Joint Heating Allows Winter Construction on Linn Cove Viaduct

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Synopsis

Winter erection of precast concrete segments is always difficult when epoxy is used in the joints, because this material will not harden when temperatures fall below a certain level.

For erection of the Linn Cove Viaduct to continue through the winter, the epoxy in the joints needed to be heated to at least 40 F (4.4 C) to cure properly.

This paper gives results of three tests used to develop a system for heating and insulating joints, describes the heating methods used, and makes recommendations for development of such systems for other projects.

The Linn Cove Viaduct, located near Grandfather Mountain in North Carolina, is a 1243-ft (379 m) multispan precast segmental bridge being erected by the progressive placing method. Fig. 1 shows the construction progress through February 1982.

The project is owned by the National Park Service. The Federal Highway Administration (FHWA) is doing all of the contract administration for the project and has retained the services of the authors' firm to provide segmental construction expertise. Jasper Construction Company is the general contractor.

The design of this project was complicated by the fact that the surrounding terrain is among the most rugged and environmentally sensitive in the eastern part of the United States. The use of precast segmental construction for both sub- and superstructure construction, with all erection being done from the top (Fig. 2), was the solution chosen to the challenge of building the

Fig. 1. Linn Cove Viaduct constructed with precast segments erected by progressive placing. This photo shows progress through February 1982.

bridge around Grandfather Mountain without damaging the terrain. The only work being done at ground level is the drilling of the microshaft piles.

All materials, including microshaft reinforcement, subfooting, footing concrete, and pier segments, are placed with the stiffleg crane mounted on the end of the completed superstructure. The stiffleg is also used to erect the superstructure segments. A general description of progressive placing erection is included in References 1 and 2.

All erection activities must be accomplished from the completed portion of the superstructure. To keep from falling behind schedule, the contractor, in the early fall of 1981, decided to develop a method for erecting segments during the cold winter months. Although the project is located in North Carolina, the 4500-ft (1373 m) elevation of the site brings in rather severe winter weather with snow, subfreezing temperatures and very high winds.

Fig. 2. All substructure and superstructure erection is being done from the top. Here, a precast pier segment is being lifted by the stiffleg crane.

