

Considerations for Epoxy Grouting and Foundation Repair of Reciprocating Equipment

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Improvements in grouting of reciprocating equipment installations and associated foundation repairs have made significant contributions to lowering maintenance costs, improving equipment performance and increasing the longevity of both equipment and foundation. The technical aspects of grouting can be a source of frustration to those who must pull their knowledge of the subject off the shelf when it becomes time to grout. Very few attend to this subject on a regular basis, so it is appropriate that an overview be offered to recall some important considerations.

General Considerations for Grouting

The most common questions regarding maintenance grouting of reciprocating equipment are simply why and when should it be done? Prior to the early 1970's, little thought was given to the subject of regrouting as a way to optimize performance and reduce operating costs of equipment. As the need for regrouting became a priority due to the increasing service lives of many foundations, a number of considerations developed into benchmarks for determining the need for regrout operations that we use today.

Why regrout?

The foremost priority for optimum reciprocating equipment performance is the maintenance of crankshaft alignment or its pre-determined position in a three-dimensional aspect. Whether or not crankshaft web deflections fall within recommended service guidelines are dependent on:

1. Foundation condition

A foundation consists of a "monolithic" system of concrete and reinforcing steel. It is intended to create a stable platform for machinery capable of withstanding the static and dynamic (unbalanced) loading conditions imposed upon it. Enough rigid mass must be present to provide the equal and opposite forces necessary to resist these loading conditions. Through proper design this will hold true, but will be diminished if the actual concrete and/or reinforcing fails to meet design criteria or proper installation procedures are not followed. Forces acting on the foundation will exceed its resistive forces and cause cracking. Once these cracks develop, a natural progression begins. Through the introduction of oils into these cracks and the porous composition of the concrete, sulfates in the oil aid to break down the concrete and intensify the process of foundation deterioration.

Load transfer through concrete cannot bridge cracks that develop. Only the reinforcing steel is available for transfer of these imposed loads. The reinforcing steel is designed to work in conjunction with the concrete to resist tensile forces due to concrete's weakness in this area, but is not intended to compensate for all loading conditions acting on the concrete.

2. Grout interface condition

Deterioration of the grout interface can be attributed to many factors. Many are a result of problems caused by the other components in the equipment/foundation system being discussed here. Others can be directly attributed to the grout interface as a source for foundation deterioration.

Direct grout problems are many times a result of improper planning and installation. Factors such as inadequate support due to excess air entrained in the grout during the mixing procedure; lack of bonding to the concrete substrate; and cracking due to thermal changes during and after curing. Lack of consideration regarding locations of expansion joints will provide an opportunity for cracks to develop in critical areas along soleplates and anchor bolts. Because of the impervious nature of epoxy grout, any breach occurring in the grout cap will provide an avenue for the introduction of oil into the concrete foundation.

3. Anchor bolts

Anchor bolts are the single greatest cause of foundation-related problems. Improper design and installation or failure to perform regular bolt inspections and maintenance serve to establish anchor bolts as the root of a problematic equipment/ foundation system.

4. Mechanical condition of reciprocating equipment

The mechanical condition of reciprocating equipment is a major contributor to diminished service life of a foundation. Increased unbalanced forces transferred from equipment to foundation create a continuous hammering effect that serves to weaken and break down the concrete. When combined with foundation problems caused by or to other components in the equipment/foundation system, foundation deterioration increases significantly.

Unbalanced forces can be minimized through proper attention to crankshaft alignment; disproportional weight of machinery components such as pistons, power rods and counterweights; and bearing clearances.

When to Grout

Unless it is a reactionary measure as a direct result of equipment or foundation failure, when is a regrout necessary? When should funds be allocated to improve operating conditions and performance? What guidelines can be followed to accomplish this in the most cost effective manner? All of the factors discussed earlier contribute to these decisions. A substandard equipment /foundation system results in higher maintenance costs as a rule. But funds are carefully administered. Which foundations should be given priority?

