

Temperature Stresses In Large
Gravity Type Dams

Thesis for Degree of C. E.

C. E. Slaughter

THESIS

Hydraulic system

LIBRARY
MICHIGAN STATE COLLEGE
OF AGRIC. AND APP. SCIENCE



PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE
02/14/2009		

TEMPERATURE STRESSES IN LARGE
GRAVITY TYPE DAMS

A Thesis Submitted to
The Faculty of
The Michigan State College
of Agriculture and Applied Science

By.

Clare E. Slaughter
Candidate for the degree,
Civil Engineer

June 1929

THESIS

Acknowledgement

The purpose of this thesis is to develop a method of determining stresses in gravity type dams from consideration of the temperature distribution in the concrete. In order to do this certain data and telemeter readings furnished by the Southern California Edison Company have been used and the permission to do so is hereby gratefully acknowledged.

Los Angeles

April 21, 1929

Table of Contents

Introduction.....	Page 3
Shaver Lake Dam;.....	7
Relation between outside temperature and temperature distribution within the dam	17
Causes of strain.....	19
Strains caused bu thermal expansion of concrete immediately surrounding the telemeter	20
Strain due to stress.....	21
Stresses induced bu non-uniform temperature distribution.....	26
Comparison of calculated and actual strains..	49
Conclusions.....	52

-

10-10-2024 10:10:10

10-10-2024 10:10:10

10-10-2024 10:10:10

10-10-2024

10-10-2024 10:10:10

10-10-2024 10:10:10

10-10-2024

10-10-2024 10:10:10

10-10-2024

10-10-2024

INTRODUCTION

Immediately after the failure of the St. Francis Dam in the spring of 1928 one of the first official actions was to initiate an investigation into the cause of the failure. The fact that no cut off wall had been provided and that the foundation material consisted of mica schist and red conglomerate which is not the best material for a dam foundation led to the suspicion that the primary failure had occurred at this point. This was the report given by the committee after due deliberation and subsequent investigating bodies have taken a similar view.

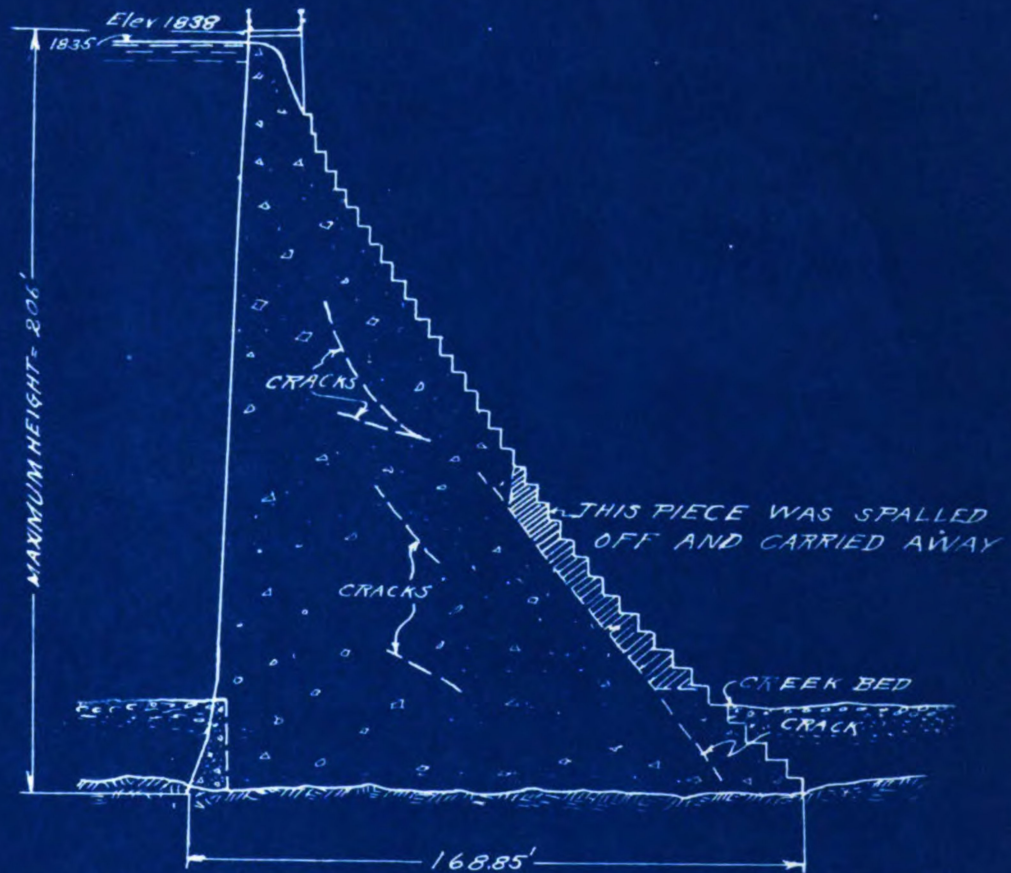
Faulty foundation is the reason ascribed to the failure of most gravity dams. Inasmuch as the maximum compressive stress as determined by the ^{present} ~~old~~ theories of design, rarely exceeds 200 pounds per Sq. inch and even the poorest concrete should stand this safely there is a temptation to blame the foundation as the only remaining cause of failure. However there is a growing suspicion that high internal stresses and concentration of stress may occur as a result of shrinking and swelling, and deformation due to non-uniform temperature changes.

The failure of the St. Francis Dam, exposing the interior of the structure furnished the startling evidence of

of several extended cracks, shown in Fig. 1. For several days following the failure of the dam water is said to have flowed from these cracks. Moreover the broken faces of the fragments scattered along the path of the flood showed considerable discoloration indicating that failure had occurred along cracks that had formed long before the dam was finally destroyed.

Such cracks are a common occurrence in gravity type dams and their presence indicate a dangerous condition. Obviously a crack leads to concentration of stress. Water seeping in allows a full hydrostatic uplift to act over the extent of the crack. The surface is lubricated by a film of water so that sliding may occur and water is permitted to gain access to the foundations where it may carry off the soluble content and soften the material. These cracks which are so common in gravity type dams could never result from the comparatively low stresses that are considered in the ^{present} theories of dam design. Their presence is indicative of much higher internal stresses, possibly occurring in tension.

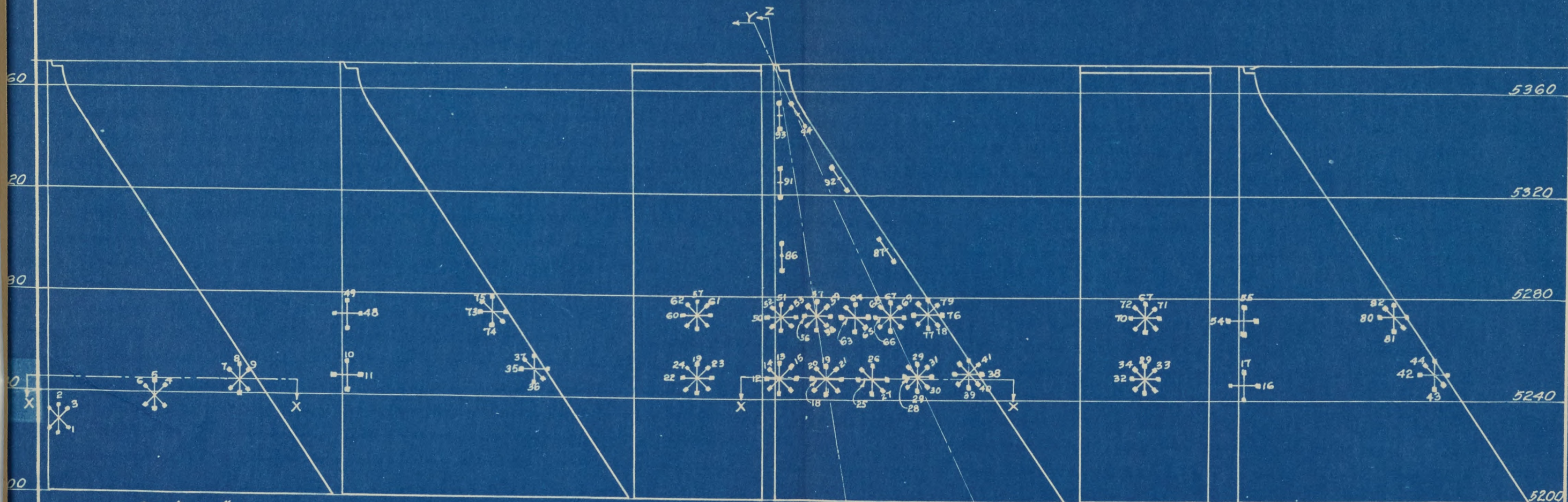
For the first time provision has been made for the study of these internal stresses in the construction of Shaver Lake Dam. When the dam was built 93 telemeters were embedded in the concrete in one of the sections and their behavior indicates that unpredicted stresses of high intensity do exist within the Dam.



MAXIMUM SECTION ST. FRANCIS DAM
SHOWING CRACKS

Fred A. Noetzli in Hydraulic Engineering
Dec. 1928

Fig. 1



Section #10
Sta. 5+90

Sta. 7+04

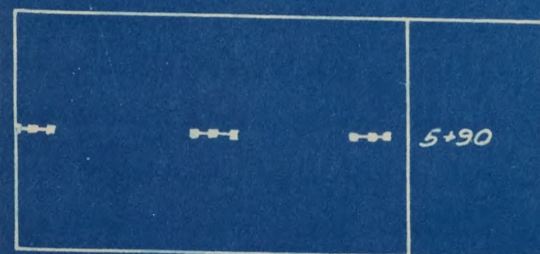
Vert. Sect. Z-Z

Sta. 6+90

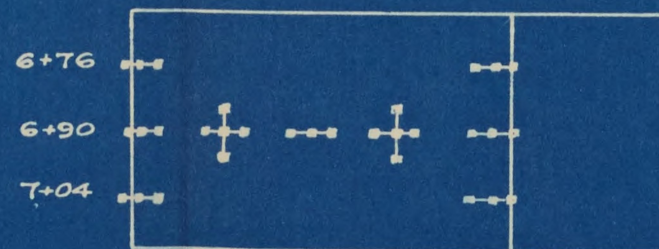
Vert. Sect. Y-Y

Sta. 6+76

Section #12



Section X-X



Section X-X

DRWG. No. _____ DESCRIPTION CROSS REFERENCES		No. _____ REVISIONS NOTE: LOCATION SHOWN THUS:			DATE _____ ENGINEER _____ APPROVALS		REQ. _____ CHECKED _____ DRAWN _____ W.G.P.		LOCATION-SHAVER LAKE DAM LOCATION & NUMBERS OF TELEMETERS SOUTHERN CALIFORNIA EDISON COMPANY	
		DESIGNED	TRACED	COMPARED						

Fig. 2

When section 12 of Shaver Lake Dam was constructed, 93 telemeters were installed at the location shown in Fig. 2, at this section the dam is 160 feet high and has a cross section as shown in the isothermic charts.

A telemeter consists essentially of a water-tight tube containing a carbon stack which is held between two bearing plates so that the strain in six inches of concrete is transmitted to the stack. The electrical resistance across the stack is a function of the sum of the distances between the carbon discs.

These distances will be affected not only by the strains in the concrete, but also by the temperature of the telemeter itself. A correction must therefore be made in order to determine the actual strains in the concrete. This correction amounts to 0.000016 per unit per degree centigrade. The telemeter is considered as standard at 20° C. and the formula for the correction is

$$C = (T - 20) 16 \times 10^{-6}$$

C = Correction

T = Temp. in Deg. Cent.

The relation between strain and resistance was determined by calibration and drawing a calibration curve for each instrument.

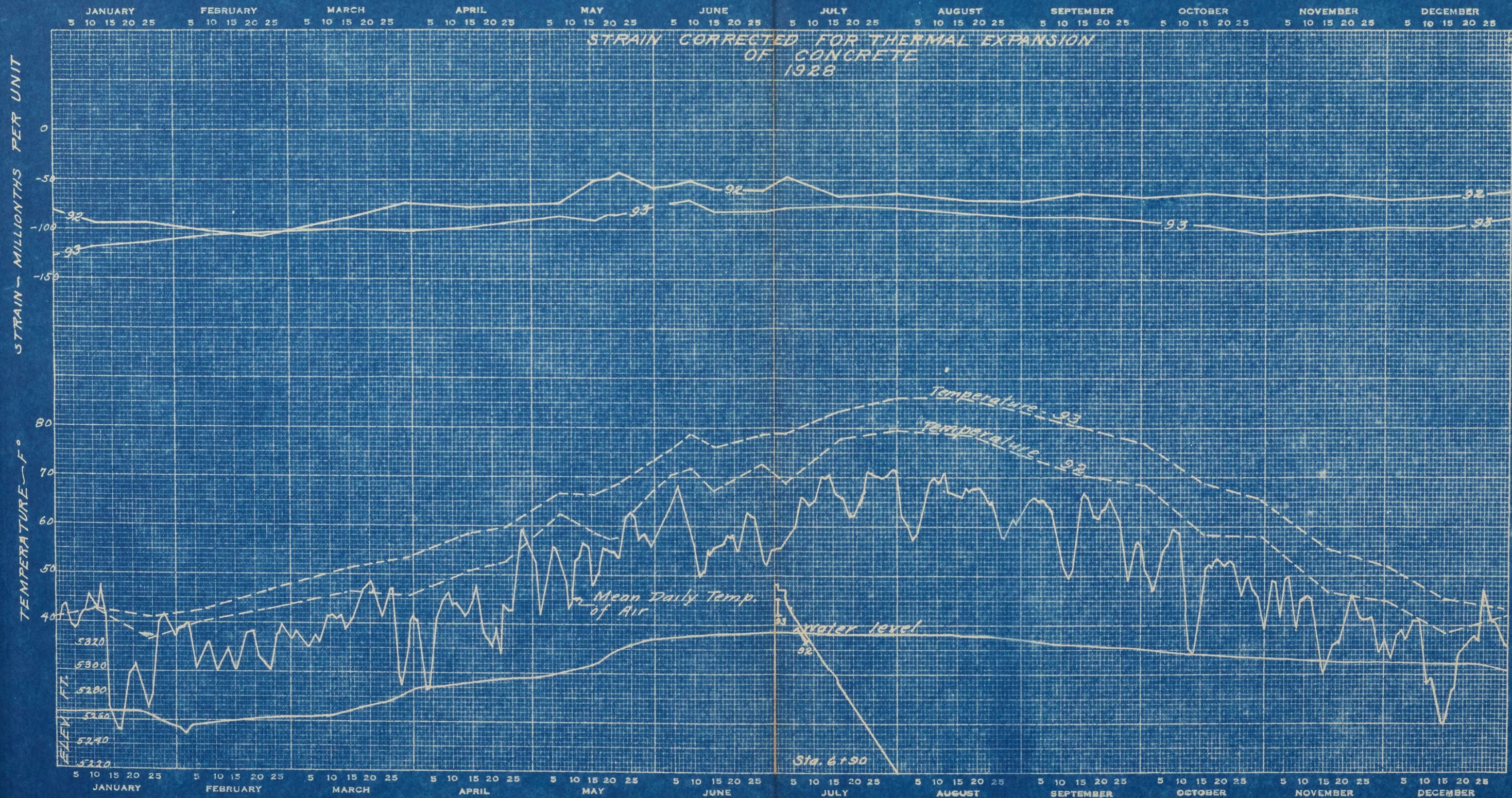
A temperature coil is included in each telemeter. It is a well known property of metals that the resistance

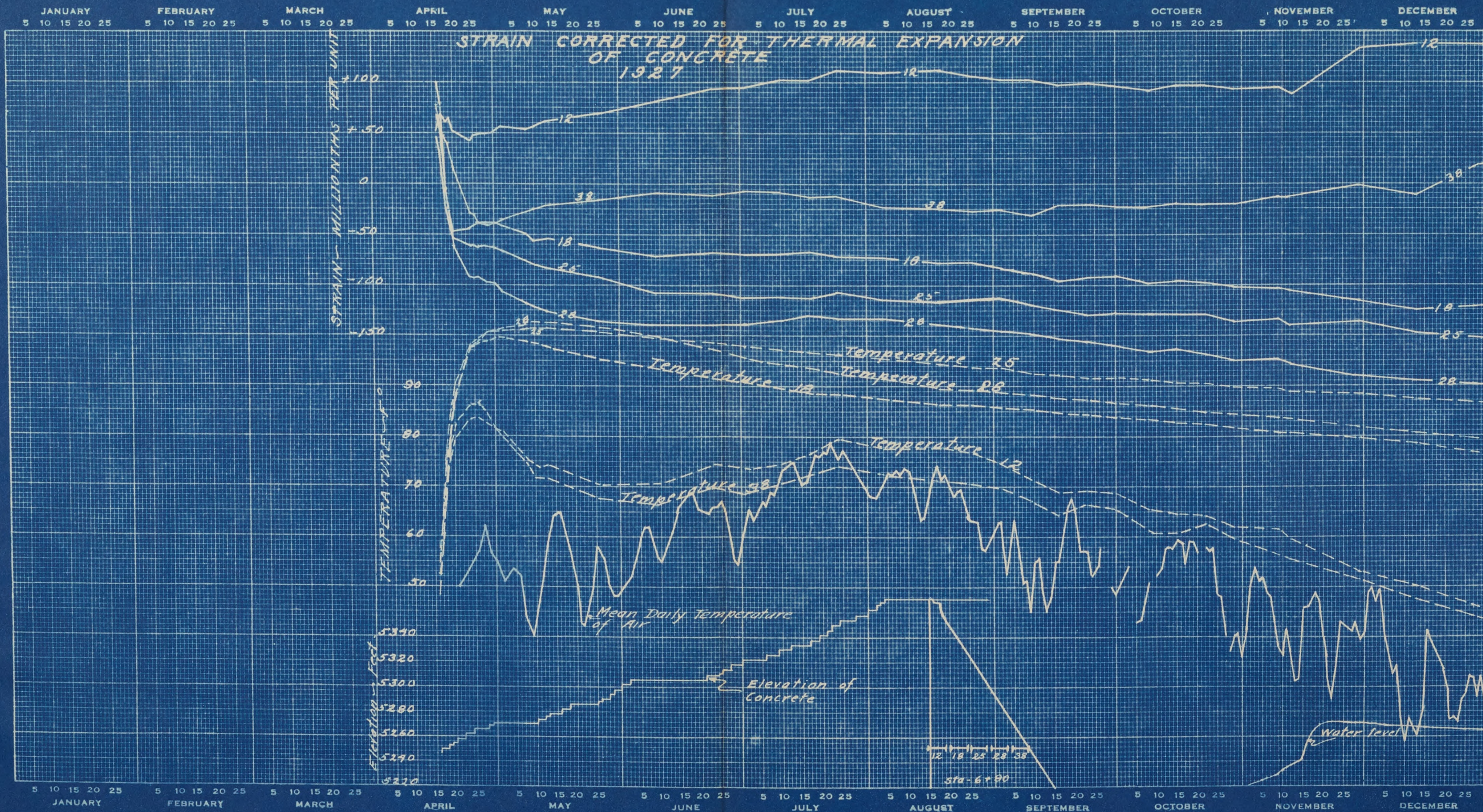
varies with the temperature according to the coef. of thermal conductivity.

