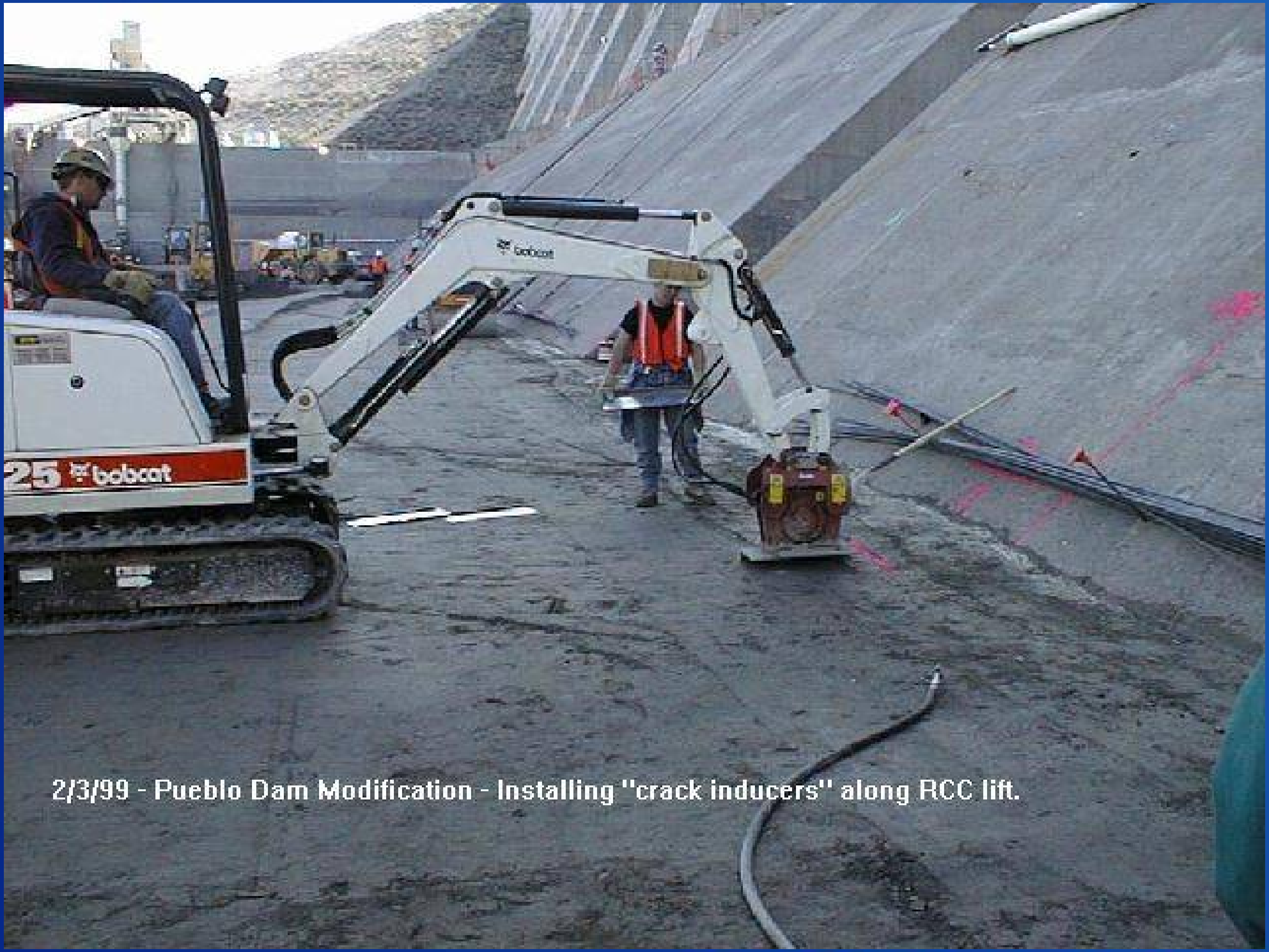

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Pueblo Dam Spillway and Foundation Buttress – 1999

Pueblo Dam Spillway RCC “Toe Block”

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Pueblo Dam **Spillway** – RCC "Toe Block"

- **Vibrating plate compactor – 2 H : 1 V side slope**

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Pueblo Dam Spillway and Foundation Buttress – 1999

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RCC Spillway Construction

- RCC spillways vs. dams
  - Smaller volume of RCC per lift
  - Long spillway lanes – 50 to 500 m
  - Pervious filter and drains on slope
  - Series of “steps”
  - Edge compaction and durability

