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PRECISION GROUTING OF TURBOMACHINERY

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ABSTRACT

Rotating equipment being installed in industrial environments, including refineries and chemical processing plants, are critically aligned with exact tolerances. When in operation, this equipment experiences heavy dynamic and repetitive loading with high vibration, and in some cases, high temperatures and chemical exposure. Due to these extreme forces and environments, this equipment requires maximum support by using a high-quality precision grout able to properly transfer those forces, providing a long-term solution resulting in maximum operation efficiency, increased reliability, and reduced maintenance. Techniques to utilize epoxy grouts will be described to provide adequate equipment support.

INTRODUCTION

Properly installed precision grout transfers dynamic forces evenly through the grout into the foundation, maintaining critical alignment. The rotating equipment and heavy machinery cannot simply be placed on the concrete foundation since the irregularities in both the machine base and concrete surface will create point loads even if the required alignment could be achieved. Concrete foundations are not designed to withstand that type of loading, impact, or potential chemical exposure. Once the critical aligned equipment has been properly leveled, the space between the equipment and foundation is filled with a high-quality precision grout to provide linkage and load transfer from the equipment into the foundation and eventually the earth. There are two types of precision grouting material most often used in these applications are: non-shrink cementitious grout and epoxy or polymer grouts.

Grout is defined by ASTM C125 terminology as “a mixture of cementitious material and water, with or without aggregate or admixtures that is used primarily to fill voids.” ASTM takes that definition a bit further when describing “grout, non-shrink”: “a hydraulic-cement grout that produces a volume that, when hardened under stipulated test conditions, is greater than or equal to the original installed volume, often used as a transfer medium between load-bearing members.” Besides hydraulic cement-based grout, polymer binders can also be used for a similar purpose to provide improved chemical resistance, faster strength development, higher ultimate compressive strengths, and bond strength between the concrete and steel base plate.

The Difference between Polymer and Cementitious Grouts

Cementitious grouts (non-shrink) consist of a dry powder containing a hydraulic binder, aggregates and additives to enhance flowability, volume stability, control setting, enhance strength, and maintain homogeneity once mixed with water. Cementitious grouts are capable of being placed over a wide temperature range, require damp substrates, and have similar chemical and physical properties (such as coefficient of thermal expansion and modulus of elasticity) to the substrate concrete. The mixed consistency can be adjusted by varying the amount of mixing water. Cementitious grouts require moist curing and clean up and disposal of materials is similar to general construction debris. Strength develops over several days to weeks and the material cost is usually significantly less than for polymer grouts.

Typically, polymer grouts consist of a resin, hardener, and dry aggregate components packaged separately. Usually the resin and hardener are mixed together, and then the aggregate is immediately mixed into this blend until it is completely wetted, with no dry aggregate is present. Polymer grouts should be placed as close to room temperature as possible. Colder temperatures produce longer working time but also a much higher viscosity resulting in reduced flow of the material. The placement viscosity of polymer grouts tends to be much higher than most cementitious grouts and changes dramatically with the temperature of the material. The coefficient of thermal expansion and creep of polymer grouts also tends to be significantly higher than either cementitious grouts or concrete, but the modulus of elasticity is usually somewhat lower. Compressive, tensile, and bond strengths of polymer grouts are higher than their cementitious counterparts. Many polymer grouts are potential allergens or sensitizers so careful attention to the material safety data sheet and application guidance from the material producer is necessary to avoid health and safety issues when handling these materials.

Although polymer grouts and cementitious grouts have these different physical properties, their use as a load transfer linkage between the loads of equipment and the foundation is functionally equivalent. Both materials must be capable of being mixed and placed under the equipment to maintain intimate contact between the metal support structure and the foundation. This intimate contact is generally known as effective bearing area or EBA which combines the placement properties with the volume stability of the grout during and after placement. The effective bearing area is measured by the area of contact between a baseplate and the hardened grout. Higher compressive strength is usually assumed to imply better load transfer. While compressive strengths are an extremely important physical property to consider, there are several other performance properties which should be taken into consideration when selecting the best precision grout for a specific application. Various standardized tests are used to evaluate these properties with different methods used for polymer and cementitious grouts. For cementitious grouts, many of these methods and minimum acceptable values are summarized in the industry specification ASTM C1107. No similar document or guideline exists for polymer grouts. Unfortunately, these different standards do not provide a correlation allowing a direct comparison of the data between cementitious and polymer grouting materials.

Standard Test Methods for Grouts

ASTM C1107 is a specification requiring minimum compressive strength as measured in 2" x 2" x 2" (50 mm) cubes and limits both plastic and hardened volume change over the manufacturer's maximum working time, extreme mixing, placement and curing temperatures using the maximum mixing water or most fluid placement consistency. In other words, C1107 requires testing for compliance using the worst-case conditions allowed by the material producer, but the performance requirements for these properties are fairly easy to achieve and are usually exceeded by most materials.

For example, ASTM C1107 requires a minimum compressive strength of 5000 psi (34 MPa) for cementitious grouting materials. When considering that most concrete foundations in industrial facilities are between 3000 psi (21 MPa) to 4000 psi (27.5 MPa), this is not a very high barrier and may not provide adequate compressive strength for support of some rotating or very heavy equipment. While ASTM C1107 provides the industry with a great standard for manufacturers to evaluate "non-shrink" precision grout products, it is critical to know and understand the capabilities and limitations of specific product to ensure the best product is used for each installation.

Other critically important physical properties not addressed in C1107 for cementitious grouts are bleeding and segregation. Bleeding is defined as the autogenous flow of mixing water from newly placed grout caused by settlement of solids or aggregate. Bleeding occurs in cementitious grout after placement of the material when the aggregate falls out of suspension and the water mixed with material rises to the top of the grout surface. The bleed water occupies load bearing space under the equipment baseplate that eventually dissipates from the surface of the grout, resulting in a loss of effective bearing area and a reduction in physical properties (due to high water to cementitious content) at that critical interface. ASTM C940 is the standard test method used to test for bleeding of precision grout.

