Grout systems for rotating and reciprocating machinery

Multiple factors determine success in establishing, ensuring longevity in equipment foundations.

By **Neetin Ghaisas**, **Christopher Matthews-Ewald** and **Fred Helfmann**

The reliability of plant equipment is a critical component of and has a direct impact on the profitability of industrial and production facilities. A large variety of rotating and reciprocating machines are installed in modern petroleum, petrochemical and gas processing units in general and special-purpose process applications. Owners and operators of machinery strive to attain and maintain higher efficiency and reliability of their equipment to achieve lower operating costs and realize greater productivity. Both have a direct and positive impact on the bottom line.

Rotating and reciprocating machines, their piping, auxiliary or support systems, equipment mounting, grouting, anchoring and foundations all have a constructive relationship with long-term reliability. Comprehensive engineering, robust specifications, proper selection and use of the best practices in design, manufacturing, installation, operation and maintenance contribute to optimum equipment performance.

Grout is an integrated component of equipment systems in that it forms monolithic contact between the equipment and their foundations for effective load transfer, energy dissipation and damping. The vital role of grout; specifically epoxy grout, in equipment performance, reliability and low life-cycle costs cannot be overemphasized.

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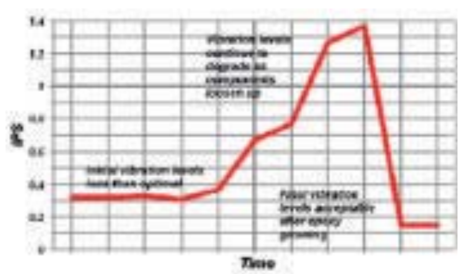
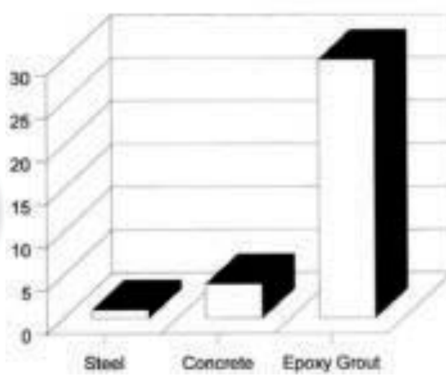
Purpose of grout

Grout works in tandem with a machinery anchoring system (mounting plates and anchor bolts) to maintain the aligned position





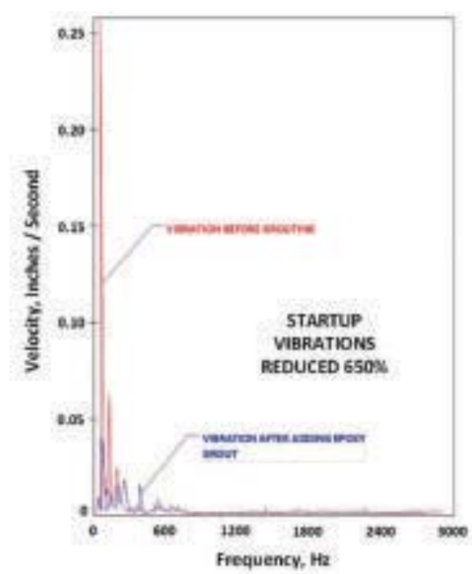


FIGURE 1
Vibration damping characteristic of epoxy grout

of the equipment. It resists downward and lateral acting loads on the concrete foundation. While cementitious grouts have been used in the industry for many years for machinery grouting, epoxy grouts are now widely used due to their superior performance characteristics, which are explained below.

- **a** Exceptional resistance to shear, tensile and compression loads.
- **b** Maintains precise equipment alignment by securing their set position and resisting downward and lateral loads.
- **c** Higher adhesive bond strength to concrete and steel than that of cementitious grout.
- **d** Greater resistance to shrinkage and fretting.
- **e** Excellent vibration dampening capability that further helps in the dissipation of dynamic loads (Figure 1).
- **f** Resistance to chemicals, moisture and chlorides.
- **g** Greater endurance to heat and thermal cycling than cementitious grout.
- **h** Fast curing for quicker service strength.

Concrete and similarly cementitious grout has about three-to-five times the vibration absorption capacity as steel. Low modulus epoxy grouts have nearly 30 times the vibration absorption capacity as steel and six-to-10 times the capacity of cement-based products.

Machinery foundations, anchor bolts

API RP 686 provides recommended practice for machinery installation and installation design. ACI 351.3R-18 is American Concrete Institute's standard titled "Report on Foundations for Dynamic Equipment". They are widely used in the industry. The best practices described in this paper are intended to complement them.

