USE OF AN H_2O METER FOR DETERMINATION OF CONCRETE MOISTURE CONTENT IN THE FIELD

FINAL REPORT

by

THOMAS D. BUSH, JR.
Principal Investigator

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16. ABSTRACT

The ability to accurately determine concrete bridge deck moisture content could increase the probability of satisfactory performance of water repellent treatment materials through choosing favorable conditions for material application. This study was undertaken to determine whether moisture content in an existing deck slab could be accurately assessed using an available measurement device (moisture meter), and to document variations in deck moisture content in the field. The moisture meter examined was a compact device which measures the dielectric properties of the tested medium (concrete). Laboratory tests were conducted to evaluate the accuracy of the moisture meter, and a field study was undertaken to examine the drying properties of a bridge deck through measurements obtained using the moisture meter.

Results of laboratory tests indicated that the moisture meter is not well suited to providing the needed information on absolute concrete moisture content. Considerable variability in meter readings, primarily due to the meter's sensitivity to smoothness and evenness of the concrete surface, precluded accurate measurement of moisture content. Field study measurements, which were more variable than laboratory measurements, indicated that trends in **relative** change of deck moisture content were reflected in moisture meter readings, provided a large number of data points were used to compute the deck's global moisture content. However, absolute moisture content could not be reliably determined from the data.

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METRIC (SI*) CONVERSION FACTORS

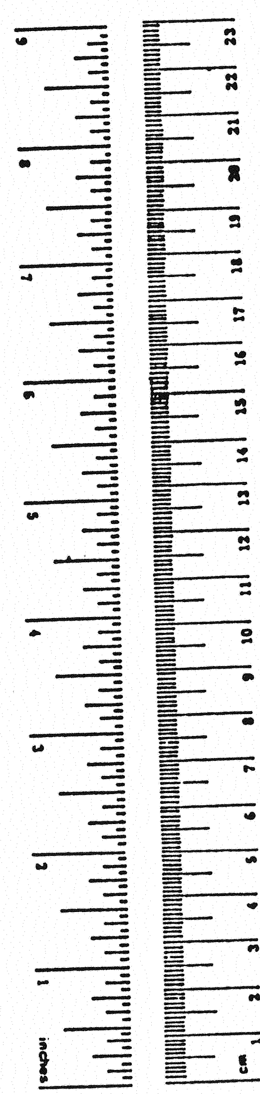
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

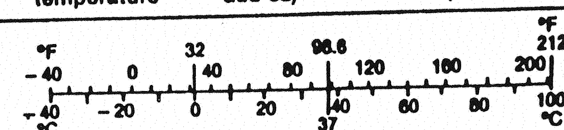
* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

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USE OF AN H_2O METER FOR DETERMINATION OF CONCRETE MOISTURE CONTENT IN THE FIELD

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Studies (Smith 1986, Kamel et al. 1993, McGettigan 1990) have verified that the performance of silane water repellent treatment materials may be affected by concrete moisture content at the time of treatment. In particular, the depth of silane penetration is sensitive to concrete moisture content. Other studies (Carter 1993) suggest that absorption properties of treated concrete may be affected as well. The ability to accurately determine concrete bridge deck moisture content in the field is likely to increase the probability of satisfactory silane performance through choosing favorable treatment conditions. **The purpose of the study is to determine whether concrete moisture content can be accurately assessed using an available measurement device, and to document variations in moisture content of concrete in the field.** The study utilized an H_2O Moisture Meter (manufactured by James Instrument Co.), and included both laboratory and field tests. The study is a pilot project, and is not intended to be comprehensive in nature.

1.2 OBJECTIVES

The objectives of the research study are to:

1. Determine the accuracy of the H_2O Moisture Meter in measuring concrete moisture content through comparison with laboratory obtained data utilizing weight measurements.
2. Evaluate the drying properties of concrete during curing.
3. Evaluate drying properties of bridge deck concrete through field measurements.

These objectives were addressed through the tasks described in later sections of this report.

1.3 ABOUT THE MOISTURE METER

The H_2O Moisture Meter (Model M-49, James Instruments Inc., Chicago, Illinois) is a compact (about the size of a hand-held calculator), lightweight, battery-operated device intended to measure the moisture content of materials with a fairly smooth surface. According to the manufacturer's operating instructions, the device determines moisture content by "measuring the dielectric constant of the material within the electromagnetic field produced by the instrument." The working principle is that the dielectric constant of water is much higher than that of other materials typically encountered in construction materials. The target area of the meter is placed against the surface of interest, and the moisture content is produced on a digital display (to 0.01% resolution). The operating instructions state that the operator's hands should be far removed from the target area (since they contain a large amount of moisture), and the meter should be placed firmly against the surface, avoiding air gaps between the meter and the surface. The meter has switch settings for measuring the moisture content of low, medium, or high density materials. Concrete is considered to be a high density material.

1.4 RESEARCH TASKS

1. Task 1 - Correlation of H_2O Moisture Meter Readings with True Moisture Content: Laboratory tests were conducted to calibrate readings obtained from the moisture meter with moisture contents obtained through weight measurements under controlled conditions. Test blocks with broom, tine, and smooth finishes were air-dried in a temperature/humidity controlled environmental chamber, and moisture contents were determined at various stages both using the moisture meter and using weight measurements.
2. Task 2 - Meter Measurement of Drying Properties of Freshly Cast Concrete: A test slab was cast outside the laboratory and moisture content monitored using the moisture meter during curing. Half of the slab received a broom finish, and the other half a tine finish. The slab received initial water curing (using wet burlap), and was then exposed to environmental conditions outside the laboratory.
3. Task 3 - Meter Measurement of Field Moisture Content of a Bridge Deck: A small county bridge was monitored over a time period of approximately nine weeks to examine changes in deck moisture content under various environmental conditions. Deck moisture content

was measured at designated locations using the moisture meter. Temperature and humidity conditions were continuously recorded using a thermohygrograph which remained at the site during the study. Deck moisture content measurements were made at various time intervals to gain information on both long- and short-term drying, depending on environmental conditions. General wind conditions were also documented over the study period.

CHAPTER 2

PROCEDURES USED TO OBTAIN DATA

2.1 GENERAL PROCEDURE FOR USE OF H_2O METER

The procedure for obtaining moisture content readings using the moisture meter evolved over the course of the study. Most readings were obtained using the following simple, direct procedure: 1) set the meter density switch to "high", 2) place the target of the meter against the concrete surface (allowing the meter to free stand with hands well away from the meter), and 3) record the moisture content shown on the display. Very large variations in repeated readings for a given location were sometimes observed; for instance, differences in successive readings could be as much as 5-6% moisture. This range is of the same order as the total difference in moisture content between completely dry and saturated surface dry concrete.

The manufacturer states that any air gap between the meter and the concrete surface should be minimized. Meter readings were found to be *extremely* sensitive to the quality of the contact between the meter target surface and the concrete surface. Slight local variations in the concrete surface ("hills", "valleys", or "bumps") which prevent good contact of the meter target area (90 x 25 mm (3.5 x 1 in.)) with the concrete influence the resulting meter readings. Therefore, there is considerable scatter inherent to successive readings taken on a given concrete sample. It follows that readings obtained from concretes with the same actual moisture contents but different surface finishes, say tine vs. smooth, would be quite different; also, the degree of scatter for readings would be expected to be affected by the type of surface finish.

The presence of air gaps between the meter and the concrete surface results in a lower meter reading of moisture content, while good contact of the meter with the concrete surface produces higher meter readings (for concrete with a given moisture content). Since a tine finish inherently has air gaps which cannot be avoided by the measurement field of the moisture meter, means were pursued to minimize this effect. It was hoped that a thin cushion or pad of appropriately selected deformable material could be used to fill the air gaps and produce full, positive contact with the meter. Several viscous (non-hydrous) fluids were examined, none of which produced satisfactory results. The meter manufacturer was also contacted for suggestions, but was unable to provide a solution.

The manufacturer suggests that the meter's initial reading ("zero reading") should be examined periodically for drift. It is implied that a measurement of the ambient air should produce a meter reading near zero, and that if sufficient drift occurs the meter's zero adjustment screw should be used to rezero the meter. However, the manufacturer's technical information does not provide clear guidance as to how large an initial reading can be tolerated without significant change in readings. It was found that an initial reading of a few tenths of a percent could drastically alter the resulting meter reading. In other words, the zero adjustment screw on the meter does not cause a linear shift of the resulting reading; it instead produces a change in the *sensitivity* of the meter. Therefore, the initial zero of the meter should be checked often, and readjusted if the initial reading is more than about 0.05%.

Through experience, the procedure described below evolved and was used in the latter stages of data collection. It relies on simply obtaining positive contact of the meter target and concrete surface as best as possible, and accepting the resulting scatter.

1. Set the meter's density switch to the "high" position.
2. Check the meter's initial reading. Rezero if necessary.
3. Select the location on the concrete surface where readings are desired.
4. Place the meter's target directly on the selected location, allowing the meter to free-stand (with hands far removed).
5. Examine the contact between the meter target plane and the concrete surface. The meter target plane should be solidly in contact with the plane of the concrete surface. The end of the meter containing the target is slightly beveled. If the meter is properly placed, when disturbed (rocked "front to back") and released, the meter should return solidly to rest on the target plane. Similarly, no "side to side rocking" of the meter should be possible. Finally, no large gaps (other than that caused by presence of a groove on a tine finish) should be evident. If good contact cannot be obtained directly on the desired location (a highly probable scenario), the meter should be shifted slightly (within 20-30 mm of the desired location) until positive contact is achieved.
6. The displayed moisture content should be allowed to stabilize (usually within a few seconds), and the meter reading recorded.
7. Steps 4-6 are repeated to obtain three meter readings at the desired location.

The procedure described, although not rigorous, tends to reduce the scatter of successive readings. Eventually the operator develops a "feel" as to the degree of positive contact between the meter and the concrete surface, and can obtain meter readings fairly quickly. It should be noted that, in general, the described procedure will result in *higher readings (percent moisture)* for the desired location than would be obtained by placing the meter without regard to the contact between the target surface and the concrete surface.

2.2 TASK 1 - CORRELATION OF H_2O METER READINGS WITH TRUE MOISTURE CONTENT

Data was obtained to evaluate the correlation between concrete moisture content obtained using the H_2O meter versus that obtained through weight measurements. Three test blocks were used: 1) two ODOT Class AA mix blocks containing a broom surface finish, and 2) one High Density mix block with a tine finish. The bottom surface of the specimens, which was cast directly against wood forms, also provided a smooth surface finish for comparison. The specimens were surplus from a previous study (Kamel et al., 1993). The AA mix specimens were 203 x 203 x 50 mm (8 x 8 x 2 in.), and the high density mix specimen was 305 x 305 x 76 mm (12 x 12 x 3 in.). All test specimens were initially oven-dried to constant weight. After cooling to room temperature, the specimens were immersed in water for a minimum of 5 days, and allowed to air dry in the environmental chamber (23° C, 50% RH). When the rate of drying slowed considerably, the specimens were placed in a tank (inside the environmental chamber) containing a dehumidifier to encourage moisture loss. At various intervals, specimen weight and H_2O meter readings were recorded.

Meter readings were obtained for each of three surface finishes: tine and broom (primary finishes), and smooth (secondary finish). For the broom and tine finishes, readings were taken with the H_2O meter oriented both parallel and perpendicular to the surface finish. (For example, parallel orientation for a tine finish is such that the reading direction of the meter's digital display is parallel to the grooves in the concrete surface.) The top and bottom test block surfaces were each divided into zones, and three readings were obtained from each of three zones using the procedure described in sec. 2.1. Therefore, a total of 27 meter readings were obtained from each specimen at any time: 3 readings/zone x 3 zones x 3 surface conditions (parallel to primary finish, perpendicular to primary finish, and smooth finish).

2.3 TASK 2 - METER MEASUREMENT OF DRYING PROPERTIES OF FRESHLY CAST CONCRETE

A 610 x 914 x 152 mm (24 x 36 x 6 in.) specimen was cast on June 3, 1993, using ODOT Class AA mix concrete. A tine finish was applied to half the top surface, and a broom finish was applied to the other half. The specimen was initially cured using wet burlap for a period of four days. The forms were then stripped and the specimen placed on a movable dolly. No further curing measures were taken. The specimen was placed just outside the laboratory for much of the period until an age of two weeks was reached; it was rolled back into the laboratory for overnight storage, and whenever rain was anticipated. For the remainder of the recording period (approx. seven weeks), the specimen was stored primarily inside the main bay of Fears Laboratory (general temperature conditions similar to outdoor ambient conditions). H_2O meter readings were obtained from each of the two surface finishes. Readings were obtained with the meter oriented both parallel and perpendicular to the surface finish. Each surface finish was divided into eight zones. A single reading was obtained from each of the eight zones, without strict attention given to the surface contact between the meter target and the concrete.

2.4 TASK 3 - METER MEASUREMENT OF FIELD MOISTURE CONTENT OF A BRIDGE DECK

A single span, two lane county bridge was monitored over a period of approximately 2.5 months. The bridge is located in McClain County, OK, approximately 3 km (2 mi) south of Highway 9 West (of Norman), and 0.8 km (0.5 mi) east of Sante Fe. The bridge is oriented east-west and spans approx. 20 m (60 ft) across a small creek, and has a slight skew. Initially, 18 points were selected to observe changes in meter reading (moisture content) in the bridge deck, which has a tine finish. Nine of the points were arranged across the traffic lanes in a line adjacent and parallel to the abutment at the east end of bridge; the remaining nine points were spaced across midspan in a line parallel to the abutments. A continuous recording thermohygrometer remained at the site to monitor local temperature and humidity changes, and a rain gage was also place at the site. General wind speed data was obtained using a hand-held anemometer; wind speed measurements were recorded whenever meter readings (moisture content) were taken. Available local weather information was also obtained from the Oklahoma Climatological Survey.

A typical data collection trip to the site involved: 1) recording weather information, 2) obtaining meter readings (at designated locations, with readings taken both parallel and perpendicular to the tine surface), and 3) again recording weather information to make sure changes were noted. Deck moisture content was monitored (using the H_2O Meter) to examine typical drying characteristics in the field. Data was collected at irregular intervals, but particularly after significant rain events and during extended dry periods. Initial measurements began in early June 1993. At this time, the procedure described in sec. 2.1 had not been finalized; therefore, only two readings (one each parallel and perpendicular to the tine surface) were recorded at each of the 18 locations on the bridge deck. A reasonable effort was made to obtain good contact between the meter and concrete surface, although the specific procedure described in sec. 2.1 was not followed. In the last stages of data collection (early August 1993), three meter readings were taken at each location using the procedure of sec. 2.1.

CHAPTER 3
RESULTS

3.1 INTRODUCTION

As mentioned in Chapter 2, the importance of achieving good contact of the meter with the concrete and the sensitivity of the meter to its initial (zero) reading were eventually recognized. All three research tasks were conducted simultaneously; unfortunately, much of the data was collected before the effects of these parameters on the meter were fully understood. This lead to a higher degree of scatter in the data obtained prior to late July 1993. Tests which could be re-evaluated using the modified procedure were conducted; however, due to time constraints other tests could not be re-examined.

3.2 TASK 1 - CORRELATION OF H_2O METER READINGS WITH TRUE MOISTURE CONTENT

Test data was initially collected in mid May through mid July 1993 for this phase of the study. After examination, this data was not used and the study was repeated. Factors which influenced this decision included: 1) discovery of the more reliable procedure for use of the meter during the term of data collection, and 2) an unexplained trend in the data at moderate moisture contents (probably related to the previous factor). The results presented are from repeating the study using the procedure discussed in Chapter 2.

For a test specimen at any recorded moisture content, nine meter readings were obtained (3 readings/zone x 3 zones). The average of the nine readings was computed and plotted vs. the moisture content obtained using weight measurements. Linear regression was performed using the true moisture content (from weight measurements) as the independent variable, and the average of the meter readings as the dependent variable. Results of the regression analyses for the concrete mixes and surface finishes tested are shown in Table 3.1. R^2 values are fairly high, especially for the HD specimen; however, R^2 values are less reliable with fewer data points. Linear regressions performed using all data points (instead of the average readings) yielded prediction equations very similar to those contained in Table 3.1. The resulting prediction equations are plotted in Fig. 3.1 (over the range from which moisture content data was actually obtained). The smaller range of moisture content data for the HD mix specimen can be explained by the difference in absorption characteristics of AA and HD concretes. After a minimum of five days immersion in water, the HD mix specimen absorbed a smaller percentage of water than the AA specimens, resulting in a lower initial moisture content at the beginning of the test.