Segregation is another form of separation within both polymer and cementitious grouts. The dense aggregate settles to the bottom of the grout prior to hardening, resulting in dissimilar physical properties between the binder rich upper layer in contact with the baseplate and the aggregate rich layer against the concrete foundation. With both cementitious and polymer binders, the high binder contents usually result in a reduction in performance of critical physical properties such as creep, strength, volume stability, etc.

No document similar to ASTM C1107 exists for polymer grouts. Compressive strength is measured by several methods in addition to the cube type specimens used for cementitious grouts. The most commonly reported test method (ASTM C579) allows three specimen types 1" x 1" (25 x 25 mm) length to diameter cylinders, 2" x 2" x 2" (50mm) cubes, and cylinders with a length twice the diameter without any correlation between the various specimens for strength results. Shrinkage, coefficient of thermal expansion, creep, modulus, and other properties are reported with a multitude of test methods without any possibility to compare values. Both ACI committee 351 and ICRI 320 are developing guidance to provide the specifier with guidance to standardize this chaos. Currently ACI 351 publishes 351.1, 351.2, and 351.3 that provide guidance on grouting for both dynamic and static equipment.

For either a polymer or a cementitious grout to be placed it must flow under the baseplate. The flowability of a precision grout is a critical physical property that must be taken into consideration when selecting the appropriate precision grout for a specific application. A precision grout that possesses high flowability will:

1. Greatly increase the likelihood of a successful grout pour
2. Provide maximum effective bearing area under the baseplate
3. Uniformly transfer load from the equipment, through the grout, into the foundation
4. Resist the dynamic, repetitive loading occurring from the rotating equipment and machinery
5. Fill voids, keep them full, and remain durable
6. Maintain the equipment's precision alignment

The industry has often used adjectives to describe the consistency of a precision grout as "plastic", "pourable", "flowable", "high-

flow”, or “fluid” interchangeably; however, there are specific ASTM definitions for several of these different consistencies of precision grouts.

When we are evaluating cementitious precision grouts, there are four consistencies to consider that are defined as follows:

1. Dry pack – placing of zero slump grout by ramming into a confined space
2. Plastic – 100% - 125% flow on a flow table per ASTM C1437
3. Flowable – 125% - 145% flow on a flow table per ASTM C1437
4. Fluid – Precision grout passes through a flow cone between 10 to 30 seconds per ASTM C939. Different producers tend to further restrict the flow cone time to between 20 or 25 seconds and 30 seconds in order to achieve greater strength and avoid bleeding and segregation issues caused by excessive mixing water.

ASTM C1437 is the test method that uses the flow table specified by ASTM C230 but the method is modified for use in testing of precision grouts and many other mortars. The flow table is used to test plastic and flowable consistencies. This test consists of a 10” (254 mm) circular brass table where a 4” (102 mm) conical ring mold is placed in the center (see Figure 1). The precision grout product to be tested is mixed according to the manufacturer’s instructions and the material is placed into the 4” (102 mm) ring mold (see Figure 2). The ring mold is then lifted and flow table is then dropped 5 times within 3 seconds allowing the material to flow on the table. Once the material has stopped flowing, the measurements (see Figure 3) are taken to determine how far the material traveled in the flow table. For plastic consistency, the grout must measure between 100% and 125% and for flowable consistency the grout must measure between 125% and 145%.

Following is an illustration of how ASTM C1437 using the C230 flow table is performed:

Figure 1: 10” (254 mm) Circular Brass Table with 4” (102 mm) Ring Mold



Figure 2: Precision Grout is placed into 4” (102 mm) ring mold and dropped 5 times within 3 seconds



Figure 3: Measurements Are Taken to Determine Total Distance Traveled



When evaluating fluid high precision cementitious grout, a different ASTM test method is used: ASTM C939 commonly called the “flow cone” (see Figure 4). The flow cone is used to measure the time for 1725 ml of fluid grout to pass through the ½ inch diameter orifice of a funnel of defined dimensions. The same volume of water (1725 ml) is used to verify calibration of the flow cone and must exit in 8 +/- 2 seconds. The precision grout product to be tested is mixed according to the manufacturer’s instructions and the material is placed into the flow cone (see Figure 5). The test begins when the ½” (12 mm) diameter opening is unplugged and does not stop until all of the material has passed through or a break occurs within the grout discharge stream (see Figure 6). In order to be considered fluid, the material must pass through this flow cone in less than 30 seconds.

Here is an illustration of how ASTM C939 is performed:

Figure 4: Example of a Flow Cone

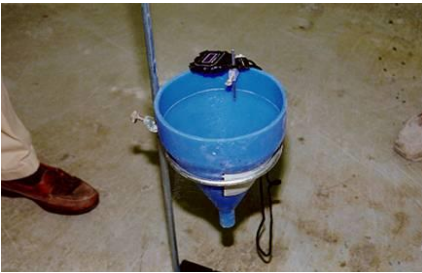


Figure 5: Fill Flow Cone to the Specified Level and have Stopwatch Ready



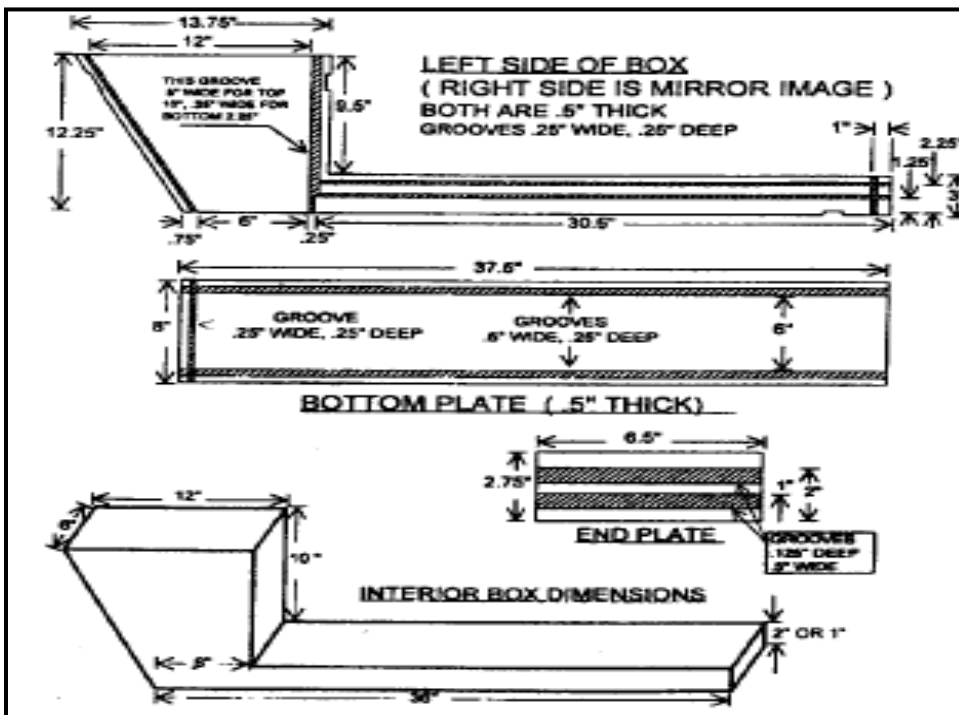
Figure 6: Measure the Time it takes for Grout to pass through the Flow Cone



The test method that is used to determine the flowability of a polymer grout is ASTM C1339, also known as the grout flow box test (see Figure 7). Unlike cementitious grouts where different categories of flowability are defined, this test for polymer grouts records two time elements:

1. Fill Time – the time it takes polymer grout to reach the top of the cover plate over its entire length
2. Flow Time – the time it takes the polymer grout to come in contact with the end plate

Figure 7: A schematic and dimensions of the ASTM C1339 Flow Box:



Once the grout flow box is assembled, a clear acrylic plate on the top of the horizontal surface is placed to form a grout depth of either 2" (50 mm) or 1" (25 mm) clearance. The mixed polymer grout is placed into the hopper to an 11" (279 mm) depth for a 2" (50 mm) clearance and an 8" (203 mm) depth for a 1" (25 mm) clearance. The polymer grout then sits in the hopper for 5 minutes when the front gate is lifted, allowing the material to flow and start time of flow measurement. The two time elements of fill time and flow time are recorded as described above. The time required for the grouting material to reach the end of the grout box as well as to completely fill under the acrylic plate are recorded as indicators of the flowability of the polymer grout. The grout is allowed to harden and the percent of contact area of the grout after abrading the surface of the grout is the effective bearing area discussed in the following sections of this paper.

Factors Effecting Grouting

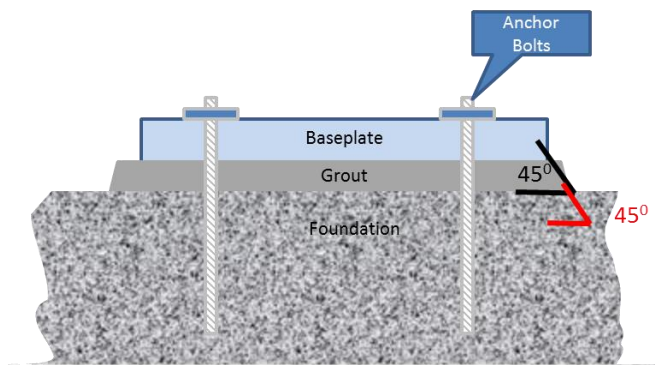
Temperatures do have an effect on the flowability of a precision grout. Cementitious grouts do not change dramatically in consistency over their recommended placement temperature range. Polymer grouts, however become very thick at low temperatures and typically

are not placed below 50 ° F (10° C). At higher temperatures, polymer grouts have lower viscosity, but also much shorter working times. Addition of aggregate to polymer grouts will reduce the flow and grout placement characteristics. The amount of aggregate added is usually controlled by packaging the polymer grouts as kits, with some commercial products providing guidance for different aggregate contents depending on an acceptable compromise between placement conditions and physical properties.

The amount of time where the mixed grout remains in a consistency where it will fill the area to be grouted or within defined ranges of flowability (including remixing that may be necessary for cementitious grouts) is the working time. Eventually the grout begins to stiffen and set at the end of the working time. For polymer grouts (and to a much lesser extent in cementitious grouts) this is almost always accompanied by a significant temperature rise known as the exotherm. Addition of aggregate to grouts helps act as a heat sink to compensate for this exotherm and the beginning of this exotherm is usually taken as the end of the working time of polymer grouts. Cementitious grouts will slowly increase in viscosity after mixing. Once fluidity cannot be restored with brief remixing and no additional water, a cementitious grout should be discarded as the working time is over.

The critical physical properties of both cementitious and polymer grouts have several things in common. For proper load transfer, the compressive strength of the grout should be at least equal or preferably greater than the compressive strength of the concrete foundation because load forces from the baseplate transfer into the grout and then into the foundation. Even though these forces may be combinations of compressive, shear, flexural, impact, and tensile vectors, compressive strength is usually assumed as an indicator of the grout's ability to transfer load. At each interface, the area affected by the load becomes greater, often assumed to increase at about a 45-degree angle from each interface into the next (see Figure 8).

Figure 8: Baseplate forces are transferred into the grout and from the grout into the foundation at approximately a 45-degree angle.



Due to the nature of petroleum refining and chemical processing precision grouting applications, these materials can be exposed to extremely high service temperatures. The elevated temperatures will have an effect on the performance of the precision grout and are a critical factor that must be taken into consideration when selecting the most appropriate precision grout for a specific application. Cementitious grouts can be exposed to temperatures not exceeding 400° F (205° C). Polymer grouts decrease in strength as service temperature increases and start to lose physical properties above about 140° F (60° C) to 170° F (77° C). Each polymer grout will experience a wide range of performance changes as service temperatures increase. The polymer grout must be carefully selected based on its properties at the temperature of equipment operation.

