# Temperature distributions in concrete bridges for Indian summer conditions - 2*

**D. S. Prakash Rao**

*The first part of the paper, published in the August issue of the Journal, dealt with studies regarding the influence of various parameters. This second and last part of the paper, presented here, discusses the critical temperature distributions in concrete bridges for Indian summer conditions.*

It is obvious from the studies presented in the first part of the paper that the temperature distribution in a bridge section is affected by a number of factors. A single type of distribution, such as is usually recommended for designs, will not always be adequate[2,4]. Only the distributions given by Priestley take into account the variation in the temperature distributions in the web and the flanges[1].

The proposed temperature distributions were developed for the ambient conditions shown in Figure 1, a wind velocity of 1.5m/s, a blacktop thickness of 50mm and the material properties indicated in Table 1. As actual temperature distributions are highly non-linear and, thus, rather difficult to manage for practical analysis, it was attempted to simplify these such that the resulting soffit tensile stresses in the structure remained the same. For the slabs, the proposed distributions yield the same average temperatures and curvatures as do the actual temperature distributions. For the webs, the soffit stresses are the same for the actual and the proposed distributions, Figures 11 and 12. Thus, the soffit tensile stresses remain practically the same when the simplified proposed distributions are used instead of the actual distributions. The difference between the stresses for the actual and the proposed temperature distributions was less than 10 percent for most of the cases, which should be adequate for practical designs, considering the possible variations in the material properties and other values assumed in the analysis.

In addition to the induced longitudinal stresses the top flange of the superstructure will be subjected to transverse moments due to temperature gradients through the slab. Unfortunately, the critical temperature gradients for transverse moments are not always the same as those to be considered for the analysis of longitudinal stresses. The temperature distributions for transverse moments in the flanges are given separately in Figures 13 and 14.

Actual temperature values, rather than the relative values are given for the proposed distributions in view of the several types of elements involved in a typical bridge cross-section.

## Temperature distributions for longitudinal stresses

### Slabs and webs

The soffit tensile stresses in slabs and beams were generally the highest between 2000 to 2200 hours (cold-top condition) for fully restrained condition. Only for slabs thinner than 200mm were the soffit tensile stresses highest at 1700 hours (hot-top condition). The temperature distributions at 2100 hours in slabs and webs of depths 0.1 m to 4.0m are plotted in Figure 11. For the sake of simplicity as well as accuracy, three distributions are proposed that are valid for slabs of thickness less than 0.3m, slabs and webs of depth 0.3m to 1.0m and webs of depth greater than 1.0m, Figure 11.

### Slabs enclosing the air cell in box girders

As mentioned already, the air gap between the top and bottom slabs of a box girder affects the temperature distribution in these slabs. In addition, the box girder may be provided with large openings for ventilating the air cell, which causes the air temperature inside the cell to be the same as the ambient temperature at any point of time. However, if the air cell is not ventilated, the air temperature inside the cell will be different from the ambient temperature. Both these cases were considered in the heat-flow analysis.

