EFRC Training Workshop
Foundation design for reciprocating compressors

Anchor Bolts Design Considerations

Harry Lankenau, NEAC Compressor service

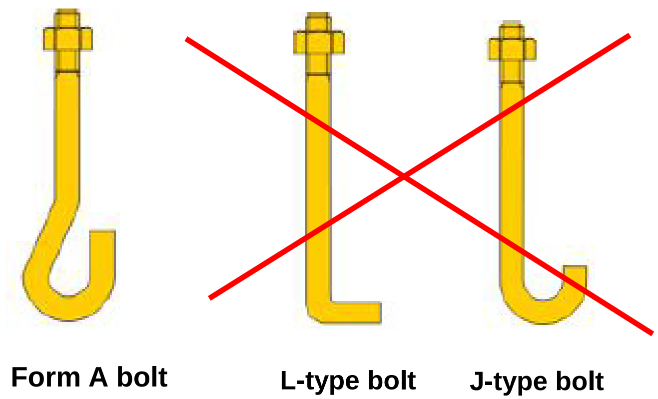
Anchor Bolt Design Considerations

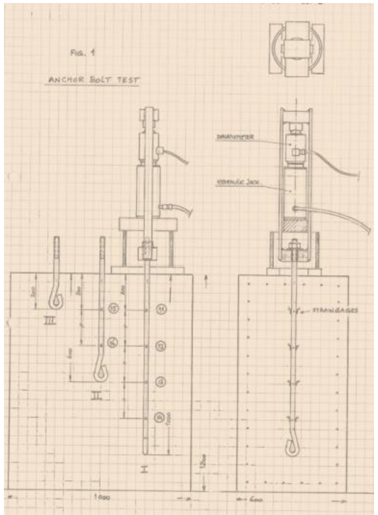
Contents

- Anchor bolt type and selection
- Friction coefficient, edge distance and spacing
- Anchor bolt, installation and execution
- Fatigue and thermal expansion considerations

Anchor Bolt Type

L- and J- bolts only for auxiliary equipment



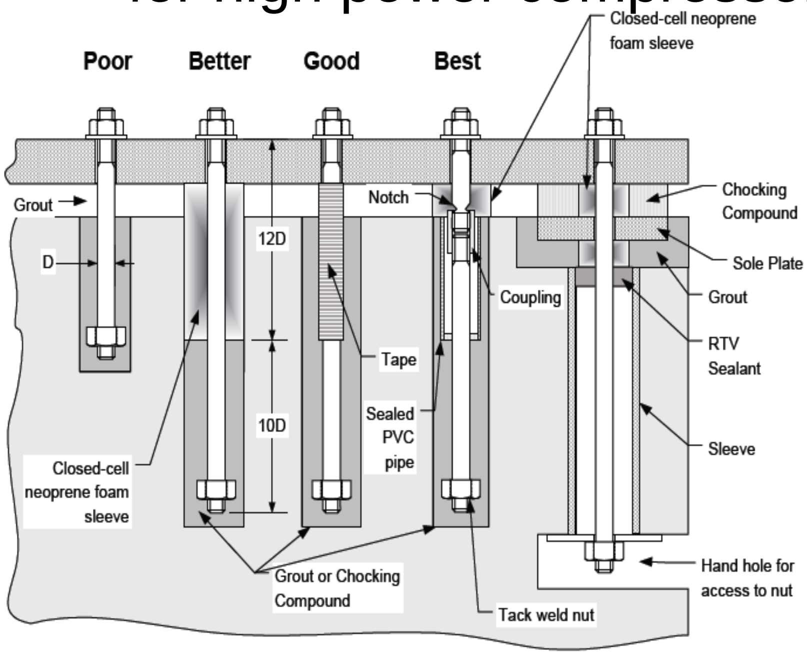


Example of an A-type anchor Source HTC

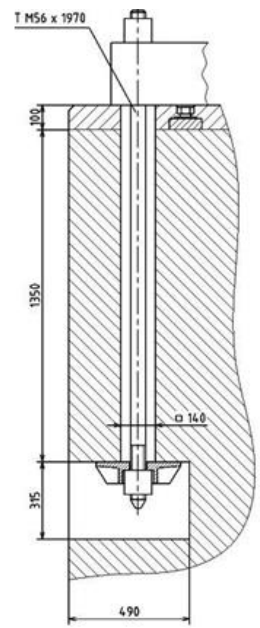
- Form A type bolts have been applied for many years
- A type bolts have been applied for many years by the OEM's.
- The size and power of the compressors have been increased the last decades
- The effect of an increased preload load for this bolt termination is unknown. The loads may already be close to the limits for the current Grade 5.6 material.

