National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: August 3, 2007

In reply refer to: H-07-15 through -19

Honorable J. Richard Capka
Administrator
Federal Highway Administration
1200 New Jersey Ave, S.E.
Washington, D.C. 20590

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 Interstate 90 (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]

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

[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).

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.

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.

[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 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 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.

[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.

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

> 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

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

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 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.

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

[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.

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.

A creep testing protocol is specified in International Conference of Building Officials Acceptance Criteria 58, *Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements*, but this is a pass/fail test that is conducted using one load at a single temperature for a specified time. Such a test may be appropriate as a screening tool to identify adhesives that should never be used for long-term tensile loads (such as the Power-Fast Fast Set epoxy, which had failed the test), but it does not provide any data that could be used to predict the operational lifetime of an adhesive. Nor does it provide information to assist users in establishing appropriate inspection intervals for adhesive anchors under different loads or at different temperatures.

ASTM International (ASTM) Standard D 2990-01, *Standard Test Method for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics* (first adopted in 1971 and most recently reapproved in 2001), includes standardized testing guidelines and information in a series of appendixes. The appendixes describe a number of well-established and complementary methods for predicting the long-term properties of polymers and for ensuring their safe use under creep conditions. The introduction to the appendixes notes that

> Since the properties of viscoelastic materials are dependent on time, temperature, and rate of loading, an instantaneous test result cannot be expected to show how a material will behave when subjected to stress or deformation for an extended period of time.

The standard itself discusses various methods for testing plastics (polymers) to assess their behavior (creep) under sustained loads; it does not address adhesive anchors. The test methods described in the standard could, however, be adapted, through specific testing protocols, to generate data that would aid designers and others in evaluating the suitability of adhesive anchors for a particular application.

For example, one method for predicting long-term properties discussed in ASTM D 2990-01 involves conducting a number of tests over a range of applied loads (similar to the sustained load tests performed at several load levels by the FHWA as part of this investigation) to determine the time to failure as a function of load. These data can then be extrapolated to estimate the load at which failure will occur for times beyond the range of the tests.

A second method outlined in an appendix to ASTM D 2990-01 employs laboratory testing coupled with time-temperature superposition to calculate the creep compliance over a wide range of time. Because the creep compliance is directly related to the displacement of an anchor under a constant load, this method could be used with a maximum displacement criterion to predict the expected useful life of an adhesive anchor. The results of this testing could also be used to assess the effect of variations in temperature over the life of the installation. The time-temperature superposition tests performed for the Safety Board at the National Institute of Standards and Technology (NIST) predicted that the room temperature displacement of an anchor installed with Power-Fast Fast Set epoxy would increase by a factor of 3.5 after 1 month and by a factor of 14 after 10 years. The results of the FHWA creep tests and the NIST material evaluations appear comparable (except for the Fast Set anchors loaded at 4,000 pounds, which in the FHWA tests demonstrated a nonlinear behavior suggesting yield or damage accumulation in the adhesive), although a rigorous comparison has not yet been attempted. In any event, use of either of these methods as a part of the preparations for construction in the D Street portal would have demonstrated that the Fast Set epoxy was not suited to this application. NIST also performed experiments suggesting that moisture absorption could have a significant effect on the material properties of the Fast Set and Standard Set epoxies. These experiments were performed on small samples that allowed for rapid saturation and therefore might not reflect actual-use conditions; however, they indicate that a testing plan to assess the long-term durability of polymeric materials must consider environmental effects in addition to temperature.

Because consistent, comprehensive standards for testing adhesive anchors currently do not exist, the Safety Board believes that the FHWA and AASHTO, building on current test standards from ASTM or other sources, should work jointly to develop standards and protocols for the testing of adhesive anchors to be used in sustained tensile-load 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 also recommending that AASHTO incorporate them into the *AASHTO Construction Quality Assurance Guidelines*.

The Safety Board is also concerned that, without such standards and protocols, adhesive anchors may be used in sustained tensile-load overhead highway applications where failure of the adhesive would result in a risk to the public. For that reason, the Safety Board believes that the use of adhesive anchors in these applications should be prohibited until testing standards and protocols can be developed and implemented and therefore recommends that the FHWA and the transportation departments of the 50 States and the District of Columbia prohibit the use of adhesive anchors in sustained tensile-load overhead highway applications where failure of the adhesive would result in a risk to the public. Concurrently, the Safety Board is recommending that AASHTO use the circumstances of this accident to emphasize to its members through its publications, Web site, and conferences, as appropriate, 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.

To address the potential risk associated with adhesive anchors that may already have been used to support overhead signs or traffic control devices where a failure could result in injury or death, the Safety Board is further recommending that the transportation departments of the 50 States and the District of Columbia review the use of adhesive anchors in highway construction within their jurisdictions and identify those sites where failure of the adhesive under sustained load could result in a risk to the public. This recommendation goes on to state that, once those sites have been identified, a repair and inspection program should be implemented to ensure that such failures do not occur.

Requirements for Tunnel Inspections

The Safety Board's investigation of the I-90 ceiling collapse also highlighted the lack of regulatory requirements for tunnel inspections. The investigation revealed that no tunnel inspections were performed to determine the physical and functional condition of the D Street portal ceiling system from the time the I-90 eastbound connector tunnel was opened to traffic on January 18, 2003, until the day of the fatal accident.

In November 2003, in response to the contract scope of services, B/PB published an inspection manual entitled *Inspection Manual for Tunnels and Boat Structures*. Although the manual was a comprehensive and detailed guide for inspecting CA/T tunnels, the Massachusetts Turnpike Authority (MTA) (the owner of the CA/T project) did not use it between November 2003 and July 2006, and the tunnels were not inspected.

