Articulated Concrete Chute Design

March, 2011

Review of Existing Chutes

- Inconclusive
  - Some in good shape after experiencing large events

Review of Existing Chutes

- Inconclusive
  - Others experienced erosion under blocks or failure

Review of Existing Chutes

- erosion under blocks or failure

Review of Existing Chutes

- Inconclusive
  - Performance did not reflect the Henrich Q/W guidance
    3:1 – Q/W < 8.49 cfs/ft
    4:1 – Q/W < 12.58 cfs/ft
  - Performance did not reflect the current Factor of Safety analysis (resisting forces/overturning forces)

Review of Existing Chutes

- The lack of a connection directly between erosion under the chutes and the computed factor of safety suggests that other factors play into the stability of these chutes.
- Decided to base the recommended design guidelines on the most current design procedures
  (mostly)

Design Recommendations from Dr. Chris Thornton, CO State

- The drainage layer is very important to the successful functioning of ACB revetment.
- It is important to have a properly designed geotextile or granular filter underlying the system. Both filtration and permeability are important to allow water to be able to move/drain freely.
- The drainfill layer beneath the block should be confined with a geosynthetic geogrid, to prevent the drainfill from being plucked out through the openings in the blocks during a flow event. The geogrid should be designed so that its grid opening size is no larger than the d50 of the drainfill material it is confining.

Design Recommendations from Dr. Chris Thornton, CO State

- Certain assumptions used in the design procedure for ACB sizing have been found through his research to be incorrect. In designing the block, the assumption was that the lift force on the block was equal to the drag force on the block from the water flowing over it. This assumption is true for lower ranges of velocity, but as velocity increases, lift begins to exceed drag, and the old equations are no longer conservative.

  Dr. Thornton was asked how the lift=drag assumption would affect our design on a ND PL566 auxiliary spillway lining rehab project. He indicated that for the typical design velocities (16 fps), the old equations should still be adequate.

Design Recommendations from Dr. Chris Thornton, CO State

- Critical Shear values for ACB systems should be computed using the latest ASTM D7276 and D7277 (2008).
- He had concerns about use of wet-cast products in that on the ones he's seen (Cable Concrete) the blocks all line up in a uniform grid, leaving long unprotected strips of ground in the direction of flow in between the blocks. He felt that this type of product should be used for low-velocity applications only.
- Sliding of blocks has not been considered as a failure mechanism.

HCFCD Manual

- The current "state of the art" design procedure is a manual put together by the Harris County Flood Control District (HCFCD), Texas. This dates from September 2001.

  This document is the basis for NRCS's TS14L, which is essentially a shortened version of the HCFCD guidance.

HCFCD Manual

- Design is based upon the factor of safety for overturning of an individual block.
  - Overturning forces.
    - Shear stress of the water flowing across the block which is modified by the tested critical shear stress of the block on a horizontal surface
    - Water momentum acting on an assumed block projection.
  - Resisting forces
    - the weight of the block
    - inter-block resistance.
- Failure is defined as any lifting or loss of intimate contact between the block and the subgrade.

Recommended Articulated Concrete Block (ACB) Minimum Design Criteria

1. The basis for design shall be the publication *Design Manual for Articulating Concrete Block Systems*, Harris County Flood Control District (HCFCD).
2. Critical Shear values for ACB systems shall be computed using the latest ASTM D7276 and D7277.
3. Maximum chute slope shall be 3:1.
4. Enough tailwater shall exist to cause the hydraulic jump to form on the chute.

Recommended Articulated Concrete Block (ACB) Minimum Design Criteria

5. Factor of safety against overturning shall be a minimum of 1.5 and may disregard the side slope gravity component.
6. A block projection of 0.5" shall be assumed in the factor of safety computation. An assumed projection of zero may be used if the blocks are tapered a minimum of 0.5" from downstream to upstream (thickest block portion placed downstream)

Recommended Articulated Concrete Block (ACB) Minimum Design Criteria

7. A minimum 6" thick granular drainage layer shall be placed under the ACB's. A geogrid shall be placed on top of the drainage layer, directly under the ACB's to prevent movement of drain material through the ACB matrix. The maximum geogrid opening shall be equal to or less than the d50 of the drainage layer material.

Recommended Articulated Concrete Block (ACB) Minimum Design Criteria

8. If seepage is concern or the subbase is composed of non-plastic silts, NEH 633 Ch. 26 filter requirements shall be met for the drainfill, subbase interface.
   - A Geotextile may be considered as an alternative to the Ch. 26 granular filter requirements.
   - Geotextiles shall be designed using the HCFCD design manual. Non-woven geotextiles shall not be used.

Recommended Articulated Concrete Block (ACB) Minimum Design Criteria

8. If seepage is not a concern and the subbase is composed plastic fines, no filter is required.
   - Old MN-TR3 reference regarding leaching of finer material underlying riprap:
     - Leaching can be controlled by … providing a riprap thickness of 3 x D_{50}
   - Current TR-59 (p.17) suggests a rock thickness of 3 x D_{50} if a filter layer is not used.