Anchor Bolts with Termination Plate

- Anchor bolts with a termination plate are applied nowadays for high power compressors



Different plate type bolts with terminations acc. to ITW Technical Bulletin #660 A



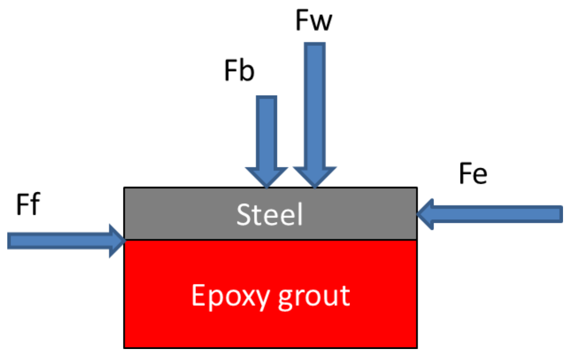
Hammer bolt application
Source Neumann & Esser

Requirements termination plate diameter:

- To meet bearing load requirements: $3xD_{bolt}$
- GMRC SWRI Report No. TR 97-6: termination plate diameter: 3-4x D_{bolt}
- GMRC: plate termination thickness:1.35- $1.5xD_{bolt}$

Friction, Edge Distance and Spacing

- Compressors are kept on its place by means of friction (not by shear)
- Bolt design and load to meet a safety factor of 2 on the friction force



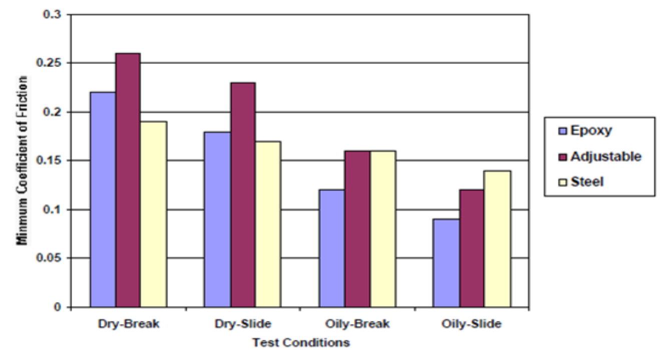


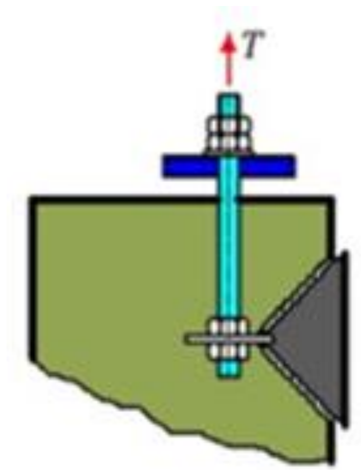
Figure 2-56. Minimum Friction Coefficient for Cast-Iron on Various Other Materials, from GMRC Technical Report TR97-3 [2]

$$F_f = (F_b + F_w)\frac{\mu}{\alpha}$$

F_e horizontal dynamic load (N)
F_w deadweight (N)
F_b required bolt preload (N)
F_f minimum required friction force(N)
M friction coefficient (-)
A design factor (-)

Friction, Edge Distance and Spacing

- To avoid blow out the edge distance according to the API RP 686 shall be: the greater of 150 mm or $4xD_{bolt}$



