Winter Bridge Building With Relief Labor

Concrete-arch structure about 1,000 ft. long built in Saskatoon, Canada, during period when temperature range was from zero to 40 deg. below—Aid to unemployed was substantial—Continuous concrete temperature readings kept

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WHEN IN 1931 it was proposed to undertake, under the auspices of federal, provincial and municipal authorities, a program of public works for relief purposes, the city of Saskatoon selected a bridge project over the South Saskatchewan River. A reinforced-concrete structure of five deck arches, with girder approaches, was designed for the site selected. It was to be known as the Broadway Bridge. The project contains several elements of technical interest both in its design and construction, and in addition is of importance because of its relief labor aspects.

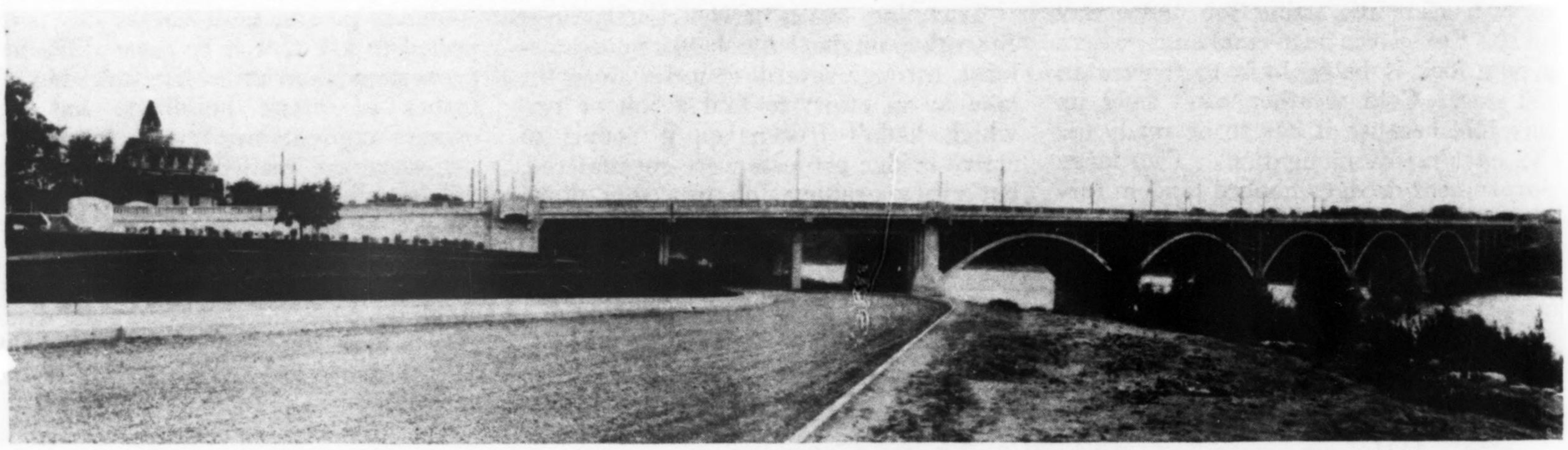

FIG. 1—BROADWAY BRIDGE, Saskatoon, Saskatchewan, built in eleven months by a contractor using relief labor and hand methods. Work carried on through severe winter. View taken downstream.

The conditions set down by the authorities handling relief added greatly to the natural difficulties of the job. In the first place only a month was available between the time the project was authorized and the letting of the contract on Dec. 12, 1931. The year allowed for completion was further restricted owing to climatic and fluvial conditions which made it necessary to build the cofferdams and construct six piers, involving 9,000 cu.yd. of concrete, within a period of eleven of the most severe winter weeks, with the average daily temperature below zero most of the time and minimum temperatures of 40 deg. below zero prevailing for several days. Furthermore, the flood conditions of the river in June made it impossible to construct falsework in the river until early in July, and since subfreezing temperatures are common after the middle of October, the construction period for such work also was limited. Moreover, all labor had to be obtained on requisition from the relief office, and the use of machinery was restricted.

