CSDA Sponsors University of Toledo Engineering Project

Half-inch Drop-in Anchor Produces Surprising Results

Drop-in concrete anchors are a method of fastening non-structural items to existing concrete. In concrete core drilling, drop-in anchors are used to mount the core drill rig to a concrete wall during core drilling. Drop-in anchors typically come with a pre-installed expansion plug that is used to expand the anchor after it has been dropped in a drilled hole. The anchor is expanded with repeated hammer blows and this expansion creates local crushing and compression within the concrete wall. The friction that results is the main method used by the anchor to carry the load.

Half-inch drop-in anchors are a common method within the concrete industry to attach core drilling equipment to concrete structures. Holes up to 24 inches in diameter are drilled using a rig mounted with a single ½ inch drop-in anchor, a practice that has been the industry standard for more than 40 years.

Typical Drop-In Anchor (Full Sectional) Failure of ½-inch drop-in anchors were the topic of the University of Toledo Engineering Department Student Project.

Over the course of the last few years, CSDA members have been observing failures when using these anchors and many assumed the problem was with the anchors. The majority of failures have occurred in the internally threaded region of the anchor, causing half of the anchor to remain in the concrete and the other half to be pulled out. This mode of failure poses a serious hazard to operators, as 260 pounds of equipment could suddenly fall on them. Anchor failure could also result in the rotation of the entire core drill around the drill bit that could also cause serious injury to an operator.

In order to evaluate the reasons behind drop-in anchor failures, the Concrete Sawing and Drilling Association and Ohio Concrete Sawing and Drilling, Inc. sponsored a senior engineering project at the University of Toledo College of Engineering. Skip Aston, owner of Ohio Concrete Sawing and Drilling, and chair of CSDA Safety Committee, had worked with the University of Toledo Engineering Department in the past and believed a project of this nature would benefit both the engineering students and members of the Concrete Sawing and Drilling Association.

Hoping that he could make a comprehesive enough presentation that would pique the interest of some of the seniors, Aston made his presentation to the seniors who would be completing their projects and three seniors in the Department of Mechanical, Industrial and Manufacturing Engineering decided to take on this anchor failure project. Andrew Smith, Andrew Grieser and Ian McCallister titled their research project, the "Evaluation of Performance of ½-inch Drop-in Anchors in a Core Drilling Application."

PROJECT TEAM

Andrew Smith acted as team leader. He was responsible for general project management. Specific responsibilities included coordinating paperwork, scheduling meetings and maintaining adequate team progress with respect to the timeline. He also served as the primary contact between Skip Aston, the client adviser and faculty adviser, Dr. Ali Fatimi, a full professor who holds a Ph.D. in Material Failures.

Ian McCallister acted as the technical liaison. He was in charge of coordinating work with the machine shop and third party fabricators. In addition, he was responsible for acquiring a portable tensile tester, designing and programming the load analysis software, assisting with designing the strain gage test setup and analyzing test results.

Andrew Grieser served as the purchasing agent, budget coordinator and web page designer. He was responsible for ordering all of the materials for the project. He was also responsible for compiling testing specifications, generating three-dimensional models, performing finite element analysis and creating the project website.

A call was put out to CSDA members to send in both new and failed anchors for this project and CSDA members, Tim Beckman, Carl Jones, Steve Mattiola and Frank Gobright responded.

PROJECT OBJECTIVES

The objective of the project was to evaluate the performance of ½-inch drop-in anchors in a core drilling application. The project was divided into four phases: an analysis of stress in the anchor; a comparison of strength in five popular brands of drop-in anchors; a determination of the effects of installation parameters on anchor strength; and development of design recommendations to the core drill set-up as well as the development of an additional method to reduce anchor loading.

Anchor failures, such as these, were replicated by the students in field testing.

PHASE I: ANCHOR STRESS STATE ANALYSIS

Phase I focused on determining the type and magnitude of stresses in the anchor during a core drilling application. The purpose of this phase was twofold; first to obtain stress levels in the anchor and compare them with safe working stresses and second, to determine the loads that imparted the most stress on the anchor. The anchor stress level was determined using two methods. The first method was a free-body analysis of the core drill system. This method was inexpensive and quick. The second method was an experimental measurement of loadings using strain gages. This method proved to be highly accurate and eliminated the need for estimating load conditions.

Many conclusions were reached by completing Phase I. Most importantly, the orientation of the core drill rig is extremely important. In the case where the drill bit is above the anchor, the moments due to weight and feed force are additive. In the case where the drill bit is below the anchor, the moments due to weight and feed force counter each other. The result is that when the drill was oriented above the anchor, the load carried by the bolt was 149 percent higher than when the drill bit was oriented below the anchor. In the case where the drill bit was located sideways from the anchor, the loading on the anchor was 189 percent to 600 percent higher (depending on the location of the nut) than when the drill was oriented below the base plate.

UT Engineering Students rigged electronic sensors to the anchor holding this 24-inch core drill rig mounted to a wall. The sensors measured the force that was put upon the anchor.

They also found that the friction force between the pivot edge of the base plate and the concrete wall was sufficiently high to carry all the shear load, indicating the anchor and threaded rod were not subjected to any shear loading.