Recommended Articulated Concrete Block (ACB) Minimum Design Criteria

9. Wet cast ACB's shall have air entrainment.
10. Dry cast ACB's shall conform to ASTM D 6684. Blocks shall have a minimum design strength of 5800 psi at 28 days when tested in accordance with ASTM C 140; and a maximum water absorption of 7.0% when tested in accordance with ASTM C 140. Blocks shall have less than 1% loss in 100 freeze/thaw cycles when tested in accordance with ASTM C 1262 using a distilled water solution, and less than 1.0% loss in 50 freeze/thaw cycles when tested in accordance with ASTM C 67.

Spreadsheet Design Tool

- Spreadsheet developed by Ft. Worth NRCS following HCFCD manual

  Modified by the Minnesota State Office to remove the side slope gravity forces acting on the side slope blocks since all failures to date have been on the bottoms of the chutes, not the side slopes. This modification to the spreadsheet results in a slightly higher factor of safety.

  NEH654-CH14-vs031606 bed.xls

Spreadsheet Design Tool

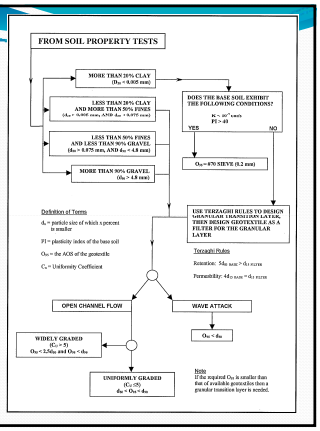
- H:\excel\Articulated Concrete Blocks\NEH654-CH14-vs031606 bed.xls

Geotextile Design

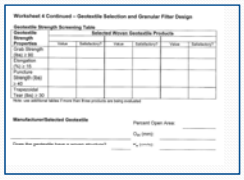
- To provide filtration between drainage layer and subgrade when needed.
- Reference to use when designing geotextiles associated with ACB's is the HCFCD Manual.

HCFCD Manual, p. C34 Geotextile Design Flow Chart

% Clay = % smaller then .005 mm



HCFCD Manual, Geotextile Worksheet



ND Example

- Two PL566 Dams experiencing frequent auxiliary spillway flows.
- Decision made to line the spillways with ACBs.

ND Example, Absaraka Dam

- Auxiliary Spillway flow = 2,100 cfs
- Bottom Width = 120 ft
- Slope (variable) = 9% = 11:1
- Max Auxiliary Spillway Velocity = 16.2 cfs
- Target Factor of Safety = 2.9
- Smallest tapered block (Armorflex 40T) provided a Factor of Safety = 3.8
  Slightly heavier non-tapered block, FS = 1.6

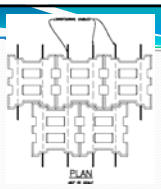
ND Example, Absaraka Dam

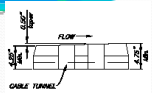
- Drainfill:
  - 6" thick
  - Gradation based on available geogrid
    Smallest found had ½" openings
  - d_{50} of drainfill = ½"
    ASTM C33 Size No. 467

ND Example, Absaraka Dam

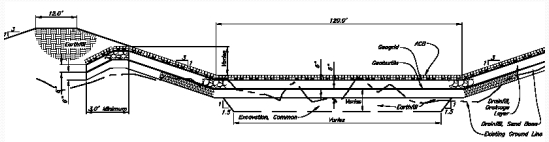
- Subgrade/Drainfill Interface:
  - Subgrade – SM's and CL's
  - Subgrade seepage
  - Subgrade and Drainfill not filter compatible
  - Subgrade not compatible with geotextile
  - Placed a 6" C33 concrete sand layer against subgrade. Designed geotextile to be compatible with this C33 sand layer.

ND Example, Absaraka Dam



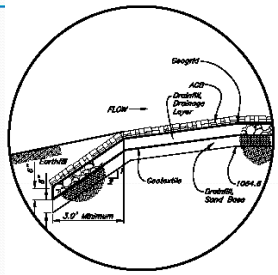


SIDE VIEW
NOT TO SCALE



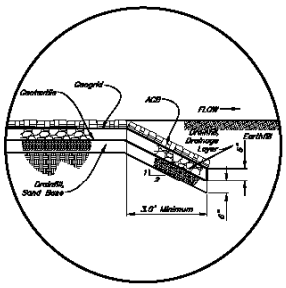
TYPICAL CROSS SECTION,
STA.3+95 to 7+50
NOT TO SCALE

ND Example, Absaraka Dam



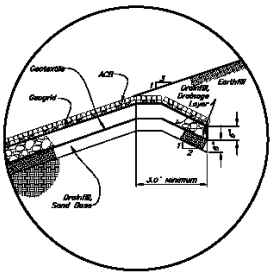
UPSTREAM ACB
TERMINATION TRENCH
NOT TO SCALE

ND Example, Absaraka Dam



DOWNSTREAM ACB
TERMINATION TRENCH
NOT TO SCALE

ND Example, Absaraka Dam



SIDE SLOPE ACB
TERMINATION TRENCH
NOT TO SCALE

ND Example, Absaraka Dam

ND Example, Absaraka Dam

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ND Example, Absaraka Dam

ND Example, Absaraka Dam