Early Age Temperature Distributions in Concrete Bridge in the Middle of Iraq (Experimental Study)

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Abstract: The temperature difference between the inside and outside of the concrete bridge causes the appearance of early cracks in the concrete bridge. The thermal cracks are appeared on surfaces or inside the bridge body. The sources of the thermal loads come from solar radiation, air temperature, wind speed, and the heat of hydration of cement after pouring concrete (at the early edge of concrete). Concrete T-section used to study the temperature distribution at the early edge, fourteen thermocouples used to measure the temperature during the day; these thermocouples were placed in the different location inside the concrete bridge as well as on its surface. The temperature-time curves were obtained for each thermocouple, from these curves it was found that the effect of cement hydration on the internal temperature was during the first 48 hours, while the effect of solar radiation was evident during daylight hours on the top surface of the model. The effect of solar radiation continues while the effect of cement hydration vanished after 48 hours.

Keywords: Concrete bridges, solar radiation, thermal loads, temperature distribution, and cement hydration.

1. Introduction
Concrete structures are affected by many factors, including thermal effects and thermal loads. In early ages, surface cracks are often caused by the evaporation of water, but there are internal cracks that result from nonlinear temperatures. The heat sources to which any bridge is exposed is either external, such as solar radiation and air temperature, or internal, such as the heat of cement hydration after casting of concrete, which is limited in the early ages. Therefore, the sources of heat in the early ages are more, and in return, concrete is weaker to withstand the stresses that result from the heat. Therefore, it produces a group of cracks that are inside or outside the concrete section[1,2]. The rising temperatures are not considered to cause cracks but cracks are caused by the difference between surface temperature and core temperature [3]. In early ages, the cracks that occur are not dangerous, but over time, the concrete deterioration increases, and as a result, the life of the concrete bridge decreases [4].

Choi et al. [5] studied the effect of many factors on temperature and relative humidity in the early ages of a composite bridge under the influence of environmental loads. The temperatures of the composite section were measured by eight thermocouples, four of the thermocouples placed in the concrete slab and four placed on the steel section. For studying the effect of different factors (solar radiation, air temperature, thermal conductivity coefficient, and compressive strength), a theoretical study was done for the composite
bridge. The authors concluded that the effect of solar radiation is greater than the air temperature on the distribution of temperature and humidity in early ages. Chen et al. [6] studied temperature distribution and thermal stress in the early ages of a prestress box girder bridge in the field. The authors divided the periods of heat resulting from rehydration in concrete into four stages. The first stage in which there is a rise in temperature, then the second stage comes which reflects the stability in temperatures. While, the third stage shows a rapid decrease in temperatures, and finally the fourth stage has a slow decrease in temperature. The authors concluded that the temperatures due to rehydration of cement might cause thermal stresses that result in cracks in the prestress box girder section. They also found that the temperature distribution is linear and changes according to the environmental conditions (air temperature, solar radiation, wind speed, relative humidity) during the day, and from these changes, fluctuations in the thermal stresses that may result in cracks occur. Krauss and Rogalla [7] presented a report about the cracks resulting from thermal stresses as well as temperature distribution in different bridge sections. They recorded many factors that effect on the cracks caused by thermal stresses, especially in early ages, as they showed that thermal stresses in early ages from hydration have a great effect on composite bridges and composite concrete bridges (when casting the concrete deck slab after casting concrete girder such as precast bridges). Figure 1 shows the distribution of the thermal stresses resulting from the temperatures, the first model in which the thermal stresses are less than the other models. The second model produces acceptable stresses in the concrete surface, but in the steel girder bridge the stresses were 53.4 MPa and 17.2 MPa that are considered influential and cannot be neglected, the third model of temperature gave a tensile stress of 5.9 MPa, this stress is sufficient to result in crack. Abid et al. [4] studied temperature distribution in a concrete box girder at an early age. The duration of the study continued for fourteen days after concrete pouring. The temperatures were measured in the model using forty-eight thermocouples in conjunction with the external environmental effects (sunlight, air temperature, wind speed). The authors concluded that the heat of hydration had a significant effect within 48 hours after casting of the concrete and vanished after four to five days. They also noted that the temperatures of the thermocouples were greatly affected by the external conditions (sunlight, air temperature, and wind speed) more than the heat of hydration for the thermocouples near the surface, while the thermocouples in the core of the concrete are affected by the heat of hydration more than the external conditions. William et al. [8] studied a composite bridge (steel I beam with concrete deck slab) in West Virginia, the bridge is consisting of three spans and a total length of 44.8 meters. Two hundred and thirty-two sensors were placed to measure the temperature, strain, expansion and contraction of the span, and cracks width in the concrete slab of bridge, these data were recorded every thirty minutes. The results identified four reasons for the development of cracks in the concrete slab. One of these reasons was the thermal stresses in the concrete slab during the first days of the bridge’s life, and the second reason was the irregular lateral temperatures distribution in the concrete slab. They also concluded that the stresses resulting from the shrinkage and the temperature changes are relatively high when compared to the stresses resulting from the traffic loads. Lee [9] presented three reasons that lead to the collapse of prestress concrete girders during the construction stage, as shown in Figure 2. One of these reasons is the lateral camber deformations of the prestress girder, this reason results from construction errors. The second reason is the deformations resulting from changes in the temperature distribution, finally, the slope of the support.

