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A ROTATING ARM AND MANEUVERING BASIN

by

W. F. Brownell

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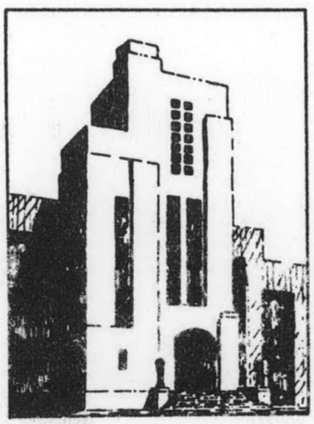

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ABSTRACT

A new Rotating Arm and Maneuvering Basin for the David Taylor Model Basin is described. Design information concerning the test facilities, electric drives, auxiliary equipment, instrumentation, building and basins is presented.

INTRODUCTION

The functional specifications of a new Rotating Arm and Maneuvering Basin for the Taylor Model Basin were completed in March 1952[1]. Phase I Advance Planning Design Studies [2,3] for the building and test facilities were carried out and completed in July 1954 by Mackenzie, Bogert and White, Architects-Engineers and the engineering divisions of the Model Basin. The Phase I design was critically reviewed and revised by the Model Basin Staff in order to reduce the total estimated cost of the project.

A supplementary Phase I Advance Planning Study[4] and the final bidding plans and specifications were prepared by Sverdrup and Parcel, Consulting Engineers, with the exception of the model positioning equipment and the six component balance for the Rotating Arm which were designed by the Model Basin, Industrial Department, Engineering Divisions. Funds for the construction of the project were provided in the Department of the Navy Public Works Program for 1956. Contract NOy 86453 [5] for the construction of the complete facility was awarded in May 1956 with a completion date of November 1958.

The Rotating Arm and the Maneuvering Basin are two separate and complete test facilities housed in a single building. Figures 1, 2 and 3 show plan views and elevations of the test facilities and the building and Figure 4 is a view of a 1:120 scale model of the Rotating Arm and Maneuvering Basin.

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[1]References are listed on page 31.

ROTATING ARM TEST FACILITY

The Rotating Arm Facility will be used to provide design information relating to the directional stability, maneuverability and control of high speed submarines, torpedoes and surface ships. The facility consists of a circular basin 260 ft. in diameter having a water depth of 20 ft. A rotating arm radially spans the basin and supports test models by a system of tracks, model tow carriage, positioning apparatus, towing struts and balance. The arm pivots on a bearing located on the center island and will be driven by a pair of electric motors, directly coupled to two wheels which support the arm and run on an outer peripheral rail.

It will be possible to test submarine models up to 20 ft. in length at depths up to 10 ft. at any arm radius between 12 ft. 6 inches and 120 ft. Indicators, recorders and control instrumentation for measuring the forces and moments acting on the test models, model attitudes and arm speed will be located either in the operating console or racks, in the arm inner bay area. Steady state arm speeds of 30 knots at the 120 ft. radius will be attained in less than 1/2 a revolution of the arm and 50 knots at the same radius in less than 2-1/2 revolutions. These speeds are the equivalent of about 3 and 5 knots respectively at the 12 ft. 6 inches arm radius. For tests of a 2,600 pound, 20 ft. submarine model at 10 ft. depth, a 12 knot speed can be attained within 1/2 a turn for any radius between 48 and 120 ft. In addition, surface ship models can be tested at any radius within the designed arm speed and powering.

ROTATING ARM

The rotating arm shown in Figure 5 has a span of 129 ft., a width of 20 ft. and a maximum height of 20 ft. The arm structure is primarily a tubular aluminum Parker truss. The chord members are 10 inch O.D. by 3/8 inch wall, the web members 8 inch O.D. by 3/16 inch wall, the tie rods are 3-1/2 inch O.D. by 3/16 inch wall and the half span rods are of stainless steel tubing 3-1/2 inch diameter by 3/16 inch wall. The contractor has the option of using either welded or bolted construction for the fabrication of the arm. Aluminum alloy fairings are provided for the main members along the outer half of the arm to reduce windage drag and thus the drive power required at high speeds.

The estimated weight of the arm structure is about 37,500 pounds. The calculated natural frequencies of the arm are: vertical 3.3 cps, horizontal 3.2 cps, and torsional 4.0 cps. These are considered to be acceptable for the conducting of the submerged submarine tests. There will be a walkway along the center of the arm, extending from the outer end to the control and operating area which is located at the inner bay of the arm.

CENTER PIVOT BEARING

The pivot for the rotating arm includes a Kaydon tapered roller bearing assembly designed to take the maximum centrifugal force of the arm which is about 145,000 pounds. The outer race of the bearing will be connected to and rotate with the arm and the inner will be fastened through a steel structure to the concrete center island. The bearing will have a 61.5 inch bore, 71.125 inch outer diameter and 5 inch width. The radial rating of the bearing at 500 rpm is 206,000 pounds and the thrust rating at 500 rpm is 192,000 pounds. The maximum speed of the arm is about 7 rpm for the 50 knot test speed at the 120 ft. radius. Figure 6 shows the pivot bearing assembly. The concrete center island is 7 ft. in diameter at the top to a point 6 ft. - 0 inches below the basin water surface where it starts tapering out to an 18 ft. - 0 inch diameter at the basin floor.

PERIPHERAL TRACK

Figures 7 and 8 show a layout of the rail and a typical section through the track which will be located on the top of the basin wall. The construction consists of individual lengths of machined cast steel rail chairs bolted to the concrete basin wall. In turn flat plate ground rail sections will be bolted to the top of the rail chair. Scarf joints are used for the rails and vertical bolted butt joints for the chairs. The rail material is of hardened alloy steel (R/C 30-32). The chair and rail will be set to the following tolerance: plus or minus 0.006 inches in height above the water, plus or minus 0.001 inch waviness per 6 inches of track and plus or minus 0.125 inches in diameter of track at any point.

CARRIAGE AND TRACKS

The model tow carriage is remotely positionable by means of a windlass and cable to any radius between 12 ft. 6 inches and 120 ft. from the center of rotation, as shown by Figure 9. For testing submerged models a model yaw table adapter and bearing will be attached to the carriage and a moveable assemblage consisting of the model positioning apparatus, towing struts, balance and model will be connected to the yaw bearing. In addition, a detachable towing beam for surface model tests may be connected to the carriage.

In general, the carriage structure, Figure 10, is of aluminum alloy fabricated beams welded together. Support rollers and guide rollers attached to the carriage support the carriage during positioning and maintain its alignment in the horizontal plane. Hydraulically actuated toggle clamps hold the carriage firmly in place during tests.

Aluminum alloy tracks will be fastened to the bottom chords of the arm to support the model carriage. Figure 11 shows a detail of the track construction. The support tracks, when installed, will be straight within plus or minus 1/64 inches in any 10 ft. and plus or minus 1/32 inch in the entire length of horizontal finished track and vertical reference surface. At any radial position a line normal to the radius across the finished surface of the two tracks will be level within plus or minus 1/32 inch in 20 ft. The guide roller track attached to the bottom trailing arm chord will have the same tolerance for the guiding surface in the vertical plane.

MODEL POSITIONING APPARATUS

Submerged models will be positioned in yaw, roll and pitch from a remote control station over the center island. The functional requirements are that the angular setting of a submerged test model be maintained within plus or minus one degree during tests and that the model attitude be measured and recorded within plus or minus 0.02 degrees. The arm carriage and tracks are designed to meet this requirement. A schematic arrangement of the towing strut and model positioning apparatus is shown in Figure 12. Submerged models will be attached to the twin struts shown. The model struts will be connected at the upper end to a strut beam attached to a rotatable yaw table, pitch and roll assemblage. The yaw table is bolted to the yaw bearing contained in the towing carriage. Individual electric drive systems will be used to position the model at any attitude. For pitch and yaw the model can be rotated without changing the test location of the submerged model. However, for roll both the model and struts are pivoted about a point in the overhead roll positioning unit and thus are displaced. Locating a remotely controlled roll positioning apparatus inside the model was considered, but discarded, because of problems connected with closure of the required strut slot in the model hull for rolling.

This equipment will permit testing through the following range of model attitudes:

yaw - plus or minus 30 degrees;
roll - 10 degrees outboard, 40 degrees inboard;
pitch - plus or minus 15 degrees.

The struts can be oriented into the flow as desired since they are rotatable. Also, strut spacings of 3 ft. 6 inches to 10 ft. can be obtained thus providing towing flexibility for various length models.

The towing struts will be stainless steel with machined outside surface and of the streamlined EPH type section. At the model their cross section is 3 by 0.857 inches for an adjustable length of 20 inches. At this point the strut connects to a section which tapers from 7 by 2 inches cross section to 24 by 6 inches in a length of 31 inches. The remaining upper 6 ft. 3 inches length of strut is 24 by 6 inches in cross section.

WAVE ABSORBER

Around the periphery of the basin a 15 degree slope wave absorber will be installed. The absorber will be made of two layers of permeable bar type concrete beach units resting on an impermeable concrete shelf. Figure 13 shows dimensions of the beach unit. An impermeable beach unit of 15 degree slope will be installed around the periphery of the center island as shown by Figure 14. The primary purpose of these absorbers is to reduce the time required for the water surface to become quiet after a test run. These units were selected as a result of a series of tests at the St. Anthony Falls Hydraulic Laboratory[6] and short length absorbers with slopes of 5, 10, 15 and 20 degrees of both the permeable and impermeable type were tested. Since the space for the beach is limited due to the requirement of model tests at extreme radii of the arm, it is not possible to use the most efficient absorber in the Rotating Arm Basin. However, it is estimated that the absorber selected will reduce the settling time of the basin from 1/3 to 1/4 of that required if no absorber were used.

SLIP RING SYSTEM

A slip ring system will be used for the transfer of power, control and instrumentation circuits from the shore to the rotating arm. In this application the brushes rotate about stationary slip rings. The slip ring system is supported by a stationary steel shaft rising from the center pylon structure of the arm. Figures 5, 15 and 16 show the location of the slip ring assemblage, an elevation of the slip ring structure and a section through the slip rings. The slip rings will be mounted on a stationary, vertical hollow steel shaft of 14 inches outside diameter. The shaft is divided into four bolted vertical sections for power, instrumentation and control circuits. Power circuits above 600 volts and below 600 volts will be on separate sections of the shaft. The base of the slip ring shaft rests on the support shaft and also supports the brush structure by means of a support and alignment bearing at the bottom and an alignment bearing at the top. The slip rings will be connected to the shore by means of cables running along the overhead building structure. The overhead cables run to junction boxes located on top of the stationary part of the slip ring structure. The brushes connect to the rotating arm equipment by cables.

Slip Rings

Slip rings used for the power compartments will be of a high conductivity copper alloy. There will be nine slip rings in the above 600 volt compartment, each capable of carrying 250 amperes. There will be ten slip rings in the below 600 volt power compartment of which three will be spares, each capable of carrying 200 amperes. The slip rings in the instrumentation and control compartments will be of fine silver. The instrumentation and control compartments will each have 59 slip rings available.

Brushes

The power brushes will be of copper graphite composition 3/4 inch wide, 1-3/4 inch thick and about 2 inches long, capable of carrying 150 amperes per square inch of cross section area. The brush holders will be of copper-alloy. There will be two brushes per brush holder and two brush holders per slip ring located 180 degrees apart.

The instrumentation and control brushes will be 1/8 inch wide, 1/4 inch thick and about 1/4 inch long and will be of silver-graphite material. Two brushes per holder will be used and two holders per ring, mounted at 180 degrees spacing and suitable for 600 volt operation.

ARM DRIVE SYSTEM

Mechanical Drive

The driving force for the rotating arm will be provided by two 30 inch diameter ground steel tired traction wheels which are preloaded against the track surface by means of steel tired keeper wheels mounted on pivoted shafts and loaded by nested compression springs. Figure 17 shows the drive assembly and its location. Each drive unit includes one main traction wheel directly coupled through a 12 ft. shaft to an electric motor, two keeper wheels, and two sets of double nested springs adjusted to provide a total normal force of 61,000 pounds per drive wheel. The two drive units will be mounted in the outer bay of the rotating arm and will be symmetrical about its centerline. Flexible disk type couplings are provided to provide flexibility between the motor and traction wheel.

Electric Drive

The electric drive is an adjustable voltage d-c system with automatic feedback control. A block diagram of the system is shown by Figure 18. The actual motor ratings for the drive motors were not specified, in order to obtain maximum competition from the manufacturers. Instead operational requirements, weight limitations (drive motors, holding brakes, blowers and supporting rails not to exceed 28,000 pounds) and limitations on torque and current were specified. A safety factor of 25 percent is available in the total power. It is anticipated that one possibility for the drive will be two 250 hp d-c mill motors capable of delivering 300 percent of rated torque during acceleration of the arm. Control for the arm drive will be from a console located at the inner arm bay near the center island.

Capabilities: The drive system will be capable of accelerating the arm to an angular velocity of 0.425 radians per second (30 knots) within 90 degrees and stabilizing at this speed within plus or minus 0.1 percent within the next 90 degrees of arm angular displacement. It will also be possible to accelerate the arm to a steady state speed of 0.71 radians per second in less than 2.5 revolutions. Continuous operation at arm speed of 0.425 radians per second and operation for at least 20 minutes at a speed of 0.71 radians per second will be possible. The estimated arm speed constancy is within plus or minus 0.000425 radians per second for arm speeds up to 0.425 radians per second and plus or minus 0.1 percent of the speed between 0.425 to 0.71 radians per second.

Arm speeds will be preset by means of a selector switch and precision potentiometers located at the control console. Preset accuracy of speed is estimated to be within plus or minus 0.00106 radians per second below 0.425 radians per second, and within plus or minus 0.25 percent of speed between 0.425 to 0.71 radians per second.

An inching control is provided to exactly position the arm. Inching speed will be adjustable from zero to about 0.10 radians per second by means of an inching potentiometer at the console.

Drive: The drive system will consist of two d-c series connected 420 rpm shunt wound motors capable of constant torque application to 700 rpm. The drive motor will be capable of reverse operation up to 210 rpm (15 knot arm speed). The power supply will consist of a motor generator set which includes optionally one or two 900 rpm shunt wound d-c generators capable of supplying not less than 700 kw to the drive motors and having a voltage rating compatible with the drive motors, and a synchronous motor with a rating of not less than 1000 hp, 2300 volt, 3 phase, 60 cycle, 0.8 p.f. and

900 rpm, for reduced voltage line reactor start. The synchronous motor will be supplied from a 2400 volt switchgear unit.

The minimum torque required for the drive motors is estimated to be 18,534 pound-ft. The maximum that can be provided is 22,900 pound-ft. which corresponds to the maximum tractive effort which can be developed between the drive wheels and the tracks. The maximum drive motor current will not exceed 3000 amperes and the maximum motor voltage is estimated to be between 350 to 400 volts per motor for 700 rpm speed.

The excitation for the shunt fields of the main drive motor will be from a separate source of 250 volts d-c supplied by a package type motor generator set consisting of an a-c motor and a d-c generator. A d-c rotating amplifier of approximately 30 kw capacity will furnish exciting current for the main drive d-c generator and will be driven by a 440 volt, 60 cycle 3 phase induction motor.

Speed Regulation: A high-gain closed-loop electronic speed regulating system operating from a tachometer feedback signal will control the d-c generator output voltage and thus the drive motor speed. Current limit circuits which can be preset by potentiometers at the console are included for control of rates of acceleration and deceleration. Two tachometers will be used so that greater accuracy can be obtained in the low speed range of 0 to 0.212 radians per second. The tachometers will be driven by an idler wheel which runs on the peripherial drive track.

Braking: Regenerative braking will be used for stopping and this, together with drag braking, should result in a deceleration rate not exceeding the peak acceleration rate of 0.12 radians per second per second. For holding the arm in place, brakes of the spring set shoe type will be mounted on the shaft extension of the drive motor.

Protective Devices: Overvoltage, slip detection, zero voltage, loss of field, overcurrent, overtemperature, zero speed, overspeed, ground detection and undervoltage devices protect the equipment from malfunction or component failure. In addition, a complete system of mechanical and electrical interlocks prevents improper arm drive operation. Malfunction of the arm control, drive system, or protective device will be detected by indicating lamps on the console or by a target on the protective device.

DRY DOCK

A moveable drydock which can be flooded or evacuated is provided so that sub-surface models can be moved from the fitting room area into the rotating arm basin to be attached to the rotating arm at any desired test radius. Normally, a submarine model will be fitted with model motors, balance, support struts and model positioning apparatus in the fitting room. The complete assemblage and instrumentation will then be checked out under water in the fitting room test basin.

After checking, the model with support struts and positioning apparatus will be moved to the drydock that will be stored in the well at the northwest side of the basin. With the drydock it will be possible to make adjustments and repairs to the models without removing them from the rotating arm.

The drydock is supported by a system of rails on the basin floor and guide wheels. Cast iron ballast will be used to prevent flotation of the drydock when it is evacuated. The travel and positioning of the drydock will be by means of a cable drive system having sheaves at the center island and driven through a high ratio gear reducer by a $7\frac{1}{2}$ hp, 3 phase 440 volt 60 cycle 1800/900 rpm electric motor equipped with a magnetic holding brake. One end of the drydock frame is hinged to act as a door for the entrance and exit of the model, attached to the rotating arm. Two 2000 gpm vertical pumps driven by 15 hp electric motors are provided for pumping out the drydock. Toggle type flood valves will be used for filling the drydock.

The drydock will be of carbon steel painted with red lead and with aluminum phenolic except for under water fittings and moving parts which generally will be of corrosion-resistant material. The inside dimensions of the drydock are 26 ft. long by 16 ft. wide and 18 ft. deep. This size will permit the handling of 20 ft. submarine models with either vertical centerline towing struts or L struts mounted on each side of the model.

INSTRUMENTATION

Submarine Balances

Balances are provided to measure the forces and moments acting on submerged bodies. A forward and aft assembly, Figures 19 and 20 will be used. The forward assembly consists of 3 individual force balance units and a roll moment balance unit. This assemblage will be connected to the forward towing strut and to the test model. The aft assembly will be attached to the aft towing strut and the model and will consist of three individual force balance units joined together and a strut fitting. The balances are of the linear differential transformer type which converts the force or moment into an electrical voltage signal. This type transducer consists essentially of an armature which is positioned freely inside two pairs of primary and secondary coils. An alternating voltage is applied to the primary coils which induces a voltage in the secondary coil. When the armature is centered, there is no voltage output but when the armature is displaced by a force there is an output voltage. The balance is designed for the following forces and moments:

Drag	1000 pounds	Roll Moment	650 lb ft
Lift	450 pounds	Pitch Moment	1750 lb ft
Side Force	800 pounds	Yaw Moment	4900 lb ft

The forces and moments will be obtained from combinations of measurements from the individual force balance units. The roll moment will be obtained directly from the roll moment balance. A dead weight system is provided for calibrating the balances.

Balance Instrumentation

Instrumentation to measure, indicate and record the steady state or slowly varying forces and moments acting on the test model will be furnished. Figure 21 shows a block diagram of this measuring, indicating and recording system. The instrumentation will be suitable for operation with either the linear differential transformer type transducers with 400 cps a-c voltage excitation that are furnished with the balance, or for strain gage type transducers with d-c voltage excitation.

The system consists of a servo-balancing circuit including a-c and d-c gage control units, amplifiers and demodulating chopper amplifiers, servo motor tachometer generators with associated gear train and potentiometers, analogue to digital converters, digital recorders of the adding machine type, graphic recorders and dial type remote indicators. The balancing circuit detects any unbalance in the system and supplies a signal to the potentiometer drive motor. This activates the balancing potentiometer to null the signal and simultaneously rotate the input shaft of the analogue to digital converter to an angular position which when read out produces a number on the printer corresponding to the measured value. The total estimated inaccuracies of measurements at the digital recorders are expected not to exceed $\pm$ 0.2 percent of full scale and $\pm$ 0.3 percent of scale for the graphic recorders. Digital recording will be in accordance with a signal from a programmer unit. The minimum rate of printing for the digital recorders will be one record per second and the scale will be minus 999 to plus 999. The graphic recorders will have a full scale pen travel and balance time of not more than 1/4 second and a useable scale width of at least 10 inches.

Model Attitude Measurement

Submerged model roll, pitch and yaw angles will be measured, indicated and recorded. The supporting structure will be used as a reference for these angular measurements. The indications and recordings will be in digital form and in degrees and hundredths of a degree. The transducers are analogue to digital converters which connect directly to the remotely controlled attitude drive systems located at the yaw bearing. Recording will be controlled by signals from a programmer and continuous readout will be provided by the digital indicator at the console.

Arm Speed Measurement

The arm speed pick-up consists of a large gear fastened to the fixed slip ring support post. The gear teeth will be meshed to the external gear of a pulse generator transducer located on the rotating arm structure just above the yaw bearing. The transducer includes a housing which is a stator with internal gear teeth and a magnetic pickup coil. The rotor includes the transducer external gear and a magnet. As the rotor shaft turns a change in reluctance occurs between the shaft gear and the housing gear thus inducing a voltage pulse in the pickup coil.

The speed measuring system, Figure 22, includes a dual set of electronic counters with the necessary switching to permit one set to count pulses while the other set is being de-coded and the reading recorded on printers. The counting period will be one second with the electronic gate control supplied by the programmers precision time base. The electronic counters count and indicate 9,999 pulses per second. There will be continuous indication of arm speed at the console by 4-decade digital in-line indicators and digital recordings will be printed at one second intervals and totalized at the end of a run as directed by the programmer. Arm speed measurement and recording will be in radians per second and the accuracy of the digital recorder and the digital indicator will be within plus or minus one pulse ($\pm$ 0.0001 radian per second).

Two additional speed measuring systems exclusive of the transducers, identical to the arm speed measuring system, are furnished for future connection to ship model propeller shaft revolution per second transducers.

Programmer

A programmer will be used to synchronize the recording of data from several sources to insure that all readings are taken at the same time. The programmer includes a precision time base for use in the synchronizing circuit and to furnish electronic gate control to electronic counting units. The time base unit will be crystal controlled with a crystal having a minimum stability value of 5 parts in 100,000 and a short time stability of at least one part in 1,000,000.

Automatic recording of data will be started by the operator using controls furnished in the instrumentation console. Push buttons on the console provide the operator with a means of inserting record identification information into the printers and graphic recorders, in digital form. The day of the year, run number and component identification will be printed with each reading and each total by the digital recorders and at the end of the test run for the graphic recorders. The run number advances automatically at the end of four and ten reading test runs when the digital recorders totalize. Auxiliary operation pens in the graphic recorders will mark the graphic charts at the time digital recordings are made. Also, an indicator is provided in the console to indicate the chart identification information being printed.

Pushbuttons will be used to start the record sample data, record four points and totalize, record ten points and totalize, and space records cycles. The records sample data cycle causes all printers to take one reading, clear and add spaces to the record and cause graphic charts to run, mark records at the instant the printers operated, and add space to the record. The chart identifying printers in the graphic recorders will not print during the sample data cycle. Operation of the four point and ten point record cycles will be similar to the sample data cycle; however, at the end of the four and ten point cycles the printers will totalize and clear, and the identification printers in the graphic recorders will operate. At the end of these cycles the run number will be increased automatically. Selector switches will be available to permit the operator to run the graphic and digital recorders continuously.

MANEUVERING BASIN TEST FACILITY

The maneuvering basin, equipped with wavemakers, will be used to conduct model tests concerned with the loss of sea speed, the improvement of the seakeeping characteristics of surface vessels and the prediction of ship motions in rough water. Information will also be obtained relating to the maneuverability and control of surface ships and submarines in smooth and rough water and the performance of submarines running near the surface in waves.

The maneuvering basin is a rectangular concrete basin 240 ft. by 360 ft. with a water depth of 20 ft. except for one section 50 ft. by 322 ft. 6 inches that has a depth of 35 ft. The deeper section is intended for free-running submerged model tests.

Pneumatic wavemakers generating waves from 3 ft. to 40 ft. in length and up to 24 inches in height will be located on two adjacent walls of the basin. Fixed bar type concrete wave absorbers will be installed along the opposite basin walls. A steel bridge having tracks attached to the underside, along which a controlled model towing carriage runs, spans the length of the basin. Trolley wires suspended below the bridge provide power for model motors, carriage drive, instruments, lighting and control. The bridge will be supported on a rail system that permits the bridge to traverse one-half the width of the basin and to rotate at angles up to 45 degrees from the longitudinal centerline of the basin. This rotating feature permits models to be towed in head or following seas at any angle from zero to 90 degrees. Figures 1, 2 and 3 show plan and elevation views of the maneuvering basin facility.

Ship model tests in waves will generally be conducted with 20 ft. or 10 - 12 ft. models. The top speed of the carriage will be about 15 knots and for 10 knot carriage speed a minimum steady state test run of 210 ft. will be available along the length of the basin.

