National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

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In reply refer to: H-07-32

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The National Transportation Safety Board is an independent Federal agency charged by Congress with investigating transportation accidents, determining their probable cause, and making recommendations to prevent similar accidents from occurring. We are providing the following information to urge your organization to take action on the safety recommendation in this letter. The Safety Board is vitally interested in this recommendation because it is designed to prevent accidents and save lives.

This recommendation, which addresses the risks associated with using adhesive anchors in sustained tensile-load applications, is derived from the Safety Board's investigation of the July 10, 2006, ceiling collapse in a portion of the Interstate 90 (I-90) connector tunnel, in Boston, Massachusetts,[1] and is consistent with the evidence we found and the analysis we performed. As a result of this investigation, the Safety Board has issued 19 safety recommendations, 1 of which is addressed to the American Concrete Institute. Information supporting this recommendation is discussed below. The Safety Board would appreciate a response from you within 90 days addressing the actions you have taken or intend to take to implement our recommendation.

About 11:01 p.m. eastern daylight time on Monday, July 10, 2006, a 1991 Buick passenger car occupied by a 46-year-old driver and his 38-year-old wife was traveling eastbound in the I-90 connector tunnel in Boston, Massachusetts, en route to Logan International Airport. As the car approached the end of the I-90 connector tunnel, a section of the tunnel's suspended concrete ceiling became detached from the tunnel roof and fell onto the vehicle. Concrete panels from the ceiling crushed the right side of the vehicle roof as the car came to rest against the north wall of the tunnel. A total of about 26 tons of concrete and associated suspension hardware fell onto the vehicle and the roadway. The driver's wife, occupying the right-front seat, was fatally injured; the driver was able to escape with minor injuries.

The National Transportation Safety Board determines that the probable cause of the July 10, 2006, ceiling collapse in the D Street portal of the Interstate 90 connector tunnel in

[1] For more information, see <http://www.ntsb.gov/publictn/2007/HAR0702.pdf>. National Transportation Safety Board, *Ceiling Collapse in the Interstate 90 Connector Tunnel, Boston, Massachusetts, July 10, 2006*, Highway Accident Report NTSB/HAR-07/02 (Washington DC: NTSB, 2007).

Boston, Massachusetts, was the use of an epoxy anchor adhesive with poor creep resistance, that is, an epoxy formulation that was not capable of sustaining long-term loads. Over time, the epoxy deformed and fractured until several ceiling support anchors pulled free and allowed a portion of the ceiling to collapse. Use of an inappropriate epoxy formulation resulted from the failure of Gannett Fleming, Inc., and Bechtel/Parsons Brinckerhoff to identify potential creep in the anchor adhesive as a critical long-term failure mode and to account for possible anchor creep in the design, specifications, and approval process for the epoxy anchors used in the tunnel. The use of an inappropriate epoxy formulation also resulted from a general lack of understanding and knowledge in the construction community about creep in adhesive anchoring systems. In addition, Powers Fasteners, Inc., failed to provide the Central Artery/Tunnel project with sufficiently complete, accurate, and detailed information about the suitability of the company's Fast Set epoxy for sustaining long-term tensile loads. Contributing to the accident was the failure of Powers Fasteners, Inc., to determine that the anchor displacement that was found in the high-occupancy vehicle tunnel in 1999 was a result of anchor creep due to the use of the company's Power-Fast Fast Set epoxy, which was known by the company to have poor long-term load characteristics. Also contributing to the accident was the failure of Modern Continental Construction Company and Bechtel/Parsons Brinckerhoff, subsequent to the 1999 anchor displacement, to continue to monitor anchor performance in light of the uncertainty as to the cause of the failures. The Massachusetts Turnpike Authority also contributed to the accident by failing to implement a timely tunnel inspection program that would likely have revealed the ongoing anchor creep in time to correct the deficiencies before an accident occurred.