To provide an indication of the scatter in the data, the mean, standard deviation, and coefficient of variation was calculated for each set of nine meter readings at all recorded specimen moisture contents. The average standard deviation and coefficient of variation for each surface finish condition is shown in Table 3.2. A visual indication of the scatter in the data can be seen in Figs. 3.2-3.3. Shown are plots of true moisture content vs. meter reading for readings taken parallel to tines (Fig. 3.2) and perpendicular to tines (Fig. 3.3). The dashed line represents an exact prediction of the concrete moisture content by the moisture meter. It can be seen that the scatter of the average meter readings is considerably lower than for individual readings. These two plots are representative of relationships with fairly high and low scatter, respectively, as measured by the average standard deviation of the readings (Table 3.2). Prediction equations and scatter of average meter readings for other surface finishes can be seen in Figs. 3.4-3.7.

From Fig. 3.1, it can be seen that the slopes of the prediction equations for readings obtained parallel to the tine finish and perpendicular to the tine finish are similar (HD mix). Slopes of prediction equations are also similar to each other for readings taken on the broom finished specimens (AA mix). In both cases, readings taken parallel to the surface finish are slightly higher, on average, than those taken perpendicular to the surface finish.

Prediction equations for a smooth finish for class AA and class HD concretes do not exhibit similar slopes to each other (Fig 3.1). In fact, the prediction equations for a given mix appear to be approximately parallel to one another, irrespective of surface finish. Therefore, there may possibly be a mix design effect on the correlation of meter readings with true moisture content. It is not clear whether this effect is real, as evidenced by the individual data points for a smooth finish for both mixes shown in Fig. 3.8. The data for the HD mix specimen is not clearly removed from the scatter of the data for the AA mix specimens; the range of moisture content for which data was obtained for the HD specimen is too narrow to draw a definite conclusion.

Table 3.1 Results of Linear Regression Analyses

Finish (meter orientation)	Mix Type	DOF	Constant b	Coeff. m	R^2	Std. Error of Coeff.	Std. Error of Estimate
Tine(parallel)	HD	10	-6.084	3.877	0.964	0.236	0.340
Tine(perp.)	HD	10	-5.646	3.502	0.952	0.248	0.358
Smooth	HD	10	-2.224	4.415	0.964	0.271	0.381
Broom(parallel)	AA	20	-0.438	1.889	0.841	0.184	0.725
Broom(perp.)	AA	20	-0.570	1.750	0.884	0.142	0.560
Smooth	AA	20	2.109	2.538	0.888	0.201	0.795

Note: estimate of Meter Reading = b + m x (moisture content)

Table 3.2 Scatter in Meter Readings on Controlled Specimens

Specimen No.	Mix Type	Finish (meter orientation)	Avg. Standard Deviation	Avg. Coeff. of Variation, CV (% of mean)
1	AA	Broom (parallel)	0.67%	15
1	AA	Broom (perpendicular)	0.68%	18
1	AA	Smooth	0.66%	7
2	AA	Broom (parallel)	0.61%	12
2	AA	Broom (perpendicular)	0.62%	14
2	AA	Smooth	0.40%	5
3	HD	Tine (parallel)	0.82%	15
3	HD	Tine (perpendicular)	0.56%	12
3	HD	Smooth	1.06%	10

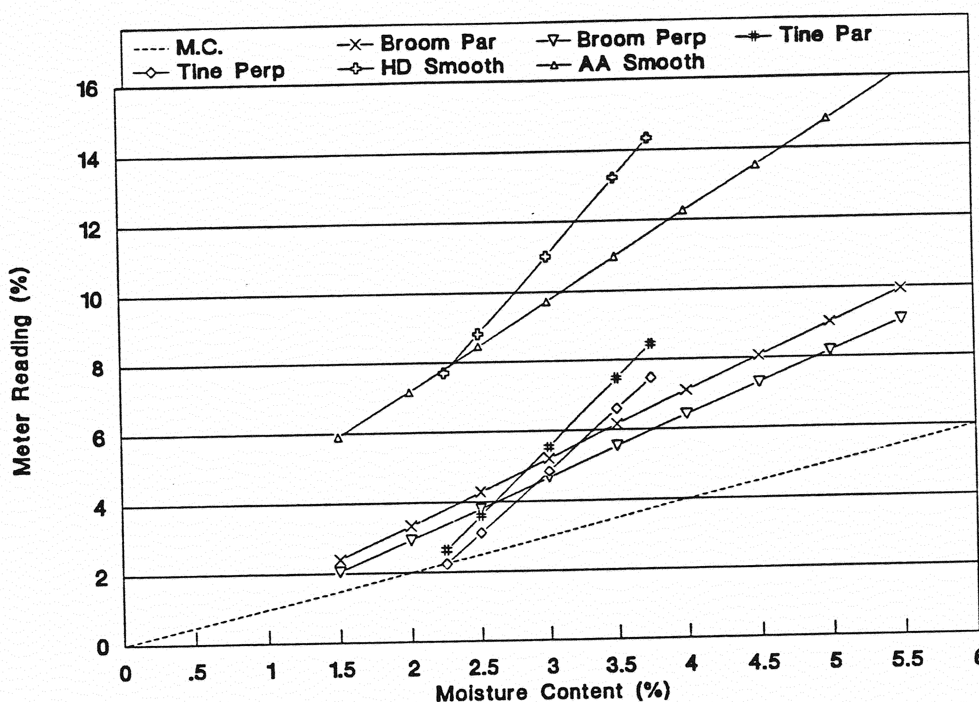

Fig. 3.1 Prediction Equations for Moisture Meter Readings (Controlled Study)