MANEUVERING BRIDGE AND TRACKS

The maneuvering bridge will be a 376 ft. free span steel bridge weighing about 230 tons. It is of the bow-string or tied arch type with a mid-span depth of 35 ft. and a constant width of 20 ft. Figure 23 shows a plan and elevation of the bridge. The upper chord will be constructed of 12 inch by 99 pound wide flange beams, the lower chord of two 15 inch by 40 pound channels and the web members mainly of seamless steel tubing of varying sizes up to $7\frac{1}{2}$ inches outside diameter by 1/4 inch wall. The main bridge members and bracing will be connected in the field by 3/4 inch high strength steel bolts or welded in some instances. Hardened steel tracks will be attached to the bridge lower chords to support the maneuvering basin tow carriage. Also, a centerline hardened steel track attached to the bottom of the bridge will provide a rolling surface for the carriage drive and guide wheels. The design of the bridge is such that by means of built-in bridge camber and adjustable shimmed tracks, the vertical alignment of a fixed point on the towing carriage will maintain its elevation within 1/8 inch when the carriage traverses the center 200 ft. of the bridge. Figures 24 and 25 show details of the supporting rail and the drive rail.

An elevated rail system, Figure 23, is provided at each end of the maneuvering basin. This allows the bridge to traverse one-half the width of the basin and rotate 45 degrees to the centerline. The rail will be of steel, 80 pounds weight and the track of 4 ft. 8½ inch gage supported on steel ties that are embedded in a concrete box girder. They will be aligned and leveled so that the difference in elevation of rails at opposite ends of the basin, with the bridge in any orientation, is within ± 1/16 inch.

MANEUVERING BRIDGE TRUCKS

The maneuvering bridge will be supported through pivots by four trucks, one under each corner of the bridge. One truck at each end of the bridge is a powered drive truck and the other an idler truck. Each truck has four single flanged forged steel wheels which will run on the elevated rail system. Because of the width of the bridge there will be considerable end motion of the bridge structure relative to the trucks, when the trucks enter the curved section of tracks. This end motion is taken care of by a small four-wheeled transverse truck carrying the bridge support pivot socket. The truck will be mounted on top of the main truck on rails set perpendicular to the main truck axis.

MANEUVERING BRIDGE ELECTRIC DRIVE

The bridge drive is a Ward-Leonard type system. Four 2 horsepower drive motors will be used, two at each end of the bridge, each rated 115 volt d-c gear type, 84 rpm and capable of constant torque over an 8:1 speed range. The motors will be mounted on the power trucks and the output shafts fitted for gear connection to the drive shafts of the bridge trucks. The d-c power supply will be a motor generator set consisting of a 250 volt d-c shunt wound, separately excited generator and a 440 volt, 3 phase 60 cycle, squirrel cage motor that drives the d-c generator and exciter. Control rheostats in series with the drive motor field will be located at the control panel for control of each end of the bridge in combination with the generator field control. A stepless field control rheostat provides voltage control of the generator output. A rotating type exciter provides excitation for the d-c generator and the drive motors. A spring-held, magnetically-release type brake will be mounted on each drive motor shaft extension with a capacity equal to the motor torque.

Control of the direction, speed of travel, skew and positioning of the bridge will be from a control console located on the east end of the bridge. The maximum speed of the bridge will be about 30 ft. per minute with the speed variable over the 8:1 range. A system of mechanical indicators and a skew indicating and control system permit accurate positioning of the bridge. The maximum permissible bridge skew is 18 inches. A selsyn system consisting of two transmitters driven by gears on two of the motor shaft extensions, two differential receivers and two indicators show the skew. The transmitters will be directly connected to a drive motor at each end of the bridge. One indicator indicates skew during rotary motion, the other during translatory motion. The overall accuracy of the system is within 5 percent of the maximum permissible skew. Selsyn mounted switches will be installed at each receiver to prevent excessive skew.

The bridge operator, through the use of scales and indicators, can accurately position the bridge at one foot intervals on the straight track and one-half degree intervals on the curved tracks. Scales will be painted on the west and east sides of the basin and pointers mounted on the bridge. A closed circuit television system will be used to view the position of the west indicator.

MANEUVERING BRIDGE CARRIAGE

The carriage will be a welded aluminum tubular truss structure. Aluminum is used to reduce the power requirements that would otherwise be needed if steel construction were used. The test personnel, carriage operator, carriage and model controls, test instrumentation and recording equipment will be carried on the carriage. The basic carriage is rectangular in shape, Figure 26, 20 ft. wide by 21 ft. 9 inches long and 6 ft. 8 inches high. The estimated weight is approximately 20,000 pounds exclusive of equipment. The tubular members are 3 inch outside diameter with varying wall thickness from 0.125 to 0.500 inches. A 24 ft. long aluminum alloy detachable towing beam is provided along the longitudinal centerline of the carriage. This is not of the floating girder type and will be adjustable in height. The lower face of the beams can be positioned between 32 and 60 inches above the still water level of the basin. The centerline of the lower chord of the carriage truss will be 6 ft. 2½ inches above the basin level. These clearances have been specified to provide for present and future wave tests on 10 to 30 ft. ship models. A centerline open bay approximately 8 ft. wide by 10 ft. long is provided in the lower horizontal carriage truss to aid in conducting special tests.

There will be working platforms on the carriage along each side of the ship models. Provision is also made for outrigger towing of ship models for turning tests. The detachable tow beam will be located outboard of the north side of the carriage and the test model accelerated up to speed by means of struts attached to the tow beam.

Electrical trolleys will be supported from the upper horizontal plane of the carriage trusswork. In addition, the carriage drive equipment and the arresting gear striker which engages with the arresting gear at each end of the bridge, will be supported on top of the carriage. All equipment and structure are designed to take a maximum rate of deceleration of 1.3g in either direction of carriage travel.

The carriage will be supported from the bridge by four idler trolleys which run on the bridge tracks and are located at the extreme top corners of the carriage Each support trolley includes two 10 inch diameter hardened steel wheels and one 4 inch diameter steel keeper wheel, both contained in a housing which bolts to a pad on the carriage. The support wheels of each trolley will ride on the inner surface of the track flange. The keeper wheel of the trolley will be snugged up to ride against the face of the same flange. Also the carriage will be guided along the bridge by four 8 inch diameter hardened steel guide wheels, two of which are spring loaded. The guide wheels fasten to pads located at the top and the fore and aft ends of the carriage in the same horizontal plane as the drive wheels. The guide wheels ride against the vertical surface of the main traction rail of the bridge.

MANEUVERING BRIDGE CARRIAGE DRIVE SYSTEM

Mechanical Drive

The driving force for the carriage will be provided by two rubber tired traction wheels preloaded against the vertical faces of the main traction rail of the bridge. Each wheel will be driven by an electric motor through an $8\frac{1}{4}$ to 1 worm gear reducer. Figure 27 shows the drive.

The reducer, motors, and a tubular aluminum truss work will be mounted on a steel subbase fastened to the top of the carriage. Each traction wheel will be mounted on a solid shaft which passes through a preload bearing and will be coupled by a flexible disc type coupling to the hollow output shaft of the reducer. The preload bearing housing on each shaft will be supported on both sides by a sliding block arrangement attached to the trusses. The sliding block arrangement is the means of transferring the tractive effort of the traction wheels into the trusses. It also permits adjustment of the reducers due to tire wear. The traction wheels are pressed on solid industrial tires of $22\frac{1}{2}$ inch diameter on a 16 inch diameter steel wheel. The tire base width is 12 inches and will have a grooved tread. The nominal rolling radius of the wheels when loaded is 10.8 inches.

The traction wheels will be preloaded to develop tractive effort without slippage by a hydraulic cylinder common to both drives which transmits its force through the preload bearings to the shafts of the traction wheels. A hand operated pumping unit charges an accumulator to provide the required holding pressure. For maximum acceleration a preload of about 12,000 pounds is required at each traction wheel. For lower acceleration the preload can be decreased by means of a slow release valve.

Electrical Drive

The primary electric drive is an adjustable voltage d-c system with automatic feedback control. Figure 28 shows a block diagram of the system. As in the case of the rotating arm drive, the motor ratings were not specified so that maximum competition could be obtained from the electrical manufacturers. Instead, operational requirements and weight limitations were spelled out. Control of the carriage in either the eastward or westward direction will be from a control console at one end of the carriage or an auxiliary control station at the other end of the carriage.

Capabilities: It is extremely important that a maximum steady state test run be available for the taking of data. This requires that the carriage accelerate to a given speed and stabilize at that speed in as short a distance as possible and also decelerate in a short distance. The drive system will be capable of accelerating the carriage from rest to a speed of ten knots, towing a 1000 pound model, within about 11 ft. (this corresponds to an average acceleration rate of 0.4g). The system will stabilize at this speed within plus or minus 0.25 percent in about three seconds (48 ft. of carriage travel). It will also be possible to accelerate the carriage to a speed of 7.5 knots, while towing a 6000 pound model (this corresponds to average acceleration rate of 0.33g within 7 ft.) and stabilize at this speed within an additional 38 ft. of carriage travel. In addition, a speed of 15 knots can be obtained while towing a 200 pound model by accelerating to speed within 50 ft. (about 0.2g). Figures 29, 30, and 31 show the specified operating conditions for the drive system.

The estimated steady-state carriage speed constancy during a test run is within plus or minus 0.025 knots under 10 knots, and plus or minus 0.25 percent of carriage speed between 10 and 15 knots.

Carriage speed will be preset by a selector switch and precision potentiometer calibrated in increments of 0.01 knot. The preset accuracy is estimated to be within plus or minus 0.5 percent of speed between 10 to 15 knots and plus or minus 0.05 knot for speeds less than 10 knots.

In addition to the east and west operation of the carriage, an inching control system is provided so that the carriage may readily be positioned along the arm. The inching speed will be adjustable from zero to 0.5 knot.

Drive: The drive system consists of two d-c series-connected shunt-wound motors, capable of reverse operation. They will be coupled through 8.25: 1 gears to the rubber tired drive wheels and be capable of reaching a speed of 2211 rpm which corresponds to a 15 knot carriage speed. The rubber tires of the drive wheels limit peak tractive effort which can safely develop at the drive rail to 17,500 pounds (including current limit overshoot). However, it is estimated that a tractive effort of only 13,200 pounds (including current limit overshoot) is required at the drive rails.

The maximum drive motor current will not exceed 600 amperes and the maximum motor voltage required is between 325 to 375 volts per motor. The motors will have a minimum nominal continuous rating of 30 horsepower at 1474 rpm and a 1.15 service factor. The torque requirements will probably require a much larger frame size.

The power supply consists of a motor generator set which includes optionally one or two d-c shunt wound generators having a speed of 1200 rpm. The supply will be compatible with the peak power and voltage ratings of the drive motors. A synchronous motor rated at 2300 volt, 3 phase, 60 cycles, 0.8 p.f., 1200 rpm supplies power to the d-c generator. Power for the synchronous motor will be supplied from the 2400 volt switchgear.

The excitation for the shunt fields of the main drive motors will be from a separate source 250 volt d-c supplied by a package type motor generator set with current regulated output. The exciting current for the main drive d-c generator will be provided by a rotating type amplifier of about 15 kw capacity, driven by a low slip (3% or less) induction motor.

Speed Regulation: The speed regulating system consists of a high-gain closed-loop electronic regulating system which operates from either a tachometer feedback signal or a loop voltage signal. The regulator will control the d-c generator output voltage and thereby control the drive motor speed. An open-loop control system will also be available in case of regulator failure. In this case the regulator circuit to the exciter control field will be replaced by an adjustable voltage supply from the drive motor field source. All regulator components except the control exciter will be mounted on the carriage.

Current limit circuits are provided for controlling d-c loop current and thus rates of carriage acceleration and deceleration.

The tachometer which supplies the feedback signal will be vertically mounted on a hinged platform and be driven by a spring loaded idler wheel on the drive rail.

Braking: An arrestor cable and hydraulic arresting gear system of the aircraft carrier type will be used at each end of the bridge for stopping the carriage when a maximum run is desired. The arrestors require about 20 ft. to stop the carriage regardless of speed. The inertia of the moving parts of the arrestor produces an initial instantaneous peak deceleration rate of about 1.3g which drops to a nominal value almost immediately.

If less than a maximum run is desired regenerative braking can be used. The amount of the normal regenerative braking effort can be established by presetting the deceleration current limit potentiometer located on the control console. The deceleration rate under regenerative braking will not exceed the maximum acceleration rate of the carriage. Brakes of the spring-set, shoe type mounted on the shaft extension of the carriage drive motors will be used for holding the carriage in a given position but not to stop the carriage since they will not have sufficient thermal capacity.

Protective Devices: Protective devices similar to those for the rotating arm drive system will be provided to protect the equipment from malfunction or component failure. Also a similar alarm system and interlocking system is provided.

MANEUVERING BRIDGE TROLLEY SYSTEM

Power, control and instrumentation circuit connections between the maneuvering bridge and its carriage will be by a trolley system. The connections to the bridge will be by means of extra flexible cable fed from stationary cable reels. The cable reels will be installed on steel angles suspended from the building roof structural steel approximately over the midpoint of the lateral travel of the center of the maneuvering basin bridge. The reels permit two-way pay-out of cables from one side to the other as the center of the fixed mounted reels is passed during maneuvering bridge travel. The cable reels will connect to shore by means of cables running along the overhead of the building structure to junction boxes at the top and mid-span of the bridge.

The trolleys selected are of the figure eight, insulated type. The conductors will be rolled copper bars about 3/8 inch by 1 inch finished having a continuous carrying capacity of 300 amperes. The insulation around each conductor will be of the non-burning type with a minimum wall thickness of 0.075 inches. The insulation, of inverted U shape, will allow a gap of about 1/4 inch at the bottom of the conductor where the collector makes contact with the trolley. The connection from the bridge to the trolley will be by means of clamp-type feeds. The collectors will be insulated, spring loaded assemblies with replaceable shoes made of sintered metal consisting of 90 percent copper and 10 percent graphite thus being self lubricating and permitting wear on the shoe rather than the conductor. Supporting structure for the collectors will be mounted on the carriage.

Figure 32 shows the number of trolleys, spares or space provided. There is provision for 27 trolleys on the south side of the bridge and 22 on the north side.

INSTRUMENTATION

The instrumentation for the maneuvering basin will be located on the carriage and consists of six channels of general purpose graphic recorders, three speed measuring, digital indicating and recording systems, a multi-channel programming system and operating consoles from which the carriage and model speeds will be controlled. The equipment and instrumentation required for the various test programs to be conducted in this facility is either available or will be provided separately.

The general purpose recorders include a-c and d-c gage control units and non-balancing potentiometer type graphic recorders similar to the units for the rotating arm. The gage control units will be for operation with either differential transformer or strain gage type transducers in dynamometers. The carriage speed transducer will be of the same type as that used for measuring the rotating arm speed. It will connect to the shaft of the tachometer-generator used in the carriage drive motor speed control system.

The carriage speed measuring system is in units of feet and hundredths of a foot per second. The digital indicating and recording of speed will be similar equipment to that used for Rotating Arm speed. Digital recordings will be printed at one second intervals and totalized at the end of a run as dictated by the programmer. The programmer also is a control system similar to that used for the rotating arm. The estimated inaccuracies at the digital recorders should not exceed 0.01 ft. per second.

MANEUVERING BASIN WAVEMAKERS

Pneumatic type wavemakers will be provided along the west end and the north side of the maneuvering basin as shown by Figure 33. The west bank consists of 8 individual wavemaker units and the north bank of 13 individual units.

Wavemakers

The wavemakers will generate waves from 3 to 40 ft. in length with corresponding maximum heights of about 2.5 inches to 24 inches. Figure 34 shows a typical wavemaker assembly. The wave generator dome will be partially submerged in water, of $\frac{1}{4}$ inch carbon steel, inverted U-shape, and about 24 ft. 6 inches long. The dome units will be separated from each other by end plates. The interior of the dome will be 5 ft. wide and fitted with a grid of vertical baffle plates which aid the vertical oscillation of the water by damping cross movements of the water. The spacing of the grid plates is one ft. across the dome width and 2 ft. along the dome length. Two baffle doors form part of the grid and these can be used to close off either two ft. or four ft. of the dome width, thus controlling the amount of water in action. This in effect makes available three sizes of wavemakers for test operations, namely; a one ft., three ft. and five ft. wide wavemaker.

An adjustable stabilizer consisting of vertical plates, open at the bottom and in the direction of the wave travel, eliminates transverse waves which are sometimes initiated by wavemakers. The submergence of the front dome lip, which forms part of the stabilizer, can be adjusted so that the bottom of the lip ranges from $9\frac{1}{4}$ inches to $22\frac{1}{2}$ inches below the basin water level. This adjustment provides further flexibility in the control of waves since for short waves less submergence of the lip is required than for long waves.

Wavemaker Operation

The waves will be generated by alternately varying the dome air pressure from positive to negative. This is accomplished by means of blowers located in the blower equipment room, connected to the dome by 26 inch inside diameter 10 gage carbon steel ducting and pairs of oscillating valves. The valve system is arranged so that when air is drawn from the atmosphere it will be forced into the dome and when air is drawn from the dome it will be forced into the atmosphere. The frequency of the oscillating valves determines the frequency and thus the lengths of the deep water waves in accordance with the formula $T = 0.4424 \sqrt{\lambda}$, where λ is the wave length in feet and T is the period in seconds. The phase of each valve pair may either be synchronized with each other or hand set to operate at different phases by means of a phase change crank incorporated in the valve drive system. Wave amplitudes can be varied by adjusting the blower speed and by setting butterfly type damper valves located in the discharge duct of the blower.

All the blowers in each bank will by synchronized electrically so that they always operate at the same speed. In addition, each bank of blowers can be synchronized electrically so that the two banks operate at the same speed. The oscillating valves in each wavemaker bank will be synchronized both in phase and frequency by torsionally rigid shafting and positive power takeoffs. Also, both banks of valves can be synchronized by means of a clutch and miter gear at the corner of the basin where the drive shafts meet. The main wavemaker controls will be on a control console located on an elevated platform at the mid-length of the north wall of the maneuvering basin building.

A change order to the construction contract has been requested for programming and individual control of wave lengths and wave amplitudes for each of the 8 wavemaker units in the west bank. This will be accomplished by 8 additional individual valve drives and 8 additional individual blower damper valve drives programmed by a magnetic tape system. Programming of the valve frequencies of each wavemaker bank, when each bank operates at synchronized speeds, will also be possible by means of the magnetic tape system.

Wavemaker Models

The wavemaker design is based on the results of a development program that culminated in the installation of a 51 ft. wide pneumatic wavemaker in the Taylor Model Basin deep water basin. The 51 ft. unit is physically the equivalent of two of the maneuvering basin wavemakers. In addition, a 1/10 model of the maneuvering basin was built and tested. The 1/10 model was constructed primarily to check the performance of the wavemakers and the wave absorbers. The physical dimensions of the wave absorbers, basin and wavemakers are to scale, except for the powering and control systems. The results of the 1/10 model test program will be reported on in a separate Model Basin report.

Blowers

The blowers will be single wheel, single inlet centrifugal blowers with overhung wheel and shaft. The blower shaft connects directly to the drive motor by means of a gear type coupling. The wheel and shaft will be balanced statically and dynamically for smooth operation at speeds from 100 to 1600 rpm. Head-cfm characteristic curves for the blower at constant speed will be parallel to those given in Figure 35 within a tolerance band of plus ½ inch water head.

Baffle Doors

The bottom baffle doors in each wavemaker dome unit will be operated by an electric motor-driven, worm-geared valve operator with automatic torque switch cutoff. The unit will be equipped with torque switches which detect the torque imposed on the connecting shaft for either direction of rotation and switch off the motor at a preset torque. The torque switches will be separately adjustable over a range of 150 - 750 inch pounds and will accurately monitor the position of the doors and make contact at the end of the opening and closing stroke. The motor will be 440 volt, 3 phase 60 cycle with maximum output torque of 750 inch-pounds and output speed of about 30 rpm.

Damper Valves

The dampers will be round, single vane, center pivoted, variable position, remote control electric motor-operated valves. These valves will be used to balance the blowers as required by manufacturers tolerances of blowers and motors and also as an auxiliary means of varying the amplitude of waves for individual wavemakers. The valves will be suitable for 35,000 maximum cfm and a maximum pressure difference of 20 inches of water with the valve closed. The damper valves on the west bank blowers will be automatically controlled and programmed.

Main Valve Drives

There will be two main valve drive systems — one for each bank of wavemakers. The valve motion and synchronization will be obtained by mechanical linkages driven by a 2 - 3/16 inch outside diameter carbon steel line shaft. The line shaft runs the entire length of each wavemaker bank. The valve drive systems are Ward-Leonard type drives, controlled by a high-gain, closed-loop electronic speed regulating system which operates from a direct-driven tachometer feedback signal. A block diagram of the system is shown by Figure 36.

Capabilities: The valve frequency will be continuously variable from 18 to 80 cycles per minute. One cycle of valve operation corresponds to about 7.5 revolutions of the line shaft so that the maximum line shaft speed will be about 600 rpm. Steady state speed constancy (cyclic average) within plus or minus 1/8 percent of top speed and a preset speed error within plus or minus ½ percent of top speed is estimated.

Drive: The valve drive motors are 250 volt d-c, 1750 rpm, separately excited shunt types capable of producing full torque at all speeds over a speed range of about 4:1. The valve drive motor for the west bank of wavemakers is rated at 10 horsepower and that for the north bank at 15 horsepower, with a 125 percent rating for two hours. The drive motor connects to the line shaft by means of a right angle gear reducer which has a maximum input of 1750 rpm and a ratio of 2.91:0.

The west bank line shaft drive motor may be changed to 20 hp and the north bank drive motor to 30 hp in order to accomodate future programming of each synchronized bank of valves. If the drive motors horsepower ratings are increased, compatible changes will be made in the power supply, speed reduction gearing and control equipment.

The variable DC power supply consists of a motor generator set for each valve system. The sets include an induction motor rated at 440 volts, 60 cycles, 1.15 service factor, 1750 rpm, having 25 horsepower for the north wavemaker bank and 15 horsepower for each bank, and a d-c shunt wound generator rated at 15 kw for the north wavemaker bank and 10 kw for the west bank, 1750 rpm and 125 percent for 2 hours.

The power supply for the motor fields will be either rectifiers or rotating equipment at the option of the manufacturer.

Speed Regulation: The control system consists of balancing a tachometer output against a high-accuracy reference voltage and feeding the differences into a precision regulator. This controls the field of the m-g set generator and thus the speed of the drive motor. The d-c tachometer for the valve drive speed control will be directly connected to the valve drive motor shaft. Precision type potentiometers located atthe wavemaker control console and calibrated in increments of one rpm from 435 to 1750 rpm are provided for setting valve motor speed. Current limit circuits are provided to limit the current which can be safely commutated.

Speed Indicators: Two speed-indicating systems will be provided for each valve drive. These consist of a coarse indicator of the d-c voltmeter type and a fine indicator of the high-accuracy transducer and electronic counter type. Both provide visual indication, read continuously and will be calibrated to indicate actual valve period in milliseconds. The d-c voltmeter measures the signal produced by a d-c permanent magnet tachometer that will be driven from the valve drive motor shaft. The high accuracy valve-period indicator consists of an a-c transducer and an electronic counter which will count cycles of a reference frequency between a given number of impulses from the transducer. The transducer will be direct driven from the shaft extension of the speed-control tachometer. The electronic counter reading is expected to have an accuracy within $\pm$ 0.1 percent of full speed of the drive motor.

Individual Valve Drives

The eight individual valve speed drives for the west wavemakers will be adjustable voltage d-c drives. The individual drives will be designed to permit quick and easy changeover to the main valve drive system. This will be accomplished by connecting the main drive line shaft to one electric coupling per wavemaker unit, then to the individual main valve drive motor, then to a fixed gear reduction box and finally through the phase changer to the pair of valves. The electric coupling will be used for disconnecting and connecting from the main drive system to individual drive operation.

Each individual drive system will probably consist of a 3 hp, 575 rpm, 230 volt d-c shunt drive motor capable of accelerating or decelerating a pair of valves from 18 to 80 rpm within 0.75 seconds. Each drive motor will receive its adjustable voltage from a 3-kw, 250 volt d-c rotating amplifier. The drives will be controlled by a closed-loop electronic regulating system which operates from a voltage feedback signal. Speed changes will be obtained by variations of the reference signal received from the programming system. Programming and control of the drives will be from a console at the wavemaker operating platform. The accuracy of the valve speed constancy will be within $\pm$ 0.8 rpm for any speed between 18 - 80 rpm.

Blower Drives

Figure 37 is a block diagram of the drive systems. Each blower drive consists of a group of low-slip induction motors operated at the same respective speed from a variable frequency bus. The variable frequency power will be supplied by means of an induction frequency converter for each system. The induction frequency converters will be electrically powered from 2400-volt, 3-phase, 60 cycle switchgear and are mechanically controlled by means of Ward-Leonard type drives with a common motor driving the generators of the main m-g set. The blower speed in each drive will be controlled by frequency control through a high-gain, closed-loop combination electronic and rotating amplifier type speed regulating system which will operate on the fields of the main generator.

<u>Capabilities</u>: The operating frequency range of the blowers will be about 8 to 80 cycles per second (160 to 1600 rpm blower speed). The 8 to 80 cycle frequency range will be obtained by operating the frequency convertors from 1040 rpm in the forward direction through zero to 400 rpm in the reverse direction. Although the main d-c machine connected to the convertor is called a motor it will operate as a generator in the frequency range below 60 cycles. This machine will have a base speed of 400 rpm and will operate above this speed in the forward direction with automatic field weakening. Also, although the main m-g set is shown as a synchronous motor with two main d-c generators the power flow will be in the opposite direction when the system operates below 60 cycles.

Steady state speed constancy within plus or minus 1/4 percent of top speed and a preset error within plus or minus 1/2 percent of top speed is expected.

