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Thermal Design Loads for Concrete Roofs

Charge thermique de toits en béton

Thermische Lasten für Betondächer

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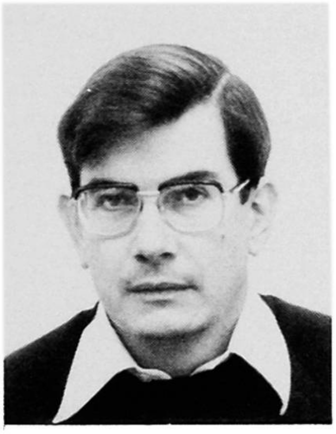


Malcolm Hirst graduated in 1965 at Leeds University, U.K. He worked on the rebuilding of Ronan Point and Westgate Bridge before beginning his academic career at Melbourne in 1973. In 1976 he accepted an appointment at Adelaide. He has a major research interest in the thermal loading of structures.

SUMMARY

This paper describes a procedure to determine characteristic values of thermal loading with a known return period for the design of concrete roofs and presents evidence for the viability of the approach. As illustration, design charts prepared on normal probability paper are presented for two roofs of different construction in two diverse Australian climate regimes.

RESUME

L'article décrit une méthode de détermination des caractéristiques des sollicitations thermiques en fonction de la fréquence d'apparition de celles-ci pour le calcul des toits en béton et prouve la validité de cette méthode. Comme exemples d'application, des diagrammes sont présentés pour deux toits différents dans deux diverses régions climatiques d'Australie.

ZUSAMMENFASSUNG

Ein Verfahren für die Ermittlung von Bemessungswerten für die thermische Beanspruchung von Stahlbetondächern in Abhängigkeit von der Auftretenshäufigkeit wird beschrieben. Die Gültigkeit eines solchen Verfahrens wird nachgewiesen. Als Anwendungsbeispiele werden Bemessungsdaten auf normalem Wahrscheinlichkeitspapier für zwei unterschiedliche Dächer in zwei verschiedenen Klimagegenden Australiens dargestellt.

1. INTRODUCTION

In many parts of the world thermal loading from solar radiation is a significant component of the total loads on a structure. For Australia, Campbell-Allen [1] reports that temperature related effects are responsible for 21% of cases of distress to concrete buildings.

While design guidance is available for the thermal loading of concrete bridges [2], this is not the case for concrete roof slabs. An international code [3] on temperature actions is in preparation. However, with the introduction of limit state codes there is a need to evaluate characteristic values of thermal loading with a known probability of occurrence in the same way that information is currently available for wind loads.

This paper describes a procedure to determine characteristic values of thermal loading for the design of concrete roofs and presents evidence for the viability of the approach. As illustration, the paper concludes by presenting design charts for two roofs of differing construction in two diverse Australian climate regimes.

2. THE PROCEDURE

Thermal loading is a function of climate and is extremely variable, showing daily and seasonal variation as well as geographic diversity. As a basis for computing characteristic design loads short term experiments may be unrepresentative. The procedure described here brings together, short term measurements, theoretical models, and the long term records of the weather bureau.

Firstly, a theoretical heat transfer model is established which can compute the daily temperature variation in a roof slab from its material properties and standard meteorological data. The model is then calibrated from field measurements so that its accuracy is known for a range of meteorological conditions.

Temperature variations in the roof are characterised by two loading parameters for structural design. The in-plane movement of the roof is a function of the effective temperature, T_E, where

$$T_E = \frac{\Sigma(EAT\alpha)}{\Sigma(EA\alpha)} \qquad (1)$$

and bending is a function of the fully restrained thermal moment, M_O, defined as

$$M_O = \Sigma(EA\alpha Ty) \qquad (2)$$

In equation (1) and (2) the concrete roof is assumed uncracked and composed of a series of layers. Each layer of cross-sectional area A is assumed to be at uniform temperature T. The centroid of the layer is a distance y from the centroid of the whole slab. For each layer α is the coefficient of thermal expansion and E is the Young's Modulus. If the degree of structural restraint is known then any deformation or thermally induced stress can be evaluated from T_E and M_O by the usual methods of structural analysis.

