DESIGN OF A HYDRO-ELECTRIC POWER PLANT.

by

MARSHALL ELSAS.

HARVEY B. HUBBARD.

J.E. COOLEY.

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In determing the feasibility of utilizing Water-power to operate electrically the industries of any city, many things must necessarly be taken in to careful consideration. Among which are; the amount of water-power available. Cost of developing this power. The interest on this amount. Demands for power. Comparsion of water-power with that of steam with respect to cost. All of these and many others seemingly non-important items must be taken in to consideration in order that the financial out-come of such an investment as a water power plant may be determined.

Charles. T. Main makes the following statement as to the value of Water-power. " The value of an undeveloped variable power is usually nothing if the varation is great, unless it is to be supplemented by a steam-plant. It is of value then only when the cost per horse power for the double plant, is less than the cost for steam-p power under the same conditions as mentioned for a permanent power. And its value can be represented in the same manner, as the value of a permanent power has been represented.

The value of a developed power, is as follows:- If the power can be run cheaper than steam, the value is that of the power plus the cost of the plant less depreciation, if it can not be run as cheaply as steam considering its cost,etc, the value of the power is nothing, but the value of the plant is such as could be paid for if new, which would bring the total cost of runing down to the cost of steam power, less depreciation".

Mr. Main's comparison has been criticised by a great many because it is in favor of a steam plant, which in reality is no more economical than water-power. Mr. Main has based his calculations, that he has made, on large engines, 1000 horse-power for instance, with good steam pressure etc. He figured the cost down to about $20 per horse-power, while in practical every day experience the cost per horse-power is from 40 to $50 while with water-power it can be furnished practically for about $25 per horse power.

In regard to the power generated for the city of Manhattan. Power can be developed from the Blue river at Rockyford much cheaper than can be generated by a steam plant of the same capacity, and it is our purpose in this Theses to design a hydro-electric plant capable of utilizing the water power at the point mentioned.

The old ford known as Rockyford is located on the Big Blue river about 4 miles northwest of Manhattan. The river at this point has a solid rock bottom, and varies in depth from about 15 inches to 30 inches below low water level. The east bank at this point is about 20 feet in height above bed rock. and at a point due north of the Rockyford bridge, the bank measures about 18 feet above low water level. A high bluff forms the west bank for about 40 rods above and below the ford.

A dam 12 feet in height will cause back water to a point about six miles up stream, damaging from fifty to sixty acres to %75 of its value.

The Dam.

The material used in the construction of the dam will be rubble masonry and reinforced concrete. The concrete shall be composed of one part Portland cement and two parts sand and four of lime stone. The sand shall be of the size to be caught by a 600 mesh sieve. The lime stone shall be such as to pass through a two inch ring and be caught by a 9 mesh seive. The rubble masonry shall consist of a good quality of lime stone laid in lime mortar, having the ratio of 1 of lime to 2 of sand.

The dimensions of the dam are as follows:-

Length out side of power-house 311 feet.

Total width of base 13 1/2 feet.

Total width at top 4 feet 9 inches.

Thickness of concrete on upper side is 15 inches.

Thickness of concrete on lower side and bottom is 18 inches

Thickness of concrete on top is 2 feet.

Plate I shows a longitudinal section of the dam, and Plate II is a cross section of the dam, giving dimensions and also shows the location of the center of gravity of the dam,(marked by a cross near center of dam.) The two component forces are also shown, that due to gravity, and that due to the force of the water acting parallel to the base. The point, P, the point where the resultant of these two moments strike the base, gives the point at which the dam might be supported and still be in equilibrium and so, owing to the extension of the 'toe' of the dam there is no possibility of the dam overturning. The mathematical consideration of this is as follows.

The total area of the cross section of the dam in the center of the river is 89.08 square feet. The total area of the rubble masonry is 31.54 square feet.

Considering the average weight of the dam to be 150 pounds per cubic foot. The total weight of the dam per linear foot is 12562 pounds. This quanity represents the vertical component. The horizontal component, or that due to pressure of the water, was taken with an overflow of water on the dam, of 2 feet. The reason for taking an overflow of 2 feet, was because of the fact that an increase in head above this would also cause a corresponding increase in the height of the water below the dam; thus causing a back pressure to counteract the pressure down stream. The numerical value of the force acting at P, was found to be 6000 pounds per linear foot then completing the parallelogram, considering 6000 pounds equal to 1 inch, we found the resultant to strike the base at the point P.

In order to prevent the dam from slipping there will be 3 rows of sills placed across the river about 3 feet apart as shown in plate II. These sills will be 9" by 12" in cross section and will be bolted firmly to the rock. The concrete for the bottom of the dam, will be laid in between and on these sills. This arrangement will prevent any possibility of the dam slipping.

There will be a track laid along on the crest of the dam, the rails will be fastened firmly to steal ties, these being placed about 6 feet apart and laid firmly in concrete.

Arrangements will be made for the construction of flash boards 1 1/2' in width and in sections 10' in length. These will be hinged to the rail on the upper side of the dam, thus making it possible when the boards are tripped for them to fall down in between the rails putting them out of the way of any ice cakes or floating trash.

— Power-house —

The power-house is so located that it forms 52 feet of the east end of the dam. The object of this arrangement being to eliminate the use of canals, thus greatly reducing the cost of construction.

The inside dimensions of the house are 36 feet by 72 feet. 20' of the length is built on the bank, the other 52' forming part of the dam as stated above.

The foundation and the floor is constructed of concrete masonry and the walls above the floor are of stone. The concrete is to be the same as used for the dam. The dimensions showing the thickness of the walls are given in detail in the drawings of plate III, IV, V.

There will be four windows placed in each side of the building in the positions shown in plate IV. There will also be one large window in the west end of the building immediately above the end of the dam. This window is placed in this position in order that heavy machinery may be lifted from the track out side into the building. There are two doors in the building both in the east end, one opening directly in to the generator room, the other opening into the office in the northeast corner of the building. This office is for the use of an attendant also for a tool room.

The building will be supplied with a traveling crane for the purpose of carrying heavy machinery.

That part of the power-house which forms part of the dam, contains three flumes, each 14 feet in width. These are separated by

3 feet concrete walls as shown by plate IV, each flume being provided with 2 turbines having a capacity of 150 horse-power each, at full gate opening. The turbines at full gate opening require about 8000 cu.ft per minute, or 133 cubic feet per second, thus making a total amount of water discharged per second 533 cu.ft. The exciter turbine will require about 23 cu.ft. per second, making the total discharge from all the turbines equal 556 cu.ft. per second. According to the government report on the discharge of the Blue river(House Documents Vol. 94, Water Supply and Irrigation Papers, 93-96.) we can obtain this amount of discharge on an average of nine months per year.

The floors of the flumes are 8 1/2 feet below the crest of the dam, thus giving a depth of water of about 9 feet in the flume. For the cross-section given above the velocity of the water in the flume will be 2.2 feet per second.

Each flume has a double oak floor, the upper being one inch flooring, and the lower floor being 4" timber laid on 12" standard, I, beams, these 'I' beams are 2 feet apart.

For the back end of the flume there is a 3' concrete wall supported by two 14" standard 'I' beams, there will be three one inch bolts through each 'I' beam to the top of the wall, this will prevent the sagging of the floor under the wall when the flume is filled with water. The ends of all of the 'I' beams, will be laid on iron plates which are laid in the concrete wall. The top of the flume is arched over as shown in plate V. Each flume will be supplied with a sliding gate these being operated from the generator room. There will be a screen placed the entire length of the 3 flumes as shown in plates III and IV, the purpose of this screen being to protect the turbine from ice and large trash.

The walls under the turbines will be 4' thick, projecting 6" on each side, leaving the width of the tailrace 13 ft. The tail races will be connected by 2 large open arches in each wall as given in plate V, the object of these arches being to assist in keeping the level of the water in the three tail races the same.

The depth of the water in the tail race is 9 feet this gives the velocity in the tail race about equal to that in the flume. This depth shall be maintained for some distance into the channel of the river, thus allowing plenty of room for the tail water to get back into the channel with out any loss of head on the turbines.

The Generators.

The generating equipment will consist of two, 150 K.W. alternators each bevel geared, to two vertical shaft 45" Sampson turbines and two 10 K.W,D.C. exciting generators geared to 23" Sampson turbines.

The alternators are General Electric 3 phase 60 cycle 5000 volts revolving field type, speed 360 revolutions per minute.

