Evaluation of Shear Plates and Grouted Shear Key Joint Performance of a Three-Sided Precast Culvert

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The effectiveness of shear plates and a grouted shear key joint system in providing load transfer across three-sided bridge sections is evaluated. Because of the flat-top culvert geometry accommodating pavement directly on top of the sections, it was important to determine the structure's response to differential deflections between adjacent sections when subjected to live loading. Prompted by research that evaluated shear plates on tongue-and-groove jointed box sections with spans up to 12 ft, the project focused on a three-sided structure with a substantially longer span (30 ft) and a grouted shear key joint system. Deflection results are presented for various combinations of shear plates and the keyed joint when subjected to simulated live loading. The results indicate that the grouted shear key joint system is an effective means of distributing the load between the precast sections. The addition of shear plates does not enhance the structural response of the grouted structures. Shear plates alone are ineffective.

In today's culvert and small bridge replacement markets, three-sided structures have been successfully installed under a variety of conditions in several parts of the country. The three-sided bridge system is a rigid frame design that incorporates a flat-top geometry (see Figure 1). By providing a flat-top structure, the system allows pavement to be placed directly on top of the structure, thereby decreasing project time, backfill requirements, and potential for differential backfill settlement. Before testing of the structure, the policy associated with the system was to provide a grouted shear key joint accompanied by shear plates (see Figure 1) when combinations of long spans (more than 16 ft) and shallow earth covers (0 to 2 ft) were encountered. In a load test on an installed structure the following two issues were investigated:

1. How does the system behave structurally when a live load is applied?
2. To what degree do grouted, keyed joints or shear plates (or both) enhance the structure with respect to resisting loads?

The design loading for this bridge was AASHTO HS20-44. For design purposes, this required less steel than for the Interstate loading. The tension steel provided in the bottom of the bridge deck (As2) was between the requirement for an HS20-44 and an Interstate load, as shown in the following (units are in.^{2}/ft):

Technology Division, Price Brothers Company, 367 West Second Street, Dayton, Ohio 45402.

Required for HS20-44 loading: 0.901
Provided: 0.960
Required for Interstate loading: 1.048

Therefore, the Interstate load is a more rigorous test because of the "under steel" with respect to the Interstate design.

TEST PROGRAM

A three-sided bridge structure was identified for the load test in Bloomfield Township, Michigan. The structure contained 35 linear ft (seven sections of 5 ft each) of 30-ft span × 7-ft rise with a 30-degree left forward skew. The sections were installed on two separate cast-in-place footings supplied by the contractor. The backfill was placed to the top of the structure and was ready for testing to begin. A test procedure was developed and sent to an independent licensed engineer for review.

The preliminary steps of the test procedure were as follows:

1. A hydraulic jack was calibrated to provide a chart of applied load in pounds versus gauge readings of hydraulic fluid pressure in psi.
2. Dial indicators with adjustable support rods, 8W24 beams, 2- × 10- × 20-in. wood bearings (simulated wheel loadings) and steel plates were procured.
3. The loaded truck was driven into position and deflection readings from the truck wheel loads were recorded.
4. The hydraulic jack was activated and load was applied in increments of 7,800 lb to a maximum of 31,200 lb, representing the wheel load with 30 percent impact for the Interstate alternate axle load as presented in ASTM C850. Deflection readings were taken from each of the dial indicators at each increment.
5. Steps 3 and 4 were performed for each of four test conditions.

Load Tests 1 and 2

Deflection Tests 1 and 2 were conducted with the joint conditions as described in Figure 2. In Test 1 the deflection was measured for a "butt type" joint (no grout and no shear plates). In Test 2 the deflection was measured on the same joint with the shear plates in place.

