National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 3, 2007

In reply refer to: H-07-25 through -28

Mr. Rick Weiland
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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 recommendations in this letter. The Safety Board is vitally interested in these recommendations because they are designed to prevent accidents and save lives.

These recommendations, which address anchor adhesive qualification and installation, are 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 are 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, 4 of which are addressed to the International Code Council (ICC). Information supporting these recommendations 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 recommendations.

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.

[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).

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 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

[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.

traffic through the I-90 connector tunnel (including the D Street portal) averaged 43,000 vehicles per day.

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.

[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.

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 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.

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

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

> 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-test 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 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

[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.

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 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.

Use of Fast Set Versus Standard Set Epoxy

As the investigation revealed, the use of Power-Fast Fast Set epoxy virtually assured future problems with the D Street portal ceilings. The obvious question, then, is how did Modern Continental come to use an epoxy formulation that had been shown to be inappropriate for this application.

The investigation found no evidence that Modern Continental was offered a choice or made a conscious decision to use one epoxy formulation over another. As noted previously, at the time Modern Continental entered into the purchase agreement for the anchoring system, Powers was packaging only the Fast Set version of its Power-Fast epoxy for "private label" distribution by Newman Renner Colony. The NRC-1000 Gold cartridge labeling at the time did not indicate that the material was Fast Set but showed the catalog no. 8431, which was identified by Powers as the Fast Set formulation.

According to internal Powers correspondence dated June 3, 1999 (the same day Modern Continental signed the purchase agreement with Newman Renner Colony), Powers was beginning the process of having the Power-Fast Standard Set epoxy also packaged as NRC-1000 Gold. According to this correspondence, the Standard Set material was being provided to Newman Renner Colony in anticipation of a need for the slower-setting epoxy for future projects. The addition of Standard Set epoxy to the Newman Renner Colony line would require new labeling to indicate Fast Set or Standard Set. The correspondence indicated that Newman Renner Colony had placed an order for 1,000 units of the catalog no. 8431 (Fast Set) material and had placed an initial order for 120 units of the newly packaged Standard Set epoxy to be used for U.S. Department of Transportation (DOT) projects requiring an International Conference of Building Officials (ICBO) certificate (the correspondence did not indicate which DOT projects were being referenced). The correspondence stated, "We [Powers] have told them [Newman Renner Colony] that production for this product [the Standard Set formulation packaged as NRC-1000 Gold] would be 4-6 weeks." Evidence was found during the course of the investigation that some of the epoxy Newman Renner Colony provided for the D Street portal contract was packaged as Power-Fast epoxy, but this was the same Fast Set product that the company was supplying under its own NRC-1000 Gold label.

Installation of the anchors in the D Street portal began in July 1999, using epoxy purchased from Newman Renner Colony. No evidence was found that Modern Continental had any information at that time to suggest that the epoxy it was using was susceptible to creep. The

Safety Board therefore concludes that Modern Continental was not aware, when its employees installed the adhesive anchors in the D Street portal, that the epoxy being used was susceptible to creep and was therefore unsuitable for this application.

The draft reissue of ICBO evaluation report 4514 (ER-4514), which Modern Continental submitted to Gannett Fleming in December 1999 in its fourth attempt to have the anchors approved by the design consultant, did refer to two epoxy formulations and did state that the Fast Set version was approved for short-term loads only. But this documentation, as well as the ultimate load figures submitted to show that the anchor capacities were sufficient to support the calculated design loads, was supplied by Powers, and none of the documentation specified which epoxy formulation had been supplied for use in the D Street portal. Modern Continental apparently assumed, based on information provided by Powers, that the epoxy it was using was suitable.

Further, Gannett Fleming did not include a contract specification identifying long-term performance (creep resistance) of the anchor adhesive as an issue that should be addressed by contractors. In the specification for ceiling support anchors, Gannett Fleming indicated that the selected adhesive material should "remain unaffected by continuous humidity and by chemicals present in a vehicle exhaust type of air duct environment," but the design consultant said nothing about the potential for creep in such materials and thus of the necessity of verifying that the selected material could support substantial tension loads indefinitely. Had it done so, the construction contractor would have at least been made aware of the potential for anchor creep so that it could have specifically considered this factor when selecting the anchor adhesive. The Safety Board concludes that had Gannett Fleming, in the construction contract for the D Street portal finishes, specified the use of adhesive anchors with adequate creep resistance, a different anchor adhesive could have been chosen, and the accident might have been prevented.