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Design elements

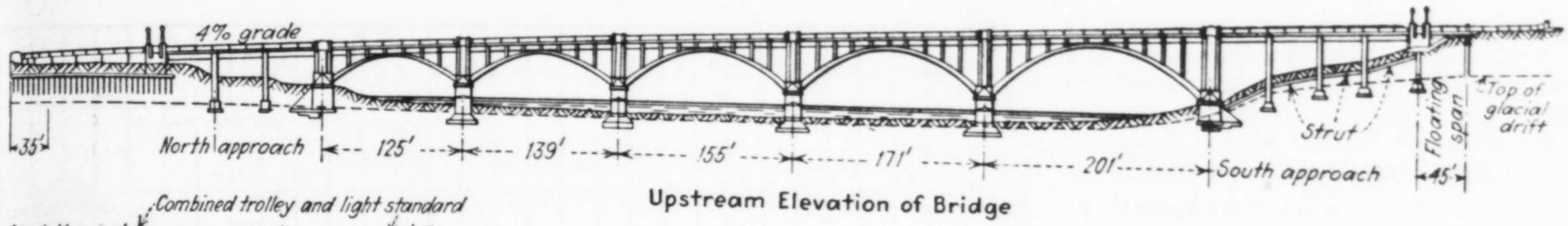
At the bridge site the elevation of the existing street intersection on the south bank was approximately 63 ft. higher than on the north bank, some 1,300 ft. away, giving an indicated grade of nearly 5 per cent. The river at high water is more than 800 ft. wide. It was decided to limit the grade of the proposed bridge to 4 per cent. The concrete-arch type for the main bridge was selected as being best suited esthetically and also because it would provide the greatest amount of local employment. The difficult problem of proportioning a bridge to connect two points of different elevations was solved by placing all arch springing lines at the same elevation and making the arches of varying span, but with an approximately constant rise-span ratio. It was decided that no pretentious ornamentation, portals or pylons would be suitable on a relief project. It was further decided to emphasize the straight line of the deck, making it continuous and well defined by using a simple poured railing, a heavy sidewalk fascia beam and a simple curtain wall to fill in the space between the top of the arch crowns and the floor system. This gave a line about 11 ft. deep. The arch rings and piers are plain, and the floor system is carried to the two arch rings by simple columns.

On the south the bank rises steeply to 100 ft. above the river and has a tendency to slip, being a glacial drift of blue clay overlaid with layers of sandy clay and quicksand. As built, the south approach consists of four girder spans from 40 to 48 ft. long, supported on four-column bents which rest on pedestals in the glacial drift. Each bent is braced laterally, and in a longitudinal direction a continuous line of struts is used, about 8 ft. below ground surface. The design was made on the basis that if the four columns at the refuge bay (Fig. 2) acted as a solid retaining wall of a length equal to that of the entire width of the bridge, the pressure of the pedestals against the glacial drift on the bottom would prevent the base from moving and the struts would carry the thrust at the top of the columns northward to the abutment shore pier. The southernmost span was designed as a floating span resting on a cap supported by piles; it was completely separated from the main bridge.

The arches being of varying spans, the column and floor-beam spacing had to be varied from 16 to 19 ft. both for esthetic and mathematical reasons. Each floor beam was carried on four columns, two on each arch ring at 12 ft. 8-in. centers with the two inner columns at 18 ft. 4-in. centers. This arrangement gave nearly equal column reactions on the arch ring and, in designing, the weight was considered as equally distributed.

Expansion joints for the deck were located over the piers only on the arch spans and at split columns on the approaches, of which there was one set in each approach. On the arch spans the pilasters over the piers were built as a vertical cantilever completely separated from the columns and deck, which move freely under changes in temperature.

