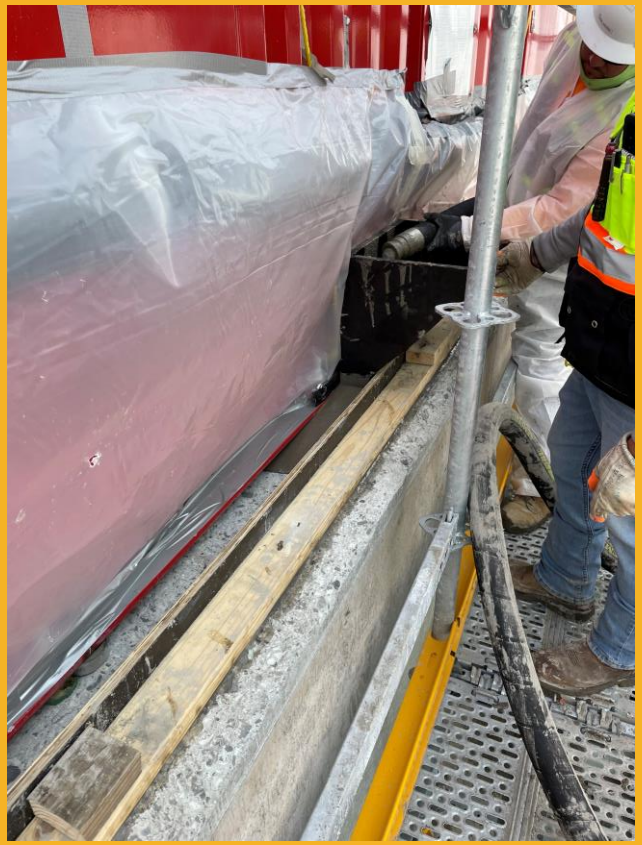
PRINCIPLES OF GROUTING CRITICAL EQUIPMENT



CHRIS HARDY
DISTRICT MANAGER

BUILDING TRUST

INTRODUCTION

20 years of industrial and commercial concrete experience

Concentration in civil construction, grouting, and infrastructure repair/restoration

COAST

MASTER® BUILDERS SOLUTIONS

structural

A Structural Group Company

Sika®

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SIKA GROUT HISTORY & COMMITMENT

- Over 100 years of experience, innovation, & expertise
- A dedicated team supporting a full range of solutions to the Power and Industrial Sector
- Inventor of non-shrink cementitious grout and epoxy grout
  - Developed first non-shrink, cement grout in the 1920's
  - Introduction of MasterFlow epoxy grouts in the 1950's laid the foundation for stable equipment infrastructure

MASTER® BUILDERS SOLUTIONS

Sika®

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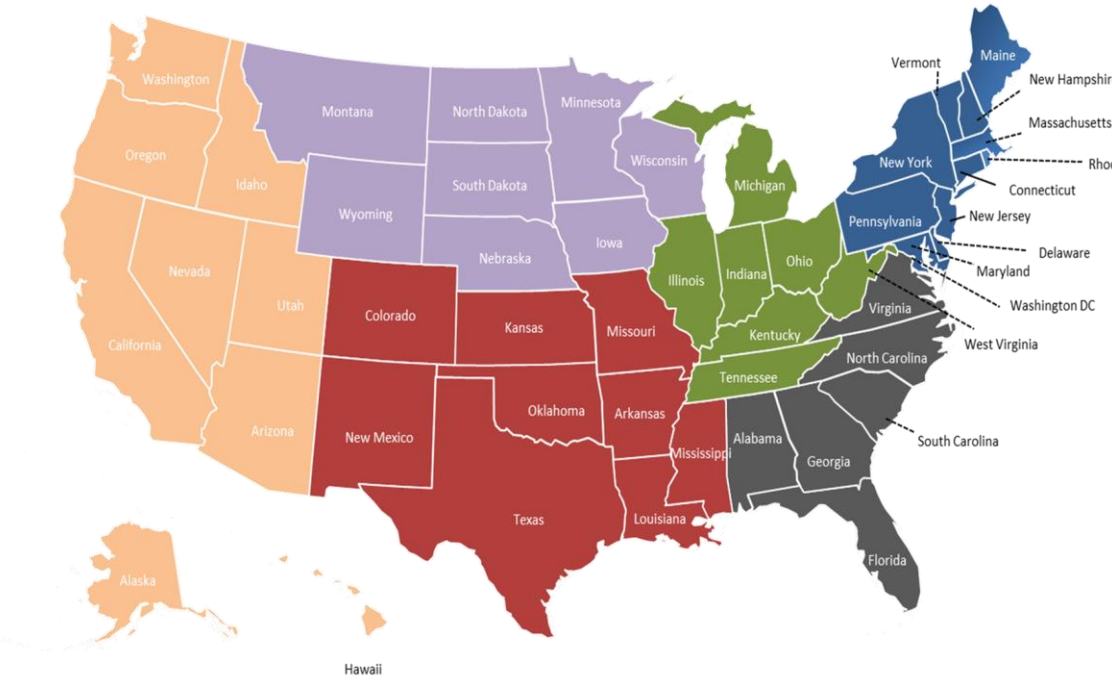

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DISCUSSION TOPICS / AGENDA

What is Grout?

Why is Grout Used?

Types of Grouts

The Equipment Foundation System *(the elements and how they work together)*

Grout Selection & Properties

Preparation, Proper Mixing, Installation, & Testing of Grout

Case Studies

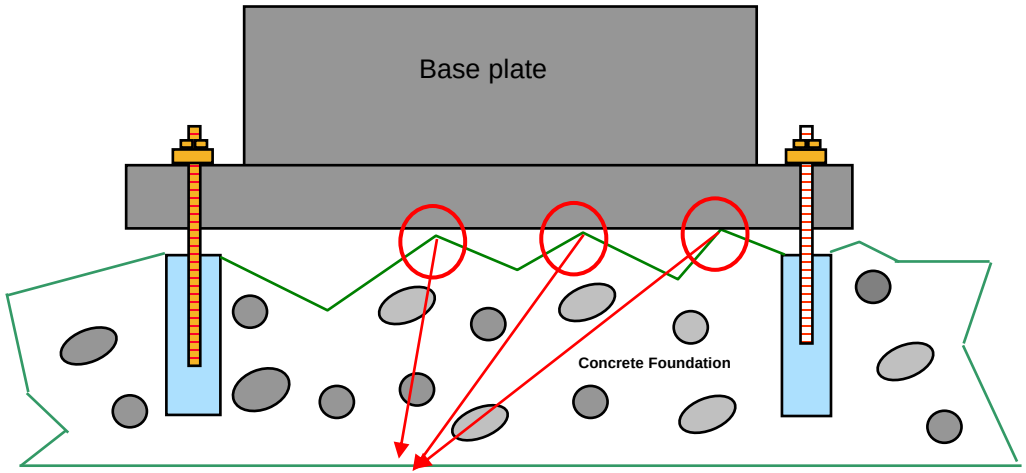
WHAT IS GROUT?

- Grout (governed by ASTM C1107) is defined as a material composed of hydraulic cement, fine aggregate, and other ingredients intended to be used **under an applied load where changes in height below the initial placement height are to be avoided.**

WHY IS GROUT USED?

Why not drill and fix plates directly to concrete foundations?

- Uniformly transfer load to foundation
- Resist applied forces
- Irregularities between foundation and plate
- Fill voids, keep them full, remain durable



Uneven concrete foundation leads to poor support and probable failure due to extreme loads at contact points

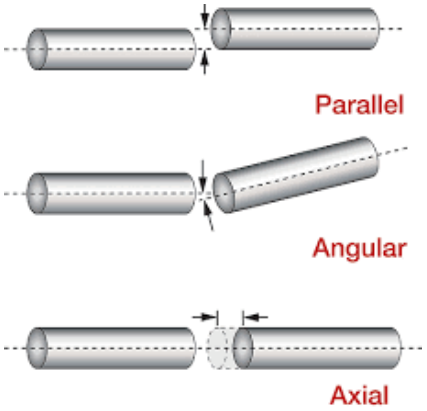
CAUSES OF EXCESSIVE VIBRATION IN EQUIPMENT

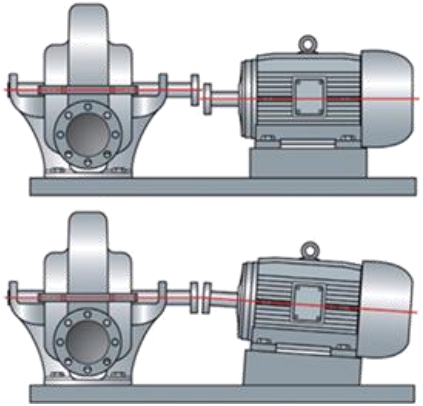
Misalignment and induced vibration:

- Poor alignment during install
- Misalignment from wear and excess vibration of internal components (unbalanced/high pulsation)
- Grout (or lack thereof) induced misalignment

Types:

