GB3 (Revised): Rock Cut Slope and Catchment Design

Steve Taliaferro, P.E., OGE
TYPICAL TEMPLATE CUT DESIGN 1950’s TO 1980’s
TYPICAL CUT DESIGN 1980’s TO 2000’S
GB3 BACKGROUND

DEVELOPED IN 2006 TO AID IN CONSULTANT DESIGN OF TWO NEW DESIGN PROJECTS.

- 8 MILES OF ROAD RELOCATION WITHIN THE PENNSYLVAanian COAL MEASURES
- 16 MILES OF NEW ROAD PREDOMINATELY WITHIN MISSISSIPPIAN MASSIVE SANDSTONES
GB3 BACKGROUND

- GB3’06 BASED ON PAST PRACTICES OF THE OFFICE OF GEOTECHNICAL ENGINEERING
- SLOPE DESIGN QUALITATIVE BASED ONLY
- CATCHMENT DESIGN BASED ON FHWA
GB3 BACKGROUND

- AFTER USING GB3’06
  → DEFICIENCIES NOTED!

- DECIDED TO ADDRESS THROUGH A RESEARCH PROJECT.
GB3 BACKGROUND

**GB-3’06 BASED ON:**

- RQD
- SLAKE DURABILITY
- COMpressive STRENGTH

Provided

- SLOPE ANGLE
- RECOMMENDATIONS
### GB3 Table A – Rock Cut Slope Recommendations

<table>
<thead>
<tr>
<th>Unconfined Compressive Strength (psi)</th>
<th>ODOT Rock Index Property Classification (GB3 Figure 1)</th>
<th>Cut Slope (H:V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;5000</td>
<td>Very Good</td>
<td>0.25:1 or 0.5:1</td>
</tr>
<tr>
<td>&gt;5000</td>
<td>Good</td>
<td>0.25:1 or 0.5:1</td>
</tr>
<tr>
<td>&gt;5000</td>
<td>Fair</td>
<td>0.5:1 or 1.0:1</td>
</tr>
<tr>
<td>&gt;5000</td>
<td>Poor</td>
<td>1.0:1</td>
</tr>
<tr>
<td>&gt;5000</td>
<td>Very Poor</td>
<td>1.0:1 or 1.5:1</td>
</tr>
<tr>
<td>3000-5000</td>
<td>Very Good</td>
<td>0.25:1 or 0.5:1</td>
</tr>
<tr>
<td>3000-5000</td>
<td>Good</td>
<td>0.5:1 or 1.0:1*</td>
</tr>
<tr>
<td>3000-5000</td>
<td>Fair</td>
<td>0.5:1 or 1.0:1*</td>
</tr>
<tr>
<td>3000-5000</td>
<td>Poor</td>
<td>1.0:1 or 1.5:1</td>
</tr>
<tr>
<td>3000-5000</td>
<td>Very Poor</td>
<td>1.5:1 or 2.0:1</td>
</tr>
<tr>
<td>1500-3000</td>
<td>Very Good</td>
<td>1.0:1</td>
</tr>
<tr>
<td>1500-3000</td>
<td>Good</td>
<td>1.0:1</td>
</tr>
<tr>
<td>1500-3000</td>
<td>Fair</td>
<td>1.0:1 or 1.5:1</td>
</tr>
<tr>
<td>1500-3000</td>
<td>Poor</td>
<td>1.5:1 or 2.0:1</td>
</tr>
<tr>
<td>1500-3000</td>
<td>Very Poor</td>
<td>2.0:1</td>
</tr>
<tr>
<td>&lt;1500</td>
<td>N/A</td>
<td>Special Design**</td>
</tr>
</tbody>
</table>

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**Notes:**

- **SDI (%)** refers to the Standard Deviation of Index (a measure of the variability of a data set).
- **Unit RQD (%)** refers to the Percentage of Rock Masses of RQD (a measure of rock quality).
- **Very Good** indicates the highest quality rock.
- **Fair** indicates moderate quality rock.
- **Poor** indicates low quality rock.
- **Very Poor** indicates extremely low quality rock.
- **Special Design** indicates the need for more detailed engineering analysis.