For the design of the columns at the expansion joints, the deck, columns and arch rings were considered as rigid frames. Excessive moments at the bottom of the shorter columns, which could not be relieved by bending in the columns themselves, were eliminated by



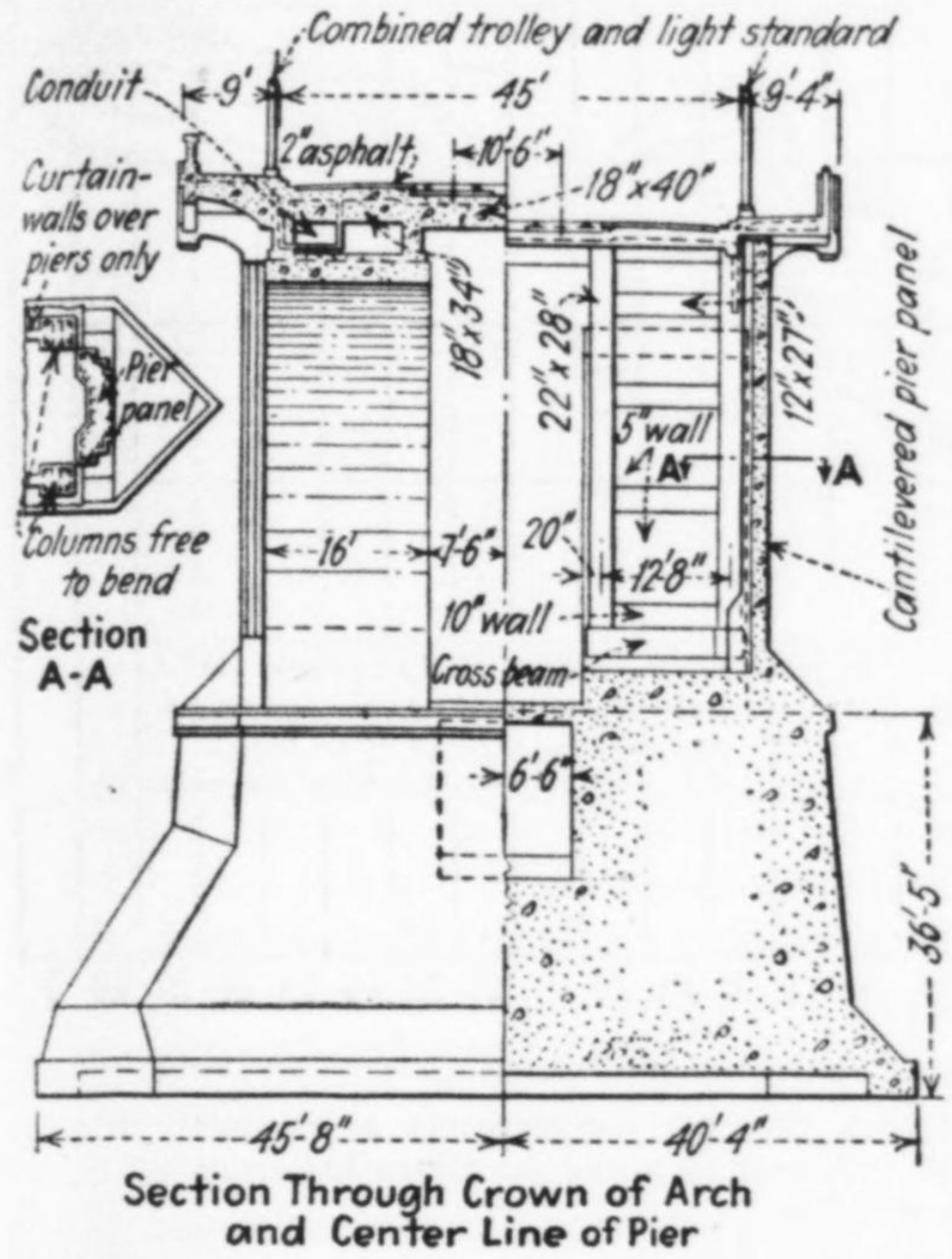


FIG. 2—ELEVATIONS AND SECTIONS of Saskatoon bridge. Built on a 4 per cent grade, arches have different spans but constant rise-span ratio.

using hinges similar in design to those used in Europe for arch rings.

In designing the arch rings the extreme temperature variation of the region (from 110 to minus 60 deg. F.) was taken into consideration, resulting in a wide, thin section. No allowance was made for deck participation.

Foundations for the bridge are carried on a glacial drift of boulder clay. The excavations extended about 10 ft. into this drift.

The construction period was divided naturally into three parts: first, winter—from Dec. 12, 1931, to the middle of March, 1932, during which time the river piers were constructed; second, the spring—from March to July, during which time floods caused work to be concentrated on the shore approaches; and third—the summer, from July to the middle of October, when the arch rings and floor system of the river spans were built.

