ELECTRIFICATION OF MILWAUKEE BRANCH
OF THE
CHICAGO AND NORTHWESTERN RAILWAY

BY

H. L. CASE
F. FERNANDEZ - MAREQUE
A. F. SCHOEMBS
R. W. WHITMORE

ARMOUR INSTITUTE OF TECHNOLOGY

1914

PROPOSED ELECTRIFICATION
of
THE MILWAUKEE BRANCH
CHICAGO & NORTHWESTERN RAILWAY

A THESIS

PRESENTED BY

H. L. Case
F. Fernandez-Mareque
A. F. Schoembs
R. W. Whitmore

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

May 1914

Approved
E. H. Freeman
Professor of Electrical Engineering
H M Raymond
L. C. Monin

C O N T E N T S.

INTRODUCTION.

This thesis covers in a brief way, the design of a complete railway installation for the proposed "Electrification of the Chicago-Milwaukee Branch of the Chicago and Northwestern Railway".

We have attempted to indicate a general method of procedure, including sample calculations and conclusions drawn therefrom; estimate the cost of the installation and maintenance; and compute the net earnings of the proposed system.

In the preparation of this thesis many valuable suggestions have been made by Professors Freeman, Snow, and Nichols, of the Armour Institute of Technology.

No attempt has been made to enter into the details of all or any particular portion of the design. Such a task as a detail design could only be accomplished by a Board of Engineers with at least two or three years time to devote to the subject.

THE SPEED TIME CURVE.

In the preliminary calculation and determination of the speed-time curve the following factors have been considered:

(a) Choice of acceleration, involving distance between stops, the average speed, and weight of car.

(b) The profile of the line.

(c) Choice of motor and gear ratio.

(d) Frequency of the service.

Choice of Acceleration.

The general solution of the problem is here considered because of its important relation to the choice of motors, a factor which directly determines the initial cost of the entire system.

Referring to Fig. 1, an arbitrarily assumed straight line speed-time curve for a straight and level track, the following notation has been used:

a - Acceleration in miles per hour per second along OA (=DA+OD)

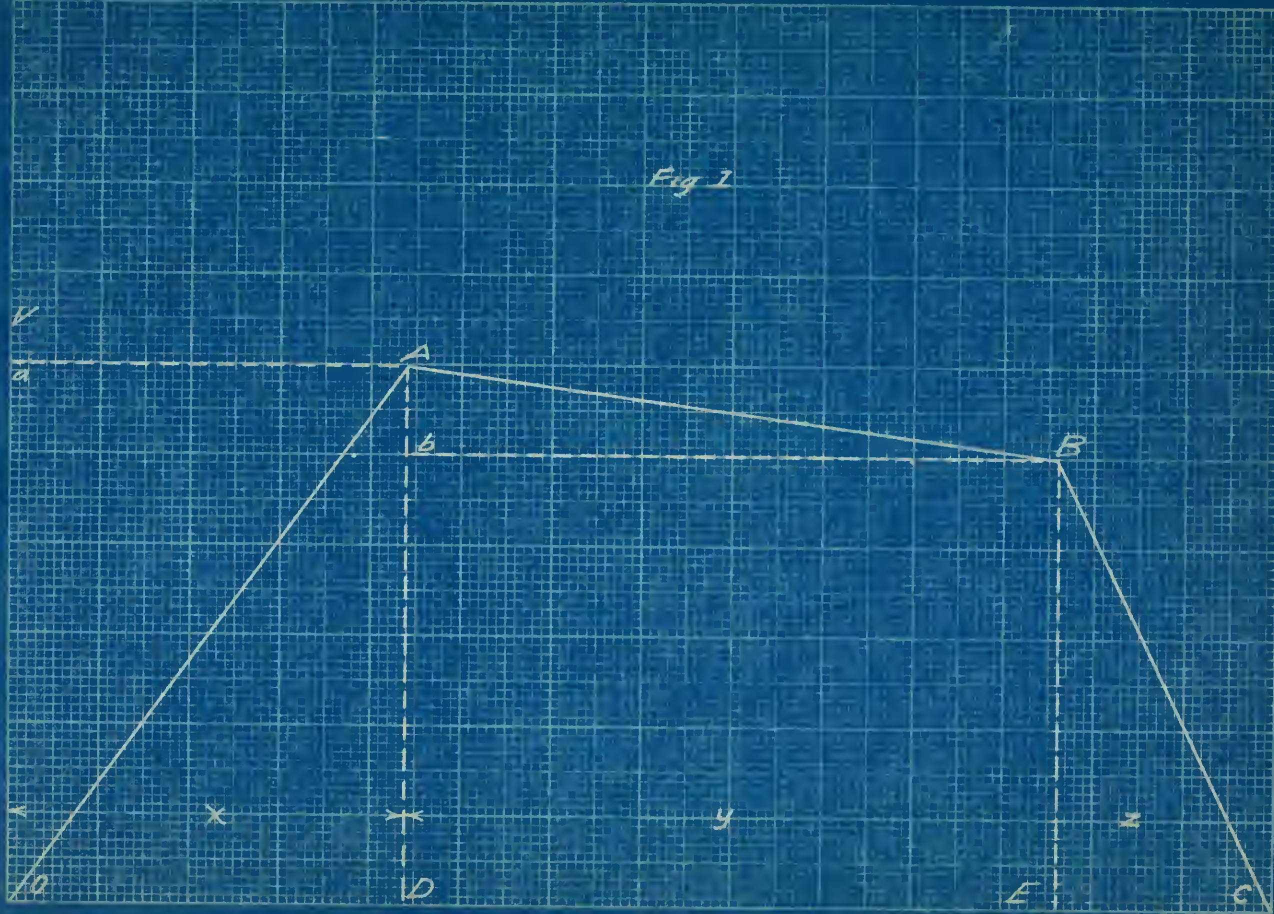


Fig 1
V
a
A
b
B
x
y
z
O
D
E
C

$\dot{b}$ - Retardation during braking ($=Ab \div ED$)

c - Retardation during coasting($=BE \div EC$)

x - Time required to go from O to A.($=OD$)

y - Time for AB ($=DE$)

z - Time for BC ($=EC$)

s_1- Distance for OA. (=Area OAD)

s_2- Distance for AB. (=Area DABE)

s_c- Distance for BC. (=Area EBC)

T - Total time of run. (=OC)

L - Total distance. (=Area OABC)

V - Average velocity. ($=0.682\ L \div T$) (one mile per hour = 0.682 feet per second)

As indicated in the figure the car is assumed to be moving with a constant acceleration up to its maximum speed for a time OD, then is retarded at a constant coasting rate for a time DE, and finally is retarded during braking at a constant acceleration over a period of time equal to EC.

The velocities, times, and distances referred to in the foregoing discussion may be represented by the three following equations:

(1) $ax - by - cz = 0$

(2) $x + y + z = T$

(3) $ax^2 - by^2 + cz^2 + 2axy = 2 \times 0.682\ L.$

Put: $\frac{x}{T} = \xi$; $\frac{y}{T} = \eta$; $\frac{z}{T} = \zeta$

Then: $\xi + \eta + \zeta = 1$

$$a\xi - c\eta - b\zeta = 0$$

$$a\xi^2 - a\zeta\eta + b\eta\zeta + b\zeta^2 = 2\frac{L}{T^2} = 2A$$

Where $A = 0.682\ L \div T^2$.

$$\eta = \frac{b - (b+a)\xi}{b - c}$$

$$\zeta = \frac{(a+c)\xi - c}{b - c}$$

"ζ", is now found in terms of "a" and "A". This is accomplished by assuming average values for coasting and braking as 0.15 and 2.0, respectively, substituting same in the preceding equations, and solving for   for different values of "A" and "a". The results of such a calculation are shown by the curves of Fig. 2.

By use of the general equations of the speed-time curve, table 1 was calculated, a sample of the procedure being given below:

$A = 0.682\ L \div T^2$, where L is the average length of run, a factor which was determined

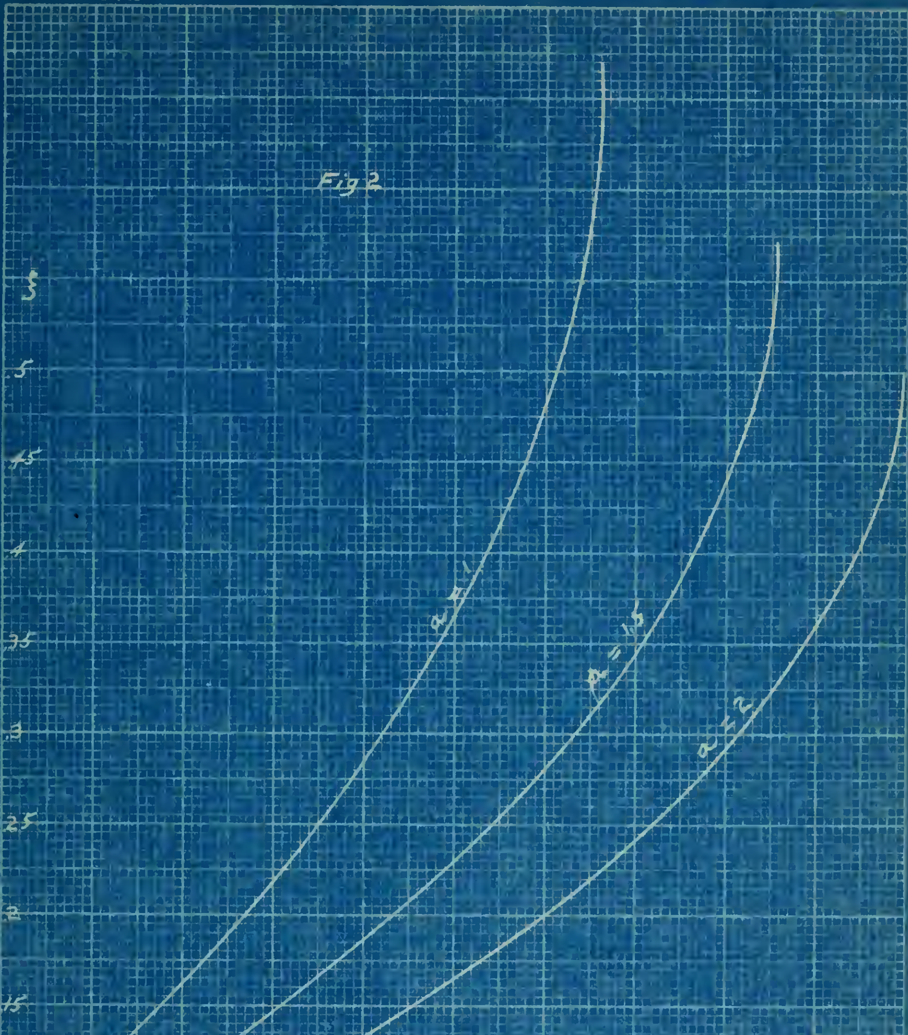


Fig 2
ξ
.5
.45
.4
.35
.3
.25
.2
.15
.1
.05
.1
.15
.2
.25
.3
.35
.4
a = 1
a = 1.5
a = 2

TABLE 1.

a	A	T	S	x	w-70	KW./ton	
1.0	.15	175.9	24.30	38.7	48.9	4.08	.220
	.20	152.3	27.70	43.3	61.2	4.57	.284
	.25	136.1	30.70	49.4	79.8	5.21	.363
	.30	124.3	33.30	59.3	114.8	6.26	.477
	.35	115.1	35.65	----	-----	----	----
	.40	107.6	37.90	----	-----	----	----
	.45	101.5	39.80	----	-----	----	----
1.5	.15	175.9	24.30	26.7	50.2	6.06	.152
	.20	152.3	27.70	28.9	58.7	6.56	..190
	.25	136.1	30.70	31.9	71.3	7.25	.234
	.30	124.3	33.30	35.0	86.1	7.95	.282
	.35	115.1	35.65	39.4	108.7	8.95	.342
	.40	107.6	37.90	47.0	155.0	10.67	.437
	.45	101.5	39.80	----	-----	-----	----
2.0	.15	175.9	24.30	19.87	47.9	7.80	.113
	.20	152.3	27.70	21.00	53.5	8.25	.138
	.25	136.1	30.70	23.15	65.1	9.10	.170
	.30	124.3	33.30	25.30	77.4	9.94	.203
	.35	115.1	35.65	27.18	89.6	10.68	.236
	.40	107.6	37.90	31.10	117.5	12.24	.289
	.45	101.5	39.80	36.20	159.3	14.22	.357

following an investigation of the number of stops and the distance between same. The particular run under consideration was chosen as that between Chicago and Waukegan, because the maximum traffic occurs between these two points.

Then 0.682 L = 4640

Then from curve of Fig. 2, for A=.15 and a=1

$$T = \sqrt{\frac{4640}{.15}} = 175.9$$

S= miles per hour = $\frac{0.682\ L}{T + \gamma}$, where is the stopping time (=15 seconds).

Therefore $S = \frac{4640}{175.9\ 15} = 24.3$

$X = \xi T = .220 \times 175.9 = 38.7$

(ξ obtained from curve.)

W_{70} = Watts per tone mile at 70% efficiency.

$$W_{70} = \frac{[91.1a^2 + fa]\xi}{0.7\ A} = 48.9$$

f = Lbs. friction per ton =15.

$$KW/ton = \frac{(91.1a + f)\frac{ax}{2} \cdot 1.47 \cdot 0.746}{550} = 4.08$$

After a careful study of Table 1, an acceleration of 1.5 with a running time of 136.1 seconds was chosen as being the most economical acceleration and time of run.

Choice of Motors and Gear Ratio.

From practical operating conditions of roads similar to the one under consideration the car weight including 62 passengers was set at 45 tons. The motor capacity was estimated at about 460 H.P., equally divided among four motors.

Of the various motors considered the 303A Westinghouse Railway Motor was found best adapted to the conditions. This conclusion was arrived at as follows: the performance curves of the given motor were plotted for different values of gear ratio, as shown in Figs. 3, 4, and 5; the data being obtained from the manufacturer. From the appearance of a few preliminary speed-time curves, the tim of run was set at 140 seconds. A sample calculation and outline of the method employed in plotting the speed-time curve is given below:

Straight and level track assumed.

Given:

Gear ratio=2.21; a=1.5; f=15; car weight

of 45 tons; 4 - 115 H.P. motors.

Therefore, tons per motor=45÷4 =11.25

Since 91.1a=p - f, where p = Lbs. tractive effort per ton,

Then 91.1 x 1.5=p - 15.

Or, p=151.7 Lbs. per ton.

From the motor curve for a tractive effort of 1710=151.7 x 11.25, I is found to be 182 amperes. Then when I=182 amperes, V=27.5 (from Fig. 4).

It is evident that by varying the current supplied to the motor, the tractive effort can be kept constant up to a speed of 27.5 miles per hour, at which time the motor will operate according to its characteristic. The accelerating portion of the curve was then drawn; it being a straight line up to 27.5 . A sample calculation for the motor curve is given below and the data used in plotting the curve is given in Fig. 2.

$$dt = \frac{91.1\ dv}{p - f} = \frac{91.1 \times 2.5}{106.7 - 15} = 2.48 .$$

dv, assumed at 2.5, then V=27.5+2.5=30.

When V=30, $p = \frac{P}{11.25} = \frac{1200}{11.25} = 106.7$; (P taken from tractive effort curve).

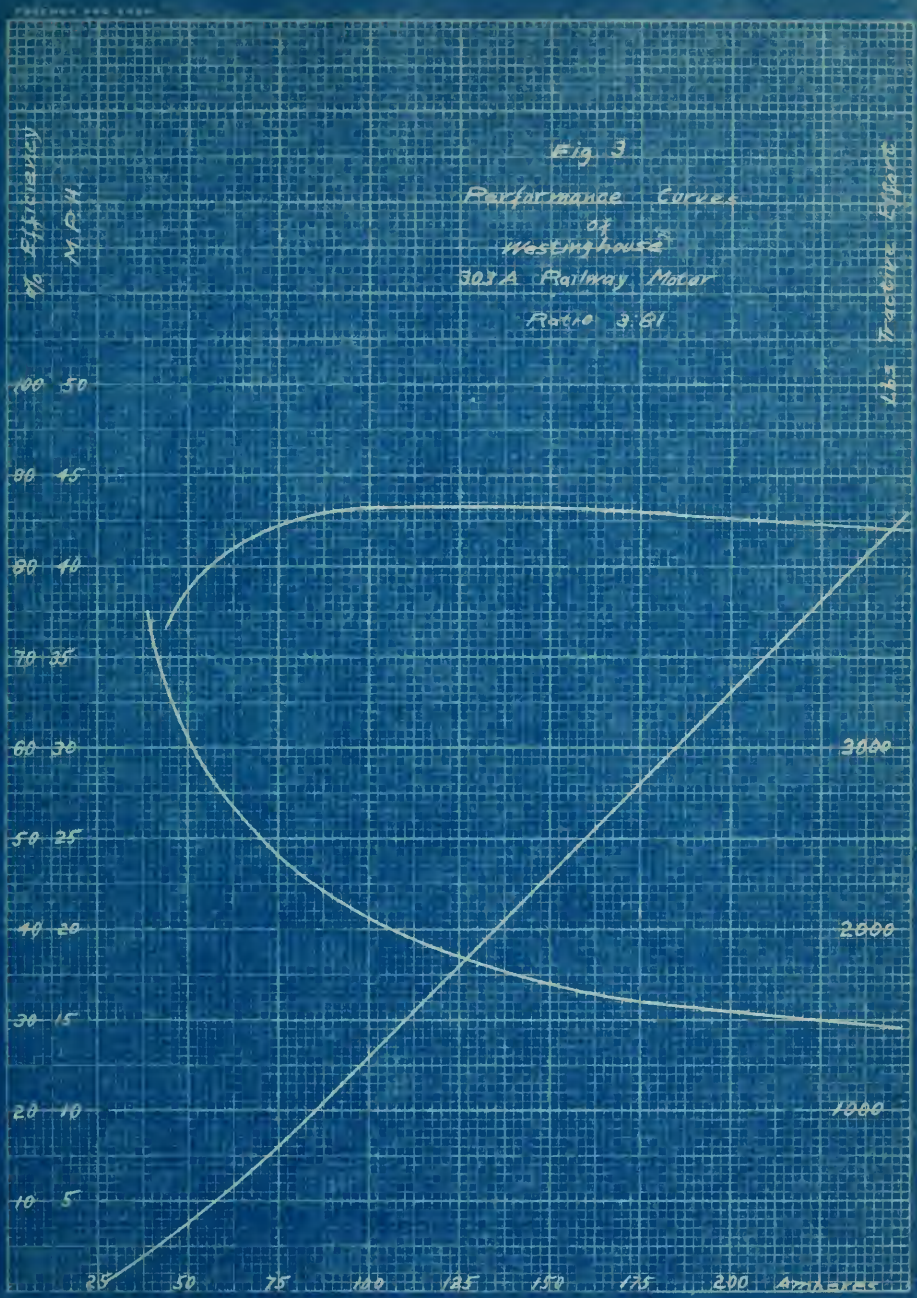
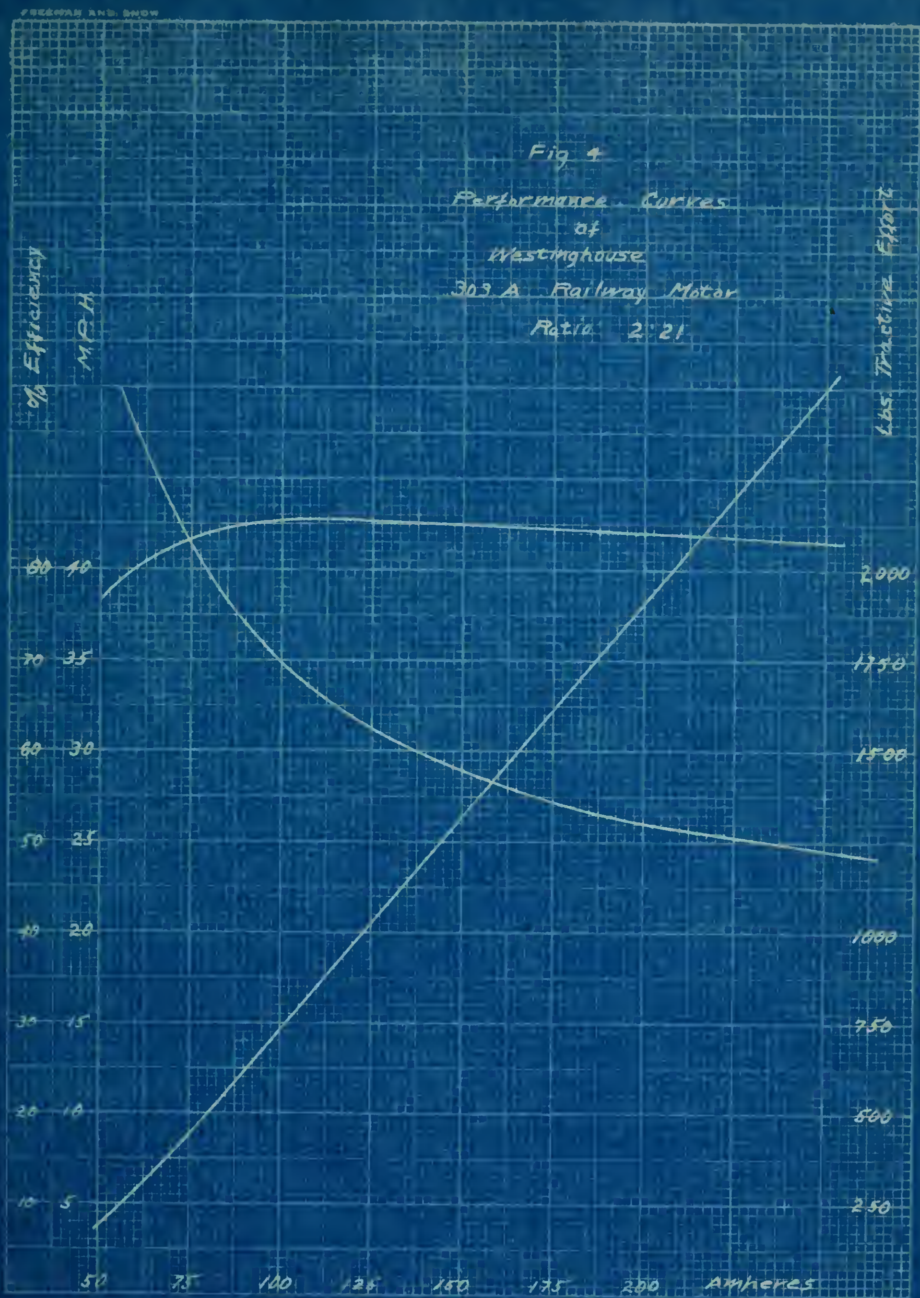


Fig. 3
Performance Curves
of
Westinghouse
303 A Railway Motor
Ratio 3:81
% Efficiency
M.P.H.
Lbs Tractive Effort
100 50
90 45
80 40
70 35
60 30
50 25
40 20
30 15
20 10
10 5
3000
2000
1000
25
50
75
100
125
150
175
200
Amperes


FREEMAN AND SNOW
Fig 4
Performance Curves
of
Westinghouse
303 A Railway Motor
Ratio 2:21
% Efficiency
M.P.H.
Lbs. Tractive Effort
80 40
70 35
60 30
50 25
40 20
30 15
20 10
10 5
2000
1750
1500
1000
750
500
250
50
75
100
125
150
175
200
Amperes