**Continued from August 1987 issue*

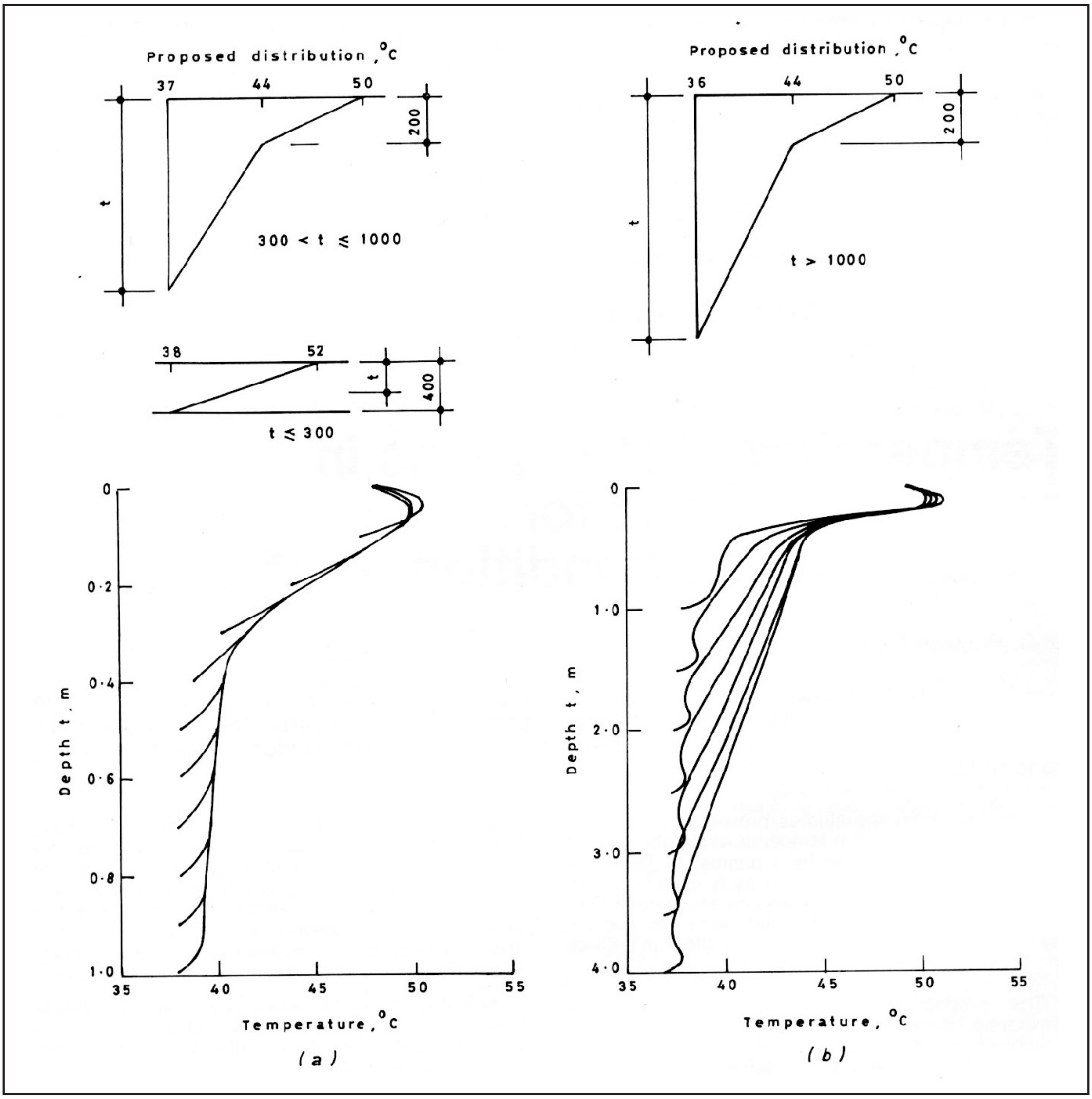


**Figure 11. Computed and proposed temperature distributions for various depths of beams/slabs for e= 0.9 and $t_b$ = 50mm**

The temperature distributions in the top slab for unventilated air-cell condition and in the bottom slab for both ventilated and unventilated air-cell conditions for an air gap of 1.0m are plotted in Figure 12. For the slabs above a ventilated air cell, the distributions given in Figure 11 are valid. The actual temperature distribution is replaced by a bi-linear distribution for slabs of thickness greater than 300mm. For slabs of thickness less than 300mm, a uniform temperature rise is proposed since the flexural stresses in such slabs are negligibly small. In the case of slabs below the air cell, the temperature distributions shown in Figures 12b and 12c for unventilated and ventilated air-cell conditions are replaced by uniform temperature distributions. The flexural stresses in these slabs are very small, except for slabs thinner than 150mm. The proposed values of temperature are slightly on the conservative side and extreme refinement of the values is avoided. However, for slabs thinner than 200mm, the proposed temperatures yield slightly smaller soffit tensile stresses than those for the actual distribution.