Blow out failure

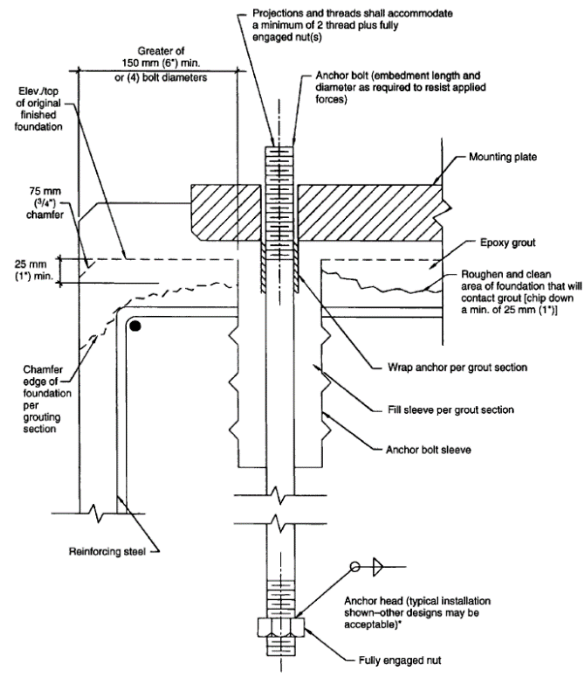
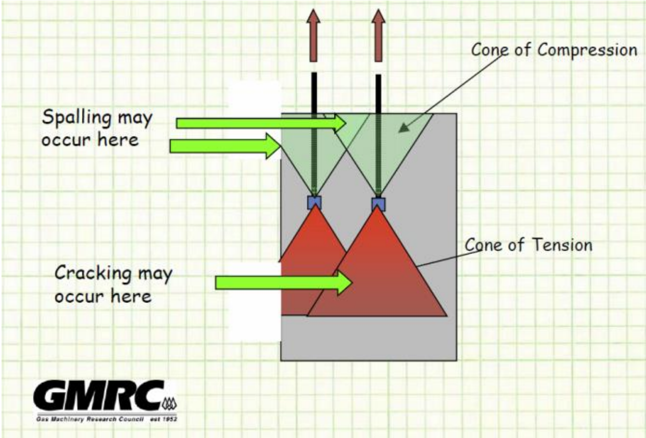
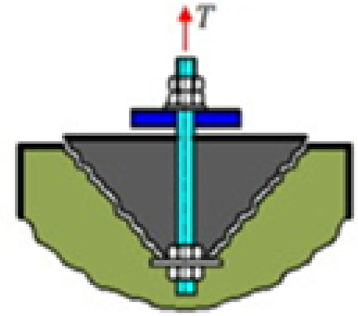


Figure A. 4 from API RP 686

Friction, Edge Distance and Spacing

- Overlap of cones of <u>compression</u> lead to compressive failure and spalling of concrete from sides of concrete foundation.
- Overlap of the cones of <u>tension</u> lead to concrete cracking.
- Bolt distance according to
- PIP STE05121: 6xD_{bolt} for torqued cast-in anchors plus the plate width if the termination plate is used at the bottom of the anchor bolt