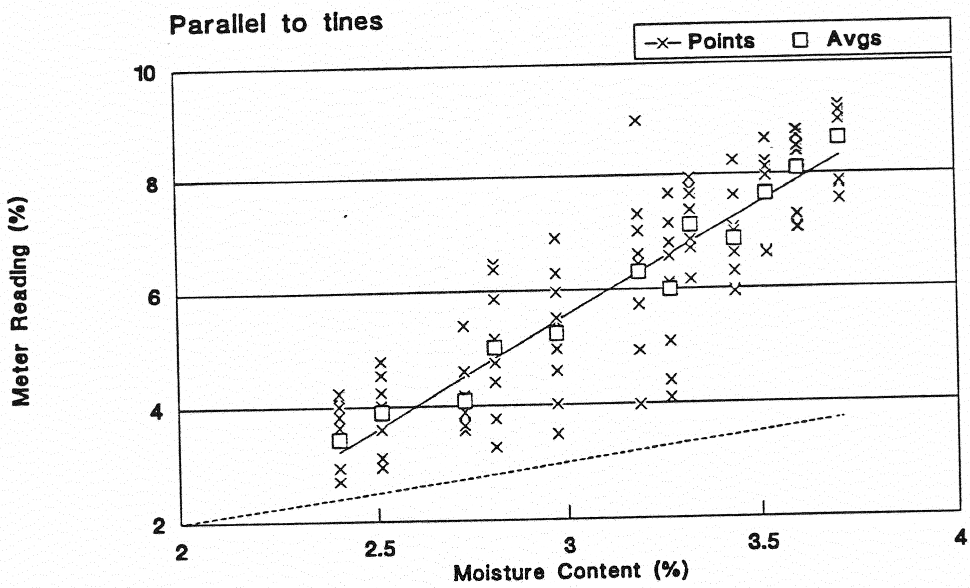

Fig. 3.2 Scatter in Data for Tine Finish, Readings Parallel to Tines

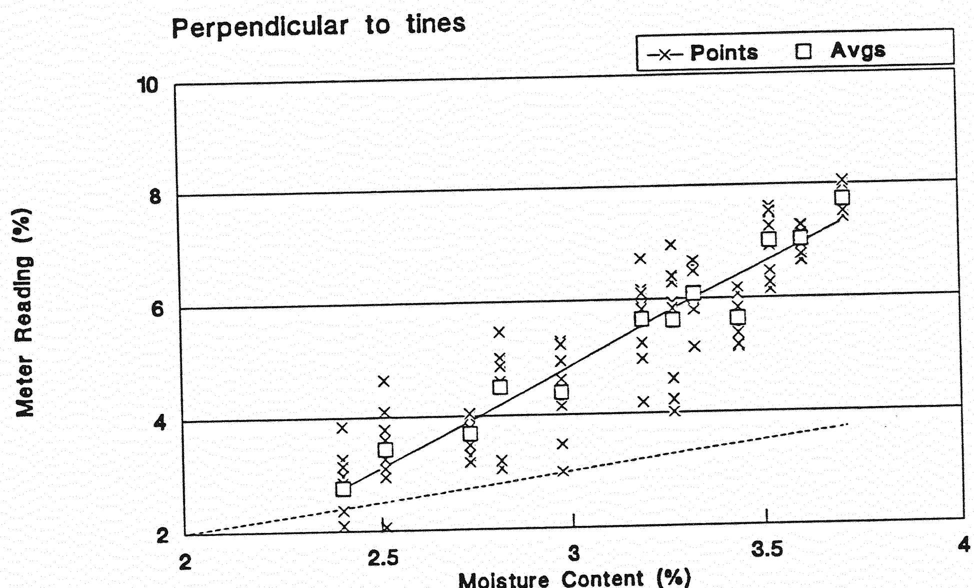

Fig. 3.3 Scatter in Data for Tine Finish, Readings Perpendicular to Tines

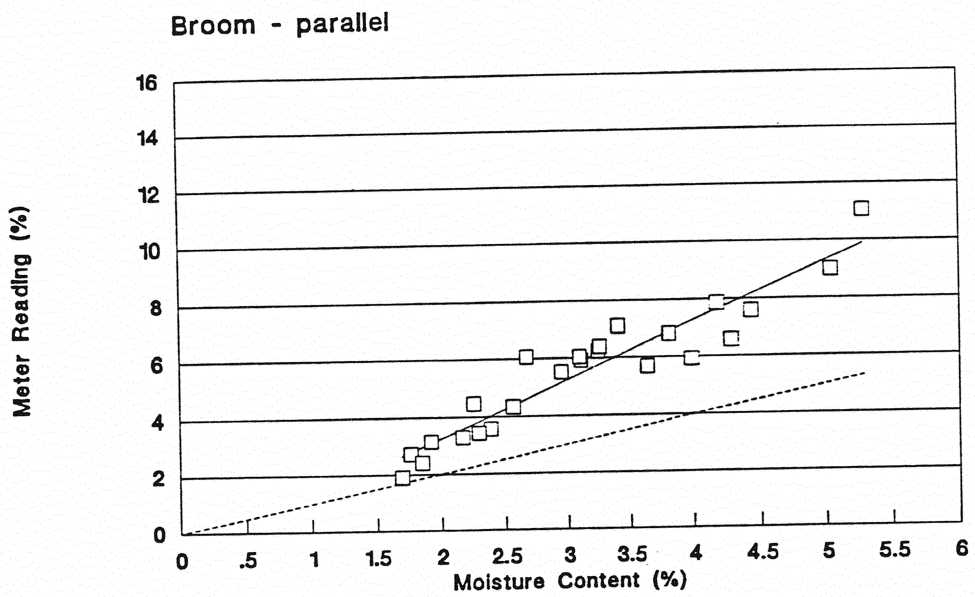

Fig. 3.4 Average Readings for Broom Finish, Readings Parallel to Finish

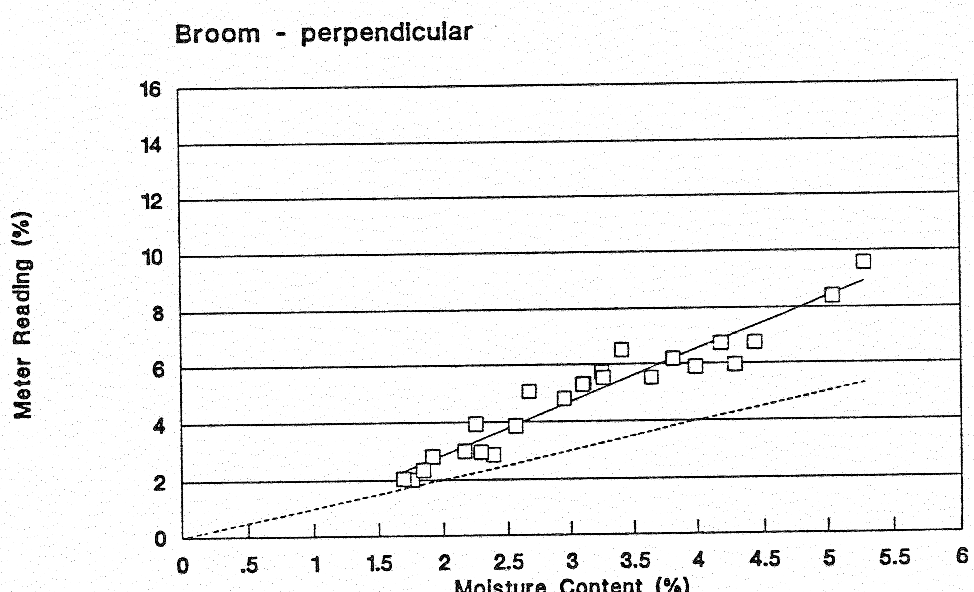

Fig. 3.5 Average Readings for Broom Finish, Readings Perpendicular to Finish

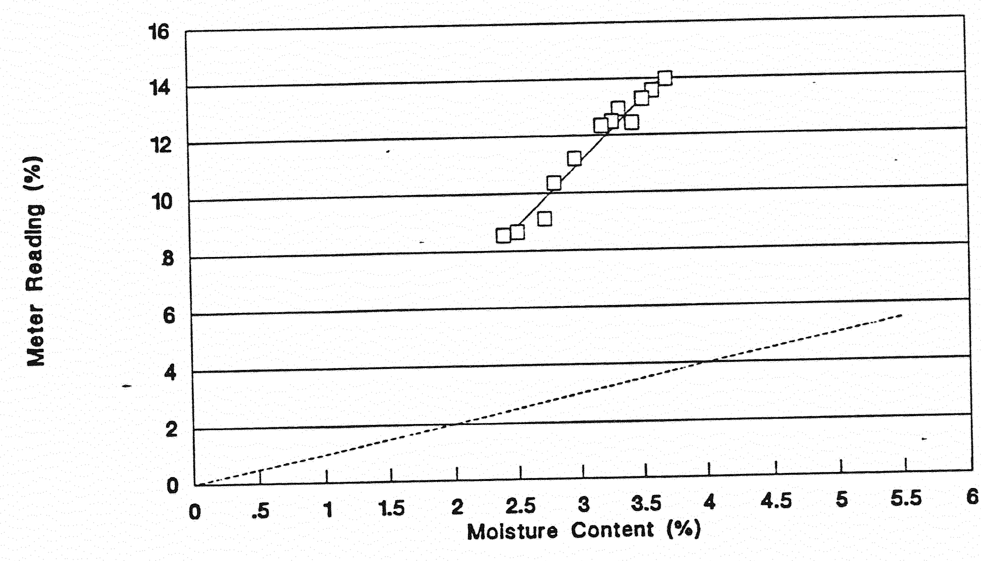

Fig. 3.6 Average Readings for Smooth Finish, High Density Mix

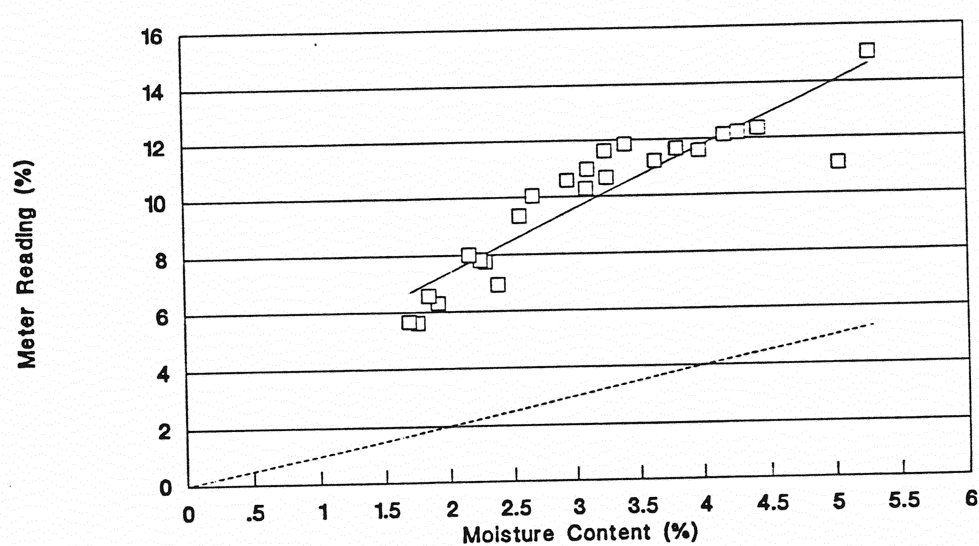

Fig. 3.7 Average Readings for Smooth Finish, Class AA Mix

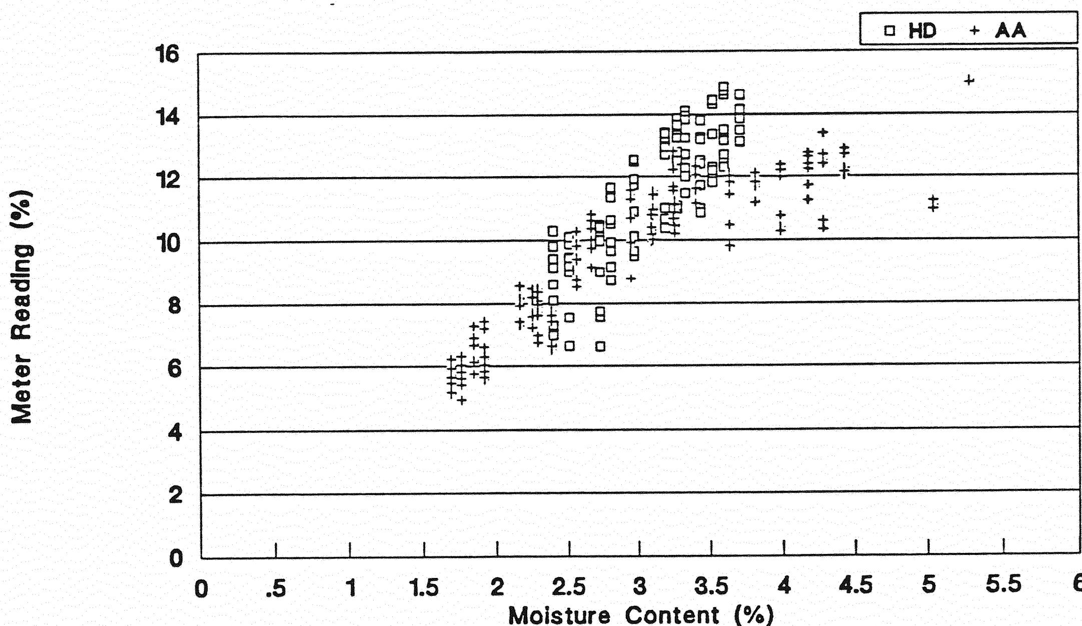

Fig. 3.8 Data Points for Smooth Finish, Mixes HD and AA

3.3 TASK 2 - METER MEASUREMENT OF DRYING PROPERTIES OF FRESHLY CAST CONCRETE

Two surface conditions, broom and tine finish, were examined on a single test block. At designated concrete ages, one meter reading was recorded for each of eight locations for each surface finish (16 measurements total). Examination of average meter readings vs. time from casting unfortunately yielded no useful information. The scatter in the data masked any trend in moisture content change during curing. Plots of meter reading vs. time from casting are presented in the Appendix for completeness (Figs A.1-A.4). The plots also contain the average meter readings. The large scatter in the data is obvious. It should be noted that the meter readings were taken with no special precaution to ensure good surface contact.

Comparison of statistical parameters of the data obtained with similar parameters from Task 1 (meter correlation) provides some indication of the improvement the sampling procedure described in sec. 2.1 offers. The numbers of data points sampled per surface finish condition at each date was similar for both: nine for Task 2, and eight for Task 1. Average standard deviations of meter readings (parallel and perpendicular) for tine finished specimens from Task 2 were about 0.55% moisture, which is of a similar order to those shown for Task 1 specimens in Table 3.2. However, the average coefficients of variation were 2-3 times higher for the specimens of Task 2 (average CV ≈ 35%, as compared to 12-15% for Task 1). Standard deviations of meter readings were about twice as high for the broom finished specimen of Task 2 than for those of Task 1; coefficients of variation were about 40% of the mean, as compared to approx. 15% in Task 1.

3.4 TASK 3 - METER MEASUREMENT OF FIELD MOISTURE CONTENT OF A BRIDGE DECK

Data obtained from field measurements was examined from the following standpoints: 1) to assess the scatter in meter readings at a fixed point in time (spatial variation of data with measurement location on deck), 2) to examine the range of scatter of meter readings over time for given points on the deck, and 3) to examine potential correlation of meter readings with observed weather events and conditions. These issues are addressed in the following paragraphs.

With respect to spatial variation in meter readings (at any given time), no pattern was discernable. The locations where meter readings were taken were chosen to include points directly above the superstructure's prestressed girders, in between prestressed girders, near the abutment and at midspan, and points near the deck guard rails. There did not appear to be any systematic correlation in meter readings with respect to location on the deck.

The degree of scatter with time can be seen by tracing meter readings for a few arbitrary points on the deck over a short time period. Meter readings for points 1, 5, 10, and 15 on the deck are shown for the time period from June 7-17, 1993, in Fig. 3.9. Points 1 and 5 are located at midspan; points 10 and 15 are near the east abutment. Differences in successive meter readings of as much as 3% moisture can be seen. In addition, successive meter readings for different points do not necessarily follow similar trends; meter readings may increase for one location, but decrease for another (for the same time interval). Thus, even though all locations on the deck are subject to the same environmental conditions, the scatter in the data may be masking trends for individual test locations.

Possible correlation of data obtained with the moisture meter with observed weather/environmental conditions was examined by extracting data from various time periods. It should be noted that moisture meter readings were not continuously sampled with time; there are gaps in the data. However, data in the plots presented have been simply connected with lines to aid in visualizing trends. Global average readings (using all 18 data locations), maximum observed readings, and minimum observed readings are plotted vs. date in Figs. 3.10 and 3.11. The two extracted time periods are June 7-17 and July 12-August 5, 1993. Weather information recorded for all trips to the site is contained in Table 3.3; data (max/min temperature, rainfall) from the Oklahoma Climatological Survey for Norman, OK, is shown in Table 3.4. The weather data recorded at the site corresponds to conditions at the time meter readings were made. Recorded rainfall was cumulative since the previous visit to the bridge site; however, data was usually collected immediately after a rainfall. Differences in the weather data (particularly rainfall) of Tables 3.3 and 3.4 can be explained by the fact that the two sites are approximately 15 km (10 mi) apart. Continuous temperature and humidity data recorded at the site are contained in the Appendix.

Observing the maximum and minimum meter readings in Figs. 3.10-3.11, it is apparent that the range of scatter is large, usually on the order of 5-6% moisture. However, the global average appears to reflect changes in environmental conditions at the site. For example, in Fig. 3.10 the global average meter reading increases after rains on 6/8, 6/10, and 6/15. Moderately strong winds may have contributed to the rapid drying suggested by the curve on 6/8. Similarly, in Fig. 3.11 an increase in global deck moisture content is suggested during and after the period of rains on or around 7/13-7/14. Readings then declined during the following extended hot, dry period.

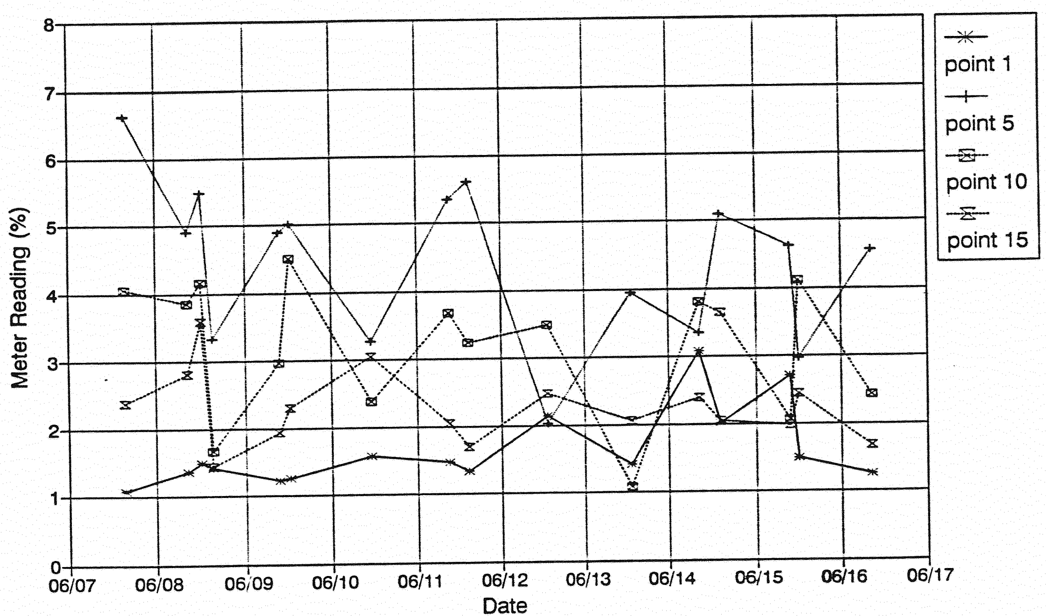

Fig. 3.9 Variation of Measured Moisture Content with Time (Four Locations on Deck)

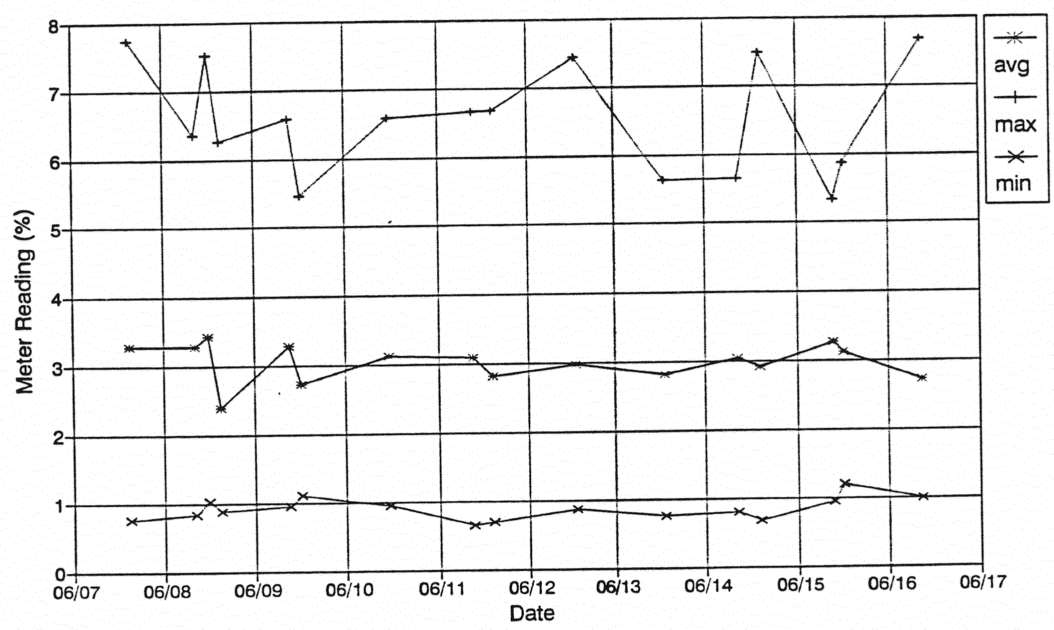

Fig. 3.10 Variation of Measured Moisture Content, Early Summer (Readings Parallel to Tines)

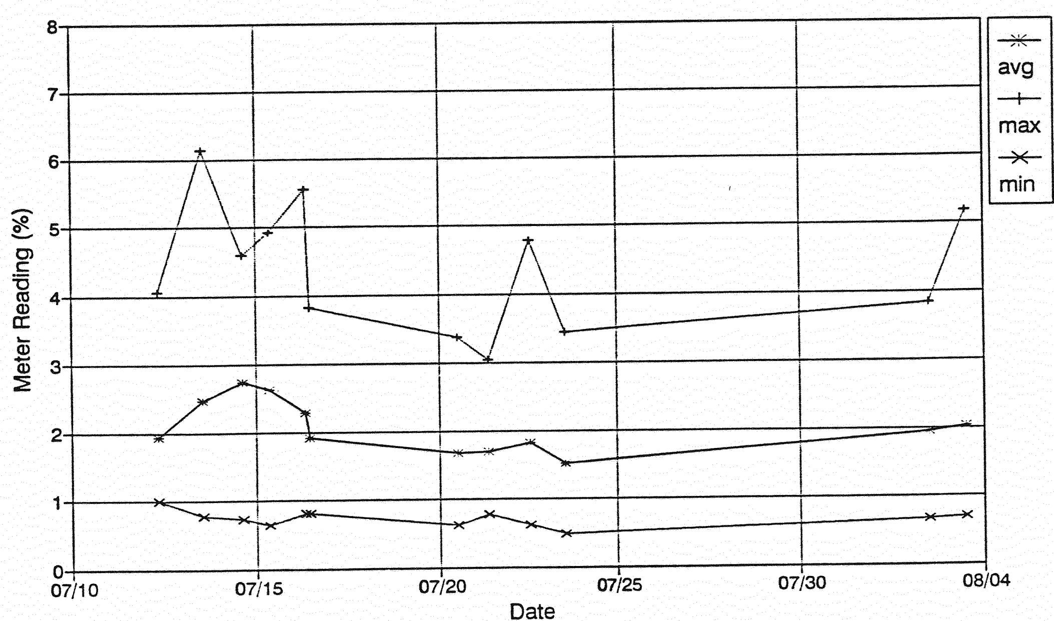

Fig. 3.11 Variation of Measured Moisture Content, Late Summer (Readings Parallel to Tines)

Table 3.3 Weather Conditions Recorded at Bridge Site

Date	Time	Temp	Hum.	wind sp.	dir.	precip	notes
6/7	1515	80	78	5-10	S	0	rain in past 1/2 hr.
6/8	820	76	82	5-15	S	0	overcast, drizzle
6/8	1120	72	74	15-20	S	0	mostly cloudy, recent rain
	1200	69	85	5-10	S	0	
6/8	1450	78	74	15-20	S	0	partly cloudy
		80	67	15-20	S	0	
6/9	840	74	84	0	S	0	overcast
	915	74	83	0	S	0	
6/9	1130	80	76	0	S	0	mostly cloudy
	1215	82	70	5-10	S	0	
6/10	1030	72	70	0	S	3.25	partly cloudy
	1125	74	64	0	S	3.25	
6/11	815	72	76	0	S	0	mostly cloudy
	930	73	75	0	S	0	
6/11	1420	75	74	5-10	S	0	hazy
	1450	73	82	5-10	S	0	drizzle
6/12	1230	78	64	0	S	0	partly cloudy
	1315	80	58	0	S	0	
6/13	1300	84	50	0	S	0	partly cloudy
	1345	86	46	0	S	0	
6/14	830	74	78	0	S	0	partly cloudy
		78	72	0	S	0	
6/14	1410	90	51	0	S	0	partly cloudy
	1430	90	52	0	S	0	
6/15	900	76	84	0	S	0.25	mostly cloudy
	935	78	81	0	S	0.25	
6/15	1130	84	60	0	S	0	partly cloudy
	1205	86	44	0	S	0	
6/16	810	74	82	0	S	0	partly cloudy
	835	76	80	5-10	S	0	
6/28	820	78	74	0	SE	0.25	partly cloudy
		80	70	0	SE	0.25	
6/28	1115	84	57	0	S	0	partly cloudy
	1130	86	53	5-10	S	0	
6/30	1115	86	58	10-20	S	0	partly cloudy
	1135	88	57	10-25	S	0	
7/6	800	80	83	10-20	S	0	mostly cloudy
		82	77				
7/8	1145	88	54	5-15	S	0	partly cloudy
	1205	88	50	5-25	S	0	
7/12	800	78	78	0	S	0	partly cloudy
	835	79	74	0	S	0	
7/13	1315	80	80	5-10	S	0.25	drizzle
	1330	80	82	5-10	S	0.25	drizzle
7/14	1515	78	82	0	W	?	light rain
	1525	78	82	0	W	?	light rain
7/15	800	74	82	5-10	S	0	mostly cloudy
	840	77	78	0	S	0	
7/16	800	76	78	5-10	S	0	partly cloudy
		77	78	0	S	0	
7/16	1115	88	50	0	S	0	clear
	1130	89	48	5-10	S	0	
7/20	1130	90	41	5-10	S	0	clear
	1140	92	42	5-10	S	0	
7/21	800	79	80	5-10	S	0	clear
	830	85	75	5-10	S	0	
7/22	1145	90	54	5-15	S	0	partly cloudy
	1200	92	54	10-20	S	0	
7/23	1200	94	50	5-15	S	0	clear
	1215	94	47	10-20	S	0	
8/2	1145	87	35	0	NE	0	partly cloudy
	1200	88	35	0	NE	0	
8/3	1215	86	55	0	E	0	mostly cloudy
	1245	88	51	0	E	0	
8/6	1145	70	70	0	E	?	overcast
	1215	71	66	0	E	?	
8/6	1545	81	48	0	NE	0	partly cloudy
	1615	80	49	5-10	NE	0	
8/9	1130	92	47	5-10	S	0	partly cloudy
	1200	94	40	5-15	S	0	
8/15	1430	102	29	5-15	S	0	partly cloudy
	1500	102	28	5-10	S	0	

Note: ? in precipitation column indicates rain occurred, but amount not measured

Table 3.4 Weather Data from Oklahoma Climatological Survey

col 1 = day of month; cols 2 & 3 = max, min temperature (° F); col 4 = precipitation (in.)

