Because cracks are dangerous they must be avoided. Prestressed concrete, by virtue of its definition and of the idea which led to its invention, has no cracks. To avoid cracks need not necessarily be expensive.

The system described in this paper produces crack-free concrete economically. The success of the system is demonstrated by the bridges that have been built using it.

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Rehabilitation of Steel Truss Bridges Using a Superimposed Arch System

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ABSTRACT

A system for reinforcing steel truss bridges has been developed. The system consists of superimposed arches with hangers supporting the existing floor beams, which may be reinforced or replaced with new ones, as well as additional intermediate floor beams. To date this system has been applied to three bridges ranging in span from 74 to 136 ft. The first application was to a 100-year-old, 74-ft Pratt truss bridge at Coudersport, Pennsylvania. For a total cost of $62,000, including painting of the bridge, the borough of Coudersport was able to increase the posted weight limit of the bridge from 3 to 20 tons. Given reasonable routine maintenance, the bridge could provide service for another 100 years. During the installation of the reinforcing system, which took 3 weeks, traffic flow was maintained.

In the U.S. highway network there are still many steel and wrought-iron truss bridges of the prefabricated, pin-connected type built during a 50-to-60-year period around the turn of the century. These bridges were designed for loads considerably lighter than the AASHTO H-20 or HS-20 loadings, to say nothing of the trucks that are permitted and contemplated on our Interstate system. Over the years little has been done to improve the carrying capacity of these bridges; in fact, accidents and limited maintenance have usually led to serious deterioration.

There is ample evidence that many steel truss bridges on secondary highways and local roads are in need of replacement or major structural repair. These truss bridges typically have pin connections, and rust as well as corrosion and fatigue damage to the pins and the eyes of the truss members cannot be detected. It is clear that all of these bridges cannot be replaced and that the problem is worsening. When resources are limited, all bridges, particularly aged ones, should be looked after. Thus a cost-effective program of reinforcement and rehabilitation of these aging truss bridges is needed.

The present procedure for determining the maximum safe live load capacity of existing bridges is supposed to consider the effect of deteriorated portions of the bridge such as (a) rusted and dislocated end supports, (b) deformed and corroded members, (c) stretched or otherwise loosened I-bars that can no longer be counted on to carry their planned share of the load, and (d) inconsistent and uncertain quality of the material of the members.

The most critical regions, where most structures fail, are the joints. These portions are virtually impossible to inspect to determine the extent of deterioration. The only way to inspect such portions accurately is to completely disassemble the bridge joints, which would typically require the disassembly of the entire bridge. In the absence of such detailed inspection and evaluation of the joints, the presently posted weight limits for steel truss bridges are questionable, yet they severely limit the utility of many of our rural roads.

Many of the old, locally owned bridges are narrow. However, there is little evidence that serious accidents occur on these bridges, primarily because of the openness of the truss structure that permits easy visibility of oncoming traffic and the low volume of traffic on most of these bridges. Therefore it would be a low-priority use of public funds to provide wider bridges at many of these locations. Many of the roads leading to these bridges are only slightly wider than the bridges themselves; providing a modern-width, two-lane bridge would make little practical sense.

PROPOSED SOLUTION

Because it is virtually impossible to accurately predict the carrying capacity of even an individual member, not to say an entire bridge, it makes little practical sense to attempt the repair of any but the most obviously deficient members of a bridge. The resulting increased weight limit would still be highly uncertain and inadequate. What is needed is the superposition of a new structural system that will completely bypass all existing members and joints except those that can be expected to reliably carry modern loadings. The proposed reinforcement scheme to increase the load carrying capacity and to extend the life of a truss bridge consists of

1. Superimposed arches anchored to the existing abutments, or piers, or both. If necessary the piers and abutments are reinforced to resist the thrust of the arches.
2. Additional floor beams and hangers midway between existing floor beams.
3. Replacement or reinforcement of existing floor beams if they are deteriorated or overloaded.
4. Connection of the existing vertical members, which now act as hangers, to the arches and to the existing floor beams or replaced floor beams.
5. Additional stringers if needed.