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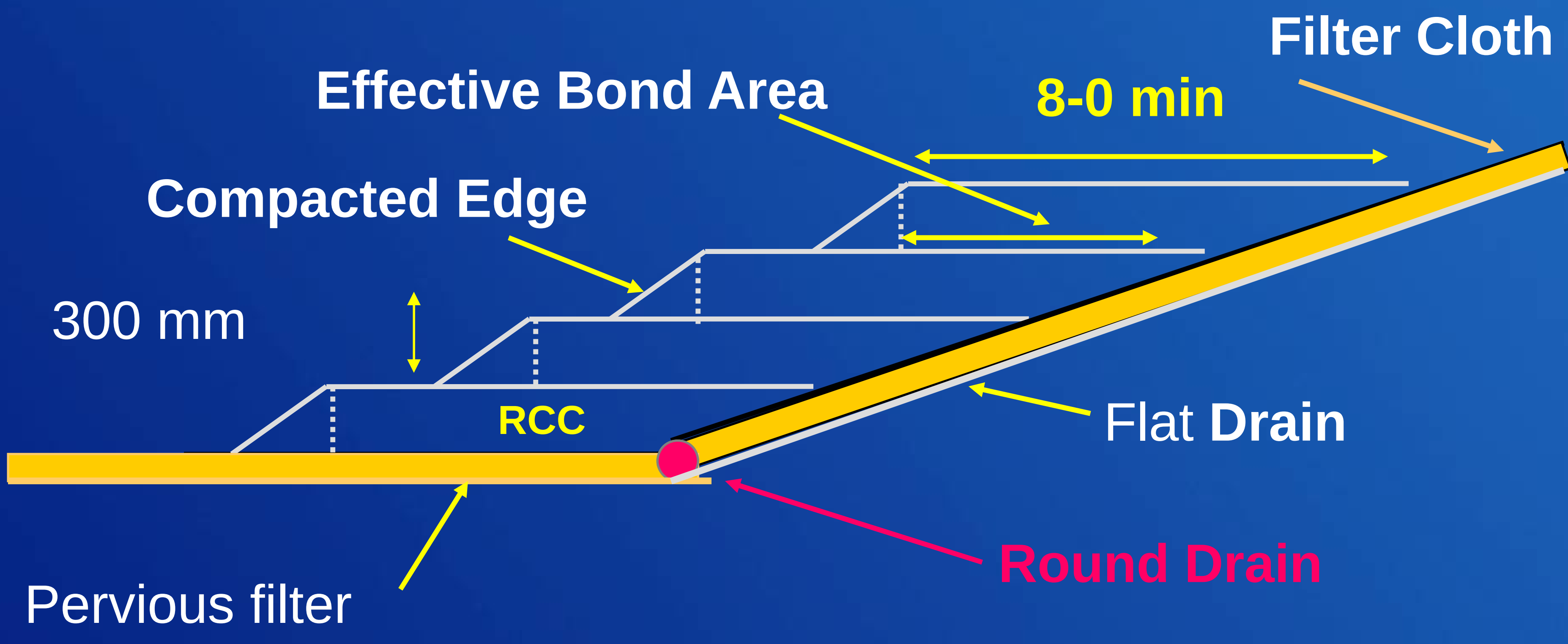
RCC Spillway Construction Sloped Sidewall Details



RCC Spillway Design Considerations

- Open channel flow conditions and facing requirements
- Design loads and uplift considerations
  - Lift bonding
  - Cracking and stagnation pressures
  - Drains
- Spillway layout
  - Allowable slopes
  - Turns
- Durability

Cold Springs Dam Spillway - 1995

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Cold Springs Dam Spillway - 1995

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Cold Springs Dam Spillway – Turn Layout

