# "MACHINERY BASES --- CHEMICAL DEPENDENCY"

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## *INTRODUCTION*

*Carefully manufactured epoxy resin grouting materials bring forth many important properties to help the end user or contractor maintain permanent precise alignment of machinery bases for a long period of time. These materials provide reduced maintenance because of less downtime required to install the machinery whether it be the initial installation or a regrouting application. The epoxy grouts exhibit excellent resistance to chemical and physical degradation due to their high impact and compressive strengths and therefore have a longer service life. These unique properties make epoxy grouts ideal for applications where permanent precise alignment is necessary.*

*Epoxies are a broad family of polymer materials (a polymer is a set of numerous natural and synthetic compounds of usually high molecular weight consisting of millions of repeated linked units, each a relatively light and simple molecule). Epoxies are used as grouting materials, coatings, adhesives, floorings, composites and other construction materials in every major industry including computers, aircraft, automobiles, heavy industrial and many others.*

*The use of epoxy type repair compounds in the industrial environment is rapidly becoming the rule rather than the exception. Early formulations of sand and cement grouting techniques that exhibited very poor mechanical capabilities have been replaced by sophisticated systems designed for specific applications. Whereas, at one time epoxies were looked upon as temporary patches, these modern systems have successfully performed repairs that have outlasted the original equipment.*

*Many problems of early formulations such as product uniformity, limited shelf life, toxicity, resin stability and poor performance have been eliminated. As more industrial experience is gained, the use of epoxies will become more and more a common place.*

## HISTORY

*The history of epoxy materials began around 1875 when the first synthesized organic compound was formulated. The compound known as "Urea" (a white crystalline or powdery compound found in body fluids, synthesized from ammonia and carbon dioxide) became the foundation of virtually the entire science of plastics.*

*Research involving high polymers in an industrial or commercial atmosphere was actually started due to a severe shortage of ivory in the United States. When a newspaper offered a $10,000 reward for the invention of an ivory substitute in 1868, John Wesley Hyatte won the prize by merely mixing nitrocellulose, alcohol and camphor. This first plastic was not only used for the replacement of ivory but had many other useful applications as well.*

*Until the mid 20th century, an external heat source was required to cure all plastics (endothermic reaction). In the late 1940's there was a major breakthrough in resin technology; an exothermic reaction which requires no external heat source for curing of an epoxy. That new discovery 40 years ago has led to the development of most commercially available epoxies in use today.*

*Most commercially available epoxies fall into three chemical families. They are as follows:*

- A. *Bisphenol Epichlorohydrin*
- B. *Novolacs*
- C. *Bishpenol Formaldehyde*

*Many epoxies are blended from two or more of the above resins to achieve the characteristics desired by the manufacturer. Although chemistry of the epoxies are of little interest to the end user, it must be remembered that they are organic compounds and by definition have some inherent limitations.*

There are hundreds of epoxy formulations which range from very high quality to very poor. Obviously, as the quality diminishes, the product's limitations increase proportionally. The range of properties between epoxies is enormous, therefore the end user should do his best to obtain a product designed for his particular application and one that will perform consistently well in regards to quality control from the factory and physical properties when cured. Epoxies have made it possible to perform emergency on site repairs, thus eliminating excessive downtime.

ENGINEERED MATERIALS

Initially, the principal use of epoxies was for adhesives and coatings, however the technological advancement of epoxy formulations in the past 25 years has been astounding and there are new formulations and new applications for epoxies being discovered on a continuing basis.

Although the mechanical properties of epoxy resins are lower than structural metals, cast resins can outperform metals in many critical applications. Because they are easily cast into shape, high performance epoxy resins can replace ferrous or nonferrous metals, and at the same time, reduce manufacturing costs. They are widely used in electrical engineering as pourable encapsulants and in low-expansion, printed circuit boards, and now are being accepted more in mechanical designs. When they are used it is generally as grouting products or adhesives. Their mechanical properties are frequently compared to concrete and inevitably so are their capabilities, which can be a false premise.