Because the existing truss system, with braced portals and lateral bracing in the planes of the top and bottom chords, will provide lateral restraint for the superimposed arches, the arches can be of light rolled sections and thus quite economical. Doubling the number of floor beams, by adding a new floor beam between each pair of existing floor beams, cuts the effective stringer span in half so that live load moments are reduced by a factor of two and dead load moments are reduced by a factor of four. Because the new and replacement floor beams are installed from below, it is often possible to use the existing deck and stringer system without modification. Because the superimposed arches will pick up all floor beam loads, all existing members except the stringers and floor beams will be largely relieved of live load stresses. The arches can be designed to be strong enough to carry both dead load and live load forces. The hanger connections for the new intermediate beams as well as for the existing or replacement beams completely bypass all of the lower chord pin connections. Thus this reinforcement scheme would provide structural integrity even if existing bottom joint connections were to fail. Typically, such joints consist of several I-bars connected by a pin, and these bottom joints are usually in the most serious condition because of their proximity to the bridge roadway.

In a test of a 1-to-7 scale model of a typical bridge of this type, a simulated truck load of 40 tons was supported by the arch system even after both lower chords had been severed by the removal of a pin near midspan. The removal of the pin caused increased deformations in the loaded model, but the model did not collapse.

Some advantages of the system are that

1. Costs are reduced compared with replacement costs.
2. The reinforcing system can be designed to increase the load carrying capacity to any desired level so that, from the standpoint of structural safety, the bridge will be new.
3. By reducing the span of the stringers, the stresses in the floor system are reduced enough that, in many cases, the floor and stringers need not be involved in the rehabilitation.
4. In contrast with replacement bridges, the rehabilitated bridge involves no additional encroachment on the waterway or changing of the approaches to accommodate a higher roadway elevation.
5. The short construction period--the erection of a typical span will take 2 to 3 weeks--means that traffic can be maintained with little or no interruption.
6. The critical pin connections in the bottom chords are completely bypassed so that they are much less likely to fail, by fatigue or other causes, and failure of such a connection will not affect the overall integrity of the bridge.

APPLICATION

The system can best be described by referring to its first application, a 74-ft-long Pratt truss crossing the upper reaches of the Allegheny River on Seventh Street of Coudersport, Pennsylvania. This bridge was one of two connecting a group of about twenty-five homes to the rest of the borough. One bridge had been closed because of extensive corrosion of the stringers and floor beams, and the other, the bridge in question, had had its load limit reduced to 3 tons. Thus this part of the borough was effectively without the services of fire trucks, school buses, trash collection trucks, and large delivery trucks such as those carrying heating oil. A new bridge, built to current standards of width, was estimated to cost in excess of $180,000 and would have required the complete isolation of this part of the community for at least several months while the old bridge was removed and the replacement installed. Also, to maintain the necessary waterway opening with current standard bridge designs of steel or concrete girders would have required increasing the elevation of the approach roadways by at least 2 or 3 feet. This would have caused serious disruption of the front yards of several adjoining properties.

Figures 1 and 2 show the bridge in its original condition and after the rehabilitation system had been installed. The arches of this bridge consisted of 13-in. channel sections welded and bolted to form four segmental arches, one inside and one outside each existing truss. Each arch was shop welded to form three separate lengths, each about 25 feet long and weighing less than 800 pounds, that could be easily transported and erected. In fact, because of the proximity of power lines to one side of the bridge, two of the arches were completely erected by means of hand-operated hoists attached to the exist-

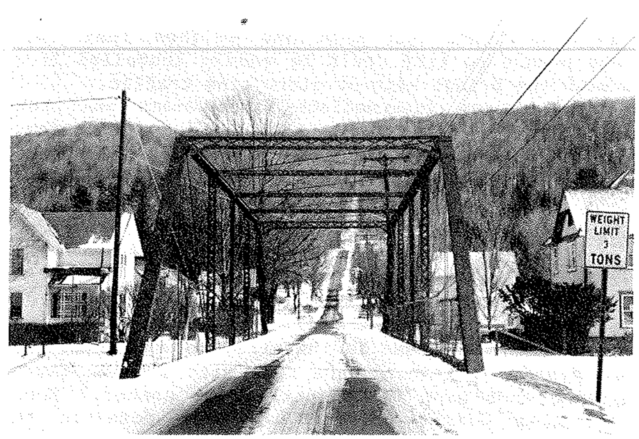

FIGURE 1 Coudersport bridge before rehabilitation.