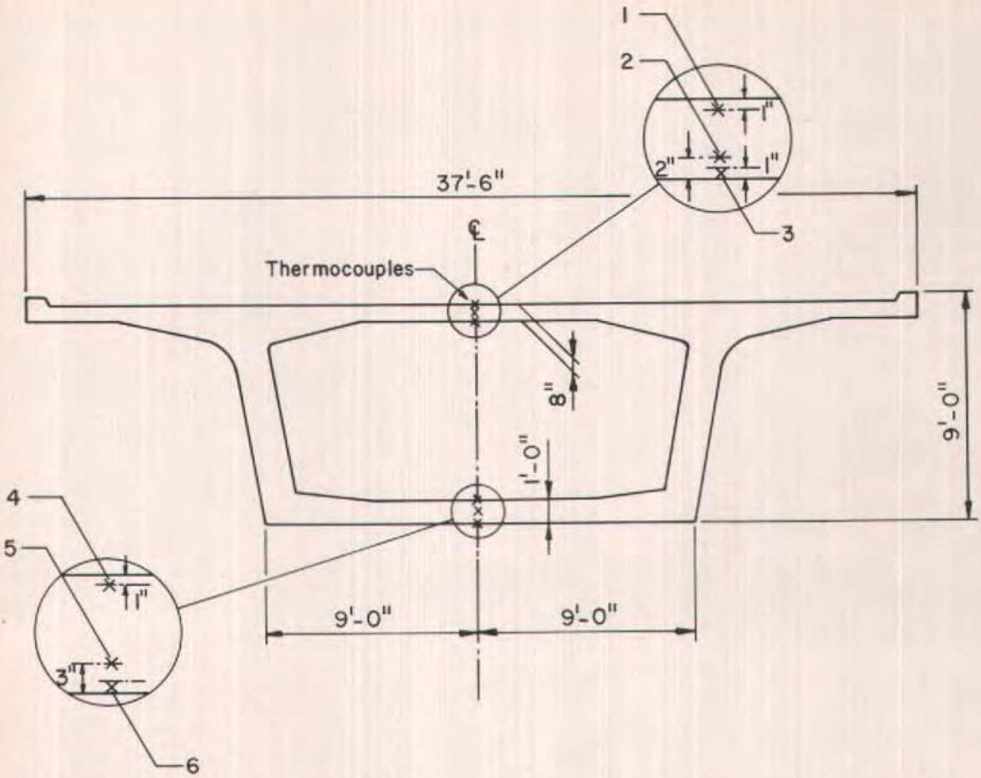

Fig. 3. Thermocouple locations in instrumented segments. The thermocouples were used in the test program to evaluate joint heating.

Table 1. Test I Data, 10/21/81, Weather: sunny and calm.

Time	Air Temp.	Thermocouple Readings					Comments
		1	2	3	4	6	
12:15 p.m.	50	48	47	46	45	43	Thermocouple #5 not working.
1.35 p.m.	56	49	49	48	52	45	
2:25 p.m.	57	50	50	50	53	47	
4:10 p.m.	56	51	51	51	58	49	
6:15 p.m.	50	52	52	52	56	52	

Note: Temperatures given in F. C = 5/9 (F − 32).

Table 2. Test II Data, 10/22/81, Weather: sunny and calm.

Time	Air Temp.	Thermocouple Readings					Comments
		1	2	3	4	6	
8:15 a.m.	43	51	51	51	49	49	Blanket on overnight No heat
9:00 a.m.	49	51	51	51	49	51	
10:00 a.m.	50	51	51	51	49	49	
11:30 a.m.	56	51	51	51	52	50	Heat applied approximately 12:30 p.m.
1:00 p.m.	56	53	53	52	55	51	
1:55 p.m.	58	53	53	53	56	52	
3:25 p.m.	56	56	55	56	56	53	Temperature between blanket and concrete = 65 F (18.9 C)
4:30 p.m.	55	58	58	59	56	54	Temperature between blanket and concrete = 65 F (8.3 C)

Note: Temperatures given in F. C = 5/9 (F − 32).

The Linn Cove project, like all other precast segmental projects with epoxy joints, is subject to an epoxy specification requiring the concrete temperature to be above 40 F (4.4 C) for applying and curing the epoxy. Therefore, a safe, economical method of heating and maintaining the temperature of the joints had to be developed.

TEST PROGRAM

To obtain information which would assist the FHWA in evaluating contractor proposals for winter erection, the consulting engineers and the contractor cooperated in instituting a test program to determine the thermal properties of the segments.

The FHWA is instrumenting the bridge, and had placed thermocouples in three segments. One of the three segments was used for the heating tests while in storage. Fig. 3 shows the location of the thermocouples in a typical instrumented segment. Three tests were run on the instrumented segment to determine whether the joints could be heated, and if so, at what rate.

Test I

Test I was run without any artificial heat applied to determine the natural relationship between the concrete and ambient air temperatures. Table 1 gives the data taken during this test.

This test showed, as expected, that the concrete temperature followed the ambient temperature, but with some lag. The thin flanges of the box section allow a fairly rapid temperature increase in the concrete, with little gradient in the top slab. Because the segment was sitting on the ground, the bottom slab showed a gradient. This implied that the joints could probably be heated by insulating and heating the surrounding air.

The initial idea for heating the cantilevered flanges of the segments was to use electric blankets. The contractor obtained two electric blankets which were 9 x 15 ft (2.7 x 4.6 m). The manufacturer claimed the blankets would maintain a substrate temperature of 50 F (10 C) for an ambient temperature of as low as 20 F (6.7 C).

Test II

Test II was run with an electric blanket wrapped over the edge of the segment so that the concrete surrounding the top slab thermocouples was heated from both directions. No insulation was provided, and the thermocouples in the bottom slab received no artificial heat. Fig. 4 shows the test segment with the blanket as placed for Tests II and III. Table 2 shows the data for Test II.

This test showed that the blanket could heat the concrete, but it was difficult to determine how much of the heat was from the blanket and how much was from the sun. The temperature rise in the bottom slab was equal to that in the top slab. To eliminate the effects of the sun, it was decided to run another test at night.

