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Use of Adhesive Anchors to Resist Long-Term Loads

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Background

In 2006, a portion of a suspended concrete ceiling system in a Boston tunnel collapsed causing a fatality. An investigation by the National Transportation Safety Board (NTSB) concluded that adhesive anchors supporting the concrete ceiling panels failed resulting in the collapse. The anchors, which were exposed to a sustained gravity load, had reportedly pulled out of the concrete tunnel lining slowly over time—a behavior known as *creep.* The adhesive anchor system that was used had not been qualified for resisting long-term sustained loads such as those that were present in the concrete ceiling panel application. The NTSB raised questions about the suitability of adhesive anchors for use in applications where they must resist long-term sustained loads. The NTSB also stated that there was a general lack of understanding and knowledge in the construction community about the creep behavior of adhesive anchoring systems under long-term sustained loads.

This article will examine how adhesive anchors behave under long-term loading and how this behavior is evaluated by manufacturers. It will also suggest how to select adhesive anchor products that are suitable for long-term sustained load applications.

Adhesive Anchors Defined

An adhesive anchor system consists of a steel threaded rod or rebar, and a chemical adhesive that are inserted into a hole that is drilled into cured concrete or masonry. The drill bit diameter used is typically 1/16 to 1/8 in. larger than the diameter of the threaded rod or rebar. The drilled hole must be cleaned according to the adhesive manufacturer's instructions (usually with compressed air and a brush) before the adhesive and the threaded rod or rebar are installed. The adhesive can be delivered into the hole in one of several ways. Currently it is most common for the adhesive to be a two-part chemical system where the two reactive components are packaged in side-by-side cartridges. In this type of system the components are mixed automatically by dispensing them through a special mixing nozzle directly into the hole using a dispensing tool. (See Figure 1.) The performance characteristics of adhesive anchors are formulation specific and can vary greatly even between products with similar chemistries.

Figure 1: Adhesive delivery using a mixing nozzle and dispensing tool.

Creep of Adhesive Anchors under Long-Term Loads

Chemical adhesives are viscoelastic materials. This means that they exhibit both viscous and elastic behavior when loaded. The same behavior applies to adhesive anchors. When subjected to short-term loads, adhesive anchors will respond rigidly. However, when subjected to sustained long-term loads, all adhesive anchors will exhibit some amount of time-dependent deformation. Designers must be aware of this phenomenon and consider this behavior when selecting adhesive anchor products that will resist long-term sustained loads. For such load applications it is critical that the adhesive anchor be pre-qualified for long-term load resistance at a defined load level that is established through rigorous creep tests. These creep tests have been developed to evaluate the product's long-term load carrying potential and ensure that the load data provided to the designer for such products accounts for the effects of creep.

Testing of Adhesive Anchors for Creep Resistance

Several test criteria currently exist for qualifying adhesive anchor systems for long-term load applications. In each creep test, an anchor is subjected to a constant load and the anchor's displacement is measured for a specified period of time. The displacement is then extrapolated out to a given time and evaluated against a specified maximum displacement criterion. Adhesive anchors with projected displacements less than or equal to the displacement criterion are considered qualified for resisting long-term loads. Adhesive anchors that exceed the permitted displacement are considered unsuitable for resisting long-term loads; such anchors are generally limited to short-term load applications, such as those that resist wind or seismic forces only. Experience shows that in order to meet the displacement criterion, the rate of deflection of the adhesive anchors must be substantially diminishing over time. (See Figure 2.)