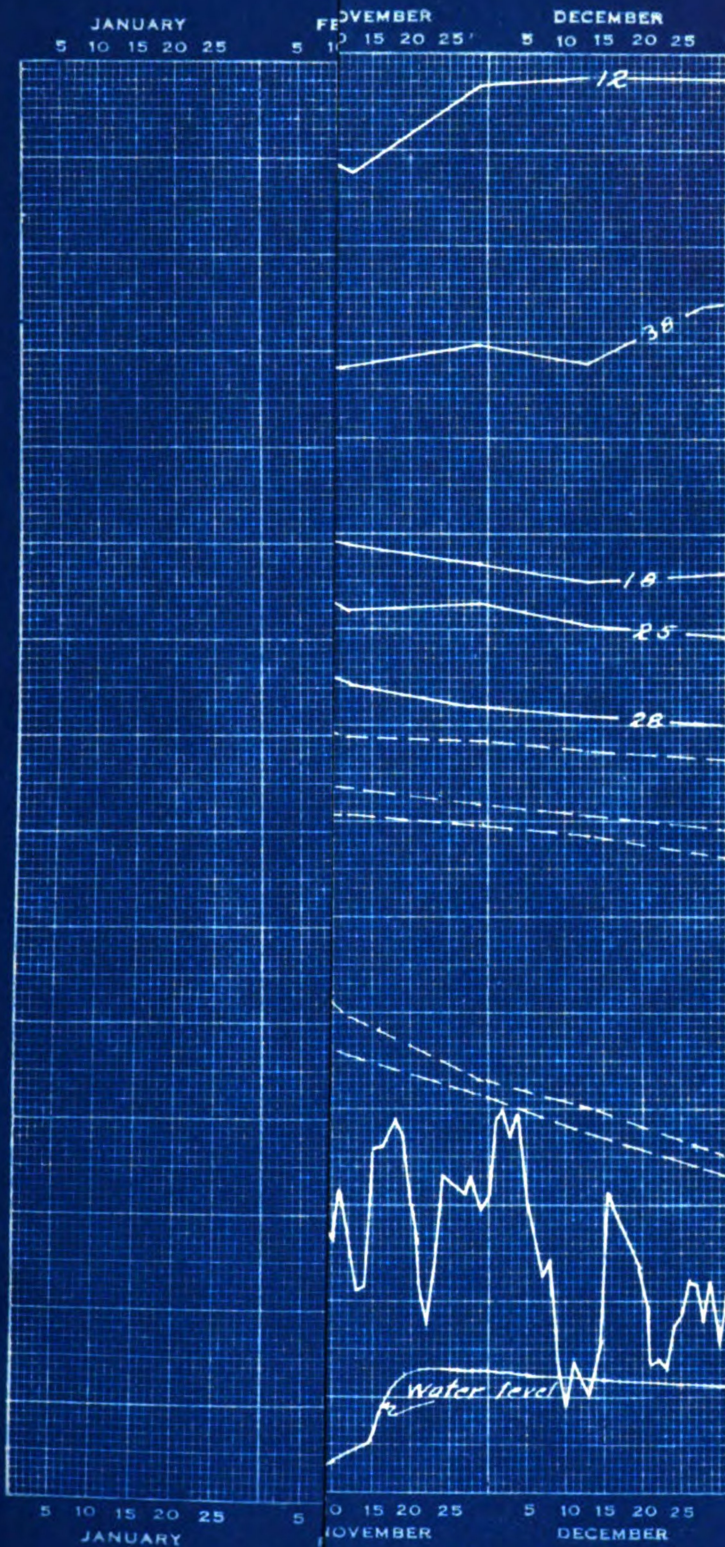
The temperature coef is merely a coil of fine copper wire of such length that its resistance will vary 2 ohms for each degree centigrade. The resistance is measured with a modification of the ~~Wheatstone~~ bridge. Knowing the resistance of each coil at some standard temperature it is possible to calculate the temperature of the coil from its resistance at any time.

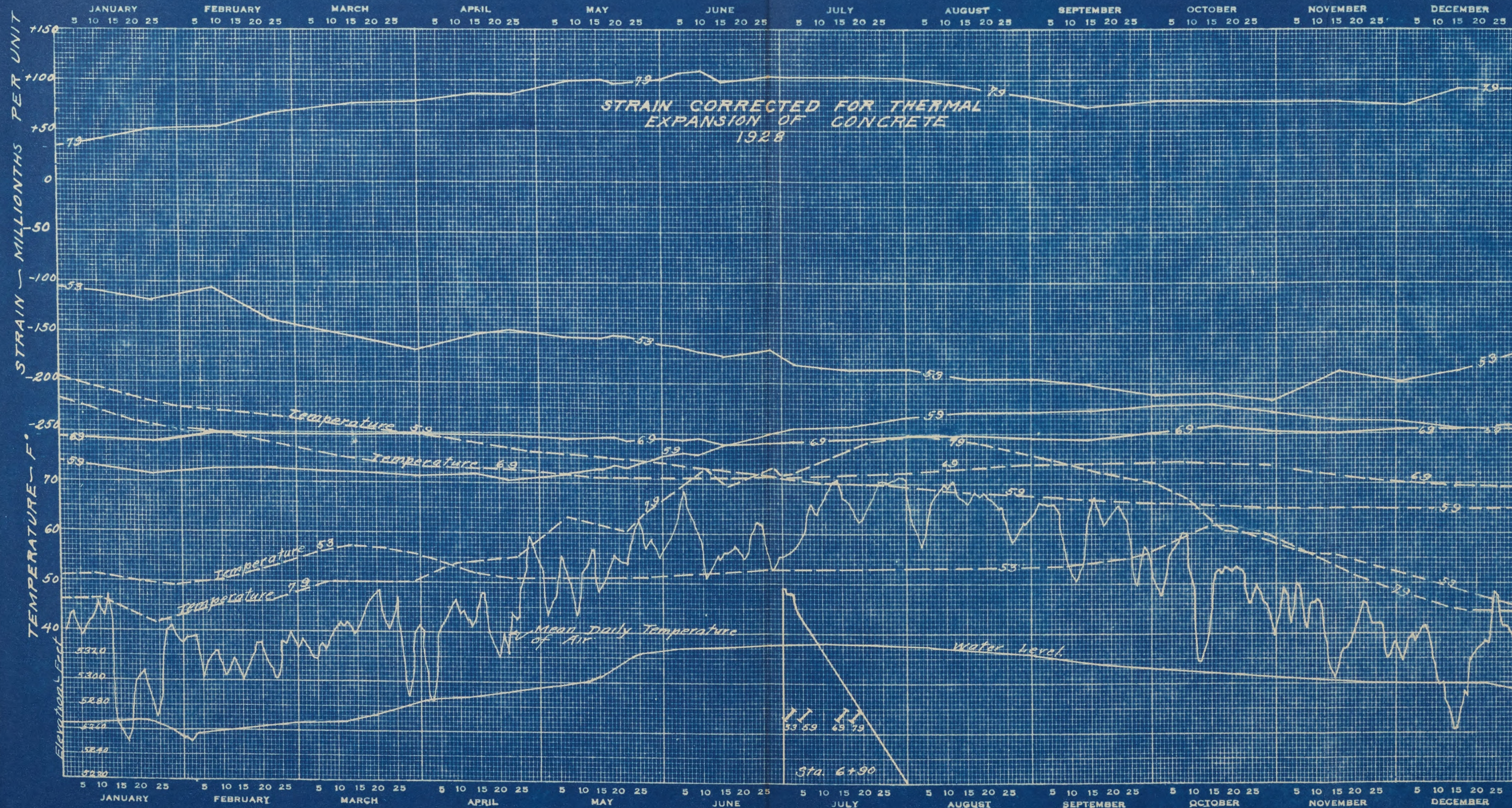
During the period of nearly two years since the dam has been built a few of the telemeters and temperature coils have become unreliable. Some have failed entirely, possibly due to a break in the circuit or a breaking down of the insulation. While others still seem to be functioning properly, but have passed beyond the calibrated range; as in the case of telemeter No. 14. In a few cases the temperature coil failed while the telemeter continued to give fairly consistent results. This was probably due to the fact that a slight break in the insulation causing a slight decrease in resistance would cause a much greater error in the temperature coil than in the telemeter, the resistance of the former being about ten times that of the latter.

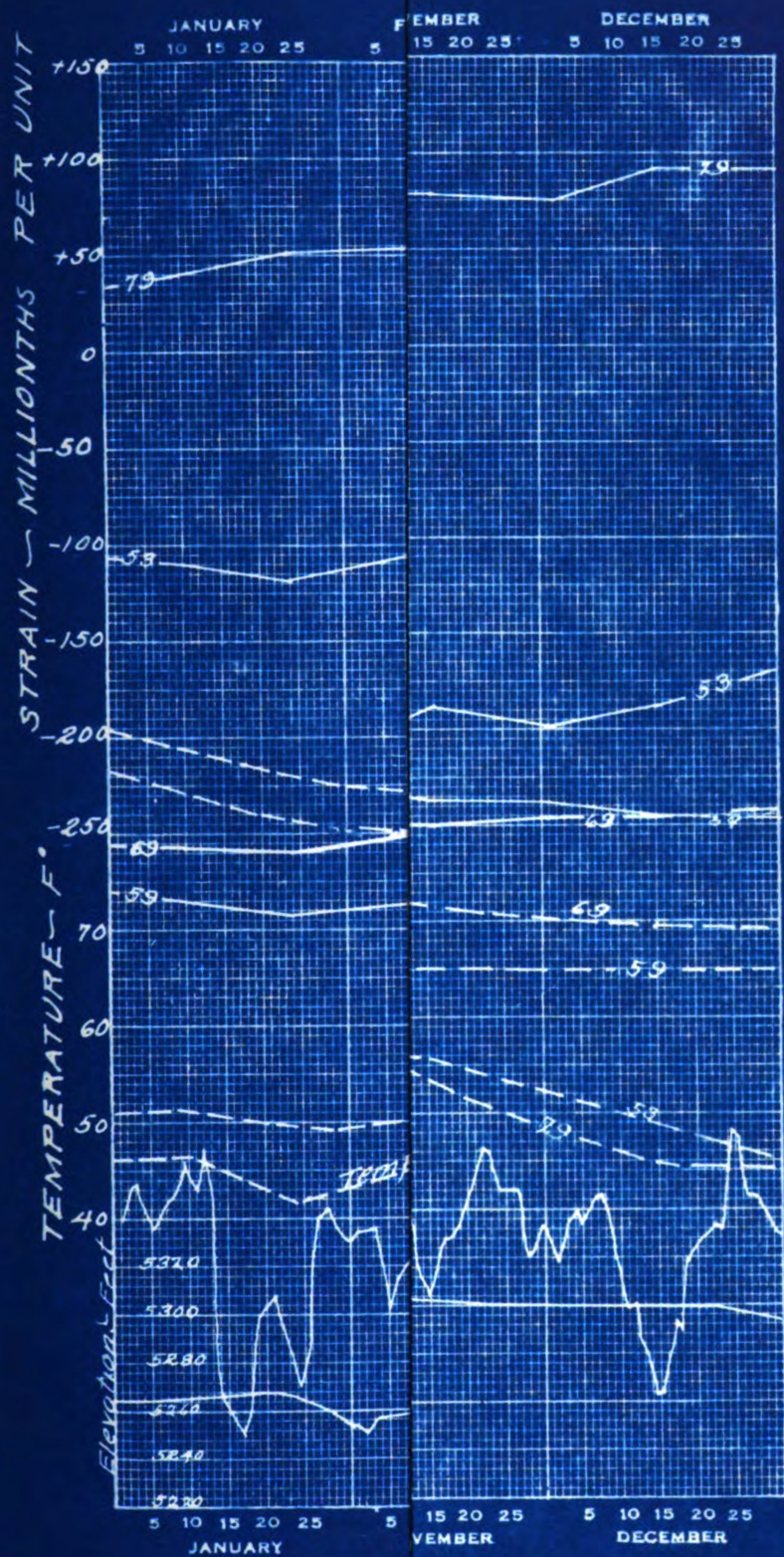
In practically all cases, however, there have been enough consistent temperature coils in each group to determine the temperature of the concrete at that point with certainty.

