PROJECT

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Precast's Durability Helps Bridges Resist Fire Damage

— Craig A. Shutt

A major bridge fire doesn't necessarily mean the structure must be replaced; precast concrete designs can help keep bridges open even after intense blazes

Engineers are well aware of the strength and durability that precast concrete components offer for bridge designs, allowing longer spans and long-term lifecycles with minimal maintenance requirements. But several recent accidents at precast concrete bridges have shown that concrete's inherent noncombustible nature can help ensure that fires that would incapacitate or collapse other bridge structures can be shrugged off following a reassuring review.

The key problem is that bridge fires tend to be exceptionally hot, as they're caused by an external source of intense heat, such as fuel from an overturned truck or tanker cars carrying chemicals, says Richard B. Stoddard, acting bridge design engineer with the Washington Department of Transportation. Stoddard recently inspected a fire-damaged bridge in his region.

Although flame temperatures at this methanol-fueled tanker fire in Puyallup, Wash., reached 3,000 °F, the precast concrete bridge was reopened to traffic the next day.

Following an in-depth inspection, the precast concrete bridge was reopened to traffic immediately after the fire.

The heat from the Puyallup bridge fire was intense enough to cause some spalling, which left some exposed strands, but it left them undamaged.

The pink color shown in this girder from the Puyallup bridge fire indicates that the concrete was exposed to temperatures higher than 500 °F.

"Tanker fires caused by highway fuel trucks or railway tanker cars are explosive in nature and greatly exceed the temperatures and rate of heating prescribed in the ASTM fire-resistance test," he said in his report. "Additionally, the heat-transfer mechanism in tanker fires is dominated by radiant energy as opposed to hot-air and heat convection." Precast concrete, with its high specific heat, can better endure these relatively short-duration, high-temperature fires.

Past articles in *Ascent* (Summer 2002 and Spring 2005) have shown the impact that such intense heat has had on steel bridges in Alabama. In those cases, truck collisions within miles of each other destroyed two structures near Birmingham. In cases such as these, the heat reaches such levels that the metal deforms and even melts, causing the bridge to sag and become unstable. Recent examples have shown that precast concrete can withstand high temperatures with less distress than other materials.

Testing After The Fire

Hardness testing is a key way to detect if a fire has damaged a precast concrete structure. PCI's "Design for Fire Resistance of Precast Prestressed Concrete" manual (MNL-124) suggests that fire-damaged concrete structures should be evaluated as quickly as possible once the fire is extinguished. The limits of the concrete damage often can be ascertained by testing with an impact-rebound hammer. An average hammer reading should first be obtained in the obviously undamaged areas for each type of unit. Readings in the damaged areas generally will be substantially lower. By taking a large number of readings in the areas of suspected involvement, the severely damaged areas can be identified.

If further testing is required, concrete core samples can be taken for petrographic examination, to review concrete mix changes, crack frequency or distribution and discoloration of paste and aggregate.

Common Concrete Changes During Heating Phase

Up to 200 °F: Little or no concrete damage.

500 °F: Localized cracks; iron-bearing aggregates begin to acquire pink/red color.

700 °F: Cracks appear around aggregate; numerous microcracks present in cement paste observed in thin-section. Typical normal-weight concrete has lost about one half of its compressive strength.

900 °F: Purple-gray color appears if enough iron and lime are present. Portlandite (calcium hydroxide) alters to calcium carbonate. Paste has a patchy appearance in thin sections.

1,000 °F: Serious cracking of paste and aggregates due to expansion. Purple-gray color may become more pronounced.

1,500 °F: Cement paste is completely dehydrated with severe shrinkage cracking and honeycombing. Concrete may begin to be friable and porous.

2,200 °F: Some components of concrete begin to melt.

2,550 °F: Concrete is completely melted.

Source: "Design for Fire Resistance of Precast Prestressed Concrete" Manual (MNL-124), Precast/Prestressed Concrete Institute, 2005.

A visual inspection can quickly determine if any spalling or other changes have occurred following a fire, especially through color change. A pink/red color appears when the precast component has been exposed to heat above 500 °F, and a purple-gray color begins to appear above 900 °F. The concrete won't show signs of melting until the heat reaches 2,200 °F or more (see the sidebar for more details).

Although the interior prestressing strand will lose strength due to the heat, it typically returns to its full strength after cooling. PCI's Fire Resistance Manual notes that prestressing steel retains its full strength when it is heated to temperatures as high as 750 °F and then cooled. It retains about 70 percent of its strength when temperatures reach 900 °F and about 50 percent of its strength when temperatures reach 1,100 °F.

