GROUT OF THIS WORLD

Grout is the 'system link' that ties the rotating equipment to the foundation. Improper installation techniques of grout can result in chronic rotating equipment issues. Proper grouting techniques improve the economical life of the equipment, reduce vibrations and equipment downtime, while enduring the economical life of the equipment. This article discusses the effects of improperly supporting the internal structural skid beams that are required to maintain the sensitive alignment of the supported equipment. The long term performance and reliability of skid mounted rotating equipment is reduced when proper grouting techniques are not executed. Surface preparation, skid grouting techniques and simple measures to reduce resonant vibrations will be the focus.

Importance of support

A skid is a matrix of transverse and longitudinal structural steel members used to support equipment during the fabrication, transportation and plant



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ARGUES THE NECESSITY OF PROPERLY GROUTED SKID MOUNTED EQUIPMENT.

operational stages. While skid mounted equipment reduces the installation cost, it may also reduce the equipment's productivity, reliability, efficiency and economical life. A steel I beam is more suitable for static loading as opposed to a combination of static and dynamic loading. Steel excels in strength but lacks rigidity, whereas concrete is the opposite. Combining the best attributes of concrete and steel can yield an extremely strong and rigid structure. The unbalanced forces of the equipment create the majority of the vibrations encountered by reciprocating compressors. During a typical startup, the equipment may pass through several modes of resonance. Occasionally, the operating frequency of the equipment may be close to the natural frequency of the skid.



Figure 1. Edge lifting on outdoor installation.

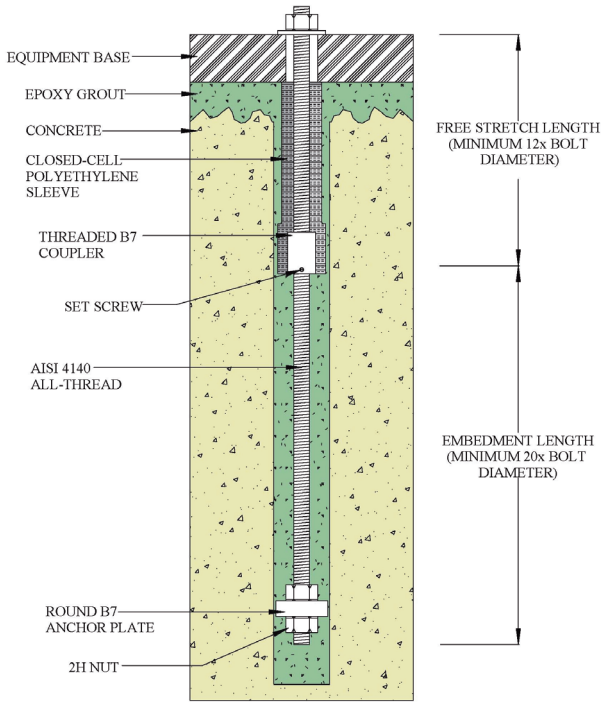


Figure 2. Concepts of proper anchor bolt design.

Different needs, different grouts

When selecting a grout, the following attributes must be considered: compressive and tensile strength, bond and sheer strength, temperature range, chemical resistance, viscosity and length of service. Many resources were invested into the design of the concrete foundation and skid package. Grout is the critical (yet often overlooked) link between the foundation and the equipment. The success of the equipment and foundation depends on the functionality of the grout.

If the service need of a skid is temporary, a cementitious grout should be considered. The bond strength of cementitious grout is lower compared to epoxy grout. Unfortunately, cementitious grout is porous and vulnerable to oil soak. Once oil soaked, a gradual decline in both the compressive and tensile strength is inevitable. To protect against this, a novolac or aliphatic urethane coating should be applied to the concrete and grout surfaces. Furthermore, if the proper water to cementitious grout ratio is not achieved, an undesirable shrinkage of the grout may occur, causing the grout to pull away from the load bearing surfaces of the skid.

If the service need of a skid is permanent, an epoxy mortar grout should be used. Epoxy mortar grout bonds well to steel while remaining resistant to oils, lubricating fluids and some mild chemicals. The load bearing surfaces of the outer skid beams are anchored in place by the combined weight of the skid, equipment and anchor bolt load. The increased bond and tensile strength of epoxy mortar grout helps to anchor the internal support beams that are critical in maintaining equipment alignment.

