TUTORIAL ON API 686 FOUNDATION AND GROUTING SYSTEMS

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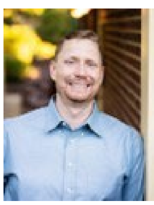	*Christopher Matthews-Ewald is the Senior Technical Services Engineer at ITW Performance Polymers. In this role, he offers expert technical support and guidance on the design and installation of dynamic equipment foundations, as well as training to engineering, construction, operations, and reliability teams globally in both industrial and marine applications. Prior to this, Chris supported the upstream Oil & Gas sector by providing engineering and operations expertise for well isolation, abandonment, and completion technologies. He holds a degree in Civil & Environmental Engineering from the Georgia Institute of Technology and serves on the Technical Committee for API RP 686 Chapter 5.*

ABSTRACT

To ensure the reliability of rotating equipment, it is critical that foundation systems as a whole, and especially precision epoxy grouts which provide the primary support mechanism underneath the machinery, are engineered and installed correctly. Far too often, both the foundation and precision epoxy grout are overlooked as a critical component of the complete system. Just like our homes, if we experience foundation and support issues, this will lead to a host of other problems which compound over time. With rotating equipment, there is no difference. If our goal is maximum reliability, our equipment must be placed on a solid foundation and properly epoxy grouted.

The good news is the American Petroleum Institute publishes a document called API 686, Recommended Practice for Machinery Installation and Installation Design, which provides design, engineering, and installation guidance on foundations and precision epoxy grouting. Technical committee members, Dan Termunde and Chris Matthews-Ewald will detail the information found in this document as it pertains to foundation, concrete, reinforcing steel, and anchor bolt design, as well as the proper installation techniques for installing precision epoxy grout. Additionally, interpretations will be offered on some of the most common points of confusion within the standard, and examples provided for recommendations from the guiding document. Utilizing these best practices will result in the highest equipment reliability and operating efficiency while reducing overall maintenance costs.

INTRODUCTION

Costs associated with unplanned downtime have increased significantly over the past 5 years, with Heavy Industries seeing a near fourfold increase in the cost of an hour of downtime since 2019. Much of this increase is due to the global rise in energy prices. Given these staggering statistics, it is critical to control costs associated with maintaining a fleet of equipment, especially with consideration to reducing overall operating costs and increasing the Mean Time Between Failure (MTBF). While often overlooked, designing and installing an effective foundation system plays a vital role in controlling these aspects, especially considering that more than 85% of the total life cycle costs of dynamic equipment installations are related to energy consumption. Creating a reliable foundation system is directly associated with increased operating efficiency and increased MTBF.

This paper will discuss the usage of API Recommended Practice 686, currently in its 2nd Edition, as it related to the specific recommendations for the design and installation of foundation systems for equipment. The goal of this paper is to highlight some of the most important aspects of the specification as they apply to the design and installation of soil-supported foundation systems, primarily as found in Chapter 4 - Foundations & Chapter 5 - Mounting Plate Grouting within the specification. This paper is not intended to replace reading the specification but will focus on highlighting and adding details on some of the often overlooked or misunderstood aspects of the document.

FOUNDATION SYSTEM

Without a properly designed and executed foundation system, equipment will commonly experience high vibrations, reduced service life of seals and bearings, and an overall increase in mechanical failures. To be effective, a foundation system must completely connect the individual components of the system and create what is, in essence, a single structure. The primary goal of an effective foundation system design and installation is to create a monolithic structure, where the individual components are interconnected and act as a single structure. This is especially imperative for foundations of dynamic equipment, where foundation systems will also mitigate the forces generated during operation in addition to supporting the position of the equipment.

While the specific components considered within a foundation system will vary, this paper will focus on the best recommendations for the design and installation of soil-supported foundation systems of special purpose machinery. Special purpose machinery includes those that are usually not spared, have higher power outputs, or are deemed to be in critical service. The typical components of a special purpose foundation system will include the Subsurface/Soil, General Concrete/Mat, Concrete Foundation Block, Anchor Bolts, Epoxy Grout, and the Mounting Plate/Base plate of the equipment, as shown in *Figure 1*.

