Strengthening Existing Bridges by Means of Epoxy Injection

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A low-viscosity epoxy was pressure injected between portions of the concrete slab and steel stringers of a noncomposite highway bridge to determine whether the structure could be strengthened by inducing composite action. The slab was jacked off the girders at different distances to inspect for an acceptable separation for satisfactory flow of the epoxy. After epoxy injection, the slab was cut into sections stripped from the girders. Epoxy did not penetrate between the slab and girder where the slab was not first raised. A 0.8-mm (0.03-in) shimmed separation was required for flow, and then epoxy covered only 60 percent of the flange surface. Push-off tests of several slab sections showed that the natural bond between the concrete slab and the steel girders was greater than the concrete-epoxy-steel connection. It was concluded that the epoxy-injection technique shows only marginal promise of strengthening existing bridges but that the natural bond might be inducing significant composite behavior.

The objective of this research was to determine experimentally whether existing noncomposite highway bridges could be made composite by injecting epoxy between the steel stringers and the concrete deck. The scope of the experimental program was limited to injecting epoxy into part of one span of an existing, 35.7-m (117-ft) simple-span noncomposite bridge. The bridge was made of 1.5-m (5-ft) deep-welded plate girders spaced on 2.0-m (6.5-ft) centers and supporting a 190-mm (7.5-in) thick concrete deck. Three interior girders were selected for epoxy injection.

One of the most important variables of the injection procedure was the space between the steel girder and concrete slab into which the epoxy would be injected. This variable was investigated by using different spaces for each of the three girders. Because the slab was not raised from the girders for girder 1, any existing crack between slab and girder was due to loading, temperature stress, or flange corrosion. For girder 2 a space was created by raising the slab off the girder and then by lowering it back. This gap was judged to be small, but its creation ensured that the bond between the concrete and the steel flange would be broken. For girder 3 the slab was raised and shimmed so that a space of at least 0.8 mm (0.03 in) was maintained.

EXPERIMENTAL PROCEDURE

The procedure for epoxy injection was similar for each of the three girders. First, holes 6.4 mm (0.25 in) in diameter were drilled on the underside of the slab next to the side of the flange as shown in Figure 1. Holes were spaced 0.6 m (2 ft) apart on each side of a girder. The 6.4-mm (0.25-in) copper tube used for injection ports was bonded into the holes. Where slab coping was removed next to the flange on girder 3, the ports were bonded into the gap directly. All cracks and gaps were sealed with a putty-like epoxy (SikaDurGel) and the seal was checked. Finally, the epoxy-injecting gun was attached to the first port in a line of ports, and the low-viscosity epoxy (SikaDur LV) was injected under pressure as shown in Figure 2. When epoxy began flowing from the neighboring port, the first port was sealed by clamping the copper tube with pliers. The injection gun then was connected to the second port and pressure injection was resumed. The port-to-port procedure was followed until all ports were injected.

The injection pressure and amount of flow was different for the three girders. The maximum injection pressure of 1380 kPa (200 lbf/in^2) was applied to girder 1, and no flow was observed. Girder 2 required 828-kPa (120-lbf/in^2) pressure for a total flow of 2.4 L (0.6 gal). Epoxy flowed readily under 138-kPa (20-lbf/in^2) pressure for girder 3, which had the 0.8-mm (0.03-in) space; the total flow exceeded 10 L (2.6 gal).

INSPECTION OF RESULTS

Two months after the injection procedure the slab over the girder was cut through at 0.3-m (1-ft) intervals along the beam to create 0.3x1.2-m (1x4-ft) sections. Some of the sections were removed to permit inspection of the girder-slab interface and qualitative appraisal of the epoxy bond.

After removing sections from girder 1, we noted that concrete and cement paste remained firmly bonded to half the area of the flange surface. A jackhammer was used to chip off the concrete; no epoxy was observed over any of the flange surface. For girder 2, concrete remained bonded to about half the flange area. Epoxy covered about 80 percent of the remaining flange area, which illustrated that the epoxy did not flow completely through the narrow crack. For girder 3, epoxy covered

Figure 1. Ports for epoxy injection.