Foundation construction

The river piers were inclosed in double-wall circular cofferdams made up of 6x12-in. tongue-and-groove sheetpiling with a clay puddle between. Excavation, under relief regulations, had to be done by hand, although air chisels were necessary to break up the drift. The excavated material was raised in buckets by hoists. Difficulty was encountered with ice which at one time rose to within an inch of the top of the cofferdam. A specially built combination piledriver and hoist, weighing about 12 tons, was for the most part moved directly on the ice, being carried on timbers which spread the weight over 280 sq. ft. An 18-in. thickness of ice was adequate to carry the load. In building the cofferdams a channel about 7 in. wide was cut with ice saws around the outline of the piers and the sheetpiling was set in place.

All concrete was mixed and placed under cold-weather conditions. Aggregates came from a pit 10 miles from the city, and great difficulty was encountered in keeping the roads open. Screening apparatus would not operate on the frozen material, and so pit-run gravel was accepted during the winter months. Crushed rock and a very fine sand had to be mixed with the gravel at the site to obtain a satisfactory grading. The pit-run material was analyzed from hour to hour, and the consistency of the concrete checked regularly by slump tests. The specified strength of 2,250 lb. per sq.in. was obtained by using 4.75 bags of cement to the yard with a maximum slump of 2 in. The aggregate was delivered by trucks directly on top of the aggregate shed, which was built into a side hill. Perforated 1½-in. steam pipes were laid at 6-ft. centers across the floor of the shed, and the aggregate was piled on top and heated to a temperature varying from 70 to 100 deg. F., depending on