Grouts must be stable in volume. This means that the dimensions of the grout once placed remain nearly constant to provide the proper load transfer from the equipment baseplate into the foundation. Grouts that shrink or lose effective bearing area allow the baseplate to move resulting in misalignment of equipment and excessive vibration to cause premature equipment failure.

Grout Volume Stability

Cementitious grouts are tested for plastic expansion using ASTM C827, commonly called the “light-ball method”. In this test, a ball floats halfway submerged on the grout surface and height changes are measured using a projected light to magnify the shadow of the ball as the grout hardens. The usefulness of this test remains somewhat controversial as bleeding, evaporation of water, and restraint of the specimen during hardening are poorly controlled. Hardened volume change is measured for cementitious grouts using the ASTM C1090 test. Here a cylinder of grout is cast in a rigid mold and restrained with a glass plate for 24 hours. If bleed water, entrapped air, or settlement occur; the grout pulls away from the glass plate and can be easily observed when it is removed. The grout is restrained in all dimensions much like under a baseplate while hardening. The height changes of the grout surface with respect to the initial placement height using a reference plate are measured while the grout is maintained in a moist condition through 28 days. Polymer grouts do not have a specific test for volume stability during hardening, but a simulation of grout placement is commonly used as described in ASTM C1339. The mixed polymer grout is placed using a headbox under a defined geometry plastic plate and

the flowability of the grout determined by measuring the time from initial grout placement until the grout completely fills under the plate and contacts the discharge end of the flow box. After hardening, the plate in contact with the polymer grout is removed, the exposed grout surface is abraded to open any trapped bubbles, and the amount of surface area in contact with the plate is estimated by comparing with reference photographs to report as the percent of effective bearing area (EBA). Air bubbles that are trapped by the high polymer grout viscosity usually rise as the grout hardens and account for most of the reduced EBA. Polymer grouts do experience some shrinkage during hardening. This can be measured by several test methods such as ASTM C531, but these volume changes are usually small and are minor factors influencing the EBA. Shrinkage during hardening is usually offset by the flow of grout from the head box or shoulders. For very deep installations, low exotherm polymer grouts should be considered to minimize the difficulty of placing grout in lifts or the requirements of complex internal reinforcement configurations.

Another volume stability factor is the coefficient of thermal expansion (CTE). Most materials expand as they become hotter and contract when cooler. The rate of this expansion or contraction per degree of temperature change along a length of the material is the CTE. Cementitious grouting materials are usually compositionally similar to the foundation concrete and have similar CTE. Polymer grouts usually have much higher CTE than the foundation and can crack and debond if large temperature changes are experienced after hardening. Addition of aggregate to polymer grouts reduces this difference in CTE.

A third factor of volume stability for grouts is a combination of creep and modulus. Modulus is the elastic (recoverable) deflection under load and creep is the plastic (non-recoverable) deflection under sustained load. A piece of rubber when compressed will bounce back to its original shape once the load is removed. The change in height compared to the amount of load is one way of defining modulus. Higher modulus materials are stiffer, deforming less under load than low modulus materials. Cementitious grouts have a similar modulus to the concrete foundation, again from their compositional similarity. Addition of aggregate to polymer grouts tends to increase the modulus and the compressive strength of cementitious grouts can be used to estimate the modulus with higher strength indicating a higher modulus. As service temperature increases the modulus of polymer grouts becomes lower but little change occurs with cementitious grouts until the temperature becomes sufficiently high that chemical changes occur in the hydraulic binder. Modulus for polymer grouts usually refers to ASTM C580 Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacing, and Polymer Concretes which allows three different methods using different sized specimens. Modulus for cementitious grouts is either calculated from the compressive strength or determined using ASTM C469.

Creep occurs slowly and under sustained load. Like compressive strength and modulus, polymer grouts change in an unfavorable direction (creep increases) as temperature increases. Increasing aggregate content reduces these changes. Creep testing of polymer grouts is usually performed according to ASTM, however, the specimens may either be bonded or unbonded in the test device and the exposure temperature and time are determined by the person running the test, making comparison of materials difficult unless tested under identical conditions. Cementitious grouts may have significant creep at early ages, but as curing and strength increase, the creep becomes much less than polymer grouts. At later ages, cementitious grouts have approximately the same creep as concrete of similar strength. Cementitious grouts are usually tested for creep according to ASTM C512 at 40% of their compressive strength.

Traditional Precision Grout Installations

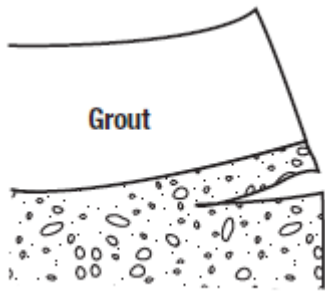
Proper installation of precision grout starts at the foundation. To ensure successful placement of material, proper surface preparation will need to take place before the material is installed. When failures occur, they are most often due to improper surface preparation, so it is very important that the details of proper surface preparation are followed.

For cementitious grout, the concrete surface to be grouted must be clean, sound, have a concrete surface profile, or CSP of 5-10 to 3/8" (9.5 mm) according to ICRI 310.2 where heavy dynamic loading is expected, and saturated with water for at least 24 hours prior to placement. This pre-saturation is called "quenching" the foundation which produces better flow and bond of the material as well as helps equilibrate the temperature for grout placement. This also ensures that a dry concrete foundation does not consume the water that was added to the precision grout when mixing the material.

Epoxy grout concrete foundation preparation is very similar to cementitious grouts, except the substrate must be completely dry and the foundation must be shaded from sunlight for 24 hours before and 48 hours after grouting. When attempting to obtain the appropriate CSP, it is not recommended to use a bush hammer as this can cause micro-fractures ("bruising") and weaken the foundation. It is best to roughen with a lightweight sharp pointed chisel or mitigate bruised substrates with abrasive or shot blasting.