The reason for choosing 2 generators instead of one is for the convenience in arranging the turbines and so that at times of light load one of the machines may be shut down and the other left to run at a more economical load. This arrangement will help materially in case of very low water, for by the use of the flash boards on the dam, the extra water during light loads may be stored up for use in times of heavy loads. Another reason is for ecomony of repairs because the repairs on hand would answer for both machines.

The reason for using such low speed generators, which are the lowest speed standard belted type made, is because it is difficult to obtain gearing that will with-stand the wear when working under high speed, there is also less friction in low speed.

Our object in choosing sixty cycles is that the load is both, light and power, and neither sufficient to justify the use of a frequency changer.

Our object in choosing 5000 volt machines, is to eliminate the use of step up transformers at the power station. The distance between the power plant and center of distribution being to great to use less than 5000 volts economically(for theory see line). And this voltage can be handled easily on the bus bars with reasonable care.

The gearing frame and gearing will be furnished by the Sampson turbine Co. along with the turbines.

The speed of the turbines is 120 revolutions per minute, with a head of eleven feet and the ratio of gearing is such as will give the required speed to the generators.

One pair of turbines will be regulated by the use of an ordinary hand wheel which opens and closes both turbines similtanously The other pair of turbines is controlled by Lombard Type N Water wheel govenor. The Lombard Company, have recently perfected an invention which enables the operator to start up, stop or alter the speed of the turbine at will, from the switch board.

The apparatus for accomplishing this result is extremly simple, consisting merely of two small push buttons, on the generator panles which connect three wires to a small electric motor of about one sixteenth Horse-power this motor through suitable mechanism acts upon the valve stem of the govenor in such a manner as to lengthen or shorten the connection between the centrifugal ball and the valve itself. The power required is exceedingly small being only about 1/100 horse-power, and can be run if necessary by the use of dry batteries. The advantage of this mechanism is that the operator can bring the machines to synchronism from the switch-board thus obviating the necessity of an assistant.

The exciter units are both 10 K.W. direct current, shunt wound generators with fields wound for a tirrill regulator. They are geared to two 23 inch Sampson turbines and furnish exciting current at 125 volts to the alternators. The turbines as shown in plate IV are fed by one of the main flumes and are set with their shafts parallel to the shafts of the alternators.

Our reasons for choosing two exciters were; First, To avoid shut down. Second. Also that the idle exciter may furnish power for the crane.

Auxillaries.

Each unit is provided with a high speed four cylinder gas engine. The position of each unit is indicated in plate IV. These engines are all belt connected to the generators and are arranged so that they may be thrown in when ever needed, by means of cut-off couplings. The turbines can also be cut out by the same method thus leaving the generators to be driven by the engines alone.

The reason for using auxillaries is obvious for the data taken by the government on the discharge of the Blue river, shows that several times during each year the flow of the river is inadequate to supply the required power, also at certain times in the Spring and Fall the rise in the river is of sufficient height to cause the tail water to back up thus diminishing the head on the turbines.

The reason for using gas engines in preference to steam are

1, The location of the power plant makes it rather expensive to use coal for fuel.

2. Less floor space is required for the gas engines than for a steam engine of the same capacity.

3. And as the auxillaries are to be used for only a short time, at different times, there would be less expense in starting and stopping gas engines than steam engines.

4. Gas engines are much more quickly started than steam engines.

Switchboard.

Next to the generator, the switch board is the most important part of the supply system. The following are some of the features to be observed in the construction of switch-boards.

1. The apparatus and supports must be fireproof.

2. The conducting parts must not over heat.

3. The back of the switch board must be easily accessible.

4. Live parts except for low potentials must not be placed on the switch board.

5. The arrangement of circuits must be symmetrical and as simple as they can conveniently be made.

6. The apparatus must be so arranged that it is impossible to make a wrong connection that would lead to serious results.

The switch board shall consist of three panels, one exciter panel and two generator panels, each one being a marble panel supported by an angle-iron frame. The bottom of the switch board is above the floor and the panels are each six and one-half feet by two and one half feet by two inches.

Exciter Panel.

The wire from the exciter generators will will be brought to the exciter panel through conduits beneath the floor. The exciter panel is supplied with one ammeter one voltmeter, one Terell regulater two field rheostats, two four pole double throw switches, one three pole switch, four two pole switches, one pair of lighting bus bars, and one pair of exciting bus bars and one set of power bus bars.

The ammeter is connected so as to read the current in the exciter bus bars, and the voltmeter connected so as to read the potential across the bus bars, these are placed beside the Terrel regulator.

The Terrel regulator is connected to the exciter through a three pole switch. The alternating current part of the regulator is supplied by current and potential transformers located on the wall back of the switch board.

The upper four pole double throw switch is connected so that it can connect either generator to the exciter bus bars and the Terrel regulator. The exciter bus bars extending back of both generator panels. The lower four pole double throw switch is arranged to connect either generator to the lower rheostat and power bus bars. These bus bars will supply power to the traveling crane.

The lighting bus bars are located below the Terrel regulator and is supplied with current at 110 volts from a five K.W. transformer, and will be used for lighting the building. Fuse circuit breakers are used at each switch on this panel. (Alternating Current panels). Each Alternating Current panel will be supplied with one Direct Current ammeter, two Alternating Current ammeters, two indicating wattmeters, one voltmeter, one rheostat, one voltmeter plug, one synchronizing plug, and two receptacles, three potential transformers, three current transformers, and one time relay circuit breaker. Also one panel is provided with the push buttons controlling the Lombard govenor. The other panel has the synchronzing lamps. There will also be two electrostatic ground detectors placed on a frame above the center panel.

The two Alternating Current ammeters (A_1 and A_2) measure the current in the two outside wires of the generator. The other ammeter (F A) is a direct current instrument and measures amperes in the Alternating Current field.

The voltmeter (V) by means of the voltmeter plug, can be connected, between any two wires of the generator. The indicating wattmeter, (I'W') receives its current from the current transformer in the middle wire of the generator and its potential coils are connected to the leads that supply the voltmeter.

Our reasons for choosing this combination of instruments can best be shown by use of an example; Suppose, for instance that the field circuit of one of the machines be broken the ammeter and voltmeter will still continue to read but the wattmeter reading will be reversed and the field ammeter will read 0 which will show at once that the trouble is in a broken field connection. Or for some reason suppose that the motive power for one of the generators fails, and the machine runs as a snychronous motor. The field ammeter, the voltmeter, and the two alternating current ammeters, will still continue to read but the wattmeter reading will be reversed as in the other case. This shows the advantage of using two ammeters and one indicating wattmeter instead of three ammeters. Another advantage in using one wattmeter for each generator is, in case that for any reason one pair of turbines should tend to slow down this will be shown by a difference in reading of the wattmeters connected in the two generator circuits. Therefore by the use of this combination the operator can locate almost any trouble connected with the machines.

The indicating wattmeters (I,W,) measure the total output from the bus bars.

The three potential transformers are connected to the three wires leading from the generator to the oil switch which connects the generator to the bus bars. These potential transformers are connected in delta and furnish voltage for the wattmeter and voltmeter and are also of sufficient capacity to furnish current to the synchronizing bus bars.

There is a double set of synchronizing bus bars each set being supplied with a synchronizing plug receptacle. These receptacles are of such shape that with only two synchronizing plugs it is impossible to connect both generators to the same set of bus bars simultaneously. By this method any number of panels may be added by simply extending the bus bars and putting in similar receptacles.

The synchronizing lamps are placed on the front of the board just below the rheostat and are connected to synchronize dark.

The push buttons(P) which control the Lombard governor are located under the field rheostat of the other panel as shown in scheme.

The current transformers are placed just back of the oil switch connected in the circuit leading from the oil switch to the bus bars. Our reason for putting the current and the potential transformers in this position is to keep all high tension wires from the switch board.

The time-relay (T) is operated by the same current that passes through one of the ammeters. And when the current through this relay becomes excessive it closes the direct current circuit thus energyizing the solenoid, placed back of the switch board, which in turn trips the oil switch.

The electrostatic ground detectors (G D) are capable of carrying the full voltage of the generators each instrument has one terminal connected to the ground and the other terminal connected to the bus bars. The wires connecting these pass over head from the instruments to the wall, by using two detectors connected in this manner, the operator is able to detect a ground in any line.

Bus Bars.

