REPAIR AND REHABILITATION OF TURBOMACHINERY FOUNDATIONS

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ABSTRACT

The developing of solutions to foundation problems is no longer the frustration it once was. Experience has led to better understanding of problem causes. Technology is evolving to the state that repairs are reliable. Typical problem areas are identified and the solutions discussed include skid stiffening and special grouting techniques. Sketches and photographs taken on actual field repairs are provided.

INTRODUCTION

In many instances vibration problems in turbomachinery can be attributed to faulty support. Once the problem areas have been identified, correcting defects can be a logical procedure. What is novel is the fact that this result can often be accomplished through the proper selection and application of adhesives.

Most turbomachinery is mounted on structural steel platforms sometimes referred to as base plates or skids. These platforms are then installed on a mass of concrete at the jobsite, either through direct grouting or by mounting on sole plates, to become the machinery foundation. Platforms should always be considered as part of the foundation rather than as part of the machinery. Because much has already been written about adhesive repair of concrete blocks [1, 2, 3], the emphasis here is on field improvement of the platform. Platform defects can also be cured through redesign, but this subject is beyond the scope of this paper.

Problems with platforms fall into one or both of the following categories:

- Improper installation
- Insufficient mass and/or rigidity

Improper installation is not a design weakness. This defect can be corrected rather easily in the field at any time after installation. Insufficient mass or rigidity is a design weakness brought about by the complexity of the origin of vibration in high speed rotating machinery and its sensitivity to vibration. The fact that few compressor trains are identical in every respect does not help in gathering experience on which to base a prediction of vibration problems. Nevertheless, mass and rigidity can be increased in the field, but it is more of a task to do so than the mere correcting of installation defects.

INSTALLATION DEFECTS

A typical compressor train containing a turbine and two compressor stages is illustrated in Figure 1. The "I" Beams on the platform are grouted to the concrete structure. When proper grouting techniques are carried out during the original installation, the grout should contact the entire lower surfaces of all longitudinal and transverse "I" Beams.

Figure 2 is a fine example of correct grout placement. This photograph, showing the grout intact after platform removal, would not have been possible if epoxy grout had been used in the original installation. Cement based grouts will not bond well to the platform load bearing surfaces. Note that portions of this grout are oil soaked. Over a period of time, lubricating oils will severely degrade both cement grouts and concrete. This problem is further aggravated by the fact that most platforms are not designed with oil drains. On several occasions the author has noted as much as 6 to 8 inches of oil trapped within the platform cavities. This condition not only provides head-pressure for an increased rate of oil penetration, but also creates a *severe* fire hazard.

All platforms, regardless of the type of grout to be used, should be designed with oil drains. Epoxy grouts are recommended on platform installations because they bond well to load bearing surfaces and because they provide an excellent oil barrier for the concrete below. Cement grouts should be used only for temporary installations.

Figure 3 is a fine example of poor grout placement. Note the lack of support in the center where most of the machinery weight is concentrated. Long, unsupported spans are an invitation not only to resonance vibration problems but also to progressive sagging with age. Progressive sagging would cause continual misalignment problems. The obvious solution to this defect is simply to grout in the unsupported sections. Since cement grout will not bond well to itself or concrete, any regrouting should be carried out with an epoxy grout because of the inherent bonding properties of epoxies. Some epoxies will even bond to oily surfaces [4].

When differences in vibration amplitudes can be detected between the lower flange of the platform beams and the concrete structure, the decision to bond the entire lower surfaces of the platform to the concrete structure should be made. Bonding can be accomplished using a technique known as pressure-grouting. With this technique, holes are drilled through the lower flange at locations near the web on centers of approximately 18 inches. These holes are then tapped and ordinary grease fittings installed. The arrows in Figure 4 locate grease fittings and this configuration represents a typical injec-