Foundation transmits dynamic forces from the mounted machinery to soil. Therefore, soil property analysis becomes critical to foundation design. Geotechnical data – such as soil weight density; dynamic shear modulus; shear wave velocity; dynamic modulus of sub-grade reaction; allowable soil bearing pressure; or pile load-carrying capacity – and Poisson's ratio is collected and used for evaluating the soil/pile stiffness and damping coefficients. This information is used in the static and dynamic design of foundations.

A block foundation consists of concrete mass block, piers and mat. Mass of the block foundation should be at least three times the weight of rotating machines and five times the mass of reciprocating machines. Dynamic analysis of the foundation system might dictate a different mass ratio for some installations. The width of the foundation should be at least 1.5 times the vertical distance from the bottom of the foundation to the centerline of the shaft/rotor.

The center of mass of the machine foundation (machine and foundation system) should coincide with the centroid of the soil foundation or pile group resistance. Horizontal eccentricity should be limited to 5% of the corresponding foundation dimension. The minimum thickness of the concrete mat should be one-fifth of the least foundation dimensions or one-tenth of the largest foundation dimensions, whichever is greater.

Freshly poured concrete should be allowed to cure completely. The moisture content and shrinkage of the concrete should be at its minimum before applying epoxy grout. The standard cure time for concrete is 28 days. At this time, the concrete foundation usually achieves a minimum 4000 psi (276 bar) design strength. ASTM C 157 test is conventionally used to determine moisture and shrinkage levels. Wireless sensors to monitor temperature and strength of the poured concrete is one of the methods available to the construction industry. Sensors are embedded in the foundation form before concrete pour (typically located 2 in. [50.8 mm] from the surface) and real-time data is wirelessly communicated to the display hardware to optimize conditions that affect the curing rate (Ref:11).

Before pouring epoxy grout, the foundation top surface is prepared by using hand-held pneumatic chipping hammer(s) to remove all cement-rich laitance from the top of the foundation. Additionally, all outside edges of the foundation are chamfered at a 45-degree angle. A good surface profile

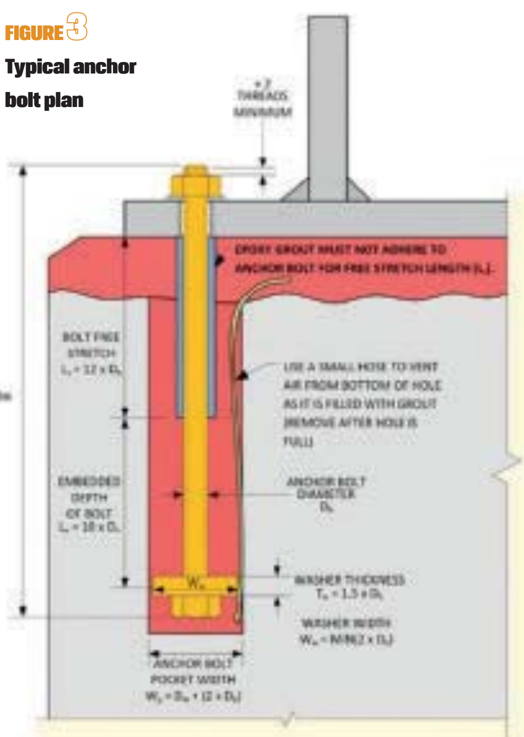
FIGURE 2
Prepared top surface of machinery concrete foundation

exposes the coarse aggregate that is the strongest part of the foundation and it serves to form a monolithic bond with the grout. Figure 2 shows the prepared top surface of a machinery concrete foundation.

Anchor bolts resist the upward and lateral forces imposed by the dynamic loads produced by the mounted machinery. Epoxy grout resists downward forces produced by equipment deadweight. This action of the anchor bolts and epoxy grout in unison provides effective dynamic load transfer to the foundation for absorption and dissipation of energy and helps to maintain the aligned position of the machinery.

Anchor bolts should be installed at the specified position and within the tolerance stated on the construction drawing. Embedment length of anchor bolts in the foundation is typically 10 x bolt diameters with 8 x bolt diameter of isolation for free stretch in centrifugal compressors and

FIGURE 3
Typical anchor bolt plan



12 x bolt diameter of isolation for free stretch in reciprocating compressor applications. Anchor bolts are generally ASTM A193 grade B7 and nuts ASTM A194 grade 2H. A recommended anchor bolt plan is shown in Figure 3.

