ROCK SLOPES STABILIZATION MEASURES – REINFORCEMENT METHODS

Lesson 8 – Topic B
LESSON 8B – ROCK REINFORCEMENT METHODS

Learning Outcomes -

- List Rock Reinforcement Methods;
- Identify Primary Components of Rock Bolting System;
- Design Stabilization System for Planar Failure using Rock Bolts
- Discuss shotcrete and drainage systems
Stabilization by Rock Reinforcement

- Rock Bolts
- Shear Keys
- Tied-back Wall
- Shotcrete
- Buttress
- Drainage
- Shot-in-place Buttress

Figure 10-5
Stabilization by Rock Reinforcement

1. Reinforced concrete shear key to prevent loosening of slab at crest
2. Tensioned rock anchors to secure sliding failure along crest
3. Tieback wall to prevent sliding failure on fault zone
4. Shotcrete to prevent raveling of zone of fractured rock
5. Drain hole to reduce water pressure within slope
6. Concrete buttress to support rock above cavity
Concrete shear keys
Rock Bolting – Design Procedure

- Tensioned Bolts/Untensioned Dowels
- Resin/ Cement / Mechanical Anchorage
- Bond Length

\[ L_b = \frac{T}{(\pi d_h \tau_a)} \]

Allowable Bond Stress \((\tau_a)\) - Table 10-3

- Corrosion Protection
- Tensioning - Load/Movement Measurements - PTI Acceptance Criteria
a) Stabilization of displaced block with tensioned bolts

b) Pre-reinforcement of cut with fully grouted, untensioned dowels along crest
Drill hole diameter compatible with drilling equipment – e.g. 5 in (125 mm) dia. hole
Crane access to face – costly, disruptive to traffic
Bencher drill and spider cage – low cost, 2-1/2 inch diameter hole, 40 ft. depth. Little disruption to traffic
Reinforced concrete, tied-back grid in Japan
Reinforced concrete grid construction in Japan
Double corrosion bar anchors

- Smooth sheath – stressing length
- Corrugated sheath – bond zone
- Centering sleeve
- Grout tube
Double corrosion protected bar anchor
**Ultimate vs Yield Strength Grade 150**

0.85 in² x 150 ksi = 127.5 kips = Ultimate

### R71 150 KSI All-Thread-Bar - ASTM A722

<table>
<thead>
<tr>
<th>Bar Diameter</th>
<th>Minimum Net Area Thru Threads</th>
<th>Minimum Ultimate Strength</th>
<th>Minimum Yield Strength</th>
<th>Nominal Weight</th>
<th>Approx. Thread Major Dia.</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot; (26 mm)</td>
<td>0.85 in² (549 mm²)</td>
<td>127.5 kips (567.1 kN)</td>
<td>102 kips (453.6 kN)</td>
<td>3.09 lbs./ft. (4.6 Kg/M)</td>
<td>1-1/8&quot; (28.6 mm)</td>
<td>R71-08</td>
</tr>
<tr>
<td>1-1/4&quot; (32 mm)</td>
<td>1.25 in² (807 mm²)</td>
<td>187.5 kips (834 kN)</td>
<td>150 kips (667.2 kN)</td>
<td>4.51 lbs./ft. (6.71 Kg/M)</td>
<td>1-7/16&quot; (36.5 mm)</td>
<td>R71-10</td>
</tr>
<tr>
<td>1-3/8&quot; (36 mm)</td>
<td>1.58 in² (1019 mm²)</td>
<td>237 kips (1054.2 kN)</td>
<td>189.6 kips (843.4 kN)</td>
<td>5.71 lbs./ft. (8.50 Kg/M)</td>
<td>1-9/16&quot; (39.7 mm)</td>
<td>R71-11</td>
</tr>
<tr>
<td>1-3/4&quot; (45 mm)</td>
<td>2.60 in² (1664 mm²)</td>
<td>400 kips (1779.2 kN)</td>
<td>320 kips (1423.4 kN)</td>
<td>9.06 lbs./ft. (13.48 Kg/M)</td>
<td>2&quot; (50.8 mm)</td>
<td>R71-14</td>
</tr>
<tr>
<td>2-1/2&quot; (65 mm)</td>
<td>5.19 in² (3350 mm²)</td>
<td>778 kips (3457.0 kN)</td>
<td>622.4 kips (2765.8 kN)</td>
<td>18.20 lbs./ft. (27.1 Kg/M)</td>
<td>2-3/4&quot; (69.9 mm)</td>
<td>R71-20</td>
</tr>
</tbody>
</table>
# Ultimate vs Yield Strength Grade 75