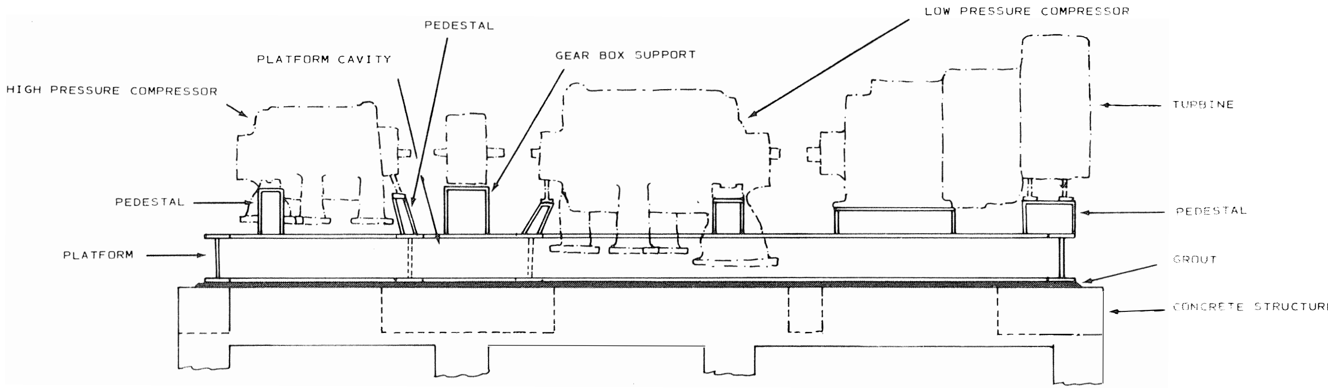

Figure 1. A Typical Compressor Train Containing a Turbine and Two Compressor Stages.

Figure 2. A Properly Grouted Platform which Later was Removed from its Concrete Pad. Note that 100% Contact had been Obtained by the Grout on All Longitudinal and Transverse Supporting Beams.

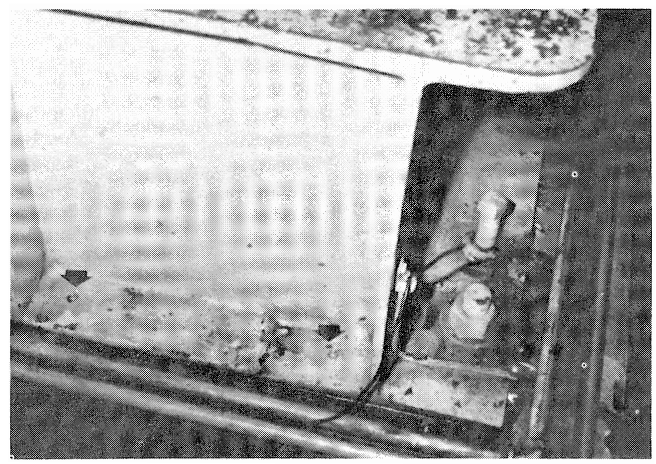

Figure 4. A View of a Corner of a Platform where the Lower "I" Beam Flange has been Pressure-Grouted with Epoxy to Bond the Platform to the Concrete Foundation. Arrows Indicate the Points of Injection Through Grease Fittings.

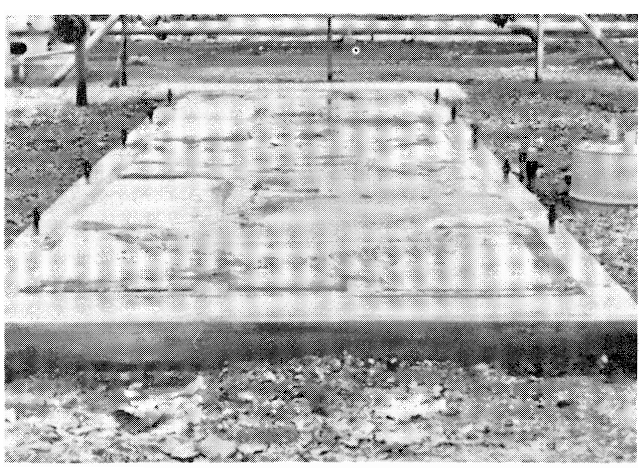

Figure 3. An Improperly Grouted Platform which Later was Removed from its Concrete Pad. Note that Very Little Contact was Made in the Center with Supporting Beam Flanges. Proper Contact was Obtained Only on the Outer Periphery of the Platform.

tion site pattern. Pressure-grouting can then be carried out with either automatic injection equipment or with conventional grease guns. Figure 5 is a view from the inside of the platform after pressure-grouting, and this view shows the bleed of excess epoxy from beneath the flange. Almost 100% coverage has been obtained. In cases where the gap between the structural member and concrete is too wide for the epoxy liquid to maintain capillary contact, and at the same time, too narrow to be filled with epoxy mortar, the epoxy can be thickened to near grease consistency by adding a thixotrope to the mix. This thixotropic fluid can then be pressure injected between the two surfaces and will maintain capillary contact. This technique is illustrated in Figure 6.