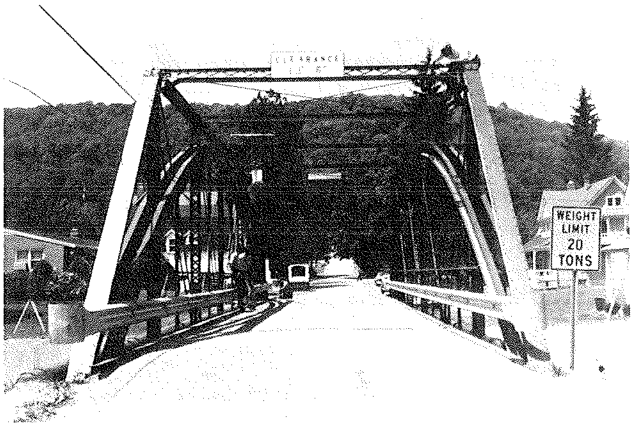

FIGURE 2 Coudersport bridge after rehabilitation.

ing truss. For this first application, the arches and floor beams were made of A-572 grade 50 steel and all other new members were of A36 steel. In the two additional applications of the system to date, all new members have been of A36 steel.

For the Coudersport bridge it was possible to use the existing abutments to resist the thrust of the arches. This was because the bridge had been raised 2.5 ft to accommodate the channel lining work that was done as part of a flood control project in 1953. At that time combined abutment and wing walls of reinforced concrete were cast in place on top of the earlier stone abutments. These concrete monoliths were found to be able to develop enough soil resistance to provide the required thrust. If the existing abutments had not been found adequate, two alternative solutions would have been possible: (a) reinforce the abutments with a facing of reinforced concrete or (b) resist the thrust by means of ties.

After the installation of the arches, the next task was the installation of hangers, additional intermediate floor beams, and stringers. The additional stringers were needed to reduce the span of the existing timber deck so that it could safely carry the wheel loads of an AASHTO H20 loading. If the floor deck had been metal grating or reinforced concrete, it might not have been necessary to add stringers because the introduction of intermediate floor beams cuts the span of the stringers in half thus reducing their bending moment by a factor of at least two. The intermediate floor beams were suspended from the arch by hangers, which were welded assemblies of light rolled shapes, and a pair of 1-in.-square hanger rods with 1.5-in. round threaded ends (Figure 3). The floor beams were 16-in.-wide flange sections, and each one weighed less than 1,000 pounds so they could be easily installed from beneath the bridge without disrupting traffic.

When the new intermediate floor beams had been installed, it was possible to replace the existing, laterally buckled floor beams. Because the number of floor beams had been doubled and only one existing floor beam was removed at a time, it was possible to keep the bridge open for traffic. Figures 4 and 5 show the original U-bolts supporting the existing floor beams and the new hangers for the replacement floor beams. The new hangers for the replacement floor beams are similar to those for the new intermediate beams in that they terminate in the same system of 1-in.-square rods with 1.5-in. round threaded ends used for adjusting the camber. However, they differ in that wherever possible an existing vertical truss member was used for the upper portion of the hanger. This permitted the