Epoxy grout

Temperature is the key parameter for grout pour. The chemical reaction that results when epoxy resin and hardener are mixed causes the epoxy molecules to cross-link with each other and form a rigid, structural lattice as shown in Figure 4.

The heat released due to exothermic nature of the chemical reaction between epoxy resin and hardener depends on many factors, such as the mass of epoxy, the ambient temperature, the chemical formulation of the epoxy, the component temperatures at the time of mixing and ability of the surrounding surfaces to absorb heat.

After the initiation of the polymerization process, epoxy changes from a liquid to a solid state over time. This is the gel point of epoxy grout and also the time when the maximum temperature is reached and where the epoxy grout is in equilibrium. After the gel point is reached, the temperature starts to drop. Complete curing of epoxy grout is accomplished by ambient heat or, if it is too low, from an externally applied heat source. The effect of the coefficient of linear thermal expansion after grout temperature falls below the peak exothermic reaction temperature is depicted in Figure 5.

A high exothermic cure temperature can help and hurt an epoxy grout installation. The higher the exothermic cure temperature, the faster the epoxy grout will cure. However, the higher the exothermic cure temperature, the more the epoxy grout will contract and shrink as it cools to the surrounding (ambient) temperature. Figure 6 shows the exotherm curve for two types of grouts.

During extremely hot or cold ambient temperatures, sheltering and preconditioning of all grouting materials and equipment is necessary for controlling the temperature of the products throughout the installation and cure cycle. It is equally important to protect the materials from undesirable elements such as rain, snow and wind. Established preconditioning temperature of the grouting materials should be achieved and maintained for at least 24 hours before mixing and use.

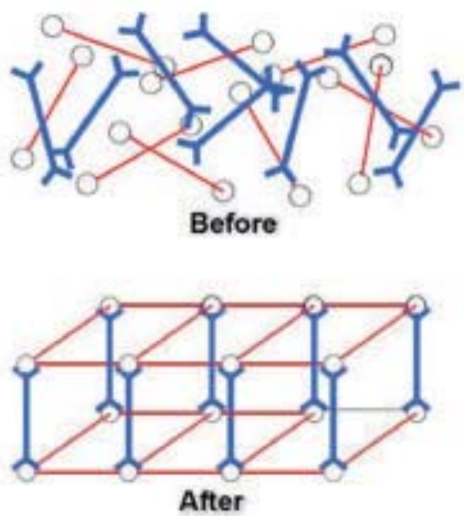


FIGURE 4 **Structural lattice of epoxy grout**

Edge lifting, cracks in epoxy grout

Edge lifting after grout pour occurs if the reduction in temperature due to external circumstances cause the epoxy grout to contract faster than the concrete to which it is bonded. Tensile stresses develop at the foundation edges and corners directly below the bond line between the epoxy grout and concrete. If the forces exceed the tensile strength of the concrete, cracks can develop around the perimeter of the foundation, typically 0.5 in. to 8 in. (12.7 mm to 203.2 mm) below the bond interface. Edge lifting can be prevented or controlled by creating a 45-degree chamfer around the foundation perimeter or by drilling and placing steel dowel pins around the foundation perimeter. Edge lifting is shown in Figure 7.

The difference between the initial peak exothermic temperature during grout pour and the lower potential temperatures that might be experienced in the environment later influences the probability and frequency of crack development. Cracks can develop as soon as the epoxy grout cools down after the initial exothermic reaction. They can also occur weeks, months and even years after installation if ambient conditions in the immediate surroundings drop far enough to continue building up and eventually overcome the physical limits of the cured grout. This phenomenon is also valid for edge lifting.

Cracks are typically perceived as a failure in the grout. However, cracks are a known occurrence and common in many materials, such as concrete, that react chemically and undergo a heat-related cure (see Figure 8).