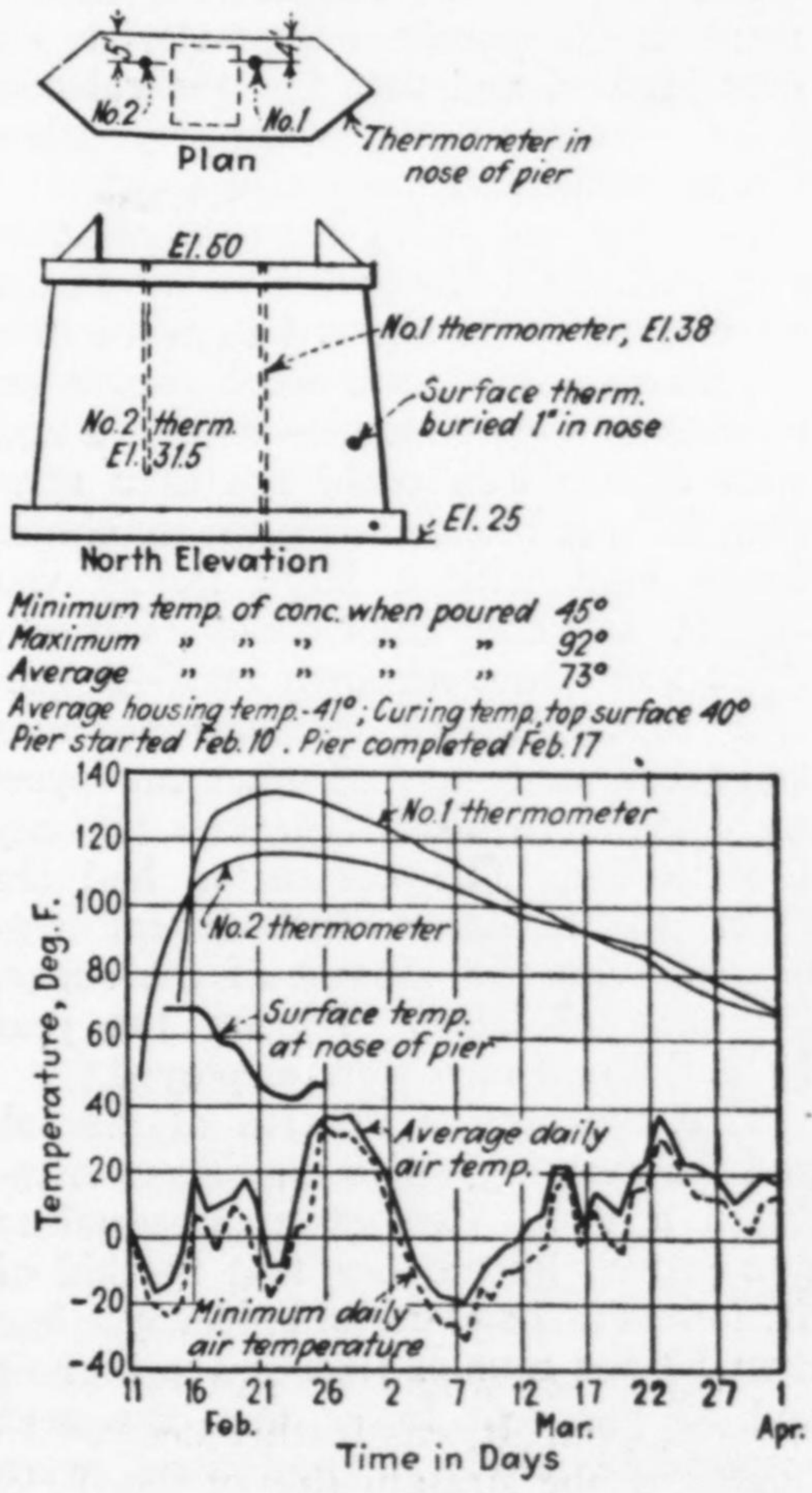


FIG. 3—CONCRETE TEMPERATURES in a typical pier from time of pouring, early in February, until April 1. Concrete was protected by tarpaulins while pouring, and thereafter by timber forms alone.

outside conditions. Mixing water also was heated.

Relief restrictions required that the concrete be wheeled by laborers from the mixers to the piers. For this purpose a trestle runway was built at the level of the springing line of the arches. The common procedure was to pour a 2-ft.-thick mat in the open directly against the clay, there being no side forms. The portion from that elevation to about river-ice level was also poured in the open without protection, but forms were built up as work progressed. The portion from ice level to springing line, about 25 ft., was usually housed in and heated by steam and stoves.

As typical of the work, concrete was poured for two days and three nights continuously with a temperature of about 25 deg. below zero. On this pier the concrete was wheeled about 1,000 ft. It left the mixer at an average temperature of 90 deg. and lost only 2 deg. in transit. As the concrete was dumped into the footings, the top exposed surface froze quickly, but the frost did not penetrate far since each layer was soon covered over with a heated mass and thus thawed out; there was no alternate freezing and thawing.

When forming was started, tarpaulins were used to cover the surface of one end while pouring was concentrated at the other. In the interior of the pier the temperature of the concrete rose rapidly and within a few hours stood at 100 deg. The forms alone gave such protection that the thermometer against the forms never read below 50 deg. In the center of all piers tubes were installed (Fig. 3), and temperatures read daily.

As soon as high water receded in the spring, work on the river spans was undertaken. Most of the falsework for supporting the arch rings was made up of spruce poles, 7 in. in diameter at the top for main members and 3½ in. for bracing members. As this material was obtained from northern Saskatchewan, it not only provided local labor but was economical, since after demolition it was sawed into firewood. The falsework material was delivered at the water's edge on the south bank, sorted and cut to length.

Protecting thin members

The last part of the work, the superstructure, presented some unforeseen difficulties, since the first two weeks of October, 1932, were the coldest on record, with an average minimum temperature of 23 deg. and an average mean temperature of 34.25 deg. Arrangements were made to heat the aggregates and mixing water, but it was not possible to protect the finished concrete. As the various members were poured, however, resistance thermometers with temporary leads were buried and a record was kept of the temperature maintained at the various points, to determine when and if forms might be removed. Concreting was under way on the floor slabs of one of the arches when the temperature started to drop (to a minimum of 18 deg.) The sidewalk, as it was finished, was covered with hot sand, sawdust and tar paper, but the road slab was too large to be protected in this manner. Fortunately there was available a steam boiler that had been used to heat the mixing water, and the only thing possible was to run hot water over the slab. This was done for three days and four nights until the weather moderated, and by this expedient the temperature in the center of the roadway was kept up to 56 deg. for the first day, 48 deg. for the second and well above freezing for the duration of the cold snap. No harm was done to the roadway, but the sidewalk was affected superficially at the curb edges. The hand rail was poured under these temperature conditions, and the top of the coping covered with tar paper, boards and manure. The forms, being quite heavy, also afforded protection.