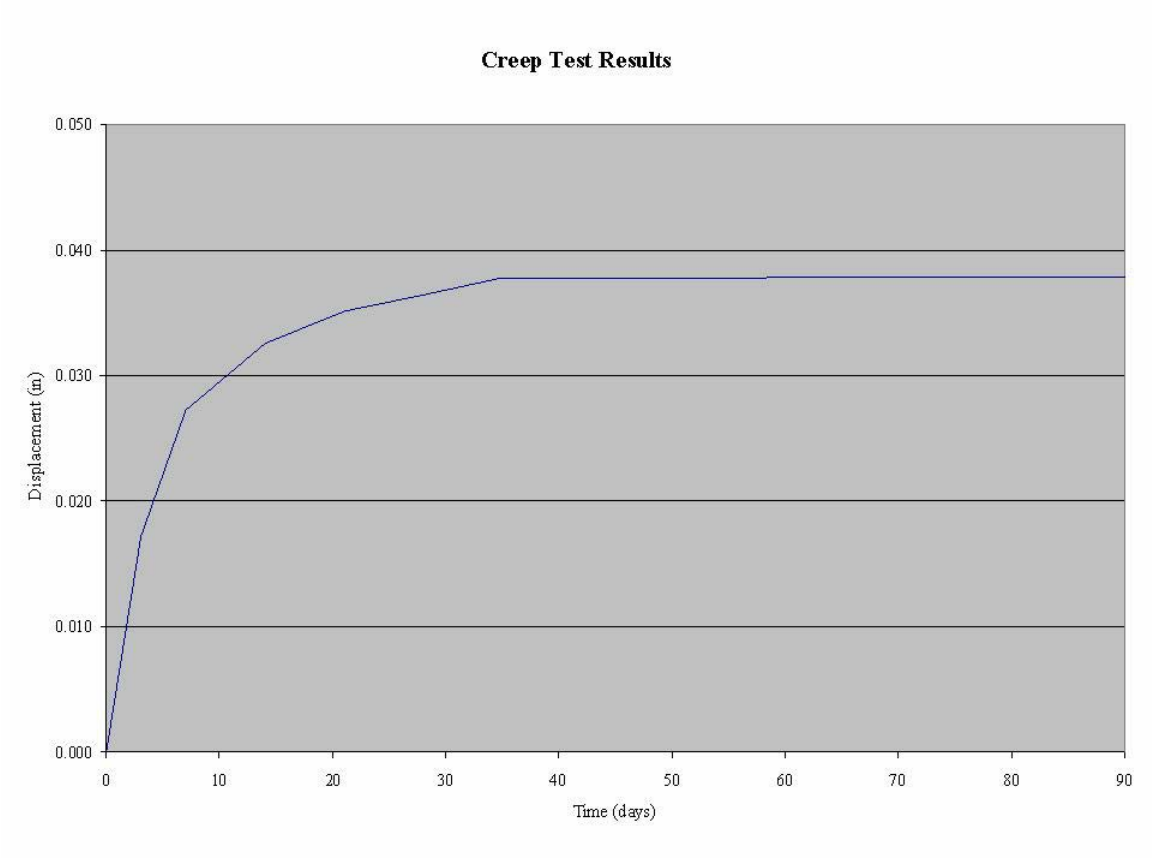

Figure 2: Sample displacement vs. time plot for a creep-resistant adhesive anchor system.

In most design applications, it is difficult to determine the exact magnitude and duration of the long-term load that an adhesive anchor will be subjected to over its service life. For example, dead load is clearly a long-term load, but some fraction of live load may also be a long-term load. Therefore, creep test protocols make assumptions about what magnitude of sustained load will be applied to the anchors in

service and also conservatively presume that the assumed sustained load will be present over the anchor's entire service life. Two creep test protocols for qualifying adhesive anchors are in use today and a brief overview is given below.

ICC-ES AC 58 *(Acceptance Criteria for Adhesive Anchors in Masonry Elements)* **-** This acceptance criteria was adopted in 1995 and until recently was also used by ICC-ES to qualify adhesive anchors in concrete base materials under allowable stress design. The criterion includes a creep test. The test procedure utilizes ½-in. diameter anchors at a 4½-in. embedment depth. First, static tension tests are performed at an ambient temperature of 70ºF to determine the average ultimate capacity of the adhesive anchor system. Static tension tests are also performed on anchors conditioned to an elevated temperature of 110ºF to determine the anchors' average displacement at ultimate load. Finally, creep tests are performed. (See Figure 3.) In this test, the applied sustained load is set equal to 40% of the ultimate load from the ambient temperature tests. Since allowable loads under AC 58 are typically 25% of the average ultimate load, the sustained load in the creep test equates to 160% of the allowable design load. This is quite conservative because the entire design service load, including all live loads, is presumed to be a long-term load. This sustained load is maintained for a minimum of 42 days at a temperature of 110ºF while the anchors' displacement over time is monitored. At the end of the 42-day period, the displacement vs. time relationship is plotted and extrapolated to 600 days. The criterion requires that the average displacement at 600 days must be less than the smaller of the average displacement at ultimate load from the elevated temperature tension tests or 0.12 in. If this requirement is met, the adhesive is considered suitable for resisting long-term sustained loads. It should be noted that creep testing is optional under AC 58; however, anchors that are not creep tested are prohibited from use in long-term load resisting applications.

