Introducing precast concrete bridges to the United States

Andrew Osborn and Helmuth Wilden

In this column, our focus over the past year has been to show the influence and benefits of past PCI-funded research and development projects on current design and construction practices with precast concrete. In this issue on innovation, we chose to deviate from what we've done and describe the first prestressed concrete bridge built in the United States, the Walnut Lane Memorial Bridge in Philadelphia, Pa., which was completed in 1950. As part of the original design and construction, a full-scale girder was tested to destruction to demonstrate the adequacy of design of this previously unknown (to U.S. engineers) structural system: prestressed concrete. PCI had no role in funding this test since PCI did not exist until 1954, four years after the bridge was built.

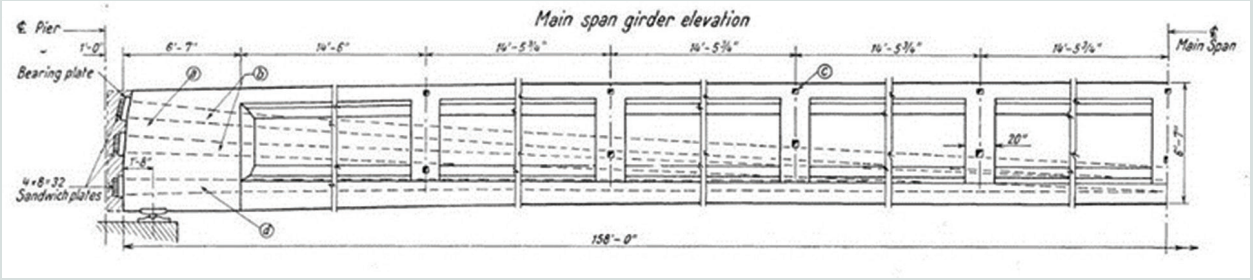
The use of prestressed concrete for this purpose in the United States was truly innovative. A confluence of events was necessary to bring it about.[1–7] Although the bridge was actually a post-tensioned structure, each girder was cast at a set location on falsework, tendons were stressed, and ducts were grouted, and then the girder was slid on rails to its final position making it somewhat like what we call precast, prestressed today.

The city of Philadelphia wanted to have a bridge built to carry traffic on West Walnut Lane over Lincoln Drive in Fairmont Park. A reinforced concrete arch bridge was designed and approved in 1931 and again in 1947. In both cases, the bids came in above the engineer's estimate, requiring that the design be revised. The city wanted a less expensive but aesthetically acceptable alternative.

Between 1947 and 1948, city engineers were meeting with Preload Enterprises Inc. on an unrelated project. Preload had developed a specialty: designing and installing prestressed concrete circular tanks. Preload had never done a linear prestressed concrete structure before, but one of its engineers, Charles Zollman had been a student and advocate of Gustave Magnel, a professor at the University of Ghent in Belgium. Magnel had visited the United States in 1946 and at a series of lectures extolled the virtues of prestressed concrete. Preload contacted Magnel, who jumped at the chance to introduce the United States to this amazing new structural system.

Walnut Lane Memorial Bridge spanning Lincoln Drive and Monoshone Creek in Philadelphia, Pa. Source: Wikipedia.

Magnel had written the first textbook on the design of prestressed concrete structures, *Le Béton Précontraint*,[8] in 1948. Zollman helped translate it from French into English and the first English translation, *Prestressed Concrete*,[9] was published the same year. With help from Preload, Magnel went on to design the Walnut Lane Memorial Bridge and Preload provided a bid that was substantially lower than the engineer's estimate. The bridge was aesthetically acceptable to the art jury, which had to approve any structures to be built in the park. Magnel convinced the Philadelphia Bureau of Engineering (BOE) to approve the design. The BOE, in turn, required that a full-scale prototype be built and tested to failure and that all of Mangels' instructions be followed to the letter during construction. Construction drawings were developed by a young engineer at Preload, Ted Gutt.

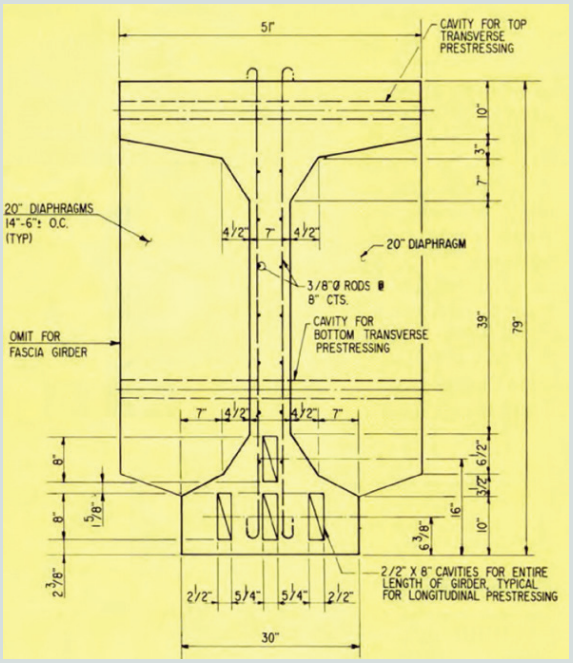


Half girder in elevation. Source: Fornerod (1950).

