52ND TURBOMACHINERY & 39TH PUMP SYMPOSIA

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Recommended Mounting of Turbomachinery

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Author Bios

Christopher Matthews-Ewald is the Sr Technical Services Engineer at ITW Performance Polymers, where he provides technical support and guidance on the design and installation of dynamic equipment foundations, as well as training, to engineering, construction, operations, and reliability teams globally in industrial and marine applications. Before this role, Chris provided engineering and operations support for well isolation, abandonment, and completion technologies to the upstream Oil & Gas sector. He holds a degree in Civil & Environmental Engineering from the Georgia Institute of Technology and is a member of the team advising updates for the API Recommended Practice 686 specification.

Ahren Lehner is an Applications Engineer at Techmar responsible for technical inquiries, classroom grout training, and on-site field support. He has assisted in grouting projects for Marathon Petroleum refining and pipeline, British Petroleum (BP) in refining and pipeline, and Cargill to name a few. Ahren is based in Northing Illinois and is originally from a Chicago suburb. He earned a degree in Mechanical Engineering from the University of Tennessee, Knoxville, and is a licensed professional engineer in Illinois. He has been in the construction and industrial industries his entire career.

Robert Barron is a Professional Engineer with Adhesive Services Company in Houston, Texas for Projects and Technical Services. He has demonstrated his technical expertise, professionalism, supervisory, and project management capabilities on numerous projects nationwide for Fortune 500 chemical, oil/gas, utilities, mining, and manufacturing facilities. He has led technical presentations emphasizing the importance of periodic foundation inspections and proper grouting techniques for vibration reduction. Robert acquired his Bachelor of Science degree in Mechanical Engineering from Texas Tech University in Lubbock, Texas, and is a licensed Professional Engineer in the State of Texas.

Abstract

- This tutorial will provide users with detailed information on the proper and recommended methods for the design and installation of foundation systems for dynamic machinery, with a specific focus on the effective usage of epoxy grout. With a strong focus on the Second Edition of API Recommended Practice 686, updated guidance on the current best recommendations will be discussed. It will be intended for equipment manufacturers, civil/mechanical contractors, and individuals responsible for the decision-making or influencing of the requirements for effective machinery installation.

Tutorial Objectives

To provide attendees with an understanding of critical contribution of the foundation system to overall operational efficiency and reliability.

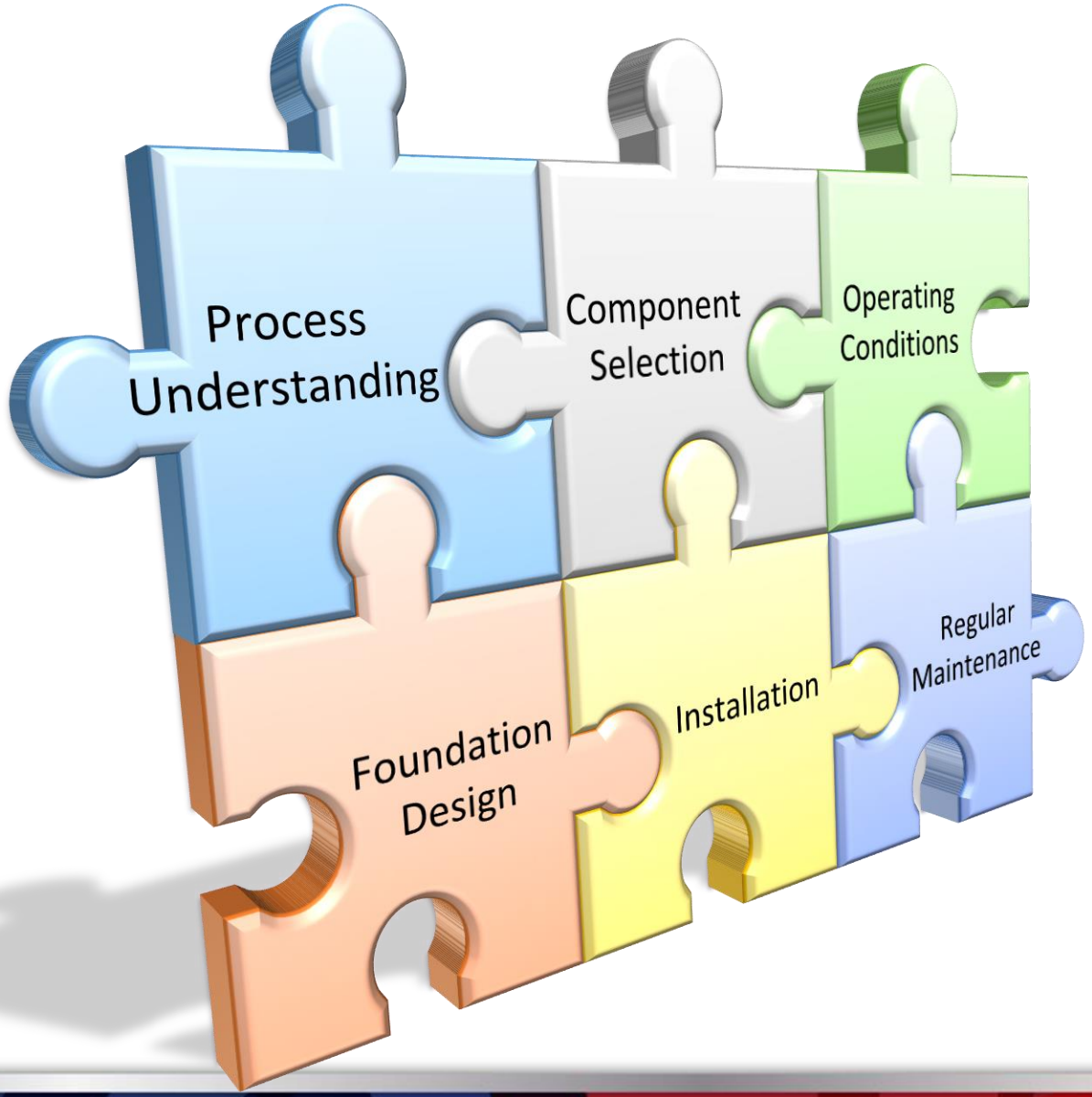
To provide attendees with detailed best practices and recommendations for the design and installation of foundation systems for dynamic machinery.

Tutorial Agenda

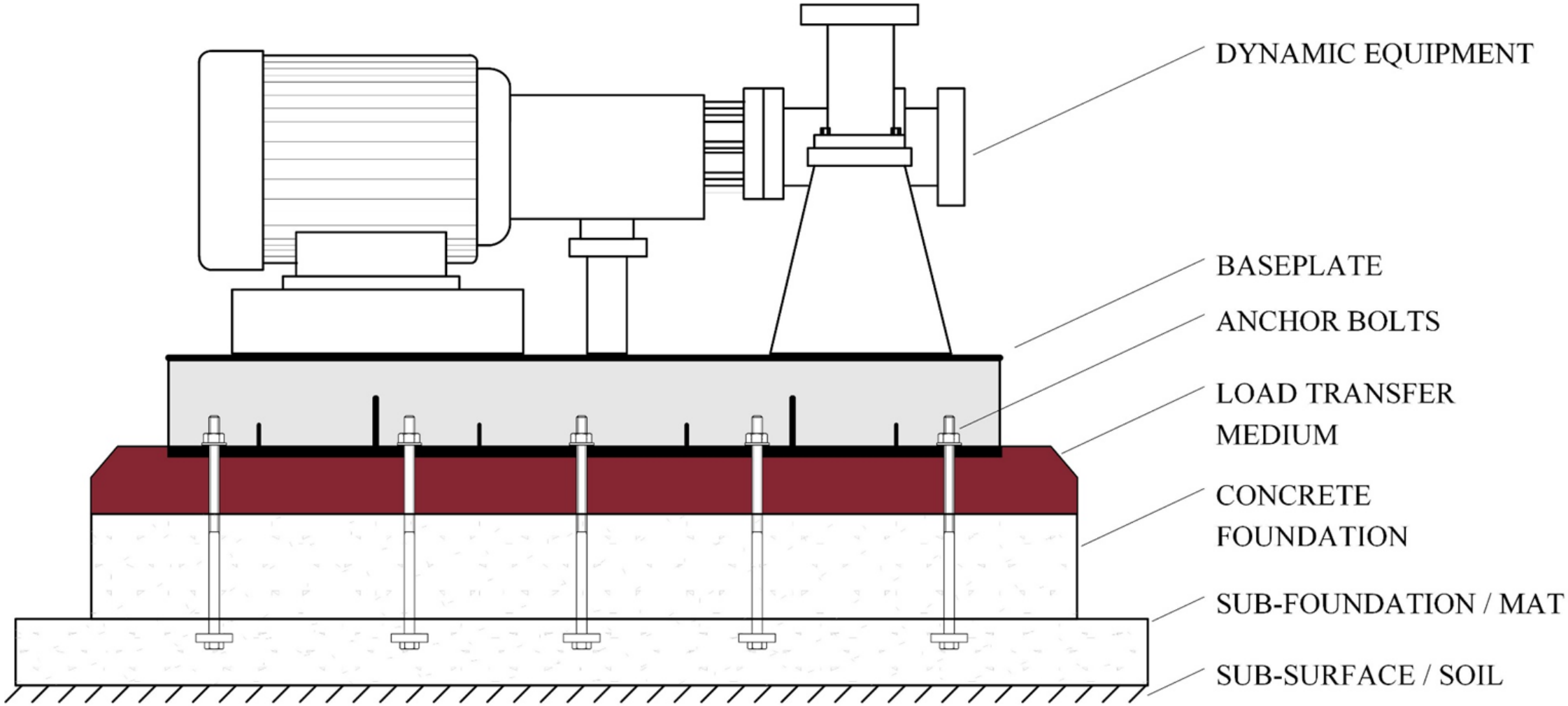
- SYSTEM CONSIDERATIONS TO PROMOTE RELIABLE MACHINERY FOUNDATIONS
- SELECTION OF TRANSFER MEDIUM TECHNOLOGY BASED ON APPLICATION REQUIREMENTS
- TREATMENT OF ANCHOR BOLTS IN THE FOUNDATION SYSTEM
- SPECIFICS OF PRE-INSTALLATION PREPARATION & PREPARATION OF MOUNTING SURFACES
- POUR PREPARATION
- EFFECTIVE MIXING & INSTALLATION RECOMMENDATIONS
- CURING TIME OF MOUNTING PRODUCTS & FINISHING GUIDANCE
- APPLICATION EXAMPLE