Preparing the surface

Having ascertained the grout design criteria, the concrete and metal surfaces must be prepared to provide an optimal bonding surface for the grout. The top surface of the concrete should be chipped to a 25.4 mm - 38 mm peak to valley profile, and should continue until coarse aggregate has been exposed and fractured. This is best achieved with a chipping gun, as opposed to sandblasting, pecking or bushing, which are comparatively poor methods of concrete surface preparation. The concrete surface should be protected from all contaminates that may compromise the surface bond of the grout.

Hand tool cleaning or power tool cleaning are the suggested surface preparations for cementitious grout, as recommended by the Steel Structures Painting Council. The National Association of Corrosion Engineers, meanwhile, specifies a near white metal finish or white metal finish for surface preparation for epoxy mortar grout. This is to be achieved through abrasive grit blasting. A medium to fast cutting grit media provides a premium surface bond for grout; soft grit media should be avoided, as they will polish the metal surface. If a delay is expected between surface preparations and grouting, some grout manufacturers recommend applying an epoxy primer to the steel surfaces. Over time, the bond between the epoxy primer, the epoxy mortar grout and the steel surface deteriorates. Each component added to a system creates a wider margin for failure. The system could conceivably be simplified by removing unnecessary layers that are susceptible to failure.

Consideration of conditions

Fresh grout, whether cementitious or epoxy, is sensitive to the environmental curing conditions. Each has a minimum and maximum curing temperature. Moist curing a cementitious grout provides the maximum compressive strength. Epoxy grout cures through an exothermic reaction, and thus is extremely sensitive to

ultraviolet or infrared light, as well as moisture. Exposure to any of these elements will accelerate the curing rate, and promote the development of thermal stresses within the grout that will lead to curing cracks. Most grout manufacturers recommend shading the foundation at least 24 hours before grouting and 48 hours after grouting. Ideal surface and ambient temperatures for mixing, pouring and curing grout is between 24 ˚C and 32 ˚C.

Special considerations for outdoor skid installations must be considered, because different thermal absorption and dissipation rates exist between epoxy mortar grout and concrete. Thermal cycles throughout the day and night create thermal induced stress cracking in the concrete. During the cool nights, as the surface of the epoxy mortar grout cools, it begins contracting, placing the underlying concrete foundation in tension. The condition reverses during the warmer days, placing the underlying concrete foundation in compression. Since the tensile strength of concrete is 8 - 10% of its compressive strength, the concrete eventually cracks just below the grout cap as shown in Figure 1. The thermal cycles will continue to propagate the cracks towards the base of the skid. This condition, known as edge lifting, can be avoided by implementing one of three techniques. Installing vertical rebar pins on the foundation's periphery, or 'keying' the edges of the foundation transforms the tensile stress into shear stress. An inflexible grout shoulder is created when the width of the shoulder is reduced to half the thickness of the grout depth.

Briefing on bolts

A function of grout is to provide lateral restriction to movement. The primary function of anchor bolts is to hold down the equipment to the foundation; not to provide lateral resistance to movement. Anchor bolts should be properly isolated to prevent grout from surface bonding. Not properly isolating the anchor bolt from the grout is a main cause for premature bolt failure. Free stretch of the upper anchor bolt stud is required for transmitting vibrations deep into the foundation and maintaining the anchor bolt's hold down load. It is common for the length of equipment to thermally grow once the operating temperature has been reached and isolating the upper portion of the anchor bolts allows for minor adjustments to the new bolt spacing. The concepts of proper anchor bolt design are illustrated in Figure 2. The minimum anchor bolt embedment and free stretch lengths should be 20 times and 12 times the anchor bolt diameter, respectively. Closed cell polyethylene sleeves are manufactured in a wide range of sizes and fit tightly around the anchor bolt. Anchor bolts that are located in critical areas of the equipment, such as mainframes and crosshead guides, should be fabricated with a lower and upper stud coupled together. In the event that the upper stud fails, it may be replaced without performing extensive anchor bolt or foundation repairs.