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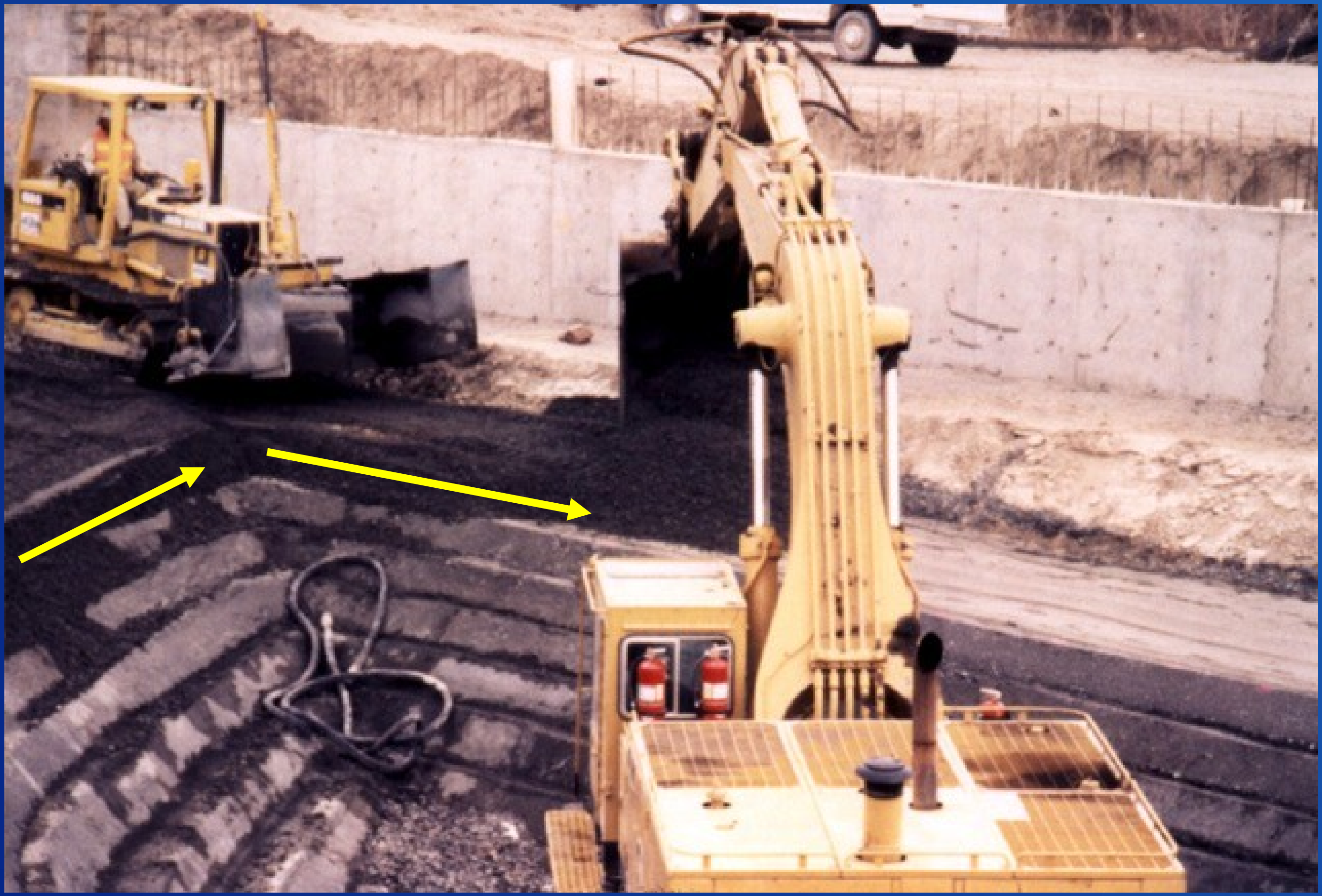
Cold Springs Dam Spillway - 1993



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Cold Springs Dam Spillway Modification

- Dozer mounted vibrating plate compactor
- 1-1/2 : 1 side slope

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Ochoco Dam Spillway Modification - 1996

- RCC Plunge Pool
- Redirect flows
- Artesian aquifer
- Non-uniform foundation
- RCC weirs for tail water

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Many Farms Dam Spillway - 2000

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Many Farms Dam Spillway - 2000

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Many Farms Dam Spillway - 2000

Upstream approach

Hand Operated Vibrating Plate Edge Compaction

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Many Farms Dam – 2:1 side Slope

- **Track-hoe with vibrating plate compactor**

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Many Farms Dam Spillway - 2000

