Underground Mining of Metalliferous Deposits
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Lecture 47
Rock Bolting II

DESIGN OF ROCK BOLT SYSTEM

There are several reinforcement design methodologies available. An integral part of any design is rock-mass characterization, identification of possible failure modes, selection of a reinforcement system, design, implementation, and monitoring of performance.

The important parameters for designing rock bolt support system are:

- Choice of bolt type
- Length of bolt
- Diameter of bolt
- Spacing of bolt
- Pattern of rock bolt
- Angle of bolting

For adequate and safe design we also require

- Properties of host rock
- In situ stress field
- Bolt material properties
- Bolt tension
- Time of installation/and after installation
- Size and shape of excavations (width, height, length)
- Ground water condition

METHODS OF DESIGN

- Empirical rules
- Empirical approaches (Engineering Rock Mass Classifications)
- Analytical approaches
- Numerical approaches
- Compliance (Mining law) approach

EMPIRICAL RULES

- Several rules of thumb exist that are applicable to selecting the reinforcement type and dimensions. Example: U. S. Corps of Engineers 1981 (for the estimation of length and spacing).
- Any empirical rules, however, give only a preliminary configuration for rock reinforcement, which must be checked, analyzed and, as necessary, modified to meet the requirements of a specific rock-reinforcement design.
- Most empirical rules are based on past practice, which is often influenced by a variety of other nontechnical factors such as legislation and preferences.

ENGINEERING ROCK MASS CLASSIFICATION APPROACH

There are many Engineering Rock Mass Classifications which are used for support design. There are two ways to employ rock mass classification systems. In the first case, such systems are used to select a support system, and, in the second, to determine the support. In practice, the majority of operations rely on the **Q system** (Barton, Lien, and Lunde 1974) and the Rock-mass Rating (RMR) system (Bieniawski 1973). The Q system, a popular rock mass classification system, employs six parameters; RQD, J_n (joint set number), J_r (joint roughness number), J_a (joint alteration number), J_w (joint water reduction number), and SRF (Stress Reduction Factor).

Q INDEX APPROACH

The Q index is linked to the excavation span to provide guidelines on the stability of an excavation as well as to select an appropriate support system. The more recent guidelines are presented in Figure. Using the Excavation Support Ratio allows the user to select the level of safety required based on the type of excavation.

ANALYTICAL APPROACHES

Various methods have been suggested following analytical methods for rock bolting system

Wedge support

Rock bolting can be used to stabilize a sliding block or a block that is susceptible to falling under gravity. A basic assumption is that the blocks are discretely defined.

Bolting of wedge of rock free to fall under its own weight

$$N = \frac{W \times f}{B}$$

where, spacing between bolts = 3 × joint spacing, f = usually 2 to 5

N =number of rock bolts, W= weight of wedge, f = safety factor, B=bearing capacity of bolt (tons)

Bolting of wedge of rock free to slide under its own weight

$$\boxed{N = \frac{W(f \sin\beta - \cos\beta \tan\phi) - cA}{B(\cos\alpha \tan\phi + f \sin\alpha)}}$$

f= usually 1.5 for grouted bolts and 2.0 for mechanical bolts

where,

N =number of rock bolts, W= weight of wedge, f=safety factor, B=bearing capacity of bolt (tons), β=dip of the sliding surface, φ=angle of friction of the sliding surface, c= cohesive strength of the sliding surface, A=base area of the sliding surface,α=angle between the plunge of the bolt and normal of the sliding surface.

Suspension of weaker strata from strong strata

In horizontal-bedded sedimentary rocks, the roof is controlled by the bedding plane weakness. The beam or slab concept for bedded rock with overlaying competent strata is used in horizontally-bedded rocks. The bolts can be used for support of the bedding planes by anchoring to the overlaying solid strata.

The number of bolts required is calculated, using only the dead load of the rock.

$W = f \times s \times c \times h \times \gamma$ $\quad\quad$ $B \geq W, \quad L > h + 0.75\ m$

Where,

W= weight of rock to be supported by a single bolt (ton), f=safety factor (usually 1.5 to 3), B=bearing capacity of bolt (ton), s =bolt spacing, perpendicular to the axis of excavation (m),

c = bolt spacing (m), along the axis of excavation, h = thickness of unstable layer of rock (m),

γ = rock density (ton/m^3), L = bolt length (m)

<u>Beam building of weaker strata</u>

In horizontal-bedded sedimentary rocks, clamping a number of thin layers of the immediate strata into thicker one using rock bolts reduces sagging and eliminates separation between the bedding planes. Tensioned bolts can be used to make the bedding planes interact and thereby increase the stability of the roof.

Panek (1973) formulated a practical design procedure for tension bolts using a design chart with the following inputs.

- Mean thickness of individual layer of rock
- Tension applied on bolt (~0.6 × pull strength of bolt)
- Bolt length (choose a bolt length to be anchored in a layer of sufficient thickness)
- Number of bolts per set (in each row). Spacing between bolts should be ≤ 3 × joint spacing
- Spacing of sets along the axis of the opening

<u>The rock arch concept</u>

- The introduction of rock bolts close to each other results in a load-carrying arch within the rock mass stabilizing the excavation back. The figure provides design guidelines for moderately and heavily jointed rock masses.
- **For opening in moderately joined rock:**
- $L = 1.40 + 0.184\omega$ (for use of non-tensioned bolts)
- **For opening in heavily joined rock:**

Tensioned bolts to be used to reinforce the loose zone below the natural arch, forms an artificial arch near the ceiling of the opening.

L/s *should be* ≥ 2, $s \leq 3e$ *and* $0.5B < T < 0.8B$

Where, L = bolt length, ω = width of excavation, s = bolt spacing, perpendicular to the axis of excavation e = joint spacing, B= bearing capacity of bolt and T = applied tension to the bolt.

TESTING OF ROCK BOLT

<u>Pull Test</u>

- This is intended to measure the short-term strength of a rockbolt anchor installed under field conditions. The test is a destructive and should not in general be made on bolts that form part of the actual rock support system.
- Rockbolt pull test consists of (a) Anchor bolt (b) rockbolt couple device (c) reaction frame (d) hydraulic jack with hydraulic pump and pressure gauge (e) dial gauge assembly

- Rockbolt strength is measured by a pull test in which bolt head displacement is measured as a function of the applied load to give a displacement-load curve.
- **TORQUE WRENCH TEST**
- This method is used for applying a specified tension during rock bolt installation or to estimate loss of tension in a previously installed bolt.
- The method is also used for verifying that anchor strength is greater than a specified value consistent with the maximum tension that can be applied with the wrench.
- The uses a torque wrench preferably with maximum torque indicator along with a hydraulic jack with a pressure gauge. A graph of tension verses torque is plotted. The slope of the tension-torque curve is used for estimating tension on the bolt for any value of torque.

MONITORING OF ROCKBOLT TENSION

- Rock bolt load cells are used for monitoring change in tension that occurs in rock bolt over an extended period of time following installation.
- The load cell should have reversible and preferably linear calibration with pressure indicator.
- The load cell should be capable of withstanding the effect of nearby blasting, water, dust over long periods of time.
- The load cell is installed on the selected rock bolt at the time of installation of the support system.
- Tension reading should be taken immediately following installation and again a few hours later. Further readings may be taken at intervals depending on the rate at which reading are changing.