Since Test II was started the morning after Test I and the blanket was placed immediately after the end of Test I, the insulating properties of the blanket could be generally evaluated. For an ambient temperature drop of 7 deg F (3.9 C), the temperature of the concrete under the blanket only dropped 1 deg F

Fig. 4. The test segment being heated with an electric blanket. The blanket was wrapped around the edge of the segment and fastened.

(0.6 C). On the other hand, the temperature change of the unprotected bottom slab was 7 deg F (3.9 C), the same as the ambient temperature change. It was therefore concluded that the electric blankets would provide some insulating value.

Test III

Test III was run with the same blanket arrangement as Test II (see Fig. 4). As mentioned before, this test was run at night and somewhat later in the year to test the blankets in the absence of sun and with colder weather. Table 3 presents the data taken for Test III.

The results of Test III were by far the most interesting. The data showed that the concrete could be heated even under severe conditions. The wind conditions were ideal for observation of heat loss, as demonstrated by the 12 deg F (6.7 C) temperature drop in the uninsulated bottom slab. However, the temperature rise was steady in the top slab and only dropped 6 deg F (3.3 C) in 7½ hours after the heat was shut off. At this point in time the joints could be heated.

APPLICATION

The contractor evaluated several ideas for heating the joints before submitting the final scheme for approval by FHWA. An insulating frame was built to fit tightly around the bottom slab, webs, and the bottom of the wings. Fig. 5, a photo of this insulating frame, shows two bar joists supporting a plywood form.

Insulation was provided by fastening fiberglass batts to the outside of the plywood and attaching a foam strip on the inside. The foam strip assured a tight fit around the bottom of the box section and created a dead air space around the concrete.

Table 3. Test III Data, 11/6-7/81, Weather: cold with wind gusts to 60 mph.

Time	Air Temp.	Thermocouple Readings				Comments
		1	2	3	6	Gauge 4 not working.
5:00 p.m.	47	54	53	54	—	
6:05	43	54	53	54	46	Heat applied at 5:00 p.m.
7:15 p.m.	38	57	57	58	45	
8:05 p.m.	35	59	58	60	44	
9:20 p.m.	34	61	61	62	43	
11:00 p.m.	34	65	64	65	41	Heat stopped. Blanket remained.
6:30 a.m.	31	59	59	59	34	
10:00 a.m.	41	57	57	47	34	

Note: Temperatures given in F. C = 5/9 (F − 32).

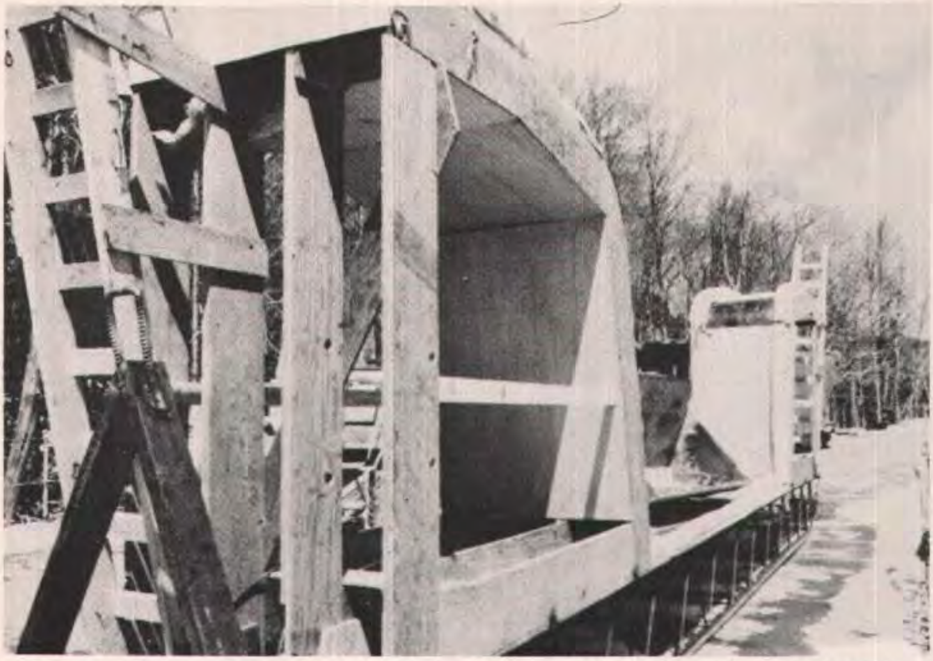

Fig. 5. The insulating frame was built to the general configuration of the outside of the box girder. The out-to-out width is 4 ft (1.2 m).