Even though Gannett Fleming made no provisions in the initial design specifications regarding the long-term performance of the adhesive anchors, the company could have addressed that issue during the approval process for the anchoring system selected by Modern Continental. Gannett Fleming engineers reviewed all of the documentation relating to the contractor's proposed anchoring system and even rejected the first three submittals, each time requesting more information. With its fourth anchor adequacy submittal, Modern Continental included the draft revision of ICBO ER-4514, which stated that the Power-Fast Fast Set epoxy formulation was approved for short-term loads only. Although the guidance in the report was somewhat ambiguous, Gannett Fleming had the responsibility to carefully review all of the anchor adequacy documentation. Such a review of the draft ICBO ER-4514 should have prompted Gannett Fleming to inquire as to which epoxy formulation Modern Continental was using. A query from Modern Continental to Newman Renner Colony or Powers would likely have revealed that the Fast Set version was being provided to the job, and work could have been stopped and corrective measures taken. Instead, the Gannett Fleming reviewer authorized Modern Continental to proceed with work installing the anchors (by this time, the anchors that would be involved in the accident had already been installed). The Gannett Fleming reviewer apparently evaluated Power-Fast/NRC-1000 Gold epoxy as a single product and focused only on the bond strength as shown in the tables. The Safety Board concludes that Gannett Fleming approved the D Street portal anchors without identifying which epoxy formulation was being

used, even though the company was provided with information indicating that one version of the Power-Fast epoxy should be used for short-term loading only.

International Code of Building Officials Evaluation Report (ICBO ER-4514)

Powers was updating its ICBO listing for Power-Fast epoxies in 1997, which required that the epoxies be independently tested in accordance with ICBO guidelines. As part of the qualification testing, an optional 120-day creep test was performed on the Standard Set epoxy. In response to a change in ICBO acceptance criteria 58 (AC58), *Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Element*, the results of the 120-day test of Power-Fast were extrapolated to 600 days. The Standard Set epoxy met the standards for creep in both the 120- and extrapolated 600-day tests. No creep tests were reported for the Fast Set formulation (although such tests had been performed, as will be discussed below).

The version of ICBO ER-4514 on Power-Fast epoxy that was reissued in February 2000 had few references to Fast Set epoxy, and those could easily have been overlooked without a careful reading. In the product description, the report noted that the epoxy was available in two formulations and that the Fast Set version had additives to speed curing. (A table of relative curing times was also included.) The most significant mention of Fast Set epoxy was in the "Findings" section where, in a long paragraph presenting the 10th finding, the use of the Fast Set formulation with threaded rods was "permitted for short-term loads, such as those resulting from wind or earthquake forces only."

Another mention was in a footnote to the table of allowable tension loads for threaded rods in concrete. According to the footnote, when using Fast Set, the allowable loads from the table should be reduced "by 25 percent based on a safety factor of 5.33." The footnote made no reference to any difference in long-term performance under load between Fast Set and Standard Set epoxy. In total, the report said very little about Power-Fast Fast Set epoxy except in its finding that this formulation should only be used for short-term loads.

At the time the anchors were installed in the D Street portal, the ICBO (or its umbrella organization, the ICC) required, in AC58, that a design safety factor of 5.33 be used for anchors in concrete when the epoxy formulation had not passed the optional creep test (either because it was not tested or because it failed the test). Thus, the footnote specifying a safety factor of 5.33 for Power-Fast Fast Set epoxy indicated that this material had not passed the optional creep test. There was no requirement to report that a material had failed the optional creep test.

Tables contained in ICBO ER-4514 showed that the allowable load for Power-Fast Standard Set epoxy, with the anchor size and embedment used in the D Street portal and with a safety factor of 4, was 5,150 pounds. Based on this load and the recommended 25-percent reduction, the allowable load for Fast Set epoxy would be about 3,860 pounds. This was about 1,200 pounds more than the design load of 2,600 pounds calculated by Gannett Fleming for the D Street portal anchors and only about 600 pounds more than the initial 3,250-pound proof-test loads (and considerably less than the 6,350-pound proof-test load applied to some of the anchors).