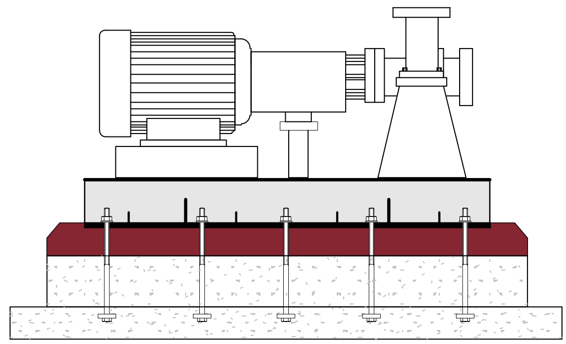

Figure 1: Components of a foundation system

As with any project, the first step in the creation of a foundation system is to determine the scope and extent of the system. When multiple machines are in close proximity with well understood static and dynamic loading conditions, it may be an economical alternative to combine them into a single mat foundation. Original Equipment Manufacturers (OEMs) can typically provide guidance on the expected forces generated during operation of the machinery to evaluate if this approach makes sense.

SUBSURFACE/SOIL DESIGN AND INSTALLATION

While completing a comprehensive and thorough geotechnical analysis is the most effective way to ensure that all aspects are considered, there are a few key points about the soil and subsurface design and installation to emphasize. The design must not exceed the allowable bearing capacity of the soil, and the overall foundation system does not result in excessive or unacceptable settlement. When settlement does occur due to exceeding the bearing capacity of the soil, this commonly results in excessive stress or damage to the piping system connections and loss of alignment between or within machinery components. The general consideration is that the expected combined static and dynamic loads should not exceed 75% of the soil bearing capacity. Additionally, the foundation size should be large enough to minimize the potential for differential settlement across the foundation footprint.

Foundation footprints should be constructed on soils that are undisturbed or on fill material that has been properly compacted.

GENERAL CONCRETE DESIGN & INSTALLATION

Whether used for the block or the mat, concrete mix design should consider the operating environment, including all potential environmental and chemical exposures. Typically, the concrete mix will be a minimum 28-day compressive strength of 28 MPa (4000 psi). If approved by the equipment user, a high-early design may be used.

Once on-site, a concrete mix design should be verified by ensuring that the delivered mix has a maximum slump of 100-mm (4-in), though this can be increased to 200-mm (8-in) if using a high-range water-reducing agent. Adding water on-site to the mix should be performed only if explicitly approved by the equipment user. While adding additional water on-site will typically result in increasing the slump and the overall workability of the concrete mix, it will also result in decreased physical strength properties and increased potential for excessive shrinkage.

Prior to pouring the concrete, an effective and proper reinforcement steel design and spacing should be constructed, with specific attention to the requirements of ACI 301 and PIP STS03001. In addition to the recommendations in those guides, the perimeter reinforcement should have less than 300-mm (12-in) spacing on centers and a minimum bar size of 12.7-mm (#4).

RECTANGULAR CONCRETE BLOCK DESIGN & INSTALLATION

Proper design of the concrete block for dynamic equipment will consider that all machinery loads are supported by the foundation block exclusively, and not by any platforms or extensions. The machine and the driver should share a common foundation block to prevent differential settlement between two separate foundation blocks. The overall foundation dimensions need to enable effective grout placement under the equipment baseplate/mounting plate. This typically requires a shoulder of 75 to 150-mm (3 to 6-in) around all outside edges of the mounting footprint. For installations with a wider shoulder, edge pins may be required and will be discussed in more detail later in the *Surface Preparation* section.

The mass of the foundation block should be at least 2-3x the mass of the equipment for centrifugal and rotary screw machines, and at least 5 times the mass for reciprocal machines for effective damping. Additionally for machines operating with significant lateral loading, such as reciprocating compressors, the block shall be embedded into the soil directly to handle these unbalanced loadings. For all equipment, the top of the foundation block should be at least 100-mm (4-in) above the surrounding grade to prevent damage due to flowing water such as during a rainstorm or facility washdown.