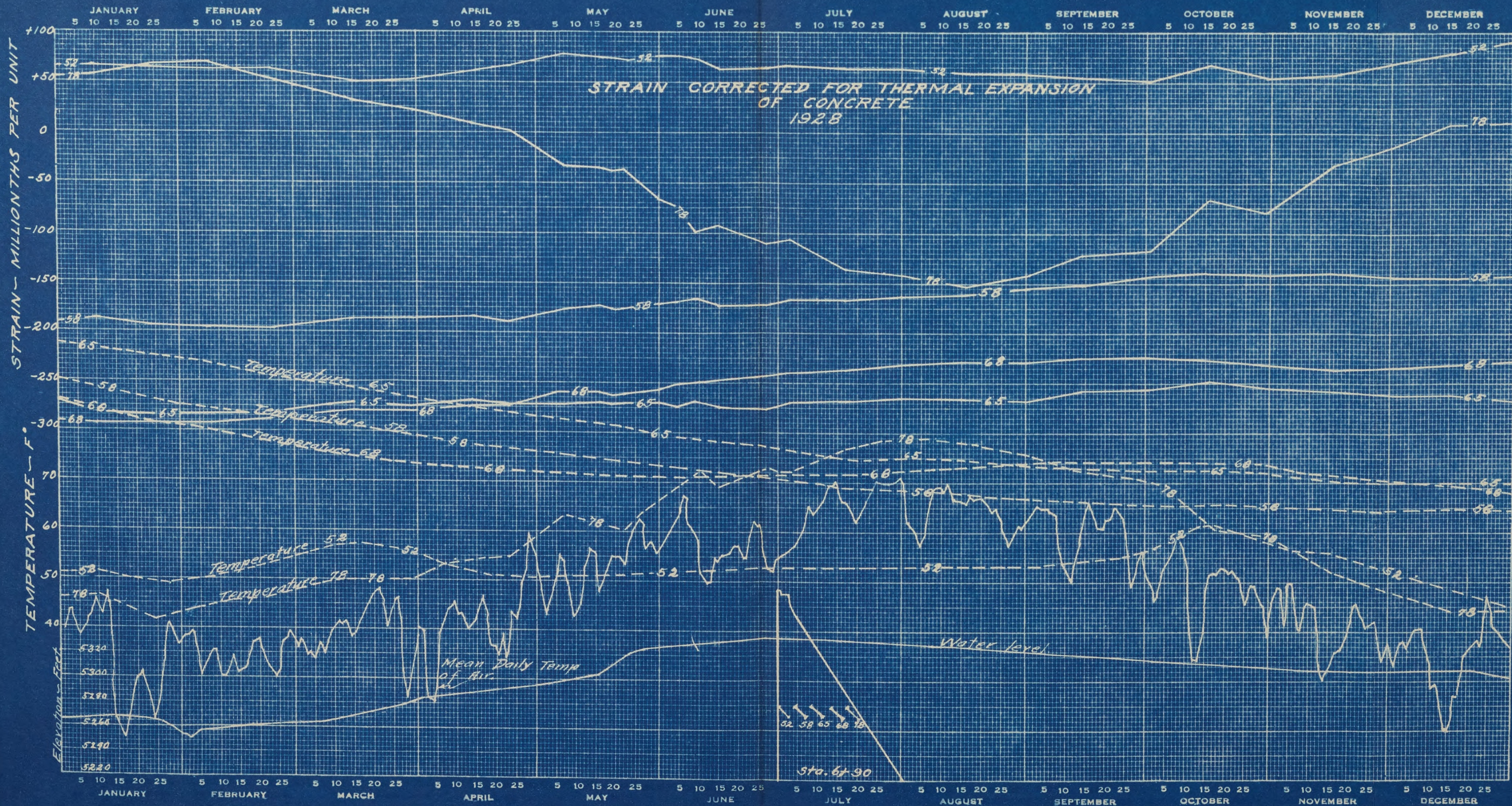


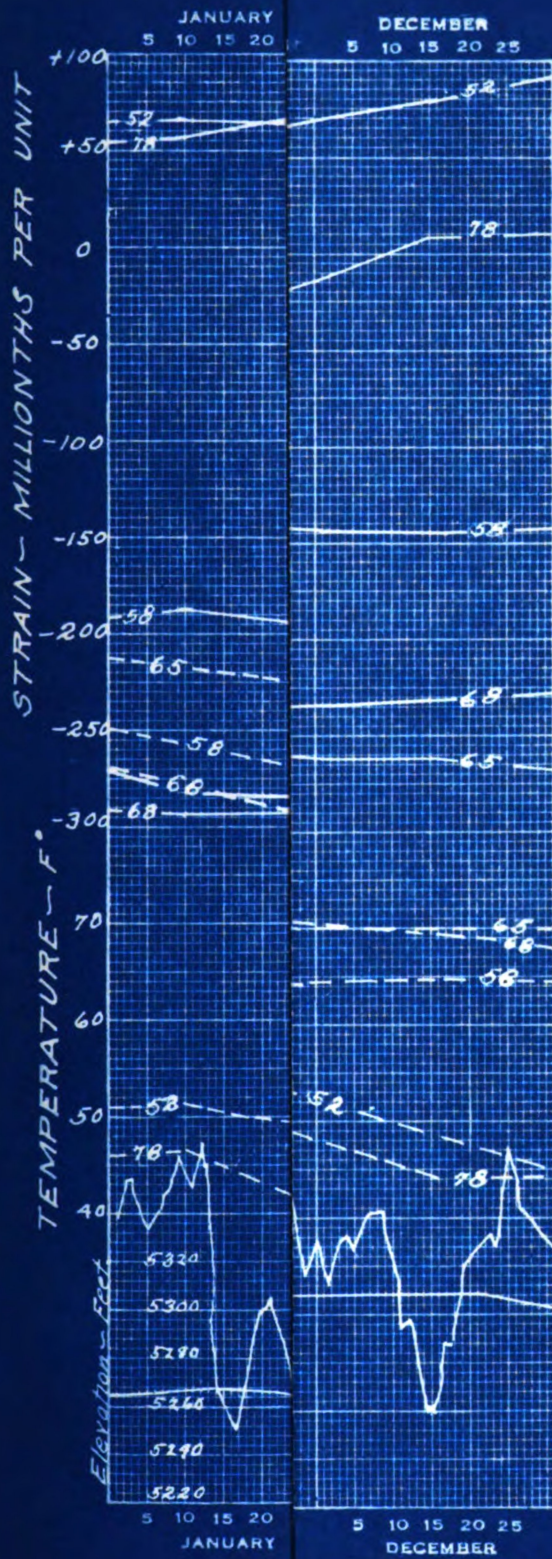


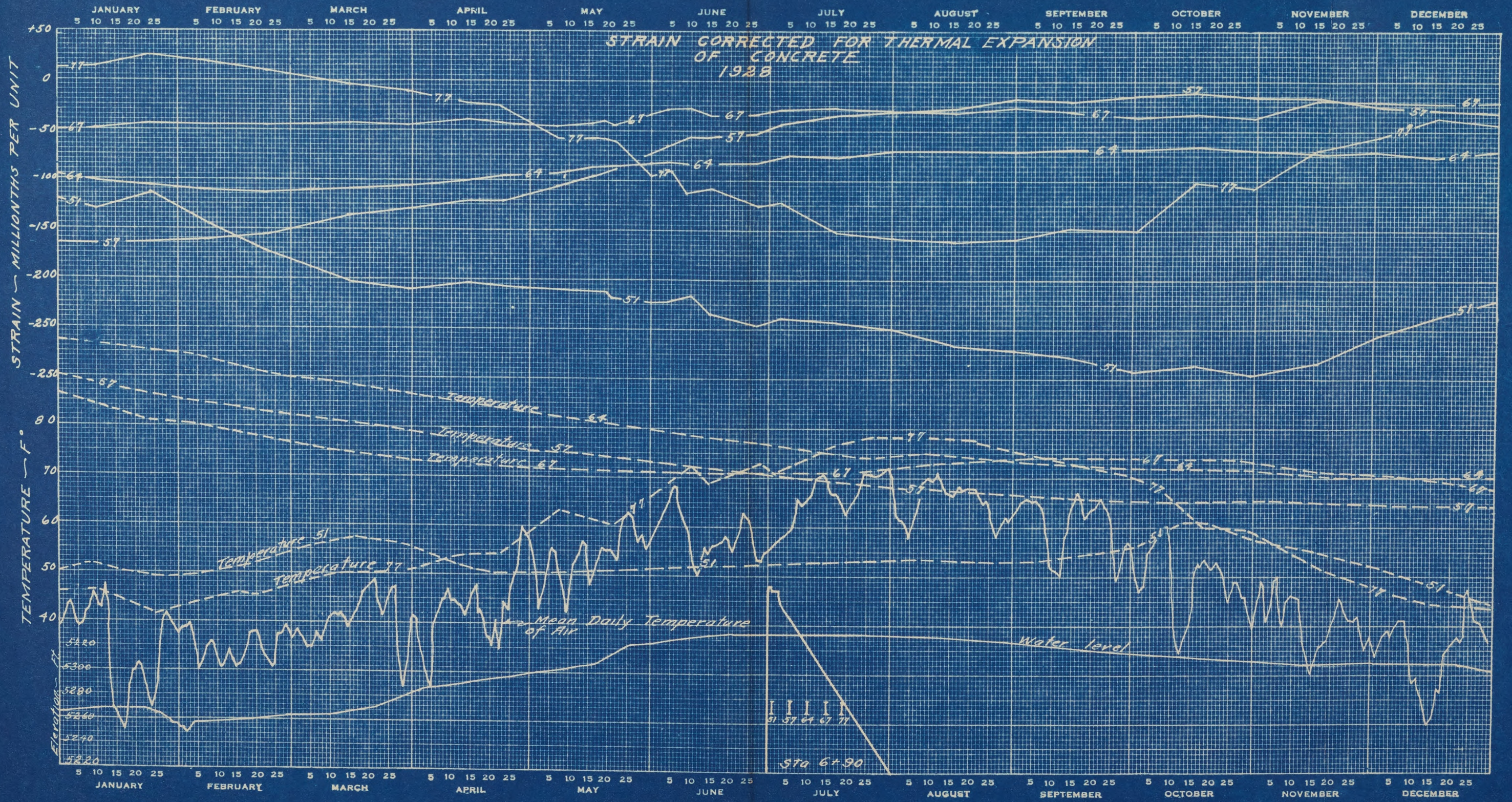


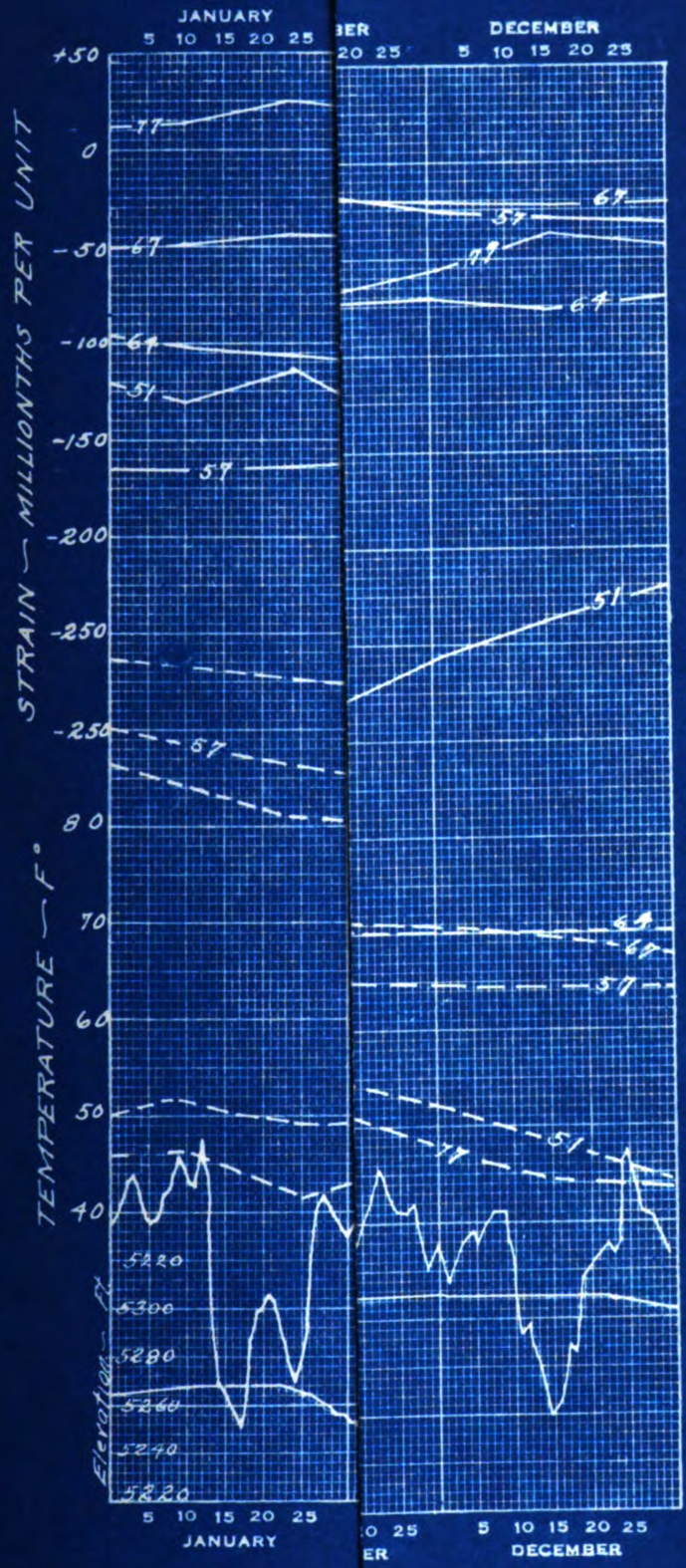


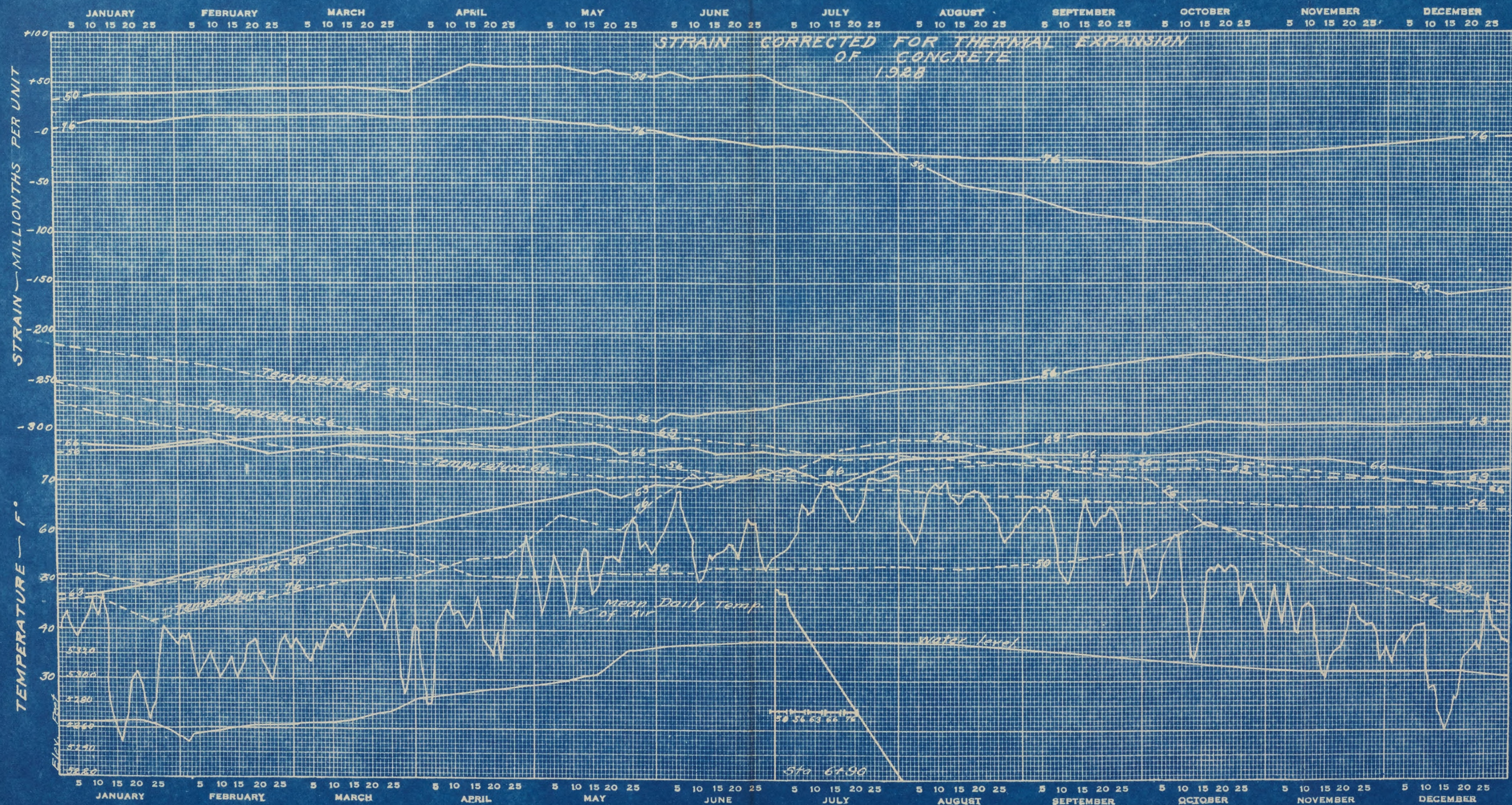


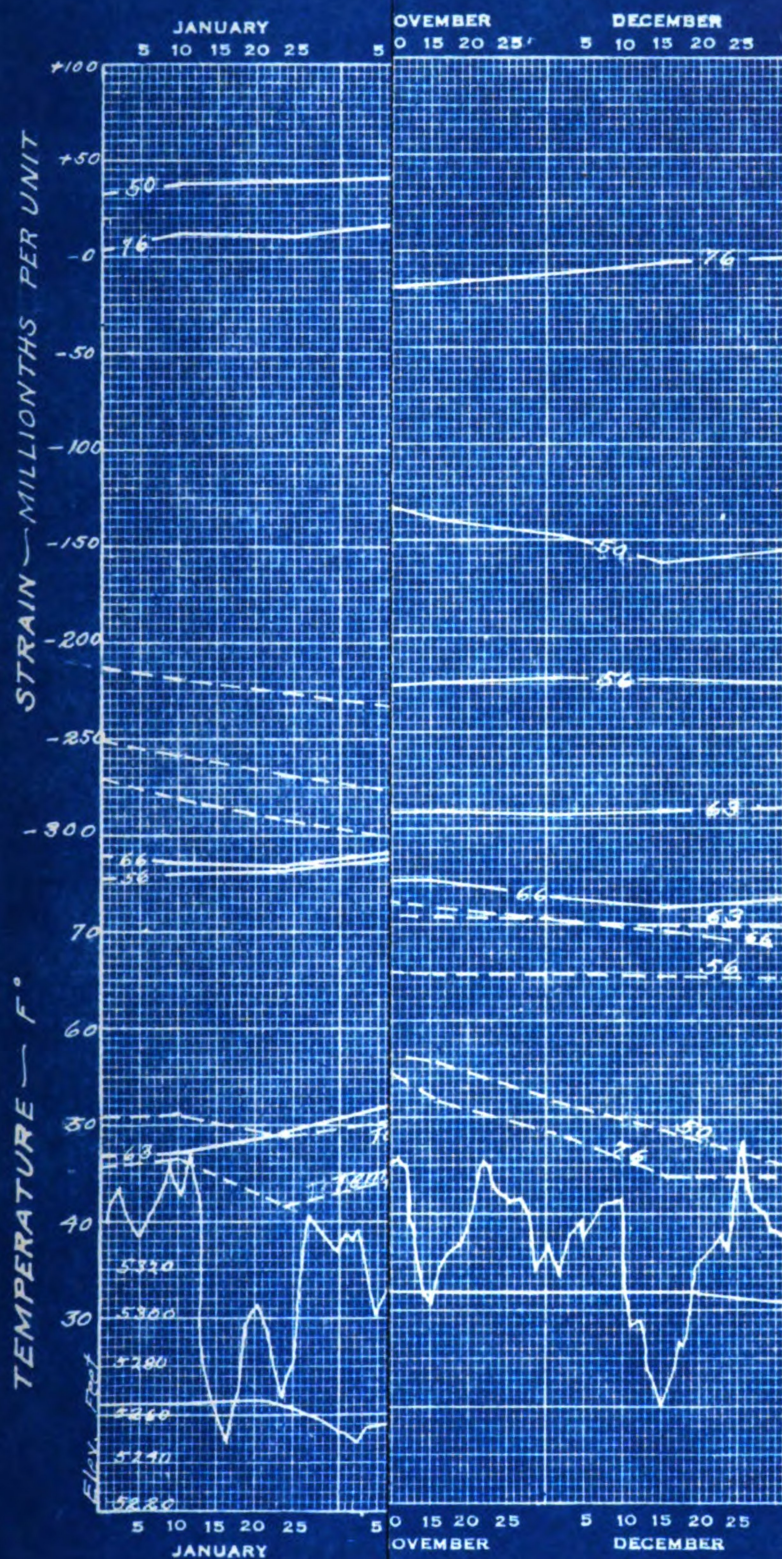


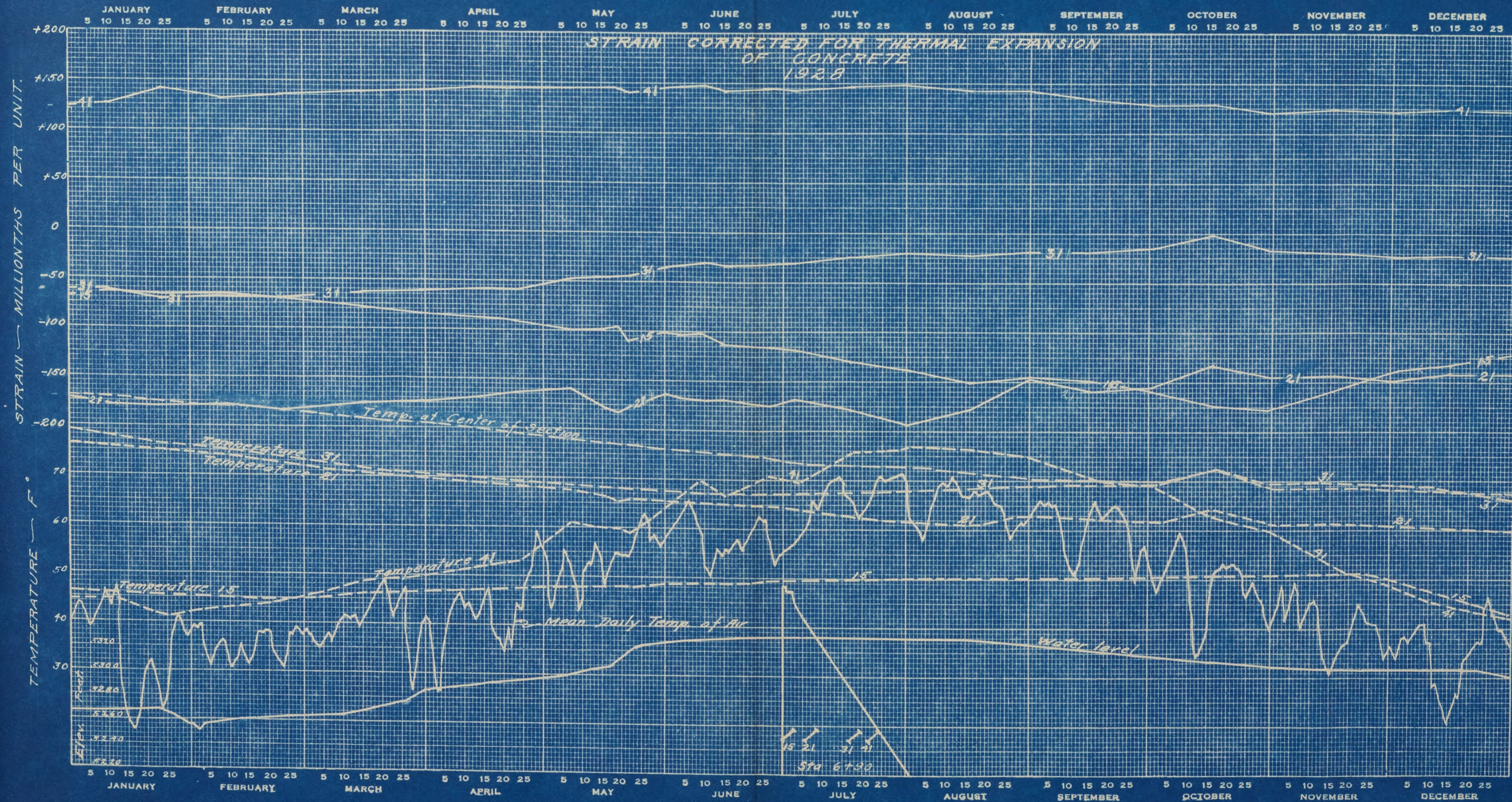


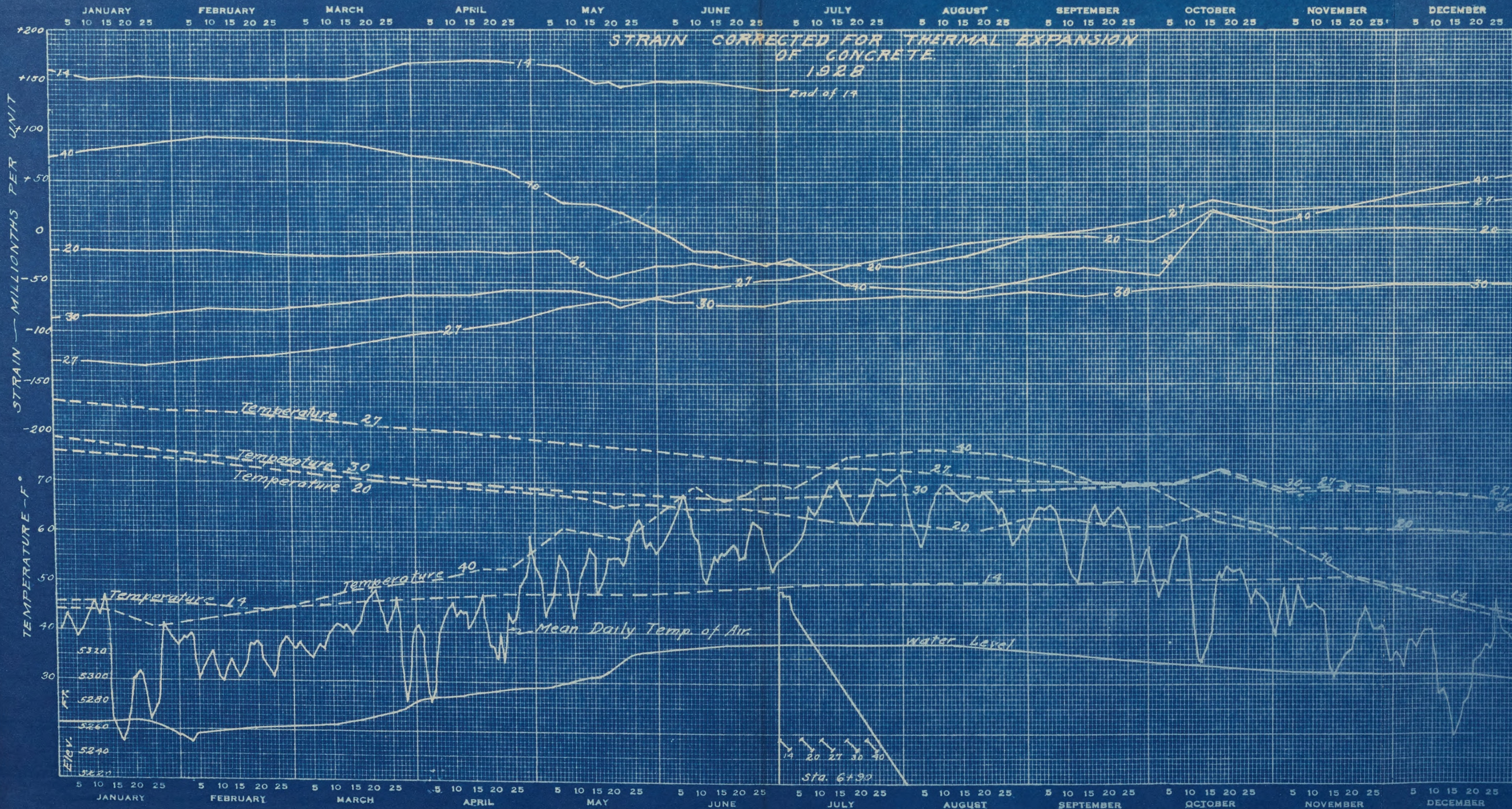


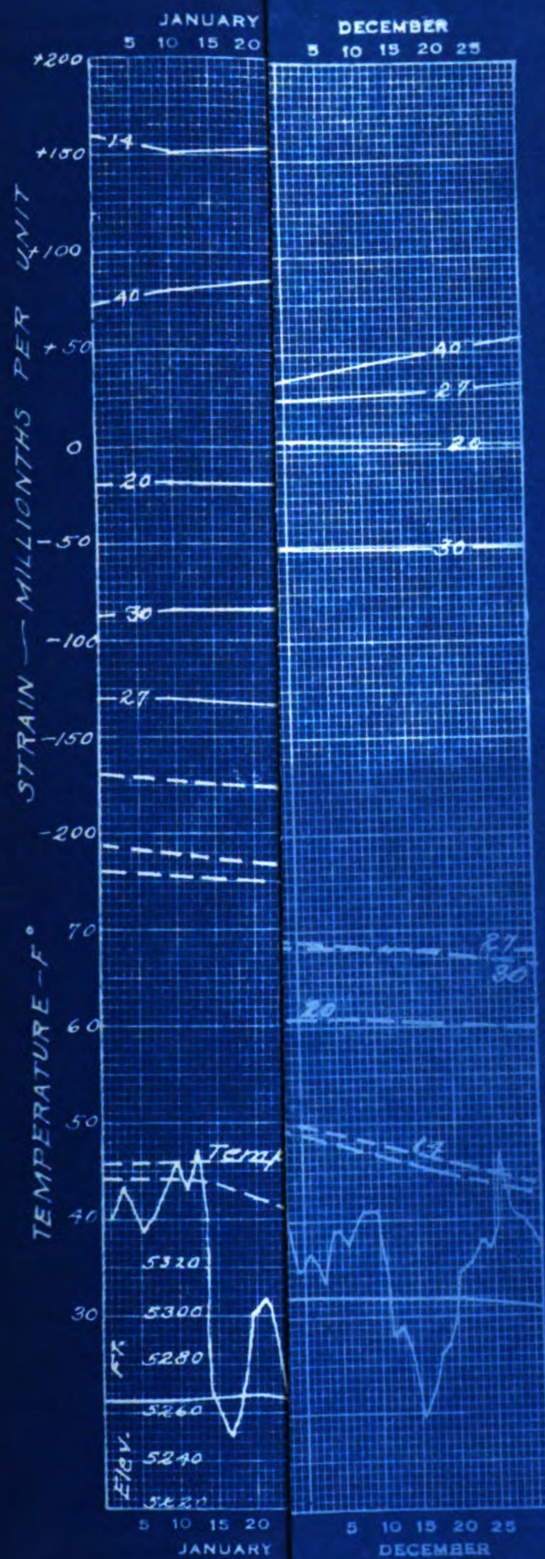


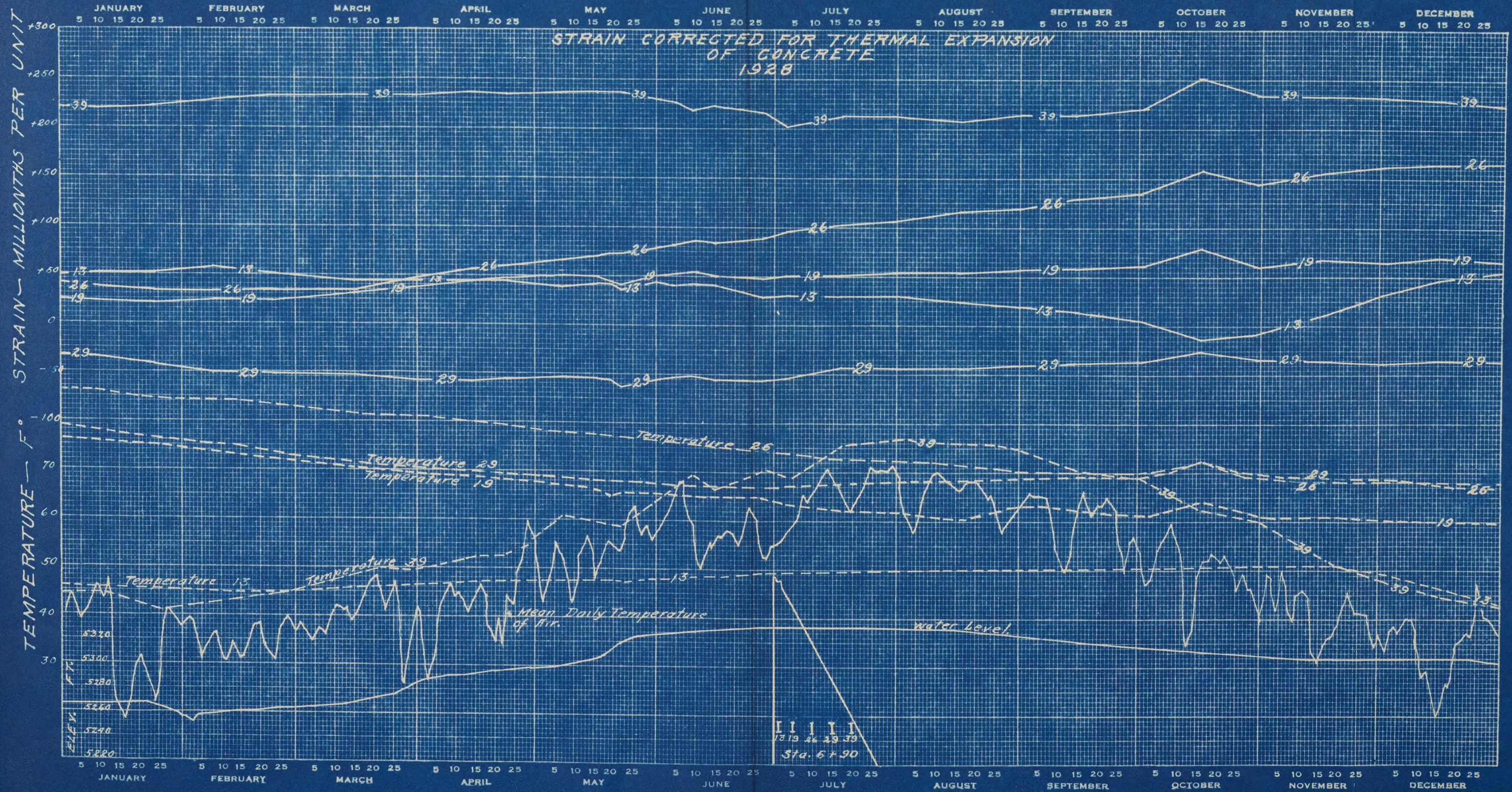


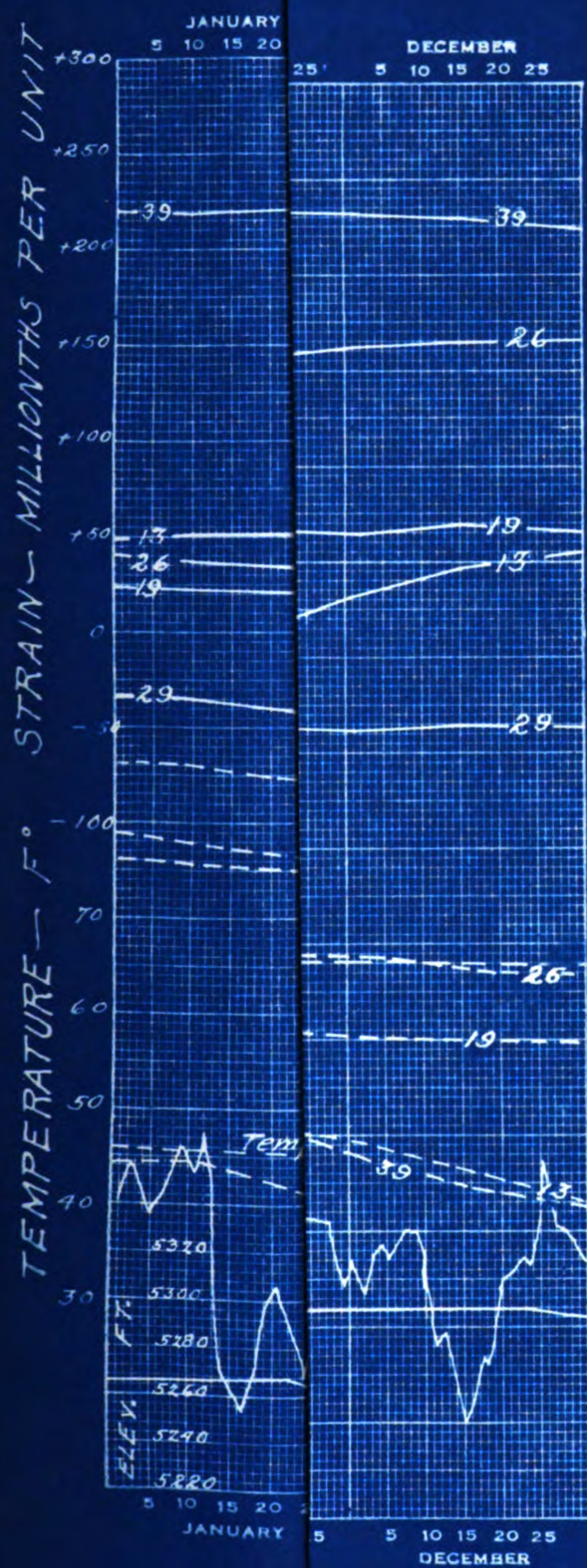


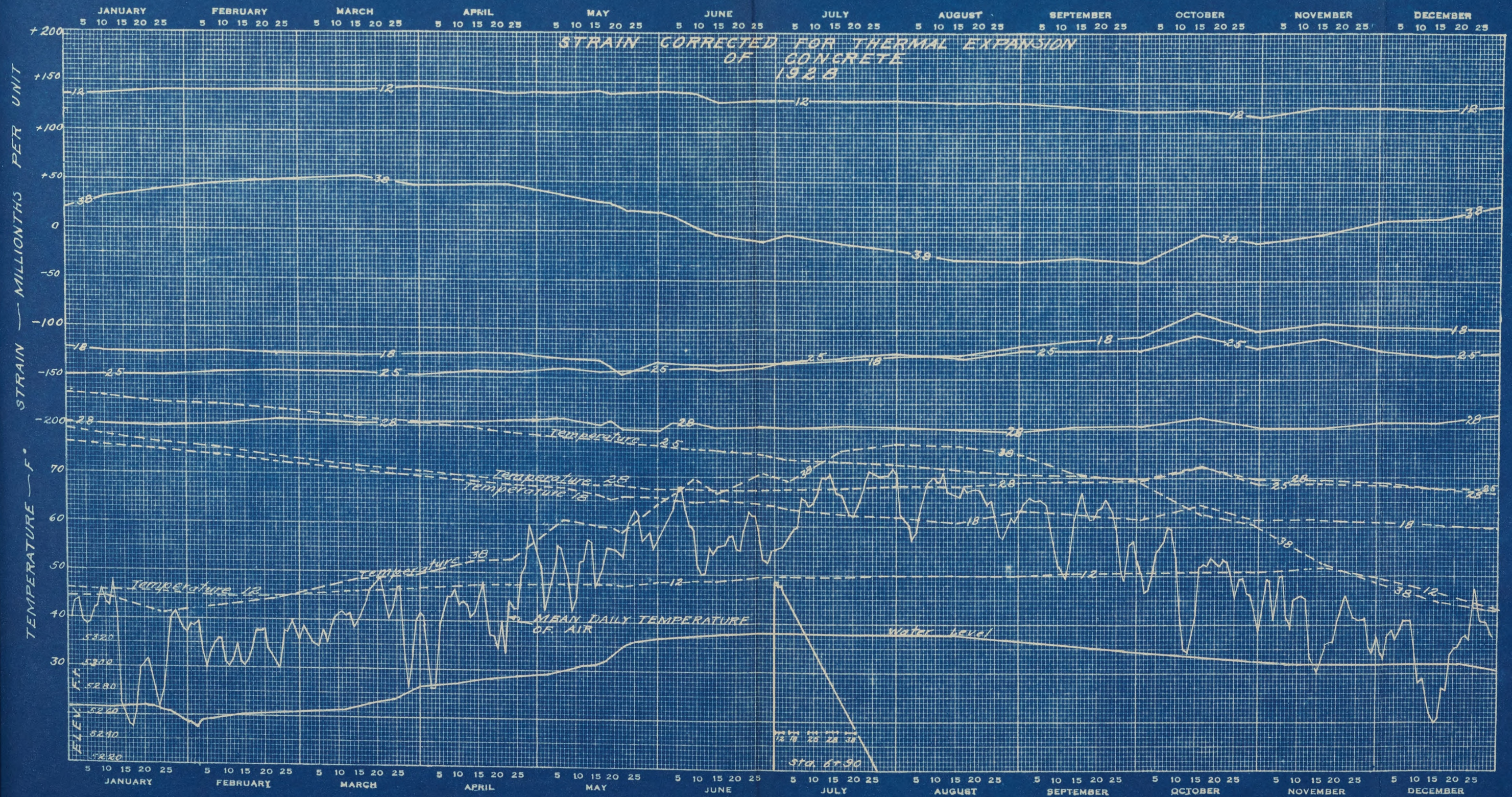


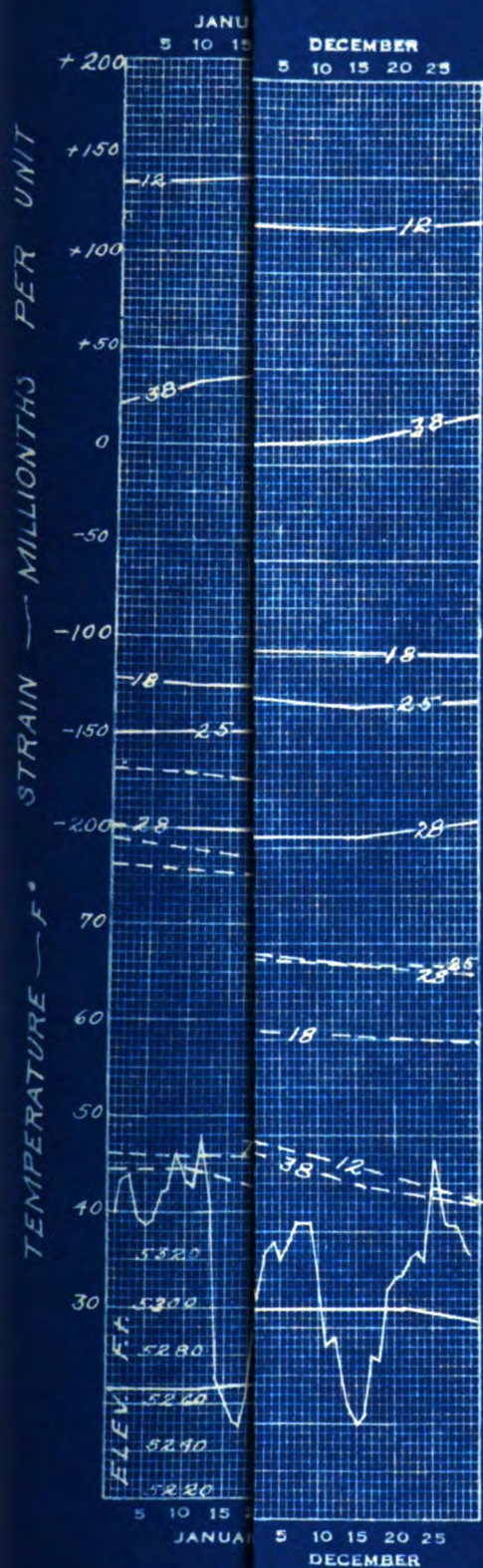












The strains, corrected for thermal expansion of the concrete, and the average temperature of each group of telemeters have been incorporated in the accompanying charts which embody all the essential data that have been collected since the measurements started on April 16, 1927.

RELATION BETWEEN OUTSIDE TEMPERATURE AND TEMPERATURE DISTRIBUTION WITHIN THE DAM.

This relation has received some attention in similar structures.

In the Arrow Rock dam near Boise, Idaho, temperature coils were embedded in the concrete and measurements were made during 1913-1915. High and low temperatures of the air for short periods had no influence 3 feet below the surface. It took 4 and 5 days for a continuous high or low temperature to appear within the dam.

In the Boonton dam the transmission of the exterior heat into the dam is expressed by Professor Merriman as

$$t_c = \frac{t_a}{-3\sqrt{d}}$$

applicable for $0.5 < d < 20$ ft. when

$t_a = 75^\circ$ F. - Average yearly temperature difference of the air.

d = distance from the face of the dam in feet.

In the Kensico dam, New York, the law expressing

the transmission of temperature was found to be

$$t_c = 48 - 12.3 \log_e d.$$

applicable for $d < 40$ ft. and a mean yearly temperature of the air of 73° F.

d = the distance from the face of the dam in feet.

In Shaver lake dam the temperatures were indicated at various points within the dam by the temperature coils included in each telemeter. A few conclusions are apparent from the charts.

1. Near the center of the dam the temperature rises $40-50^\circ$ F during the first month due to the chemical action of the cement while setting.

2. Six or seven days of continued high or low temperature must elapse before an appreciable effect is observed at a depth of $2 \frac{1}{2}$ feet.

3. At a depth of 57 feet slight seasonal variations of a few degrees occur.

Probably the transmission of exterior heat into the dam can be expressed by a law which will be of value in designing similar structures in the future but it was believed that the project could best be served at this time by using the actual temperatures as indicated by the temperature coils. For this reason the study of heat transmission has been largely left to a later date when more data are available.

CAUSES OF STRAIN

The strains in the concrete

CAUSES OF STRAIN

The strains in the concrete are due to three principal causes.

- (1) Swelling and shrinking of the concrete.
- (2) (2) Thermal expansion of the concrete immediately surrounding the telemeter.