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**Design Tables:**

- GB3 (Revised): Rock Cut Slope and Catchment Design
- GB-3,06 DESIGN TABLES
GB3 RESEARCH (2007-2010)

SELECTED RESEARCH TEAM CONSISTED OF:

✓ KENT STATE UNIVERSITY
✓ BEAVER CONSTRUCTION, INC
✓ JANOD ENTERPRISES, INC
✓ DR. MARTIN WOODARD & DR. BRENDAN FISHER
✓ DR. SKIP WATTS
GB3 RESEARCH (2007-2010)

RESEARCH FINDINGS

CONCURRED WITH GB3’06

➢ Rigorous rock mechanics – unnecessary
➢ Catchment ditch widths
➢ Use of various types of benches

DISAGREED WITH GB3’06

➢ Criteria for determination of slope angle(s)
GB-3\textsubscript{06} DESIGN TABLES
GB3 (REVISED)

**BASED ON:**

- ROCK TYPE
- LIMITED ROCK PROPERTIES

**PROVIDES:**

- SLOPE ANGLE
- RECOMMENDATIONS
GB3 (REVISED)

TYPICAL OHIO GEOLOGY

✓ 1/3 of Ohio is non-glaciated
✓ Geologic ages Ordovician to Permian
✓ Relatively flat lying bedrock
✓ Little major geologic structure
✓ Wide variations of rock properties
✓ Differential weathering and intersecting joint sets are primary modes of failure
INTERSECTING JOINT SETS
GB3 (REVISED)

**DESIGN UNITS**

- COMPETENT DESIGN UNIT
- INCOMPETENT DESIGN UNIT
- INTERLAYERED DESIGN UNIT
<table>
<thead>
<tr>
<th>Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
</tr>
<tr>
<td>Siltstone</td>
</tr>
<tr>
<td>Cut 0.5H:1V</td>
</tr>
<tr>
<td>0.25H:1V option - Thick Bedded</td>
</tr>
<tr>
<td>Adjust based on RQD</td>
</tr>
</tbody>
</table>

**GB3 (Revised): Rock Cut Slope and Catchment Design**
# GB3 (REVISED)

## COMPETENT DESIGN UNIT

### RQD CONSIDERATIONS

<table>
<thead>
<tr>
<th>RQD (%)</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>Cut slope to 1H:1V or consult with DGE</td>
</tr>
<tr>
<td>51-75</td>
<td>Review global stability and design based on engineering judgment or consult with DGE</td>
</tr>
<tr>
<td>76-100</td>
<td>Slope grade of 0.5H:1V or 0.25:1V</td>
</tr>
</tbody>
</table>
### INCOMPETENT DESIGN UNIT

- **Shale**
- **Claystone**
- **Friable Sandstone**

Based on SDI Results

- Angles from 1H:1V to 2H:1V
- Steeper angle with approval
# GB3 (REVISED)

## INCOMPETENT DESIGN CHART

<table>
<thead>
<tr>
<th>SDI (%)*</th>
<th>Slope Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>2H: 1V or flatter – Special design; contact DGE</td>
</tr>
<tr>
<td>20-60</td>
<td>2H: 1V</td>
</tr>
<tr>
<td>60-85</td>
<td>1.5H: 1V</td>
</tr>
<tr>
<td>85-95</td>
<td>1H: 1V</td>
</tr>
<tr>
<td>95-100</td>
<td>1H: 1V or steeper – contact DGE</td>
</tr>
</tbody>
</table>

* Based on second cycle $I_d^2$ according to ASTM D 4644
GB3 (REVISED)

INTERLAYERED DESIGN UNITS

TYPE A:
Thick bedded *competent* unit underlain by *incompetent* unit(s)

TYPE B:
Med.*-Thick *sandstone/siltstone* interbedded with *incompetent* unit(s)
*likely will be changed to thin-thick bedded
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INTERLAYERED DESIGN UNIT

- **TYPE C:**
  Med.-Thick bedded *limestone* interbedded with *incompetent* unit(s)

- **TYPE D:**
  Thinly bedded *limestone* interbedded with *incompetent* rock (variable proportions)
## TYPE A STRATIGRAPHY