Some manufacturers recommend that their platforms be installed on rails or on sole plates which have been grouted to the concrete foundation. Occasionally the installation will be either poorly designed or the contractor will fail to clean the plates before grouting. Loss of adhesion may result in excessive vibration or movement of the plate in the grout. When this occurs, pressure grouting can be accomplished with a relatively high degree of success if proper techniques are used.

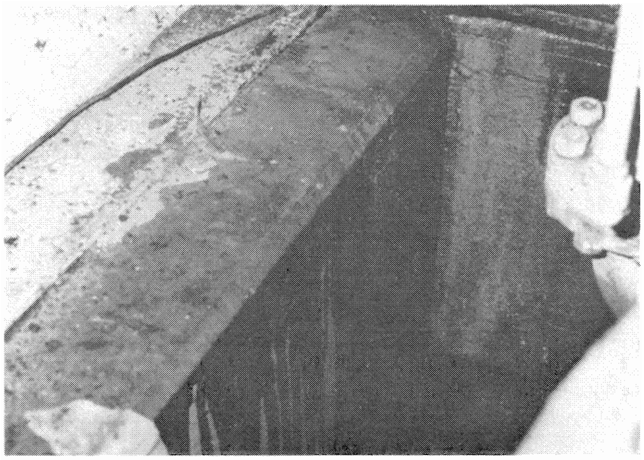

Figure 5. Bleed of Excess Epoxy from Beneath the Internal Edge of the Lower "I" Beam Flange.

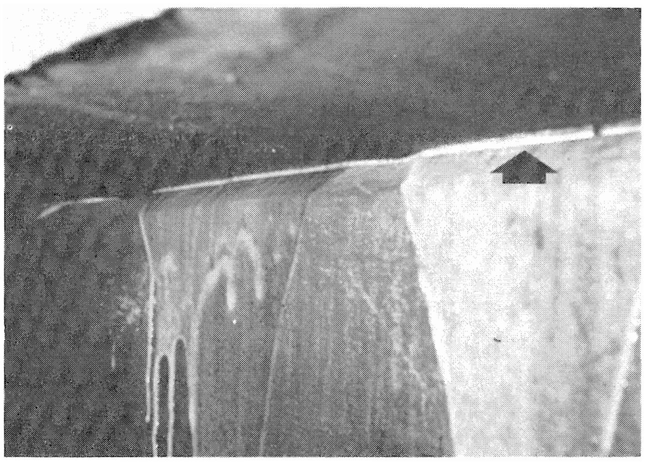

Figure 6. Bleed of Excess Epoxy from Beneath a Steel Plate Stiffener which was Field Installed. Because of the Large Gap, a "Thickened" Epoxy was used in Order to Maintain Capillary Contact Between the Two Surfaces.

In Figure 7 small pilot holes were drilled in the exposed edges of the sole plate. These holes were then reamed out to accommodate a ⅛ inch pipe tap. Fittings were installed and epoxy liquid injected in the voids until excess epoxy escaped around the outer periphery of the sole plate. Usually, oil or, in this case, water is driven from beneath the sole plate with the epoxy flush. This flushing should continue until clear epoxy is emitted from the crack. If necessary, the position of the plate can be monitored while pressure-grouting with dial indicators. In any case, the grease fittings should be removed after injection is complete and before the epoxy has gelled in order to bleed off remaining pressure. If satisfactory results are not obtained during the first attempt, the holes can be redrilled, tapped and new grease fittings installed for a second pressure-grouting. Pressure grouting of sole plates seldom changes level or alignment because grease fittings are removed immediately after pressure-grouting to release pressure and because the weight of the equipment discourages lifting. When anchor bolts are tight, movement is further restricted.