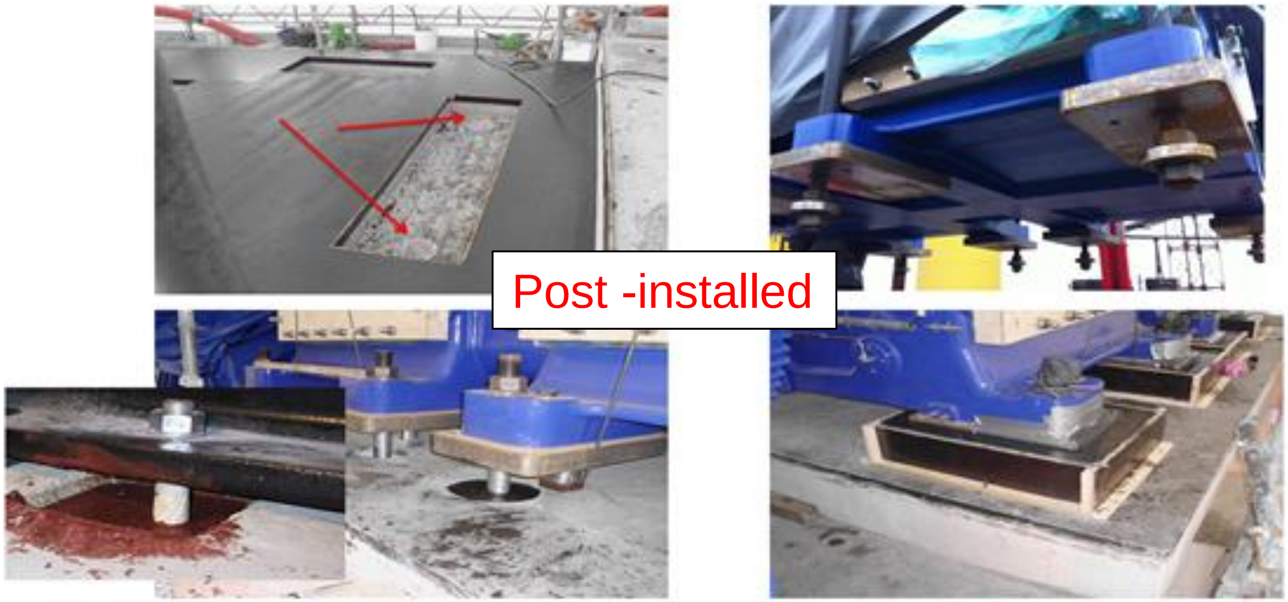




Cone failure for tension

Anchor bolts

Pre-installed versus post-installed



Anchor bolts

Bolt Material and Preload

Materials	standard	Grade 8.8	A193 B7
Minimum specified Yield strength (Mpa)	300	640	724

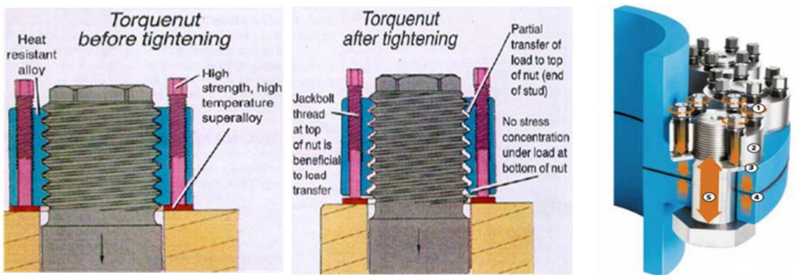
- Bolt preload:
  - Is defined as a % of the minimum specified yield strength
- Factors to be considered:
  - Calculations are based on the tensile stress only.
  - Applied tools determine the total stress (torque, shear, tensile)
  - Fatigue stress range which is determined by the pre-stress.
  - Local stresses in the concrete, chocks and plates
  - Bolt sizes.
  - Stress intensification and corrosion.

Bolt Tightening (torque-tension)

- Calibrated manual torque wrench or hydraulic torque wrench:
  - introduction of torsional loads
- Hydraulic jack or the use of special nuts (preferred):
  - no torsional load on and torsional deformation of the anchor bolt during tightening

Manual torque wrench

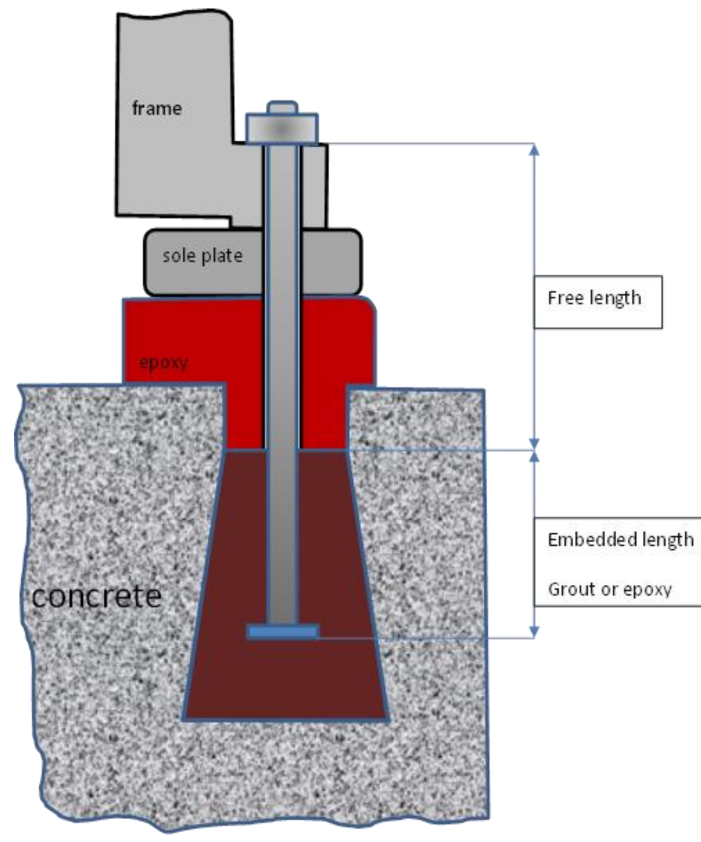
Working principle of a hydraulic nut



Multi bolt tensioner principle

Bolt Length: free, embedment

- **Free length:** length of the bolt which is not bonded to the concrete or grout
  - necessary to permit proper elongation during bolt tightening to reduce the cyclic stress in the bolt
  - provide clearance to allow thermal expansion of the frame
  - ≈ 250 mm for bolts with a diameter <1”
  - ≈ $12xD_{bolt}$ for bolts with a diameter ≥ 1”
- **Embedment length:** length which is encapsulated by the concrete/grout
  - ≈ 200 mm for bolts with a diameter <1”
  - ≈ $12xD_{bolt}$ for bolts with a diameter ≥ 1”

