AUSTRALIAN NATIONAL ANTARCTIC RESEARCH EXPEDITIONS

ANARE RESEARCH NOTES 6

Steam aided curing of concrete in Antarctica.

Paul J. McDonald

ANTARCTIC DIVISION
DEPARTMENT OF SCIENCE AND TECHNOLOGY

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A N A R E

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N O T E S

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STEAM AIDED CURING OF CONCRETE IN ANTARCTICA

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ABSTRACT

Cast in-situ structural concrete is being used in buildings constructed during the redevelopment of Australia's Antarctic stations. Low pressure saturated steam is used to protect concrete from freeze damage during curing, and to accelerate the development of early concrete strength. Steam can also be used for many other purposes on an Antarctic construction site.

1. INTRODUCTION

The Australian Antarctic Division is at present undertaking a rebuilding program at each of its three Antarctic stations. This program is scheduled for completion in 1990. Feasibility studies showed the most durable and economic structural solution for the buildings involved anchoring concrete slabs or pedestals to the ground and erecting structural steelwork and insulated panels on this foundation.

This solution, however, introduced the need for batching, placing, finishing and curing of concrete in the severe Antarctic environment. The main concern of these concreting operations is the curing of the concrete at ambient temperatures below zero.

This paper deals with the problems and solution of curing concrete in these sub-zero temperatures.

2. CURING OF CONCRETE IN COLD ENVIRONMENTS

The use of site batched concrete in Antarctica is not a common practice. However, experience in these conditions has shown that the following criteria should be met to aid curing and to attain full compressive strength of site batched concrete in Antarctica.

(a) An accelerator should be used to increase the hydration rates of the setting cement/aggregate matrix.
(b) An air-entrainment agent should be used to increase workability and aid concrete placement. Workability is also enhanced by the use of warm water (to a maximum temperature of 60°C) during the batching process.
(c) The concrete must not be placed on frozen ground or against frozen formwork.
(d) The placed concrete must be maintained at a temperature at or above 5°C for approximately 4 days. By this time a 30 MPa concrete mix design has attained a minimum strength of 15 MPa and it is almost immune to freeze attack.

If these criteria are not met the newly poured concrete will almost certainly be permanently damaged through freeze attack. Freezing concrete has two major effects:

(a) The expansion of water in the voids of the cement/aggregate matrix causes spalling and cracking. This causes deterioration of the bond between the concrete, steel reinforcement and aggregate. The compressive strength of the concrete itself is also greatly diminished. These factors combine to cause a total loss in structural integrity of reinforced concrete.
(b) The frozen water is incapable of reacting in the hydration of Portland cement. Thus the curing process is stopped and the compressive strength of the concrete is never attained.

Due to the importance of maintaining concrete temperatures above 5°C for the first 4 days of curing, experiments were conducted on the feasibility of steam aided curing of in-situ structural concrete at Casey Station, Antarctica, during January, 1982.

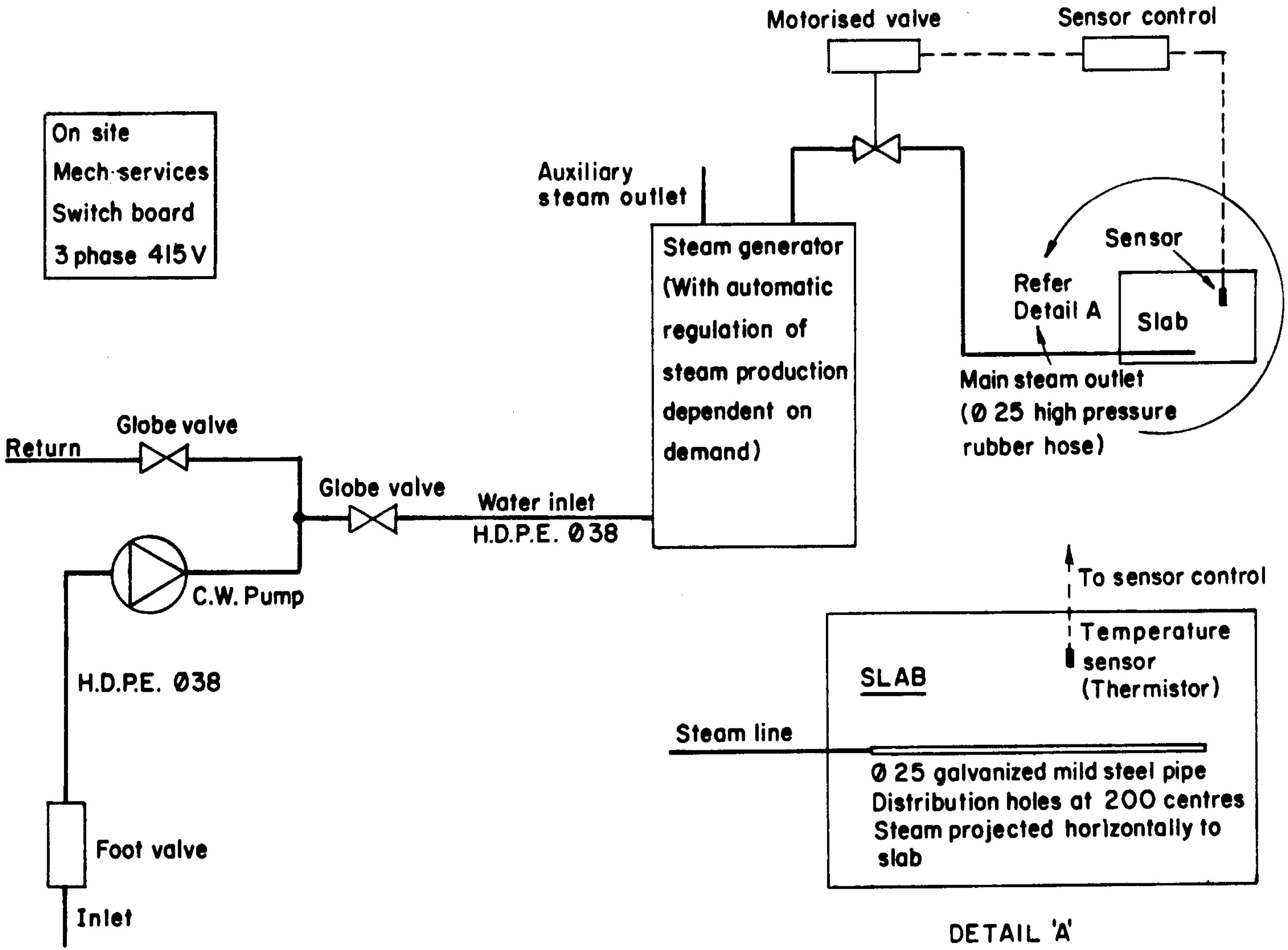


Figure 1. Schematic diagram of steam generating and curing system.

3. LOW PRESSURE STEAM AIDED CURING OF CONCRETE

3.1 ADVANTAGES

The use of steam for curing concrete has three major advantages in sub-zero ambient temperatures:

(a) The temperature is kept above 5°C thus preventing freezing of the concrete.
(b) The application of steam greatly expedites the hydration process and concrete strength is consequently attained much quicker than using other curing techniques. Standard low pressure steam curing techniques will cause development of a normal 28 day compressive strength within 3 days. Fifty percent of ultimate strength is normally developed within 24 hours of commencement of steam curing.
(c) Although the hydration rate of the cement paste is accelerated, there is no deterioration in quality or durability of the final concrete product.

The early attainment of high strength means load bearing structural steel can be erected much sooner than under curing techniques which do not use steam. This expedites the entire construction program. In view of the limited time during summer for outdoor construction activity this creates significant savings in construction expenditure and generally enhances morale of construction personnel.

3.2 CONTROL PARAMETERS

(a) No steam was applied to the concrete before an initial maturity of 40°C/h was achieved. This involved leaving poured concrete for approximately 3 hours after pouring.
(b) The maximum increase in temperature was maintained at a rate of 24°C/h until an optimum curing temperature of 80°C was reached.
(c) The insulated covers were left on the concrete for at least 24 hours after the steam was withdrawn. This minimised thermal shock to the slab when it was exposed to the natural elements.

3.3 LAYOUT OF SITE

A steam generator was mounted inside a 6000 x 2400 x 2400 mm modified insulated seatainer. Water was pumped from a fresh water tarn on a continuous ring main and was drawn off this main by the steam generator. The steam was then fed from the generator to the concrete pour site by high pressure rubber hose and circulated onto the pour by a 20 mm diameter perforated mild steel pipe. The pour was covered with insulated blankets which initiated the regulation of the amount of steam entering the pipe. This maintained a constant curing temperature of 80°C under the insulating blankets.

Figure 1 shows a complete schematic layout for the entire steam generator/curing operation.

4. EQUIPMENT USED FOR LOW PRESSURE STEAM AIDED CURING OF CONCRETE

4.1 OIL-FIRED STEAM GENERATOR

The charactristics of the steam generator's operation and performance are attached in Appendix A.

The generator as supplied was not housed in a protective shelter. A standard 6000 x 2400 x 2400 mm insulated seatainer was modified to house the steam generator. This involved the raising of the roof at one end and including an entrance door (Figure 3). Fuel, oil and water inlets and the steam outlets were installed with standard vapour proof penetrations.

An electric heater was mounted in the seatainer to maintain a temperature above zero at all times. This prevented water freezing in the generator during shut-off. The completed seatainer unit is shown in Figures 2 and 4.

4.2 STEAM DISTRIBUTION TO SITE

A 25 mm diameter flexible high pressure rubber hose was used to distribute steam from the generator to the concrete slab. At the delivery end the hose was connected to a 25 mm diameter galvanised mild steel pipe with 3 mm diameter holes drilled at 20 mm on each side of the pipe. The pipe was laid on the slab and the holes were placed so steam was projected horizontally rather than vertically. A vertical steam projection causes severe pitting and temperature differentials on the concrete surface.

The steam was contained over the slab by a series of insulating blankets. These consist of several standard 500 x 400 x 75 mm thick fibreglass insulating batts which are held together and covered on both sides by plastic sheeting. The average dimension of each blanket is 3000 x 800 x 75 mm.

These are held above the newly poured concrete by timber, and canvas tarpaulins are placed over the blankets. The tarpaulin is then anchored securely around the concrete and attached to the underlying insulating blanket. This forms an adequate enclosure for steam curing.

4.3 STEAM MODULATION

The supply of steam to the newly poured concrete was modulated so that a temperature of 80°C was maintained under the blankets.

A thermistor was placed on the concrete during curing as a temperature sensor. This was connected to an electronic control box, situated in the seatainer, which was set to monitor the thermistor at 80°C (±5°C). The opening and closing of the motorised valve on the main steam outlet was then activated by this control box so a constant temperature was maintained.

The steam generator automatically regulated its steam production according to the demand for steam from the main steam outlet.