After the concrete block has been poured, it must have completed the majority of its cure before proceeding with foundation preparation or setting of equipment. If a high-early mix design was used, the majority of the ultimate strength of the material needs to be achieved and not just the design strength for the material. It is not uncommon for high early mixes that are able to achieve the design strength of 28 MPa (4000 psi) in 3 to 7 days to continue gaining in strength and reach ultimate strengths of greater than 41 MPa (6000 psi).

ANCHOR BOLT DESIGN & INSTALLATION

Anchor bolts will typically connect the equipment feet to the mounting plate, as it is not recommended to directly mount the equipment feet to the foundation. They must be properly sized to mitigate the lateral or shear loadings resulting from the operation of the equipment on their own or together with shear attachments. While the epoxy grout usually provides shear resistance in the form of adhesion to the concrete and the mounting plate, this should not be considered for mitigating unbalanced lateral or shear loads.

For the design of anchor bolts cast into the concrete block, it is imperative to provide an effective stretch length for achieving proper preloading of the bolts. The bolt must be isolated from direct contact with concrete or grout for the top portion of the bolt. This is typically achieved with a sleeve surrounding the top portion of the bolt at least 150-mm (6-in) long or 10 to 15 times the bolt diameter, whichever is greater, and an inner diameter at least twice the bolt diameter. For a 25-mm (1-in) OD bolt, the protecting sleeve around the top portion of the bolt should be at least 50-mm (2-in) ID and provide a free-stretch length of at least 250 to 375-mm (10 to 15-in) under the nut when fully engaged. The anchor bolt should also extend above the nut a minimum of 2 threads. Finally, the nearest edge of the sleeve should be located at least 4 bolt diameter, or 150-mm (6-in), away from the edge of the foundation block. Please see *Figure 2* for specifics on these recommendations.

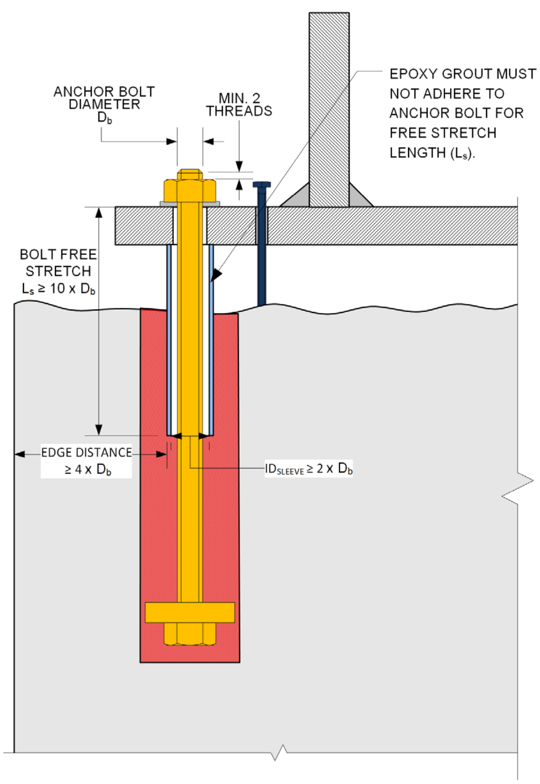

Figure 2: Recommended Dimension of Anchor Bolt

When installing anchor bolts into the concrete block, they should be placed properly to align with the thru holes on the mounting surface of the equipment. Anchor bolts must be perpendicular to the bottom of mounting surfaces. Using a template to assist in accurately positioning the anchor bolts is highly recommended. After placing a sleeve or other method to isolate the anchor bolt threads from the concrete and/or grout, it should be filled with a flexible and sealing material to prevent the sleeve from filling with water, concrete, or grout. Using a rigid material is not recommended, as this would prevent the anchor bolt stretch required for achieving effective bolt preloading. During the surface preparation of the concrete, anchor bolt threads should be covered and protected to prevent damage during the chipping and grouting operations.