- Parallel
- Angular
- Axial





EXCESS VIBRATION

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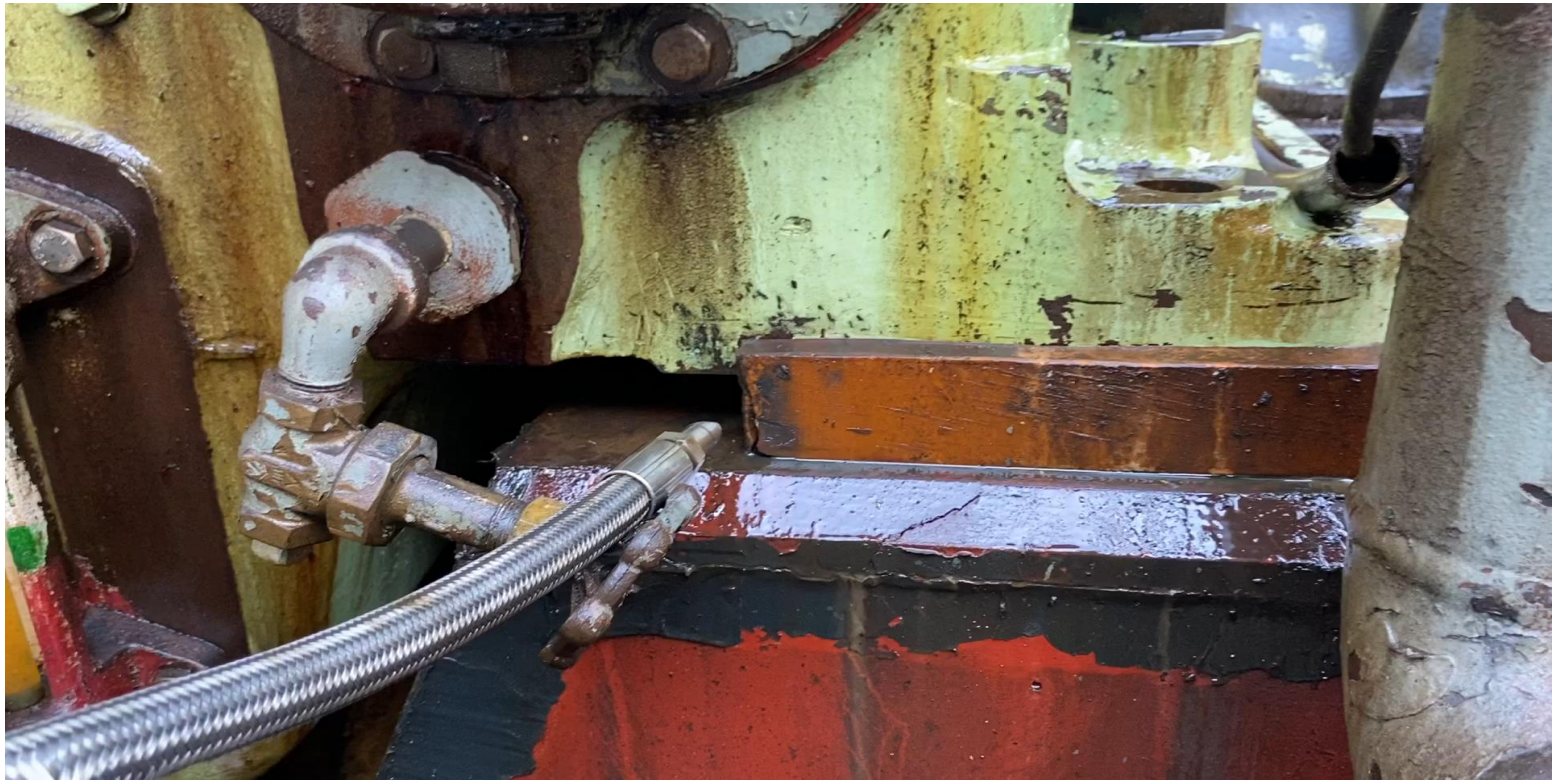
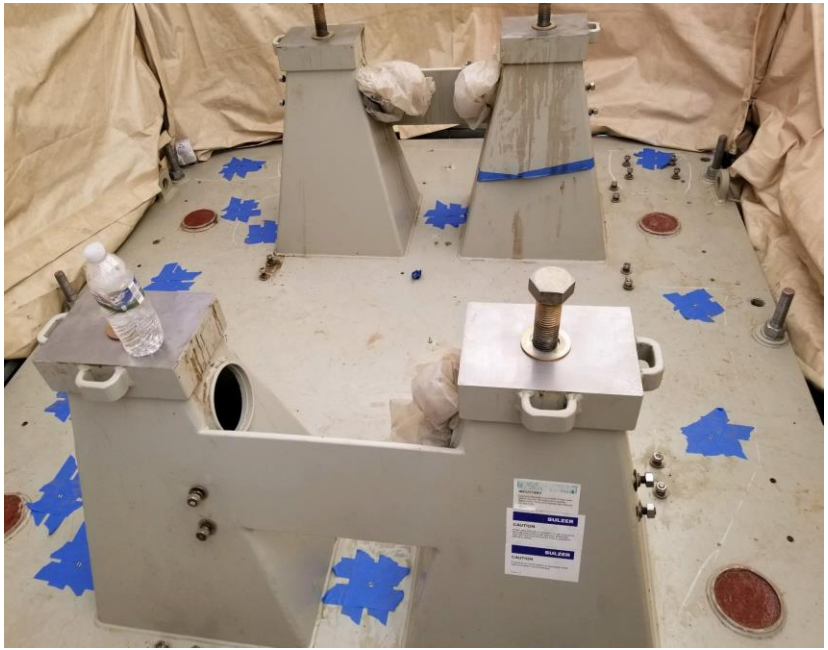


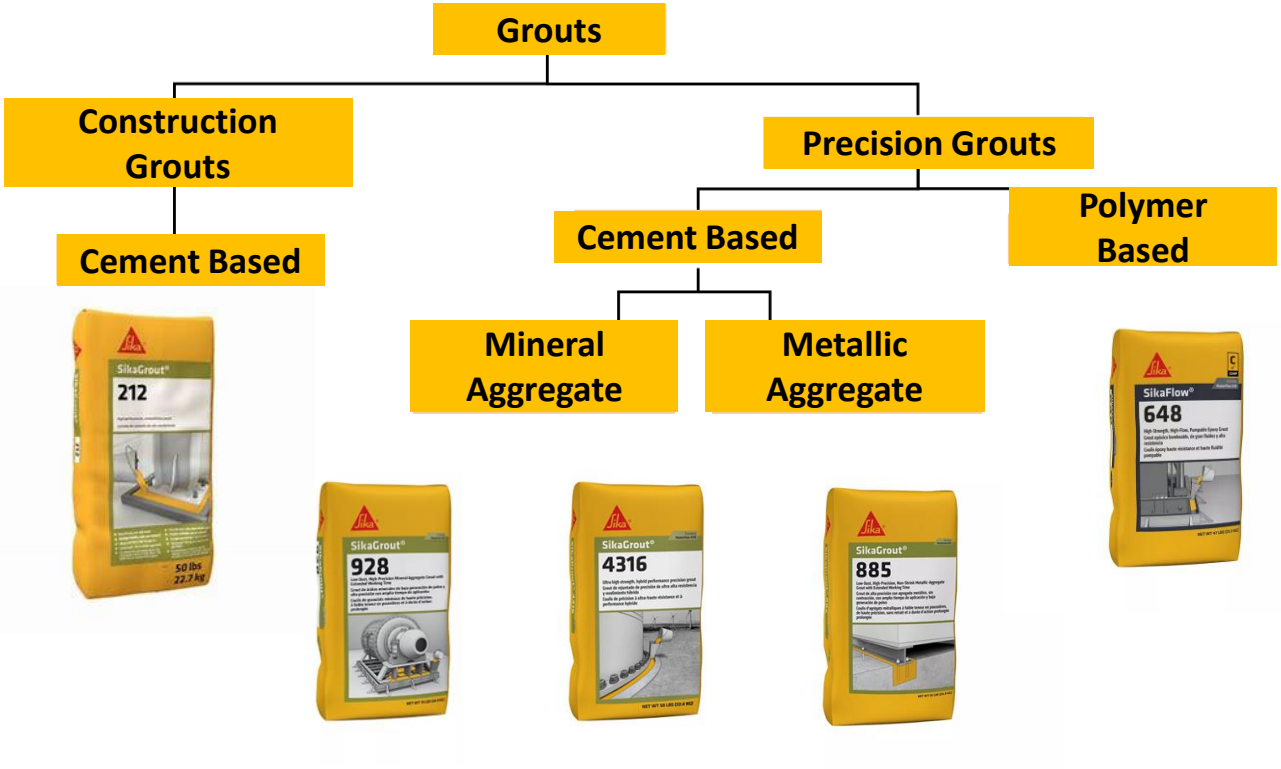
WHY IS VIBRATION IMPORTANT TO AN OWNER?

- Excess vibration can cause premature wearing of critical components and reduce MTBF
- Safety
- Facility Maintenance strategies
- Set up based on two types of costs:
  - Repair costs
  - Production downtime costs