Drive: The synchronous motor for the main m-g set is rated at 2300 volts, 3-phase, 60 cycles, 1200 rpm, 800 horsepower 0.8 p.f. and 125 percent for two hours. The main m-g set d-c generators are rated at 600 volts, 1200 rpm and 200 kw for the west wavemaker system and 300 kw for the north system.

The blower drive motors are 3-phase, squirrel cage, six-pole induction motors. They are rated at 133 horsepower continuous at 80 cycles (1600 rpm) and 100 horsepower continuous at 60 cycles. The voltage rating at 60 cycles is about 2300 volts and at 80 cycles it is 4/3 of the 60 cycle rating. Secondary switchgear is provided which consists of one fused disconnect switch for each blower motor and an incoming line cubicle for connecting the blower motors to the secondary bus.

The frequency converters provide a source of variable-voltage, variable-frequency power to the two drive systems and will be capable of rotation in either direction. They will have a nominal speed rating of 1200 rpm and will operate from 400 rpm in one direction to about 1100 rpm in the other direction. The primary will be designed for 2300 volts, 60 cycles and the secondary for operation at all frequencies from 8 to 80 cycles with an 80 cycle no load voltage as near to 3000 volts as feasible. The west bank converter nominal horsepower rating is 1500 and the east bank 1000 horsepower.

The 600 volt convertor drive motors have a base speed of 400 rpm in both directions and will be capable of attaining a speed of 1200 rpm in one direction by field weakening.

Speed Regulation: Speed control will be automatic with blower speed preset by a precision type potentiometer at the wavemaker control console calibrated in increments of one rpm from 160 to 1600 rpm. The control system consists of balancing a tachometer output against a high-accuracy reference voltage and feeding the differences into a precision regulator. This controls the field of the m-g set generator and thus the speed of the blower drive motor. The generator control exciter will be a rotating amplifier. Excitation for the d-c motors will be by 125 volt rotating amplifiers. In addition, an auxiliary exciter may be used to regulate the main motor field for speeds above base speed of the motor.

The speed control tachometer will be driven by a synchronous motor which receives its power from an auxiliary frequency converter that is coupled to the shaft of the main frequency converter. Speed of the synchronous motor will be determined by its supply frequency which is the same as the blower motor supply frequency. Current limit circuits will be provided which limit the d-c loop to safe values.

A bias exciter (auxiliary d-c generator) direct driven from the main m-g set may also be used to provide excitation for bias fields in order to obtain operation in both directions.

Speed Indication: Rough blower speed indicators of the voltmeter type will be provided, calibrated in rpm. These measure a voltage produced by a d-c permanent-magnet tachometer driven from the speed control-tachometer drive motor. The error of speed indication will be within plus or minus one percent of full scale speed. The preset value will be used for data purposes.

Protective Devices: Protective relays will be provided to disconnect any machine or group of machines when an abnormal load condition or fault is encountered in either the blower drive or valve drive systems.

Individual Damper Valve Drives

The eight individual blower damper valve drives for the west wavemakers will probably be adjustable voltage d-c drives. The valve drive motor will be connected to the valve through a gear box and a slip coupling. The slip coupling will permit the motor to drive the damper valve at full power into either the 0 or 90 degree stop of the valve without damage to the motor. Self-locking gears will probably be used between the drive motor and damper valve to aid in reducing the time in changing from individual to synchronized wavemaker operation.

Each drive will probably have a 3 hp, 575 rpm, 230 volt d-c, shunt drive motor capable of driving the damper valve from full open to full closed (0 to 90 degrees) or vice versa within 0.8 seconds. The drive motor will receive its variable voltage, reversible polarity d-c supply from a 3 kw, 250 volt d-c rotating amplifier. The drives will be controlled by a closed-loop electronic regulating system which operates from a position feedback signal. The valve position will be sensed by a servo potentiometer on the valve shaft. The accuracy of the valve position constancy will be within $\pm$ 1 degree. Programming and control of the damper valves will be from a console at the wavemaker operating platform.

MANEUVERING BASIN WAVE ABSORBERS

Wave Absorbers

Wave absorbers will be located along the south side and east end of the maneuvering basin to reduce the reflection of the generated waves to a practical minimum. A contract was arranged with the St. Anthony Falls Hydraulic Laboratory, University of Minnesota to conduct an intensive model program aimed at furnishing information to assist in the design of the maneuvering basin wave absorbers. Figures 38 and 39 show the design and details of the absorber selected as a result of the laboratory test program.[7,8]

The wave absorber will be a discontinuous 12 degree slope type. It will be made up of 7 permeable layers resting on an impermeable beach. In order to obtain the benefits of mass production it was decided to make the permeable portion of the beach of rectangular precast concrete bar panels. The panels will be 7 ft. wide by 12 ft. long and 5 inches deep at the girders. The bars will be 2 inches wide by 2½ inches deep and spaced at 2 inches, the absorber thickness 2 ft. 11 inches, and the length of the absorber 36 ft. This length was specified as the maximum which could be used in the maneuvering basin since it is most important to have the longest steady state model test run possible.

The range of wave lengths of primary interest is 3 ft. to 30 ft. and the wave steepness range (H/L) of primary interest extends from 0.02 to 0.06, where H is the wave height and L is the wave length. Tests[7,8] were conducted with a 1:20 and a 1:4.45 scale model of the prototype absorber to determine its efficiency. In addition various type wave absorbers were tested and their coefficient of reflection (H_R/H_I) compared. The beach having the smallest reflection coefficient is considered to be the most efficient, where H_R is the height of the reflected wave and H_I is the height of the incident wave. The measurements of wave reflection were made with a continuous train of incident waves and using a moving capacitance type wave height probe. The average predicted coefficient of reflection for the selected wave absorber based on the 1:4.45 scale model tests is 0.051. Table I shows the predicted coefficients of reflection as a function of wave steepness and L/d ratio where d is the water depth in feet. A full scale section of the wave absorber has been installed in the deep water basin at the Model Basin and is performing satisfactorily.

Barriers

Retractable hollow steel barriers hinged below the water line will be provided for use in front of the wave absorbers. The barriers can be raised or lowered by means of pneumatic flotation chambers within the barrier panel structure. There will be 15 panels along the south side of the basin and 9 panels along the east end. The purpose of the barriers is to avoid the disturbance which would be created by the wave absorber when waves are generated either down or across the basin. When both wavemaker systems are in operation, the barriers will be down and hang almost vertically in the 35 ft. depth and lie almost horizontally on the basin floor in the 20 ft. depth basin.

MODEL POWER SUPPLY SYSTEMS

Three sources of model-motor power will be provided, one each, for the rotating arm, maneuvering basin and the fitting room. The systems are designed so that any two of these supplies can be used at any of the three test sites. Motor generator sets located in the switchgear room supply the model power. The outputs of the generators will be fed through contactors to the test area. Two high-gain, closed loop electronic speed regulating systems which operate from either a tachometer or a loop voltage feedback will control the d-c generator output voltage and thus the model motor speed, will be provided at each location. Control of the model motor speed, current limit and associated functions will be from the instrumentation console on the rotating arm, the model power console on the maneuvering bridge carriage and a control panel in the fitting room. Figure 40 shows a block diagram of the model power supply systems.

Each m-g set consists of a synchronous motor and a d-c generator. This generator is a 30 kw, 400 volt d-c, 1800 rpm, shunt wound, separately excited machine capable of supplying 20 horsepower at 230 volts. The output will be variable from 20 to 400 volts with a maximum output of 75 amps. The generator field will be excited by a rotating-amplifier type control exciter controlled by the output of the electronic regulator, and directly connected to the generator shaft. The synchronous motor is rated at 40 horsepower, 440 volts, 3 phase, 1800 rpm, 0.8 p.f. The synchronous motor excitation will be provided by a direct drive exciter.

TABLE 1

Coefficient of Reflection as a Funtion of Wave Steepness and L/d Ratio for the Wave Absorber

L/d	Wave Steepness H_I/L			
	0.01	0.02	0.04	0.05
0.2	0.11	0.09	0.05	0.02
0.4	0.14	0.11	0.06	0.01
0.6	0.13	0.06	0.03	0.02
0.8	0.10	0.05	0.04	0.03
1.0	0.07	0.06	0.04	0.04
1.2	0.08	0.06	0.04	0.03
1.4	0.09	0.07	0.04	0.04
1.6	0.10	0.08	0.05	0.05
Average H_R/H_I	0.102	0.072	0.044	0.030

Three similar field supplies consisting of an a-c induction motor and a d-c generator will be provided for the model fields. The generator is a 5 kw, 125 volts d-c, shunt wound separately excited machine with a variable output range of 20 to 125 volts and a maximum output of 40 amps. The motor is rated $7\frac{1}{2}$ horsepower 440 volts, 3 phase. A continuous type regulator will hold the generator voltage within $\pm 1\frac{1}{2}$ volts of a preset value in the range between 20 and 125 volts.

Reference precision potentiometers calibrated in units of one volt from zero to 399 volts will be used for presetting the model motor speed. An auxiliary speed control will be provided by another potentiometer calibrated in 4 volt units from zero to 399 volts. This auxiliary control can be used to vary the model motor speed when the model is partly restrained, permitting the model to adjust its speed to that of the tow carriage.

BUILDING

The maneuvering basin, rotating arm basin and fitting room will be housed in a continuous steel arch building about 695 ft. long by 275 ft. wide. Figures 1, 2, 3 and 4 show views of the building.

The primary building structure foundations, footings, basin floor and walls will bear on solid ledge rock (micaceous schist) which underlies the site. The 9 ft. deep trussed steel roof arches will be on 29 ft. centers except for the two end ones. The arches will be fixed at the ends and supported by reinforced concrete buttresses. The crown of the top chord of the arch is about 86 ft. above the basin still water level. Trussed steel purlins will support fabricated metal coated sheet steel roof decking. The sheet steel decking will weigh about 2 pounds per square foot before it is formed into ribs about $1\frac{1}{2}$ inch deep and coated.

Each end of the building will be made up of insulated metal wall panels supported by steel columns and girts. The outside sheet of the insulated panel will be 0.049 inch minimum thickness fluted aluminum and the inside sheet 0.046 minimum thickness metal coated steel. The footing foundations and walls will be reinforced concrete for a minimum height of about 3 ft. above the first floor level. The sides of the building will be constructed of the same type metal panels used for ends of the building and reinforced concrete.

The steel roof deck will be covered with thermal roof insulation of either 4 inch thick cellular glass blocks or two layers of fibrous boards of $2\frac{1}{2}$ to $3\frac{1}{2}$ inches total thickness with waterproof facings on each side of the fibrous board. Placed over the insulation will be two layers of asphalt saturated felt, followed by two layers of white mineral-surfaced 36 inches wide selvage roofing. The selvage roofing will be applied on the felt roofing in a coating of roofing cement. The built-up roofing will be nailed as required to nailing strips and all roofing will be applied with the length of the roll at right angles to the eaves of the roof.

HEATING AND VENTILATING SYSTEM

The building heating and ventilating system will maintain an indoor temperature of 67 degrees F and 60% of relative humidity when the outdoor ambient temperature is 0 degrees F. One complete change of building air can be made per hour in the summer. The heating and ventilating units will be wall type, and hung from the perimeter walls of the building. The units will be provided with blower fans, filters, mixing boxes with outside air and return air dampers, face and by-pass dampers and steam heating coils. Exhaust ventilation will be provided by motorized roof exhausters.

The heating and ventilating control system automatically controls the heater unit dampers, steam coils and the roof exhausters. The amount of outdoor air entering the building through the heater units and the amount of air exhausted from the building through the roof exhauster will be under constant control of thermostats and humidistats to maintain preset temperature and relative humidity.

Room type thermostats will control a modulating damper motor which operates the heater unit face and bypass dampers to provide a mixed air temperature. When the face damper is closed a two position valve on the steam heating coil closes.

A remote bulb temperature control, with the bulb located in the fresh air box of one of the unit heaters, controls the operation of all fresh air, return air and relief air dampers. The fresh air dampers will start to modulate open from a minimum position at an outdoor temperature of 60 degrees F and become wide open at 67 degrees F.

A humidistat located in the fresh air intake of one of the unit heaters will control the steam coil valves. It closes all fresh air dampers, relief dampers and turns off all exhaust air fans when the relative outdoor humidity reaches 60 percent or above, or whenever the outdoor air is above 45 degrees F. The humidistat is inoperative when outdoor air is below 45 degrees F.

Three 6900 cfm roof exhaust fans will run continuously unless turned off by the humidistats. Seven 24,000 cfm roof exhausters start running whenever the relief dampers reach 100 percent open. At the same time that these fans start, all relief dampers will go 100 percent closed. The fresh air intake dampers and relief dampers will normally be closed and will assume that position when the fans are not running.

OVERHEAD TRAVELING CRANES AND MONORAIL HOISTS

The electric equipment room will have a 10-ton overhead electric traveling crane, pendant controlled from the floor. The calibration room will have a 2-ton overhead electric traveling crane that is also pendant controlled from the floor.

The fitting room area will have a monorail system with two 5-ton hoists. In addition, a 5-ton monorail hoist system supported at the roof trusses will run from over the center island of the rotating arm, along the center line of the building, over the drydock and extend partway over the maneuvering basin. The wavemaker blower rooms will have a 2-ton monorail hoist system running the length of the blower rooms and directly over the drive equipment.

ELECTRICAL

Primary Service

The primary service for the Rotating Arm and Maneuvering Basin is a 13,800 volt, 3 phase, 60 cycle, effectively grounded system. Power distribution will be from the main Model Basin substation to 13.8 kv indoor switchgear by means of 15 kv 350 MCM shielded paper insulated lead covered cable in an underground duct system.

13.8 kv Switchgear

The 13.8 kv switchgear will be located in the electrical equipment room and consist of one incoming line unit, three feeder units and one auxiliary unit. The switchgear will be used on the 13,800 volt, three phase grounded 60 cycle systems and the power buses will have a continuous current carrying capacity of 1200 amperes.

The auxiliary switchgear unit contains two 14,400-120 volts potential transformers of the drawout disconnecting type for metering.

Outdoor Substation

One of the 13.8 kv switchgear feeder units will be connected by 15 kv cable to an outdoor substation located adjacent to the south wall of the new building. The outdoor substation is rated 5000/(6,250 future) kva, 13,800/2400 volt. The low-voltage bus duct will have a continuous 2000 ampere rating and run from the transformer to 2400 volt switchgear in the electrical equipment room. The transformer will be of the oil immersed, self-cooled type with provision for future forced air cooling.

Indoor Substation

The remaining two 13.8 kv switchgear feeder units connect to a double ended 13,800/480 volt unit indoor substation. The two transformers are each 750 kva, three phase, 60 cycle, dry-types with provision for future fan cooling and thus a supplementary rating of 1000 kva each. Each of these transformers feeds a section of low voltage switchgear. A tie breaker permits connection of the two low voltage bus sections if desired. Building service, motor control centers and panel boards will be supplied at 480 volt, 3 phase 60 cycles by these substations.

2.4 kv Switchgear

The 2.4 kv switchgear will be for use on a 2,400 volt, three phase, effectively grounded 60 cycle system. The equipment will consist of one auxiliary unit for incoming line and street lighting circuits, 10 main and auxiliary units for control and starting of three synchronous motors and two main units for the a-c source to two frequency converters for a total of 13 units. The power buses will have a continuous rating of 2000 amperes.

Auxiliary Regulated Power Supplies

Regulated a-c power for instrumentation and miscellaneous test purposes will be provided at the test locations. These will include 115-volt, 60 cycle power supplies and 115-volt, 400 cycle power supplies.

Lighting

The building lighting and receptable system except for street lighting is 120/208 volts, 3 phase, 4 wire. The source of the power will be individual transformers connected to the 440 volt power system and located adjacent to the lighting and receptacle panel boards. The source of power for the 6.6 ampere series street lighting system will be a constant current transformer and associated equipment in a unit of the 2400 volt switchgear.

Communication and Fire Alarm Systems

A telephone system connected to the existing station system is provided with outlets conveniently located throughout the building and facilities. A complete coded fire alarm system and a paging system connected with existing station systems will also be provided.

WATER SUPPLY, STEAM & SEWER LINES

Potable, basin fill, recirculating and fire water lines will be provided and connected to existing station lines.

The water for filling the basins will come from the existing Station Water Treatment Plant. This plant has a capacity of about 2100 gpm. Two cartridge type water filters, each having a capacity of 1350 gpm at 2 psi pressure drop with removal of particles 50 microns and larger, will be located in the Rotating Arm and Maneuvering Basin Building. These filters will be used to locally filter the basin water by recirculation and thus relieve the main filter plant of the Station.

The basins will be gravity drained by means of 24 inch cast iron pipe which connects the basin floor drains with a wet well in the building. The wet well will contain two vertical turbine pumps. Each pump will have a capacity of 2200 gpm at a total head of 150 ft. and will be driven by a 440 volt, 100 hp a-c motor. The water will be discharged to a storm sewer. In addition, the discharge may be valved into the fire line to provide additional water reserve for the station.

A basin make up water level system will be provided. This consists of a water pressure tank, 4 ft. in diameter and 14 ft. long, designed for 100 psi working pressure with the necessary control valves and piping and a deep well pump installation. The deep well pump will have a capacity of 100 gpm at a 525 ft. head and will be driven by a 20 hp, 440 volt, a-c motor. The pump controls will be arranged to provide discharge directly into the fitting room test basin, the main basins or into the make up water pressure tank.

A sanitary sewer system, including lines, sewage lift station and auxiliary equipment, will be connected to the station system.

Steam for the unit heaters will be provided by an underground, insulated, waterproof metal enclosed steam distribution system that connects to the station boiler plant. It will be delivered to the building at about 60 pounds pressure and a reducing station provides 40 pound steam for delivery to the unit heaters. A condensate return piping system is also provided.

OVERHEAD PLATFORMS AND OBSERVATION ROOMS

Catwalks and camera platforms will be suspended from the steel trusses over the maneuvering and the rotating arm basins. These platforms will be used for overhead observation and photography. The maneuvering basin and rotating arm basin will each contain an observation room located in the basin wall. Windows will be located on the water side of the room for visual observation and photography of special tests that run in the vicinity of the wall.

REFERENCES

1. Brownell, W.F., "Functional Specifications of a Rotating Arm and Maneuvering Basin for the David Taylor Model Basin", Taylor Model Basin File N8/1(518:WFB:bed), March 1952.

2. "Phase I Advance Planning - Rotating Arm and Maneuvering Basin for the David Taylor Model Basin", MacKenzie, Bogert & White, Architects & Engineers, 9 April 1954, Bureau of Yards & Docks Contract NOy-81416.

3. "Rotating Arm and Maneuvering Basin - Basic Design of Testing Equipment", Facilities and Instrumentation Divisions, David Taylor Model Basin, 26 July 1954.

4. "Advance Planning Study for a Rotating Arm and Maneuvering Basin at the David Taylor Model Basin", Sverdrup & Parcel, Inc., Consulting Engineers, 22 November 1954, Bureau of Yards & Docks Contract NOy-85481.

5. Contract NOy-86453, "Rotating Arm and Maneuvering Basin at the David W. Taylor Model Basin", Bureau of Yards & Docks, Navy Department.

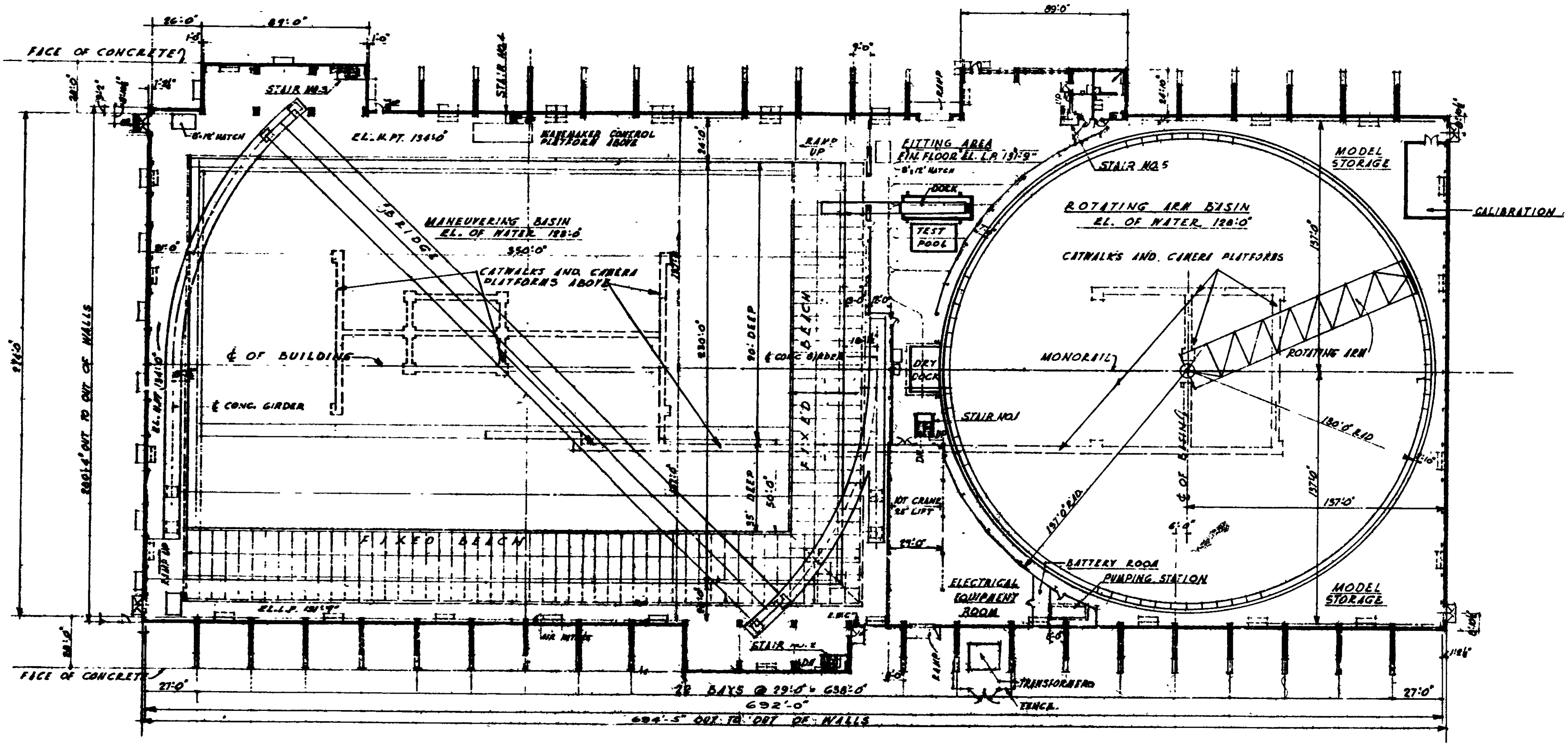
6. Bowers, C.E., Herbich, J.B., and Ziegler, J., "Experimental Model Study of Absorber for Rotating Arm Basin", St. Anthony Falls Hydraulic Laboratory, University of Minnesota Memorandum No. M-38, July 1955.

7. Herbich, J.B., "Preliminary Experimental Data on Bar-Type Wave Absorbers", St. Anthony Falls Hydraulic Laboratory, University of Minnesota Memorandum No. M-31, May 1955.

8. Herbich, J.B., "Experimental Studies of Wave Filters and Absorbers", St. Anthony Falls Hydraulic Laboratory, University of Minnesota Project Report No. 44, January 1956.