(Photo-Top) A blazing car fire caused damage to a bridge in Washington County, Ore., but the effects were minimal and the bridge was reopened to traffic after an inspection.

(Photo-Bottom) Some spalling and exposed aggregate was noted during the inspection of the Washington County, Ore., fire, but it was not sufficient to even require repairs.

Puyallup River Fire

The durability that precast concrete can provide to a bridge, and the benefit of having such fire resistance, can be seen in several recent projects where the prestressed concrete bridge was subjected to intense heat during accidents. In December 2002, a railroad tanker-car collision occurred under the precast, prestressed concrete girder bridge over the Puyallup River in Washington. The bridge featured three continuous spans of 146-foot long girders with 7,000-psi concrete girders and a deck and columns with 5,000-psi concrete.

The fire was fueled by 30,000 gallons of methanol and engulfed the eighth span of the bridge, maintaining a high flame temperature for about one hour, says Stoddard, who inspected the bridge. Engineers estimated that flame temperatures approached 3,000 °F and surface temperatures on the soffit of the prestressed girders may have reached 1,700 °F. Internal temperatures in the bottom flange and webs ranged from 500 °F to 1,100 °F.

"The concrete heating rate was rapid and the cooling rate was accelerated by water spray from fire trucks," Stoddard says. Even though these could have caused significant problems, both factors contributed only a small amount of damage and didn't impact the bridge's capabilities.

"The interstate freeway was immediately closed to traffic and remained closed pending an all-night structural inspection," he reports. But the inspectors found no significant loss of capacity. The bridge displayed no unusual deflections or misalignments and was reopened to commuter traffic and legal truck loads the next day.

To be sure, the heat caused significant heat damage in some areas. The impact was most critical in one key span, where the concrete in the girders suffered extensive spalling. Both columns supporting the span had 2-inch-deep concrete spalls that exposed spiral reinforcement for the pier's full height, Stoddard says. Some delaminations also occurred within the concrete core. Crossbeams at this point showed concrete spalling to depths of ½ inch, but no reinforcement was visible. The flanges in all 15 lines of girders in the span turned a whitish-gray, and those patches could be removed to expose the outermost prestressing strands for a length of about 94 feet.

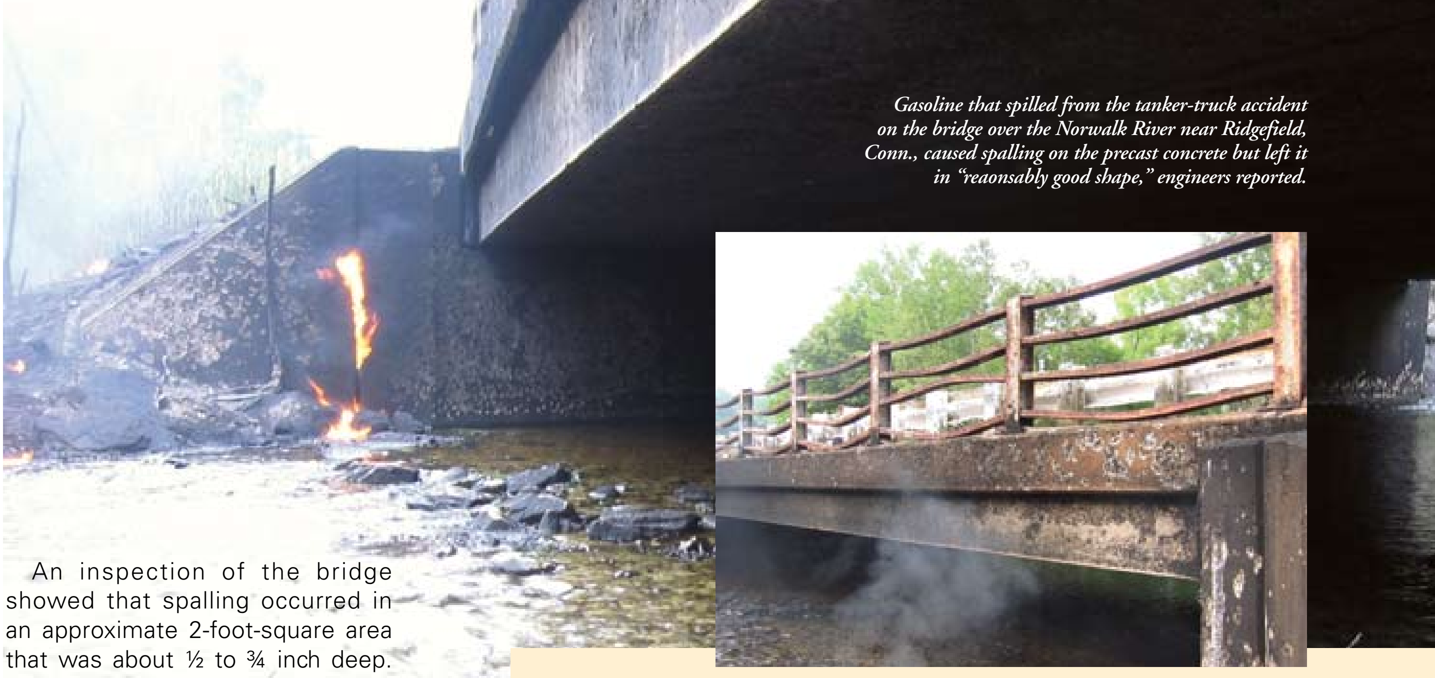
At the same time, no changes in vertical or horizontal alignment were seen, and the soffit of the concrete deck escaped damage, Stoddard reports. "The prestressing steel survived the fire without noticeable loss of prestress despite being embedded in concrete that was heated to 900 °F," he reported. The conductive property of the steel apparently transferred heat to cooler regions in the girder, keeping the steel in the hotter portions from yielding.