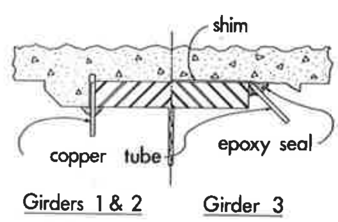
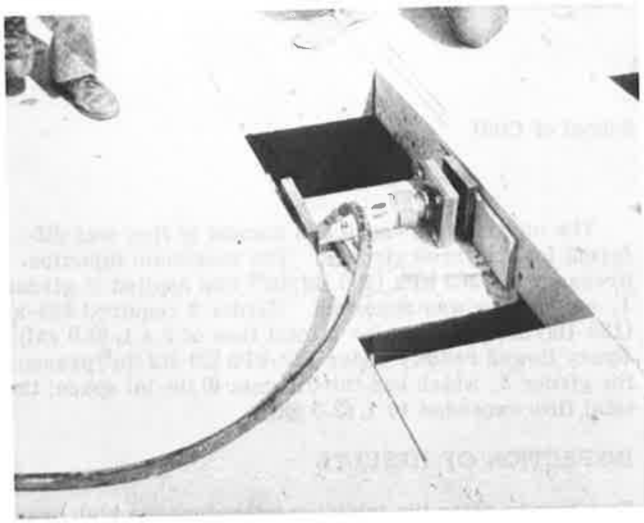


Figure 2. Epoxy injection mixed in the gun.

Figure 3. Push-off test.



60 percent of the steel flange. In other areas the epoxy was bonded on top of a segment of concrete that in turn was joined to the steel. There were no clear flange areas on girder 3; the flange was covered with bonded concrete or bonded epoxy. Apparently, when the slab was raised (girder 2) or raised and shimmed (girder 3) initially, large sections of concrete adhered to the steel. When the epoxy was injected, it flowed over those sections of concrete as well as over the portions of exposed steel. Therefore, only a portion of the flange was epoxy bonded to the slab.

Quantitative measures of the slab-to-girder bond were determined by conducting push-off tests of the remaining sections as shown in Figure 3. The maximum load in the horizontal jack was recorded when each section began to slip. The average of the push-off loads for sections on each girder are listed below; this load was divided by the gross area of the section to give a nominal bond stress (1 N = 4.49 lbf; 1 kPa = 0.145 lbf/in^2).

Girder	Push-Off Load (N)	Nominal Bond Stress (kPa)
1	249 750	979
2	162 850	946
3	89 720	716

The results of the push-off tests show that the natural bond between the concrete and the flange was greater than that achieved by the epoxy-injection process. A net bond stress for the epoxy was calculated by dividing the push-off load by the actual area of flange covered by the epoxy. The average net bond stress was 1395 kPa (202 lbf/in^2). If a clean separation between the slab and girder had been achieved, the epoxy would have significantly increased the bond between the two.

Four existing noncomposite highway bridges of spans ranging from 8.8 to 17.7 m (29 to 58 ft) were analyzed to determine whether the maximum shear-bond stress at the slab-flange interface was greater or less than the nominal bond stresses found experimentally. The four bridges were designed originally for H15 loading, for which the calculated bond stresses were 21-137 percent less than the natural bond determined for girder 1. This result implies that under the design loading the bridges have been functioning as composite structures.

CONCLUSION

The feasibility of using epoxy injection to strengthen existing noncomposite bridges was found to be marginal. Epoxy was injected satisfactorily only when the slab was raised and shimmed above the girder, but the lifting and injecting process was not difficult, and the injected epoxy developed a bond strength greater than that of the concrete. However, the shear-bond capacity of the epoxy was reduced because fragments of concrete prevented the epoxy from covering the total flange area.

An important experimental finding was that the natural concrete-to-steel bond was significant; calculations demonstrated that existing bridges originally designed as noncomposite structures may be behaving as composite structures because the shear-bond stresses between the slab and girder are less than the natural bond stress.

Theoretical calculations showed that the section modulus of the girder-slab system of noncomposite bridges could be increased between 15 and 60 percent by making the system composite. While this concept strongly suggests a means by which to strengthen existing bridges, the method of using epoxy injection has been shown to hold little promise.

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