(3) Stress.

SWELLING AND SHRINKING OF THE CONCRETE

Swelling and shrinking of the concrete due to variations in moisture undoubtedly constitute a minor cause of change in strain. B.F. Jacobsen in the 1924 Transactions of the American Society of Civil Engineers states that when the upstream face is continually wet a swelling of about 0.0001 may be expected.

Experiments made by Professor White of the University of Michigan indicate that concrete will swell and contract with changes in moisture content for a long period of time after being placed.

Experiments made by R. E. Davis of the University of California indicate that concrete quite similar to that used in Shaver dam swells and shrinks alternately with changes in moisture content. However, the depth to which this takes place depends upon the permeability of the concrete.

Swelling of the concrete near the up stream face is noticeable as the water rises ~~from~~ the up stream face. Between November 10 and 29 a swelling of 40 millionths occurred at this point. A similar swelling of 25 millionths occurs at telemeter No. 50 between March 30 and April 14 immediately after the water rose over the telemeter for the first time.

This telemeter is 2.5 feet from the upstream face.

Telemeter No. 56 located 17.05 feet from the upstream face indicated a slight swelling starting about July 3, 1928, 100 days after the water level reached the elevation of the telemeter.

Telemeter No. 18 located 20.5 feet from the upstream face indicated no change until August 16, 1928 when a slight swelling started 8 months after the face was submerged.

STRAINS CAUSED BY THERMAL EXPANSION OF THE CONCRETE IMMEDIATELY SURROUNDING THE TELEMETERS.

It is evident that a certain amount of strain will be produced at the telemeters due to the thermal expansion of the concrete immediately surrounding the telemeter. This, in itself, produces no stress. A correction had therefore been made to eliminate this effect.

The correction to be applied depends upon the coefficient of thermal expansion of the concrete and is expressed by the following formula.

$$C_c = a (68 - T)$$

C_c = Correction for thermal expansion of concrete in Millionths.

a = Coefficient of Thermal expansion of concrete

T = Temp. in degrees Fahrenheit

68° F was taken as an arbitrary reference temperature.

The coefficient of thermal expansion for concrete of the class used varies within fairly narrow limits and the quantity 5×10^{-6} was selected as an average value.

That this value is very nearly right is shown by the behavior of telemeters 92 and 93. These telemeters are located near the top of the dam where the winter and summer temperature varies between 36° F and 86° F yet the temperature distribution throughout the relatively small mass of concrete is nearly uniform. Consequently they should be subject to very little change in stress. The fact that no seasonal change occurs in the strain curves for these telemeters shows that the correct allowance was made for strain due to the thermal expansion of concrete.