Using the calibrated theoretical model, daily extremes of the loading parameters are computed for everyday of the complete weather record available for a locality. Statistical analysis of this daily data shows the annual extremes of effective temperature and thermal moment appear to follow a normal distribution. Accordingly, design charts can be prepared by plotting annual extreme results on normal probability paper. For a given roof and geographic location the design value with a selected return period is simply read off the appropriate chart.

3. THEORETICAL MODEL

White [4] references a number of theoretical heat transfer models that have been developed for the thermal loading of structures. The model used in this study is a development of that first proposed by Hunt and Cooke [5].

When the roof consists of different layers, for example weatherproofing over a concrete slab plus a false ceiling, the heat conduction equation becomes:

$$K_j \frac{\partial T}{\partial x} = p_j c_j \frac{\partial T}{\partial t} \qquad (1 \leqslant j \leqslant m) \qquad (3)$$

where T represents the temperature at depth x for time t and k_j, p_j, and c_j are respectively the thermal conductivity, density, and specific heat of the material in the jth layer of the m layer system.

Solution of equation (3) requires a knowledge of ambient conditions at each time step. Relationships have been developed [6] for Australian conditions to compute instantaneous values from standard daily meteorological data. A power law of the form

$$I(t_s) = \frac{KI}{a^{n+1}} \left(a^n - |t_s - a|^n\right) \qquad (4)$$

is used to compute solar irradiance, $I(t_s)$, at time t_s from the daily total of global radiation, I, for a solar day of 2a hours. The constant k and the exponent n are derived from a comparison with measured values. Simple linear interpolation is used to compute ambient temperature from daily extreme values. Following ASHRAE [7], the surface heat transfer coefficient is a function of wind speed.

4. CALIBRATION OF THE MODEL

In 1981 an isolated experimental concrete roof panel, as shown in Figure 1, was set up on the roof of the Engineering Building at the University of Adelaide. Until March 1983, the temperature profile of this panel was monitored every hour by a computer data logging system. From the experimental record and known material properties of the slab, daily extreme values of effective temperature, T_E, and thermal moment, M_O, were computed for 317 days. As illustration of the range of conditions monitored, Figure 2 shows a histogram of daily maximum and minimum effective temperature.

A simulation of the behaviour of the experimental panel was also carried out using the theoretical model for the same 317 days. Comparison of the experimental data with values predicted by the theoretical model shows the coefficient of variability to be 7.6% and 28.3% for effective temperature and thermal moment respectively.

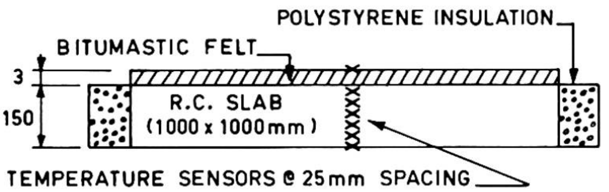


Fig. 1 Experimental Roof Panel

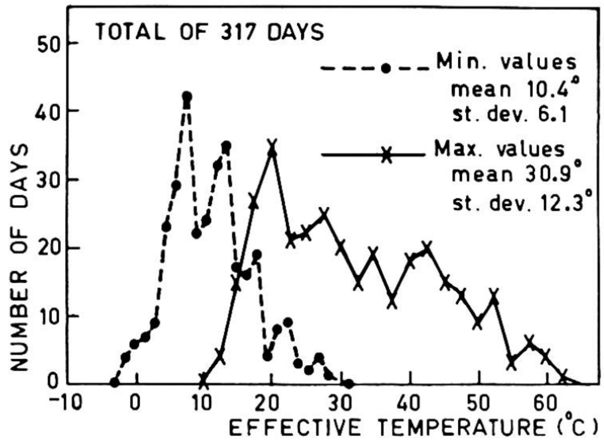


Fig. 2 Histogram of Effective Temperatures Recorded in Experimental Panel.

