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Recommended Mounting of Turbomachinery

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ABSTRACT

At the heart of nearly all industrial environments, dynamic and critical equipment must be ensured to have high reliability and efficient operation. An effectively designed and executed foundation system is imperative for meeting these objectives. A proper foundation system is vital to preserving the precise alignment of the machinery throughout the service life, effectually handling unbalanced forces and cyclical loads, all while preserving the integrity of the overall system.

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 to increase clarity around the effective recommendations.

Specific topics to be discussed will include, but not be limited to:

- System considerations to promote reliable machinery foundations.
- Usage of epoxy-based formulations versus alternative technologies.
- Specifics of pre-installation preparations, including preparation of mounting surfaces, establishing alignment, and conditioning the application area.
- Effective mixing and installation recommendations.
- Curing time of mounting products.
- Treatment of anchor bolts in the foundation system.

INTRODUCTION

While the initial expenditures associated with the procurement and installation of dynamic equipment are typically less than 10% of the total life cycle costs, a focus on this portion of the process is vital to achieving the overall goals of operating with high reliability and efficiency through the life of the equipment. Specifically, more than 85% of the total life cycle costs of most dynamic equipment are associated with energy consumption. In evaluating the common causes associated with wasted energy in pumping, only 6% are commonly associated with operational issues but 34% are due to decisions made during the initial design. Many of these poor decisions have been attributed to the practice of fast-tracking or using common and typical designs and methods that do not consider the unique operating environment and requirements. In an analysis of failure causes of pumps, nearly 85% could be traced back to a lack of proper consideration for the design and installation of the equipment as a component within an effective foundation system.

To create a foundation system enabling high operating efficiency and overall reliability, a design and installation must consider the unique aspects of the operating environment that will be experienced by a piece of dynamic equipment. It is important to remember that there is no “one size fits all” approach when designing and executing the foundation system, even when using industry guidance such as API Recommended Practice 686. Key to creating this understanding is early and ongoing engagement with key stakeholders and influencers, including knowledgeable representatives of the manufacturers of the foundation system components as well as experts in the on-site execution of the design. The inclusion of these stakeholders ensures an understanding of designing the entire foundation system to meet the true requirements of the application and ensure a successful field installation.

This paper will provide guidance on selecting, designing, and installing an effective transfer medium of the foundation system based on a thorough understanding of the operating environment. Further, it will be shown how the effective collaboration between foundation experts promotes the long-term integrity of these critical systems which directly increases energy efficiency and operational reliability, leading to increased overall asset profitability.

SYSTEM CONSIDERATIONS TO PROMOTE RELIABLE MACHINERY FOUNDATIONS

When performing a comprehensive design of an effective foundation system, the following components should be considered at a minimum:

- Dynamic equipment
- Baseplate/mounting footprint of dynamic equipment
- Anchor bolts
- Alignment devices
- Load transfer medium
- Concrete foundation
- Sub-foundation/concrete mat
- Sub-surface/soil

Please see *Figure 1* for more details on the components of a foundation system.

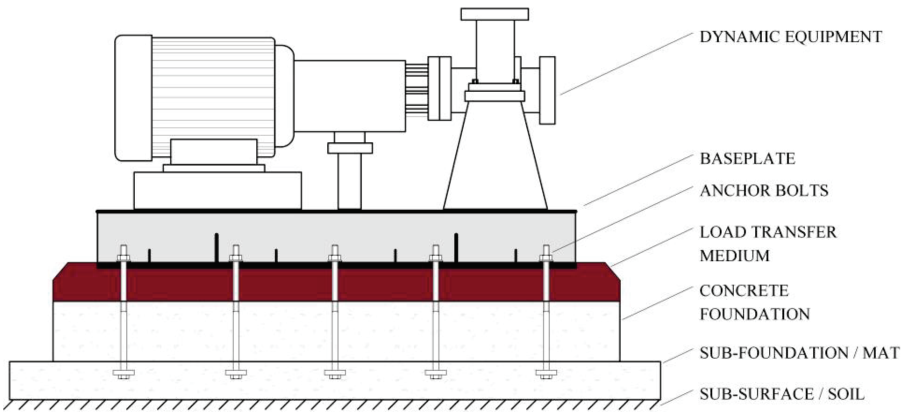


Figure 1: Components of a foundation system

To be effective, a machinery foundation design must accomplish the following primary functions:

1. Preserve the position of the equipment within established tolerances.
2. Mitigate vibrations and other forces generated during equipment operation.
3. Protect the foundation system from the operating environment.

While the primary functions of a mounting system may be considered simple, effective execution is typically more complicated. Achieving reliable, long-term operation of machinery relies upon establishing an interconnected foundation system without separation between the individual components, referred to as a "monolithic" structure. A monolithic structure integrates the individual components into what behaves more as a seamless, rigid body without any breaks between the components. In practice, this means that all the components must be connected such that they act as a single entity.

SELECTION OF TRANSFER MEDIUM TECHNOLOGY BASED ON APPLICATION REQUIREMENTS

While there are many decisions to be made regarding the selection of components for an effective foundation system, one of those that receives the most attention is the selection of a transfer medium technology to connect the equipment to the remainder of the foundation system. From the perspective of creating an overall monolithic system, the transfer medium serves the following primary functions:

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

The most common types of transfer medium technology that are considered include concrete, cement-based grout, and epoxy-based grout. There are multiple industry groups and sources that attempt to provide guidance, and these are summarized below.

Guidance for the usage of concrete

In general, concrete is recommended for general-purpose or mass-filling types of installations. A common example of the usage of concrete as a component of dynamic equipment installations is typically for the main foundation block or the foundation mat.

Guidance for the usage of cement-based grout

In general, non-shrink cement-based grout technology is commonly recommended for static installations as well as equipment with low criticality or low dynamic forces generated during operation (or both). It is recommended that any cement-based grout should conform to ASTM C1107 at a minimum. A common example of the usage of cementitious grout as a component of dynamic equipment foundations is as a reduced-time concrete substitute in foundation block repairs. In addition, specially formulated cementitious grouts are often used in high temperature applications that exceed the allowable limits of epoxy-based grouts, such as mounting of turbines and boilers.

Guidance for the usage of epoxy-based grout

Epoxy grout formulations are the preferred recommendation for transfer mediums under equipment considered critical to asset operation and/or experiencing high dynamic loadings. These include installation under common high-dynamic equipment such as pumps, compressors, fans, blowers, and mills. Unlike cement-based grout formulations, there is currently no standard to establish minimum physical properties.

