FORM INSULATION FOR BRIDGE CONCRETE

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The Bridge Construction Division first allowed fastening of insulating blankets to concrete bridge forms to obtain proper curing temperatures under winter conditions, when permission was granted to use insulated forms as an alternate to the specified method of heating and housing the concrete, in an addendum to specifications dated January 23, 1958, for the structure carrying I 94 (Edsel Ford Expressway) over the Detroit Terminal Railroad (X14 of 82-22-10). This addendum covered the required type of insulating blanket and proper procedures for application of such blankets.

As a result of this development, the Research Laboratory Division, in cooperation with the Bridge Construction Division, organized a program to study the properties of insulating blankets and concrete curing temperatures when such blankets were used, as a background for preparation of supplemental specifications.

For the first test, in March 1958, the Bridge Construction Division selected an I 96 structure near Portland, where pouring operations were in progress. Subsequently, a second test was conducted on another I 96 bridge project near Portland in July 1958, to obtain summer data for interpretation and comparison with the winter test results. Finally, a third test, for additional winter pouring data, was provided on a US 27 structure in Lansing, in February 1959.

The Department's Supplemental Specification 5.01.17 (Protection of Concrete), dated May 15, 1959, contained the following provision: "When depositing concrete against previously cast concrete, the blanket insulation shall be extended at least 14 inches and securely held in place against the previously cast concrete." This provision was added as a result of the first I 96 study, which indicated that new wall concrete poured against unprotected footing concrete, previously cast, cooled very rapidly due to the "cold reservoir" beneath it.

The data accumulated during this study were reported informally after preliminary analysis. This report provides a summary of the field results and states the resulting conclusions.

Keefer Rd Overpass over I 96 (S04 of 34044)

The first project studied was an abutment of an overpass located about 2 mi west of Portland. Heat liberation during the period of cement hydration was measured under winter construction conditions, in March 1958.

The abutment was constructed of concrete containing 5.5 sacks of Peerless air-entraining portland cement per cu yd. Nine thermocouples were installed to measure concrete temperatures, located as shown in Fig. 1. A tenth thermocouple measured ambient air temperature. A continuous record of both concrete and ambient temperatures for the first seven days, while the abutment was protected with insulated forms, was made with a Leeds and Northrup automatic temperature recorder.

The forms were fabricated of 3/4-in. plywood backed by 2- by 4-in. vertical wood studs spaced at 12-in. intervals. Spaces between the studs were filled with 2-in. thick Cell-U-Forms manufactured by the Wood Conversion Co. of St. Paul, Minn. Fig. 2 shows the abutment with the insulation in place, and the top of the abutment was covered with 5 to 6 in. of straw as shown in Fig. 3.

At the time of pouring the air temperature was 38 F, and during the seven days of full protection, the blanketed abutment was exposed to air temperatures ranging from 26 to 45 F. Maximum concrete temperatures and maximum temperature drops recorded in four and seven days are listed in Table 1. Temperatures within the concrete as placed varied between 55 and 62 F, during pouring. During the ensuing seven days, as shown in Fig. 4, recorded temperatures ranged from a low of 41 F to a high of 120 F. Maximum temperatures were reached in 24 hr or less at seven of the thermocouple locations, and in about three days at the other two locations.

Thermocouples 4, 5, and 6, placed on the centerline of the abutment, registered maximum temperatures of 96, 115, and 120 F, respectively, in 24 hr. These temperatures dropped gradually to 56, 66, and 69 F, respectively, by the seventh day when the forms were removed. Thermocouple 3, located at an upper corner beneath the forms, reached a maximum of 86 F in 24 hr, dropping gradually to 51 F at the end of the seventh day. On the other hand, Thermocouple 9, placed at a lower corner, did not exceed 48 F at any time.