The cables from the current transformers pass through conduits under the floor back to the wall and up the wall to the bus bars. The bus bars are placed between marble shelves which are fastened to the wall back of the switch board. All wires leading to and from the bus bars, passing through the different shelves, are placed in porcelain tubes. This is for thorough protection from an accidental short circuit. This method of placing the bus bars in between the shelves makes it almost impossible for a person to accidentally come in contact with the bars.

The current transformers are placed in the bus bars between the generator and the distribution switches. These three transformers supply current to the total out-put wattmeters and the Terrel regulator and they also assist in protecting the machine from lightning discharges because of the induction. The three potential transformers fastened to the wall just above the bus bar shelves supply potential to the total out-put wattmeters and the Terrel regulator.

The oil switch connecting the transmission line to the bus bars is placed on the floor just below the bus bars and is provided with a time relay. The transmission cables pass from the oil switch, up the wall to the roof girders, and along on these to the west end of the building, and are supported by porcelain insulators.

The lightning arresters are connected as shown in plate VII The cables and transmission lines are connected by means of an aluminum sleave just in-side of the power house.

The Line.

The power will be transmitted from the generator station to the sub-station by a three phase three wire system. The reason for this is discussed under Sub-station distribution.

We will use aluminum conductors from the power station to the sub-station. The reason for this is reduction in cost as shown by the following data:-

The impedance for number 00 copper wire is .724. Our conductors will cary one hundred amperes, there-fore the C. R. drop equal 100 times .724 equals 72.4 equals drop per mile but the total distance of transmission is 4.3 miles hence the total drop 312.32 volts.

The weight of one mile of 00 copper is two thousand one hundred twenty nine pounds for four and three tenths miles equals 9154.7 pounds, to reduce this to aluminum wire capable of carrying the same power with the same loss, we multiply 9154.7 pounds by .48 which gives 4394 pounds for one aluminum wire. The value .48 is the ratio of the weight of aluminum wire to weight of copper wire of same conductivity. And as the prices per pound of these conductors are practically the same and as it requires less than one-half as many pounds of aluminum as pounds of copper, the saving in cost will more than counter balance the disavantages of using this conductors.

Poles.

The poles for this line will be cedar poles thirty feet in length, twenty two inches in circumference at the top, and thirty four inches in circumference six feet from base. The distance between poles will be one hundred and seventy six feet, thus making thirty poles per mile.

The depth of the setting of these poles shall be five and five tenths feet. All corners and angles above ten degrees shall be guyed.

The cross arms shall be made of yellow pine. They shall be three feet in length and three and one-half inches by four and one-half in cross section. The distance of the cross arms from the top of the poles shall be eighteen inches. The pins shall be made of a good quality of oak.

The insulators shall be double petticoat, red glass, and tested for 20000 volts.

Red insulators shall represent high tension and green insulators will represent low tension through out the system.

Sub-Station.

In connection with such a plant as we have here designed it is necessary to have a sub-station, or distributing station at or near the center of distribution.

The same conditions determining the location of this station would enter in, that figure in the location of a central station for a town site, with the exception of those of water and fuel. As we will use high tension primary distribution, it is not so essential that this station be centrally located. The following conditions are to be considered. The lines in the system of distribution from the sub-station. The choice of the system itself as to whether the direct current or alternating current should be used, is dependent upon the area of the territory of distribution. In small districts in which the power consumed is denser and where the distribution can be placed approximately in the center of this area, it would probably be best to convert from alternating current to direct current and use the two wire direct current low potential system. This system is uneconomical however when the mean length of the feeder becomes greater than one half to three quarters of a mile.

The Edison three wire direct current low potential system may be used economically for feeders of one mile in length.

As the feeders for supplying the city of Manhattan would be required to exceed the above length it is evident that high potential should be used, and it is needless to consider direct current any further.

The next essential factor is to decide upon series or parallel distribution. For series distribution alone the station can be economically located any where on the perimeter of the circle. For multiple distribution however it is a much more important matter, because in this case the current is the governing factor in copper used, instead of the potential as in the series distribution. The losses in the line vary as the square of the current flowing and the resistance of the conducting system. Namely (C^2R), and as the supply of a definite territory requires a definite current, also the resistance "R" is the only varriable at our command. Hence from the stand point of economy, and good regulation, the expense of the conducting system must be reduced to the lowest possible amount.

The question of deciding between series and parallel distribution is a simple one when the energy is to be utilized for power, incandescent and arc lighting, because the latter is the only factor in favor of series distribution.

Having decided upon parallel distribution, it is evident that we want to locate this station near the electrical center of distribution as possible. To properly determine this center, a reasonably accurate map should be made of the city, with a careful canvas of all the probable customers, obtaining as nearly as possible the amount of energy they are likely to demand.

The next important factor in locating this station is the cost of realestate, the extra cost of the land must be balanced against the extra cost for copper, in locating for this, and a medium obtained.

This station will be located between Humbolt and Leavenworth streets on first street.

The Building.

The building will be a one story brick building containing three rooms, It will contain as many windows as possible so as to give plenty of light. The transformer room will be strictly fire proof, having a cement floor and iron window frames, We will not go in to detail on the construction of the building as that is a problem for the architect, The engineers need only determine the amount of room required for the machinery.

There will be an office for the superintendent of the company a transformer and switch board room, and a general stock and repair room.

The high tension wires from the generator station enter the transformer room in the same manner as described in leaving the plant As soon as these lines enter the building they are tapped directly through a time relay oil switch to the three single phase Delta connected step-down transformers. These transformers being suspended in the air on a steel structure built up from the floor and out from the wall.

The transformers are the General Electric type, 100 K. W. capacity 60 cycle 5000 volt oil cooled; with a transformation ratio of 50 to 22 and an efficiency of 98%.

A skelteton frame of one and one-half inch iron pipe is connected in front of these transformers, and three feet behind the switch board, which carries the feeders and the oil switches connected with the switch board.

The bus bars are carefully insulated and are bolted on the back of the switch board. Only one set of bus bars is used, the distributing lines are connected directly off through an oil switch.

After stepping the voltage down to 2200 volts the lines are carried down the frame on glass insulators, then through an oil switch to the bus bars, from which it is distributed.

Time relays are used on all the oil switches instead of using fuses in the circuits, These relays are explained in the plans for a power plant switch board.

Sub-Station Switch Board.

The switch board will consist of two panels of 1.5 inch marble which are 60 by 24 inches. They are set on iron legs thirty inches above the floor. The panels are supported by bolts to angle irons, which are braced by iron rods to the constructed frame, at a distance of three feet in front of it, so as to give ample room for the bus bars, oil switches, etc,between. The board can be enlarged at any time business would demand, by placing other panels to the right of the two mentioned. The switch board will be in plain view of the office, and is easily accessible from the repair room.

The following plates shows the scheme of connection, into and out of the sub-station, also a front view showing the arrangement of the switch board.

A switch board for a sub-station does not require the apparatus, required in a central station. The board is equipped with the following; one main oil switch"A" three 150 amperes alternating current ammeters "B" one being in each phase, one voltmeter "C" with potential transformers, the voltmeter is arranged so as to take the potential across either phase; it is also arranged for a ground detector, by touching the key "K" to the ground contact, then changing the three way switch "D" to either phase the potential between the grounded phase and the ground wire will be read on the voltmeter. Three oil time relay switches "S" are used for the distribution; one for each circuit. There are also two recording wattmeters "W" used for recording all the power out put of the station. Series transformers are used for furnishing current to the ammeters and wattmeters The potential transformer for the voltmeter is of sufficient capacity to furnish light for the sub-station, two of which are located on the switch board.

Method of Distribution,

We have all ready decided upon alternating current distribution for the city, we must next decide upon a method of distribution.