Considerations when determining transfer medium technology for a specific application

While there are valuable industry recommendations available to assist, the decision of which class of technology is most appropriate is not always straightforward. Industry specifications including API Recommended Practice 686 and ACI 351 are good places to start, though many in-house specifications provide specific technology selection criteria based on operational factors, such as the size, weight, throughput, or engine power. In addition, it is recommended to consider the following aspects when determining the most appropriate type of technology for a given application:

- The expected service life of the foundation system
- Environmental & operational exposures and conditions
- Requirements for high adhesive connections
- Expected static loading
- Alignment tolerances
- Expected dynamic loads
- Potential for vibrations

- Criticality of asset
- Time available for equipment to be offline

For installations of dynamic equipment, epoxy-based grout technology is typically recommended and used because of its low shrinkage during curing, high adhesive capabilities, high resiliency to dynamic loads, and overall high physical properties.

One more important consideration - while most epoxy-based grout formulations will not publish an absolute service temperature range, they will commonly be less effective above temperatures of 200°F (93°C). There are cement-based formulations that are published for operation at elevated temperatures that may be suitable solutions.

Considerations when selecting a specific transfer medium solution for an application

The final decision related to transfer medium selection is choosing from a range of potential solutions after determining the most appropriate class of technology for the application. Depending on the technology, a comparison of relevant physical properties is often performed, with guidance available from industry standards such as PIP STS03600 for cement-based grouts or PIP STS03601 for epoxy-based grouts. Recommended considerations include the workability of the product, usually measured by working time/pot life and flow evaluation, volume change, strength, and durability, often measured by chemical and impact resistance.

TREATMENT OF ANCHOR BOLTS IN THE FOUNDATION SYSTEM

Anchor bolts are an integral part of the setting of a piece of dynamic equipment. Simply stated the transfer medium, grout, holds the equipment up and the anchor bolts hold the equipment down. When the dynamic force of rotating equipment spins in the vertical direction, the anchor bolts provide resistance to this motion. The transfer medium, through proper preparation of the base and the foundation, offers adhesive properties, and the anchor bolt keeps this transfer medium loaded in compression.

There are different types of anchor bolt installations. Some anchor bolt systems are embedded in the foundation, embedded in the epoxy grout, or core drilled and set in epoxy.

Anchor bolts that are embedded in the foundation are installed within the rebar cage of the foundation block. The anchor bolt assembly at a minimum should have a nut at the bottom or even a resistor plate used as an anti-pull-out device. The precise location is set in the x, y, and z planes and tied to the rebar cage of the foundation block. The upper portion of the anchor bolt will either be wrapped or have sleeves around it. Once these are located the foundation is poured typically in concrete and the entire foundation block is poured in one lift. This will have material above and below the bottom of the anchor bolt's anti-pull-out device. When the anchor bolt is pulled it will load the cured concrete in compression.

Like embedding anchor bolts in concrete, they can also be embedded in epoxy. This option may be chosen to accelerate the curing of the foundation, as epoxy typically cures in a day rather than 28 days like concrete. Epoxy will also allow for multiple lifts and the next layer will chemically bond the previous layer forming a monolithic pour with no cold joints like would be found in multiple lifts of concrete. When you cannot set in the exact location of a piece of equipment the foundation may be poured, and large holes may be formed out in the foundation allowing for the equipment to be set in place using the equipment frame as a template to locate the anchor bolts. Once this location is set the pocket can be filled, typically with epoxy grout encapsulating the anchor bolt.

When there is an existing concrete foundation and a new piece of equipment being installed often the anchor bolts don't line up with the existing anchor bolts in the foundation. Another common occurrence is the bolts may have failed and sheared off. When this is required, the foundation is core drilled. The core is typically a half-inch or so wider in diameter than the nut or resistor plate diameter at the bottom of the anchor bolt. A rule of thumb would be three times the nominal diameter of the anchor bolt. For example, a 1" (25-mm) anchor bolt would have a 3" (75-mm) diameter hole cored to set in the anchor bolt. Please see *Figure 2* for additional detail. This is to

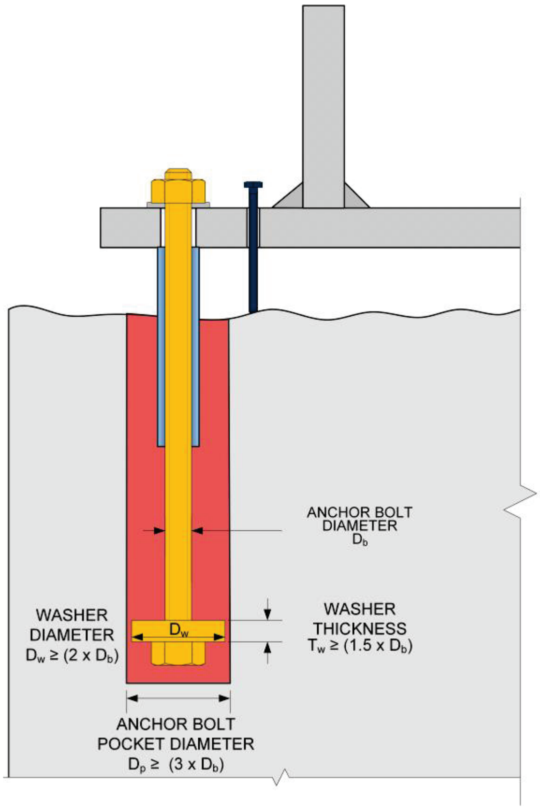


Figure 2: Recommended Dimension of Anchor Bolt Pocket

allow the epoxy to fill the void around the anchor bolt and pass below the resistor plate or nut on the bottom. You want to have a little mass to the epoxy that is poured in so it will generate enough heat in the exothermic reaction to properly cure. When installing an anchor bolt in this method it is recommended that the anchor bolt not touch the bottom of the core and be suspended when the epoxy is being poured and during the curing process.

When we look at the design of an anchor bolt, the first thing that is considered is the type of material from which the bolt is made. The material chosen is directly related to its physical properties determining the strength needed in the clamping force on the system. Most anchor bolts are made from a mild steel, such as ASTM A36 Grade, which has an ultimate tensile strength of around 58,000 to 79,000 psi (400 to 545 MPa). This is written in many specifications, however, more commonly used today is an ASTM A193 which has an ultimate tensile strength from 75,000 to 125,000 psi (517 to 862 MPa). This is typically the more commonly used material for anchor bolts. There are steel choices that are stronger than this, like ASTM A286 which is aircraft or nuclear quality and often not required or used for dynamic equipment outside of that specific setting.