## R61 Grade 75 All-Thread Rebar

### ASTM A615

<table>
<thead>
<tr>
<th>Bar Designation &amp; Nominal Dia.</th>
<th>Minimum Net Area Thru Threads</th>
<th>Minimum Ultimate Strength</th>
<th>Minimum Yield Strength</th>
<th>Nominal Weight</th>
<th>Approx. Thread Major Dia.</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>#6 - 3/4&quot; (20 mm)</td>
<td>0.44 in² (284 mm²)</td>
<td>44 kips (195.7 kN)</td>
<td>33 kips (146.8 kN)</td>
<td>1.5 lbs./ft. (2.36 Kg/M)</td>
<td>7/8&quot;</td>
<td>R61-06</td>
</tr>
<tr>
<td>#7 - 7/8&quot; (22 mm)</td>
<td>0.60 in² (387 mm²)</td>
<td>60 kips (266.9 kN)</td>
<td>45 kips (200.2 kN)</td>
<td>2.0 lbs./ft. (3.04 Kg/M)</td>
<td>1&quot;</td>
<td>R61-07</td>
</tr>
<tr>
<td>#8 - 1&quot; (25 mm)</td>
<td>0.79 in² (510 mm²)</td>
<td>79 kips (351.4 kN)</td>
<td>59.3 kips (263.8 kN)</td>
<td>2.7 lbs./ft. (3.935 Kg/M)</td>
<td>1-1/8&quot;</td>
<td>R61-08</td>
</tr>
<tr>
<td>#9 - 1-1/8&quot; (28 mm)</td>
<td>1.00 in² (645 mm²)</td>
<td>100 kips (444.8 kN)</td>
<td>75 kips (333.6 kN)</td>
<td>3.4 lbs./ft. (5.06 Kg/M)</td>
<td>1-3/4&quot;</td>
<td>R61-09</td>
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<tr>
<td>#10 - 1-1/4&quot; (32 mm)</td>
<td>1.27 in² (819 mm²)</td>
<td>127 kips (564.9 kN)</td>
<td>95.3 kips (423.9 kN)</td>
<td>4.3 lbs./ft. (5.50 Kg/M)</td>
<td>1-3/8&quot;</td>
<td>R61-10</td>
</tr>
<tr>
<td>#11 - 1-3/8&quot; (35 mm)</td>
<td>1.56 in² (1006 mm²)</td>
<td>156 kips (694.0 kN)</td>
<td>117 kips (520.5 kN)</td>
<td>5.3 lbs./ft. (7.85 Kg/M)</td>
<td>1-1/2&quot;</td>
<td>R61-11</td>
</tr>
<tr>
<td>#14 - 1-3/4&quot; (45 mm)</td>
<td>2.25 in² (1452 mm²)</td>
<td>225 kips (1000.9 kN)</td>
<td>168.7 kips (750.4 kN)</td>
<td>7.65 lbs./ft. (11.78 Kg/M)</td>
<td>1-7/8&quot;</td>
<td>R61-14</td>
</tr>
<tr>
<td>#18 - 2-1/4&quot; (55 mm)</td>
<td>4.00 in² (2581 mm²)</td>
<td>400 kips (1779.4 kN)</td>
<td>300 kips (1334.5 kN)</td>
<td>13.6 lbs./ft. (19.63 Kg/M)</td>
<td>2-7/16&quot;</td>
<td>R61-18</td>
</tr>
<tr>
<td>#20 - 2-1/2&quot; (64 mm)</td>
<td>4.91 in² (3168 mm²)</td>
<td>491 kips (2184.0 kN)</td>
<td>368 kips (1637.0 kN)</td>
<td>16.69 lbs./ft. (24.84 Kg/M)</td>
<td>2-3/4&quot;</td>
<td>R61-20</td>
</tr>
<tr>
<td>#28 - 3-1/2&quot; (89 mm)</td>
<td>9.61 in² (6200 mm²)</td>
<td>960 kips (4274.0 kN)</td>
<td>720 kips (3206.0 kN)</td>
<td>32.7 lbs./ft. (48.60 Kg/M)</td>
<td>3-3/4&quot;</td>
<td>R61-28</td>
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</tbody>
</table>
Typical Bar Stressing Limits:

High Strength (Grade 150):
- Maximum Design Load = 50 to 60% of guaranteed ultimate tensile strength (GUTS)
- Maximum Test Load = 80% of guaranteed ultimate tensile strength (GUTS)

Low Strength (Grade 60 or Grade 75):
- Maximum Design Load = 60 to 70% of minimum yield strength
- Maximum Test Load = 90% of minimum yield strength

ALWAYS VERIFY WITH MANUFACTURER
Five-strand cable anchor

Wedge cable gripper
Double corrosion protected 3-strand cable anchor
Cement grout mixer and pump
Resin anchor cartridges
Anchor supported on lifting cradle
Rock bolts with shotcrete facing to contain closely jointed rock
Tensioning multi-strand with hydraulic jack; dial gauge to measure elongation
Performance test – cyclic loading with elongation measurements

Acceptance criteria – Line A and Line B allowable movements
Creep test – semi-log plot of time versus elongation
Student Exercise – planar slope reinforcement using rock bolts.

Student Exercises No. 4 and No. 7
Page 4-1, 4-8
Stabilization by Rock Reinforcement

- Shotcrete
Dry mix shotcreting operation – water added at nozzle
Unreinforced shotcrete on weathered rock – rapid spalling
Dry-mix shotcrete supplied in 1 cu. yd. bags
Shotcrete application from man-lift with rigid boom
Sculpted and colored shotcrete
Stabilization by Rock Reinforcement

- Drainage
Drain holes must intersect discontinuities carrying water.
Flow from drain holes collected in header pipe to prevent water infiltration into lower slope
LESSON 8B – ROCK REINFORCEMENT METHODS

Learning Outcomes -

- List Common Rock Reinforcement Methods;
- Identify Primary Components of Rock Bolting System;
- Design Stabilization System for Planar Failure using Rock Bolts;
- Discuss shotcrete and drainage systems