Although it is natural to assume the numerically superior properties of structural metals must make them superior materials compared to pourable epoxy resins, this is generally not the case. When epoxy resin chocks (liquid shims) were developed in the early 1960's to maintain *permanent precise alignment of large marine diesel engines, engine builders objected to a resin compressive strength (19,000 psi), that is only a fraction of that of steel. But for this application, the strength of the cured resin is actually more than 40 times the specific load on the epoxy chock. The resin chock's perfect "as-cast" fit and appropriate modulus of elasticity assure uniform stress distribution, plus a precise alignment and is many times less costly to install.*

*Unfortunately, the true properties of high-performance casting resins are not revealed by standard tests. Such physical tests are useful only for quality control and for comparison of similar materials. This occurs because the visco-elastic nature of an epoxy resin makes small test specimens behave very differently from practical size castings. In practice, the resulting properties are affected by actual design configurations. For more critical applications it is important to design for optimum resin properties.*

*In the past 50 years, various types of grouts have been used. One of the earliest was a sand-cement mix, which was spread under entire base-plates for full-bed grouting. In addition to low impact and tensile strengths, the cement grout will absorb water, oil, chemicals, etc., and deteriorate over a period of time. There is also a relatively high rate of shrinkage due to the addition of water in the mixing process. The optimum physical properties can only be obtained if the mixing and curing are carried out precisely as specified by the manufacturer.*

*Cement grouts serve very well in many applications and epoxy is not proposed as a universal replacement. There are, however, many applications involving expensive and critical machinery where epoxy should be the definite choice as the grouting material.*

Since there are hundreds of different types of equipment that need to be grouted it's obvious that not just one epoxy formulation would be adequate for all the various machinery base designs. A particular epoxy resin manufacturer has developed a set of five engineered epoxy grouting materials specifically formulated for machinery foundation repair and new construction applications where traditional cementitous or other resin materials fail. Their products have been used worldwide under every conceivable type of equipment in many different industries. These epoxy grouts are "state of the art".

## EVOLUTION OF "STATE OF THE ART" GROUTING MATERIAL

A new hybrid foundation grouting system has been developed for stationary engines, motors, pumps, bearing pedestals, etc. It employs the best of the grouting systems used for both marine and industrial applications.

The new system, which uses epoxy to cap the concrete foundation and epoxy chocks to support and maintain alignment of the machinery, is a result of 50 years evolution of grouting system design for both concrete block and steel beam foundations. Experience with engine and compressor installations in both marine and petroleum industries has revealed advantages and disadvantages of a variety of foundation designs. While the hybrid system essentially borrows much experience from the marine designs, an understanding of all the systems is necessary to appreciate the new "state of the art" design.

Marine engines have typically been installed on large I-beams in the ships' hulls. Adequate support was afforded, but the beam surfaces were not smooth enough to offer intimate contact with the milled bottom of the engine. This problem and the problem of alignment were overcome by using "Chocks", which are shim plates 1" to 2" thick located at each anchor bolt. The earliest marine engines used steel chocks which were hand fitted by master craftsmen in a slow and tedious operation of filing and bluing . To realign the engines, the chocks could be removed and their thickness changed.

Later, chocks made of type metal were employed. This is a lead-based alloy which does not shrink appreciably when it solidifies and is used primarily for casting type for printing presses. The engine was aligned with wedges or jack screws and asbestos or clay dams were constructed around each anchor bolt to contain the molten metal until it solidified. The type metal techniques performed satisfactorily, but it involved the safety hazards associated with the handling of hot metals. This metal also tends to pound out because of the cyclic loading.

In 1963, a specially formulated epoxy compound began to be used in the same manner as type metal. This epoxy chocking compound gained wide acceptance because it was safer to work with than the type metal. Although epoxy does not have the compressive strength as the type metal, the size of the chocks can be increased to achieve acceptable unit loading. This epoxy chock design is used extensively in the marine industry. So far they have been accepted by most stationary engine owners because of the simplicity of the application along with the ease of realignment if necessary. It has been widely accepted by the petroleum, power transmission and gas transmission companies.

These "state of the art" materials also have a place in movable bridge applications including motors, generators, pedestals, hinges, pins, gearboxes, hydraulic cylinder bases, etc. The materials have been used for setting sleuce gates, guide rails and other types of equipment needing <u>permanent</u> <u>precise</u> <u>alignment</u>. The famous RIVER THAMES BARRIER PROJECT, the world's largest movable water barrier, which began operation in 1982, has over 41 tons of this epoxy grout supporting and maintaining precise alignment on all the equipment and machinery bases. The EASTERN SCHELDT BARRIER, a storm-surge barrier constructed by the

*Dutch Government, utilizes these "state of the art" grouting products for many machinery applications.*

*FOUNDATION DESIGNS FOR ALIGNMENT OF STATIONARY EQUIPMENT*

*Stationary equipment such as motors, pumps, bearing pedestals, generators, etc., are normally installed on concrete foundations with a cementitous type grout system, or a full-bed epoxy grout.*