JUNE, 1993
6386 17 7 NORMAN 3 S

1	82	56	.000
2	92	64	.000
3	92	67	.000
4	80	62	.001
5	81	51	.000
6	90	69	.000
7	85	71	.000
8	83	73	.030
9	84	64	.020
10	83	61	1.130
11	81	64	.000
12	87	64	.000
13	88	65	.000
14	92	66	.000
15	95	69	.050
16	92	73	.000
17	90	68	.000
18	88	68	.000
19	87	71	.050
20	85	63	4.240
21	87	67	.000
22	90	67	.000
23	92	69	.000
24	90	71	.000
25	86	70	.000
26	84	65	.000
27	93	67	.020
28	93	70	.000
29	93	73	.000
30	93	73	.000
31	999	999	99.999

JULY, 1993
6386 17 7 NORMAN 3 S

1	92	73	.000
2	93	72	.000
3	93	72	.000
4	90	72	.000
5	91	74	.000
6	92	74	.001
7	92	73	.080
8	94	71	.030
9	95	75	.000
10	96	73	.000
11	98	70	.000
12	97	69	.000
13	87	74	.010
14	84	70	.280
15	93	68	.020
16	96	69	.000
17	94	72	.000
18	98	74	.000
19	99	68	.060
20	98	68	.000
21	97	73	.000
22	95	73	.010
23	98	75	.000
24	100	76	.000
25	101	77	.000
26	101	69	.000
27	101	72	.000
28	103	70	.000
29	103	70	.000
30	104	71	.000
31	105	70	.000

AUGUST, 1993
6386 17 7 NORMAN 3 S

1	92	76	.000
2	96	71	.000
3	91	68	.000
4	89	66	.040
5	92	68	.000
6	80	62	.050
7	86	59	.000
8	93	68	.000
9	99	73	.000
10	104	73	.001
11	102	77	.000
12	103	75	.000
13	103	70	.000
14	101	70	.000
15	102	73	.000
16	103	73	.000
17	101	73	.000
18	102	70	.000
19	104	68	.000
20	104	69	.000
21	103	72	.000
22	102	73	.000
23	96	72	.000
24	89	64	1.400
25	97	67	.050
26	96	68	.000
27	96	68	.000
28	97	68	.000
29	95	70	.000
30	96	71	.000
31	68	60	.150

Global average readings taken with the meter oriented parallel and perpendicular to the tine surface are shown for the entire data recording period in Fig. 3.12. The curves suggest a general decline in global moisture content through late July 1993 until rainfall on August 6, near the end of the data collection period. Also, the orientation of the meter with respect to the tine surface finish did not appear to greatly affect the global average.

The global average reading (average of all readings taken at a fixed point in time) appears to be consistent with many of the environmental conditions to which the bridge was exposed, even though the range of scatter for meter readings obtained for the bridge deck was often quite large. While the absolute magnitude of the actual deck moisture content may be uncertain, the relative changes in moisture content recorded by the meter appear reasonable, even with the large scatter, and contrary to the observations of Task 2. This may be attributed to the fact that more data points (18 vs. 8) were used to compute the global average reading for the bridge deck.

A fundamental difference in the data obtained from the bridge deck and from the controlled laboratory correlation tests should be recognized. For the bridge deck, a larger variety of conditions such as degree of surface wear, depth of tines, and surface evenness is possible due to the much larger deck surface area. Recall that three readings were taken from each of three zones for the laboratory specimens. However, the zones were very close to one another due to the small specimen size. In effect, nine total readings were obtained for a laboratory specimen of relatively uniform conditions, resulting in less scatter in the data and stronger statistical correlations. For moisture meter readings taken on the bridge deck using the procedure described in sec. 2.1, there was more variability in groups of three readings taken at any location than was observed in the laboratory tests (max. difference in readings in a group on the order of 2-3% moisture, as compared to 1-1.5% for laboratory results). However, the largest difference in average reading between points (locations) on the deck was still on the order of 5-6% moisture. Therefore, it appears difficult to directly relate laboratory results to estimating one true moisture content for the bridge deck, unless: 1) a "standardized concrete surface" could be developed, or 2) the moisture meter could be reconfigured to reduce its sensitivity to variations in its contact with the concrete surface.

Global average readings taken with the meter oriented parallel and perpendicular to the tine surface are shown for the entire data recording period in Fig. 3.12. The curves suggest a general decline in global moisture content through late July 1993 until rainfall on August 6, near the end of the data collection period. Also, the orientation of the meter with respect to the tine surface finish did not appear to greatly affect the global average.

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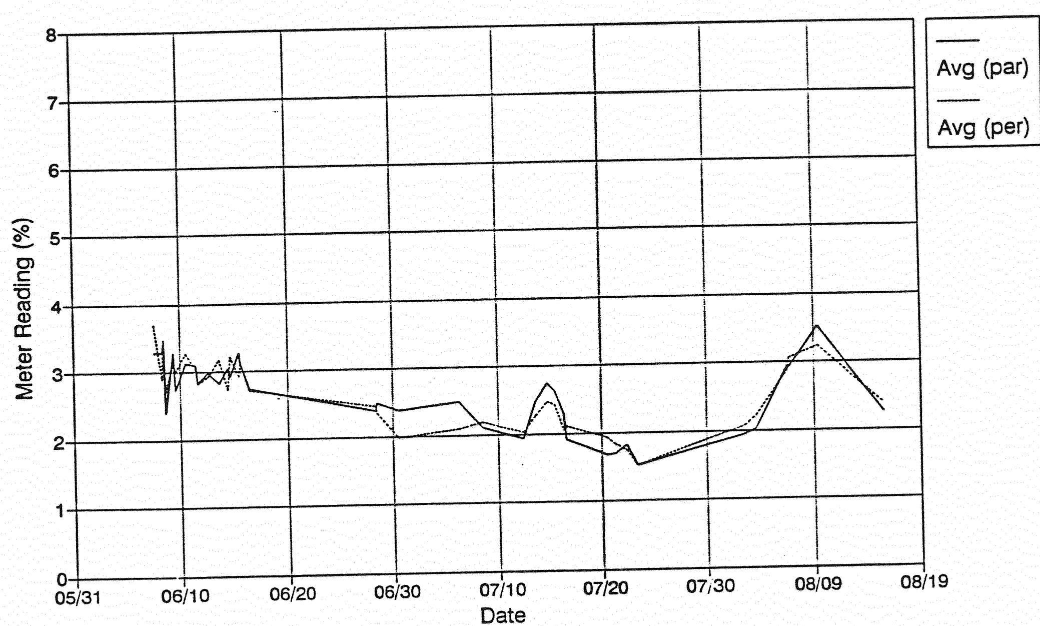


Fig. 3.12 Variation in Measured Moisture Content with Meter Orientation

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained, in the opinion of the investigator, *the use of the moisture meter to develop an acceptance criteria* for deciding whether concrete moisture content is sufficiently low to encourage good silane treatment performance *is not recommended* at this point. The data is insufficient to have confidence in predicting the absolute moisture content of the concrete, although relative differences in moisture content appear to be reflected in meter readings. Factors which support this position are listed below:

1. Meter readings are susceptible to fairly high scatter due to sensitivity of the meter to smoothness and evenness of the surface finish and to the quality of contact between the meter target surface and the concrete surface. However, this can somewhat be offset by computing an average reading from a fairly large number of data points.
2. Concrete surface smoothness is highly variable, even for specimens used in the laboratory portion of this study. Given the meter's sensitivity to the overall condition of the concrete surface, it may be difficult to develop general relationships for field use. An additional variable that should probably be considered is the degree of wear of the concrete surface (meter readings for a smooth surface are generally much higher than for a tine surface).
3. It is uncertain whether concrete mix design significantly affects meter readings.
4. The technique found to reduce scatter in meter readings results in higher moisture content readings for a given concrete surface condition. On the other hand, the desired condition for treatment of a deck with silane is a dry concrete surface (low moisture content). The possibility exists for erroneous or improper use of the meter since low readings can easily be obtained by inattention to air gaps between the meter target surface and the concrete surface. Even with proper use of the meter, the combination of more desirable high readings (from a scatter standpoint) and an upper cutoff limit on meter-obtained moisture content (beyond which treatment should not be applied to the deck) could lead to establishment of overly conservative limits.
5. Further techniques that might be pursued to reduce scatter in the data and variability in field conditions include: 1) development of a standardized concrete surface (possibly through some form of surface preparation of the deck) and/or 2) reconfiguration of the moisture meter by the manufacturer to reduce its sensitivity to local variations in the contact surface. The first alternative is less desirable since it adds complexity to the

sampling procedure. An example of the second alternative is development of a meter target surface with a very small "footprint" (on the order of 5-10 mm across) that could be placed in between grooves on a tine finished deck.

REFERENCES

Carter, P. (1993). "Evaluation of Waterproofing Performance and Effective Penetration Depth of Silane Sealers in Concrete," **unpublished, to be presented at American Concrete Institute Fall Convention**, Minneapolis, Minnesota, November.

Kamel, A., Kalluri, P., and Bush, T. (1993). "Effect of Field Variables and Test Procedures on Silane Weatherproofing Performance," **Draft Final Report**, submitted to Research and Development Division, Oklahoma Department of Transportation, February.

McGettigan, E. (1990). "Application Mechanism of Silane Weatherproofers," **Concrete International**, Vol. 12, No. 10, October, pp. 66-68.

Smith, M. (1986). "Silane Chemical Protection of Bridge Decks," **Report No. FHWA/OK 86(4)**, Research and Development Division, Oklahoma Department of Transportation, December.

APPENDIX - DATA

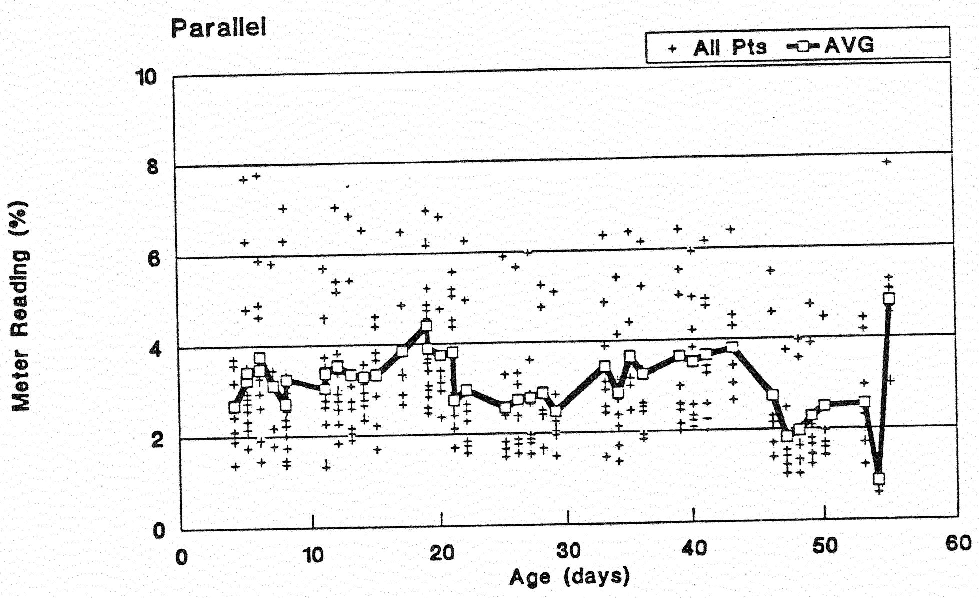


Fig. A.1 Moisture Meter Readings During Curing, Broom Finish (Parallel)

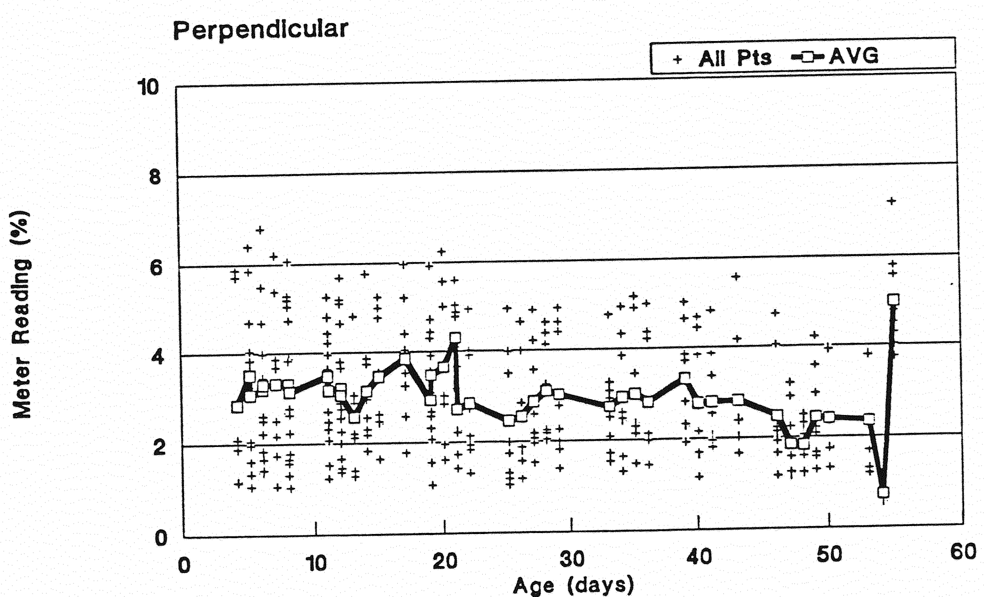


Fig. A.2 Moisture Meter Readings During Curing, Broom Finish (Perpendicular)

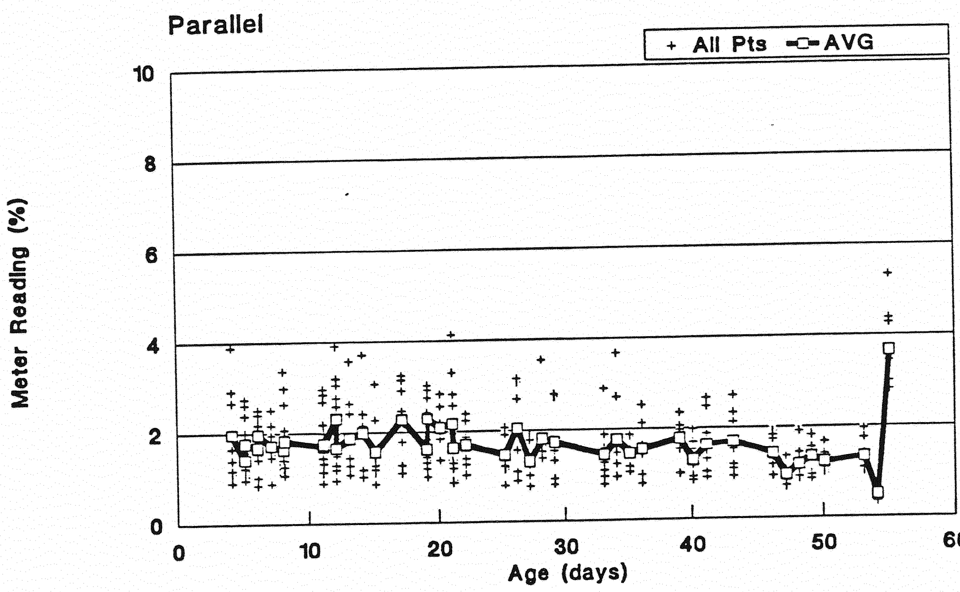


Fig. A.3 Moisture Meter Readings During Curing, Tine Finish (Parallel)