## Temperature distributions for transverse moments

The transverse moments are especially important in box girders with transverse prestress. The temperature gradient in

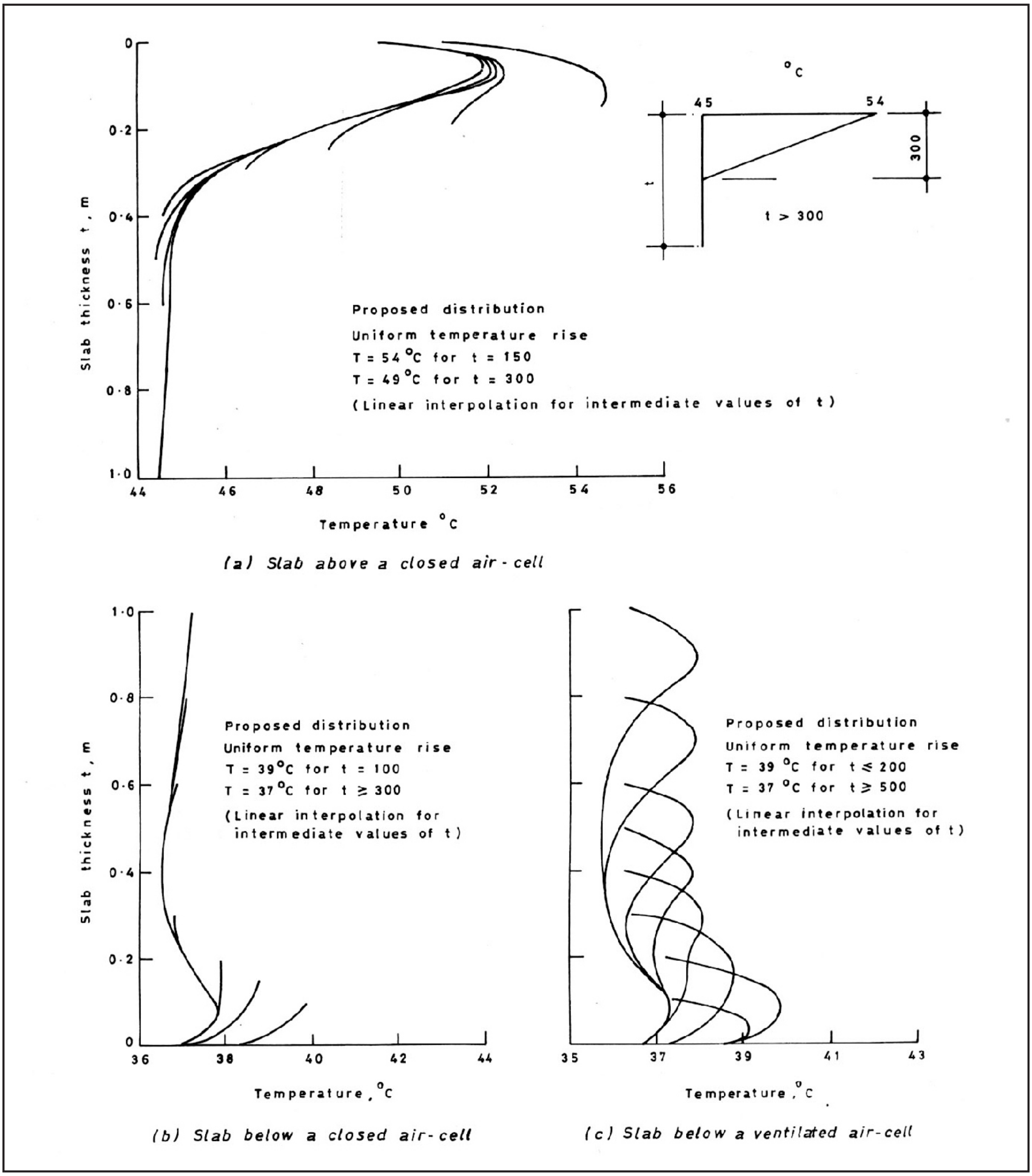


**Figure 12. Computed and proposed temperature distributions in the slab above and below the air cell of a box girder**

the top slab is more significant for the transverse moments than the difference in the average temperatures of the top and bottom slabs[1]. It was found that the temperature gradient was maximum at about 1700 hours for the cases analysed. These temperatures are plotted in Figures 13 and 14 and the proposed distributions that yield about the same curvatures and mean temperatures are also shown alongside. The temperature distributions in the top slab above an unventilated air cell and in the slabs below unventilated and ventilated air cells are shown in Figure 13, while Figure 14 shows the temperature distributions in slabs with exposed soffit, which would correspond to the top slab of a T-beam or a box girder with ventilated air cell.