Since the width of the frame was 4 ft (1.2 m), only 2 ft (0.6 m) of the segments on either side of the joint would be directly heated. The consulting engineers were concerned that the resulting temperature gradient might cause a warping of the segment to be erected. To avoid this problem, the range of heating was limited to the allowable range of the Type III epoxy, which was 40 to 25 F (4.4 to 18.3 C) for this project.

The contractor also decided, for the sake of the laborers, that erection would continue only when the weather was at least 20 F (−6.7 C). Therefore, the segment was analyzed for a possible distortion due to a 45 deg F (25 C) temperature gradient. The amount of distortion was within acceptable limits for this project because the calculated distortion was very small; experience had shown the segments on this project to be cast very accurately.

Propane heaters were used to heat the bottom slab and webs. The rate of concrete temperature change was regulated by the precast specification for accelerated heat curing. The maximum concrete temperature was 65 F (18.3 C), and the heaters could not blow directly on any part of the concrete.

Baffles were placed on the inside of the segments so that only 2½ segments were heated. This minimized the fuel consumption and allowed better control of the air temperature.

The top wing joints were heated with the electric blankets extending the length of wings. The portion of the top slab between the webs was covered with tarps. Since heat rises, we did not feel this area needed insulating. In fact, we were concerned about it getting too hot. The tarps allowed enough heat to escape to keep the top slab within reasonable temperature limits.

The heating system was used in one of two ways, depending on the concrete temperature when the erection process commenced. If the substrate temperature was above 40 F (4.4 C) but the weather forecast indicated that 40 F (4.4 C) would not be maintained, the epoxy was applied and the segment attached to the cantilever in the normal manner. Then the insulating frame was placed and heat applied for a time equal to twice that which was specified for the epoxy to harden.

If the substrate temperature of the concrete started below 40 F (4.4 C), the segment to be erected was suspended about 6 in. (152 mm) from the end of the cantilever. Support was provided by the stiffleg crane, and the temporary post-tensioning thread bars were installed and hand tightened as a safety precaution.

The insulating frame was then brought up and heat was appled until the concrete temperature was above 40 F (4.4 C). Then the frame was dropped, the epoxy applied, and the temporary bars stressed. Finally, the joint was again sealed by the frame and heated to assure hardening of the epoxy.

PROTECTION OF TENDONS

The minimum specified temperature for grouting the post-tensioning tendons was 35 F (16.7 C). Since this temperature was not reached for a long enough period for grout to cure, a tendon corrosion protection system had to be used for the tendons installed and stressed during the winter months. Also, blockouts and open ducts had to be sealed to prevent water from entering and freezing.

A vapor phase inhibitor (VPI) was used to protect against tendon corrosion. VPI crystals were periodically blown with compressed air through grout tubes into the stressed tendons. The grout tubes were then bent over and wired to seal the tendons. Since VPI crystals have a definite effectiveness time limit, the engineers kept records on all tendons and required reapplication before the VPI effectiveness expired.

QUALITY CONTROL

The consulting engineering firm handled all quality control for the erection and heating of the segments. A hand-held thermocouple was used to determine the concrete temperature of both the segment to be erected and the end of the cantilever. Thermocouples were also placed in all joints heated. Joints were monitored throughout the heating period with a digital thermometer which had jacks for attaching the thermocouple lines.

The digital thermometer was also used to monitor the inside air temperature. In addition, a recording thermometer was used to record the air temperature for the heating period.

For the first few joints, a close visual inspection was performed to detect any cracking caused by a temperature gradient through the webs or slabs. This inspection confirmed that the design temperature gradient was sufficient.