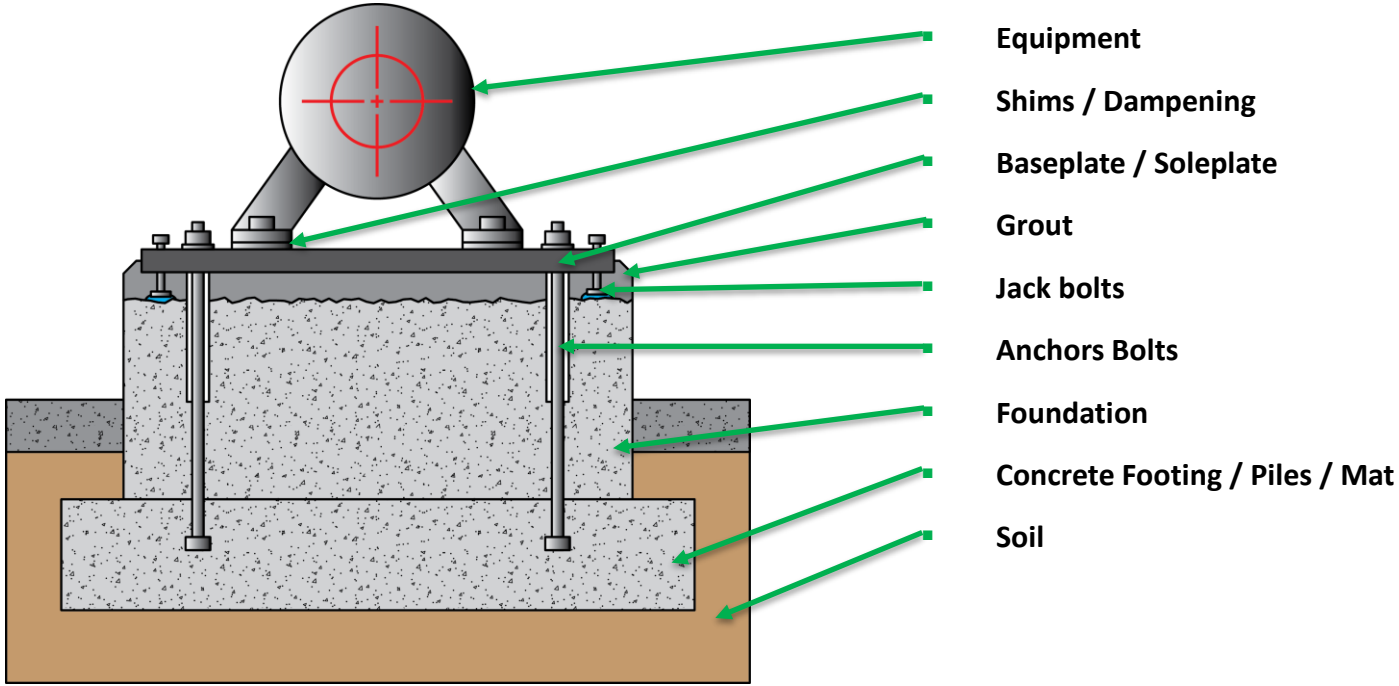
TYPES OF GROUT

- **Precision Non-Shrink Grout**
  - Cement based grout, volume change well defined, versatile Use
- **Metallic Aggregate Grouts**
  - Cement based grout, impact resistant, high temps, steel mills
- **Hybrid Grouts**
  - Cement based, very high strength
- **Epoxy Grouts**
  - Developed in the 1960's, dynamic loading and vibration damping

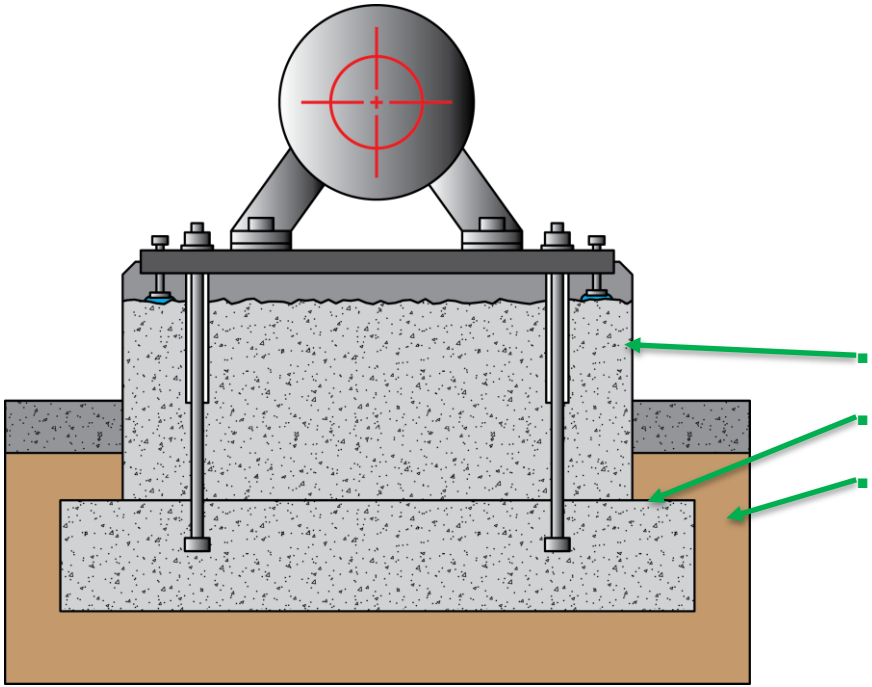


EQUIPMENT FOUNDATION SYSTEM

Transfer static/dynamic loads, vibration, impact and rotational torque from equipment, through the grout and into the foundation to maintain alignment and limit wear and tear on machinery parts



THE FOUNDATION



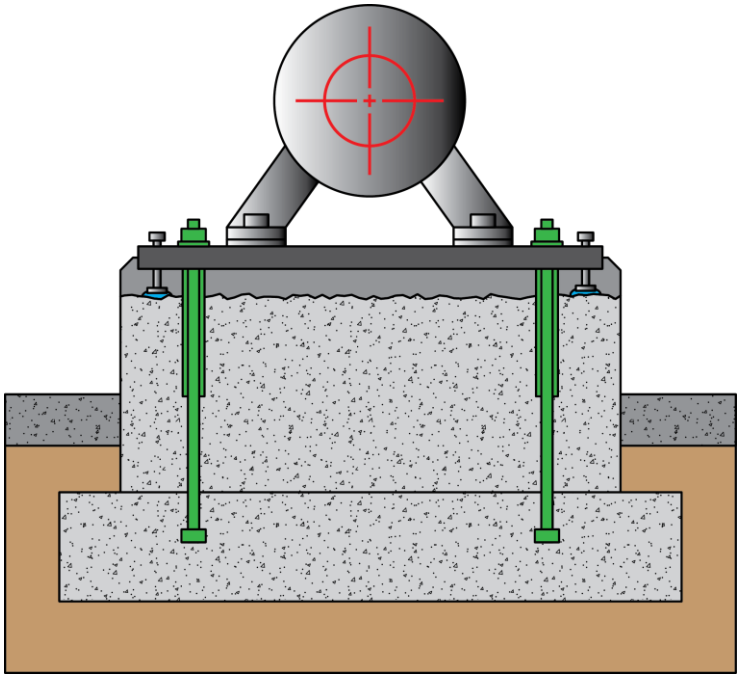
Reinforced Concrete Foundation Block

Concrete Footing / Piles / Mat

Soil

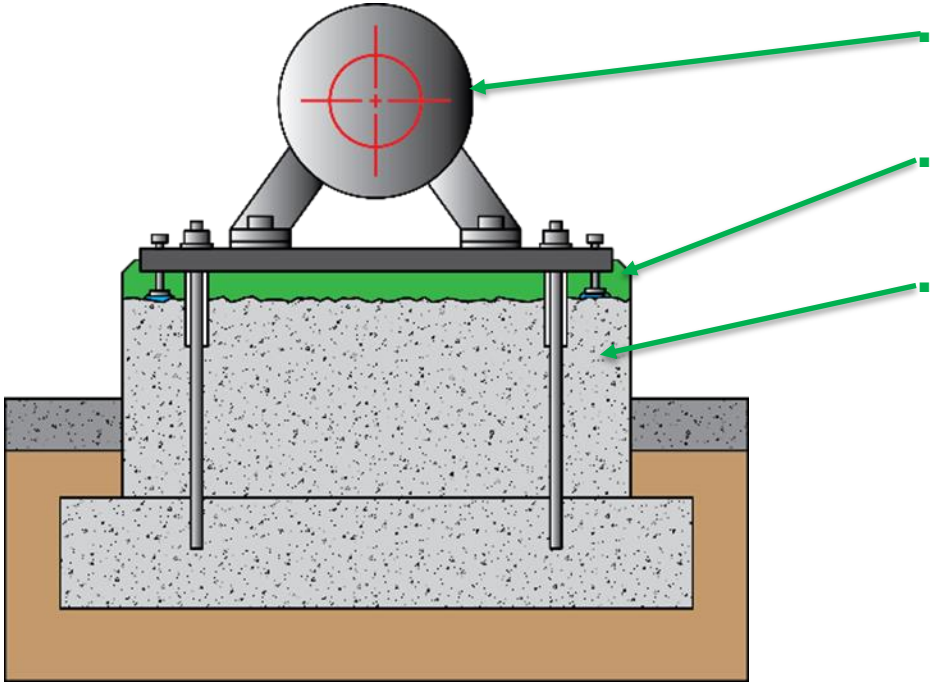
ANCHOR BOLT PURPOSE

- **Attach equipment firmly to the foundation**
  - Stretched elastically like a spring
- **Transmit loads from equipment to the foundation**
  - Just as important as grout
  - Grout – prevents downward movement
  - Bolt – prevents upward movement
- **Resist horizontal forces**
  - Must be placed under sufficient tension (thru stretching of bolts) to resist horizontal forces acting against the bolt
- **Anchor bolt "system"**
  - Bolt or stud, nuts and washers
- **Technology improvements**
  - GMRC Research



THE VITAL LINK

"Bridging Structural Engineering with Mechanical Engineering"



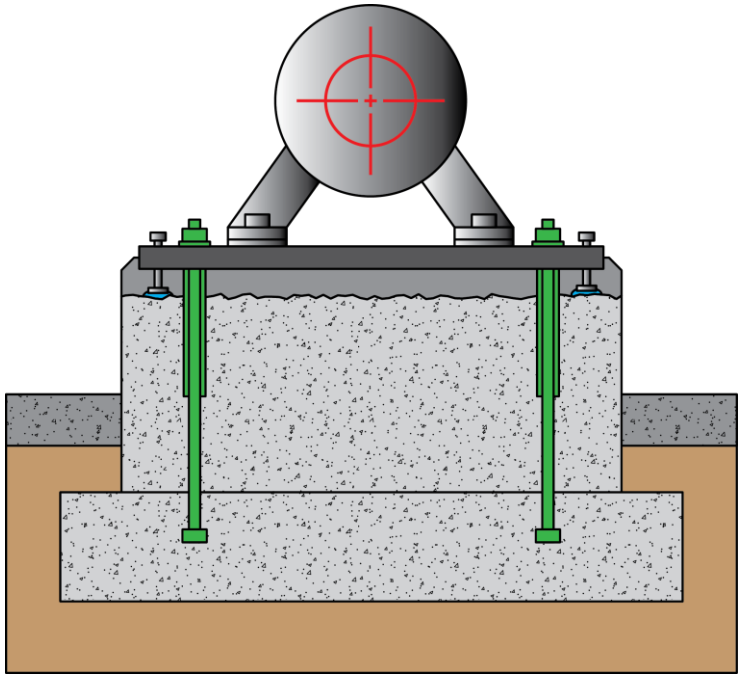
Equipment (Mechanical Engineering)