Controlled surveys may be used in an attempt to set parameters which can determine when a regrout is necessary. This enables one to consider each candidate for regrouting using the same guidelines. Greater efficiency in prioritizing and budgeting projects results. Figure 1 represents an example of a survey for a reciprocating engine or compressor:

Figure 1

Equation: $(2 \times A) + (2 \times B) + C + D + E = \underline{\hspace{2cm}}$

Scale

- 1 to 4 Indicates a reliable installation
- 5 to 8 Indicates a borderline installation
- 9 to 12 Indicates a problem condition, monitor closely
- 13 or Greater Indicates the need to regrout

A. Web Deflection

- 0 - Within Manufacturer's Specifications
- 1 - Borderline
- 2 - Out of Specification

B. Engine or Compressor Movement

- 0 - No Movement
- 1 - Movement, oil pump end
- 2 - Movement, flywheel end
- 3 - Both ends moving

C. Concrete & Grout Condition

Concrete

- 1 - Good
- 2 - Fair
- 3 - Poor
- 4 - Immediate need

Grout

- 1 - Good
- 2 - Fair
- 3 - Poor
- 4 - Immediate need

D. Existing Machine Support System

- 1 - Adjustable support system _____
- 2 - Epoxy machine chock
- 3 - Steel chocks
- 4 - Full Bed

E. Anchor Bolt Condition

of broken anchor bolts _____

Band-Aid or Like New?

Sometimes the need is there but the funds are not. A full regROUT is out of the question. The question is though, what can be done in the way of foundation repairs to increase the life of an existing equipment/foundation system until a full regROUT can occur? While this is situation dependent , the main point to be realized is that any partial repair is, in most cases, only a temporary solution. If temporary repairs are made, continue with plans for a complete repair in the future.

Common Grouting Configurations for Reciprocating Equipment

Different mounting configurations have been used over the years to support engine and compressors. The most common methods are described here:

Epoxy Machine Chock - A method of mounting where poured epoxy chocks (or shims) support the reciprocating equipment at pre-determined points, usually at each anchor bolt location. Epoxy chocks are formed and poured in place. Epoxy chocks are most commonly poured on top of the grout cap. This method allows for air-flow underneath the equipment, reducing upward thermal growth of the foundation and minimizing crankshaft deflection.

Adjustable Machine Chock / Soleplate - The reciprocating equipment is supported at pre-determined points, usually at each anchor bolt location by a two-piece steel or composite material chock. The chock is supported on a soleplate embedded in the epoxy grout cap. A shim pack is situated between the two-piece chock, allowing for realignment of the equipment . This method also allows for air-flow underneath the equipment, reducing "thermal humping".

The poured epoxy chock and adjustable machine chock methods are the most widely used methods of support for integral engine-driven compressors.

Full Bed - The entire top surface of the foundation is topped with a grout cap. All points of the reciprocating equipment frame are supported by the grout. This was the standard method of grouting prior to the 1980's but has since been replaced in favor of Epoxy Chock or Adjustable Chock / Soleplate systems.

Skid Mounting - The reciprocating equipment is mounted to a prefabricated skid. The skid is grouted where all bottom flanges are supported by the grout. The entire top surface of the foundation is topped with a grout cap. This method is most common with HS compressor packages.

Rail Mounting - Rails are embedded in grout. The reciprocating equipment is supported on one-piece chocks or shims placed between the machine frame and rail.

Physical Characteristics of Epoxy - Based Grouts

The initial function of an epoxy grout, in whole or in part, is to create a stable interface between the reciprocating equipment and its foundation that is designed to resist the downward forces acting on the foundation. The majority of the downward forces are static, resulting from the equipment deadweight and clamp-down force of the anchor bolts. The unbalanced forces present during equipment operation will also produce downward forces that will create a significant impact to this loading condition. It is a critical design consideration that epoxy grout retain its initial position in each dimensional plane for crankshaft alignment to be maintained.

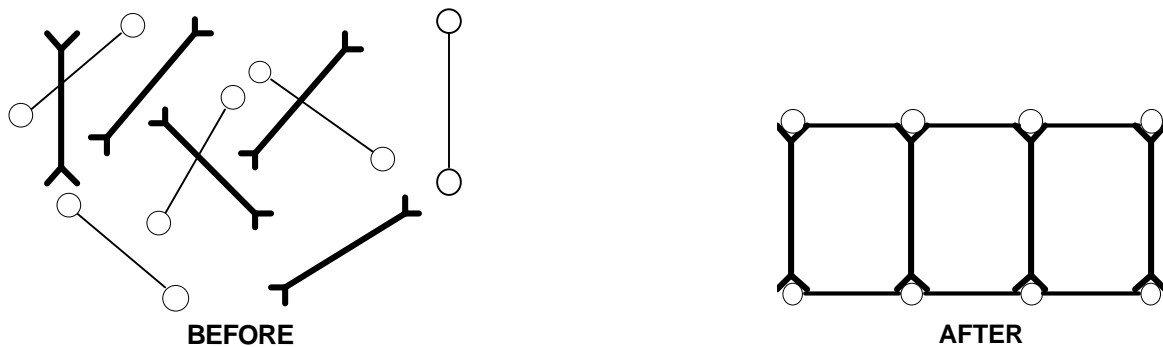
What is an epoxy grout?