Background

The accident occurred in the eastbound travel lanes of the I-90 connector tunnel[2] at mile marker 135.25, just west of the entrance to the Ted Williams Tunnel, which carries traffic underneath Boston Harbor to Logan International Airport. The accident site was within a 200-foot-long section of the I-90 connector tunnel that, for the purposes of this investigation, was referred to as the D Street portal. The D Street portal actually comprised three tunnels—a two-lane westbound tunnel, a two-lane (with an acceleration lane) eastbound tunnel (the accident location) located south of the westbound tunnel, and a one-lane eastbound high-occupancy vehicle (HOV) tunnel located south of the other two tunnels.[3] The Ted Williams Tunnel, the I-90 connector tunnel, and the D Street portal were all built as part of Boston's Central Artery/Tunnel (CA/T) project.

The D Street portal was built in 1993, before completion of either the Ted Williams Tunnel or the remainder of the I-90 connector tunnel. The accident site area was opened to traffic on December 14, 2000. Traffic was not routed through all the bores of the tunnel until the remainder of the connector tunnel was completed and opened to the public in January 2003. According to 2005 data provided by the Massachusetts Turnpike Authority (MTA), eastbound traffic through the I-90 connector tunnel (including the D Street portal) averaged 43,000 vehicles per day.

[2] In the accident report, "I-90 connector tunnel" referred to the I-90 tunnel between the Interstate 90 and 93 interchanges in downtown Boston and the entrance to the Ted Williams Tunnel.

[3] A short one-lane westbound exit ramp (Ramp F) tunnel paralleled the other tunnels at the accident location, but this tunnel had no suspended ceiling and was not considered during this investigation.

The suspended ceiling in the D Street portal was made up of individual ceiling "modules." Each module consisted of a number of concrete panels supported by a steel framework that was, in turn, supported by a system of steel rods and turnbuckles attached to steel hanger plates. These hanger plates were affixed to the tunnel roof by stainless steel threaded rods (anchors) inserted into holes core-drilled in the concrete tunnel roof and held in place with an epoxy adhesive.

The ceiling module at the site of the accident comprised 15 panels of reinforced concrete: two rows of five 12- by 8-foot concrete panels about 4 inches thick, each weighing about 4,700 pounds, and a single row of five 6- by 8-foot concrete panels about 4 inches thick, each weighing about 2,500 pounds. The complete ceiling module at the accident site measured 30 feet wide and 40 feet long. The weight of the 15 concrete panels was about 60,000 pounds; the support beams, rods, hanger plates, and ductwork weighed an additional 17,000 pounds, for a total module weight of about 77,000 pounds.

The accident module, which was erected in November 1999, was secured to the tunnel roof by a total of 76 adhesive anchors. Twenty of these anchors secured the most heavily loaded support beam, a beam that supported one end of the 10 largest panels. The investigation determined that, during the accident sequence, all 20 of these anchors detached from the tunnel roof and allowed the 10 panels to collapse onto the roadway and onto a passing vehicle. The total weight of the concrete panels and supporting hardware that fell was about 52,000 pounds.

In all, 654 adhesive anchors were used to support ceiling modules in the D Street portal. After the accident, the remaining 634 anchors were examined, and 161 were found to have measurable displacement, that is, they showed evidence of having gradually pulled out of the tunnel roof under the sustained tension load of the concrete ceiling panels. The Safety Board concludes that by the time of the accident in July 2006, a significant portion of the adhesive anchors used to support the D Street portal ceilings had displaced to the extent that, without corrective action, several of the ceiling modules in the three portal tunnels were at imminent risk of failure and collapse.

The adhesive anchoring system used in the D Street portal was chosen by the construction contractor, Modern Continental Construction Company (Modern Continental), and approved by the section design consultant for the D Street portal finishes,[4] Gannett Fleming, Inc. (Gannett Fleming). The anchoring system selected by Modern Continental used an epoxy material formulated by Sika Corporation; packaged by Powers Fasteners, Inc. (Powers); and distributed by Newman Renner Colony, LLC (Newman Renner Colony). The epoxy provided was Power-Fast Epoxy Injection Gel, which was packaged by Powers for Newman Renner Colony and supplied to the CA/T project as NRC-1000 Gold epoxy.