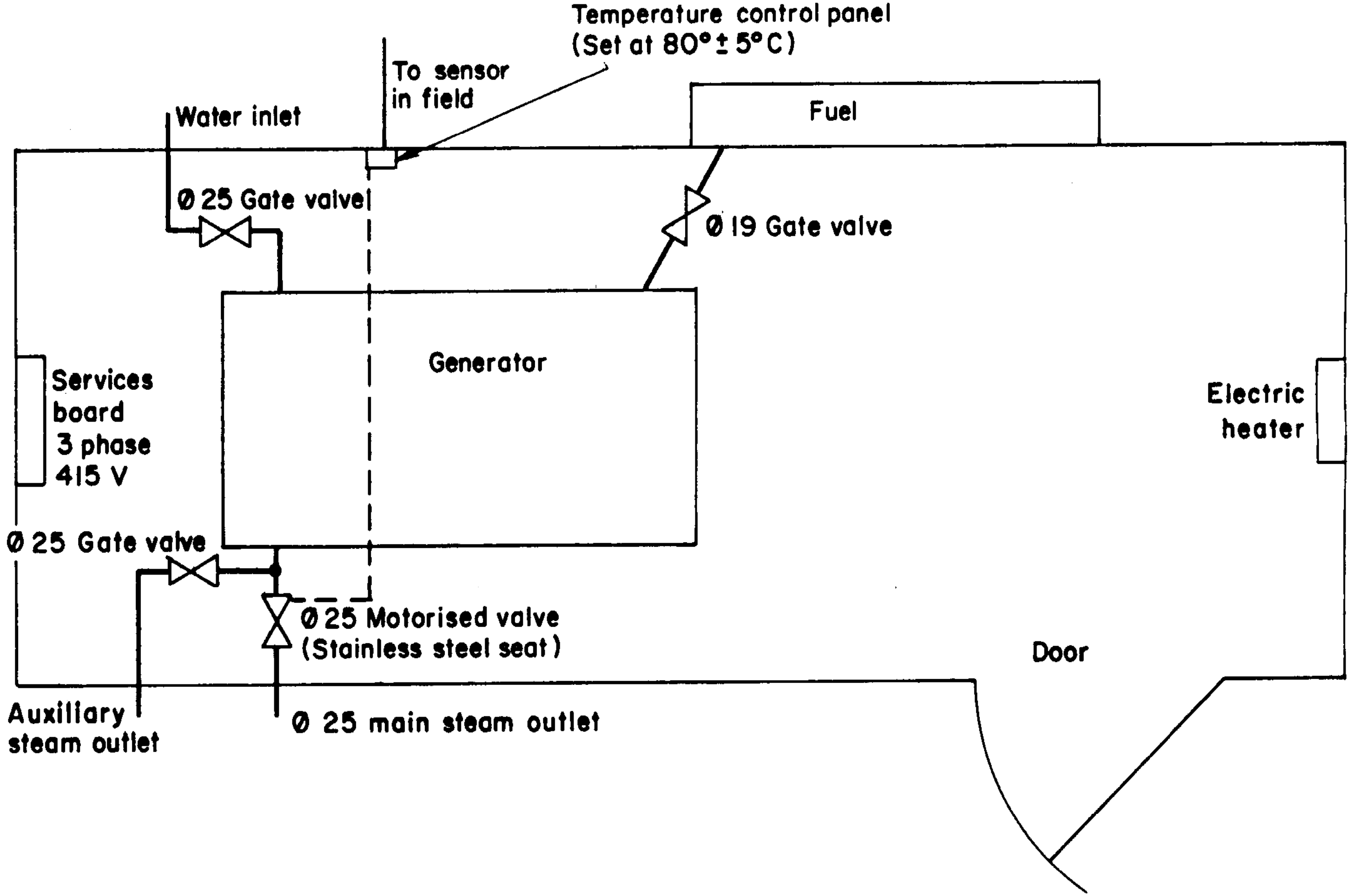


Figure 2. Schematic diagram of steam generator.

4.4 WATER SUPPLY PUMP AND DELIVERY PIPES TO THE STEAM GENERATOR

The water supply for the steam generator was a freshwater tarn about 100 metres from the generator. A self priming pump was chose with an open reinforced, abrasion-resistent impeller and stainless steel wear plate. This was placed at the tarn and the water was pumped through a 38 mm diameter High Density Polyethylene (HDPE) pipe against an elevation head of approximately 6 metres.

The HDPE pipe was laid such so that water was pumped to the generator and returned to the source water supply. This ensured that water in the pipe was always in a dynamic state, preventing any chance of freezing.

The suction end of the HDPE pipe was fitted with a 38 mm diameter foot valve which ensured instantaneous priming of the pump after a stoppage. A Tee-section was placed in the HDPE pipe at the inlet to the steam generator and a 38 mm diameter globe valve was attached. This valve allowed manual regulation of the water intake according to the steam generation requirements.

5. OTHER USES OF THE OIL FIRED STEAM GENERATOR

The production of steam proved to be beneficial for many tasks on an Antarctic station. A steel blow-pipe of approximately 1500 mm length and 10 mm diameter with a tapered nozzle was attached to the rubber hose from the Main Steam Outlet. The flow-pipe was then used to direct steam for the following purposes:

(a) Scabbalding of concrete for construction joints. If the steam is applied within 24 hours of the pour, the steam pressure is adequate to expose aggregate for a satisfactory construction joint.
(b) Clearing and warming of natural and excavated earth foundations prior to pouring of concrete. This creates a foundation free of foreign material and minimizes the chances of lower boundary freezing.
(c) De-icing, warming and clearing of formwork. Manual removal of snow from formwork which encloses in-situ steel reinforcement is a difficult and time consuming task - the use of the steam generator to clear the snow through a weep hole in the formwork is a speedy process.
(d) Heating of the 1 cubic metre agitator bowl on the concrete truck. Steam is sprayed on the bowl prior to its departure from the batching plant. This prevents any premature set or icing of the concrete mix prior to its delivery on site.
(e) Removal of any articles which may be frozen into ice or snow.
(f) Heating and de-icing of plant to facilitate starting during extremely low temperatures.

6. TEMPERATURE MEASUREMENTS OF CONCRETE DURING CURING

6.1 THE CONCRETE MIX

The design compressive strength of the concrete mix was 30 MPa and was constituted in the following weight ratios:

12 mm graded aggregate : sand : cement
= 2.37 : 2.34 : 1
The maximum slump was 75 mm.

A low water/cement ratio of 0.44 is specified to facilitate early strength development and to minimise the risk of freeze attack. To improve the workability of the concrete, its resistance to frost effect, and to reduce the normal hardening time, an air entraining agent and an accelerator were added to the mix.

6.2 MONITORING OF TEMPERATURES WITHIN CURING CONCRETE

As the concrete was poured thermocouples were covered at various points within the slab. The thermocouples were made from Type T, Copper/Constantan Teflon-coated thermocouple wire. The twisted bare ends of each thermocouple wire were coated with a clear epoxy. This prevented ingression of alkaline solutions between the Copper and Constantan and the creation of a galvanic cell between the two metals. Laboratory tests showed the epoxy coating made no difference to temperature measurements in a non-corrosive environment.

The thermocouple wires were then monitored by a 16 Channel Data Logger which can be programmed to automatically record thermocouple temperature measurements at a pre-determined time interval.

The Data Logger was housed in a temperature controlled seatainer. This maintained temperatures above zero for optimum efficiency of its electronic components.

For the first 24 hours measurements were taken at half hourly intervals but were later increased to hourly intervals. The temperatures in various locations of the curing slab were monitored for approximately 140 hours after the initial pour.

6.3 EXPERIMENTAL RESULTS

Thermocouple probes were attached to the steel reinforcement prior to pouring. The temperatures of two concrete slabs were monitored during the initial curing stages:

Slab 1: A slab with no steam aided curing. The curing was done by placing insulating blankets over the slab and not applying any heat or moisture from an external source. The slab was moist before it was covered.

Slab 2: A slab aided with steam curing. The external ambient temperature was monitored simultaneously with the slab temperatures. These temperatures are shown in Figures 6 and 7.

The dimensions of each slab and the positioning of the thermocouples within each slab are shown in Figure 8. The position of thermocouples was designed to give an indication of the temperature gradient from the edge to the interior of the slab and vertically through different sections of the slab.

Results of concrete temperatures for all thermocouple probes in Slabs 1 and 2 are contained in Appendix II.

6.3.1 Concrete Temperatures During Curing of Slab 1

The graph in Figure 9 shows a rapid rise over the first 24 hours after application of the insulating blankets. These blankets capture the initial heat of hydration from the cement and cause a rise in concrete temperature to approximately 31°C.

Once equilibrium is achieved between heat generation and heat loss the temperature declines steadily to 24°C over the next 40 hours. At this point the danger period for frost attack has expired as the hydration process has advanced sufficiently to ensure structural integrity of the slab.

From this point (i.e. at approximately 60 hours) the heat evolution is not sufficient to override ambient temperature fluctuations and the slab temperature also fluctuates (Figures 6 and 9). At no stage does the slab temperature fall below zero.

6.3.2 Concrete Temperatures During Curing of Slab 2

The graph in Figure 10 shows a very rapid rise in concrete temperature at points A and C where steam was applied.

The gradual loss of heat as shown from points X to E is not markedly affected by any fluctuations in ambient temperature (Figure 7). However, at point E the insulated curing blankets were removed from the slab and there was a drop in temperature of approximately 10°C in an hour. The curing was adequately advanced to withstand this thermal shock and no cracking was evident in any areas of the slab during subsequent inspections.

Once the curing blankets were removed the concrete temperatures fluctuated in accordance with ambient temperature fluctuations. At no stage in the 140 hour monitoring perod did the concrete temperatures fall below zero.

6.3.3 Longitudinal and Transverse Temperature Maxima and Minima

Figures 11 and 12 show the following trends for both steam cured and non-steam cured slabs:

Longitudinally
(a) The maximum temperature of the concrete increases from the poured concrete edge inwards. (i.e. from Probe 1 to Probe 7 etc.).
(b) The minimum temperature of concrete remains stable from the poured concrete edge inwards. (i.e. from Probe 1 to Probe 7 etc.).

Transversely
(a) The maximum temperatures decrease from the top of the slab downwards. This indicates that at peak temperature the heat of hydration trapped under the insulation covers heats the top of the concrete more than the bottom layer; however, the bottom layer still remains above zero.
(b) The minimum temperatures increase from the top of the slab downwards.

From approximately 65 hours to the completion of monitoring the slab temperature is conditioned more by ambient temperatures than the trapped heat of hydration. Appendix II shows that the maximum temperature of the slab is higher and the minimum is lower the closer the concrete is to the surface of the slab. Thus climatic fluctuations and the exothermic hydration reaction have a greater effect on concrete temperatures the closer the concrete is to the surface.

6.3.4 Concrete Temperatures on Inside Face of Timber Formwork

Probe 10 monitored the temperature performance of concrete in contact with formwork. This formwork was exposed to climatic fluctuations and was not covered by curing blankets. During curing of Slab 1 the following trends are evident:

(a) The maximum and minimum concrete temperatures of Probe 10 are lower than for all internal slab temperatures and all edge temperatures where the slab is abutting previously poured concrete.
(b) The fluctuations in concrete temperature correspond to fluctuations in ambient temperature from the start of curing. Unlike the curing blankets, the formwork effects no noticeable retention of heat from cement hydration.
(c) At no stage are sub-zero temperatures attained.

During curing of Slab 2 the following trends are evident:

(a) The maximum temperature attained is higher than newly poured edge concrete which abuts existing concrete but is lower than the maximum temperatures attained internally. This is mainly due to the distribution of steam under the curing covers.
(b) The basic form of the temperature graph (Figure 14, Probe 10) and reasons for this form, are similar to those exhibited in Figures 9 and 10 as explained in 6.3.2.
(c) At 65 hours when the insulating blankets were removed the maximum and minimum temperatures were both lower than the internal maximum and minimum temperatures. This indicates that the formwork offers less protection from external temperatures than the surrounding concrete itself.
(d) At no stage are sub-zero temperatures attained.

7. CONCRETE TEMPERATURES IN EXPOSED CONCRETE

The temperature of an exposed block of concrete was monitored during the periods that Slabs 1 and 2 were monitored. Figure 13 shows the dimensions of the block and the position of thermocouples within the block.

Reference to Appendix III shows the graphs of the concrete temperatures against time. The following trends are evident from these graphs:

(a) The temperature fluctuations of the concrete block are subject to ambient temperature fluctuations.
(b) The maximum and minimum concrete temperatures increase from the surface to the internal and external centre of the concrete block.

(c) Sub-zero temperatures of the concrete were attained. The freezing of this block caused severe cracking of the concrete and a deterioration of its structural quality. This highlights the necessity for retention and addition of heat during the curing process.