*In the earliest type grouting, a sand and cement grout was poured or packed under the machinery base which had several disadvantages:*

A. *Low impact strength*
B. *The grout often deteriorated due to water, oil, salt water absorption*
C. *Cracking due to excess shrinkage and freeze/thaw cycles*
D. *Realignment was impossible without completely regrouting*

*Another disadvantage of sand and cement grout is that it experiences a relatively high rate of shrinkage when curing. This tendency is compounded if an excessive amount of water is used to help make the grout more fluid and easier to place under large machinery bases. Grouts with metallic fillers were developed to help combat this high rate of shrinkage. However, this probable solution had its drawbacks too. The ferrous metal fillers which were used would tend to corrode and expand, causing corrosion of the base.*

*Since the introduction of epoxy grouts as a reolacement for cementitous types in the late 1950's, many equipment manufacturers and design engineers are specifying epoxy type grouts for machinery bases. They offer great increases in compressive, tensile and shear properties and a very high resistance to oil, salt water and most chemicals. The major advantage however is achieving permanent precise alignment with a minimal amount of downtime.*

## DESIGN CONSIDERATIONS

There are many types of machinery foundation designs and all should be looked at on an individual basis whether it be a regrout or new construction. Anchor bolts and foundation cracks are the two most common problems encountered in regrouting and are often related. Ideally, bolts should be easily removable and replaceable, but more importantly, the bolts must have sufficient shank length free of grout bond to permit them to stretch when tightened.

When making foundation repairs it is essential to chip down to clean, oil free concrete prior to pouring an epoxy grout on top of it. The bond to clean concrete is greater than the tensile strength of the concrete. When a new concrete foundation is involved, it is necessary to chip off the top concrete surface in order to remove the laitance build up. A minimum of 1/2" of the new concrete should be chipped off to expose the coarse aggregate. The use of rebar is not necessary with some epoxy grouting materials since their physical properties are much stronger than those of concrete. The excessive use of rebar can lead to cracks in epoxy grout due to the differences between the coefficient of thermal expansion and contraction of the two dissimilar materials. We will go into detail on the use of reinforcing bar later.

When using epoxy chocks they should not be considered as bonding agents but more as "shim packs" which provide vertical support. Resistance to any lateral forces is provided by the clamping force of properly installed and torqued anchor bolts plus the high frictional forces developed between the resin chocks and machinery bedplate. If the need arises to remove the machinery from the foundation at a later date, it is not necessary to chip the underlying foundation grout. Since the equipment is not bonded to the epoxy chocks it can be raised off the foundation quite easily. To reinstall the machinery all that is needed is to realign and cast new epoxy chocks. This procedure saves quite a lot of unnecessary equipment downtime and labor costs.

Many equipment baseplates do not require individual epoxy chocks and are designed for full bedplate grouting. When this is the case, the type product used is dependent on the actual grout depth to be poured under the machinery. In new construction applications 1" of epoxy grout is more than adequate. When regrouting is necessary and large amounts of deteriorated concrete have been removed, it is very economical to repour the foundation with epoxy grout regardless of the depth. Epoxies are available that may be poured well over 18" deep in one pour and they will not crack or create excess shrinkage. Obviously the cost to pour a foundation with epoxy is greater than concrete but the cure time of the epoxy is much shorter which means minimal downtime on the equipment. This loss of downtime dollars is much greater than material costs to rebuild a foundation.

FOUNDATION PREPARATION

New concrete foundations must be completely cured before positioning machinery on the foundation and pouring epoxy grout. In the case of a repair application, the old concrete must be taken out until a good sound surface has been attained.

To achieve a good grout bond, chip the foundation surface to a rough finish to expose aggregate using a chipping hammer or equivalent. Avoid deep holes or grooves that could hinder the flow of the grout.

Under no circumstances should the surface of the foundation to be grouted be soiled by oil, grease, water, etc.

Remove all loose concrete pieces from the top of the foundation and from within the grout pockets. All surfaces to come in contact with the grout must be blown free of dust and particles with oil-free air or swept with a stiff bristle brush.

Most epoxies will not cure below an ambient temperature of 55°F, therefore it is necessary to preheat the concrete foundation before pouring an epoxy grout on it. Likewise, in extremely hot conditions it is a good practice to cover the foundation to keep direct sunlight from causing the epoxy to become warmer than desired during its cure period. Excess exothermic reaction can cause shrinkage and stress cracks in the material as it cools back down to the ambient temperature. The foundation should also be covered to prevent any rain water from falling on the concrete or the epoxy itself before it cures.