LIST OF ILLUSTRATIONS

Figure



FIRST FLOOR PLAN

Figure 1 - Rotating Arm and Maneuvering Basin - Floor Plans

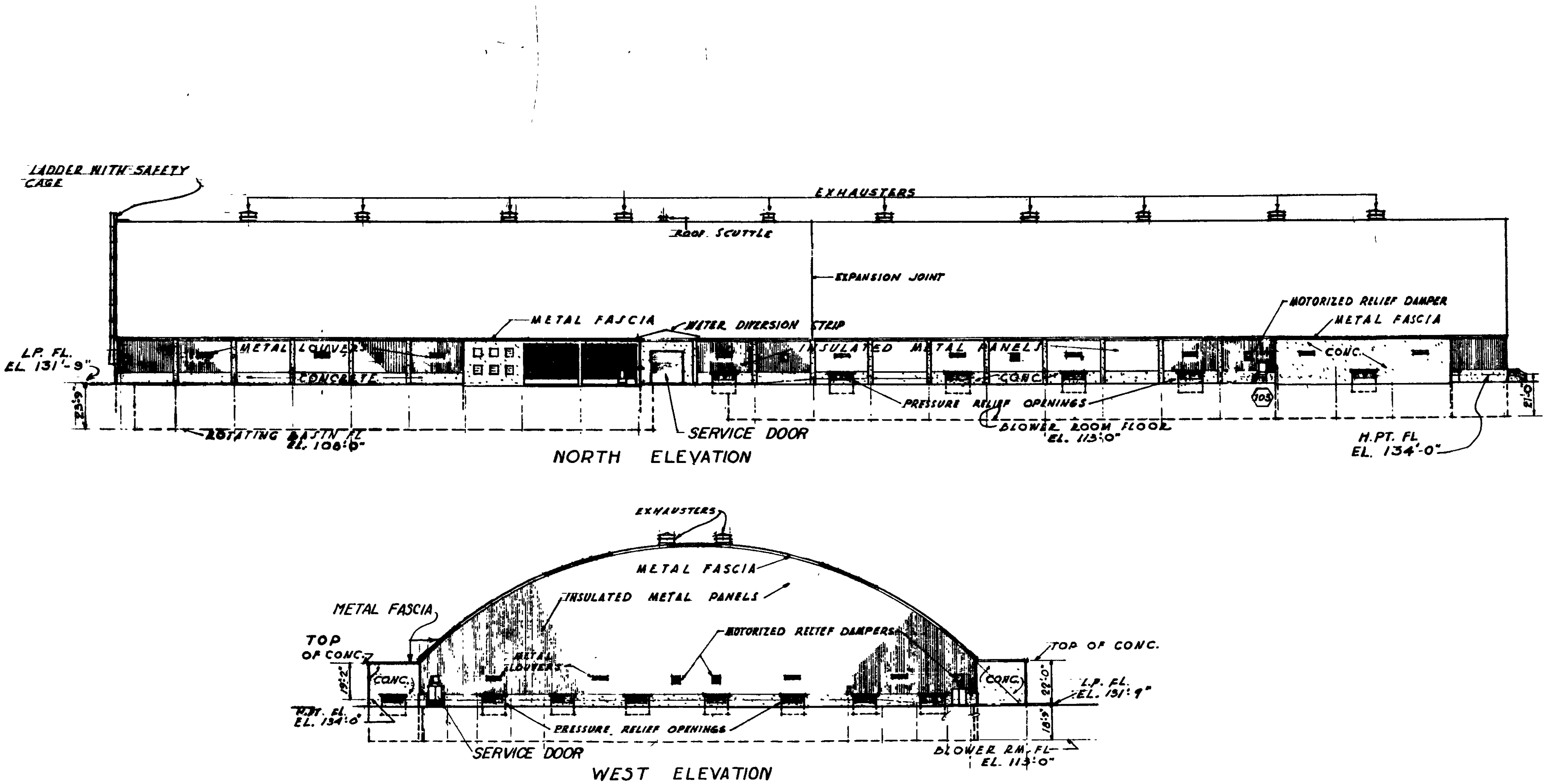


Figure 2 - Rotating Arm and Maneuvering Basin - Elevations

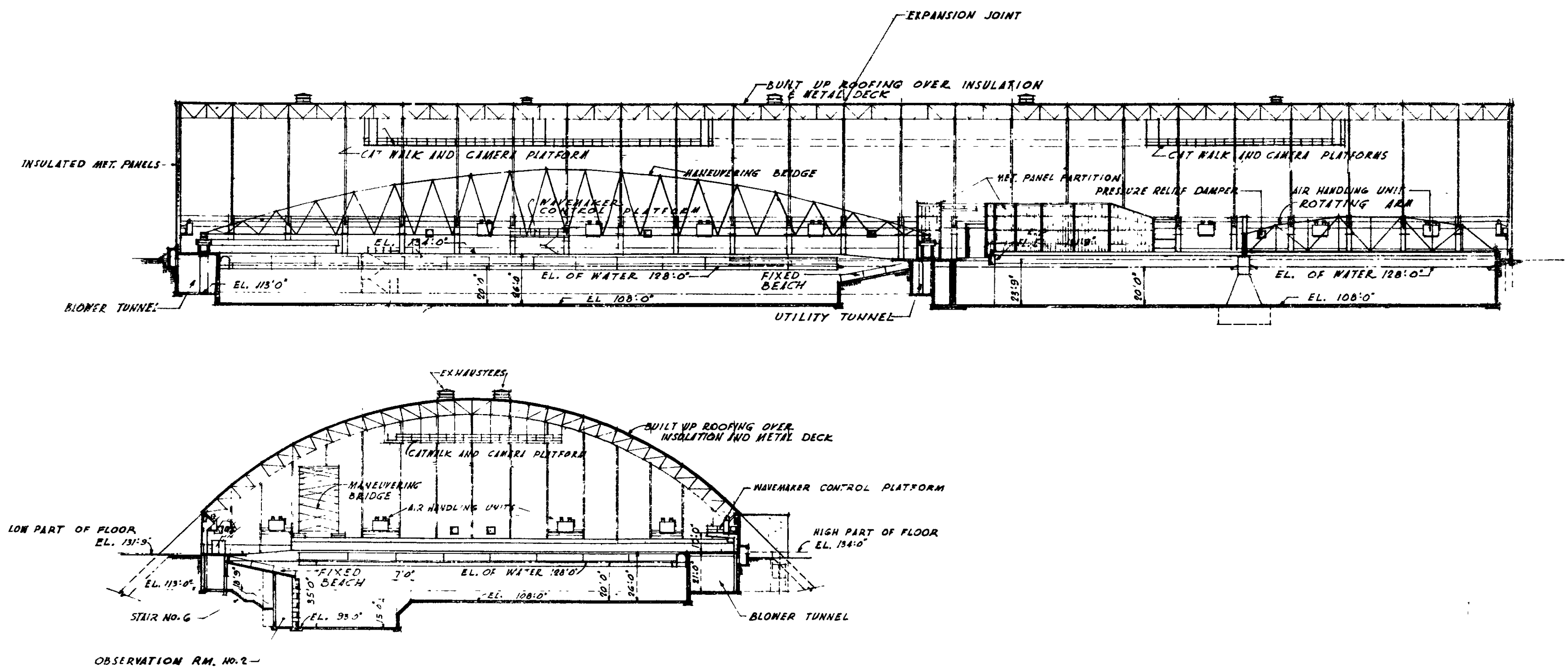
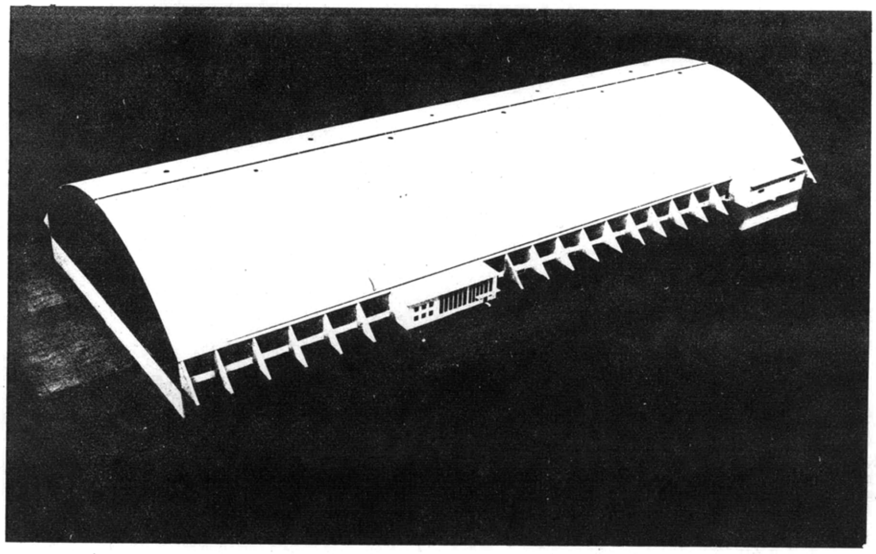


Figure 3 - Rotating Arm and Maneuvering Basin - Sections



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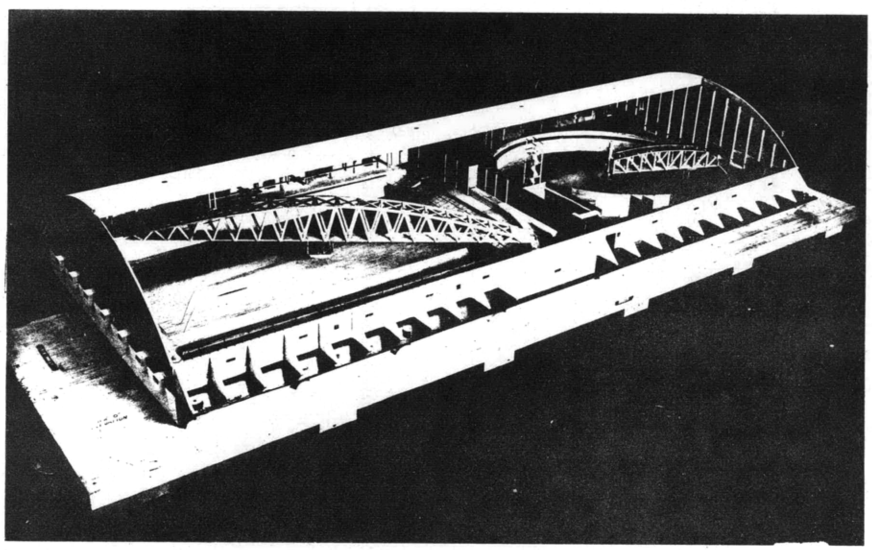

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Figure 4 - 1:120 Scale Model of Rotating Arm and Maneuvering Basin

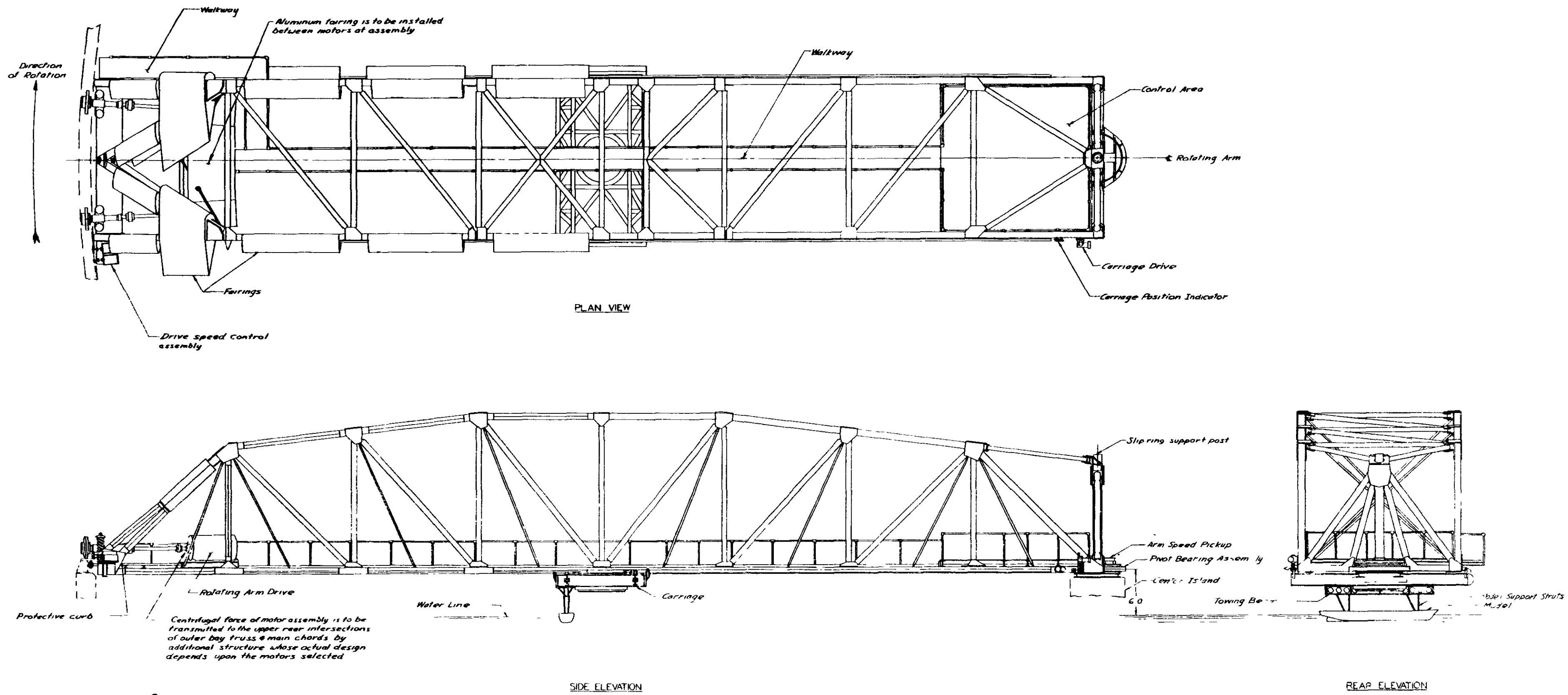


Figure 5 - Rotating Arm General Assembly

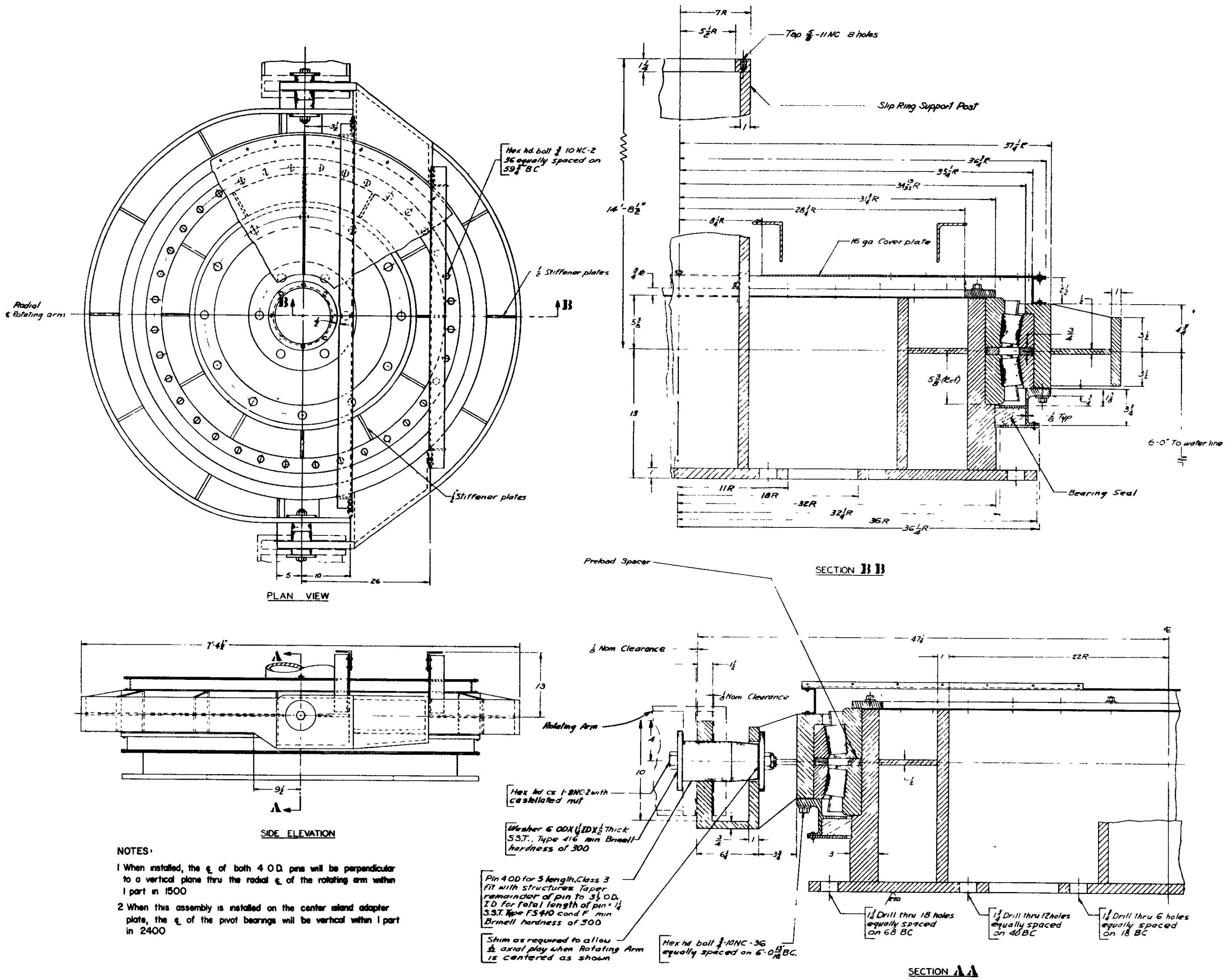
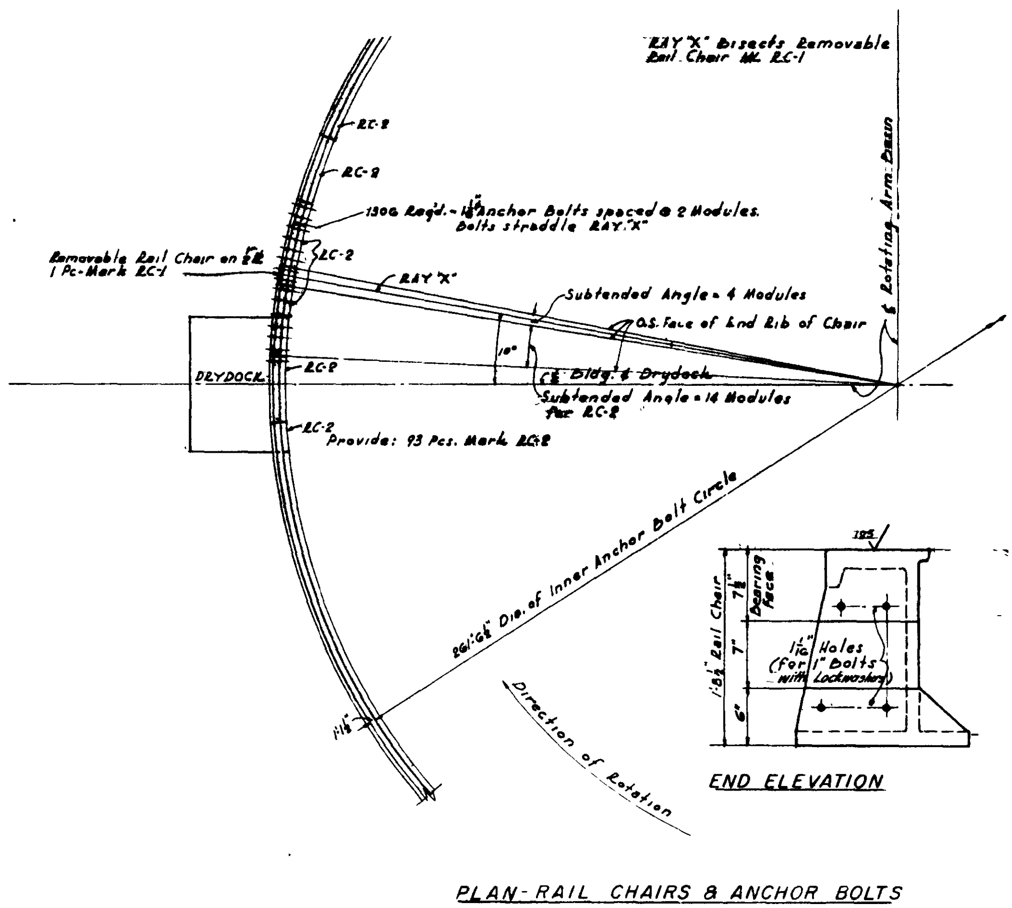