AC 58 is presently the most widely utilized anchor creep test standard in the United States. Adhesive anchor products that have been qualified to resist long-term loads under this criterion have an excellent record of performance in long-term sustained load applications.

ICC-ES AC 308 - *(Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements)* **-** This acceptance criteria was first adopted in 2005 and provides ultimate strength design procedures for adhesive anchors. Although creep testing in accordance with this acceptance criteria is similar in concept to that of AC 58, there are some differences that are worth highlighting. First, in AC 308, two separate creep tests are conducted. One creep test is conducted at a temperature of approximately 73ºF. The other creep test is conducted at an elevated temperature that is selected by the manufacturer. The selected temperature is defined as the "maximum long-term temperature" for the product. Second, the sustained load applied during testing is set equal to 55% of the adhesive's bond strength corresponding to the temperature at which the creep test is conducted. The bond strength is determined by performing reference static tension tests at both the standard and elevated temperatures. The magnitude of the sustained load is intended to provide a margin of safety between the sustained test load and the anticipated long-term service load that is similar to that provided by the AC 58 creep test.

Like AC 58, the sustained load in both AC 308 creep tests is maintained for a minimum of 42 days, and at the end of the period the displacement vs. time relationship is plotted and the displacement relative to time is extrapolated. For the creep test conducted at standard temperature, the displacement is extrapolated to 50 years. For the creep test conducted at elevated temperature, the displacement is extrapolated to 10 years. The average displacement at both 50 years and 10 years must be less than the average displacement when adhesive slip occurs in reference static tension tests conducted at the corresponding temperatures. Finally, at the completion of the sustained load portion of each creep test, a static tension test is performed to measure the anchors' residual tension strength. Each residual tension test must achieve at least 90% of the load achieved in the corresponding reference static tension test.

If all of these requirements are met, the adhesive is considered suitable for resisting long-term sustained loads at the temperature conditions selected by the manufacturer. Unlike AC 58, creep testing is mandatory in AC 308. If the requirements are not met, the manufacturer may reduce the sustained load and repeat the tests until they are met. However, if the sustained load is reduced, the design bond strength will also be reduced by the same proportion.

AC 308 is currently being used to qualify products for ultimate strength design in cracked and uncracked concrete, and is more consistent with the qualification requirements for mechanical expansion anchors found in ACI 318, Appendix D. Use of this standard to qualify adhesive anchors for long-term sustained loads will become more commonplace as new products are introduced to the marketplace.

Figure 3: Creep test setup.

How Designers Can Identify Products Suitable for Resisting Long-Term Loads

The most important step in the selection of an adhesive anchor system is to first consider whether or not long-term sustained loads will be present in the application. Of course, a conservative approach is to assume that long-term loads always exist regardless of the application.

If long-term load resistance is determined to be a design requirement, the designer should check the product literature provided by the adhesive manufacturer and/or ICC-ES evaluation report to verify that the product has passed long-term creep tests, such as those specified in AC 58 or AC 308. The following statements are examples of those commonly found in product literature and evaluation reports, and identify whether or not an adhesive anchor system is suitable for resisting long-term loads. The key words that the designer should focus on are underlined.

Product is Suitable for Long-Term Sustained Loads

- "Used for dead, live, wind, and earthquake load applications."
- "Anchors installed in concrete are suitable for long-term or short-term loads."

Product is Not Suitable for Long-Term Sustained Loads

- "Anchors are limited to short-term loads due to wind or seismic forces."

Of course, the adhesive manufacturer can always be contacted when there are questions about the suitability of a particular product for resisting long-term loads.

Products that have not been evaluated for creep behavior should be assumed to be inappropriate for long-term sustained load applications.

Conclusion

Adhesive anchors have a long history (more than 25 years) of successful use and performance in construction applications when properly installed. However, as with any construction product, the more thorough of an understanding that designers, specification writers and building officials have about a product's behavior, the better informed they will be to consider important design factors and to select the most appropriate product for the application. The performance of adhesive anchors under long-term sustained loads is a factor that must be considered in product selection. When long-term sustained loads are anticipated, it is critical that adhesive anchor products that have been appropriately qualified through creep testing be selected and used.