



Structural Integrity: designing against failure

Kinzua's Weakest Link

Francesca Hunt, Narrator

The Allegheny National Forest in North Western Pennsylvania is the site of the Kinzua rail viaduct. First built out of wrought iron in 1882 it was at one time the highest bridge in the world. In 1900, it was rebuilt using steel and then remained open to rail traffic for over 100 years.....

Trestle 'space frame' bridges like this were exploited to open up the American West. They were fast to build, coming in kit form with a railroad deck supported by towers which were anchored firmly into the ground.

But on July the 21st 2003 catastrophe befell the viaduct. The centre of this huge metal structure collapsed when it was hit by a tornado – despite having been designed to resist high winds.

Thankfully nobody was hurt but, other than that saving grace, it was an engineer's worst nightmare come true. In fact, the forensic investigation to find out what went on here, has also been able to cast more light on the causes of another disaster over 120 years earlier:- the collapse of the central section of the Tay rail bridge in Scotland; with 75 people killed, the worst ever disaster to befall a trestle bridge. A failure in strong winds led to the disintegration of its metal towers but the manner of failure has been a matter of controversy We'll be returning to this later.....

The debris at Kinzua is destined to remain where it fell. But let's take a look at how it came to be built

The viaduct has been of huge importance to the area for many years. The Director of the vacation bureau in the Allegheny National Forest is Linda Devlin.

Linda Devlin

We promote travel and tourism into the Allegheny National Forest region, and we're located in north western Pennsylvania, and it's a very rural beautiful part of...of the State of Pennsylvania.

When the bridge was first constructed in 1882, it was done with the idea of commerce but it immediately became a tourist attraction so on the weekends, you would have excursions coming in from Buffalo and Pittsburgh because it gave the sensation of flying.

In 1900 the bridge was rebuilt to address the need to carry heavier loads and larger trains.

The Big Boy train, which was the largest locomotive ever utilised, was now going to be used on this particular viaduct, so the...the bridge structure was rebuilt out of steel.

It was done in less than 94 days with 125 men, and what they did was they actually started on both sides replacing the previous wrought iron with steel structures, working towards the middle. And a major decision that was made at that time was not to replace the anchor bolts that anchored into the cement structures on the bottom.

Francesca Hunt, Narrator

In the new trestle bridge they not only changed the materials from wrought iron to steel, they also changed the original diagonal bracing by replacing it with a much stronger and stiffer form, incorporating multiple elements as additional trussing. But no matter what the structure, the state of any bridge needs to be checked continuously.

Eugene Comoss

My name's Eugene Comoss; I'm the Chief Engineer for the Pennsylvania Department of Conservation and Natural Resources

My staff of engineers had a general concern about the condition of the bridge. For a long time, we felt a full inspection was needed to determine its structural stability.

Francesca Hunt, Narrator

The need to inspect the many hundreds of old metal trestle bridges in the USA is a major problem. Another spectacular example is to be found here in SW Pennsylvania at Mingo creek. The trestle bridge here, like all trestle bridges, needs inspection and maintenance. What's involved in inspecting bridges of this sort? Tom Leech is a bridge engineer.

Tom Leech

One important thing that an engineer does is inspect the bridges on a periodic basis. Here are some of the things we would look at. We look critically at the girders, especially for corrosion, where the girders connect to the towers, that connection, that critical base, that bearing. Corrosion is something's very important. As we look to the tower bases, we look at all the joints, we examine every single joint. The most critical joints are those joints which are at the base of the towers.

In 2000, the Kinzua Viaduct was inspected. What inspectors found then was many instances of large corrosion holes in the structure, other deterioration at the joints and they closed the structure for public safety.

Eugene Comoss

It became obvious that a lot of the corrosion damage was due to our inability to keep water and dampness out the structure. For example, in each tower leg, there was a stiffener plate placed at each connection point, and the original designer had the foresight to put drain holes, but obviously, early on, the small drain holes clogged, and once they clogged, these, uh, stiffener plates became places for moisture to collect, and it was at these stiffener plates where the most severe corrosion damage occurred.

Francesca Hunt, Narrator

The WM Brode Company specialises in bridge construction, Steve Brode is vice president.

Steve Brode

We were the contractor hired to do the emergency steel repairs to the Kinzua Viaduct. Our contract for the refurbishment of the bridge was focused, when we started, mainly on the steel repairs in the towers where they had severe deterioration. In particular, at the different joints where everything framed together, there was a lot of deterioration because of some horizontal angles that held the water, and our go...our role was to develop shop drawings, uh, and create replacement pieces in actually strengthening plates at those locations. Some locations required us to replace pieces in kind. There were some moon-shaped gussets that we had fabricated locally to replace in kind, but most of it, again, was in the towers themselves, nothing really with the girders.

Eugene Comoss

When the structure was designed to withstand the prevailing winds, the design provided for the towers on the west side of the structure to be fixed with anchor bolts into the pedestal bases. On the, uh, east side, uh, the towers were fitted with roller bearings to allow for some movement either from wind load or thermal expansion.

Voice over - Francesca (as US weather girl)

An intensive system of severe weather is moving into Pennsylvania from Ohio. There are reports that this system is packing tornados... among winds of well over 50 miles per hour, the system is tracking North by North West...

Eugene Comoss

When the tornado struck the bridge repairs were approximately 50% complete. As a result of the tornado striking the bridge, uh, the Department convened a board of inquiry to investigate the cause of the failure.

Tom Leech

I led the board of inquiry investigation. Our first task was to assemble a professional team. Our task consisted of forensic engineers from my firm, Gannett Fleming. We also engaged the Meteorological Department of Pennsylvania State University and the fracture, uh, engineers of Atlas Lehigh University.

In the course of the investigation, we looked for forensic markers. What we disclosed at the site was four specific forensic markers. The four markers we found were order markers. Order markers are looking for clues of what member is on top of what member. We looked for directional markers; directional markers such as the orientation of the trees that collapsed, the direction of the debris field. We noticed separation markers, clean separation of the superstructure from the substructure. And finally we looked for fracture markers; tell tale signs of cracking in members that may have precipitated the collapse.

Francesca Hunt, Narrator

Finding forensic markers like these are a routine way of investigating large structural failures. There was, however, another piece of evidence that was nearly missed.

Tom Leech

One important part of our investigation was making good use of the high resolution aerial photography. As we were trying to determine precisely the sequence of collapse, I was viewing on my computer screen the high resolution photography and I noticed, quite suddenly, large skid marks. These are the marks where the towers actually had gone airborne, slid down the hill and made large depressions in the ground. These depressions were unnoticed by any of us who had wandered all over the site during our day of our board of enquiry investigation. These were crucial in determining the precise sequence of collapse.

Francesca Hunt, Narrator

The testimony of workers at the bridge site was important in determining the sequence of events as the tornado struck. As they were retreating at the time the tornado hit they could only report on what they heard.

Steve Brode

Some employees had no idea anything had happened. This gentleman here only talks about raining and thunder and lightning, uh, but Mr Quillin's report, in particular, has some more information. Uh, he says he had sent the crew home because of weather and he was leaving the site when the winds picked up and he had a crew member with him and they were leaving the site "when I heard four to five loud booms. I wasn't sure what the booming was" uh, but at that time he went and determined that part of the bridge had actually fallen down.