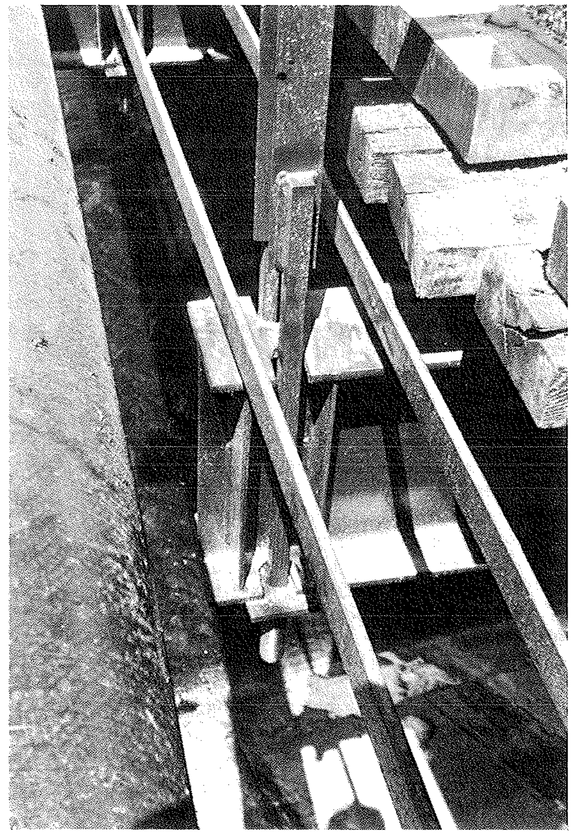

FIGURE 3 Intermediate floor beam supported by hanger rods.

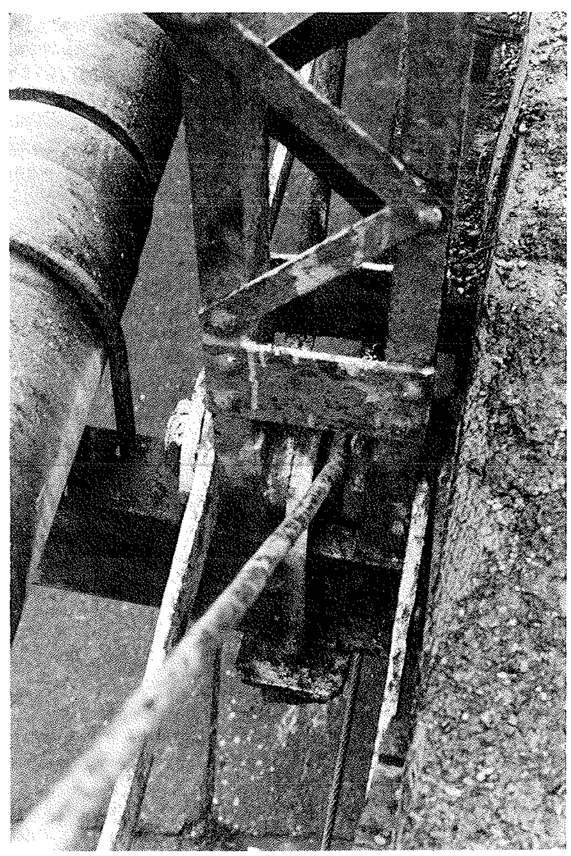

FIGURE 4 Original bottom pin-U-bolt joint for floor beam.

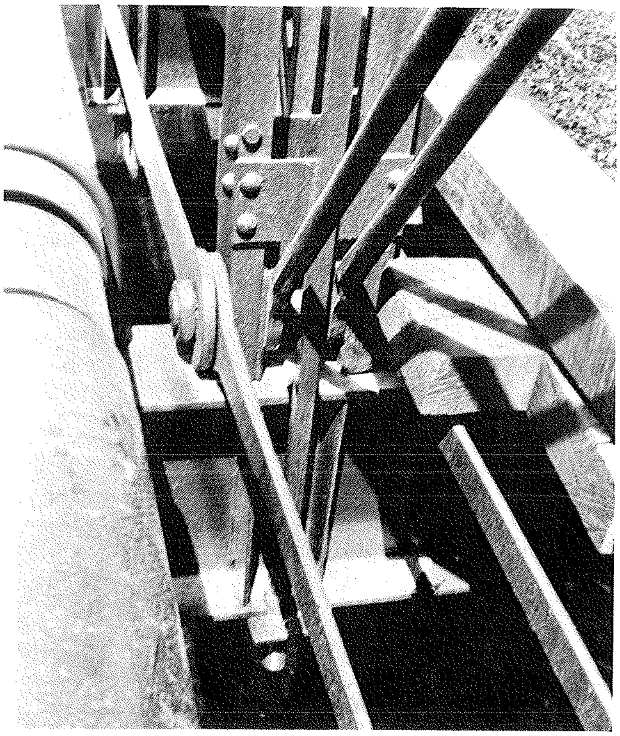

FIGURE 5 1-in.-square rods to support replaced floor beam.