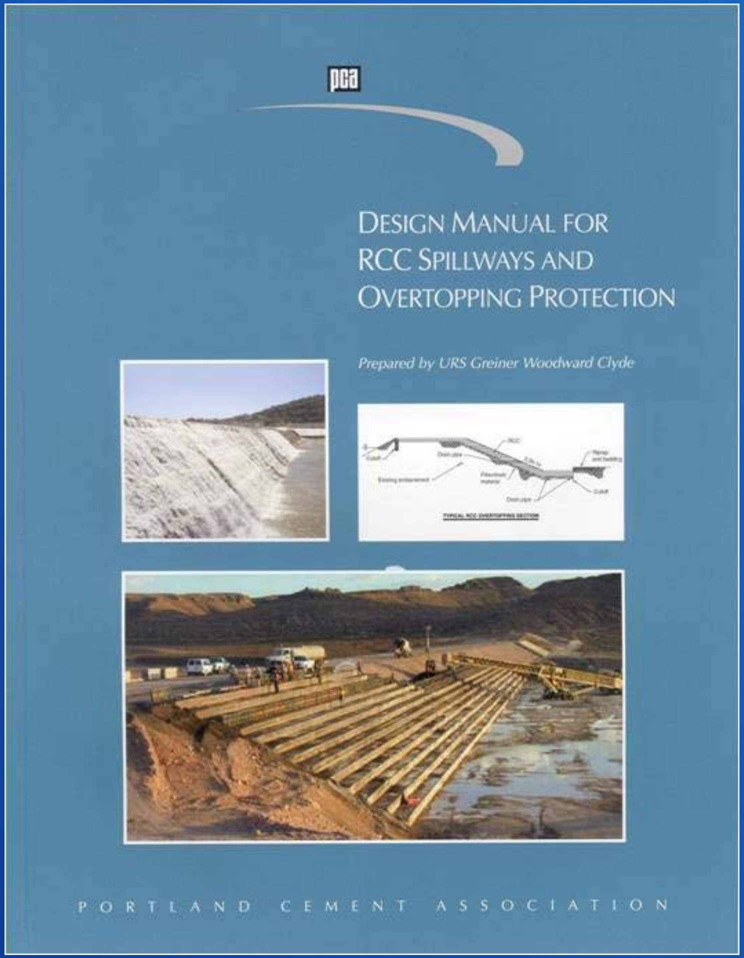
- **Track-hoe with vibrating plate compactor**

