A New SKEW.

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Abstract: Focuses on the Old Plank Road Trail bridge designed by Teng & Associates Inc. in Chicago under the direction of the Illinois Department of transportation. Description of the bridge's structure; Difference of the bridge from other conventional cable-stayed bridges; Analysis of the bridge structure; Estimate on the cost of building the bridge.

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A NEW SKEW

A new cable-stayed bridge concept for skewed crossings produces a striking appearance as well as economic and safety advantages.

The geometry of bridge crossings nowadays is dictated far more by functional considerations and traffic safety than by structural efficiency. The result is an increasing resort to skewed crossings.

But despite their wider use, skewed bridge designs typically are little more than concepts developed for square crossings that have been stretched and bent to fit the skewed condition. The span is increased to account for the greater length of the skewed crossing, and the abutments and piers may be turned to be parallel to clearance lines. But these attempts to adapt conventional bridge designs to skewed crossings produce inefficient and expensive structures that are often unsightly as well.

However a new bridge in Frankfort, Illinois, demonstrates a concept developed specifically for skewed crossings. It is a cable-stayed bridge in which a diagonally oriented support tower straddles both the suspended deck and the spanned element below (see figure 1). This particular structure carries a walkway and bicycle path over a highway, but the concept is applicable to a wide range of skewed bridges for walkways and highways over land or water. It could also be adapted to square crossings, although with some loss of efficiency.

This crossing in Illinois, the Old Plank Road Trail (OPRT) bridge, carries a bicycle path and pedestrian walkway over U.S. Route 45, a four-lane divided highway. The bridge was designed by Teng & Associates, Inc., of Chicago, under the direction of the Illinois Department of Transportation and was completed in 1999.

The defining structural feature of the OPRT bridge is an A-frame pylon whose legs straddle the highway at right angles. Thus, the main load-carrying component, the pylon, spans the shortest distance across the highway. The skewed deck structure is suspended from the pylon by cables. There are no piers; from abutment to abutment the deck superstructure is supported only by the cables extending from the top of the pylon.

The abutments are set well back from the edges of the highway, yielding a total bridge length of 180 ft (55 m) measured along the skewed deck. Four hanger cables from the top of the pylon, two on each side of the deck, divide the skewed superstructure into three 60 ft (18 m) segments.

The fundamental difference between the OPRT bridge concept and conventional cable-stayed bridges is that in the OPRT design the pylon straddles the clear span. In conventional cable-stayed bridges, the pylon is at the edge of the clear span. The top of the pylon in the OPRT design is braced in the out-of-plane direction by the cables to the deck structure. This is made possible by the large angle between the plane of the pylon and the deck structure, that is, the skew. If the deck were essentially perpendicular to the clear span and parallel to the pylon, the cables would be close to the plane of the pylon and would not be able to brace it in the out-of-plane direction. Thus, the overall structural concept is one in which the pylon supports the deck vertically while the deck supports the pylon laterally, so the pylon legs do not have to be restrained against rotation at the base.

As shown in figure 1, the pylon is 82 ft (25 m) high and its legs are 114 ft (35 m) apart at the base. The highway below is 73 ft (22 m) wide overall, including four traffic lanes, shoulders, and a median. The suspended structure is 180 ft (55 m) long, at a skew of 43 degrees.

The suspended structure is framed in steel (see figure 2). The main longitudinal girders are W27 rolled beams 12 ft (4 m) apart. W14 floor beams at 12 ft (4 m) centers span between the longitudinal girders and support a cast-in-place deck of reinforced concrete. The girders and floor beams are of grade 50 steel. Shear studs at the top flanges of the floor beams and at the upper part of the girder webs connect the steel framing to the concrete. The railings are of custom design; their height of 4 ft (1.2 m) is dictated by the standards for bicycle paths. The overall depth of the suspended structure, excluding the railings, is 27 in. (305 mm).

The suspended deck structure is supported by four hangers, each a 1 1/2 in. (38 mm) diameter bridge strand with galvanized wires. Standard open-strand sockets are used at both ends of all the hangers.