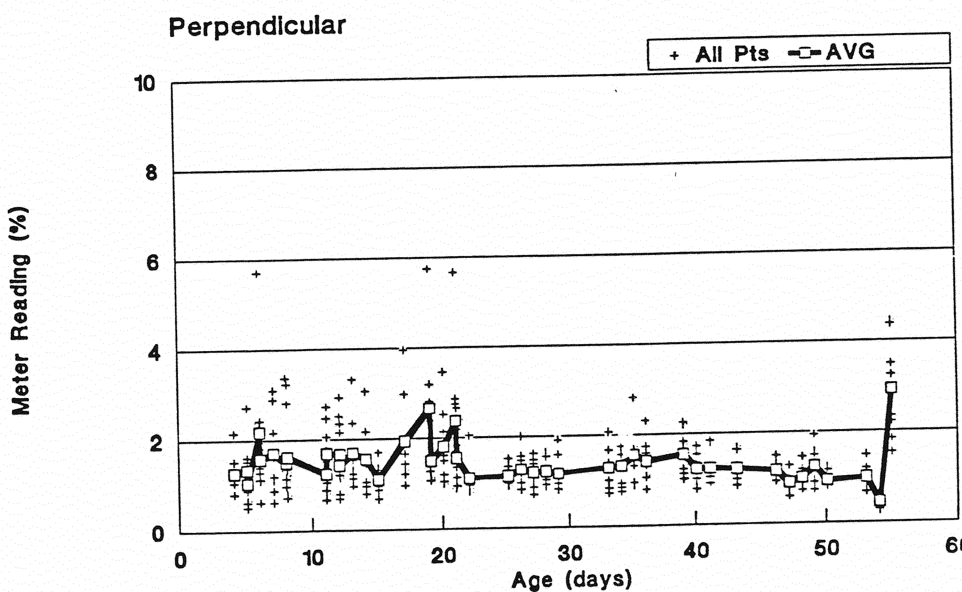


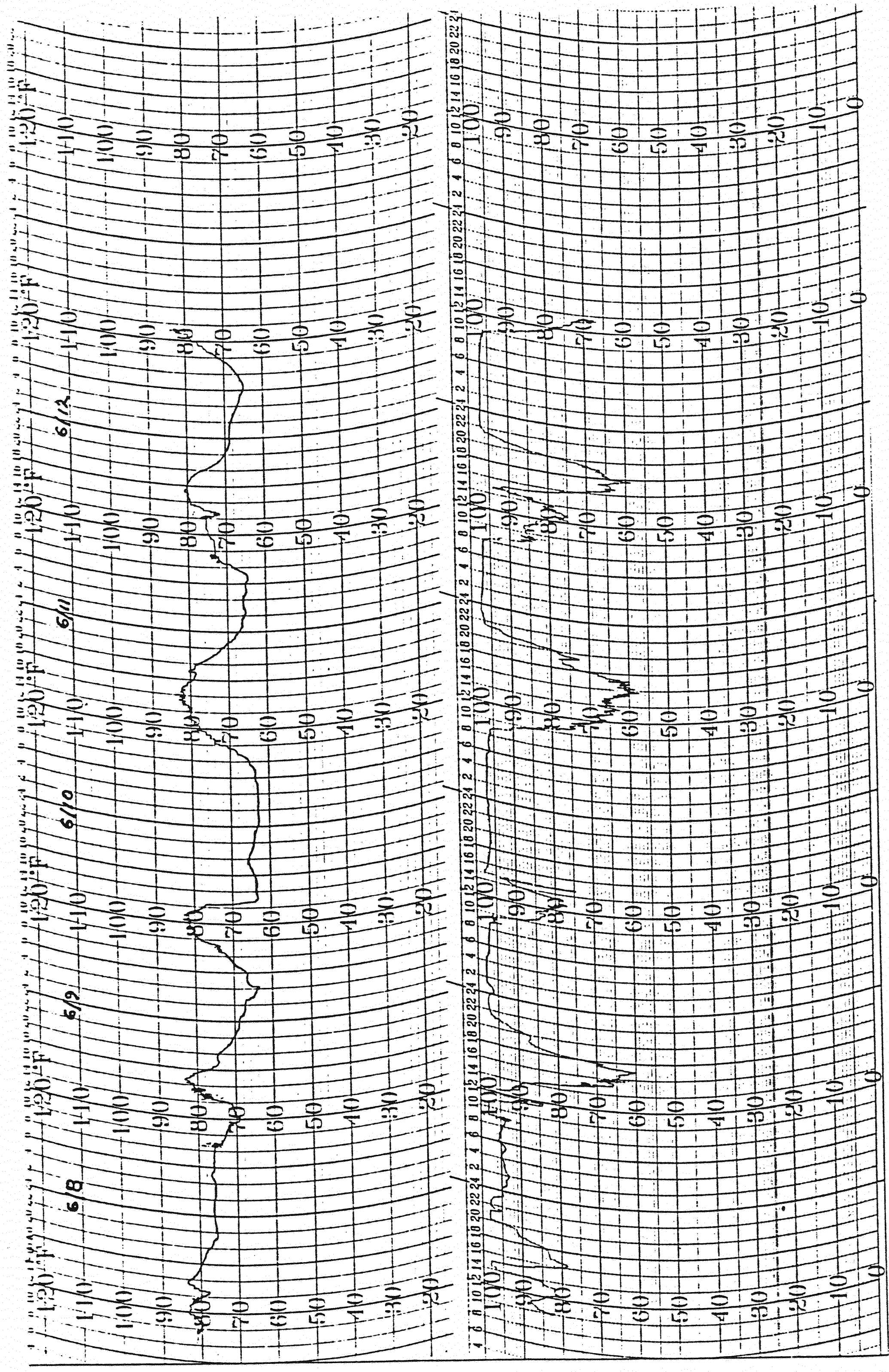
Fig. A.4 Moisture Meter Readings During Curing, Tine Finish (Perpendicular)

DATA FROM BRIDGE SITE

On the following pages are meter readings (measured deck moisture content) and temperature and humidity strip charts from the continuous recording thermohygrometer. Applicable dates are handwritten on the charts. The thermohygrometer was calibrated in the controlled climate chamber of Fears Laboratory. To obtain the proper humidity, a value of 10% should be subtracted from that shown on the strip chart.

Bridge Deck Readings				parallel to tines									point #									Global Average		Max Read	Min Read
trip #	date	Temp	Humidity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18				
1	06/07	80	78	1.08	3.81	4.21	5.33	6.64	7.74	3.22	1.45	1.6	4.06	0.84	2.85	2.83	2.86	2.38	3.01	4.3	0.77	58.98	3.2767	7.74	0.77
2	06/08	76	82	1.36	1.99	4.29	4.74	4.91	5.78	1.96	4.83	1.34	3.85	0.84	1.8	3.25	4.29	2.8	3.44	6.37	1.2	59.04	3.28	6.37	0.84
3	06/08	71	79	1.5	3.43	4.54	4.56	5.5	7.51	2	4.26	1.38	4.16	1.04	1.95	2.45	3.23	3.58	3.78	3.43	3.43	61.73	3.4294	7.51	1.04
4	06/08	79	70	1.42	1.48	3.29	3.6	3.33	5.08	1.3	1.09	0.97	1.67	1.02	1.79	1.66	2.78	1.44	4.05	6.27	0.9	43.14	2.3967	6.27	0.9
5	06/09	74	83	1.22	4.14	5.57	6.29	4.89	6.59	2.05	1.12	4.48	2.96	1.32	2.81	3.37	3.4	1.93	3.2	2.81	0.96	59.11	3.2839	6.59	0.96
6	06/09	81	73	1.26	2.75	3.96	4.08	5.02	5.47	2.65	1.11	1.34	4.52	1.18	1.56	2.65	2.61	2.3	2.66	2.53	1.46	49.11	2.7283	5.47	1.11
7	06/10	73	67	1.58	4.12	5.59	4.75	3.26	6.58	1.78	1.18	1.69	2.38	0.95	2.03	3.72	3.17	3.04	4.06	3.12	3.12	56.12	3.1178	6.58	0.95
8	06/11	72	75	1.48	3.03	3.95	5.81	5.35	6.67	1.18	0.95	4.04	3.68	1.12	1.81	2.58	5.33	2.04	4.55	1.53	0.66	55.76	3.0978	6.67	0.66
9	06/11	74	78	1.33	3.96	2.34	4.62	5.62	6.68	2.11	1.24	4.3	3.24	1.17	1.17	2.83	2.43	1.7	2.9	2.54	0.7	50.88	2.8267	6.68	0.7
10	06/12	79	61	2.15	4.17	3.87	4.76	2.03	7.44	1.6	1.66	1.22	3.48	0.94	2.25	1.98	4.84	2.48	3.59	4.44	0.87	53.77	2.9872	7.44	0.87
11	06/13	85	48	1.42	4.4	4.3	3.71	3.95	5.63	1.66	1.77	5.64	1.09	0.77	1.26	2.71	2.87	2.07	1.8	4.88	0.76	50.69	2.8161	5.64	0.76
12	06/14	76	75	3.07	3.68	3.09	3.96	3.35	5.66	2.26	1.61	4.53	3.8	1.24	2.22	4.65	0.97	2.39	4.37	3.23	0.82	54.9	3.05	5.66	0.82
13	06/14	90	51	2.02	4.64	5.33	3.66	5.1	7.48	1.26	1.17	1.21	3.64	1.4	2.77	2.72	2.76	2.05	3.18	1.39	0.68	52.46	2.9144	7.48	0.68
14	06/15	77	82	2.71	1.67	5.13	5.29	4.63	5.34	2.49	1.26	4.94	2.06	0.95	2.46	5.32	3.72	1.99	2.25	3.26	3.26	58.73	3.2628	5.34	0.95
15	06/15	85	52	1.5	3.93	4.39	4.9	2.96	5.87	2.4	1.21	1.39	4.12	1.27	2.61	2.43	5.27	2.44	4.04	2.44	3.13	58.3	3.1278	5.87	1.21
16	06/16	75	81	1.25	3.73	4.95	3.13	4.56	7.68	1.18	1.05	2.4	2.43	1.12	1	2.17	3.09	1.68	3.6	3.03	1.15	49.2	2.7333	7.68	1
17	06/28	79	72	0.97	1.58	4.48	2.31	2.67	5.92	1.96	1.24	3.9	2.02	0.78	1.97	1.93	2.9	2.09	2.62	2.88	0.66	42.88	2.3822	5.92	0.66
18	06/28	82	55	1.09	3.54	3.74	3.3	3.06	6.25	1.99	1.1	1.37	2.77	0.74	1.81	2.02	4.29	1.88	2.26	2.81	0.79	44.81	2.4894	6.25	0.74
19	06/30	87	57	1.25	3.23	4.78	3.19	2.28	4.61	1.84	1.09	1.33	2.89	0.59	1.99	3.09	3.41	1.81	3.11	1.52	0.94	42.95	2.3861	4.78	0.59
20	07/06	81	80	1.24	2.83	3.45	2.36	2.69	4.89	2.1	0.96	4.63	2.16	0.72	1.2	2.82	3.07	1.8	3.47	3.8	0.49	44.68	2.4822	4.89	0.49
21	07/08	88	52	1.38	3.17	4.07	3.08	2.13	5.77	1.57	0.97	0.92	1.6	0.88	1.14	1.81	4.63	1.45	0.99	1.6	0.81	37.97	2.1094	5.77	0.81
22	07/12	78	76	1.4	1.18	4.05	3.93	1.58	2.92	1.16	1.62	1.42	1.17	1.07	1.01	3.09	2.83	1.23	2.21	1.61	1.26	34.74	1.93	4.05	1.01
23	07/13	80	81	1.51	3.53	4.17	3.82	2.26	6.15	1.04	0.79	0.94	2.79	0.98	1.19	2.5	3.7	1.74	2.44	2.47	2.47	44.49	2.4717	6.15	0.79
24	07/14	78	82	0.94	3.37	4.52	4.16	4.3	4.59	1.22	1.07	0.89	3.09	0.73	1.21	4.39	4.6	1.74	3	2.74	2.73	49.29	2.7383	4.6	0.73
25	07/15	76	80	1.11	3.21	4.48	3.61	3.14	4.68	2.03	2.54	4.92	2.9	0.91	1.32	3.6	2.21	1.49	3.07	1.51	0.64	47.37	2.6317	4.92	0.64
26	07/16	77	78	1.45	2.8	4.82	2.88	1.91	4.29	1.27	0.91	5.56	1.16	1.1	1.35	3.73	1.83	1.14	1.96	2.03	0.81	41	2.2778	5.56	0.81
27	07/16	88	49	1.1	3.19	2.12	3.82	2.65	3.56	1.15	1.05	1.16	1.29	0.84	1.63	1.55	3.53	1.68	1.5	1.95	0.82	34.59	1.9217	3.82	0.82
28	07/20	91	41	1.05	1.96	2.18	2.81	2.49	3.38	1.44	1.15	0.92	2.76	0.78	1.23	1.52	2.34	1.22	1.36	1.22	0.63	30.44	1.6911	3.38	0.63
29	07/21	82	77	1.01	2.4	2.95	1.82	1.94	3.04	1.17	1.47	2.05	1.27	0.79	1.32	2.35	1.29	0.97	1.81	1.99	0.96	30.6	1.7	3.04	0.79
30	07/22	91	54	0.88	2.45	3.42	2.94	2.04	4.79	1.27	1.24	0.86	2.39	0.62	1.3	1.27	2.05	1.18	2.08	1.26	0.69	32.73	1.8183	4.79	0.62
31	07/23	94	48	1.14	1.96	2.98	2.08	2.36	3.44	1.14	1.06	0.84	1.69	0.58	1.06	1.38	1.25	1.29	1.3	1.33	0.49	27.37	1.5206	3.44	0.49
33	08/02	87	35	1.17	3.01	3.18	3.84	1.46	3.76	1.55	2.24	0.98	1.84	0.8	1.03	1.68	3.62	1.36	1.5	1.36	0.67	35.05	1.9472	3.84	0.67
34	08/03	87	52	1.15	3.19	2.06	3.51	2.2	5.18	1.01	2.68	1.04	1.54	0.71	1.25	1.2	1.08	1.17	2.06	3.95	1.47	36.45	2.025	5.18	0.71
35	08/06	70	68	2.12	3.92	4.88	4.55	4.46	7.34	1.94	3.7	1.28	2.93	0.82	1.67	3.2	3.63	2.01	2.62	1.13	0.53	52.73	2.9294	7.34	0.53
36	08/06	81	48	1.4	4.81	4.93	5.22	3.81	7	2.41	1.89	1.53	2.95	0.85	2.1	2.26	3.5	2.33	2.37	2.07	0.95	52.38	2.91	7	0.85
37	08/09	93	43	1.24	3.5	3.6	3.91	5.08	7.28	2.58	4.8	1.42	4.42	1.03	2.3	2.43	4.71	2.04	4.18	7.26	1.42	63.2	3.5111	7.28	1.03
38	08/15	102	28		2.6		3.78		3.96		0.78		1.5		1.47	1.17	2.5		1.61	3.12		22.49	2.249	3.96	0.78
sum		81.03	65.6389	1.38	3.07	3.88	3.79	3.39	5.46	1.7	1.64	2.17	2.62	0.91	1.66	2.57	3.08	1.84	2.71	2.76	1.19	45.828	2.546	5.460541	0.905135
Max point		102	83	3.07	4.81	5.59	6.29	6.64	7.74	3.22	4.83	5.64	4.52	1.4	2.85	5.32	5.33	3.58	4.55	7.26	3.43	63.2	3.5111	7.74	1.21
Min point		70	35	0.88	1.18	2.06	1.82	1.46	2.92	1.01	0.79	0.84	1.09	0.58	1	1.2	0.97	0.97	0.99	1.13	0.49	27.37	1.5206	3.04	0.49