SYSTEM CONSIDERATIONS TO PROMOTE RELIABLE MACHINERY FOUNDATIONS

Long-Term Equipment Reliability



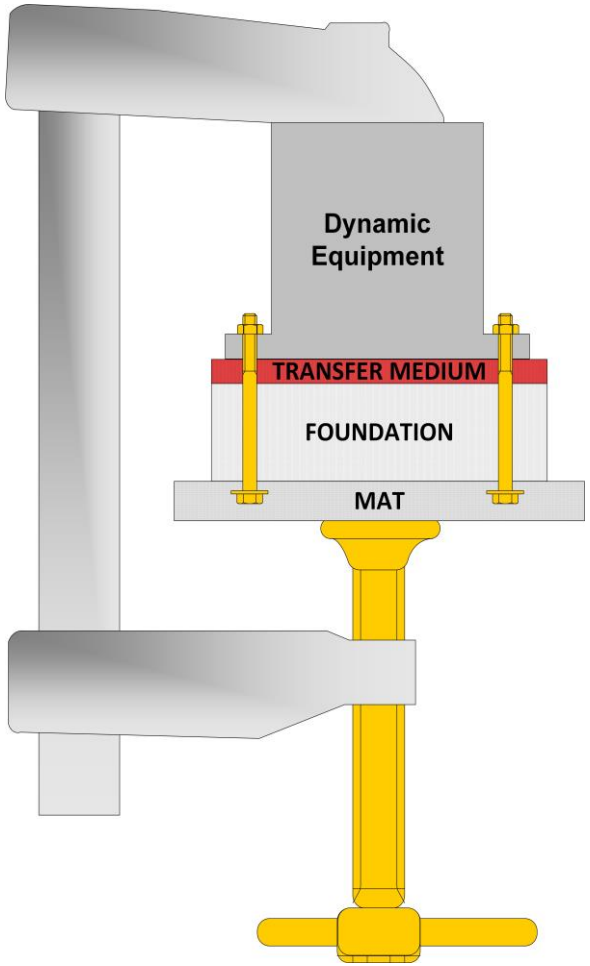
The Equipment System



Foundation Design for Machinery Dependability

What is the role of an effective transfer medium in dynamic equipment foundations?

1. Fully and effectively fill interface between equipment and foundation
2. Maintain precise alignment throughout lifetime of equipment
3. Effectively transfer vibrations and unbalanced loads generated during equipment operation
4. Protection of foundation system



SELECTION OF TRANSFER MEDIUM TECHNOLOGY BASED ON APPLICATION REQUIREMENTS

Role of Specific Transfer Mediums

Concrete	Large Masses, General civil/construction installations
Cementious Grout	Static or low dynamic loaded equipment needing alignment, High temperature applications (≥ 200°F (≥ 93°C))
Epoxy Grout	Dynamic equipment requiring high loading resistance, high chemical resistance and precise alignment

* Based on Industry Recommendations, including API RP 686

Characteristics of Transfer Mediums

	Concrete	Cementious Grout	Epoxy Grout
Composed of…	Cement, water, aggregate	Cement-aggregate blend and water	Resin, hardener and bags of aggregate
Consistency	Water-dependent	Water-dependent	Lumpy Oatmeal
Flowability	Water-dependent	Water-dependent	Fair to Poor
Working Time	2 to 3 hours	1 to 1.5 hours	1 to 4 hours
Initial Cure Time	28 days	7-21 days	18 - 72 hours
Cost	$	$$	$$$

Characteristics of Transfer Mediums

	Concrete	Cementious Grout	Epoxy Grout
Compressive Strength	3000 – 5000 psi *20 - 35 MPa*	3500 – 9000 psi *25 - 60 MPa*	11,500 – 18,000 psi *80 - 125 MPa*
Tensile Strength	200 – 600 psi *1.5 – 4.0 MPa*	350 - 1200 psi *2.5 – 8.3 MPa*	1500 – 3000 psi *10 - 20 MPa*
Shrinkage	Water-dependent	Water-dependent	0.04%
Adhesive Bond	Very Low	Low	Very High
Vibration Damping	Very Little	Little	High
Typical Installation Life	5-10 years	10-15 years	>30 years

Fan Case Study

Problem:

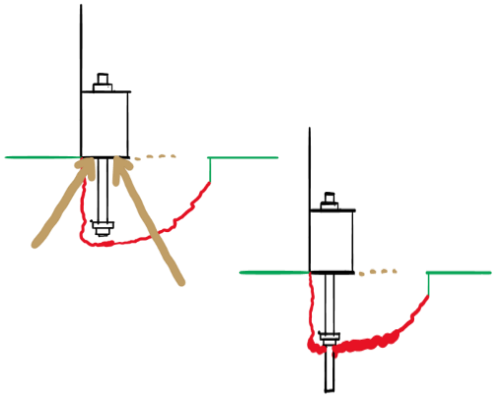
The main fan for a process facility was experiencing the following:

- Consistently high vibration readings
- Premature bearing failures (~every 9 months)
- Continuous cracking on the fan housing
- Not anchored properly
- Not grouted to the foundation

Outcome:

The Fan had better vibration readings than expected on a brand-new installation. The bearings are currently approaching 4 years in service and counting.

Fan Case Study



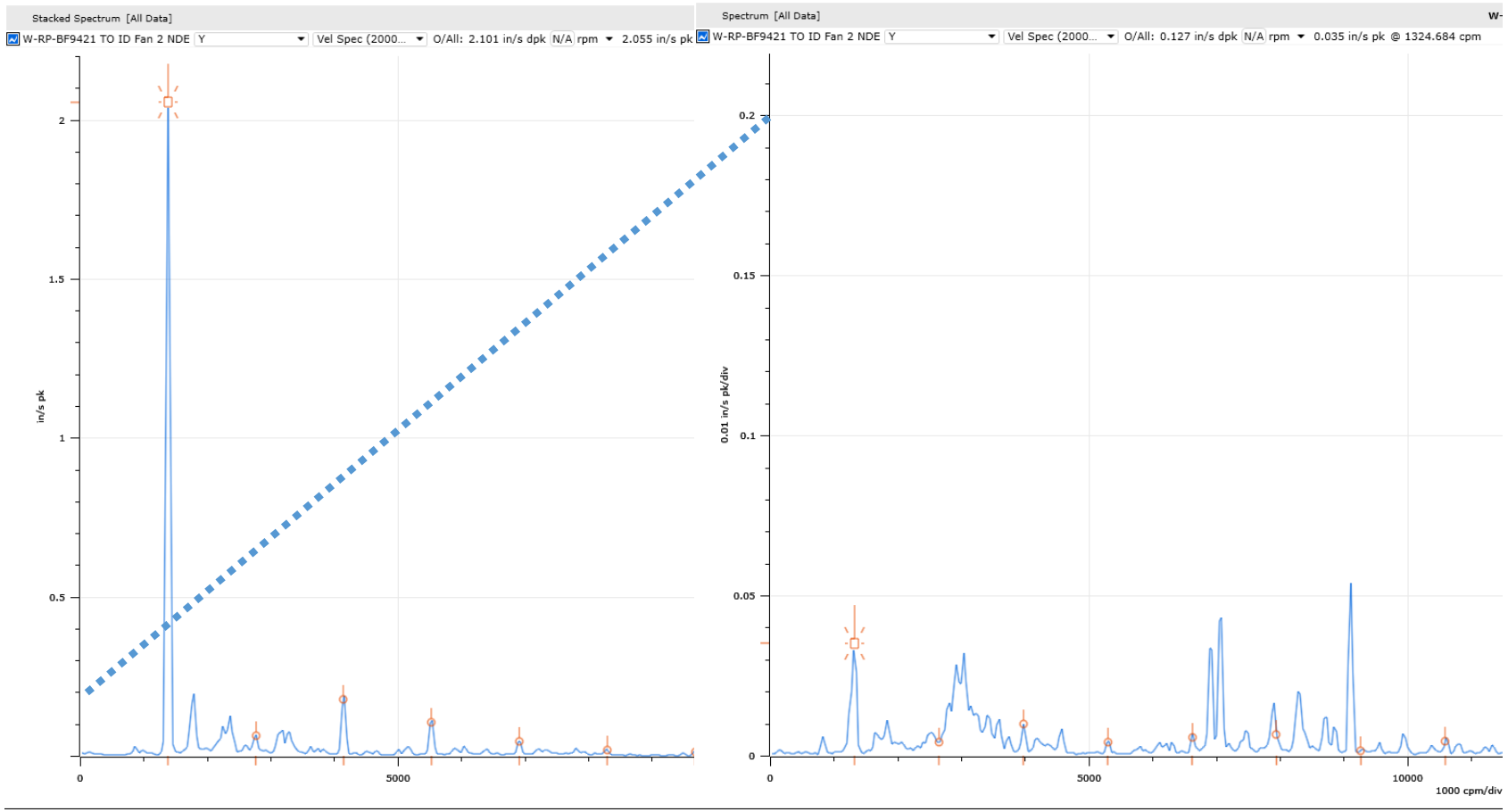
Anchor Bolt Design

Foundation Preparation

Grout Pour

Final Product

Fan Case Study



Initial Vibration Readings

After Outage Vibration Readings

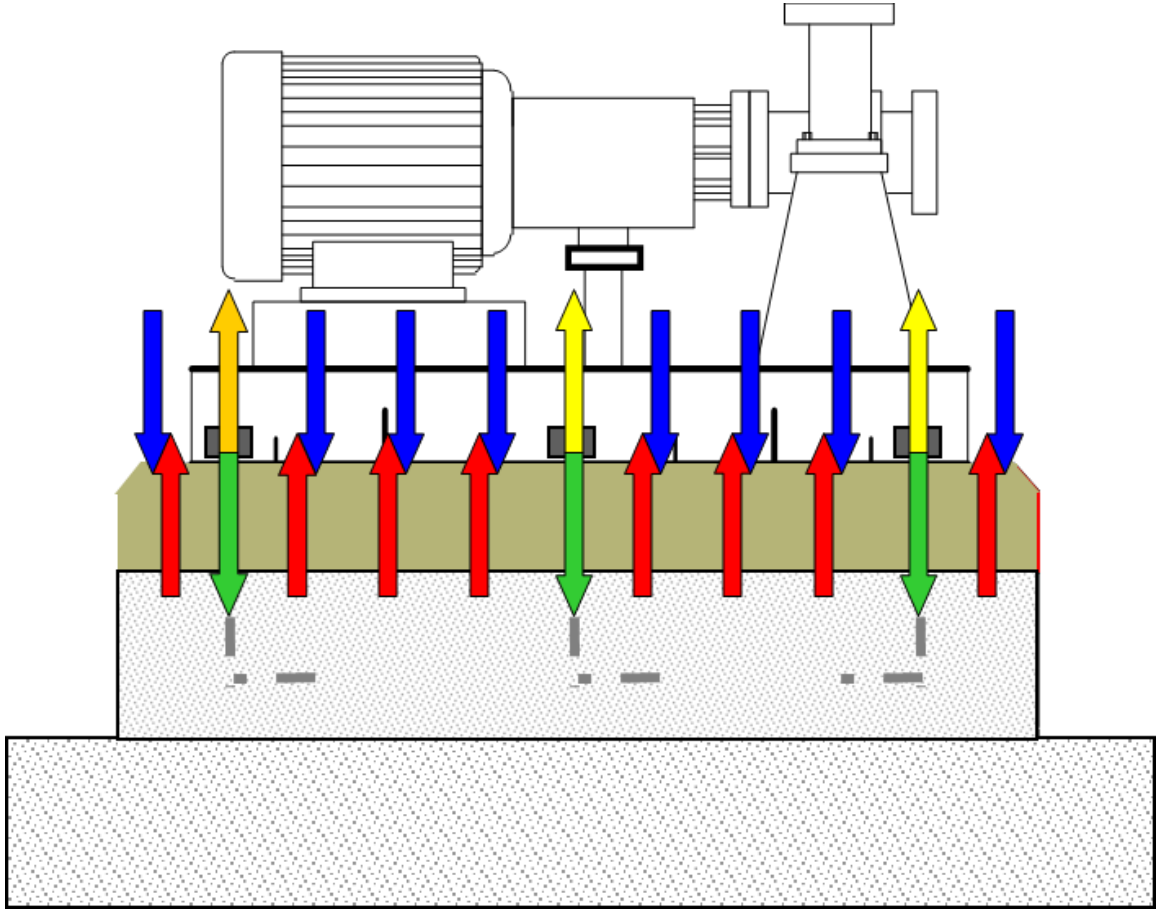
Conclusion:

- This overcame a Type A looseness Frame/Base Looseness
- Phase (180° phase shift)
- Existing foundation was solid, however base had too many degrees of freedom
- No work was done on bearings or fan during outage, only foundation work

TREATMENT OF ANCHOR BOLTS IN THE FOUNDATION SYSTEM

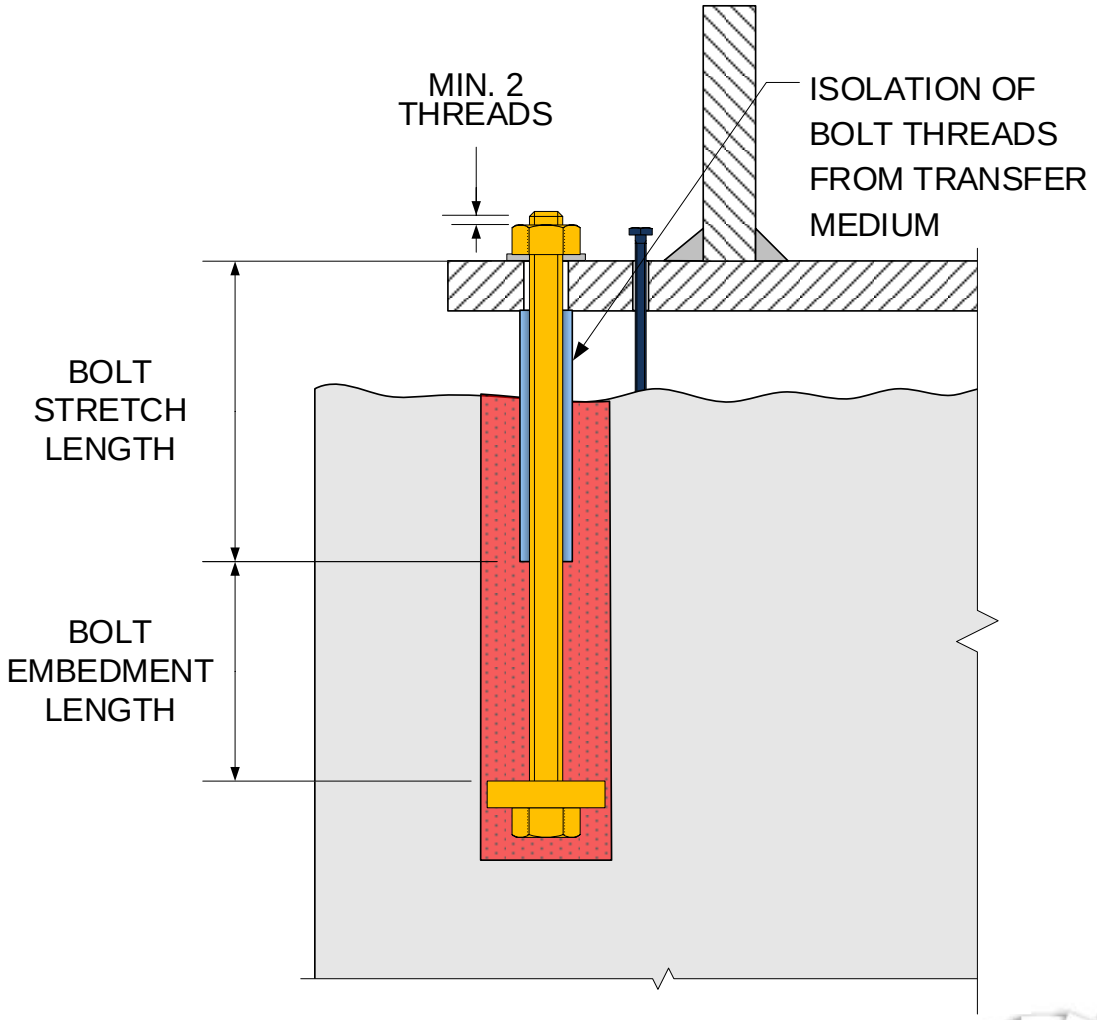
Role of Anchor Bolts

- Provides a downward anchoring force to prevent upward movement of equipment.
- Works in tandem with properly installed transfer mediums to maintain the aligned position of the equipment.

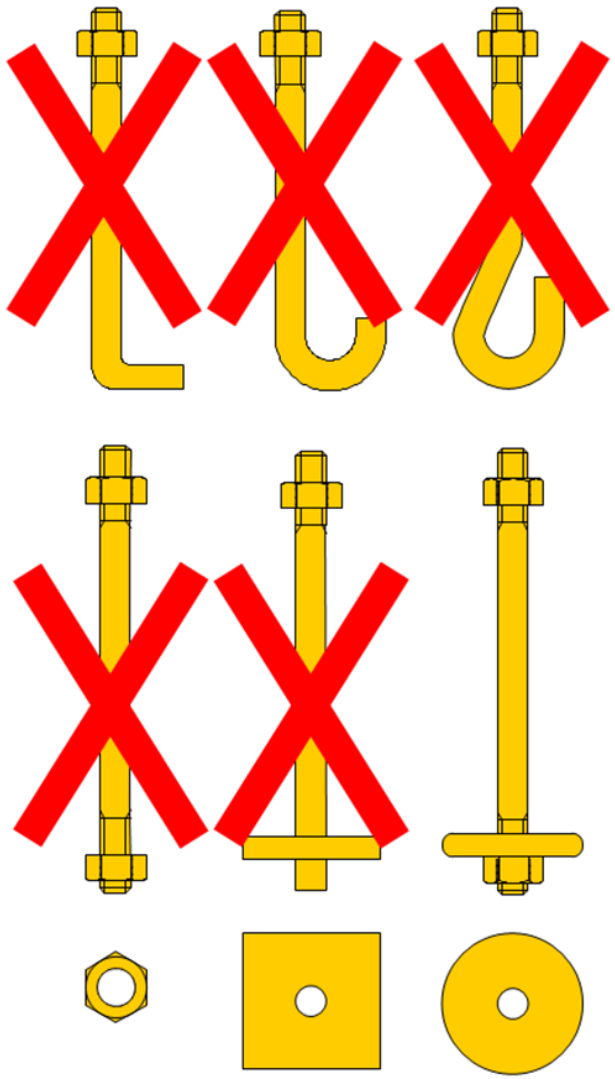


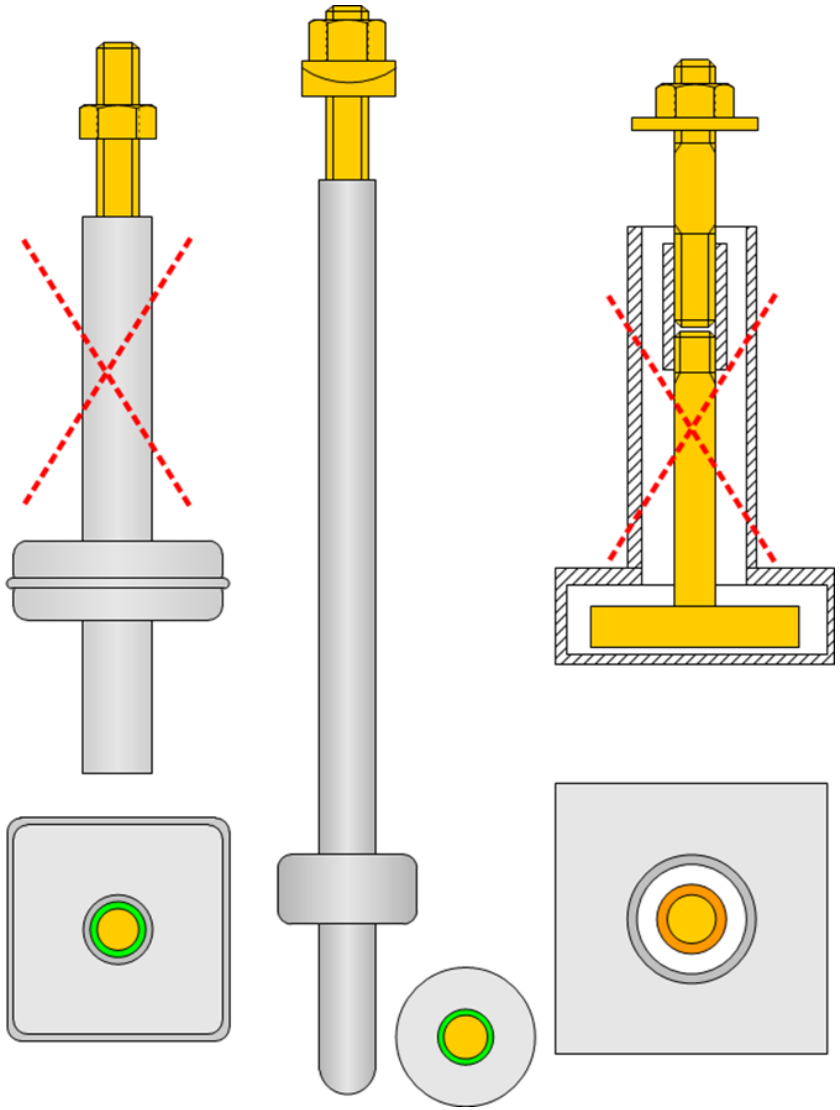
Role of Anchor Bolts

- Part of the system to maintain equipment alignment.
- Must be designed properly.
- Must be sized properly.
- Must have sufficient free stretch length.
- Must be kept tight.