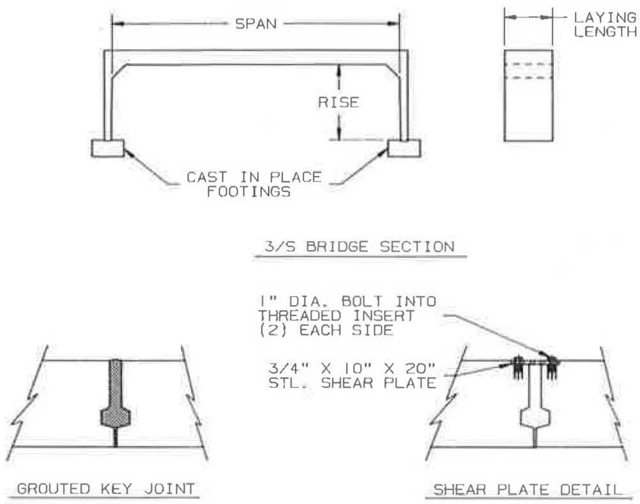

FIGURE 1 Three-sided bridge system.

The tests were set up in accordance with Figures 2 and 3. All dial indicator readings were taken before the positioning of the truck. This was the zero reading.

After the truck was in position, measurements were taken to record the location of the wheels relative to the applied test load. Figures 4 through 6 show the test arrangement for Tests 1 and 2. The load was applied according to the procedure described, and the deflections, as determined by the dial indicators, were recorded at each load increment. After Test 2 was completed both of the ungrouted joints were grouted.

Load Tests 3 and 4

Tests 3 and 4 were conducted in the same manner, except the load was positioned at the location shown in Figure 7. Test 3 was conducted with the grout and shear plates in place. Test 4 was conducted on the grouted joint without shear plates.

TEST RESULTS

Load-deflection results for the applied jack load (Figure 3) are given for the four joint conditions in Tables 1 through 4. The tables do not include tne deflections due to the truck wheel loads. The deflections corresponding to the truck wheel loads were 0.028, 0.015, and 0.008 in., respectively, at Dial Indicators 1, 2, and 3 for Tests 1 and 2. For Tests 3 and 4, the corresponding deflections were 0.010, 0.012, and 0.012 in. As the load was applied by jacking the truck up, the truck wheel loads were reduced somewhat. Therefore, the deflections due to the truck wheels were reduced. The deflections due to these truck wheel loads were considered negligible in the analysis.

The load-deflection results corrected for apparent bridge settlement are shown in Figures 8 and 9. The test details are shown in Figures 4 through 6. The differential deflections across the joint versus jack load are shown in Figure 10.

DISCUSSION OF RESULTS

For each joint condition presented in Tables 1 through 4, a maximum load of 31,200 lb was applied in 7,800-lb increments. This load was applied, released, and reapplied so that deflections due to bridge settlement could be established by taking "no load" dial indicator readings after the first load cycle. In this manner dial indicator readings were corrected for apparent bridge settlement, and the results are presented in Figures 8 and 9. Analysis of Figure 8 indicates that deflections at Dial Indicator 2 (loaded side of joint) were greatest in Test 1 (ungrouted joint with no shear plates). Deflections at this dial indicator were reduced the most in Tests 3 and 4 (grouted joint with and without shear plates, respectively). Analysis of deflections at Dial Indicator 3 (unloaded side of joint) in Figure 9 indicate that deflections increased progressively from Test 1 (ungrouted and no shear plate) to Test 3 and 4 conditions. Results for Tests 3 and 4 were iden-

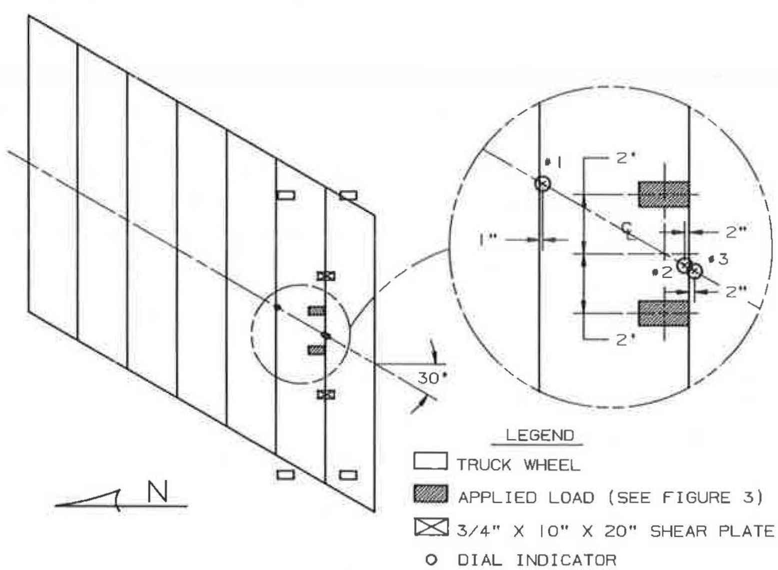

FIGURE 2 Test 1 (ungrouted without plates) and Test 2 (ungrouted with plates).

