CONDITION ASSESSMENT, DURABILITY AND CORROSION OF ROCK REINFORCEMENTS

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17th ANNUAL TECHNICAL FORUM

GEOHAZARDS IMPACTING TRANSPORTATION IN THE APPALACHIAN REGION

Session #6

"Rock Reinforcement "

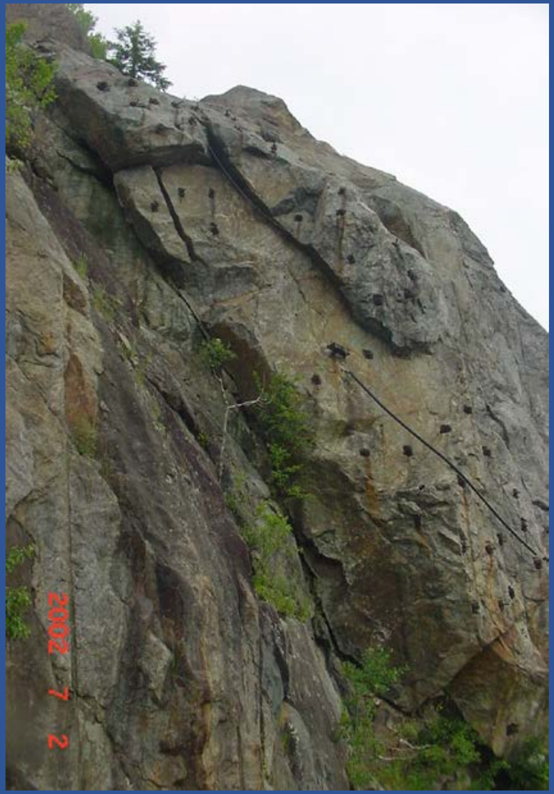
Blacksburg, VA
Wednesday, August 12, 2015

ERTesting

McMahon & Mann
Consulting Engineers, P.C.

TOPICS

1. Rock Reinforcement Types and Installation Details
2. Chronology of Rock Reinforcement Types
3. Corrosion & Corrosion Protection
4. Existing Performance Data
5. NDT
6. Service Life Modeling
7. Conclusions



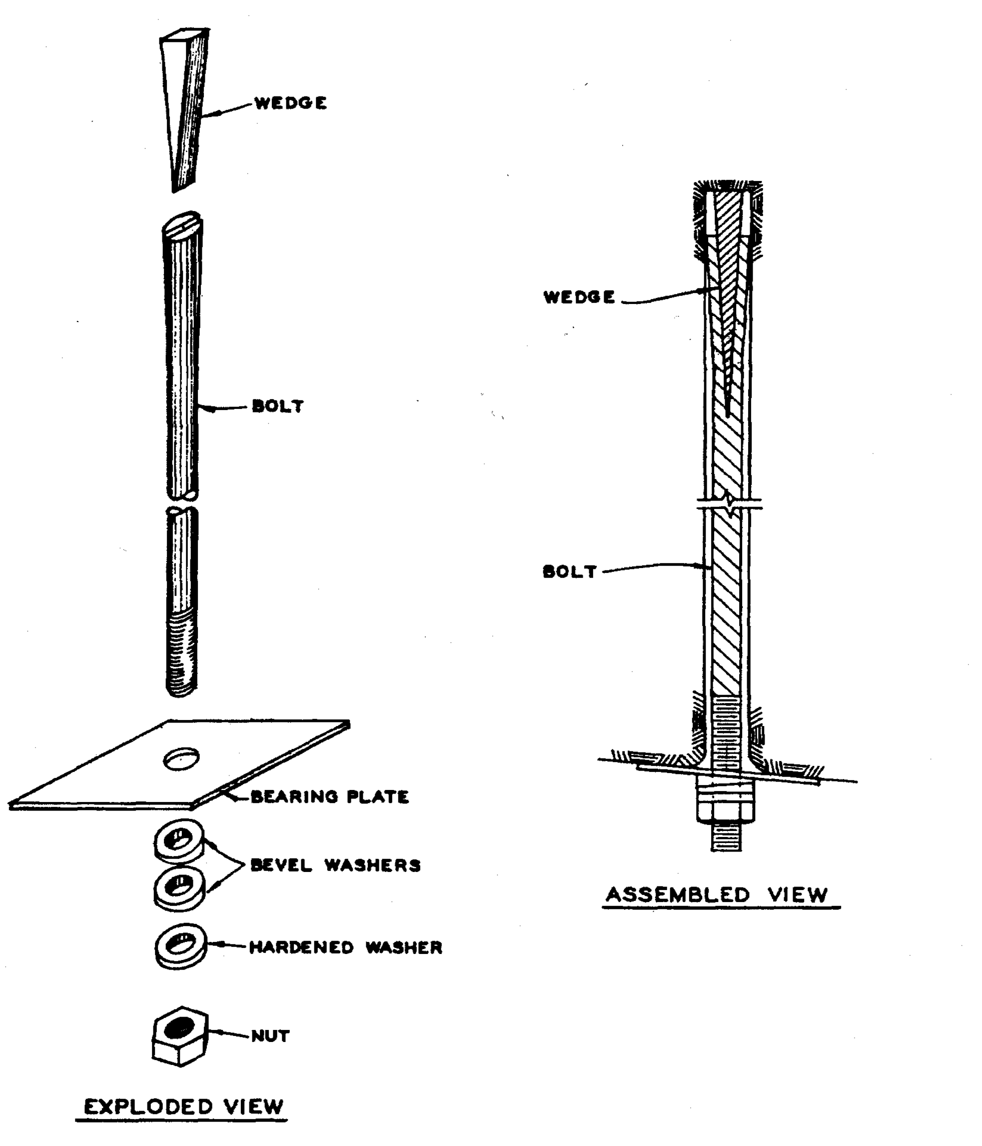
1. TYPES OF ROCK REINFORCEMENTS

System Type	Tendon Type	Anchorage Type	Corrosion Protection
Rock Anchors	Strands or Bars High Strength Steel	Cement Grout in Bonded Zone	Class I or Class II Protection
Rock Bolts	Bars Strands Mild Steel or 150 ksi	Mechanical, resin grout or cement grout	Epoxy coating, galvanized, grout cover. May have no protection other than grout cover.