<table>
<thead>
<tr>
<th>Depth</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5H</td>
<td>1V</td>
<td>Competent Bench</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incompetent</td>
</tr>
<tr>
<td>0.25H</td>
<td>1V</td>
<td>Competent Bench</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incompetent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Treat as 2 separate Design Units</td>
</tr>
</tbody>
</table>

GB3 (Revised): Rock Cut Slope and Catchment Design
TYPE B STRATIGRAPHY: Case 1

Sandstone/Incompetent Unit
Ratio > 0.5
(> 50 % sandstone)

Cut Entire Slope
1.5H: 1V

Cut Entire Slope
0.25H: 1V

(Provide catchment possible stabilization at top of cut)
TYPE B STRATIGRAPHY: Case 2

Sandstone/Incompetent Unit
Ratio < 0.5
(< 50 % sandstone)

Cut Entire Slope
1.5H: 1V

Evaluate Drainage Control Measures
**TYPE C STRATIGRAPHY: Case 1**

| Limestone to Incompetent Unit | Ratio $> 0.5$  
|                             | (> 50 % limestone) |

- **Cut Entire Slope**  
  - 0.25H: 1V  
  - (Slope Height $\leq$ 25 ft)  
  - 0.5H:1V  
  - (Slope Height $> 25$ ft)

- Evaluate stabilization options (e.g. shotcrete) for Incompetent Units
## TYPE C STRATIGRAPHY: Case 2

<table>
<thead>
<tr>
<th>Limestone to Incompetent Unit Ratio $&lt; 0.5$ ($&lt; 50 %$ limestone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Based on Incompetent Design Chart</td>
</tr>
<tr>
<td>Construct slope as a <em>serrated</em> slope and provide adequate catchment</td>
</tr>
</tbody>
</table>

GB3 (Revised): Rock Cut Slope and Catchment Design
### TYPE D STRATIGRAPHY

<table>
<thead>
<tr>
<th>Thinly bedded Limestone inter-layered with Incompetent rock units (variable proportions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut Entire Slope 1H: 1V</td>
</tr>
<tr>
<td>Provide adequate catchment (possibly barrier)</td>
</tr>
</tbody>
</table>

GB3 (Revised): Rock Cut Slope and Catchment Design
GB3 (REVISED)

BENCHES

OVERBURDEN:
- Required for overburden thickness > 10ft.

GEOTECHNICAL (LITHOLOGIC):
- Placed on top of less durable rock when overlain by more durable rock.

CONSTRUCTION:
- 5 ft offsets to allow for blasting.
- Placed at a maximum of 30 ft vertical heights.
GEOTECHNICAL BENCH
Changes in testing:

Unconfined Compression Strength Tests (ASTM D 7012)

- Limestone or sandstone described using field parameters as slightly strong, weak, or very weak (less than 3,600 psi for unconfined compressive strength) based on SGE 605.5

- If insufficient sized samples - use Point Load Test.
Slake Durability Test (ASTM D4644)

- Limestone or sandstone described as slightly strong, weak, or very weak (less than 3,600 psi for unconfined compressive strength) based on SGE 605.5 and a unit weight less than 140 pcf: required.
- Siltstone: required.
- Incompetent Design Units: required.
- Interlayered Design Units: required (incompetent lithology only).
GB3 (REVISED)

CATCHMENT DESIGN

BASED ON FHWA POOLED FUND STUDY:
FHWA-OR-RD-02-04

DESIGN CHARTS BASED ON SLOPE ANGLE AND CUT SLOPE HEIGHTS

CONFIRMATION BY RUNNING COMPUTER SIMULATION (CRSP OR SIMILAR)
CATCHMENT DESIGN

GB3 (Revised): Rock Cut Slope and Catchment Design
### Recommended catchment widths for varying slope and catchment foreslope angles.*

