THE DETERMINATION OF INTERNAL TEMPERATURE RANGE IN CONCRETE ARCH BRIDGES

BULLETIN No. 30 of the Iowa State College, engineering experiment station, contains a treatment of this subject by Messrs. C. S. Nichols, assistant director of the station, and C. B. McCullough, assistant engineer, Iowa Highway Commission. The experimental data from which their conclusions were deduced, relates to observations on a number of concrete structures, taken by themselves and others during the past four years. The report contains the results in detail, while only the introduction and the conclusions arrived at are published herein.

The use of the arch in bridge construction dates back over two thousand years, although it was not until the latter part of the nineteenth century that reinforced concrete was used for such structures. The invention of this type of construction is generally conceded to Joseph Monier, of Paris, the date of the building of his first arch bridge usually being given as 1867. In the year 1894 F. Von Emperger introduced the "Melan" system of reinforced concrete arch construction into this country, and built the first reinforced concrete bridges of considerable span. Edwin Thatcher was also a pioneer in this work, building bridges as early as this date.

While it is thus seen that the use of reinforced concrete in arch bridges is of comparatively recent date, yet the growing sentiment in favor of it, because of its peculiar esthetic value, is so great as to warrant the belief that this type of structure as a highway bridge will not be replaced by staticly determinate structures, at least not within the lifetime of the present generation of bridge builders.

One of the main arguments used against the adoption of this type of construction is our present limited knowledge of the actual internal forces for which the structure should be designed. Particularly is this true of the range of internal temperature. The immediate necessity for an investigation of this temperature range in arch bridges was therefore manifested in two ways:

(1) There is at present a very great diversity of practice among our western bridge companies in allowing for internal temperature variation in their arch bridge design. It has been ascertained, from good authority, that several of the prominent construction companies of the West are designing their structures to withstand temperature variations of from 15 degrees to 30 degrees F. each way from normal. Others are allowing a fixed percentage of the dead load stresses, this generally being, in highway construction, from 10% to 20 %, while analysis according to the elastic theory for the range to be expected in this latitude gave temperature stresses (in the case of one arch) as high as 206% of the dead load stresses at the crown, and 123% of the dead load stresses at the spring time.

One of the prominent concrete engineers of the east wrote: "We allow, in this latitude, (New York) or anywhere in the northern states, a range of 40 degrees in temperature, or 20 degrees each way from the mean. This may or may not be sufficient."

(2) There are scarcely any available experimental data on the range of temperature in concrete having a direct bearing upon the design of reinforced concrete arch bridges. The replies to a large number of letters sent out prior to the beginning of the tests, brought out very strikingly the fact that, while there were considerable available data and many theories concerning the expansion and contraction in concrete, yet very little was known concerning the actual internal variation of temperature in concrete structures.

Conclusions.—From the results, the writers draw the following conclusions:

I. The yearly range in temperature in a reinforced concrete arch structure, typical of the highway arch construction in this State, is, in this latitude, not far from 80 degrees F.

II. The relation between the depth of concrete covering at any point and the yearly temperature range may be obtained from a curve plotted from the results obtained on bridges under test. The curve that most nearly passes through the centre of the results can be represented by the equation

$$y = 90 - \frac{53}{100} x$$

wherein y = the yearly temperature range in degrees Fahrenheit, and
x = the distance from the nearest exposed surface in inches.

However, the effect of the different factors, such as the presence of a water surface, direction of prevailing winds, etc., so modify the results that the writers prefer to state their conclusions as in I., giving an average value for points throughout a structure of this type.

III. The amount of direct sunlight modifies somewhat the actual temperature in the concrete for a considerable distance into the interior of the mass, although, on account of the meagre nature of the data gathered, no definite conclusion can be stated.

IV. The data seem to show that in structures of this type the minimum temperatures are attained in time intervals anywhere from less than one day to four days after the atmospheric minimum. This interval depends upon the position of the portion of the structure considered, and is roughly proportional to the distance from the nearest exposed face.

V. Because of the high temperature in the concrete when it attains its set, and the effect of atmospheric temperature upon this maximum, other conditions being equal, the pouring of an arch ring at a temperature near the atmospheric mean annual operates to materially lower the stresses in the ring induced by temperature variation.

VI. When uninfluenced by other factors than atmospheric variation, the rise and fall of an arch ring agree quite closely with theory.

VII. The shrinkage of concrete, if unrestrained by reinforcing, amounts, in 100 days after placing, to about 4/1000 per cent. This induces bending stresses analogous to those produced by a temperature drop, but these are so modified by the initial stresses due to shrinkage that the chief effect is to cause a high compression in the steel on the compression side of the bending. When, due to other forces acting on the structure, a high compressive stress in the steel is encountered, the effect of this shrinkage should be carefully studied.

VIII. To render an arch ring structurally safe, provision should be made, in this latitude (Iowa) for stresses induced by a temperature variation of at least 40 degrees F. each way from an assumed temperature of no stress. Particular circumstances may demand that a greater variation be used for drop in temperature to prevent the appearance of cracks. This will always remain largely a matter of judgment with the designing engineer.