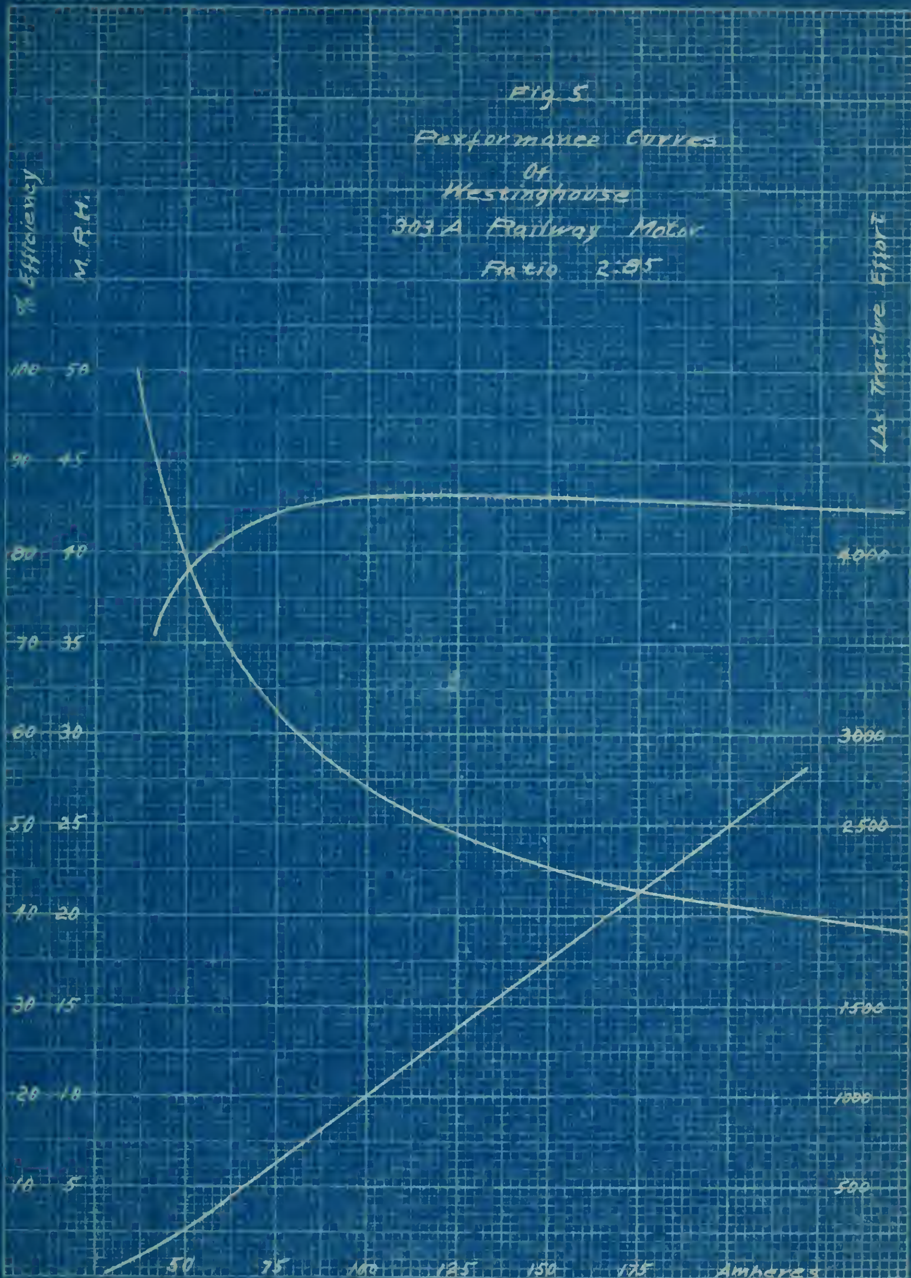
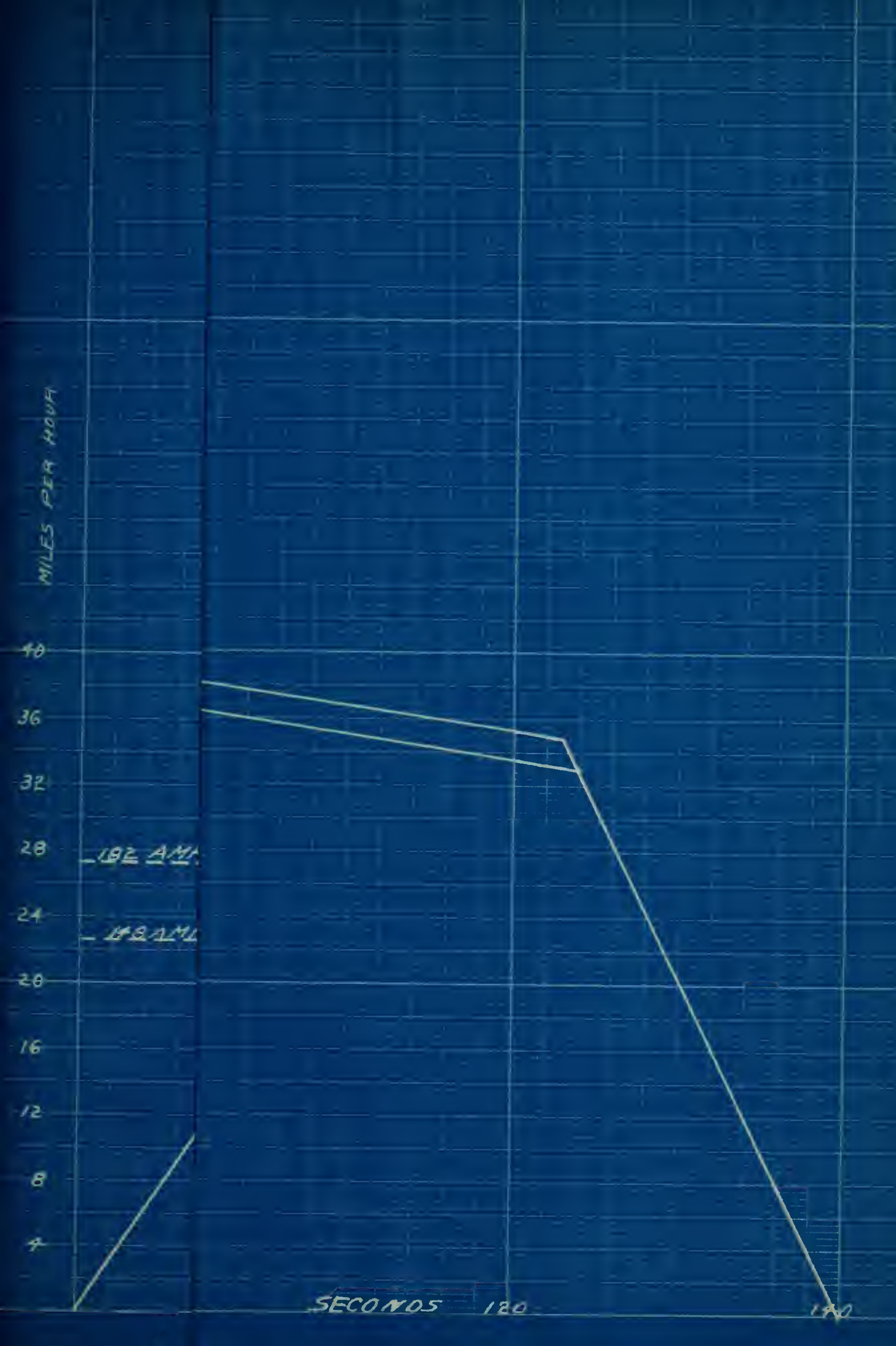


Fig. 5
Performance Curves
Of
Westinghouse
303 A Railway Motor
Ratio 2:85
% Efficiency
M.P.H.
Lbs Tractive Effort
100 50
90 45
80 40
70 35
60 30
50 25
40 20
30 15
20 10
10 5
4000
3000
2500
1500
1000
500
50
75
100
125
150
175
Amperes



MILES PER HOUR
40
36
32
28
24
20
16
12
8
4
SECONDS
120

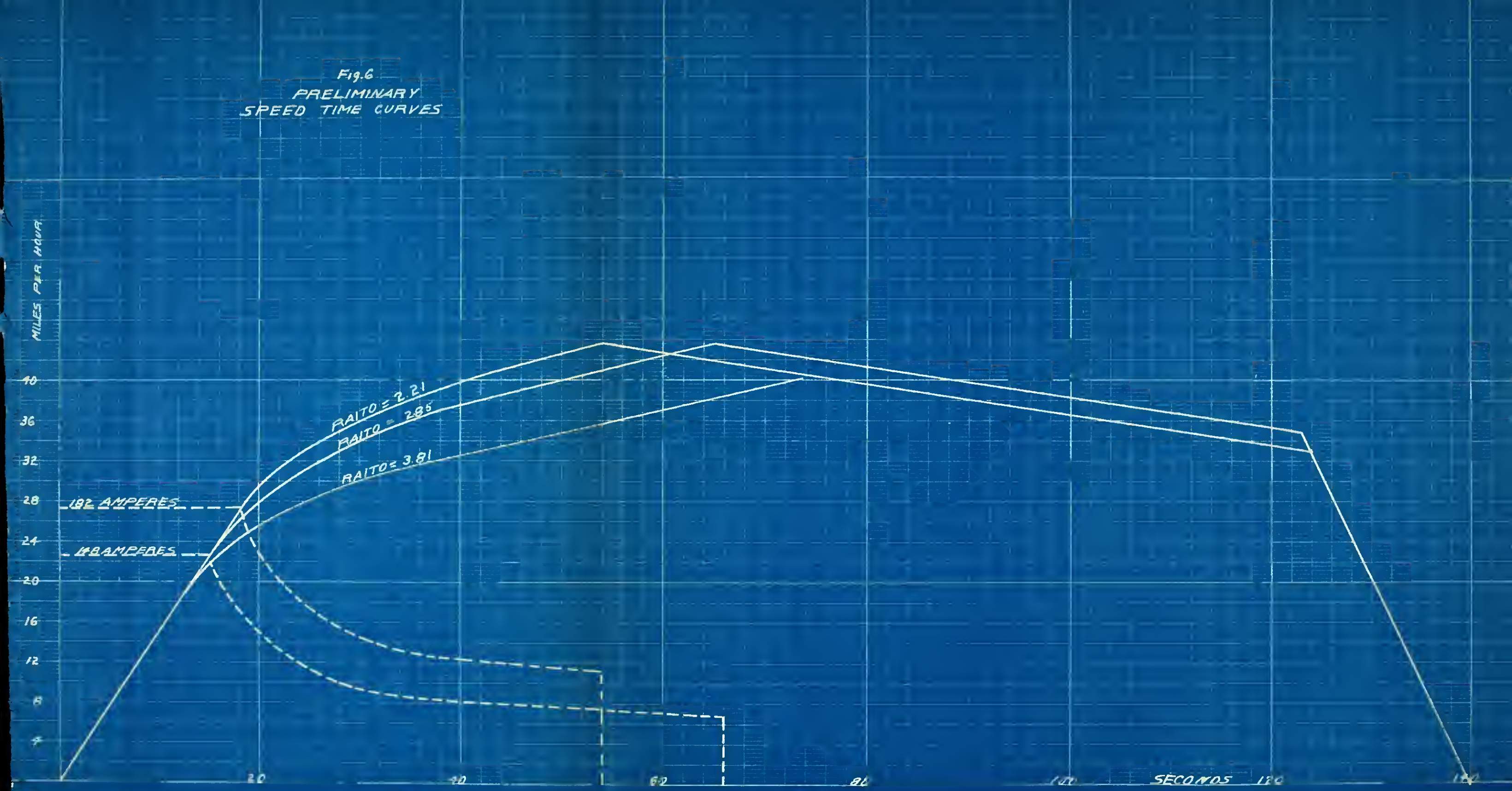


Fig.6
PRELIMINARY
SPEED TIME CURVES
MILES PER HOUR
RAITO = 2.21
RAITO = 2.85
RAITO = 3.81
182 AMPERES
148 AMPERES
40
36
32
28
24
20
16
12
8
4
20
40
60
80
100
SECONDS
120
140

TABLE 2.

dv	V	dt	t
.	27.5	----	18.3
2.5	30.0	2.48	20.78
3.0	33.0	4.20	24.98
3.0	36.0	5.80	30.78
3.0	39.0	7.14	37.92
3.0	42.0	9.85	47.77
3.0	45.0	12.20	59.97
3.0	48.0	18.00	77.97
3.0	51.0	37.90	115.87
3.0	54.0	97.50	213.37

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

The braking line was then drawn with a slope of 2.0, in such a position as to meet the time axis at 140. The coasting line of slope 0.15 was placed in such a manner that the area of the curve was equal to the length of the run.

Curves for the other two gear ratios were plotted in a similar manner and it was found that the motor with a ratio of 3.81 could not make the run in the required time. The problem was then reduced to a selection of one of the two remaining ratios.

The final choice was made by plotting current curves for each gear ratio, and as can be seen from Fig. 6, the motor with a gear ratio of 2.85 consumed the smaller amount of power. The mean effective value of current was calculated and as this came within the continuous rating of the motor and at the same time was not too low, a factor which would condemn the motor as being too large, the motor of 2.85 ratio was chosen.

The type of motor having been decided upon

the final speed-time curves were plotted and are shown on Plates 1 and 2. The calculations for these curves are the same as those mentioned heretofore, with the exception that retarding forces due to grades and curves were considered, same being obtained from the profile of the line. The retarding or accelerating force "G" due to grades, depending on whether the grade is positive or negative, was taken as 200 times the per cent grade; and the retarding force per ton due to curves was set as 0.5 x the degree of curvature. A general equation is:

$$91.1a = p - f - G - C.$$

In case the car is to be started on an up-grade the value of "a" must be calculated because the acceleration for a level track was set at 1.5 and the rheostat was designed accordingly, therefore the starting torque per ton is not to be greater than 151.7, as computed for a straight and level track. The value of "a" for any condition is readily determined by substituting the values of p, f, G, and C in the above equation.

The curves as plotted are for a 600 volt 303A motor, therefore since the series-parallel operation is to be used with a trolley voltage of 1200, the current per car is given by the current curve for such times as all motors are in series. At other points the current per car is twice that shown by the curve.

SCHEDULE.

The traffic over the line having been well established for operation as a steam road the matter of drawing up a schedule for the proposed system was a more or less simple matter. Conditions of traffic operation were considered with the General Passenger Agent of the road and our conclusion as to the best schedule to be followed is indicated on plates 3 and 4. The trains to be operated in accordance with this schedule consist of seven cars for all trains from Chicago to Milwaukee or vice versa; five cars for the Chicago-Waukegan and intermediate, and of two cars for the Kenosha-Milwaukee service.

Without doubt it is true that it would, if possible, be better to have a more frequent schedule of fewer cars per train thus making a saving in the first cost of the feeder system, but upon investigation it was found that the traffic at the present time and for some time to come was of such a nature that trains made

up of several cars would be required for all through trains to Milwaukee.

CARS AND EQUIPMENT.

The cars suggested, are those of The McGuire-Cummings Manufacturing Company's standard type passenger coach with a seating capacity of 62 persons, equipped with four 600 volt 303A, Westinghouse Railway Motors. The motors gear drive to 33-inch wheels with a ratio of 2.85 . The starting equipment is to be that of the Westinghouse multiple-unit control system. The general specifications for car and equipment are the same as those adopted by the American Car Builders Association. The estimated cost of car complete with equipment, was set at $9000.

[illegible]

[illegible]

DISTRIBUTION SYSTEM.

Spot Map.

On inspection of the schedule, speed-time and power curves it was found that the maximum load occured between 7:40 A.M. and 8:30 A.M. A spot map as shown on Plate 5 was then plotted, the total length divided into 28 sections and the average number of cars per section noted. The current per section was calculated on the assumption that each car consumed 100 amperes as an average value. It will be noted that the sum of all the average number of cars when multiplied by 100 amperes is equal to the maximum current indicated by the power curve; therefore it is evident that the spot map represents an average maximum condition.

Substations.

The number of substations for the system was determined by means of the following equation:*

$$\lambda^2 = \frac{n' w l + k_3 f_3' m L}{1.71 L I_0 \sqrt{\rho w k_2 C_2 C_3} + \frac{\rho^2}{\delta^2}\left(\frac{C_3' g_3 k}{L m}\right)} \text{ feet}$$

*(From "Electric Traction and Transmission Engineering", Sheldon & Hausman - P.186.)

n' - attendants per station - - - - - - - 3

w' - attendants salary per year - - - $800.

L - length of road in feet - - - - 446,910

p_3 - annual rate covering interest - $0.15

f'_3 - cost constant - - - - - - - - - - 4600

u - number of units - - - - - - - - - - 3

I_o - mean effective amperes per foot .015

- conductor resistance in ohms - - - 10

w - weight per mil-foot in lbs.- .00000303

p_2 - annual charge against the contact conductor - - - - - - - - $0.06

c_2 - cost of conductor per lb. - - - $0.18

c_3 - cost of power per kilowatt hour delivered from substation - - - $0.01

P - maximum capacity

- rated installed capacity $\frac{P}{2}$ = 20,000

c'_3 - cost /KW Hr delivered to substation $0.01

g_3 - constant for conversion.

h - equivalent annual hours of operation.

The solution of the equation resulted in the choice of seven subatations.

Location of Substations.

The trolley sections previously decided upon were divided into seven parts and the proper location of the substations determined by finding the center of gravity of each division. The current per trolley section was considered as a mechanical load. As a result of this scheme the most economical location of the stations, in thousand feet from Chicago, were found to be: 24.5; 70.6; 115.0; 178.0; 262.0; 350.0; and 418.0

The location of the substations having been decided upon the size of the feeders was calculated on a basis of a 200 volt drop between station bus and end of any feeder. The sizes of positive feeders for one subatation are shown on Plate 6.

SUBSTATIONS.

General Description.

The seven substations previously decided upon are suggested as being of the rotary converter type of 2000 K.W. rated capacity. Each station is to be equipped with three six-phase 1000 K.W. General Electric synchronous converters connected to switch gear apparatus in such s manner that any two of the machines can be operated in series on the direct current side. The alternating current end of each rotary is to be connected to a bank of three single phase oil cooled Allis-Chalmers transformers, delta connected on both high and low tension sides. The oil switches connecting the transformers with the high tension bus are to be of the General Electric H_6 type. The one extra converter has been supplied in insure continous service. The lightning arresters and choke coils have been so chosen and arranges as to give ample protection from storm disturbances.

Operation.

In connection with the starting apparatus of the synchronous converter a field breakup and reversing switch is to be mounted on the frame of each machine. At the moment the machine is connected to the alternating current side, the field switch must be open. The converter being started as an ordinary induction motor by varying the impressed voltage by means of a three pole double throw switch connected to low voltage taps of the transformers as indicated in the wiring diagram.

Full voltage is not to be applied to the machine until the polarity has been determined. As soon as the rotary has nearly reached synchronism, the voltmeter which is located on the switchboard and connected across the direct current terminals of the machine, will indicate the polarity of the apparatus. In case the polarity happens to be the one desired the field switch is closed and the full alternating voltage applied. In case the direct voltage builds up

reversed the field switch is thrown to the reversed position. This operation causes the field flux to oppose the armature flux with the result that the armature flux is in effect pushed aside and the converter "slips a pole". The polarity at the same time is reversed.

Either of the two remaining rotaries is then started in a similar manner and finally put in series by means of switches which are so interlocked that the operator cannot connect any two machines in parallel on the direct current side.

The speed limit device must be tested so as to obtain proper operation before the machine on which it is to be installed is put into service.

The apparatus is protected on both sides of the machine with overload relays.

Specifications.

The specifications of all apparatus will be standard, only the performance being consid-

ered in this discussion.

Rotary Converter.

After a run of 24 hours at full load the temperature rise of the armature and field coils shall not be more than 35° C. The machine when operated at 150% overload shall not indicate a temperature rise of more than 55° C. after a two hour run.

Relative to overload capacity, the machine must be of such design as will carry a 50% overload without movement of the brushes and without injurious sparking, and an overload of 100% at full voltage momentarily without flashing over or injurious sparking.

The efficiency of the machine to be as follows:

150%	Full load	- - - - 97.0%
100%	" "	- - - - 96.5%
75%	" "	- - - - 96.0%
50%	" "	- - - - 94.5%

Transformers.

After a run of 24 hours at full load, the rise of temperature of any part of the transformer shall not exceed 35° C. The transformer must be of such design as will carry an overload of 25% without greater rise of temperature than 57° C.

The efficiency is to be as follows:

150%	Full load	98.3%
100%	" "	98.3%
75%	" "	98.2%
50%	" "	97.8%
25%	" "	96.2%

TRANSMISSION LINE.

Choice of Wire.

The distance between the power house and substation No. 5 is 63,000 feet. The load up to this station is 6250 K.W.

Assume the following:

Phases - - - - - - - 3

Receiver voltage 30000

Cycles - - - - - - 25

Loss - - - - - - - 2%

Loss = 125 K.W.

Loss per wire = 46.1 K.W.

I = 120 amperes.

R = 41600 ÷ 120^2 = 2.9 ohms.

R per 1000 feet = 2.9 ÷ 63 = 0.046

Wire required: #0000 copper or 400,000 cir. mils aluminum.

Consider a #0000 copper wire.

Resistance per 1000 feet = 0.048

Line resistance = 0.048 x 63 = 3.2

Power loss = 120^2 x 3.2 = 46,000 watts.

Cost of 46 K.W. per year = $4030.

Cost of 1000 feet #0000 wire =$400.

Cost of 63,000 feet = $25,200.

Interest and depreciation = $1512.

Annual charge against copper = $26,712.

Consider a #000 copper wire.

Resistance per 1000 feet =0.06 ohms.

Line resistance = 3.78

Power loss = 54.4 K.W.

Cost of 54.4 K.W. per year = $4660.

Annual charge against copper = $23,956.

Saving on copper=$26,712.- $23,956= $2756.

Increase in cost of power = $630.

Net saving = $2756. - $630. = $2126.

Consider a #1 copper wire.

Resistance per 1000 feet = 0.1215

Line resistance = 7.65

Cost of power lost = $9600.

Annual charge against copper = $13,356.

A #2 copper wire indicates a small saving over the #1, but inasmuch as the current would not be well within the current carrying capacity

the #1 wire was selected as being the most economical size of wire as far as first cost and copper wire itself were concerned.

Consider a #000 aluminum wire.

Resistance per 1000 feet = 0.0996

Line resistance = 6.2

Power loss = 90.400 watts.

Cost of 90.4 K.W. per year = $7920.

Cost of wire = $13,800.

Annual charge against aluminum= $14,628.

Consider a #00 aluminum wire.

Resistance per 1000 feet = 0.125

Line resistance 7.87

Power loss = 113,000

Cost of 113 K.W. per year = $9900.

Cost of wire = $11,500.

Annual charge = $12,190.

Saving on aluminum = $2438.

Increase in cost of power = $1980.

Net saving of $350.

The wires now considered are the #000 aluminum and the #1 copper. The relative costs are given below:

Wire	Cost of wire	Cost of power.	Total
#000 Al.	\$14,628.	\$7920.	\$22,548.
#1 Cu.	\$13,356.	\$9600.	\$22,956.

The #000 aluminum wire was selected because of its first cost; weight, a factor which determines the size of the towers or poles; and because of its greater tensile strength.

Spacing of Wires.

The wires are to be arranged in delta, 36 inches apart.

Capacity and Inductance per Wire.

The inductance per wire equals L.

$$L = 2\left(\log_e \frac{2}{r} + \frac{1}{4} - \log_e \frac{2}{D}\right)$$

L per foot = L_1.

$$L_1 = 2 \times 12 \times 2.54\left(\log_e \frac{2 \times 12}{.41} + \frac{1}{4} - \log_e \frac{24}{36}\right) 10^{-9}$$

$$= 264 \times 10^{-9} \text{ henrys.}$$

Length of line = 63,000 feet.

Inductance per wire = 0.01662 henry.

Capacity in farads per mile equals C.

$$C = \frac{38.8 \times 10^{-9}}{\log_{10}\frac{2D}{d}} = \frac{38.8 \times 10^{-9}}{\log_{10}\frac{72}{.41}}$$

$= 17.4 \times 10^{-9}$ farads per mile.

Therefore the line capacity to neutral is:

207×10^{-9} farads.

The natural period of the circuit is given by the equation:

$$2\pi\sqrt{LC}$$

$$= 2 \times 3.1416\sqrt{0.01662 \times 207 \times 10^{-9}}$$

$$= 0.00036.$$

Therefore there is no danger of resonance taking place.

The voltage at the generating station equals E_g.

$E_g = E \cosh PS + z_o I \sinh PS.$

P= propagation constant.

$P^2 = \sqrt{(r + jpL)(g + jpC)}$

r - resistance per mile = 0.52

L - inductance per mile = 0.0014.

C - capacity per mile = 17.4×10^{-9}

$p = 2\pi f = 157$

$pL = .22$

$pC = .273x10^{-5}$

$S =$ distance in miles 11.9

$P = \sqrt{(.52\ j.22)(0\ j.273x10^{-5})}$

$.00154\ 56^{o}\ 28'$

$\cosh P = \cosh x \cos y + j \sinh x \sin y$

$Z_o = \sqrt{\frac{r\ jpL}{g\ jpC}}$

$E_g = 17900$

To check this value of E_g the following method has been used:

$X_c = 10^9/2\ 25x207 = 30800$

$I_c = 30000/2x30800x1.73 = .282$

$RI_c = 6.18x.282 = 1.742$

$X_L I_c = 2.62x.282 = .738$

$RI = 6.18x133.5 = 825$

$X\ I = 2.62x133.5 = 350$

From the diagram on page 34:

$BA = 7451.2 + 350 = 7801.2$

$OB = 16373.5$

Therefore,

$OA = 18000$

$E_o = E_g / 1 - X_L/X_c$

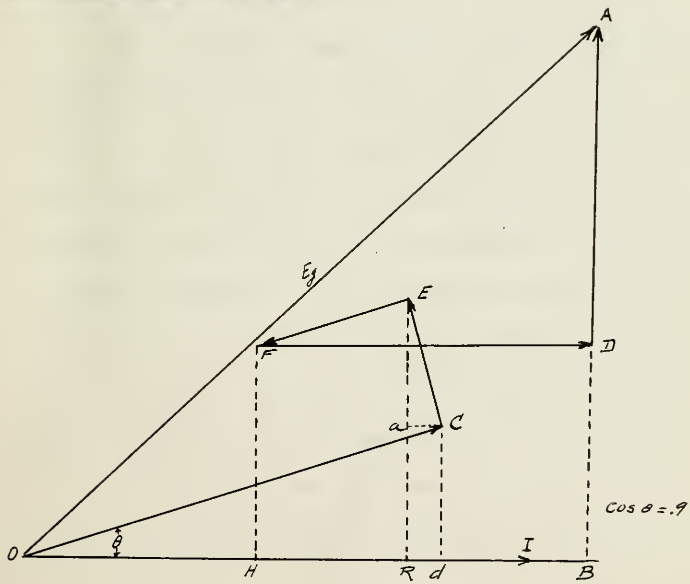
E_o = No-load voltage

E_g = Generated voltage

$$E_o = \frac{18000}{1 - \frac{2.62}{30800}} = 18000.$$

$$Reg. = \frac{18000-17320}{17320} \times 100 = 3.97\%$$

The economical sizes of wire between stations 5 and 6, 6 and 7, were found to be No. 0 aluminum and No. 1 aluminum respectively.



POWER HOUSE.

Location.

The power house designed to carry the load of the proposed electrification is to be located on the bank of Lake Michigan at a point near the city of Beach, 37 miles from Chicago. This location was found most suitable from the load conditions of the road and for operating facilites of the plant.

Power Curve.

The capacity of the power house was determined from the load curve shown on plate 7. This load curve was obtained by finding the current taken by each car on the road, from the current curve for every ten minutes. The total current expressed in K.W. with an additional 19 K.W. per car to take care of heating, lighting, and air brake equipment, was plotted against time. This resultant curve constitutes the load curve.

From this curve the peak loads were found to be 14,500 K.W. and 14,000 K.W. occuring at

8:00 A.M. and 6:00 P.M., respectively, and the average minimum load to be about 2500 K.W. at 3:00 A.M.

The generating units were chosen so that the plant would operate at about the same efficiency for all loads. In order to make the plant flexible and accomplish the mentioned result the following units were selected: three 5000 K.W. and one 3000 K.W., making a total of 18,000 K.W. rated capacity. The additional capacity was provided to serve as a reserve in case of breakdown of some unit.

Equipment.

The driving units are high pressure turbines of the Curtis horizontal type, equipped with Wheeler surface condenser of 18,000 square feet for the 5000 K.W. units and 14,000 square feet for the 3000 K.W. units.

The condensing pumps are: circulating pump, 18-inch, D.A. Volute pump, turbine driven, 24-inch suction and discharge; hot well

pump, 23 inch, 2 stage, turbine driven; vacuum pump, Wheeler tandem rotary dry vacuum pump for 18,000 and 14,000 square feet condenser, respectively.

The exciters: one 200 K.W. 110 volt General Electric, driven by Curtis non-condensing steam turbine, and one 200 K.W. 110 volt motor driven.

One 40 ton Century Crane.

The transformers, K_2 oil switches, low tension buses, and selector switches are located on the main floow at the side of the engine room. The H_6 oil switches, high tension buses, and operating board are on the second floor. The lightning arresters, choke coils, and line outlets are on the third floor.

