

America's Deadliest Bridge Failure - The Silver Bridge

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The Point Pleasant Bridge was a 1,460-foot suspension type bridge that spanned the Ohio River to connect highway 35 between Point Pleasant, West Virginia and Gallipolis, Ohio. The bridge had a 700-foot main span and two 380-foot side spans with a 22-foot two-lane roadway and a 5-foot pedestrian walkway. The bridge was unique in many respects and incorporated many first-time applications in the United States. Among these unique applications was the use of aluminum paint to protect the bridge and gave it its silver color causing it to become commonly referred to as the Silver Bridge.

Below, Figure 1: Photograph of the newly completed Point Pleasant Bridge as seen from the Ohio side looking south-east. Storm clouds foretold the heavy rains that would fall later that day, May 30, 1928, during its opening celebrations.



Ten minutes before sunset at 4:58 on December 15, 1967, the entire suspended portion of the Silver Bridge along with its two 130-foot towers collapsed and fell into the Ohio River in less than 20 seconds. At the time of the collapse, the bridge was crowded with 37 westbound vehicles heading toward Ohio. Most of these vehicles were stopped on the bridge waiting for a signal light to change. The vehicles on the bridge included two heavily loaded gravel trucks and several tractor-trailers. On average, trucks made up about 20% of the traffic on the bridge. 31 of the 37 vehicles on the bridge fell with it, 24 fell into the Ohio River and 7 fell onto the Ohio shore, there were no pedestrians on the bridge at the time of the collapse. The 6 vehicles that did not fall were on the West Virginia side approach and were stopped behind the car of Charlene Wood, who, upon entering the suspended WV side span would not proceed any further due to the shaking of

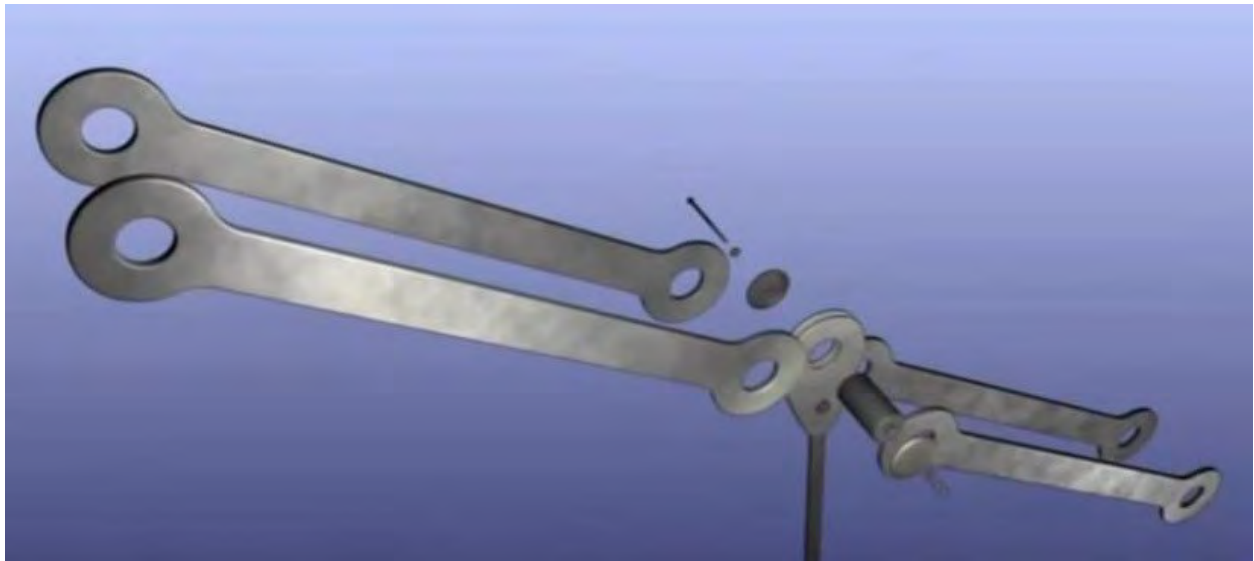
the bridge. Ms. Wood put her car into reverse and tried backing off the bridge when the increasingly violent shaking caused the car's engine to stall; her car continued to roll backward as she witnessed the progressive west to east collapse of the bridge. Most of her car had reached the relative safety of the approach when the bridge deck fell from beneath her front wheels leaving these wheels hanging from the precipice. Ms. Wood's caution and actions prevented other vehicles behind hers from entering the side span and likely saved several lives in addition to her own. In all, 64 people fell with the bridge, of these, 46 were killed and 9 seriously injured. The vast majority of the fatalities were from drowning with the remainder from trauma and hypothermia. Only five survivors were pulled from the 42-degree water of the Ohio River. First responders and volunteers reached the disaster site quickly, but conditions were difficult. It was dark and cold, just 21 degrees F. Nevertheless people tried to help survivors trapped in cars and trucks, many upside down or on their sides. Many victims never made it out of their vehicles and some of those that did escape were injured and drowned before help could reach them. In terms of lives lost, this incident remains the deadliest roadway bridge failure in United States history.