EPOXY GROUT DESIGN AND INSTALLATION

Precision epoxy grouting is the critical connection piece between the rotating equipment and the foundation. Epoxy grout is the transfer medium in the equipment system which plays several key roles. First, the epoxy grout must fill the interface between the equipment and the foundation, providing a chemical bond to the properly prepared concrete foundation and maximum effective bearing area to the equipment baseplate, soleplate, and/ or pump skid. This will result in maintaining precise alignment throughout the equipment's life and uniformly transfer vibrations and dynamic loads during equipment operation.

Per API 686, Chapter 5, “Unless otherwise specified, all machinery shall be grouted using epoxy grouts.” Based purely on their chemistry, epoxy grouts provide several advantages over cementitious grouts and are the best for preserving alignment with extreme precision, offering superior load transference and vibration absorption, while at the same time providing outstanding chemical resistance to protect the entire foundation system.

Taking into consideration the three main materials used in foundation construction and the interfaces these components interact with, that being steel, concrete, and epoxy, it is important to understand how these substrates perform as they pertain specifically to vibration absorption. Steel, as one would expect due to the material’s high modulus of elasticity, is extremely poor in vibration absorption. Concrete, similarly, other cement-based materials including cementitious grout, performs slightly better, having about 3 to 5 times better absorption capacity than steel. However, when evaluating epoxy grout chemistry, due to the low modulus of elasticity physical properties, it provides nearly 30 times the vibration absorption capacity of steel and 6 to 10 times better than cement-based chemistry, as shown in *Figure 3*.

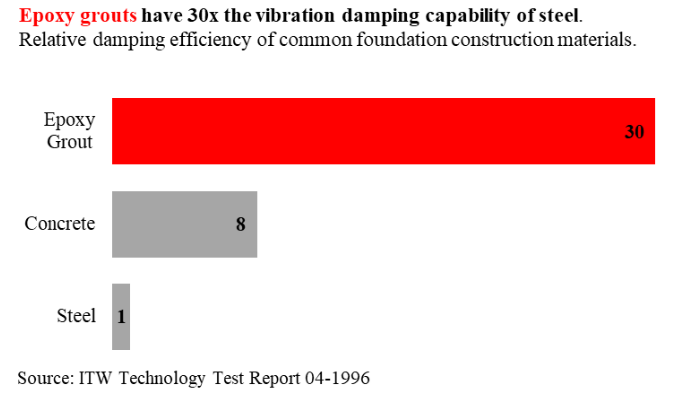

Figure 3: Vibration Absorption Capacity of Common Foundation System Materials

Given the role and benefits epoxy grout chemistry provides, to achieve those benefits, the epoxy grout installation must be performed correctly. When it comes to epoxy grout installation, Chapter 5 of API 686 provides a step-by-step process which helps guide the contractor through the installation process. Following the steps is critical not only to proper installation, but the reliability of the critical equipment the epoxy grout is supporting. The contractor only has one shot at performing this installation correctly, so it is of the utmost importance that the installation steps are followed with extreme attention to detail. Otherwise, the equipment asset owner inherits an unreliable machine resulting in increased maintenance and operation costs and loss of production capacity.

Before any grout work is executed, a pre-job grout meeting is highly recommended and increases the likelihood of a successful epoxy grout pour. It is recommended to have the pre-grout job meeting one week prior to grout placement to clearly walk through the application's specifics and define roles and responsibilities. All stakeholders should be represented in the pre-grout job meeting, including a representative from the asset owner, the grout manufacturing technical representative, the designated machinery representative, the foreman in charge of the grouting activity, a site safety representative, and a representative from the independent testing lab, if a field compressive strength test is going to be performed.

