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Numerical Technique to Simulate Temperature Distributions in Bridges

Méthode numérique d'evaluation des températures dans les ponts

Numerische Methode für die Schätzung der Temperaturfelder in Brücken

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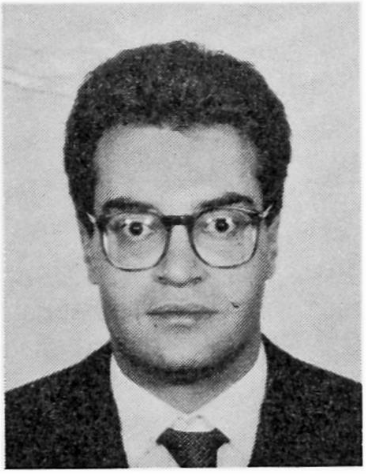

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SUMMARY
A numerical method for the evaluation of the temperature distribution in bridges, based on a finite element solution of the Fourier equation, is presented and illustrated with some examples. Heat exchanges due to convection, thermal and solar radiation are considered. For concrete bridges the construction phases and the associated heat of hydration temperatures are also analysed.

RÉSUMÉ
Une méthode numérique d'evaluation des températures dans les ponts, consistant en une résolution par éléments finis de l'équation de Fourier, est présentée et illustrée avec quelques exemples. Les échanges thermiques associés à la convection et à la radiation solaire et thermique sont considérés. Pour les ponts en béton, les phases de bétonage et la libération de la chaleur d'hydratation sont aussi analysées.

ZUSAMMENFASSUNG
Eine numerische Methode für die Schätzung der Temperaturfelder in Brücken wird dargestellt. Für die Lösung der Fouriersche Gleichung wird die Methode der Finite Elemente benutzt; und einige Beispiele werden gezeigt. Wärmeaustausch sowohl von Konvektion als auch von Ausstrahlung und Sonnenstrahlung wird berücksichtigt. Die Untersuchung der Temperaturen, die während der Bauphase einer Brücke aus der Hydratationswärme des Betons resultieren, wird auch gemacht.

1. INTRODUCTION

The thermal effects on bridges are of major concern to design engineers. The bridge superstructures are subjected to seasonal and daily temperature changes arising from the heat transfers associated with the air temperature and sun radiation.

The seasonal variation corresponds to the maximum mean temperature change that can be expected and its value is usually referred in the design codes. The daily temperature variations are mainly associated with the thermal differentials in the structure and their definition usually needs a special analysis of the bridge characteristics and environment.

These temperature gradients have been the source of several problems mainly associated with excessive displacements during construction (steel structures) or cracking problems during service life (concrete structures).

During the construction of concrete bridges the temperatures due to heat of hydration may also be a source of cracking problems if the thermal gradients lead to tensile stresses exceeding the tensile strength of young concrete.

In this paper a numerical technique to evaluate the temperature differentials in bridges considering the environment interaction and the heat of hydration is presented. The use of this technique is illustrated with the study of the thermal behaviour of composite box girder bridges during construction and of a railway concrete box girder bridge.

2. METHOD OF ANALYSIS

To study the temperature distribution in a bridge a two-dimensional analysis is considered, since temperature is assumed to be constant along the bridge axis. The basic equation of the transient thermal phenomena, which relates the temperature **T**, in each point of the cross section, to the time **t**, is:

$$\rho c \; \partial T / \partial t = k \left(\partial^2 T / \partial x^2 + \partial^2 T / \partial y^2 \right) + q_v \qquad (1)$$

where **k, ρ, c** are the thermal conductivity, specific mass and specific heat of the material, respectively, and q_v is the rate of heat generated (by hydration, for example) per unit volume.

The boundary conditions associated with **eq. (1)** may be expressed as

$$k \left(\partial T / \partial x \, . \, n_x + \partial T / \partial y \, . \, n_y \right) + q = 0 \qquad (2)$$

where n_x, n_y are the direction cosines of the unit outward vector normal to the boundary surfaces and **q** is the amount of energy transferred between the surface and the environment due to convection, thermal irradiation and solar radiation **[1]**.