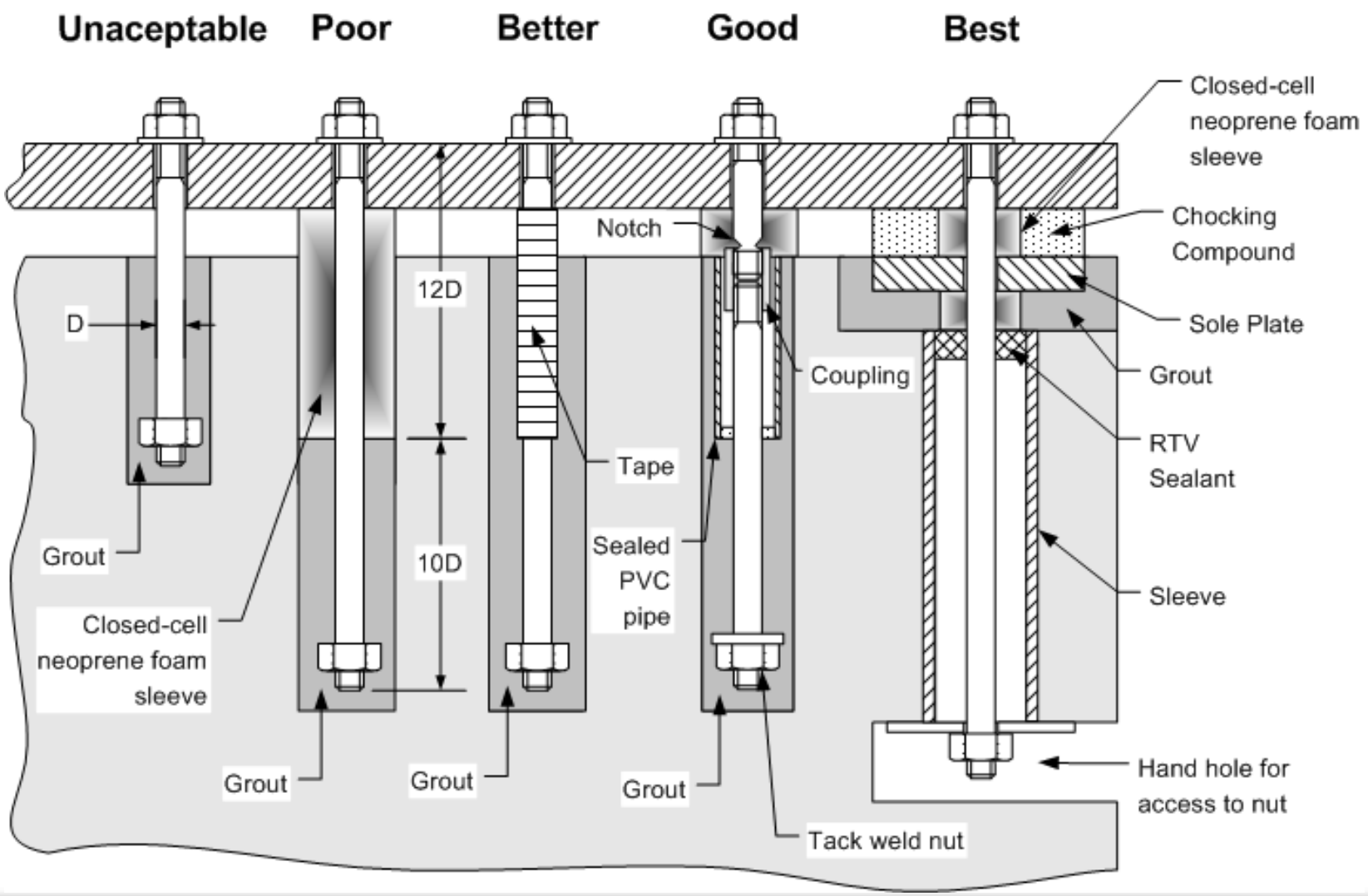


Types of Anchor Bolts





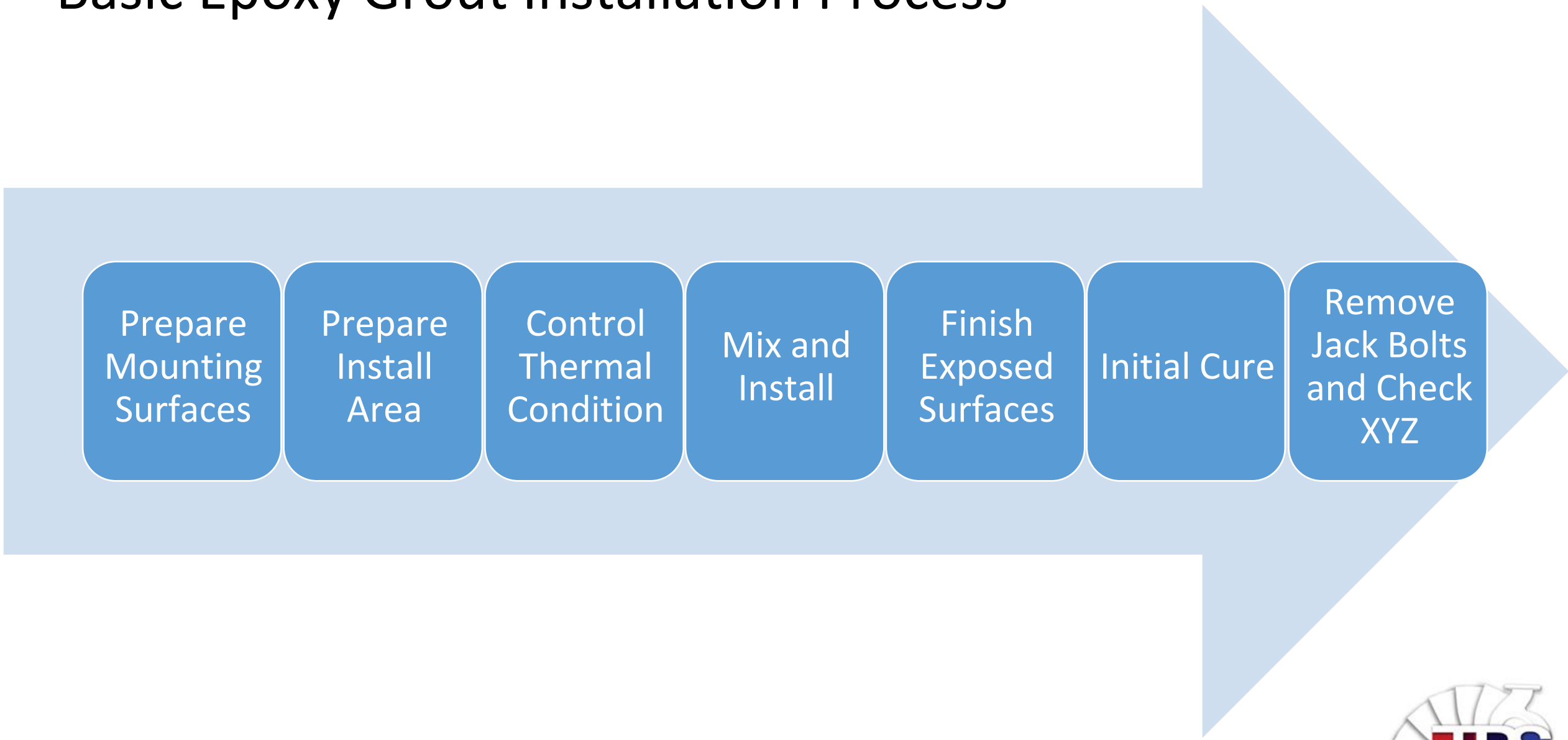
Best Anchor Bolts



Examples of Effective Anchor Bolt Installations

SPECIFICS OF PRE-INSTALLATION PREPARATION & PREPARATION OF MOUNTING SURFACES

Basic Epoxy Grout Installation Process



The Foundation – Before Chipping Begins

- Does the foundation meet all design criteria?
  - Subsoil meets all requirements to support the project
  - Min. 4,000 psi (27.6 MPa) compressive strength
  - Anchor bolt locations verified
  - All dimensions verified against latest construction drawings
  - Hydration cycle complete (typ. 28 days)
  - No structural cracks, voids, or missing components
  - Concrete is clean, dry, and uncontaminated

Concrete Cure Recommendations

- Min. 4000 psi (27.6 MPa) compressive strength
- Hydration cycle should be mostly completed.
- Potential ways to measure
  - ASTM D4263-83 “Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method”
  - ASTM C109 - Review of compressive strength test results for leveling of curve gain