The rheostats and storage batteries are located on the basement floor.

Boiler Room.

The boiler equipment consists of 16- 750 boiler horsepower Babcock and Wilcox water tube boilers equipped with chain grate automatic

stokers and superheater, furnishing steam at 200 lbs. gauge and 150 degrees superheat.

The water heater: 1 #8 Stilwell, horizontal 1200 H.P. heater.

Boiler feed pumps: two Alberger turbine driven boiler feed pumps of 5000 boiler horse power capacity, operating in multiple.

The coal and ash handling equipment consists of two sets of bucket conveyors running parallel to the length of the boiler room. Each set of conveyors handles both coal and ash for one row of boilers. Coal bunkers of sufficient capacity are placed above the boiler settings and have gravity feed downspouts.

Chimneys: four 9-foot diameter brick chimneys, 150 feet high.

The over-all dimensions of the plant are: length: 212 feet; width: 197 feet; height: 64 feet.

SWITCHBOARD.

The switch board is of the desk type. The operating stand is so situated that the operator has a clear view of the whole engine room. The instruments are above the operating stand.

The list of instruments is as follows:

7 D.C. Ammeters.

14 A.C. Ammeters.

3 D.C. Voltmeters.

5 A.C. Voltmeters.

4 Power factor indicators.

6 Indicating wattmeters.

4 Recording wattmeters.

1 Frequencymeter.

These instruments comprise the D.C. and A.C. sides of the operating board. The D.C. instruments are used for the field excitation and exciters.

The control is all of the remote type. For the low tension side there are:

11 K_2 Oil switches.

8 H_3 Oil switches.

4 Motor controlled governors.

6 Remote controlled rheostats.

The K_2 and H_3 oil switches and the circuit breakers are all solenoid operated. The engine governors are controlled from the operating stand through a small motor.

The general arrangement of the switchboard is made up of a storage battery panel for emergency, a steam driven exciter panel, an induction motor driven exciter panel, four steam driven generator panels, and one feeder panel. The battery panel has an ammeter and voltmeter with a switch and rheostat for charging or discharging the batteries. The steam driven exciter has an ammeter and voltmeter with circuit breaker control. For the induction motor starting, a compensator is used, giving half voltage for starting. This panel has an ammeter and voltmeter. The generator panels each have three ammeters, a voltmeter, power factor indicator, indicating wattmeter, and recording wattmeter. An overload signal lamp is also used. The feeder panels have two ammeters

and two indicating wattmeters, one ammeter and one wattmeter being used on each outgoing line. This is made possible by having a balanced load at all times, since all of the power is supplied to rotary converters.

The operating stand is 14 feet long, 5 feet wide, and 8 feet high. The desk stand is 2 feet 8 inches high at the front and 3 feet 4 inches high at the rear.

The voltage generated is 6600 volts and this is stepped up to 30,820 volts through three single phase transformers connected to each generator. The capacity of the transformers for the 3000 K.W. unit is 1000 K.W. each and for the 5000 K.W. unit is 1600 K.W. each.

PLATE Nº 3

NORTHBOUND SCHEDULE

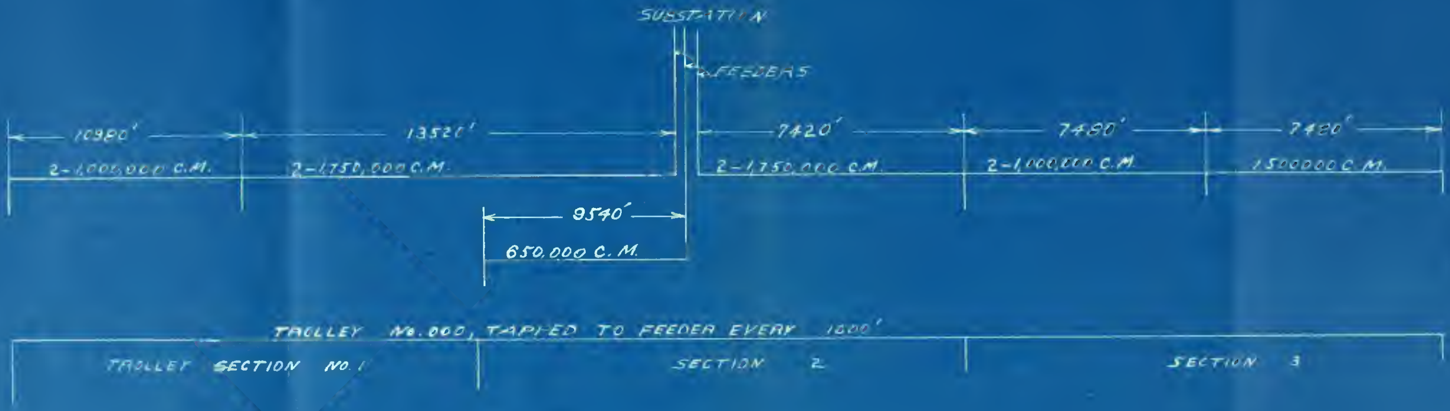
	1–163 (A.M./P.M.)
Passenger Terminal	[illegible]
Calhoun	[illegible]
Deering	[illegible]
Grand Park	[illegible]
Cuyler	[illegible]
Ravenswood	[illegible]
Summerdale	[illegible]
Rose Hill	[illegible]
Kenmore	[illegible]
Rogers Park	[illegible]
Main St. (Evanston)	[illegible]
Dempster St. (Evanston)	[illegible]
Davis St. (Evanston)	[illegible]
Central St. (Evanston)	[illegible]
Wilmette	[illegible]
Kenilworth	[illegible]
Winnetka	[illegible]
Hubbard Woods	[illegible]
Glencoe	[illegible]
Ravinia	[illegible]
Highland Park	[illegible]
Highwood	[illegible]
Fort Sheridan	[illegible]
Lake Forest	[illegible]
Lake Bluff	[illegible]
Great Lakes	[illegible]
North Chicago	[illegible]
Waukegan	[illegible]
Beach	[illegible]
Zion City	[illegible]
Camp Logan	[illegible]
Winthrop Harbor	[illegible]
Kenosha	[illegible]
Tessenville	[illegible]
Racine Junction	[illegible]
Racine	[illegible]
County Line	[illegible]
Carrollville	[illegible]
South Milwaukee	[illegible]
Cudahy	[illegible]
Allis	[illegible]
Milwaukee	[illegible]

PLATE No 4

SOUTHBOUND SCHEDULE

	2	4	6	8	10	12
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.
Milwaukee	1:30	3:00			5:30	
Allis	1:33	3:03			5:33	
Cudahy	1:45				5:45	
So. Milwaukee	1:51				5:51	
Caledonia	1:56				5:56	
County Line	2:01				6:01	
Racine	2:11	3:36			6:11	
Racine Junct	2:14				6:14	
[illegible]	2:21				6:21	
Kenosha	2:27	3:52			6:29	
Winthrop Harbor					6:37	
Camp Logan					6:43	
Zion City					6:46	
Beach					6:50	
Waukegan	2:51	4:26	5:00	5:35	6:57	5:57
North Chicago			5:08	5:42	7:05	6:03
Great Lakes			5:10	5:44	7:07	
Lake Bluff			5:15	5:50	7:12	6:09
Lake Forest			5:19	5:56	7:16	6:13
Fort Sheridan			5:24	5:57	7:21	6:18
Highwood			5:27	6:02	7:24	6:21
Highland Park	3:16	4:41	5:30	6:05	7:26	6:24
Ravinia			5:32	6:08	7:30	6:27
Glencoe			5:37	6:11	7:34	6:31
Hubbard Woods			5:40	6:15		6:34
Winnetka			5:43	6:17		6:36
Kenilworth			5:45	6:20		6:39
Wilmette			5:47	6:23		6:41
Central St. (Evanston)			5:50	6:26		6:46
Davis St. " "	3:34	4:57	5:53	6:28	7:41	6:47
Dempster St. " "			5:55	6:30		6:49
Main St. " "			5:56	6:31		6:50
Rogers Park			6:01	6:36		
Kenmore			6:03	6:38		
Buena Vista			6:05	6:40		
Summerdale			6:07	6:43		
Ravenswood			6:09	6:45		
Cuyler			6:11	6:47		
Irving Park			6:13	6:49		
[illegible]			6:16	6:52		
[illegible]			6:18	6:54	8:06	
Terminal Station	3:56	5:21	6:26	7:00	8:10	7:21
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.

PLATE-6



POSITIVE FEEDERS
FOR
SUBSTATION No 2

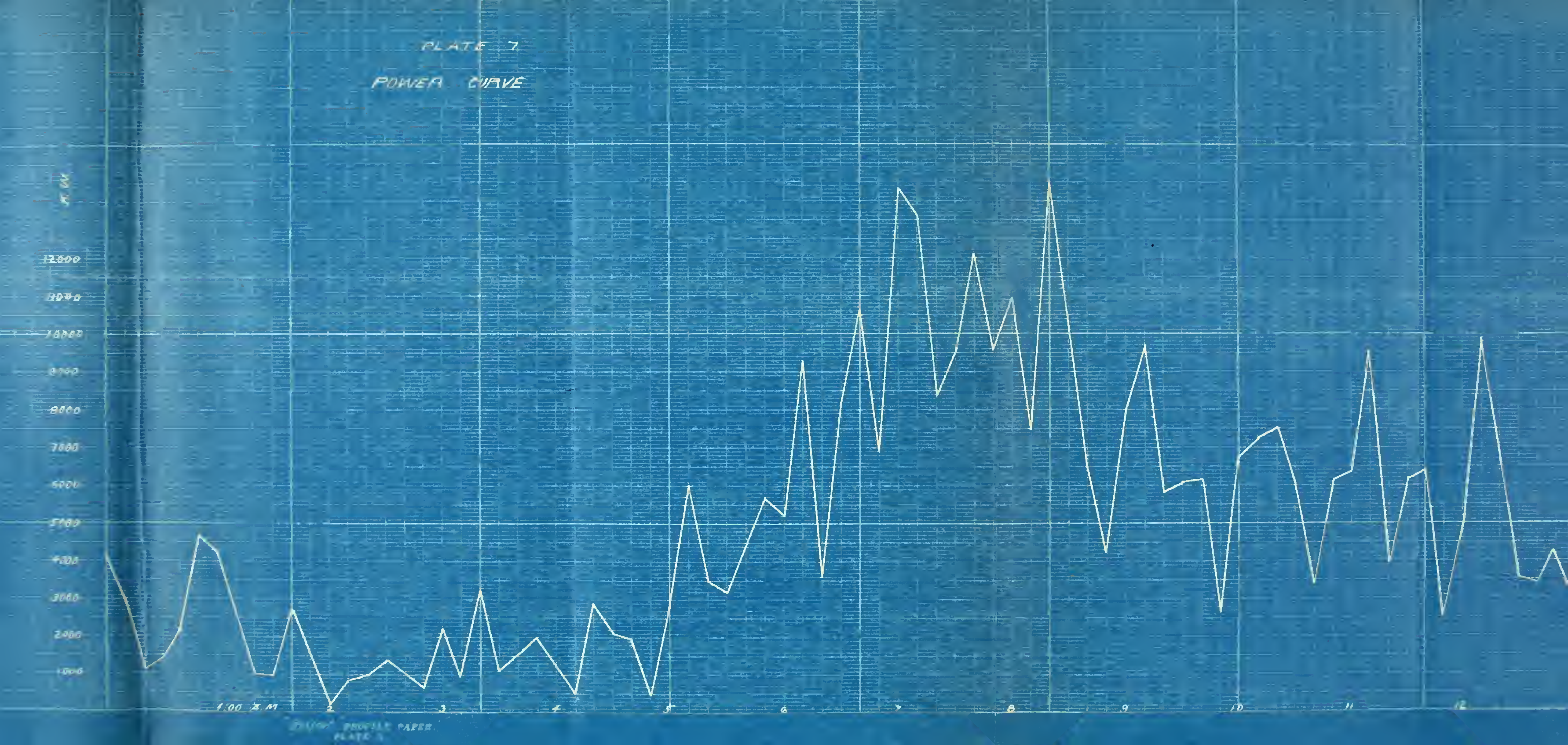
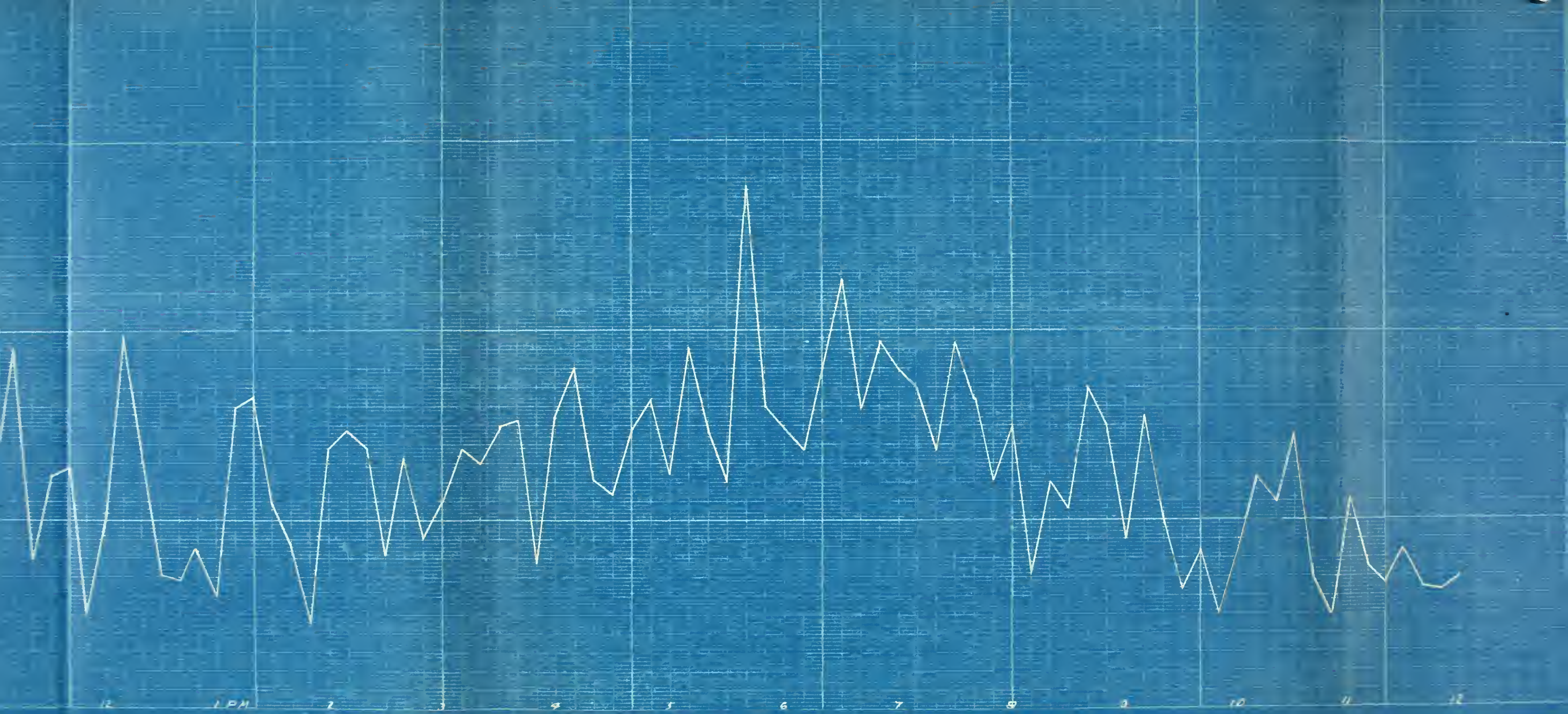
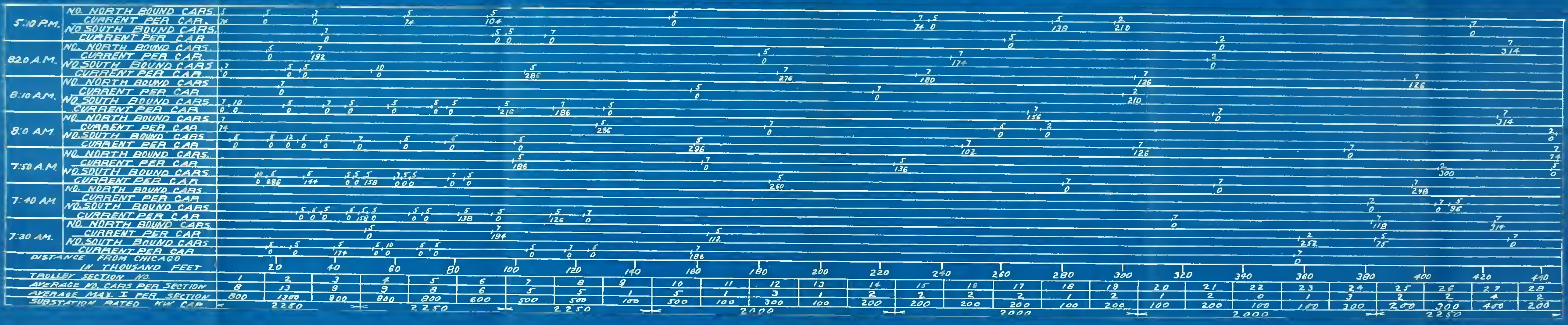


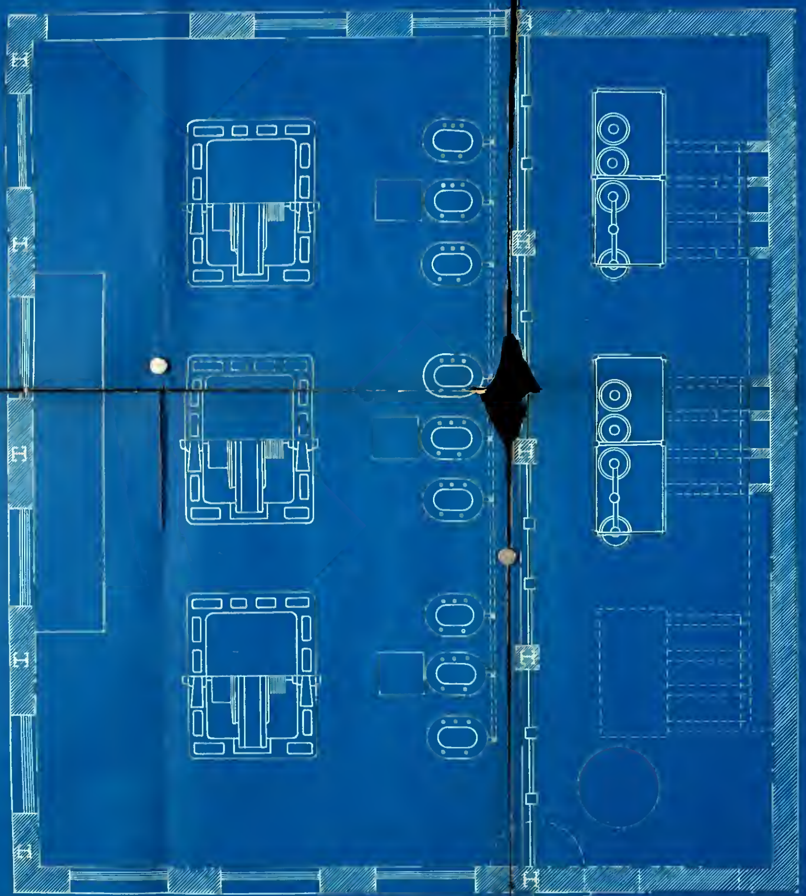
PLATE 7
POWER CURVE
K.W.
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
1:00 A.M
2
3
4
5
6
7
8
9
10
11
12
PROFILE PAPER

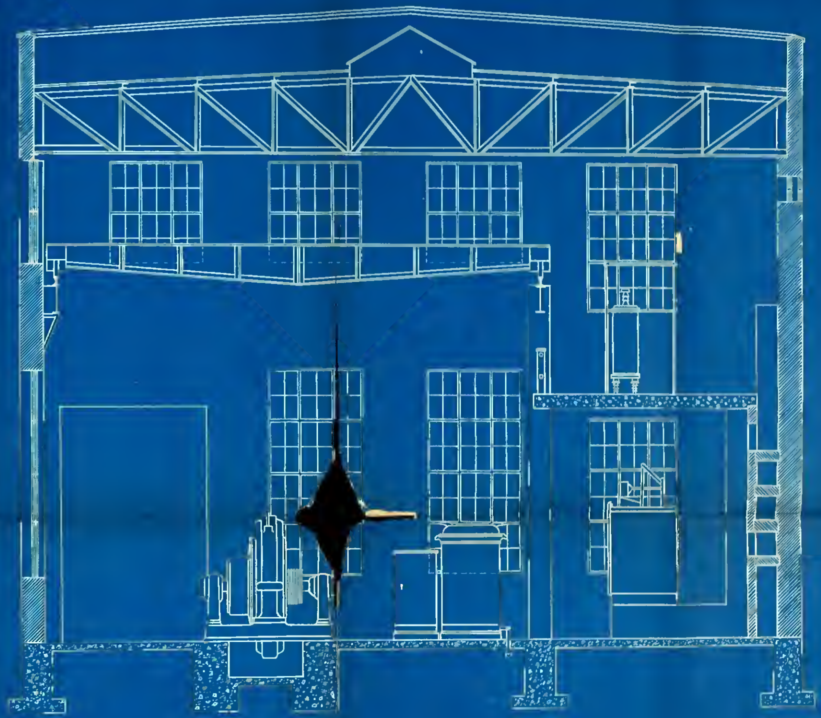


12
1 PM
2
3
4
5
6
7
8
9
10
11
12

AM. AND P.M. RUSH
SPOT MAP
PLATE 5







SUB-STATION

FOR

PROPOSED ELECTRIFICATION

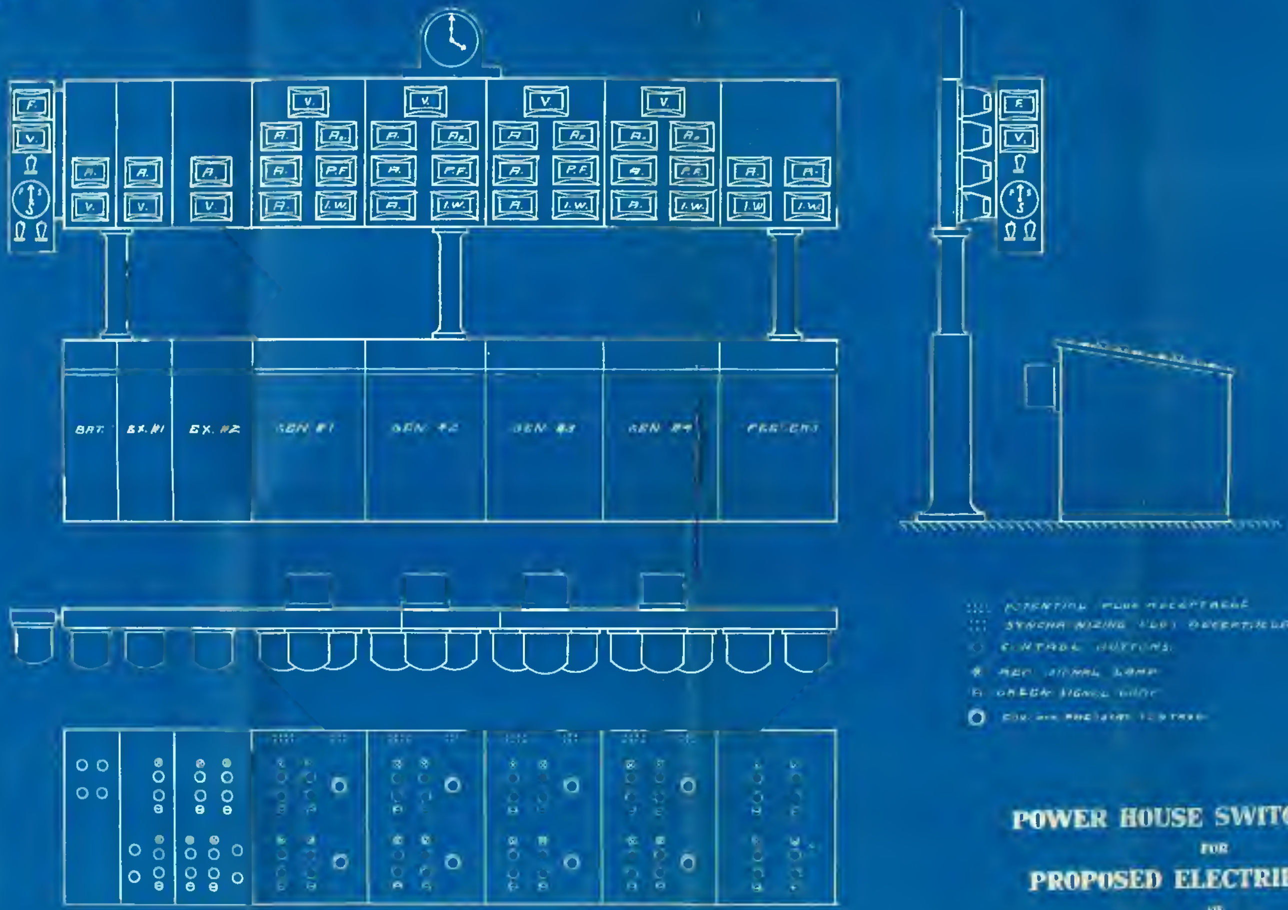
OF

THE MILWAUKEE BRANCH

CHICAGO AND NORTHWESTERN RY.