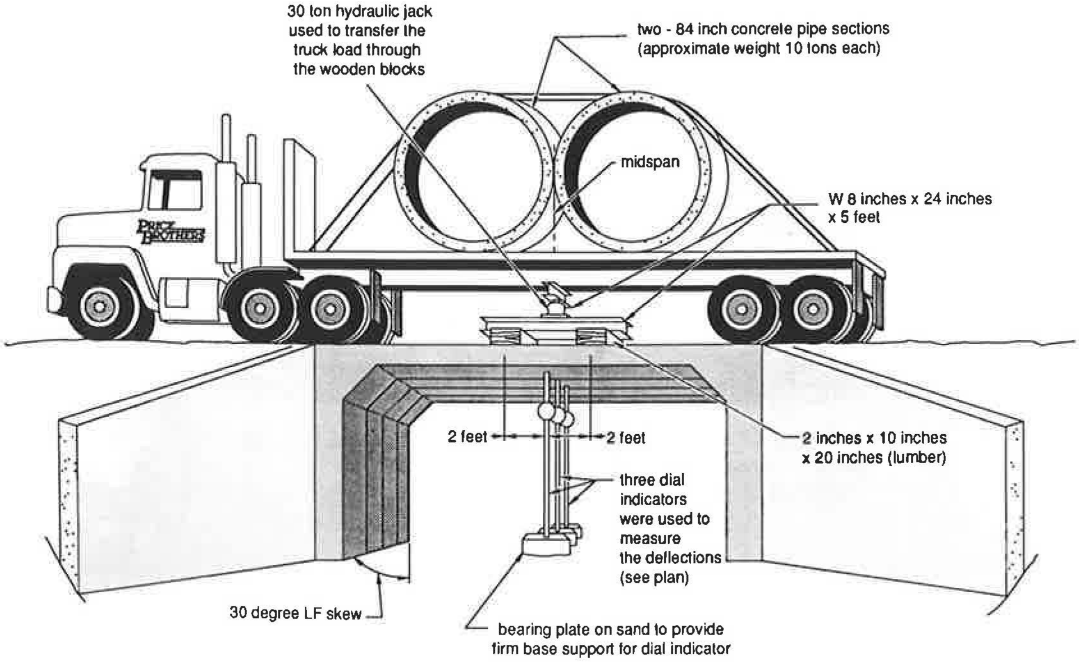

FIGURE 3 Load test arrangement—diagram.

FIGURE 4 Load-deflection test arrangement for three-sided bridge.

FIGURE 5 Load was applied by hydraulic jack in 7,800-lb increments to a maximum load of 31,200 lb. Load was distributed on the 10- × 20-in. bearing areas at 4-ft centers to simulate truck wheel bearing areas. The 31,200-lb load is equivalent to the ASTM C850 Interstate alternate axle loading.

FIGURE 6 Deflections were obtained by three dial indicators. Locations relative to the load points are indicated in Figures 1, 2, and 7.