Jack bolts should be used during the level and alignment process of the equipment. Compared to other alignment methods, jack bolts offer infinite adjustability and removability. The use of rigid shims is not recommended, as they prevent the grout from fully supporting the weight of the equipment. Over time, corrosion of the shims will cause misalignment of the equipment. Jack bolts should be located adjacent to each anchor bolt. Additional jack bolts may be required for large spans or excessively heavy equipment. To avoid buckling of the jack bolts, a grade B7 bolt is recommended. The use of a levelling plate is required for effectively aligning equipment with jack bolts. Ideally, the levelling plate should be a steel disk with rounded edges. Square levelling disks introduce unnecessary stress risers within the grout. When a sufficient compressive strength of the grout is reached, the jack bolts may be removed to transfer the weight of the equipment to the grout. The jack bolt holes should be filled with an oil resistant silicone.

Expansion joints should be located at high stress areas where cracking of the grout cap is anticipated. Examples of high stress areas are anchor bolt locations, sharp corners and inside corners. The top of expansion joints should be sealed with an elastomeric and oil resistant silicone to prevent oil from penetrating the joints. Rigid foam board, fiber board or dense wood are acceptable for use as an expansion joint.

Pouring the grout

The difficulties associated with mixing and pouring grout often leaves the critical load bearing members of the skid unsupported. Without a proper grout footing, operating conditions of the equipment allow the support members to vibrate. Over a period of time, excessive vibration and flexing of the skid may lead to crankshaft bearing failures and crankshaft misalignment. For large pours, it may be necessary to 'wet' the concrete surface with several units of a resin rich grout mix. Beginning large pours with resin rich mixtures lubricates the concrete and steel surfaces and helps the full grout mix to flow greater distances. The viscosity of the grout is dependent upon the ambient temperatures at which it is poured. During warmer months, additional aggregate may be needed to increase the viscosity of the grout, and vice versa during the colder months.

The typical factory skid design requires the grout to be poured from the edges of the skid. For narrow or short length skids, flowing grout in the direction of the shortest distance may be adequate. The elevation of the grout forms relative to the base of the skid is critical in maintaining adequate grout head pressure. The greater the distance the grout must flow, the higher the forms must be above the base of the skid. Head pressure is often maintained through the use of a grout head box. The direction of the grout flow should coincide with the shortest distance of the skid. To minimise the amount of air pockets underneath the load bearing areas of the skid, the grout must be poured behind the grout contact line. Mechanical vibrators should never be used to flow grout. The larger the skid installations become, the more difficult it is to achieve 100% grout contact. Larger skids require additional access holes to be cut into the deck plates.

Adding mass to the skid is an effective measure to further separate the natural frequencies of the skid and operational frequency of the equipment. The additional mass helps dampen the vibrations transmitted through the skid. Cementitious grout extended with pea gravel may be pumped into the compartments of larger skids. The cementitious skid fill operation is shown in

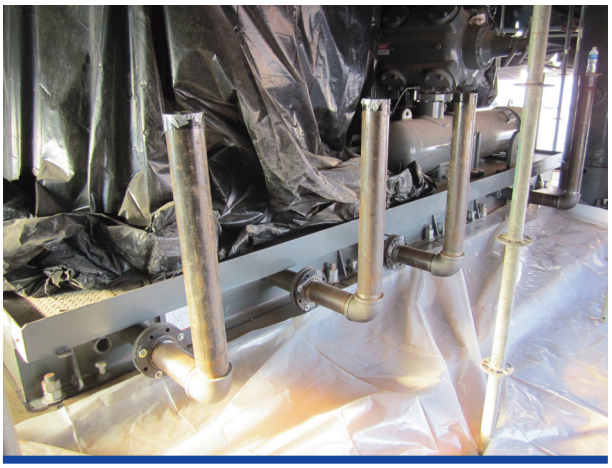


Figure 3. Cementitious skid fill operation.



Figure 4. Foam boards embedded in grout cap.