The origin of the Silver Bridge can be traced to a physician named Charles Holzer who had practiced medicine in the region since 1909. Without a bridge across the river, getting to patients was difficult and some patients died waiting for help simply because the doctor could not reach them in time. After a particularly dangerous winter crossing, Dr. Holzer decided that action needed to be taken. In the 1920's Holzer organized community groups to spearhead a plan to build the bridge. Those community groups eventually merged into the West Virginia Ohio River Bridge Company with Holzer remaining in control. The company intended to recover the cost associated with the construction and on-going repairs of the bridge by operating it as a tollway which it did until selling it to the state of West Virginia in 1941 for 1.04 million dollars. The bridge became toll-free in 1951. The design concept chosen for the bridge was prepared by the Baltimore MD firm of J.E. Greiner Company who were then retained by Holzer to design the bridge. The Greiner design called for an elegant suspension bridge that used a familiar combination of steel wire cables, a distinct stiffening truss system and towers that were rigidly fixed to their supporting piers. Holzer's company had secured \$950,000 in backing for the project and received three bids for the construction of the bridge that were to be based on Greiner's design. The lowest bid for the construction of the bridge was \$892,000 and came from the U.S. Steel subsidiary – American Bridge Company and this bid was accepted by Holzer.

Included in their winning bid, American Bridge had proposed some changes to Greiner's design which would make the bridge novel and less expensive to build. Rather than suspension cables, it would use "chains" of eye-bars (Figure 2 below). The eye-bar pairs would form a link and there would be 76 of these links on the bridge. The links varied in length from 55 to 44 feet depending on their location and the eye-bars that formed the links would be 1 foot wide and 2 inches thick across the beam section. The eye-bars would be linked together bicycle chain style with 11-inch diameter steel pins passing through 27-inch diameter eyelets at the eye-bar ends to form the main part of the suspension system. From these link pin joints, high strength steel hanger bars would support the bridge deck through its truss work. In addition to the eye-bar chain suspension system, the American Bridge proposal included other novel features that also had not been applied in any bridge in the U.S. before. Because the eye-bar links would join with

a link pin at the top of each tower, the towers could not be firmly affixed to their concrete piers but instead needed to rock or tip on hinged joints at their base to allow for changes in chain length due to varying bridge loads and temperature. Another very notable deviation from convention was the plan by American Bridge that the suspension chains in some places also doubled as the top chord of the trusses that stiffened the roadway deck. Ordinarily, these top chords would be in tension, however, the use of a chain as the top truss chord when combined with the pivoting bridge towers meant that these members could never act in compression and continue to temporarily support the bridge deck in the event of other bridge system failures. Neither of these concepts had been applied in U.S. bridge construction at that time.

Below, Figure 2: Typical eye-bar assembly used on the Silver Bridge suspension chain.