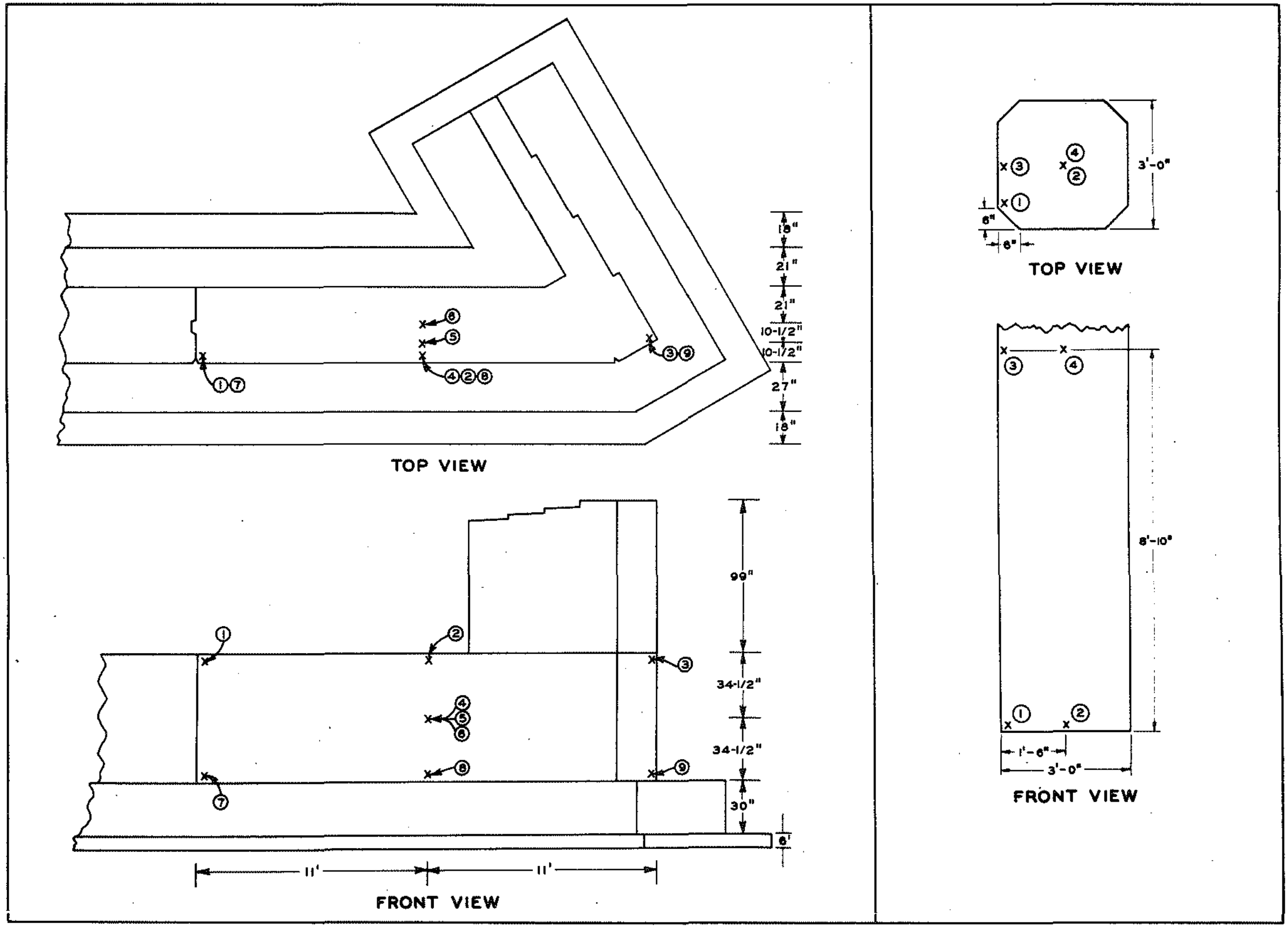

Figure 1. Thermocouple locations on concrete abutments (left, I 96 Overpass over Keefer Rd and M 66-State Rd Overpass over I 96) and on a concrete pier (right, US 27 Overpass over C&O Railroad).