Bridge Deck Readings				perpendicular to tines									point #												
Trip #	date	Temp	Humidity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Global Average		Max Read	Min Read
1	06/07	80	78	1.95	2.38	6.26	6.9	5.52	8	3.02	2.25	2.08	4.27	0.98	1.95	2.51	5.63	2.18	2.79	5.82	2.06	66.55	3.6972	8	0.98
2	06/08	76	82	1.01	1.34	2.68	4.24	3.45	5.86	2.15	1.47	1.27	3.6	1.01	2.08	2.46	5.13	1.98	4.78	5.65	1.85	52.01	2.8894	5.86	1.01
3	06/08	71	79	2.28	3.46	5.23	5.89	3.97	6.27	1.86	2.53	1.01	3.91	1.01	3	3.27	5.7	1.88	4.17	3.46	3.46	62.36	3.4644	6.27	1.01
4	06/08	79	70	1.54	1.45	3.67	5.33	4.44	6.71	1.12	1.33	0.78	3.75	0.72	1.62	1.73	3.91	0.81	2.11	5.51	1.97	48.5	2.6944	6.71	0.72
5	06/09	74	83	1.88	1.29	1.83	4.71	4.03	6.6	1.35	2.31	5.25	3.6	0.99	2.74	2.01	4.36	1.7	4.94	5.08	1.46	56.13	3.1183	6.6	0.99
6	06/09	81	73	1.83	2.04	5.48	5.25	3.9	6.37	2	1.81	1.38	3.7	0.93	2.64	1.99	3.29	1.44	4.31	4.57	1.08	54.01	3.0006	6.37	0.93
7	06/10	73	67	1.59	1.7	4.11	7.16	3.36	6.88	2.29	3.02	3.05	1.26	1	2.7	2.16	6.3	2.37	3.34	3.26	3.26	58.81	3.2672	7.16	1
8	06/11	72	75	1.47	1.84	3.05	4.91	4.18	5.84	2.19	1.2	4.53	3.69	0.97	2.65	1.29	4.83	0.93	4.65	4.83	1.5	54.55	3.0306	5.84	0.93
9	06/11	74	78	1.22	1.55	4.35	4.23	6.34	5.22	2.33	1.51	4.67	3.14	1.33	2.3	1.47	1.1	1.35	3.66	3.16	1.99	50.92	2.8289	6.34	1.1
10	06/12	79	61	1.29	2.36	4.08	5.8	2.83	6.63	1.62	2.56	0.92	3.26	0.94	2.95	1.67	4.74	1.86	4.72	2.88	1.41	52.52	2.9178	6.63	0.92
11	06/13	85	48	1.64	2.21	2.16	3.15	4.66	5.95	2.46	1.34	5.91	3.97	0.96	2.56	2.13	4.68	1.43	4.69	5.41	1.65	56.96	3.1644	5.95	0.96
12	06/14	76	75	0.76	1.4	4.33	4.43	3.33	6.7	1.51	1.93	4.53	4.27	1.3	3.1	2.47	2.2	0.9	1.81	3.18	0.81	48.96	2.72	6.7	0.76
13	06/14	90	51	1.55	2.99	3.89	4.82	5.08	6.13	2.01	1.81	1.07	3.83	1.13	2.76	2.16	4.11	2.17	4.62	5.74	2.11	57.98	3.2211	6.13	1.07
14	06/15	77	82	1.59	1.3	5.05	4.8	4.24	4.34	2.84	2.84	4.42	1.51	0.92	2.26	2.61	4.33	0.92	2.64	2.91	2.91	52.43	2.9128	5.05	0.92
15	06/15	85	52	1.86	2.32	4.63	3.48	3.37	6.89	2.22	2.13	1.23	4.57	1.21	3.01	2.05	4.73	1.9	4.53	3	3.13	56.26	3.1256	6.89	1.21
16	06/16	75	81	1.07	1.17	5.56	4.16	2.79	5.34	1.89	1.72	1.8	3.15	0.89	1.52	1.2	4.17	1.26	4.62	4.97	1.52	48.8	2.7111	5.56	0.89
17	06/28	79	72	1.59	2.65	3.53	3.53	3.32	4.86	2.08	1.11	2.7	2.89	0.48	1.96	2.72	4.34	1.25	2.74	1.21	0.99	43.95	2.4417	4.86	0.48
18	06/28	82	55	1.37	2.07	3.76	5.52	2.13	5.71	1.36	1.32	1.37	2.67	0.84	1.75	1.38	3.31	1.37	3.74	1.55	1.14	42.36	2.3533	5.71	0.84
19	06/30	87	57	1.12	1.27	3.22	4.78	2.31	4.66	1.23	1.22	0.94	2.63	0.81	1.3	1.07	2.22	1.14	3.07	1.21	1.41	35.61	1.9783	4.78	0.81
20	07/06	81	80	0.95	1.16	4.01	3.73	2.83	5.81	1.77	1.23	1.33	2.58	0.74	1.18	1.86	1.81	1.4	1.56	2.13	1.57	37.65	2.0917	5.81	0.74
21	07/08	88	52	1.06	1.8	2.95	4.44	1.65	5.63	1.17	1.27	0.95	2.1	0.75	1.47	1.29	2.59	1.26	3.32	4.34	1.29	39.33	2.185	5.63	0.75