STRAIN DUE TO STRESS

Aside from the effects of varying moisture and the thermal expansion of concrete which have just been discussed the principal cause of strain is stress.

The stresses which are commonly considered in the design of dams are those due to the weight of the dam itself and the overturning moment of the water pressure. These stresses are quite well understood and may be calculated

with a fair degree of certainty. Of the two only those stresses due to the over turning moment will vary after construction is complete.

The method used in the calculation of these stresses is based on the theorem of principal stresses and is developed as follows:

Let Fig. 2 represent a rectangular block of concrete within the dam the thickness normal to the plane of the paper being unity.

The block is acted on by a vertical ~~and horizontal~~ stress of intensity V ~~and S_n respectively~~ and a vertical and horizontal shearing stress of intensity S_s . The stress of intensity V which may be calculated from the overturning moment of the water load.

$$V = \frac{12 M v}{L^3}$$

M = Moment due to water load

v = Distance from telemeter to neutral axis

L = Length of section.

In certain instances the block might be acted on by a stress normal to the downstream face and also a shearing stress of intensity s , as shown in the enlarged diagram Fig. 2(b). The stresses are considered as acting in tension in order to make the signs positive.

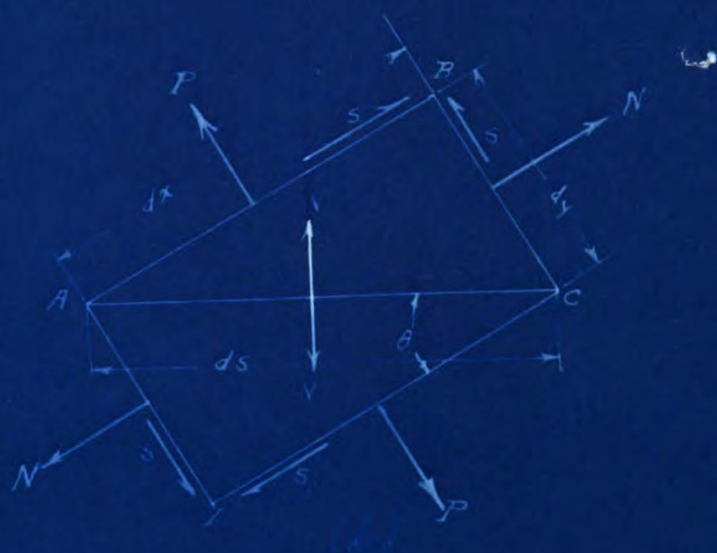


Fig. 3

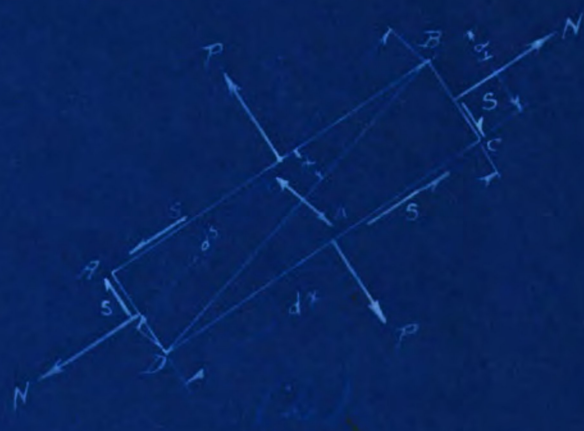
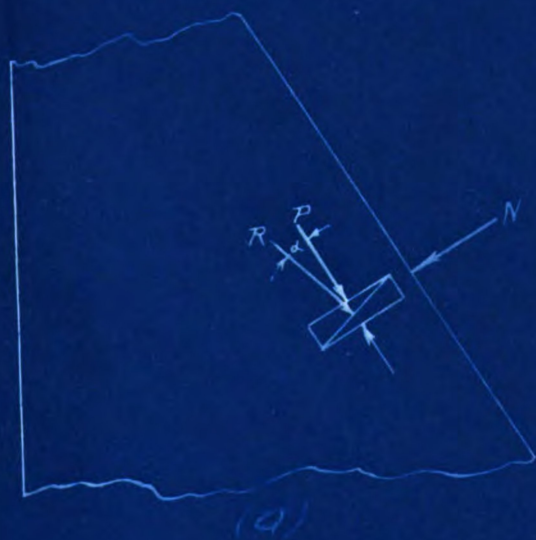


Fig. 4

The block is divided diagonally by a horizontal plane AC making an angle θ with CD. Taking either half at the free body in equilibrium.

$$V ds = N dy \sin \theta + S dx \sin \theta + S dy \cos \theta + P dx \cos \theta \quad (1)$$

Dividing by ds and substituting $\frac{dx}{ds} = \cos \theta$; $\frac{dy}{ds} = \sin \theta$

$$V = N \sin^2 \theta + 2 S \sin \theta \cos \theta + P \cos^2 \theta \quad (2)$$

If the block is near the surface as is the case with telemeters 40 and 78 then $N = 0$ and $S = 0$

Then (2) becomes (3)

$$V = P \cos^2 \theta$$

$$P = \frac{V}{\cos^2 \theta} \quad (4)$$

In which P is the stress acting parallel to the downstream face.

Telemeters 40 and 78 are inclined 45° downstream and make an angle α with P. To find the stress, R, occurring along their line of action consider Fig. 5 (b). Here P is known and $N = 0$; $S = 0$. Resolving perpendicular to BD,

$$\text{Fig. 5 (b)} \quad R ds = N dy \sin \alpha + S dx \sin \alpha + S dy \cos \alpha + P dx \cos \alpha \quad (5)$$

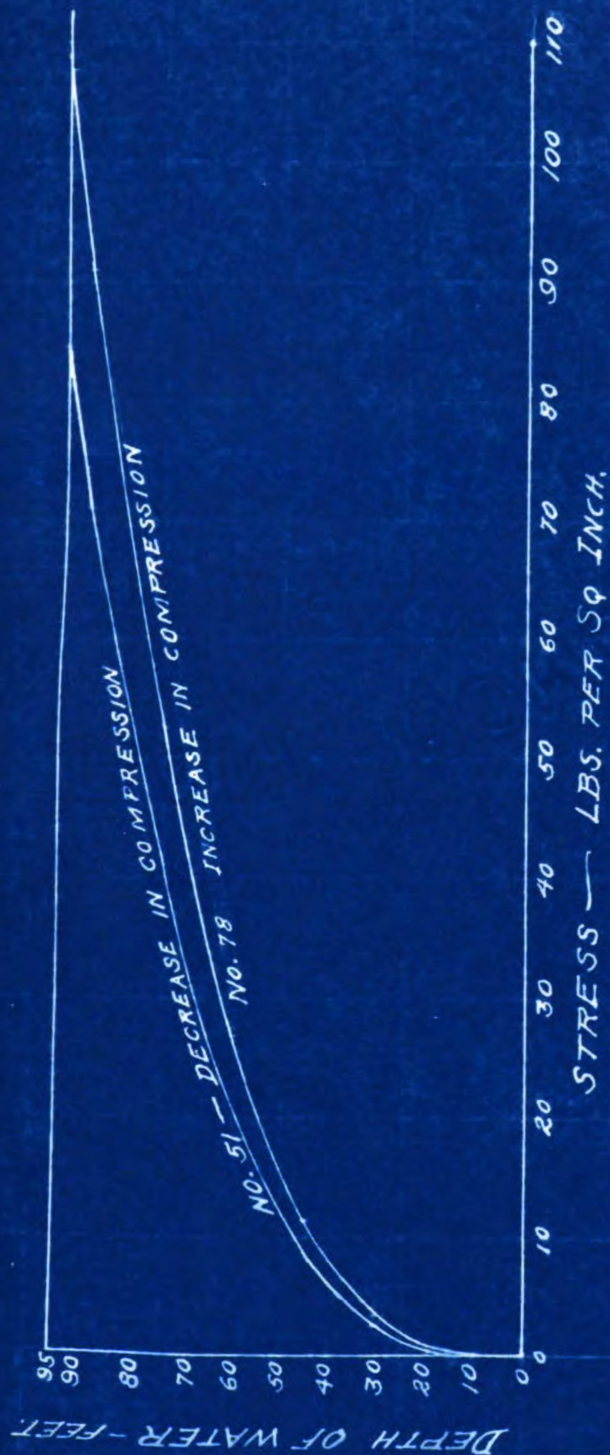
dividing by ds and substituting $\frac{dx}{ds} = \cos \alpha$; $\frac{dy}{ds} = \sin \alpha$

$$\frac{dy}{ds} = \sin \alpha$$

$$R = N \sin^2 \alpha + 2 S \sin \alpha \cos \alpha + P \cos^2 \alpha \quad (6)$$

Since $N = 0$ and $S = 0$

$$R = P \cos^2 \alpha \quad (7)$$



INTENSITY OF STRESS
DUE TO WATER LOAD AT
TELEMETERS 51 & 78

Substituting (4)

$$R = \frac{V \cos^2 \alpha}{\cos^2 \theta} \quad (8)$$

STRESSES INDUCED BY NONUNIFORM TEMPERATURE DISTRIBUTION

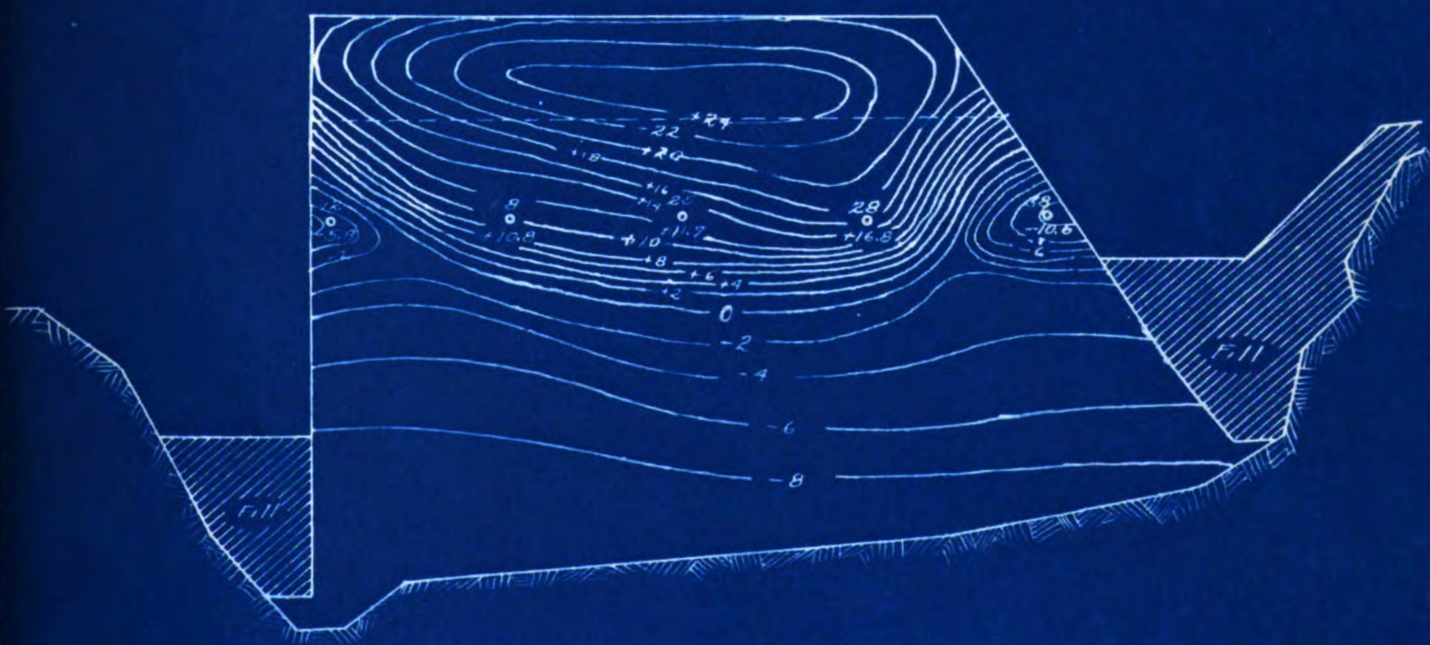
The maximum change in stress due to the overturning moment of the water load, just discussed, is generally considered a controlling factor in dam design. However, it is only a small part of the change in stress that has occurred, as an example consider the situation at telemeter 13 (vertical). So far the maximum stress due to water load, and neglecting the weight of the concrete which is constant is 27 lb. per sq. in. which assuming a modulus of elasticity of 4×10^6 for concrete of this class would result in a strain of only 6.75 millionths. As a matter of fact the actual change of strain due to stress has been 145 millionths representing a change of stress of 580 pounds per sq. in. or over twenty times that due to water load. Similar unexpected stresses exist throughout the dam.

The object of the following analysis is to explain the relation between strain and non-uniform temperature distribution

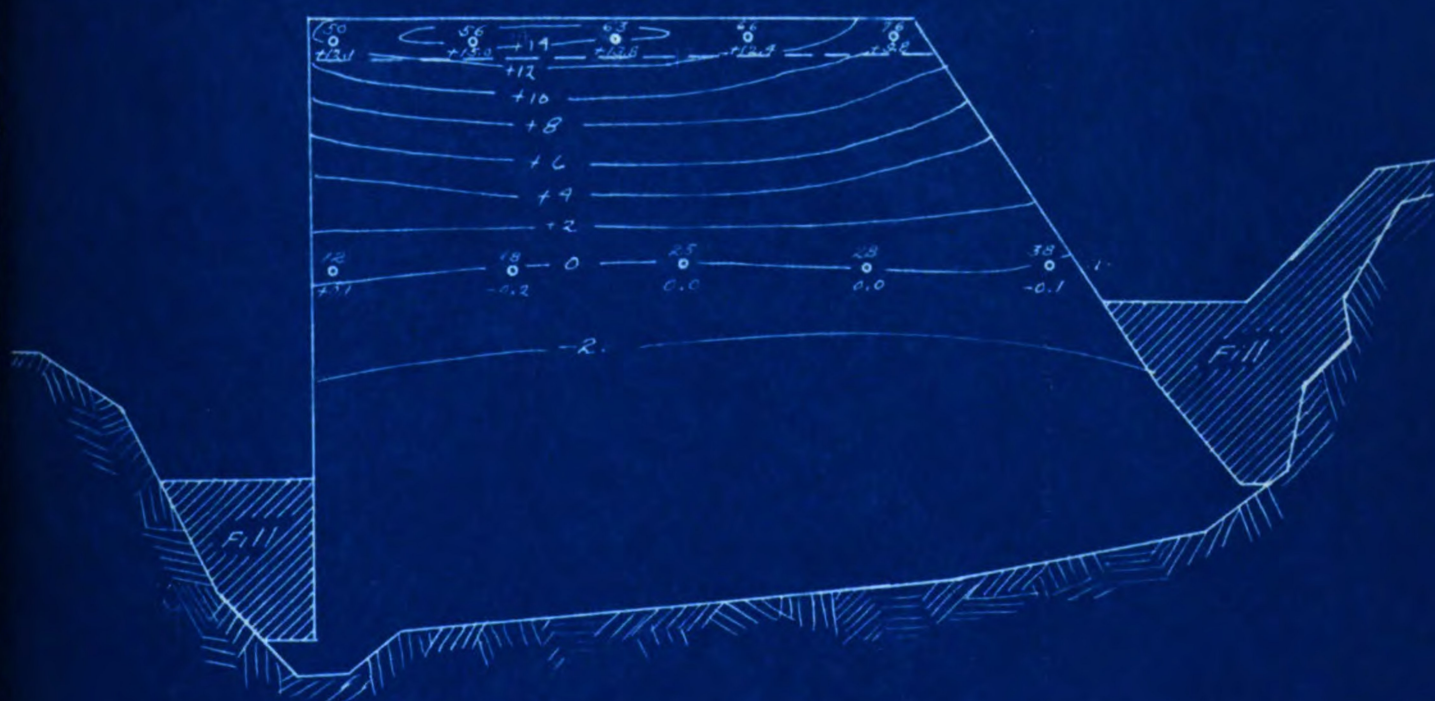
For this purpose the time since April 16, 1927, when the lower telemeters were covered to the present time, has been divided into periods, as follows:

- 1 - April 16 - 20, 1927.
- 2 - April 20 - May 10
- 3 - May 10 - May 11
- 4 - May 11 - May 13
- 5 - May 13 - May 17
- 6 - May 17 - June 9
- 7 - June 9 - June 23
- 8 - June 23 - Aug.
- 9 - August 4 - Sept. 30
- 10 - Sept. 30 - Nov. 29
- 11 - Nov. 29, 1927 - Jan. 24, 1928
- 12 - Jan. 24 - April 14, 1928
- 13 - April 14 - June 15
- 14 - June 15 - Aug 16
- 15 - Aug 15 - Aug. 16 - Oct. 1
- 16 - Aug. 1 - Nov. 16
- 17 - Nov. 16 - Dec. 29

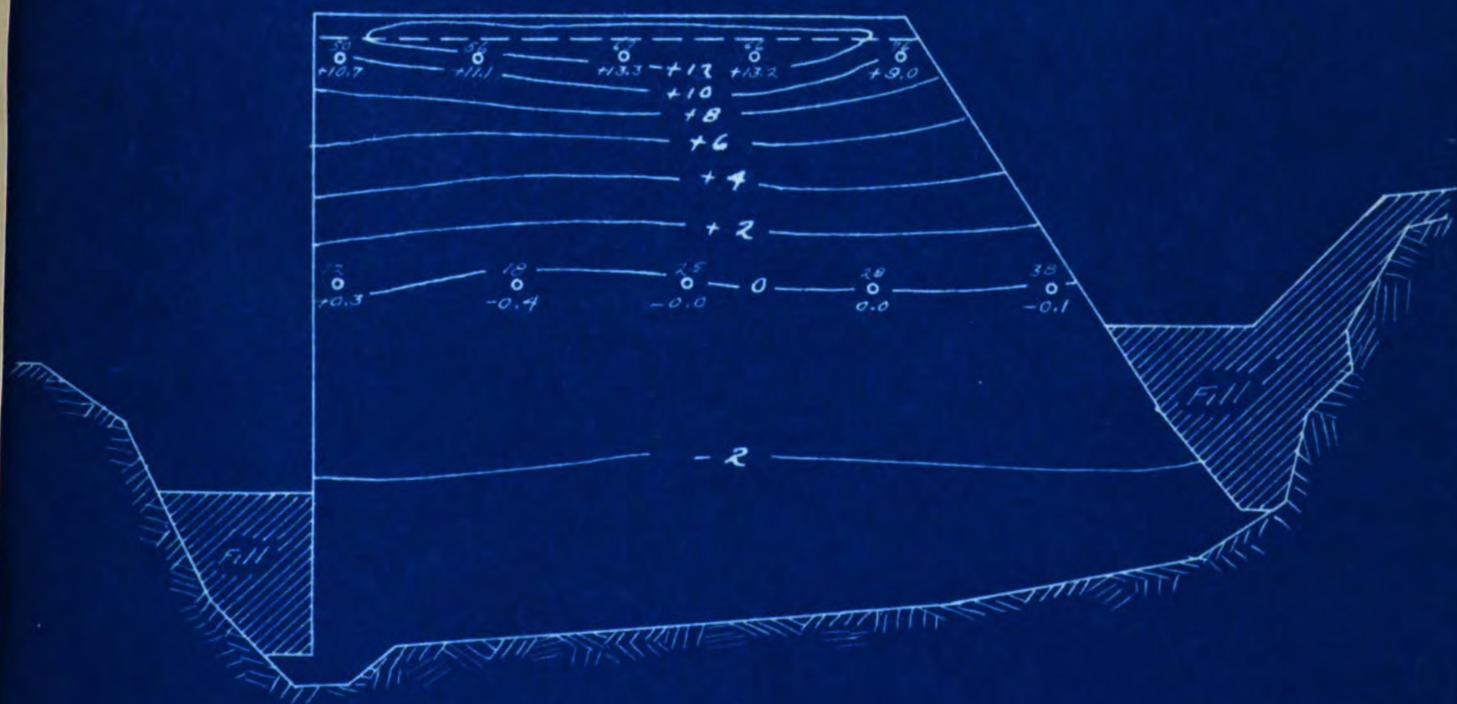
These periods are of such length that the changes in temperature and strain during any one period are not too great to handle conveniently. The following charts were constructed by plotting the change in average temperature of each group of telemeters that occurred during the period. Lines were then drawn connecting points of equal change of temperature. In this discussion these lines have been called isotherms.