Products classified as an epoxy grout consist of an organic thermosetting epoxy resin system combined with blended, inorganic aggregates composed of silica or quartz. The mixed combination of these materials produces a product characterized by high compressive, tensile, flexural and shear strengths; an impervious quality for excellent chemical resistance; superior vibration damping efficiency; and negligible shrinkage.

Exotherm

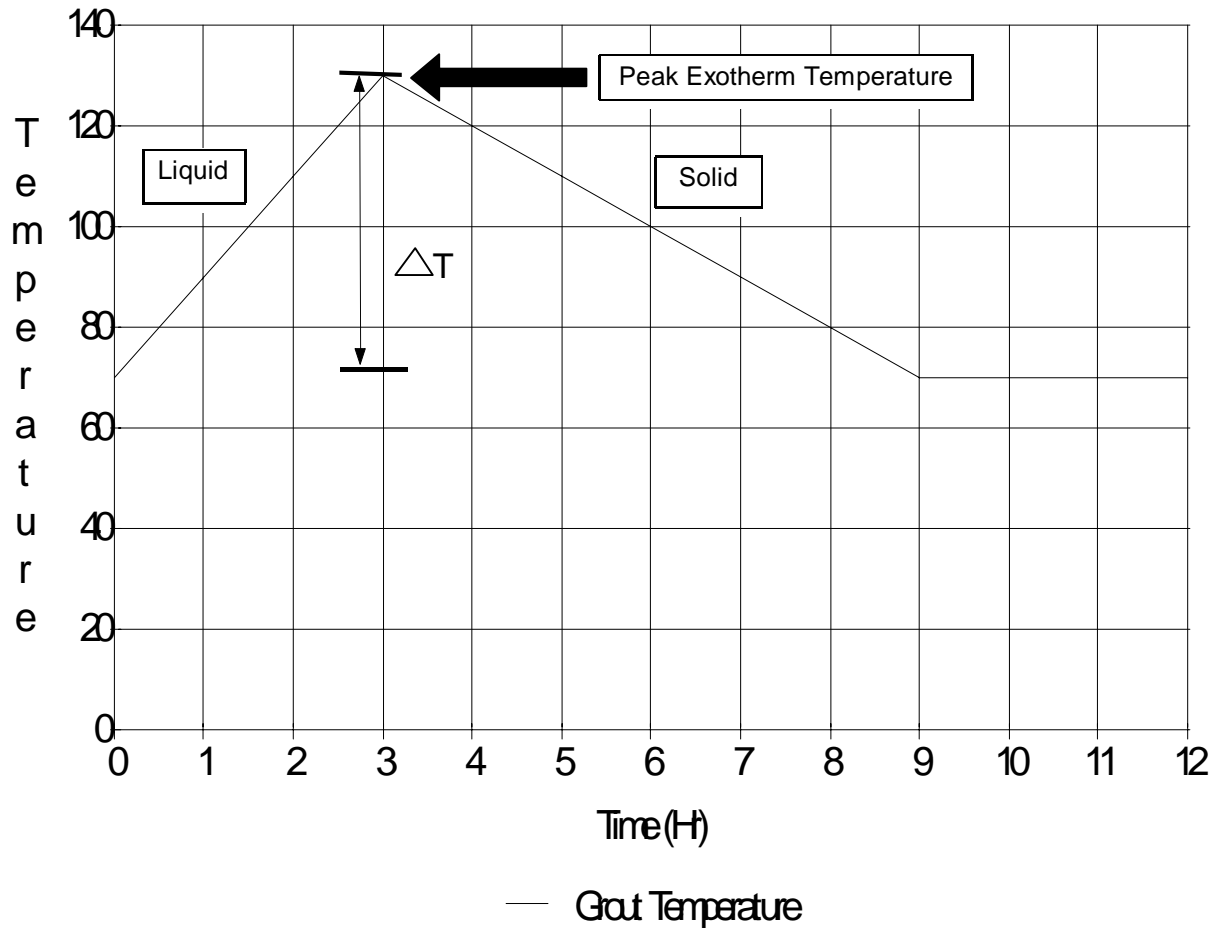
Much like concrete or cement-based grouts, epoxy grouts develop their characteristics as a result of a curing process producing heat. When resin and hardener components are mixed, the molecules of each become active and "cross-link" to form a rigid structure (Figure 2). The active nature of the resin and hardener molecules during cross-linking creates the physical heat reaction or "exothermic reaction".