The unique construction approach proposed for the Point Pleasant span would be very similar to a slightly longer bridge that the company had built in Brazil in 1924 which remained in service until decommissioned in 1991. While the bridge built in Brazil also used long links of eye-bar chains for suspension which doubled as the top chords of stiffening trusses and employed rocker type tower mounts, the bridges would differ in two subtle but very significant ways. The truss work, towers and eye-bars of the Brazil Bridge were all made from grade A7-24 common structural steel in a fully annealed and stress relieved condition. This steel had an ultimate tensile strength of 55,000 psi, tensile yield strength of 30,000 psi with an elongation before fracture of 18%. Pairs of eye-bar chain links made from A7-24 did not possess the strength needed to support the 4 ½ million-pound bridge and its 750,000-pound design live load. Because the A7-24 steel was the best material available for the eye-bars in 1924, the Brazil Bridge was built with four eye-bars per link in order to maintain a safe design tensile stress of

about 21,000 psi through the eye-bars 2" x 12" beam section. By 1926, the parent company of American Bridge, the U.S. Steel Corporation, had developed a new high carbon steel that could be heat treated to an ultimate tensile strength of 105,000 psi and a tensile yield of 75,000 psi. In this condition, this steel had an elongation before fracture of only 5%. At the time of development, the composition and heat treatment of this new steel were considered trade secrets however it is nearly identical to what is referred to today as AISI alloy 1060 steel. The much higher strength of this new alloy when heat treated allowed American Bridge to propose using only two eye-bars per link when the eye-bar chains were made from it. The use of only two eye-bars per suspension chain link eliminated any redundancy in the structure at this point since the failure of a single eye-bar would cause the entire bridge to collapse. Suspension bridges using traditional multi-strand cables such as the Brooklyn Bridge have a natural redundancy due to the nature of failure mode of these cables with the most highly stressed wires failing first. The well-known Tacoma Narrows Bridge was suspended by cables made up of 4,200 individual wires per cable. This bridge was entirely destroyed in 1940 when its deck entered violent wind-induced oscillations however its cables did not fail despite the fracture of approximately 500 of the 4,200 wires per cable. The use of only two eye-bars per link also made removal of individual eye-bars for inspection impossible since the removal of a single eye-bar would break the chain. Some who reviewed the proposed design found these deficiencies unsettling and pointed out that variations in temperature or eyelet pin hole center distance due to machining tolerance could easily cause one of the two eye-bars in any one link to carry more load than the other. American Bridge Engineers were highly confident in their safety factor and convinced anyone with concerns that they were unwarranted.

American Bridge had used a design load tensile stress of 44,000 psi through the eye-bar beam section which would have provided a theoretical safety factor of 75/44 or 1.7 for these components when using the heat treated 1060 steel. Based purely on cross-sectional areas, the beam section of the eye-bars were considered to be the point of failure should a failure occur. Residual stresses in steel caused by the quenching operation of heat treatment were not fully understood in 1927. The eye-bars used in the Point Pleasant Bridge were heat treated by heating the eye-bars to their austenitizing temperature of 1,600 degrees F and rapidly cooling (quenching) in water. They were then tempered by reheating to 1,175 degrees F and allowed to air cool slowly. This procedure resulted in a non-homogenous micro-structure. The heat-treating procedure caused the resulting material to be characterized as a "slack quenched" steel in which the desired martensite state with its fixed carbon distribution was formed only in a layer .25" to .40" from the eye-bar surfaces and a ferrite-pearlite structure was formed in the interior of the bars. Hardness testing of recovered eye-bars confirmed this with exterior hardness values of 32 – 34 Rc and a material hardness gradually reducing to about 21 Rc near the center. This condition resulted in residual compressive stresses in the outer "shell" of the eye-bars and residual tensile stresses of up to 20,000 psi in the interior of the bars. These effects were most pronounced at the eyelet ends of the bars perhaps due to the greater cross section of the eye-bars in these areas at the time of heat treatment. The eye-bars were made by hot rolling the 1060 steel to the 2-inch thickness and 12-inch width. The eyelet end areas were left thicker during rolling to provide the additional material needed to open die forge the ends of the eye-bars to their finished diameter of

27 inches while maintaining a 2-inch finished thickness. The multi-sized, slightly figure “8” shaped holes for the 1 1/2-inch link pins would be cut after heat treating.