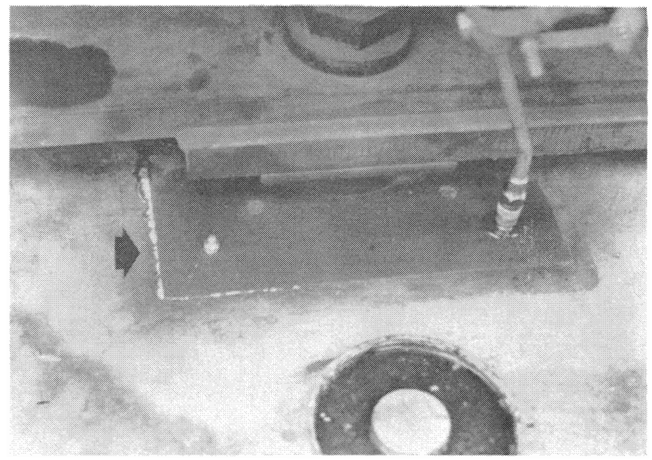

Figure 7. Pressure-Grouting of Voids Beneath a Sole Plate. Note the Water Being Flushed from the Crack Between the Edge of the Plate and the Cement Grout.

Figure 8 illustrates four problems on one installation. First, the chock block between the equipment base and the sole plate is inadequate to transmit the load evenly to the sole plate. Secondly, the corners on the edges of the sole plate should have been rounded to a 2 inch radius in order to prevent the creating of stress risers and subsequent cracking at the corners. The third problem is caused by an insufficient quantity of aggregate in the epoxy mortar. Note the distinct layer of unfilled epoxy on the surface of the mortar. The linear coefficient of thermal expansion of the unfilled epoxy can be expected to be on the order of magnitude of $6\text{-}8 \times 10^{-5}$ inches per inch of thickness per degree F. The linear coefficient of thermal expansion for the epoxy mortar below can be expected to be on the order of magnitude of 2×10^{-5} inches per inch of thickness per degree F. This difference in thermal expansion rates will encourage crack propagation, particularly on cooling when the system is subjected to cyclic temperatures as between day and night. The fourth and most severe problem, though not obvious in the photograph, is the presence of a foam surface immediately below the sole plate. This problem is also caused by an insufficient quantity of aggregate in preparing the epoxy mortar.

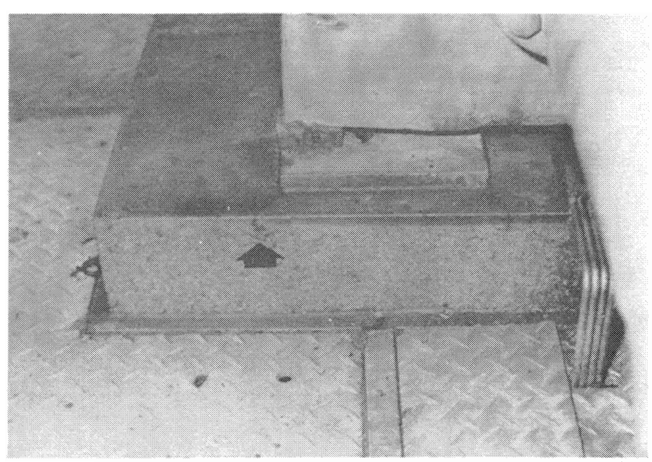

Figure 8. A Poorly Designed and Grouted Sole Plate. Sharp Corners of the Plate Promote Corner Cracking.

The epoxy adhesive has a density of about 9 lbs. per gallon [4]. The aggregate has a *bulk* density of about 14 lbs. per gallon [5] which assumes about 25 to 30% voids. In preparing an epoxy mortar, the resin and hardener components are always mixed together before the addition of aggregate. When the aggregate is added to the mix, it obviously falls to the bottom and introduces air into the mix. If a soupy mortar is prepared, the air will simply rise to create a weak, foamy surface. Figure 9 is a close-up photograph of a soupy grout mix poured under a clear Plexiglas plate. Note the layer of foam trapped immediately below the plate. It is estimated that 90 per cent of the load bearing capability of the epoxy mortar has been lost. This problem can be corrected in the field by pressure-grouting as shown in Figure 7, but it may be necessary to machine new chocks in order to re-establish alignment.

Pressure-grouting of cracks caused by stress risers at the corners of rails or sole plates may be accomplished using the technique shown in the photograph of Figure 10. Here, holes have been drilled into the cracks, injection tubes installed and sealed in place with epoxy putty. After curing of the epoxy putty seal, the crack is pressure-grouted. This repairs the epoxy mortar in a stress relieved condition.