In 1983 similar hourly monitoring of temperature began for a 220 mm prestressed concrete slab that forms the roof of an Adelaide office building. Figure 3 shows the roof in cross-section. The behaviour of this roof was also simulated using the theoretical model. Figure 4 shows a comparison of measured and computed values for the coldest night and hottest day since measurements began.

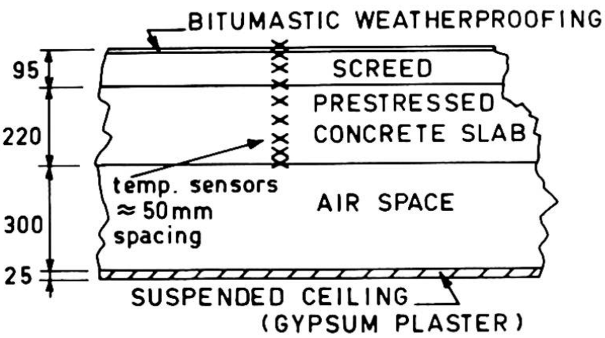


Fig. 3 Details of Office Roof

For both roofs there is a discrepancy between the actual and predicted rate of cooling particularly with an overcast night sky. Greater error was expected for thermal moment since the model must accurately predict the difference in temperatures either side of the centroidal axis. However, the results show the versatility of what is essentially a clear sky model to accurately represent a wide range of meteorological conditions.

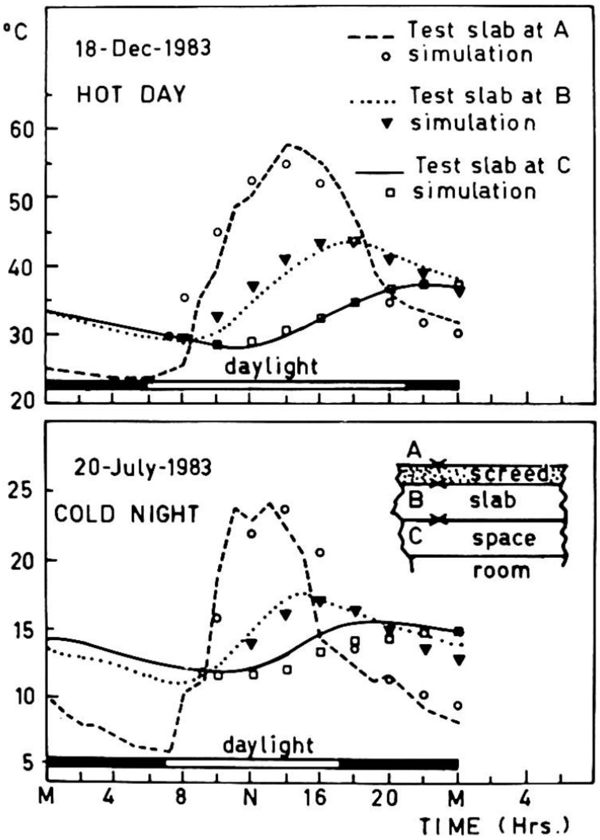
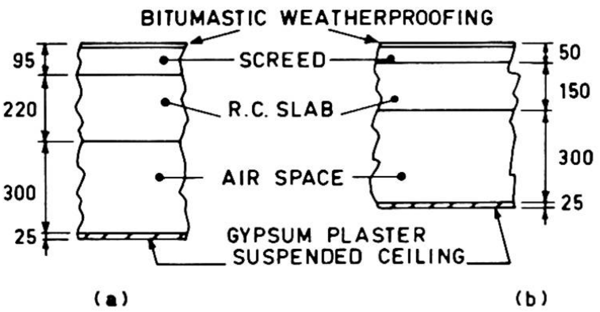


Fig. 4 Temperatures of Office Roof

5. PRODUCTION OF DESIGN CHARTS

In Australia the weather bureau records solar radiation at a number of sites. The network of stations was commissioned in 1968. In Adelaide, the Waite Agricultural Research Station has recorded solar radiation since 1958.