In designing an anchor bolt, we typically look at the anchor bolt in two parts, the upper and lower sections or free stretch and embedment. The upper part of the anchor bolt includes the length through the base plate, washer, nut, a minimum of 2 threads above the nut, and a minimum of 12 bolt diameters below the bottom of the base. The minimum 12-bolt diameter is known as the free stretch length. This free or stretch length is typically embedded in the foundation and inside a sleeve. The area of the anchor bolt stretch length that runs through the grout is typically wrapped with duct tape or foam round insulation to isolate it from the transfer medium. We want this upper length to stretch when the nut is tightened, or the bolt is torqued. This is where your clamping force is applied. The lower portion or embedment is what is in the foundation and encased in the foundation concrete or epoxy. This portion of the bolt is what does not move and holds the bolt in place. The bottom of the bolt has a minimum requirement to have a nut on the bottom to act as an anti-pullout device. It is more common practice to install a resistor plate that is a larger diameter than the bolt and circular to not cause any stress risers in the concrete foundation. This gives a larger surface area to load the material above the resistor plate which is typically concrete in compression. This helps to ensure that the anchor bolt does not move. This is typically around 3 times the bolt diameter with varying thicknesses depending on the size of the anchor bolt. Please see *Figure 3* for additional information.

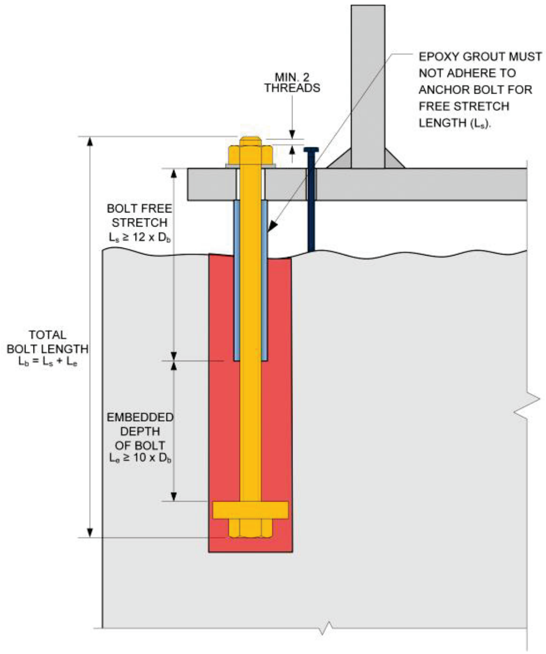


Figure 3: Recommended Dimension of Anchor Bolt

The manufacturer of dynamic equipment will often fabricate and supply a base plate for their equipment and leave a hole(s) in the outer perimeter of the base plate for anchor bolts. This hole size dictates the nominal diameter of the anchor bolt for that system; however, it does not take into consideration stretch or embedment. The holes are typically a quarter inch wider than the nominal bolt size that goes through the hole. The locations along the base are to evenly distribute the clamping force to the base and load the transfer medium in compression to have the system maintain precise alignment.

The anchor bolt's purpose is to apply and maintain a clamping force on a base and load the transfer medium in compression. The anchor bolt is not meant to support the base before it is grouted in with a jam nut below the base supporting it. The anchor bolt should only have a nut on top of the bolt to torque and one embedded as an anti-pull-out device on the other. When applying the clamping force in the bolted connection the energy can be stored in one of three ways:

- Elastic Energy of the stretched bolt.
  This offers the most amount of stored energy in the system.
- Elastic energy of the compressed transfer medium
  This offers a small amount of stored energy.
- Elastic energy of the compressed metal parts.
  This also offers a small amount of stored energy.

This is why it is so important to allow for the stretch length as that provides almost all the stored energy in the system.

If the anchor bolt is not tight or properly torqued, then it is not applying an effective clamping force. When applying load to a new anchor bolt, the bolt should be torqued and released at least two times before the final torque. This will get the bolt moving for applying the effective clamping force. Additionally, the bolt tensions should be verified after the equipment has been in operation for enough time to reach the expected operating temperatures, as heat generated by the equipment may heat the bolt, resulting in thermal expansion which can reduce the effective clamping force. Once the equipment is up and running, it is recommended to verify the torque values at 7 days, a month, six months, and every six months. Based on the results of the initial checks, the frequency of verification can be adjusted.

SPECIFICS OF PRE-INSTALLATION PREPARATION & PREPARATION OF MOUNTING SURFACES

Foundation Preparation

Before the grout installation, the foundation must be prepared to ensure the intended longevity of the foundation-grout-equipment system. This includes verifying the foundation meets all design criteria. Per industry standards, the compressive strength of the concrete in the foundation should be reached prior to performing foundation preparation. The compressive strength of the concrete should be 4,000 psi (27.6 MPa), minimum, or as designated by the user. Sufficient compressive strength ensures that the foundation will be able to handle the load of the equipment and its imparted dynamic forces throughout its intended lifecycle. The physical dimensions of the foundation should be verified to be within design constraints. Sufficient mass is necessary to resist the forces enacted upon it by the equipment during all modes of operation and should be large enough to support the entire load-bearing area of the equipment. Foundation anchor bolt locations should be verified to coincide with the equipment mounting bolt locations as required by the equipment manufacturer. A best practice is to ensure that every entity involved with the foundation construction has the most up-to-date revision of drawings to prevent major setbacks in the field.

After the foundation has been poured, appropriate cure time must be observed to allow the concrete to reach its desired strength and allow the capillaries to dry to remove excess moisture. The typical minimum curing for standard concrete is 28 days unless high early strength formulas are used and approved through design. Curing time can also vary with ambient conditions, with cooler temperatures and wet conditions slowing the process, while warmer, drier conditions accelerate the process. Throughout the curing and foundation prep process, the foundation concrete should be maintained uncontaminated, as porous concrete can absorb oils, coolants, etc. that can inhibit the grout bond. Water or excess moisture in the concrete causes uneven curing of epoxy mortar grout.

Figure 4: A 33lb. Rivet Buster with a 1" Chisel Bit

The subsoil is a critical component that supports the entirety of the project. It must meet the design criteria for content, compaction, and bearing capacity. Issues such as groundwater migration or contamination must be mitigated before the installation of the foundation. Improperly prepared subsoils can lead to structural failure of the foundation, high equipment vibration, and alignment issues, shortening the life of the equipment and increasing maintenance costs.