ARMOUR INSTITUTE OF TECHNOLOGY

SCALE ¼" = 1'



POWER HOUSE SWITCH BOARD

FOR

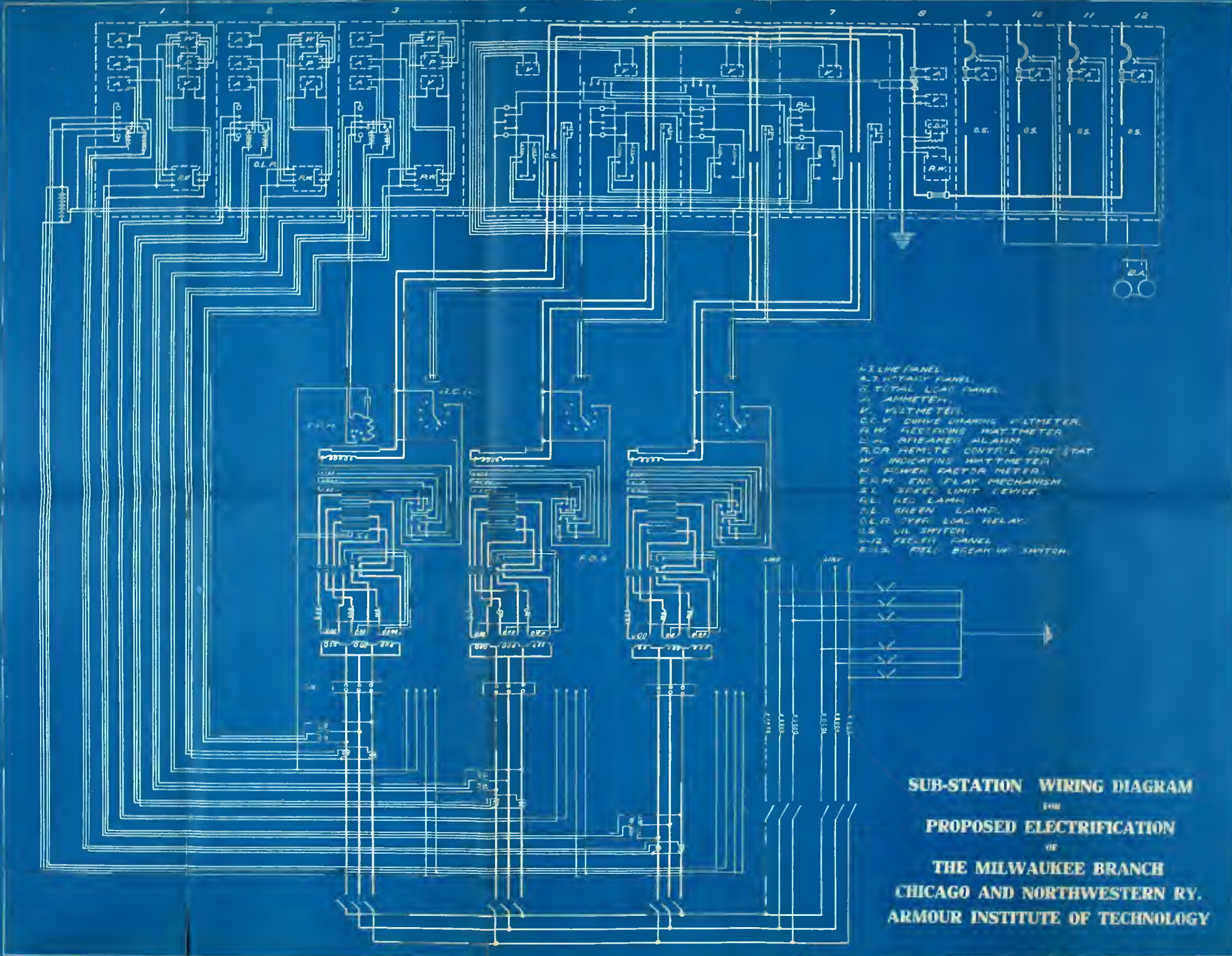
PROPOSED ELECTRIFICATION

OF

THE MILWAUKEE BRANCH
CHICAGO AND NORTHWESTERN RY.

ARMOUR INSTITUTE OF TECHNOLOGY

SCALE $\frac{1}{2}$" = 1'



SUB-STATION WIRING DIAGRAM

FOR

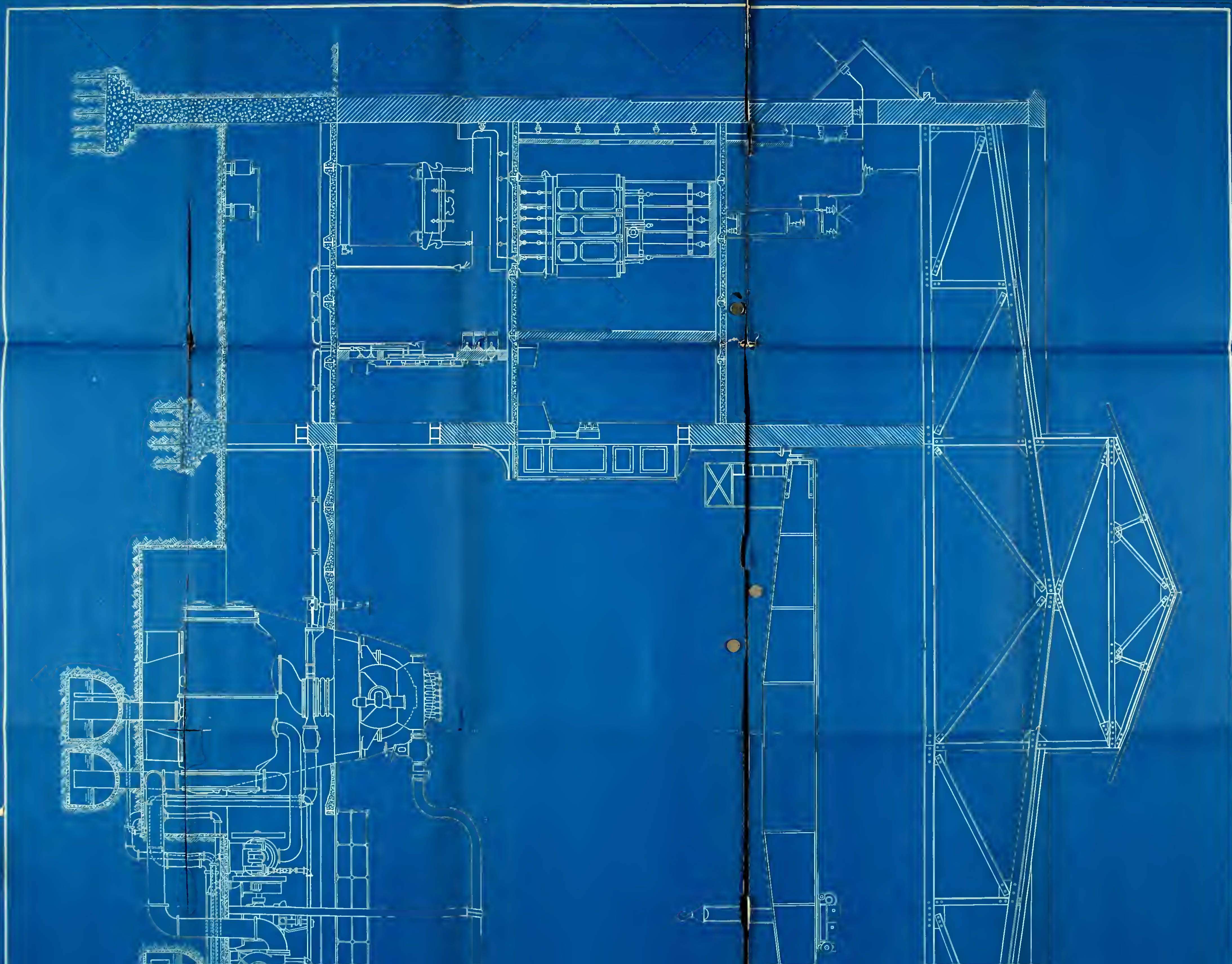
PROPOSED ELECTRIFICATION

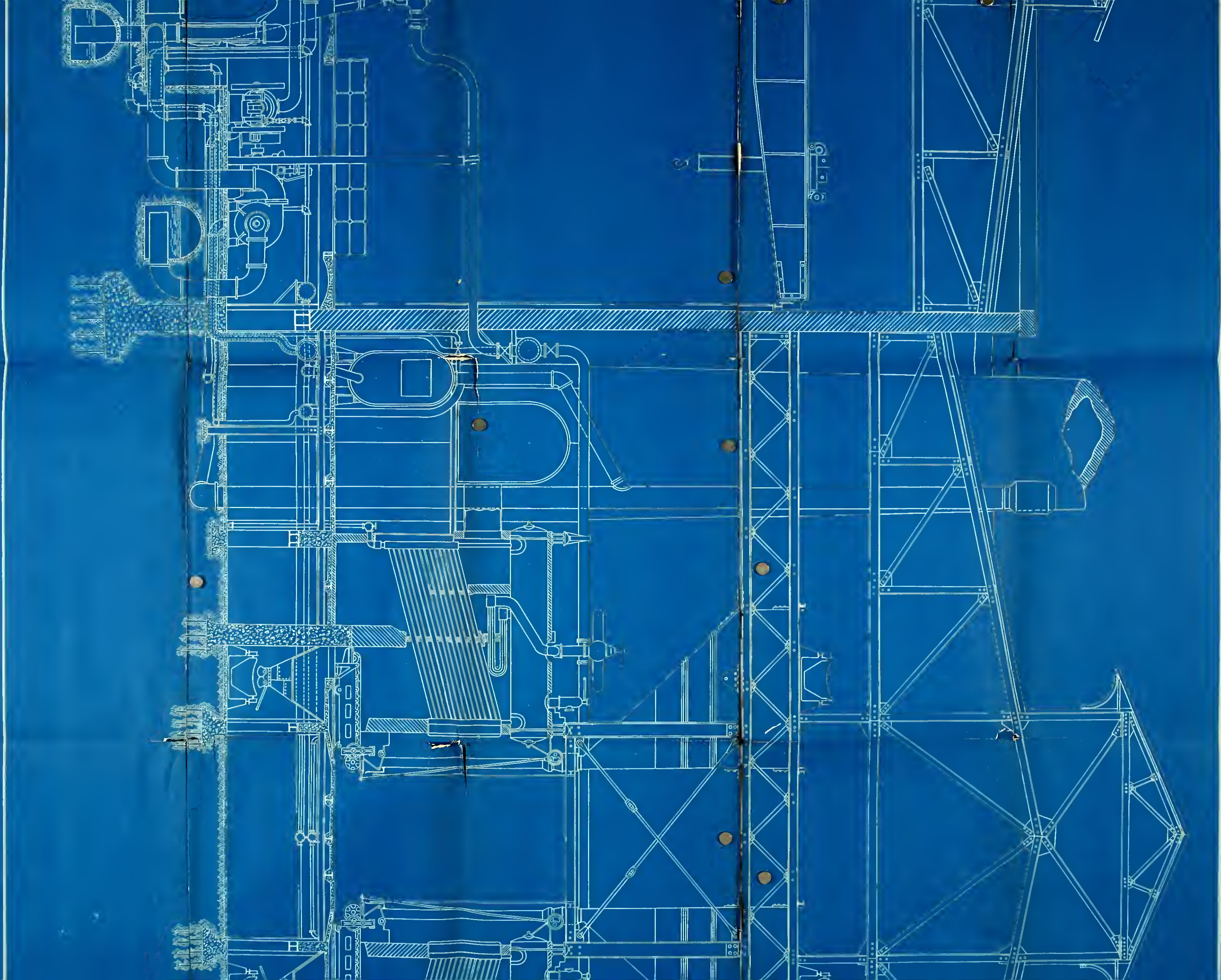
OF

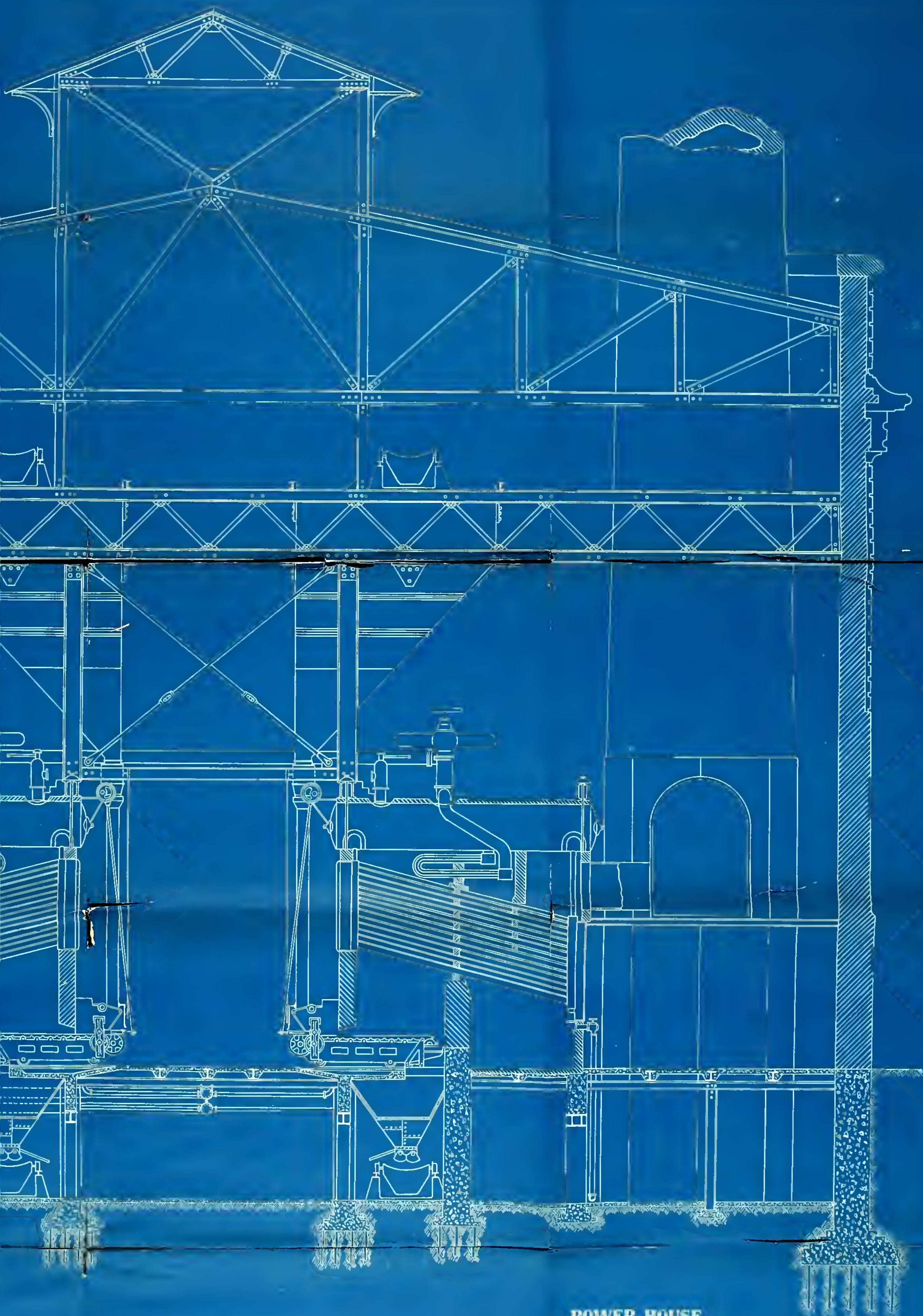
THE MILWAUKEE BRANCH

CHICAGO AND NORTHWESTERN RY.

ARMOUR INSTITUTE OF TECHNOLOGY







POWER HOUSE

FOR

PROPOSED ELECTRIFICATION

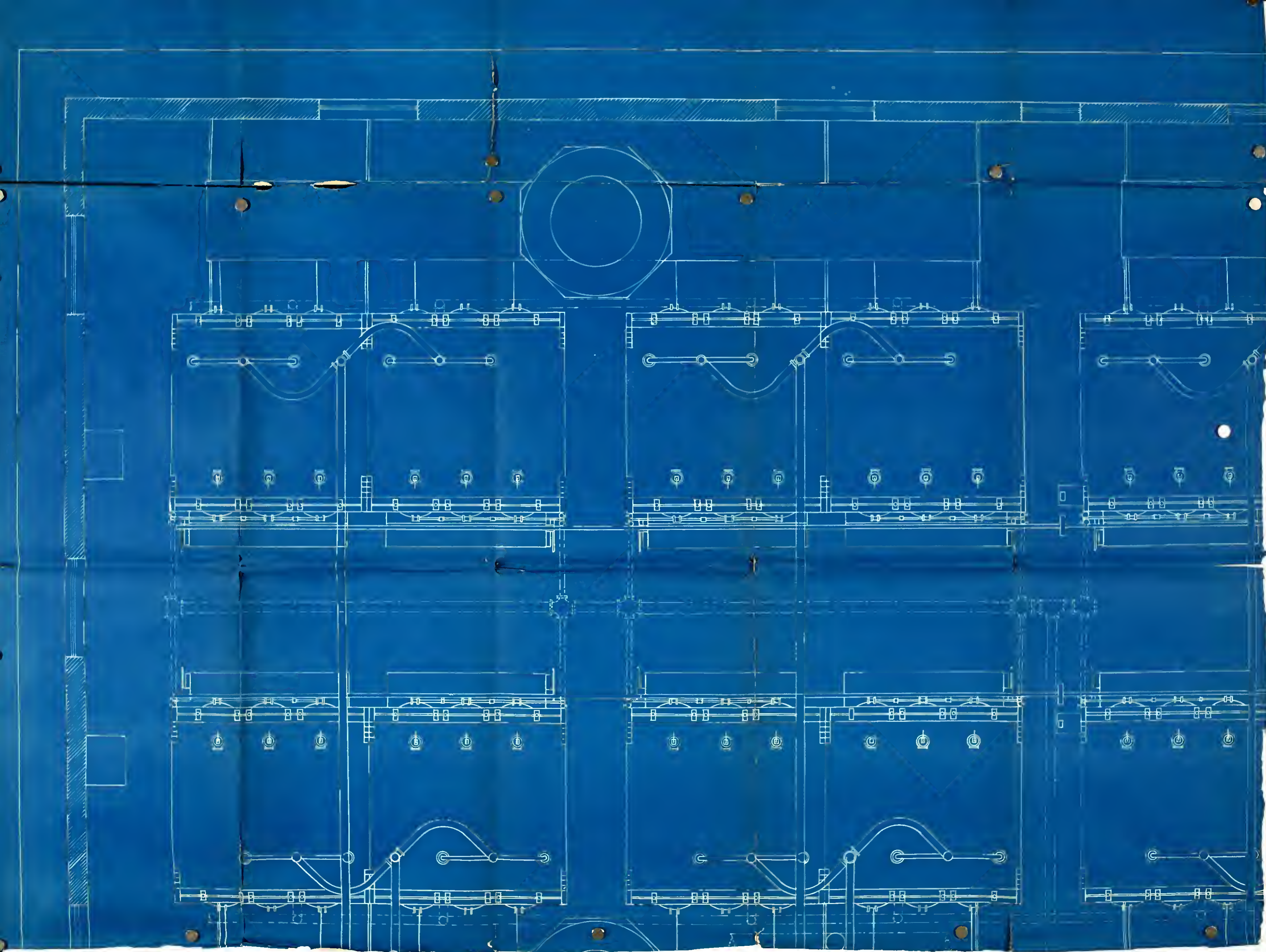
OF

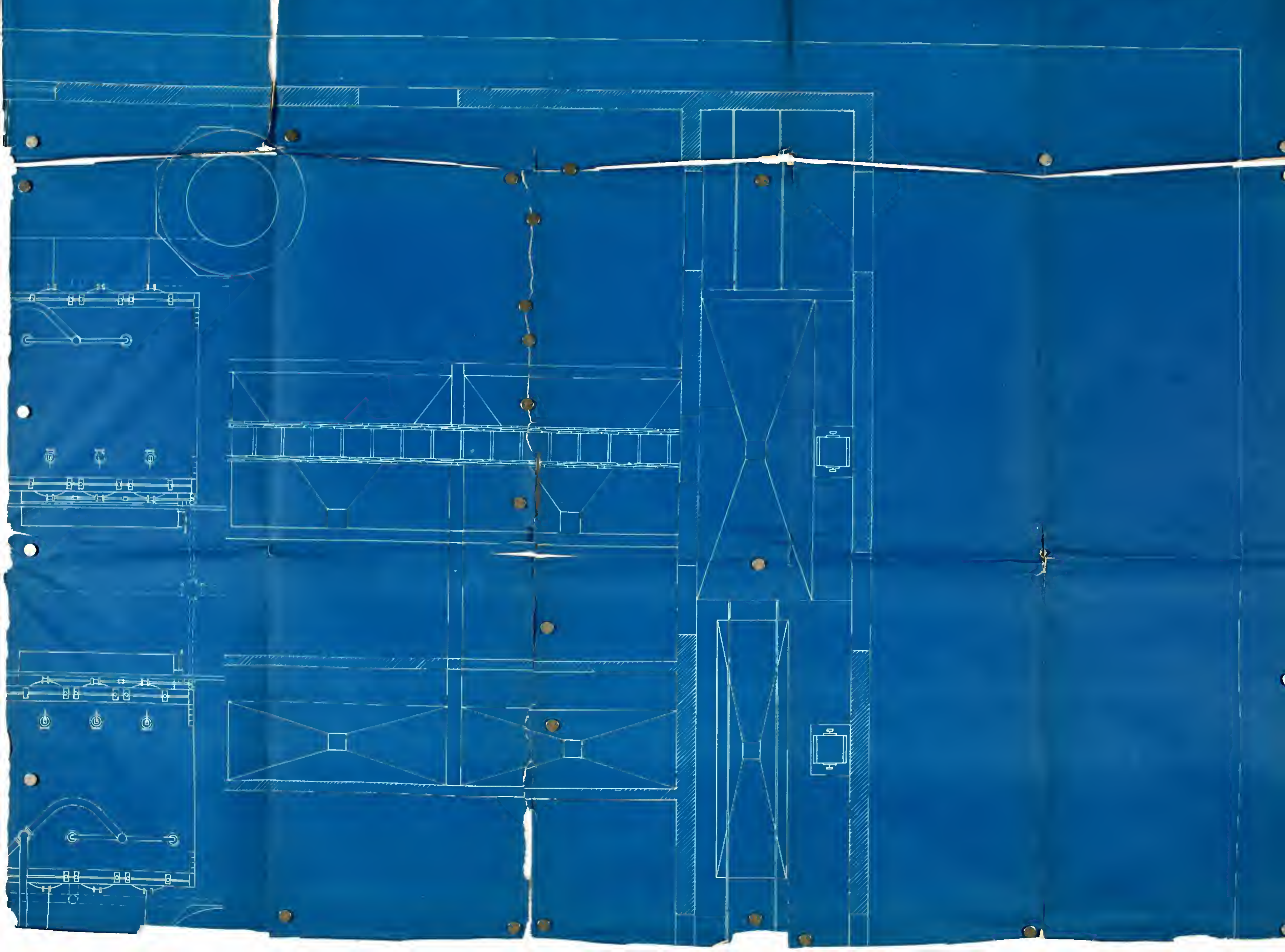
THE MILWAUKEE BRANCH

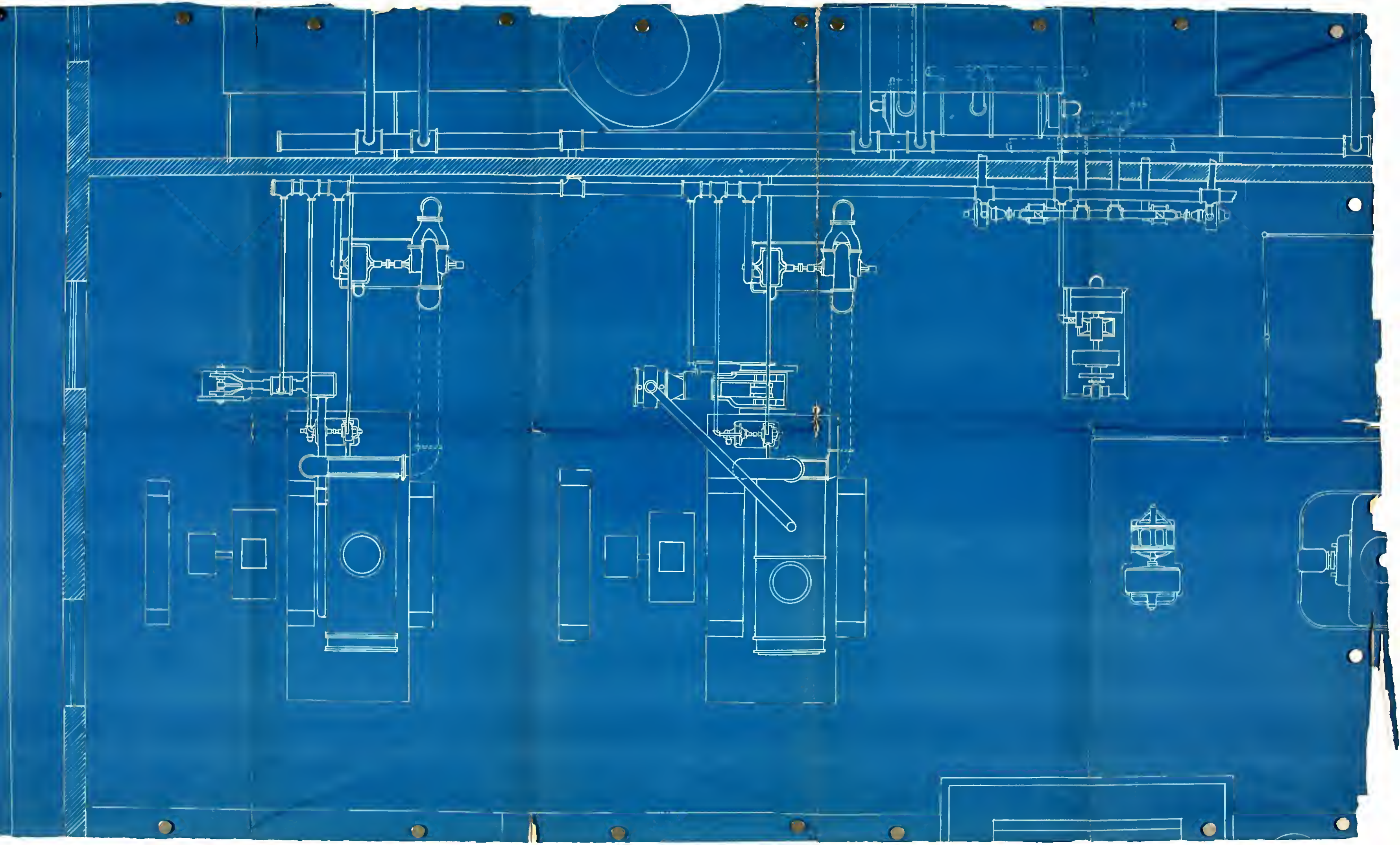
CHICAGO AND NORTHWESTERN RY.