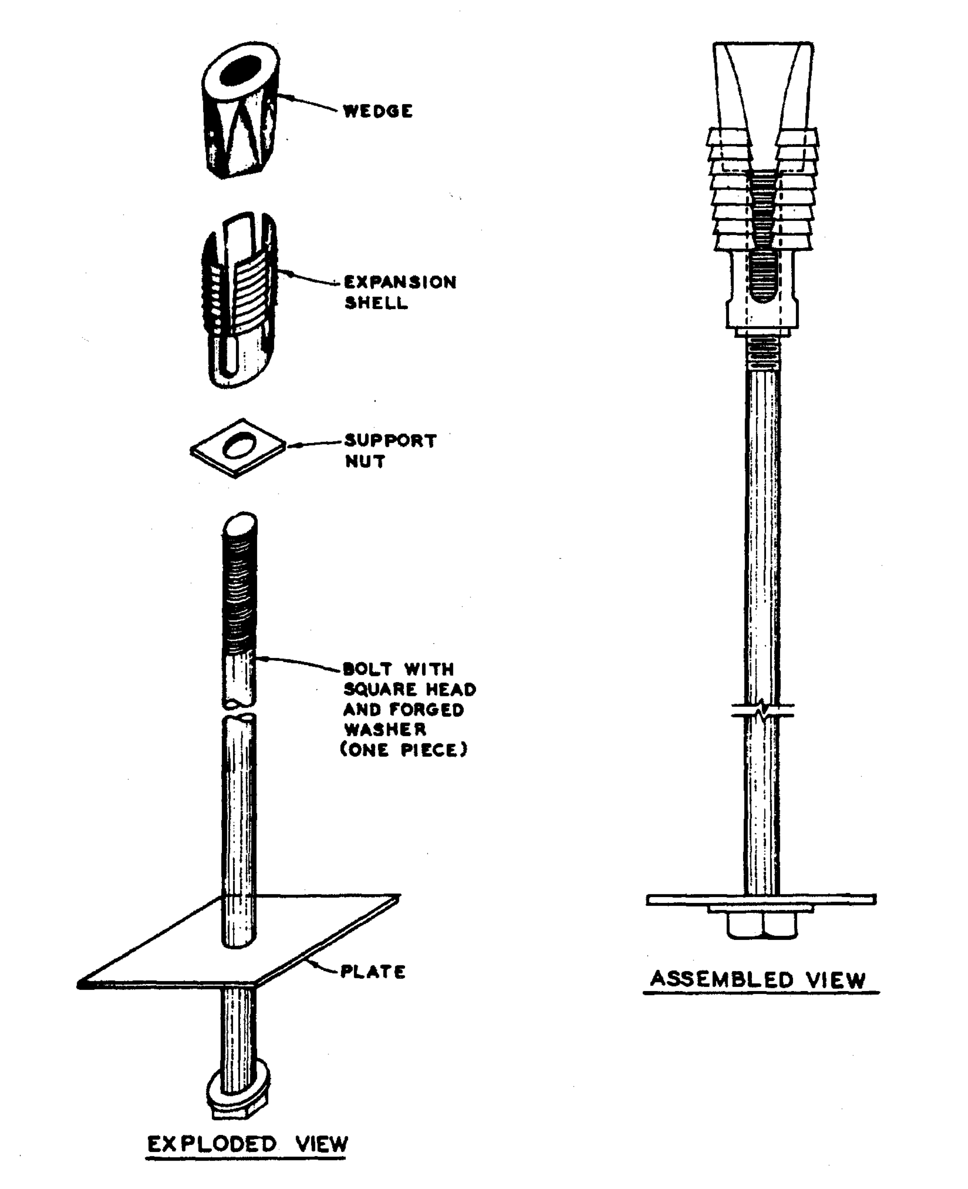
ROCK BOLTS

- **Mechanical anchorage**
- **Grouted anchorage**

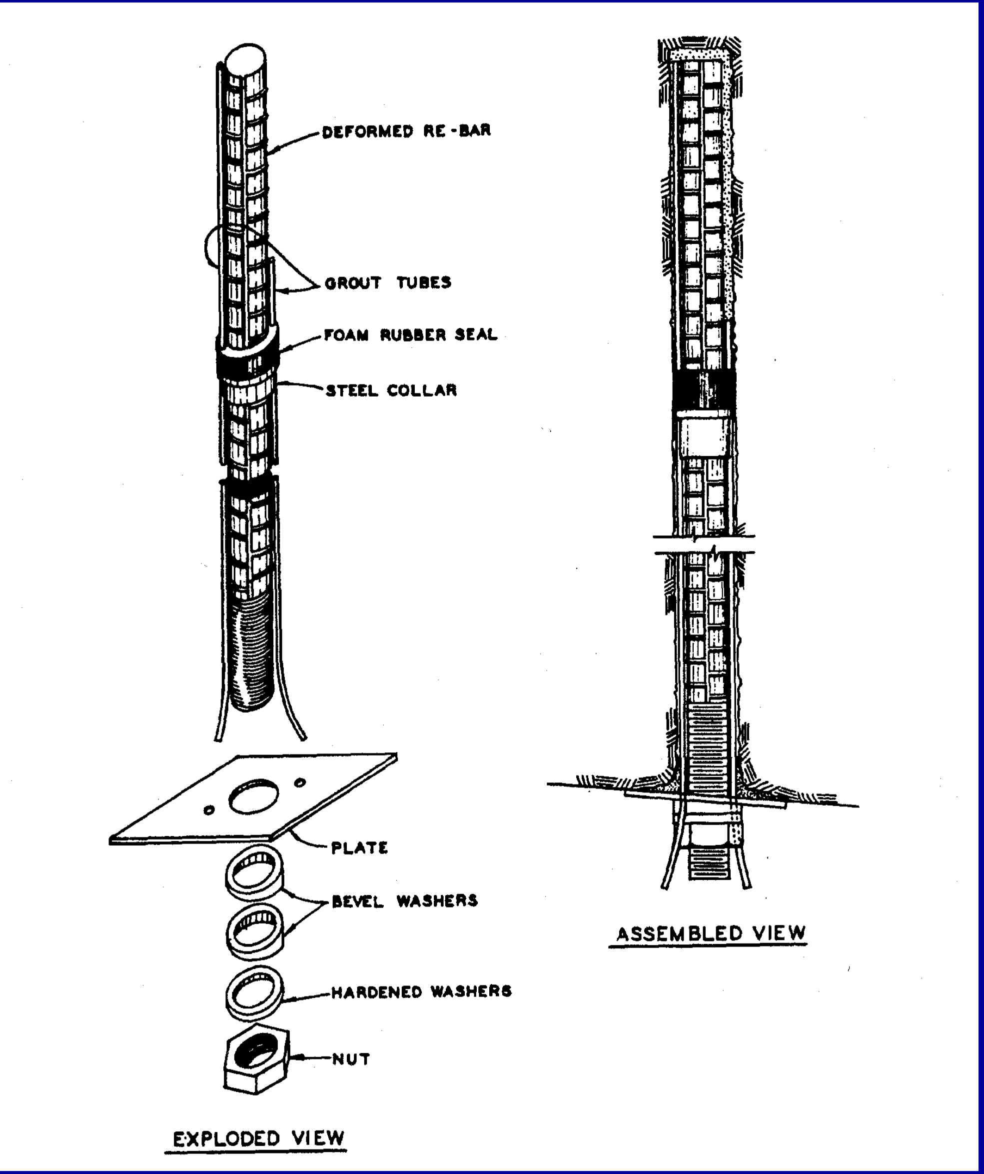
Sledge & Wedge Rock Bolt



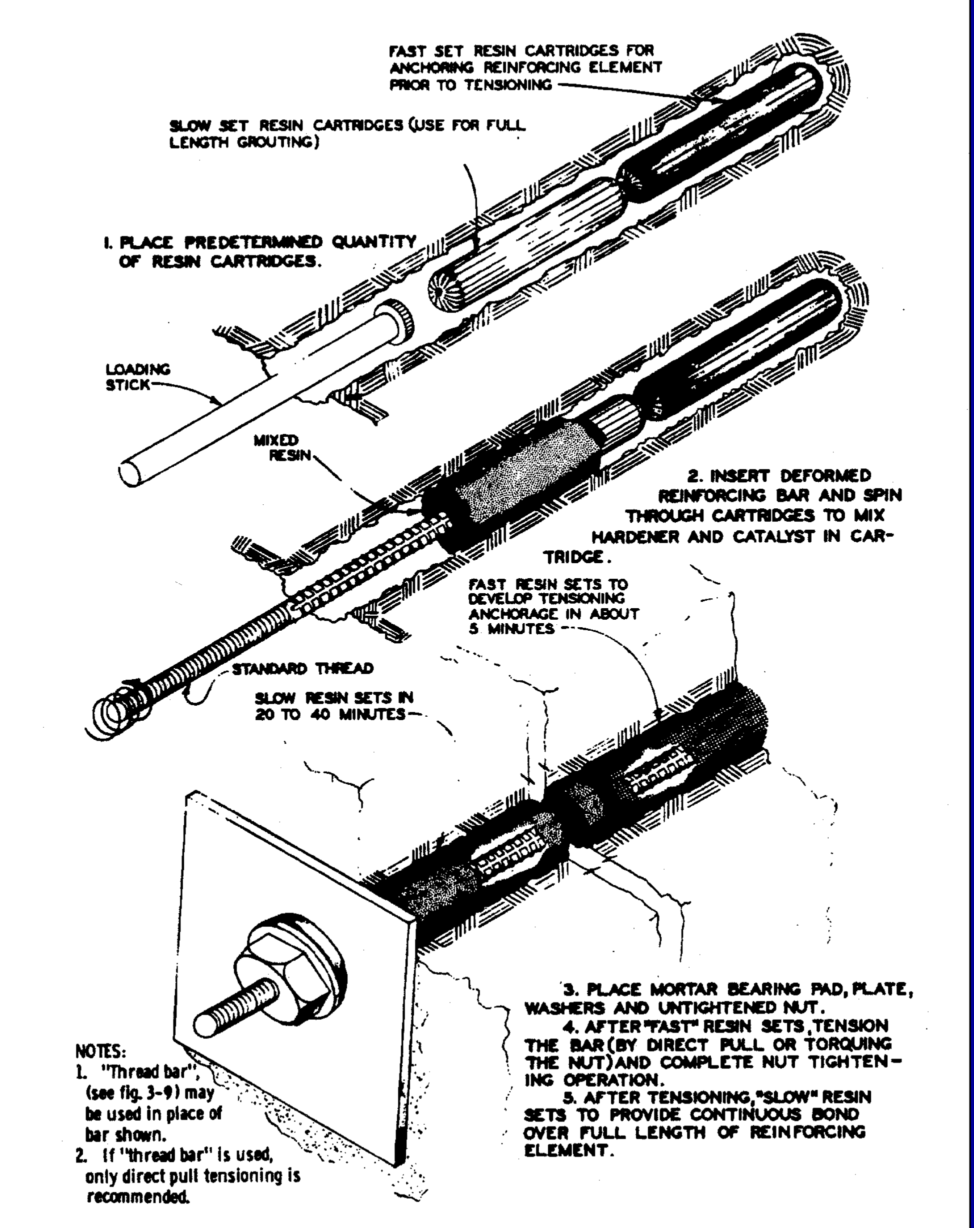
Expansion Shell Anchorage



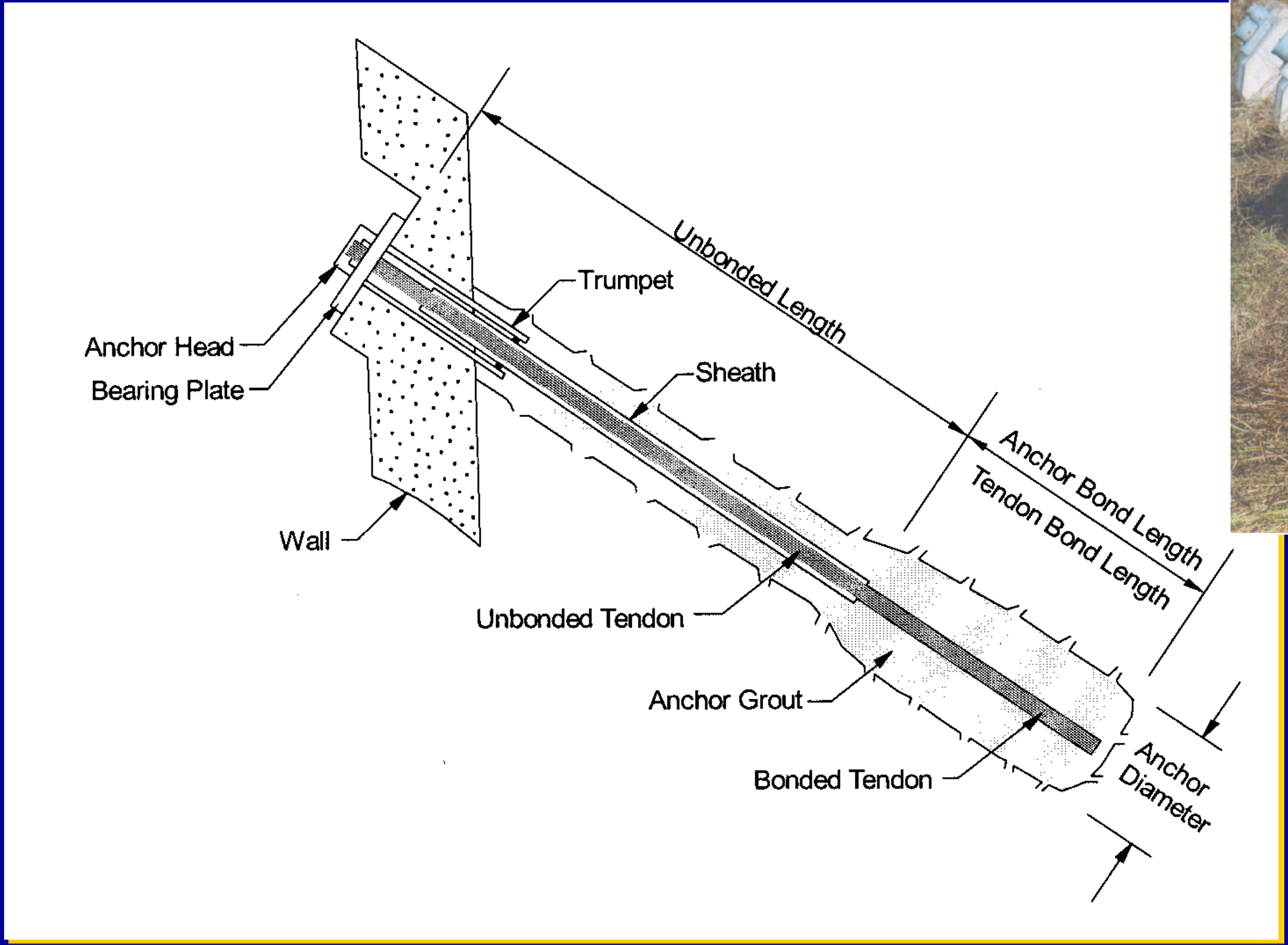
Cement-Grouted Anchorage



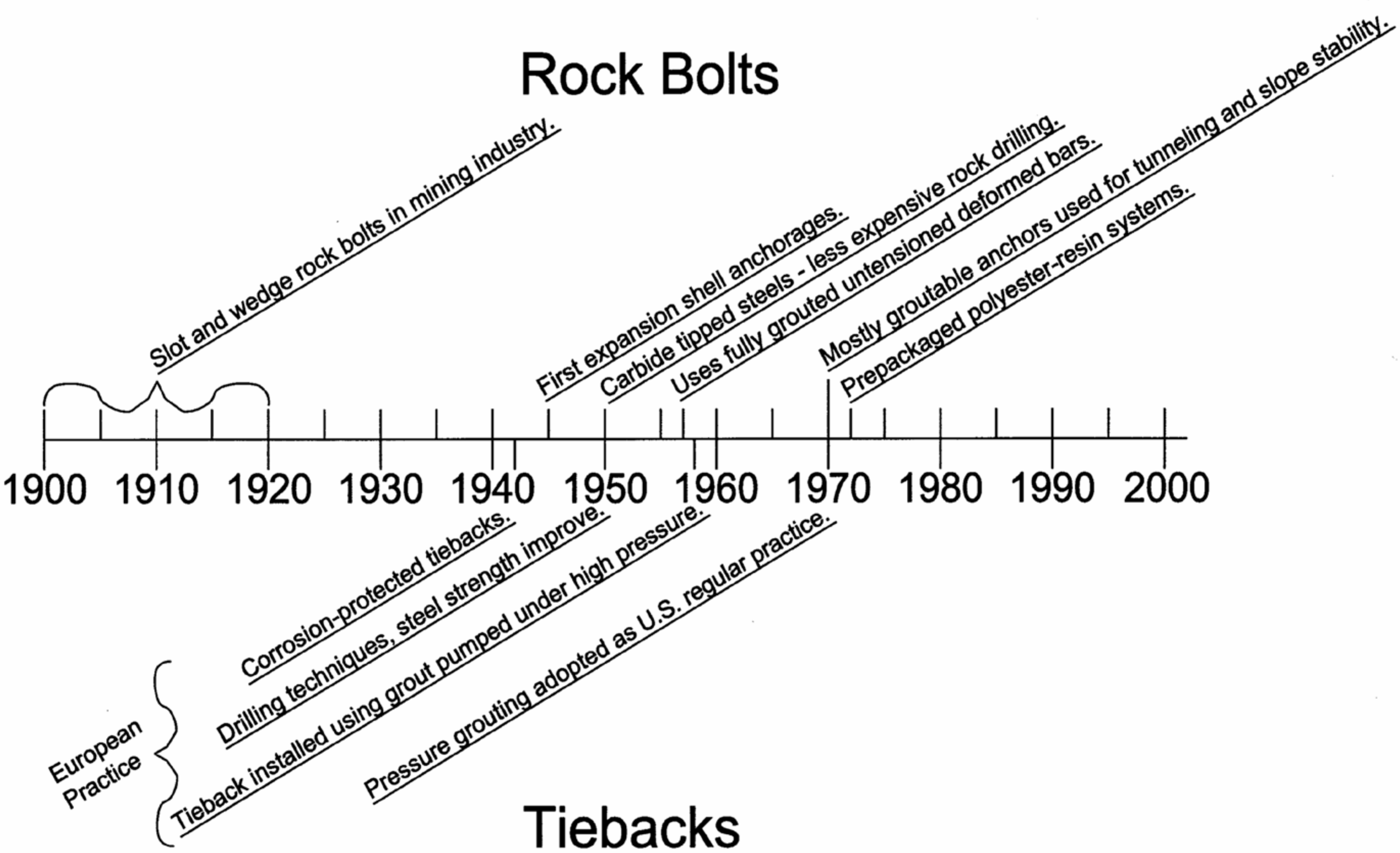
Resin-Grouted Anchorage



Ground Anchor



2. CHRONOLOGY

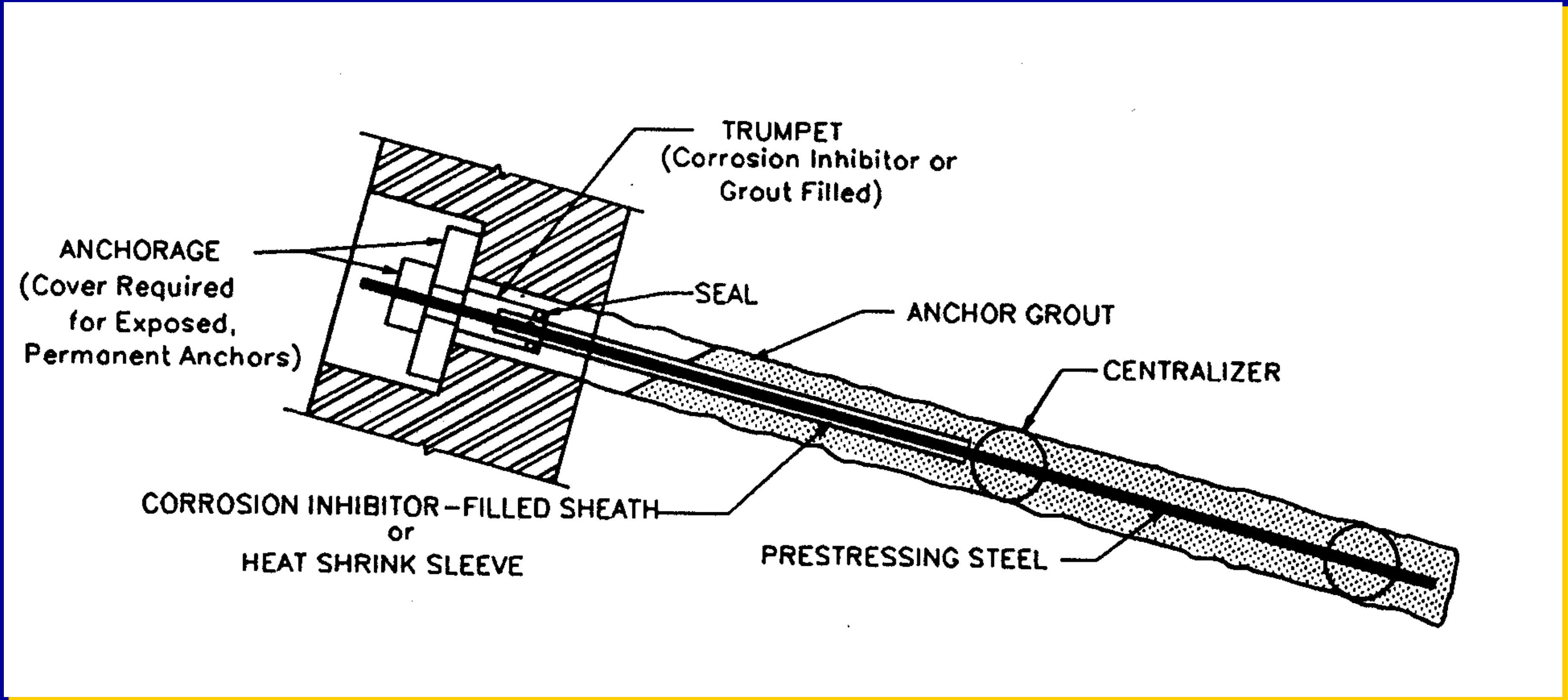


3. TYPES OF CORROSION

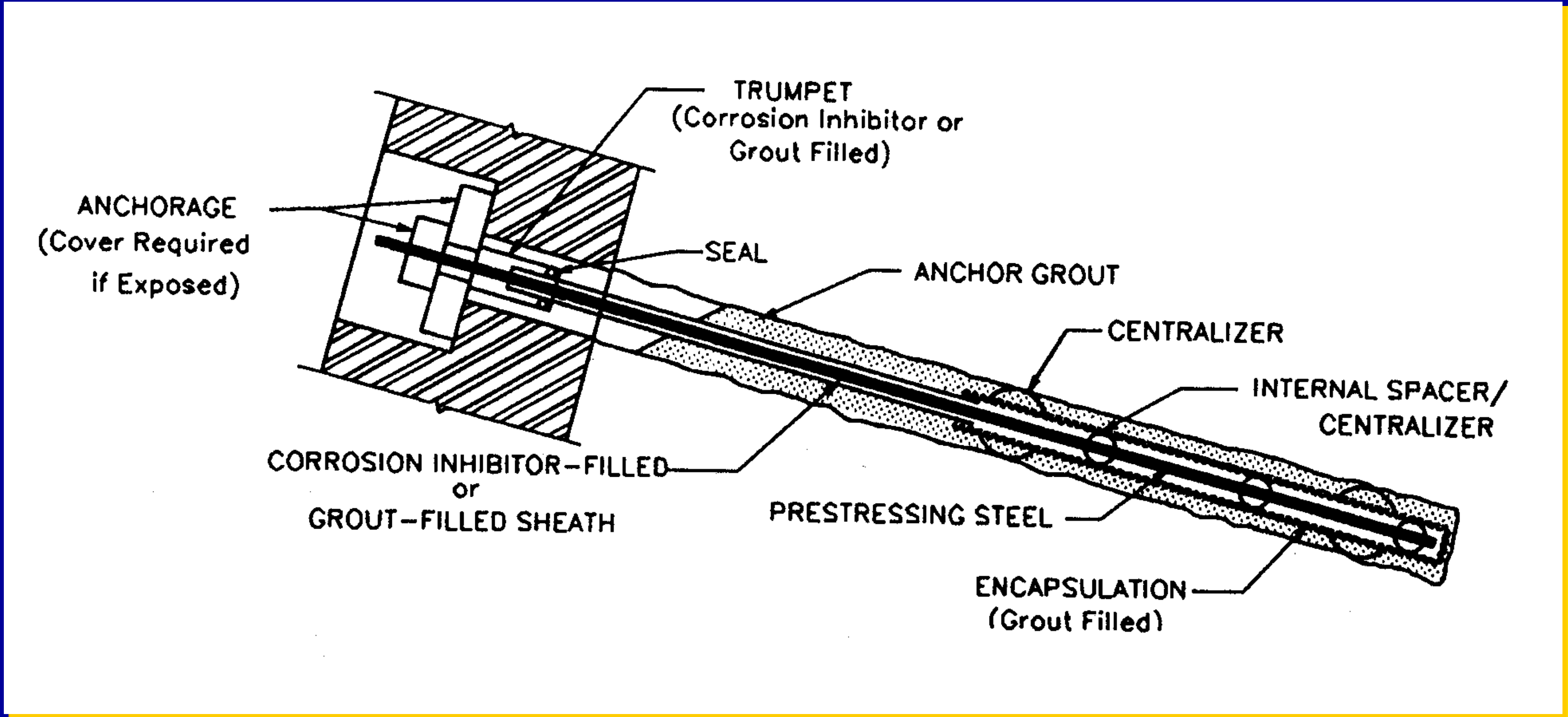
- Uniform corrosion
- Pitting corrosion
- Crevice corrosion
- Stress corrosion cracking
- Hydrogen embrittlement
- Stray-current induced corrosion
- Micro-bacterial induced corrosion

CORROSION PROTECTION SYSTEMS

Class II (PTI, 2007)



Class I (PTI, 2007)



4. LONG TERM PERFORMANCE OF ROCKBOLTS (Baxter, 1987; Kendorski, 2003)