Surface Preparation

Prior to any foundation surface preparation being performed, the foundation must be allowed to cure for a minimum of 7 days to allow for hydration and cure to occur. Also, epoxy grout should never be placed on “green” concrete. Epoxy grout is volume stable, and if placed on concrete that is still hydrating and shirking, this could lead to debonding issues at the grout/ concrete interface. After the foundation is allowed enough time to cure, surface preparation can occur. API 686, Chapter 5 recommends a concrete surface profile of 25-mm (1-in) from peak to valley. This aggressive profile will remove the weak concrete laitance/ cement paste and increase the surface area promoting maximum bond to the foundation of the epoxy grout. While not listed in API 686, Chapter 5, the best practice includes a concrete surface profile that contains a minimum of 50% fractured coarse aggregate, as shown in *Figure 4*. The fractured aggregate is an excellent indicator that the contractor has reached structural sound concrete. If, while performing the

Figure 4: Example of Proper Concrete Surface Preparation

foundation preparation, the aggregate is seen "popping" out of foundation, this is an indication that additional surface preparation may need to be performed, or the concrete is poor.

When performing the surface preparation, a light duty pneumatic or 6.8-kg. (15-lb.) corded chipping hammer with a chisel bit, as shown in *Figure 5*, should be used. The use of a scarifying tool, heavy duty jackhammer, or bushing hammer bit should never be used. Far too often, a bushing hammer is used to perform surface preparation. Industry does not recommend a bushing hammer as this pulverizes the top surfaces of the foundation, causing micro-fracturing and weakening of the system.

When possible, it is recommended to allow a 50 to 75-mm (2 to 3-in) grout shoulder around the perimeter to the baseplate, which will allow for enough room for the epoxy grout to be placed and air to escape. Minimizing the grout shoulder will reduce the possibility for issues, such as cracking or edgelifting, to occur, as we are reducing the amount of unrestrained area. In some instances, such as undersized foundations, the epoxy grout will need to be taken to the edge of the elevated concrete foundation. If the epoxy grout is being taken to the edge of the foundation, API 686, Chapter 5, recommends a 50-mm (2-in) chamfer at 45-degree angle be cut in to the corners of the concrete around the perimeter. While not listed in API 686, Chapter 5, the best practice for the edge of slab concrete detail is to install rebar pins to assist with epoxy grout bond to the foundation, especially for installations with grout shoulders greater than 150-mm (6-in) outside the perimeter of the baseplate. The pins should consist of the following:

Figure 5: Example of a Chisel Bit

- Hammer drill a hole in the concrete for a minimum of at #3 rebar/ pin
- The pin should be placed on the inside of the top vertical mat of concrete foundation and a minimum of 100-mm (4-in) below the horizontal top
- Pins should be placed every 300 to 450-mm (12 to 18-in) on-center around the perimeter
- The pin can be dowelled in using a post-installed chemical anchoring adhesive or the epoxy grout that will be used for the equipment grouting
- Pins should have a minimum of 25-mm (1-in) of epoxy grout cover

Combining proper concrete surface profiling, edge of slab detailing, and pinning will result in the greatest likelihood that edgelifting will not occur. Please see *Figure 6* for an example of effective pinning of the edge of a foundation.

After concrete surface preparation has been completed, the foundation must be thoroughly broomed and/ or air-blown, using clean, oil-free air, to free the surface of dust. The foundation must also be kept free of any bond-breaking contaminants, such as oil, dirt, and water. Plastic sheeting is effective to help protect the properly prepared foundation prior to epoxy grouting.

It is also critically important to check and perform proper surface preparation to the underside of the skid, baseplate, soleplate, etc., prior to installing the epoxy grout. The OEMs are instructed to apply a "grout compatible" primer to the underside of the mounting plate which aids in both corrosion protection and epoxy grout bond to the primer. Oil, grease, dirt, etc. shall be removed by solvent wiping the grout surfaces of the mounting plate prior to grouting.

If the OEM has not installed a "grout compatible" primer, the mounting plates shall be blasted to "near white metal" to remove any rust/ scale and care must be taken to avoid damage to machined surfaces. Final cleaning shall be performed by solvent wiping the area, allow the solvent to flash-off, and then immediately apply a "grout compatible" primer before oxidation is allowed to take place.