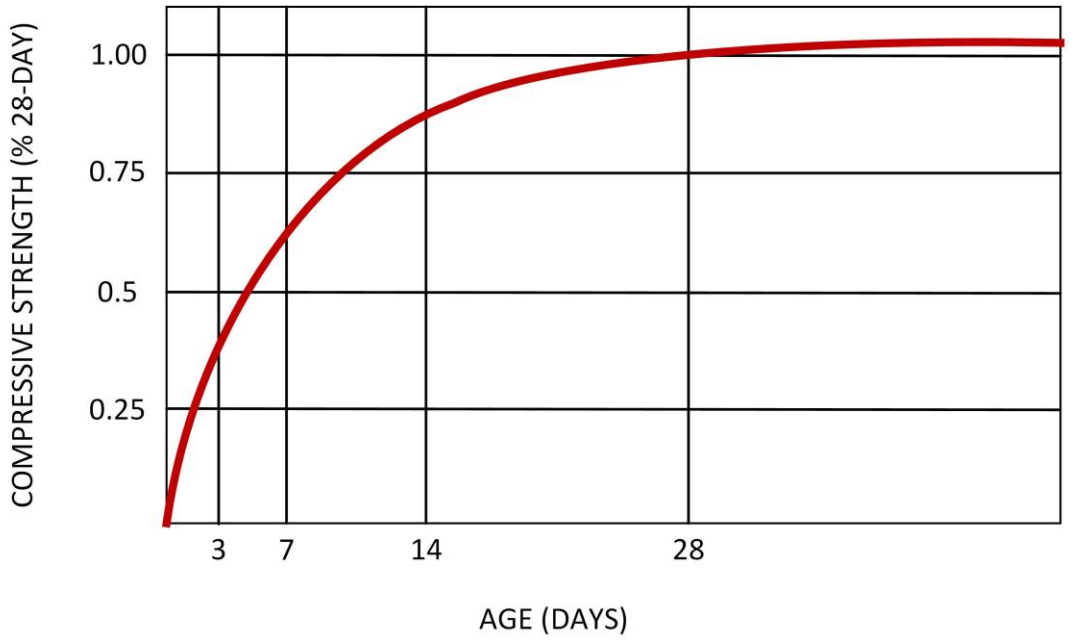


FIGURE : TYPICAL STRENGTH-GAIN CURVE OF CONCRETE

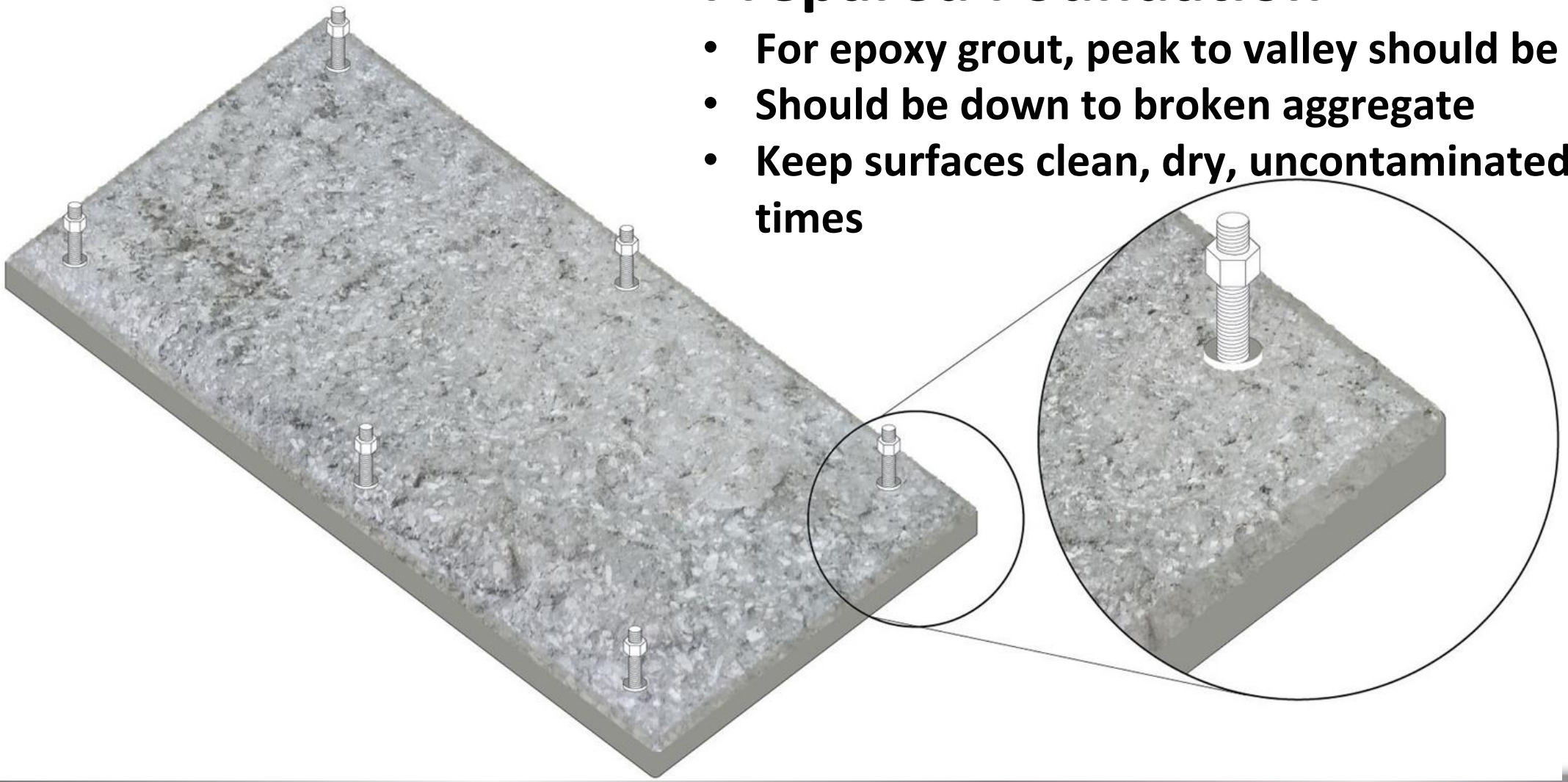
Foundation / Concrete Surface Preparation

- Laitance – weak top surface of concrete that must be removed to expose sound concrete.
- Removal
  - Remove 1” minimum
  - Use Rivet Buster or chipping hammer fitted with chisel tip.
  - Fractured coarse aggregate over pop-out.
  - Create a minimum 2” gap between equipment and top of concrete.
  - 1”- 1 ½ “ peak-to-valley profile.
  - No bushing, abrasive blasting, scarifying, or pointed tips.

Foundation / Concrete Surface Preparation

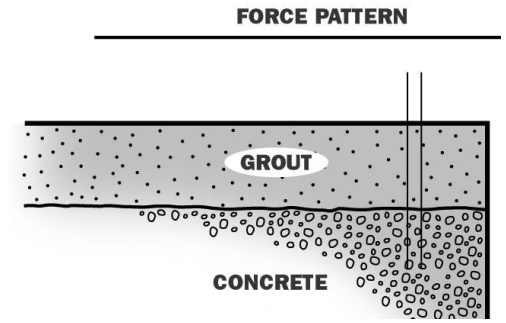
Prepared Foundation

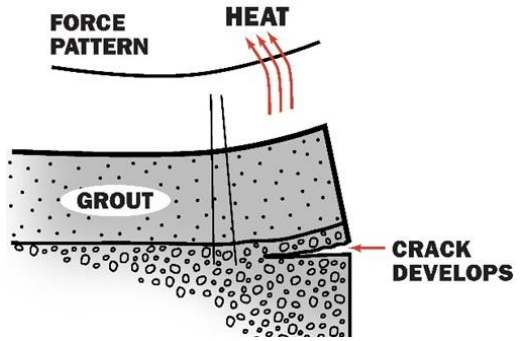
- **For epoxy grout, peak to valley should be 1”-1½”**
- **Should be down to broken aggregate**
- **Keep surfaces clean, dry, uncontaminated at all times**

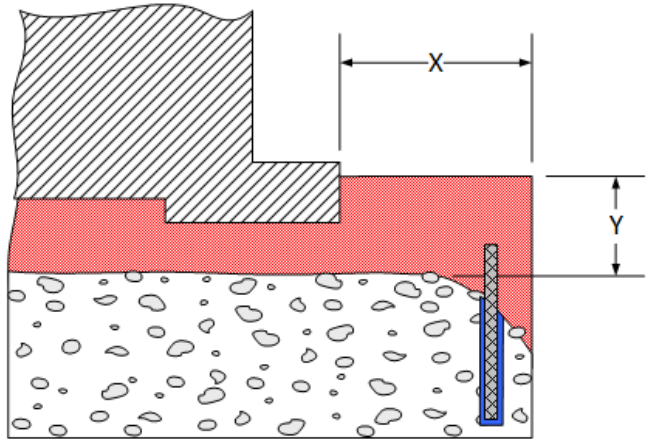


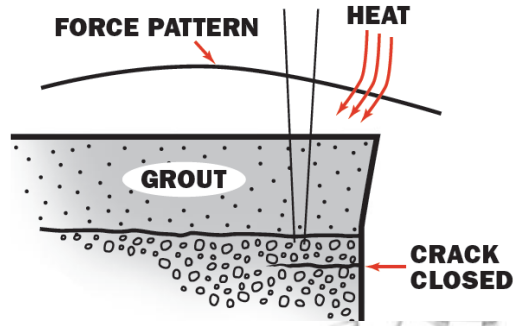
Foundation / Concrete Surface Preparation

- Edge Lifting
  - Occurs due to difference in thermal expansion. coefficients between epoxy grouts, concrete, and steel.
  - Allows contamination and degradation of the underlying concrete and separation of the grout cap.
- Precautions
  - Reduce shoulder width-to-depth ratio to less than 1:1.
  - Install a chipped 2” chamfer.
  - Installing a grout “key”.
  - Epoxy-installed rebar dowels around foundation periphery.







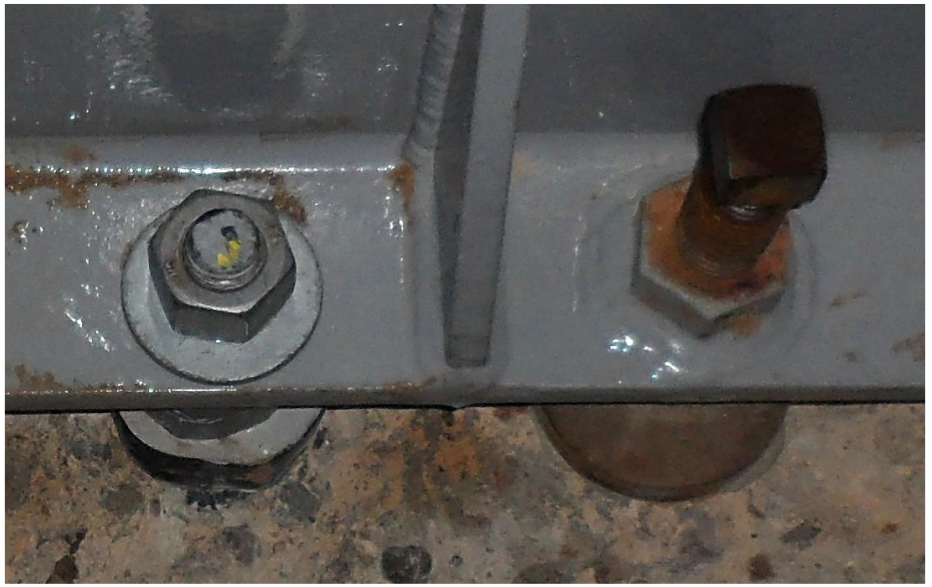


Foundation / Concrete Surface Preparation

- Leveling Disks
  - Leveling should only be done using removable means (No hard shims, wedges, or supporting equipment on the anchor bolts).
  - Provides level, flat surface for jack bolts when setting equipment.
  - Install leveling disks, 2”-3” diameter stainless steel, ½” thick at each jack bolt location using epoxy adhesive.

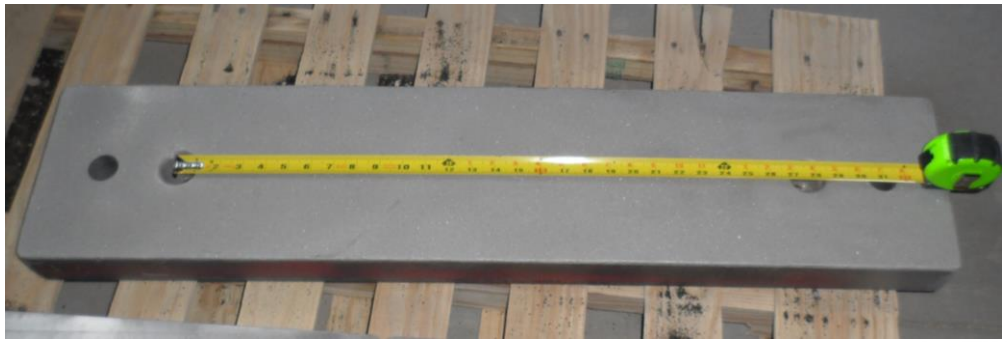
Foundation / Concrete Surface Preparation

- Anchor Bolts
  - Should be isolated from grout contact a predetermined length (12x-15x diameter) to allow elastic deformation during torquing and equipment operation.
  - Typically accomplished with supplied sleeves or pipe insulation tightly wrapped with duct tape.
  - Sleeves should never be filled with grout or concrete.