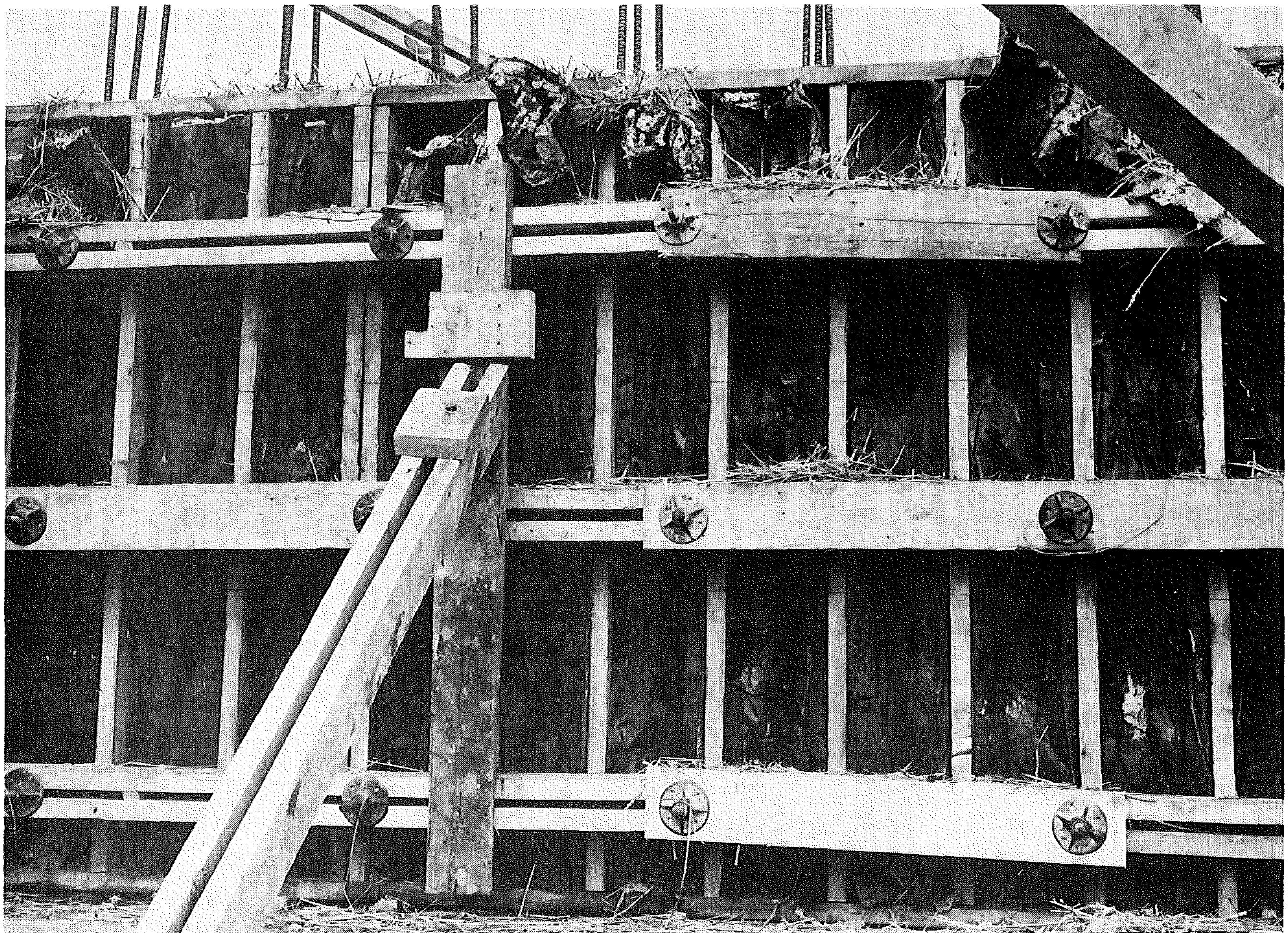

Figure 2 (above). Concrete abutment with insulating blankets in place.

Figure 3 (left). Top of the abutment showing surface covered with straw to retain heat; reinforcement rods project above straw.