Every anchor in the D Street portal was thus tested to within a few hundred pounds of the catalog allowable load for that anchor, using guidelines in the ICBO report, and some of these

were tested to the 6,350-pound allowable load listed in Powers' literature. Yet many of the anchors began to pull away from the tunnel roof after being under constant load for 2 months or less. The Safety Board therefore concludes that, as shown by the displaced anchors in the D Street portal, the maximum load capacity of an adhesive anchor, which relates to short-term loading, does not indicate that the anchor will be able to support even lighter loads over time, and thus a larger design safety factor cannot compensate for an adhesive material that is susceptible to creep.

The Safety Board learned during this investigation that the Power-Fast Fast Set epoxy had been tested for creep performance in 1995 and 1996 and had failed to meet the standard. That alone would explain the ICBO ER-4514 proscription against using the Fast Set epoxy for long-term loads. But this load restriction was only shown in the report recommendations. In the bond strength tables, footnotes indicated only that the allowable loads shown should be reduced sufficiently to allow a safety factor of 5.33 (rather than 4) if the Fast Set material was to be used. Nothing in the tables or the footnotes indicated that the Fast Set epoxy should not be used for long-term loads regardless of the safety factor employed.

Given that the ability to sustain a load over a period of time is a typical requirement for almost any type of fastener, the Safety Board is concerned that the ICC has previously allowed creep testing of epoxy adhesives to be optional. A design engineer or contractor should be provided with all of the relevant information about a product before it is used in a safety-critical application; therefore, the Safety Board believes that the ICC should require creep testing for the qualification of anchor adhesives and disqualify for use in sustained tensile loading any adhesive that has not been tested for creep or that has failed such tests. The capabilities of Powers Power-Fast epoxy anchor systems are now covered in the ICC Evaluation Service, Inc., evaluation report ESR-1531, which has replaced ICBO ER-4514. Although the bond strength tables in the report have separate listings for the Fast Set and Standard Set epoxies, the report does not address the difference in long-term performance between the two formulations or indicate that Fast Set should be used only for short-term loads. Because of the possibility that the critical difference in the two epoxies could still easily be overlooked, the Safety Board is also recommending that ICC Evaluation Service, Inc., revise evaluation report ICC ESR-1531 to state explicitly in the text and in the bond strength tables that the Fast Set formulation of Powers Power-Fast epoxy is approved for short-term loads only.

Powers Design Manual

According to Powers, in the second edition of its *Fastening Systems Design Manual*, the only difference between the Power-Fast Standard Set and Fast Set epoxies was their respective gel and curing times. Except for the ICBO report itself (which, as noted earlier, was somewhat ambiguous), none of the documentation submitted by Powers to support the qualification of the NRC-1000 Gold epoxy suggested a possible difference in long-term performance between the Standard Set and Fast Set formulations.

Powers should have made a clear distinction in all of its literature between the relative capabilities of its Standard Set and Fast Set formulations. It did not do so, even though, before the epoxy was provided to the D Street portal project, the company had conclusive evidence that

its Fast Set epoxy was susceptible to creep and that it was therefore inappropriate for long-term tension loading in a safety-critical application.

Powers was aware that Modern Continental was using the Power-Fast product for long-term tension loads; it was also aware that the NRC-1000 Gold formulation being used was the Fast Set material. But there is no evidence that the company ever communicated with the contractor in regard to which formula should be or was being used in the D Street portal.

Only in May 2007, more than 10 months after this accident, did Powers revise its product literature to indicate that the Power-Fast Fast Set epoxy should be used for short-term loads only. The Safety Board notes that this is the only Powers product literature obtained during this investigation that explicitly alerts designers or contractors of a difference in creep resistance between the company's two epoxy formulations. The Safety Board therefore concludes that the information that was provided by Powers regarding its Power-Fast epoxy was inadequate and misleading, with the result that Modern Continental used the Fast Set formulation of the epoxy for the adhesive anchors in the D Street portal even though that formulation had been shown through testing to be susceptible to creep under sustained tension loading.

