COMPOSITE CUT-OFFS FOR DAMS

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1. Alternative Definitions of “Composite” Cut-Offs

A. By Technology
   Using two or more technologies to:
   A. Create the cut-off (e.g., concrete cut-off through alluvium with grout curtain in rock below).
   B. Permit the construction of a concrete cut-off by pretreating the rock mass.

B. By Material
   Using two or more distinct families of grouts to form a multicomponent curtain (e.g., LMG, HMG, polyurethanes and hot bitumen to stop large fast flows).

   Note: Cut-offs may be conceived and designed as composite prior to construction, or can become composite, out of necessity, after construction begins.
2. Review of Individual Cut-Off Technologies

Basically there are two groups of Cut-off technologies:

1. Cut-offs comprising some type of concrete wall. Such walls can:
   - be constructed by different methods
     - Diaphragm wall (grab or cutter/mill)
     - Secant pile wall
     - DMM
     - TRD
   - comprise a variety of materials from high strength concrete, to plastic concrete

2. Cut-offs formed by drilling and grouting techniques. Such cut-offs can:
   - be created in rock (fissure or void grouting) or in soil (jet grouting, permeation grouting, hydrofracture grouting)
   - can deploy a wide variety of materials depending on the project goals and conditions
Each family of cut-offs has advantages and disadvantages (both real and perceived). We have traditionally elected to “live with” the consequences of one technology.

### Advantages

**Concrete Cut-Offs**
- “Positive” long-term solution (if constructed properly).
- Low uniform permeability assured through all ground penetrated.
- Simple concept but sophisticated equipment.

**Drilled and Grouted**
- Excellent recent record in hard fractured rock masses.
- Can focus on targeted zones.
- Smaller equipment, sophisticated methods and materials (responsive).
Disadvantages

Concrete Cut-Offs
- Cost.
- Not “flexible” in response to variable in-ground conditions, i.e., much of wall may be wasted.
- Rock properties (hardness, rippability) pose major controls over feasibility and productivity.
- Can be high risk to dam slurry loss.
- Site logistics and space.
- Alignment.
- Depth limitations.

Drilled and Grouted
- Efficiency will decline in soluble/erodible conditions.
- Therefore, not perceived as “positive.”
- Historical bias. GEOSYSTEMS, L.P.
2. Review of Individual Cut-Off Technologies

1. Diaphragm Wall Techniques
   - Cutters/Mills

Development of Trench Cutters
Development of Bauer Trench Cutters
Diaphragm Wall Panel Construction Sequence

- Pre-Excavate
- Excavate 1st Bite
- Excavate 2nd Bite
- Excavate 3rd Bite
- Place Concrete
- Complete Section
Panel Excavation

The cutters continuously remove the soil from the bottom of the trench, breaks it up and mixes it with a bentonite slurry in the trench.

The slurry charged with soil particles is pumped through a pipe to the de-sanding plant where it is cleaned and returned into the trench.
2. Review of Individual Cut-Off Technologies
   - Conventional grabs (cable or hydraulic)
2. Review of Individual Cut-Off Technologies
   - Secant Pile Wall Technique
Verification of Cut-Off Wall Design Criteria
At Various Elevations
Khao Laem Dam, Thailand
DMM Method at Jackson Lake Dam, WY
TRD Method
Trench cutting & Re-mixing
Deep wall method since 1993

Up to July 2003,
Number of job sites: over than 220,
Max. depth: about 53m (170 ft.)

September, 2003
M. Aoi &
K. Tsujimoto
Process of insertion

Idler Bottom → Standard post with chain & cutting teeth

Power assembly

Lift up

Join power assembly & post

Move

Roll down & excavation

Roll down & excavation

Cut off & moving

40m (131 ft) depth takes normally about 16-20 hours.
2. Drilling and Grouting Techniques
   2.1 Rock Fissure Drilling and Grouting
2. Drilling and Grouting Techniques

2.2 Rock Void Drilling for Grout Holes

Groundwater connection through an underground conduit, and geyser.
2. Drilling and Grouting Techniques
   2.3 Treatment of Soil by Permeation
2. Drilling and Grouting Techniques
2.3 Treatment of Soil by Hydrofracture
2. Drilling and Grouting Techniques

2.3 Treatment of Soil by Jet Grouting
## 3. Illustrative Case Histories

<table>
<thead>
<tr>
<th>Location</th>
<th>Wall Type</th>
<th>Grouting Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed as Composites (Two Components: as Facilitation: Materials)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diaphragm (Mill/Cutter)</td>
<td>Secant</td>
</tr>
<tr>
<td>1. Papadia, Greece</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Diavik, NWT</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>3. W.F. George, AL</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4. Clearwater, MO</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>5. Tims Ford, TN</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>6. Cape Girardeau, MO</td>
<td></td>
<td>✓</td>
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<tr>
<td></td>
<td></td>
<td>Modified during construction to become composites.</td>
</tr>
<tr>
<td>7. Mud Mountain, WA</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>8. Mississenewa Dam, IN</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>9. Peixe Dam, Brazil</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
1. Papadia Dam, Greece