TABLE 1
CONCRETE TEMPERATURES ON THE
I 96-KEEFER RD OVERPASS (S04 of 34044)

Thermocouple Location*	Maximum Temperature, deg F	Maximum Temperature Drop, deg F	
		in 4 days	in 7 days
1	74	1	1
2	78	13	35
3	86	17	35
4	96	20	40
5	116	30	50
6	120	30	51
7	58	1	8
8	54	0	7
9	47	0	6

* See Fig. 1 for schematic diagram of thermocouple locations.

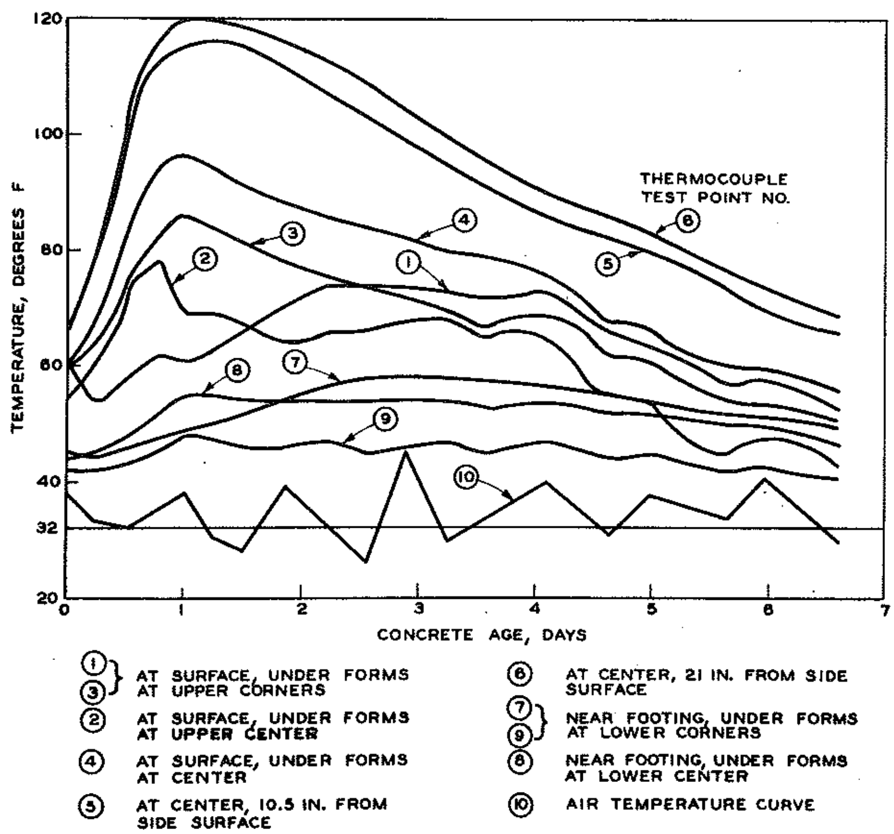

Figure 4. Temperature changes in abutment due to heat liberation of cement (winter work: I 96 overpass over Keefer Road).

M 66 (State Rd) Overpass over I 96 (S01 of 34044)

At the second site, concrete temperatures were measured during and after construction of an abutment for an overpass located about 4 mi west of Portland. The measurements were obtained under summer construction conditions in July 1958, for comparison with the data obtained the preceding March.

Concrete for this abutment contained 5.5 sacks of Aetna portland cement per cu yd. Nine thermocouples also were installed in the mass concrete here, at the same locations shown for the earlier abutment in Fig. 1. Again, a tenth thermocouple was used to measure air temperature. Temperatures of the concrete and air, however, were recorded for four days rather than seven (as had been the case in March).

The forms were of the same type used in March, and the curing method conformed to the then-current specifications for summer bridge construction without the use of any thermal insulation. The forms remained in place for 19 hr, the removal occurring within the period of 12 to 48 hr after pour specified for construction under normal conditions.

Air temperature ranged from 59 to 83 F during the four-day test period (102 hr from start of pouring). The temperature of the concrete during pouring varied from 75 to 85 F. These temperatures and those for the thermocouples recording at the center, top surface, corners, and footing are shown in Fig. 5. In this summer construction, temperatures at all nine thermocouples in the concrete reached maximums in slightly less than 24 hr, or shortly after removal of the forms. Records may be noted for two thermocouples placed within the concrete 34.5 in. from the abutment top:

1. Thermocouple 6, located 21 in. from a vertical surface, recorded the greatest heat measured, a temperature of 142 F maintained for 7 hr.