Using the theoretical model, daily extremes of effective temperature and thermal moment have been computed for the two roofs shown in Figure 5 assuming they are located in Adelaide and Darwin. The roof shown in Figure 5(a) is similar to that of the Adelaide office building mentioned above. The roof shown in Figure 5(b) is a thinner slab with less screed.

Fig. 5 Roofs for Design Charts

These two localities span the range of Australian climates. Adelaide has a mediterranean climate typical of much of Southern Australia. The Darwin climate is tropical with a summer wet season and is representative of the coastal margins of northern Australia. Allowing for equipment failure and the effects of cyclone Tracy in Darwin, a complete 20 year record is available for Adelaide but only a nine year record for Darwin.

Statistical analysis of the daily data yields the design charts given in Figures 6, 7 and 8. The extreme values appear to follow a normal distribution but there is an S shape to the scatter of points on the maximum value charts. The reason for this pattern is unknown. Detailed analysis of the results shows they fit the normal curve better than any other standard probability density function. However, given the scatter on the charts it is not recommended that they be used to estimate design values with a return period greater than 100 years.

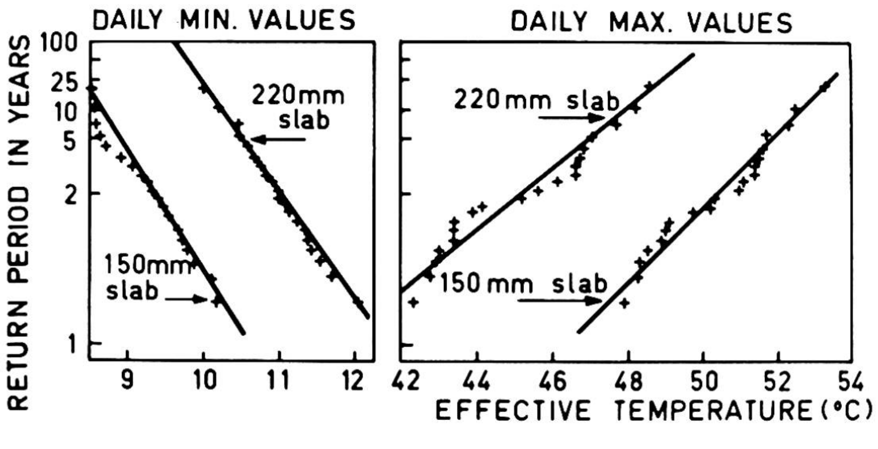


Fig. 6 Design Values of Effective Temperature - Adelaide.