Figure 6: An example of Grout Pinning

Anchor Bolt & Jackscrew Preparation

When it comes to anchor bolts, it must be verified that the anchor bolt sleeves/ cans are filled with a non-bonding, moldable material that will prevent the epoxy grout from entering. A frequent practice is to use expandable, insulating foam for this application. This material will prevent water accumulation in the anchor bolt sleeves/ cans and is pliable enough to allow for a small anchor bolt movement for alignment purposes. Per API 685, Chapter 5, anchor bolt sleeves are not intended to provide sufficient movement to allow for gross misalignment of anchor bolts to their mounting plate holes. Lateral movement for alignment purposes should not exceed 12-mm (½-in).

It is critically important to isolate the anchor bolts prior to epoxy grout placement. The anchor bolt threads should be covered with duct tape, foam pipe insulation, or other suitable means to keep them clean, to prevent any damage that might occur during the chipping and grouting operation, and to keep the epoxy grout from bonding to them. Ensure that the anchor bolt stretch length after grouting will provide a minimum of 10 to 15 bolt diameters of stretch length. Jackscrews must also be isolated to allow for removal after grout has properly cured and final anchor bolt torquing is going to be performed.

The baseplate level is achieved by adjusting the jackscrews and then tightening with minimal torque of not more than 10% of final torque value to the anchor bolt nut to hold the baseplate in place. Shims and wedges are not to be used as these devices cause point loading of the foundation, leading to potential future foundation issues. Furthermore, the use of shim and wedges does not allow the epoxy grout to be put in compression which results in zero load transfer and excess equipment vibration.

Expansion Joints
The expansion joint breaks up the epoxy grout pour into smaller volumes. Breaking up the grout pour provides a couple of key benefits. One, by breaking up the pour, the volume of epoxy grout that is placed in each section is controlled. By controlling the volume of epoxy grout, this helps to control the exothermic reaction of the epoxy grout during the curing process. When mixing epoxy grout, epoxy resin is combined with a hardener, which results in a chemical reaction. The chemical reaction is considered exothermic, so the material will produce heat during curing. By controlling the volume of epoxy grout, the volumetric effects of the chemical reaction can be considered to control the exothermic reaction, resulting in a reduction of potential issues, such as cracking and edgelifting.

The expansion joint also provides the epoxy grout room to expand as in-service temperatures rise during operation. The coefficient of thermal expansion epoxy grout is about 2 to 4 times greater than concrete and steel. So, as in-service temperatures rise and fall, the epoxy grout expands and contracts at much higher levels, so the expansion joint allows for this movement to occur.

Figure 7: An example of a typical Expansion Joint Layout

Per API 686, Chapter 5, expansion joints shall be made up of 25-mm (1-in) wide, closed-cell neoprene and shall be placed at approximately 1.4 to 1.8-m (4 to 6-ft) intervals down the length in the grout foundation. Please see *Figure 7* for an example of placing expansion joints. The breaking up of the large epoxy grout pour into these smaller epoxy grout pours makes placement of the epoxy grout much easier for the installer, resulting in a high-quality installation. While staying within the 1.4 to 1.8-m (4 to 6-ft), it is important, if possible, not to bridge internal crossmembers and/ or mounting plate and keep a minimum of 75-mm (3-in) away from anchor bolts and jackscrews to allow for proper epoxy grout filling of the pour area. The depth of the expansion joint should be about 12-mm (½-in) thicker than the grout pour itself. For example, if the grout pour is 50-mm (2-in) deep, the expansion joint should be 62-mm (2 ½-in). Oversizing the expansion joint and "glueing" the expansion joint with RTV silicone, combined with the weight of the equipment, will allow the expansion joint to remain in place during the grout pour.

Formwork
At this stage of the grouting preparation, it is time to install the formwork. Per API 686, Chapter 5, all grout forms shall be built of materials of adequate strength and securely anchored and sealed to withstand the head pressure and forces developed by the grout during placement. Grout forms shall be attached to the foundation with drilled anchors, and using a power actuated tool is not permitted. The inside surfaces of all grout forms shall have three coats of paste wax applied to prevent grout adherence. It is important to apply the wax prior to placing the grout forms to prevent wax from contacting the foundation, resulting in contamination of the grout bonding surface. Grout forms shall be properly sealed to prevent grout leakage. Grout leaks will not self-seal. RTV silicone rubber can be used for sealing forms, but a non-curing sealant would be needed for sealing leaks in formwork. Grout forms shall have 25-mm (1-in.), 45° chamfer strips at all vertical corners and at the horizontal top surface of the grout. All chamfer edges required in the grout should be incorporated into the forms as epoxy grout cannot be easily cut or trimmed after hardening. Smoothing and cleanup of rough areas can be accomplished with a disc grinder after the grout has cured and forms are removed.