8. CONCLUSION

A steam generator was successfully used in providing steam for the curing of newly poured concrete.

The concrete temperatures of curing concrete were successfully monitored on a regular time interval for 24 hours per day for approximately 140 hours. Temperature measurements during curing with steam showed a maximum increase of 40°C over concrete temperatures evident when curing without steam. The increase in temperature together with condensation of the steam on the slab surface provided more favourable conditions for curing than are attainable when curing without steam. The use of steam aided curing eliminated the risk of freeze attack during the initial curing stages. The chances of freeze attack are high if there is no external source of heat and moisture.

The use of steam aided curing for 3 days ensured a strength in the concrete which was immediately capable of accepting structural steel erection. When using curing methods without steam a waiting period of at least 14 days must be allowed before structural steel can be safely supported.

The time saved during the curing process meant there was a reduction in the time of getting a building to its lock-up stage. As time for construction work in Antarctica is practically limited to the summer months, steam aided curing of concrete is recommended as a useful technique for expediting any activity which cannot continue until concrete attains a predetermined compressive strength.

It is expected that studies will soon be initiated to accurately assess the overall economic advantages of using steam curing for concrete in Australia's current Antarctic rebuilding program.

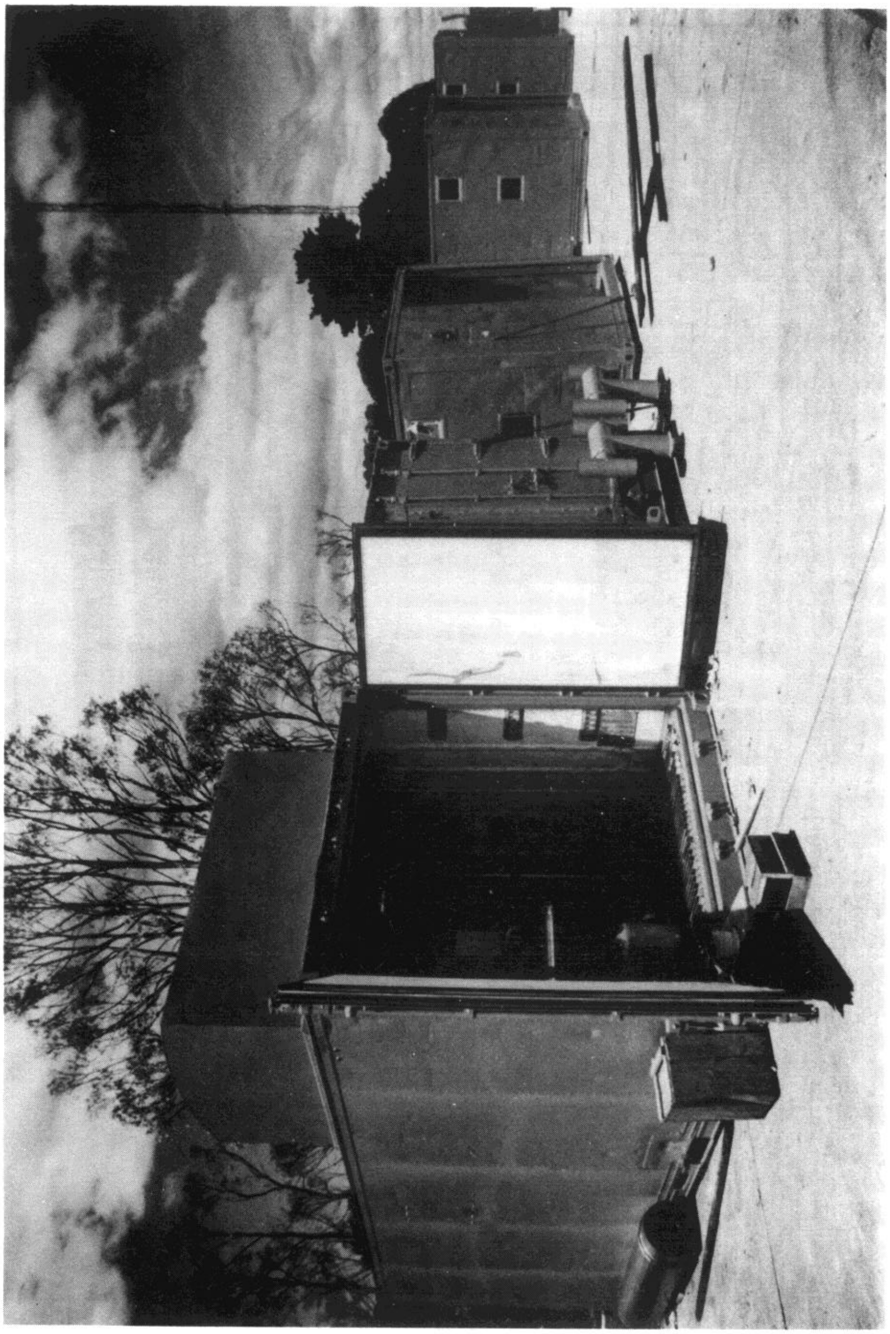


Figure 3. The modified seatainer.

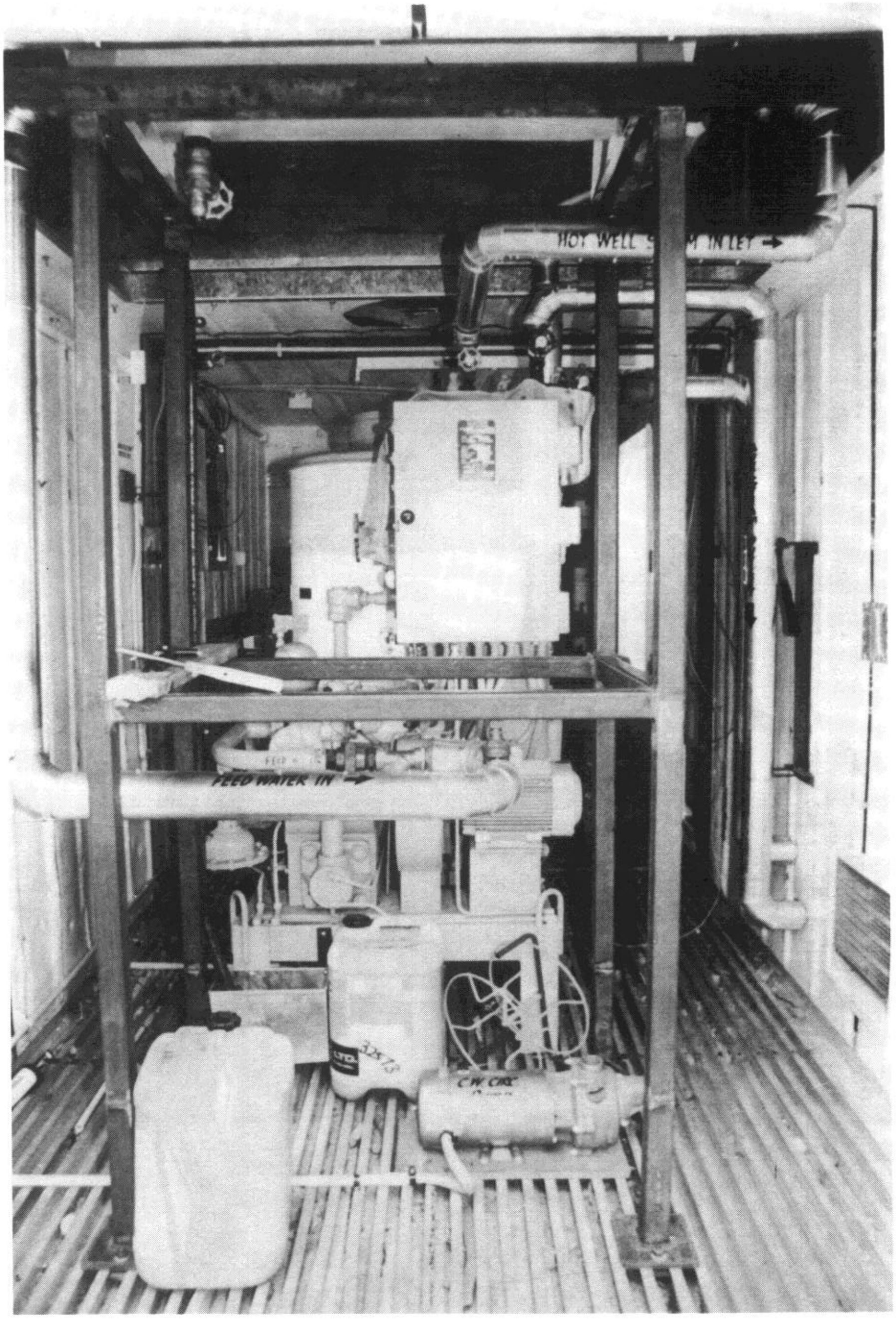


Figure 4. Interior of seatainer showing completed steam generator.

Figure 5. Using steam for releasing frozen materials.

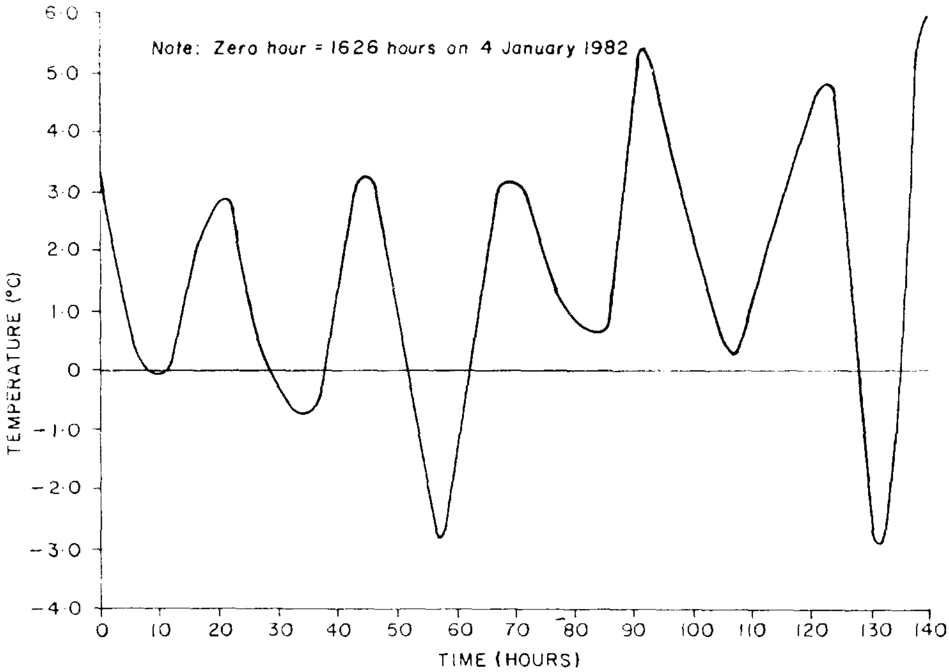


Figure 6. Ambient temperature during curing of Slab 1.

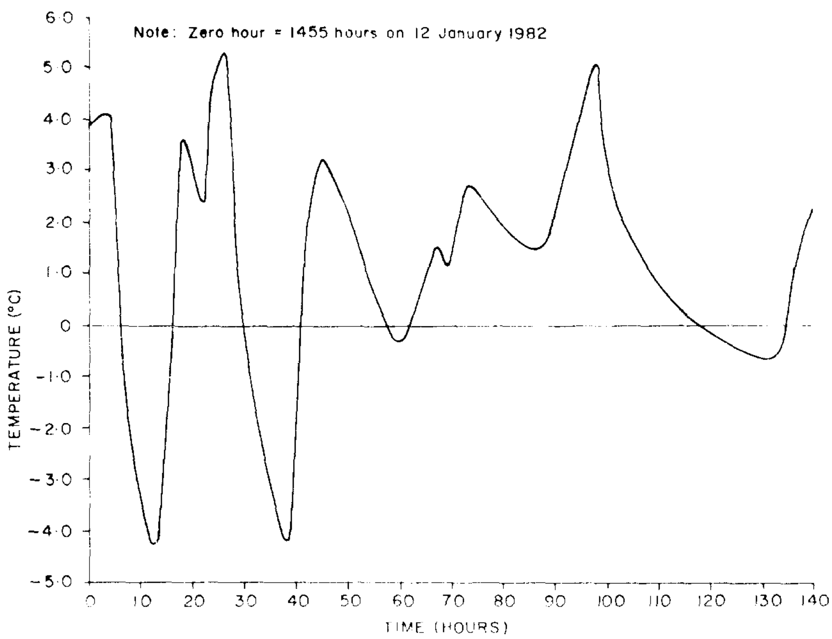


Figure 7. Ambient temperature during curing of Slab 2.