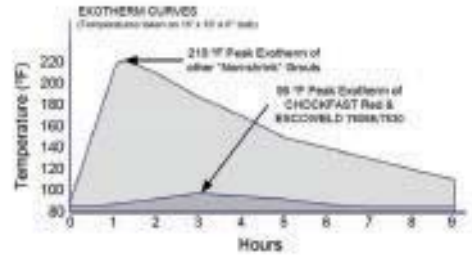


FIGURE 6 **Exotherm curves, ITW Chockfast red and escoweld grouts**

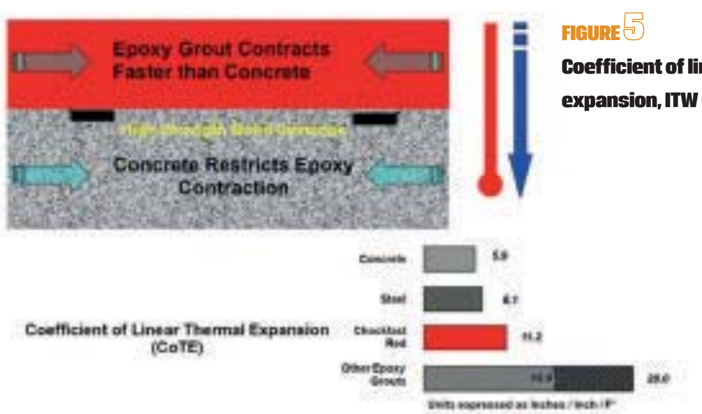


FIGURE 5 **Coefficient of linear thermal expansion, ITW Chockfast red epoxy**

FIGURE 7 **Edge lifting in the foundation**

FIGURE 8 Temperature-induced cracks in concrete

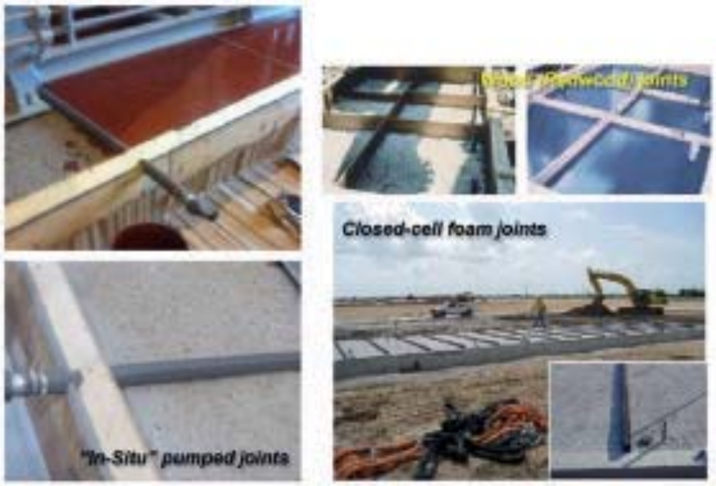


FIGURE 9 Types of control joints in epoxy grout

Thermal cracks can be anticipated and mitigated through the considerate and intentional placement of prefabricated control joints (commonly referred to as expansion joints) in the epoxy grout.

Control joints form bulkheads when placed, segmenting the large pour areas into smaller, more manageable sections to better facilitate and control the grout placement process. Control joints help facilitate the movement of the grout in directions where it is most desired to move and allow for potential disruptions in the grouting process, such as material shortage and hardware breakdowns. Some types of commonly used control joints are shown in Figure 9.

Grout forms and pouring techniques

Grout forms are installed to contain the epoxy grout until it has properly set. The forms are required to be free of leaks and typically constructed from suitable forming materials such as 0.75 in. (19.1 mm) plywood that is thoroughly braced (see Figure 10). The surfaces of forms that will contact epoxy grout are coated with a minimum of three coats of paste wax and 45-degree chamfers are placed on the inside and outside corners of the form to prevent sharp corners.
Two-stage epoxy grout pour is commonly used. In the first stage, grout is poured between the bottom of the machinery baseplate and the top of the concrete to form a mat. After the first pour cures, the second pour of epoxy grout fills the gap between the underside of the machinery baseplate and the top of the first pour.

In the single-stage grout pour method, horizontal form covers are installed over the area between the top of the machinery baseplate flange to the top of the form around the complete perimeter.

Head boxes, standpipes or troughs serve to pour the epoxy grout with consistent hydraulic head pressure to assist in the movement and strategic placement of epoxy grout. Epoxy liquid resin is injected to fill voids in the poured epoxy grout. Two holes are drilled at each end of the void. One hole serves as the injection point and the other hole acts as a vent.

FIGURE 10 Braced grout form

Pumpable epoxy grouts

High-flow, pumpable epoxy grouts have been developed for large-volume applications and provide several benefits over the conventional pour method.

High-performance pumpable grouts have superior cured properties, such as compressive strength, tensile strength and flexural strength. Flexural strength or transverse rupture strength is the stress in epoxy grout before yielding. **CT2**

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ACKNOWLEDGMENT:
The figures in this paper are courtesy of Chinook Industrial Ltd and ITW Performance Polymers.