The foundation should be inspected and verified that there are no structural cracks, voids, or other defects that would compromise its intended design. Voids can occur when the concrete is improperly vibrated on installation. Missing components such as changes in anchor bolt pattern or quantity, locations for accessory components, etc. should be checked against the latest revision of the construction package. The finished elevation of the concrete should be verified to ensure that the proper gap is achieved after chipping to allow grout installation.

For the epoxy mortar grout to properly support the equipment, the weaker surface material on top of the foundation, or laitance, must be removed to expose sound concrete in agreement with the desired mechanical properties of the concrete. This is accomplished by chipping the top layer off the foundation, a minimum of 1" (25-mm) material removal using a rivet buster or chipping hammer fitted with a chisel tip as noted in *Figure 4*.

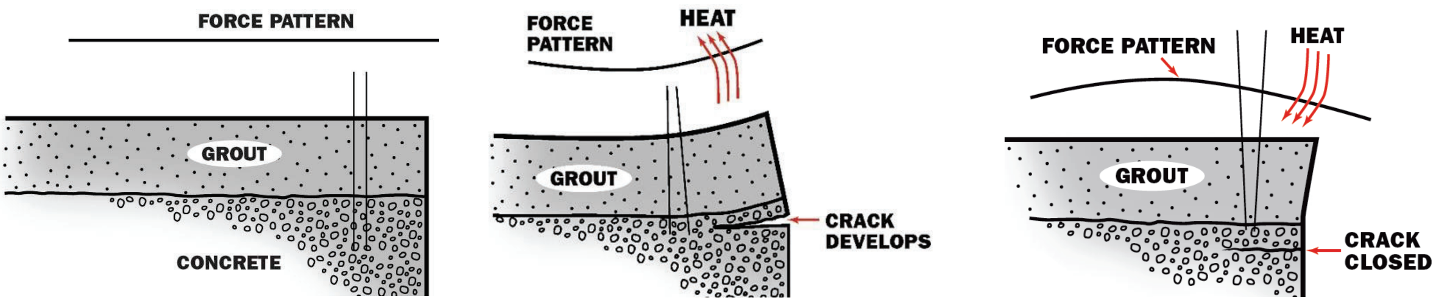
The use of pointed tips creates holes that increase air entrainment. Bushing the surface of the foundation, while commonly seen, causes micro-fissures that create a weak layer at the bond line between the foundation and the grout installation. The action of chipping also confirms proper bonding of the coarse aggregate to the Portland cement when the coarse aggregate exposed is fractured as demonstrated in *Figure 5*. If a large percentage of the coarse aggregate is observed to pop out during chipping, this indicates weaker material. Jackhammers or other heavy demolition equipment should never be used as they cause structural damage to the foundation. Abrasive blasting, shot blasting, or the use of a scarifier will not remove sufficient laitance to expose and fracture coarse aggregate. Chipping should be performed to provide a minimum 2" (50-mm) gap between the bottom of the equipment and the top of the concrete, creating a 1"-1.5" (25 - 38-mm) peak-to-valley profile for proper flow and exceptional bonding of the grout material as seen in *Figure 6*. The chipped area should be constrained, as possible, to the mounting area of the equipment or baseplate, with shoulders to allow grout installation. The shoulder should be minimized to what is necessary for

Figure 5: Fractured Coarse Aggregate

installation where possible, and a width-to-depth ratio of less than 1:1 is ideal. Grout should not be installed in unconstrained areas, i.e., significant areas that are not covered by the equipment load-bearing areas. Cleanliness is imperative to the success of the project. Rubble should be removed periodically during the chipout, and the chipped areas are thoroughly blown off with clean, dry, oil-free compressed air to remove dust and debris. Covering the foundation overnight, during breaks, or following completion of the chipping will prevent contamination from inclement weather, neighboring equipment, etc. Pressure washing to remove dust or debris leaves a thin, bond-breaking layer on the foundation that can aid in compromising the bond of grout material.

Figure 6: An example of a properly chipped foundation

Edge lifting is a phenomenon that occurs predominantly in outdoor installations due to the difference in thermal expansion coefficients and thermal absorption and dissipation rates between grout and concrete or steel. Epoxy grout has a coefficient of thermal expansion that is roughly twice that of concrete or steel. These differences create cyclic loading at the grout surfaces that are exposed to varying ambient conditions, i.e., the shoulders. As ambient temperatures increase or ultraviolet radiation from the sun occurs, the grout shoulder expands more than the underlying concrete foundation. During night-time or in cooler weather, the grout shoulder contracts at a higher rate than the underlying concrete, placing the grout-to-concrete bond interface into a tensile state. Because the weak link is concrete's tensile strength, failure of the concrete occurs at the bond interface as is depicted in *Figure 7*, allowing oil intrusion to further degrade the concrete over time, and causing eventual loss of support for the equipment. Precautions should be taken to prevent edge lifting of the grout installation. These precautions include the aforementioned width-to-depth ratio, rebar doweling, and creating a grout "key".



System in Equilibrium *System Undergoing Cooling* *System Undergoing Heat Input*

Figure 7: Edge lifting of grout

Creating a grout "key", or chipping a chamfer at the edges of the foundation/grout installation, is a method to reduce the width-to-depth ratio of the shoulder (see *Figure 8)* to less than 1:1. Industry standard states at minimum that a 2" (50-mm), forty-five-degree chamfer be chipped to reduce edge lifting. Additionally, a periphery "key" may be installed to increase shoulder depth as needed and provides a more robust shoulder. Installation of the "key" may also expose periphery rebar, allowing the grout installation to bond to the foundation structural steel, further driving unbalanced forces and stresses to deep within the foundation. As an alternative, rebar dowels may be used to reduce the occurrence of edge lifting. Rebar dowels should be installed with a 4" (100-mm) embedment depth utilizing an epoxy adhesive. Installing the rebar "dry" or hammering them in is not acceptable.

The foundation should be prepared for the installation of the equipment to minimize delays in alignment once the equipment has been set. Leveling of the equipment should only be done using removable means to prevent point loading the equipment base. Removable jack bolts prevent point loading and allow removal following grout cure so that the grout can maintain the equipment's position as it was intended. Hard, non-removable shims will cause cracking in the grout installation. Leveling disks are used to provide a suitable flat surface to rest the jack bolts on when setting the equipment, and minimize binding or walking of the equipment when adjustments are made. They should be a minimum 2"-3" (50 - 75-mm) diameter, 1/2" (12-mm) thick stainless steel plate, with one (1) being installed at each jack bolt location, roughly leveled and affixed with an epoxy adhesive.