Metal Surface Preparation

- Best Steel Preparation
  - White (recommended) or near white metal abrasive blast grouting surfaces.
  - Solvent Wash to remove any light surface blush after blasting.
- If not installed immediately
  - Compatible corrosion inhibiting epoxy primer may be utilized.
  - Cleaned and degreased before installation.
  - Primers should be installed by qualified contractors to prevent failure of the grout installation.



ESTABLISHING ALIGNMENT

Establishing Alignment

- Installation, assembly & alignment
  - Follow OEM guidelines.
  - Protect anchor bolt threads.
  - Pre-set jack bolts to elevation to minimize adjustments after setting.
  - Allow equipment to “relax” overnight to allow tweaks or stresses to work out.
  - Always re-check alignment immediately before pouring and locking in the equipment.

CONDITIONING THE APPLICATION AREA

Conditioning the Application Area

- Conditioning
  - Control the environment for best results.
  - Industry standard: 65°F-90°F (18°C-32°C)
  - Optimal: 70°F-75°F (21°C-24°C).
- Enclosure
  - Necessary in outdoor installations.
  - Protect your investment.
  - Opaque, water-tight roof.
  - Walls to prevent contamination and sunlight exposure.
  - Large enough for safe comfortable working room during form installation, grout pour, and afterward
  - May enclose equipment only, or equipment, mixing stations, and grout.

Conditioning the Application Area

- Heating/Cooling
  - Convective, indirect only – minimize hot spots.
  - Maximum differential: 10°F (5°C).
  - Maintain above dew point to prevent sweating.
  - 48hrs before / 72hrs after grout pour.
- Grout Conditioning & Care
  - Condition same as foundation and equipment.
  - Spread bags and verify internal pallet temps.
  - Keep grout dry.
  - Use within shelf life.
  - Use field test to verify if grout aggregate is dry.

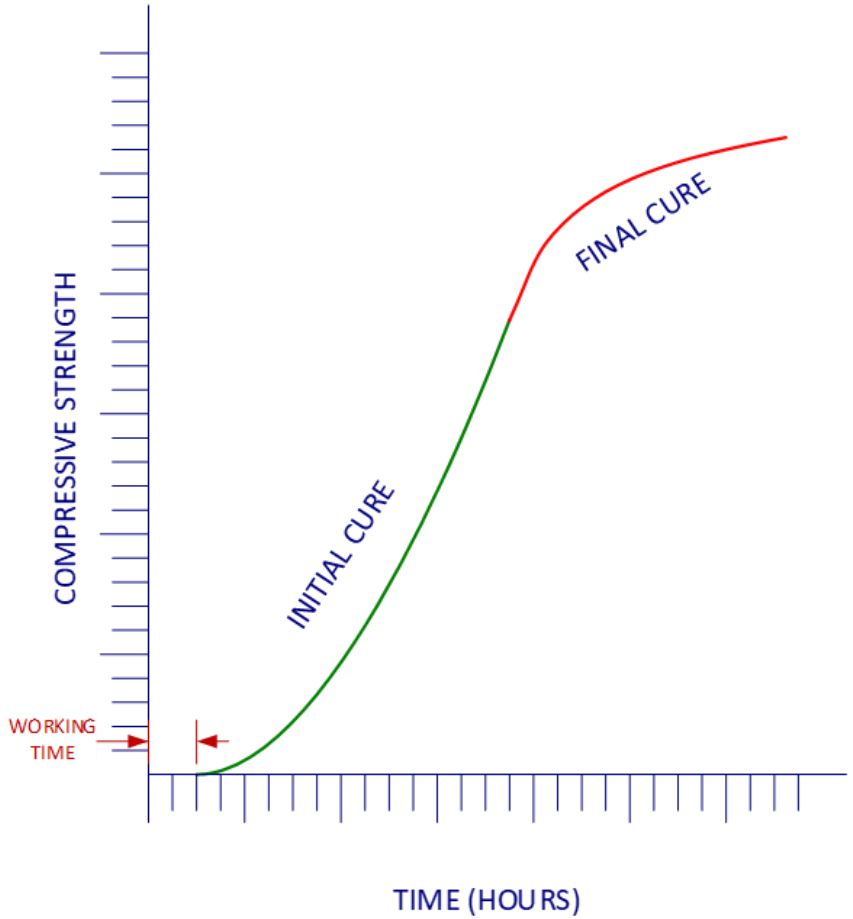
Condition Materials to Proper Temperatures

Condition Materials to Proper Temperatures

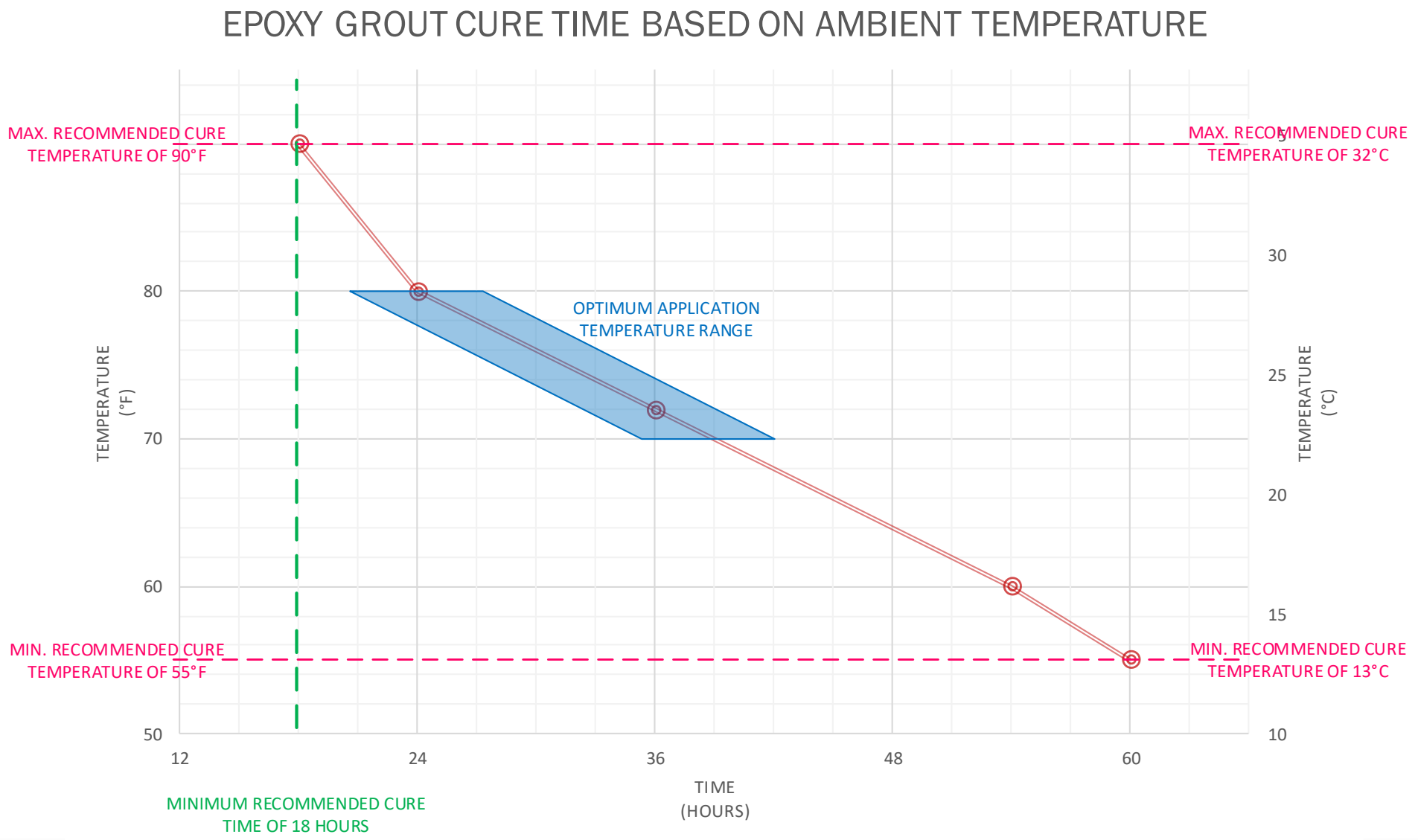
Working Time/Pot Life: Time from mixing components to transition to a solid. Effective time to place material.

Initial Cure: Where solid epoxy grouts reaches the 60% to 80% of its ultimate physical properties. (Expressed in hours.)

Final Cure: Additional time required for epoxy grouts to reach 100% of their rated physical properties. (Expressed in days.)



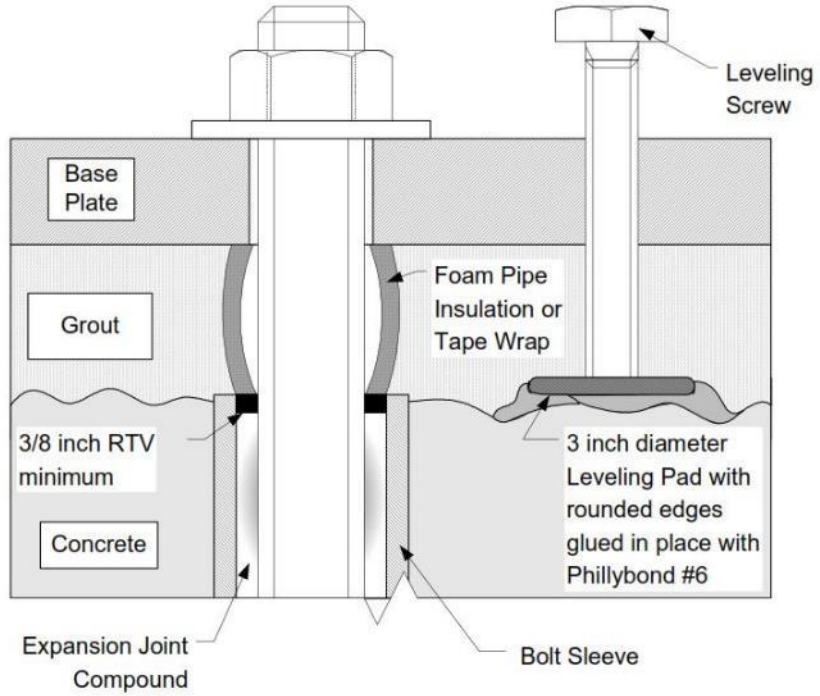
Condition Materials to Proper Temperatures



POUR PREPARATION

Pour Preparation

- Foundation
  - Verify pour depth is within tolerances for the pour material, typically 1.5”-3”.
  - Cementitious grouts may require pre-soaking the foundation.
- Equipment
  - In a “relaxed” state – no piping attached.
  - Blasted/primed surfaces are clean, dry, and uncontaminated, no wire wheels.
  - Jack bolts or leveling devices are correctly isolated.
  - Stretch portion of anchor bolts are sealed from grout contact.
  - After curing, the equipment base should be 100% supported by the epoxy and not by any alignment devices.

