EFRC Training Workshop Foundation design for reciprocating compressors

Anchor Bolts Design Considerations Harry Lankenau, NEAC Compressor service



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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





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.

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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}



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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





from GMRC Technical Report TR97-3 [2]





- F_{e} deadweight (N)
- $F_{\rm h}$ required bolt preload (N)
- F_{f} minimum required friction force(N)
- M friction coefficient (-)
- A design factor (-)

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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



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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

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Anchor bolts Pre-installed versus post-installed

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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.

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• 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):

Manual torque wrench

 no torsional load on and torsional deformation of the anchor bolt during tightening

Working principle of a hydraulic nut

Multi bolt tensioner principle

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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"

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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

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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

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.

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

- The required radial clearance can be calculated
- as follows:

 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/m²)
- F = friction between bolt nut and soleplate/grout/concrete

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