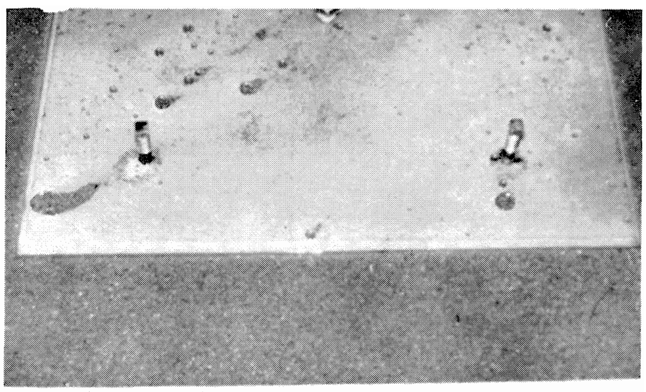

Figure 9. A Close-up Photograph of a Soupy Epoxy Mortar Poured Under a Clear Plastic Plate. Note the Foam that has been Created Under the Load Bearing Surface.

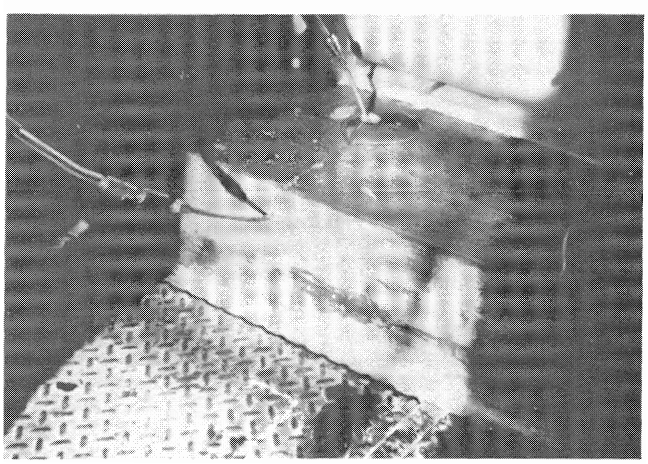

Figure 10. Pressure-Grouting a Crack Caused by Stress Risers around Sharp Sole Plate Corners. Pressure-Grouting Repairs the Grout in a Stress Relieved Condition.

INCREASING MASS AND RIGIDITY

When excessive vibration is detected in the gear box of a compressor train, shown in Figure 1, and is transferred to the platform below, a dampening effect can be created by increasing the rigidity of the support below. This can be accomplished by first filling the platform cavity and then the gear box support with epoxy mortar. Figure 11 is a photograph of the gear box support after the gear box has been removed and an access hole cut in the plate at the top of the support. At the time this photograph was taken, epoxy mortar was being poured into the cavity. Since it is impossible to fill a cavity completely with mortar, filling was stopped at a level of approximately ¼ inch below the top. The access hole plate was then welded back into position, and injection sites drilled into each corner of the support. A vent hole was then drilled in the center of the reinstalled access plate to facilitate air removal when pressure-grouting the remaining air space below the top. Figure 12 is a close-up view of a typical injection site at each corner.

One interesting observation that brings home the fact that steel structures are not very rigid is illustrated in Figure 13. In

Figure 11. The Gear Box Support Cavity is Being Filled with Successive Pours of Epoxy Mortar to Unload the Box and Gain Rigidity.

Figure 12. A Close-up View of One Injection Site. Injection Sites were Installed at Each Corner of the Gear Box Support Shown in Figure 7.

Figure 13. A Typical Vent Hole is Shown in the Access Plate After It has been Welded in Place.

this photograph we see a view of the plate covering the platform cavity alongside the gear box support. This cavity has been filled with epoxy mortar, the access plate reinstalled and pressure-grouting completed. The air vent hole in the center of the plate is one inch in diameter and the plate thickness is one inch. After pressure-grouting was completed, one workman in the process of cleaning up, placed his weight on the plate and this caused sufficient deflection to squeeze out epoxy equivalent to a volume slightly greater than the volume of the hole in the plate. In other words, the weight of one 160 lb. man was enough to cause a 0.001 inch deflection in the plate. This observation causes one to question the entire concept of platform mounting. The reason this solution has been successful is that unloading of the platform has been accomplished by providing load bearing capability all the way from the gear box to the concrete below.