22	07/12	78	76	1.25	0.85	2.48	2.65	2.61	5.77	1.76	1.04	1.61	2.35	0.84	1.3	2.49	1.37	1.13	2.89	2.77	1.32	36.48	2.0267	5.77	0.84
23	07/13	80	81	1.05	2.5	3.82	4.97	1.98	5.4	1.24	1.35	0.77	2.63	0.68	1.83	1.14	2.37	1.42	3.04	2.26	2.26	40.71	2.2617	5.4	0.68
24	07/14	78	82	1.37	1.64	4.49	4.74	3.66	6.58	1.47	1.54	0.89	2.03	0.73	1.86	1.83	2.78	1.28	2.72	2.48	2.47	44.56	2.4756	6.58	0.73
25	07/15	76	80	1.39	1.4	3.42	3.4	3.47	5.55	1.88	1.52	3.07	3.32	0.8	1.43	1.54	2.71	0.94	2.84	4.19	0.86	43.73	2.4294	5.55	0.8
26	07/16	77	78	0.93	1.24	3.01	4.09	3.01	3.32	1.69	1.02	0.93	3.25	1.42	1.06	3.5	1.84	0.91	1.54	2.89	1.08	36.73	2.0406	4.09	0.91
27	07/16	88	49	1.06	1.87	2.91	4.96	1.65	5.62	1.37	1.37	0.94	1.47	0.74	1.56	1.35	2.57	1.08	2.96	3.39	1.13	38	2.1111	5.62	0.74
28	07/20	91	41	0.96	1.71	3.06	4.01	2.81	4.68	1.44	1.21	0.88	1.59	0.74	1.42	0.92	2.56	0.95	2.79	2.2	0.95	34.88	1.9378	4.68	0.74
29	07/21	82	77	0.97	1.26	2.91	1.73	2.96	4.47	1.15	0.96	2.15	2.01	0.78	1.32	2.22	2.45	0.92	1.34	2.86	0.71	33.17	1.8428	4.47	0.71
30	07/22	91	54	1.05	1.31	2.5	3.93	1.44	4.37	0.98	1.06	0.9	1.68	0.67	1.4	1.01	2.54	0.83	2.19	2.64	0.92	31.42	1.7456	4.37	0.67
31	07/23	04	48	0.93	1.08	2.83	3.39	2.3	3.1	1.09	1.03	0.83	1.5	0.59	1.03	1.02	1.08	0.71	1.26	2.68	1.15	27.6	1.5333	3.39	0.59
33	08/02	87	35	1.04	1.54	2.78	4.52	3	5.12	1.23	1.34	0.84	2.07	0.66	1.41	1.12	2.73	1	2.68	3.21	1.02	37.31	2.0728	5.12	0.66
34	08/03	87	52	1.4	1.24	3.28	4.65	3.98	5.55	1.34	1.47	1.04	2.03	0.79	1.23	2.2	1.39	2.96	0.95	3.29	1.23	40.02	2.2233	5.55	0.79
35	08/06	70	68	0.99	3.02	5.4	6.58	4.67	6.85	2.74	1.59	1.2	2.99	0.85	2.17	1.51	1.51	1.82	3.15	3.49	1.26	51.79	2.8772	6.85	0.85
36	08/06	81	48	2.45	3.46	5.3	4.82	4.48	6.86	1.52	1.61	1.21	3.1	0.95	1.92	2.01	3.9	1.29	3.55	5.1	1.58	55.11	3.0617	6.86	0.95
37	08/09	93	43	1.6	2.57	3.5	5.1	4.52	7.07	2.29	2.8	1.44	3.89	1.09	2.19	2.15	4.87	2.12	3.75	5.29	1.84	58.08	3.2267	7.07	1.09
38	08/15	102	28		2.7		4.41		4.8		1.04		1.39		1.12	1	1.71		1.98	3.57		23.72	2.372	4.8	1
sum		81.03	65.6389	1.33	1.8	3.66	4.45	3.36	5.59	1.72	1.59	1.89	2.82	0.87	1.91	1.82	3.25	1.37	3.09	3.48	1.58	45.574	2.5319	5.586757	0.871351
Max point		102	83	2.45	3.46	6.26	7.16	6.34	8	3.02	3.02	5.91	4.57	1.42	3.1	3.5	6.3	2.96	4.94	5.82	3.46	66.55	3.6972	8	1.21
Min point		70	28	0.76	0.85	1.83	1.73	1.44	3.1	0.98	0.96	0.77	1.26	0.48	1.03	0.92	1.08	0.71	0.95	1.21	0.71	23.72	1.5333	3.39	0.48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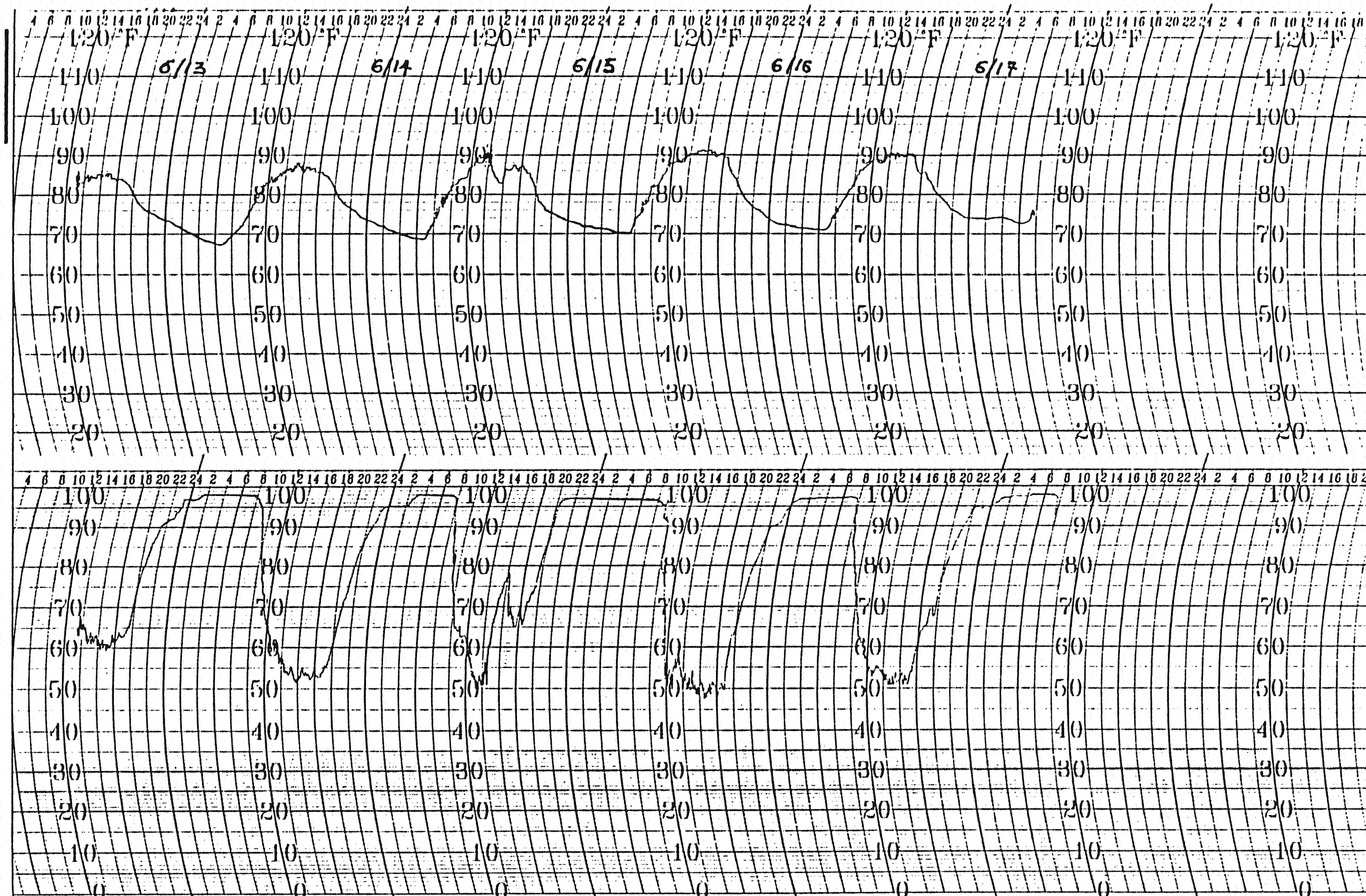
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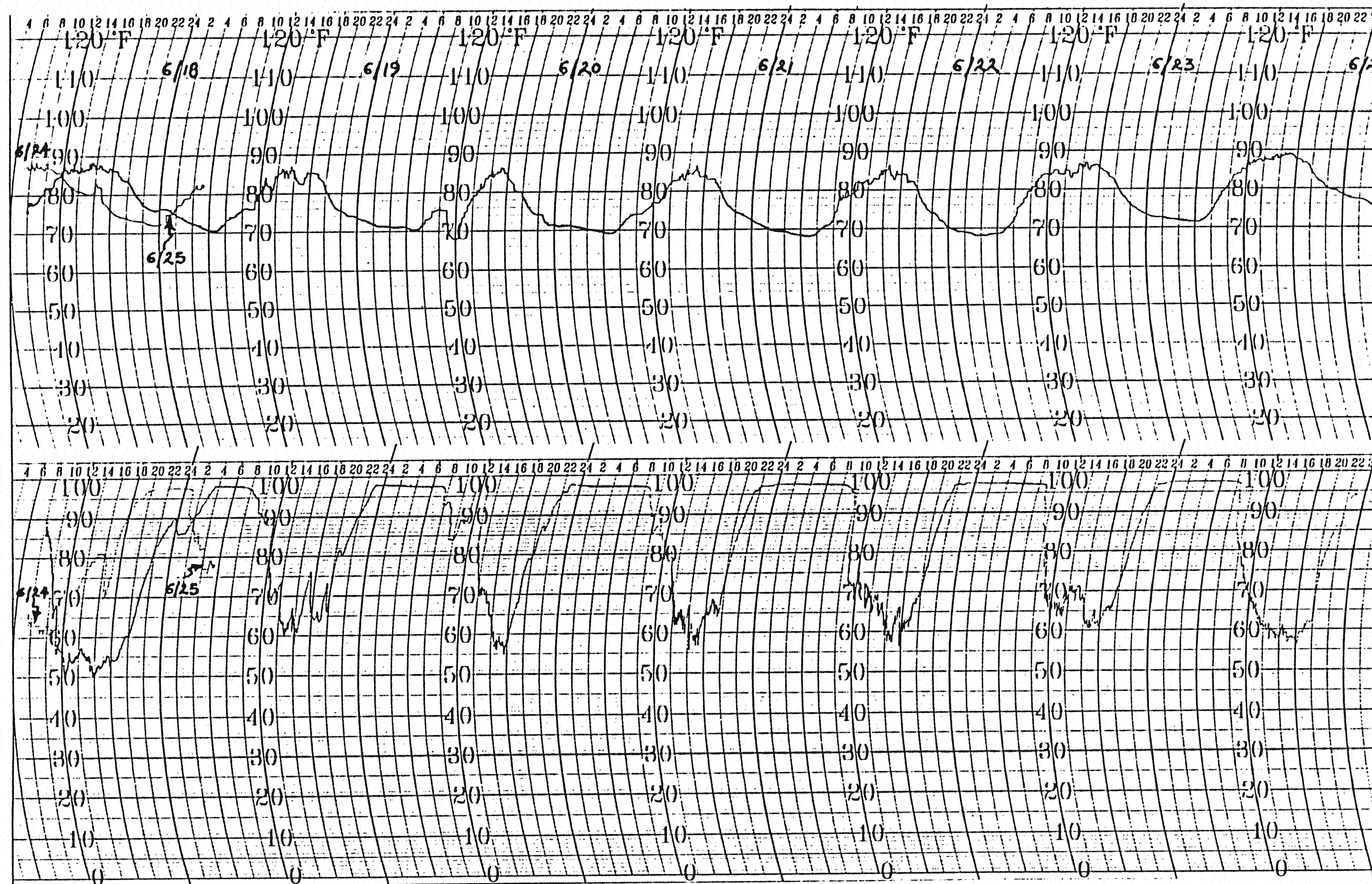
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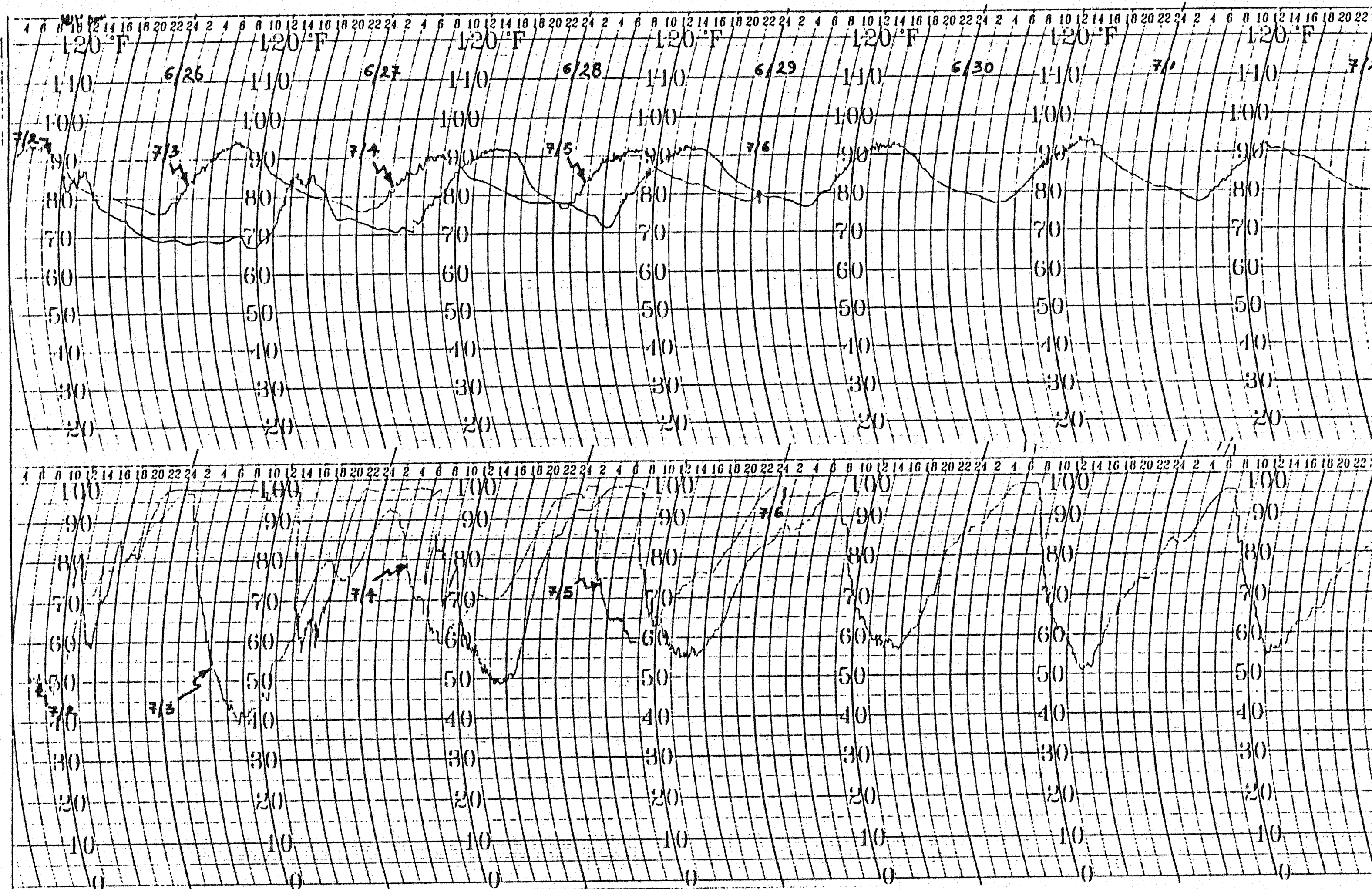
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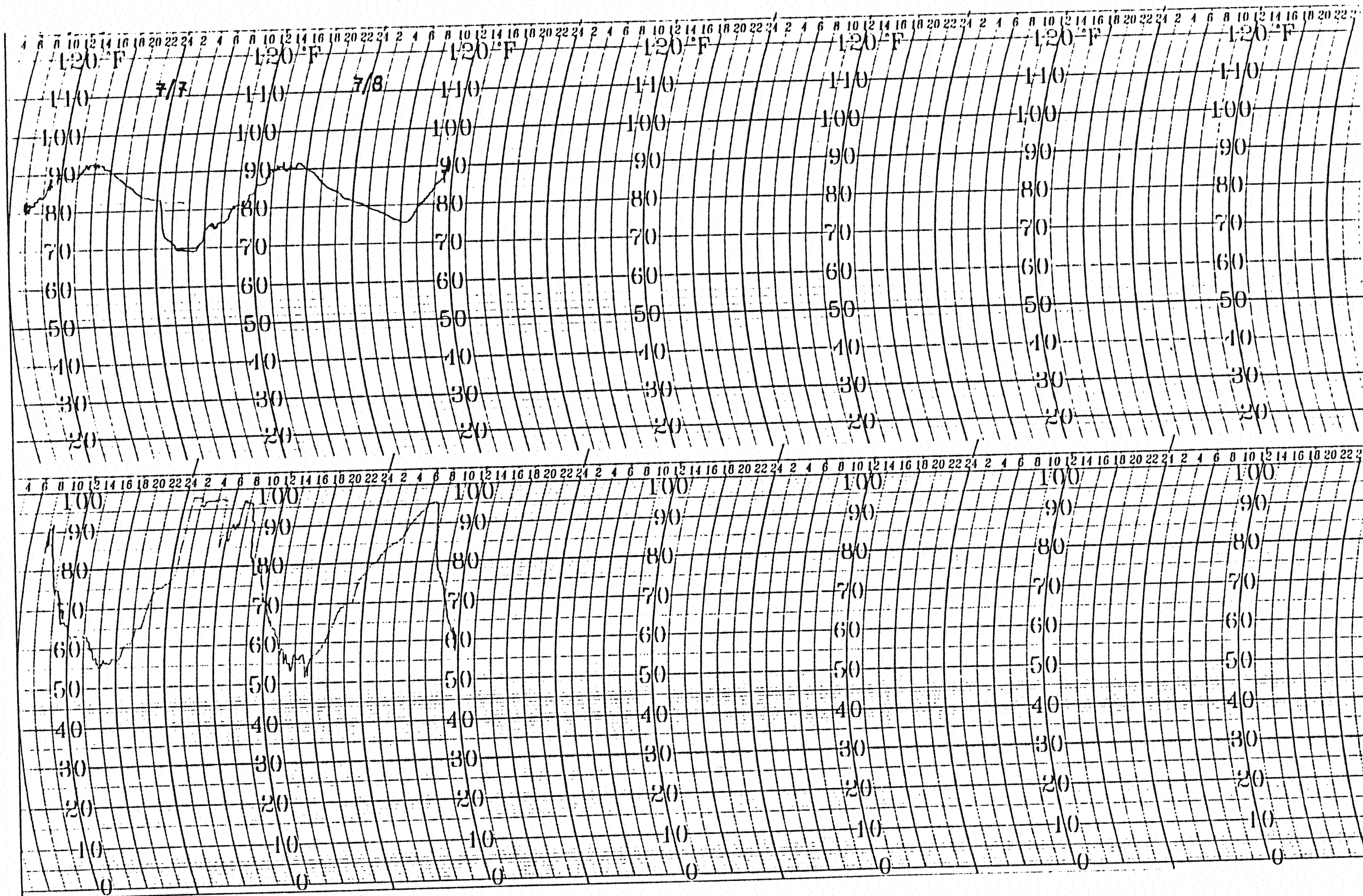
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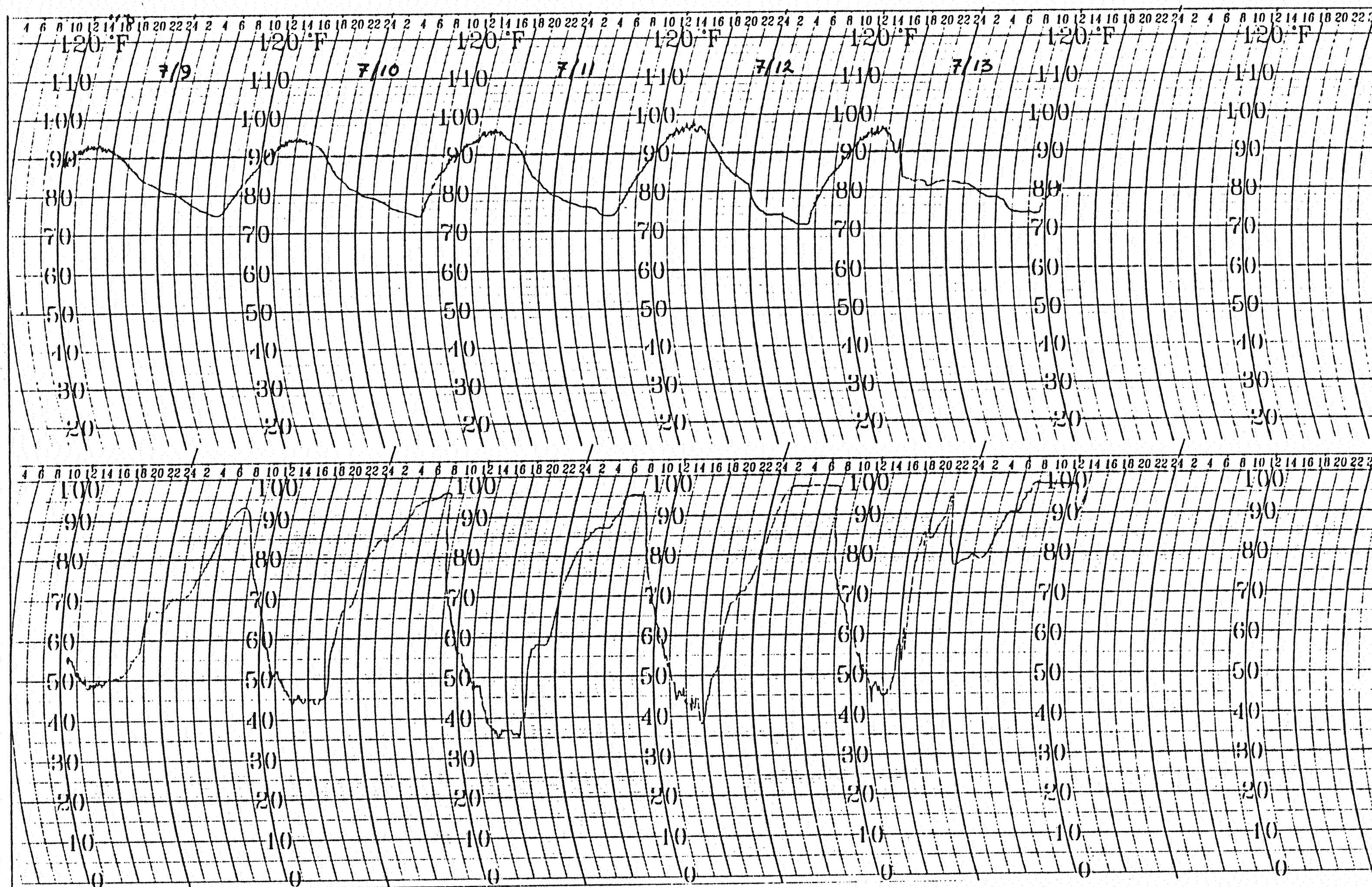