From previous research, it can be found that the temperature distortions in early age and other age do not lead to the collapse of the bridge, but contribute clearly to the deterioration of the bridge and reduce its life. The study aim is to study the thermal changes occurring in the early ages of the T-section concrete bridge in the middle of Iraq. For this purpose, the thermocouples were used to measure the temperature inside the model, and on its surface, the model was connected to a weather station to continuously monitor temperatures of thermocouples, solar radiation, air temperature, and wind speed, to understand the changes that occur in the early ages.
Concrete Properties:
modulus of elasticity of 27.6 MPa (4,000,000 psi), Poisson’s ratio of 0.2, coefficient of thermal expansion of 0.0000012/°C (0.0000005/°F).

Steel Properties:
modulus of elasticity of 20 GPa (29,000 ksi), coefficient of thermal expansion of 0.00000012/°C (0.00000005/°F).

Concrete Deck Geometry:
Unreinforced, 210 mm (8.3 in) thick, 3 m (11 ft) wide.

Steel Girder Geometry:
area of 750 cm² (116 in²), moment of inertia of 7x10⁶ cm⁴ (168,000 in⁴).

Figure 1. Thermal stresses in composite bridge section for different models of temperature [7].

Figure 2. The collapse of prestresses concrete girder [9].
2. Experimental Work
Experimental works included casting a segment of T-section concrete-segment. Figure 3 shows the dimension of the concrete segment. The segment total length was 1000 mm and the other dimensions are shown in Figure 3. The framework was made of plywood; the concrete mixture used to cast the specimen was 1: 1.5: 3 and the water-cement ratio was 40%. The segment casting ended at 1 p.m. on 29-September-2020.

The thermocouples used to measure the temperature, the thermocouples were placed in the specific location of each one as shown in Figure 3. Table 1 shows the location of thermocouples. The total number of thermocouples was fourteen; ten thermocouples were installed in the centerline of the section, two thermocouples fixed at the middle of each surface of the web, and the last two set at the bottom surfaces of the flange. The concrete was cast as shown in Figure 4. All the sides of the concrete slab and the ends of the web were completely isolated by using foam to make the sample turn out to be an internal bridge and to prevent heat transfer from these faces as shown in Figure 5.

![Figure 3](image1.png)

**Figure 3.** The cross-section dimensions and distribution of the thermocouples.

![Figure 4](image2.png)

**Figure 4.** T-section segment after casting.

![Figure 5](image3.png)

**Figure 5.** Isolated the faces of a segment.
Other types of sensors were used to measure wind speed, air temperature, and solar radiation during the day. Campbell Scientific's products were used to compose the data acquisition system of the study, the data logger type was CR1000 with multiplexers AM16/32 channel. The sensors and data logger used, are shown in Figure 6.

### Table 1. Location of the thermocouples.

| ID  | X(mm) | Y(mm) | ID  | X(mm) | Y(mm) |
|-----|-------|-------|-----|-------|-------|
| T1  | 0     | 1000  | T8  | 0     | 400   |
| T2  | 0     | 950   | T9  | 0     | 200   |
| T3  | 0     | 900   | T10 | 0     | 0     |
| T4  | 0     | 850   | T11 | -150  | 400   |
| T5  | 0     | 800   | T12 | 150   | 400   |
| T6  | 0     | 700   | T13 | -325  | 800   |
| T7  | 0     | 600   | T14 | 325   | 800   |

![Table 1. Location of the thermocouples.](image1)

![Figure 6. The data logger and sensors](image2)
3. Results

3.1. Environmental Data

The wind speed, solar radiation, and air temperature were recorded after completing the casting of the concrete segment on 29-September-2020 at 13:00 for a period of 12 days. Figure 7 shows the vibration in the air temperatures for the specified period (12 days), the air temperature at the completion of the casting was 34.58 °C, the minimum temperature on the first night after casting was 19.6 °C at 5:50 (before sunrise). The minimum and maximum temperatures during the specified period (12 days) were 14.77 and 36.22 °C respectively. Figure 8 shows the vibration in the solar radiation, in general, the maximum radiation occurs at midday, while during the night the solar radiation value is equal to zero. The solar radiation at the completion of the casting was 585.6 W/m² (after midday). The minimum and maximum solar radiation during the specified period (12 days) were 0 and 928.3 W/m² respectively. Figure 9 shows the vibration in the wind speed. The minimum and maximum wind speeds during the specified period (12 days) were 0 and 6.81 m/s respectively.

Figure 7. Air temperature variation from 29-September-2020 to 11-October-2020.

Figure 8. Solar radiation variation from 29-September-2020 to 11-October-2020.