Finish Rockbolt Research (Sundholm, 1987)

- Cracks, voids and lack of material were found in both cement grouted and resin grouted bolts.
- Large pieces of resin cartridge cover were seen between the grout and the borehole wall.
- Cement grouting of rebar seemed to offer the best protection against corrosion.
- For cement-grouted bolts damage from corrosion only occurred at the proximal end of the bolt, where the cement grout was often very poor.
- Uncovered parts of resin-grouted rebar were very badly corroded within two years

LONG TERM PERFORMANCE OF ROCKBOLTS (CONT.)

Swedish Rockbolt Research (Helfrich and Finkel, 1989)

- Approximately 50% of cement grouted bolts had reduced or insufficient grouting.
- Severe pitting corrosion was observed in cement grouted rockbolts.
- General surface corrosion was observed from uncoated bolts.
- Resin-grouted bolts indicated increasing rust formation with age.
- Cement-grouted bolts had no or poor grout quality at the distal end.
- Resin-grouted bolts showed no or poor grout quality at the proximal end.

Ground Anchor Performance

Case Studies

- 35 case studies reported by FIP (1986)
- Rock bolt experience in mining industry
- NCHRP 24-13 survey
  - Several reported incidents in transportation sector

History of Performance

- In general performance has been satisfactory
- Some corrosion problems- near anchor head, MIC, stray currents
- Creep
- Loads not anticipated in design- ice loads, poor drainage, cyclic loads

5. NDT

UTILITY OF NDT

- *Electrochemical Tests*
  - **Half cell**
  - **Polarization**

Indicate integrity of corrosion protection systems.