Figure 6 - Rotating Arm Pivot Bearing Assembly



Note:
One Module = $\frac{360°}{1306}$

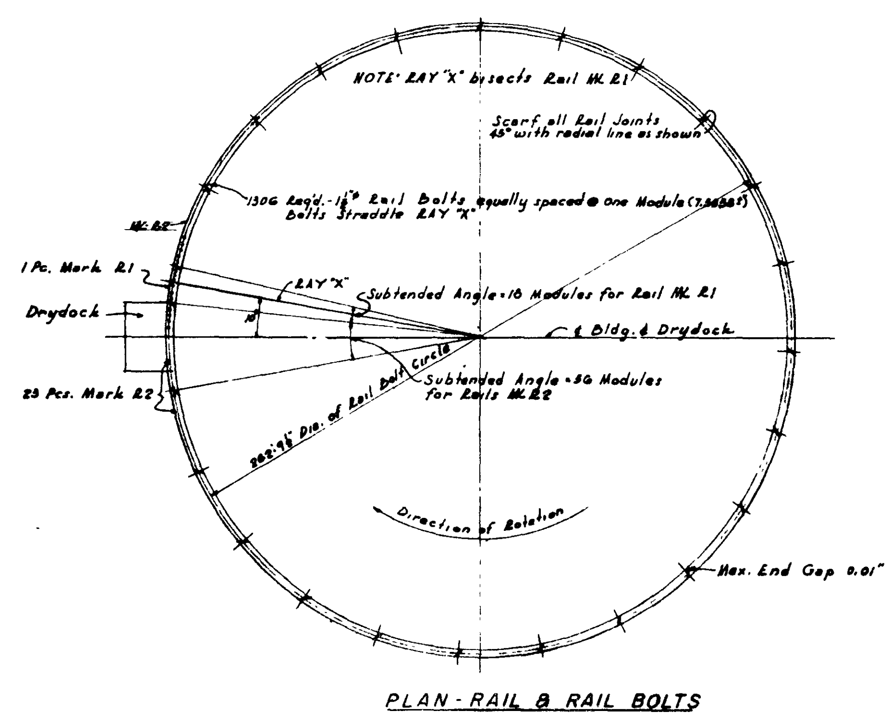


Figure 7 - Rotating Arm Peripheral Track Layout

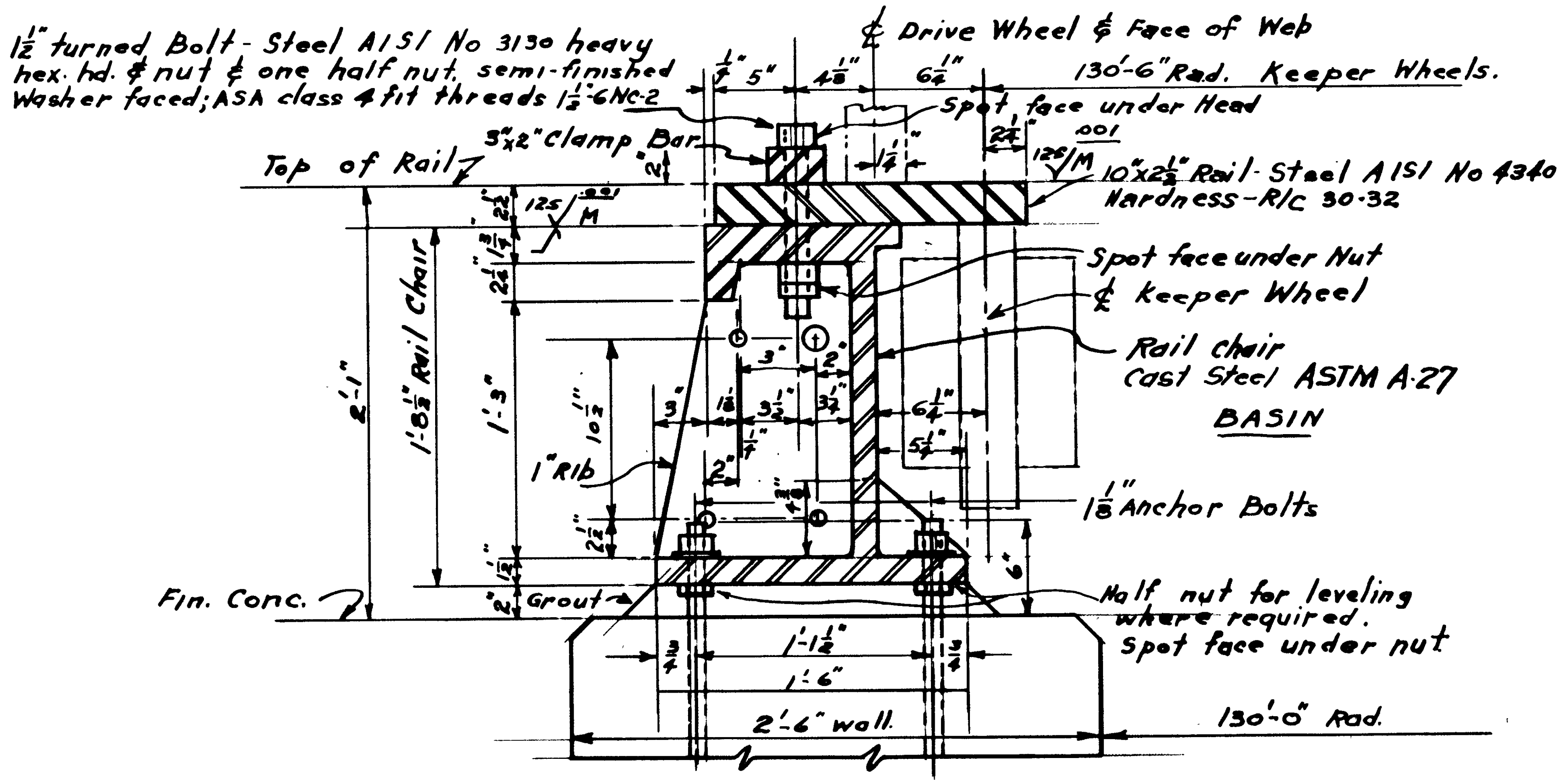


Figure 8 - Typical Section of Rotating Arm Peripheral Track

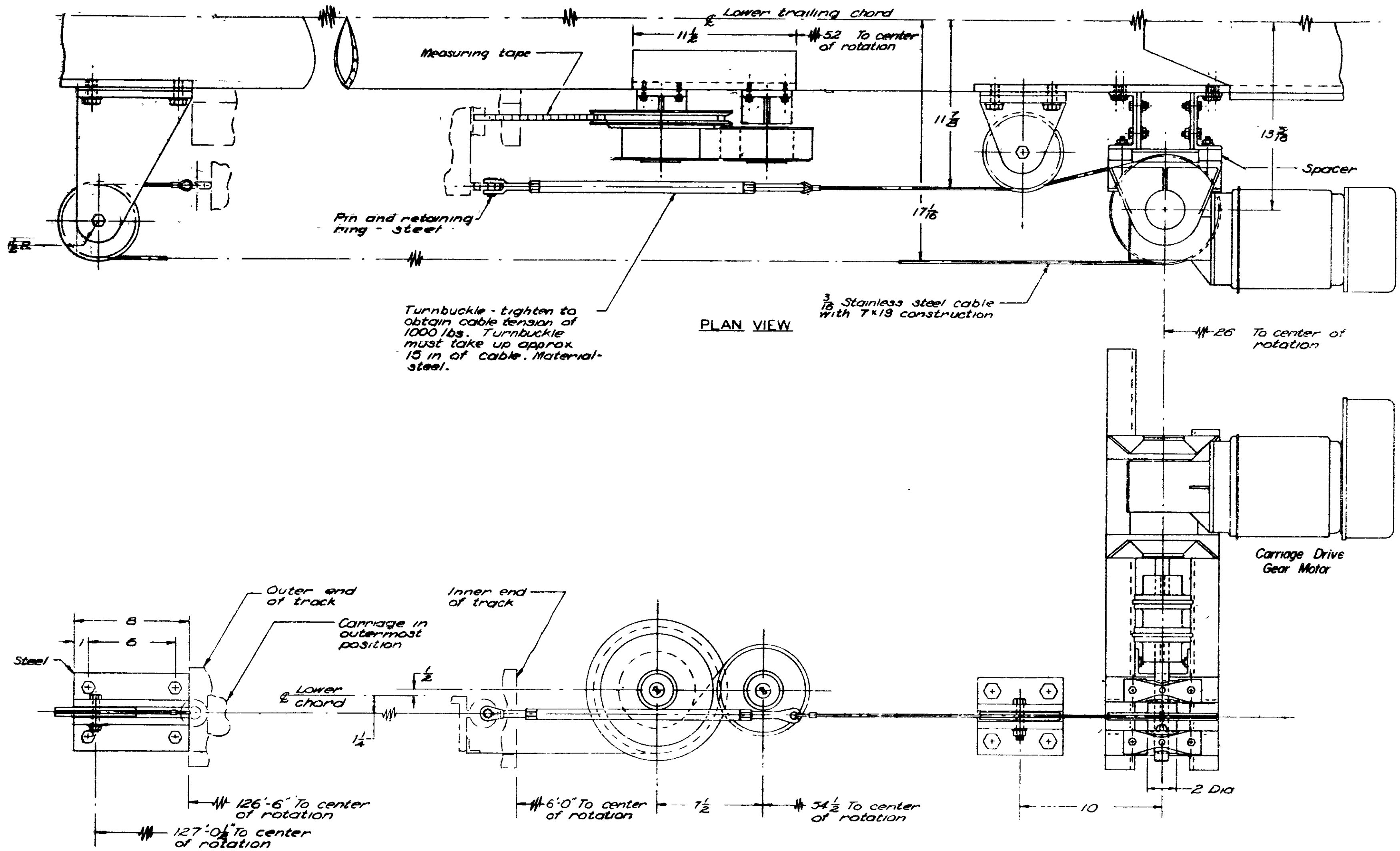


Figure 9 - Rotating Arm Tow Carriage Drive

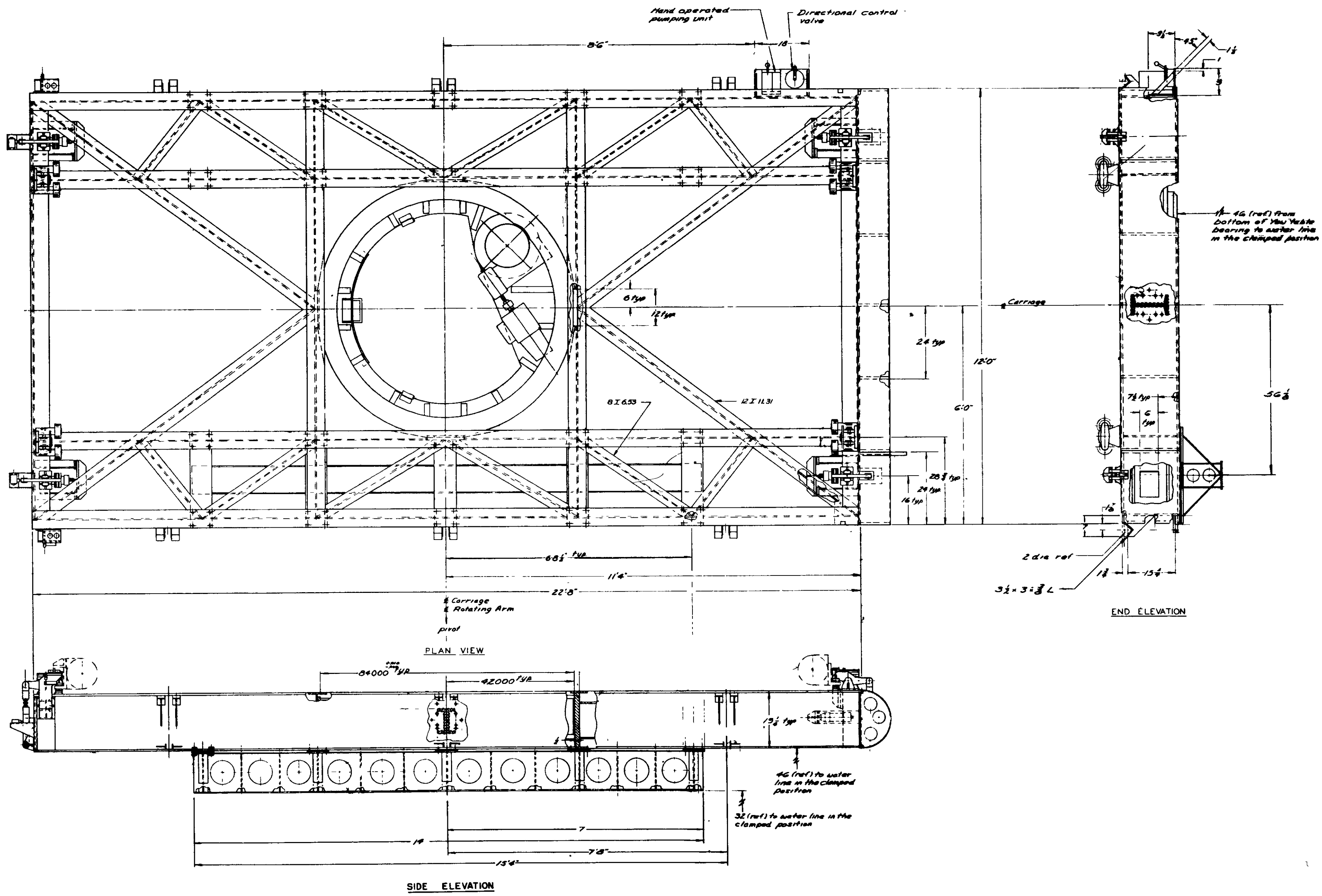


Figure 10 - Rotating Arm Tow Carriage

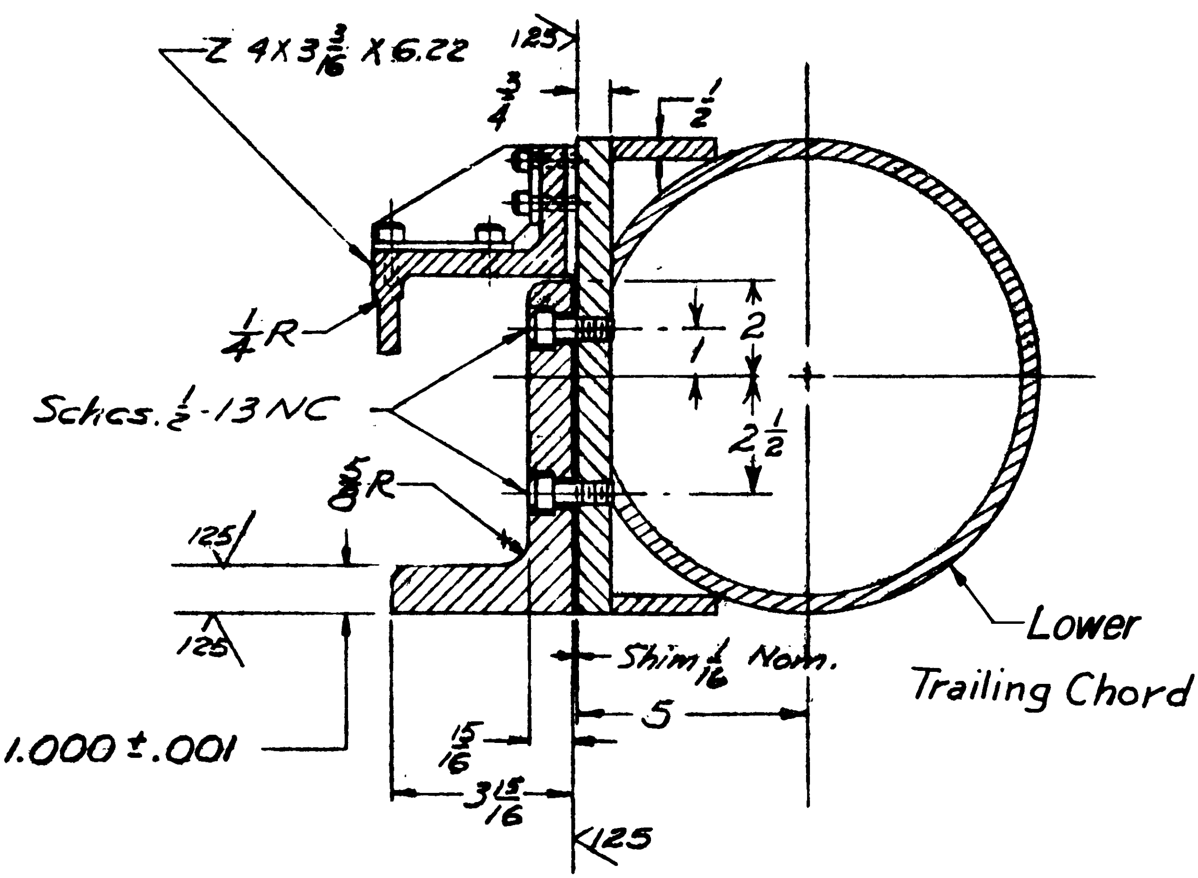


Figure 11 - Section Showing Rotating Arm Tow Carriage Track Construction

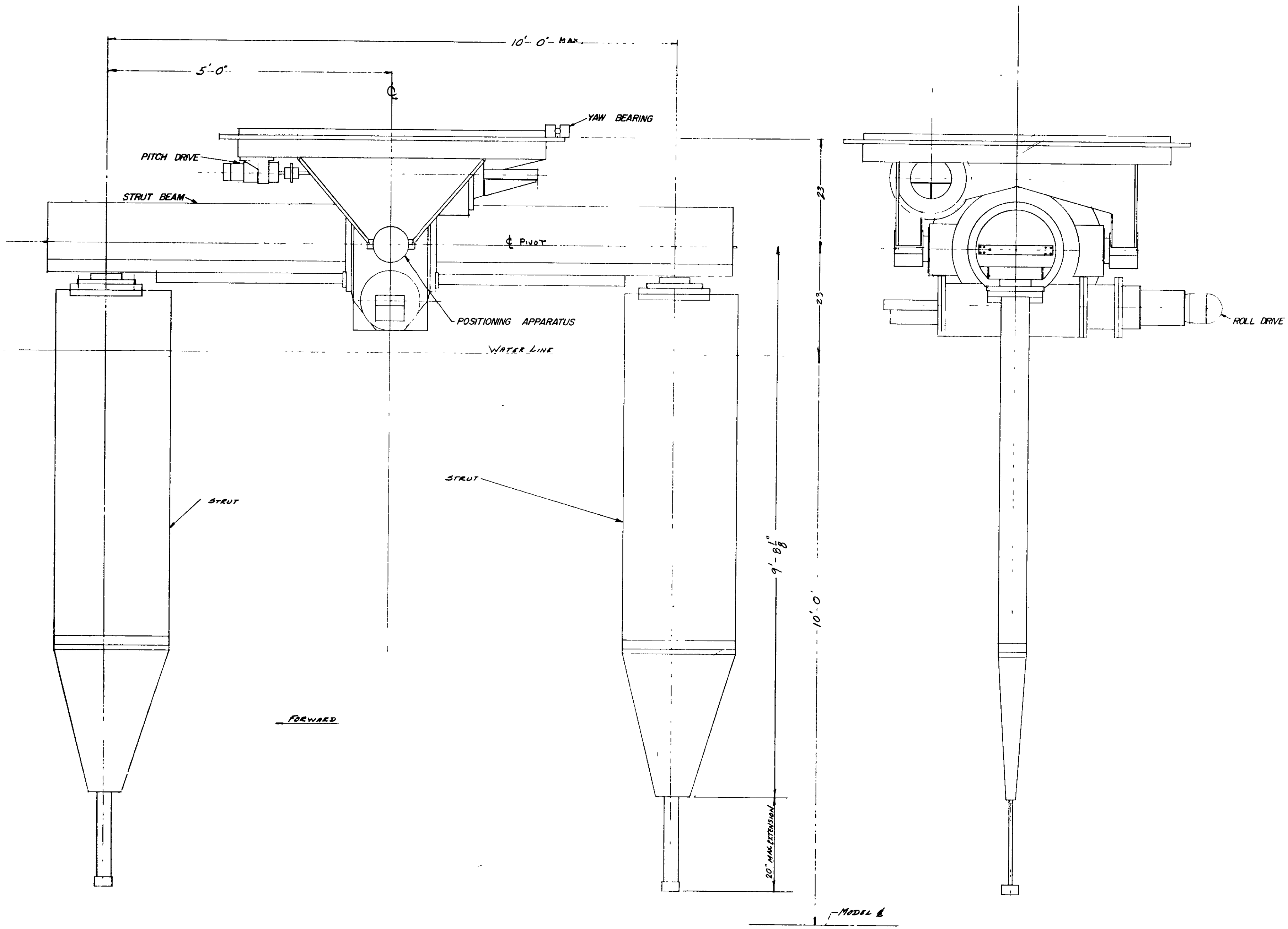


Figure 12 - General Arrangement of Model Positioning Equipment

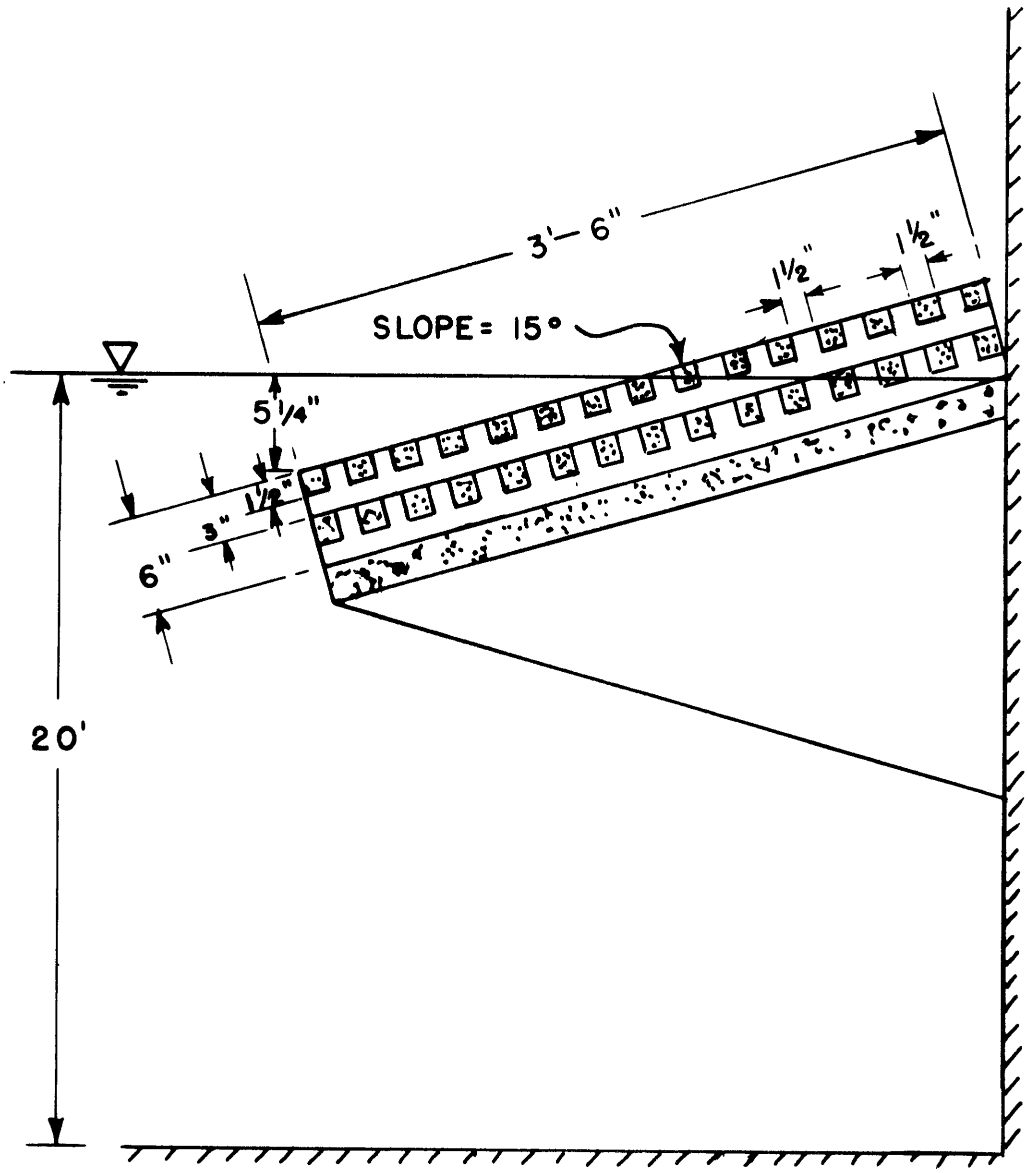


Figure 13 - Rotating Arm Wave Absorber

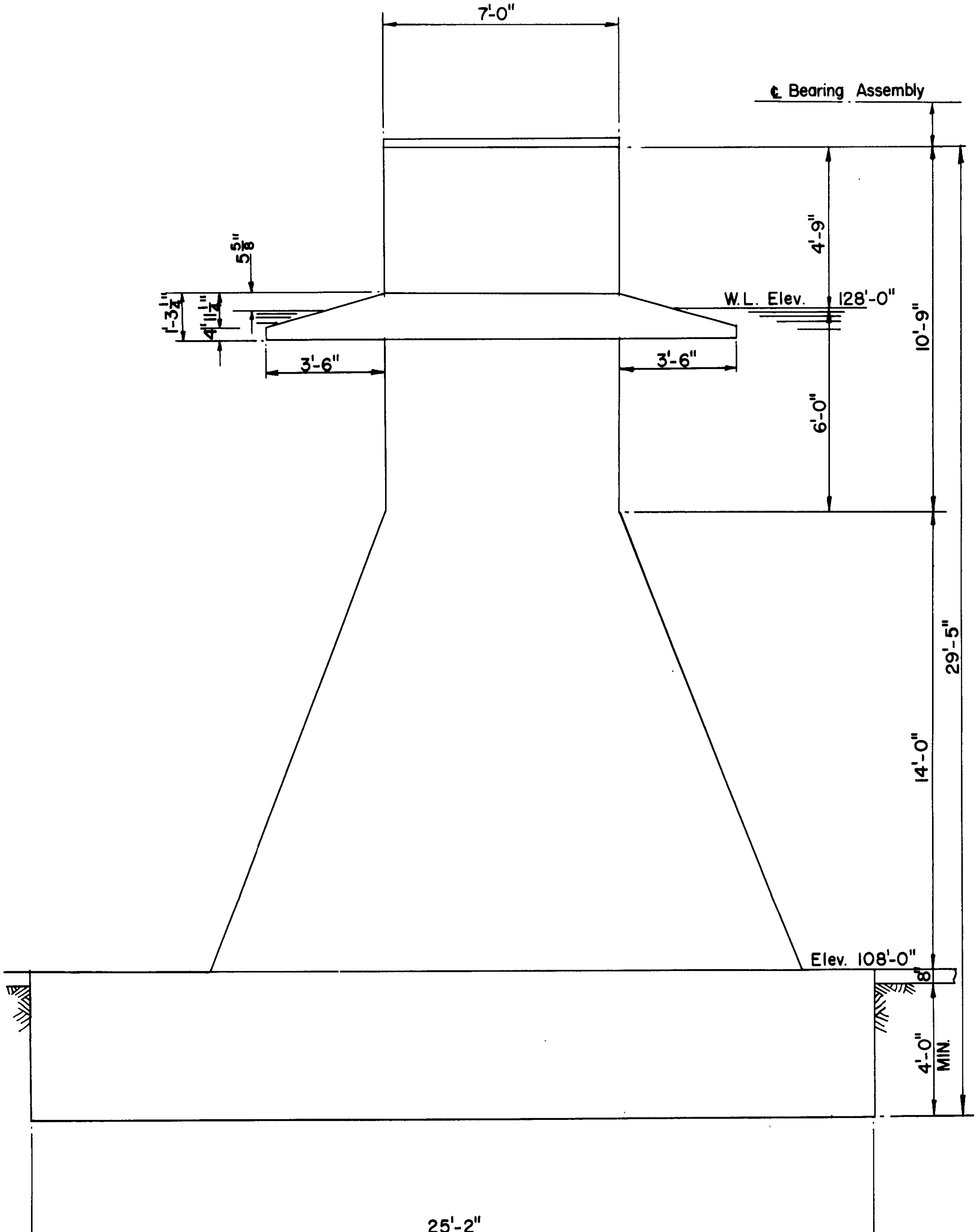


Figure 14 - Rotating Arm Center Island Wave Absorber