Work on the street railway trackway on the center line of the bridge was complicated by the fact that curing as well as frost protection was necessary. The concrete aggregates and mixing water were both heated, so that concrete left the mixer at about 90 deg. In addition, calcium chloride was added to accelerate the setting. As soon as possible the trackway was covered with tar paper, carefully lapped, and this was covered with sand and manure. Air temperatures were from 10 to 12 deg. The temperature at the surface of the pavement went down from 90 deg. on the first day to 60 deg. by the fifth day. Since the temperatures inside the slabs were undoubtedly much higher, it is felt that satisfactory curing was obtained as there was little loss of moisture through the tar paper. The tar paper and manure were kept on for a month, and after a year's use the roadway is in excellent condition.

When pouring the floating approach span, temperatures of 10 deg. below zero were experienced. Special high-early-strength cement was used, and all aggregates and water were heated so that the concrete went in at 90 to 100 deg. As soon as the surfaces hardened they were covered immediately with tar paper and manure. Twenty-four hours after the slab was poured the street-railway track was laid and the trackway pavement poured. In 48 hours the asphalt pavement was placed on the roadway portions and a 10-ton roller carried without any damage. Temperatures on the surface were maintained

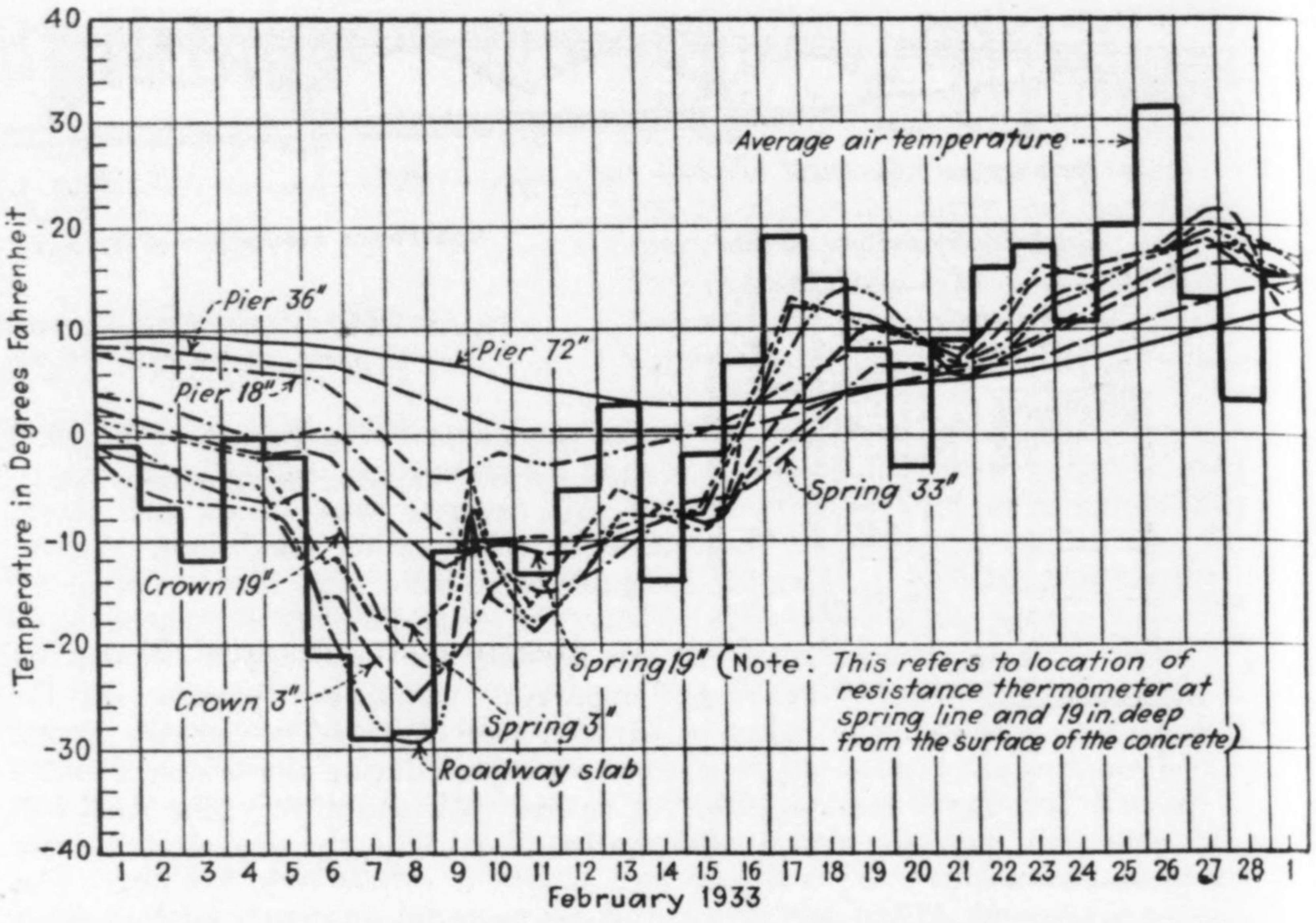


FIG. 4—COMPARISON of air temperatures with concrete temperatures at various points in finished structure. Moderating effect of river is noted on those locations near the water surface.

well above 70 deg. for several days, and in the center of the 24x48-in. stringers the temperature was over 100 deg.

The bridge was opened for traffic on Nov. 11, 1932, less than eleven months after the contract had been awarded.

Labor handling and cost items

Since at least 50 per cent of the expenditure was for local labor, it was decided that the city engineering department should purchase all materials except lumber, and that the general contract would be essentially for labor, lumber, tools and small equipment.