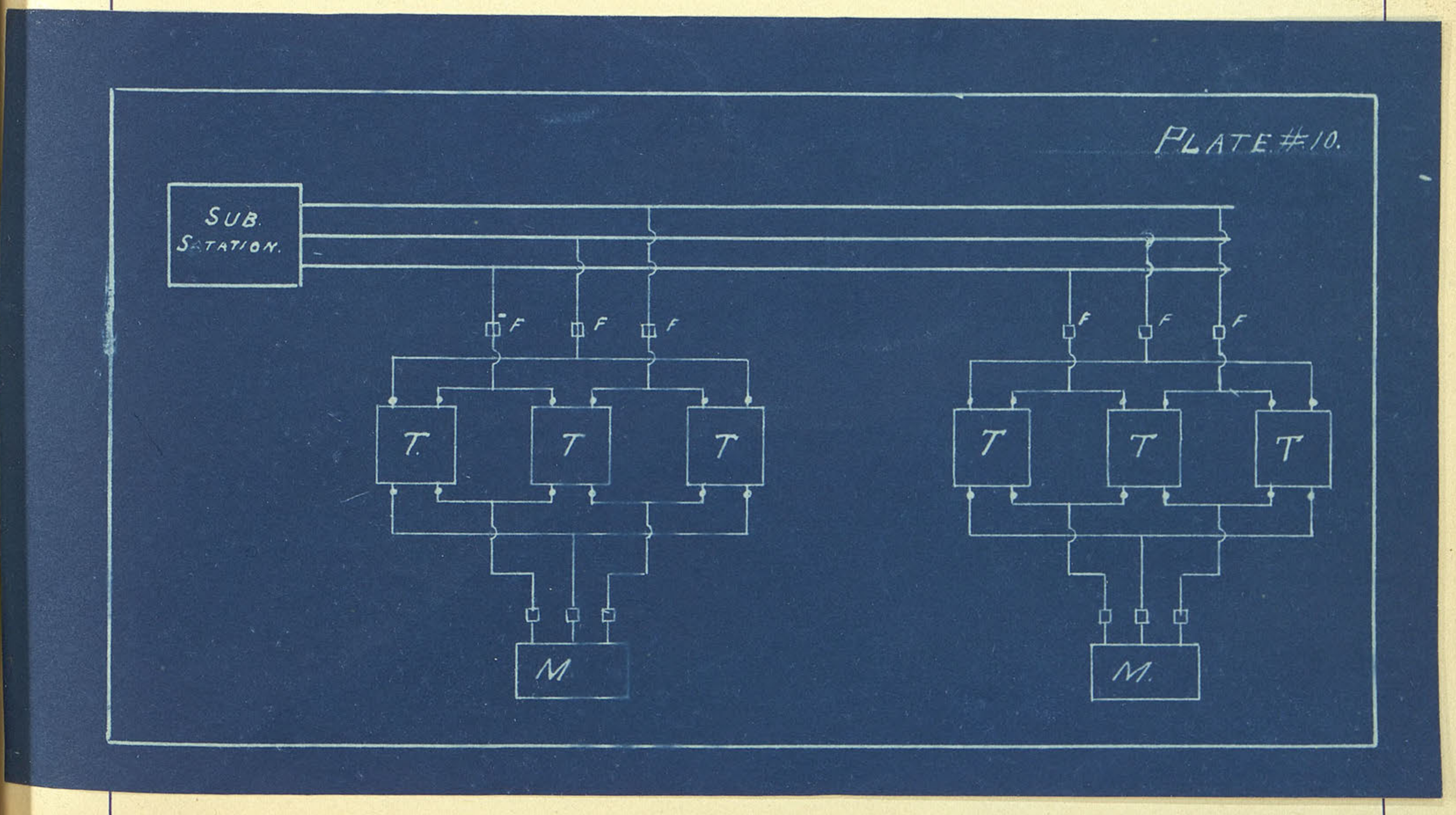
In a plant of the above capacity, where the energy is to be used for both power and lighting, the double or three phase system of distribution is the best. For just lighting alone, the single phase system is very satisfactory, but the single phase motors, do not as yet give the best satisfaction, for general service for motors above 35 horse power. There are a number of different methods of distribution, but the three above mentioned are the most convenient and efficient, the others are more or less experimental.

We now must choose between the two and three phase system. The two are on equal terms so far as operation is concerned, for both power and lighting, but the latter will deliever the same amount of energy on just seventy five percent as much copper, as would be required by any system using two wires per phase. This is proven as follows:- let R equal the resistance of one branch of a Y connected three phase circuit, the loss in this branch will then be C^2R where C is the current flowing in this conductor. The total loss of power then from the system will be 3 C^2R, that is , the loss in all three branches. Now consider the same amount of power delivered by a single phase system, with the same voltage impressed, the same percent of loss allowable has been figured, and is the same for both cases. The 3 C^2R losses of the three phase system equals this percent loss. Now let R' equal the resistance of one of the monophase conductors. The power delivered by a three phase machine is C E $\sqrt{3}$, then as the voltage remains the same, the current flowing in the conductor will be $\frac{C^2E\ 3}{E}$ equals $C^2 3$, the loss in one conductor of the monophase circuit will be (C^2R) equals 3 C^2R and for the circuit the total losses will be 2 times 3 C^2R equals 6 C^2R this loss now must equal $3C^2R$, therefore R' equals R/2 which proves that the resistance of the monophase wire must be only one-half that of a single three phase conductor. Hence the cross section of each of the monophase wires must be double the cross section of one three phase wire, then if the weight of the one three phase wire be W the total weight will be 3W and the weight of the two monophase leads of the double cross section will evidently be 4W. Which shows a saving of 25 percent of copper. The same result may be worked out for the mesh connection.

The energy will be distributed by three line circuits, a power, arc light, and incandescent circuit. Each circuit is controlled by an oil switch on the switch board of the sub-station.

Power Distribution,

The power circuit will be the same as shown in plate # 10. The feeders running direct from the sub-station to as near the center of power distribution as possible, carrying 2200 volts. Primaries will then be tapped off these feeders an run to the location of the motors, at which point the voltage will again be transformed down to 440, at which voltage the motors, will be supplied. We use three phase induction motors because they will start up from a stand still,

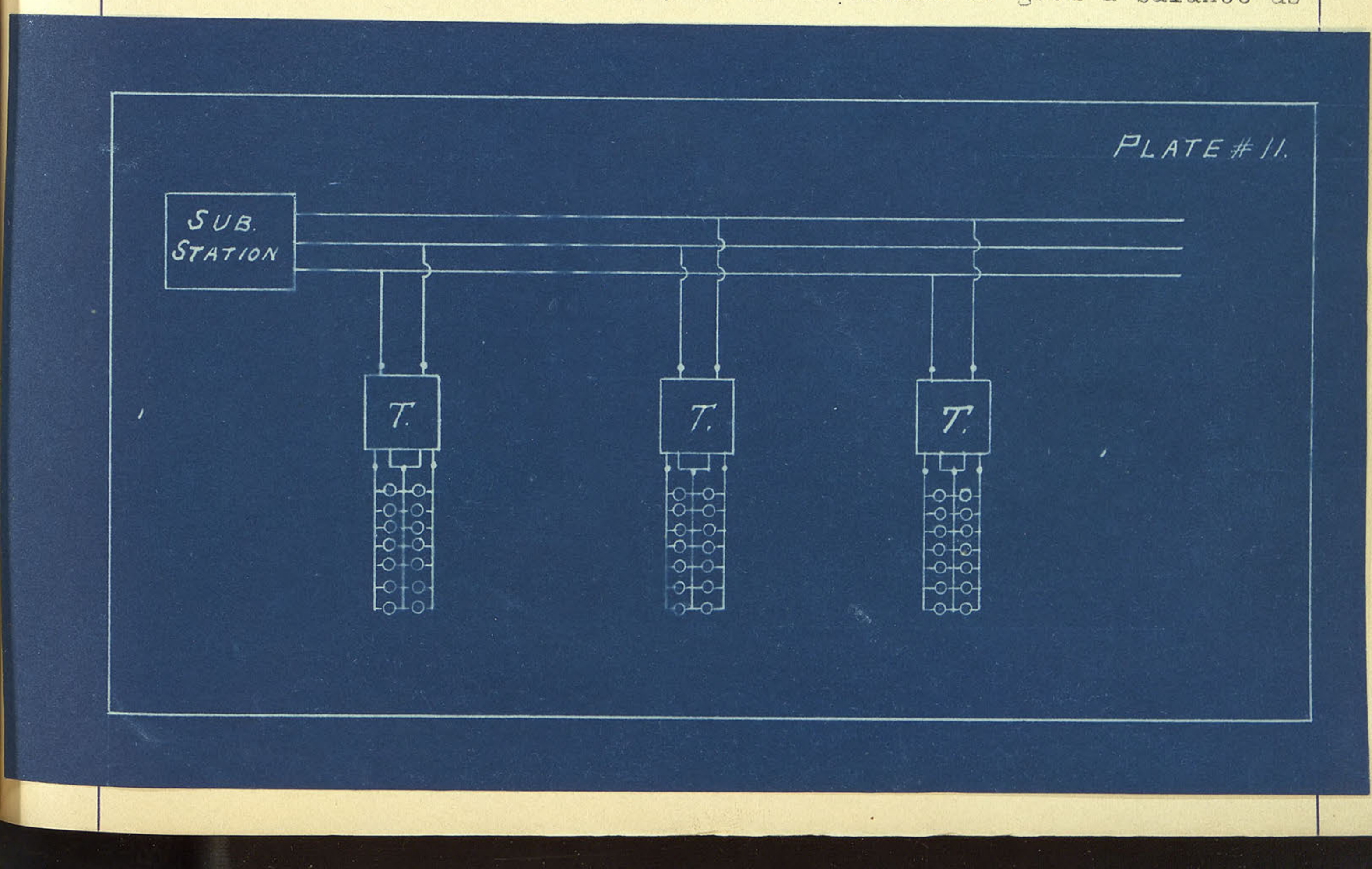


with out further starting apparatus. We chose 440 volt motors because they are some what cheaper in cost, and give just as good satisfaction as any other voltage machine.

