Roller-compacted Concrete for Dam Safety Modifications

Timothy P. Dolen and Fares Y. Abdo

Brazilian International RCC Symposium
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 100th 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
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
Reclamation Dam Safety Risk Criteria

• Estimated **Annualized Loss of Life** = (Annual Probability of Load) \( \times \) (Probability of Failure Given the Load) \( \times \) (Consequences Given the Failure [LOL])

\[
\text{ALOL} = P_{\text{event}} \times P_{\text{failure}} \times \text{LOL}
\]

• \( \text{ALOL} = (1/100) \times 0.5 \times 10 = 5 \times 10^{-2} \)
• \( \text{ALOL} = (1/10,000) \times 0.1 \times 5000 = 5 \times 10^{-2} \)

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
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
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
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

Compaction, Compaction, Compaction
Case History - Santa Cruz Arch Dam - 1990
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• 0.6 m stepped spillway
• Conventional concrete for FT durability
Santa Cruz Arch Dam - 1990
Camp Dyer Dam Buttress - 1992

Masonry Dam
Camp Dyer Dam Buttress - 1992

• Flat drains for seepage
Camp Dyer Dam Buttress - 1992

All RCC stepped spillway
Camp Dyer Dam Butterfly – 1992

RCC Facing compaction
Camp Dyer Dam Buttress - 1992

All RCC stepped spillway
Camp Dyer Dam Buttress - 1993
Pueblo Dam Spillway and Foundation Buttress – 1999
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2/3/99 - Pueblo Dam Modification - Installing "crack inducers" along RCC lift.
Pueblo Dam Spillway and Foundation Buttress – 1999
Pueblo Dam Spillway RCC “Toe Block”
Pueblo Dam **Spillway** – RCC “Toe Block”

- Vibrating plate compactor – 2 H : 1 V side slope
Pueblo Dam Spillway and Foundation Buttress – 1999

RCC facing with bedding
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

*Compaction, Compaction, Compaction*
RCC Spillway Construction Sloped Sidewall Details

- Effective Bond Area
- Compacted Edge
- 300 mm
- Pervious filter
- Filter Cloth
- 8-0 min
- Flat Drain
- Round Drain
- RCC
- Pervious filter
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
Cold Springs Dam Spillway – Turn Layout
Cold Springs Dam Spillway - 1993
Cold Springs Dam Spillway Modification

- Dozer mounted vibrating plate compactor
- 1-1/2 : 1 side slope
Cold Springs Dam Spillway Modification

- Dozer mounted vibrating plate compactor
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Cold Springs Dam Spillway Modification

- Dozer mounted vibrating plate compactor
- 1-1/2 : 1 side slope
Ochoco Dam Spillway Modification - 1996

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

0.8 H : 1 V slope
1H : 1 V slope
Many Farms Dam Spillway - 2000
Many Farms Dam Spillway - 2000
Many Farms Dam Spillway - 2000
Upstream approach
Hand Operated Vibrating Plate Edge Compaction
Many Farms Dam – 2:1 side Slope

- Track-hoe with vibrating plate compactor
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
Performance Review of RCC Spillways and Overtopping Protection

Review of RCC Spillways and Overtopping Protection

- RCC Overtopping Protection Projects
- RCC Spillway Projects
Typical RCC Overtopping Protection Cross-Section

Performance Review of RCC Spillways and Overtopping Protection
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

Portland Cement Association
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
Kerrville Dam, TX

- 1980 Clay-filled embankment with 8-inch RC facing
- RCC constructed within original embankment footprint
- Continuous flow over RCC service spillway
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/m³ cement only for most RCC (11 MPa)
236 kg/m³ cement only (with bedding) for upper 7 lifts (21 MPa)
Unformed edges
88 mm NMSA (pit run)
17,500 m³ RCC
Foundation preparation and Filter Drainage Layer - Y-14 RCC Dam Spillway

Golder Associates 2003
Vesuvius Dam – 2001
RCC Cutoff Wall
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)
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/yd³ cement
- 50 lb/yd³ fly ash
- 1-1/2 inch MSA
- 26,000 yd³
- 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

Compaction, Compaction, Compaction

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Thank you for your attention

For more information:

www.usbr.gov