Figure 3. The maneuver requires additional access holes to be field cut into the skid compartments, steel tubes installed to the access holes, communication holes between compartments, vent holes to be drilled into the deck plates, cement mixing trucks and a cement pump truck to rapidly fill each compartment. For smaller fill operations, cementitious or epoxy mortar grout may be hand mixed and poured into each compartment. Additional mass may be added with a very dense material held together by a bonding agent. Steel shot is dense, and may be used to fill small cavities. The steel shot is anchored in place by injecting the remaining voids with an unfilled epoxy grout.

After the skid filling operation is complete, the skid should be tested for grout voids. The most effective void detection method is to 'sound' the skid surfaces with a hammer. A solid grout contact area is characterised with a 'ping' sound of the hammer, and a void is characterised by a hollow sound of the skid. Detected voids should be marked and filled with an unfilled epoxy. Grout technical data sheets or grout manufacturers should be consulted for the limitations of the unfilled epoxy. Special epoxy grouts have been developed through the use of special additives that allow surface bonding through an oil and water film.

Grouting in action

A skid mounted two throw reciprocal compressor was recently installed in a US gas processing plant with numerous failed commissioning attempts. Emergency shut down devices were activated due to excessively high vibration levels during startup. Adhesive Services Company was contacted to trouble shoot and correct any problems associated with the foundation and epoxy grout cap. Upon initial inspection, several voids were detected underneath the outer support members. The previous contractor assured the equipment owner that 100% grout contact was present. A decision was made to remove the skid from the foundation, and upon removal, the root cause for the excessively high vibration levels was revealed.

In order to save on the material expenses of the project, foam boards were glued to the concrete foundation between the support beams of the skid. During the original grout pour, the foam boards restricted the grout flow underneath the skid, leaving the critical support beams unsupported. Figure 4 was captured before the original grout cap was removed. The anchor bolts were not isolated from the epoxy grout, causing three bolts to prematurely fail. Square levelling disks were used during the previous skid alignment phase. The concrete surface was poorly prepared through mechanically bushing the surface of the concrete, and not removing the concrete laitance, allowing the original grout cap to be easily removed by hand. In most areas, the epoxy mortar grout failed to bond to the painted bottom surfaces of the skid.

The original grout cap was removed, and the surface of the concrete was chipped to a 25.4 mm - 38 mm peak to valley profile with a chipping gun. The concrete surface was chipped until coarse aggregate was exposed and fractured. Fracturing of coarse aggregate while chipping confirms a good bond between the cement and aggregate. With the skid safely supported, the bottom surface of the skid that will be in contact with the epoxy grout was abrasive grit blasted to a white metal finish. Additional grout access holes were cut into the deck plate above the inner compartments. The broken anchor bolt sections were removed, rethreaded and coupled with a new upper stud. All anchor bolts were isolated 12 times the bolt diameter for proper bolt stretch. After all concrete and steel surfaces were properly prepared, the skid was set back into position on the foundation. Jack bolts with a circular levelling disk were used to support the equipment during the alignment phase of the project.

After the skid was repositioned on the foundation, an enclosure to protect the equipment and grouting surfaces from direct sun exposure was erected. After the alignment of the equipment was verified, grout forms and short vertical rebar pins were installed on the foundation's perimeter. Expansion joints were located at each anchor bolt location, and final grouting preparations on the skid and foundation were performed. After verifying the grouting material temperatures and surface temperatures of the skid and concrete, epoxy mortar grout was poured, flowing the grout in the direction of the shortest distance. The final grout level was finished to approximately three quarters the thickness of the lower skid flange elevation. After the grout cured 48 hours at 32 ˚C, the jack bolts were removed and the weight of the equipment was transferred to the new epoxy grout. After removing the jack bolts, the anchor bolts were loaded to the original equipment manufacturer's recommended torque value while monitoring base pull downs with a dial indicator.

The base of the skid was hammer tested for voids, resulting in none being detected. The expansion joints, jack bolt holes and the outer periphery of the skid were sealed with an oil resistant silicone. Contrary to the Adhesive Services Company's recommendation, the equipment owner opted to not fill the inner skid compartments with cementitious grout.

After a full bed regrouting of the skid, the internal I beams were properly supported by the new epoxy grout, greatly reducing the vibration levels. The root cause of the excessive vibration levels were directly attributed to the unsupported internal support beams of the skid. The initial savings in grout material resulted in a full year of production loss for the plant.