Although the precast concrete protected the prestressing strands during the fire, officials determined that one span ultimately needed to be replaced to provide long-term protection for the strands, as repair options did not seem practical. Repairs currently are in the planning stages to provide new prestress girders and a new slab for the damaged span. "The prestress concrete girder proved to be very durable," he says. "I was surprised to find the strands and the bond mechanism good despite the extreme damage to the surrounding concrete."

'The fire was hot enough to melt aluminum and leave it puddled on the ground.'

Washington County Fire

A similar result occurred at a precast concrete bridge in Washington County, Ore., in November 2004. A derelict car was abandoned in an area beneath the bridge and set on fire, causing charred concrete on the bridge above and disruption to traffic. The damage occurred at about mid-span on a 37.5-foot span of 18-inch-deep voided slabs. "The fire was hot enough to melt aluminum and leave it puddled on the ground nearby," reports Greg Clemmons, operations engineer for the Washington County Land Use & Transportation Department.



Gasoline that spilled from the tanker-truck accident on the bridge over the Norwalk River near Ridgefield, Conn., caused spalling on the precast concrete but left it in "reaonsably good shape," engineers reported.

An inspection of the bridge showed that spalling occurred in an approximate 2-foot-square area that was about ½ to ¾ inch deep. In several areas, the concrete also turned pink, indicating it had been exposed to heat of at least 500 °F. Following pressure-washing to remove soot, a detailed inspection took place, including hammer tests at various locations.

Following the inspection, the bridge was simply reopened to traffic. "The prestressing steel did return to its full strength without causing any deformation in the bridge girders following the fire," Clemmons reports. Debonding of the strand possibly took place at the center of the strands in the component, he notes, but central debonding would not produce any significant concern if the ends remain intact. "There was localized damage, but it did not impact the bridge's operation."

Although the department considered cleaning and repairing the spalled areas immediately, the damage was determined to be so minor that the bridge was instead put onto the county's accelerated-inspection list. "We continue to watch it and will give it a full inspection this fall, but there have not been any problems developing or any changes to its condition," he says.

Connecticut Fire

Another approach to maintaining traffic on a precast concrete bridge was used by the Connecticut Department of Transportation last summer. On July 12, a tanker truck carrying 8,000 gallons of gasoline jack-knifed during an accident, spilling its contents over and under the 80-foot-long bridge over the

Temporary Girders Speed Access

Precast concrete components also can aid bridges after fire incidents in another way — by providing temporary construction that allows the span to remain open while work on the damaged structure progresses. An example of that technique was devised in the early 1990s in Connecticut, where the Department of Transportation designed a multi-span temporary bridge consisting of precast, prestressed adjacent box beams with precast parapets to facilitate a river crossing. The beams allowed for rapid construction, rapid removal and the potential for re-use at a later time.

The beams were placed in storage after they were removed following the construction of the permanent bridge. In 2005, the beams were taken out of storage and used on another project, which offered different complexities than the bridge for which the temporary girders had originally been produced.

"Using temporary precast adjacent box beams offers a number of advantages for bridge construction," says Michael P. Culmo of CME Associates Inc. in East Hartford, Conn., who worked on the project. The beams don't require a concrete deck, which eliminates the need for forming, casting and curing that material. Construction and removal of the bridge can be completed quickly, and the bridge components are durable and can be re-used for future temporary bridges, cutting costs.