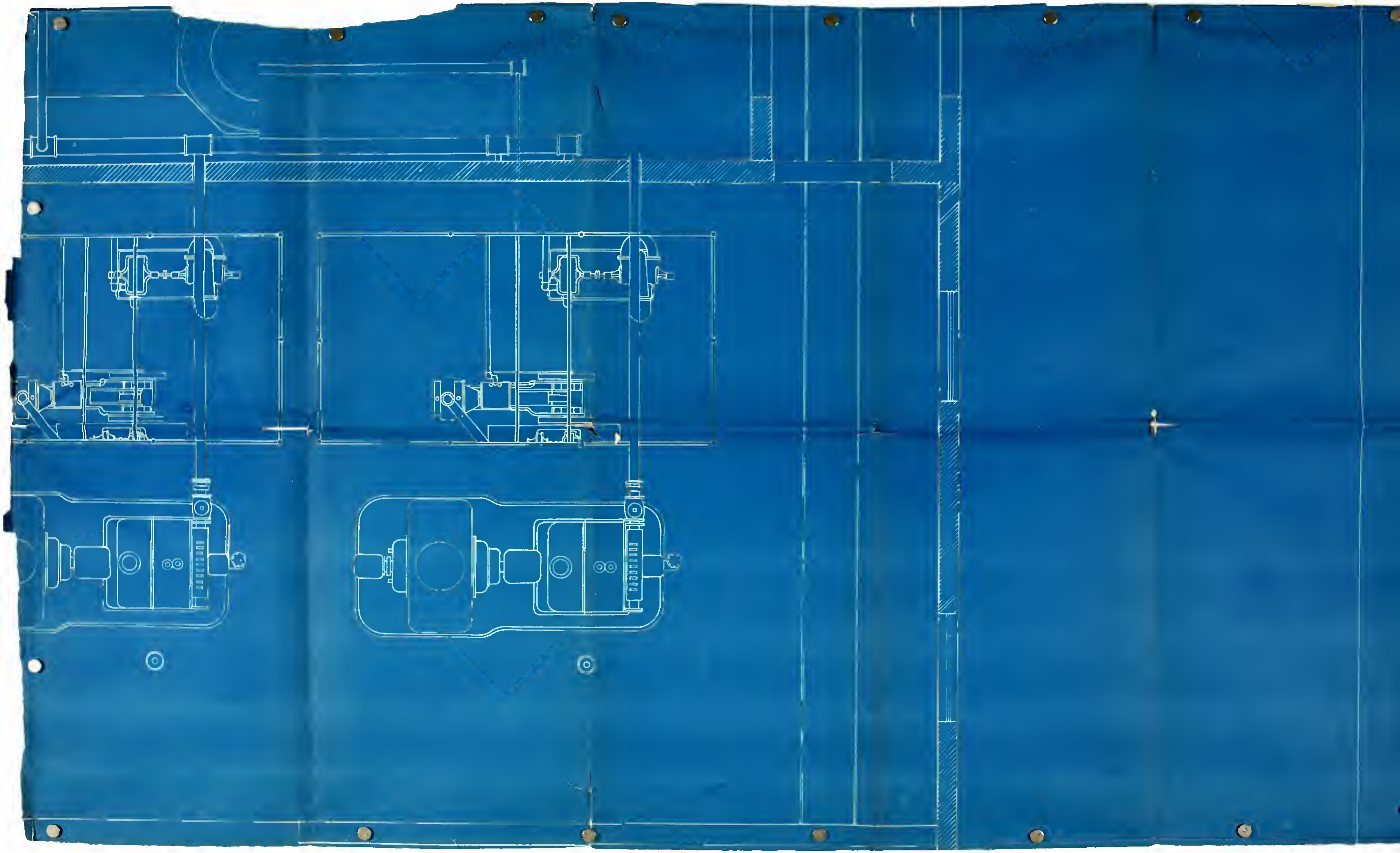
ARMOUR INSTITUTE OF TECHNOLOGY

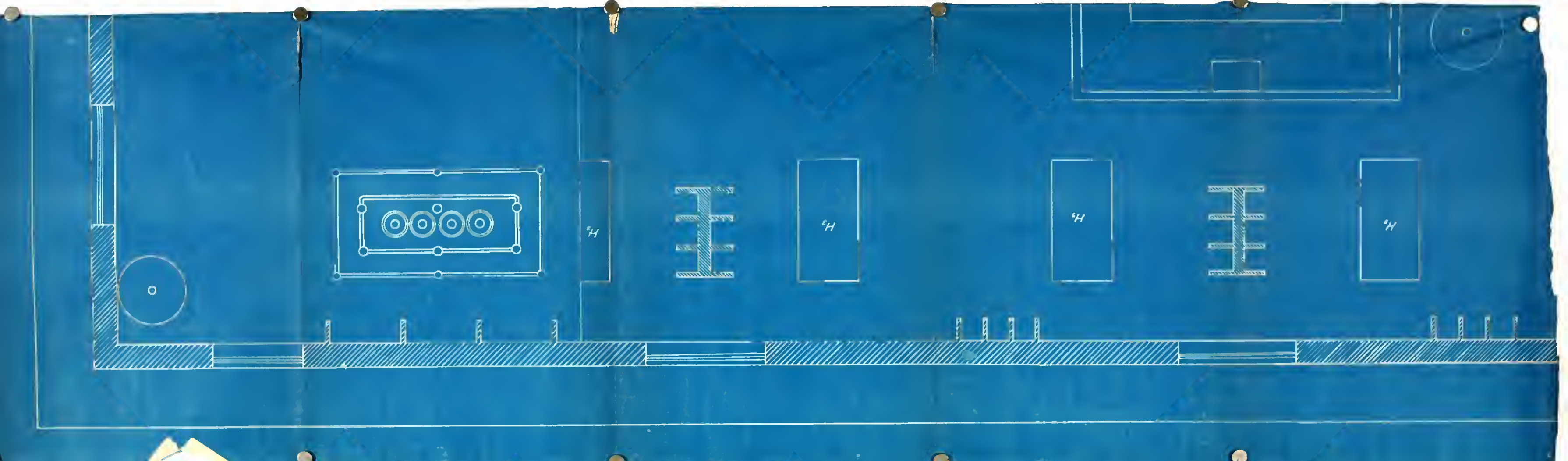
SCALE ¼" = 1'











POWER HOUSE

FOR

PROPOSED ELECTRIFICATION

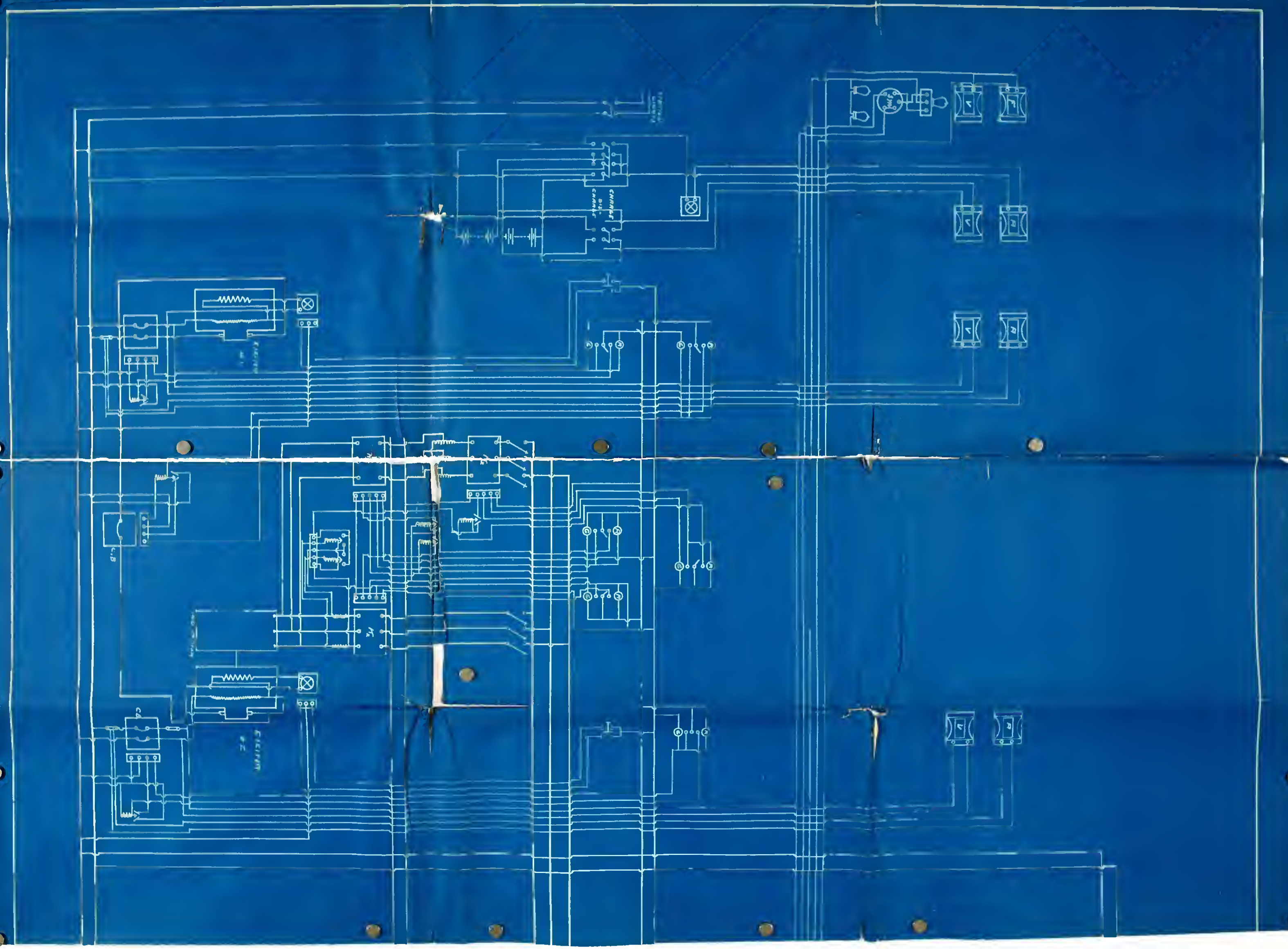
OF

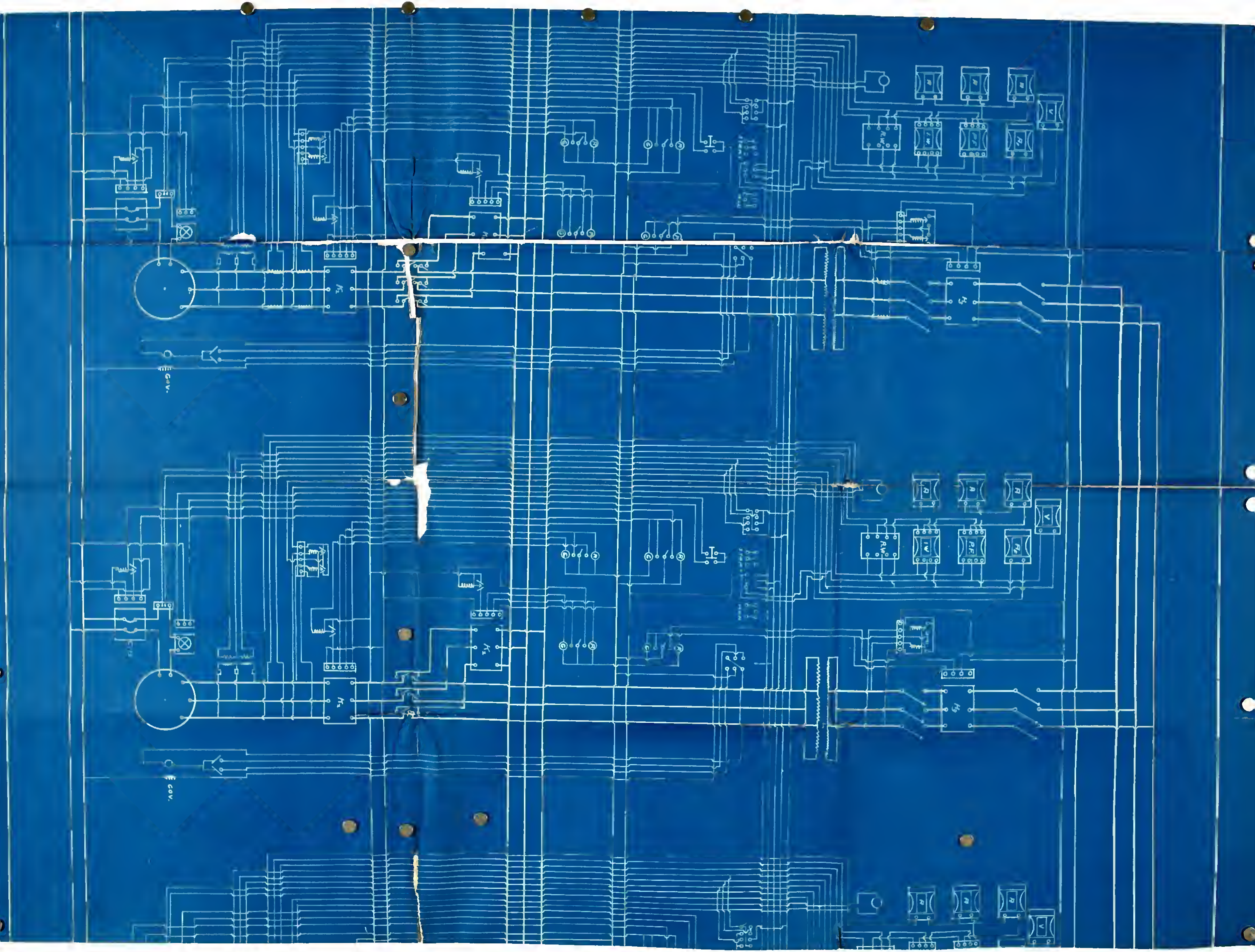
THE MILWAUKEE BRANCH

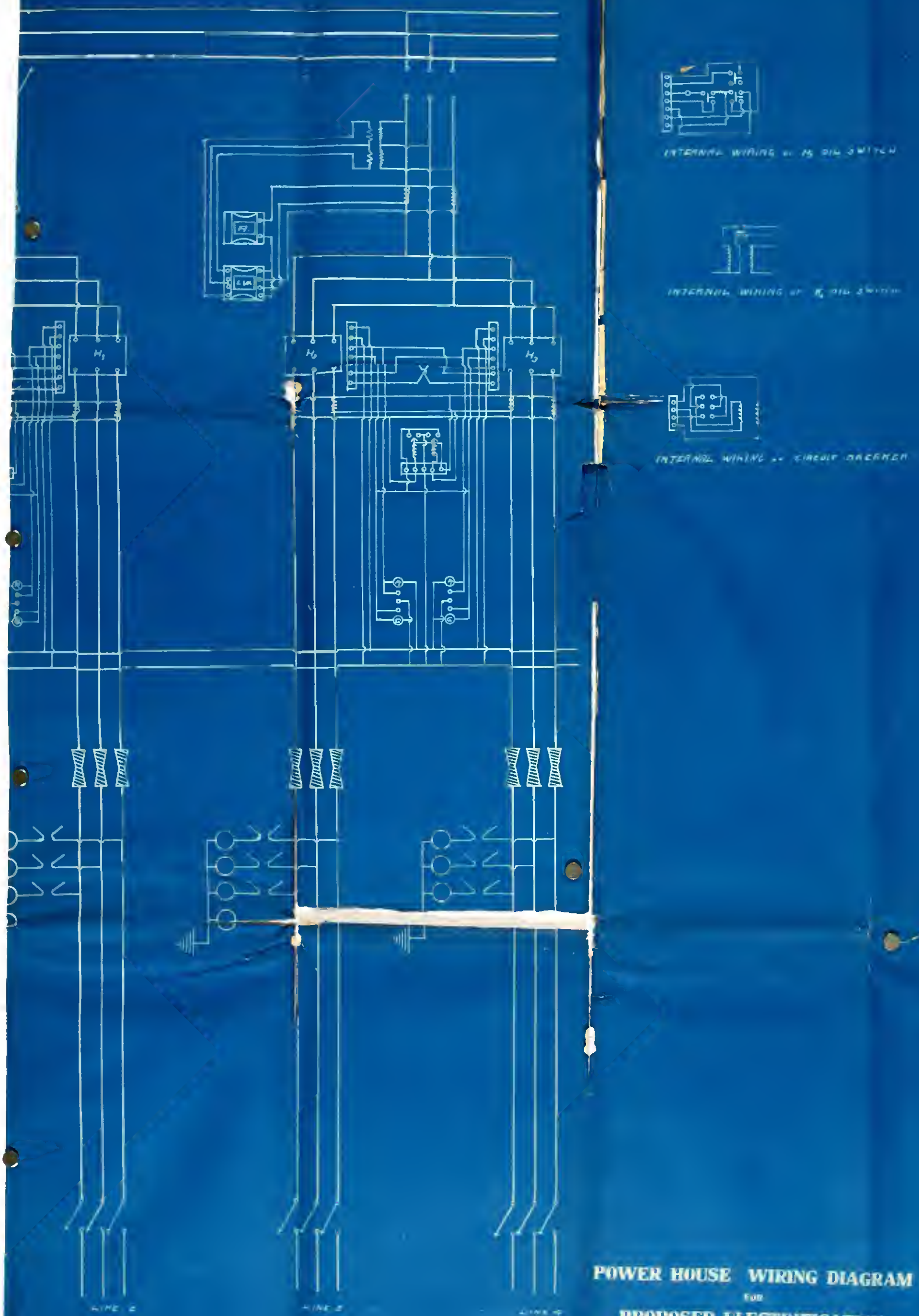
CHICAGO AND NORTHWESTERN RY.

ARMOUR INSTITUTE OF TECHNOLOGY

SCALE


CHARGE
DIS-CHARGE





POWER HOUSE WIRING DIAGRAM

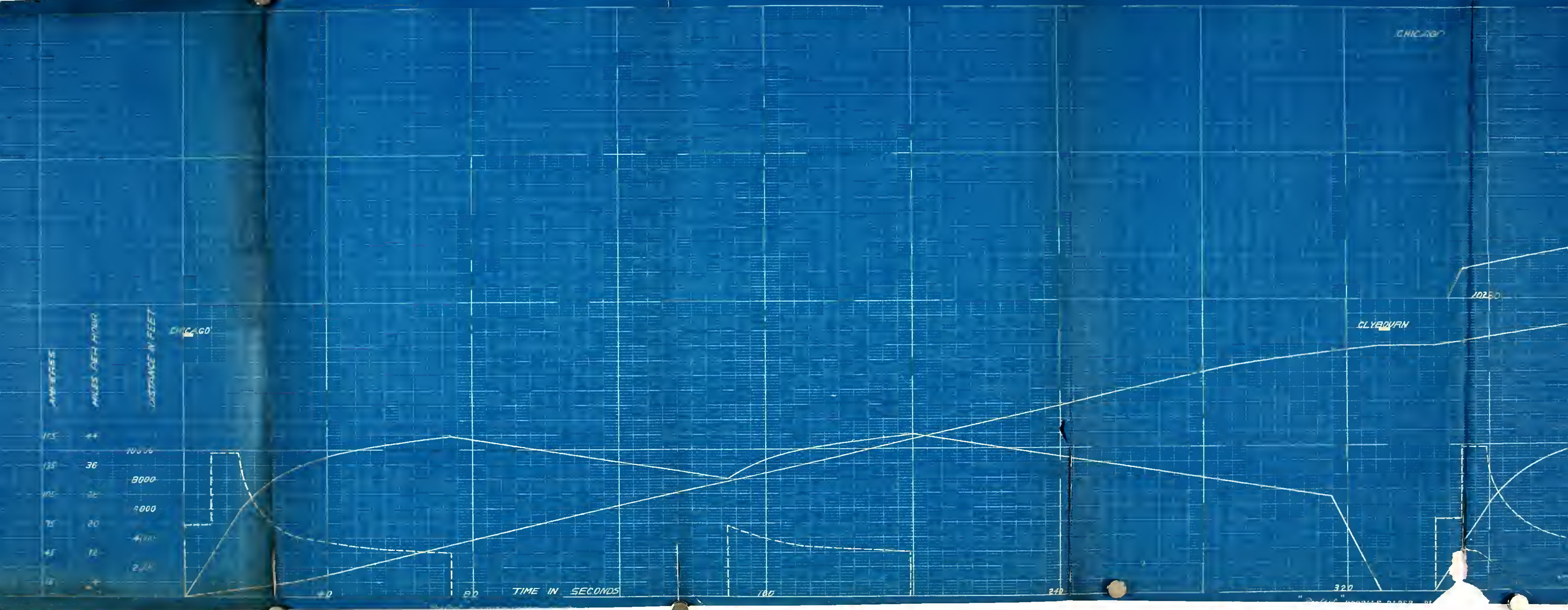
FOR

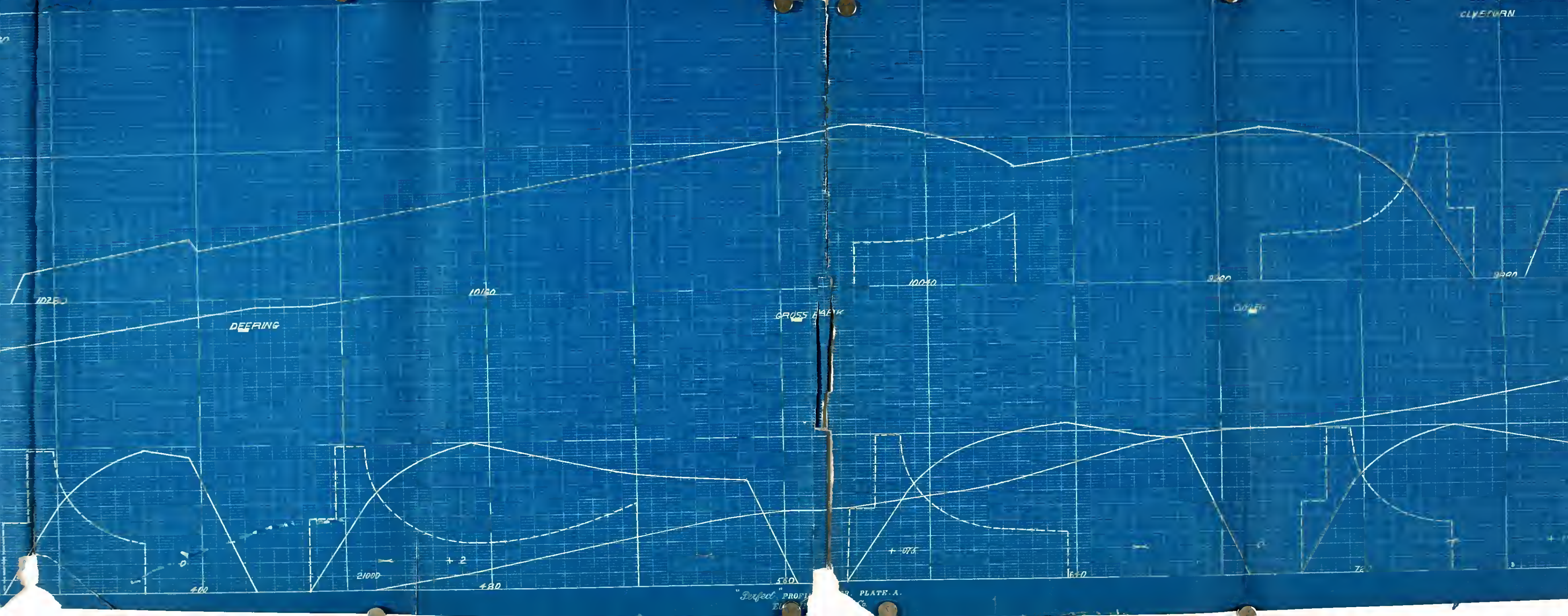
PROPOSED ELECTRIFICATION

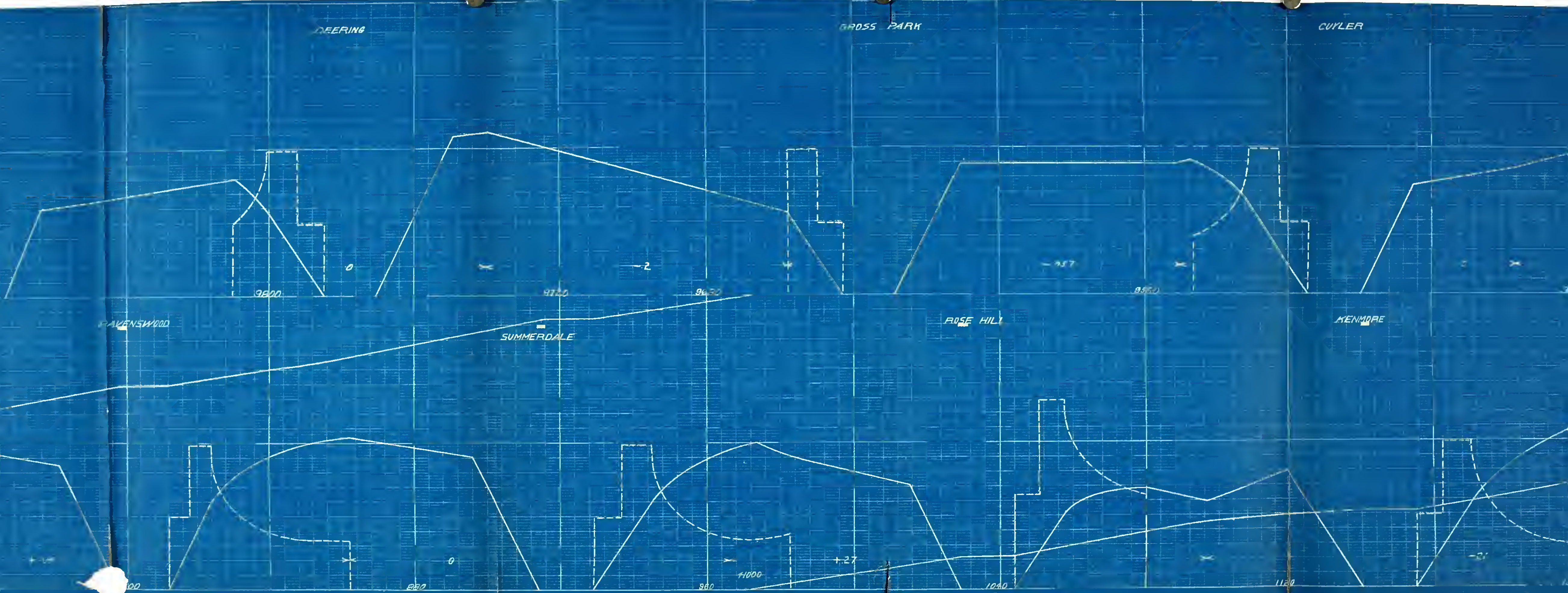
OF

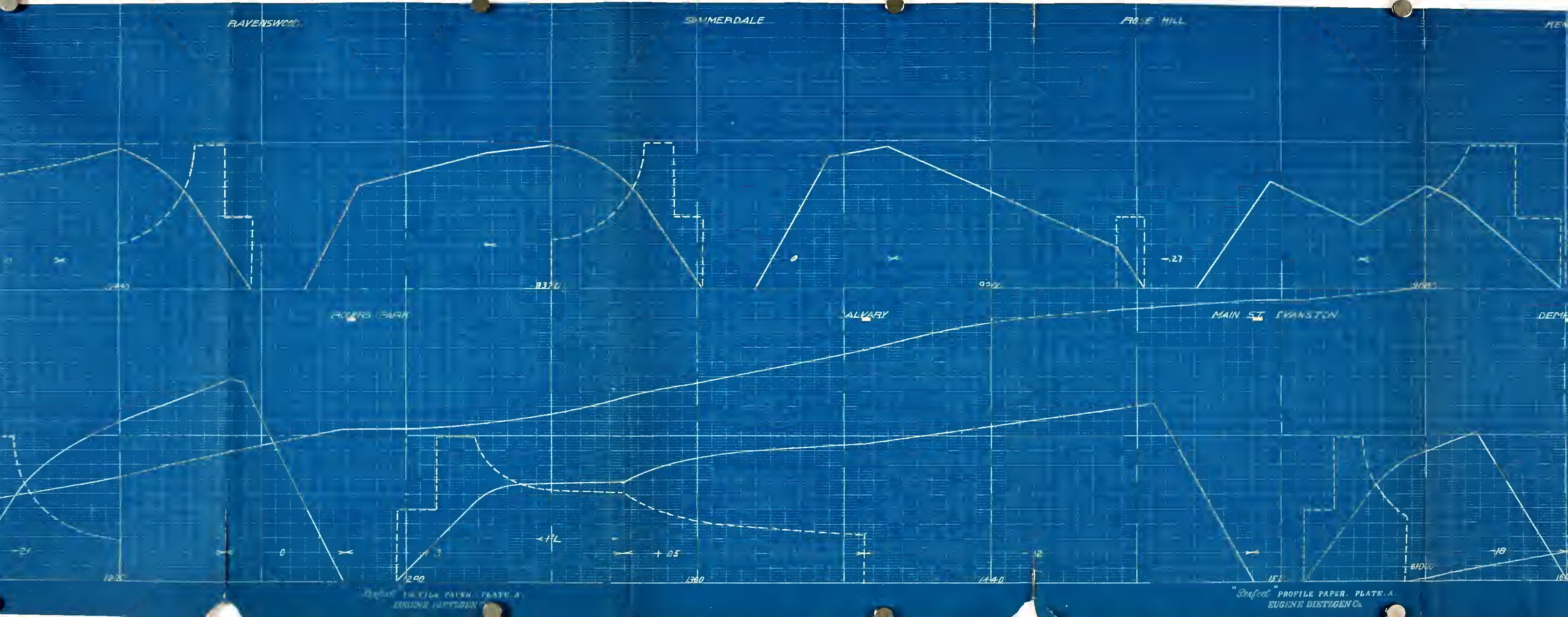
THE MILWAUKEE BRANCH
CHICAGO AND NORTHWESTERN RY.