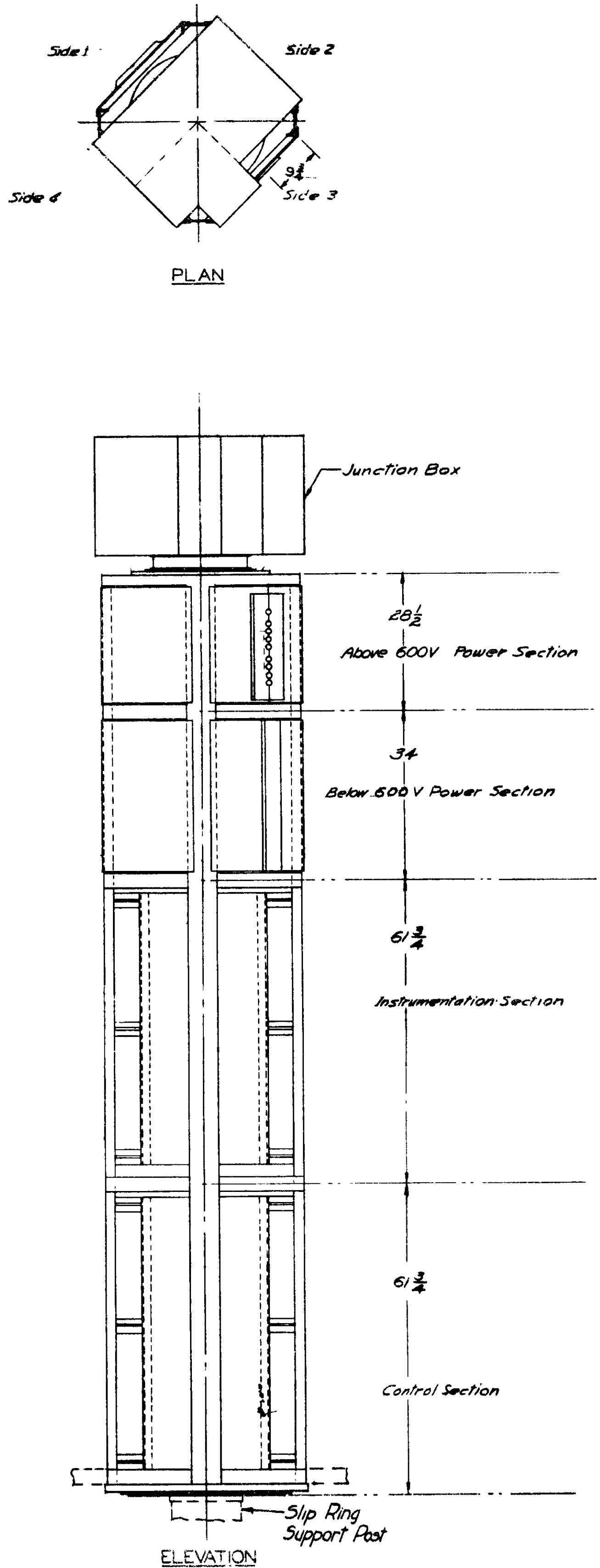


Figure 15 - Elevation of Rotating Arm Slip Ring Structure

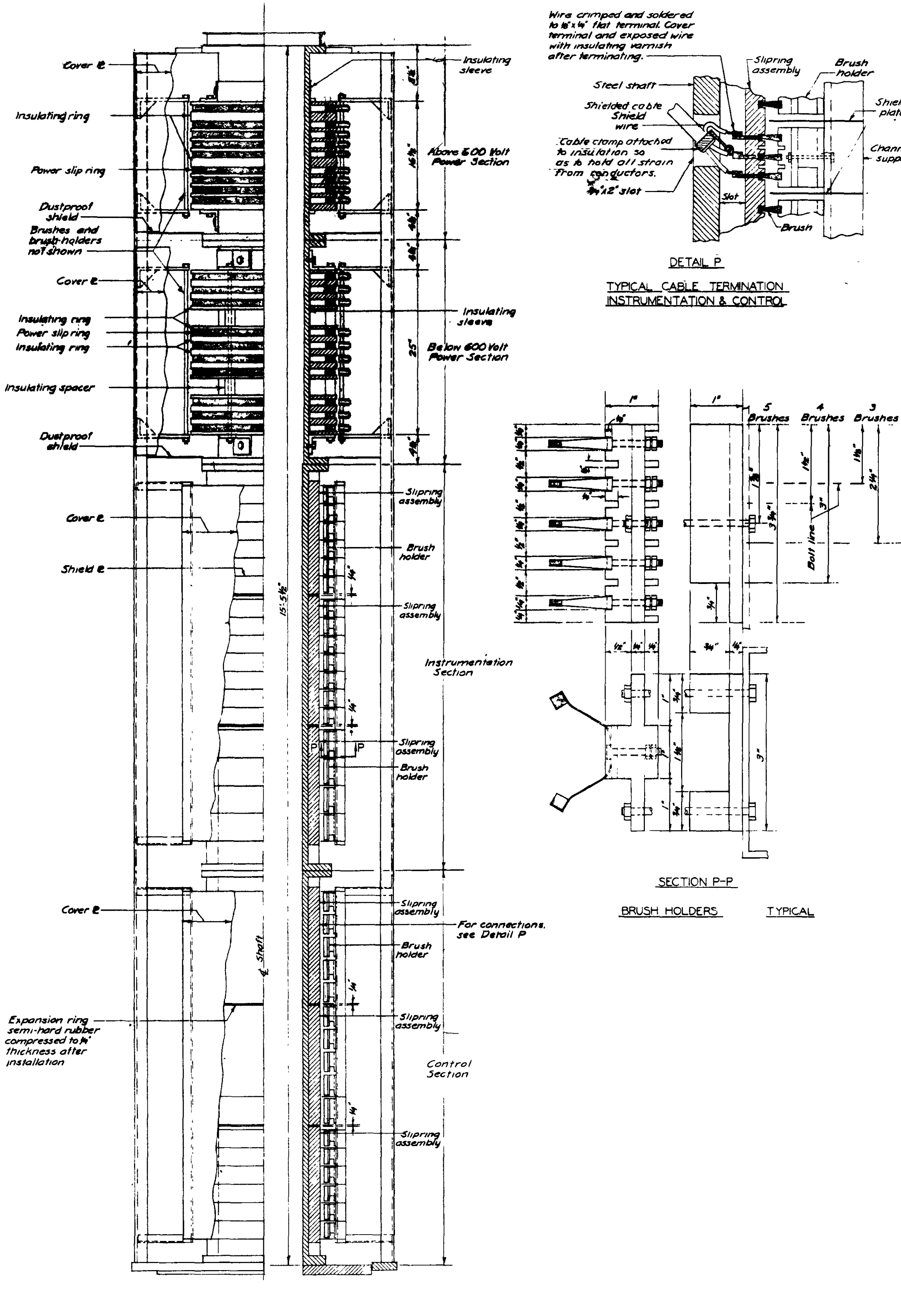


Figure 16 - Section Through Slip Rings

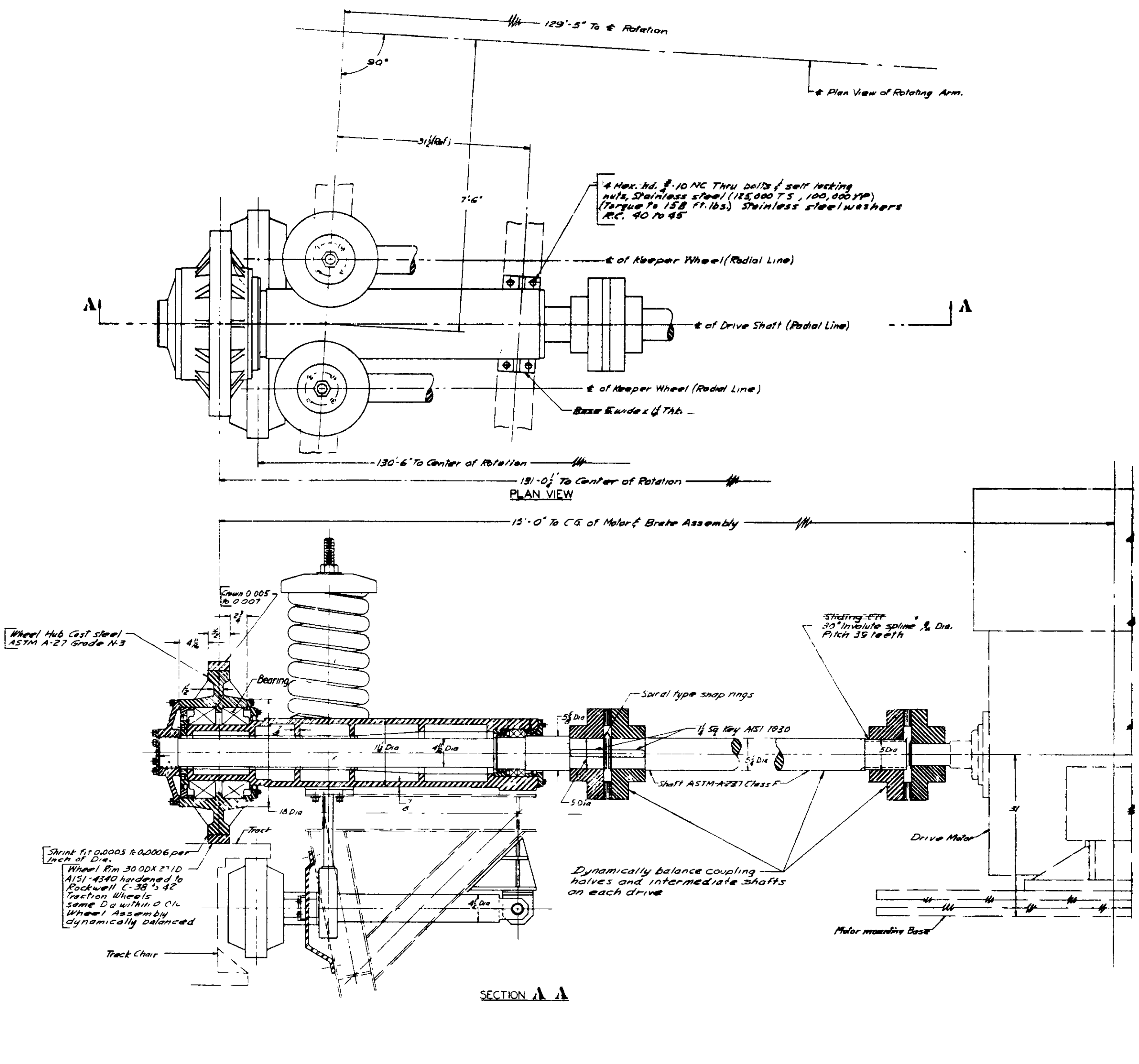


Figure 17 - Rotating Arm Drive Assembly

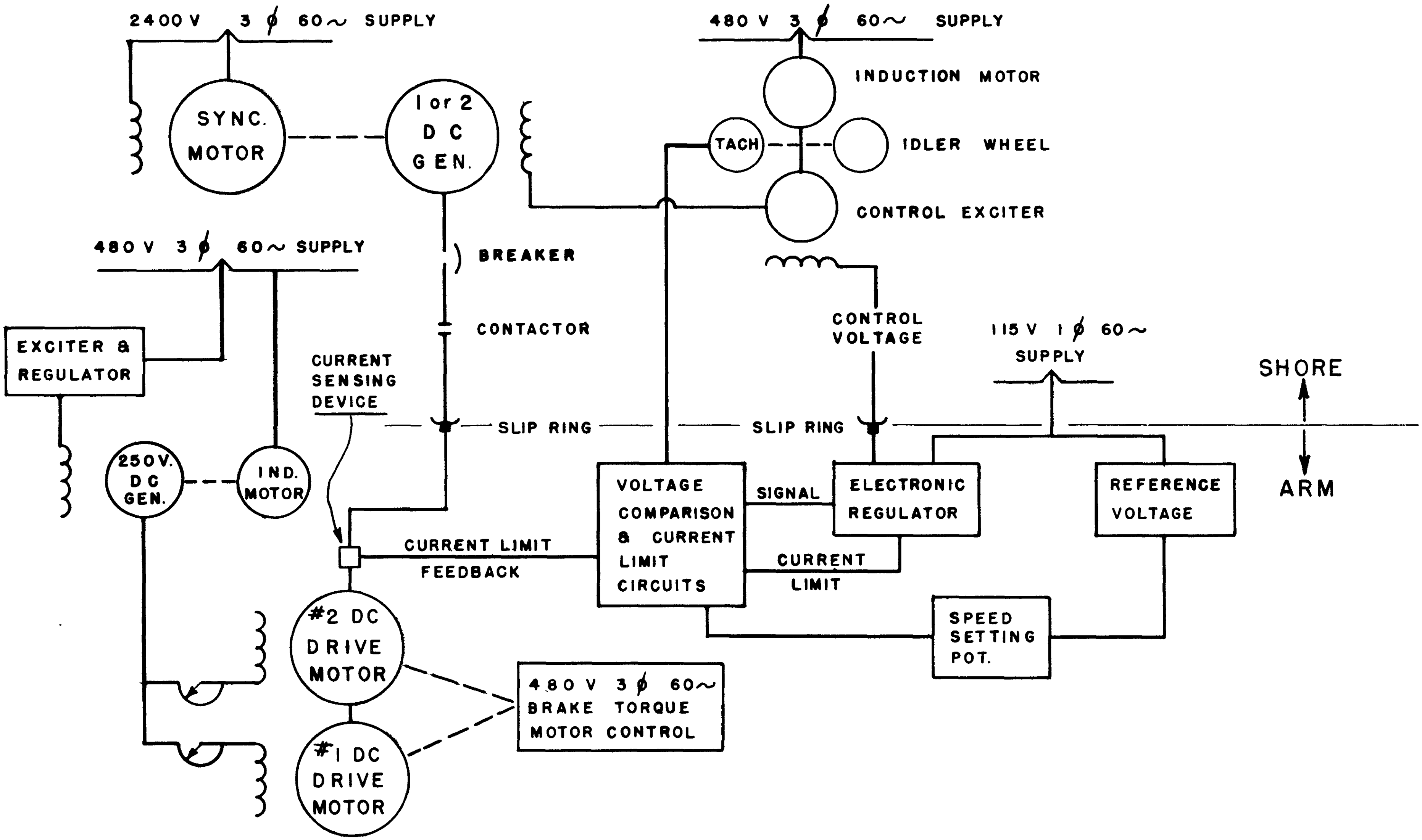


Figure 18 - Block Diagram of Rotating Arm Drive System

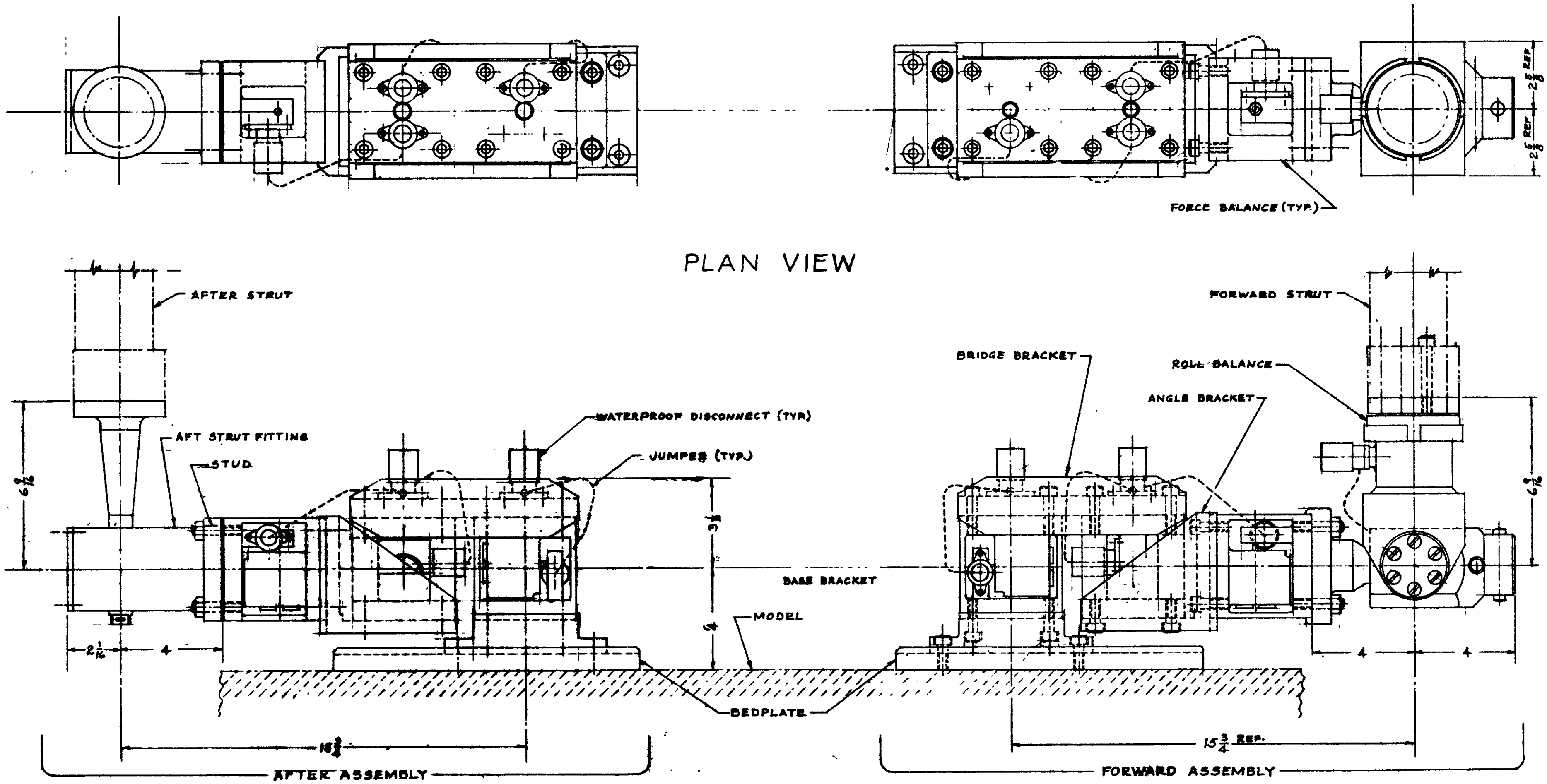
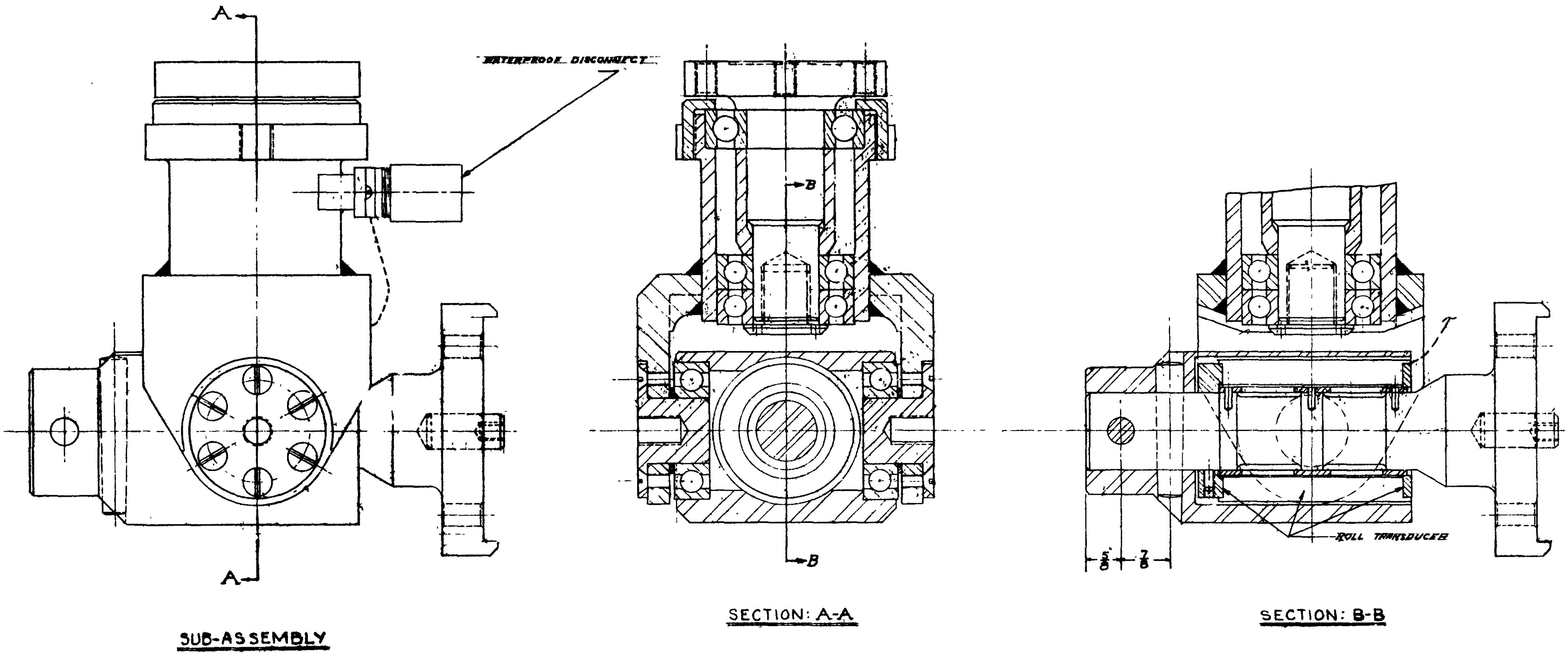
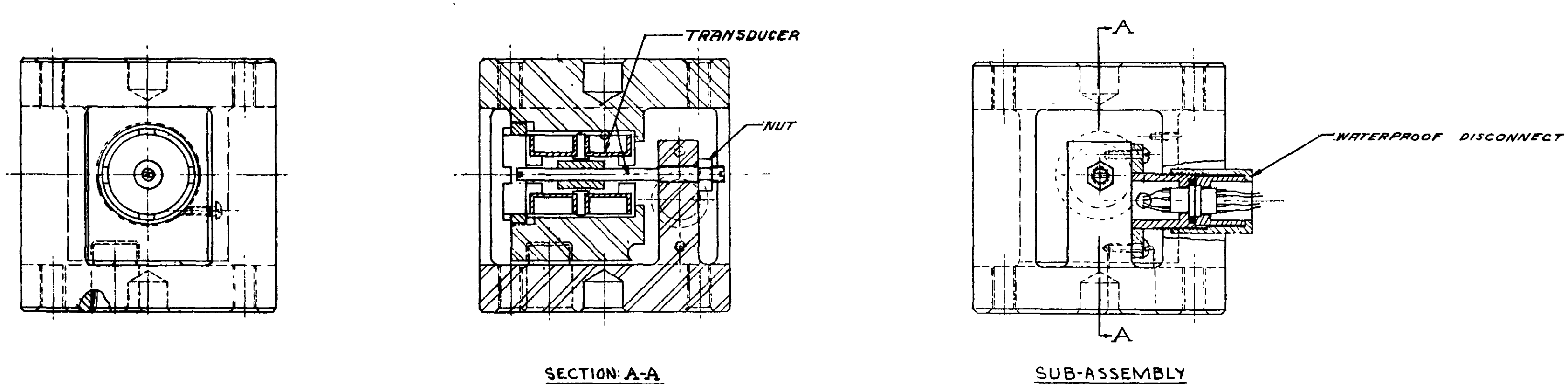


Figure 19 - General Assembly of Balances



ROLL BALANCE UNIT - SUB-ASSEMBLY



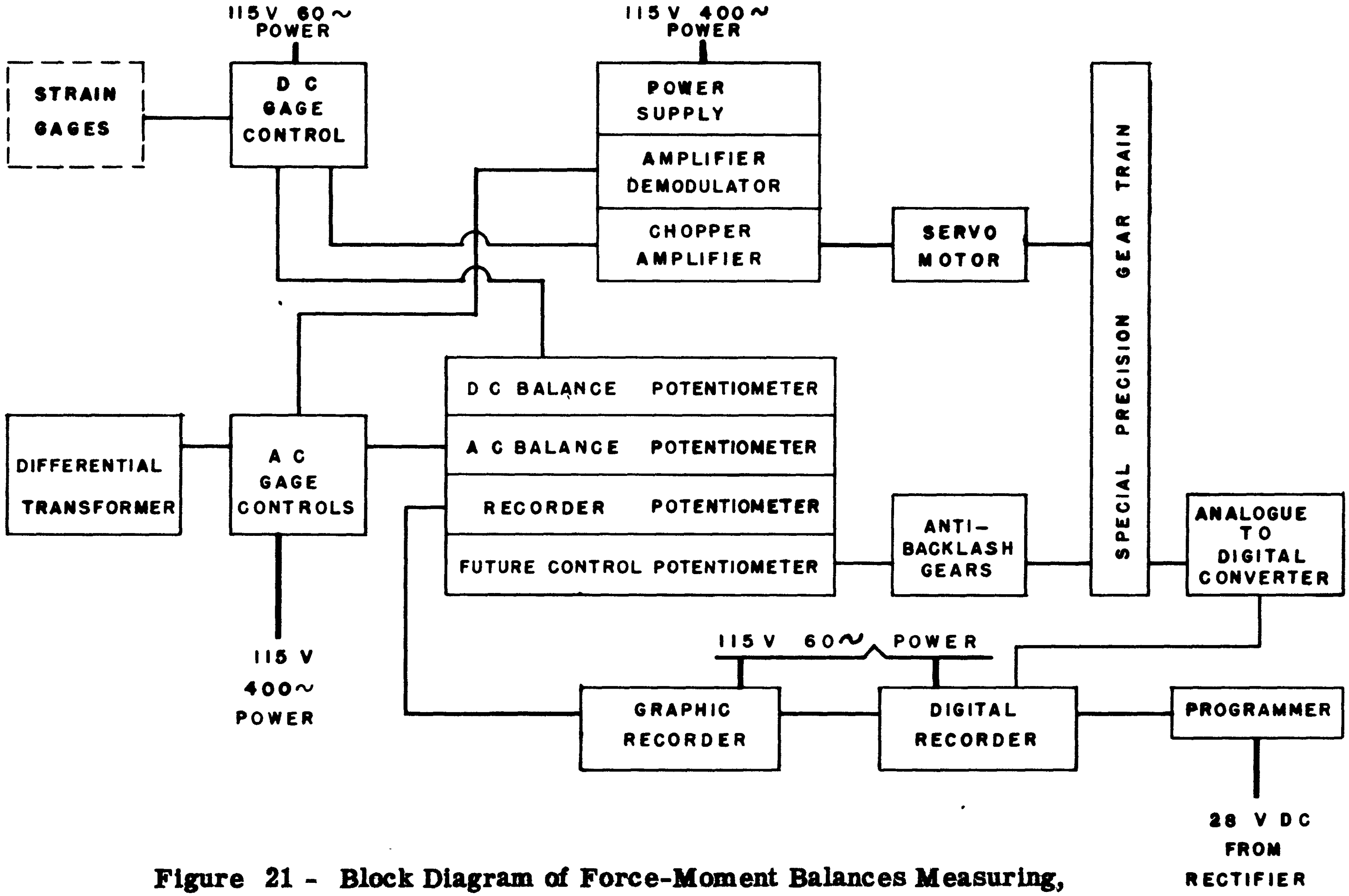


Figure 21 - Block Diagram of Force-Moment Balances Measuring, Indicating and Recording System

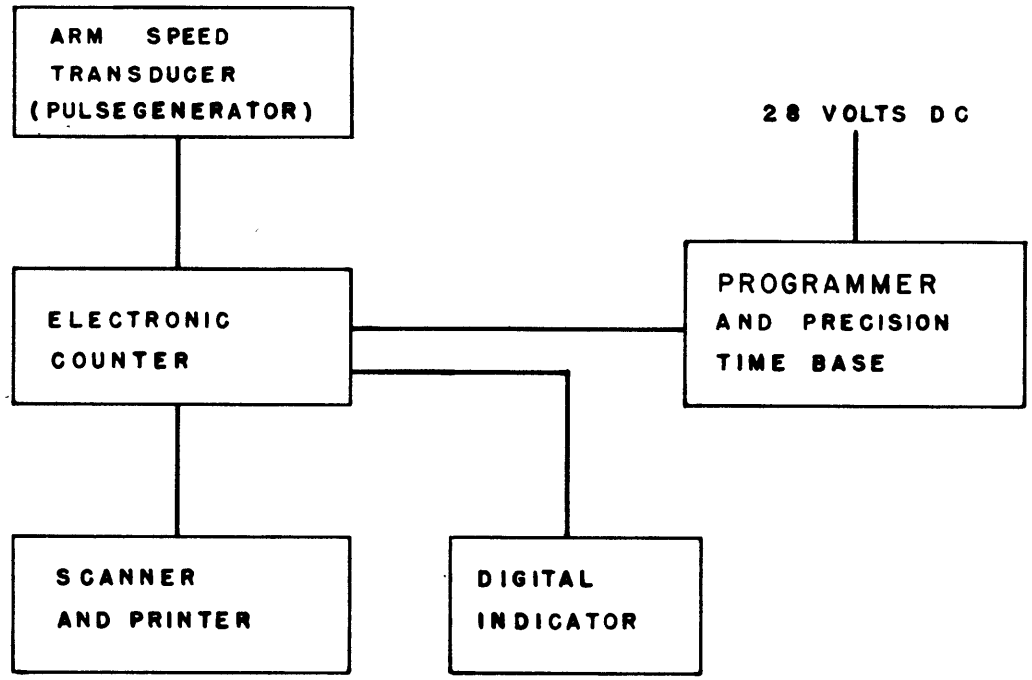


Figure 22 - Block Diagram of Rotating Arm Speed Measuring, Indicating and Recording System