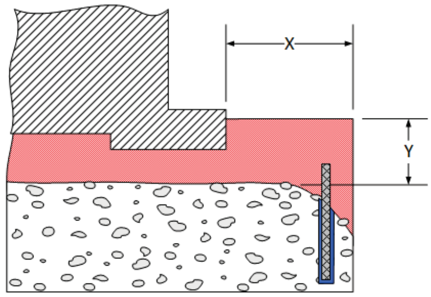


Figure 8: Width-to-depth ratio of shoulder

Foundation anchor bolts are a critical component that links the equipment to the foundation. As such, a portion of the bolt must be isolated to allow for stretching during torquing and normal equipment operation. Without the stretch length, plastic deformation of the bolt will occur during torquing due to the application of tensile force just below the nut, resulting in anchor bolt failure. In most cases, stretch length is provided through anchor bolt sleeves. Ideally, twelve (12) to fifteen (15) times the bolt diameter is the rule of thumb for minimum stretch length. This portion of the bolt, beneath the bottom of the equipment, should be isolated from grout contact with a moldable, oil-resistant material. If sleeves are not provided, then pipe insulation tightly wrapped with duct tape will be sufficient. While these sleeves may be referred to as "grout sleeves," they should never be filled with grout, concrete, or other unforgiving material.

Equipment Preparation

Once the foundation surfaces have been prepared, the equipment grouting surfaces must be prepared to accept the grout. Non-shrink grouts, especially epoxy grouts, create internal stresses during the exothermal curing process. These stresses, in combination with stresses caused by thermal expansion and contraction, can lead to cracking in high-stress areas. To minimize high-stress concentrations in the grout, the outside corners of the equipment baseplate should be rounded to a minimum 2" (50-mm) radius. The grouting surfaces must be prepared to promote grout adhesion. To do this, all bond breakers must be removed, and the proper surface profile achieved by abrasive blasting to near white metal, removing and scale, rust, paint, oil, or other coatings as seen in *Figure 9*. A NACE-1 white metal finish is recommended, as it ensures the cleanliness of the surface. The time between abrasive blasting and grout installation should be minimized to prevent surface rust on the grouting surfaces. Utilizing a wire wheel is never recommended as the deposition of material on the equipment grouting surfaces becomes a bond breaker.

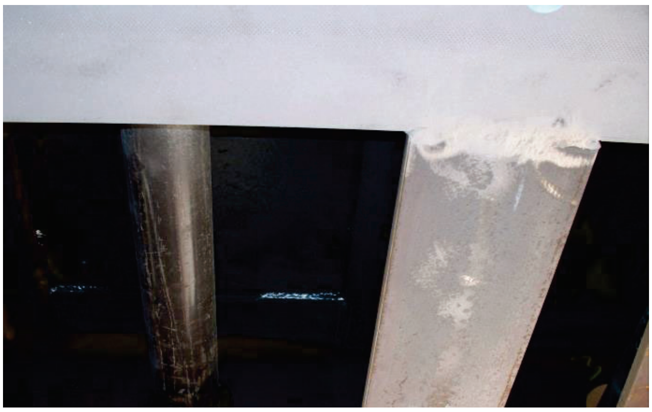


Figure 9: Abrasive blasted skid base flange

When the time between abrasive blasting and grouting is unavoidably long, an epoxy primer may be utilized to inhibit corrosion of the metal surfaces. It is critical to verify the selection of any primer for compatibility with the grout material with an authorized representative of the grout manufacturer. Always follow the manufacturer's instructions regarding mixing, application technique, film thickness, pot life, and grouting window for the primer to ensure success. Primers have a limited time frame after application during which the equipment must be grouted. Outside of that window, additional measures must be taken. Epoxy primers are only meant to inhibit corrosion, they are not bond-promoting agents.

Before setting the equipment or baseplate(s), the elevation of the leveling disks should be recorded, and jack bolts on the equipment should be pre-adjusted to accomplish the desired elevation. Pre-setting the jack bolts expedites the alignment process and prevents jack bolt damage.

Establishing Alignment

Installation, assembly, and alignment of the equipment and equipment baseplate(s), if any, should always follow OEM guidelines. When preparing to set the equipment, protect the foundation anchor bolts by wrapping them with duct tape. Once the equipment has been set, the foundation anchor bolts should have a minimum of 2 threads above the fully engaged nuts. Certain installations may require countersunk anchor bolts with fewer exposed threads. OEM tolerances should be followed. Typically, block-mounted equipment, such as full-bed grout installations, chock installations, or soleplate installations will require closer tolerances during installation as once grout installation is completed, there is little to no room for adjustment. Skid-mounted equipment may have less stringent tolerances as final alignment is usually performed after grout installation is completed, and shimming adjustment is performed at that time. Alignment is completed utilizing the jack bolts as previously noted. Once alignment has been achieved, close tolerance equipment should be allowed to "relax" overnight to provide an opportunity for tweaks or stresses to work out. Because of thermal cycling, the "human factor" and other variables that can affect alignment, performing a final alignment verification immediately prior to grout installation allows the opportunity to make any last-minute corrections before locking the equipment in permanently.

Conditioning the Application Area

Ambient conditions and temperatures of the foundation, equipment, and grout material play a key role in how well the grout pour goes, the cure time of the grout material, and the final product. An enclosure is vital to control grouting conditions and maintain the quality of the installation, whether indoors or outdoors. The enclosure should be adequate to protect the work area from inclement weather, direct sunlight, maintain appropriate grouting temperatures, and reduce the possibility of contamination, as seen in *Figure 10.* Protect the investment by maintaining the cleanliness of the foundation, and equipment for an optimal bond of the grout material. The enclosure roof should be as watertight as possible to prevent rain or other elements outside the enclosure from falling on the foundation. Additionally, covering the foundation grouting areas when work isn't being done will provide an additional level of protection. The enclosure will help to minimize temperature fluctuations, allowing a more consistent alignment. The enclosure should be appropriately sized to allow movement of personnel, during the grout installation, and may enclose only the equipment, or the entirety of the equipment, grout materials, and mixing equipment to make movement during grout installation easier.