Many Farms Dam Spillway - 2000

2H:1V and 1H:1V Side Slopes

RCC Embankment Dam Overtopping Protection

Mr. Fares Y. Abdo, Portland Cement Association



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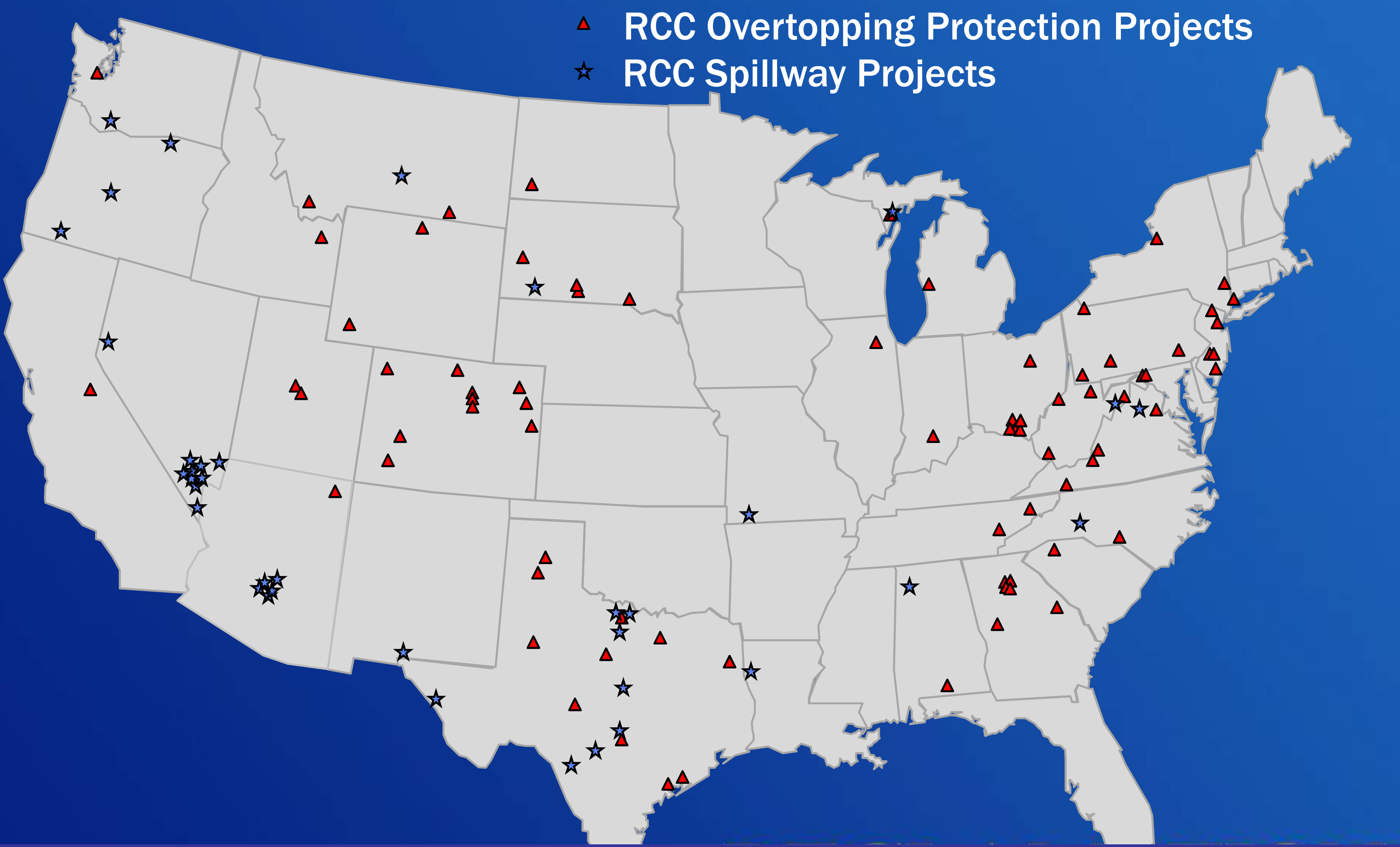
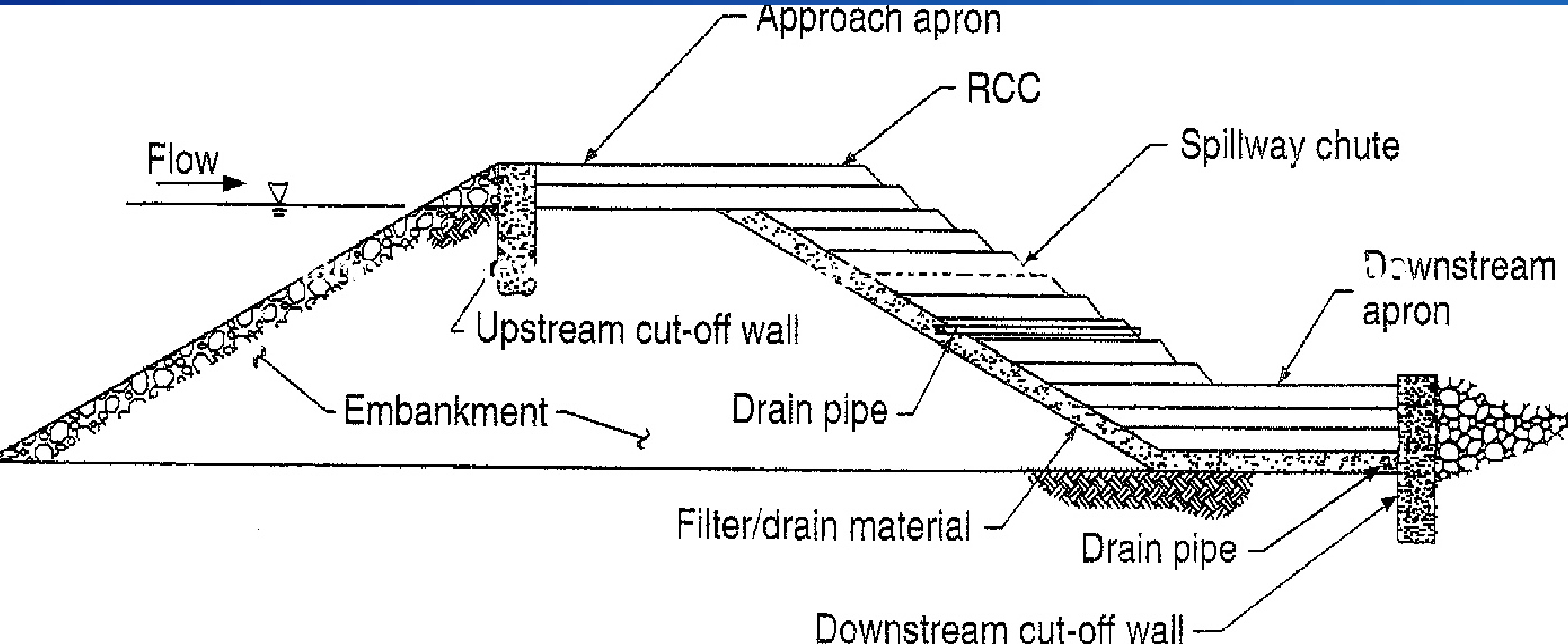
Performance Review of RCC Spillways and Overtopping Protection