All workers, with the exception of one lead man in ten, were to be rotated, no worker to be allowed to work over ten hours a day or to work over a set number of days a month—that is, a man with no children could not earn more than $25 per month, while the maximum for a man with a large family was $37.50. The contractor could select only three men from his own staff—a general superintendent, general foreman and accountant—and all other employees were to be requisitioned from the city relief office. The contractor had the right to discharge incompetent employees with the consent of the superintendent of labor. During the year 1593 different men were employed.

That the natural hazards of the job and the exacting relief conditions introduced a great element of uncertainty was proved by the fact that the bid of the lowest and successful bidder was less than 50 per cent of that of the highest and 33 per cent lower than the next responsible bidder. Quotations were asked in which the use of machinery was allowed also, and it was notable that the bids of the successful bidder under both conditions differed only slightly.

The cost of the bridge proper, exclusive of the street alterations at the approaches, was $640,000, of which $324,000 was paid in wages to residents of Saskatoon. This works out at a cost of $7.30 per sq.ft. for the entire bridge.

In one of the typical river piers actual costs were as follows: for excavation $3.60 per cu.yd.; for concrete, including all overhead expenses, $4.86 per cu.yd., made up of forming ($1.82), mixing, pouring, transportation and placing ($2.06), heating and protection (98c.) The total cost of the cofferdam was $3,914.

For the concrete in the superstructure the figure of $10.20 per cubic yard, as bid, was slightly over the actual cost.

The Arrand Construction Co., Saskatoon, was the general contractor.

Temperature readings were taken during 1933 from thermometers buried in the arch ring in a pier and in the floor system. The range of air temperatures during the year varied from a minimum of 36 deg. below zero to a maximum of 103 deg. in the shade.

One of the general conclusions arrived at is the surprising effect of the temperature flow from the water in the river through the pier and up through 100 ft. of arch ring to the crown at an elevation about 75 ft. above the water. In February (Fig. 4) when the minimum air temperature was 36 deg. below zero, the roadway slab went to 30 deg. below zero, but the mean daily temperature at the center of the arch crown was never lower than 22 deg. below zero, nor that at the center of the springing tower lower than 10 deg. below, nor that at the center of the 72-in depth in the pier lower than 3 deg. above zero. Also, in the hot periods of the summer the temperature of the crown and springing sections did not get within about 20 deg. of that obtained in the floor system.