Grout (The Vital Link)

Foundation (Structural Engineering)

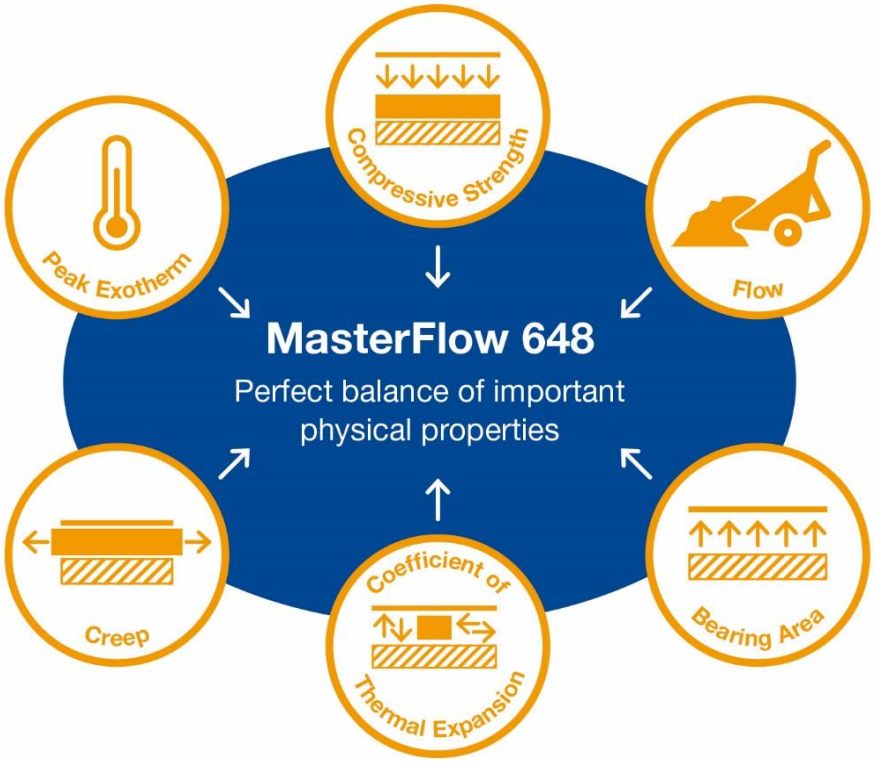
GROUT PURPOSE

- **Fills space between equipment and concrete foundation**
  - Fills irregularities / voids between concrete and plate
- **Maintains proper original alignment over life of machine (20+ years)**
- **Contains or absorbs unbalanced forces into foundation without excessive equipment movement**
  - Concrete alone cannot transmit forces
- **Minimizes machinery wear**



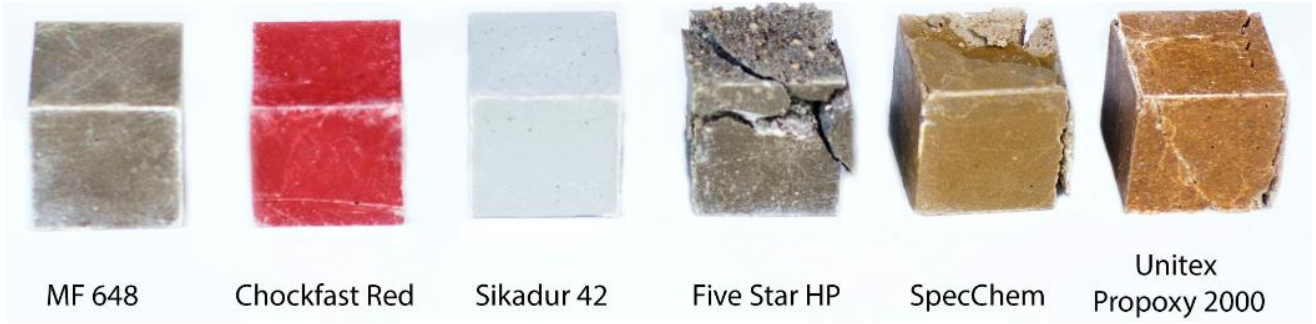
Equipment, grout, foundation, earth = one <u>system</u>

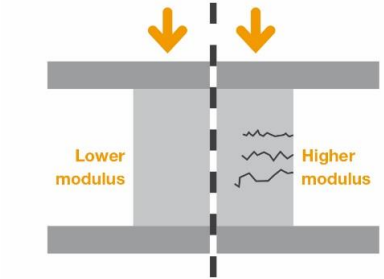
GROUT SELECTION – BALANCE OF PROPERTIES



COMPRESSIVE STRENGTH COMPARISONS

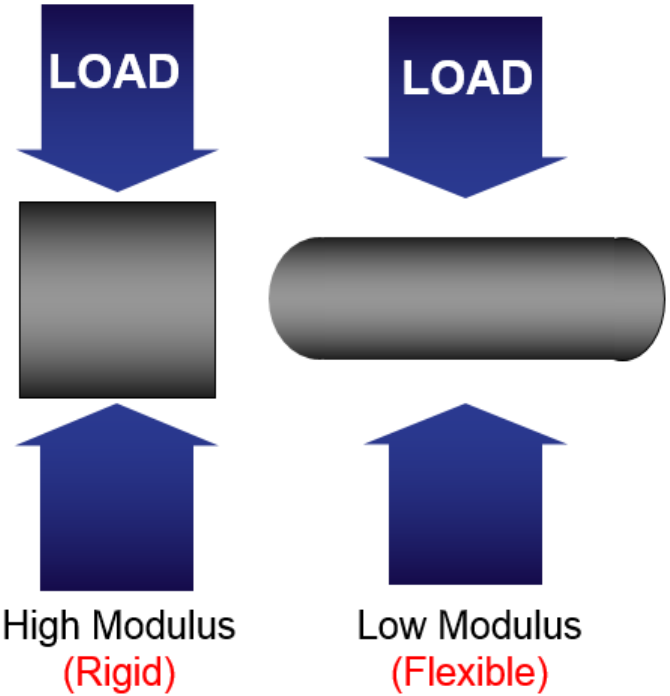
Good ductility = good cube shape under testing; doesn't shatter or fracture; not too brittle





HIGH MODULUS / LOW MODULUS

- ASTM C 580
- Measures the ability of the grout to resist deflection under load
- Lower modulus than concrete
- Ability to withstand dynamic loads
- Too low of a modulus can result in a higher potential for creep



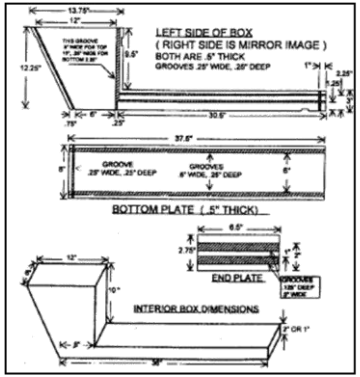
CREEP

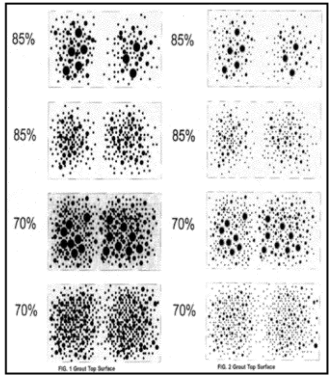
- **ASTM C1181**
  - **Measure the total compressive deflection under a sustained load**
- **Creep is defined as a permanent deformation occurring at a stress less than the yield stress.**
- **Comparisons can only be made under same load and temperature conditions**
  - Specifications should include both
- **Critical performance indicator**
  - High creep can cause deflection in baseplate, affecting machinery alignment and premature failure of rotating parts

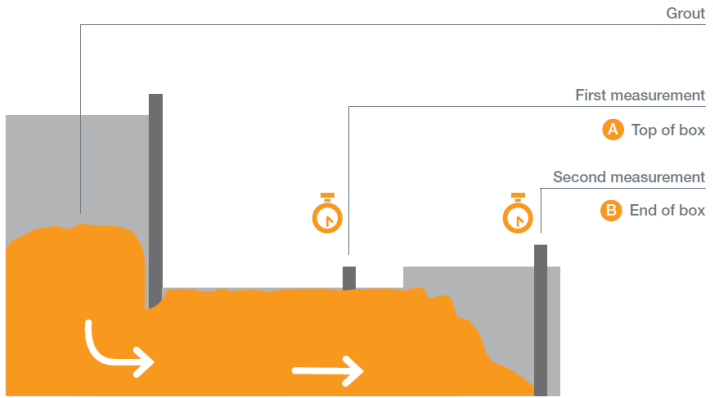
FLOWABILITY, BEARING AREA

- **ASTM C1339 (flow box testing) - Flowability and Bearing Area**
  - Measures flow time and ability to flow under and across full dimension of equipment
    - Using aggregate content specified by manufacturer per test results
    - Note: Bearing area is compromised when contractors remove aggregate in field to provide better flow