In concrete bridges, the total amount of heat **Q** generated until any instant due to hydration of cement may be computed by **[2]**

$$Q = B + E \exp(-\alpha (t_e)^{-n}) \quad (3)$$

where **B, E, α, n** are constants depending upon the mix proportions of the concrete and the type of cement, obtained from experimental tests under a reference uniform temperature T_r. The variable t_e is an equivalent time of the variable temperature process, obtained by

$$t_e = \sum_{o}^{t} 2^{(T-T_r)/10} \Delta t \quad (4)$$

where **T** is the temperature of the process, assumed constant during the time interval **Δt**.

The numerical solution of **eq. (1)** is accomplished considering a finite element analysis in the cross section and integrating with respect to time by the finite difference method **[3]**. For the study of heat of hydration temperatures sequential construction phases are considered rebuilding the finite element mesh and boundary conditions whenever a new phase begins.

3. CASE STUDIES

3.1 Behaviour of Composite Box Girder Bridges During Construction

In the last few years, composite steel-concrete box girder bridges have been widely used for intermediate span bridges. During construction, the girder is often a flexible open section, which subjected to thermal differentials may present important deformations.

Based on the numerical technique referred above the temperature distribution was determined for an open box girder instrumented during construction. The comparison between experimental and analytical results is shown in **Fig.1**, showing a reasonable agreement **[1,4]**

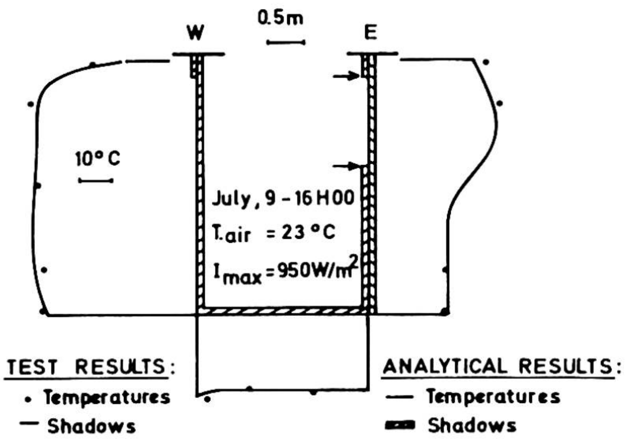

Fig.1 - Comparison between experimental and analytical results [1]

Considering typical geometries a parametric study was then developed to obtain the maximum differentials between the average temperatures of the steel plates. **Fig.2** shows the highest values obtained for summer and winter clear days.

These open box girders under temperature differentials suffer lateral displacements and twist. This behaviour can be studied using a simplified folded-plate analysis where each plate is assumed as a beam and compatibility is imposed at the longitudinal joints [1].

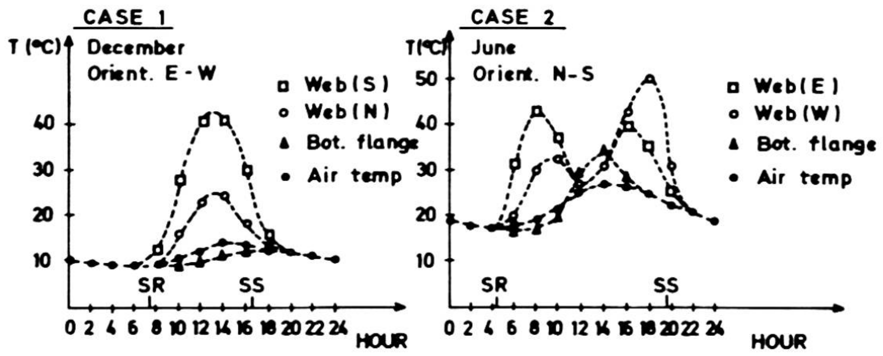

Fig. 2 - Temperatures in an open box girder [1]

Due to the temperature twist ($Ø_T$) the self weight (p) becomes an eccentric load with a sinusoidal eccentricity along the span. This effect increases the twist of the girder and the total twist ($Ø_{TOT}$) becomes

$$Ø_{TOT} = Ø_T + Ø_p \qquad (5)$$

where $Ø_p$ is the increment due to self weight, which can be approximately computed by an non-uniform torsion analysis [1]. In **Fig. 3** the self-weight rotational effect is illustrated for an open box girder.