2. Thermocouple 5, located 10.5 in. from a vertical surface, recorded the next highest temperature, 135 F maintained for 3 hr.

Although the removal of forms occurred within the period allowed by specifications, the curves in Fig. 5 show that large temperature gradients were created between the interior of the abutment and its exposed outer surface.

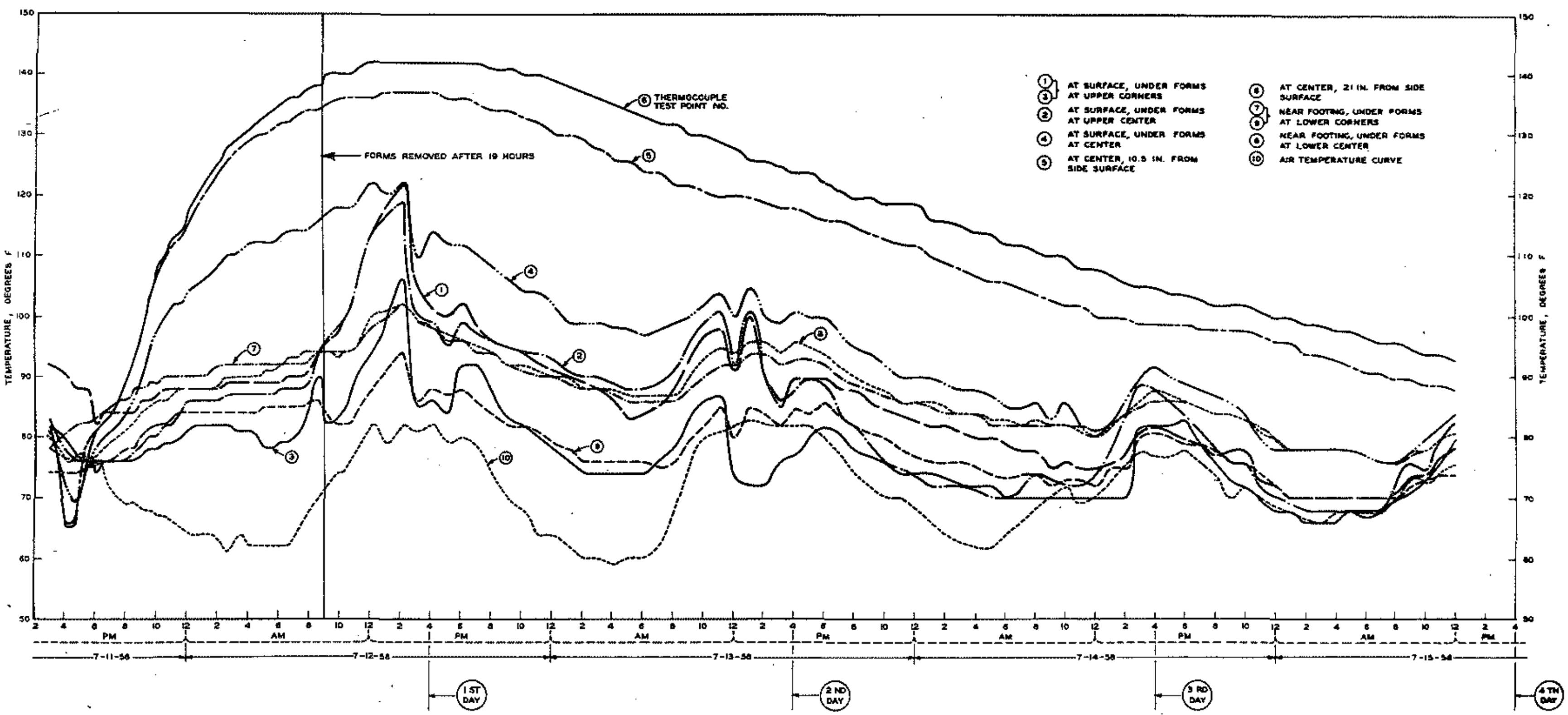

Figure 5. Temperature changes in abutment due to heat liberation of cement (summer work: M 66 Overpass over I 96).