- **Estimated 10-15% of vibration issues are due to poor grout bonding**







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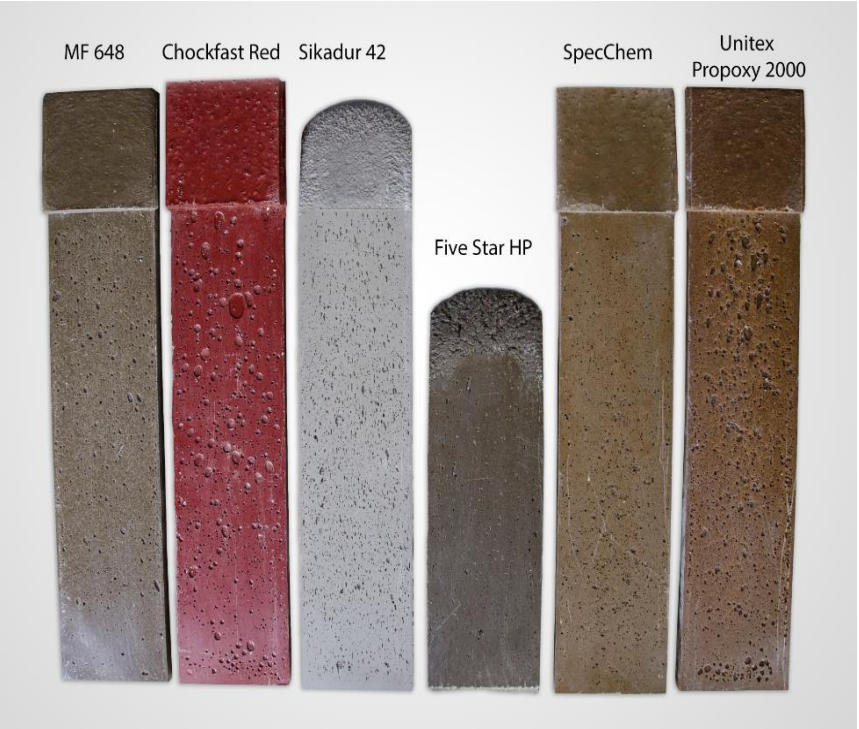
GROUT BOX FLOW TEST VIDEO

FLOW BOX VIDEO – GROUT COMPARISONS

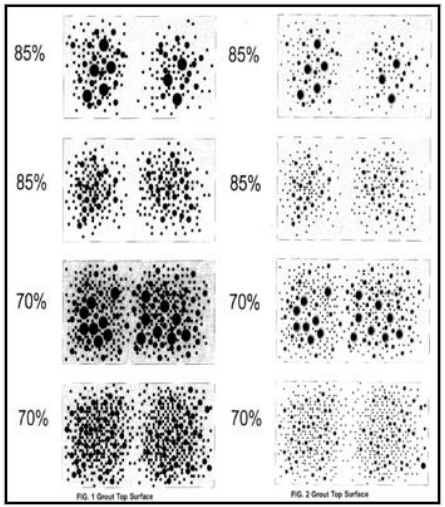
BEARING AREA – GROUT COMPARISONS

- **Visual bearing area after 16 hours in mold after flow test** – shows what is hidden in the field under steel!



BEARING AREA – QUANTIFIABLE TEST METHOD

- Remove plexiglass plate
- Wire brush grout sample
- Dust surface with white talc powder
- Photograph and scan
- Computerized histogram
- Covert scan to black and white
- Calculate percentage of light vs. dark areas
- **MasterFlow 648 > 95% contact (best performance of any material tested)**
  - % of grout actually supporting the baseplate



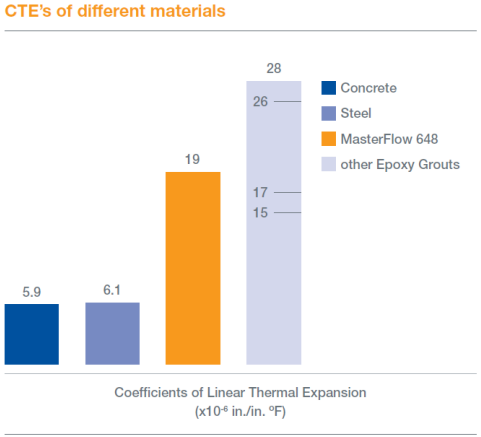
BEARING ARE ISSUES

- **Large aggregate at top of grout cap can serve as barrier between epoxy and steel**
  - Causing poor bonding
- **Voids can be caused by material, mixing, placement, excessive flow**
  - Outgassing evident in red photo
  - Air migrates to grout surface
- **A highly flowable grout may have higher polymer content and reduced aggregate**
  - Could cause shrinking, cracking because aggregate serves as heat sink and stabilizer
  - Less aggregate reduces ultimate strength of cured grout foundation

COEFFICIENT OF THERMAL EXPANSION

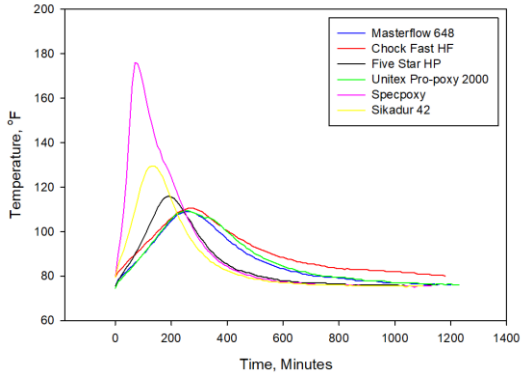
- **ASTM C 531**
  - Standard Test Method for Linear Shrinkage and CTE of Polymer Grouts
- **Measures the volume change of a material**
  - Shrinkage or expansion after hardening or as in-service temperatures increase and decrease
- **Grout, baseplate, and concrete have different CTE values and volume changes**
  - Shear stress near the concrete / grout interface exceeds the tensile strength of the concrete
  - Can cause cracking, curling (edgelifting), loss of bond

Concrete	Steel	MasterFlow 648	Other Grouts
5.9	6.1	19	>28



PEAK EXOTHERMIC REACTION

- **Maximum temperature that grout reaches during cure**
- **Differences between peak exotherm and foundation, ambient temperatures:**
  - Localized stress at bolts and bond lines, causing cracks
- **High and fast reaching peak exotherm of material can lead to brittle material and stresses**
  - Vertical cracking, Edge-lifting



Desired: Grout with low PE and gradual temperature increase, rather than rapid temperature spike allows for the dissipation of stresses that occur during curing

PROPER MIXING, INSTALLATION, & TESTING

- **Temperature Conditioning**
  - Material, foundation, and equipment ideally at 60˚F to 80˚F for 48 hours prior to and after grouting (per API 686)
  - Too cool - affects grout flowability, strength gain
  - Too hot – increases cure, material working time
- **Protective cover**
  - Wind, rain, temperature
- **Humidity, ambient and material temperatures can affect stresses locked into grout during curing**

FOUNDATION PREPARATION FOR GROUT

- **Clean, non-contaminated surface**
  - Surface profile per API guidelines
  - Exposed, fractured coarse aggregate
  - Removed oil-soaked, damaged concrete
    - Preferred chipping tools
  - Unlike concrete, epoxy won't bond well to a wet surface
- **Chamfered perimeter of concrete**
  - And/or use of anchors, wickets to resist edge lifting
- **Properly cleaned / coated baseplate**

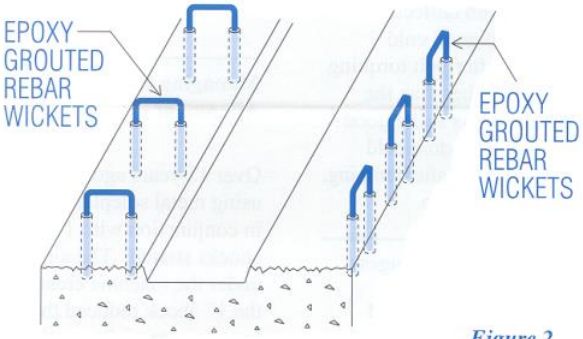
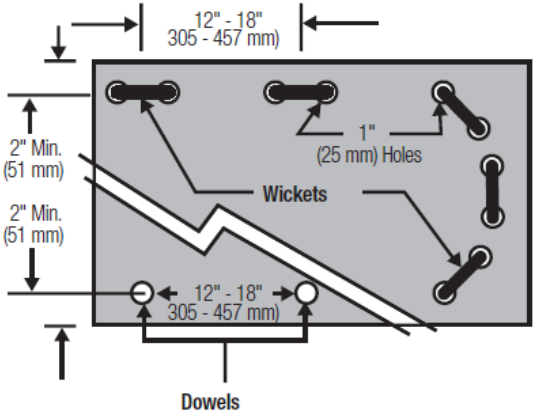