- *Wave Propagation Techniques*
  - **Impact Test**
  - **Ultrasonic Test**

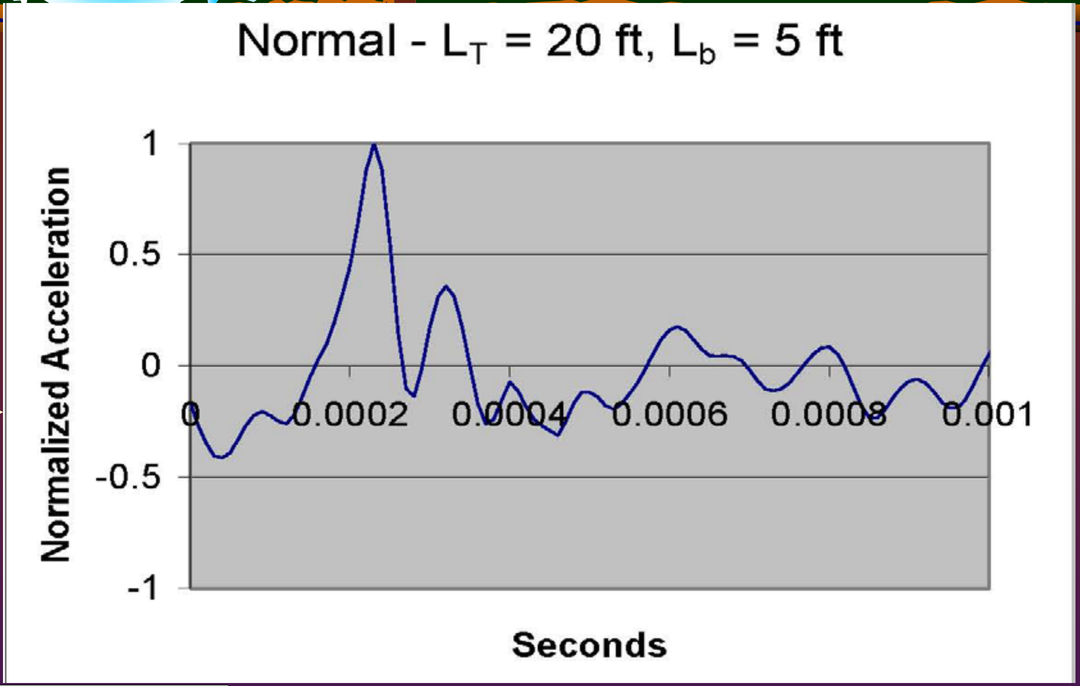
Assess the current condition of an element, i.e., severity of corrosion.

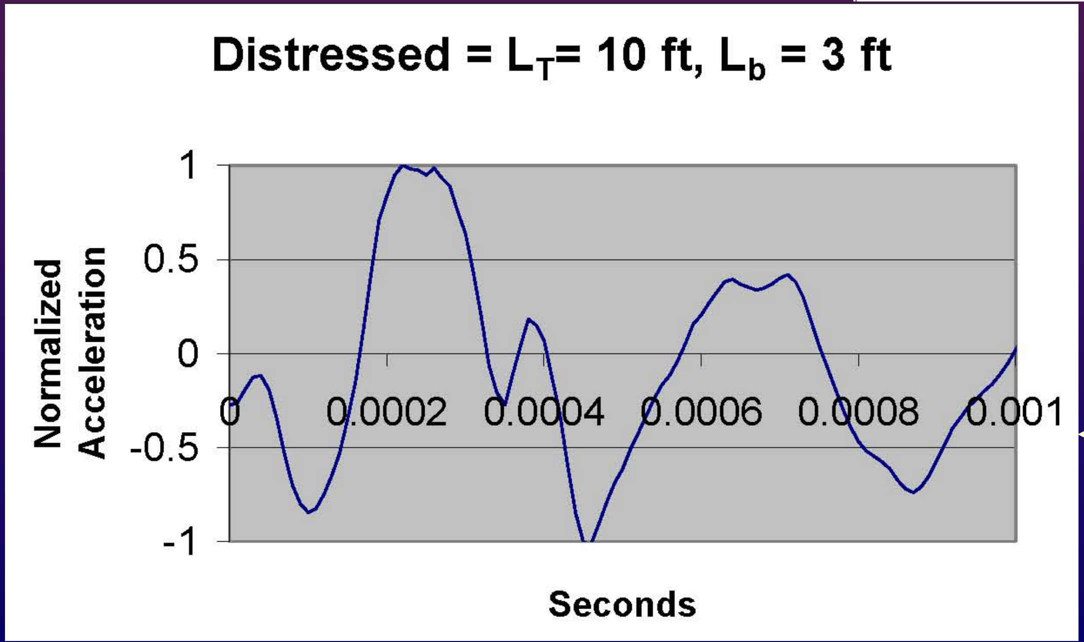
APPROACH

1. A number of monitoring techniques are included in the **test protocols for NDE of rock bolts**
2. The **SE, IR , UT, and ECT techniques** are applied to evaluate the condition of grouted rock bolts
3. **Installation details** can be distinguished with NDE, and these details are useful for **condition assessment and service life modeling**
4. **Reliability and durability** are affected by lock-off loads, and whether the design load is determined by **geotechnical or structural considerations**

