Discussion on an article published in the

Magazine of Concrete Research

Vol. 15, No. 43 : March 1963

The thermal conductivity of concrete*

by D. Campbell-Allen, M.A., A.F.R.Ae.S., M.I.E.Aust. and C. P. Thorne, B.E., M.Eng.Sc.

Contribution by N. G. Zoldners and V. M. Malhotra

(*Mines Branch, Department of Mines and Technical Surveys, Canada*)

The authors' theory giving the thermal conductivity of concrete in terms of the thermal conductivity of the constituents appears promising, but it still has to be tested at temperatures well above those used in the studies. In the conclusions, reference is made to the lack of available data concerning the variation of the conductivity of cement paste with temperature.

Table I, which is based upon work of Dr T. Harada[1], Tokyo Institute of Technology, gives values for thermal conductivity of Portland cement paste and mortars exposed to high temperatures.

We are engaged on research into the thermal properties of concretes prepared with different aggregates and cements[2,3]. These studies have also included determinations of the thermal conductivity of different concretes exposed to elevated temperatures. The test specimens used were $3 \times 13 \times 17\frac{1}{2}$ in. concrete slabs after 6 to 12 months of air-drying at 24±2°C and 65±5% relative humidity. The equipment and procedures employed for the tests were those described in ASTM designations C201-47 and C417-60.

TABLE I: **The thermal conductivity, *k*, of Portland cement paste and mortars, in B.t.u./ft h deg F.**

	Cement paste		Mortar 1:1		Mortar 1:3		Mortar 1:5	
	mean temperature (°F)	*k*	mean temperature (°F)	*k*	mean temperature (°F)	*k*	mean temperature (°F)	*k*
1	122	0·484	113	0·774	131	0·654	129	0·496
2	225	0·436	214	0·726	280	0·654	289	0·460
3	630	0·339	673	0·580	552	0·484	543	0·387
4	981	0·290	1,040	0·411	984	0·363	986	0·363
5	1,382	0·266	1,413	0·363	1,369	0·315	1,369	0·290

TABLE II*: **Factor "*k*" of concretes† made with normal Type I Portland cement.**

Expanded slag (d = 96)‡		Gravel (d = 144)		Limestone (d = 143)		Sandstone (d = 137)	
Mean temperature (°F)	*k*	Mean temperature (°F)	*k*	Mean temperature (°F)	*k*	Mean temperature (°F)	*k*
		212	0·883			202	1·317
359	0·293	327	0·883	327	0·563	336	1·313
749	0·287	756	0·746	740	0·670	763	0·887

* Table from reference 2.

† water/cement ratio by weight, 0·65 ± 0·03; aggregate/cement ratio by volume, 7·3 ± 0·7.

‡ d = density (lb/ft^3).

TABLE III*: **Factor "*k*" of concretes† made with aluminous cements.**

Expanded shale (d = 85)		Anorthosite (d = 143)		Ilmenite (d = 231)		Tinguaite (d = 135)	
Mean temperature (°F)	*k*	Mean temperature (°F)	*k*	Mean temperature (°F)	*k*	Mean temperature (°F)	*k*
290	0·358	298	0·650	330	0·826	288	0·801
570	0·274	603	0·573	654	0·689	437	0·710
1,051	0·274	1,132	0·501	1,195	0·654	662	0·506
1,484	0·285	1,577	0·512	1,470	—	1,549	0·421

* Table from reference 3.

† water/cement ratio by weight, 0·71 ± 0·01; aggregate/cement ratio by volume, 7·7 ± 0·4.

The results in Tables II and III show that the thermal conductivity of cement paste mortars, as well as that of concretes, decreases with increase of the temperature. The "*k*" factor decreases with decreas-

* Pages 39 to 48 of *Magazine* No. 43.

ing free moisture content in concrete and decreases still further when the chemically combined water is driven off from the hydrated cement paste. This causes gradual weakening of the aggregate-mortar bond and general deterioration of the fire-exposed concrete.