complete bypassing of all the existing pin connections and rendered their condition unimportant to the future performance of the bridge. All that the old truss connections are called on to do is to provide enough continuity of the existing trusses to serve as lateral bracing for the slender sections of the new arches. Without the bracing of the existing truss the arch sections would have to be much heavier and thus more expensive. The entire erection operation took less than 3 weeks. The total cost for the rehabilitation, including painting, was about $62,000.

The most recent application of the rehabilitation system, a 139-ft-span, single-lane bridge in eastern Kentucky, went out for bids in early December 1983. The result was a low bid of $91,000, less than 25 percent of what the state of Kentucky had planned to spend for a new bridge. This installation was designed for an AASHTO HS-20 loading to accommodate coal trucks serving local strip mines. The Coudersport bridge installation was designed for an H-20 loading. In both cases the current AASHTO specifications were used.

LOAD TESTS

A series of load tests on the Coudersport bridge with the heaviest borough truck fully loaded with wet sand was conducted (Figure 6). The total weight of the loaded truck was 22.5 tons and this was judged to be the heaviest load that the bridge would be subjected to. (The heaviest fire truck in the borough is a fully loaded tanker weighing 17 tons.) The maximum deflection with the truck fully loaded with wet sand was 0.20 in. at the midspan of the bridge. For the load tests the bridge was instrumented with dial gauges clamped to the bridge. The stems of the gauges were tied by means of thin wires to concrete blocks placed in the bed of the stream. The thin wires provided such low resistance to the flow of water and air that there was little random

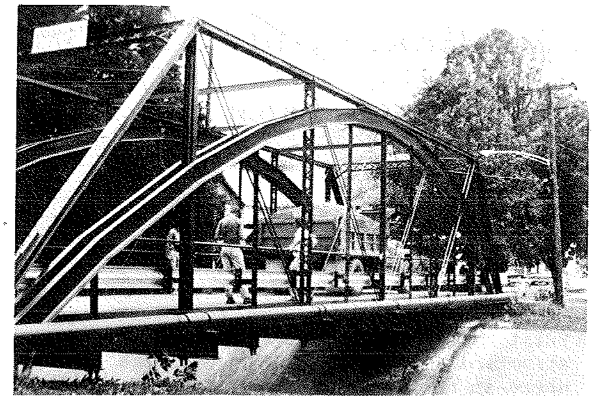

FIGURE 6 Load test with 22.5 tons.

fluctuation of the gauges and repeatability of measurements was adequate.

ADDITIONAL STUDIES

The authors are currently seeking support for a larger model, approximately 50 feet long, to be constructed and studied in the structural test facility that is being completed on the campus of Bucknell University. Such a model would be nearly full scale for some prototypes and thus would offer the following advantages: (a) It could be made of actual rolled shapes rather than the shapes milled from steel tubing that were necessary in the 1-to-7 scale model. (b) There would be no need to add weight to simulate dead load; the model could be tested to actual failure without as great likelihood of completely destroying the model. This would permit the determination of the actual failure load of the model under a variety of reinforcement configurations and loading conditions.

It is planned to use this larger model to provide three significant extensions of the previous studies: (a) more careful investigation of the need for and provision of lateral bracing for the arches, (b) the possibility of placing arches only on the outside of the main trusses so that there will be no encroachment on the width of the traffic lane, and (c) the possibility of placing the arches outboard from the main trusses so that, with the use of longer floor beams and remodeled end portal frames, the bridge can be widened. This would increase the availability of FHWA funds for these projects. Such funds can be made available for bridges of substandard width on the basis of state or county petitions for waivers; however, it may be feasible to include widening of the roadway as part of the rehabilitation system.

ACKNOWLEDGMENT

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