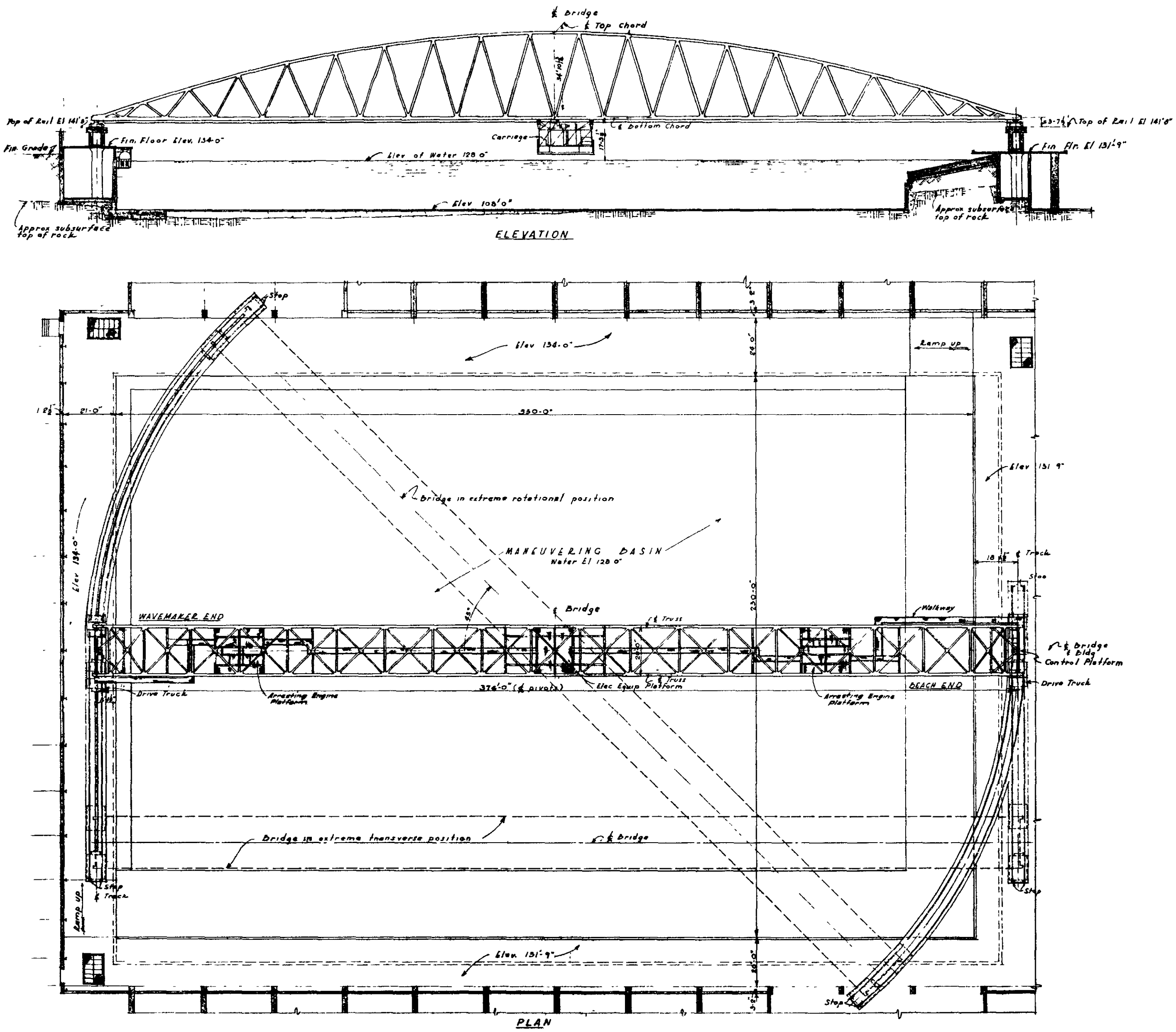


Figure 23 - Plan and Elevation of Maneuvering Bridge

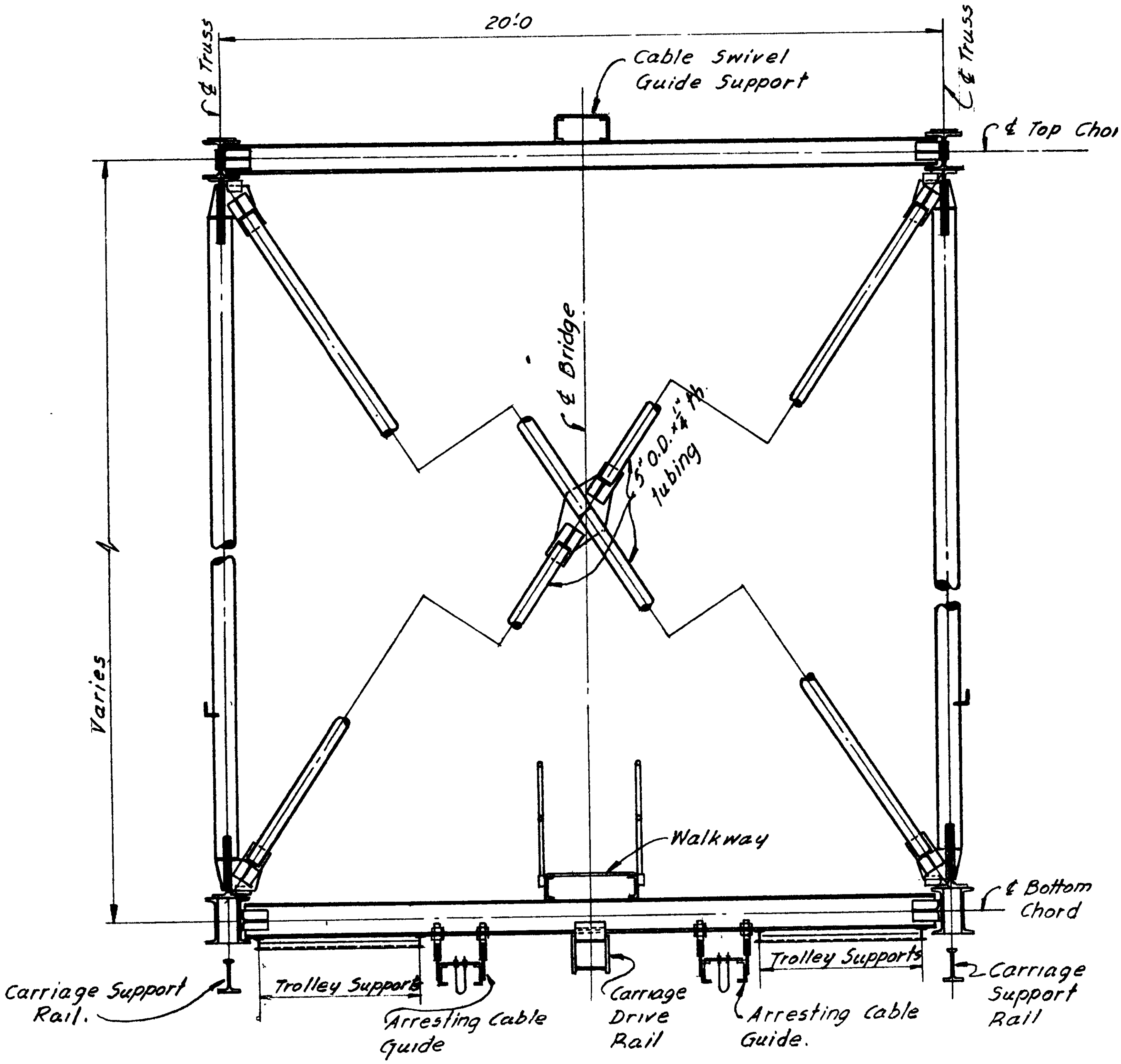


Figure 24 - Cross Section Showing Maneuvering Bridge Carriage Drive and Support Rails

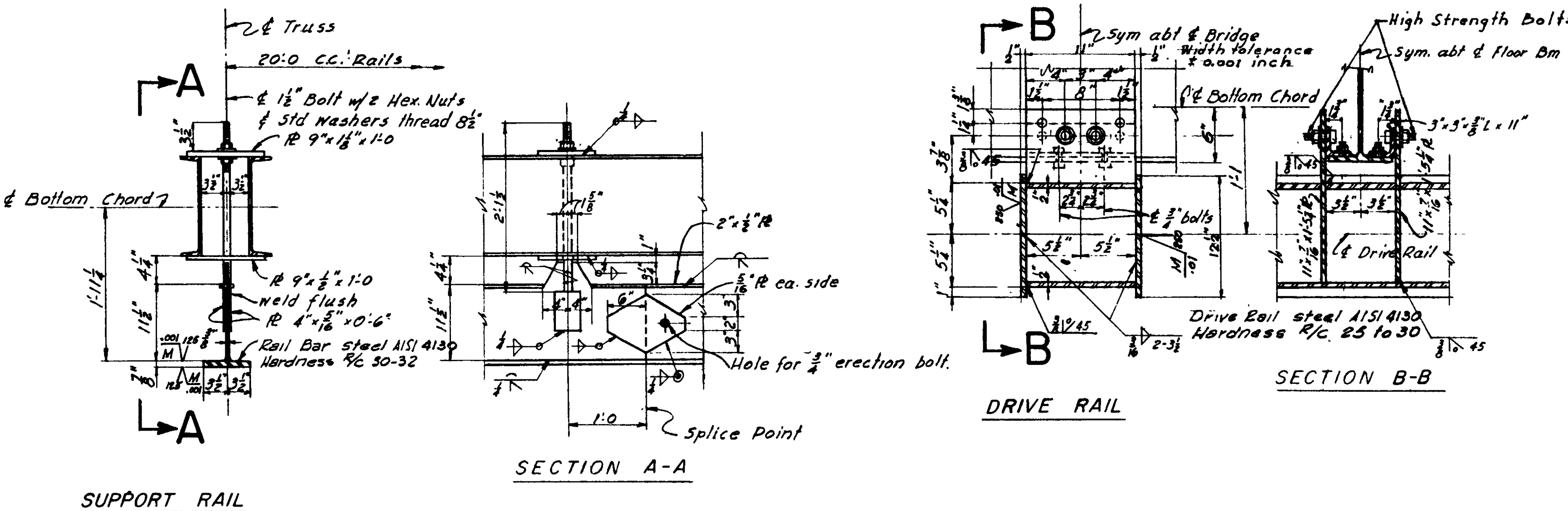


Figure 25 - Details of Maneuvering Bridge Carriage Drive and Support Rails

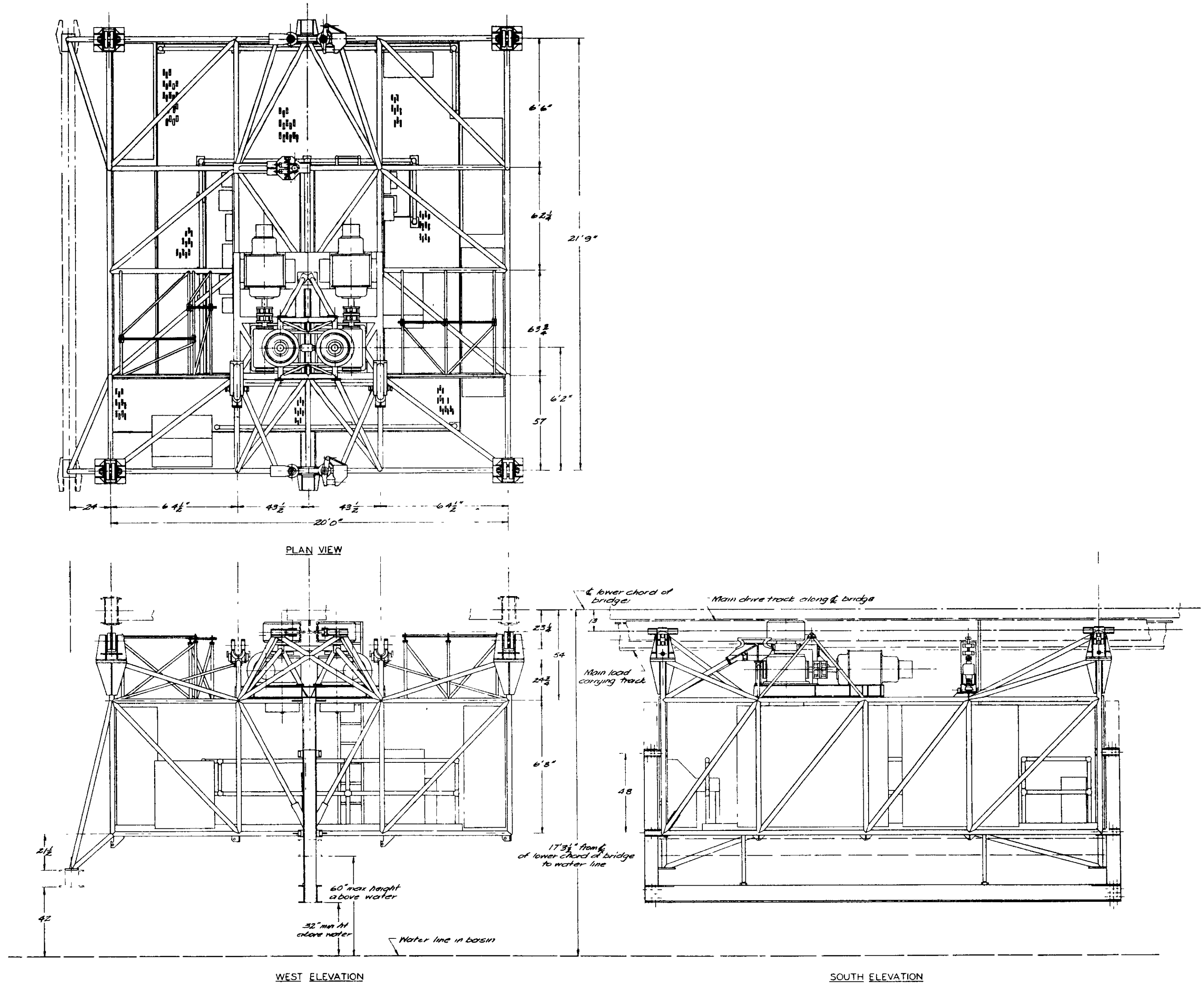


Figure 26 - Maneuvering Bridge Carriage Assembly

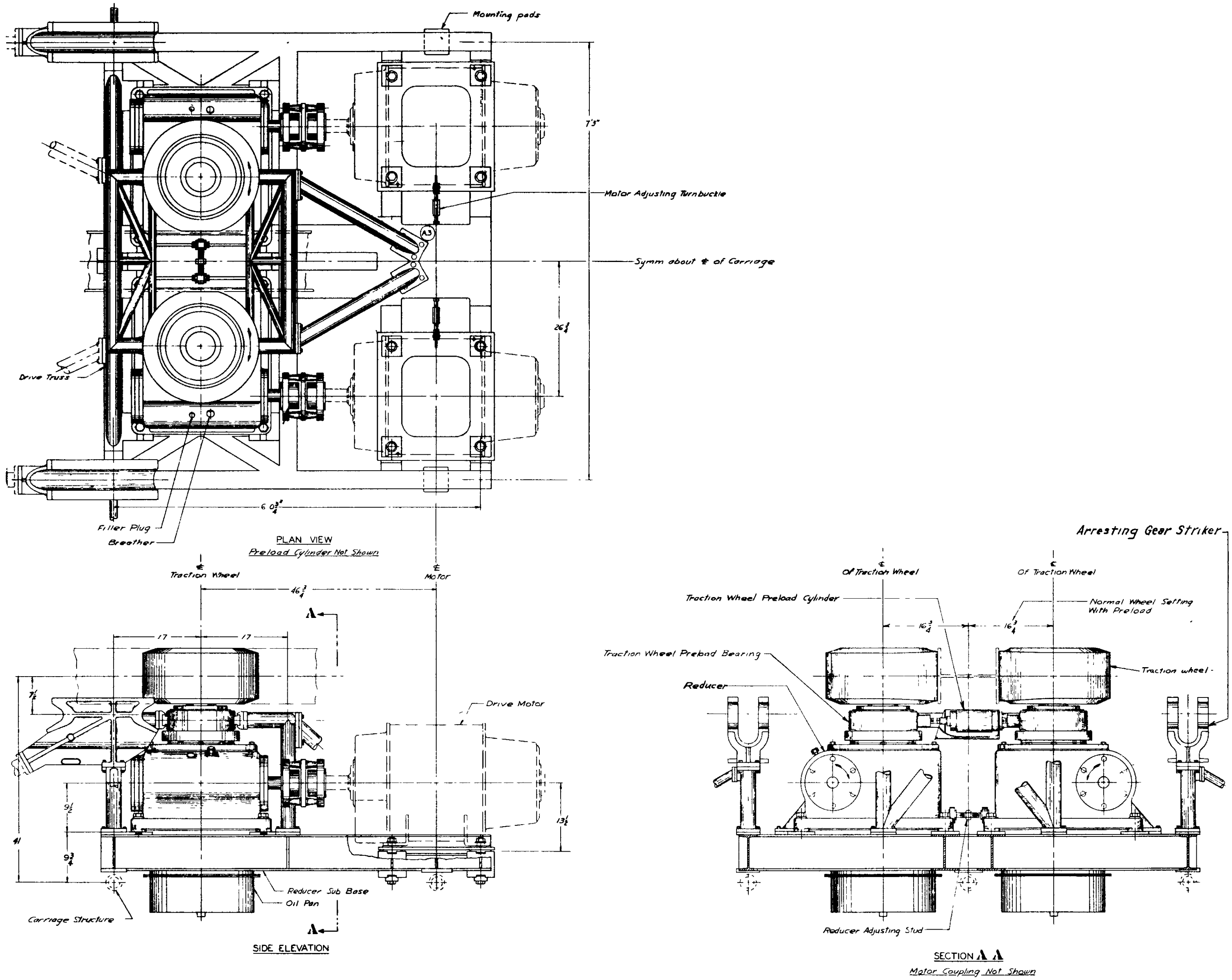


Figure 27 - Maneuvering Bridge Carriage Drive Assembly

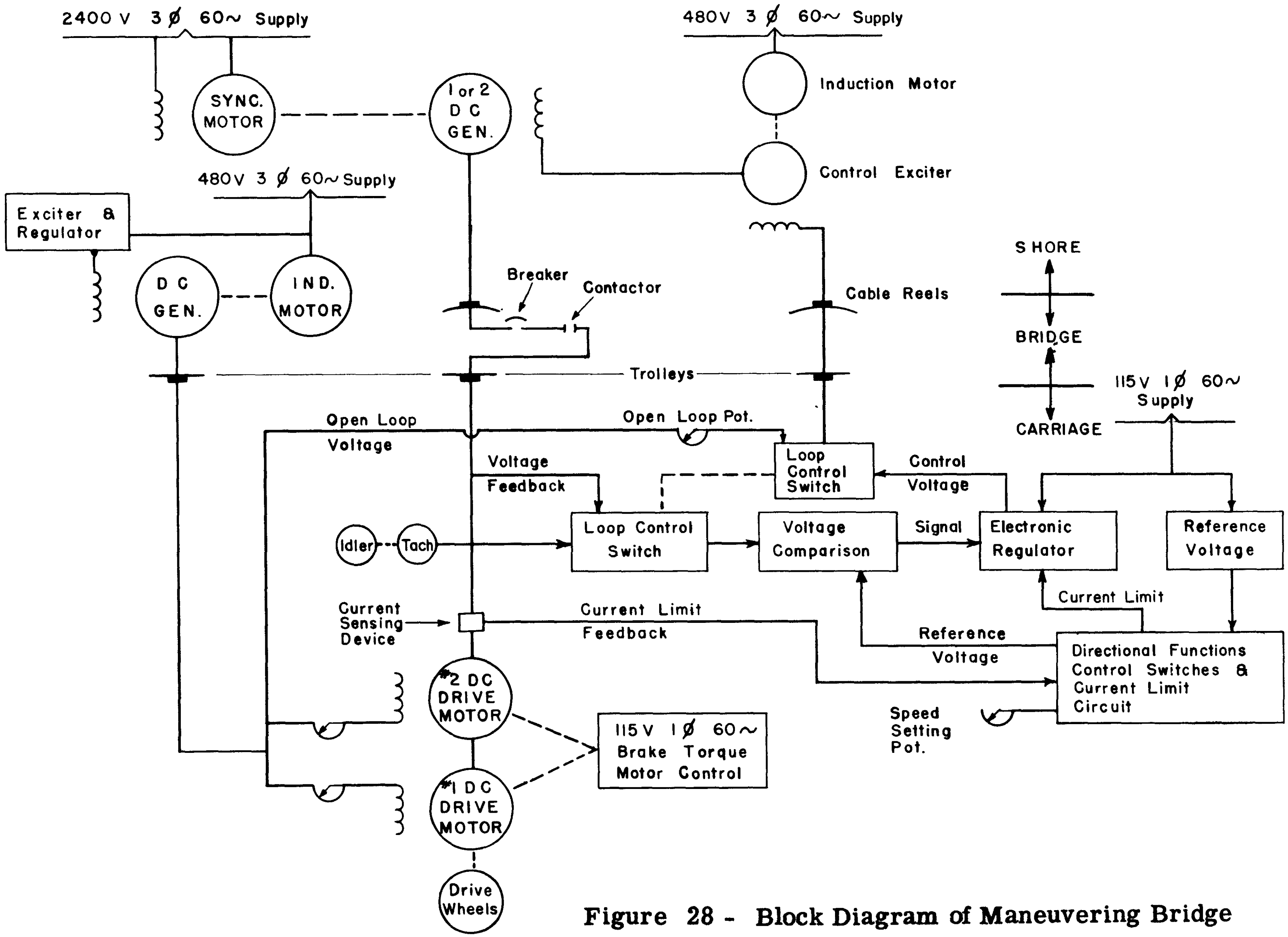
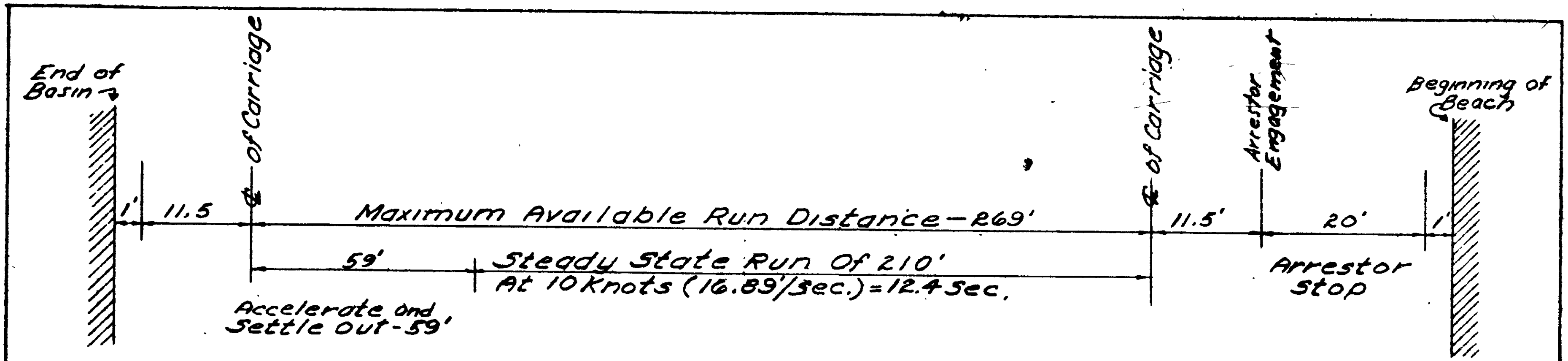


Figure 28 - Block Diagram of Maneuvering Bridge Carriage Drive



Conditions

Carriage speed	10 knots (16.89'/sec.
Gear ratio	8.25 to 1
Wheel rolling radius	10.8"
Gear input speed	1474 RPM
Peak tractive effort at drive wheels (instantaneous - including current limit overshoot)	17,500 lbs.
Min. average acceleration	0.4g
Drive system inertia (excluding motor & brakes) at motor shafts	23.2 # ft²
Total carriage wt. based on electrical equipment wt. of 8500# (including model weight of 1000#)	28,500#
Model Wt	- 1000#
Keeper wheel friction (at 10 Knots)	30# (.93 H.P)
Windage (at 10 knots)	45# (1.39 H.P)
Model drag (at 10 knots)	200# (6.2 H.P)

Duty Cycle

Test run	Accelerate & settle out—4.3 Sec, 59' Run at 16.89'/sec.——12.4 Sec, 210' Arrestor stop
Return trip	Acceleration, settling out and running time not critical. Maximum would approximate test run. Stop by regenerative braking
Down	As required by the thermal capacity of the drive motors as long as total duty cycle does not exceed 10 minutes.