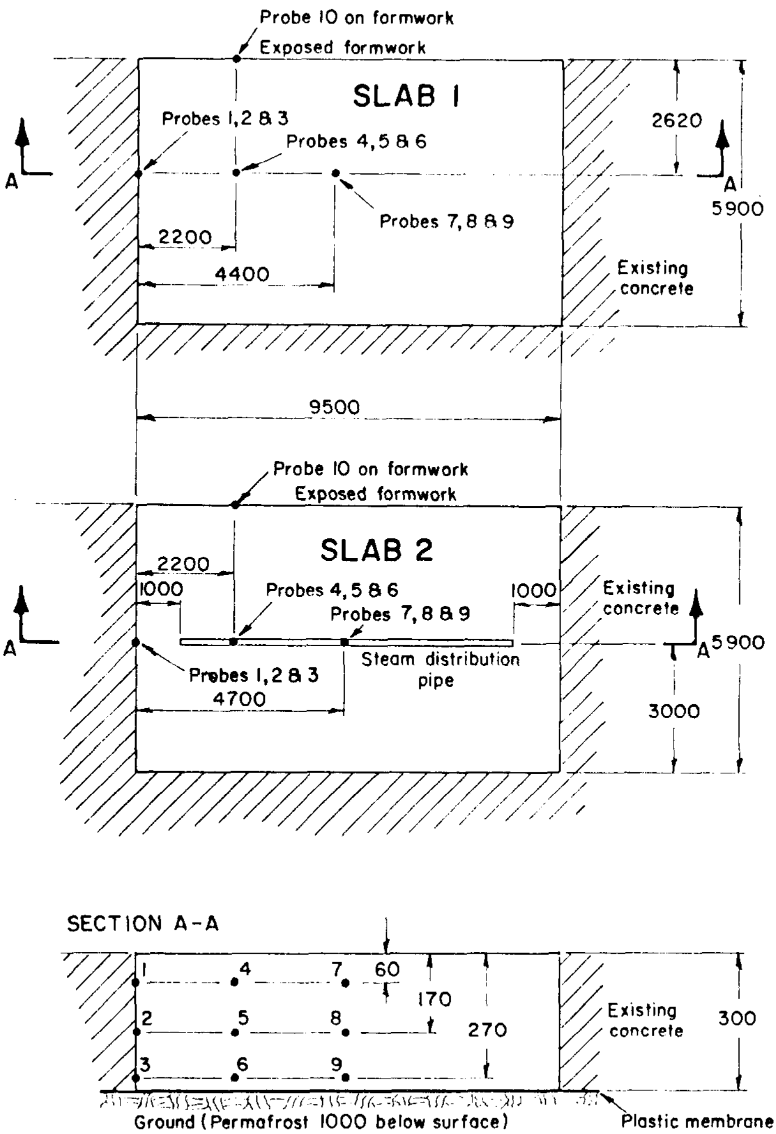


Figure 8. Probe positions for Slabs 1 and 2.

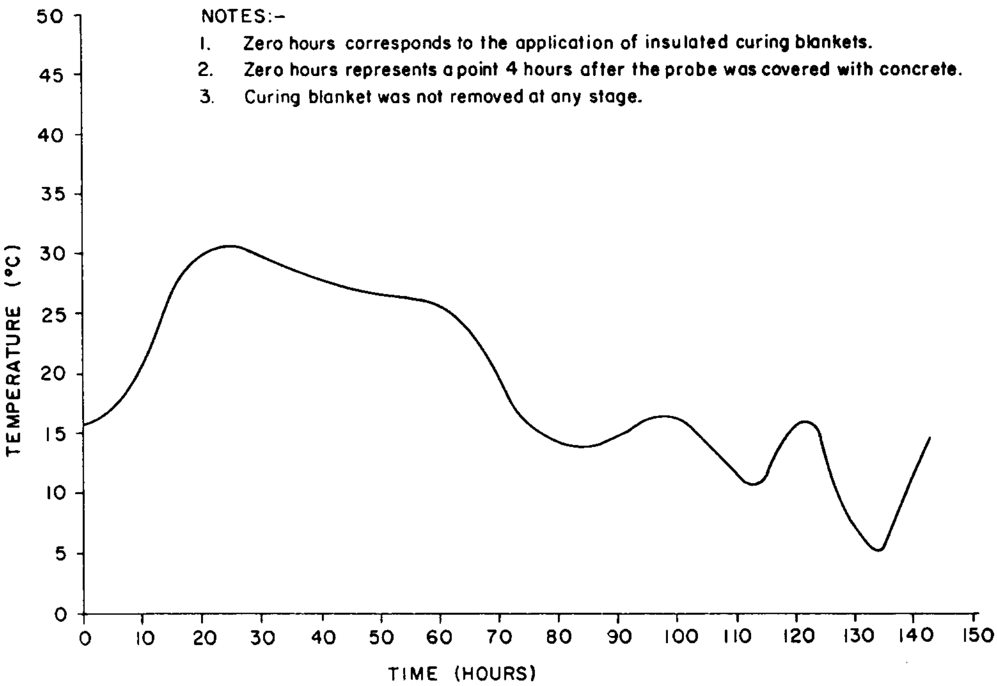


Figure 9. Typical concrete temperatures during curing of Slab 1 (no steam) - probe 4.

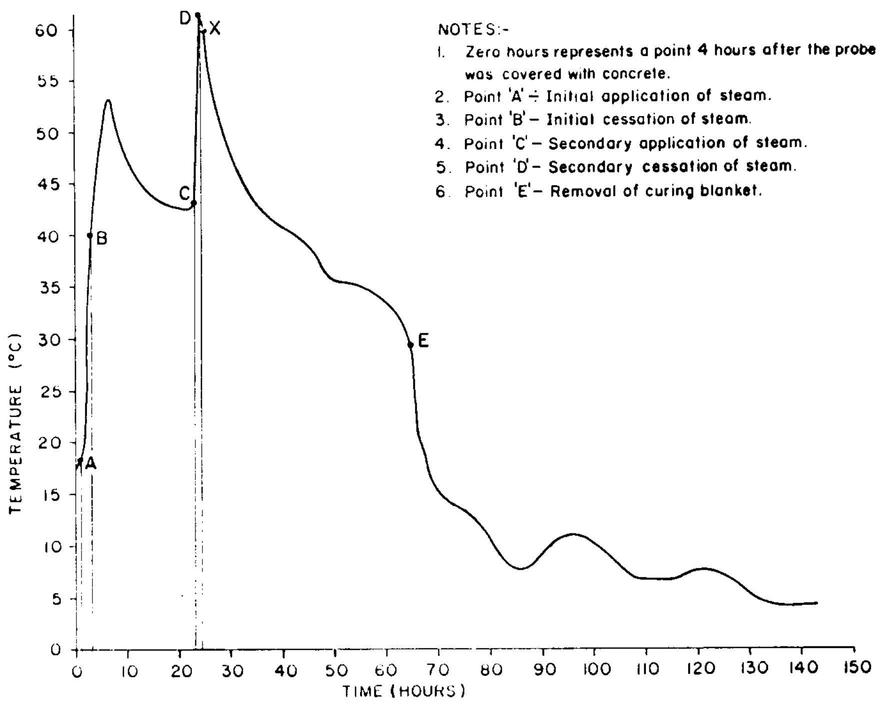


Figure 10. Typical concrete temperatures during curing of Slab 2 (steam cured) - probe 4.

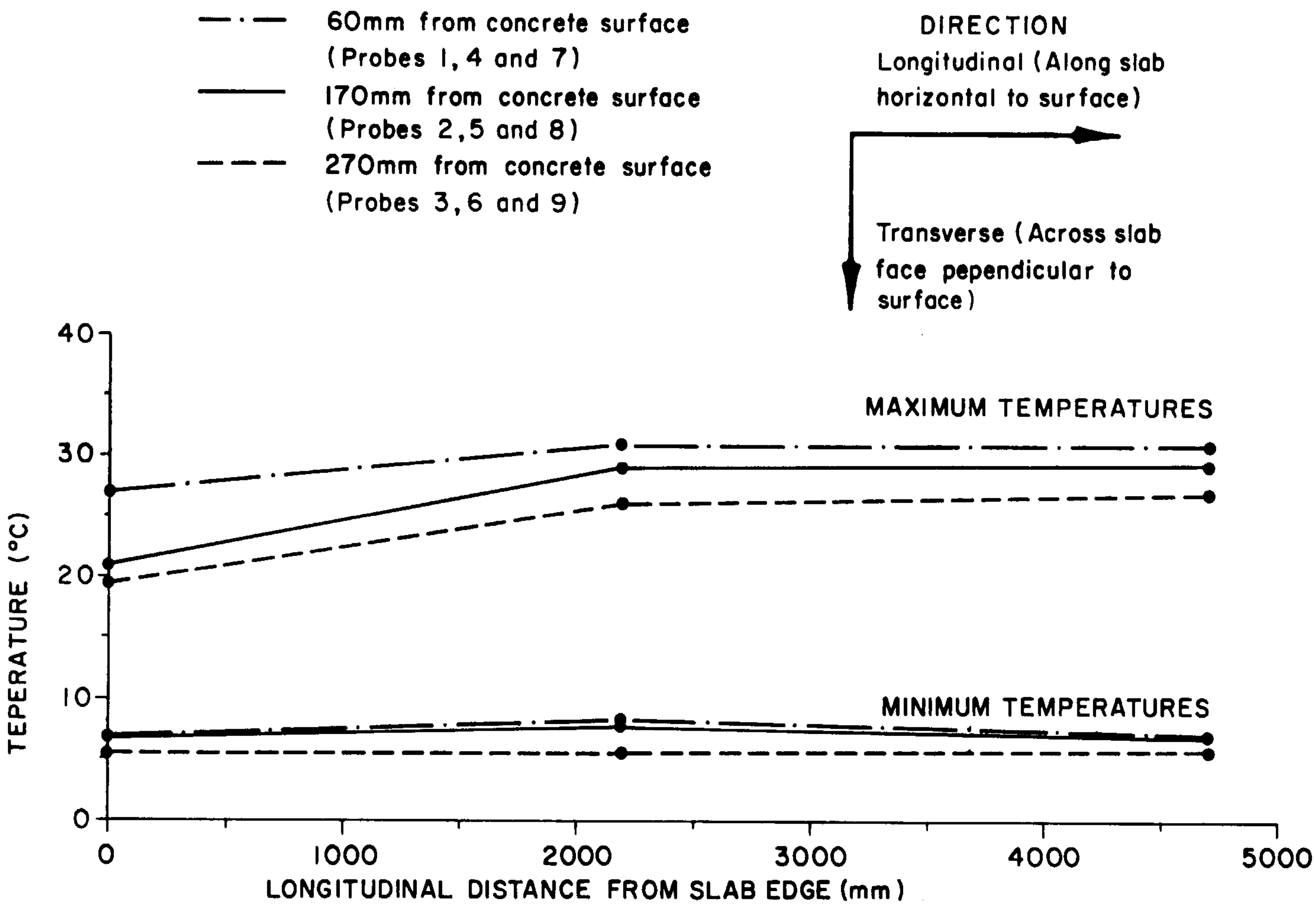


Figure 11. Longitudinal and transverse temperature maxima and minima (no steam).