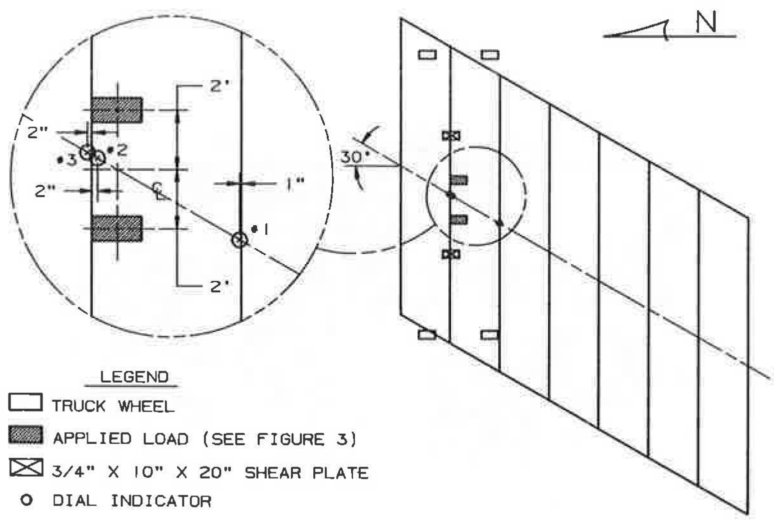

FIGURE 7 Test 3 (grouted with plates) and Test 4 (grouted without plates).

TABLE 1 THREE-SIDED BRIDGE LOAD TEST—UNGROUTED WITHOUT SHEAR PLATES (TEST 1)

Jack Load (lbs.)	Deflection (inches) Dial # 1	Dial # 2	Dial # 3
0	0	0	0
7800	.017	.030	.001
15600	.037	.065	0
23400	.074	.110	-.001
31200	.121	.166	-.001
0	.020	.017	-.003
7800	.037	.048	-.002
15600	.058	.083	-.004
23400	.085	.122	-.004
31200	.123	.170	-.004

For load and dial indicator locations, see Figures 2 & 3.

TABLE 2 THREE-SIDED BRIDGE LOAD TEST—UNGROUTED WITH SHEAR PLATES (TEST 2)

Jack Load (lbs.)	Deflection (inches) Dial # 1	Dial # 2	Dial # 3
0	0	0	0
7800	.016	.027	.004
15600	.035	.056	.008
23400	.053	.090	.012
31200	.080	.128	.016
0	0	.005	.001
7800	.019	.033	.002
15600	.036	.063	.006
23400	.055	.094	.010
31200	.079	.127	.015

For load and dial indicator locations, see Figures 2 & 3.

TABLE 3 THREE-SIDED BRIDGE LOAD TEST—GROUTED WITH SHEAR PLATES (TEST 3)

Jack Load (lbs.)	Deflection (inches) Dial # 1	Dial # 2	Dial # 3
0	0	0	0
7800	.008	.013	.013
15600	.017	.028	.027
23400	.027	.042	.041
31200	.034	.056	.054
0	0	.002	.001
7800	.009	.015	.013
15600	.018	.030	.028
23400	.027	.044	.042
31200	.035	.057	.054

For load and dial indicator locations, see Figures 3 & 7.

TABLE 4 THREE-SIDED BRIDGE LOAD TEST—GROUTED WITHOUT SHEAR PLATES (TEST 4)

Jack Load (lbs.)	Deflection (inches) Dial # 1	Dial # 2	Dial # 3
0	0	0	0
7800	.010	.014	.014
15600	.018	.028	.028
23400	.027	.042	.042
31200	.035	.055	.054
0	.001	.001	0
7800	.010	.014	.014
15600	.018	.029	.028
23400	.027	.042	.041
31200	.035	.055	.054

For load and dial indicator locations, see Figures 3 & 7.

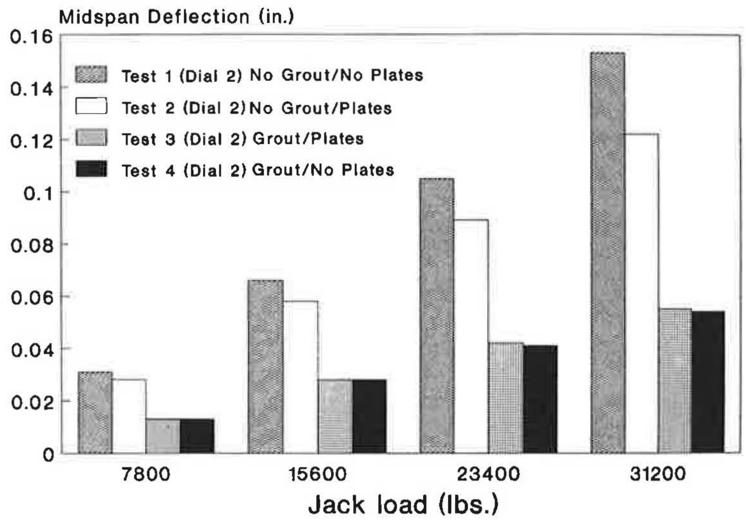

FIGURE 8 Load versus deflection (loaded side of joint).