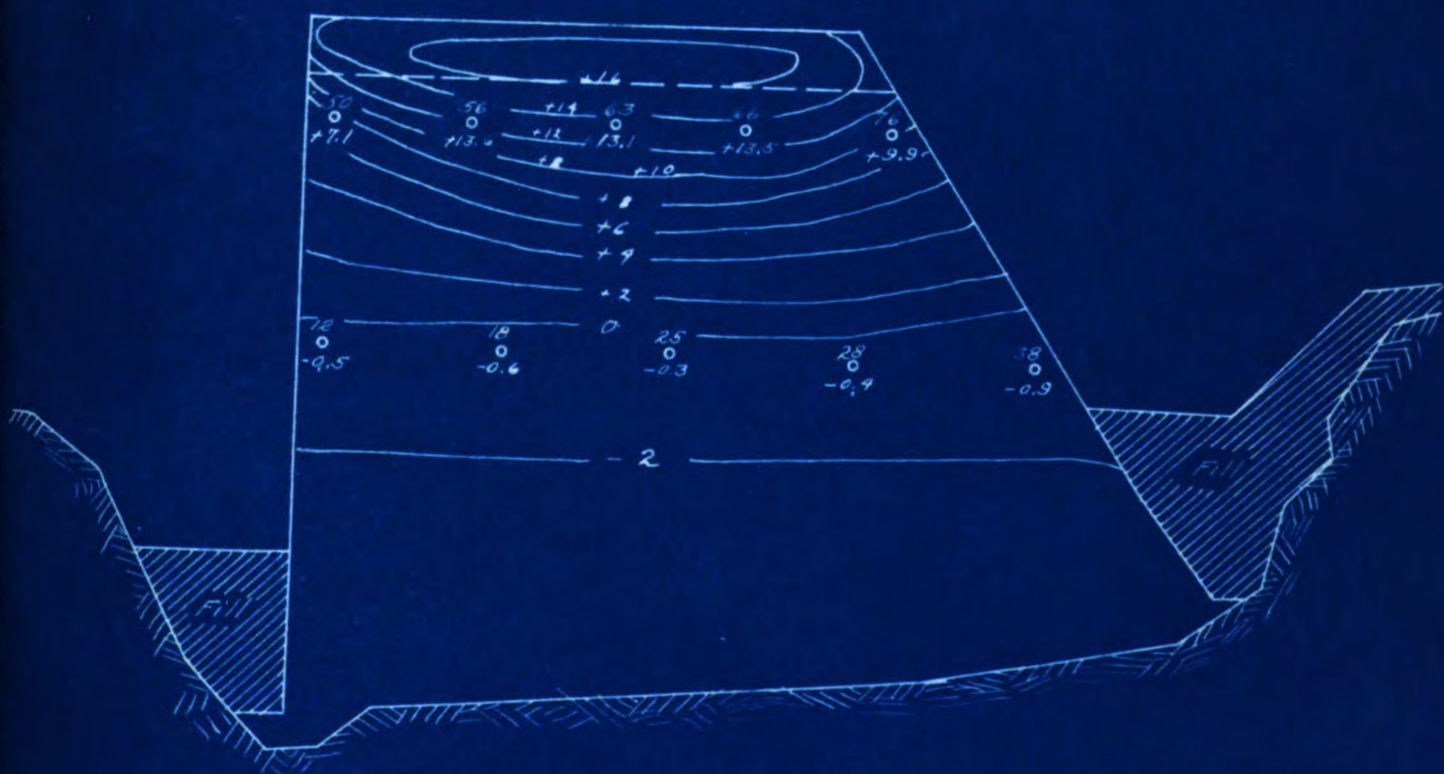
April 20 - May 10, 1927



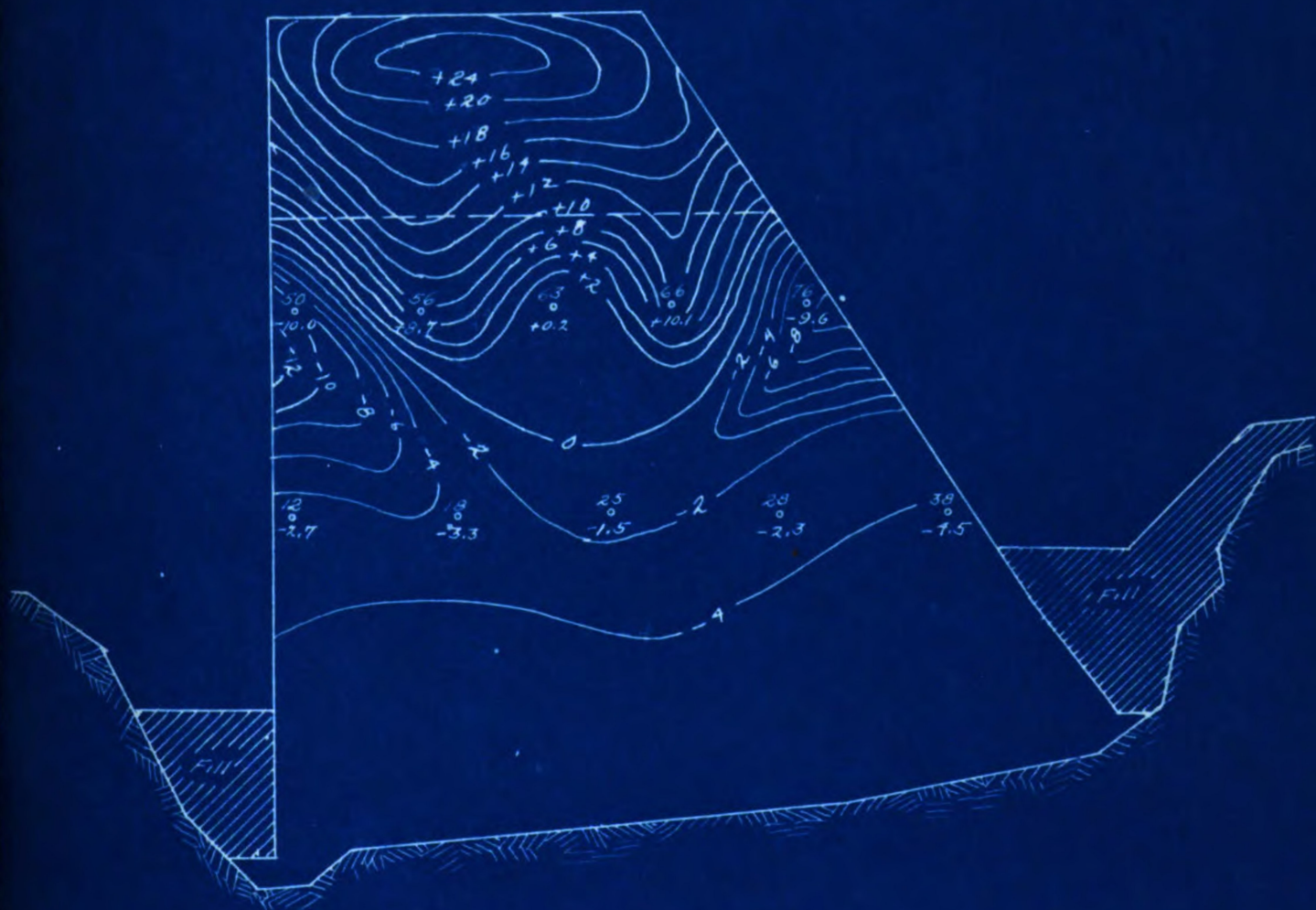
May 10 - May 11, 1927



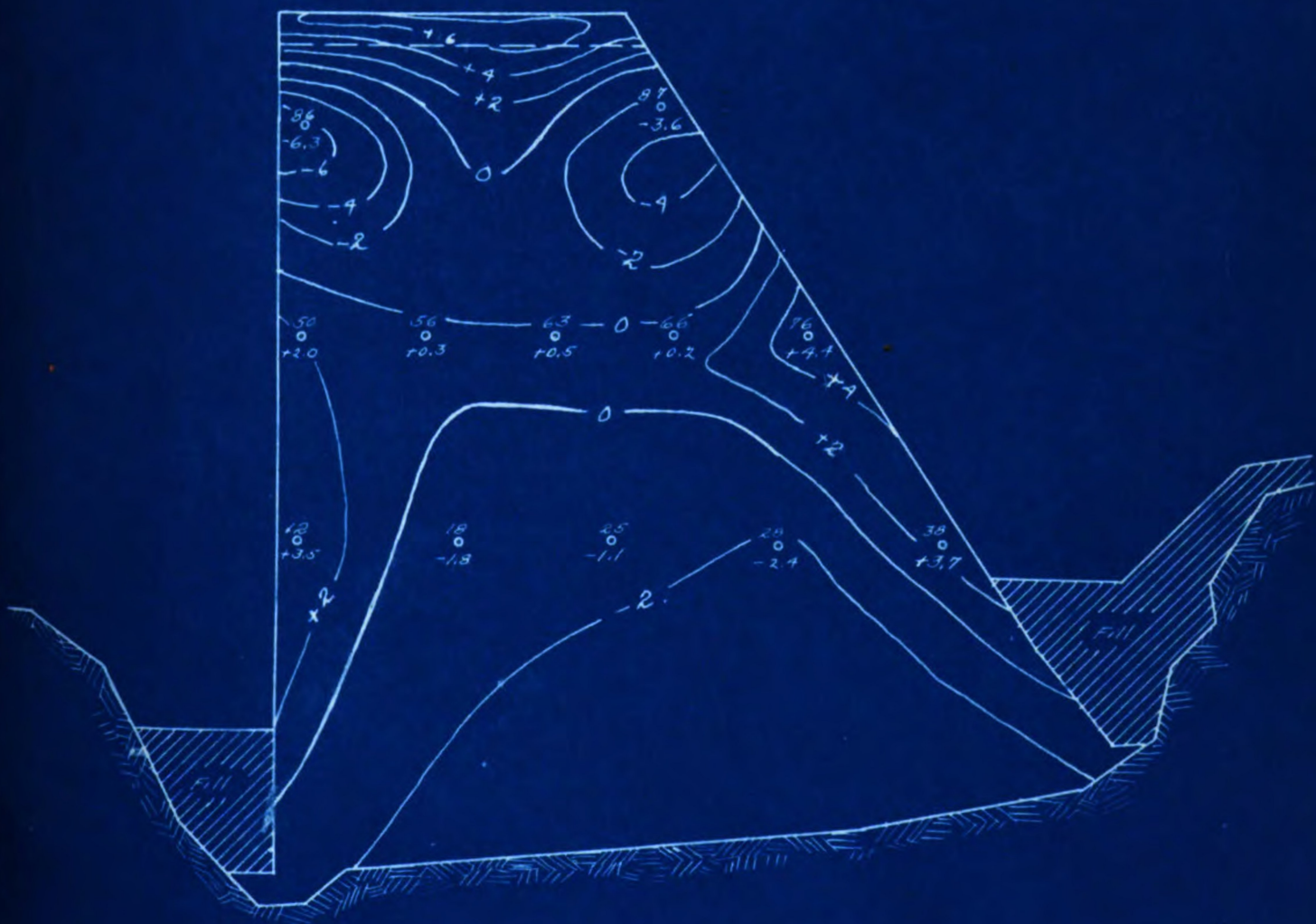
May 11 - May 13, 1927



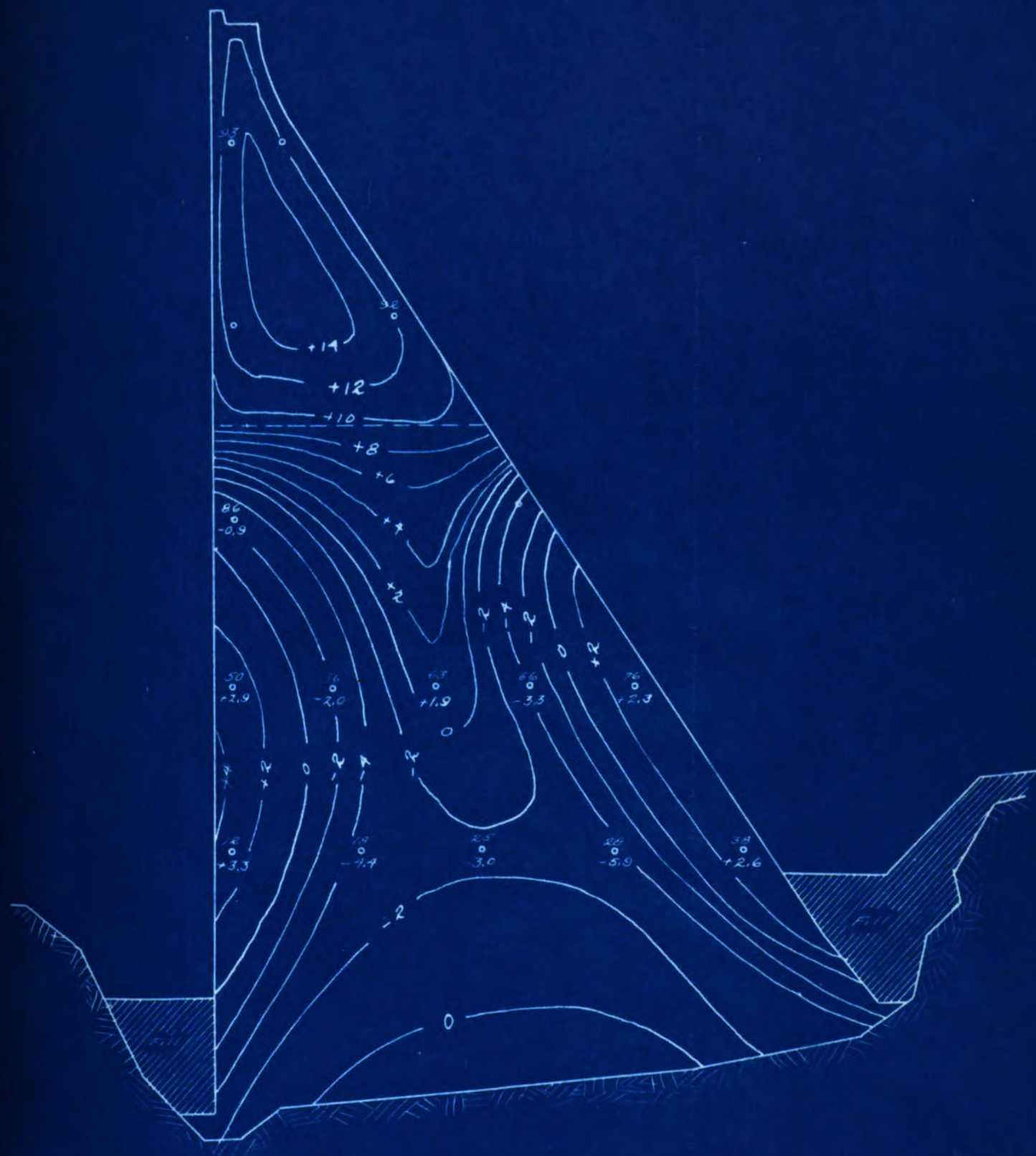
May 13 - May 17, 1927



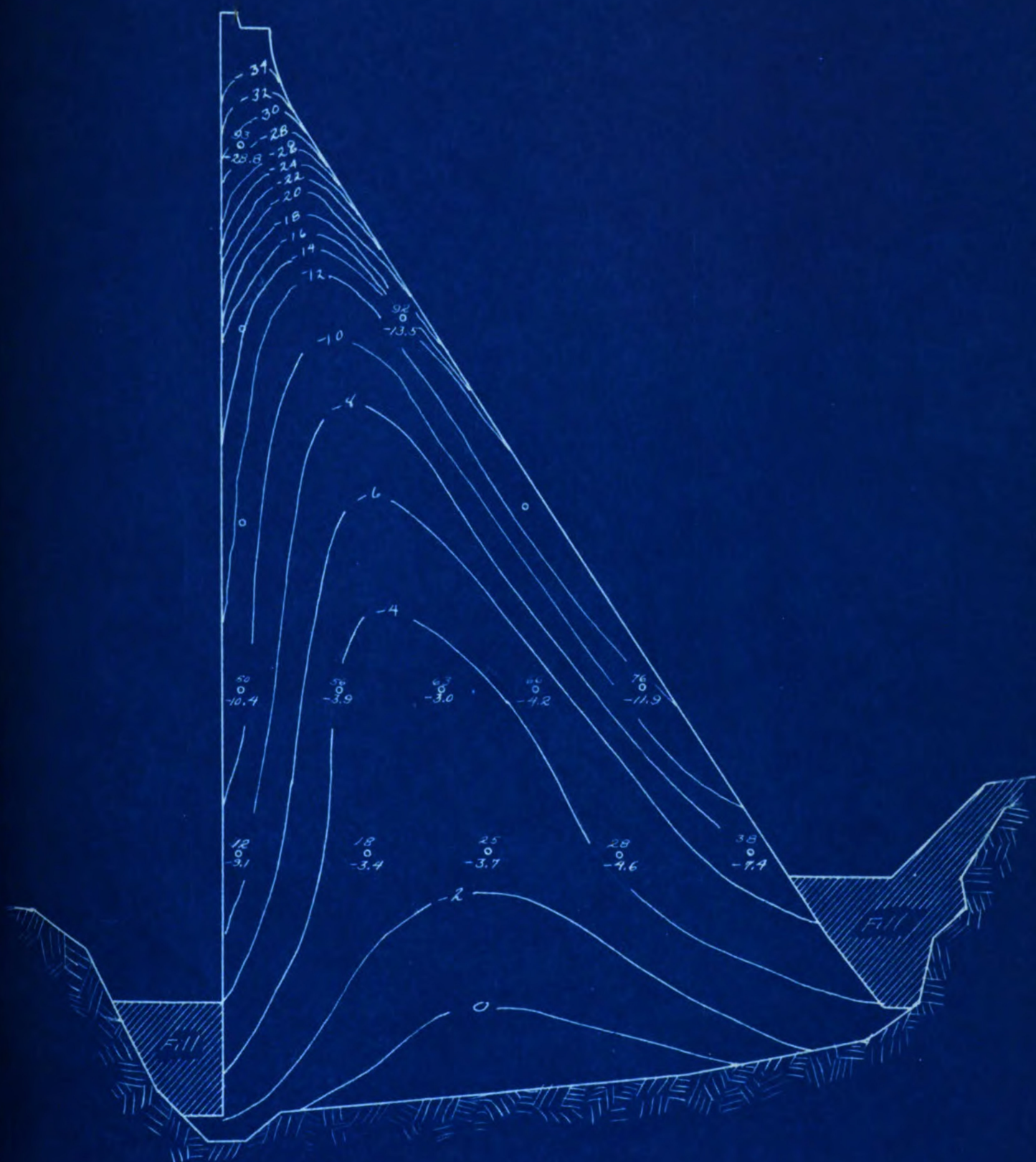
May 17 - June 9, 1927



June 9 - June 23, 1927



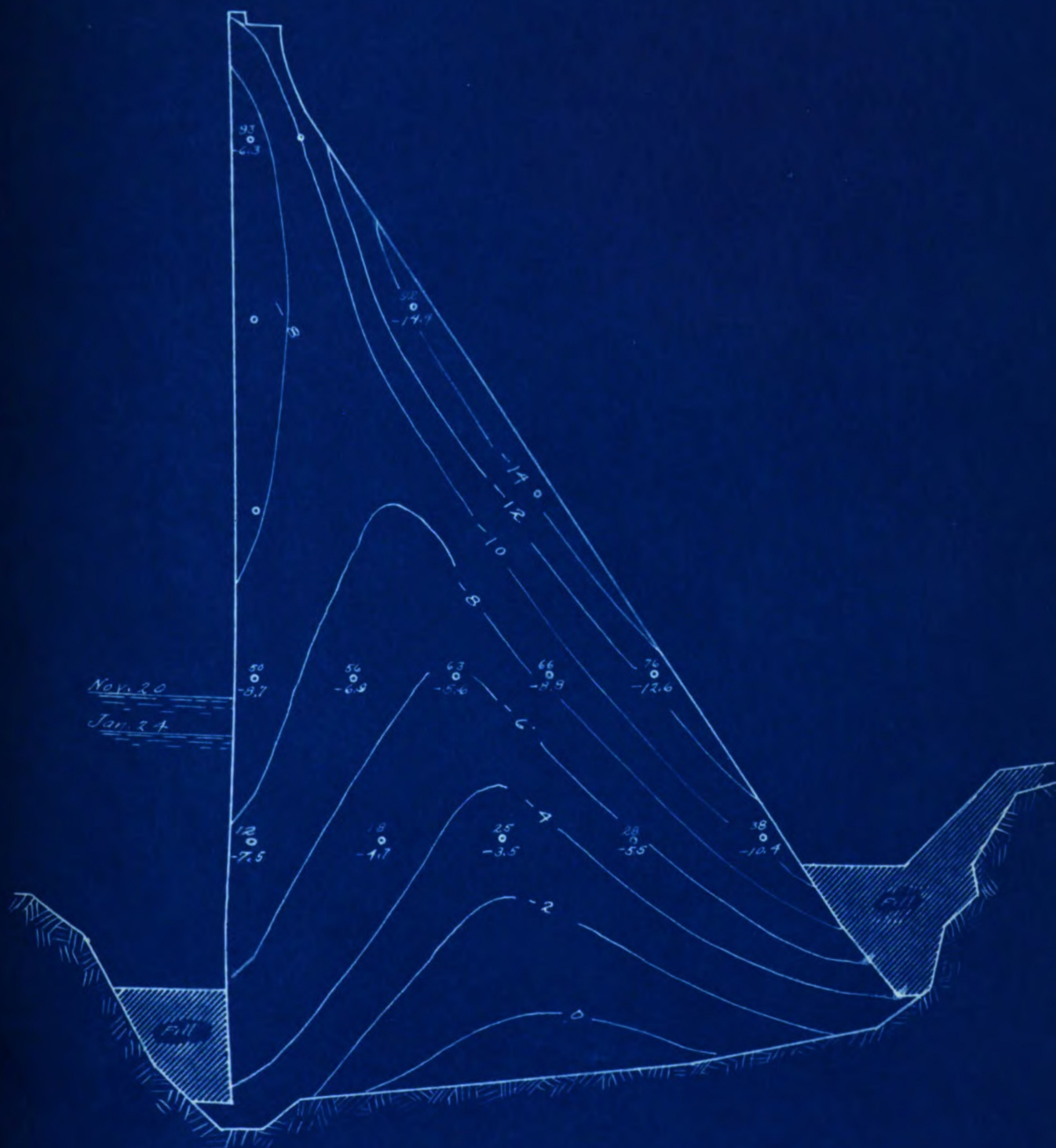
June 23 - August 4, 1927



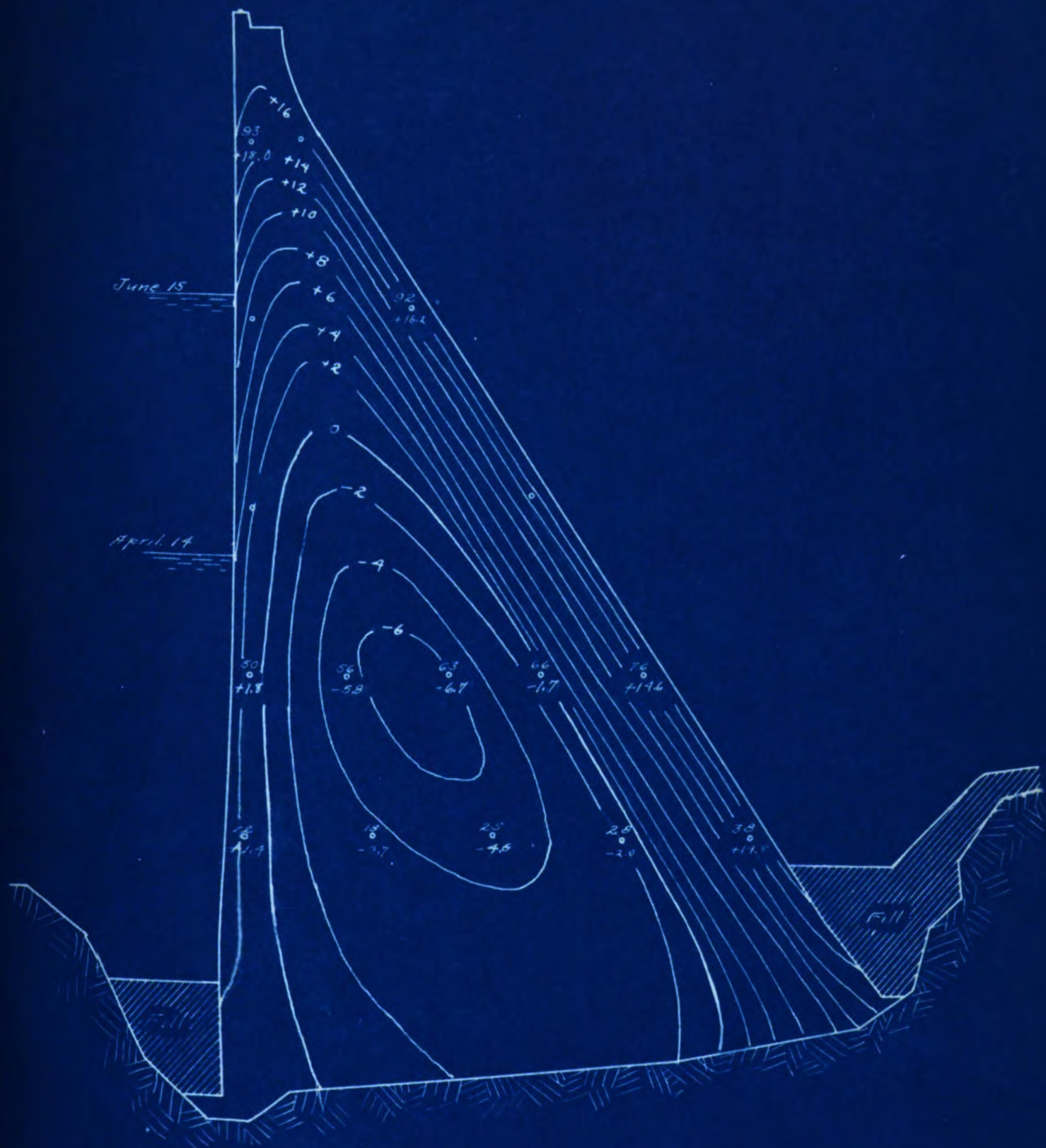
August 4 - September 30, 1927