Plastic concrete cut-off in alluvium, grouting in underlying rock.
2. DIAVIK Diamond Mines, Project in year 2018

Lac de Gras

A21

A418

A154
DIAVIK Project
Dam Section

- Dam
- Vibro densification zone
- Filter
- Cut-off wall $d = 80$ cm
- Till
- HPI grout curtain
- Granite Bedrock
DIAVIK Project
North Inlet Dike

North Inlet

Lac de Gras

Granite Bedrock

Till

HPI grouting

Dam
Cut-off wall data:

- **max depth**: 35 m
  **thickness**: 800 mm

- **artificial fill dam**: 22,000 m²
  **main equipment**: grab
  **av. performance**: 15 m²/h

- **till and frozen till**: 11,000 m²
  (cohesive with stones and boulders)
  **main equipment**: 1 cutter, 2 grabs, chisel
  **av. performance**: 2.5 m²/h
  **big boulders**: 1 m²/h
DIAVIK Project
High Pressure Grout
3. W.F. George Dam, AL

Program of investigatory drilling and grouting prior to construction of concrete cut-off wall.
**Exploratory Holes and Grouting**

- **Drilling**
  - 11,800 ft
  - 102 Holes

- **Coring**
  - 1,900 ft
  - 13 Holes

- **Grouting**
  - 450 cy
Exploratory Grouting Layout

Grout Takes

- Core Hole
- Grout Hole

Non Overflow Dam
Power House
Spillway
Lock
Ga Dike

Grout (cy)

Exploratory Grouting Holes
Drilling and Coring Using an SM-405 Rig on Flexi-Floats
PRELIMINARY INVESTIGATION

By conducting an extensive exploratory campaign the JV gained vital information which allowed it to plan the work ahead even when confronted with situations at variance from what the contract documents showed.

Advance information is relatively cheap to acquire and it pays for itself many times over in avoiding or mitigating delays and extra costs during the performance of the work.

THERE IS NO SUCH THING AS TOO MUCH INFORMATION, ESPECIALLY OF UNDERGROUND CONDITIONS!
4. Clearwater Dam, Missouri

Localized drilling and grouting program for suspected major sinkhole locations, followed by more intensive program of drilling and grouting to optimize design (depth and length) of foreseen concrete cut-off.
5. Tims Ford Dam, TN

Remedial grout curtain in karst employing three families of grout materials – HMG, Polyurethane, LMG.
6. Limestone Quarry, Cape Girardeau, MO

Grout curtain created to stop 30,000 gpm flow through karst into quarry using three families of grout – HMG, LMG and Hot Bitumen.
7. Mud Mountain Dam, WA

Treatment by grouting of fissured clay core to permit diaphragm wall to be built without catastrophic loss of slurry.
381 Crête du barrage
Plateforme de travail

Paroi du canyon

Paroi ép. 0.85 m

Paroi ép. 1.00 m

4.50 m
Pénétration minimale du rocher

353.6

Rocher
8. Mississenewa Dam, IN

Treatment by rock and void grouting techniques of karstic bedrock to permit diaphragm wall to be built without catastrophic slurry loss.
Clear example of equivalent performance of grouting to concrete cut-off wall construction.
9. Peixe Dam, Brazil

Rock grouting used in voided/fissured karstic limestone inlier. Jet grouting required to treat weathered, soil-like materials lying above fresher rock.
4. Observations and Conclusions

1. Numerous excellent construction methodologies exist. However, more than one may be required at some time, or some location on any one project to meet the design and construction intents.

2. By “shoehorning” one technology, the following outcomes often occur:
   - Ineffective seepage control performance,
   - Large construction claims,
   - Damage to structure,
   - Need for future remediation, or even
   - Abandonment of remediation efforts.
3. If water is lost in substantial amounts during initial subsurface investigations, circulation fluid (slurry, water or air) will be lost during subsequent wall construction if remediation is not carried out in advance.
4. Intensive site investigation and pretreatment (preferably under a separate contract) will:

- Prepare the site of cut-off and eliminate risk of catastrophic slurry loss.
- Explore the site and properly define project.
  - Used to define required limits for wall construction.
  - Information obtained provides unprecedented baseline data for cut-off wall construction.
  - Claims avoidance and mitigation.
- Can provide lower cost solution where cut-off is not required at depths where wall construction is problematic and increasingly expensive.
5. Configurations for Compatible Performance of Cut-Off Wall and Permanent Grouting

- Two fully grouted lines at 5 to 10 feet spacing.
- Grouting in stages to absolute refusal with balanced stable grouts.
- Verification holes along centerline (core and water pressure test).
6. Rock Conditions Suitable for Terminating a Cut-Off Wall

- RQD greater than 40%.
- Clean rock fractures.
- Some well-defined “acceptable” residual permeability.

Note: Wall depth can be varied to match encountered site conditions (i.e., can be deepened to cut-off unique features).
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