Incandescent Lighting.

For incandescent service the feeders will be run out of the sub-station in the same manner as those for power. Plate # 11 shows the method of incandescent distribution. Single phase primaries are tapped off these feeders as is shown in plate 11. The voltage is then transformed and the three wire secondary is used. The secondary coils being connected in series, hence giving 110 volts across the center and either of the out side wires, and 220 volts across the out side terminals.

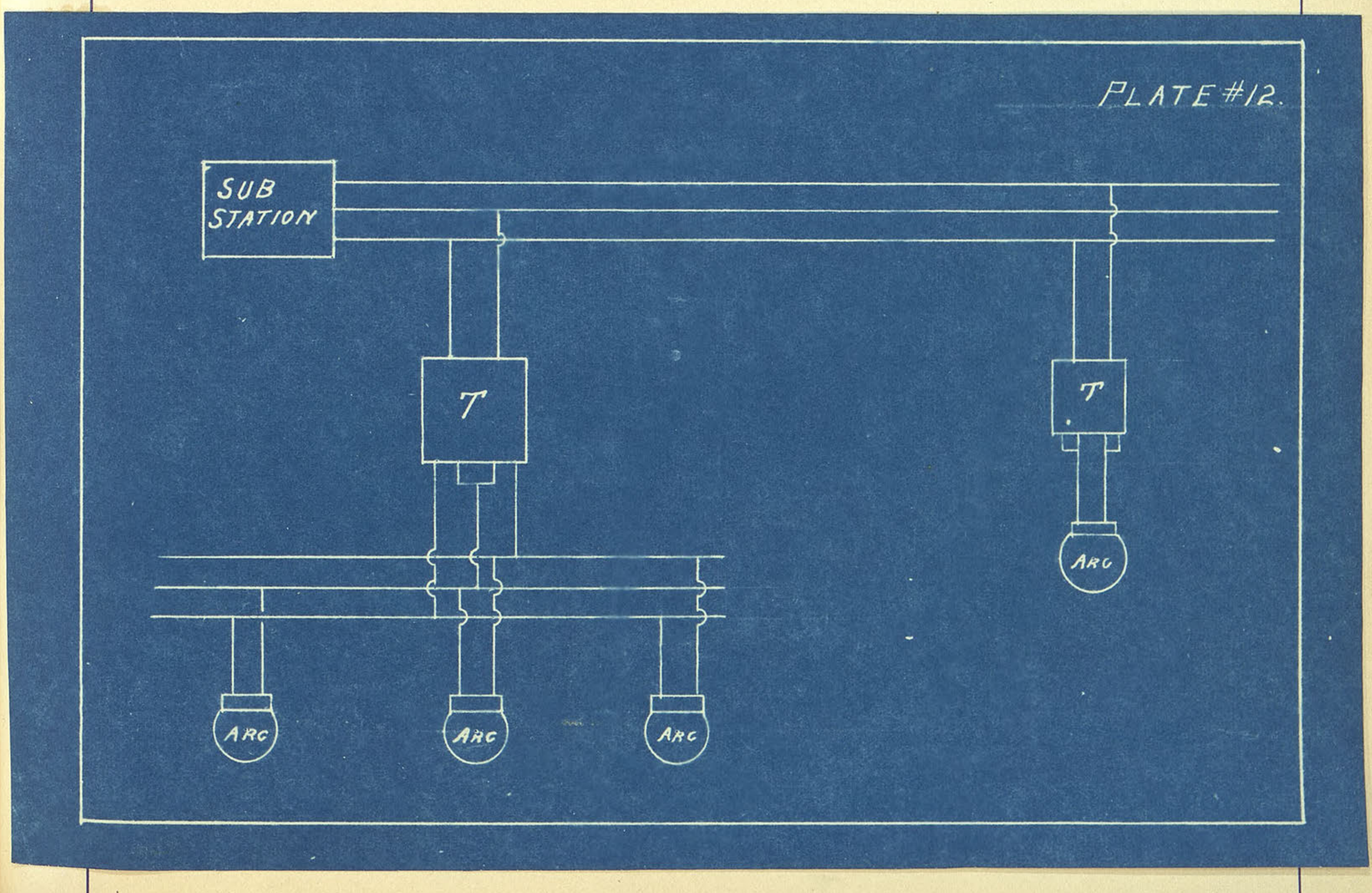
The load of incandescent lamps will be equally distributed between the three feeder phases, so as to insure as good a balance as



possible. The regulators for the lamps will be located at the generating station.

Arc Lighting.

We have decided to use the constant potential mutiple arc distribution, Plate 12 shows our method. We run the primaries in just the same manner as for incandescent lighting, also using the three wire secondary as before. In the down town districts, and elsewhere when business permits we will operate three or four arcs from one transformer. Thus out in the suburban streets, we will use single lamp transformers, thus running the high tension to the lamp. This object is to use as large transformers as circumstances will permit and keep them carefully loaded. The single lamp transformer



is of course not as efficient as a larger one, but the losses are reduced to a minimum because the transformer is always working on full load. The advantage of the multiple arc lamp is that the high potential is done away with, hence avoiding the danger to the trouble man when fixing the lamp. The breaking of one wire will not put system out of commission as in the case of series arcs. Another advantage is, that different size lamps may be used, which would be some times desired for interior lighting.