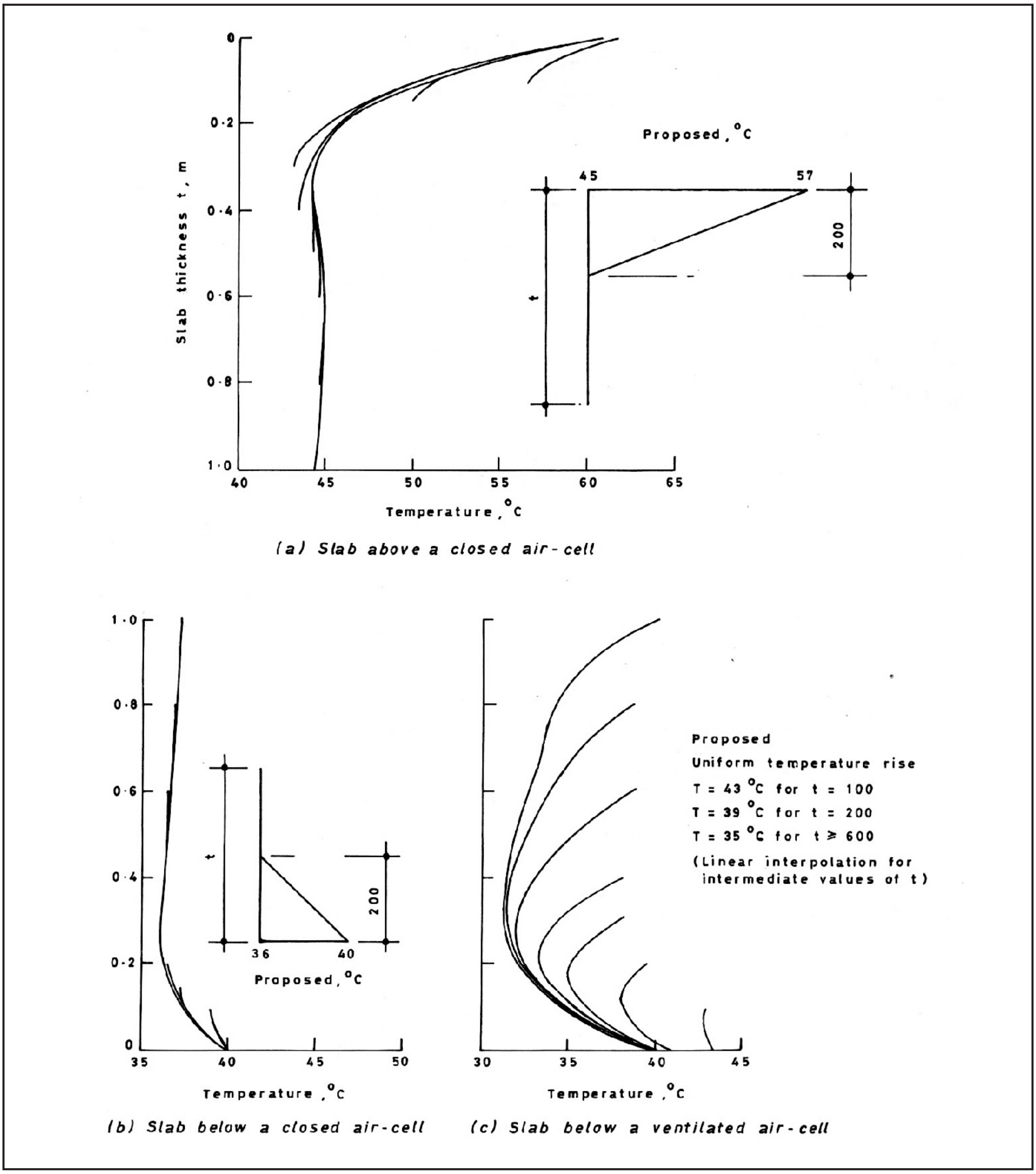


**Figure 13. Computed and proposed temperature distributions for the transverse moments in box girders**

## Comparison of stresses

The main objective of the temperature stress analysis of a bridge structure is the estimation of the soffit tensile stresses. The resulting soffit tensile stresses under the computed temperature distributions are compared with those due to the proposed distributions for box girder and T-beam sections. The tensile stresses at the web in multi-span and two-span continuous bridges are plotted in Figure 15. The stresses in box girders were computed for both unventilated and ventilated air-cell conditions. The T-beam section would represent the conditions of a bridge with three longitudinal beams. The depth of the sections was varied from 1.0m to 4.0m. The FSM was used for the proposed distributions and the approximate analysis for the computed distributions.

The Young's modulus of concrete was taken as $35GN/m^2$ and the Poisson's ratio as 0.15. The soffit tensile stresses under the proposed distributions are on the conservative side for shallow sections compared to the stresses under the computed distributions, the maximum difference between the stresses being about 17 percent for multi-span box girder of 1.0-m depth with unventilated air cell. The agreement between the stresses is better for deeper sections and the difference is less than 10 percent in most of the cases examined. The proposed distributions can thus be considered to be satisfactory for practical purposes.

In addition, the stresses due to Priestley's distribution are also plotted in Figure 15 for comparison; Priestley's temperature distributions yield higher stresses for smaller section depths and smaller stresses for larger section depths compared to the distributions computed for the ambient data assumed here. The difference in stresses under the proposed and Priestley's distributions is more pronounced for two-span continuous bridges.

## Example

The stress distributions in a two-span continuous box girder of the section shown in Figure 3 under various temperature distributions are plotted in Figure 16. The longitudinal stresses at the intermediate support are plotted at the mid-plane levels of the top and bottom slabs. Thus, the soffit tensile stresses will be slightly lower for the fifth power parabolic distribution on account of the 1.5°K temperature rise included for the soffit[1]. Nevertheless, it is obvious that the soffit tensile stresses are lower for the proposed distributions. The longitudinal stresses for the ventilated air cell are slightly lower than those for the unventilated air cell. The side cantilever slab of the box girder will have smaller stress compared to the slab above an unventilated air cell because of its lower temperature, in general.

The transverse moments in the box girder are about the same for the ventilated and unventilated air-cell conditions for the proposed distributions. These moments are higher than the moments induced by Priestley's distribution on account of larger temperature gradient in the top slab.