Presented by: Fares Abdo, Portland Cement Association

Performance Review of RCC Spillways and Overtopping Protection



Typical RCC Overtopping Protection Cross-Section

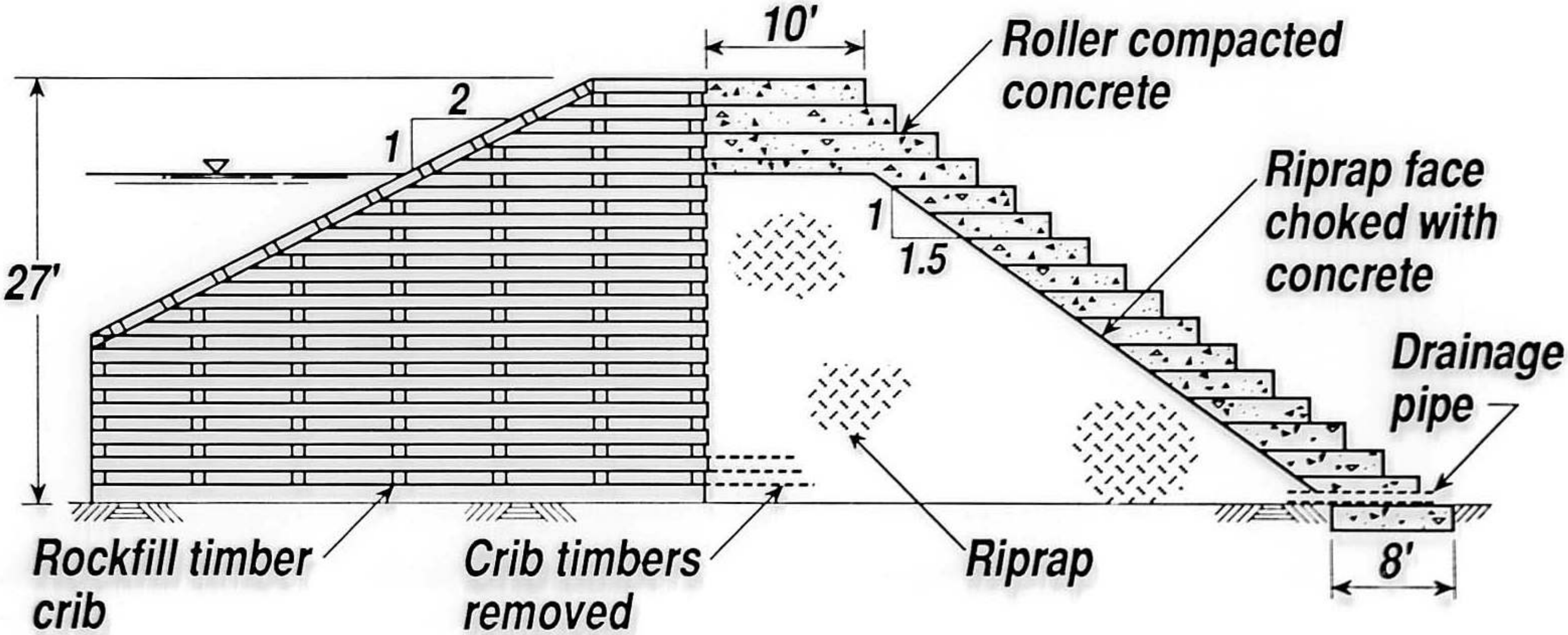


RCC Overtopping Protection

Performance of RCC Spillways and OP

- Most projects have not operated
- Paper discusses performance of six that have been subjected to repeated overtopping
  - Ocoee Dam #2, TN
  - Brownwood Country Club Dam, TX
  - Kerrville Dam, TX
  - Lower Lake Royer Dam, MD
  - Lake Tholocco Dam, AL
  - Red Rock Detention Basin Inlet Spillway, NV

Ocoee Dam No. 2, TN



- Original dam constructed in 1912   First RCC Overtopping Protection, 1980
- 10 m high by 150 m long   Specified Strength ~ 26 MPa at 28 days
- 20 mm NMSA   3,500 cm
- Unformed Steps