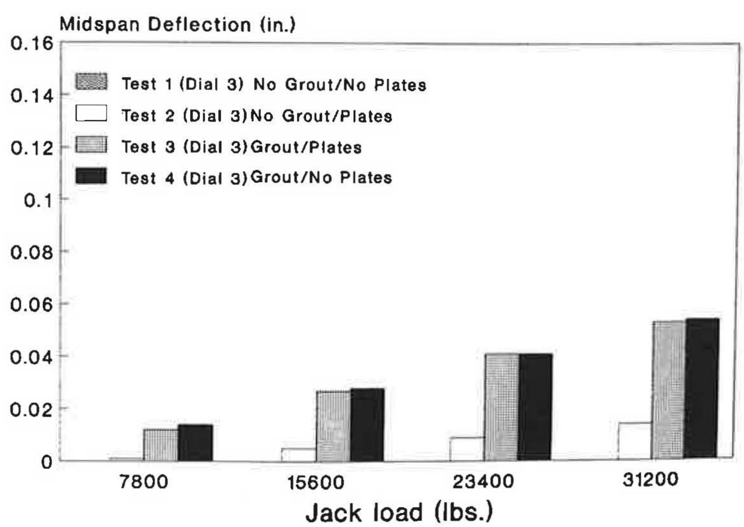

FIGURE 9 Load versus deflection (unloaded side of joint).

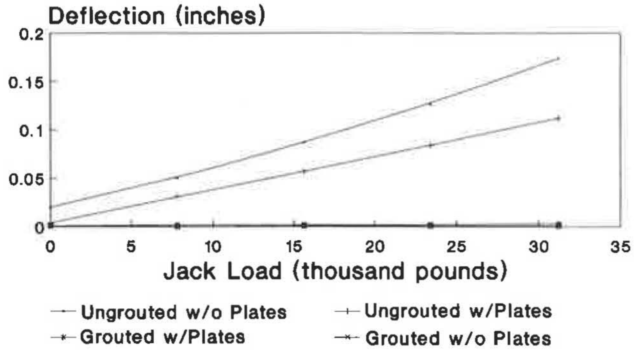

FIGURE 10 Jack load versus differential deflection across joint (differential deflection = Dial 2 − Dial 3).

tical for all practical purposes and indicated the greatest amount of distribution of load across the joint (see Figure 10). In fact, the load is completely transferred across the joint for this condition, because the deflections are the same on the loaded and unloaded side of the joint. The results of Tests 3 and 4 indicate that the grout, alone, completely transfers the load across the joint, and shear plates are redundant. In essence, the shear plates can be eliminated.

This project is typical of many in Michigan and throughout Ohio. The yardstick for total deflection used by the Ohio Department of Transportation is *L*/800. This corresponds to a deflection of 0.45 in. As indicated in Tables 1 through 4, these deflections were well under the limit of *L*/800.

CONCLUSIONS

1. The tests indicate that, both individually and combined, shear plates and the grouted keyway transfer load across the joint.
2. The grouted keyway alone provided complete load transfer across the joint.
3. Shear plates alone are ineffective because they only provided minimal load transfer.
4. By comparison, the grouted keyway was much more effective than the shear plates alone, and the difference in joint performance between the grouted joint and the grouted joint combined with shear plates was minimal.

RECOMMENDATIONS

1. The use of the grouted keyway joint should be continued to safeguard against reflective pavement cracking due to differential deflection of the bridge sections under load.
2. The use of shear plates at grouted joints should only be considered for special end treatment (headwalls, etc.) to tie the end pieces to the body of the structure.

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