In areas where the precision grout extends to the edge of the concrete, a 2" (50mm) minimum 45-degree chamfer is recommended to reduce the possibility of edgelifting. Edgelifting is a term generally used to refer to horizontal cracks around the edges and corners of grouted foundations. The crack starts on the vertical concrete surface just below the grout/concrete interface and may extend back under the grout from 2 – 6" (50 – 152 mm). This cracking is usually accompanied by slight upward movement at the edge. This movement is called "edgelifting" or "curling." (see Figure 9)

Figure 9: Detail of “edgelifting” or “curling”



The initial cracking occurs when the shear stress near the concrete/grout interface exceeds the strength of the concrete. The shear stresses are a result of a combination of factors. When the grout cures there is a certain level of trapped stress caused by the combination of the curing shrinkage and the exotherm of the grout. Additional stresses occur as the grout and foundation undergo thermal cycling. Stresses created during thermal cycling are caused by uneven heating and cooling in various parts of the structure and by differences between the coefficient of thermal expansion of the grout and the concrete.

To help prevent edgelifting, dowels or wickets should be placed in strategic locations around the base of the concrete (see Figure 10). Wickets provide the strongest anchor between the grout and the concrete base. They are made from U-shaped pieces of rod or rebar (see Figure 11). If wickets are not used, dowels should be utilized instead.

Figure 10: Dowel Installation

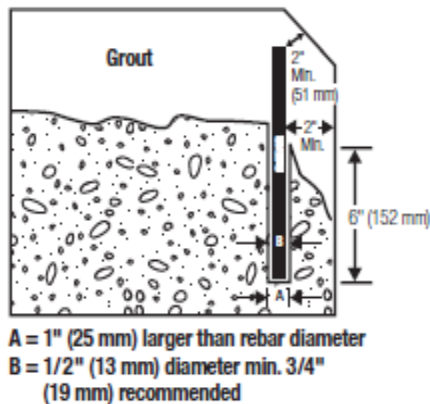
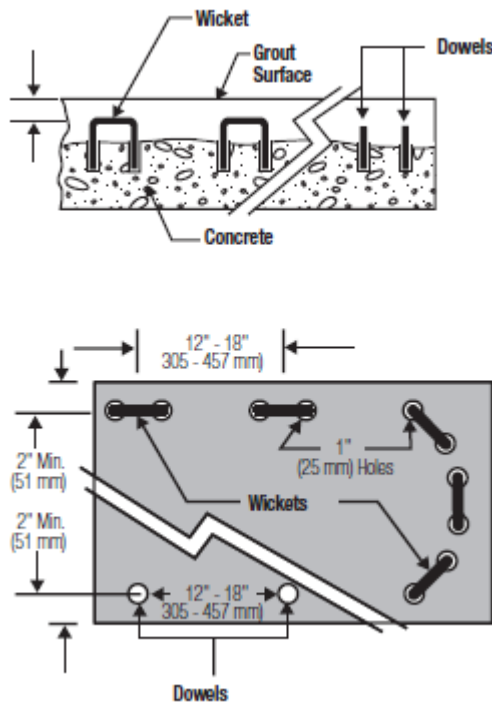


Figure 11: Dowels & Wickets

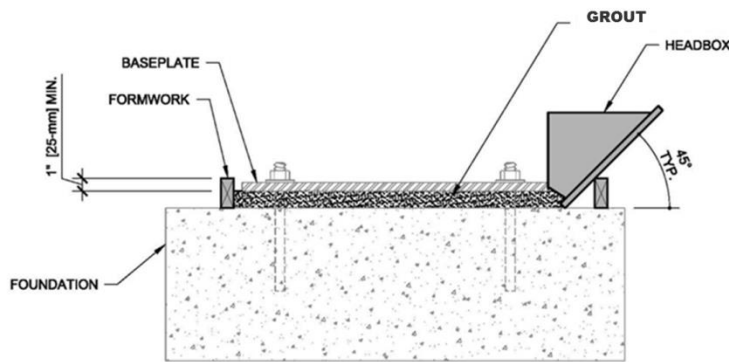


The use of expansion joints is also recommended in large placement precision grout applications to reduce the possibility of cracking. Expansion joints are typically made up of closed-cell neoprene foam between 1/2" to 1" (12.5 mm to 25 mm) wide and placed every 4' to 6' (1 to 1.8 meters) adhered to the foundation down the length of the skid. It is not recommended to place the expansion joints directly underneath the steel cross-members as this will not promote effective bearing area of the precision grout to the steel skid. It is preferred to place the expansion joint material to either side of the cross-member, approximately 1/2" to 1" (12.5 mm to 25 mm) away and allow the precision grout to contact the steel skid, uniformly transfer the dynamic load into the foundation. The precision grout has been sealed, the expansion joints are to be sealed to prevent outside elements, i.e. water, oils, chemicals, from entering.

Special attention needs to be taken for equipment bases in this grouting. The equipment bases also need to be clean, free of any paint, oil, rust, and debris regardless of whether polymer or cementitious grouts are selected. If the specification requires grouting of anchor bolts, they should be grouted in advance of the baseplate. This will prevent the precision grout from sagging into the anchor holes, creating air voids with a reduction of EBA. In many polymer grout installations, the anchor bolts are wrapped to prevent grout bond between the foundation surface and the baseplate so that once the grout has hardened and the bolts torqued, the unbonded length of the bolt can act as a tension spring to clamp the baseplate to the grout. If utilizing a polymer grout, one of the benefits is bond between the grout and the bottom of the baseplate. In order to achieve bond strength per the manufacture data sheet, the underside of the equipment baseplate should have a compatible primer or be sand blasted to white metal. The base plate should not be allowed to flash rust prior to grouting. If using a coating, note that some coatings systems have potential to be brittle and will create voids under the equipment if they debond. Certain coatings, like inorganic zincs, have higher potential of cracking and debonding if applied too thick (mudcracking) or too thin (low dry film thickness). Proper selection and inspection of the coating system prior to installing the grout is critical to ensuring performance of grout properties, like bond strength.

Regardless of the type of precision grout utilized, there are a number of effective placement methods that can be selected such as using a grout pump, a head box, and a gravity pump. In many cases, the amount of access to the equipment will influence which placement method is selected.