<table>
<thead>
<tr>
<th>Cut Slope Angle (H:V)</th>
<th>Cut Slope Height, H (ft)</th>
<th>Catchment Ditch Width, W (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~&lt;40 50 60 70 80 &gt;90***</td>
<td></td>
</tr>
<tr>
<td>3H:1V Catchment Foreslope Angle*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25:1</td>
<td>10 15 15 15 20 20 20</td>
<td>25 25 min.</td>
</tr>
<tr>
<td>0.5:1</td>
<td>10 15 20 20 20 20 20</td>
<td>25 25 min.</td>
</tr>
<tr>
<td>1.0:1</td>
<td>15 20 20 20/25** 25 25</td>
<td>30 30 min.</td>
</tr>
<tr>
<td>1.5:1</td>
<td>15 20 20 20/25** 25 25</td>
<td>30 30 max.</td>
</tr>
<tr>
<td>4H:1V Catchment Foreslope Angle*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25:1</td>
<td>10/15** 15 20 20 20</td>
<td>25 30 min.</td>
</tr>
<tr>
<td>0.5:1</td>
<td>15 15 20 20 20 20</td>
<td>25 30 min.</td>
</tr>
<tr>
<td>1.0:1</td>
<td>15/20** 20 20/25** 25/30** 30 30</td>
<td>35 35 min.</td>
</tr>
<tr>
<td>1.5:1</td>
<td>15/20** 20 20/25** 25/30** 30 30</td>
<td>35 35 max.</td>
</tr>
<tr>
<td>6H:1V Catchment Foreslope Angle*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25:1</td>
<td>15 20 25 30 35 40</td>
<td>40 min.</td>
</tr>
<tr>
<td>0.5:1</td>
<td>20 20 25 30 35 40</td>
<td>40 min.</td>
</tr>
<tr>
<td>1.0:1</td>
<td>25/30** 25/30** 30 35 40 40</td>
<td>40 min.</td>
</tr>
<tr>
<td>1.5:1</td>
<td>25/30** 25/30** 30 35 40 40</td>
<td>40 max.</td>
</tr>
</tbody>
</table>
GB3 (REVISED)

CHANGES TO CATCHMENT DITCH CONFIGURATION

- For new slopes only, consult ODOT Location and Design Manual, Volume 1, Section 307.2.1 for guidance on catchment foreslope angles

- Adjusted last slope height category to reflect FHWA tables (FHWA max. is 80’ high)
ODOT ROCK SLOPE DESIGN GUIDE

- Provides additional background on GB #3 topics
- Expanded exploration discussion
- Construction/Remediation Techniques
- Design Examples (coming soon)
### ODOT ROCK SLOPE DESIGN GUIDE

#### TYPICAL OHIO ROCK PROPERTIES

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Unit Weight (pcf)</th>
<th>Unconfined Compressive Strength (psi)</th>
<th>Slake Durability Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claystone</td>
<td>160-165</td>
<td>50-1400</td>
<td>0-60</td>
</tr>
<tr>
<td>Shale</td>
<td>160-165</td>
<td>1900-2500</td>
<td>20-90</td>
</tr>
<tr>
<td>Siltstone</td>
<td>160-170</td>
<td>1500-8100</td>
<td>65-90</td>
</tr>
<tr>
<td>Sandstone</td>
<td>155-160</td>
<td>2000-7800</td>
<td>85-99</td>
</tr>
<tr>
<td>Friable Sandstone</td>
<td>125-140</td>
<td>500-3600</td>
<td>60-85</td>
</tr>
<tr>
<td>Limestone</td>
<td>155-165</td>
<td>3500-16400</td>
<td>95-100</td>
</tr>
<tr>
<td>Dolostone</td>
<td>165-175</td>
<td>4100-10300</td>
<td>95-100</td>
</tr>
<tr>
<td>Coal</td>
<td>80-85</td>
<td>1300-7000</td>
<td>N/A</td>
</tr>
<tr>
<td>Underclay</td>
<td>125-135</td>
<td>200-400</td>
<td>0-20</td>
</tr>
</tbody>
</table>
REMEDIATION TECHNIQUES

- Supplemental Specification 862 (Rockfall Protection)
- Shotcrete
- Barrier Research
QUESTIONS??

ё GB3 and ODOT Rock Slope Design Guide:
http://www.dot.state.oh.us/Divisions/ProdMgt/Geotechnical/Pages/Manuals.aspx

ё Rock Slope Design Criteria (Research Report)
http://www.dot.state.oh.us/Divisions/TransSysDev/Research/Pages/default.aspx