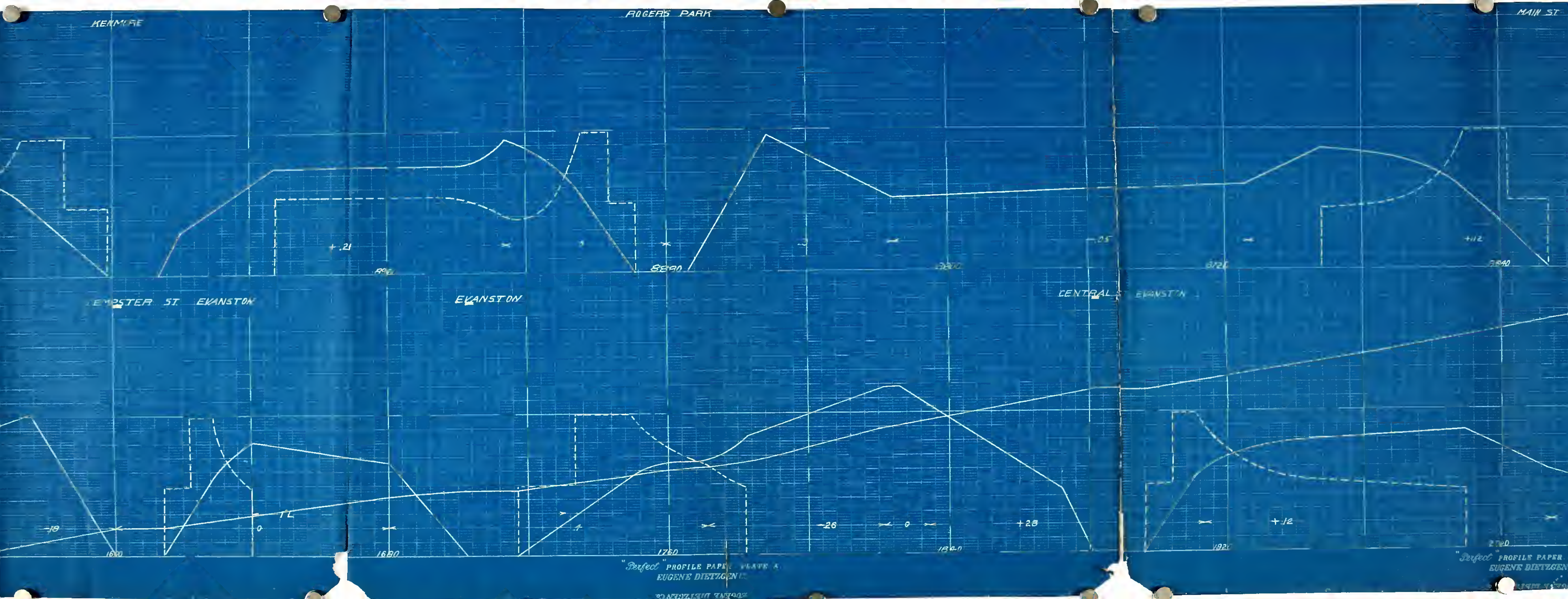
ARMOUR INSTITUTE OF TECHNOLOGY


AMPERES
MILES PER HOUR
DISTANCE IN FEET
CHICAGO
44
36
8000
6000
20
TIME IN SECONDS
80
160
240
320
CLYBOURN
CHICAGO

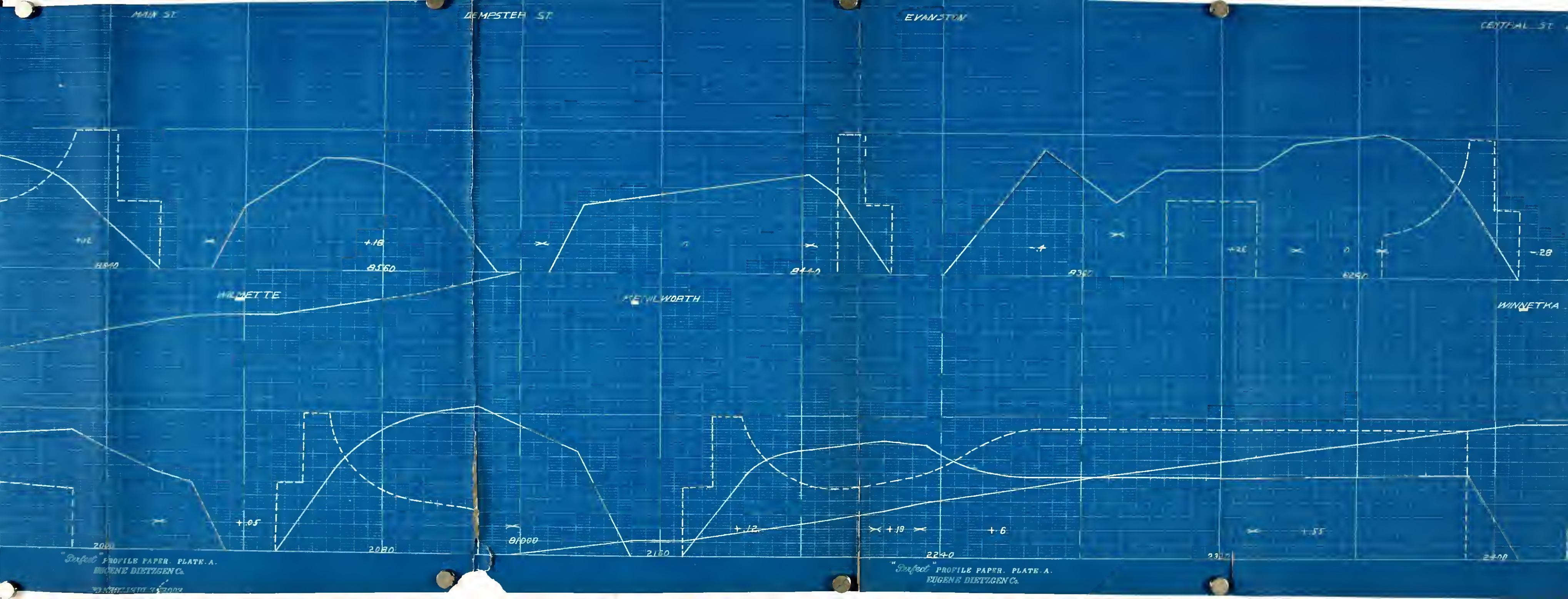

CLYBOURN
10250
10160
10040
DEERING
GROSS PARK
400
480
560
640
720
+ 2
21000
"Perfect" PROFI
PLATE. A.

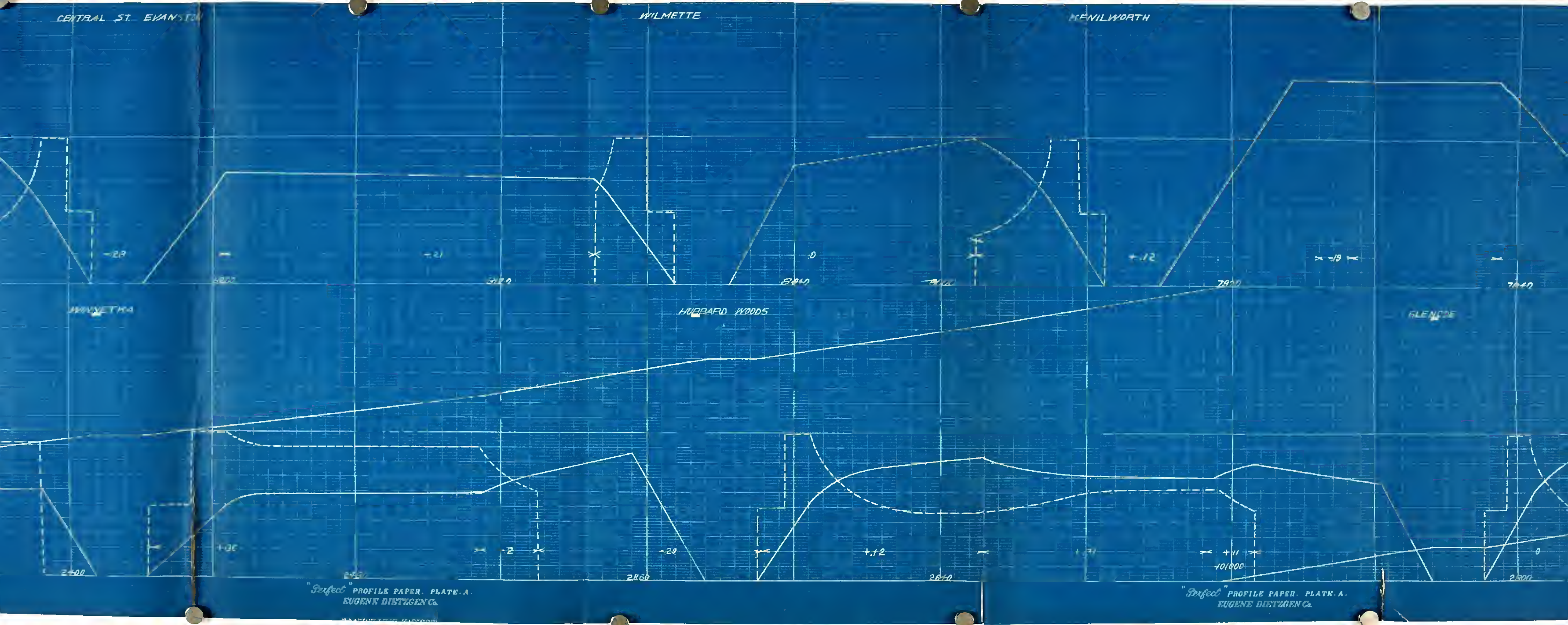

DEERING
GROSS PARK
CUYLER
RAVENSWOOD
SUMMERDALE
ROSE HILL
KENMORE

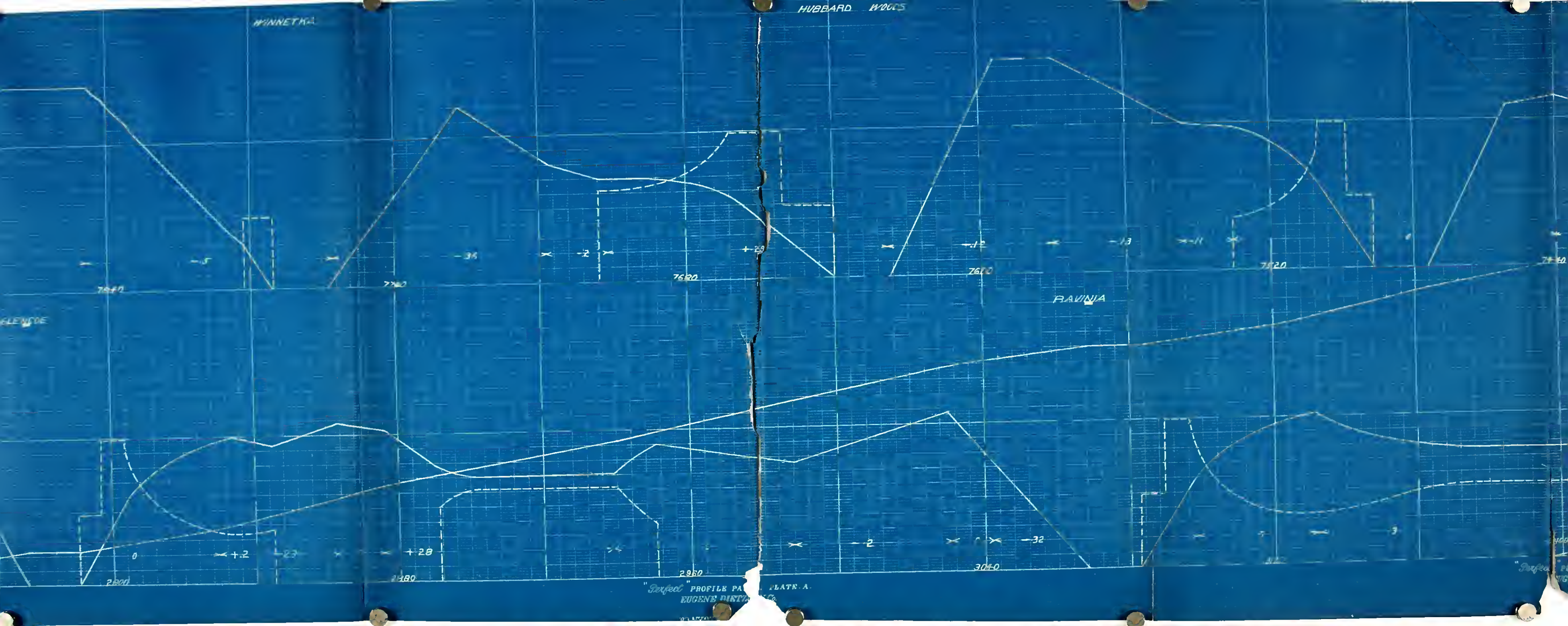

RAVENSWOOD
SUMMERDALE
ROSE HILL
ROGERS PARK
CALVARY
MAIN ST. EVANSTON
-.27
+.05
-18
1290
1360
1440
"Perfect" PROFILE PAPER. PLATE A.
EUGENE DIETZGEN Co.

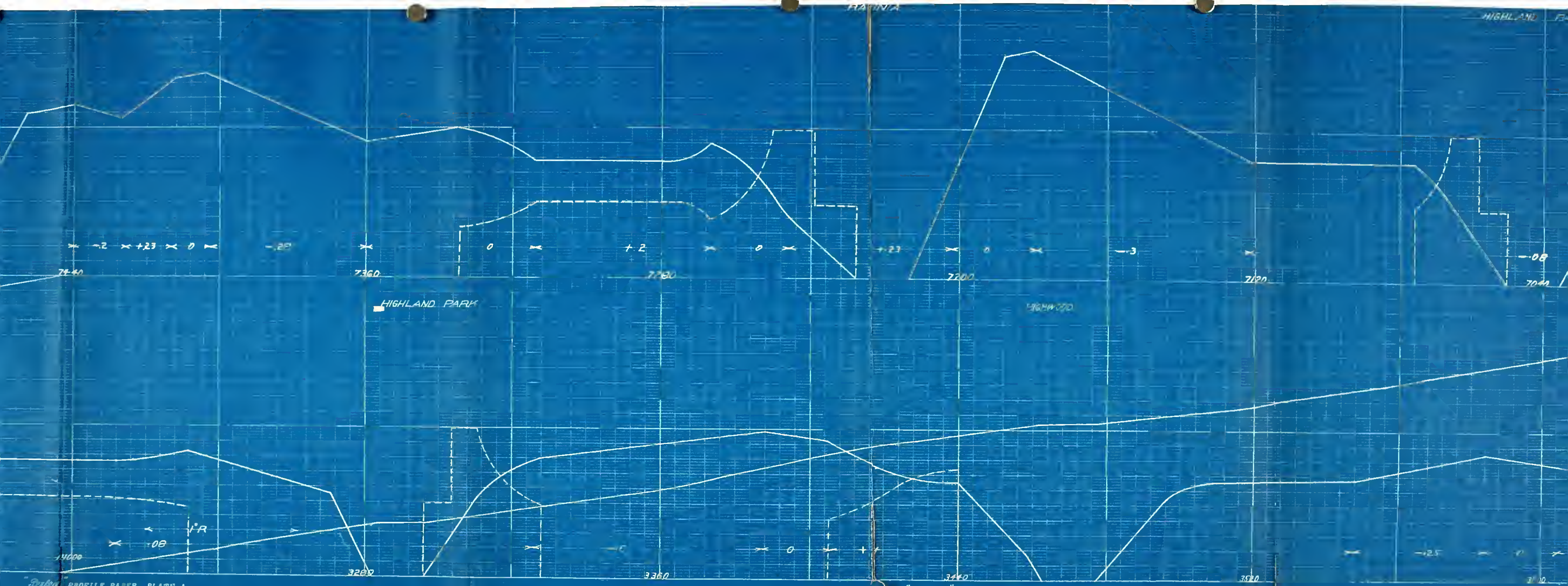


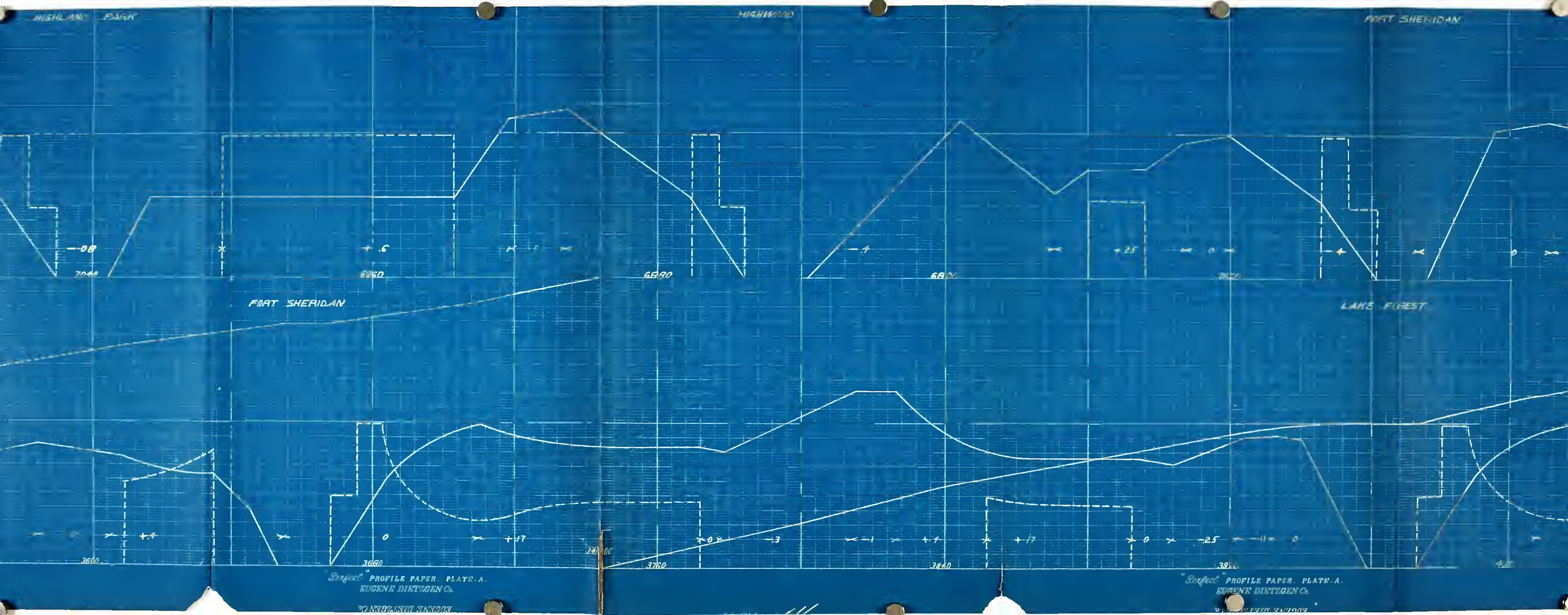
KENMORE
ROGERS PARK
MAIN ST
+.21
8960
8880
8800
-.25
8720
+.12
8640
EVANSTON
CENTRAL ST EVANSTON
-18
1600
0
1680
1760
-.26
0
+.28
1840
+.12
1920
2000
"Perfect" PROFILE PAPER PLATE A
EUGENE DIETZGEN CO
"Perfect" PROFILE PAPER
EUGENE DIETZGEN

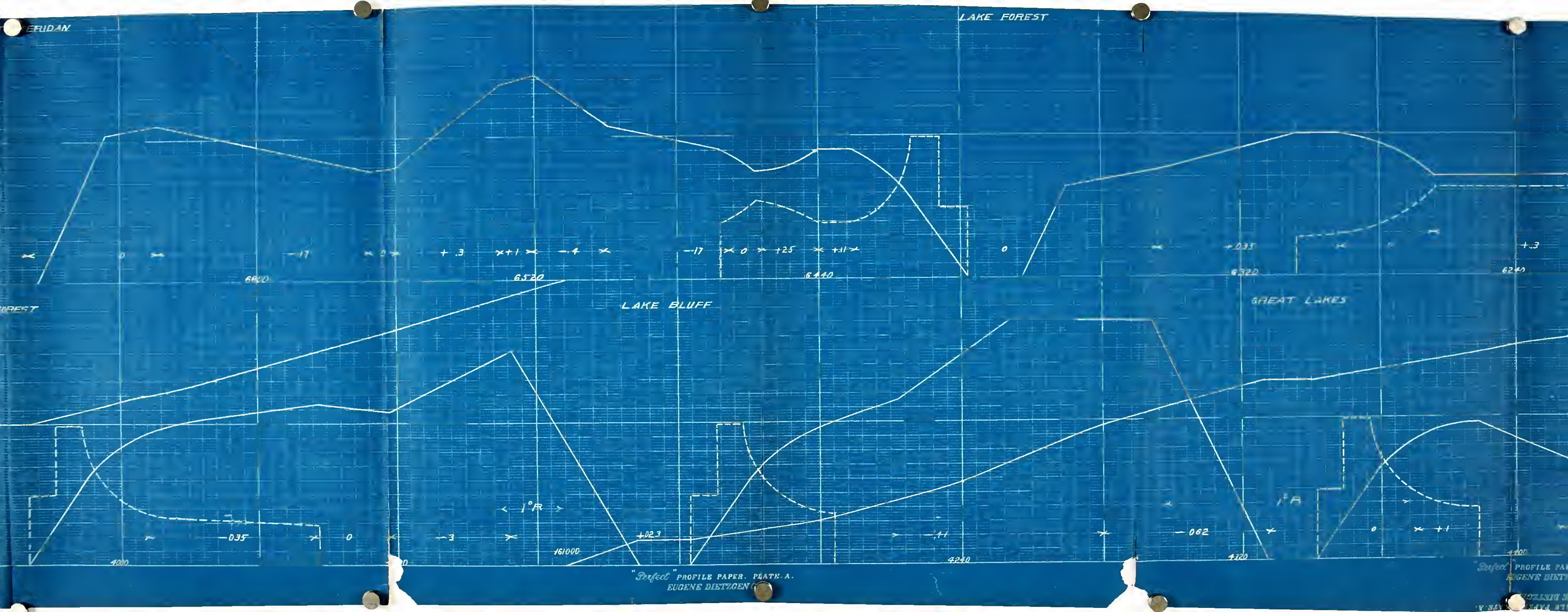

MAIN ST.
DEMPSTER ST.
EVANSTON
CENTRAL ST.
WILMETTE
KENILWORTH
WINNETKA
+.18
8560
8440
8360
-.4
0
-.28
+.05
+.12
+.19
+6
2000
2080
2160
2240
2400
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.


CENTRAL ST. EVANSTON
WILMETTE
KENILWORTH
WINNETKA
HUBBARD WOODS
GLENCOE
-.29
-.21
+.12
-.19
+.26
-.2
-.29
+.12
+.11
0
2400
2560
2640
2800
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.