Figure 12: A drawing and photograph of a grout headbox.



Grout forms need to be constructed sturdy enough to withstand grout hydraulic head pressure yet be able to easily disassemble after the grouting is complete and the grout has developed sufficient strength for removal. Grout forms should be accessible, watertight, have sufficient clearance from the baseplate to allow for grout placement and air escape, and be non-absorptive. For polymer and epoxy grouts, a bond breaker needs to be applied to the formwork to prevent the polymer grout from bonding to the forms. The most common material used as a bond breaker is paste wax, but it is important that wax is only applied to the forms and does not come in contact with the foundation.

Cementitious grout is usually limited to about 6" (152 mm) maximum depth for neat material. If grout depths are greater than 6" (152 mm), the cementitious grout may need to be extended with 3/8" (9,5 mm) pea gravel, specific percentage by weight, or the material may be placed in lifts. Epoxy grouts have limitations on depth and mass of placement as well. Epoxy grout products can range from a maximum depth of 6" (152 mm) up to 18" (457 mm) in depth in a single pour depending on the product, however, large placements may also require joints to be installed and lifts to control grout volume, peak exothermic reaction, and cracking.

When mixing cementitious grout, the proper equipment and sequence of operations must be followed. The appropriate amount of water must be added first to the mixer and then the precision grout material added to the mixer while mixing for the specified amount of time. A number of different types of mixing equipment can be used to mix cementitious grouts, including a bucket and with a drill paddle mixer, a horizontal rotating shaft paddle wheel mortar mixer, colloidal mixer, or a vertical mixer. ICRI 320.5 provides guidance on different types of mixers. Tumble type or rotating drum mixers do not provide sufficient shear to properly activate the additives in cementitious grouts.

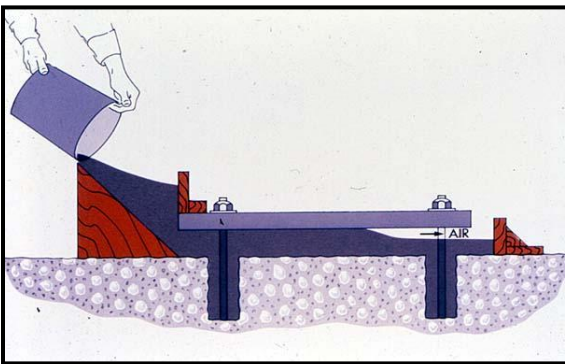
Mixing epoxy grout requires different steps than mixers for cementitious grouts. Typically, epoxy grouts are packaged in kits with a specific amount of epoxy resin and hardener (part A and a part B) along with a measured amount of special blended dry aggregates (part C). A common technique that is utilized to mix epoxy grouts is to first blend the part A and part B epoxy resin and hardener together using a slow speed drill and a jiffy-style paddle. It is important to mix the epoxy slowly to avoid creating a vortex or otherwise entrapping air. Once the epoxy resin and hardener are properly blended, it is added to the hopper of a paddle wheel mortar

mixer followed the aggregate. The mixer is then started, and the remaining quantity of aggregate is then slowly introduced to the turning paddle wheel mortar mixer. Mix the epoxy and aggregate for approximately 45 seconds to 1 minute until the aggregate is completely wet-out and the dust from the aggregate has cleared, and immediately place the polymer grout.

As stated previously, temperature has a major impact on the installation of a precision grout. Cementitious grout installation temperature ranges are typically 45° F (7° C) to 90° F (32° C) whereas a polymer precision grout can be installed usually only from 50° F (10° C) to 90° F (32° C). In temperatures less than 50° F (10° C), the use of an accelerator should be considered, and higher viscosity slow flows expected. With warmer temperatures, the flow, working and set time as well as the strength development are faster for precision grouts. All temperatures should be taken into consideration such as: ambient temperature, material temperature, water temperature, plate temperature, and foundation temperature and adjusted if possible, to the product manufacturer's recommendations. The flow should be the minimum that will reliably result in complete filling of the grouted space and water content can vary daily as well from lot to lot and manufacturing plant. Determining the flow cone time each day will assist the installer in determining the appropriate amount of water to be added to cementitious grouts.

Traditional steel base plate precision grouting usually involves placing grout from the shorter side of the form to have the material flow to the other side. If a head box is being utilized, it is critical to maintain continual head pressure and assure that the head box discharge is always immersed in the grout. Maintaining continuous head pressure will allow the grout to achieve its maximum flow characteristics, ensure air does not become trapped under the baseplate, and remove any access water (in the case of cementitious grouts) from the grout head (see Figure 13).

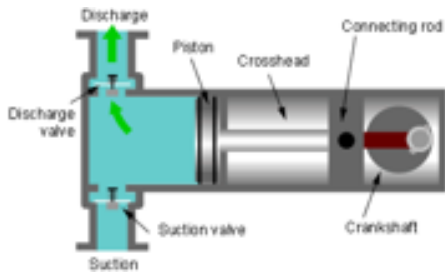
Figure 13: Example of Proper Installation with Continuous Head Pressure



Precision grout should be placed from one side of the grout form and flow to the other side. Usually the shorter side of a rectangular form is used to place the grout and the side where the grout is poured may be somewhat wider than the opposite side. It is necessary that air can escape from all sides of the grout form as the grout displaces air by filling the space under the baseplate. If there is access to the middle of the base plate, the grout can alternatively be placed from the middle of the plate and the material allowed to flow to the shoulders. If the grout flow needs assistance, the material can be strapped with smooth metal packing straps from the opposite side of placement in a slow, even motion. Never place grout from both sides of the form, vibrate the grout, or use chains to help with the grout flows as this will create voids with a reduction of effective bearing area and cause the aggregate to segregate.

Pumping is also an effective placement method for precision grouts. For cementitious grouts, the most common pump style is called a piston pump (see Figure 14). For a piston pump, cementitious grouts are suctioned in the chamber by a piston which is pulled back by the crankshaft. Material is then discharged out of the chamber when crankshaft pushed the piston forward. It should be noted standard piston style grout pumps will only pump "neat" cementitious grout. If extending cementitious grouts with 3/8" (9.5 mm) aggregate in deeper pour applications, a concrete pump will need to be utilized. Contractors are also experiencing very good success utilizing a piston pump for polymer-based grouts as well.