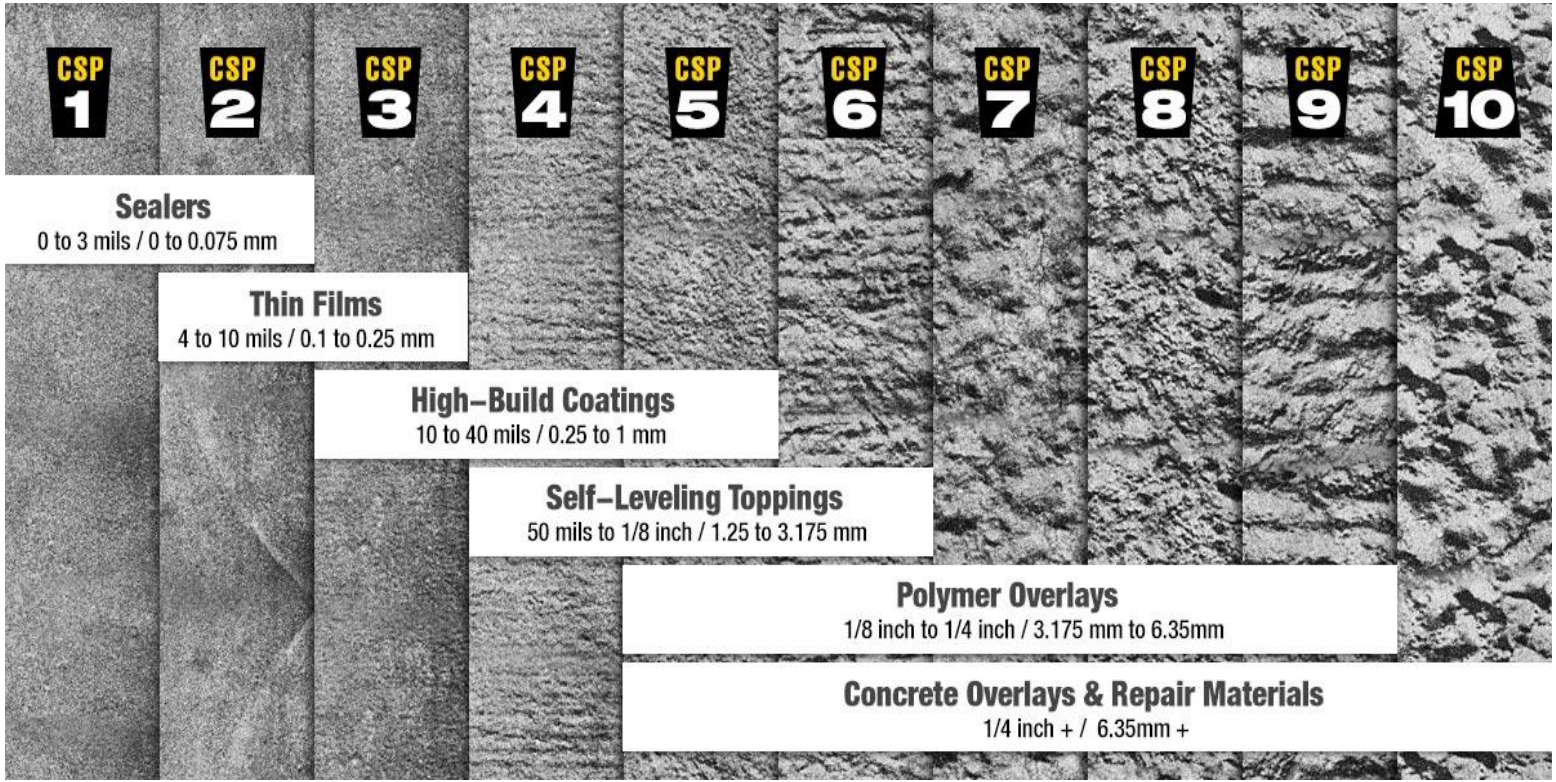
Figure 2

EDGE OF SLAB DETAIL

- Avoid placing grout to edge of slab when possible
- Limit shoulder to 2” width and apply protective coating per API 686 Chapter 5, Section 3.15.6
- If grout shoulder extends at or beyond the top mat of the horizontal and vertical rebar of the foundation:
  - Chamfer the edge of the concrete 2” at 45 degrees
  - Install wickets using #3 bar with a 5” hoop every 12” on-center embedded 3” – 4” below and behind the top mat of the horizontal and vertical bar
  - ¾” minimum clearance under wicket hoop with minimum 1” of epoxy grout cover



CONCRETE SURFACE PROFILE – INTERNATIONAL CONCRETE REPAIR INSTITUTE (ICRI)



FOUNDATION – API 686 SURFACE PREP

- **Clean, dry, sound**
- **1” (25mm) CSP**
- **No bush hammers**

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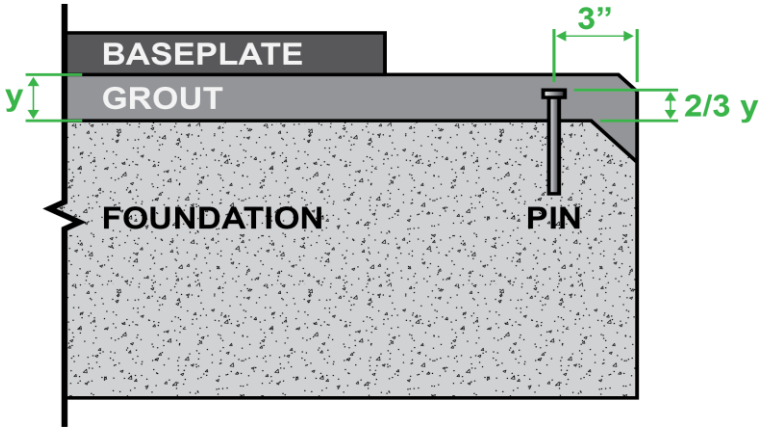
LIQUID SURFACE ETCHANT

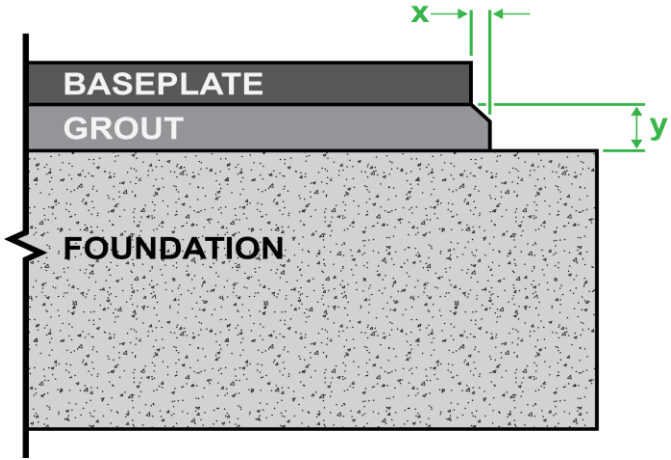
LIQUID SURFACE ETCHANT

GROUT TERMINATION DETAILS



Large Shoulders

- Large shoulder width pinning or use of wickets to secure epoxy grout



Small Shoulders

- Dimension X less than Y, shoulder width less than epoxy grout depth

BASEPLATE & SOLEPLATE PREPARATION

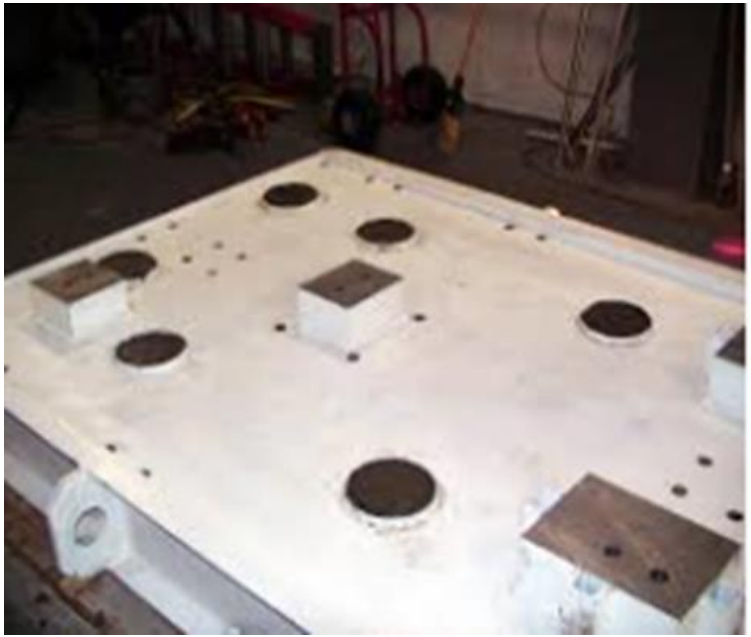
- **Proper radius on outside corners**
  - Prevent cracking due to stress concentration
- **Machined top surfaces**
- **Sandblasted bottom surface if exposure time to elements is short**
  - Otherwise, epoxy primer approved by grout manufacturer can be used, but surface should be roughened and wiped with solvent before grouting
- **Pre-grouted baseplates are acceptable for pumps but they add weight**
  - Acceptable depending on base size and accessibility

EQUIPMENT BASES – API 610

- Equipment shall be designed and constructed for a minimum service life of 20 years and at least 3 years of uninterrupted operation
- Excluding normal wear parts, i.e. wear rings, shaft sleeve, gaskets
- Single-piece drain-rim or drain-pan shall be furnished for all horizontal pumps
- Baseplate shall extend under the pump and drive-train components so that any leakage is contained within the baseplate

EQUIPMENT BASES – API 610

- All baseplates shall be provided with at least one grout hole having:
  - Clearing area of 125 cm^2(19 in^2)
  - No dimension less than 75 mm (3 in) in each bulkhead section
- Grout holes shall be located to permit filling entire cavity under the baseplate without creating air pockets
- If practical, holes shall be accessible for grouting with pump and drive installed on the baseplate
- Grout holes in drip-pan area shall have 13 mm (1/2”) diameter raised lip



EQUIPMENT BASES – API 610

- Vendor shall commercially sand-blast all grout contact surfaces of the baseplate, and coat those with a primer compatible with the grout
  - Inorganic zinc coatings are at times applied too thick, which can make them brittle and leads to chipping, scuffing and separation

- If specified, the baseplate shall be supplied without a deck plate, i.e. open skid design

ANCHORING

- **Anchor bolt sleeves are clean, dry, fill with nonbonding material**
- **Anchor bolt threads should be covered to:**
  - Keep them clean
  - Prevent damage
  - Prevent grout from adhering
- **Assure anchors are aligned with bolt pattern**
  - Lateral movement for alignment purposes shall next exceed ¼”
- **Shims and wedges are not to be used**