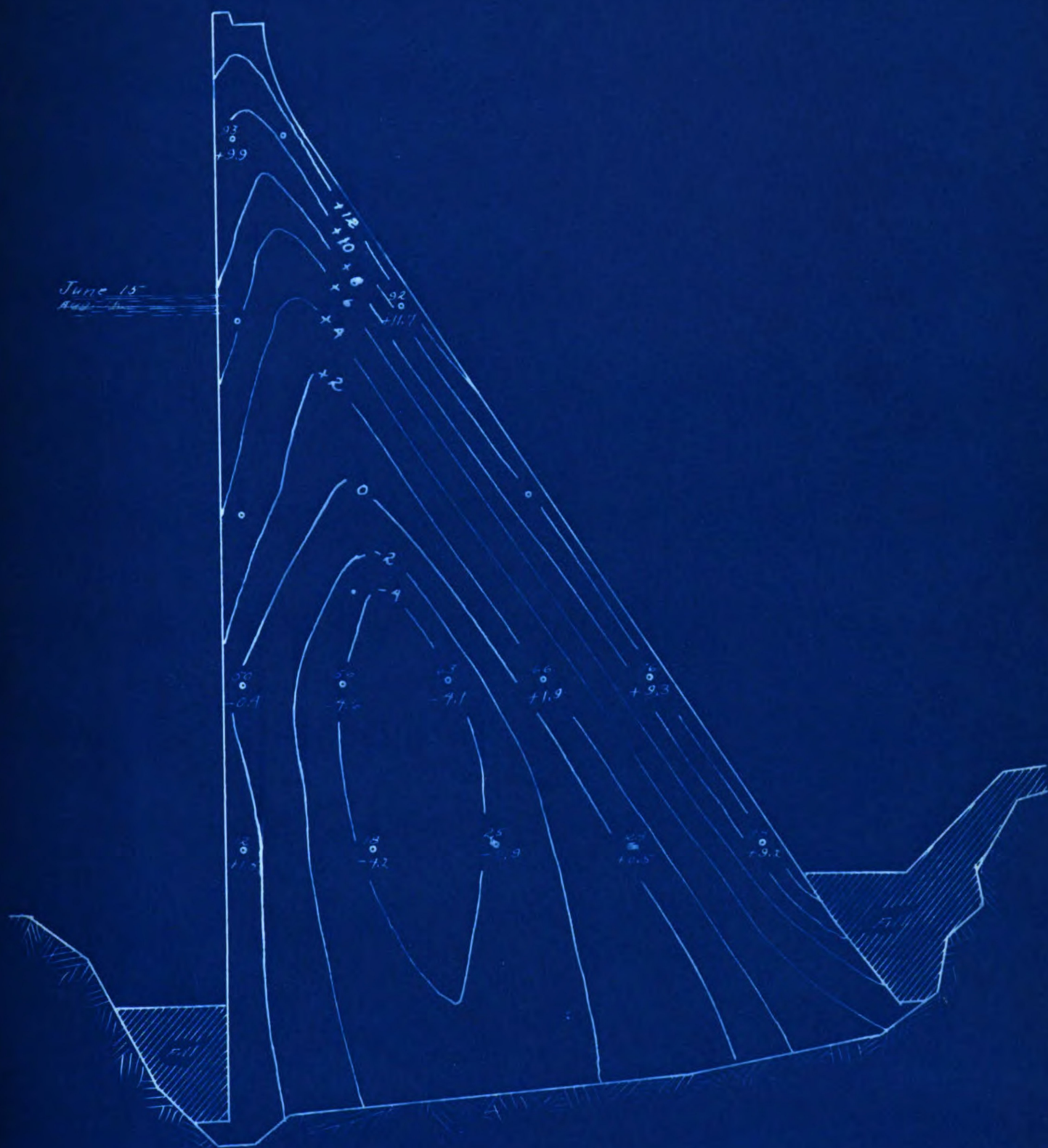
September 30 - November 29, 1927

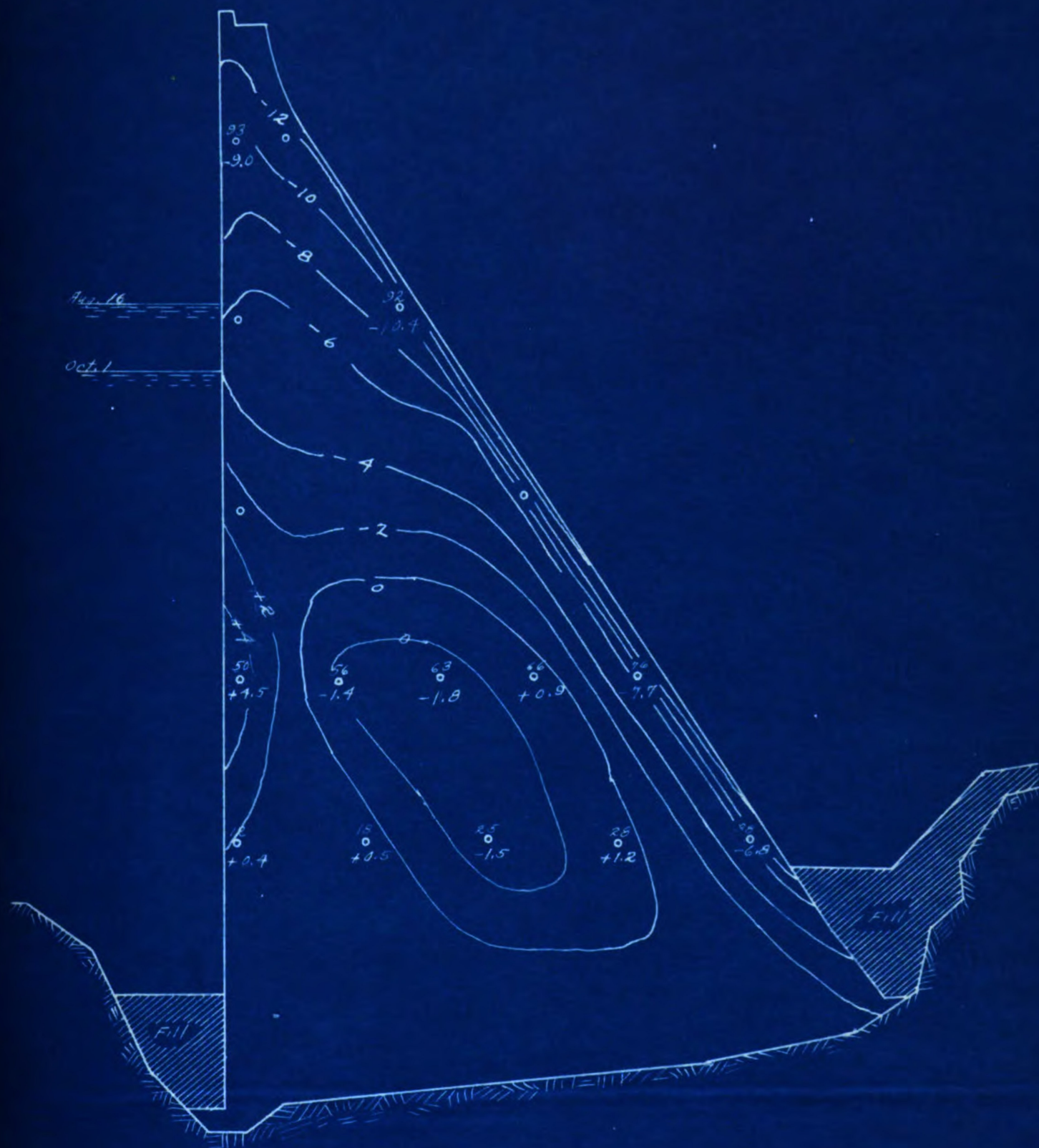


November 29, 1927 - January 24, 1928

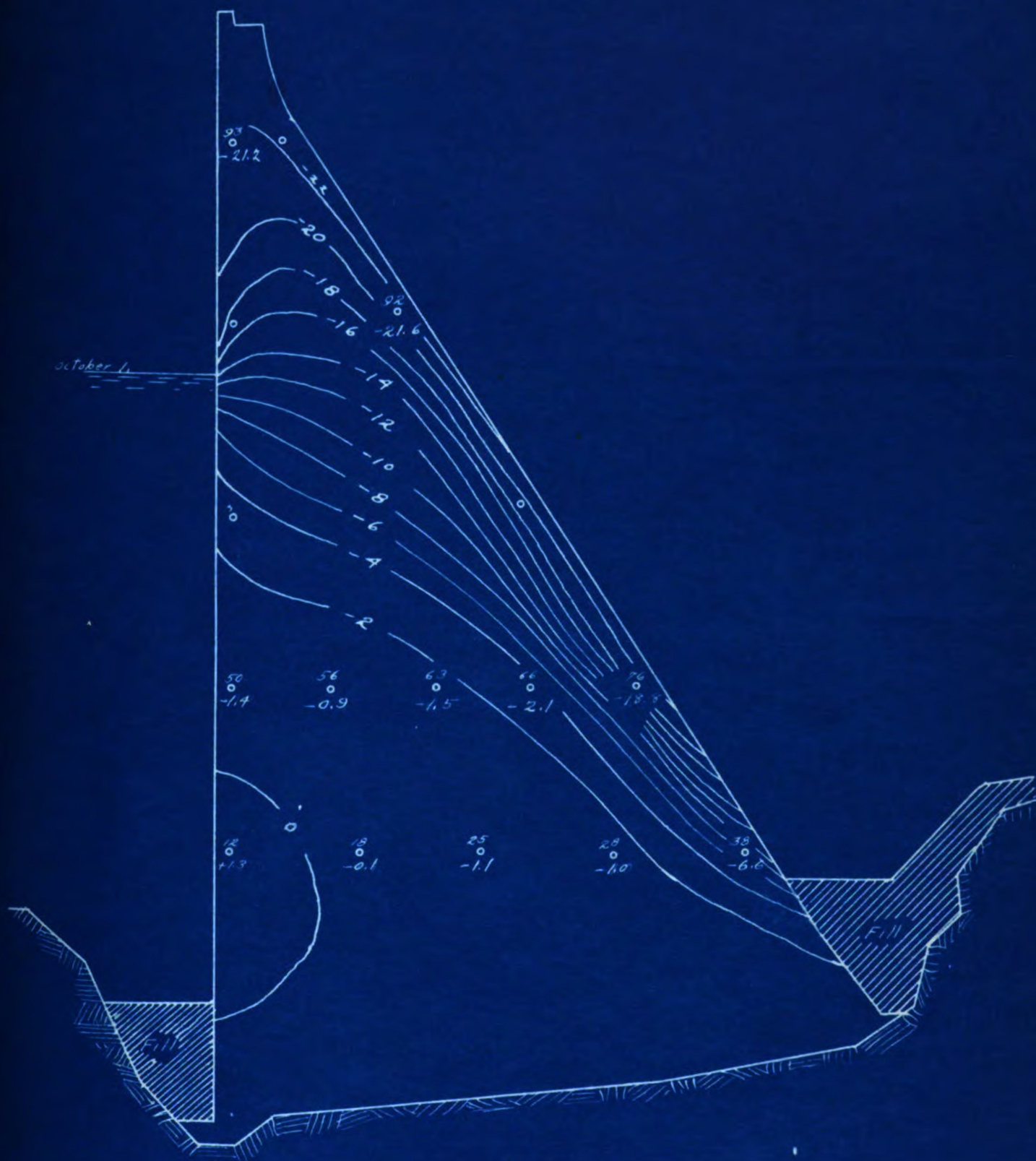


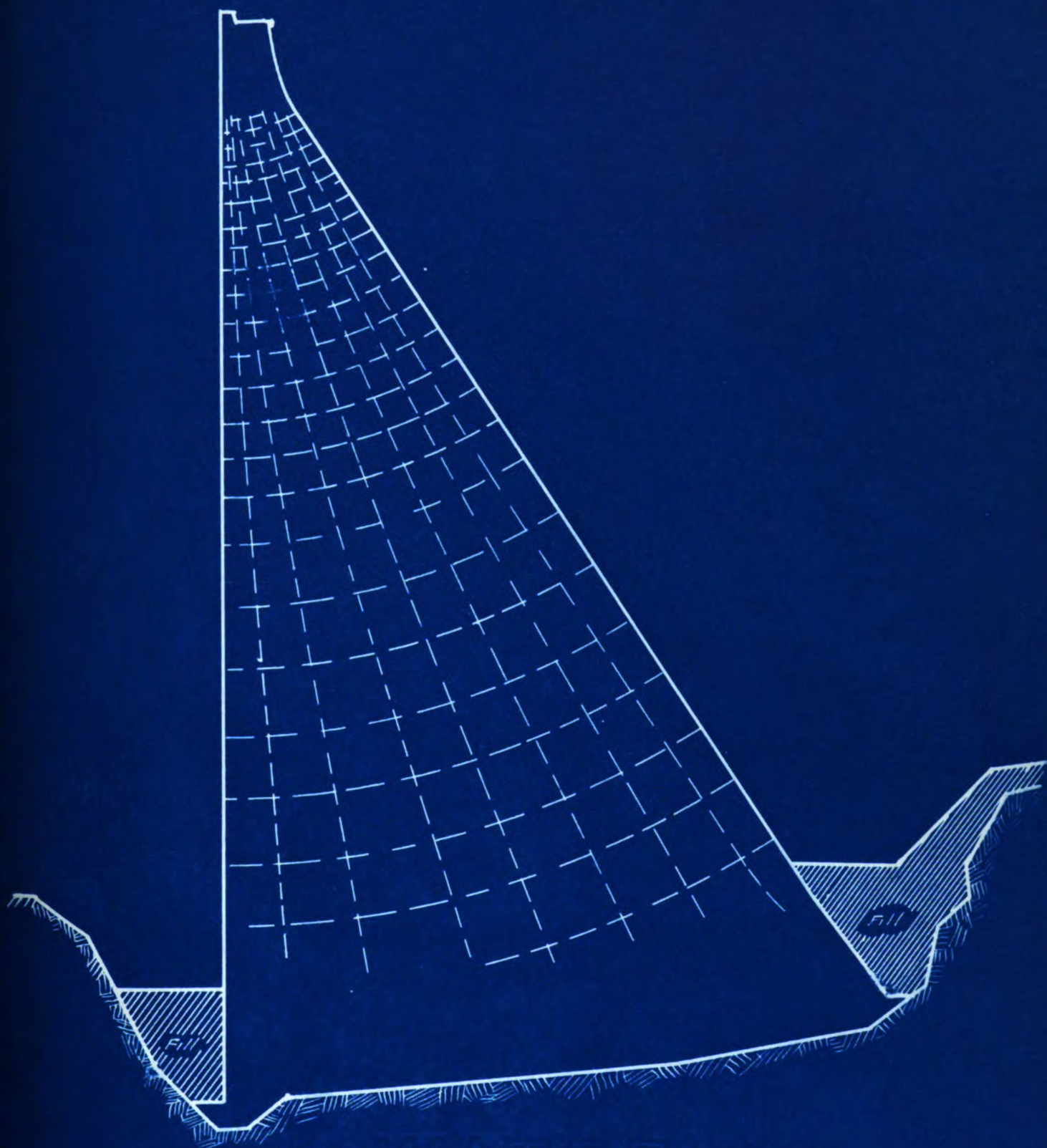
April 14 - June 15, 1928





August 16 - October 1, 1928





*DIRECTIONS OF PRINCIPAL STRAINS
AS INDICATED BY TELEMETERS
IN SHAVER LAKE DAM*

RECEIVED
JAN 20 1964
U.S. DEPT. OF JUSTICE
FEDERAL BUREAU OF INVESTIGATION
WASHINGTON, D.C.