Figure 14: Piston Pump



A rotor stator is also a very effective precision grout pump for both cementitious and polymer grouts (see Figure 15). Precision grout material is conveyed through the rotor stator, which essentially works like a screw driving the material forward.

Figure 15: Rotor Stator



One of the most effective precision grout pumps for both cementitious and polymer-based materials is the peristaltic pump as referred to as a “carrousel” pump (see Figure 16). Precision grout material is placed into the hopper which is connected to a hose which travels in a U-shape around the housing. In the center of the housing is a spinning mechanism which has large steel rollers on opposite ends. Once material enters the hose, the spinning mechanism turns, and the steel rollers squeeze the material around the U-shape and out the other end of the hose.

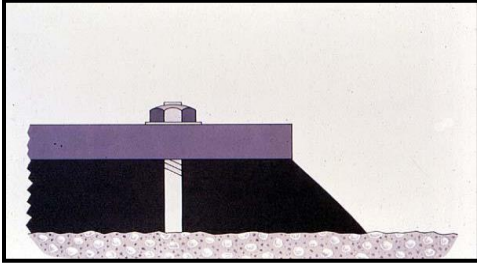
Figure 16: Peristaltic Pump



In the case of cementitious grout, proper curing is essential. Some grouts have early, and late expansion mechanisms and lack of curing can cause cracking, strength reduction, and poor volume stability in the grout. Immediately after placing the cementitious grout, all exposed grout areas should be covered with wet, cloth rags until final set and it is time to finish the exposed grout. After finishing, either the wet curing can be continued or high solids, membrane forming curing compound can be applied. Polymer grout should be air cured only.

Proper attention should be paid to detailing the shoulders. Shoulders should be chamfered at a 45° angle or perpendicular to the plate (see Figure 17). Chamfering the edges of a grout is done to remove weak square edges that are prone to cracking. With cementitious grout, the chamfering is done just prior to the final stand to reduce the incidence of cracking. For polymer grouts, the chamfers need to be built into the forms. Large shoulders should also be avoided to prevent the potential for edge lifting of polymer grouts. Commonly, shoulders are between 2” (50 mm) to 3” (76 mm) from the base plate. If larger shoulders are anticipated, it is recommend installing ¼” (6 mm) wedge anchors or concrete screws around the perimeter in a saw tooth pattern, 1” (25 mm) below the top surface of the polymer grout. This will restrain the polymer grout to the foundation to minimize the potential for edge-lifting.

Figure 17: Precision Grout Shoulder with a 45° Chamfer



Grouting Skid Mounted Equipment

Recently, there has been a trend in the way new equipment/machinery is being mounted, affecting the way precision grouting applications are performed. The new equipment being installed is mounted on “skids” or steel channels around the perimeter of the equipment with potentially steel cross members throughout the middle (see Figure 18).

Figure 18: Example of Skid Mounted Equipment



Traditionally, these pieces of new equipment would have been mounted on a solid steel base plate throughout. The industry believes that solid steel base plates are going to be a thing of the past with more equipment being skid mounted in order to reduce steel cost, equipment weight, and provide easier equipment transportation.

While skid mounted equipment appears to benefit equipment manufacturers, it represents a challenging grout installation for the contractors and owners involved. The requirements for grouting skid mounted equipment pose particular installation and engineering considerations that must be properly addressed for a successful and long-term installation.

Skid mounted equipment grouting is performed differently than solid steel baseplate grouting for several reasons, including cavities within the skid that must be filled during grouting. This drastically changes the steps of the traditional grouting process.

Below are some aspects to consider in order to perform successful precision grouting for skid mounted equipment:

- **Depths** – Skid mounted equipment can have deep cavities (14” (355 mm) or more) that are required to be filled to act as inertia blocks. As discussed above, cementitious grout is usually limited to about 6” (152 mm) of depth for neat material. For depths greater than 6” (152 mm), cementitious grout usually needs to be extended with 3/8” (9.5 mm) pea gravel or placed in lifts. Epoxy grouts have limitations as well. Epoxy grout, depending on the product, can range from a maximum depth of 6” (152 mm) up to 18” (457 mm) in depth in a single placement. Before the placing an epoxy grout, it is critical to know the placement depth and volume limitations of the product.

- **Aggregate extension** – The primary reasons for the use of aggregate extension in cementitious grout is to reduce the heat of hydration as a heat sink. When grout depths exceed the recommended maximum depth for neat grout (for applications such as mass grouting or when grout is being used in a non-precision applications).
 - Aggregate gradation and composition –When depths are greater than 6”, cementitious grout are typically extended with 3/8” (9.5 mm) pea gravel. The aggregate used must be sound, well graded, clean, saturated surface dry, non-reactive quartz and meet ASTM C 33 size #8. The preferred gradation would have 100% of the aggregate passing through a 1/2” (12 mm) sieve and be completely retained on the 3/8” (9.5 mm) sieve. The amount of aggregate to add will depend on the depth and volume of the grout pour. The preferred aggregate extension is usually specified by the producer of the grouting material but can be more or less depending on depth of the pour, the aggregate properties, and the composition of the cementitious grout.

- **Placement method** – When placement of precision grout is considered, there are two primary methods. The first utilizes a head box and pouring from one side while letting the grout flow to the other side. The second method involves either pouring or pumping the grout from the middle of the skid, letting the grout flow to the shoulders. The open cavities allow placing grout from the middle of the skid.
 - Depending on the depth of the grout pour and the type of precision grout selected (cementitious or polymer), skid mounted precision grouting applications can be placed in one or multiple lifts. One installation method would be to place the precision grout in one continuous pour to eliminate the potential for cold joints between grout layers; however this may not always be possible and greatly increases the likelihood of entrapping air and exceeding volume limitations.
 - If it is determined that multiple lifts are required, which is preferred and recommended, it is important to note that there is a timing window to reduce the potential for cold joints between lifts. The first pour is commonly referred to as the “lock-in” pour as it locks the skid into the foundation. One can place the second grout lift on top of the first lift *only* after the first lift has reached its peak exothermic temperature and begins to cool. This usually occurs in cementitious grouts when the product has reached its initial set, typically from 4 to 6 hours depending on temperature of the grout in place. For polymer grouts, the timing between lifts is typically between 16 to 24 hours, again depending on temperature.