According to test data provided by Powers and forwarded by Modern Continental to Gannett Fleming during the anchor approval process, each epoxy anchor, using a safety factor of 4, could support up to 6,350 pounds. A safety factor of 4 meant that an average anchor could be expected to support four times this weight, or 25,400 pounds, before failure of the adhesive or

[4] Tunnel *finishes* included ceiling panels and their structural support systems, light fixture support systems, tile sidewalls, walkway finishes, utility room cross passages finishes, floor and wall finishes, roadway-level exit doors and egress signage, and roadway paving and striping.

the concrete surrounding the anchor. The safety factor incorporated into the design was intended to provide a margin of safety to account for imperfect installation, weaker-than-normal concrete, unexpected operating conditions, or other uncertainties. Thus, even in less-than-ideal conditions, the anchors were expected to safely support loads of up to 6,350 pounds. A finite element analysis of the accident module conducted for the Safety Board by the Federal Highway Administration (FHWA) showed that the actual anchor loads were well below the load capacities of the adhesive anchors shown in the then-current Powers product literature.

The FHWA analysis also showed that, even with any one ceiling hanger plate completely missing, the anchor loads in the remaining plates remained below 6,350 pounds. Only when two adjacent ceiling hanger plates were removed from the model did the calculated load on anchors in the adjacent plates exceed 6,350 pounds. Even then, the loads were well below the expected average ultimate load capacity published by Powers.

All of the D Street portal ceiling support anchors had been proof tested after installation. An independent testing firm hired by Modern Continental and approved by the CA/T project had tested each anchor by applying a tension load of 3,250 pounds (125 percent of the design service load) for a specified period of 2 minutes.[5] Anchors that failed the proof test were replaced and retested until they passed.

In September 1999, a Modern Continental employee installing ventilation ductwork above the HOV tunnel ceiling noticed that several of the anchors in the tunnel had begun to pull out. When subsequent checks over the next few weeks revealed that the displacement was increasing, Modern Continental notified the CA/T management consultant, Bechtel/Parsons Brinckerhoff (B/PB), of the problem. This was the first evidence that at least some of the 3,250-pound proof-tested anchors were yielding to even lesser loads over a period of time—which, in this case, was only about 2 months since the anchors had been placed under load.

B/PB initially suspected that the anchor displacement was the result of improper anchor installation or improper erection of the ceiling panels by Modern Continental. Powers sent representatives to the site in October 1999 to help identify the source of the displacement, but in the end, as cited by Modern Continental, "based on information gathered on site, which included a visual inspection [by Powers] of the anchors in question, a determination of failure could not be made."

The "fix" for the problem that was ultimately agreed to by B/PB and the contractor was that the contractor would remove and replace all the failed anchors and proof test them to a higher load of 6,350 pounds. Additionally, all previously installed anchors in the HOV tunnel would be retested to the higher load, and subsequent new anchor installations in the I-90 tunnel would also be tested to 6,350 pounds.

In December 2001, a Modern Continental quality control inspector initiated a noncompliance report to B/PB informing the management consultant of anchor displacements noted in another section of the I-90 connector tunnel. The report stated that

[5] The investigation could not confirm that each proof-test load was held for the specified time.

> Several anchors appear to be pulling away from the concrete. The subject anchors were [previously] tested to the revised value of 6350 lbs., all of which passed…. Reason for failure is unknown.

B/PB directed Modern Continental to "set new anchors and retest." As with the HOV tunnel 2 years before, all the displaced anchors were removed and replaced, then retested to more than 6,000 pounds. No additional actions were reported.

As shown by the investigation, the higher proof-tested loads could not confirm that the anchors would be able to sustain long-term loads. These early anchor failures, as well as the subsequent failures that led to the accident, indicated that—much like the glue on an adhesive label, which will hold tightly enough to tear the paper if jerked suddenly but will yield to a slow and steady pull—the epoxy anchors in the D Street portal could resist a sudden and brief proof-test load but could not sustain a constant load over time.

Epoxy is a polymer and, like all polymers, its stiffness is time and temperature dependent. If a load is applied suddenly, the epoxy responds like a hard solid. But if that load is then held constant, the molecules within the polymer may begin to rearrange and slide past one another, causing the epoxy to gradually deform in a process called *creep*.[6] As the deformation increases, it becomes irreversible and eventually leads to damage accumulation and failure. This process can also be affected by other aspects of the operating environment, such as the presence of moisture or chemicals.