American Bridge had built another suspension bridge with two eye-bar suspension chains 75 miles upstream from the Point Pleasant Bridge which also spanned the Ohio River between St. Mary’s, West Virginia and Newport, Ohio. Known as the Original Hi Carpenter or St. Mary’s Bridge, it was completed soon after the Point Pleasant Silver Bridge, both bridges used identical construction and materials. Because the two bridges were identical, the bridge at St. Mary’s was closed three days after the Silver Bridge collapsed as a precautionary measure and ferry service was quickly established at both locations. In the early 1920’s, Allegheny County in Pennsylvania had secured bond funding for three badly needed bridges to span the Allegheny River at 6th, 7th and 9th streets in the city of Pittsburg. These nearly identical bridges are collectively known as the 3 Sisters Bridges and were designed by Engineers: T.J. Wilkerson, Vernon Covell and A. D. Nutter. The American Bridge Company was chosen to build these three bridges and the U.S. Steel Corporation supplied the steel for them however neither had any involvement in their design or in the materials specified in their construction. The 3 Sisters Bridges were completed in late 1928 and are still in use today. The Pittsburg Bridges are also eye-bar chain type suspension bridges however the eye-bars that make up their chains are made from the weaker A7-24 structural steel and eight eye-bars are used per link versus two for the Point Pleasant Bridge (Figure 3).

Below, Figure 3: View of eye-bar chain link construction used on the 3 Sisters Bridges in Pittsburg. Note the 8 eye-bars used per link and the twin hangers at each link pin.



The construction used in the Pittsburg bridges shown in Figure 3 allows for removal of individual eye-bars for inspection of the eyelet ends using liquid dye or UT which was not possible on the Silver Bridge.

The Investigation into Cause of Silver Bridge Collapse

The sudden, complete and seemingly inexplicable collapse of the Silver Bridge at Point Pleasant WV stunned a nation with over 563,000 bridges in daily service and immediately initiated the largest structural failure investigation in history. The investigation of the collapse would involve both Federal and State agencies as well as many private laboratories and Corporations and would not reach its final conclusions for nearly 2 ½ years when the NTSB would publish its final report and recommendations. Soon after the disaster, many citizens and some members of the press had concluded that the bridge fell because of higher vehicle weight common in 1967 as compared with the vehicle weights typical of 1927 when the bridge was designed and had coined the phrase “model T bridges” when referring to these older structures. Indeed the typical car of 1927 weighed about 1,500 pounds and trucks weighed no more than 20,000 pounds, by 1967 the average car weighed around 4,000 pounds and trucks routinely weighed up to 60,000 pounds. What this early conclusion considered was that the vast majority of the weight being placed on the bridge itself and that the increase in vehicle weights and increased vehicle weights and truck traffic had exceeded the design live load capacity of the bridge. Only about 41% of its design capacity was being used. Consulting Engineers and Scientists knew that the bridge was determined in order to prevent similar failures. It was known that the bridge vibrated at frequencies that were dependent on speed, weight and speed. The collapse was stopped due to the fact that the wind loading at the time of the collapse was 6 MPH and the bridge piers were supported by concrete piers. The piers were supported by concrete piers set on piles. The piers were inspected and found to be in good condition. Collisions by river boats were carried debris. The piers were inspected and found to be in good condition. Measurements were taken on the original drawings and found to be in good condition. Measurements on the shifting of the piers indicated that no

Investigators had concluded that the collapse was due to the fact that when combined with the account of the collapse, the entire collapse from the fact that her car on the W... regarding the origin of the failure.

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