EXPANSION JOINTS

- Incorporated into large epoxy grout pours to reduce the potential of cracking
- Reduce epoxy grout volume which reduces exothermic reaction temperature
- **Breaks up the epoxy grout pour into smaller pours:**
  - Reduce epoxy grout volume which reduces exothermic reaction temperature
  - Increased likelihood of successful grout installation

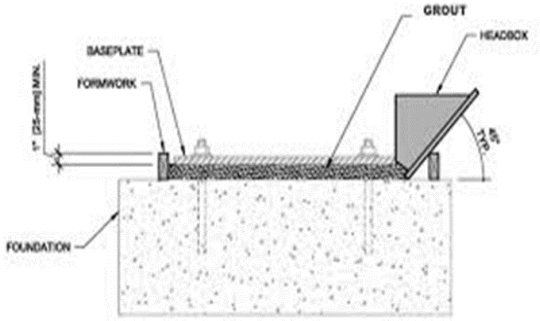
EXPANSION JOINTS

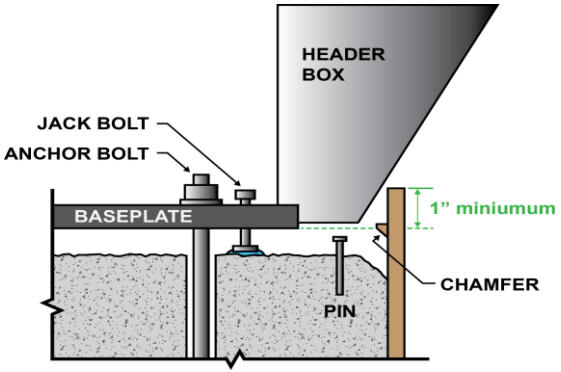
- Closed-cell neoprene foam ½” (13mm) to 1” (25mm) wide
- Placed every 4’ (1.2 meters) to 6’ (1.8 meters) intervals
- Placed ½ (13mm)” to 1” (25mm) to either side of the cross members
- Away from anchor bolts
- Glued into position with epoxy adhesive or RTV silicone
- Sealed after grout has cured with epoxy seam sealant or RTV silicone

EXPANSION JOINTS

GROUT PLACEMENT FORMWORK

- **Sturdy and suitable materials**
  - Well braced to resist grout pressure
  - Accessible, watertight, non-absorptive
- **Sufficient clearance (2’’-3’’) from baseplate**
  - For grout placement, air escape
- **Bond breaker for epoxy grouts**
  - To prevent grout bonding to forms
- **Sealed to prevent grout leakage**
- **Chamfered shoulders, corners**
  - 1’’ at 45° to remove weak edges prone to cracking





GROUT PLACEMENT PREPARATION

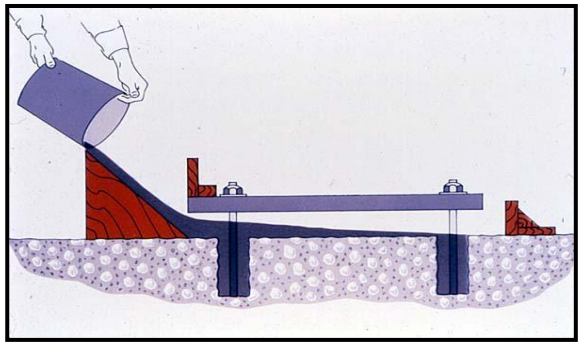
- ***Proper equipment and sequence of operations is critical to success***
  - Mixing equipment / time
  - Transportation and filling methods
  - Movement tools
  - Avoidance of air bubbles
  - Flow direction / rate, head pressure
    - Pour from one side to other, or from middle in both directions
    - Maintain continuous head pressure
  - Temperatures
    - Ambient, material, water, plate, foundation

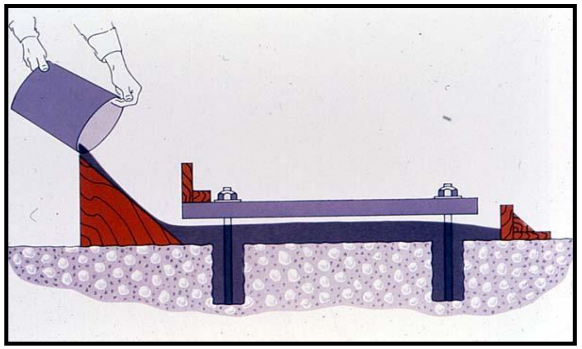
MIXING – API 686

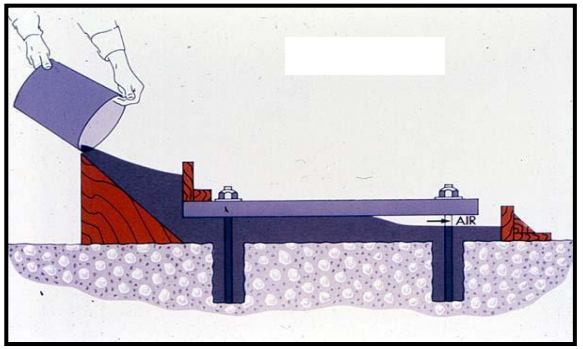
- No partial units of epoxy, resin, hardener, OR aggregate are to be used
  - Fully loaded aggregate grout systems only
- Resin and hardener are to be mixed with a jiffy mixer
- Mortar mixer used to blend epoxy and full bags of aggregate
- Aggregate must be mixed until completely wet-out
- Do NOT use free fall tumble mixers

GROUT MIXING

INSTALLATION

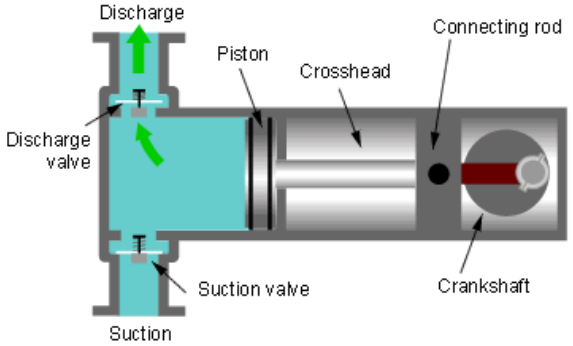


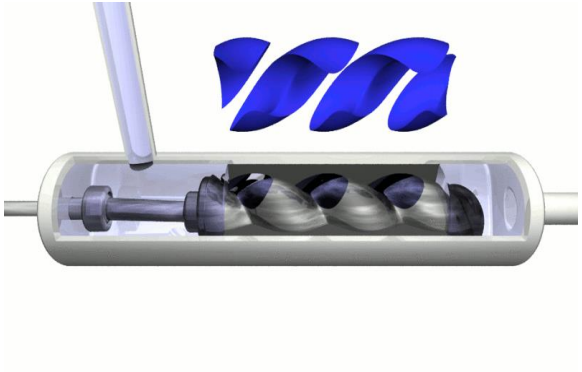


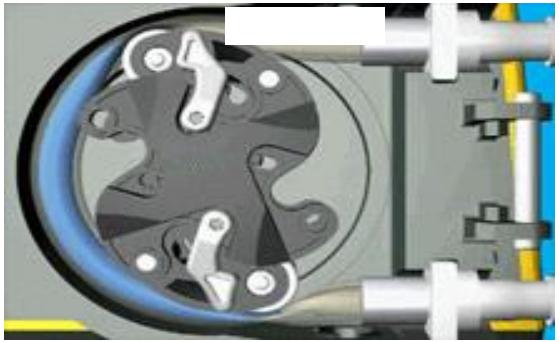


- Place from one side or from the middle out
- Maintain continuous head pressure
- Do not pour around the perimeter of the mounting plate

PUMPING PRECISION GROUTS







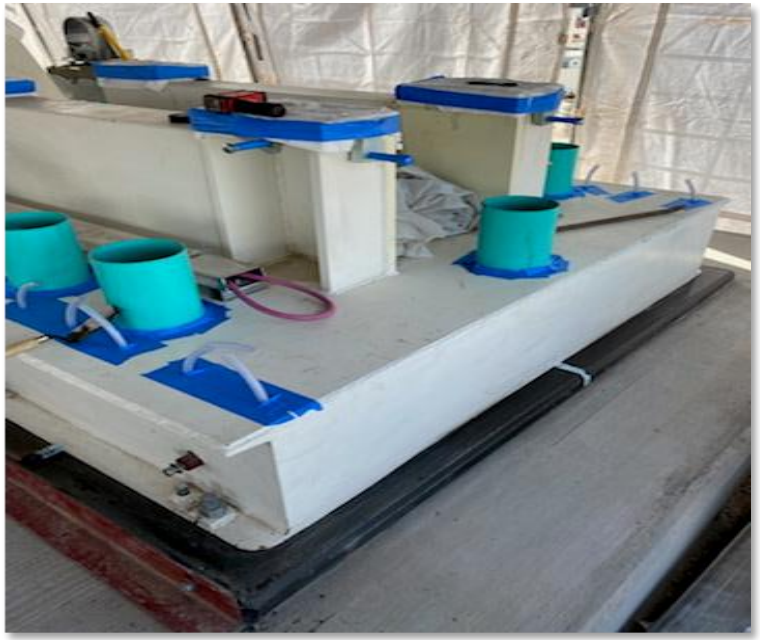
- **Equipment:**
  - Piston
  - Rotor Stator
  - Peristaltic