The method of determining stress due to nonuniform temperature distribution is illustrated by the following specific example.

Let it be supposed that the change in stress at telemeter 51 during the period of September 30 to November 29, 1927 is desired. Fig. 5 represents the isothermic chart for the period in question. Section E. F. is drawn at right angles through the telemeter. The change of temperature indicated by each isotherm is then projected as an ordinate at the point where the isotherm cuts the section.

In the element $y \, dx$ the change in temperature is represented by y . If the coefficient of thermal expansion is 5×10^{-6} then $5 \times 10^{-6} y = \text{Strain}$. This strain is made up of actual and potential strains caused by change of temperature. If the DIAGRAM IS REFERRED TO SCALE B the ordinate, y will represent the strain in millionths directly.

The term, potential strain, is used here to denote a deformation which would occur in a body if it were free to expand and contract. This deformation is supposed to be caused by some internal condition such as change in temperature. If the body is partially ^{confined} conferred the deformation that cannot occur, by reason of the confinement, is called potential strain. This potential strain manifests itself as a stress which is expressed by the following relation



Fig. 5

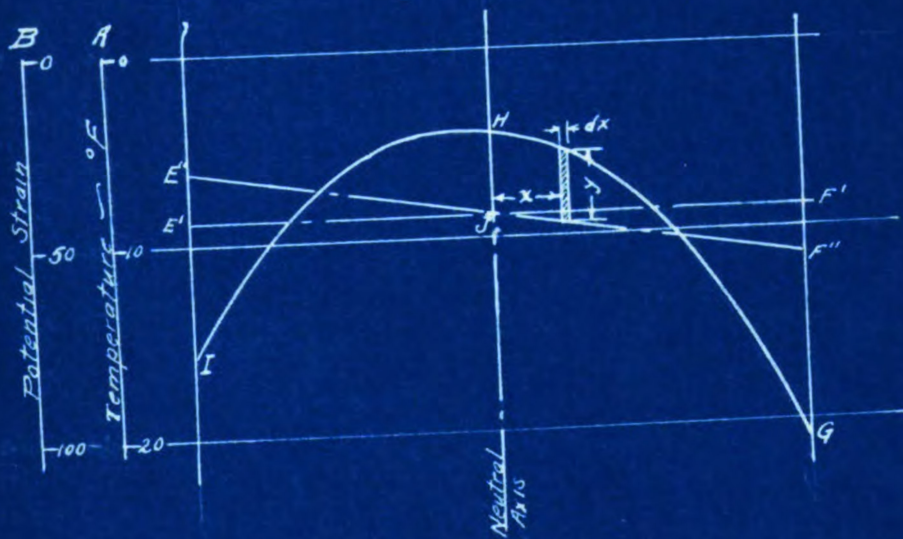


Fig. 6

$$S = \sigma E$$

S = Stress

σ = Potential Strain

E = Modulus of Elasticity

Due to the influence of the potential strains the section $E F$ will move to some position $E'' F''$ Fig. 6. This movement will be sufficient to bring about equilibrium of the stresses acting on the section and will consist of two parts.

(1) A translation along the neutral axis to position $E' F'$

(2) A rotation about the neutral axis to position $E'' F''$

The translation will be sufficient to fulfill the requirement

$$\int y \, dx = 0$$

The position of the section that fulfills this requirement is obviously at the mean height of the diagram.

The rotation about the neutral axis must be such that the moment of the vertical stresses on the section will be zero.

Expressed mathematically

$$\int xy \, dx = 0$$

The above expression is represented graphically by the moment of area $E'' F''$ CHI about the neutral axis which must also equal zero.

Moment of area E "F" GHI =

Moment of area E 'F' GHI - Moment of area E 'E"JF"F'

Moment of area E "F" GHI = 0

Therefore.

Moment of Area E 'E"JF"F' = Moment of Area E'F' GHI

$$\text{Moment of Area E'E "JF"F'} = E'E'' \times \frac{E'F'^2}{6}$$

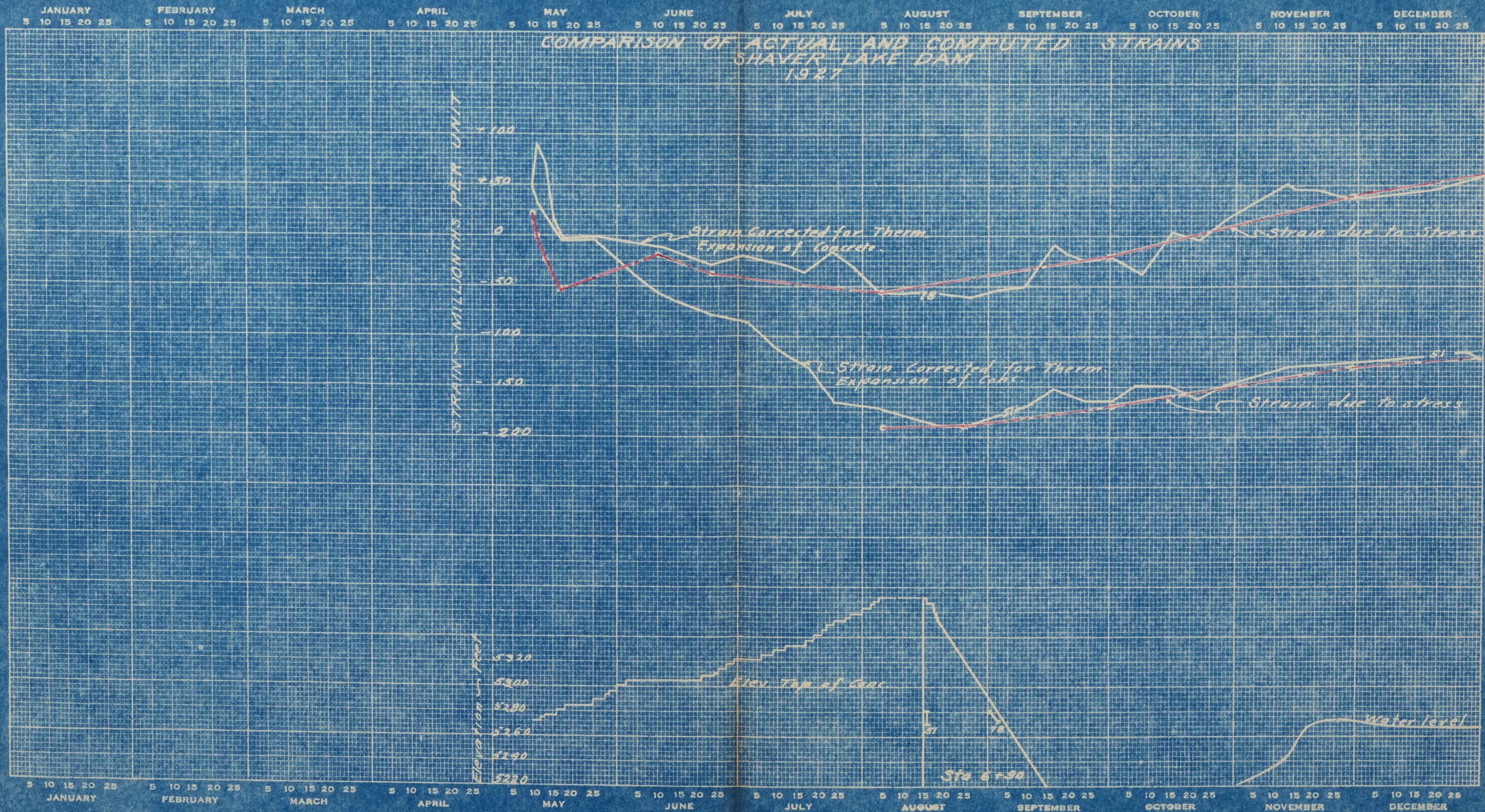
$$E'E'' = F''F'' = \frac{6 E'F'^2}{\text{Moment of Area E'F' GHI}}$$

after determining the final position of the section at E "F" the distance from the section to the curve at any point represents potential strain. The actual stress at this point may be obtained by multiplying the potential strain by the modulus of elasticity which for concrete of this class is about 4×10^6 .

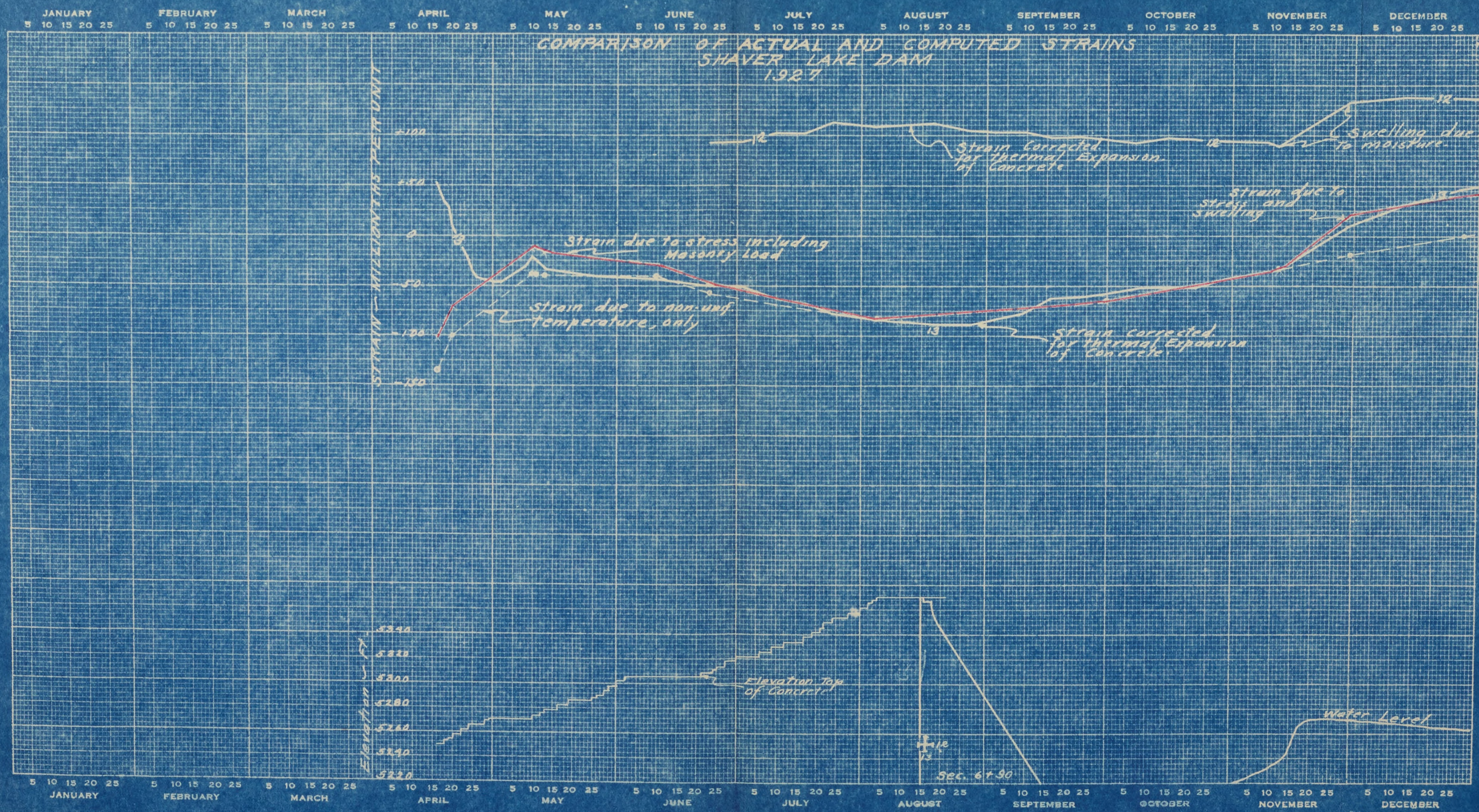
A comparison will show that this potential strain calculated entirely on the basis of the change in temperature distribution during the period of September 30 to November 29, 1927 agrees very well with the actual strain measured by the telemeters.

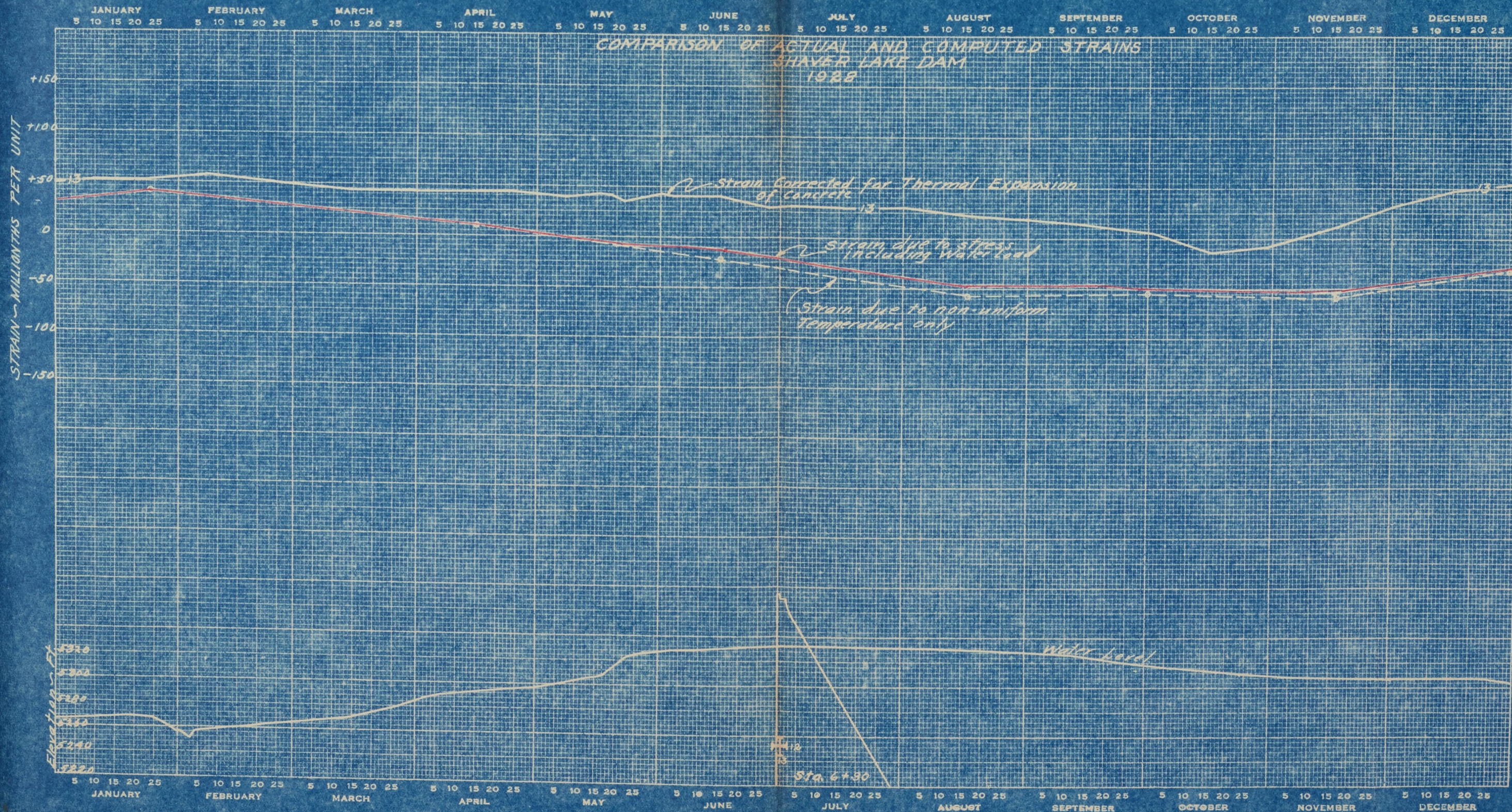
COMPARISON OF CALCULATED AND ACTUAL STRAINS

The two charts immediately following are intended to show the relation existing between the potential strains calculated on the basis of non-uniform temperature distribution and the



COMPARISON OF ACTUAL AND COMPUTED STRAINS SHAYER LAKE DAM 1927





actual strains as measured by the telemeters and corrected for thermal expansion of concrete. For purposes of comparison the calculated and actual curves are placed in coincidence on or shortly after August 4, 1927 on which date construction of Sec. 12 was completed.

In the case of telemeters 51 and 78 in the first chart the relation between the calculated and actual curves is very striking. In the case of telemeter 51 the divergence prior the August 4 is due to the increasing weight of masonry during construction and other factors such as shrinkage. To a lesser degree the same effect is seen in the early part of the curves for telemeter 78.

In the ~~next~~ chart telemeter 13 of the lower row has been treated in a similar manner. Here the two curves show a very close agreement up to the time when the face was submerged on November 15. From this time on the "strain due to stress" curve continues as indicated by the dotted line. However the actual strain curve diverges rapidly and attains a difference of 50 millionths within a month. This is evidently due to the swelling of the concrete. It will be noticed that the face is submerged at a time when the curve is on an upward trend and the concrete is probably under some tension. Horizontal hair cracks probably formed allowing the water to seep some distance into the concrete causing this swelling. A corresponding swelling is observed in No. 12, the horizontal telemeter at this point. If horizontal cracks have formed at this point the concrete would be free to expand in a vertical as well as horizontal direction.

Indeed it would seem that water might enter the cracks and cause a progressive swelling which would continue for a long time.

For the sake of comparison the swelling of 40 millionths observed in the horizontal telemeter has been added for the corresponding period to the strain curve. This accounts for the rapid climb of the curve after November 12, but from that time on the curve of actual strain runs practically horizontal showing no appreciable change in strain. This is exactly what would be expected if a horizontal crack or series of small cracks had formed near the telemeter for in that case the telemeter would be subjected to no stress and consequently no strain due to stress. And the only strain registered by the telemeter would be that due to swelling.

It is the writer's belief that, if at some time in the future it is possible to examine the upstream face at this point, these cracks will be found.

Conclusions

Four important conclusions may be drawn from this thesis.

- (1) Unpredicted stress changes of considerable magnitude occur in large gravity type dams.
- (2) These stresses are chiefly due to non-uniform temperature changes within the dam.
- (3) These stresses are most pronounced near the upstream and downstream faces.
- (4) The change in stress, over a period of time may be determined from consideration of the change of temperature within the dam as described on pages 46-49

MICHIGAN STATE UNIV. LIBRARIES



31293500234665