REINFORCING BAR

Many questions are asked concerning the use of steel reinforcing rods, or rebar, in epoxy grout foundations. Since rebar has historically been used in concrete, it seems logical that it should also be beneficial in epoxy grouts. This is not necessarily true.

Concrete, as a rule of thumb, has a tensile strength of only about 10% of its compressive strength. In other words, a 3,000 psi concrete in compression will have a tensile strength of around 300 psi. Steel rebar is used to add tensile strength to concrete members. Epoxy grouts, however, have considerably higher tensile strengths, usually in the range of 1,500 to 2,000 psi, and should not require additional reinforcement in most applications. The principal concern with using rebar in epoxies lies in their different coefficients of linear thermal expansion, or how they will "grow" or "shrink" with changes in temperature. Concrete and steel have similar coefficients and are, therefore, compatible when used together. Epoxy grouts, however, have higher coefficients and some formulations can have rates of expansion almost five times that of steel.

Epoxy grouts go from a liquid to a solid state at about their peak exotherm. When grout is poured on a concrete base with exposed rebar, the curing reaction heats both materials. As the grout solidifies, it is anywhere from warm to hot and encapsulates the steel rods. It is easy to visualize what happens as the grout and steel cool back to ambient temperatures and contract at different rates. Because the grout wants to contract more than the steel, it is put in tension and the higher the temperature differences, and the greater the difference in thermal coefficients, the greater the stresses will be. This can cause cracks in the grout that may appear shortly after it has cured, or further drops in temperature years later can increase the stresses and cause cracks. Some grout manufacturers recommend the massive use of rebar in deep pours to act as a heat sink and reduce the peak exotherm, however, this may actually be the cause of cracks if the foundation ever sees significant fluctuation in temperatures. This same phenomenon can also be the cause of loose soleplates if they are set in a hot grout with a high coefficient of expansion.

Because the total thermal expansion and contraction of a material is directly proportional to its length, the mismatch between rebar and epoxy grouts applies primarily to the long horizontal rods commonly found in large foundations. Short vertical pins placed around the perimeter to provide a mechanical lock between the epoxy grout and concrete will not usually precipitate a stress crack in a good quality epoxy grout, providing they are at least 3" in from any vertical surface.

Having a coefficient of expansion as close as possible to concrete and steel is also very important in situations where considerable decreases or increases in temperature are possible. As the temperature rises, the grout wants to expand more than the steel, if rebar is present. This puts the grout in compression and the rebar in tension, which is allowable because the strengths of these materials are very high in these conditions. The area for concern, however, is at the interface between the concrete and epoxy grout. As the grout expands at a faster rate it puts the concrete in tension, which, as discussed earlier, is not one of concrete's strengths. If the stresses are great enough, the grout will shear the concrete just below the bond line.

This tendency for the grout to shear its bond with the concrete can, however, be minimized. Again, because the amount of thermal expansion is proportional to the length, properly spaced expansion joints in the grout reduce the effective length by segmenting and thereby minimizing stresses on the bond area. The greater the discrepancy between thermal coefficients of materials, the closer expansion joints must be to insure a lasting structure.

Various physical properties are published by grout manufacturers for their materials. Compressive strength, compressive modulus of elasticity and tensile strength, while important, are over emphasized because they are far greater than concrete and usually loaded to a fraction of their limits. The most important design criteria, if an epoxy grout is to be used with other materials such as concrete and steel, is the compatibility with these materials. Since very few environments are absolutely stable, the effects of temperature changes must be calculated and undo stresses eliminated through proper design and choices of materials.

## FORMING

Wooden forms need to be carefully constructed to prevent leakage of grouting materials. Where removal of forms will be required, a coating should be placed on the inside of the wooden form with the use of a sealer (lacquer type) and a good household paste wax or the use of a high temperature nonmelt grease to prevent adhesion to the grout. A chamfer strip at all corners of the foundation forming, along with the top of the final pour will help seal all corners from leaking and provide a finish level guide, leaving a very clean looking application with the removal of the forms.

EXPANSION JOINTS

Expansion joints are used to prevent cracks in the epoxy surface caused by the inborn stresses of the curing process of epoxy. Most epoxy manufacturers are limited to the amount of material that can be placed at one time. Expansion joints are also used to allow for thermal expansion and contraction caused by weather and operating conditions. Expansion joints can be made from 3/4" styrofoam and placed according to manufacturers recommendations. One resin manufacturer provides an elastic epoxy foundation seam sealant which can be used as a permanent seal in expansion joint areas protecting the underlying concrete foundation from oil and other contaminants.