PUMPING MASTERFLOW GROUTS

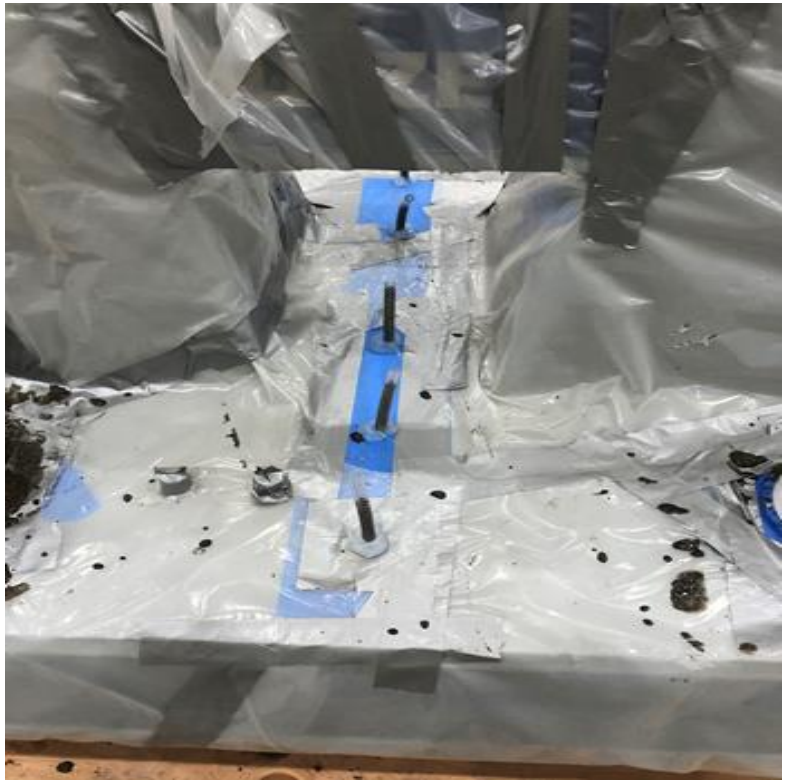
PUMPING MASTERFLOW GROUTS

LARGE SKID GROUTING WITH DEEP CAVITIES

- Lock-in skid to the foundation with initial pour
- Subsequent lifts can be placed after grout has reached peak exothermic reaction
- Overfill skid to account for any settlement



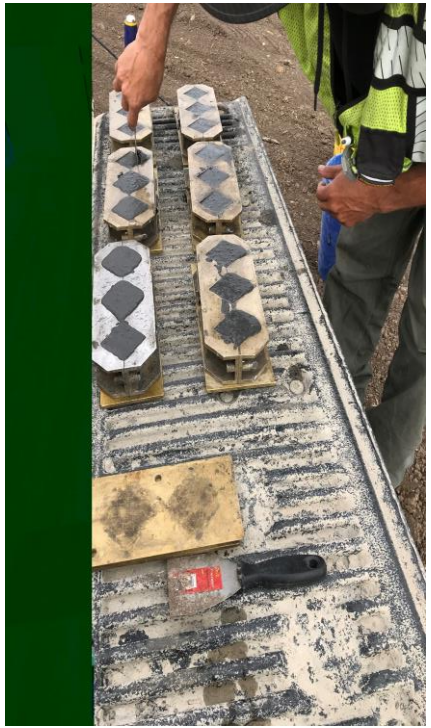
LARGE SKID GROUTING WITH DEEP CAVITIES



COMPRESSIVE STRENGTH TESTING

- **ASTM C 579, Method B, Load Rate II**
- **2” Cubes**
- **Brass Molds or Steel Molds**
- **Ductility =** measure of material’s ability to undergo appreciable plastic deformation before fracture
- **MF648 – high early and ultimate compressive strengths for early commissioning**
  - Ductile, not brittle

COMPRESSIVE STRENGTH – CASTING OF GROUT CUBES



SAMPLE FABRICATION – ASTM C-109 TAMPER PATTERN

Tamping pattern repeated for each of two lifts

1	5
2	6
3	7
4	8

5	6	7	8
1	2	3	4

LOAD CUBES IN TEST MACHINE

- **Verify that:**
  - Spherical seat moves freely
  - Cube will be loaded on two parallel molded faces (not the rough top surface)
  - Upper & Lower loading platens are clean, and perfectly aligned
  - Test machine has capacity to break at expected strengths
  - ASTM C579 Method B, load rate II

BREAK CUBES & RECORD DATA

- Cube is set with cast top surface on side
- Load at a constant rate between 200 - 400 lbs/sec for cementitious grouts
- Crosshead speed of 0.20 – 0.25 in/min for epoxy grouts (2” cubes)
- Load rate will drop as cube begins to yield near failure; do not adjust it
- Continue applying load until cube fails
- Properly prepared & loaded cubes will have an “apple core” failure pattern

WHAT CAN CONTRIBUTE TO LOW STRENGTHS?

Identifying the likely causes for low compressive strength test results

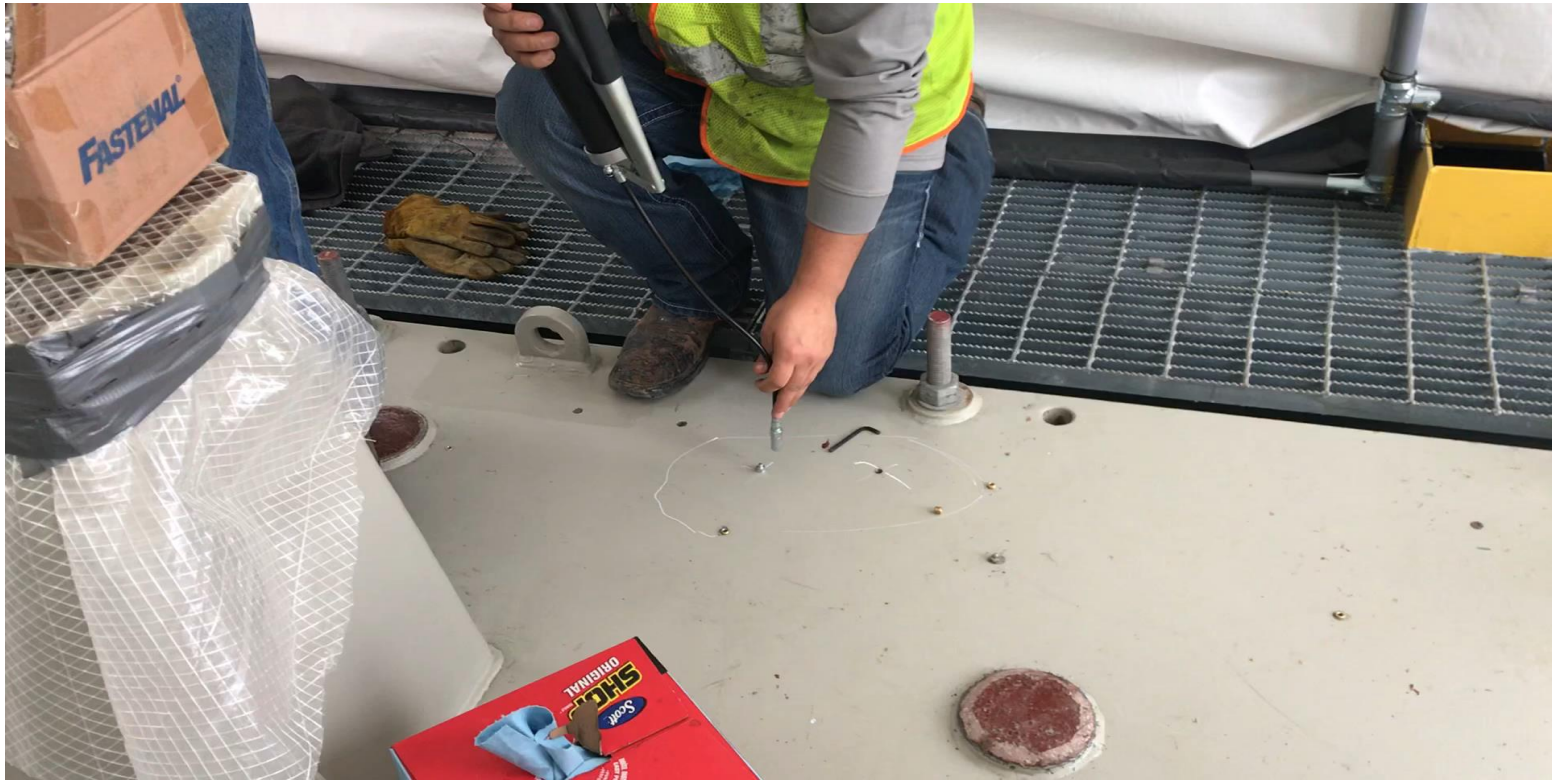
POST GROUTING COATING API 686

- Entire top surface of machinery foundation shall be painted with grout- compatible non-skid protective coating
- Protect foundation cap from oil and weathering
- Coating shall extend down from the top of the foundation at least 18”

FILLING OF GROUT VOIDS – API 686

- After grout has cured, check for voids by sounding the top deck
- **Grout voids should not be accepted as “normal”**
- Mark the void areas
- Void areas are to be filled by drilling NPT 1/8” holes in opposite corners of each void area
- One hole in each void is to be tapped for installation of a NPT 1/8” grease fitting - the other holes serve as vents
- Grout is then pumped into each void with a grease gun until the grout emerges from the vent holes

FILLING OF GROUT VOIDS



METHANOL PLANT IN GULF COAST

Included 6 Flowserve compressors grouted with MasterFlow 678

MASTERFLOW 678 LOW DUST AGGREGATE COMPARISON

PETROCHEMICAL PLANT EXPANSION – GULF COAST

MASTERFLOW 648 LOW DUST COMPETITIVE FLOW BOX VIDEO

MASTERFLOW 648 LOW DUST & COMPETITOR AGGREGATE COMPARISON

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