The pylon legs are steel pipe sections 30 in. (762 mm) in outside diameter with a wall thickness of 5/8 in. (16 mm). The material is of 36 ksi (250,000 kPa) yield stress. The bottom 12 ft (4 m) of each leg is filled with concrete to improve resistance to traffic impact. The legs are also protected from traffic by guardrails. The pylon is supported at the base of each leg by battered and vertical piles. A jointless integral abutment design, with vertical piles at each abutment, is used for the deck structure. Internally reinforced earth walls are used for the abutments and wing walls.

Current specifications of the American Association of State Highway and Transportation Officials (AASHTO), including the Guide Specifications for Design of Pedestrian Bridges, were used in designing the bridge. The design live load was a distributed pedestrian load of 65 to 85 psf (3,112to 4,070 Pa), depending on influence area, or a single truck as specified in AASHTO guidelines. The pedestrian load governed the design of all the main members.

The designers of the OPRT bridge decided not to use plastic encasement or other extraordinary measures to protect the hangers from corrosion. Instead, they made the hangers easy to inspect and replace. To this end, the suspended structure was designed to permit removal of one or all of the hangers with a single temporary support in the middle, in the median of U.S. Route 45. This design feature, which required little additional strength in the structure, was also useful during erection of the bridge.

The bridge structure was analyzed in two ways, as a two-dimensional structure and as a three-dimensional structure. In the two-dimensional analysis, the pylon was represented by a single vertical member of the same effective vertical and flexural stiffness as the A-frame. Because the actual support condition at the base of the pylon legs is expected to lie somewhere between pinned and perfectly fixed, the analysis was run with a pin support at the base of the pylon as well as with a fixed support.

In the three-dimensional analysis, the pylon legs, the longitudinal girders, the floor beams, the hangers, and the piles at the abutments were represented by linear beam elements (see figure 3). The concrete deck slab was represented by planar finite elements; each 12 by 12 ft (4 by 4 m) slab panel bounded by girders and floor beams was represented by four elements. This analysis, like the two-dimensional analysis, was run with pin supports at the base of the pylon legs as well as with fixed supports.

The members were sized initially on the basis of the simple two-dimensional analysis. The much more sophisticated three-dimensional analysis did not require a change in the size of any member. Lateral load effects could not, of course, be studied using the two-dimensional model, but these effects did not determine the size of any member.

There was also very little difference between the fixed-pylon-base analysis and the pinned-pylon-base analysis; the two yielded very similar results. For each pylon leg, the 30 in. (762 mm) diameter pipe is welded to a steel base plate that is fastened with anchor bolts to the concrete pile cap. Since this is neither a pin nor a perfectly rigid support, the envelope of the two sets of results was used to determine the design. That is, the design used whichever assumption led to the more severe stress or deflection or other design parameter. Member sizes would not have been affected by the choice of either base condition over the other.

According to the Guide Specifications for Design of Pedestrian Bridges, deflections caused by the pedestrian live load must be limited to 1/500 of the span length. The maximum live-load deflection of the OPRT bridge was found to be 2.3 in. (58 mm). This amounts to 1/940 of the full span or 1/530 of that part of the span that deflects downward under the critical loading.

The AASHTO specifications suggest two ways of obtaining acceptable dynamic performance from pedestrian bridges: keeping the fundamental frequency above 3.0 Hz to avoid resonance with pedestrian activities or providing enough weight to limit accelerations. The fundamental frequency of the OPRT bridge was calculated to be 1.0 Hz. Formulas in the guide specifications indicate that for this frequency the weight of the bridge should be at least 127 kips (565 kN). The actual weight is 340 kips (1,512kN), almost three times the required minimum.