As a follow-on to the revised product literature and as an additional safety measure, the Safety Board is recommending that Powers revise the packaging, for all distributors, of its Power-Fast Epoxy Injection Gel Fast Set formulation to state explicitly that this formulation is approved for short-term loads only. Also, because Sika Corporation, the epoxy manufacturer, markets the fast-setting version of this epoxy as Sikadur Injection Gel AnchorFix-3, the Safety Board is also recommending that Sika Corporation revise its product literature and packaging to state explicitly that Sikadur Injection Gel AnchorFix-3 is approved for short-term loads only. To address the issue of epoxy creep more globally, the Safety Board believes that the ICC should revise its building codes, qualified materials listings, and product labeling guidelines to clearly address the possibility for creep in polymeric anchor adhesives and to make end users aware of the potential lack of correlation between short- and long-term performance of these adhesives.

Introduction of Voids During Overhead Epoxy Anchor Installation

Postaccident anchor installation testing by the Safety Board determined that anchors with significant voids in the epoxy produced a lower uniform stress at peak load than anchors without significant voids, suggesting that voids, by decreasing the epoxy bond area, increase the load stresses on the remaining epoxy and compromise the ultimate load capacity of the anchor. The Safety Board found measurable void areas associated with almost all of the anchors and anchor holes that were examined after the accident. For example, the anchor holes from the failure area showed void area fractions as high as 38 percent, with 11 of the 20 holes having void area fractions of 20 percent or more.[7] These voids likely reduced the ultimate load capacity of the anchors and accelerated the rate of displacement of the anchors after installation.[8]

[7] The measured void area fractions were considered minimums because some evidence of the presence of voids could have been lost during the failure process.

[8] After the accident, the FHWA, at the request of the Safety Board, conducted pull tests on the remaining anchors in the D Street portal. These tests showed that, while the load capacity of anchors might have been reduced by voids or other installation factors, the anchors that had not already displaced due to creep retained a short-term load capacity in excess of the loads they were supporting in the tunnel.

Safety Board anchor installation simulations showed that the size and location of voids can be influenced in a variety of ways during epoxy injection or anchor insertion. More significant, however, was the finding, during installation tests conducted by the FHWA, that voids are frequently introduced even when the proper procedures are followed precisely and every effort is made to eliminate voids. This suggests that, in overhead applications, voids are introduced into the adhesive by the nature of the task itself. The Safety Board therefore concludes that installing adhesive anchors in overhead applications appears, by the nature of the task, to introduce voids into the adhesive that can reduce the ultimate load capacity of the anchor and thus the overall reliability of the anchoring system.

Because it is unlikely that independent epoxy qualification testing evaluates products in an overhead application, the load values from those tests may not reflect the reductions in load capacity that would result from the voids that would likely be introduced by such installations. In addition, overhead applications typically require use of seal plugs to contain the epoxy until it sets. If the seal plug prevents bonding between the epoxy and the concrete (as did the polyethylene plugs used for the anchors in this accident), the effective anchor embedment depth may be reduced,[9] causing a further reduction in anchor load capacity. The Safety Board therefore believes that the ICC should make end users aware of the strong potential for creating voids in the adhesive during the overhead installation of adhesive anchors and of the need to account for the reduction in effective embedment depth associated with the use of seal plugs in such applications.

Therefore, the National Transportation Safety Board makes the following recommendations to the International Code Council:

> Require creep testing for the qualification of all anchor adhesives. (H-07-25)
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> Disqualify for use in sustained tensile loading any adhesive that has not been tested for creep or that has failed such tests. (H-07-26)
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> Revise your building codes, qualified materials listings, and product labeling guidelines to clearly address the possibility for creep in polymeric anchor adhesives and to make end users aware of the potential lack of correlation between short- and long-term performance of these adhesives. (H-07-27)
>
> Use your building codes, qualified materials listings, test criteria, or other mechanisms to make end users aware of the strong potential for creating voids in the adhesive during the overhead installation of adhesive anchors and of the need to account for the reduction in effective embedment depth associated with the use of seal plugs in such applications. (H-07-28)

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; ICC Evaluation Service, Inc.; Powers Fasteners, Inc.; Sika Corporation; the American Concrete Institute; the American Society of Civil Engineers; and the Associated General Contractors of America.

[9] The seal plugs used in the D Street portal reduced the effective anchor embedment by more than 1/2 inch.

Please refer to Safety Recommendations H-07-25 through -28 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 these recommendations.

[*Original Signed*]

By: Mark V. Rosenker
Chairman