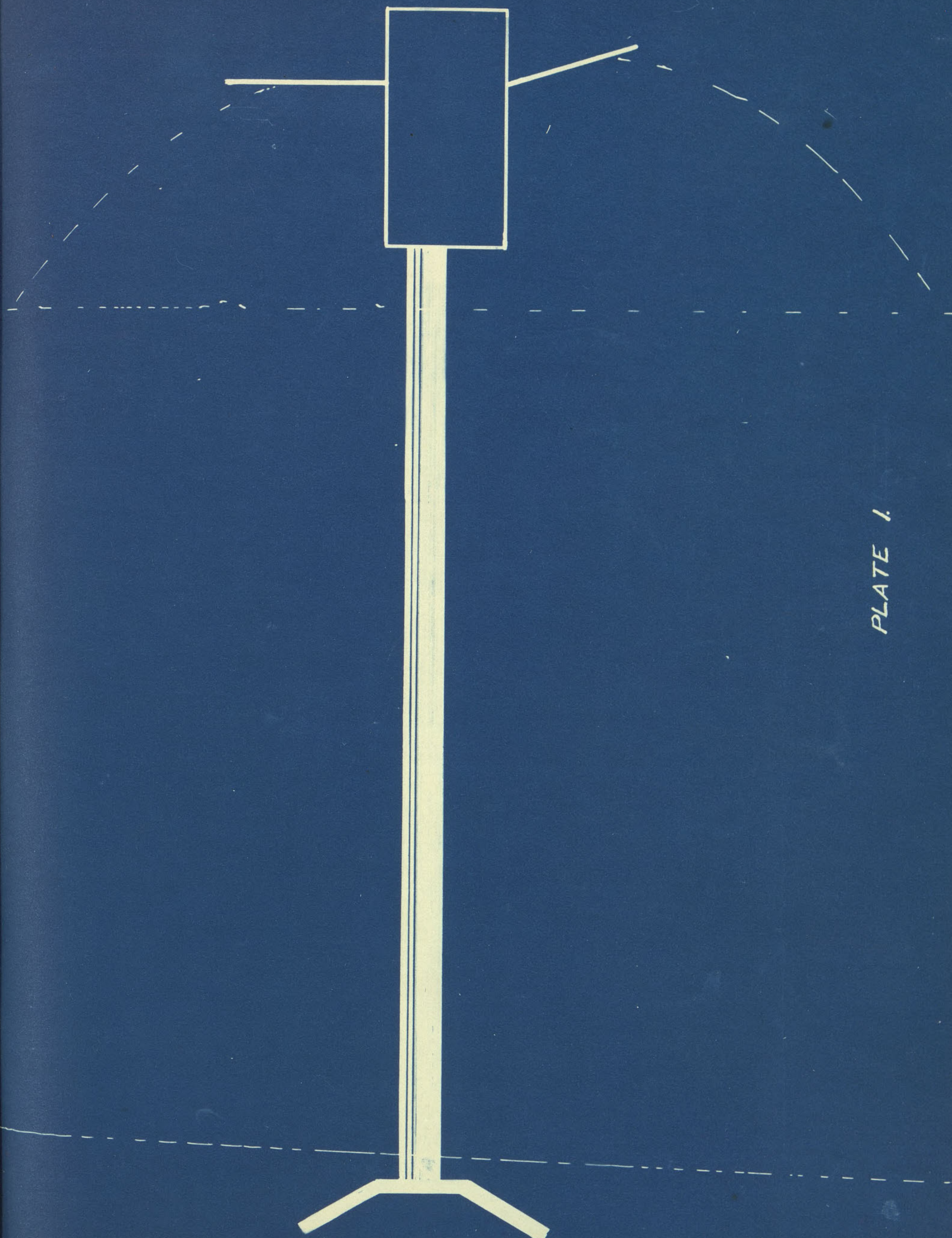
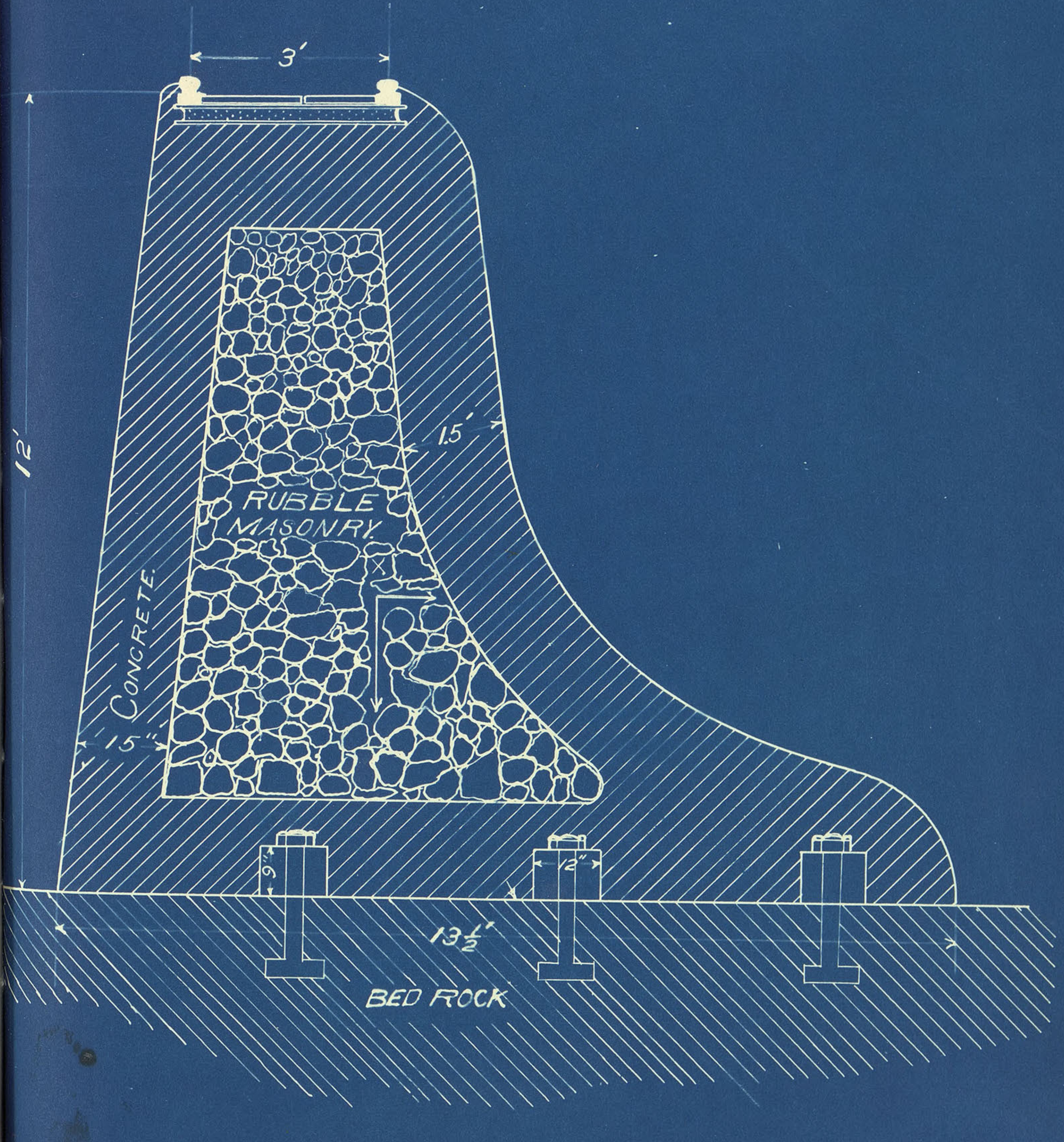
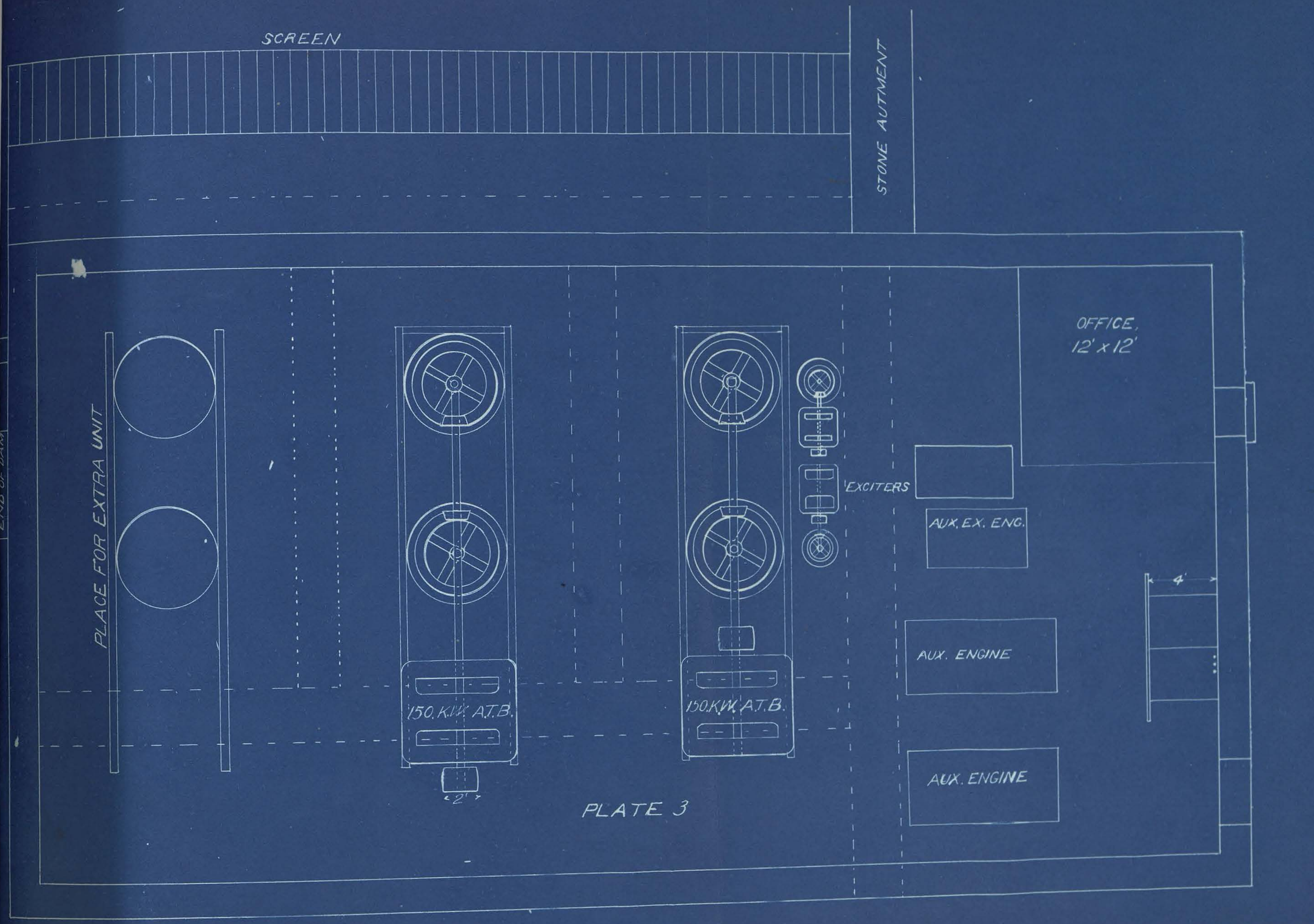
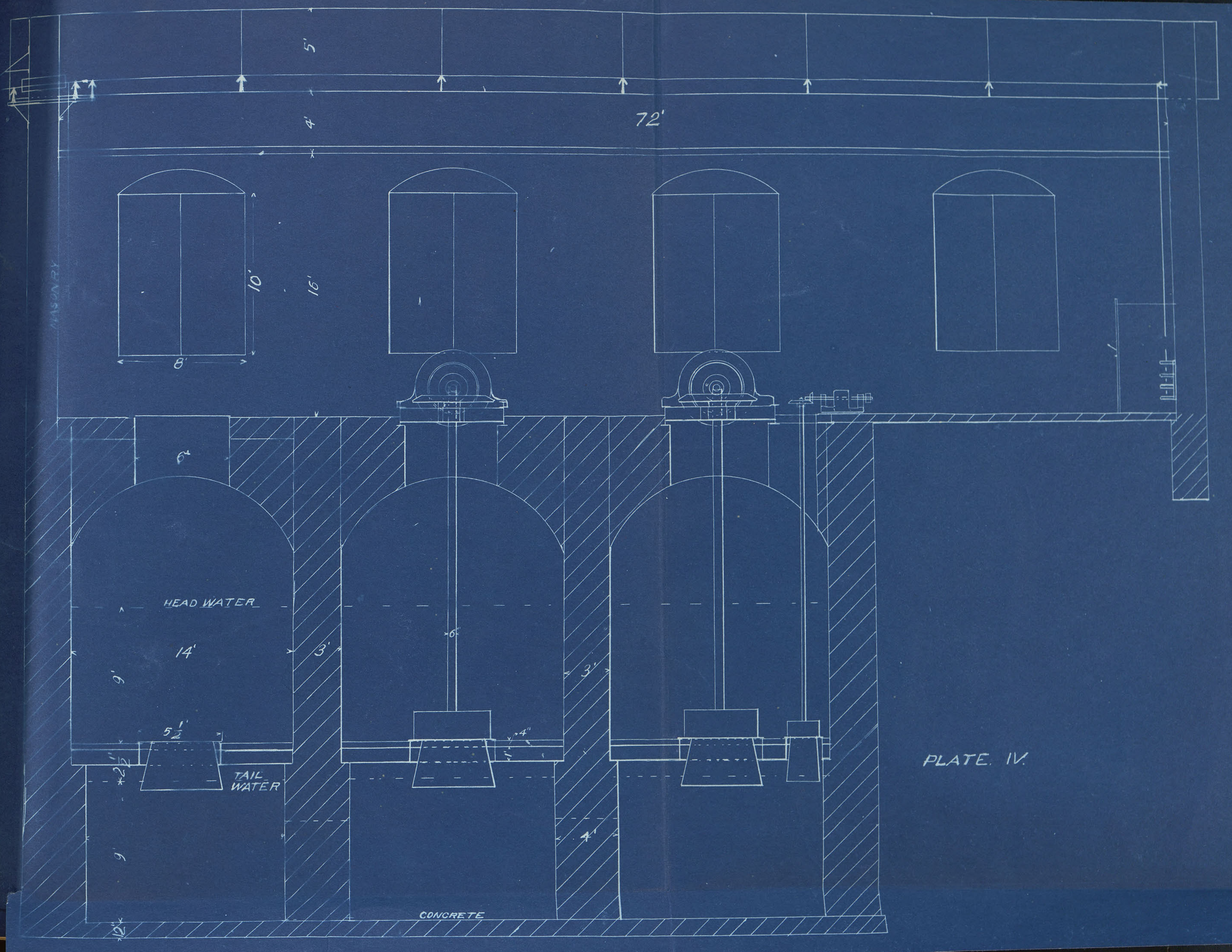