Temperatures
Ensuring proper temperatures of the complete system before, during, and after epoxy grout installation, in both hot and cold conditions,

is perhaps one of the most critical steps in the entire grouting operation and the installation step which tends to take the most time to be performed correctly. Temperatures are a major factor in the physical property development and the flowability of the epoxy grouts material. The colder the grouting operation and material, the slower the physical property strength gains, and vice versa for warm temperatures. The same holds true for the flowability of the epoxy grout in colder temperatures. The colder the grouting operation, the slower the flow of the material, whereas the warmer the material is the better the flow.

API 686, Chapter 5 does provide guidance on the temperature ranges of the equipment system. All epoxy grouting components: Part A – Resin, Part B – Hardener, and Part C – Aggregate, are to be clean, dry, unopened containers and have been stored at a temperature of approximately 18 to 29°C (65 to 85°F) for at least 48 hours prior to grouting. The foundation and metal surfaces are to be within 18 to 32°C (65 to 90°F). To help reach these temperature ranges, weather-protective cover, or shelter, may be necessary during inclement weather conditions. Wind, sun, rain, and ambient temperatures will influence the quality of a grouting installation. During hot weather, the foundation and equipment should be covered with a shelter to keep the uncured grout from being exposed to direct sunlight as well as dew, mist, or rain. In cold weather, a suitable covering to allow the foundation to be completely enclosed shall be constructed. A heating source should be provided to raise the entire foundation and equipment temperature to above 18°C (65°F) for at least 48 hours before and after grouting.

Mixing and Placement

Once all the temperatures for the epoxy grout components, foundation, and metal surfaces meet the requirements, the mix and placement of the material can begin. Per API 686, Chapter 5, no partial units of epoxy, resins, hardener, or aggregate are to be used. For example, a complete unit of epoxy grout, depending on the epoxy grout being used, consists of (Qty. 1) Part A – Resin, (Qty. 1) Part B – Hardener, (Qty. 4 - 5) Part C – Aggregate. That said, all the components of the epoxy grout material are to be used. In some situations, especially if proper temperature pre-conditioning does not take place, installers may withhold half a bag to one bag of aggregate to help the epoxy grout material with better flow characteristics. While this reduced aggregate loading does improve the flowability of the epoxy grout material, a couple other especially important aspects take place. When aggregate is reduced, every physical property of the epoxy grout is reduced, meaning the compressive strength is lower, the coefficient of thermal expansion is much greater, the propensity to induce air in the material is increased, and the epoxy grout reaches a higher peak exothermic reaction. Also, the yield per unit will be reduced, so the owner will pay more for a lower performing product. There may be instances where reducing the aggregate loading is permitted which API 686 addresses, with the use of rapid-flow grouts, though this shall be limited to applications where the depth of the grout pour is less than 19-mm (3/4-in.). The reduction of aggregate quantity in grout mixtures to improve flow properties is not permitted. Rapid-flow epoxy grouts shall not be used unless specifically approved by the user.

The resin and hardener are to be mixed at 200 rpm to 250 rpm with a jiffy-type mixer, also called a dual ribbon mixer and is attached to a drill motor, for the grout manufacturer's specified time prior to introducing the aggregate. Do not use a paint mixer as it can create a vortex that introduces air into the mixture. There should be no entrained air in the resin/hardener mixture.

The blended resin and hardener are then poured into the mortar mixer and full bags of aggregate are to be slowly added and sufficiently mixed to completely wet-out the aggregate. Grout shall be mixed in a clean, slow-speed (15 to 20-rpm) portable mortar mixer, as shown in *Figure 8*. A concrete mixer is not permitted. Mix only long enough to completely wet the aggregate. Overmixing will introduce excessive air into the mixture and reduce the grouts strength and can also result in voids. For small pours, grout can be mixed in a clean wheelbarrow with a mortar hoe.