Although the Powers Power-Fast epoxy was available in either slow-setting (Standard Set) or quick-setting (Fast Set) formulations, at the time of the original purchase agreement between Modern Continental and Newman Renner Colony, the Fast Set formulation was the only one that was being packaged as NRC-1000 Gold epoxy. Fourier transform infrared spectroscopy and headspace gas chromatography/mass spectroscopy testing of epoxy samples from most of the anchors that failed in this accident and other randomly selected anchors revealed that their chemical composition was consistent with the Fast Set epoxy. None of the anchors tested showed a chemical composition consistent with the Standard Set epoxy. Project invoices indicated that Modern Continental purchased Power-Fast Fast Set/NRC-1000 Gold epoxy during the period when the D Street portal ceiling was being installed, and no record was found of the purchase of Standard Set epoxy during this period. Based on these tests and observations, the Safety Board concludes that Modern Continental was supplied with and used the Fast Set formulation of the Power-Fast Epoxy Injection Gel when the company was installing the anchors in the D Street portal, including the anchors that failed in this accident.

Postaccident testing conducted by the FHWA's Turner-Fairbank Highway Research Center at the request of the Safety Board revealed that, while both the Fast Set and Standard Set formulations of the Powers epoxy performed similarly in short-term load tests, they differed dramatically under long-term load. The testing showed that anchors installed with the Powers Fast Set epoxy, using best practices, exhibited significant and continued displacement (creep) when subjected to loads as low as 1,000 pounds. Anchors loaded to 4,000 pounds completely

[6] As used in the Safety Board's report, *creep* refers to continuous anchor displacement under an applied load as a result of creep or damage accumulation, or both, in the epoxy adhesive.

separated from their anchor holes before the end of the 82-day test period. Given that the design service load was 2,600 pounds, the FHWA testing showed that the Fast Set epoxy, because of its susceptibility to creep, was not suitable for use in any long-term tension load application—such as supporting the D Street portal ceiling. The Safety Board concludes that the source of the anchor displacement that was found in the D Street portal tunnels and that precipitated the ceiling collapse was the poor creep resistance of the Power-Fast Fast Set epoxy used to install the anchors.

Standards and Protocols for Adhesive Anchor Testing

The Safety Board's investigation of the ceiling collapse in the I-90 connector tunnel revealed both a lack of understanding among designers and builders of the nature of adhesive anchoring systems and a lack of standards for the testing of adhesive anchors in sustained tensile-load applications. In hindsight, the installation and test procedures used for the adhesive anchors in the CA/T I-90 tunnels were clearly inadequate to ensure that the anchors would perform as required over the life of the tunnels. The proof-test procedure used, while it may have been appropriate for mechanical anchors, provided no information about the long-term strength of adhesive anchors under sustained load, or even about the anchors' ultimate short-term load strength.

In its *2002 Standard Specifications for Highway Bridges*, 17th edition, the American Association of State Highway and Transportation Officials (AASHTO) recommended that embedment anchors (defined as cast-in-place, grouted, adhesive-bonded, expansion, and undercut steel anchors) be subjected to sacrificial tests at the job site to document the capability of the anchor to achieve the full tension value as shown in the manufacturer's literature. Instead of conducting such sacrificial tests, CA/T managers and owners apparently accepted at face value the catalog load capacities provided by Powers and performed no independent testing to verify that the numbers were valid or that the anchors would perform similarly in this particular application.

Although the lack of maximum-load verification testing using overhead installations cannot be definitively shown to have contributed to this accident, testing a sample of the anchors to their ultimate loads would have been prudent given the safety-critical nature of the system. The Safety Board concludes that, because of the potential catastrophic effects of a failure of the D Street portal ceiling system, B/PB and Gannett Fleming should have required that ultimate load tests be conducted on the adhesive anchors used to support the ceiling before allowing any of the anchors to be installed.

The Safety Board recognizes that ultimate load tests alone would not have revealed the property of the epoxy that eventually led to this accident, which highlights the need for more refined and specific testing of any adhesive anchor system that is being considered for use in a sustained tensile-load application. Because no protocols or standards currently exist for such testing, public agencies and their contractors are left to devise their own tests or to conduct no tests at all. The Safety Board concludes that protocols or standards for the testing of adhesive anchors in sustained tensile-load applications will provide designers and builders with test methods designed specifically to accurately assess the long-term safety of those anchors.