Table 2 gives maximum concrete temperatures and temperature drops (following form removal), which indicate that the heat evolved during the early period of hydration was not properly controlled.

TABLE 2
CONCRETE TEMPERATURES ON THE
M 66-STATE RD OVERPASS (S01 of 34044)

Thermocouple Location*	Maximum Temperature, deg F	Maximum Temperature Drop, deg F	
		in 2 days	in 4 days
1	122	39	52
2	119	31	51
3	106	32	40
4	122	25	46
5	137	18	49
6	142	16	49
7	102	16	26
8	102	15	26
9	94	18	24

* See Fig. 1 for schematic diagram of thermocouple locations.

US 27 Overpass over the C&O Railroad (X01 of 33034)

The last of the three projects studied involved a pier for an overpass in northern Lansing, constructed in February 1959, where winter data might be obtained for comparison with winter construction of the I 96 abutment built a year earlier and also using insulated forms.

The pier was constructed of concrete containing 5.5 sacks of Huron Alpena air-entraining portland cement per cu yd. The wooden forms were lined with Cell-U-Form blankets in accordance with specifications, without any enclosure or external heat. As in the other winter study, forms were stripped after seven days. Continuous records of temperature were obtained here, however, using only five thermocouples rather than the ten used for both of the other two projects studied (four in the concrete and one for ambient air temperature).

Air temperature ranged from 1 to 38 F. Concrete temperatures for the pier top and bottom, surface and center, are shown in Fig. 6, and the maximum temperatures and maximum temperature drops are given in