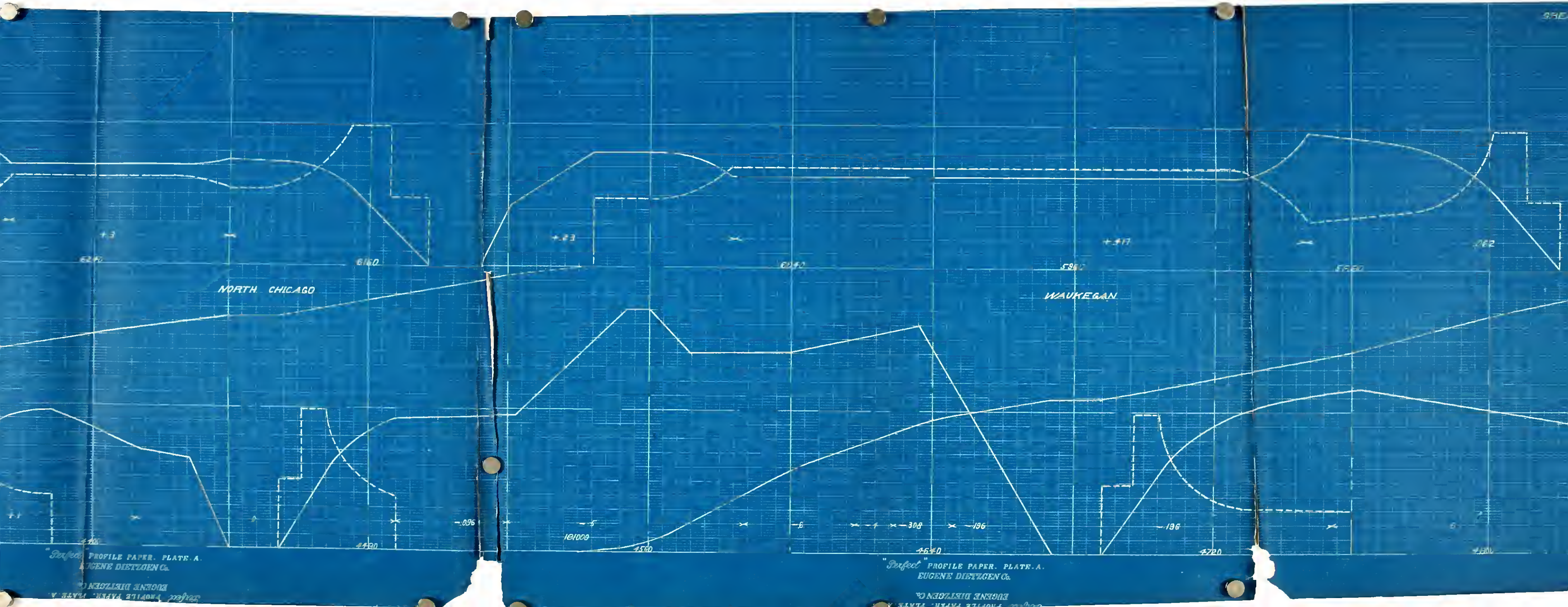

WINNETKA
HUBBARD WOODS
RAVINIA
GLENCOE
"Perfect" PROFILE PA
PLATE.A.
EUGENE DIETZ
Co.

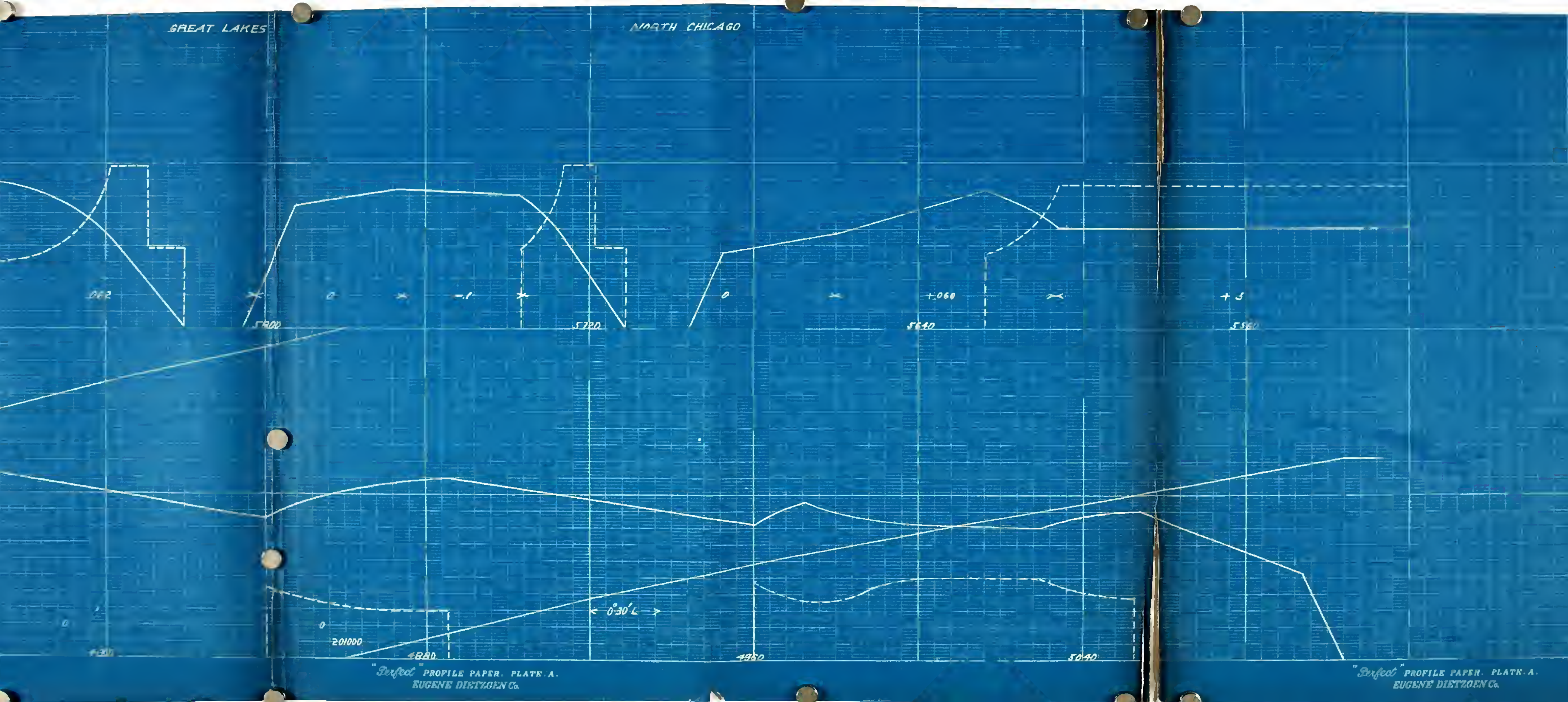

HIGHLAND PARK
HIGHWOOD
7440
7360
7280
7200
7120
7040
3280
3360
3440
3520
+.2
-.3
-.08
.08
0

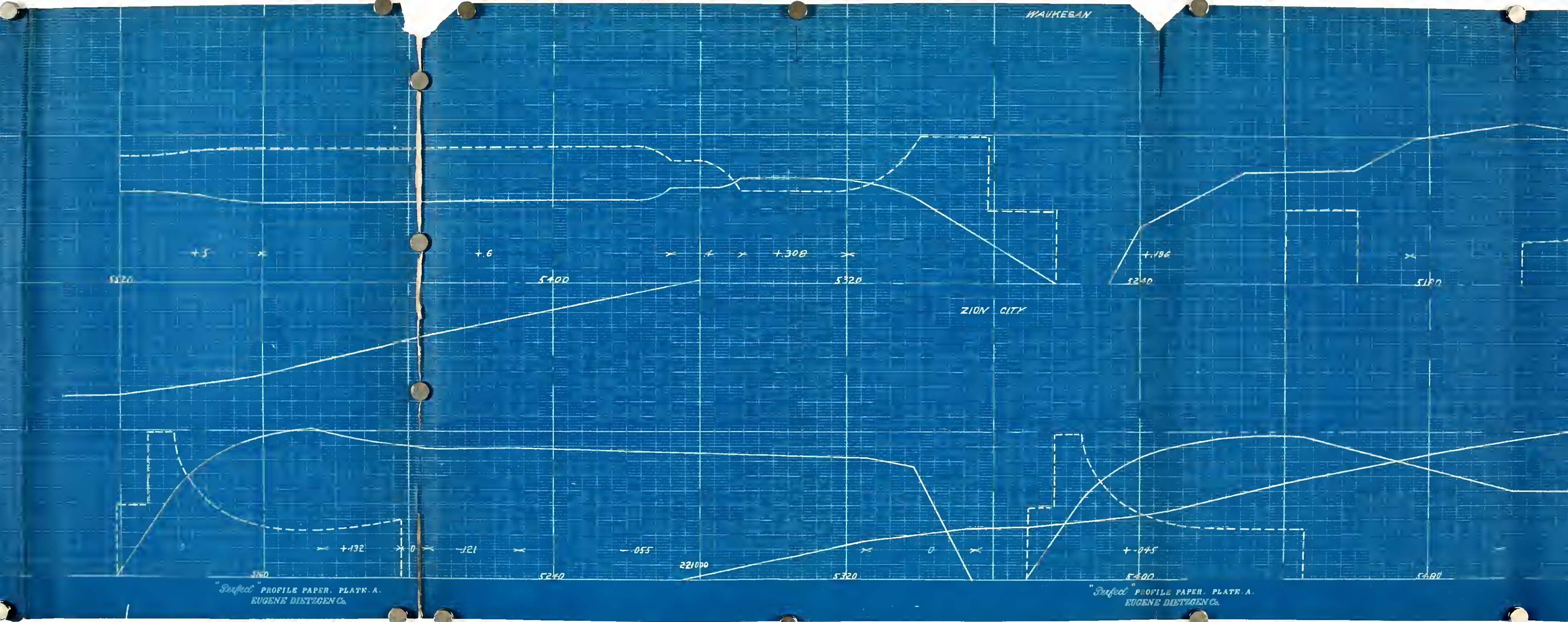

HIGHLAND PARK
HIGHWOOD
FORT SHERIDAN
FORT SHERIDAN
LAKE FOREST
7040
6960
6880
6800
3600
3680
3760
3840
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.

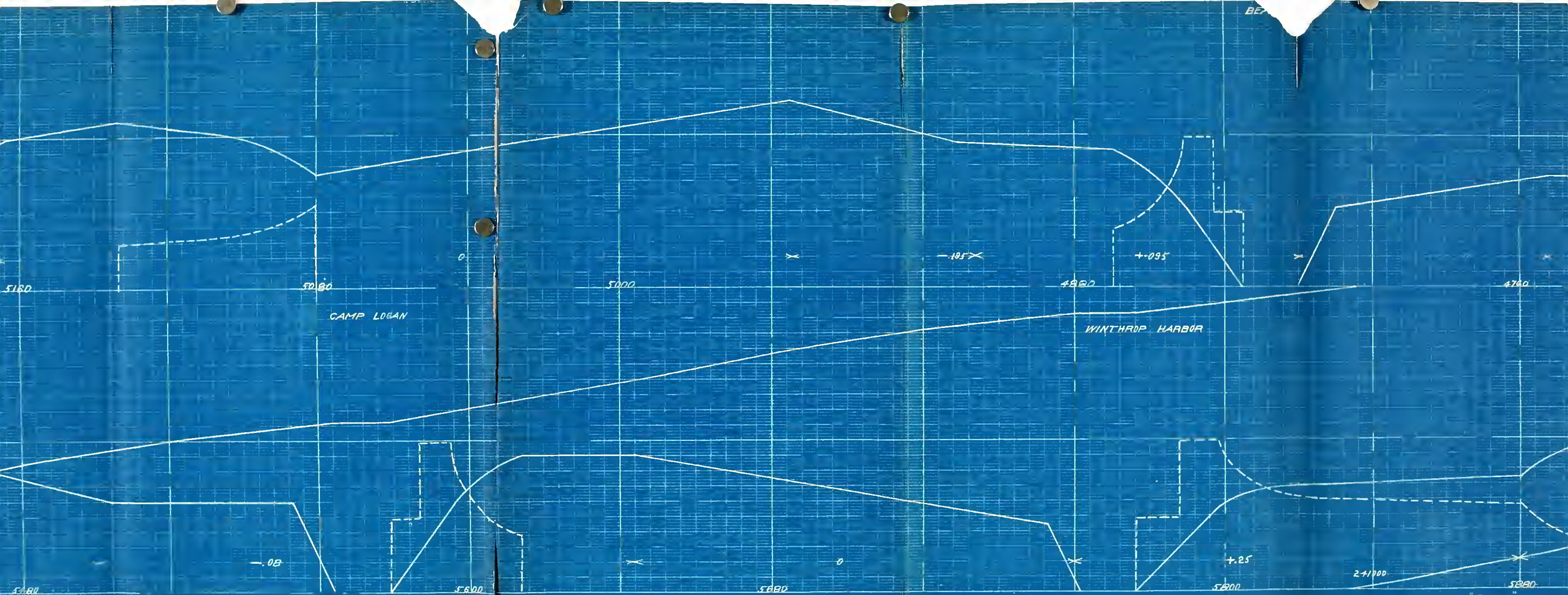


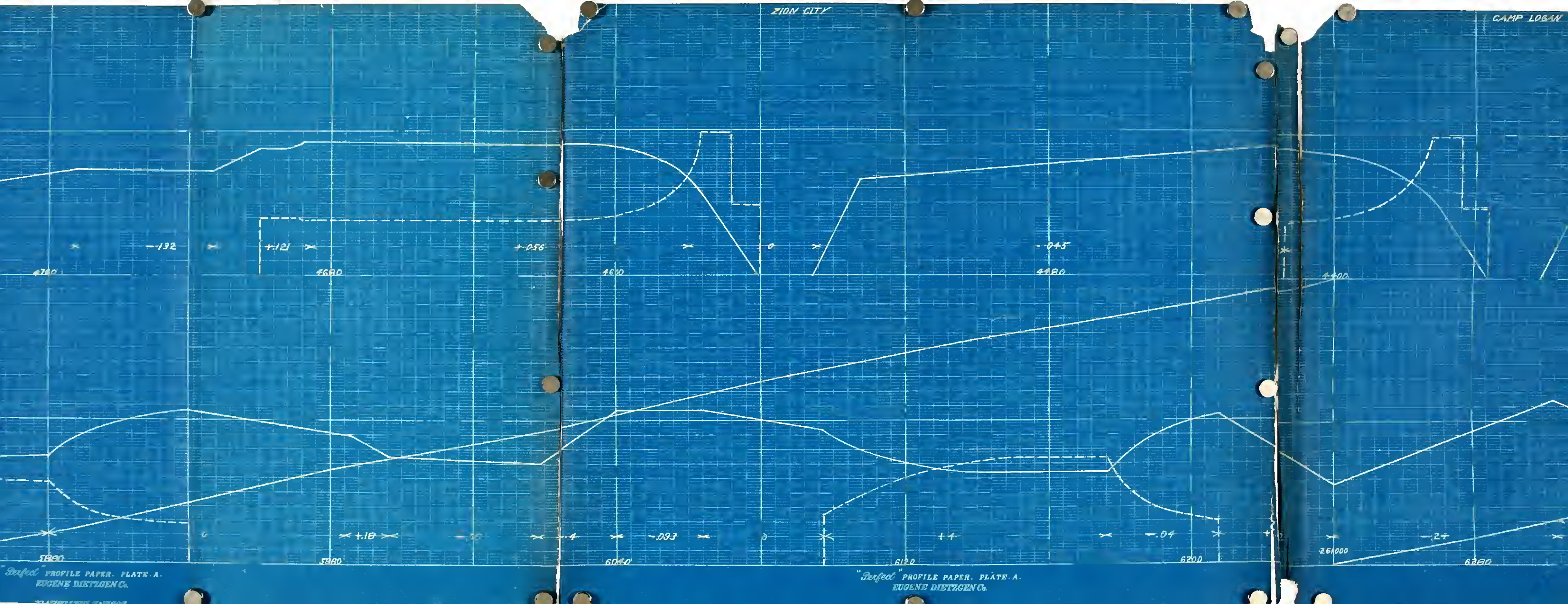
ERIDAN
LAKE FOREST
6600
6520
6440
6320
6240
OREST
LAKE BLUFF
GREAT LAKES
-.035
+.3
1° R
161000
+.023
4240
-.062
4320
1° R
4200
"Perfect" PROFILE PAPER. PLATE-A.
EUGENE DIETZGEN

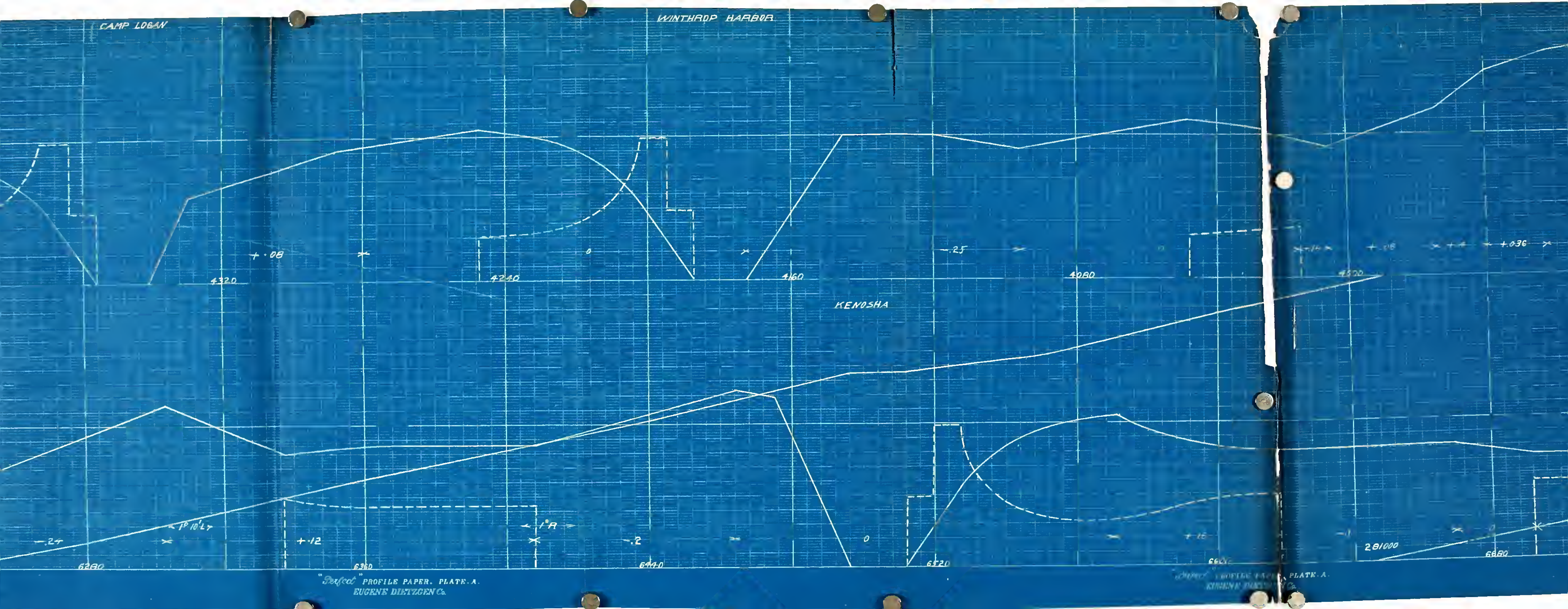

NORTH CHICAGO
WAUKEGAN
6160
4560
4640
4720
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.

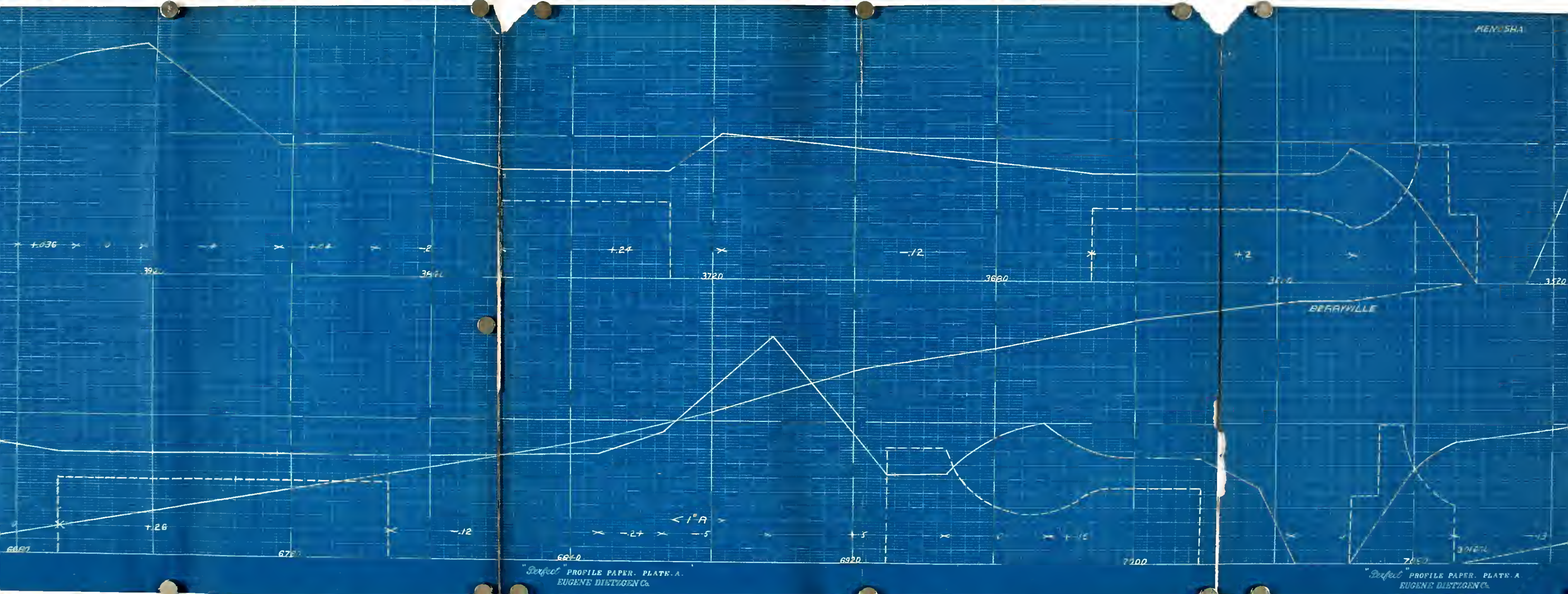

GREAT LAKES
NORTH CHICAGO
0
-.1
0
+.060
5800
5720
5640
0°30' L
201000
4880
4960
5040
"Perfect" PROFILE PAPER. PLATE A.
EUGENE DIETZGEN Co.
"Perfect" PROFILE PAPER. PLATE A.
EUGENE DIETZGEN Co.

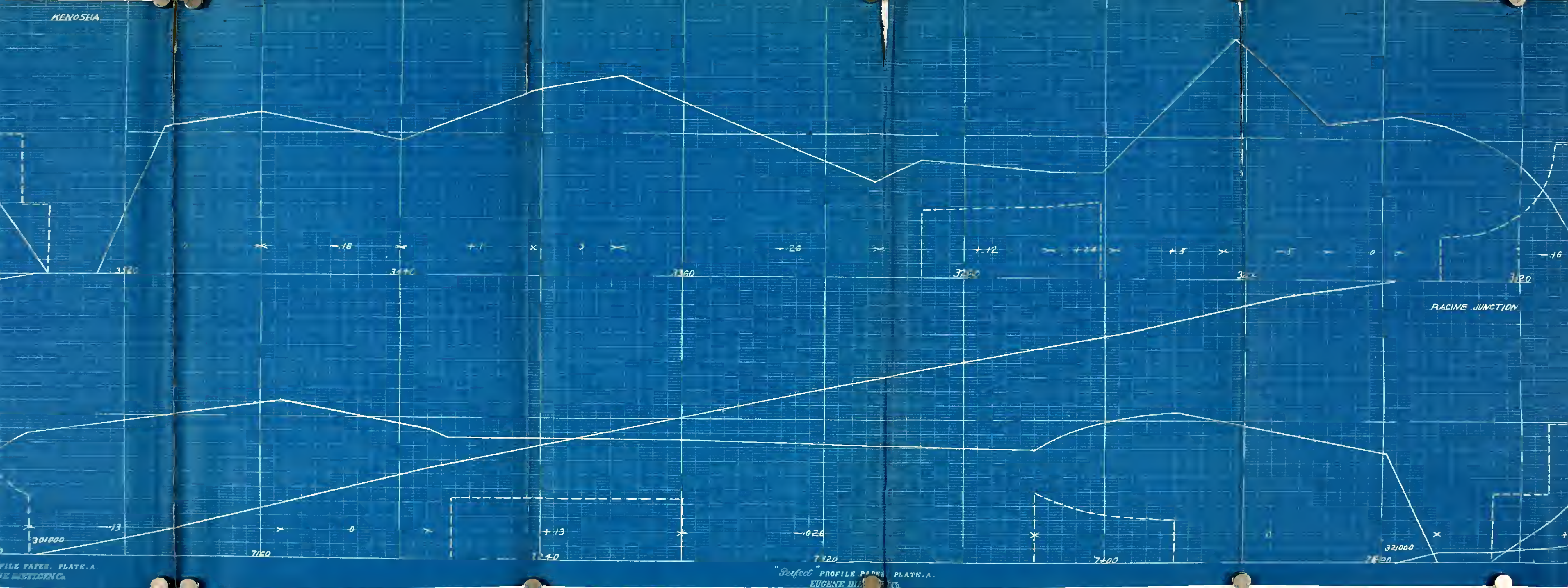

WAUKEGAN
ZION CITY
+.6
+.308
+.196
5400
5320
5240
+.132
-.121
-.055
221000
+.045
5320
5400
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.