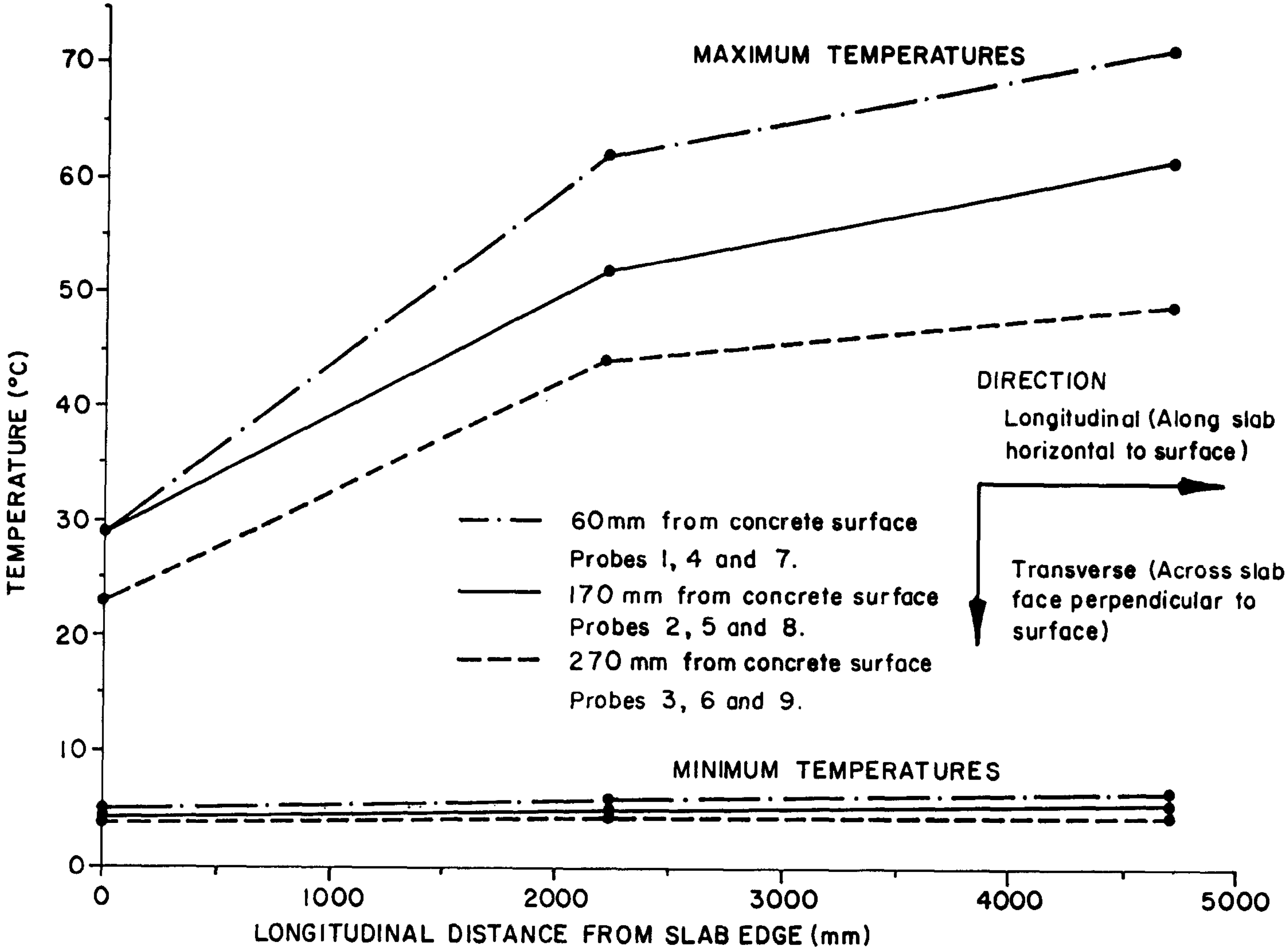


Figure 12. Longitudinal and transverse temperature maxima and minima (steam curing).

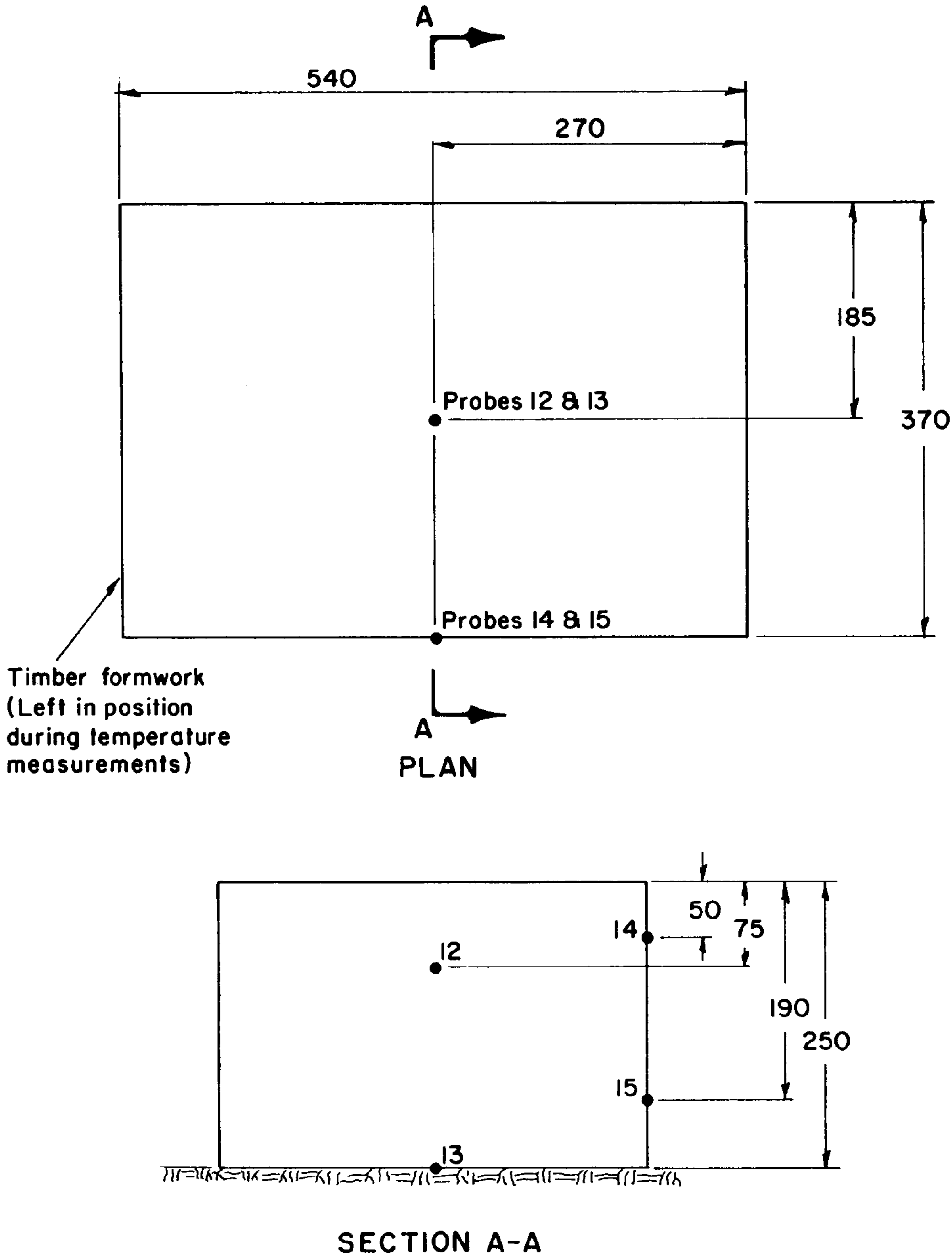


Figure 13. Positions of thermocouples in exposed concrete block (no curing protection).