PLATE 1.

PLATE II

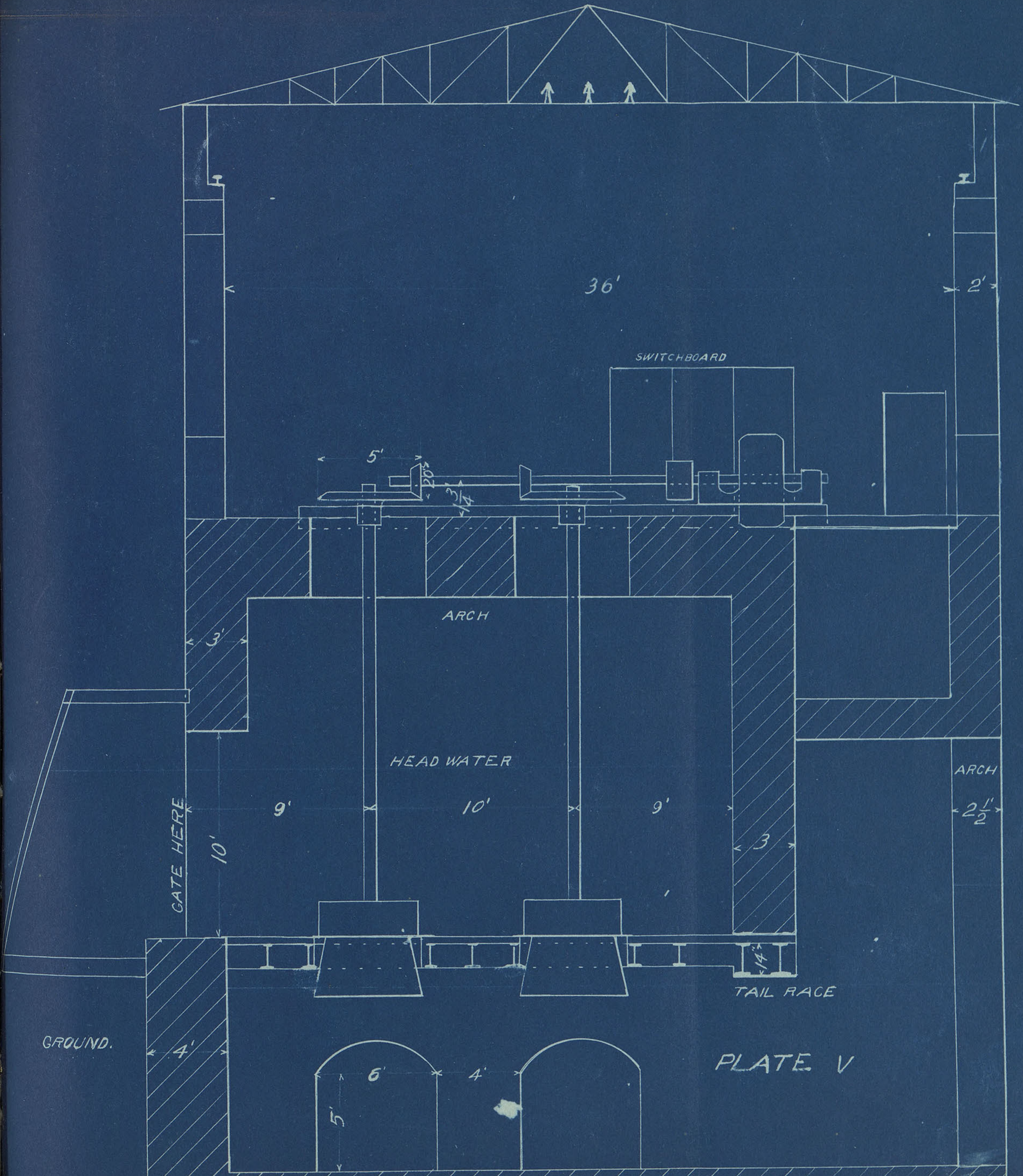



SCREEN
STONE AUTMENT
END OF DAM
PLACE FOR EXTRA UNIT
OFFICE, 12' x 12'
EXCITERS
AUX. EX. ENG.
4'
AUX. ENGINE
150. K.W. A.T.B.
150. K.W. A.T.B.
2'
AUX. ENGINE
PLATE 3



5'
4'
72'
MASONRY
10'
16'
8'
6'
HEAD WATER
6"
14'
3'
3'
9'
5 1/2'
4"
1'
2 1/2'
TAIL WATER
4'
9'
2'
CONCRETE

PLATE. IV.