Since the geometry of the turbine and compressor support pedestals is such that little cross-sectional area is provided, it is doubtful that appreciable stiffening could be obtained. Consequently, the objective became to concentrate on increasing mass of the pedestals. This was accomplished by filling the cavities with a special mortar prepared with epoxy and steel shot. The density of this special mortar was in excess of 300 lbs. per cubic foot. Figure 14 is a view of a typical compressor support pedestal. A pipe plug has been installed in the access

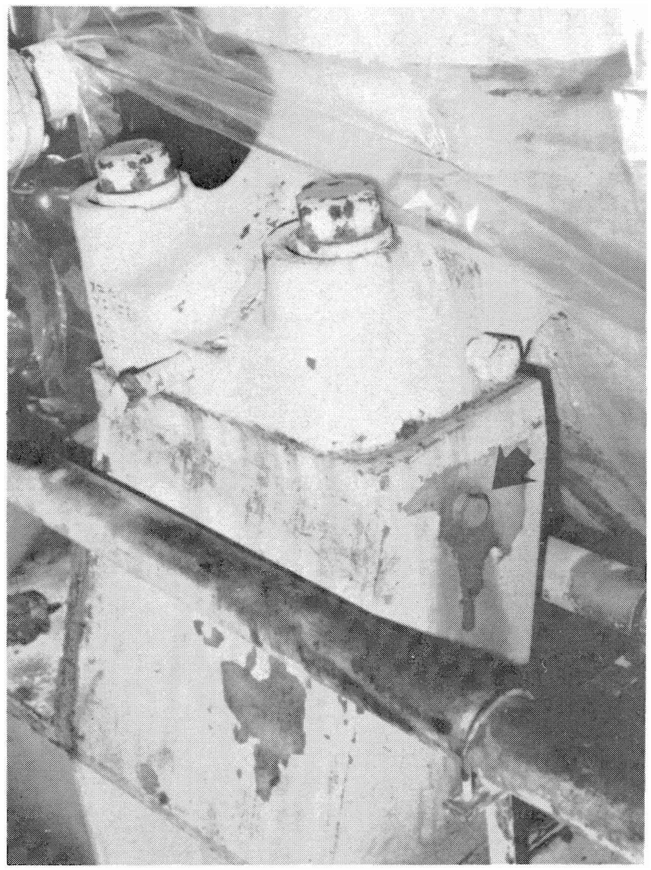

Figure 14. A View of a Pedestal Supporting the Low Pressure Stage of the Compressor Train. This Pedestal was Filled with a Special Mortar Comprised of Epoxy Liquid and Steel Shot in an Attempt to Increase Mass and Rigidity of the Support.

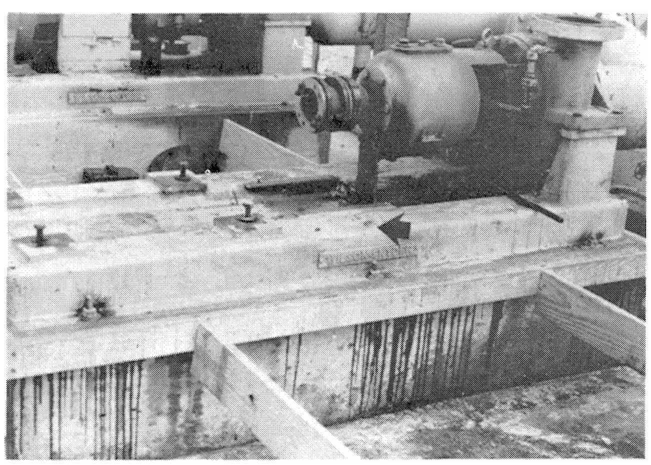

Figure 15. A Typical Stamped Metal Base Under a Centrifugal Pump which has been Grouted and is to be Pressure-Grouted thereby Filling All Remaining Voids.

hole that was drilled in the side of the pedestal near the top to allow the installation of the special mortar.

These same techniques can be employed to stabilize the foundations under much smaller equipment. Figure 15 is a photograph of a stamped metal base under a centrifugal pump. Note the access holes, indicated by the arrow, which have been grouted with epoxy mortar. As soon as the epoxy mortar has cured, holes will be drilled into voids, detected by hammer tests, and these voids pressure-grouted using the same techniques outlined above.

CONCLUSION

Epoxy adhesives used in the applications described herein have aided in solving vibration problems. From experience gained on these and other installations, it appears that platforms may have inherent weaknesses that proper use of adhesives can overcome; but adhesives should not be considered as a cure-all for vibration problems to the neglect of basic design.

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