Figure 10: Enclosure for Outdoor Installations

An enclosure should always be used in outdoor installations, or when exposure to direct sunlight may occur. Direct sunlight often causes uneven heating of the equipment and foundation, which may result in inconsistent alignment readings. Ultraviolet radiation and increased surface temperatures also accelerate the exothermic chemical reaction and the curing process of epoxy grouts, which may lead to uneven curing and crack development in the grout installation. An opaque roof helps to prevent direct sunlight exposure.

While industry standard states grouting temperatures should be between 65°F-90°F (18°C – 32°C), the ideal temperature range that provides an optimal balance between flowability and longer pot life of epoxy grouts is between 70°F-75°F (21°C – 24°C), targeting no more than a 10°F (5°C) differential between the grout material, foundation, and equipment. Heating or cooling can be utilized to maintain temperatures when ambient conditions are not favorable. Care should be taken to utilize convective, indirect heating, as opposed to infrared heaters or heat lamps. Direct heat causes unwanted localized hotspots on the equipment and foundation. Processes and piping that may pass inside or through the enclosure should be considered as well, such as steam traces, exchangers, boilers, kilns, etc. Always work to maintain the equipment, foundation, and grout above the dew point to prevent sweating. Conditioning should be performed for a minimum of 48 hours before, and 72 hours following the grout installation.

Figure 11: Conditioning of Epoxy Grout Components

The grout material must be conditioned as well to the target temperature, such as shown in *Figure 11*. All grout material should be new, unused, and within the manufacturer's shelf life. Never use different grout materials during the same pour as differing chemistry and mechanical properties will compromise the installation. Aggregates for epoxy grouts are specially selected, graded, blended, and dried materials that need to be maintained dry and verified as dry and uncontaminated before mixing and pouring. A simple field test for excess aggregate moisture is to squeeze a handful of the aggregate. If the aggregate balls up upon release, it contains too much moisture. Always make sure that a sufficient quantity of grout material is on-hand to complete the job, typically an extra 15% - 25%.

POUR PREPARATION

Foundation

In preparation for the pour, measurements should be taken of the foundation to verify that the pour depth is within the manufacturer's recommended tolerances for the material being poured. Typical pour depth is ~2"-3" (50 – 100-mm) deep. Excess pour depth can cause cracking and may require breaking up the pour into multiple lifts. Deep pours can cause voids beneath the load-bearing areas as excess entrained air will rise to the surface. Pours that are too shallow will restrict the flow of the grout material and may potentially lead to voids.

Cementitious grouts typically require pre-soaking of the foundation grouting area for a minimum of 24 hours before the pour to prevent the dry concrete from weakening the bond interface. The grout manufacturer representative should be consulted for recommendations regarding pre-soak for cementitious grouts, or any recommended bonding agents.

Equipment

After the equipment is leveled and aligned, care should be taken to ensure that the equipment is in a fully "relaxed" state without any additional outside influences or stresses that may reduce the installation's longevity. No piping or conduit should be attached. Grouting surfaces, whether abrasive blasted or primed, should be kept and verified as clean, dry, uncoated, or uncontaminated as any contaminant becomes a bond breaker. If surface blush has occurred on blasted surfaces, it can be removed with a clean rag with acetone or a similar non-residual solvent. Never use a wire wheel to remove blush as the surface deposition will become a bond breaker. All areas where grout contact is unwanted should be adequately protected, including jack bolts, anchor bolts, the top side of the equipment, and any holes where grout is to be excluded.

Figure 12: Typical drilled drop-in style anchor

As noted previously, isolating jack bolts for removal is necessary to prevent point loading. Isolation between the bottom of the equipment grouting surface and the top of the leveling disk can be accomplished with a moldable, non-hardening material like duct-seal compound, or with a heavy coat of paste wax on the threads and wrapping with duct tape. Likewise, the stretch portion of the foundation anchor bolts should be isolated with a flexible material from the bottom of the equipment grouting surface down to the bottom of the designated stretch length.

Form Installation

Forming in preparation for the grout pour should not be taken lightly. Formwork should be sufficiently substantial to handle the pressure of the grout installation, as well as the possibility of personnel or equipment bumping into them. Nothing ruins a grout pour quicker than a form failing and spilling grout all over the end user's property. The elevation of the formwork should extend well above the intended pour height, a minimum of 4"-6" (100 - 150 mm) to provide room for pour volume and any head boxes. Larger pours requiring grout to flow farther beneath the equipment will require higher form elevations to maintain head pressure. Installing forms by nail-wedging or power-nailing will cause hairline cracks at the surface of the foundation due to anchor force application at the surface of the foundation and should never be done. Forms should be installed utilizing drilled anchors, such as shown in *Figure 12*. Grout materials, especially epoxy grouts, do not self-seal, therefore, all formworks should be thoroughly sealed to the foundation. Following the installation of the forms, it must be ensured that sealants are applied outside the grouting area and never inside the grouting area.

Figure 13: Installation of formwork

Prior to installation, the forms should have 3 heavy coats of paste-wax on the inside grouting surfaces to enable easy form removal. The use of liquid waxes will not be sufficient, and grease should not be used, as it can contaminate the grout. *Figure 13* provides an example of correct form installation and isolation.

To minimize stress concentrations at the corners of the grout installation, a minimum 1” (25-mm) 45° chamfer should be installed at all vertical corners, and at the desired final elevation of the grout. The chamfer height should allow grout to be poured up the edges of the equipment flange/ baseplate. A head box, or multiple head boxes, should be utilized to direct flow and provide head pressure, especially in the case of larger pours. The head box should hold sufficient volume to maintain grout flow while waiting for subsequent units to be mixed. The head box may be fixed, moveable to cover the pour where needed, or may be incorporated into the formwork.

Expansion Joints

Due to the differences in thermal expansion coefficients between epoxy grouts and concrete or steel, expansion joints are necessary to provide a pre-determined sealed location for thermal expansion and contraction during temperature changes. Expansion joints should be placed at 3’ to 6’ intervals, perpendicular to the equipment rotational axis, as well as high stress concentration areas such as anchor bolts and inside corners. The expansion joints should be made of neoprene rubber or polystyrene foam, ½”-1” thick, adhered to the foundation in the desired location, and made to extend the full depth of the grout pour, from the edge of the equipment to the inside edge of the form as seen in *Figure 14*. The quantity, locations, and intervals of expansion joints should be carefully considered, taking into account the environmental and operating conditions of the equipment.