5180
5080
CAMP LOGAN
0
5000
-.195
4880
+.095
WINTHROP HARBOR
4760
5480
-.08
5600
5680
0
5800
+.25
2.4/1000
5880

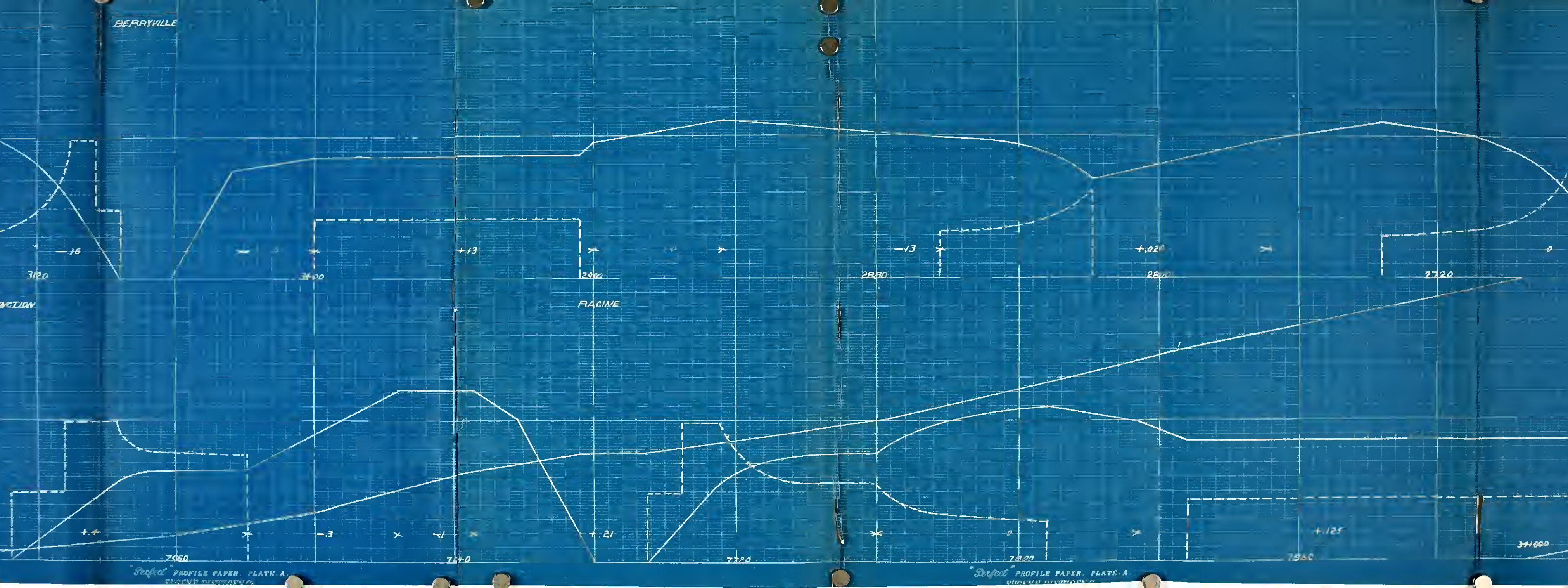

ZION CITY
CAMP LOGAN
-.132
+.121
+.056
0
-.045
4680
4600
4400
+.18
-.093
0
-.04
-.24
5960
6040
6120
6200
6280
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.


CAMP LOGAN
WINTHROP HARBOR
KENOSHA
+.08
0
-.25
4320
4240
4160
4080
-.24
1° 10' L
+.12
1° R
-.2
0
+.036
6280
6360
6440
6520
6680
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.

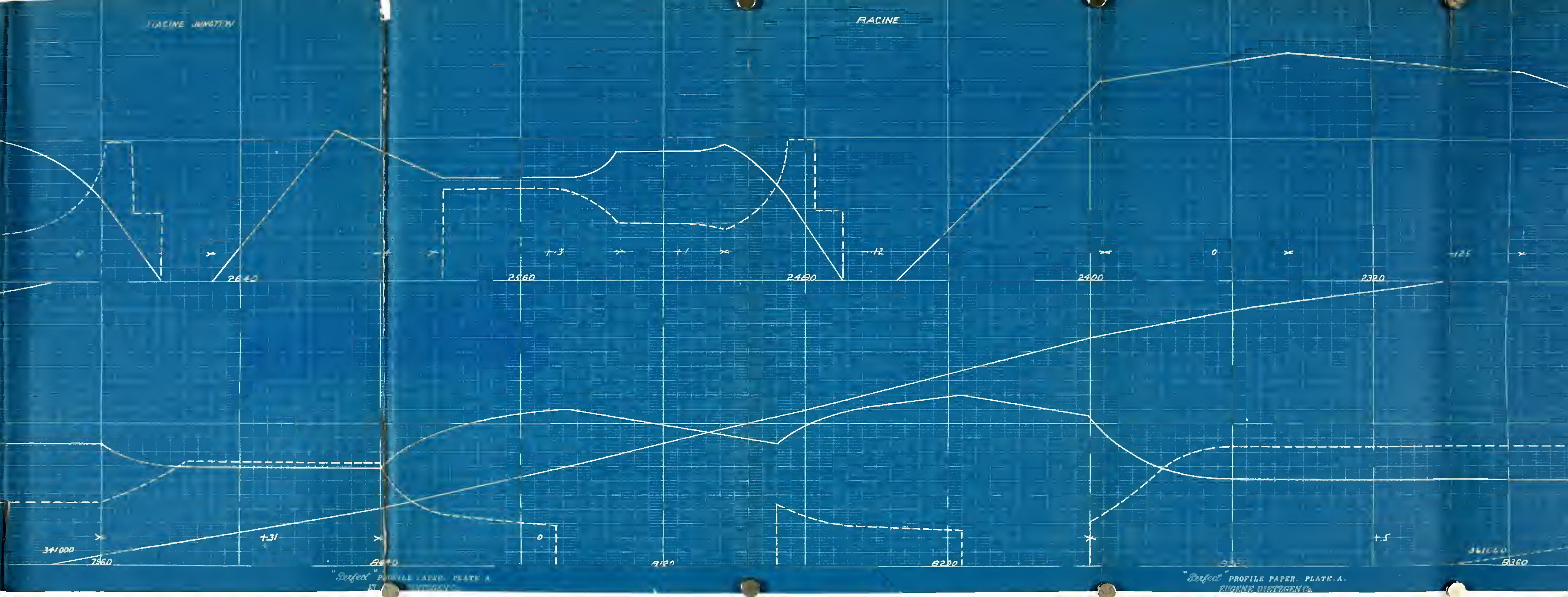

KENOSHA
BERRYVILLE
+.036
+.24
-.12
+.2
+.26
-.12
<1°A>
3920
3720
3680
3570
6680
6780
6840
6920
7000
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.



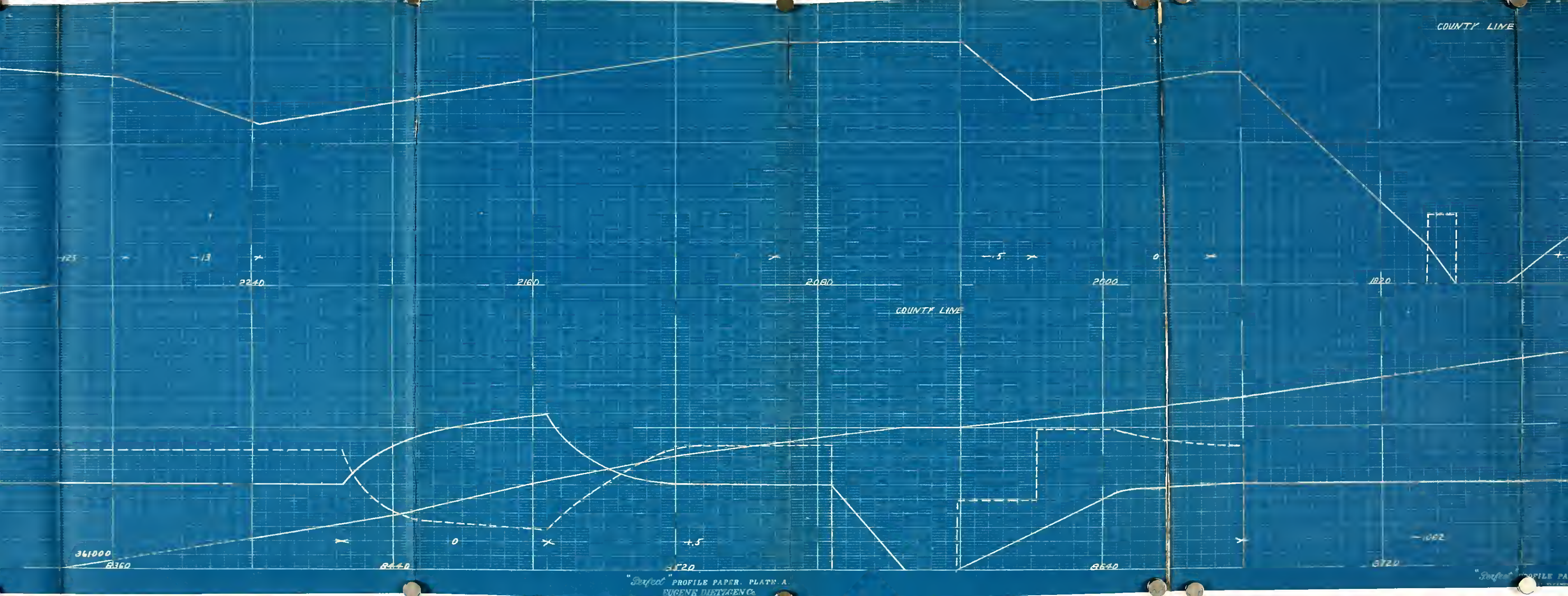
KENOSHA
RACINE JUNCTION
"Perfect" PROFILE PAPER. PLATE. A.

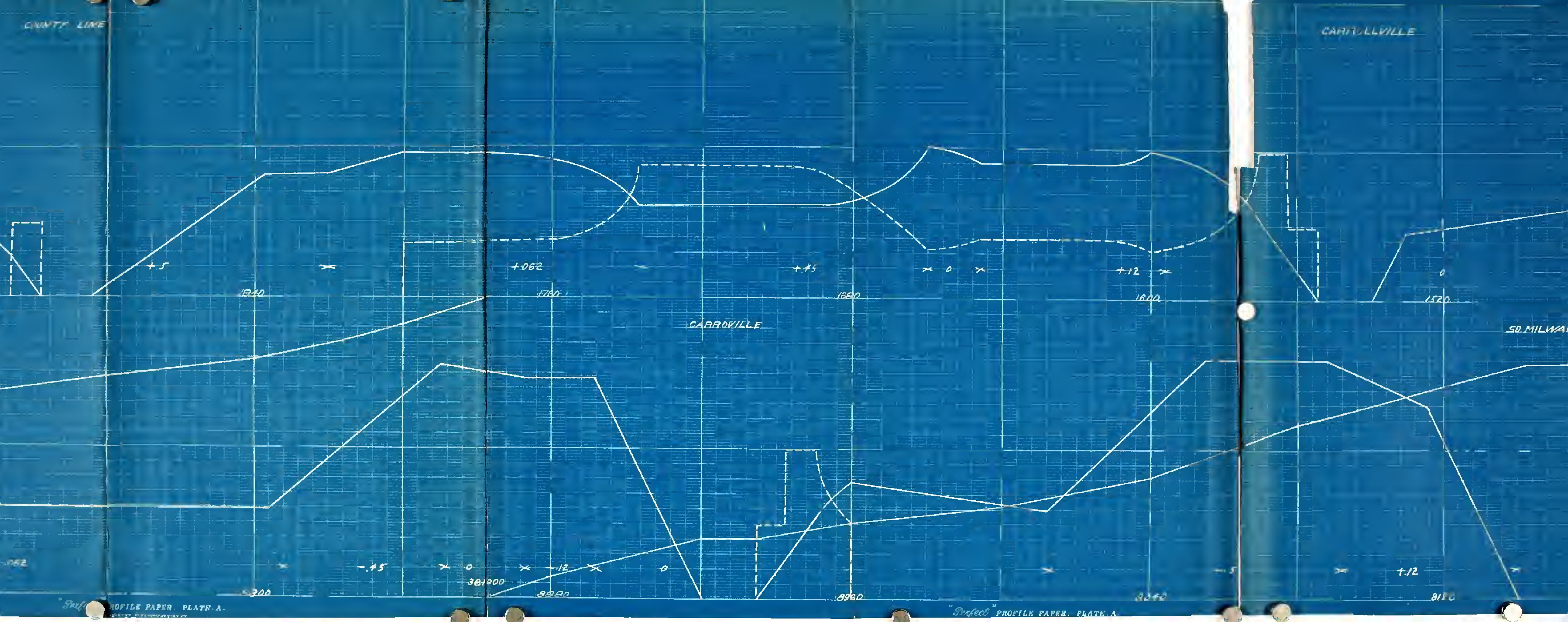


BERRYVILLE
-16
3120
3100
+13
2960
-13
2880
2800
2720
0
RACINE
-.3
-.1
+.21
0
+.125
7560
7720
7800
"Perfect" PROFILE PAPER. PLATE. A.
"Perfect" PROFILE PAPER. PLATE. A.

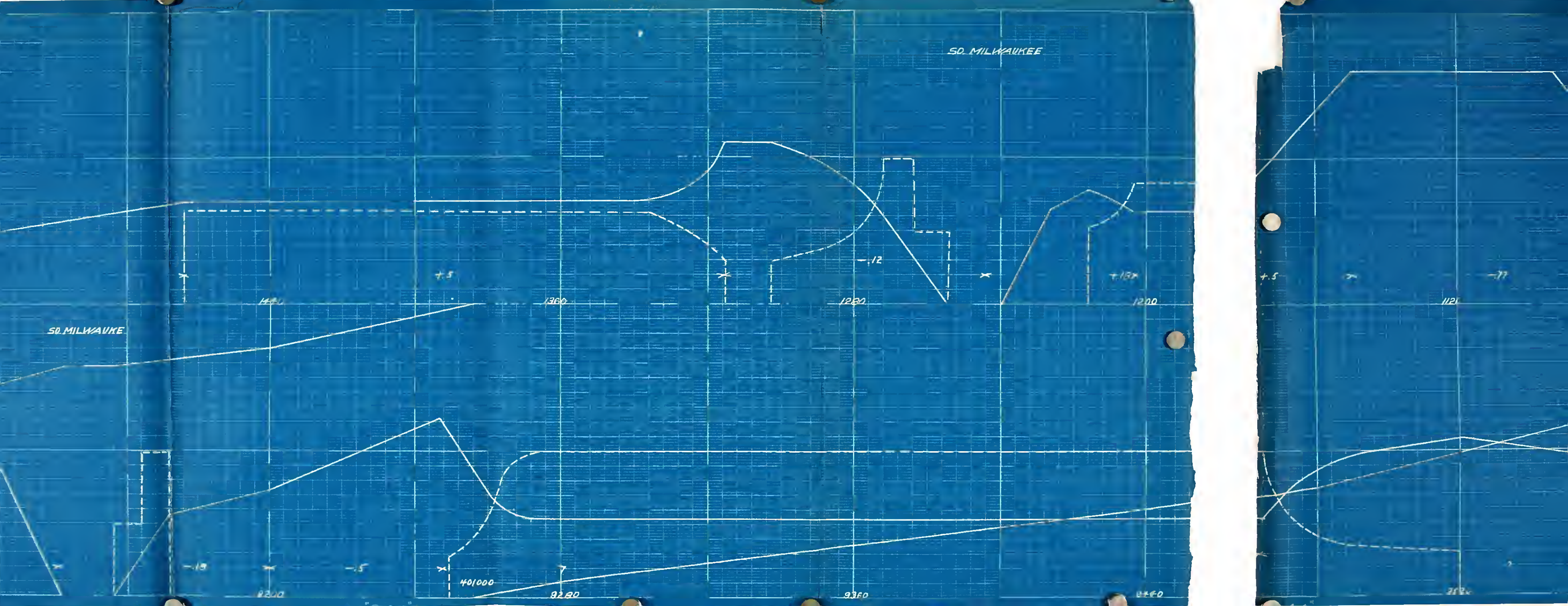


RACINE JUNCTION
RACINE
+3
+1
-12
0
-125
2640
2560
2480
2400
2320
+31
0
+5
34+000
7960
8040
8120
8200
8360
"Perfect" PROFILE PAPER. PLATE A.
"Perfect" PROFILE PAPER. PLATE A.
EUGENE DIETZGEN Co.

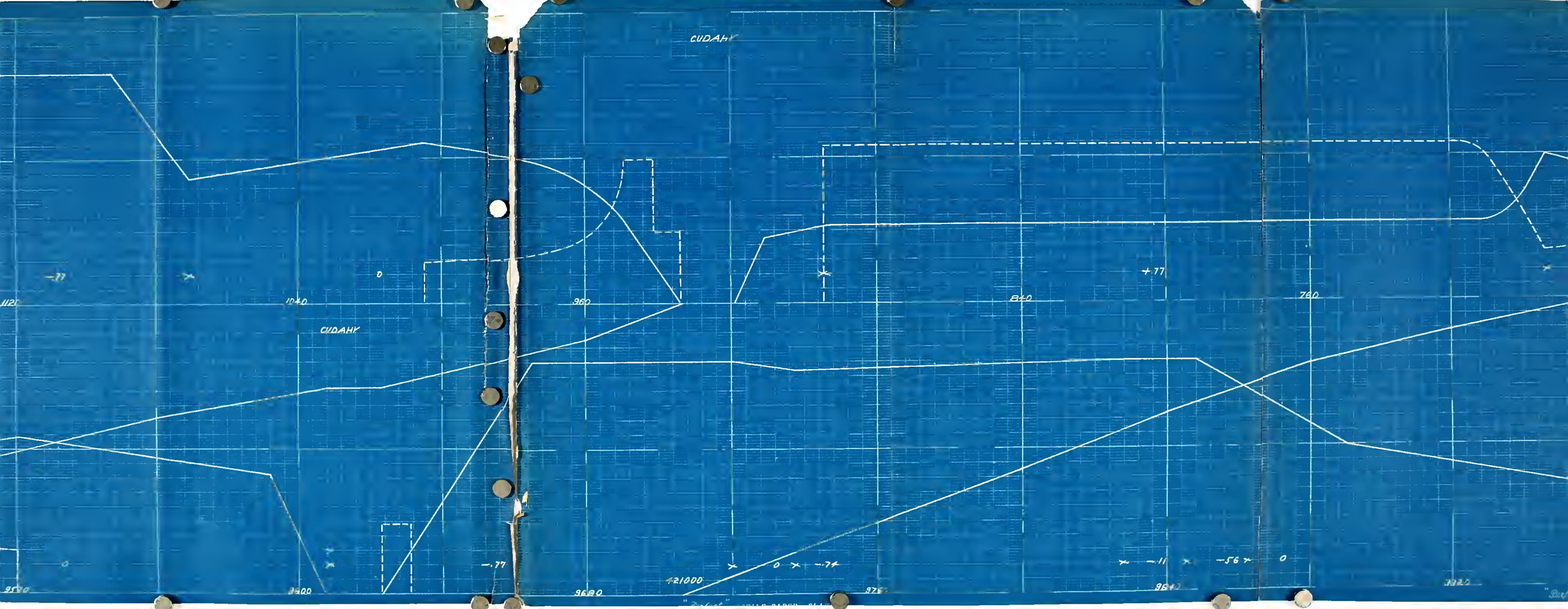

COUNTY LINE
-125
-13
2240
2160
2080
-.5
0
2000
1820
COUNTY LINE
361000
8360
0
8440
+.5
8520
8640
-1062
8720
"Perfect" PROFILE PAPER. PLATE. A.
EUGENE DIETZGEN Co.

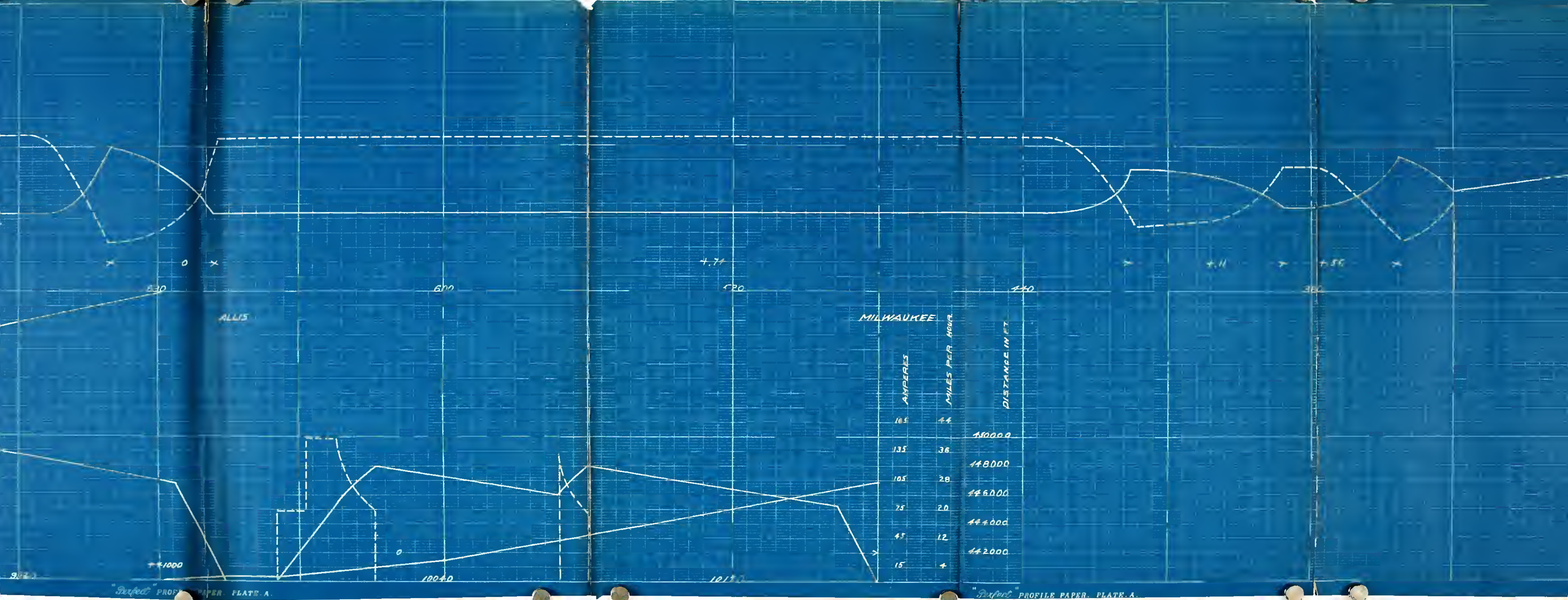


COUNTY LINE
CARROLLVILLE
+.5
+.062
+.45
0
+.12
0
1840
1760
1680
1600
1520
CARROVILLE
SO. MILWA
.062
-.45
0
-.12
0
381900
8880
8960
+.12
"Perfect" PROFILE PAPER. PLATE. A.

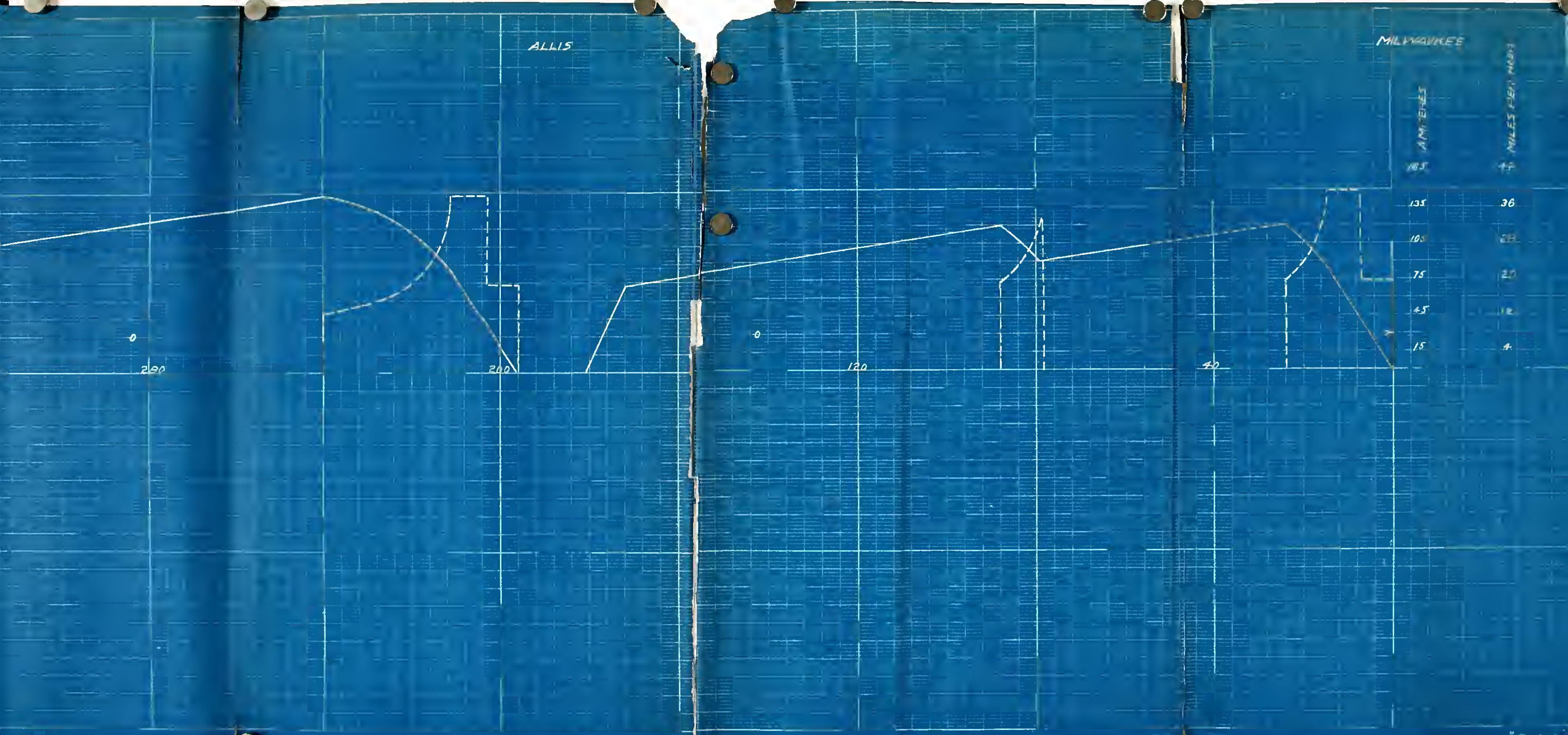


SO. MILWAUKEE
SO. MILWAUKE
1440
1360
1280
1200
+.5
-.12
-.18
-.5
401000
9280
9360


CUDAHY
1040
960
840
760
CUDAHY
+77
9680



ALLIS
MILWAUKEE
AMPERES
MILES PER HOUR
DISTANCE IN FT.
135
36
448000
105
28
446000
75
20
444000
45
12
442000
15
4
600
440
"Perfect" PROFILE PAPER. PLATE. A.


ALLIS
MILWAUKEE
AMPERES
MILES PER HOUR
165
135
105
75
45
15
36
28
20
12
4
0
280
200
0
120
40