Figure 2



The highest temperature reached during the curing process is called the peak exotherm of an epoxy grout (Figure 3). It is at this temperature that the material begins its transition from a liquid to a solid state. As a result, stresses due to temperature are locked into the grout as it solidifies. As the grout cools, it contracts. Eventually, the stresses locked into the grout are relieved in the form of cracking. The greater the exothermic cure temperature, the greater temperature difference exists between the peak exotherm and ambient temperature. The greater temperature difference will result in a greater contraction and likelihood of cracking in the grout. The last factor being of great concern due to oil penetration into the concrete through the cracks that develop. Expansion joints placed at shorter intervals will be required to control the location and number of cracks.

Figure 3



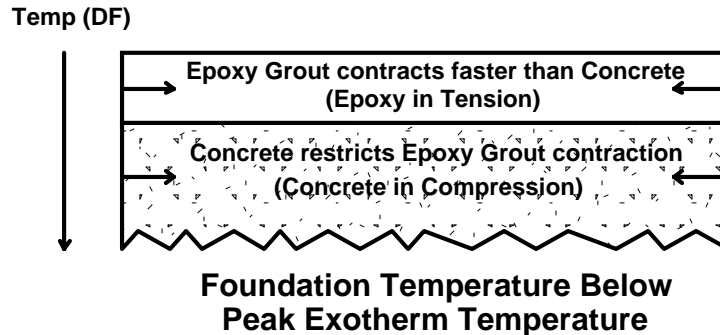
Various factors contribute to the peak exothermic temperature: grout formulation; temperature of the grout materials before mixing; ambient temperature of the work area; direct sunlight; and temperature of adjacent surfaces in contact with the mixed grout. Higher exothermic cure will also reduce working time, cure time and single pour depth.

Coefficient of Thermal Expansion

Coefficient of Thermal Expansion (CTE) refers to the rate of expansion or contraction a material is subject to according to temperature. This rate is expressed as in/in/degree F or C ("inches per inch per degree F or C"). The CTE of concrete and steel are relatively close, compared with epoxy grouts which may range from 2 to 5 times greater (Figure 4).

Figure 4

Steel	6.1 x 10(-6)
Concrete	5.9 x 10(-6)
Epoxy Grout	11.2 x 10(-6) to 27.0 x 10(-6)



Expansion joints are necessary as a result of: 1.) Stresses that may be relieved during the temperature drop after peak exotherm and 2.) The CTE of an epoxy grout. Expansion joints do not diminish the load carrying capacity of the grout but allow for pre-determined "crack" locations away from critical areas such as anchor bolts, soleplates or epoxy chocks. Expansion joints also allow the grout to compensate for temperature changes after cure has taken place.

Preparation and Installation Considerations

It is of primary importance that epoxy grouts be mixed and placed in proper fashion to maximize their design characteristics. An epoxy grout with excellent physical properties may be a substandard performer if proper guidelines are not followed before, during and after the installation.

Project Planning

Prior to any actual work being performed, it is recommended that the grout manufacturer or an approved representative be contacted to assist in the planning and execution of any grouting project for reciprocating equipment. All phases of the project including those listed below should be reviewed to insure a problem-free project and optimum performance after startup.

1. Pre-Planning

Pre-planning encompasses all design aspects including equipment type and size, support system and grout selection. The scope of work is paid special attention to ensure the proper project objectives are identified and the means to accomplish them are established through plans and specifications. A schedule is outlined for construction operations noting time constraints for the project, its various tasks and special requirements during the course of the work. The time the work is to be performed may depend on present or anticipated horsepower requirements of the client. Contract bids are solicited from contractors qualified to perform grouting and alignment procedures with a contract award considered towards the contractor with the most qualified bid.

2. Site - Preparation

Initial job-staging allows for all tools, equipment, materials and manpower to be set up on the jobsite. The work area is isolated to protect surrounding areas and observe safety regulations. When these tasks are complete, foundation demolition can commence if this is a requirement. Otherwise, advanced preparations will begin at the surface of new concrete.