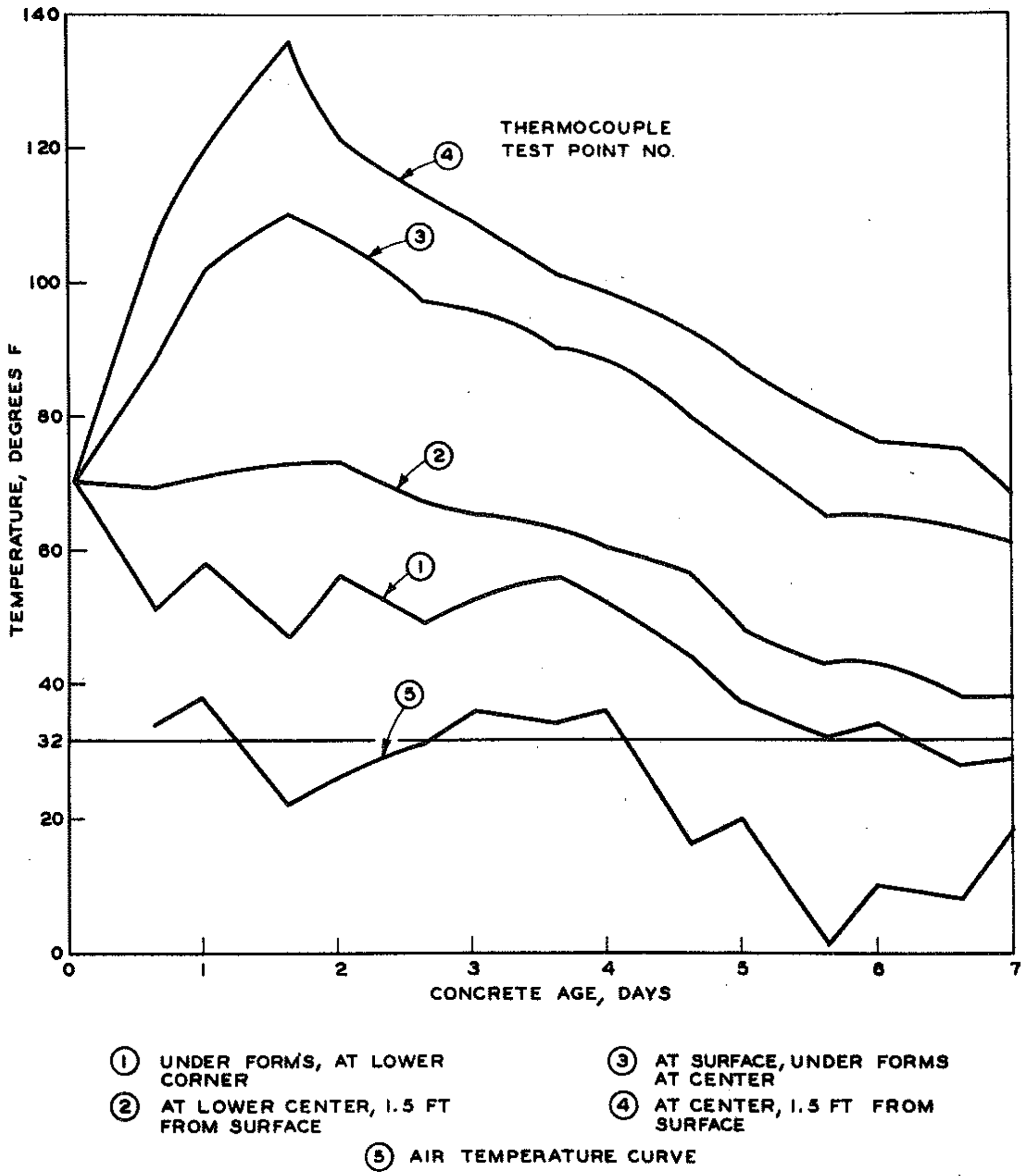

Figure 6. Temperature changes in a concrete pier due to heat liberation of cement (winter work: US 27 Overpass over C&O Railroad).

Table 3. Although all four thermocouples registered 70 F an hour after concrete was placed, Thermocouples 2, 3, and 4 did not show maximum temperatures until 1.5 to 2 days later. The initial 70 F temperature was maximum for Thermocouple 1, and at its lower corner location the temperature dropped gradually to 29 F over a period of seven days. This was the lowest temperature recorded within the concrete, the highest being 136 F for Thermocouple 4 in pier's top center.

TABLE 3
CONCRETE TEMPERATURES ON THE
US 27-OVERPASS (X01 of 33034)

Thermocouple Location*	Maximum Temperature, deg F	Maximum Temperature Drop, deg F	
		in 4 days	in 7 days
1	70	23	41
2	73	13	35
3	110	22	49
4	136	38	68

* See Fig. 1 for schematic diagram of thermocouple locations.

Summary

In cold weather, the danger of freezing at the edges and corners of newly cast mass concrete should be reduced by special protection of these critical areas. Extra insulation is particularly desirable when air temperatures below 50 F are expected. The most critical period for proper setting of concrete placed during cold weather is the first three days, and the primary object of insulating forms is the retention of heat produced by hydration of the cement, so as to maintain temperatures well above freezing during this period at all points in the mass concrete. Forms may be removed when the rate of concrete temperature decline will not exceed critical limits.

Two fundamental points of concern in using insulated forms are the following:

1. Establishing an allowable rate of surface temperature decline--for example, current specifications call for 30 deg per 24 hr as the limiting rate for low temperature housing and heating protection, and 20 deg per 24 hr for insulation of forms.

2. Limiting the maximum temperature induced at the center of the mass to a level that will not prevent proper setting or development of intended strength and soundness. Current specifications state that increase of this temperature should not be excessive.

Significant results of this study are summarized in Fig. 7, where the bars represent average cooling rates in degrees Fahrenheit per day for the three concrete pours studied. These graphs show that cooling rates in the case of the summer project reached near-specification limits in two days at four of the thermocouple locations. On the other hand, the cold weather concrete pours do not show severe cooling rates at those locations where thermocouples were installed.

The temperature graphs in Figs. 4 and 6 indicate that adequate protection was not maintained at the lower corners of either cold weather concrete pour, and in some instances protection was also inadequate at side surfaces. This indicates the need for additional protection at these critical points.