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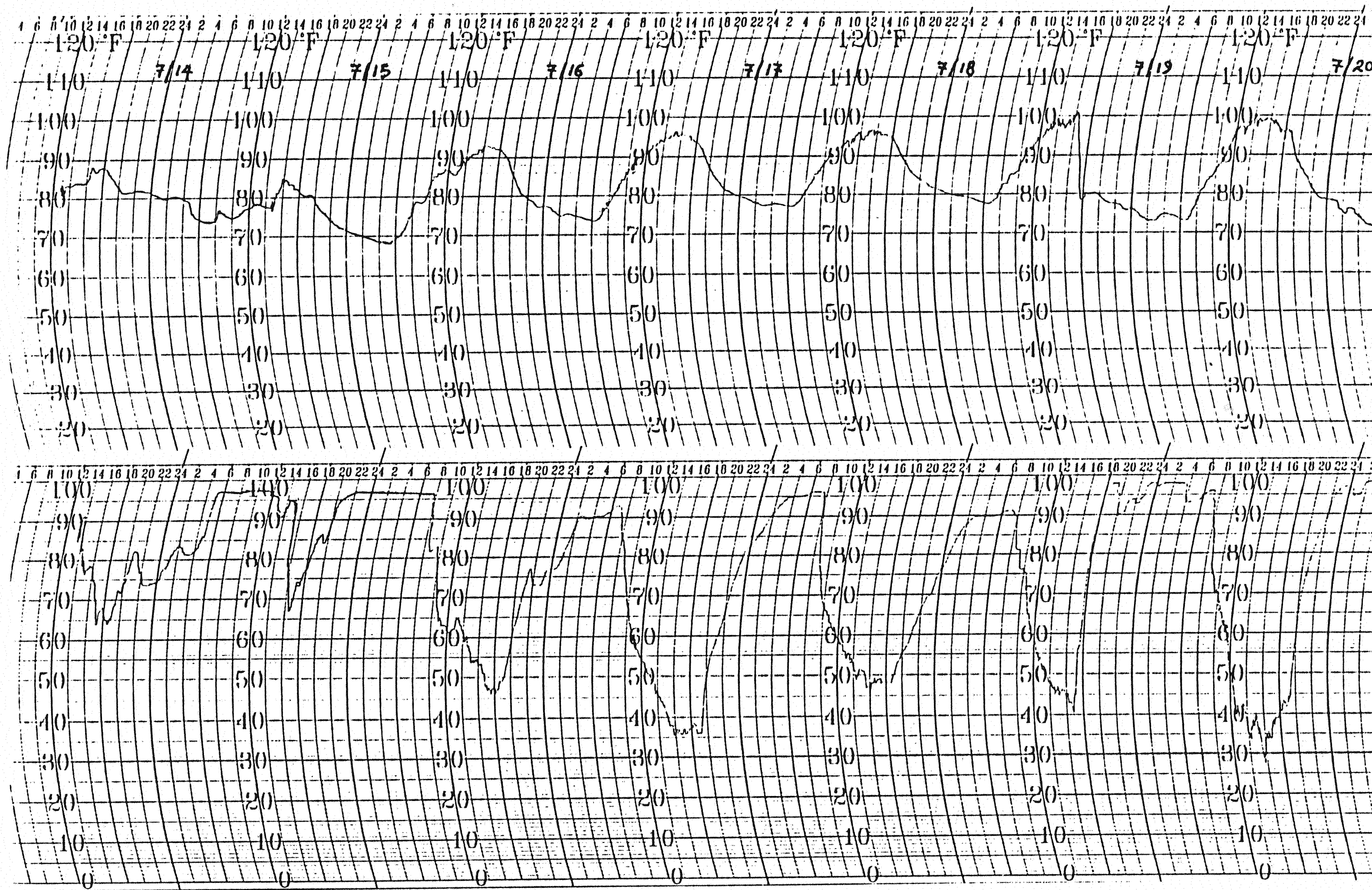
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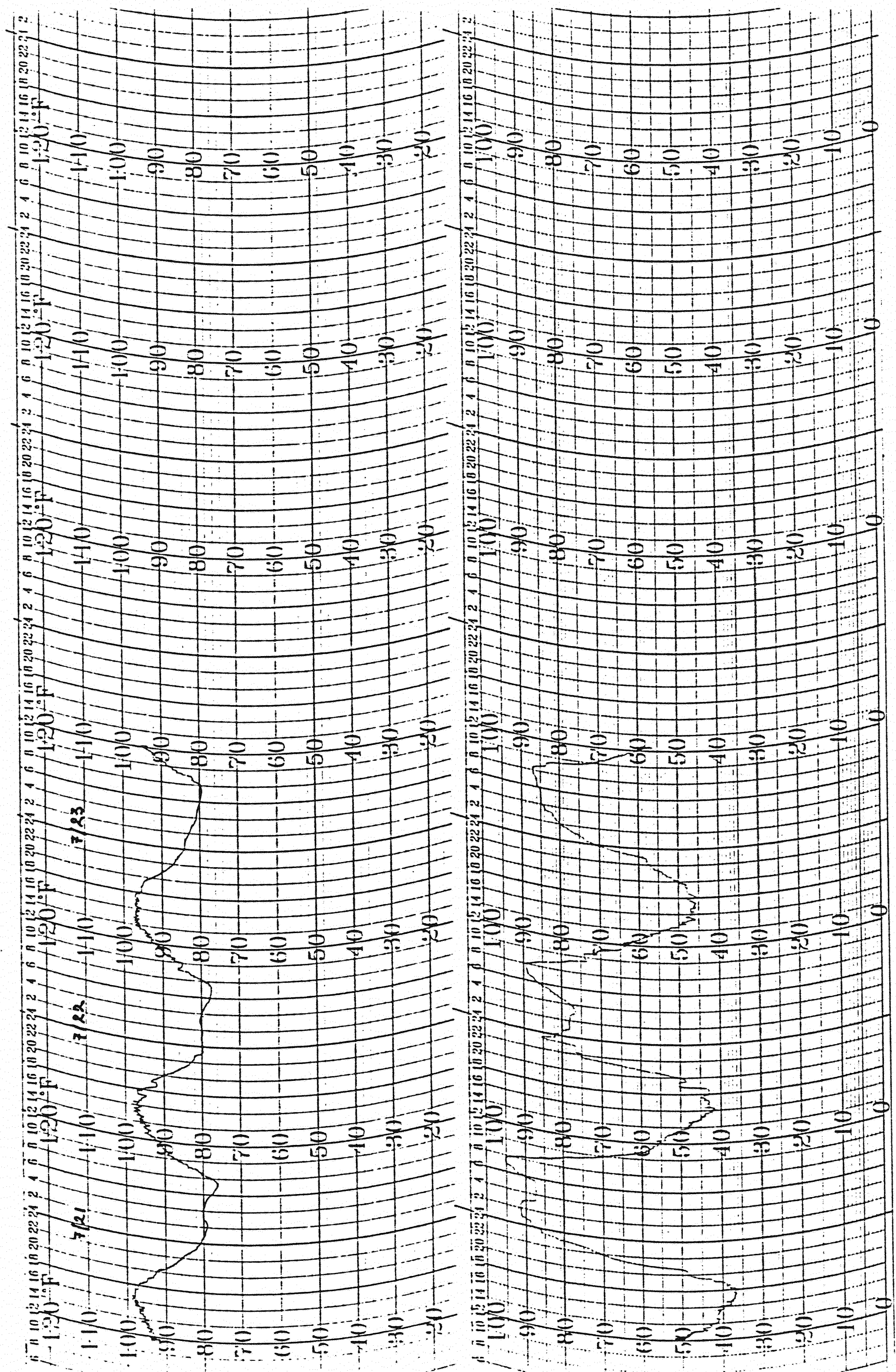
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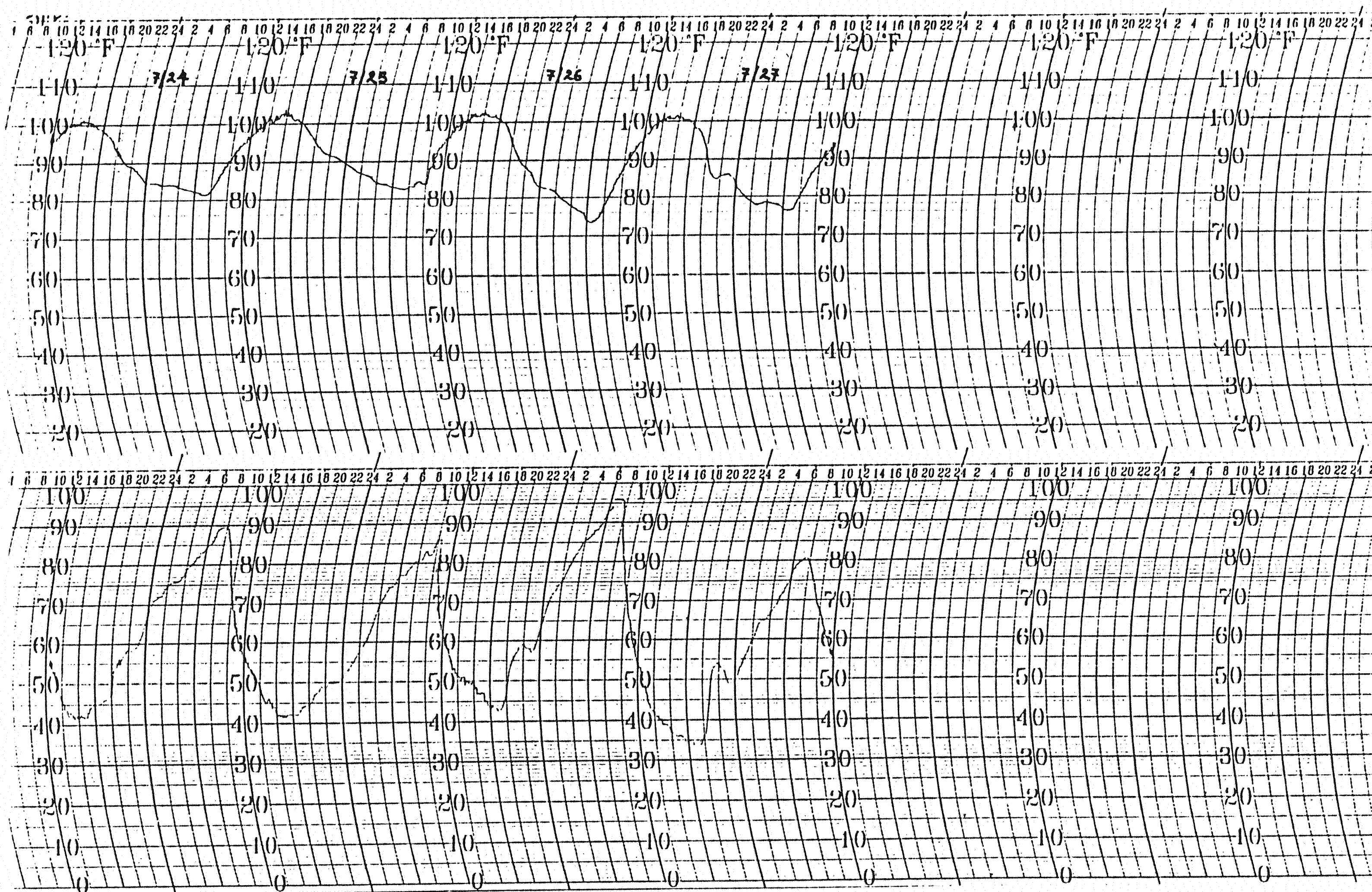
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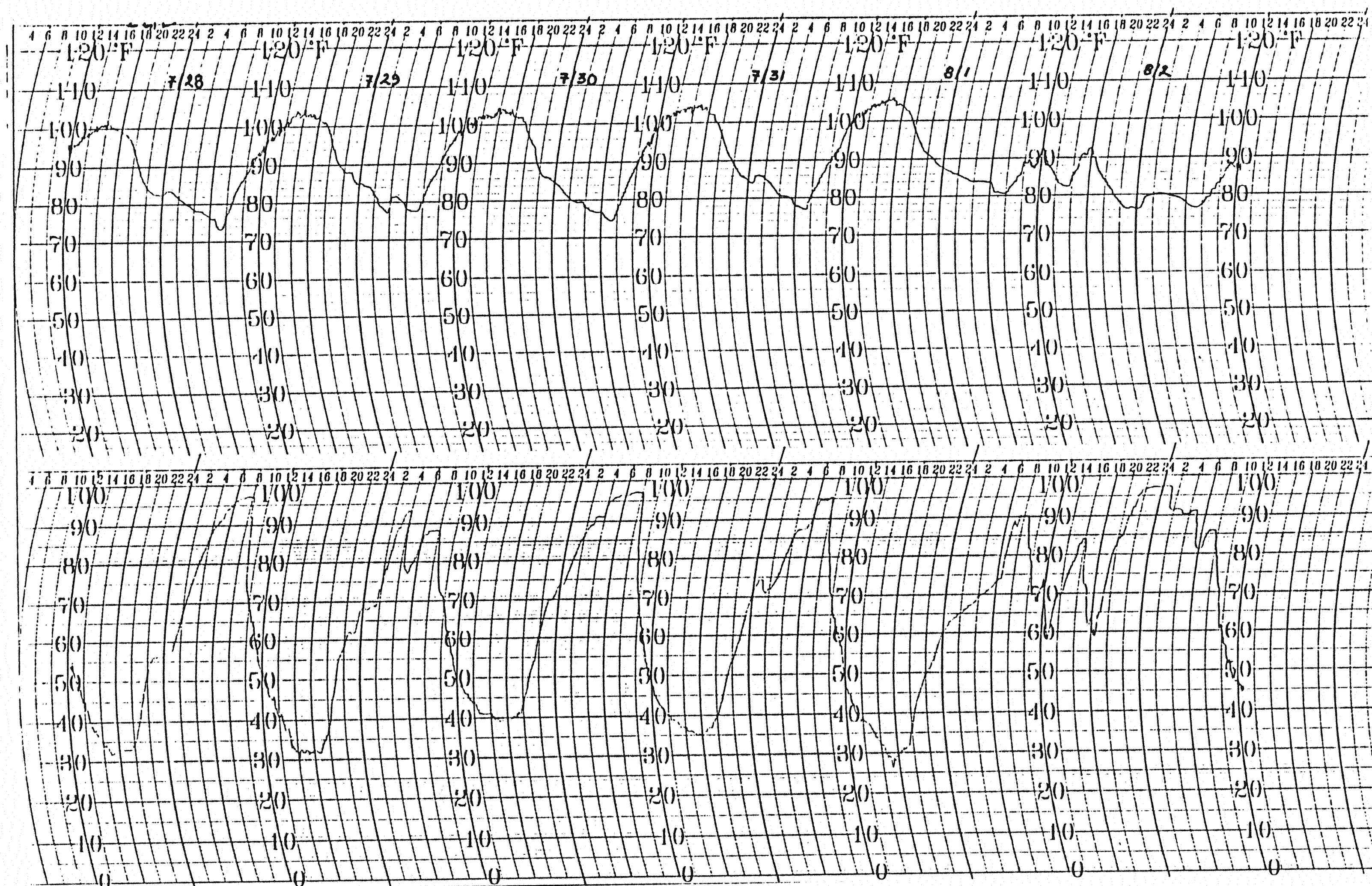
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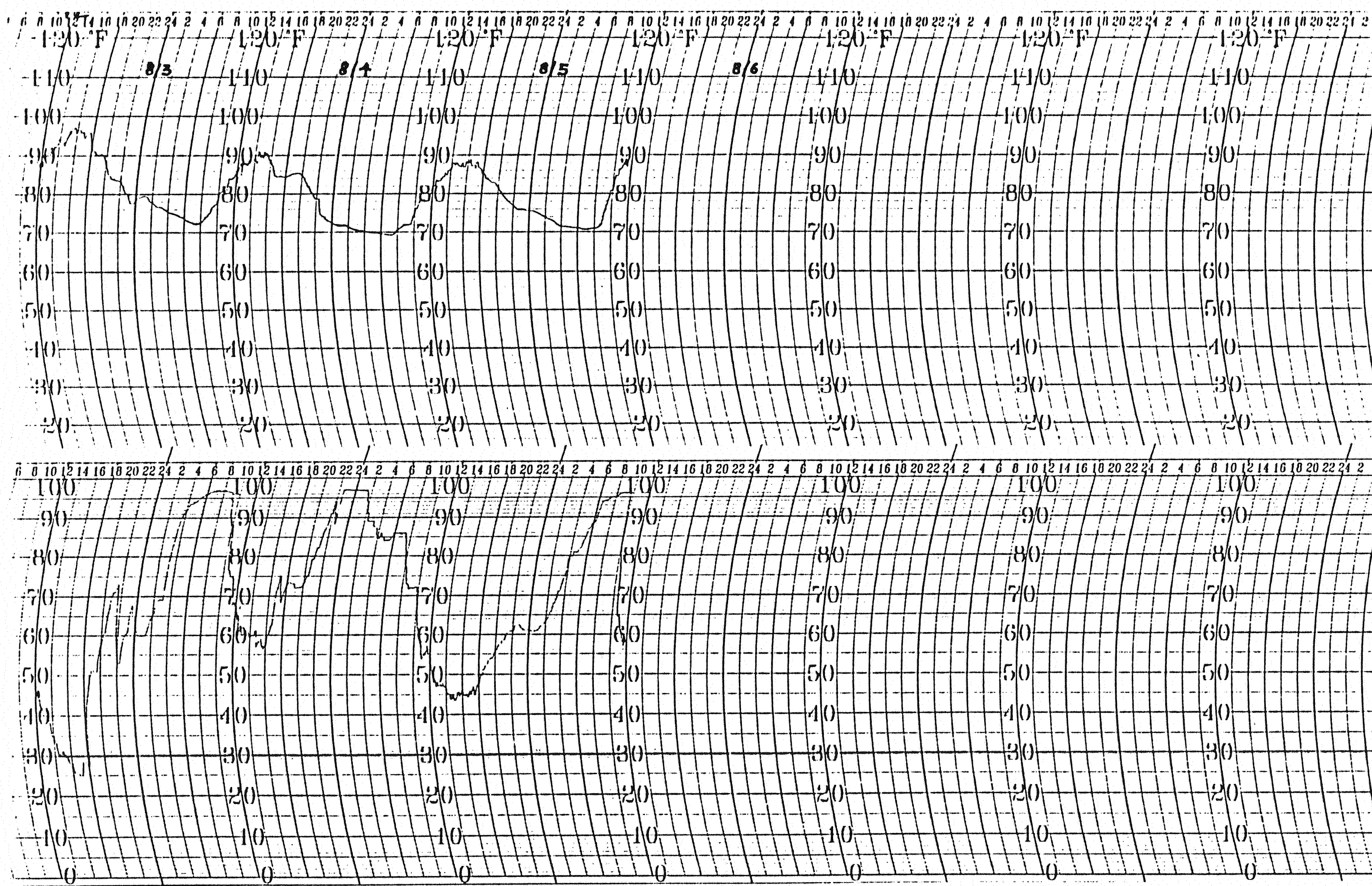
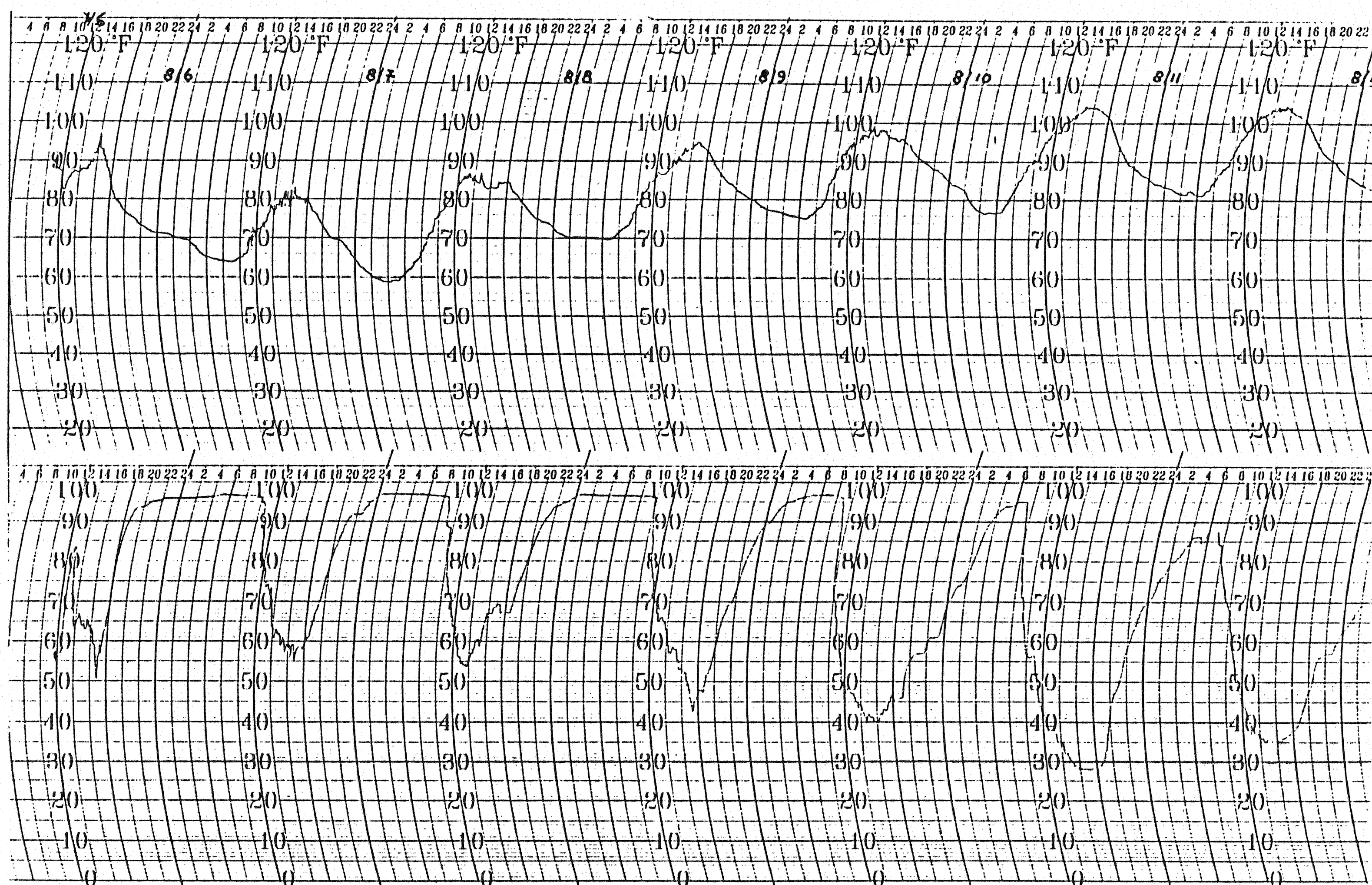
8/2
120°F



120 °F
8/3
8/4
8/5
8/6


120°F
8/6
8/7
8/8
8/9
8/10
8/11