To address the problem of inadequate testing standards, the Safety Board is recommending that AASHTO and the FHWA, building on current test standards from ASTM International or other sources, work jointly to develop standards and protocols for the testing of adhesive anchors to be used in sustained tensile-load overhead highway applications. These standards and protocols should consider site-specific ultimate strength values as well as the creep characteristics of the adhesive over the expected life of the structure. Once these standards and protocols are developed, the Safety Board is recommending that AASHTO incorporate them into the *AASHTO Construction Quality Assurance Guidelines.*

Lack of Awareness of the Nature of Adhesive Anchoring Systems

This accident investigation also revealed a striking lack of knowledge among the designers, contractors, managers, and overseers of the CA/T project about the nature and performance of polymer adhesives, even as those adhesives were being approved for use in applications where a failure would present an immediate risk to the public. No one involved with the CA/T project appeared to be aware of the potential of a polymer such as the anchor epoxy to gradually deform under sustained load. Even after being presented with evidence of anchor creep, project managers and overseers failed to recognize the inherent weakness in the epoxy adhesive—a weakness that could not be overcome even with the best installation practices or the most rigorous short-term proof testing.

The Safety Board does not believe that those associated with the CA/T project were unique in their lack of understanding of the nature of adhesive anchors. While the anchors have been in use for a number of years, they have rarely, perhaps never, been used in such numbers and in such a challenging environment as in the I-90 tunnels. In civil projects, adhesive anchors are typically used in short-term or shear load applications. Under these conditions, even if the adhesive is susceptible to creep, the displacement will likely never reveal itself, and those responsible for specifying, approving, installing, and testing the anchors will not be aware of it. Unfortunately, the lack of knowledge of the nature of epoxy anchors could lead to the use of these anchors in highway, tunnel, and bridge applications where susceptibility to creep could be a threat to public safety. The Safety Board therefore concludes that the circumstances of this accident demonstrate a general lack of knowledge and understanding among design and construction engineers and builders of the complex nature of epoxies and similar polymer adhesives, and in particular, the potential for those materials to deform (creep) under sustained tension loads. To help publicize the problems associated with adhesive anchoring systems, the Safety Board is recommending that AASHTO use the circumstances of this accident to emphasize to its members the risks associated with using adhesive anchors in sustained tensile-load applications where failure of the adhesive would result in a risk to the public.

The Safety Board expects that the implementation of its safety recommendations to the FHWA and AASHTO will serve to inform those involved in public works projects of the potential for creep in adhesive anchors. But the use of adhesive anchors is not limited to civil projects; such anchors are sometimes used in commercial construction. Therefore, the Safety Board believes that the American Concrete Institute should use its building codes, forums, educational materials, and publications to inform design and construction agencies of the potential for gradual deformation (creep) in anchor adhesives and to make them aware of the possible risks associated with using adhesive anchors in concrete under sustained tensile-load

applications. Further, because civil engineers and general contractors involved in civil and commercial construction are generally not expected to be familiar with the complex chemistry of epoxies or similar adhesives and yet may specify or use adhesive anchors in their projects, the Safety Board is also recommending that the American Society of Civil Engineers and the Associated General Contractors of America use the circumstances of this accident to publicize the problems associated with adhesive anchoring systems to their members.

Therefore, the National Transportation Safety Board makes the following recommendation to the American Concrete Institute:

> Use your building codes, forums, educational materials, and publications to inform design and construction agencies of the potential for gradual deformation (creep) in anchor adhesives and to make them aware of the possible risks associated with using adhesive anchors in concrete under sustained tensile-load applications. (H-07-32)

The Safety Board also issued safety recommendations to the Federal Highway Administration; the American Association of State Highway and Transportation Officials; the State and District of Columbia Departments of Transportation; the International Code Council; ICC Evaluation Service, Inc.; Powers Fasteners, Inc.; Sika Corporation; the American Society of Civil Engineers; and the Associated General Contractors of America.

Please refer to Safety Recommendation H-07-32 in your reply. If you need additional information, you may call (202) 314-6177.

Chairman ROSENKER, Vice Chairman SUMWALT, and Members HERSMAN, HIGGINS, and CHEALANDER concurred in this recommendation.

[*Original Signed*]

By: Mark V. Rosenker
Chairman