3. Preparation for and Installation of the Grout

Preparation of the work area consists of a number of decisions to be made and tasks completed before and during the time grout is mixed and placed. Attention to how the equipment is to be supported and environmental conditions are just a few. The actual preparation and installation procedures themselves may vary depending on which grout is used. It is suggested that preparation and installation procedures for epoxy grouts follow the recommendations of each respective grout manufacturer. A sample checklist outlining tasks and considerations during preparation and installation has been included for reference. (Attachment A)

Anchor Bolts - Their Effect on Proper Equipment Performance

While epoxy grout resists downward forces produced by equipment deadweight and anchor bolt tension, anchor bolts serve to resist the upward and lateral forces generated by operating engines and compressors. Reciprocating equipment using composite chocks or epoxy chocks rely on the coefficient of friction of the chocks to provide some measure of lateral resistance, but the majority of the resistance is provided by the anchor bolts.

While the critical responsibility of the anchor bolt has been defined, problems have existed for years and still occur today which greatly diminish the capability of an anchor bolt to perform its function for an equipment /foundation system.

Improper Design & Installation

The initial root of an anchor bolt problem may stem from the improper selection of bolt for its intended purpose. Type or grade of steel; bolt tension (usually 3 to 4 times equipment deadweight); bolt diameter; proper type or grade of nut; length; position (staggered or not?); and the type of reciprocating equipment must all be taken into account during design considerations. If new reciprocating equipment is to be installed, the manufacturer naturally takes these matters in consideration. On a regrout project the decisions may fall elsewhere.

Installation practices for anchor bolts should be as precise as the equipment being installed. While an excellent theoretical statement, the reality of this matter falls short. An anchor bolts' intended function maintains that for ideal performance, it should be perpendicular to its seat and at a point equidistant from all edges of the bolt hole in an equipment frame. If a bolt is installed out of position, the most common solution is to manipulate the bolt through the hole by some mechanical means. What this has accomplished is a bolt that is out of plumb. The nut is threaded and tensioned but is not seated properly creating an off-center loading situation. Not only does unequal loading occur to one side of the bolt but the nut will gall one edge of the seat, creating a greater friction condition when turning the nut. These may create an erroneous torque reading, leaving less tension on the bolt than believed. Products such as two-piece spherical washers are a cost effective method to correct for off-center bolt conditions.

Free Stretch

Prior to the 1970's, isolating an anchor bolt subject to predominantly tensile forces was not a general practice and resulted in a great number of fatigued or broken bolts. Free stretch of an anchor bolt asserts that when proper tension is applied to an unrestricted bolt, it will stretch. This stretch is directly proportional to the bolt's modulus of elasticity. In the stretched condition, the bolt exhibits the natural tendency to "spring-back ", creating a suitable clamp-down force. If the bolt is not able to stretch, as in the case when it is bonded to grout or concrete, its capacity is greatly diminished.

Bolt Maintenance

The lack of attention to bolt maintenance will adversely effect an equipment/foundation system. Inadequate bolt tension will allow for excess movement of reciprocating equipment . This excess movement creates increased stresses on the anchor bolts, support system, grout cap and foundation. This will greatly reduce the effectiveness and life-span of both the equipment and foundation while increasing maintenance costs. Through the establishment of regular inspection and maintenance of anchor bolts, problems can be minimized. There are a few guidelines to remember for properly and successfully maintaining anchor bolts:

Protect nut and bolt threads from damage and foreign matter (paint dirt, concrete, grout, etc.). Also ensure that the nut face and the area where the nut is seated are clean of paint and other debris. Grease threads prior to tensioning using an approved lubricant. Practicing these steps will allow for proper tightening of nuts.

Bolt tension should be checked on a regular basis to ensure conformance with recommended values. Dial indicators used to measure torque should be calibrated frequently to avoid erroneous readings. On new or maintenance grouting projects, anchor bolts should be initially tensioned and released 3 times with final tensioning accomplished on the third time. The amount of time between tensioning will depend on the type of material and its elastic properties. Seven days after equipment startup, when the equipment is at full operating temperature, bolts should be checked again for proper tension. This should be repeated again after thirty days at full operating temperature. Finally, anchor bolt tensions should be checked six months after initial testing with checks repeated every six months thereafter.

The goals associated with any new or maintenance grouting are straightforward: Create an analogous reciprocating compression system from multiple components (Machinery/Support System/Anchor Bolts/Grout Cap/Foundation) capable of performing its function with the greatest cost efficiency and longevity. Each project situation differs, but the goals remain relatively constant and while the information on the subject of grouting and related subjects can become involved, the basic criteria and considerations presented here provide the basis for successful grouting operations.