BEDPLATES (SOLEPLATES)

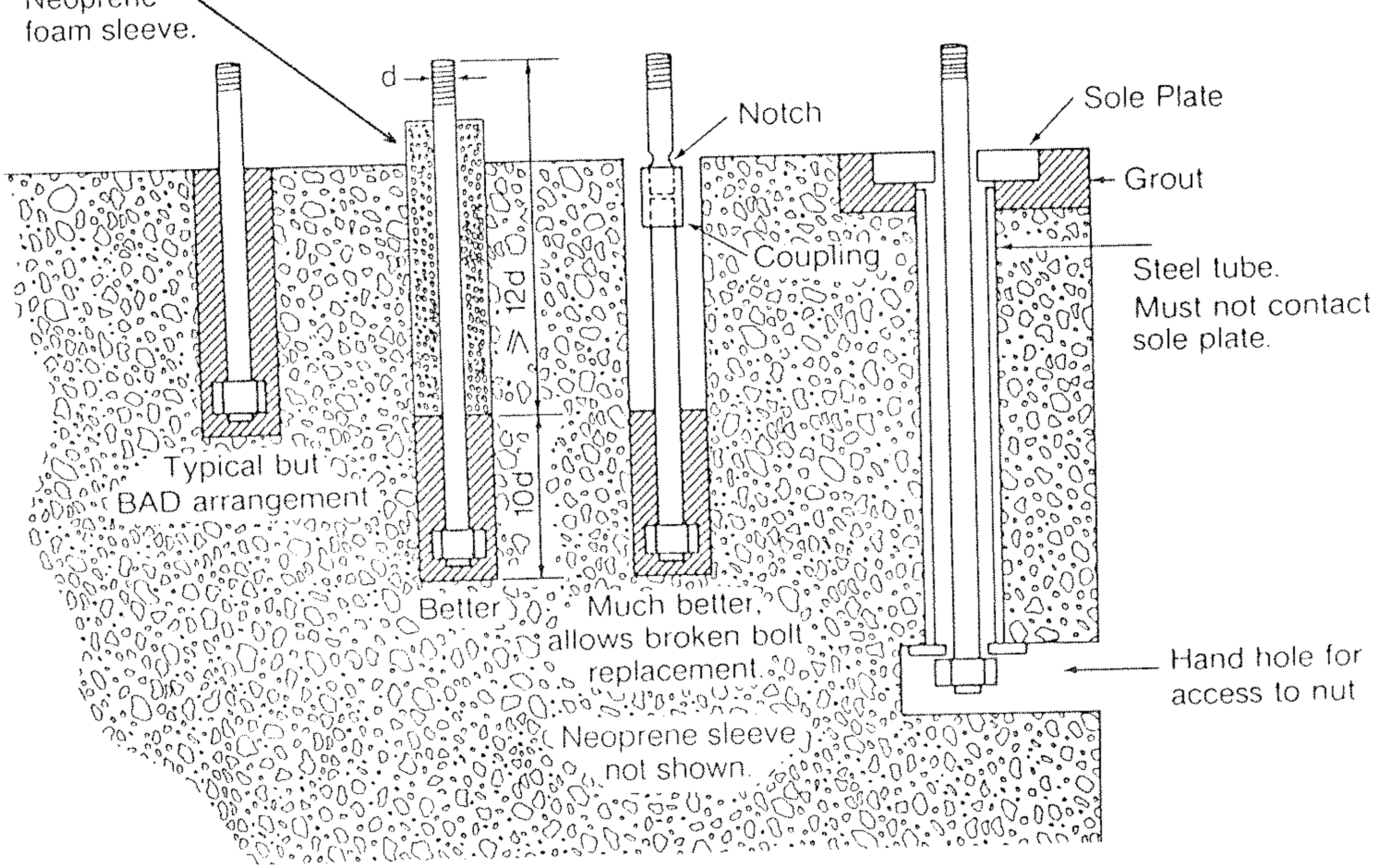
Most applications for movable bridges will involve machinery which is on a bedplate and is going to be full-bed grouted. These bedplates should be clean of grease, oil, paint, etc. If possible they should be sandblasted to a near white finish (SSPC SP 10-63T). Although the epoxy chocking method of alignment is designed to eliminate the need for costly machining of bedplates, proper smoothing of sharp frets left by previous steel chocks or pock marks left by previously used iron-filled grouts is important. Bedplates should be inspected when the maximum amount of space is available between the chipped foundation and the jack supported equipment. A fairing epoxy should be used to fill in pock marks left by the corrosive influence of iron-filled grouts. All 90° corners on the bedplates should be rounded to prevent them from cracking the grouting material much in the same way as a chisel. Also, allowable room for the expansion of the bedplates under hot running equipment should be taken into consideration since the heat of the machinery will be directly transmitted into the grouted foundation through the bedplate.