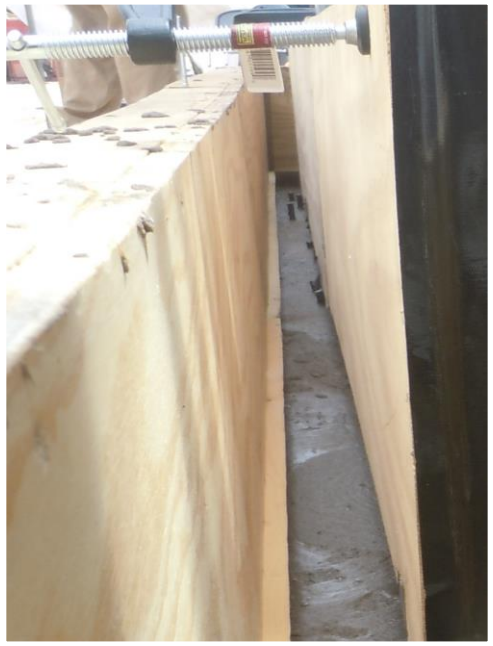


Form Installation

- Grout forms contain the epoxy grout until initial cure is completed.
- The forms should be leak free and constructed from rigid forming materials, such as ¾” (18 mm) plywood and braced with 2”x4” boards.
- Coat any form grout contact surface with at least heavy three coats of paste wax.
- Place 1”- 45°chamfer strip on all vertical corners and horizontally at the desired grout elevation.
- Protect all floor and equipment surfaces from splash and spillage.
- Install forms using drilled anchors, no power-nailing or nail-wedging.
- Seal forms from the outside.

Form Installation

- Head boxes or standpipes allow effective placement and flow of the epoxy grout using head pressure.



Expansion Joints

- Utilized in outdoor installations or installations with temperature swings
- Provide a necessary pre-determined. sealed location for thermal expansion and contraction during temperature changes.
- Located at 3’-6’ intervals and high stress areas (i.e. anchor bolts, inside corners).
- ½”-1” polystyrene foam or neoprene rubber.
- Extend from the outside edge of the equipment to the form inside edge.
- Adhered to the foundation and go full depth of the epoxy grout pour.

Importance of Proper Foundation Preparation

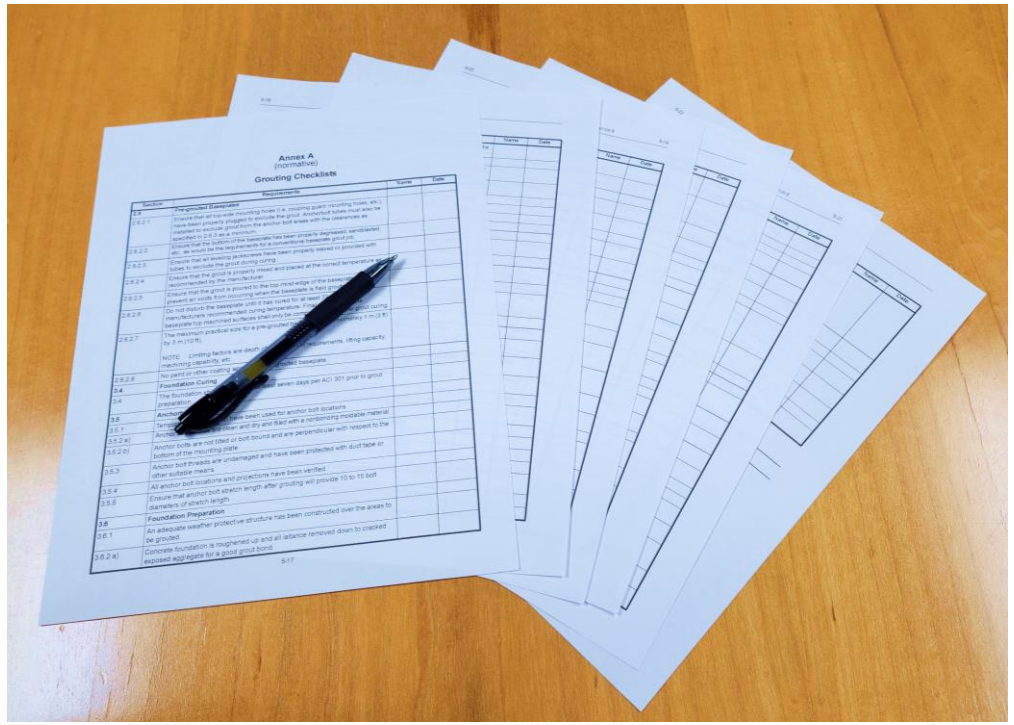
EFFECTIVE MIXING & INSTALLATION RECOMMENDATIONS

The Pre-Grout Meeting

- The final chance to get on the same page before the pour.
- Held at least 24 hrs. prior to the pour.
- Include every entity involved.

The Pre-Grout Meeting

- Verify pre-pour preparations are completed.
- Alignment has been verified.
- Sufficient material is on-site.
- Personnel, mixing equipment, support contractors, PPE, and facilities requirements.
- Discuss every aspect of the grout pour for a safe, quality grout job.
- Utilize a grouting checklist to communicate expectations and verify completion among all parties involved.



Annex A in Chapter 5 of API RP 686

Grout Mixing

- Resin & Hardener liquids are mixed together first for approximately 3 minutes with a heavy-duty variable-speed drill and “jiffy”- type mixer blade.
- Keeping mixer blade in bottom of bucket reduces entrained air.
- Only mix what can immediately be used – runaway reactions create hazardous fumes.
- Operate 200-240 RPM.

Grout Mixing

- After the mixing of liquids is complete, add the liquid blend to a mortar mixer immediately.
- Only mortar mixers are recommended for mixing aggregate with the liquid blend.
- Aggregate is slowly added, one bag at a time.
- Mix at 15-20RPM

Grout Mixing

- Mixing is complete when all aggregate is placed in the mortar mixer and no dry spots are visible.
- ***Remember: Do not over-mix. Over-mixing can entrain excess air into the grout.***
- Cementitious grout mixing times vary from epoxy grouts, follow the manufacturer's guidelines.

Mix and Install

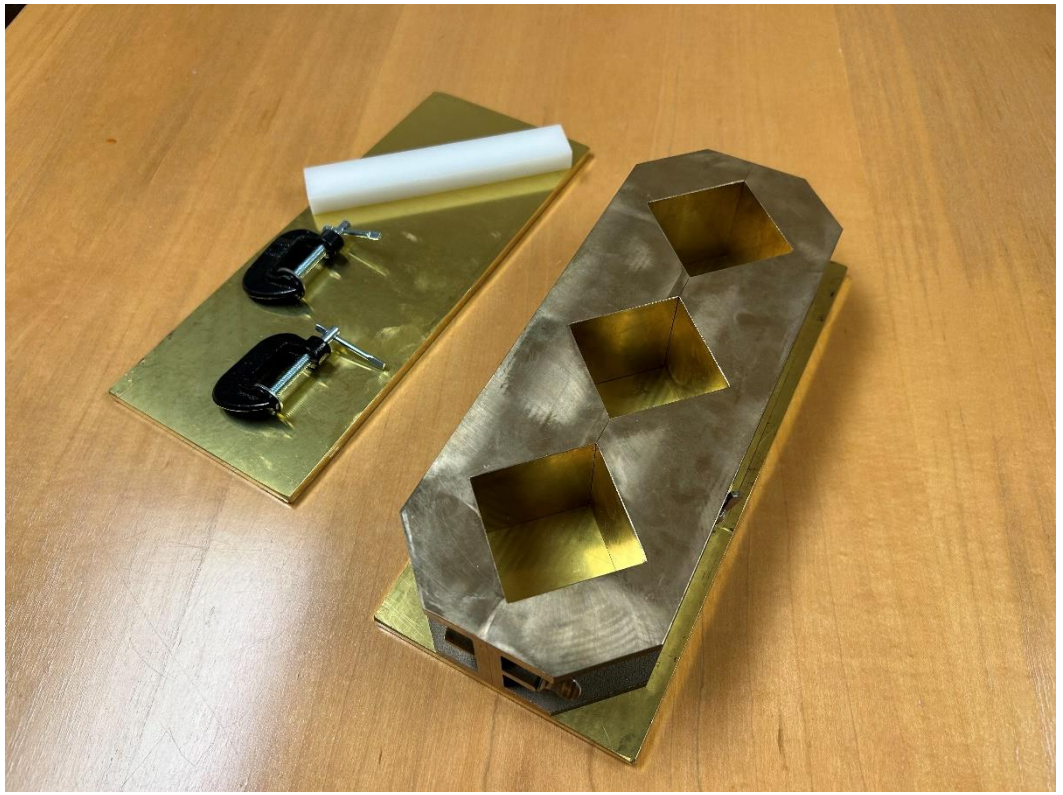
- Immediately place grout from mixer into forms/headbox.
- Pour grout across shortest distance.
- Maintain headbox fill.
- Obtain contact, maintain contact, and don’t pour in front of the contact line.
- Epoxy grout is continuously mixed and placed until all areas are completely filled and contact is made with the underside of the base.
- Let it flow! Do not use chains, rods, or vibrators as they will compromise the grout job.

Mix and Install

- Pour up on the sides of the baseplate/flange to “key” the equipment in place.
- Verify grout used with calculations.
- Don’t leave until all cleanup is complete.
- Monitor forms for leaks and seal.

Grout Sampling

- Verifies as-installed quality of the grout.
- Epoxy grouts – 2” brass cube molds.
- Sampling and testing to be performed per ASTM C579 Method B.
- Samples cure with the equipment.
- Verify testing lab is familiar with the sampling/testing standard.



Importance of Proper Grout Mixing

Clean Up After Pour

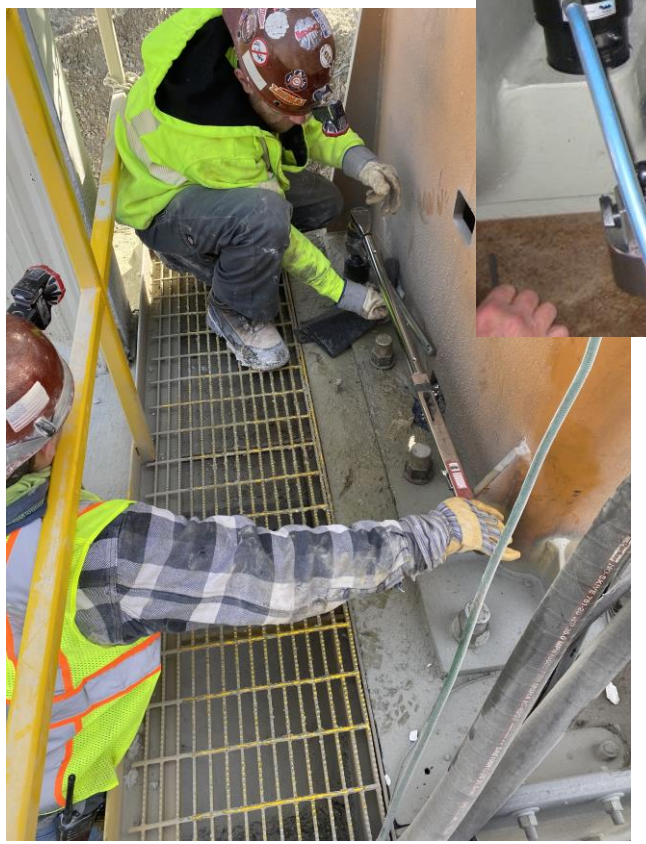
CURING TIME OF MOUNTING PRODUCTS & FINISHING GUIDANCE

Allow Material to Complete Initial Cure

- Product TDS features the initial cure time, which is the minimum amount of time that is recommended waiting before removing formwork, removing alignment devices (leveling screws), tensioning anchor bolts, and starting up machinery.
- If the temperature of the material drops below 50°F (10°C), the chemical reaction shuts down.
- When changing the temperature of foundations, especially for material that is newly poured, the rate of temperature change should be no more than 4°F (2°C) per hour.