Figure 14: Expansion Joint Locations

The Pre-Grout Meeting

The pre-grout meeting is an important event that serves as the final communication link between all parties involved in the grout installation before the grout pour is performed. The meeting should be held a minimum of 24 hours before the grout pour. Attendees should include the grout manufacturer representative, the end user representative, the equipment manufacturer, the supervision involved with the grout pour, and any supervision involved with support activities involving the pour.

Every task associated with pre-pour preparation, up to and including the grout pour, finishing, and curing procedures should be discussed, planned out, and documented so all parties involved agree with the steps. Questions about material needs, pour start time, personnel requirements, and assigned personnel tasks for the grout pour should be answered during the pre-grout meeting. A pre-grouting checklist should be formulated and utilized to communicate clear expectations for all parties. An example of a pre-grouting checklist is provided in API 686 Chapter 5. While the pre-grouting checklist provided in API 686 provides a solid starting point, modifications or additions may be necessary to tailor the checklist to the specific project. Plans should be made to determine the grout staging location, mixing location, initial pouring location, pathways to transfer grout after mixing, expected pouring progression, what will be done if there are leaks, unusable units, inclement weather, evacuations, etc. Note that during colder months, it may be advisable to plan to start the pour at midday, while during hotter months, a late evening, nighttime, or even early morning pour may be necessary. Always make sure there is enough personnel to safely and effectively perform the grout pour, without taking breaks. Once the pour has begun, it must not stop until it is complete. The grout pour isn’t complete until finishing and cleanup have been completed. A 15-minute break at the end of pouring could mean the difference between quick easy leveling and cleanup of the grout or 2 days of grinding to level the grout out.

Figure 15: Pre-grout meeting

Safety is of the utmost importance in any grout installation, safe work practices must be utilized. Grout materials, whether epoxy, cementitious, or otherwise contain irritants, toxic chemicals, and other harmful substances. The SDS for the grout materials should be available, and PPE requirements for each task associated with the pour should be discussed. The grout manufacturer’s recommendations should be reviewed in the case of chemical contact, and the availability of “just in case” safety facilities. Good communication makes the grout installation go smoothly. All parties should be aware of what is expected before, during, and after the grout pour, and any questions or concerns need to be resolved beforehand.

EFFECTIVE MIXING & INSTALLATION RECOMMENDATIONS

Grout Mixing

After preparations have been completed, signed off, and all parties agree to proceed, the grout pour is the next step. While this document is aimed at standard epoxy mortar grouts, many practices transfer over to non-shrink cementitious grouts as well. Proper mixing of the epoxy grout is the first line of defense against soft foot and pull-down when the foundation anchor bolts are torqued. The resin and hardener components are pre-measured at the manufacturer's facility to control the final properties of the epoxy grout. Never alter the resin and hardener components. Mix the resin and hardener before introducing them to the aggregate as resin and hardener molecules are both surface-active, meaning each is capable of clinging to other surfaces. Mixing of the resin and hardener should be done with a "jiffy" style dual-ribbon mixer (Please see *Figure 16* for an example), as paint mixers will entrain air. In the field, not every contractor has these specialized mixers, so good electric drills fitted with a dual ribbon mixer will typically suffice. Running the drill in reverse will cause the mixer to pull material from the bottom of the bucket, minimizing air entrainment. The liquids should be mixed at 200-240 RPM, keeping the mixing blades submerged, for the manufacturer's recommended time, typically 2-3 minutes. Key indicators of properly mixed resin/hardener blends are that the liquids become clear and transparent, no foaming or bubbling, and have uniform color and consistency. Remember, aggregate is a heat sink that slows the reaction of the epoxy, so only mix units that can be immediately used as runaway epoxy reactions create hazardous fumes.

Figure 16: Air-powered "Jiffy" Mixer

After the resin and hardener have been mixed, they should immediately proceed to the mortar mixer for the addition of aggregate. When mixing epoxy mortar grouts, the use of a horizontal mortar mixer (Please see *Figure 17*) or pancake mortar mixer is essential. The mixing action of concrete mixers will entrain large amounts of air and prevent aggregate from being properly wetted out. Always utilize a clean, dry mortar mixer to prevent contaminating your product. Add the epoxy liquid with the blades stationary, adding a bag of aggregate to the mixer, prior to starting blade rotation. Add the manufacturer-recommended quantity of aggregate expeditiously to minimize mixing time that entrains additional air. Operate the mixer at a slow 15-20 RPM for only long enough that the aggregate is completely wetted out. Once the grout aggregate is wetted out, mixing should stop until the material can be removed from the mixer. Don't include any additives unless expressly recommended by the grout manufacturer. The initial unit in the mixer may have a small decrease in aggregate as the additional liquid may be used to wet the dry mixer surfaces only.

Standard non-shrink cementitious grouts are typically mixed with only potable water. Potable water prevents contamination since "utility" water in a facility may have other chemicals in it. And while it may be tempting to mix with a concrete mixer, a mortar mixer should still be utilized to minimize air entrainment. Cementitious grout mixing times differ greatly from epoxy mixing times. Mixing times should be referenced before the pour for accuracy. In warmer climates, cold water may be utilized to extend the working time for cementitious grouts in larger pours, under the advisement of the grout manufacturer representative.

Figure 17: Example of a Horizontal-type Mortar Mixer

Grout Installation

All grouts have a "pot life" which is the time it takes for the grout to take an initial set based on an ambient conditioned temperature. For standard epoxy mortar grouts, ~70°F-75°F provides the best combination of flow characteristics and pot life. Due to the exothermic nature of the epoxy grout curing process, higher temperatures cause a domino effect regarding the effective pot life. This means that any rise in ambient temperature causes a considerable rise in the cure rate, and likewise, as temperatures go down, the cure rate slows until it is effectively stopped. Ensuring the pour is completed and the grout surfaces are finished within this pot life is necessary to prevent premature curing and voids.

After mixing is complete, the grout should be removed from the mortar mixer and poured into the head box immediately. Grout that remains in the mortar mixer too long may require disposal to prevent solidifying and locking up the mortar mixer or causing flow issues after being poured into the forms. Take note that proper pouring techniques can expedite the grout pour and ensure a quality finish. Pouring the grout across the shortest distance will expedite the pour by getting and maintaining contact quickly. The pour should start at one end of the equipment or baseplate, and continue, maintaining sufficient volume in the head box to maintain contact until the pour is complete. Do not rush contact by pouring ahead of the contact line or using chains, rods, or vibrating the grout. Using chains and rods will entrap air beneath the load-bearing area, causing voids. The use of a vibrator is never recommended with machinery grouts as the vibrating action will cause the graded aggregates to settle out of the mixture, creating a resin-rich top layer that is mechanically compromised. Utilization of head boxes will maintain head pressure and flow where and when it is needed. Pouring should not stop until complete grout surface contact has been confirmed and the final grout elevation has been achieved. Pouring up the sides of the flange or baseplate will provide additional head pressure to prevent voids beneath the load-bearing area and create a "key" to resist lateral movement and maintain alignment. Pouring up also provides additional protection to prevent intrusion of contaminants beneath the load-bearing area. Once the pour is complete, the volume used should be checked against the calculated volume to verify no large voids exist. Throughout the pour and following, the forms should be monitored for leaks as the grout won't self-seal, and any leaks observed should be sealed immediately.