SIGNAL ATTENUATION

40 Kips





SIGNAL ATTENUATION

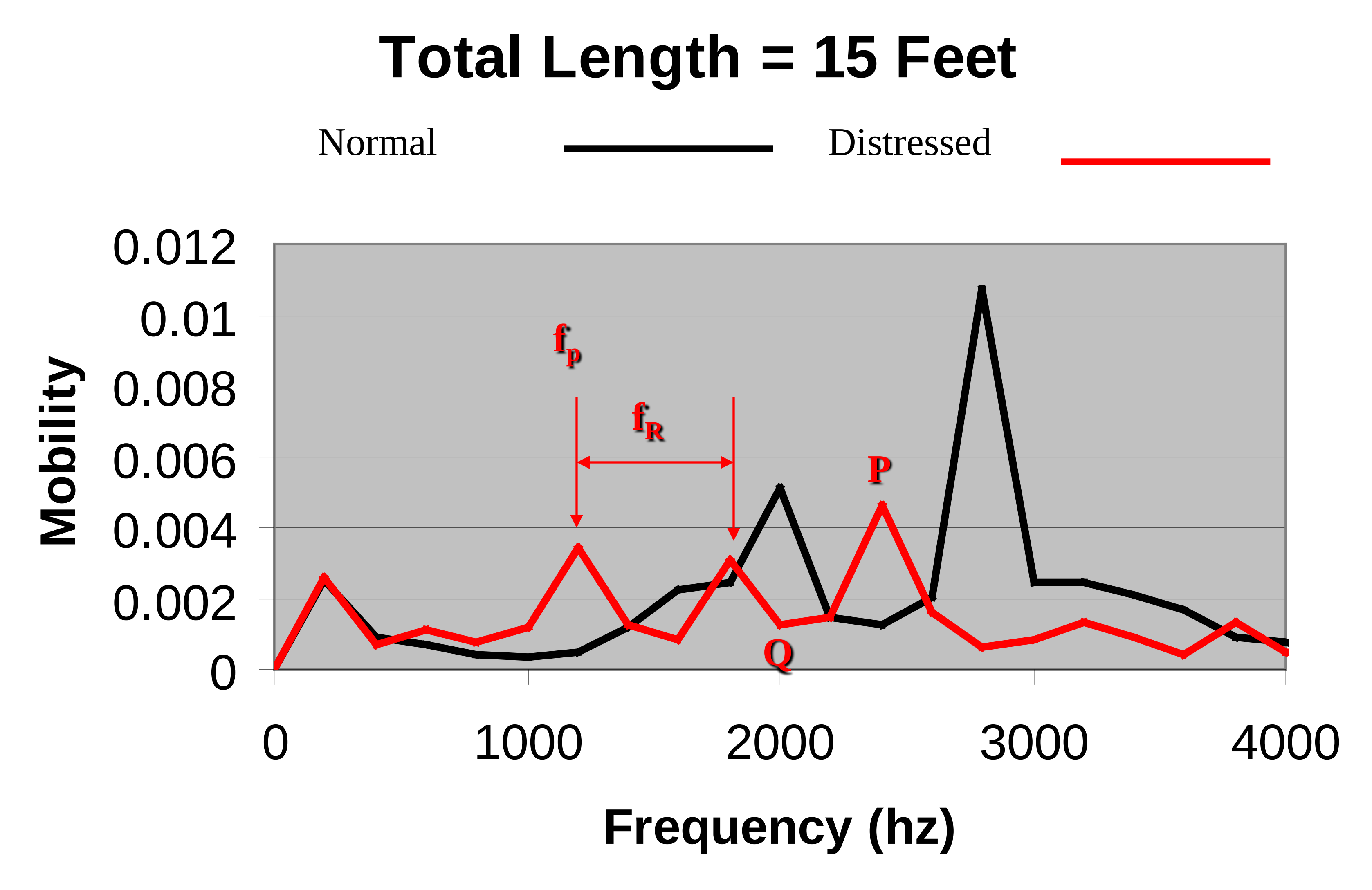
10 Kips

LIFT-OFF TEST RESULTS

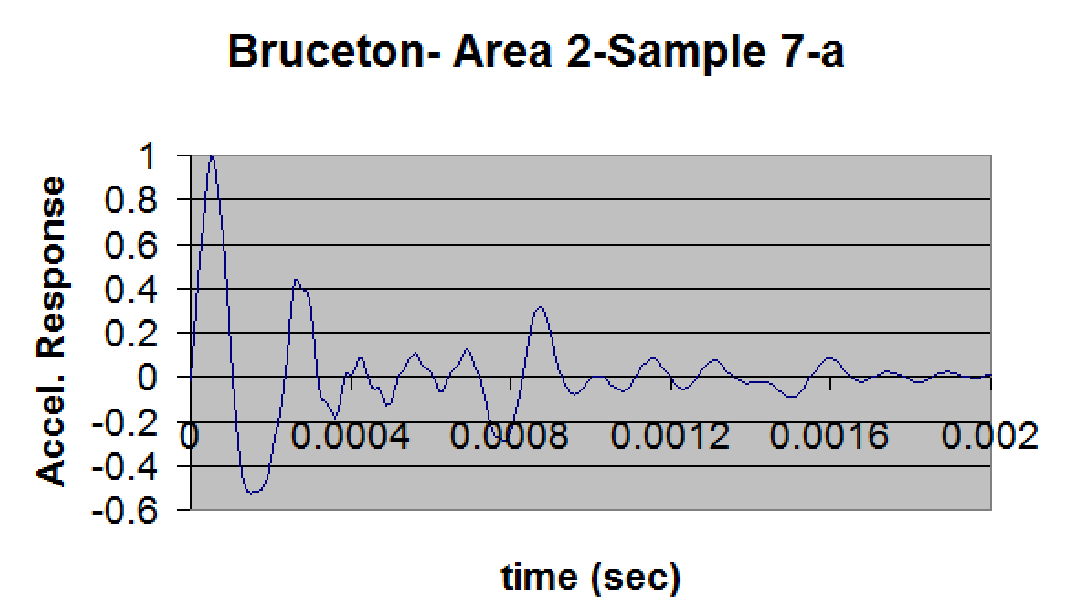
BOLT #	LIFT-OFF (Kips)	NDT RESULT	CORRECT NDT
3	36	GOOD	Y
4	38	GOOD	Y
7	17	GOOD (?)	N (?)
8	22	GOOD	N
9	20	NG	Y
G1	7	NG	Y
6	LOOSE	NG	Y
17	LOOSE	G/NG	Y (?)