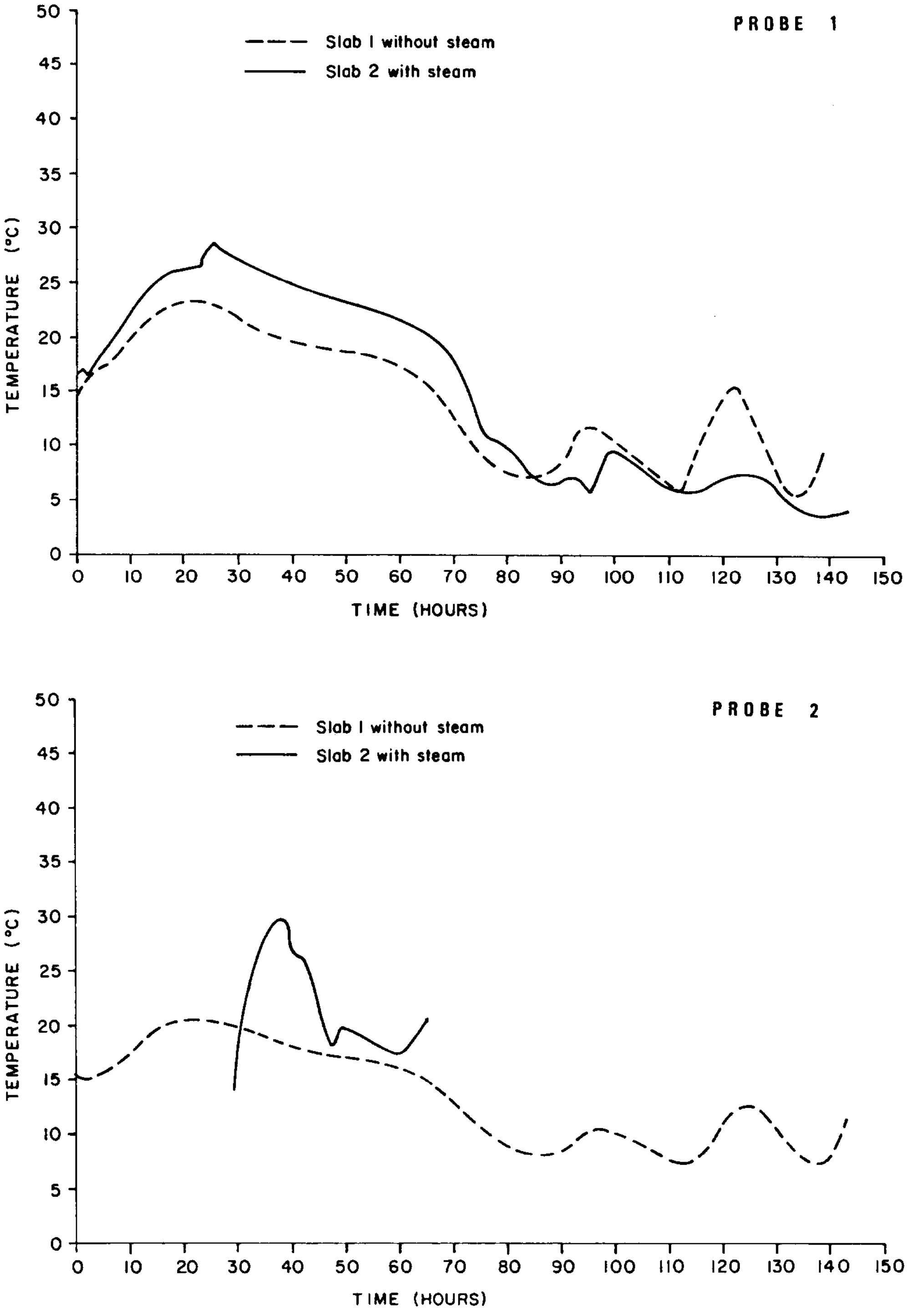
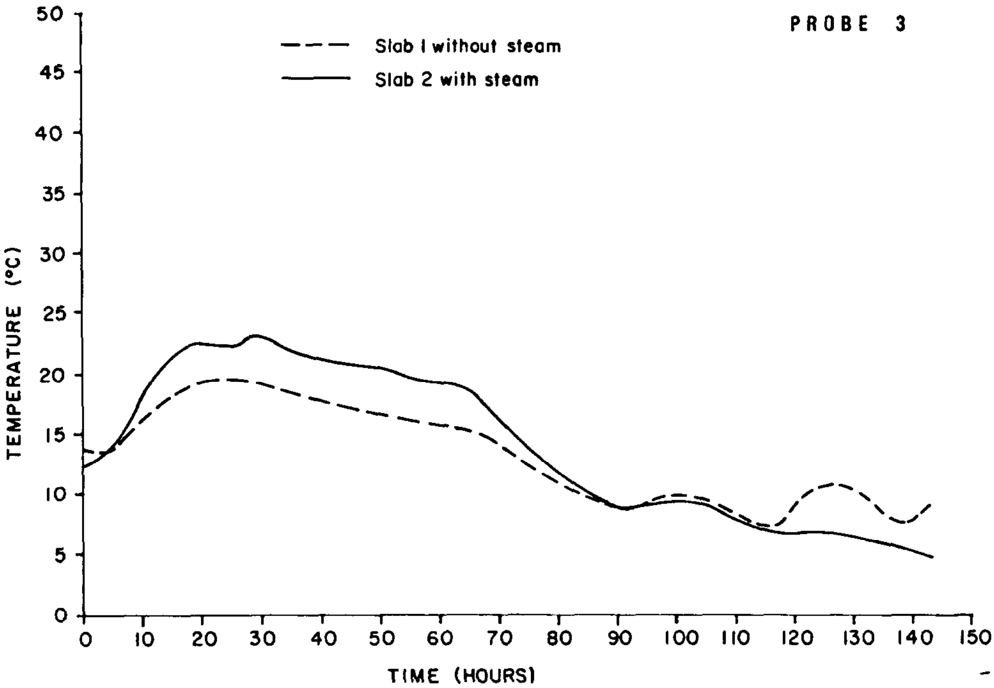
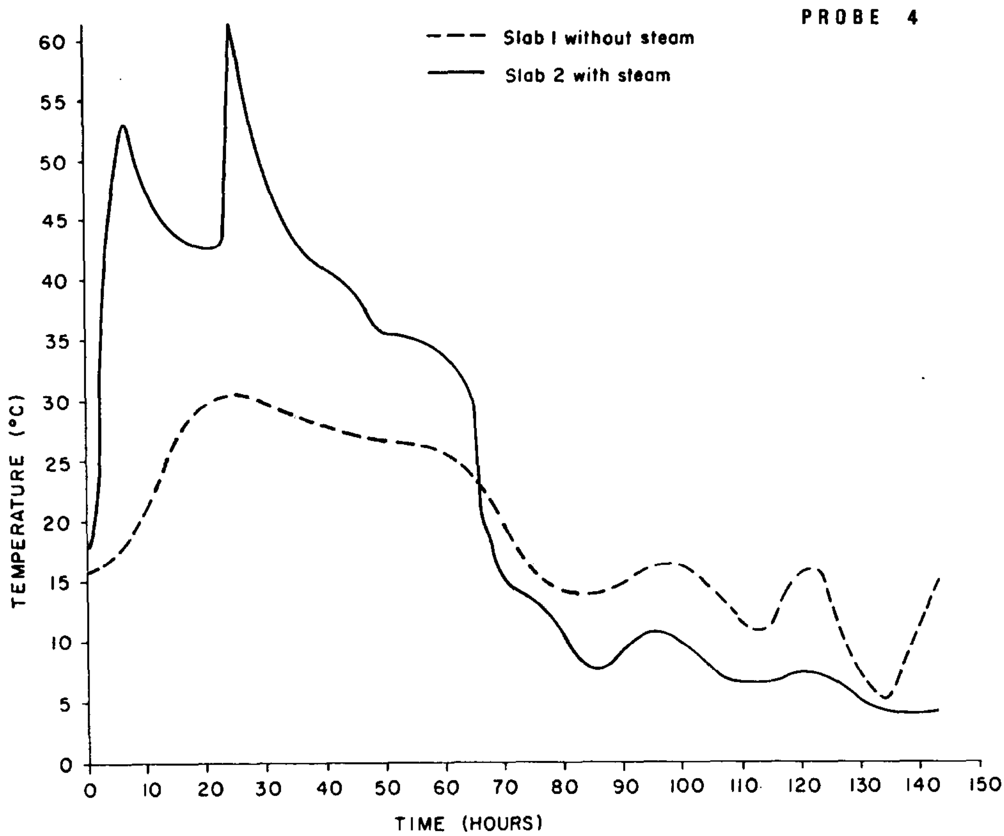
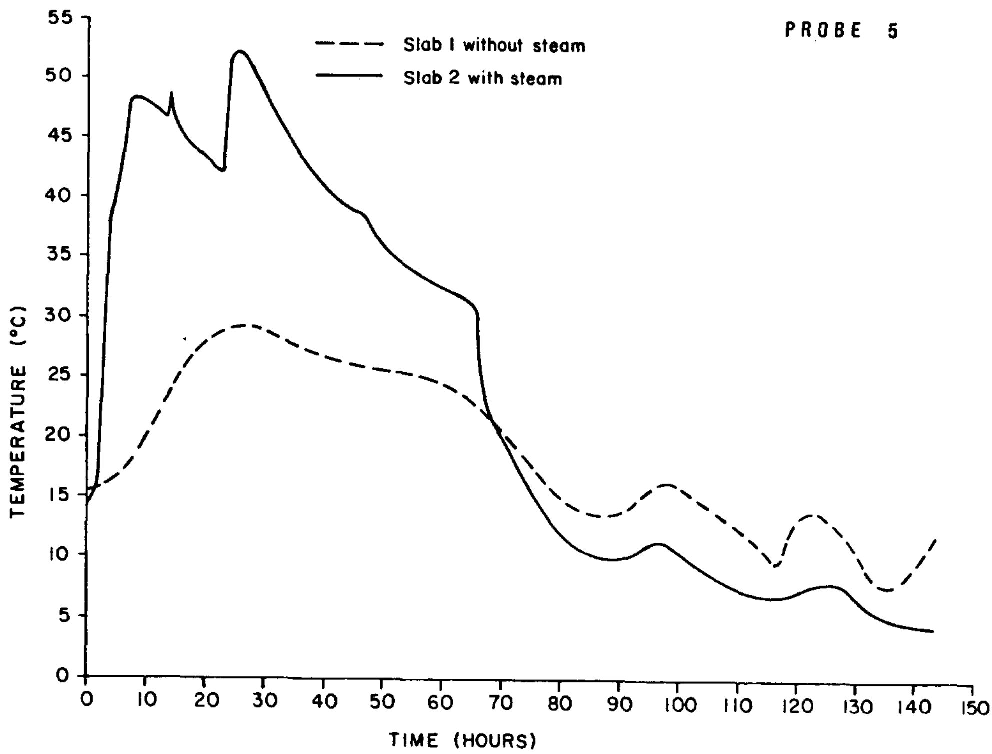
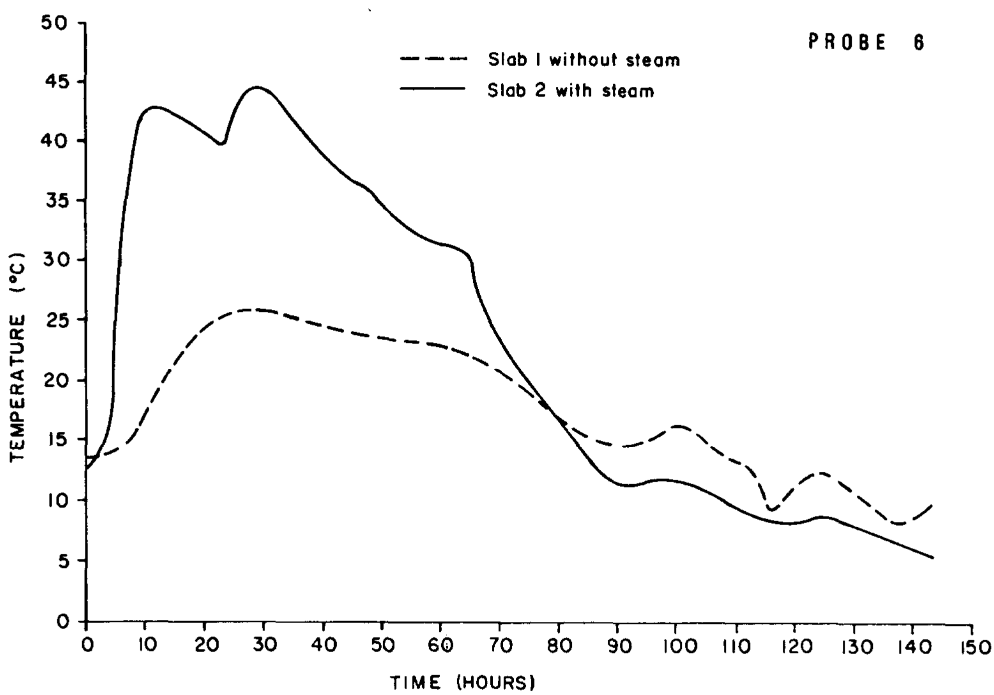


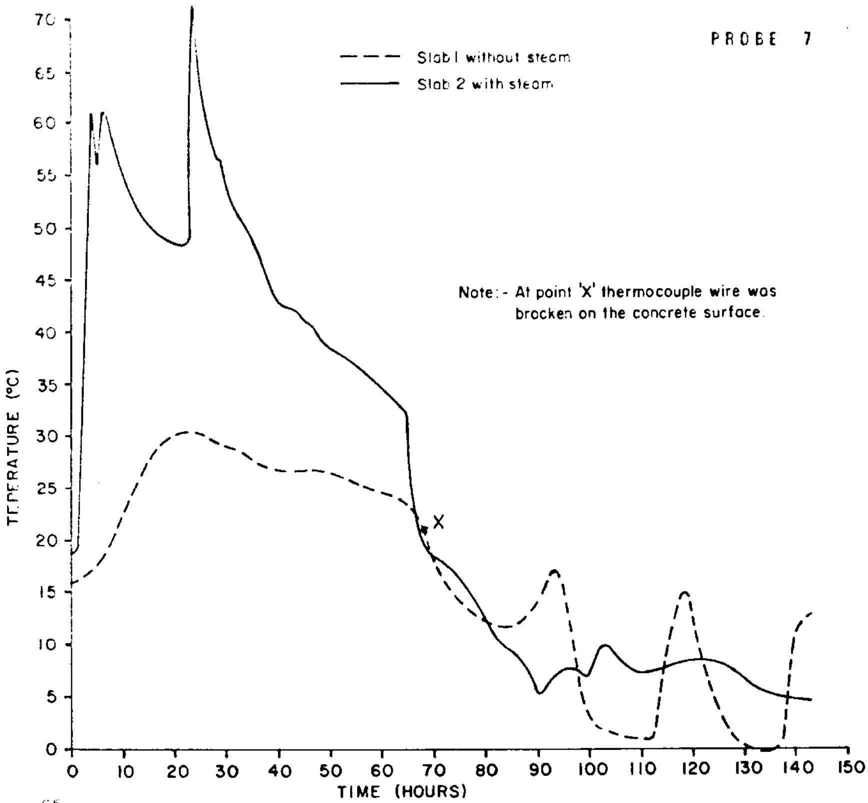
Figure 14. Concrete curing temperatures of Slabs 1 and 2.