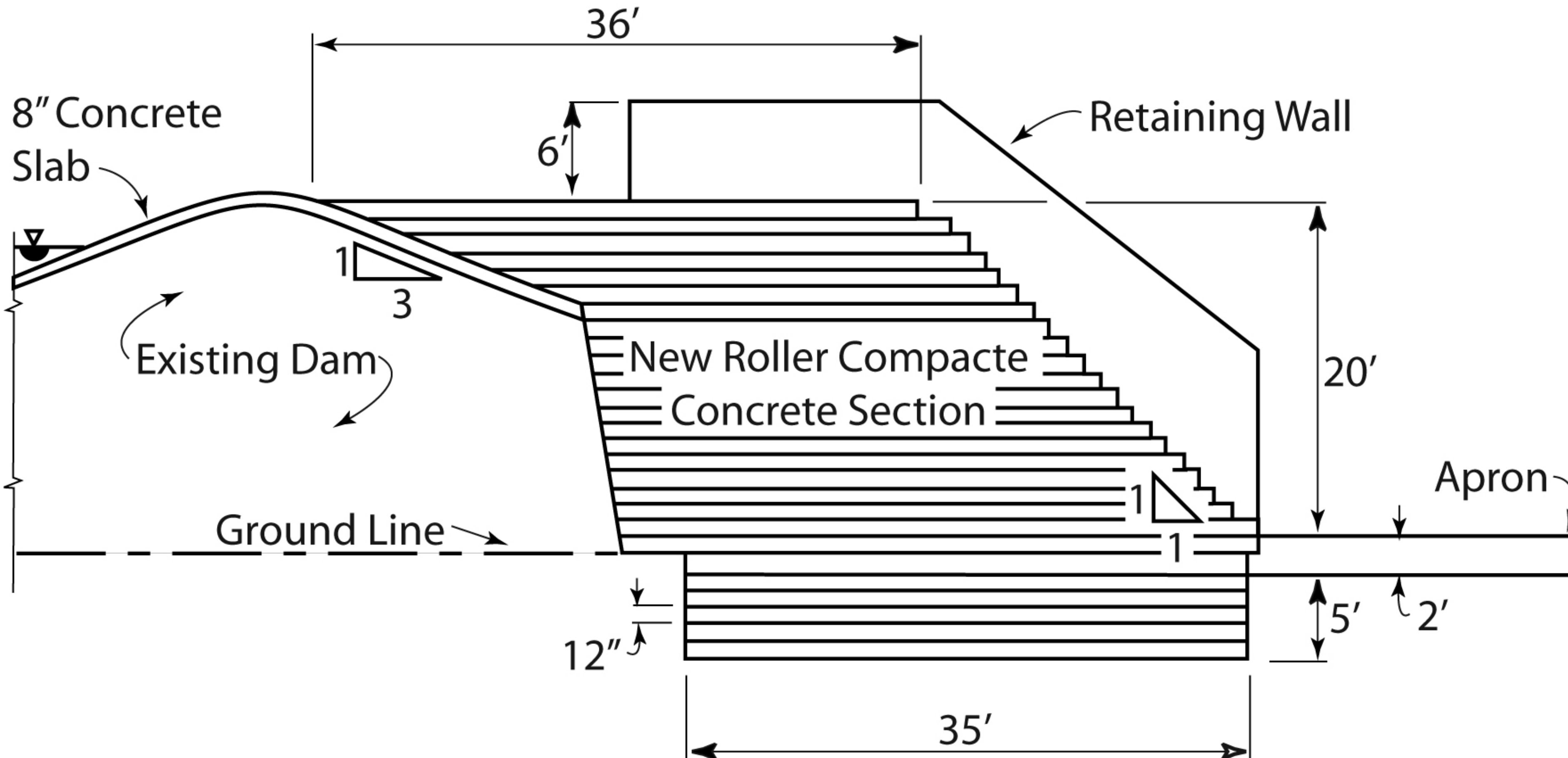
Portland Cement Association

Ocoee Dam No. 2 - 1980

Kerrville Dam, TX

- 1980 Clay-filled embankment with 8-inch RC facing
- Damaged during 3 storms between 1981 and 1984.

Kerrville Dam, TX



- RCC constructed within original embankment footprint
- Continuous flow over RCC service spillway

Portland Cement Association

- Service and emergency spillways
- Overtopped by 4.4 m one month after completion
- Overtopped by 5 m in 1987 and 3 m in 1990
- 118 kg/m^3 cement only for most RCC (11 MPa)
- 236 kg/m^3 cement only (with bedding) for upper 7 lifts (21 MPa)
- Unformed edges
- 88 mm NMSA (pit run)
- 17,500 m^3 RCC

Foundation preparation and Filter Drainage Layer - Y-14 RCC Dam Spillway

Golder Associates 2003

Vesuvius Dam – 2001
RCC Cutoff Wall

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Vesuvius Dam RCC Facing

- 2.5 H : 1.0 V slope
- Hand-operated vibrating compactor

Vesuvius Dam Facing

- RCC covered with grass
 (will erode with spillway operation)