The construction sequence specified in the contract documents began with erecting the deck framing, the girders, and the floor beams, with a temporary support in the median of U.S. 45. Then the pylon was erected and restrained laterally at the top by guy cables. The hanger cables were installed before the temporary support was removed from under the framing and before the cables were removed from the pylon. Next the concrete deck was poured. The railings were then installed, and the rest of the construction was completed. The bridge was constructed in the summer and fall of 1999.

It is difficult to estimate the true cost of the OPRT bridge, as it was part of a larger improvement project for U.S. Route 45. The total construction cost--about $10 million--included removing an abandoned railway bridge, widening and raising U.S. Route 45, and constructing more than 1,000 ft

(305 m) of large concrete box culverts. Four bids for the bridge were received, with a spread of less than 10 percent. Isolating the appropriate items from the bid tabulations indicates a total bridge price of $421,772 to $857,213, including foundations and integral abutments but excluding approaches and retaining walls. The quoted price for the steel superstructure, the A-frame pylon, and the hangers ranged from $178,845 to $595,000. The extremely widespread in bridge prices, in contrast to the fairly narrow range of bids for the entire highway project, suggests an artificial breakdown of prices by the bidders. The quoted figures for the bridge must therefore be regarded as unreliable.

Estimates prepared during the design phase of the project indicated that a conventional crossing with a pier in the median of U.S. 45 would have cost about the same as the design that was adopted. Thus the bridge's striking appearance and the safety benefits conferred by eliminating the center pier were achieved at little or no extra cost.

The concepts developed for the OPRT bridge are applicable to a wide range of crossings. For example, the same design was proposed for a bus route that was under consideration between Chicago's central business district and the McCormick Place convention center area. The project required a horizontally curved roadway bridge 42 ft (13 m) wide that would cross railway tracks at a very sharp skew. A simplified plan of the proposed crossing is presented in figure 4. The span over the tracks, between pier centers, is 240 ft (73 m). The approach spans are 80 ft (24 m) long. A pylon oriented directly across the tracks, and thus spanning the shortest distance across, supports the bridge superstructure at points one-third and two thirds of the way along the main span by means of four hangers, two on each side of the deck.

Two alternative pylon designs, an A-frame and an arch, were considered. The A-frame clearly would have been more economical, but the arch shape had aesthetic appeal. The crossties near the top of the arch were needed to reduce outward bending of the arch from the concentrated loading at the center.

The hanger supports at the points one-third and two-thirds of the way along the main span reduce the effective span of the superstructure in the main suspended span to 80 ft (24 m), which is the same as the span length in the approaches. With this arrangement the same basic superstructure design can be used throughout the length of the bridge. A steel-framed superstructure with horizontally curved rolled beam stringers and a cast-in-place concrete deck was considered. For reasons of urban planning, however, the original bridge proposal was subsequently abandoned in favor of a tunnel under the tracks.

As demonstrated on the OPRT bridge, the diagonal-pylon concept is applicable to a wide range of skewed crossings over land or water. Although the full benefits from greater efficiency and lower cost are realized in bridges that are skewed, the concept may prove to be a viable alternative to conventional designs even for certain nonskewed crossings.

Project Credits

Bridge design: Teng & Associates, Inc., Chicago

Bridge subcontractor: Herlihy Mid-Continent Company, Romeoville, Illinois U.S. Route 45 construction project: K-Five Construction Corporation, Lemont, Illinois

DIAGRAM: Fig. 1 Elevation and Plan View of the Old Plank Road Trail Bridge

DIAGRAM: Fig. 2 Cross Section of the Suspended Structure of the Old Plank Road Trail Bridge

DIAGRAM: Fig. 3 Old Plank Road Trail Bridge Model for Three-Dimensional Analysis

DIAGRAM: Fig. 4 Plan View of Proposed Crossing for Chicago

DIAGRAM: Fig. 5 Plan View of a Possible Multiple-Span Crossing

PHOTO (BLACK & WHITE): Fig. 6 OPRT Bridge Model

PHOTO (COLOR): THE OLD Plank Road Trail Bridge spans a four-lane highway using steel diagonal support towers that straddle a cable-supported steel deck.

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