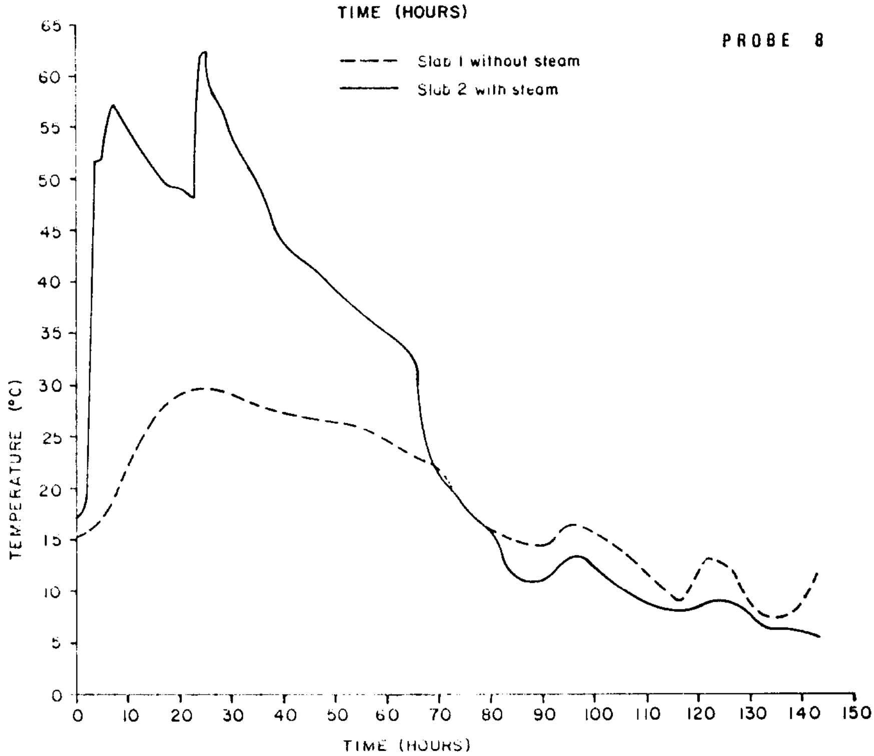

PROBE 3
Slab I without steam
Slab 2 with steam
TEMPERATURE (°C)
TIME (HOURS)

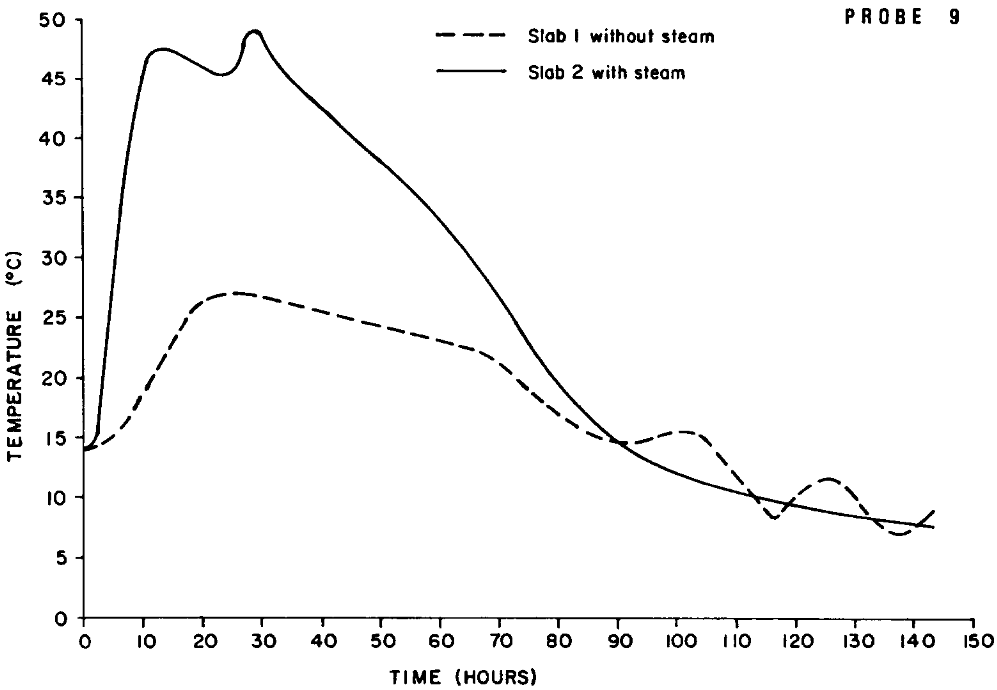

PROBE 4
Slab I without steam
Slab 2 with steam
TEMPERATURE (°C)
TIME (HOURS)

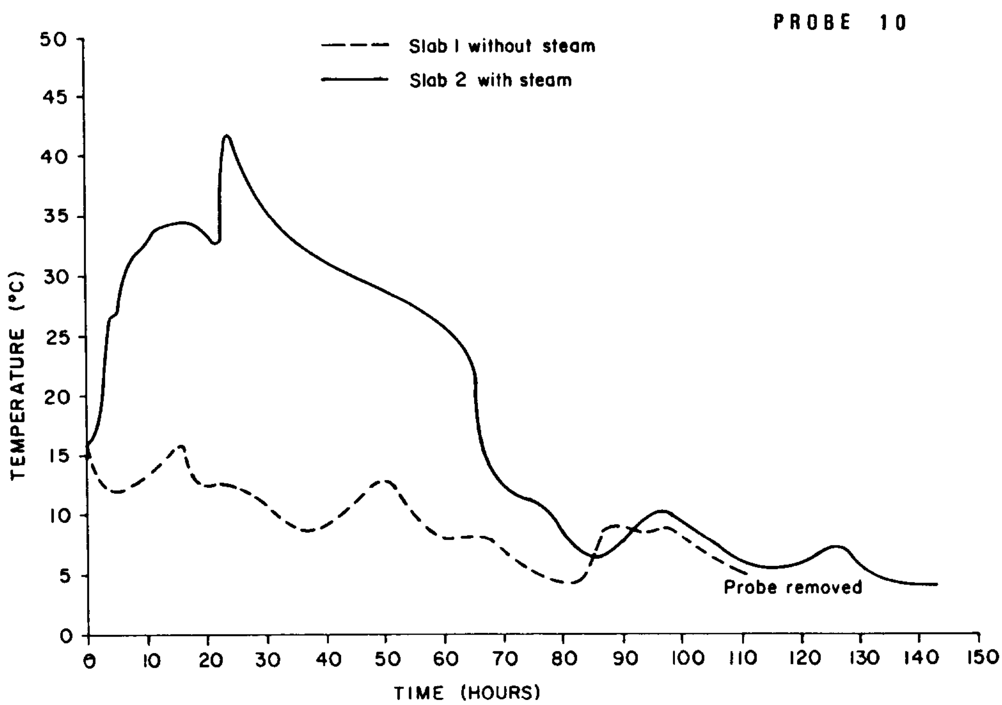

PROBE 5
Slab I without steam
Slab 2 with steam
TEMPERATURE (°C)
TIME (HOURS)
55
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


PROBE 6
Slab I without steam
Slab 2 with steam
TEMPERATURE (°C)
TIME (HOURS)
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


PROBE 7
Slab I without steam
Slab 2 with steam
Note:- At point 'X' thermocouple wire was brocken on the concrete surface.
X
TEMPERATURE (°C)
TIME (HOURS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


PROBE 8
Slab I without steam
Slab 2 with steam
TEMPERATURE (°C)
TIME (HOURS)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150


PROBE 9
Slab I without steam
Slab 2 with steam
TEMPERATURE (°C)
TIME (HOURS)


PROBE 10
Slab I without steam
Slab 2 with steam
Probe removed
TEMPERATURE (°C)
TIME (HOURS)

APPENDIX I. OPERATION AND PERFORMANCE CHARACTERISTICS

1. CONTROL SETTINGS

a.	Steam Trap Operation - time per cycle (high fire)	15 Secs.
b.	High Steam Pressure Switch, SPS - cut in	940 kPa
	- cut out	1000 kPa
c.	Modulation Pressure Switch, MPS - cut in	900 kPa
	- cut out	960 kPa
d.	Water Pump Relief Valve - Blow off pressure	3500 kPa
e.	Safety Valves - No. 1 Blow off pressure	1100 kPa
	No. 2 Blow off pressure	1100 kPa
f.	Thermostat Test - Blowdown to burner off	35 Secs
g.	Steam Temperature at 1 MPa - Thermometer reading	180°C
h.	Auxillary Thermostat, ATS, - cut-out-setting	210°C
i.	Volute Pressure	110 mmW.C
j.	CO_2 - High Fire	9%
k.	Stack Temperature - High fire	117°C
l.	Fuel Pressure Switch - Cut in (Oil Units Only)	900 kPa
m.	Nozzles (Oil Units) Capacity 2 off 3 Gals/Hr., Type	Monarch
	1 off 6 Gals/Hr., Type	PLP Semi Solid
	Spray Angle 80°	

2. EVAPORATION TEST

a.	Steam Pressure	1000 kPa
b.	Feed Water Pressure	2100 kPa
c.	Feed Water Temperature	17°C
d.	Fuel Pressure - Oil	1700 kPa
	- Gas	-
e.	Duration of Test	30 mins.
f.	Quantity of Oil Burned	29.9 kg
g.	Weight of Water Evaporated	404 kg
h.	Calorific Valve of Oil	45590 KJ/Kg
i.	Enthalpy of Steam	2776 KJ/Kg
j.	Enthalpy of Feed Water	71 KJ/Kg
k.	Total Heat Absorbed, J-K	2705 KJ/Kg
l.	Evaporation Rate	808 Kg/hr
m.	Fuel Consumption Rate - Oil	59.8 Kgs/Hr
n.	Total Heat Input, H x N	2,726,282 KJ/Hr
o.	Total Heat Output, L x M	2,185,640 KJ/Hr
p.	Equivalent Evap. F & A. 100°C $\frac{Q}{2258}$	968 Kg/hr
q.	Rated Boiler Output $\frac{Q}{3600}$	607 KW
r.	Efficiency Q/P x 100	80.16%