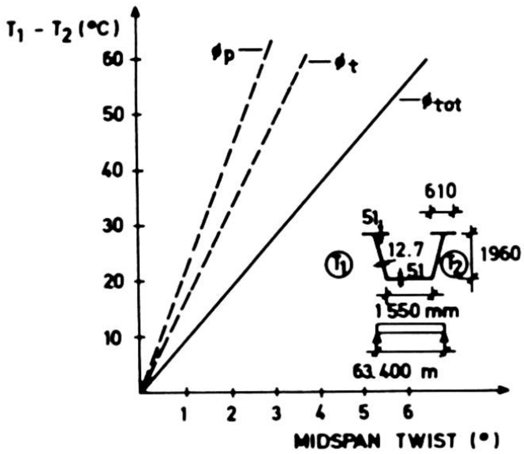

Fig. 3 - Self-weight rotational effect [1]

3.2 Behaviour of a Railway Double Box Girder Bridge

The study of the temperature distributions to be considered in the analysis of a concrete double box railway bridge is now illustrated for the construction and service phases.

3.2.1 Heat of Hydration Effects

The temperatures due to heat of hydration that may arise during the concreting of the superstructure were analysed with the referred numerical technique. First, experimental tests have been made with concrete cubes in order to estimate the concrete hydration properties **(eq. 3)**.

A reasonable agreement between analytical and experimental results was obtained **(Fig. 4) [5]**. A construction plan was then assumed for the concreting phases of the deck and the evolution of the temperatures was determined along the first 10 days **(Fig. 5)**.

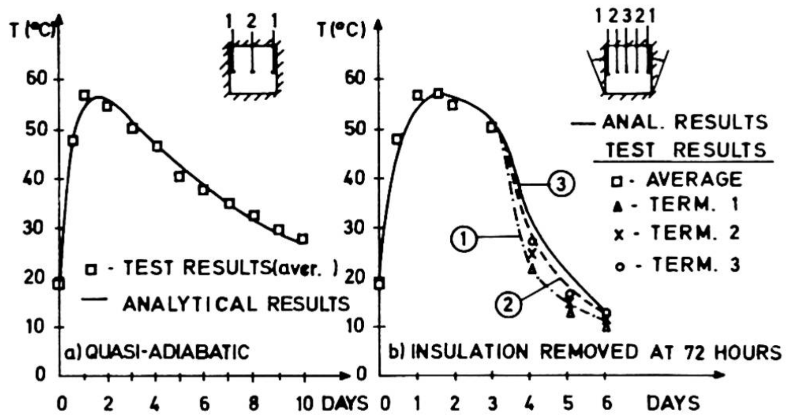

Fig. 4 - Concrete cubes testing

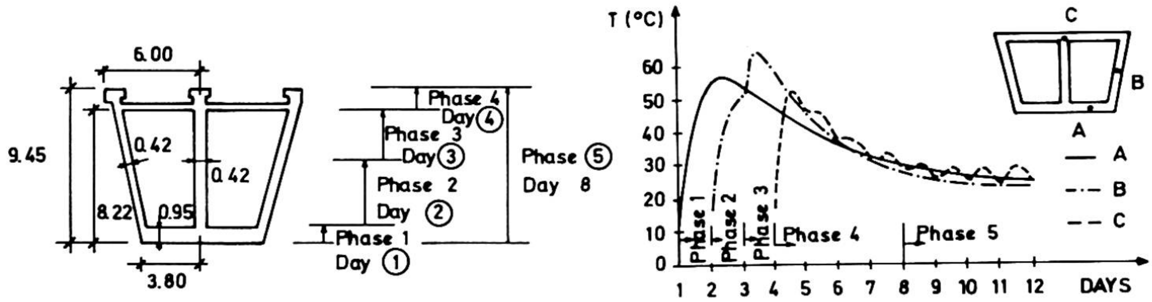

Fig. 5 - Construction plan and temperature evolution in the deck

3.2.2 Deck Temperature Gradients due to Environment Effects

The temperature distribution in each cross-section may be divided into an uniform (mean) temperature, a linear diagram and an eigen-temperature diagram. The maximum thermal gradients that are likely to occur in the girder and in the piers under summer conditions are shown in **Fig.6**, where the influence on vertical gradients of a concrete layer over the deck for support of the rails can be noticed .