It is extremely important to apply a generous coat of a high temperature grease to all jacking bolts which will come in contact with the epoxy grout. After the grout cures, these jack bolts are backed out to allow the machinery base to rest totally on the epoxy. If the jacks are not greased, the epoxy could crack while backing the jack bolts out of the grout.

ANCHOR BOLTS

Hold down bolts and foundation cracks are the two most common problem areas of a grouted foundation and are often related. The purpose for grouting a piece of equipment is to hold the machinery in its original vertical and horizontal locations so it can operate efficiently and for a long period of time. Although epoxy grouts are well suited for this purpose, they only establish a vertical elevation on which the machinery is setting. In the case of epoxy chocks, they do help hold equipment in the horizontal plane also due to their excellent coefficient of friction to the machinery baseplate. The major concern, however, is that the anchor bolts maintain their proper torque. Ideally, bolts should be easily removable and replaceable and there are designs of such bolts available. More important, however, is that the bolts must have sufficient shank length, free of grout, to permit them to stretch when tightened. As a rule of thumb, you should provide at least 12 times the bolt diameter in free length, if at all possible. (Please see detail on page 15).

# Common Hold Down Bolt Arrangements



*When you apply torque to a bolt you are stretching that bolt and if an excessive amount of length of bolt shank and/or threaded area is bonded to the epoxy, it cannot stretch as it should and therefore the bolt will lose torque in a short period of time. When anchor bolts lose torque the machinery bedplate is then susceptible to increased vibration which leads to bearing failures, cracks in the underlying foundation, broken anchor bolts and ultimately misalignment of the machinery.*

*The bolts should be parallel to the holes and the nuts should butt against a spot faced surface. The bolts should go into the concrete foundation as deeply as possible so that the foundation block is always kept in compression regardless of static and dynamic forces. It is important that all threads be clean and free of burrs. This includes the bolt and the nut. Any excess paint on the nuts or machinery bedplate will inhibit proper torque values. All threaded areas and seating surfaces should be lubricated in order to reduce the amount of friction encountered while torquing. Finally, the torque wrench should be properly calibrated.*

## *POURING OF GROUT*

*To ensure the proper mixing and pouring viscosity of the grouting material it will be necessary to condition the resin, hardener and aggregate, when used, at around 60°-80°F for a period of about 12 hours prior to mixing. Please read applicable manufacturer's instructions prior to conditioning of materials. It is particularly important to condition the aggregate as it determines the eventual temperatures of the grout. Thoroughly mix hardener and resin until a homogenous color and texture is apparent (around 3-5 minutes) using a mortar type mixer (for three component epoxies), or a suitable mixing blade driven by a 1/2" or 3/4" electric drill motor (for two component materials).*

*When placing the grout, avoid trapping air under the equipment. Equipment bases are sometimes designed with ridges to act as grout locks. Air entrapment can be avoided by grouting from one end of the base to the other while maintaining a head pressure by keeping forms full. Caution should be taken not to over mix each unit of epoxy. Over mixing tends to entrap air into the mixture which could leave a foam surface layer that cannot provide sufficient load carrying properties. After grouting is complete, the exposed surface areas may be smoothed with a trowel wetted in solvent. The solvent also tends to break up any surface bubbles that may have formed during the pour. It is important to leave the epoxy grout cure sufficiently before the jacking bolts are backed off. Back leveling screws completely free to avoid point loading of the grout; this allows the full weight of the machine to be dispersed over the grouted area. Tighten anchor bolts to manufacturer's recommendations.*

## *GENERAL REVIEW*

*We have briefly discussed the advantages of using epoxy grouting materials to set machinery bases. Properly prepared foundations, good anchor bolts, the use of expansion joints, etc., will assure permanent precise alignment and a long service life for many types of equipment. In short, there are thousands of machinery bases that are presently "chemically dependent" and many more will become "chemically dependent" in the future.*

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