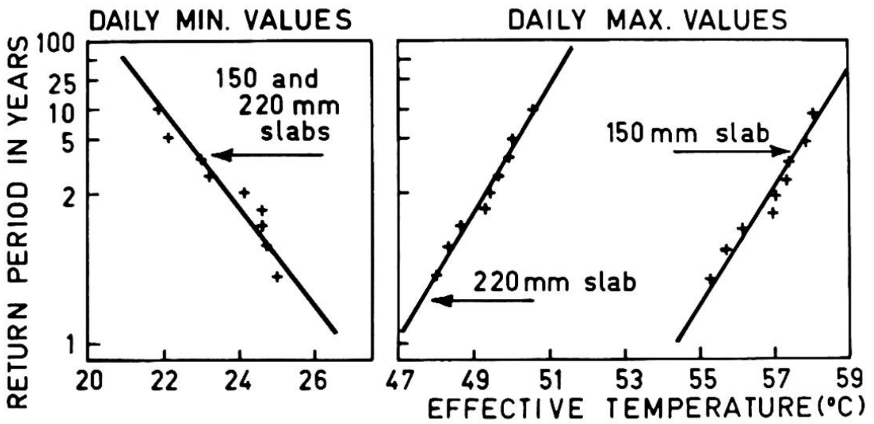
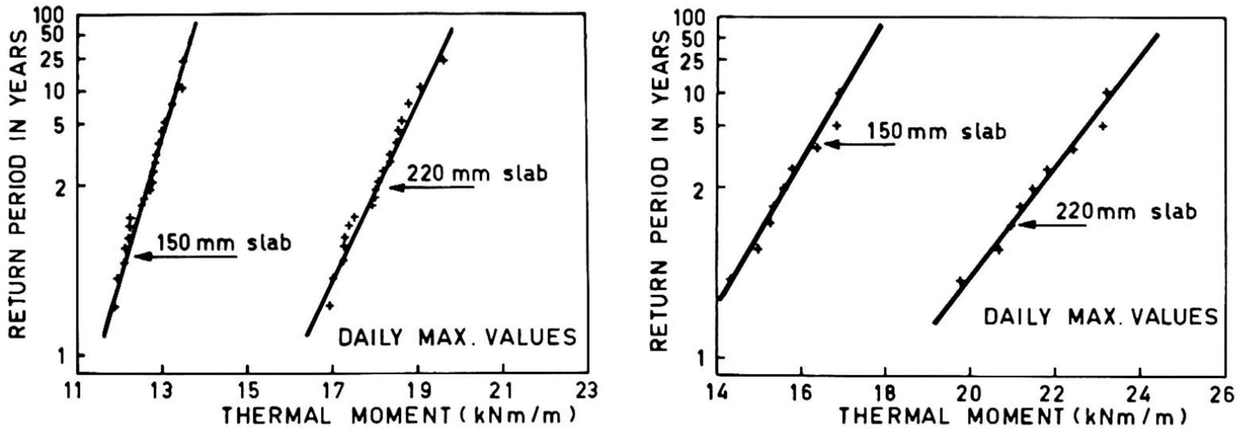


Fig. 7 Design Values of Effective Temperature - Darwin



(a) Adelaide (b) Darwin

Fig. 8 Design Values of Thermal Moment

The thinner slab with its smaller thermal mass undergoes a greater temperature range. A thin slab cools down quickly overnight and can be heated to a higher temperature during the day. In the tropical climate of Darwin, with its small ambient temperature range, both thicknesses of slab reach essentially the same minimum temperature after overnight cooling.

6. CONCLUSIONS

A procedure has been presented to determine the characteristic values of thermal loading for roof slabs heated by solar radiation.

The procedure uses a theoretical model calibrated from field measurements, to generate daily values of the thermal loading parameters from the long term meteorological record available for a locality.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. CAMPBELL-ALLEN, D. and HELFFENSTEIN, H.L., Cracking in Concrete - Its Extent and Causes. University of Sydney - School of Civil Engineering Research Report R253, September 1974.

2. NAASRA, Bridge Design Specification. National Association of Australian State Road Authorities, 1976.

3. I.S.O., Fifth Draft Proposal for an International Standard Temperature Climatic Actions. International Standards Organisation, July 1982.

4. WHITE, I.G., Non-linear Differential Temperature Distribution in Concrete Bridge Structures: A Review of Current Literature. Cement and Concrete Association (U.K.) Report No. 525, 1979.

5. HUNT, B. and COOKE, N., Thermal Calculations in Bridge Design. Journal of Structural Division - A.S.C.E., September 1975.

6. HIRST, M.J.S., Thermal Loading of Concrete Roofs. Journal of Structural Division - A.S.C.E., to be published.

7. ASHRAE, Fundamentals Handbook. American Society of Heating, Refrigeration, Air Conditioning Engineers, 1977.

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