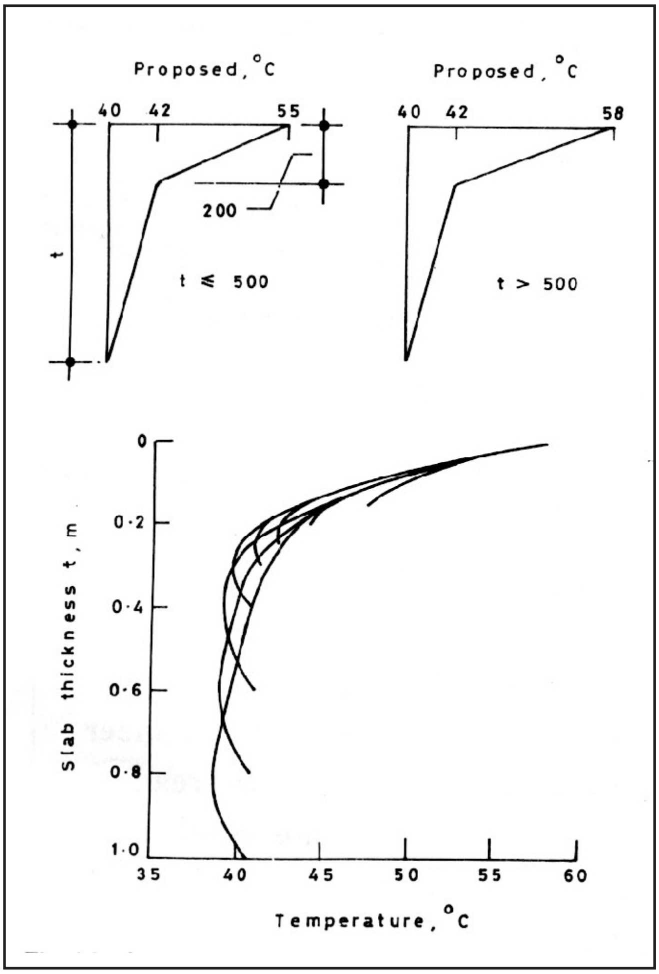


Figure 14. Computed and proposed temperature distributions for the moments in slabs

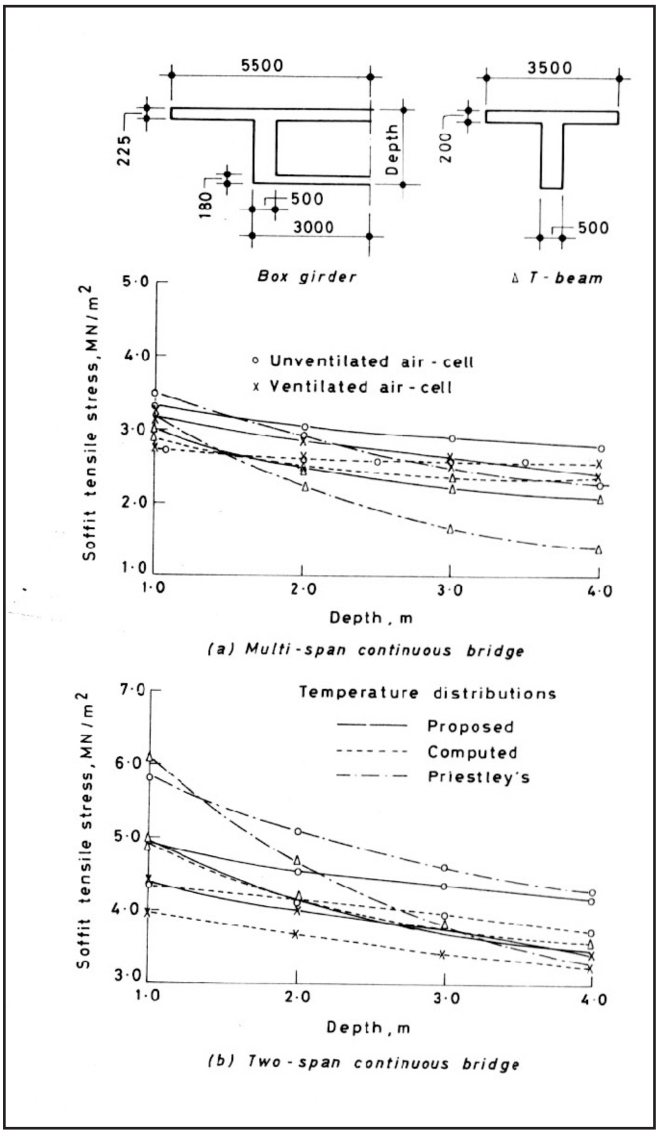


Figure 15. Soffit tensile stresses at the web under various temperature distributions