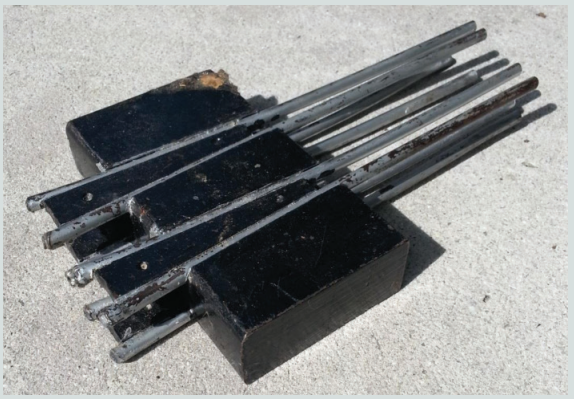
The Walnut Lane Memorial Bridge comprised three spans: 74, 160, and 74 ft (22.6, 48.8, and 22.6 m). The 160 ft center span (center-to-center of piers) is long even by today's standards. The center span comprised 13 girders that were each 79 in. (2007 mm) deep by 51 in. (1295 mm) wide. The top flanges were separated by 1 in. (25 mm). A cast-in-place deck was placed on top. Each girder was post-tensioned with 256 wires distributed equally among four ducts. Each wire was 0.276 in. (7 mm) diameter and was manufactured by Roebling Iron Works. The wires had a designated yield strength of 160 ksi (1100 MPa) and a designated ultimate strength of 210 ksi (1500 MPa). The actual measured yield and ultimate strengths were 210 and 245 ksi (1690MPa), respectively. Two of the ducts were draped and two were straight. Final prestress losses of 13% were expected. The wires were each tensioned to 126 ksi (869 MPa), which declined to 110 ksi (760 MPa) after release, indicating prestress losses at time of test already reached 13%. Hence the total prestressed force was 1680 kip (7473 kN) after initial losses. The prestress centroid was 43.9 in. (31,800 mm) from the top at the ends and 63.2 in. (40,775 mm) from the top at midspan. Prestressing utilized a "sandwich plate" anchorage that had been developed in Belgium by Magnel-Blaton.

A prototype beam was built. The protype beam was full scale with a center-to-center bearing span of 156.3 ft (47.6 m). During tensioning, the center span cambered up 1.24 in. (31.5 mm). Besides the self-weight of 1780 lb/ft (7917 N/ft), it was loaded using hydraulic rams reacting via tie rods against a counterweight. During the test, the counterweight was exceeded and additional weight had to be added at the center of the span to fail the beam. At failure, the total load on the beam (including self-weight) was equivalent to almost 7000 lb/ft (102 kN/m), creating a center span moment of more than 20,000 kip-ft (27,115 kN-m) and a deflection of about 26 in. (660 mm).

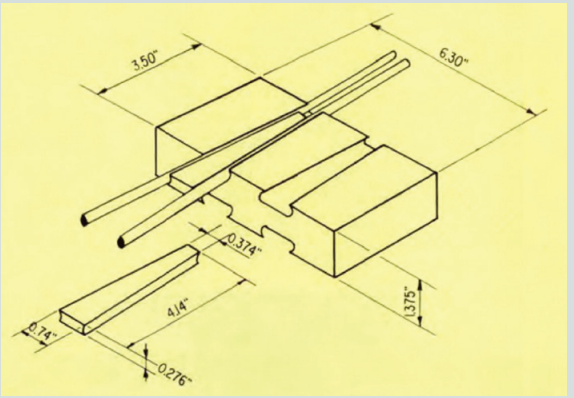
The test girder was instrumented by Arthur Anderson. Perhaps the most complete description of the test found by the authors was in an International Association for Bridge and Structural Engineering paper authored by Preload's chief engineer, M. Fornerod,[4] in 1950. However, the deflections reported by Fornerod do not match those reported by Anderson[7] or Magnel.[5,]



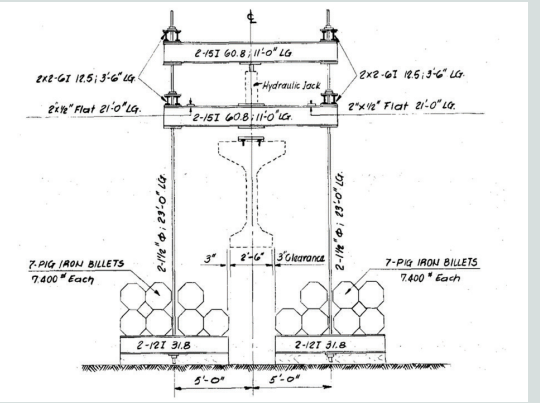
Typical main span interior girder in section midspan. Source: Zollman (1992).