RESULTS

Fig. 6 shows the insulating frame in place under the cantilever. This bridge has a very complicated geometry, with S curves, transitions, and super-elevations, but the foam gasket on the inside provided sufficient adjustment to seal around the joints as the curve shown in the photo was negotiated. The frame was suspended by and traveled along steel rails which were temporarily attached to the underside of the curb areas.

The frame incurred only one mishap. A windstorm blew the frame off the end of the bridge, and it was damaged quite extensively when it hit the rocks. How-

Fig. 6. The foam on the edges of the heating frame provided a good seal as the frame was moved from joint to joint around the curve.

ever, by the end of the next day, it was back together and ready for service.

The heating blankets did not fare as well. They were too fragile for the folding and unfolding. Also, the foot traffic of the workmen, along with dropped tools and equipment, soon had the blankets in rough shape.

As an alternative, the contractor then built four wooden boxes, 4 ft (1.2 m) wide, which when placed end-to-end would extend across the entire width of the deck. The boxes were insulated with styrofoam on the inside and each was wired for four electric heating lamps (Fig. 7). This system was very effective for heating the top slab joint. Also, as long as enough replacement heat lamps were kept on hand, this system was much more durable.

All in all, the system was very effective. From the middle of November until the middle of March, over 20 segments were erected. Without the heating system, the project would have had to shut down part time, and substantially fewer than 10 segments would have been erected.

The heating system cost approximately \$4000, not including the fuel cost, which is impossible to determine because fuel was also used for other purposes. But in retrospect, the decision by the contractor to develop the heating system proved to be beneficial and economical.

CONCLUSIONS

Winter erection of precast concrete segments is always difficult when epoxy is used in the joints because of this material's inability to harden at temperatures below 40 F (4.4 C). However, as demonstrated by this project, this inconvenience can be overcome easily and economically. This can be an important consideration when contrac-

Fig. 7. Heating box, built with plywood and insulated with styrofoam, for heating the top of the joint.

tors are bidding precast segmental projects in the northern part of the United States and Canada.

For those contractors and engineers who may consider heating joints, the following advice is offered:

1. Analyze the section to determine that temperature gradients will not cause cracking in the concrete or significant distortion of the segments. This was not a problem on Linn Cove, but it could be a problem on other projects. The cross-sectional properties and length of the segments are important.

2. Since the concrete temperature in areas other than the heated zones will most likely be below 35 F (1.7 C) during winter erection, the post-tensioning tendons cannot be grouted. Plan on devising a corrosion protection system acceptable to the owner. The post-tensioning supplier can help in this matter.

3. Use the project specifications as much as possible to control the heating. Precast curing specifications work well.

4. Exercise very rigid quality control procedures. During cold weather, epoxy will appear to harden but will soften as the temperature rises. Be very careful about satisfying the minimum required heating time to insure that the epoxy in each joint is completely hardened.

5. Develop a system with durable materials. When it is very cold outside, workmen usually take less time to care for equipment.

6. Limit the concrete temperature range to one epoxy formulation temperature range. Overlapping epoxy formulations could cause the epoxy to go off too fast due to high temperâtures or harden too slowly due to low temperatures.

7. Make the system simple and easy to follow. Both the initial cost and the cost of correcting mistakes will be lower.

After being delivered over completed portion of bridge, segment is lowered into place, making superstructure 77 ft (23.5 m) in one directional cantilever.

REFERENCES

1. Muller, Jean, "Ten Years of Experience in Precast Segmental Construction," PCI JOURNAL, V. 20, No. 1, January-February 1975, pp. 28-61.

2. Barker, James M., "Construction Techniques for Segmental Concrete Bridges," PCI JOURNAL, V. 25, No. 4, July-August 1980, pp. 66-86.

CREDITS

Owner: National Park Service.

Contract Administrator: Federal Highway Administration, Region 15, Sevierville, Tennessee.

Segmental Construction Expertise and Designer: Figg & Muller Engineers, Inc., Tallahassee, Florida.

General Contractor: Jasper Construction Co., Plymouth, Minnesota.

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NOTE: Discussion of this paper is invited. Please submit your discussion to PCI Headquarters by May 1, 1983.