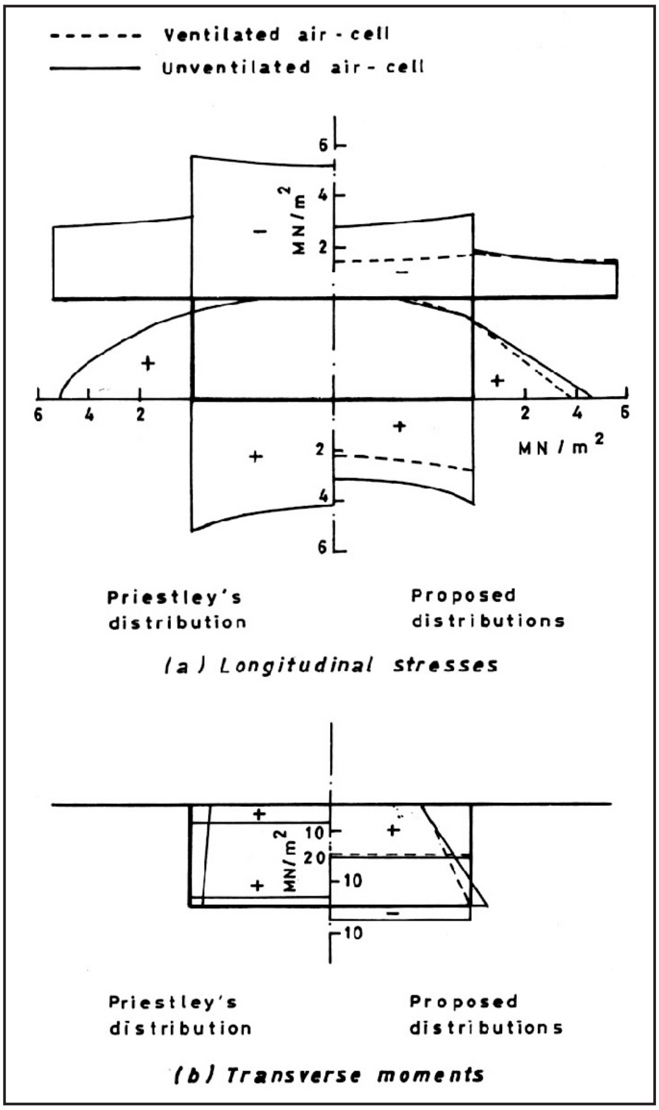


**Figure 16. Longitudinal stresses at the intermediate support and transverse moments in a 2.0-m deep, two-span continuous box girder under various temperature distributions**

The stresses in the same box girder were also computed by assuming that the same temperature gradients as in the web were valid for the entire crosssection. This approach appears to be conservative as it yields soffit tensile stress 30 percent greater than that for the actual temperature distribution.

## Conclusions

The following conclusions pertain to the maximum soffit tensile stresses and the transverse moments in continuous bridges subjected to insolation effects:

1. The solution obtained by the FDM should be iterated a sufficient number of times for obtaining the converged solution to the temperature distribution in concrete beams. When uniform initial temperatures are assumed for the nodal values, the number of iterations required range from about 2 for a 0.2-m thick slab to 80 for a 4.0-m deep web, depending upon the time and space intervals chosen. Alternatively, the proposed series solution can be used with advantage on account of its simplicity and smaller computer time and programming effort required.

2. The maximum tensile stresses occur under the cold-top conditions rather than the hot-top conditions for the high ambient temperatures assumed for the analysis.

3. A cloudy night sky generally increases the soffit stresses.

4. The temperature-induced stresses do not vary significantly with the variation in the blacktop thickness. Thus, the proposed temperature distributions can be used for blacktop thicknesses different from 50mm assumed in the analysis.

5. The magnitude of stresses does not appear to vary significantly with the depth of the box girder for the cases investigated in this article.

6. The soffit tensile stresses are lower for higher wind velocities. However, beyond a wind velocity of about 12m/s there appears to be no further reduction in the soffit tensile stresses.

7. The temperature distributions proposed in this article yield smaller longitudinal stresses than Priestley's distribution for smaller depths of the section. However, the trend is reversed for girder depths larger than about 3.0m. The transverse moments in box girders are of higher magnitude for the proposed distributions than those for Priestley's distributions.

8. The proposed temperature distributions can be used to compute the temperature-induced stresses in concrete structures under ambient conditions similar to the assumed values.


## Acknowledgement

The author wishes to express his gratitude to Dr. G. D. Base and Mr. P. R. Morgan, Department of Civil and Agricultural Engineering, University of Melbourne, Australia, for their advice and valuable discussions.



D. S. Prakash Rao, Department of Civil Engineering, University of Melbourne, Australia.



(Source: ICJ September 1987, Vol. 61, No. 9, pp. 245-250)