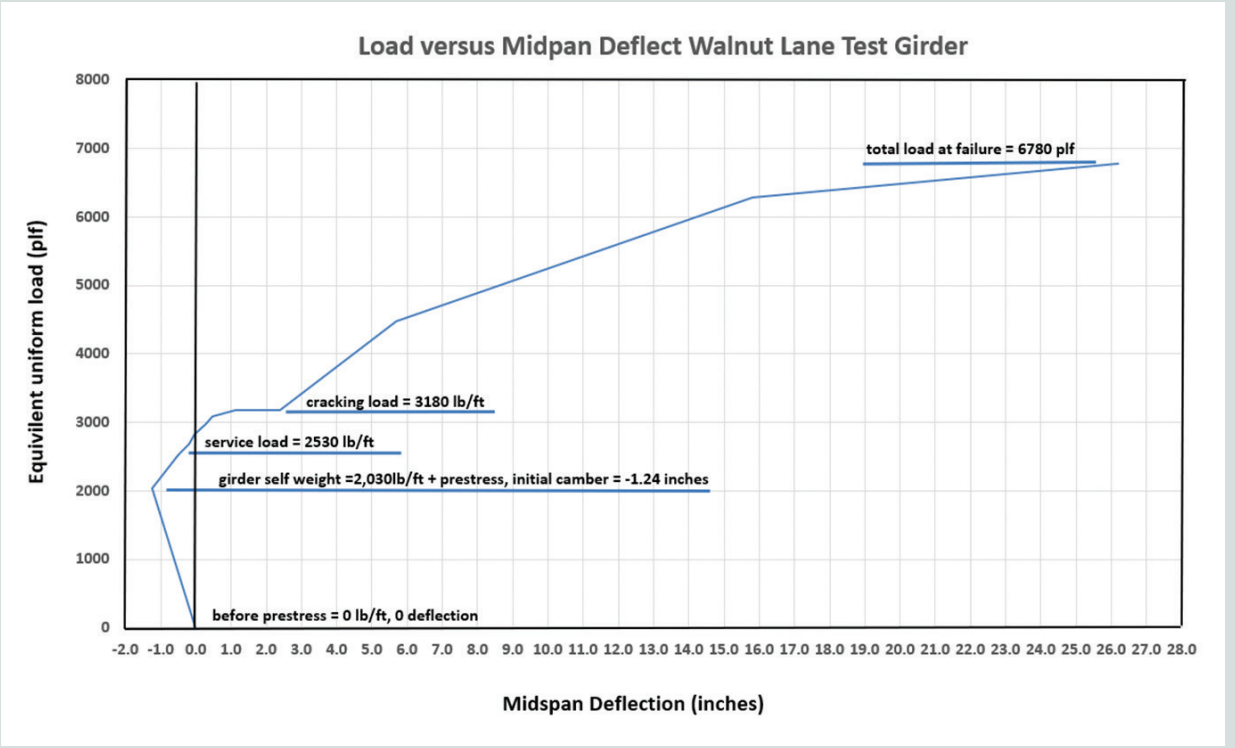
Eight-wire sandwich plate anchorage retrieved after demolition. Courtesy of Helmuth Wilden.



Schematic of eight-wire sandwich plate. Source: Zollman (1992).



Load test setup. Source: Fornerod (1950).



Load deflection relationship final load cycle. Source: Magnel (1950).

Longitudinal cracks started to appear at fascia girders in 1957. When examined in the 1960s, it was found that the ducts had been incompletely grouted and had taken on water. The entrapped water froze, expanded, and cracked the concrete surrounding the duct. Epoxy injection repairs were performed in 1969. In the ensuing years, new cracks and other apparent signs of deterioration were observed. PennDOT made the decision to demolish this historic bridge and replace it with a new one made from precast, prestressed concrete girders of similar dimensions to the original. The work was done in 1990. Zollman was still involved, nearly 40 years after his work on the original bridge. During demolition it was found that the concrete and prestressing wires in interior girders were in excellent condition. The only concrete and steel needing remediation was observed at the south fascia girder and, to a lesser extent, the north fascia girder.

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