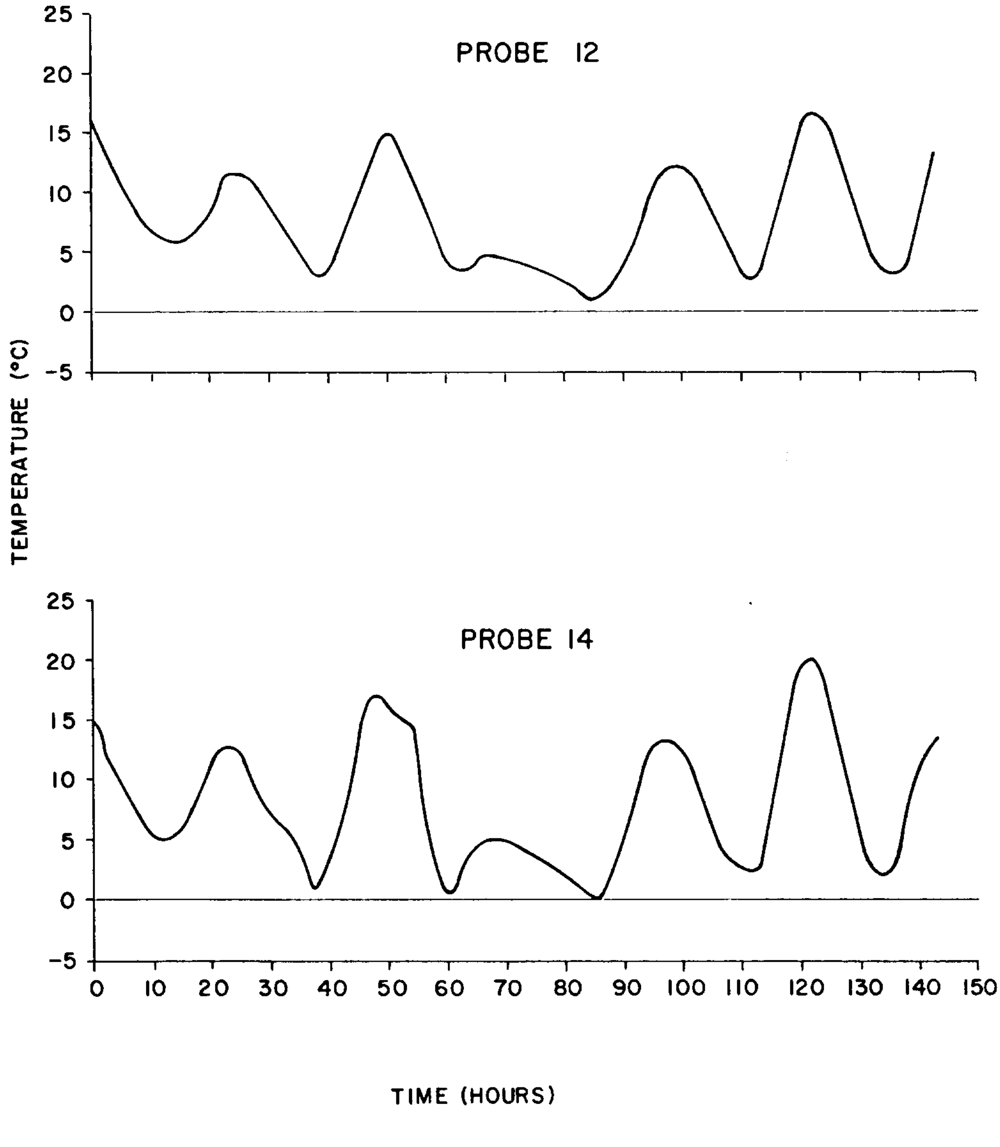
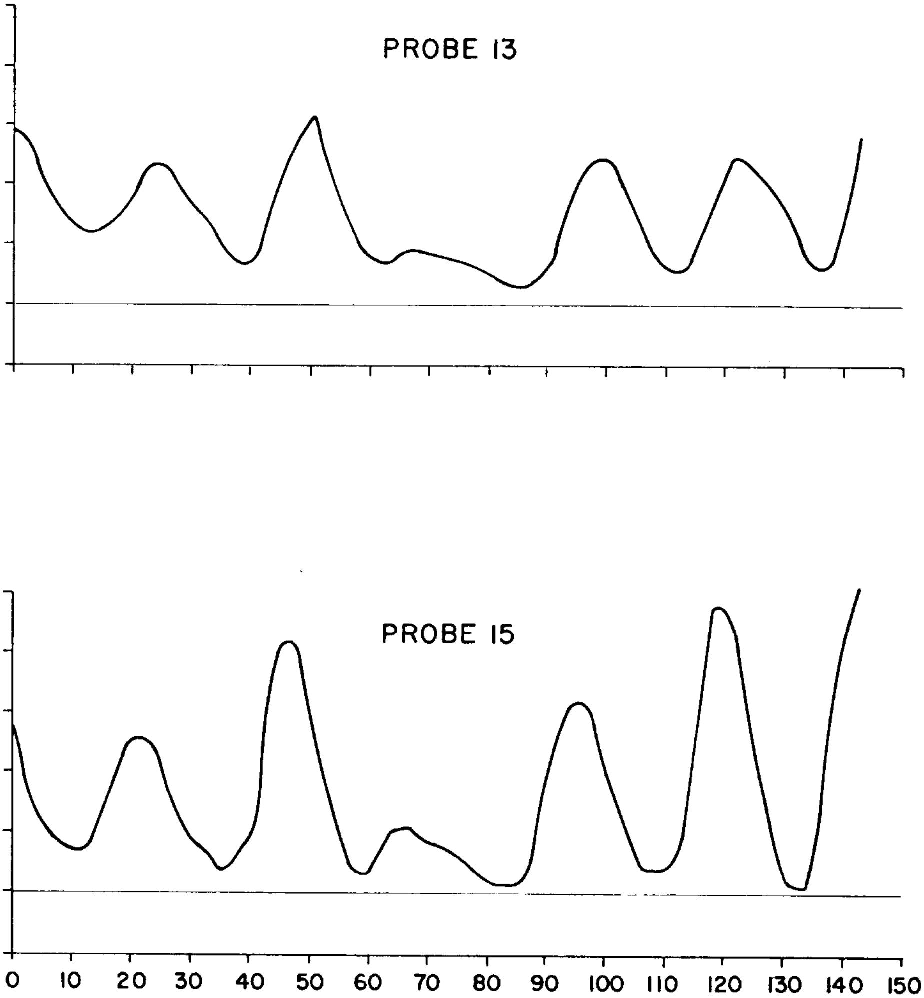


Figure 15. Concrete temperatures of exposed concrete block. Zero hours equals 1932 hours (local) on 7 January 1982.


PROBE 13
PROBE 15
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150

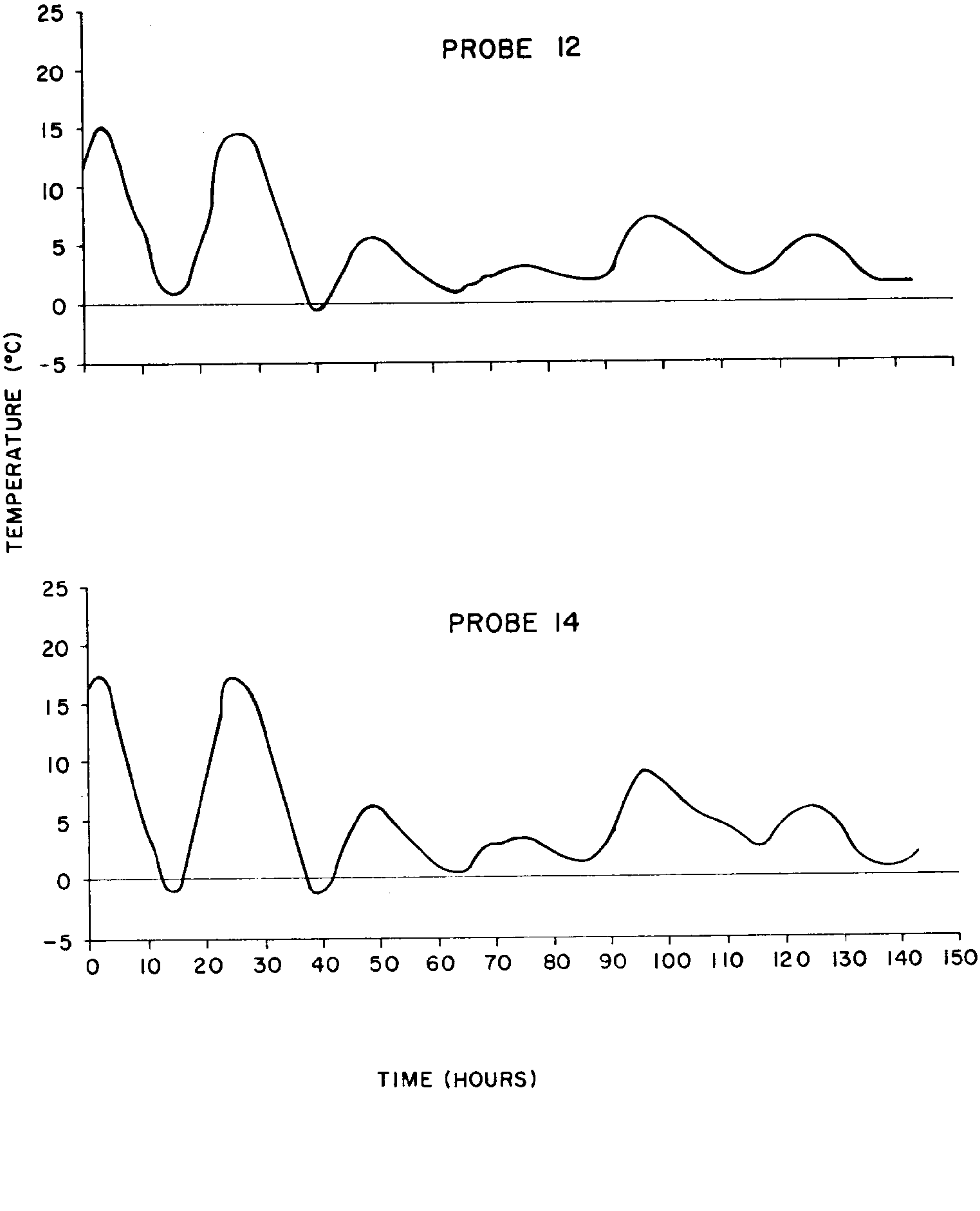
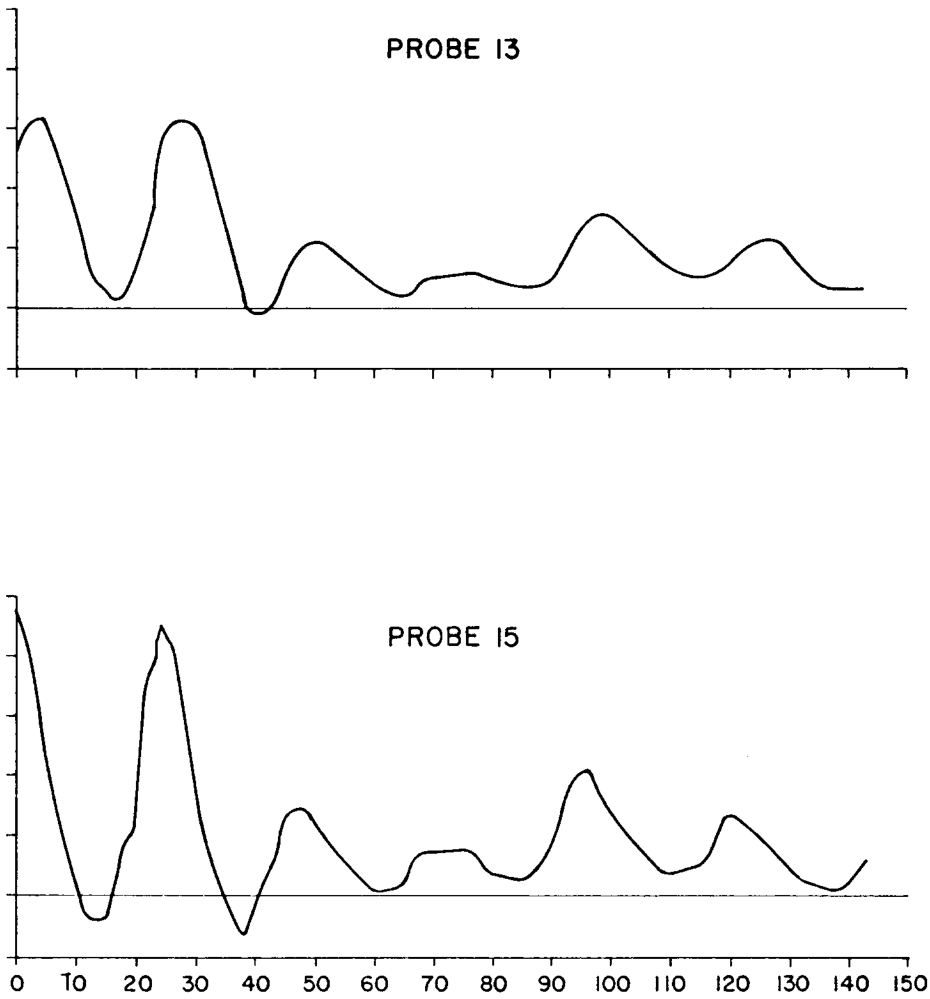


Figure 16. Concrete temperature of exposed concrete block. Zero hours equals 1455 hours (local) on 12 January 1982.


PROBE 13
PROBE 15
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150

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