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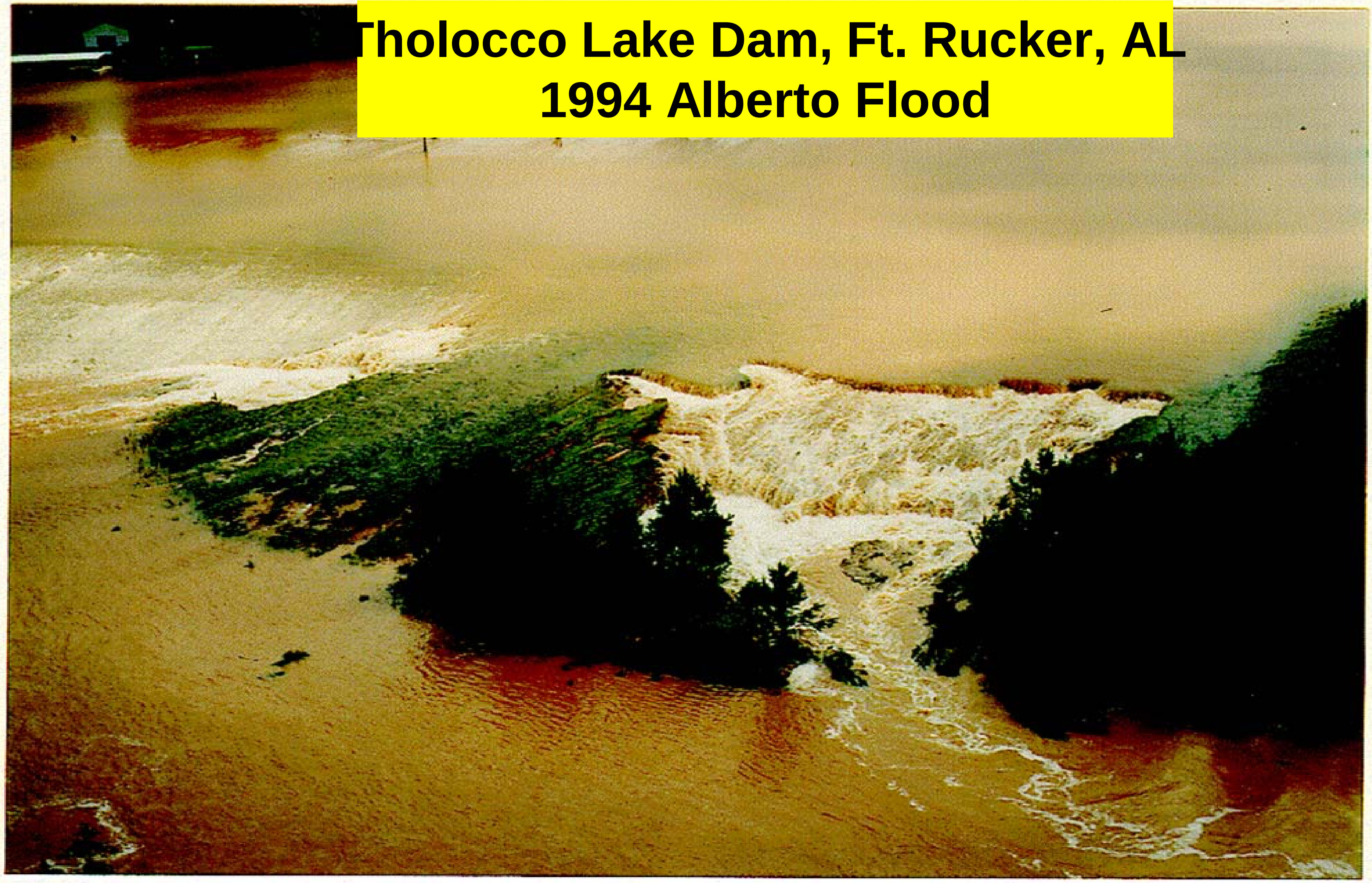
Y-14 Dam Spillway

Golder Associates 2003

Tholocco Lake Dam, Ft. Rucker, AL
1994 Alberto Flood



- 1550-ft long RCC auxiliary spillway
- 12-in-thick by 11-ft wide steps
- Slope of chute: 6H:1V
- Design max. overflow depth 6.5 ft

- 275 lb/yd^3 cement
- 50 lb/yd^3 fly ash
- 1-1/2 inch MSA
- 26,000 yd^3
- Formed steps

Thocoloo Dam – USACE May 10, 2007

Conclusions - Overtopping Protection

- In addition to proper structural design, primary factors contributing to successful performance of the RCC structures are related to mix design and construction methods
- Factors include:
  - Durable and well graded aggregates
  - Proper mix design
  - Reduced segregation
  - High density and adequate strength
- To limit edge erosion, steps should be formed and compacted to a high density

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Thank you for your attention

For more information:

www.usbr.gov

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