Grout Sampling

Grout sampling is an option that may be requested during a pour. Sampling the grout serves to verify the as-installed quality of the grout material itself, which can vary due to mixing techniques, air entrainment, and curing conditions. If requested, epoxy grouts are sampled using 2" brass cube molds following specifications listed in ASTM C579 Method B as seen in *Figure 18*. The molds should be waxed before the pour has started, with a paste wax, to allow sample removal. The samples should be taken mid-pour, and each mold should be filled approximately halfway with grout, tamped 16 times, alternating directions to allow air to escape, then filled the remainder of the way. Excess grout should be stricken off with a clean trowel. The samples should be kept at the pour site as the intention is to provide an accurate representation of the grout that has been installed. They should cure in the same conditions as the installation. After properly curing, the samples shall be evaluated according to the procedures listed in ASTM C579 Method B. It should be noted that not all testing labs are intimately familiar with sampling and testing of epoxy mortar grouts under this standard, so details should be discussed before the pour to verify compliance.

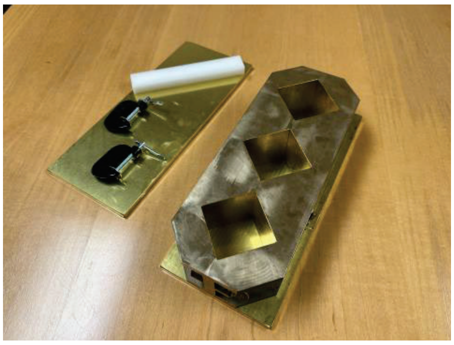


Figure 18: Brass Sample 2" Cube Mold

As previously noted, leveling of the epoxy grout should be performed immediately after the pouring has ceased to prevent finishing disasters. At this time, expansion joints should be checked to verify none have become displaced during the pour.

CURING TIME OF MOUNTING PRODUCTS & FINISHING GUIDANCE

The hard part is done after all the preparation work and mixing and placing the transfer medium or grout material. The forms are not leaking, now what do we do? Materials will cure based on temperatures and the specific type of material. To ensure full contact is achieved head pressure should be maintained through a standpipe that can be removed after the material has cured. If you have vent holes in a base, make sure each vent hole is clean and all the air has escaped with material coming out of the holes to help minimize voiding.

If supplemental heat is added such as a hooch to maintain heat for the curing process, that heat should be maintained for a period recommended by the material manufacturer. Once that cure time has passed, the manufacturer should also provide guidance on reducing the heat, specifically at what rate of a temperature decrease is recommended to acclimate to environmental conditions. Especially for epoxy-based products, this should be a very slow reduction in temperature to prevent thermal cracks in the epoxy transfer medium. Most epoxies have a coefficient of thermal expansion twice that of concrete. This means for the same change in temperature, the epoxy will experience twice the volume change; therefore a rapid decrease in temperature can lead to cracking in the epoxy transfer medium. On the other side, if temperatures are favorable or towards the higher temperature range of 65°F-90°F (18°C – 32°C), consideration should be made to keep the material cool. If the installation is in direct sunlight, the temperature of the sun combined with the exothermic reaction can overheat the grout. This may also lead to cracking in the final product due to the overheating followed by a rapid cool down.

When the material has fully cured based on the conditions and manufacturer's requirements, the grout forms can be removed. If there are any tags or jagged edges, a hand grinder can be used to smooth them out. The jack bolts can either be removed or backed off a couple of turns. If they are removed, then the hole needs to be filled with an RTV or flexible material sealant.

API Post Grouting Requirements

Once the jack bolts have been removed then the final torque can be taken on the anchor bolts. API requires checking the grout for softness. This can be done by placing a dial indicator on the base plate and checking for movement as each anchor bolt is loosened and torqued. This requires no more movement than 25 micrometers or 0.001 in.

Another requirement of API is to check the post-grout level of the machined mounting surfaces to verify they are less than 0.005-in per foot in both directions, longitudinally and transversely. If outside these criteria, the recommendations are to field machine, up to removal and regrouting of the base.

The last requirement is to provide a grout-compatible nonskid protective coating to protect the foundation cap from oil and weathering. If possible, this should extend 18” (460-mm) from the top of the foundation.

The final requirement is to check the base for voids. This is done by sounding the base plate with a ball pein hammer and listening for a hollow spot. A solid thud indicates a good, grouted area while a drumlike hollow sound indicates a void requiring filling. If a void is found, continued pinging is required to mark out or map the void on the base plate surface. Once this area is mapped out, a 1/8” (3-mm) drill bit is used to drill out opposite areas of the void and one hole in the center of the void where a 1/8” (3-mm) grease fitting can be installed. On a side note- when drilling through steel and the drill bit hits the epoxy below, it will instantly dull the drill bit, therefore one drill bit is required for each hole. The holes on the edge are used as vent holes. In epoxy, the resin/hardener is mixed per the manufacturer’s recommendations, loaded into a grease gun, and injected through the grease fitting. A grease gun is a multiplication pump and over-pressurizing can cause the void to increase. This takes the maximum amount of patience to perform this operation. Without the presence of aggregate, the material will have a much reduced pot life, so it is imperative to proceed expeditiously but without overpressurizing the injection of the material. Once mixed epoxy reaches the edge of the void and comes out of the vent holes, clean up any spilled material and allow it to cure per the manufacturer’s recommendations. After it is cured recheck the area for voids and repeat until no voids are detected.

CONCLUSIONS

To create a truly monolithic foundation system that promotes operational reliability and energy efficiency, the selection and installation of components must consider the operating environment and true requirements of an application. The recommendations presented in this paper are intended as a starting point and cannot take into account every specific situation and application. By incorporating early engagement with experts, an effective foundation design and installation can promote operational goals, directly resulting in increased asset profitability.

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