In addition, the precast girders provide an unlimited width for a temporary bridge, unlike steel options that restrict width based on the size of the floorbeams required. "Precast adjacent box beams can be arranged to meet the requirements at each site," Culmo says.

The original temporary beams that were fabricated now are being used for a bridge carrying Route 151 over the Salmon River in East Haddam, Conn. The existing three-span steel through-girder structure had had a history of scour problems, but replacing it required a 17-mile detour. To avoid that, DOT officials decided to create a temporary bridge adjacent to the original while construction was underway and to use the existing precast concrete beams for the temporary design.

The span lengths coincided, but the East Haddam bridge featured a significant skew of 45 degrees, compared to no skew at the earlier project for which the temporary girders had been built. To re-use the beams, a system of external post-tensioning was developed to accommodate the different skew. This focused on creating a framing layout that featured a saw-tooth end pattern. The detailing of the abutment backwalls was modified to accept the saw-tooth beam configuration.

Using temporary precast adjacent box beams offers a number of advantages for bridge construction.

A temporary bridge in Connecticut made use of precast concrete adjacent box beams that had been stored for more than 10 years after earlier use for another temporary bridge.

Norwalk River near Ridgefield, Conn. The resulting fire exposed the precast concrete bridge to severe heat and fire damage.

The 50-year-old bridge, one of the first precast concrete bridges ever built in the United States, suffered significant amounts of spalled concrete on its beams, reports Arthur Gruhn, chief engineer. Reinforcing was exposed in a number of locations. "We really had no idea of how strong the bridge still was," he says. Despite its age, the bridge had been in good condition, and there had been no plans to replace it.

The design team moved into action quickly, setting up a detour and providing an initial inspection on the day of the accident. On day two, a contractor and remediation crew examined the bridge to determine its status. This required teams to wear Hazmat suits due to the gasoline that still surrounded the site. The team decided that the bridge was still structurally sound but needed some temporary intermediate support to ensure its stability.

Two heavy steel support beams were added, one under either edge for the length of the span, and three additional, shorter beams were inserted perpendicular to these at the one-quarter and one-half points. In addition, a Jersey barrier was placed along the damaged bridge railings to protect traffic.

"We really couldn't gauge how much damage the fire had done, but we could see the bridge still was in reasonably good shape," he says. "We were confident that if we shortened the spans of the precast concrete beams, enough strength remained to support the loads until a replacement could be built."

Installing the support beams took two more days, and the bridge reopened to traffic only four days after the fire occurred. A temporary bridge was created adjacent to the bridge, and once it opened, work on replacing the original bridge with another precast concrete version began. That work was completed in November, producing a brand new bridge to replace the fire damaged one in only four months.

"The real heroes of this project were all of the police, fire, bridge crews and local communities who helped return this bridge to service so quickly," says Gruhn. Although the bridge possibly could have been repaired for ongoing service, other considerations led to its ultimate replacement. More importantly, the bridge was reopened to traffic only four days after the accident, reducing traffic disruption and allowing an orderly development of evaluation and plans for replacement to take place. ■

For more information on this or other projects visit *www.pci.org/ascent.*

Opportunity Missed

Michael P. Culmo, CME Associates Inc., East Hartford, Conn., noted one recent application where the temporary precast beams could have been used in his area. A tanker truck caught fire on a new steel bridge on I-95. The heat caused the steel superstructure to sag 4 feet, rendering it unusable. A modular steel-truss bridge was created as a temporary replacement. "No one thought about the precast beams during the fast design time that was required," he says. Creating the temporary bridge took six days, with a limit of three lanes without shoulders due to the fixed floorbeam length.

After the work was completed and the precast beams were recognized as an unused alternative, Culmo estimates that time could have been saved with that option. The total time to demolish the bridge, cast abutment seats, erect the beams, post-tension the components and pave the roadway would have totaled only four days. That would have saved two days and allowed the bridge to be built with shoulders for emergency use.

"By using and stockpiling precast adjacent box beams, a state or county department of transportation can have access to a temporary bridge for future construction projects and emergencies," he says. "Using precast adjacent box beams for temporary bridges has several key advantages to other temporary bridge structures."

Of course, if the bridge is built of precast concrete components initially, there may be less need for temporary bridges to handle bridge emergencies that result from fires that become incredibly hot. Precast concrete can resist those intensities and may even be able to reopen immediately after an inspection of the structure.


Methanol Fire, Washington

Flame temperatures beneath the precast concrete bridge approached 3,000° F.

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Methanol Fire, Washington

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Temporary Bridge
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