REFERENCES

1. HARADA, T. Variation of thermal conductivity of cement mortars and concretes under high temperatures. *Transactions of the Architectural Institute of Japan.* No. 49. September 1954.
2. ZOLDNERS, N. G. Effect of high temperatures on concretes incorporating different aggregates. *Proceedings of the American Society for Testing and Materials.* Vol. 60. 1960. pp. 1087-1108.
3. ZOLDNERS, N. G., MALHOTRA, V. M. and WILSON, H. S. High temperature behaviour of aluminous cement concrete containing different aggregates. *Proceedings of the American Society for Testing and Materials.* Vol. 63. 1963.

Contribution by M. Levitt, Ph.D.

(British Precast Concrete Federation)

This paper is an interesting and valuable piece of work but the theoretical treatment could have been simplified by considering the conductivity of the aggregate and cement paste together and that of the capillary water separately, irrespective of whether these capillaries were in the cement paste, the aggregate or at the paste-aggregate interfaces. The relative contribution of the water in the capillaries is low since the conductivity of water is about half that of concrete and the void volume for the absorption of water in good quality concrete is of the order of 10%. If these points had been taken into consideration, the thermal conductivity of the matrix for either a parallel or a series configuration of solid and fluid materials would have given the same formula, as the product of K and t for water could have been ignored in comparison with the product in the case of the solid.

Empirical values of conductivity have been given for various moisture contents but there is no indication in the text as to how the concretes were conditioned nor how this moisture was kept inside the block during test. The mercury coating was a good idea for heat transfer but it would be interesting to receive the authors' comments on how this was applied and kept in position and whether they relied upon this thin layer to keep the moisture inside a saturated concrete cylinder.

The units used to express thermal conductivity are a little unorthodox since in this country generally B.t.u. in/ft^2 h deg F are used and not B.t.u./ft h deg F and therefore the reader has to multiply the conductivity figures in the text by 12 to give a straight comparison.

Reply by the authors

We thank Messrs Zoldners and Malhotra and Dr Levitt for their useful discussion.

The additional data on thermal conductivity submitted by Messrs Zoldners and Malhotra for concretes which have been exposed to high temperatures are particularly useful, though it is not clear to us whether the measurements were done at the temperatures quoted or subsequently at room temperature. If the tests were done at the elevated temperatures it would be interesting to see the moisture contents at test for the materials tested in Tables I and II since this would allow a distinction to be made between the change in k resulting from loss of moisture and the change resulting from the high temperature. In static conditions the moisture content is determined by the temperature and the distinction is of no practical sigificance; in transient conditions, however, this is not the case and the distinction is both valid and necessary. The results quoted in Table II are interesting as limestone concrete shows a trend contrary to all others tested. One of the problems of assessing the behaviour of concrete in nuclear power vessels is that of determining conductivities at elevated temperatures when the moisture is not in equilibrium and this can only be done by a transient measurement. We are at present investigating techniques for this and also the interrelated problem of the rate and mechanism of movement of moisture.

The proposal by Dr Levitt to consider the conductivity of the aggregate and cement paste together would have precluded the evaluation of the effect of the conductivity of the aggregate on that of the concrete, and further simplification of the expressions by the additional approximation of ignoring terms relating to water seems hardly justified as the expressions are already simple. Further, in the concretes used which were of conventional mixes, the void volume was as high as 20% and not the 10% that Dr Levitt suggests as a maximum. The moisture content of each specimen was checked by weighing before and after each test and was not found to vary appreciably in the course of any test. The mercury was therefore apparently effective in preventing loss of moisture at the comparatively low temperatures used. The placing of the mercury, and its destructive effect on jointing materials, caused a lot of trouble as Dr Levitt surmises. The main problem was to prevent a layer of mercury penetrating under the specimen and this was successfully achieved by grinding the specimen and seating it on neoprene O-rings. The authors agree with Dr Levitt about the confusion of units in the heat-transfer field and can only plead that their choice is at least as logical as any other.