- **Forming** – Different forming is required if the grout is to be placed from side to side using a head box or from the center of the skid flowing to the perimeter of the skid section.
 - If it is determined that that the best placement method is to utilize a head box and place the grout from one side or from the middle utilizing the grout hole, and allow the precision grout to flow to the other side, proper forming techniques will need to take place as were previously described.
 - If it is determined that that the best placement method is from the middle by pouring or pumping and filling the cavity at the same time, careful attention must be placed on forming. To prevent the precision grout from flowing over the shoulders and to help build the pressure needed to fill the cavity, the shoulders must be capped (see Figure 19). When grout shoulders are capped, weep holes (usually about 1/4” (6 mm) in diameter) are required to ensure air is not trapped underneath the skid or shoulders (see Figure 20). When grout is observed coming up to the weep holes, the grout has successfully flowed to the shoulders and reduced the potential for voids and creating maximum bearing area. The weep holes are then plugged with appropriately sized wooden dowels to keep the grout from flowing out and assist with building the pressure needed to fill the cavity.

Figure 19: Examples of proper forming technique #1



Figure 20: Examples of Proper Forming Technique #2



- **Pumping** – If it is determined that cementitious precision grout will be pumped into place, different pumps must be used depending whether neat or aggregate extended grout is being placed. If the placement depths are less than 6”, the installer can use a standard grout pump such as a diaphragm or rotor stator type. However, a concrete pump such as a swing tube type is required when pumping cementitious grout extended with 3/8” (9.5 mm) or coarser aggregate. Attempting to pump 3/8” (9.5 mm) aggregate through a grout pump designed for only small aggregate will damage and plug the equipment. Polymer grouts may require special seals and parts to be compatible with the particular polymer and usually require solvents for cleaning. Polymer grouts may harden rapidly, especially in warmer conditions. Removal of hardened polymer grouts ranges from difficult to impossible, so extra attention to cleaning of equipment is needed.
- **Curing** – Curing is critical for cementitious precision grouting applications, especially in skid mounted applications. Cementitious grout has expansion mechanisms in the design mix to compensate for volume changes that occur due to the evaporation of water and hydration of the binder. When grout is unrestrained, such as not confined within a cavity, formwork or under a baseplate, the grout will continue to expand and reduce in density. As the grout continues to expand it can also crack. Exposed grout that is not cured, or is allowed to dry, can crack due to high moisture loss. That is why it is necessary to pay careful attention to grouting details and to wet cure all exposed grout immediately followed by application of a high solids, film forming curing compound compliant with ASTM C309 or C1315 after finishing.

CONCLUSIONS

These installation considerations concerning skid mounting equipment along with recommendations of qualified personnel from manufacturers of precision grouts can provide invaluable technical assistance and specifications for accomplishing successful installation. Grouting may appear to be a simple process but failure to address details and follow industry guidelines can produce costly problems and expensive equipment repair.

REFERENCES

ASTM Standards are available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA

ASTM C125 Standard Terminology Relating to Concrete and Concrete Aggregates

ASTM C1107 Standard Specification for Packaged Dry, Hydraulic Cement Grout (Nonshrink)

ASTM C940 Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced Aggregate Concrete in the Laboratory

ASTM C579 Standard Test Methods for Compressive Strength of Chemical Resistant Mortars, Grouts, Monolithic Surfacing, and Polymer Concretes

ASTM C1437 Standard Test Method for Flow of Hydraulic Cement Mortar

ASTM C939 Standard Test Method for Flow of Grout for Preplaced Aggregate Concrete (Flow Cone Method)

ASTM C230 Standard Specification for Flow Table for Use in Tests of Hydraulic Cement

ASTM C1339 Standard Test Method for Flowability and Bearing Area of Chemical Resistant Polymer Machinery Grouts

ASTM C827 Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens of Cementitious Mixtures

ASTM C1090 Standard Test Method for Measuring Changes in Height of Cylindrical Specimens of Hydraulic Cement Grout

ASTM C531 Standard Test Method for Linear Shrinkage and Coefficient of Thermal Expansion of Chemical Resistant Mortars, Grouts, Monolithic Surfacing, and Polymer Concretes

ASTM C580 Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical Resistant Mortars, Grouts, Monolithic Surfacing, and Polymer Concretes

ASTM C469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

ASTM C1181 Standard Test Methods for Compressive Creep of Chemical Resistant Polymer Machinery Grouts

ASTM C512 Standard Test Method for Creep of Concrete in Compression

ASTM C 33 Standard Specification for Concrete Aggregates

ACI Standards are available from The American Concrete Institute, 38800 Country Club Dr., Farmington Hills, MI 48331-3439 USA

ACI Committee 351 Foundations for Equipment and Machinery

351.1R-12: Report on Grouting between Foundations and Bases for Support of Equipment and Machinery

351.2R-10: Report on Foundations for Static Equipment

351.3R-04: Foundations for Dynamic Equipment

351.4-14: Specification for Installation of Cementitious Grouting between Foundations and Equipment Bases

351.5-15: Specification for Installation of Epoxy Grouting between Foundations and Equipment Bases

ICRI Documents are available from the International Concrete Repair Institute, 10600 West Higgins Road, Suite 607, Rosemont, IL 60018

ICRI Committee 320 Materials and Methods

ICRI 310.2 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays (formerly No. 03732)

ICRI 320.5 Pictorial Atlas of Concrete Repair Material Mixing Equipment

API 686 Recommended Practice for Machinery Installation and Installation Design

Wikipedia Pump Pictures