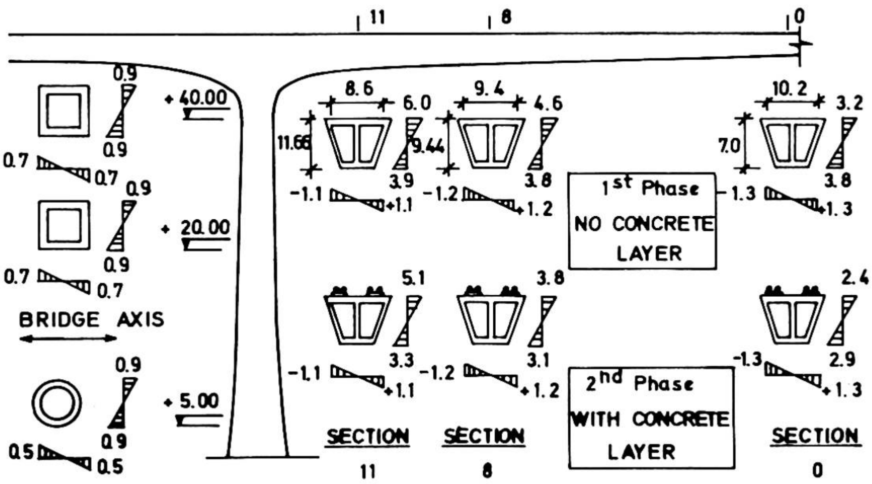

Fig. 6 - Maximum thermal gradients under summer conditions

3.2.3 Rails - Girder Differentials

The use in this bridge of long welded rails and a nonballasted deck imposed the study of the rail-structure interaction due to their temperature differential. The estimation of these differentials was also accomplished with the referred technique. taking into account the environment conditions of the bridge. **Fig. 7** shows the evolution along the day of the mean temperatures of the rail and of the girder, with a maximum value obtained around 3:00 p.m..

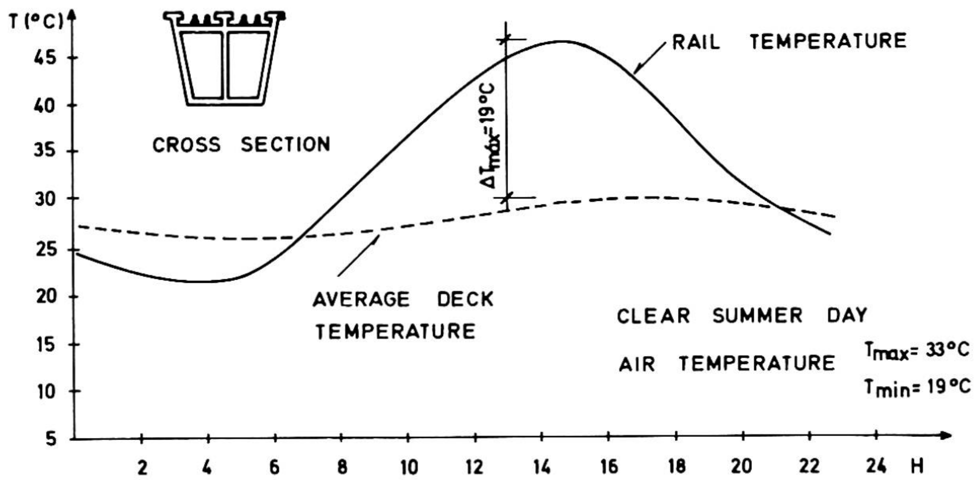

Fig 7. - Mean temperatures in the rails and in the deck

4. CONCLUSIONS

This paper presents a numerical technique to obtain the temperature distribution in bridges due to environment conditions and to cement heat of hydration. The applicability of this technique is illustrated with several examples.

ACKNOWLEDGEMENTS

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