VERIFICATION OF NDT

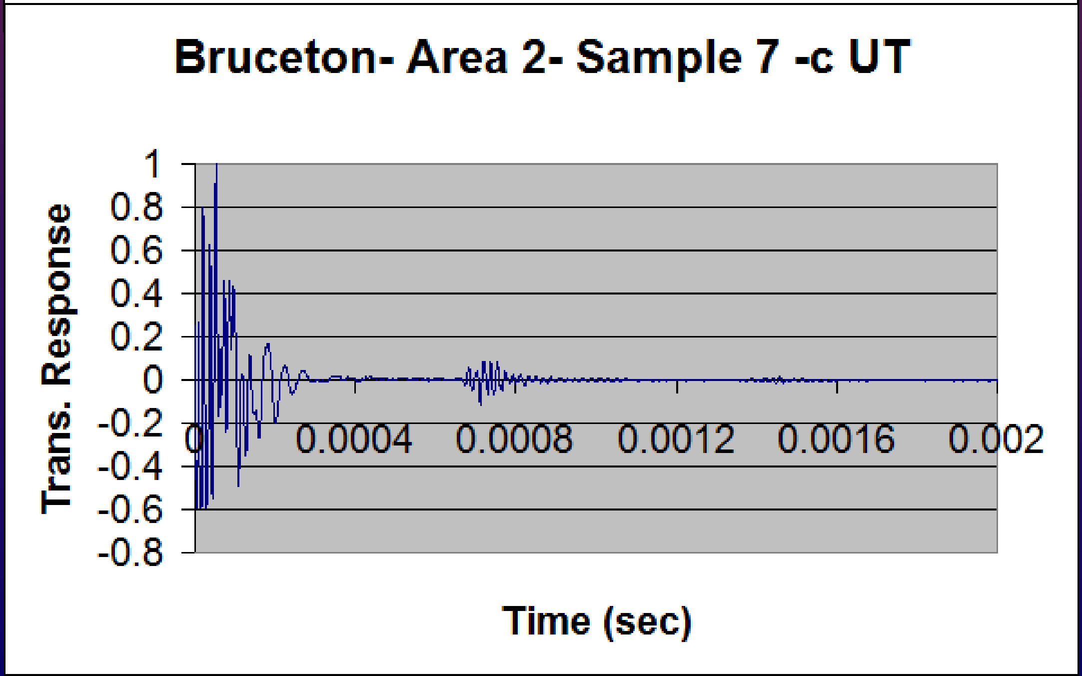
MOBILITY CURVES



Bruceton SRCM

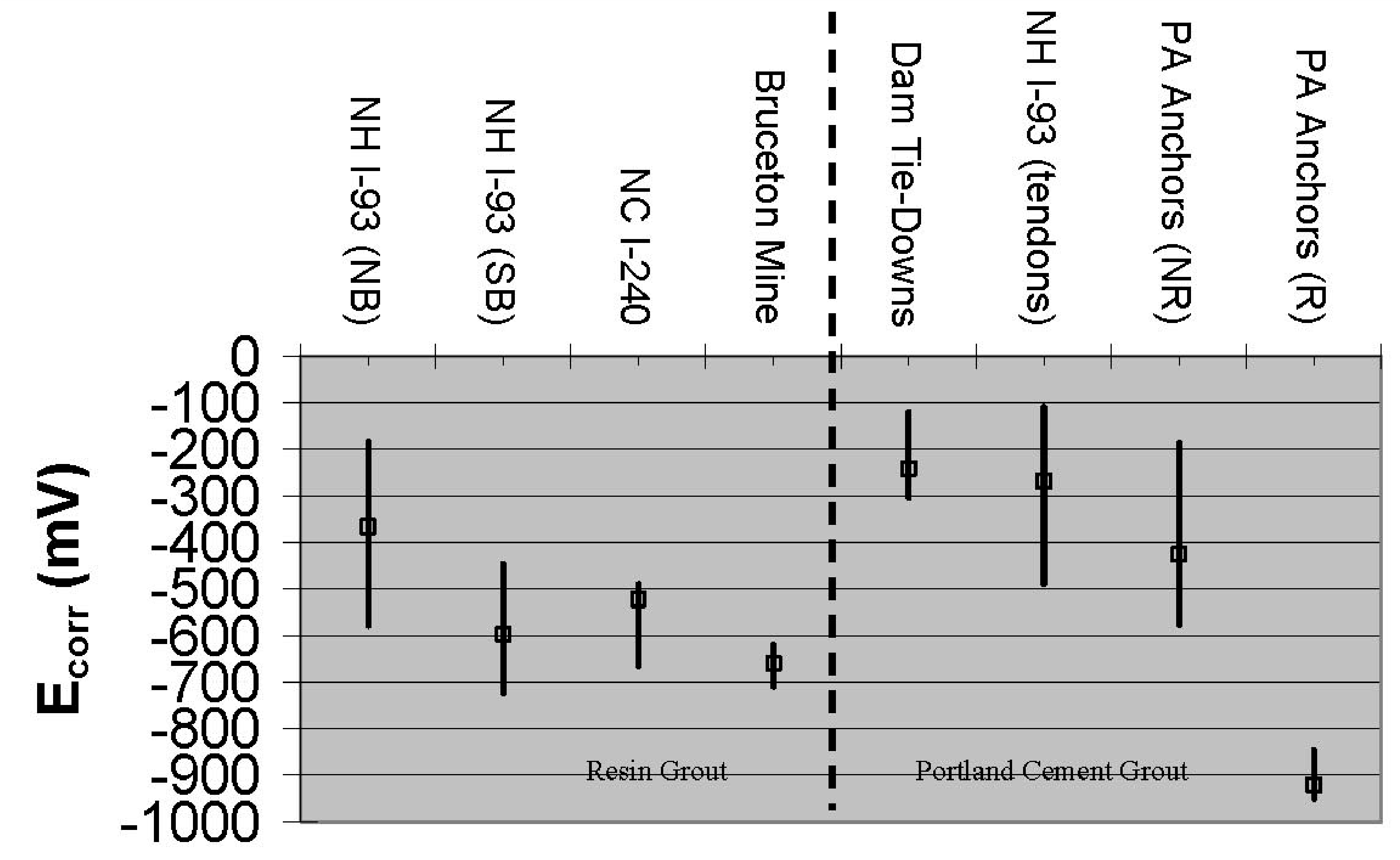


SE Test Results

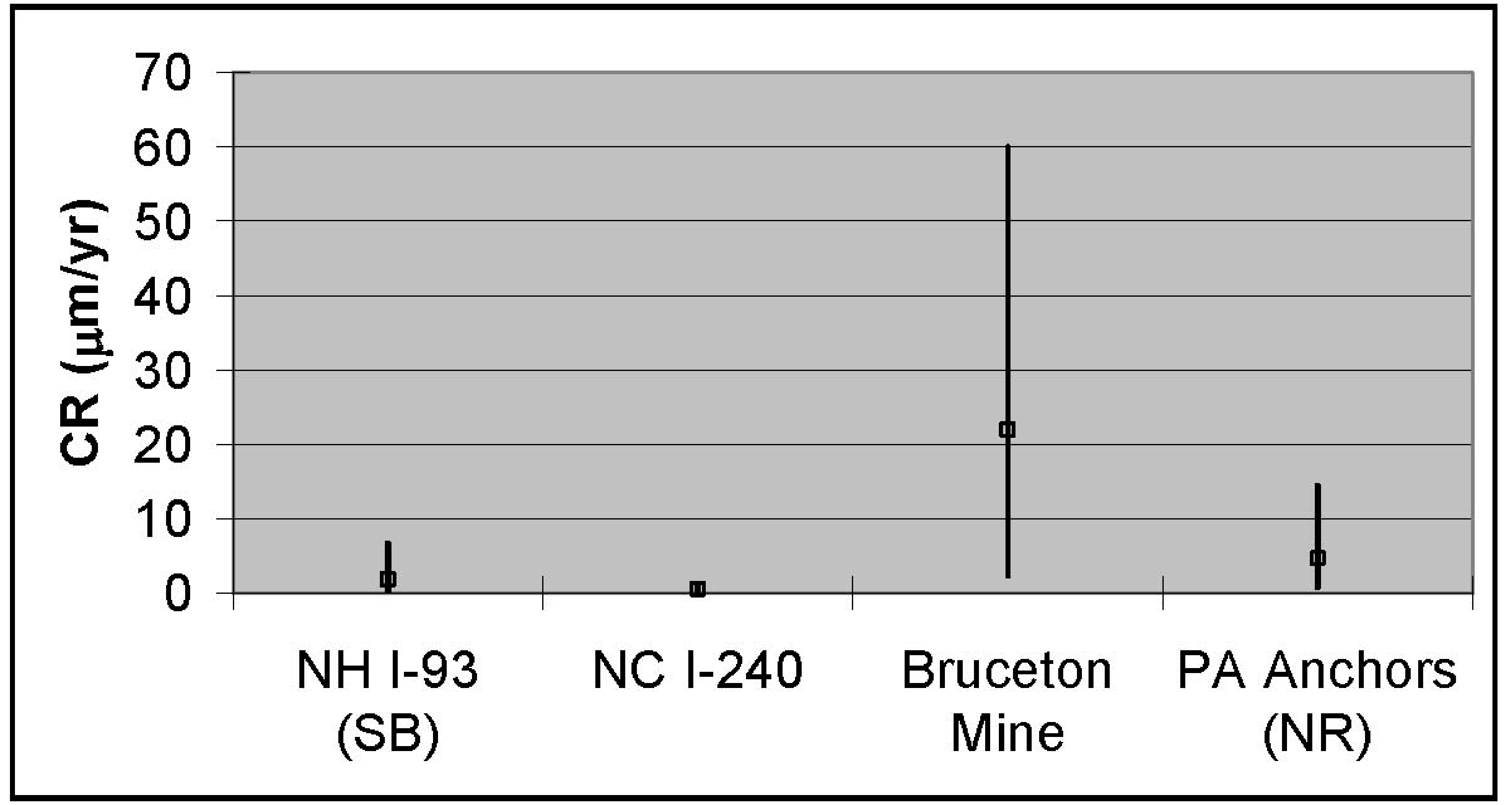


UT Results

HALF-CELL POTENTIALS



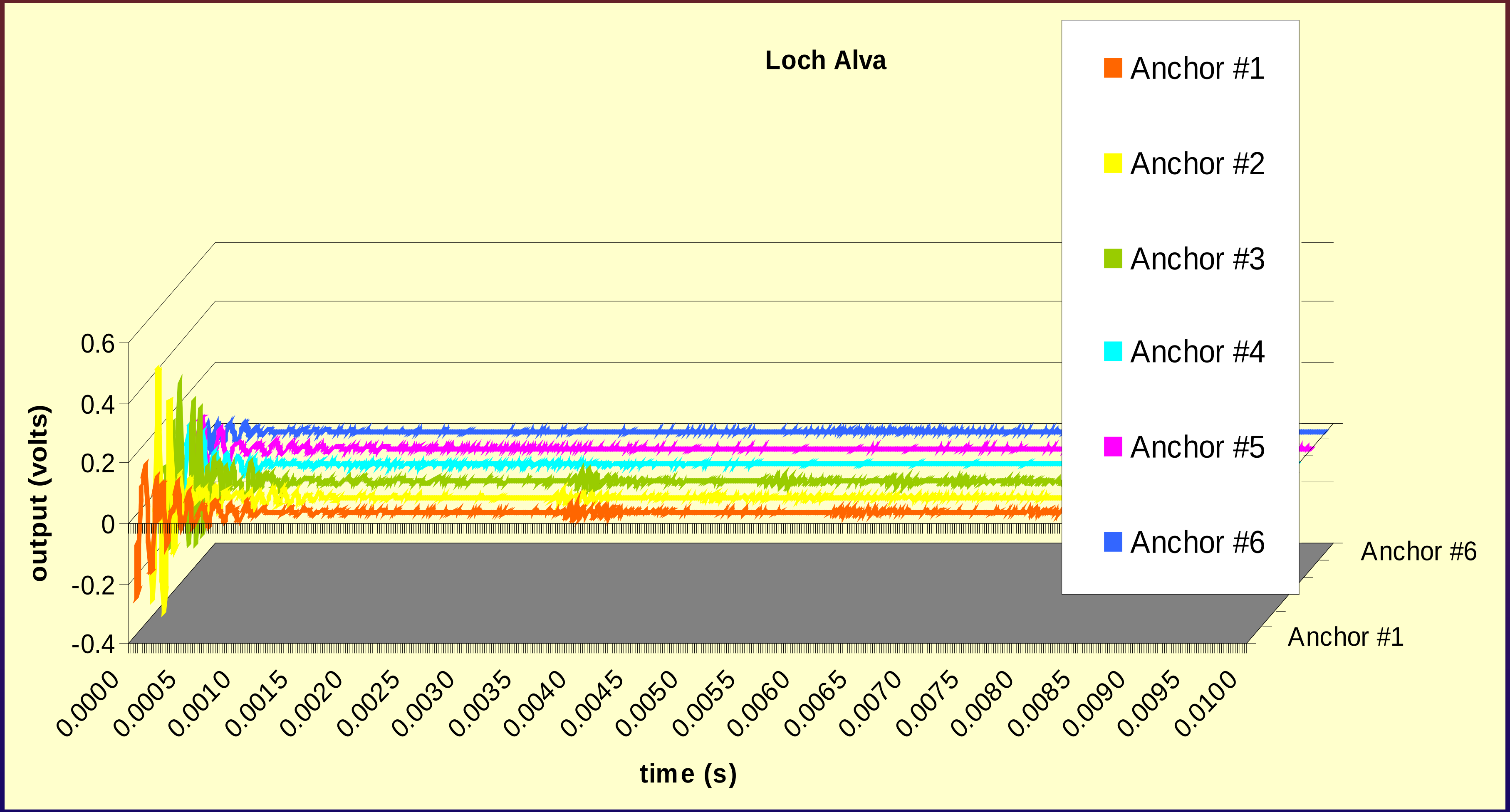
CORROSION RATES OBSERVED WITH LPR



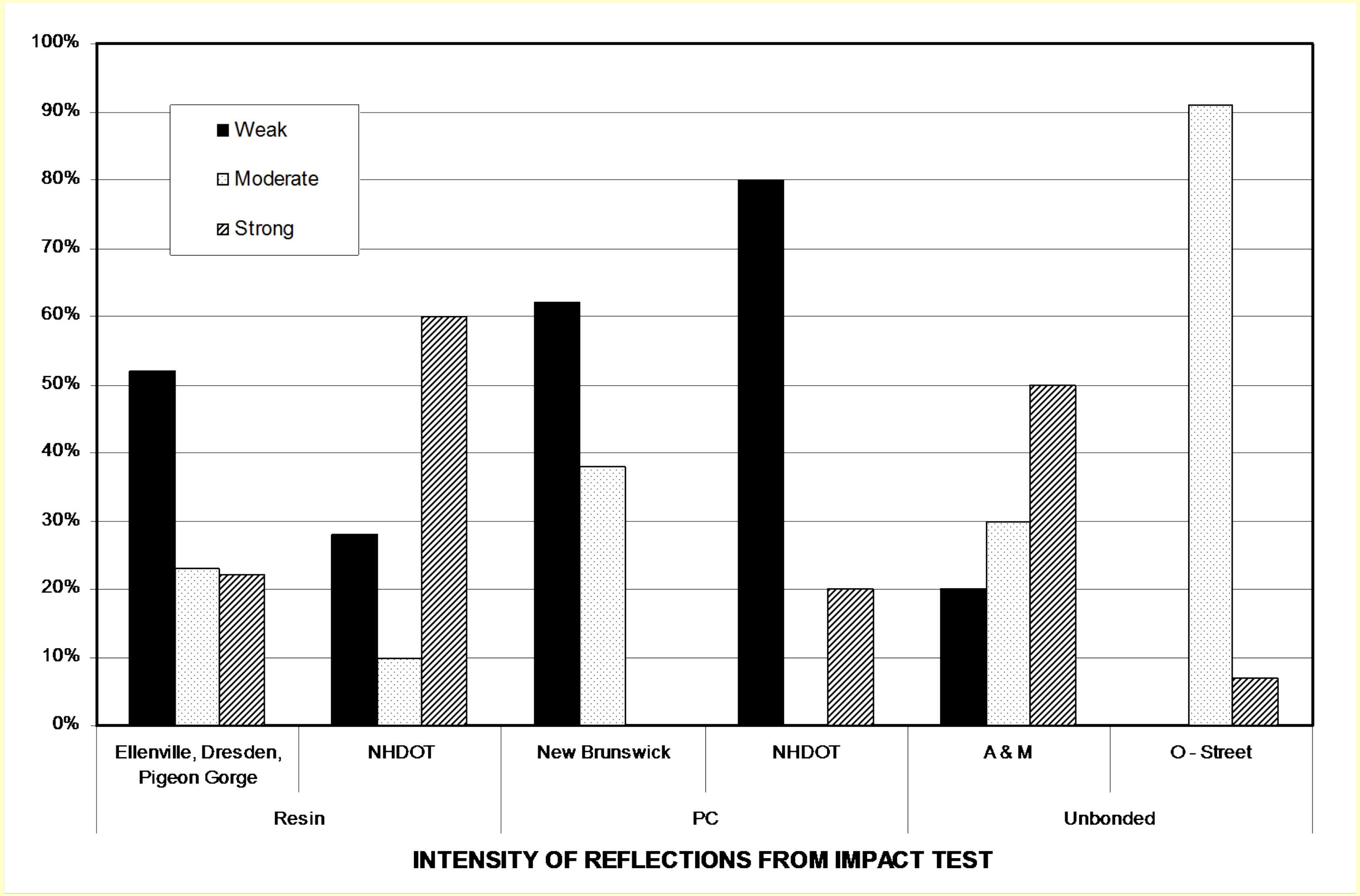
LOCH ALVA DAM

DAM TIE DOWNS - BUTTON HEAD ANCHORAGES

LOCH ALVA DAM - IMPACT TEST RESULTS



Grout Condition Assessment for Rock Bolts & Ground Anchors



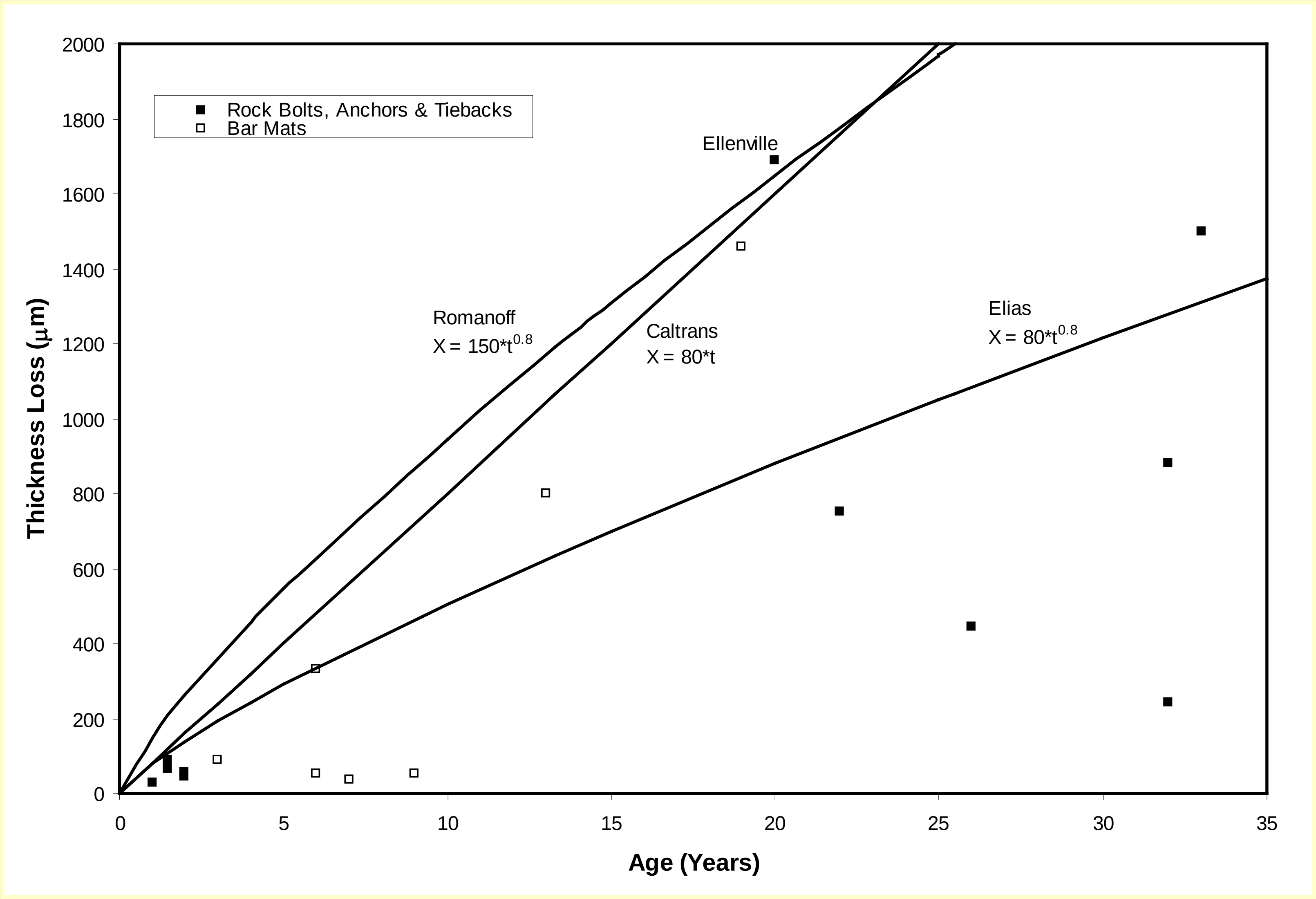
6. SERVICE LIFE MODELING

CORROSIVENESS OF SOILS

Corrosiveness	Resistivity (ohm/cm)	pH
Normal	2000 – 5000	5 – 10
Aggressive	700 – 2000	5 – 10
Very Aggressive	< 700	< 5

Recommended Parameters for Service-Life Prediction Model
(Withiam et al., 2002)

Parameter	Normal	Aggressive	Very Aggressive
K (μm)	35	50	340
r	1.0	1.0	1.0



Effect of Time on Metal Loss for Rock Bolts & Ground Anchors

SERVICE-LIFE MODEL

$$X\left(\frac{\mu m}{side}\right) = A\left(\frac{\mu m}{side}\right) \times t^{0.8}(yr)$$

Statistics for A

μ = 60 μm/yr
σ= 40 μm/yr
PDF - lognormal

7. CONCLUSIONS

- The type of rock reinforcement and installation details have a significant effect on condition assessment and durability.
- Older installations may not incorporate the same level of details and corrosion protection afforded to more modern applications.
- Existing data on performance and service life are useful to identify vulnerabilities of different systems.
- In general, systems are most vulnerable to deterioration near the anchor heads.
- NDT are useful tools for condition assessment.
- Generalized service-life models are available from the literature
- More data are needed from condition assessment to incorporate affects of climate and site conditions on performance