PHASE II: STRENGTH COMPARISON OF ANCHORS BY BRAND

Phase II was designed to evaluate and compare the performance strength of popular brands of ½-inch drop-in anchors. In the planning process, two methods were proposed for testing: tensile testing in the University of Toledo's fatigue laboratory and field testing at Ohio Concrete Sawing and Drilling. Testing anchors in concrete requires the concrete test sample to be sufficiently large to avoid cracking and edge effects. Considering the size and weight of the concrete as well as other factors, including dust contamination and sensitive equipment, it was decided that testing was not a feasible option in the University's fatigue lab. Also, it was important for testing to simulate the actual anchor environment as closely as possible, so it was decided to perform testing in the field at OCSW.

A portable tension tester was used to perform testing and measured both load and deflection. An Ohio geotechnical engineering firm in Toledo, Bowser-Morner, donated the equipment needed to conduct the test. The objective was to measure the load and displacement of the anchors as well as to determine the number of blows required to fully expand the anchors. The students performed field tests on five common brands. A calibrated hydraulic ram was used to pull anchors out of concrete. The brands were compared and found to have similar strengths and holding capacity. And during this phase of the project, no anchors failed by metal rupture. The failure mode for all samples was anchor pullout.

Although the failure modes were identical, the anchors displayed different responses to the load. Testing was conducted under ideal test conditions and all anchors were expanded with the manufacturer-specific setting tools and following manufacturer recommendations. Often in the field, installation parameters are not consistent. Two of the brands, including Hilti, required less than 20 hammer blows on average while other brands required more than 100. This is an important consideration when selecting anchors as most operators will not fully expand the anchors if the number of required blows becomes excessive.

PHASE III: EFFECTS OF INSTALLATION PARAMETERS

Phase III determined the effects of installation parameters on the performance of the anchor. Installation parameters tested were installation depth, thread engagement, installation angle and expansion plug depth. Throughout Phase III testing, the students found that improperly installing anchors could significantly reduce anchor performance and lead to sudden failure.

A core drill may be mounted in two orientations—above or below the anchor—depending upon operator preference and potential obstructions. Some of the failures came about by using the bit above the mast, instead of below, which significantly increased the load on the anchor. The students concluded that whenever possible, the core drill rig should be orientated so that the drill is located below the base plate. When the core drill rig is located above the base plate the load transmitted to the anchor is substantially increased and is negatively impacted by other loading parameters.

During Phase III, in order to provide greater understanding of anchor loading, the students designed a load-analysis software program. The program allowed the students to input drill size, weight, drilling parameters, drill rig orientation, anchor location and other relevant parameters. The program then calculated the load on the anchor and displayed the percentage of ultimate anchor load. The ultimate load values used for the software program came from official Hilti documentation.

Student researcher McCallister said, "One of the most useful items that came out of this project was the load analysis software program we developed. It allows users to get a feel for how variations in rig installation may affect the force applied to the anchor. The software calculates the loading on the anchor, which then may be used to specify an anchor type and size. A major gain from this was the understanding of how drill rig orientation affects loading on anchors."

PHASE IV: RECOMMENDATIONS

Phase IV was comprised of design recommendations for core drill setups, anchor selection recommendations and recommendations for existing setup, using the results of Phase III. Design recommendations were provided for reducing anchor loads in the existing and in a modified core drill setup. Testing indicated that improper installation could significantly reduce the load carrying capacity of the anchor.

Hilti and Sanko ½-inch anchors were found to support the greatest loads and were the easiest to install properly. The students found that Hilti and Sanko supported the highest loads by approximately 15 percent. The approved applications of other anchor brands vary between manufacturers, but should be checked before using their product.

McCallister said what he thought was the biggest problem with anchors that failed is that the limits for these anchors are not clearly understood by operators. "We found that the load put upon by these anchors on job sites was twice the limit of what it should have been subjected to holding. I believe that education and training of operators could solve many failures with these anchors. To summarize in one sentence what could be done to prevent future failures, it would be, "follow the manufacturer's instructions," he concluded.

Aston said, "I've been in the concrete sawing and drilling business for almost 30 years, and I learned a lot from this project. It was very beneficial to learn that anchors are doing a lot more than they are supposed to do. Also, I was really impressed with these young men. They possess a great work ethic – they spent many hours at our shop on Saturdays to complete their testing." He added, "CSDA really got their money's worth from this project. I think the most valuable information obtained is the importance of proper installation."

CSDA members may request a copy of the full report by contacting the CSDA office at 727-577-5004 or emailing info@csda.org. All project information and software can be viewed on the students' web site. It is located at http://www-mime.eng.utoledo.edu/design_clinic/design_expo/Fall07Pages/2007-04-03/index.html.

THE STUDENTS DEFINED A SUMMARY OF IMPORTANT INSTALLATION PARAMETERS WHEN USING ½-INCH DROP-IN ANCHORS.

- **Anchors should be installed perpendicular to the surface**
- **Anchor countersink depth should be limited to ½ inch**
- **Expansion plugs should be fully set as per manufacturer's instructions**
- **Threaded rod should be fully engaged with the anchor**
- **Leveling screws should be adjusted before the base plate is installed on the threaded rod**
- **Installation torque on the threaded rod should be limited to 19 ft-lbs**

Ian McCallister (far right) and Andrew Smith (center) explain the results of their findings to Skip Aston (left) at the University of Toledo Design Exposition.