Figure 8: Example of a Horizontal-type Mortar Mixer

The placement of the mixed epoxy grout can be performed in one of two ways: (1) placing from one side to the other as shown in *Figure 9*, or (2) placing from the middle as shown in *Figure 10*, utilizing the grout holes in the top deck of a pump skid for example. In either placement scenario, it is critical that head pressure is built and maintained. Whichever method is utilized to create head pressure, i.e., headbox, traffic cone, etc. at no time should these devices become empty as this will negatively impact the ability of the epoxy grout to flow, and greatly increase the potential for voids and trapping air under the equipment.

Figure 9: An example of using a Head Box to create head pressure

Figure 10: An example of using a cone to create head pressure

According to API 686, Chapter 5, avoid pouring grout around the entire outer perimeter of the mounting plate to prevent air entrapment. Do not use vibration to facilitate grout flow, as this can separate the aggregate from the resin binder. Instead, limited use of push tools with long strokes, rather than short jabs, may be employed to help distribute the grout. Violent ramming of the grout is prohibited.

Additionally, the grout volume should be compared against the estimated cavity volume to check for air pockets and insufficient filling. Regularly checking for grout leaks is recommended, as leaks will not self-seal and can cause voids if not addressed.

Per API 686, Chapter 5, a final check of the soleplate's elevation and level should be conducted before the grout sets. Air bubbles rising to the surface of epoxy grout on the grout shoulders can be removed by lightly troweling or brushing the surface. If necessary, spray the top surface with the grout manufacturer's cleaning solvent or another approved product. Troweling and brushing should be done in a way that prevents excessive blending of the grout solvent into the grout surface. Remove any grout head boxes once the grout has sufficiently set. Do not plug any baseplate fill and vent holes until the grout has set, as this can cause base distortion due to grout expansion.

Typically, within three days of pouring the grout, or sooner depending on ambient temperature, the grout should be hard enough to remove jackscrews and grout forms, and to perform the final torquing of the anchor bolts.

For API pumps, the post-grout cure level criteria is less than 0.417 mm/meter (0.005 inches per foot) both longitudinally and transversely. Mounting plates that settle unevenly or beyond the specified level tolerance must be corrected. Correction methods may include removal and regrouting or field machining of the equipment mounting surfaces.

Figure 11: Example of Finished Grout Shoulders

Mounting plate jackscrew holes and exposed shoulder expansion joint areas should be filled with a flexible sealant material, such as RTV silicone rubber.

Checking for Voids

According to API 686, Chapter 5, after the grout has cured, inspect for voids by tapping along the top deck of the mounting plate. Mark any void areas for proper identification when filling. A solid thud indicates a solid area, while a hollow, drum-like sound indicates a void that requires filling.

Grout voids should not be considered normal. They result from either an inadequate mounting plate design or improper grout placement. If voids are consistently found in most grout pours, a thorough review of the equipment design and grouting procedure is needed.

To fill the void areas, drill 1/8 NPT holes in opposite corners of each void. Tap one hole in each void for the installation of a 1/8" NPT grease fitting, while the other holes serve as vents. Pump neat epoxy resin into each void using a grease gun until the grout emerges from the vent holes. Exercise caution when filling voids, as high pressures from the grout gun can lift or distort the baseplate. Remove all grease fittings once the process is complete.

CONCLUSIONS

Designing and constructing the appropriate foundation system and precision epoxy gout is essential for the optimal performance of rotating equipment. The goals when executing this type of project scope are to maximize reliability, reduce maintenance costs, and extend the MTBF (mean time between failure) as much as possible so planned downtime can be optimized and unplanned downtime can be prevented. There are many details within the foundation system and precision epoxy grout to be engineered and executed in the field to assure these results are achieved and the owners of this system maximize the return on their investment. Utilizing industry standards, design criteria, and industry experts will assist in achieving a successful project.

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