Remove Alignment Devices and Start Up

- After the initial cure time has elapsed, removable alignment devices and forms are removed.
- Anchor bolts are properly tensioned.
- Equipment start-up may proceed.



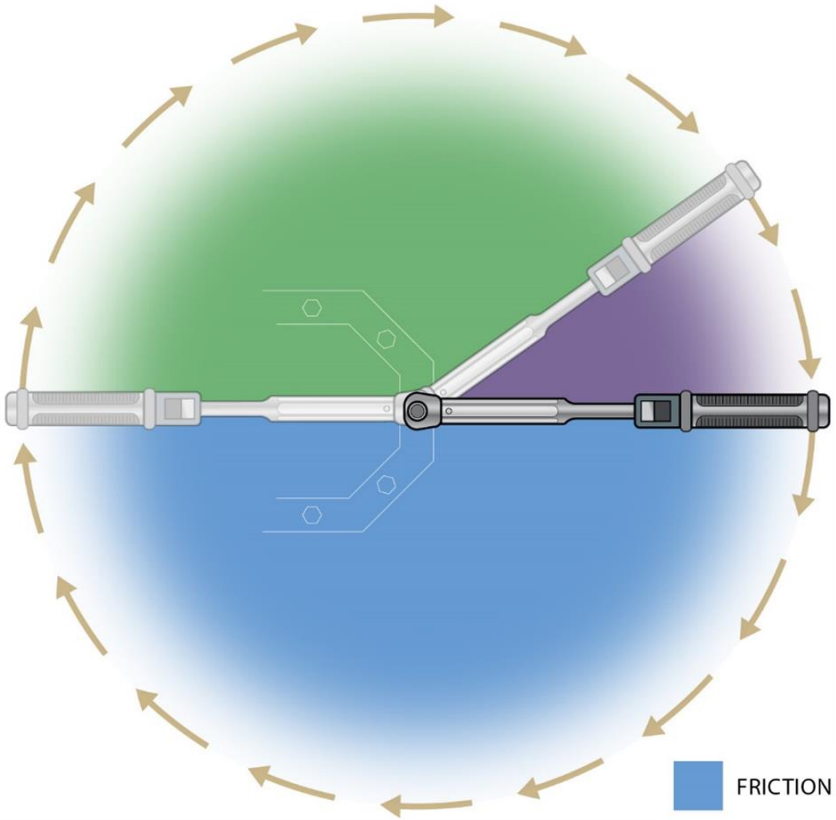
Bolt Tensioning Recommendations

- Nuts Hand-Tool tight until grout hardens
- Tension Bolts with Hydraulic Bolt Tension
- Design for a maximum epoxy grout loading approx. 3.4 MPa (500 psi)
  - Check with epoxy manufacturer for loading recommendations per product and application
- Tension bolts to maximum of 65% to 70% of their yield strength
- Re-tighten after equipment come up to temperature
- Tension and release the bolt two times. Perform final tensioning or preload on the third try.
- Recheck after the equipment has been in service for…
  - Seven days
  - Thirty days.
  - Six Months.
  - Every Six months.

Bolt Tensioning Recommendations

- Operator "Feel" +/- 35%
- Torque Wrench +/- 25%
- Angle Torqueing +/- 15%
- Load Indicating Washer +/- 10%
- Fastener Elongation +/- 5%
- Strain Gauges +/- 1%

*Industrial Fastener Institute's Estimate



Void Repair

- Voids that do occur are typically very shallow, seldom exceeding 1/32”.
- Voids are detected by “sounding.”

Void Repair Procedure-

- Map the area of the void, chalking the outline.
- Drill and tap a fill hole.
- Drill vent holes.
- Fill a cheap grease gun (remove internals) with neat epoxy mixture (liquid only) and fill the void.
- Beware of applying too much pressure which could raise, distort, or dislodge the baseplate.

Conclusion

Tutorial Objectives

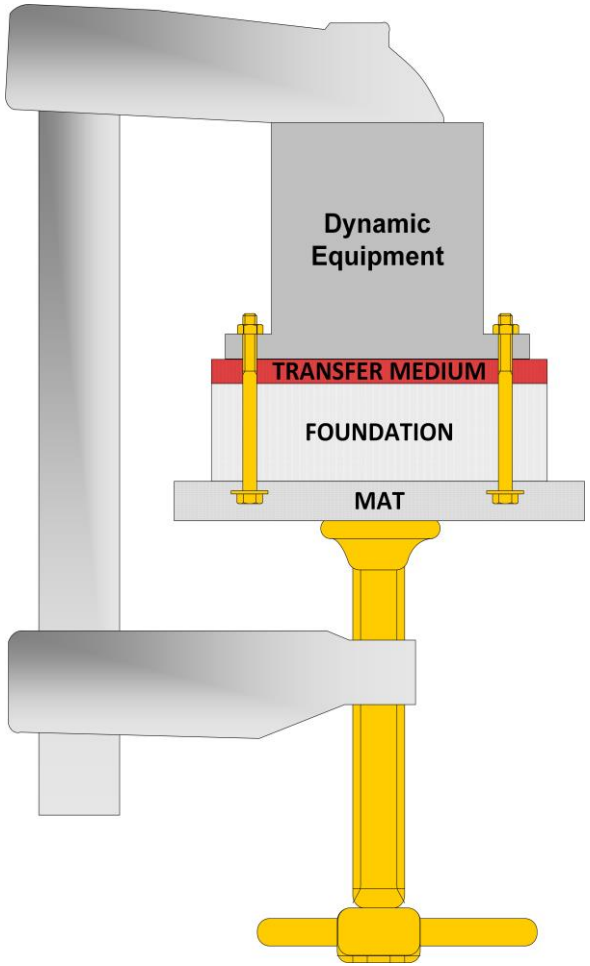
To provide attendees with an understanding of critical contribution of the foundation system to overall operational efficiency and reliability.

To provide attendees with detailed best practices and recommendations for the design and installation of foundation systems for dynamic machinery.

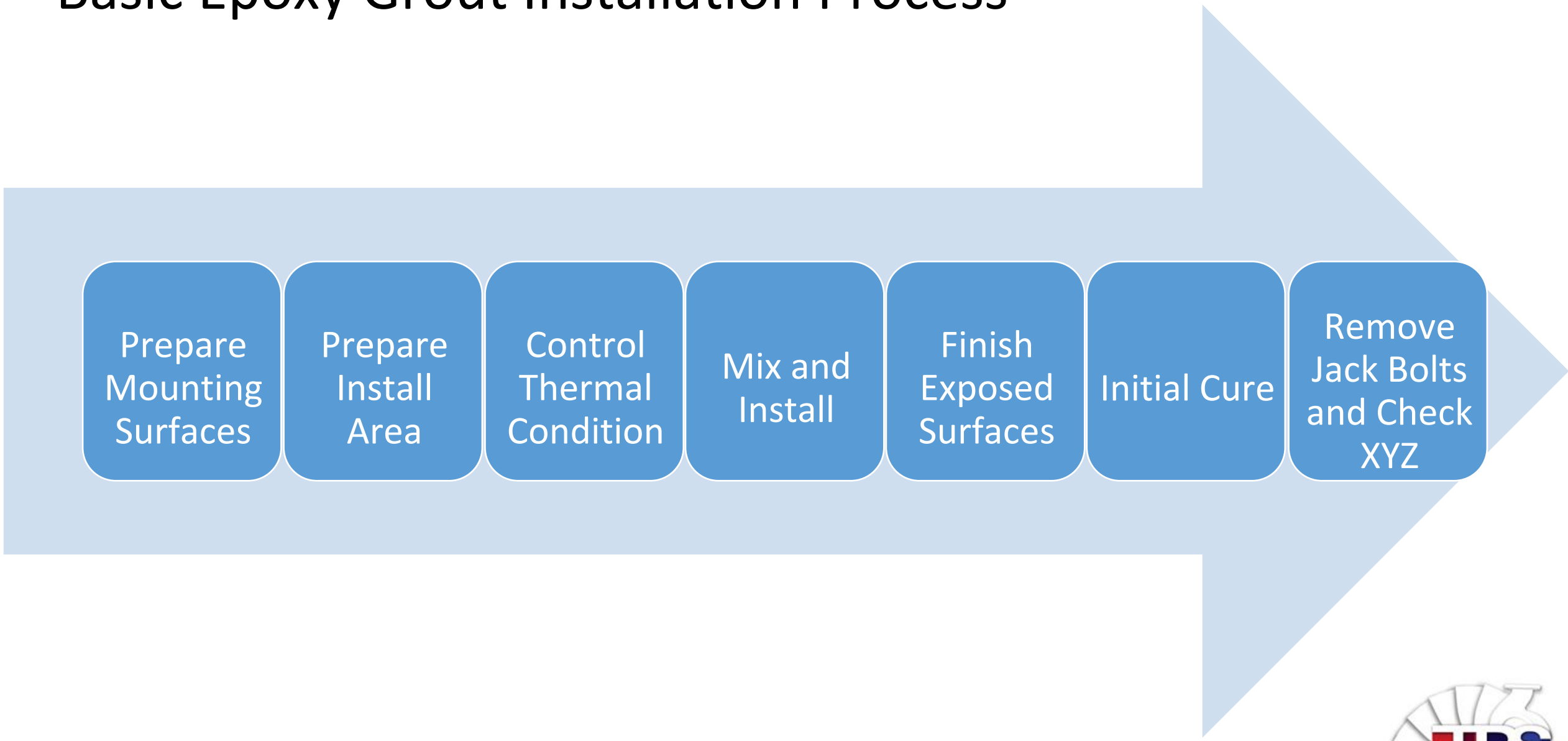
Foundation Design for Machinery Dependability

What is the role of an effective transfer medium in dynamic equipment foundations?

1. Fully and effectively fill interface between equipment and foundation
2. Maintain precise alignment throughout lifetime of equipment
3. Effectively transfer vibrations and unbalanced loads generated during equipment operation
4. Protection of foundation system



Basic Epoxy Grout Installation Process



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