36'
2'
SWITCHBOARD
5'
20"
$1\frac{3}{4}$
ARCH
3'
HEAD WATER
GATE HERE
10'
9'
10'
9'
3
ARCH
$2\frac{1}{2}$'
14"
TAIL RACE
GROUND.
4'
6'
4'
5'
PLATE V

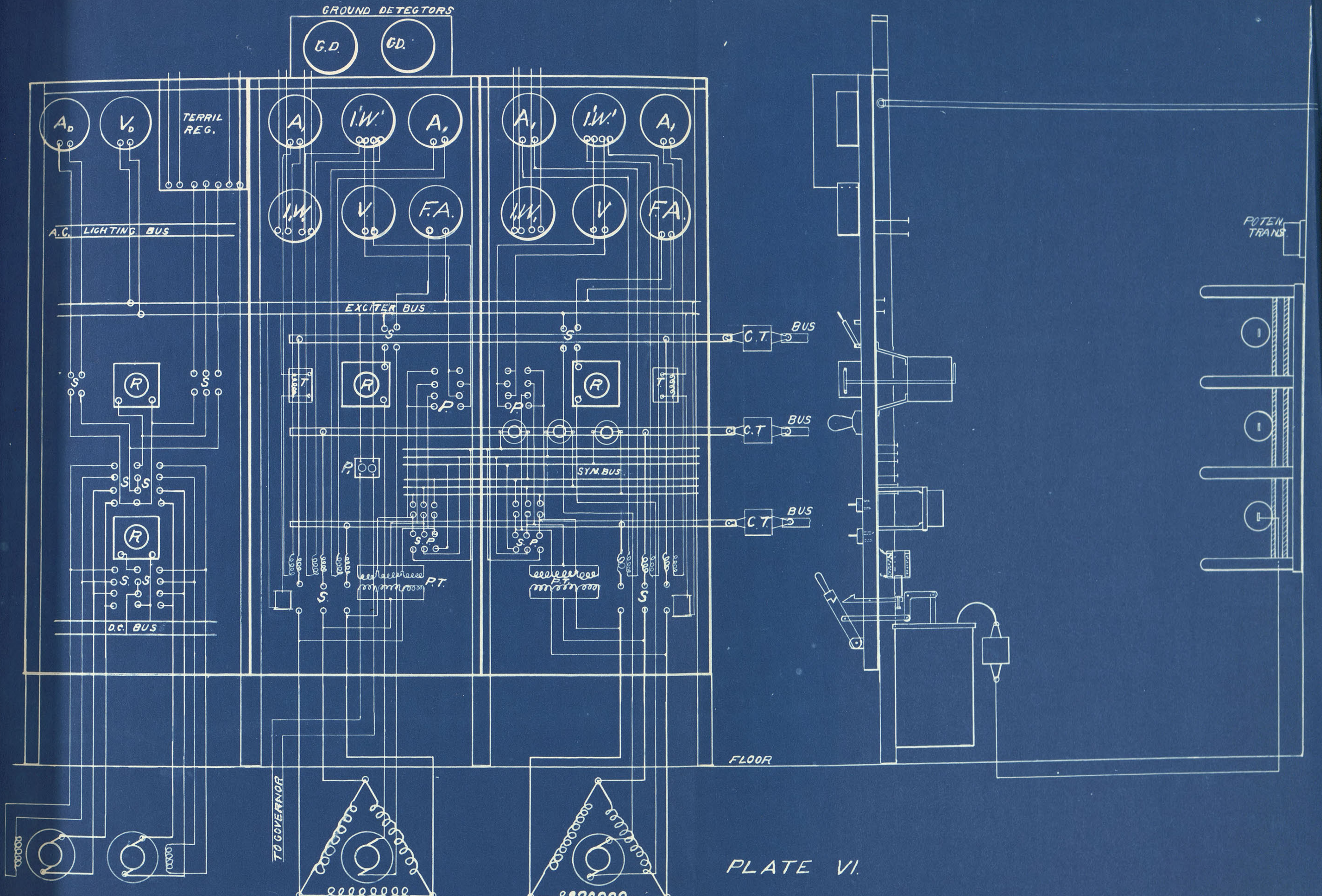


PLATE VI.

BACK VIEW.

PLATE VII.

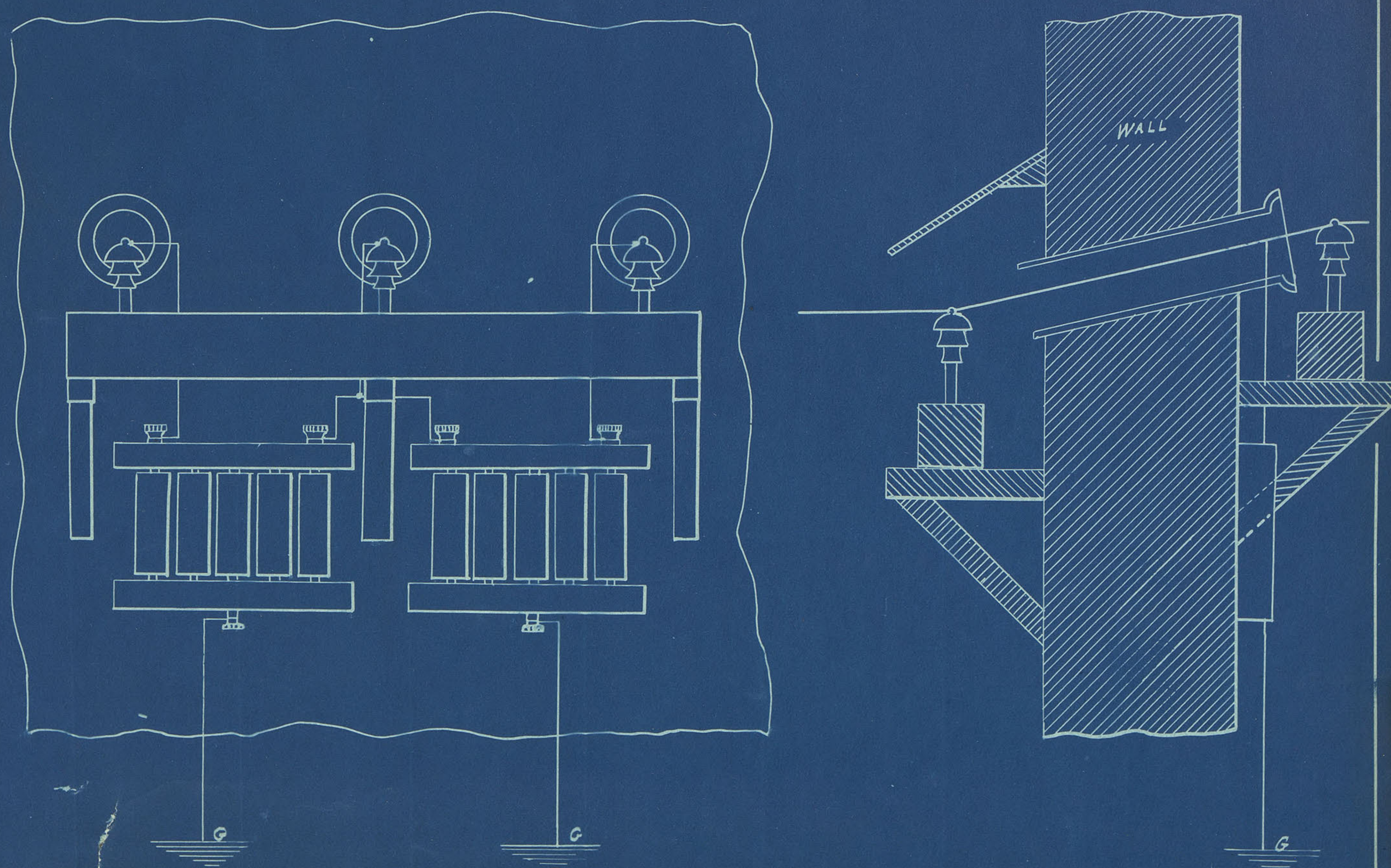


PLATE # 9.