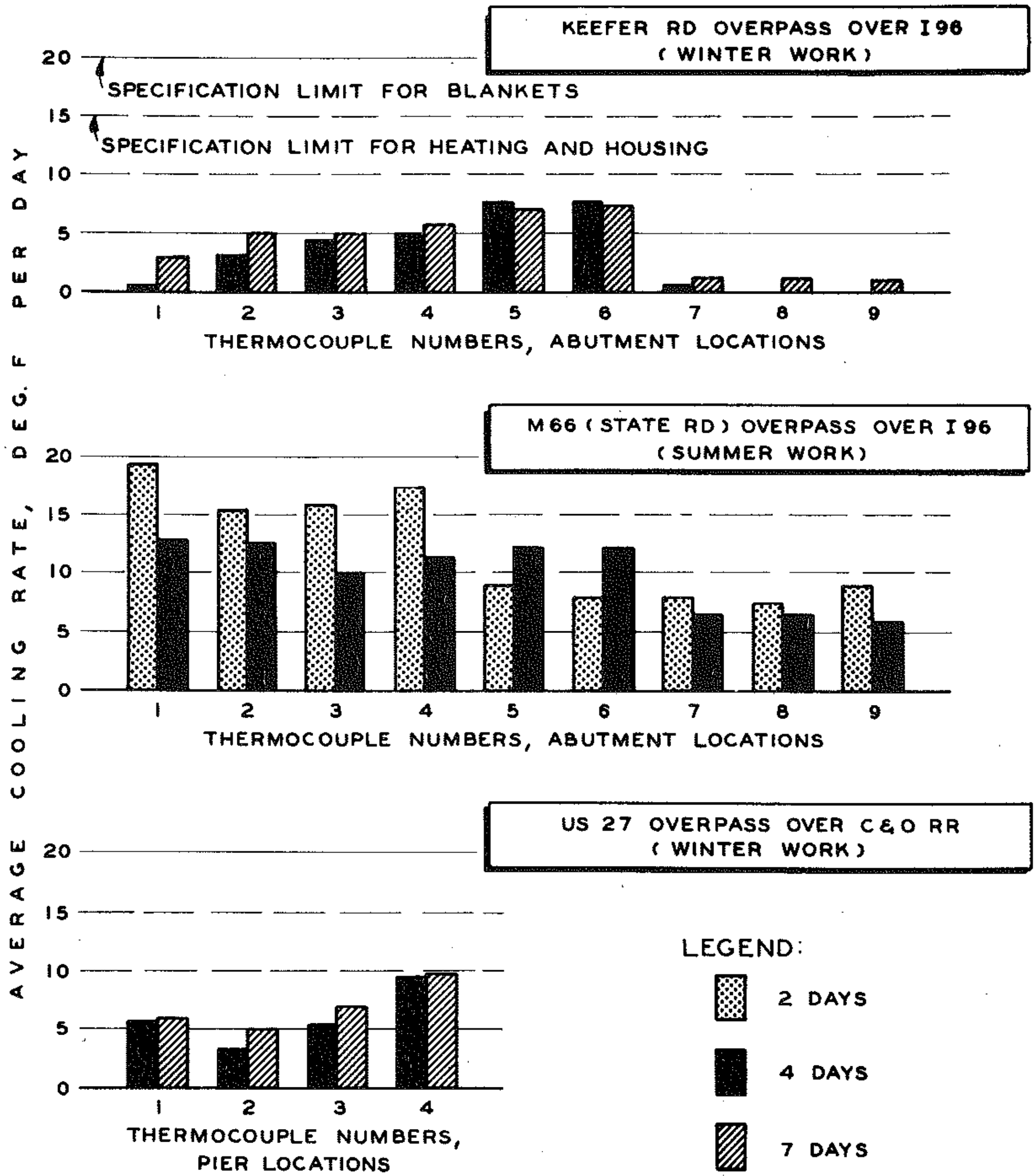

Figure 7. Comparison of average cooling rates among three different concrete structures; see Fig. 1 for thermocouple locations.