Figure 9. Wind speed variation from 29-September-2020 to 11-October-2020.
3.2. Temperatures variations

The bridges exposed to multiple climatic factors, which causes the bridges to have complex thermal stresses, which depend on the change in temperature inside the bridge. This change varies according to the geographical location, the direction of the bridge, and the thermal properties of the material. The changes in the temperature that occurs in early ages differ according to the places of the thermocouples, whether on the surface of the concrete bridge or inside it, as well as the same day as the hours of the day differ from the hours of the night and the climatic conditions. Figures 10-13 show the temperatures change during twelve days.

![Figure 10. Temperature variation in thermocouples T6, T7, T9, and T10.](image1)

![Figure 11. Temperature variation in thermocouples T11, T8, and T12.](image2)

![Figure 12. Temperature variation in thermocouples T1, T2, T3, and T4.](image3)

![Figure 13. Temperature variation in thermocouples T13, T5, and T14.](image4)

After finished the casting, notice that internal heat was generated during the next hours as a result of the hydration of cement called the heat of hydration. This temperature was directly proportional to the amount
of concrete, as the temperature increases whenever a large amount of concrete is surrounded by the thermocouple, and vice versa.

Figure 10 shows the temperature change for the thermocouples T6, T7, T9, and T10, which are located in the center of the web. It can be noticed that the temperature of thermocouples T6, T7, and T9 is higher than thermocouple T10 during the first two days, and the reason is that thermocouple T10 is located on the bottom surface of the web affected by the surrounding environment with a low amount of concrete surrounding it. The other thermocouples (T6, T7, and T9) are located inside the concrete section, which was more affected during this period by heat hydration resulting from the reaction of cement compounds. The highest temperature recorded was 60.42 °C at 22:00 on the day of the casting at the thermocouple T9, that was, after nine hours of the casting process. The lowest temperature of these thermocouples at this time was 54.19 °C and it was recorded at the thermocouples T10. The lowest temperature for these thermocouples was 36.65 °C at 6:30 (before sunrise) on 1-October-2020 at thermocouple T10. These results expected because thermocouple T10 is located on the surface of the concrete and was directly affected by the temperature of the surrounding atmosphere, while thermocouple T9 located inside the concrete section.

Figure 11 shows the temperature change in thermocouples T8, T11, and T12 that are located in the centerline of the web and at the same level. In Figure 11, it can be noticed that the emergence of the effect of hydration heat, increases the internal temperature of the thermocouples and starts after a few hours of casting and continues increase in the temperature and then decreases until the end of the first day. The figure shows that within two days the effect of the hydration heat was ended. The highest temperature was 61.44 °C at 23:30 that occurs in thermocouple T8 on the day of the casting, that is, ten and a half hours later of the casting process. The lowest temperature of these thermocouples at this time was 56.21 °C and it returns to the thermocouples T11. The lowest temperature for these thermocouples was 35.85 °C at 6:30 (before sunrise) on 1-October-2020, and it is for thermocouple T12.

Figure 12 shows the temperature change for the thermocouples T1, T2, T3, and T4, which are located in the center of the flange (vertical direction). It can be noticed that the temperature of thermocouples T2, T3, and T4 is higher than thermocouple T1 during the first day. Because the thermocouple T1 is located on the top surface with a low amount of surrounding concrete. The other thermocouples (T2, T3, and T4) are located inside the concrete section, which is far from the air temperature and is affected during this period by heat hydration resulting from the reaction of cement compounds. During the first day, the highest temperature is 53.35 °C for T4, then comes 50.48 °C for T3, 44.7 °C for T2, and finally 40.59 °C for T1, these temperatures occur at 22:45 on the day of the casting, that is, nine hours and forty-five minutes later of the casting process. The temperature of the thermocouple T1 is affected mainly by solar radiation, and therefore its behavior differs from the other of the thermocouples that are located on the surface, as the highest temperature of this thermocouple reached 52.04 °C at 15:30 on 30-September-2020.

Figure 13 shows the temperature change for the thermocouples T13, T5, and T14, which are located in the bottom flange of the segment (at the horizontal direction). It can be noticed that the temperature of thermocouple T5 is higher than thermocouples T13 and T14 during the two first days, and the reason is that thermocouples T13 and T14 are located on the bottom surface far from the sun rays is affected by the temperature of the air and also for the low amount of concrete. The other thermocouple (T5) is located inside the concrete section, which is far from the air temperature and is affected during this period by heat hydration resulting from the reaction of cement compounds. During the first day, the highest temperature is 55.54 °C for T5, this temperature occurs at 23:30 on the day of the casting, that is, ten and a half hours later of the casting process.

4. Conclusions
The T-section concrete-segment was used to study the temperature changes that occurred in concrete bridges at the early ages. The temperature variation occurred due to thermal loads from the hydration of cement,
solar radiation, air temperature, and wind speed. Where it has been observed that the heat is generated in the concrete section from the hydration of the cement on the first two days. This source of heat was added to the temperature, where its effect lasted for two days, then began to decrease until it dissipated. The higher temperature occurs in the thermocouple which surrounded by a large amount of concrete. The effect of hydration is very small for the thermocouple on the surface because the surface temperature is affected by the surrounding conditions. The highest temperatures as a result of cement hydration occur between 22:00 and 23:30, that is, nine to ten and half hours after the casting processes, and the highest temperature recorded on this day was 61.44 °C.

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