As noted earlier, postaccident inspection of the area above the suspended ceilings in the D Street portal revealed the large number of anchors that had become displaced from the tunnel roof. The displaced roof hanger plates were so obvious that even a cursory examination of this area before the accident would have revealed that the structural integrity of the ceiling system was threatened. At the time the inspection manual was published, the ceiling module that collapsed in this accident had already been in place for 4 years, and at that time at least some of its anchors had probably begun to yield to the load.

The Safety Board concludes that had the MTA, at regular intervals between November 2003 and July 2006, inspected the area above the suspended ceilings in the D Street portal tunnels, the anchor creep that led to this accident would likely have been detected, and action could have been taken that would have prevented this accident.

In the early 1970s, the FHWA, under legislative authority provided under 23 *United States Code* Section 151 and using standards promulgated in 23 *Code of Federal Regulations* Part 650, developed the National Bridge Inspection Program (NBIP). This program required that each State transportation department inspect all non-federally owned public-road bridges within its jurisdiction.

The NBIP consists of *National Bridge Inspection Standards* (NBISs) and a National Bridge Inventory (NBI). The NBISs were first established in 1971 to set national requirements regarding bridge inspection frequency, inspector qualifications, report formats, and inspection and rating procedures. The NBI data include identification of the bridge, structure type and material, age and service, geometric data, navigation data, condition, load rating and posting, proposed improvements, and inspections. The NBISs require that bridges be inspected at regular intervals not to exceed 24 months.

Tunnel inspections are addressed in the FHWA's *Highway and Rail Transit Tunnel Inspection Manual*, 2005 edition, which states that tunnel owners should

> establish the frequency for up-close inspections of the tunnel structure based on the age and condition of the tunnel. For new tunnels, this time period could be as great as five years. For older tunnels, a much more frequent inspection time period may be required, possibly every two years. This up-close inspection is in addition to daily, weekly, or monthly walk-through general inspections.

The FHWA requires that bridges, in contrast to tunnels, be inspected at least every 2 years, regardless of age. In this accident, problems with some of the anchors in the HOV tunnel were identified within weeks or months of their installation, indicating that even recently built structures are not immune to potentially hazardous defects. In the view of the Safety Board, the inspection interval for tunnels, whether new or old, should be consistent with the interval for inspection of bridges. Recognizing that the FHWA lacks the authority to establish and mandate a nationwide tunnel inspection program, the Safety Board believes that the FHWA should seek legislation authorizing it to establish a mandatory tunnel inspection program similar to the NBIP. Once such legislation has been obtained, the Safety Board believes that the FHWA should develop and implement a tunnel inspection program that will identity critical inspection elements and specify an appropriate inspection frequency.

National Standards for Design of Tunnel Finishes

The Safety Board investigation further found that no national standards exist for the design of tunnel finishes. The ceiling system in the D Street portal was designed and installed as part of the contracts for the tunnel finishes. The FHWA's 2004 manual *Road Tunnel Design Guidelines* did not address the design of tunnel finishes, despite the fact that tunnel authorities throughout the country use a wide variety of tunnel finish designs and anchorage systems with different redundant support systems and different installation requirements. The Safety Board conducted a survey of tunnel finishes and found that adhesive anchors are seldom used as an anchorage system to support suspended ceiling panels. When adhesive anchors are used, they rarely are required to act in pure tension (as was the case in the D Street portal), and they typically support lightweight panels. The most common anchorage systems used to support suspended ceiling panels are mechanical expansion anchors.

The survey also revealed that a majority of U.S. tunnels have continuous ceiling panels/slabs that extend into the concrete tunnel walls. This continuous support provides significant redundancy in that, if the hangers fail, the suspended ceiling panels are self-supported. The I-90 connector tunnel had no continuous supports that extended from the ends of the ceiling panels into the concrete tunnel walls. The struts on either side of each ceiling module prevented movement of the ceiling system in the transverse direction, but they provided no support for the ceiling panels in the event of anchor or hanger failure.

In the Safety Board's opinion, as more tunnels are built and retrofitted in the future, the need will only increase for national standards that will help tunnel owners ensure uniformity and safety in their tunnel finish designs. The Safety Board therefore concludes that national standards for the design of tunnel finishes, including tunnel suspended ceilings, will provide government entities or other organizations with ready access to information that could be useful in designing tunnel finishes that minimize potential risks to public safety and believes that the FHWA should, in cooperation with AASHTO, develop specific design, construction, and inspection guidance for tunnel finishes and incorporate that guidance into a tunnel design manual.

Therefore, the National Transportation Safety Board recommends that the Federal Highway Administration:

> In cooperation with the American Association of State Highway and Transportation Officials, 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. (H-07-15)
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> Prohibit the use of adhesive anchors in sustained tensile-load overhead highway applications where failure of the adhesive would result in a risk to the public until testing standards and protocols have been developed and implemented that ensure the safety of these applications. (H-07-16)
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> Seek legislation authorizing the Federal Highway Administration to establish a mandatory tunnel inspection program similar to the National Bridge Inspection Program. (H-07-17)
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> Once provided with legislative authority to establish a mandatory tunnel inspection program as indicated in Safety Recommendation H-07-17, develop and implement a tunnel inspection program that will identity critical inspection elements and specify an appropriate inspection frequency. (H-07-18)

> In cooperation with the American Association of State Highway and Transportation Officials, develop specific design, construction, and inspection guidance for tunnel finishes and incorporate that guidance into a tunnel design manual. (H-07-19)

The Safety Board also issued safety recommendations to the American Association of State Highway and Transportation Officials; the departments of transportation of the 50 States and the District of Columbia; the International Code Council; 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.

Please refer to Safety Recommendations H-07-15 through -19 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