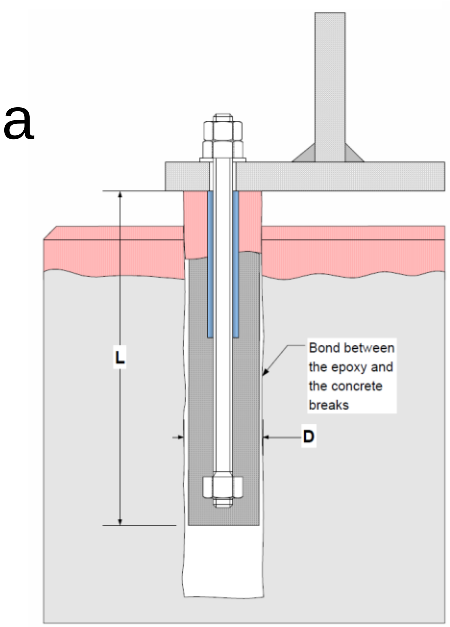


Bolt pockets (size and bond strength)

- Pocket size and depth must be large enough to accommodate the tension to avoid anchor pull out
- Bond strength between epoxy-concrete is larger than the tensile strength of concrete
- Allowable shear stress for calculations: 0.8 MPa

Square pocket

Cylindrical pocket



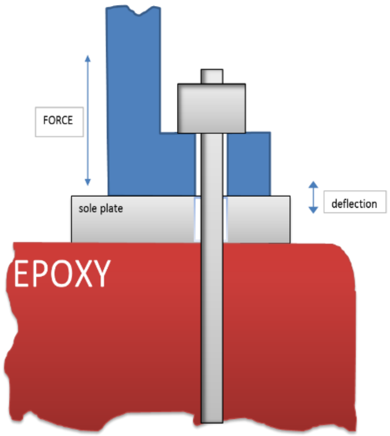
Anchor pull out

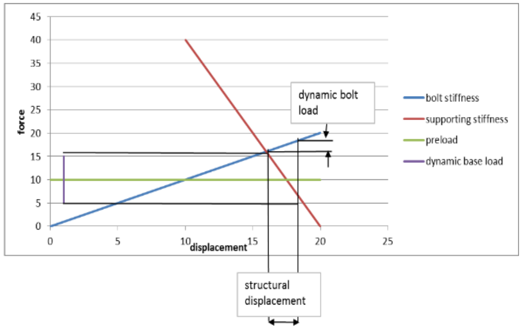
Fatigue and Thermal Expansion

- Fatigue of bolts shall be avoided
- Cyclic bolt stress can be reduced by preloading the bolt
- Bolt shall be more flexible (long bolts) than foundation structure (concrete)

Bolt fatigue

Bolt length extensions

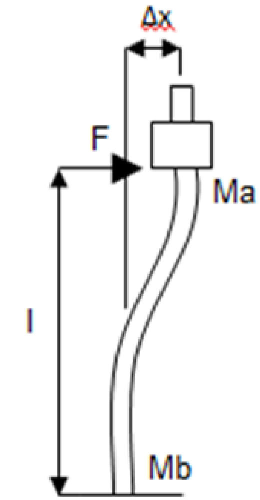




Joint stiffness diagram

Effect of Thermal Expansion of Frame

- The shear force acting on a bolt due to frame expansion depends on:
  - the diametrical bolt clearance
  - free bolt length
  - coefficient of friction.
- The required radial clearance can be calculated
- as follows:



$$\Delta x = \frac{Fv \cdot l^3}{12 \cdot E \cdot J}$$

Δx= bolt deflection caused by frame expansion (m)
F_v= bolt preload (N)
L = free anchor bolt length (m)
E = bolt Young's modulus (N/m^2)
F = friction between bolt nut and soleplate/grout/concrete