Figure 29 - Maneuvering Bridge Carrigage Drive Operating Condition #1 - 10 Knot Test

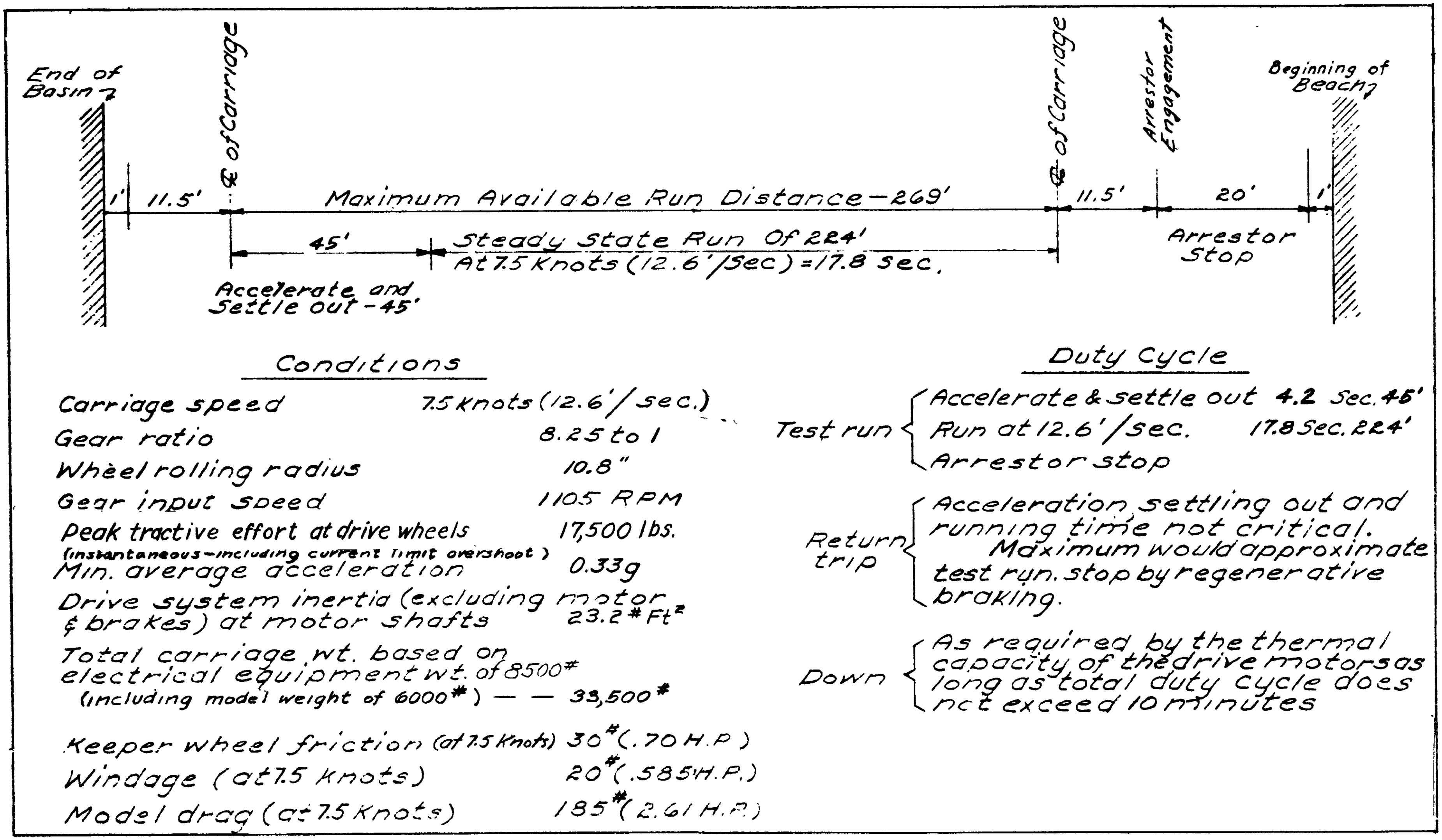


Figure 30 - Maneuvering Bridge Carriage Drive Operating Condition 2 - 7.5-Knot Test

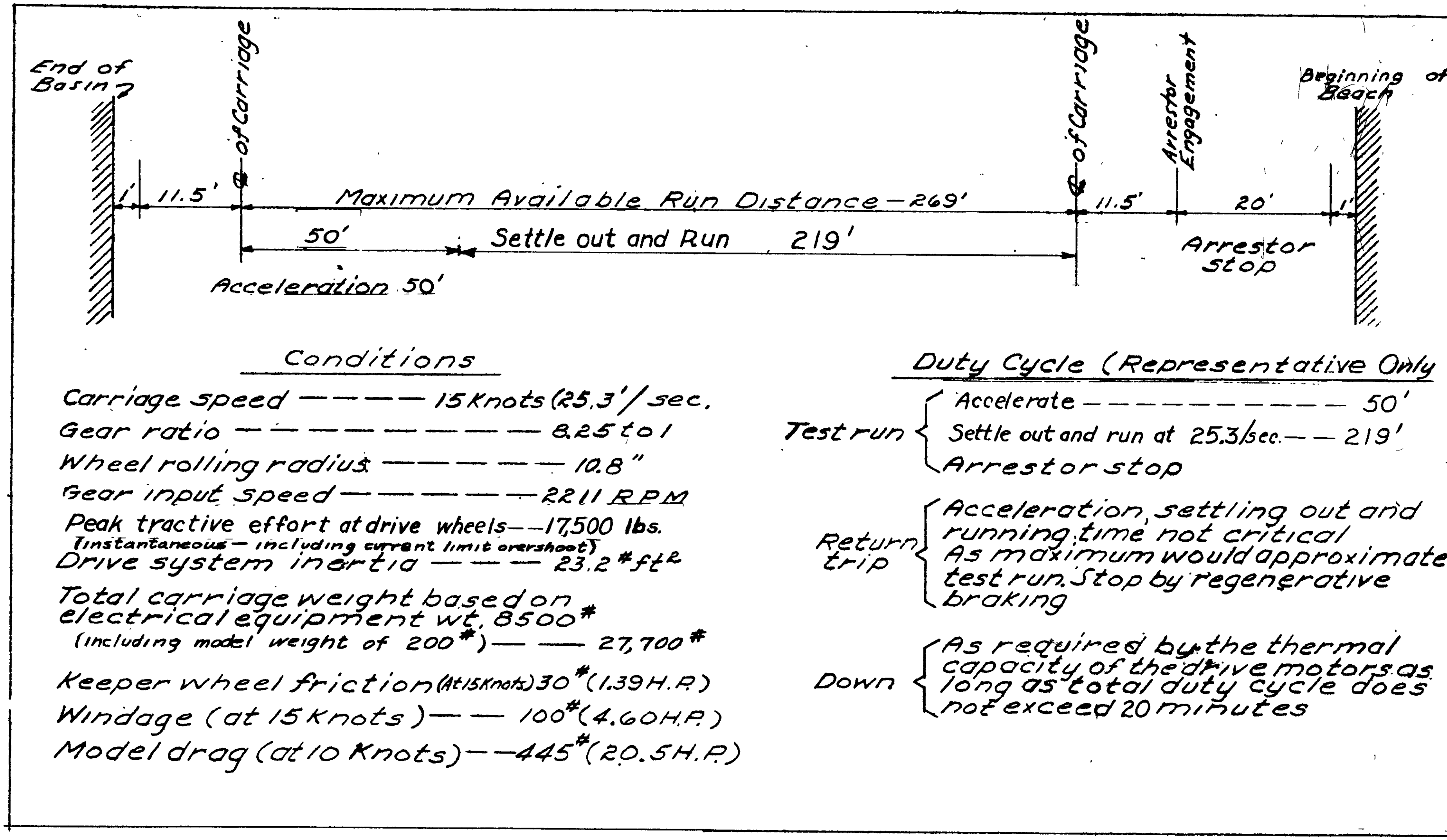


Figure 31 - Maneuvering Bridge Carriage Drive Operating Condition #3 - 15 Knot Test

TROLLEY & FEEDER SCHEDULE

Trolley			Feeder		
No.	Description	Collector Type	Conduit Size	Wire Qty.-Size	Wire Insulation
1	Space				
2	"				
3	"				
4	"				
5	"				
6	Spare	D-B06H			
7	"	"			
8	"	"			
9	"	"			
10	Carriage drive c.b. control	"			
11	"	"	1¼"	11#10	600V.
12	"	"			
13	"	"			
14	"	"			
15	"	"			
16	"	"			
17	Spare	"			
18	"	"			
19	Model power feedback	"			
20	" " "	"			
21	" " "	"			
22	" " "	"			
23	" " "	"	1¼"	11-#10	600V
24	" " "	"			
25	Carriage drive feedback	"			
26	" " "	"			
27	" " "	"			
28	Carriage drive armature	*			
29	" " "	None	2½"	4#2/0	1000V.
30	" " "	*			
31	Spare	*			
32	Model power armature	D-B06H	1¼"	2#2	600V.
33	" " "	"			
34	" " "	"	1¼"	2#2	600V.
35	" " "	"			
36	Carriage drive field	"	¾"	2#10	600V.
37	" " "	"			
38	Model power fields	"	¾"	2#10	600V.
39	" " "	"			
40	Spare	"			
41	"	"	¾"	3#10	600V.
42	"	"			
43	Regulated AC	"			
44	" "	"	1¼"	3#2	600V.
45	" "	"			
46	125V. D.C. Station Battery	"	¾"	2#10	600V.
47	" " " "	"			
48	400 cycle supply	"	¾"	2#8	600V.
49	" " "	"			

* D-T15H collector with insulated mounting

Figure 32 - Maneuvering Bridge Carriage Trolley and Feeder Schedule

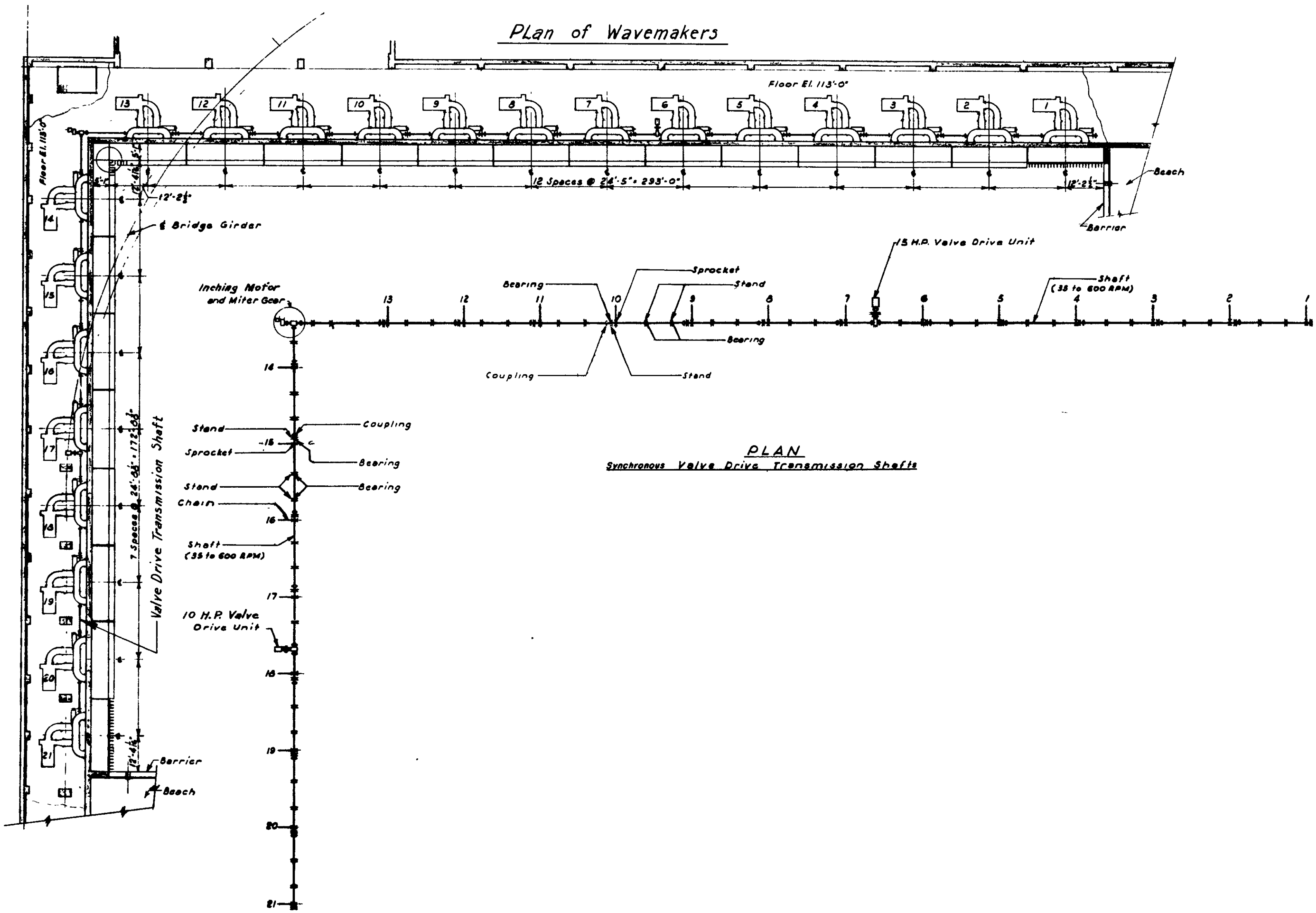


Figure 33 - General Arrangement of Wavemakers

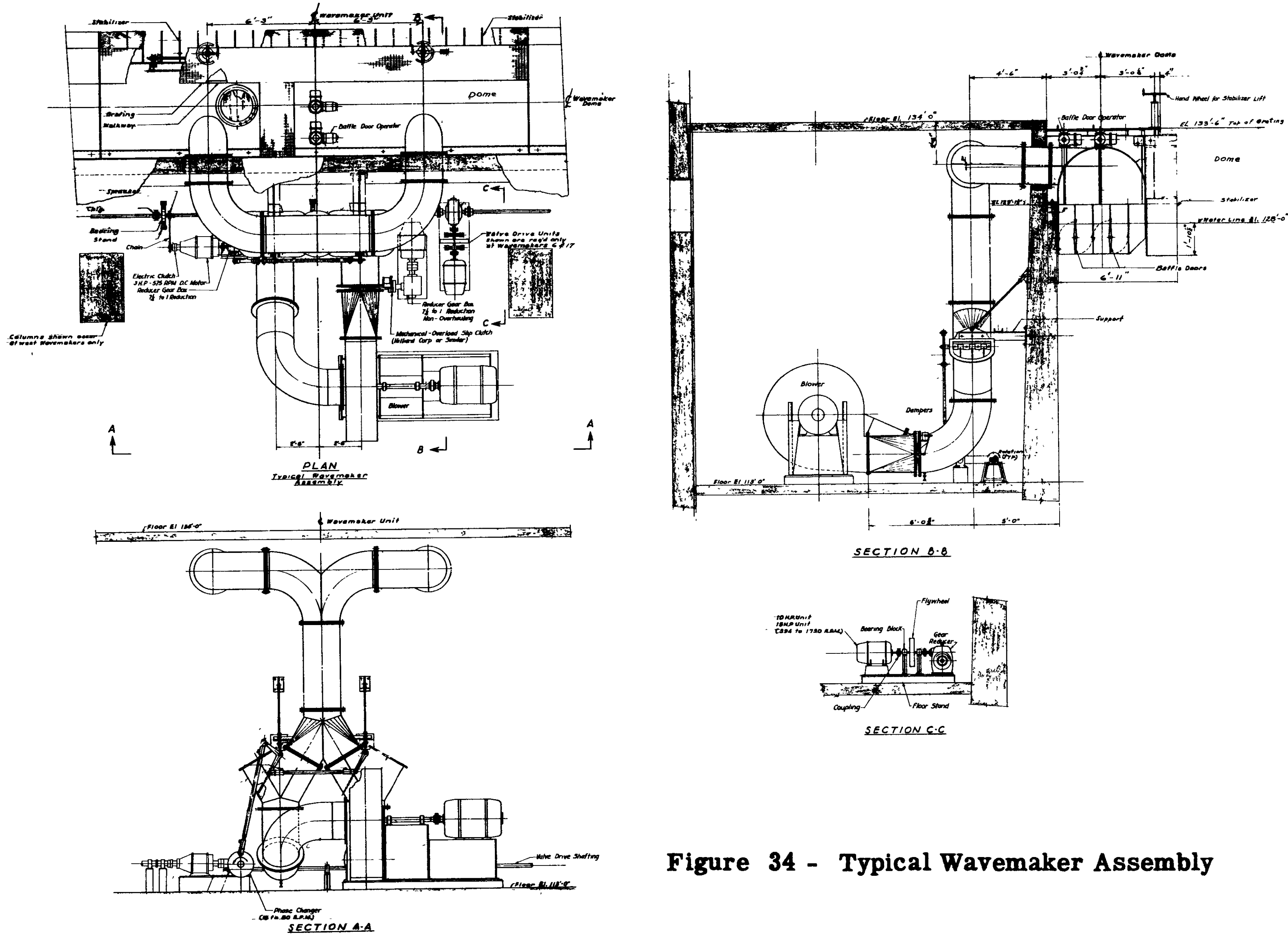


Figure 34 - Typical Wavemaker Assembly

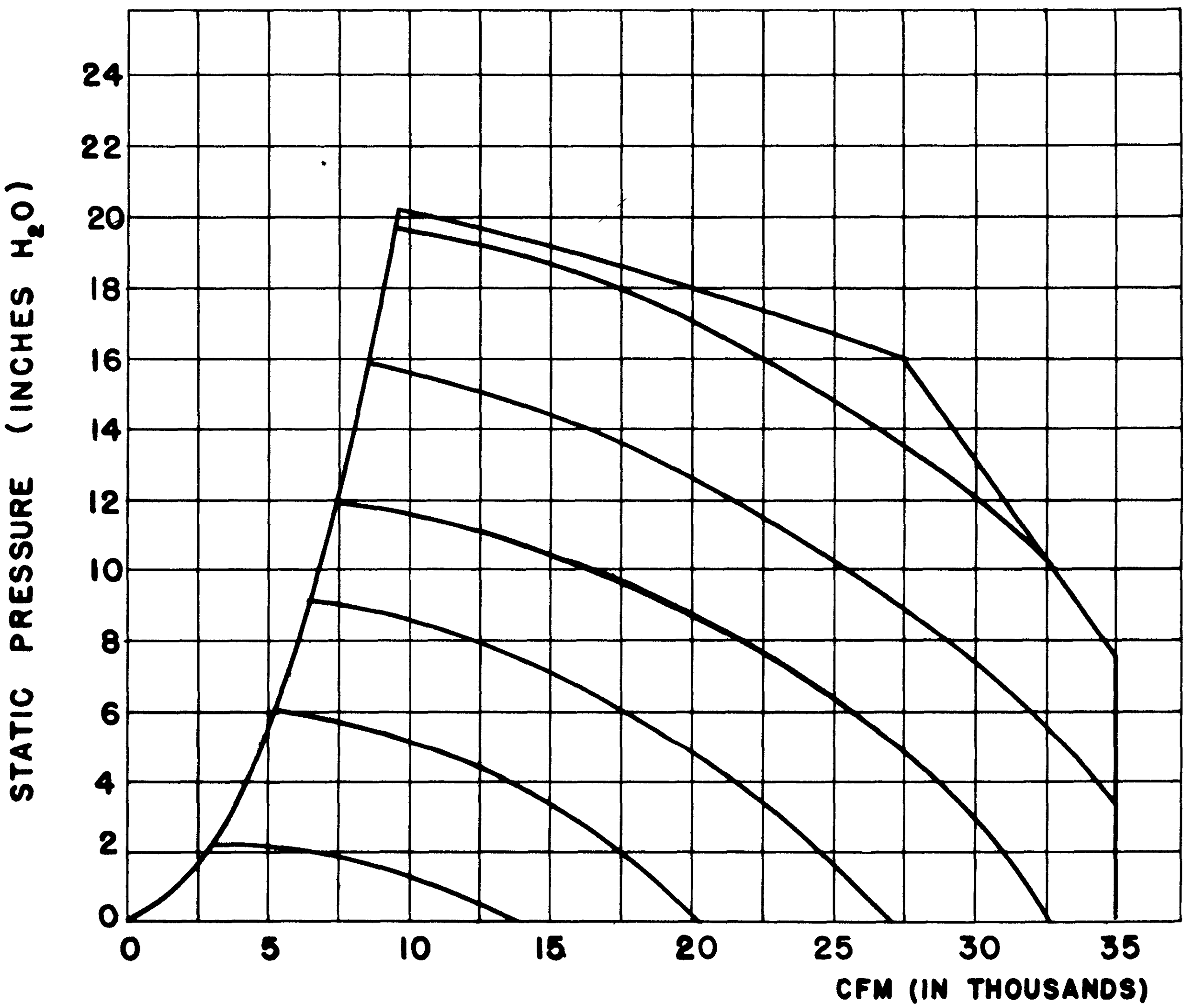


Figure 35 - Wave maker Blower Head - cfm Envelope

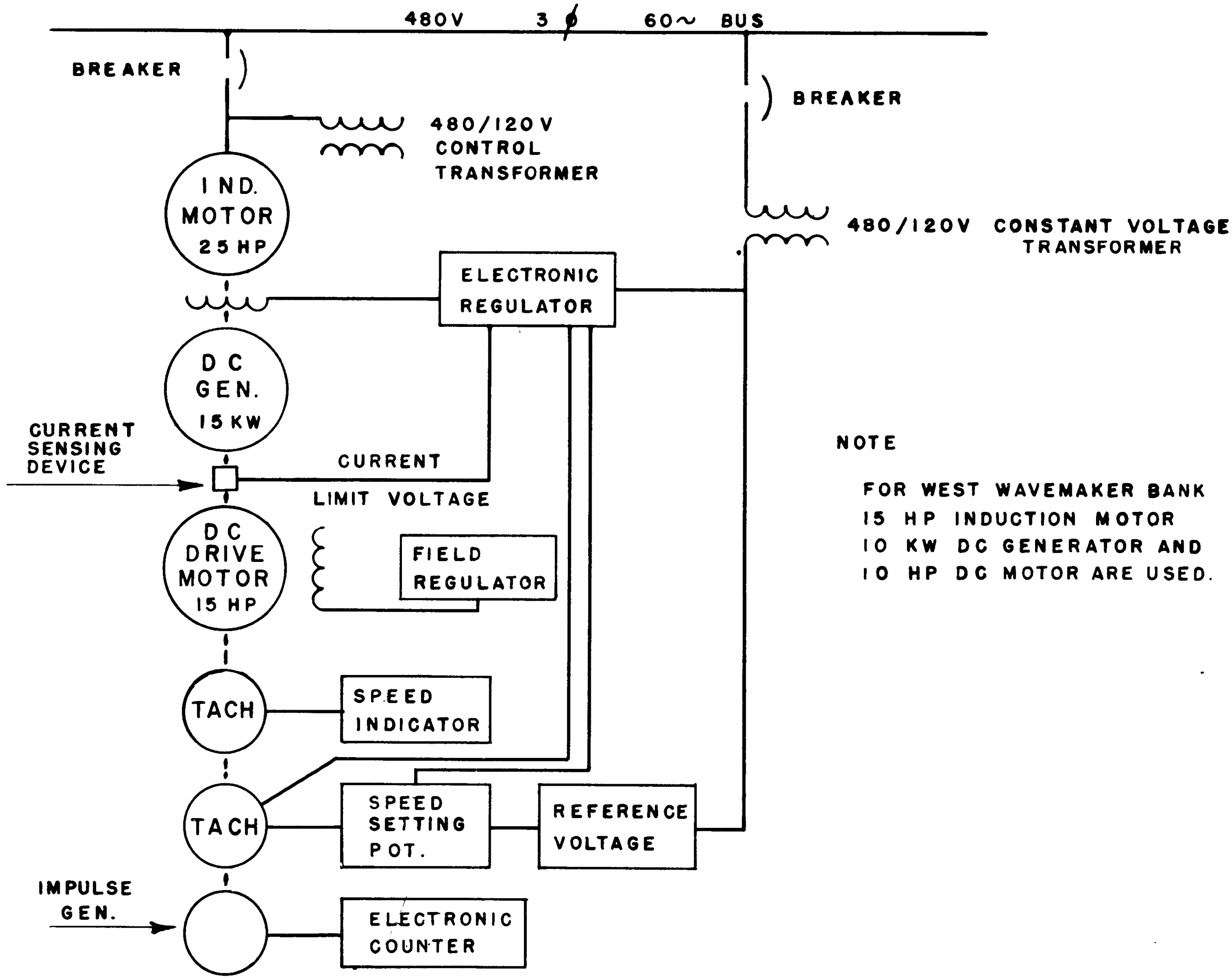


Figure 36 - Block Diagram of Wavemaker Valve Drive System

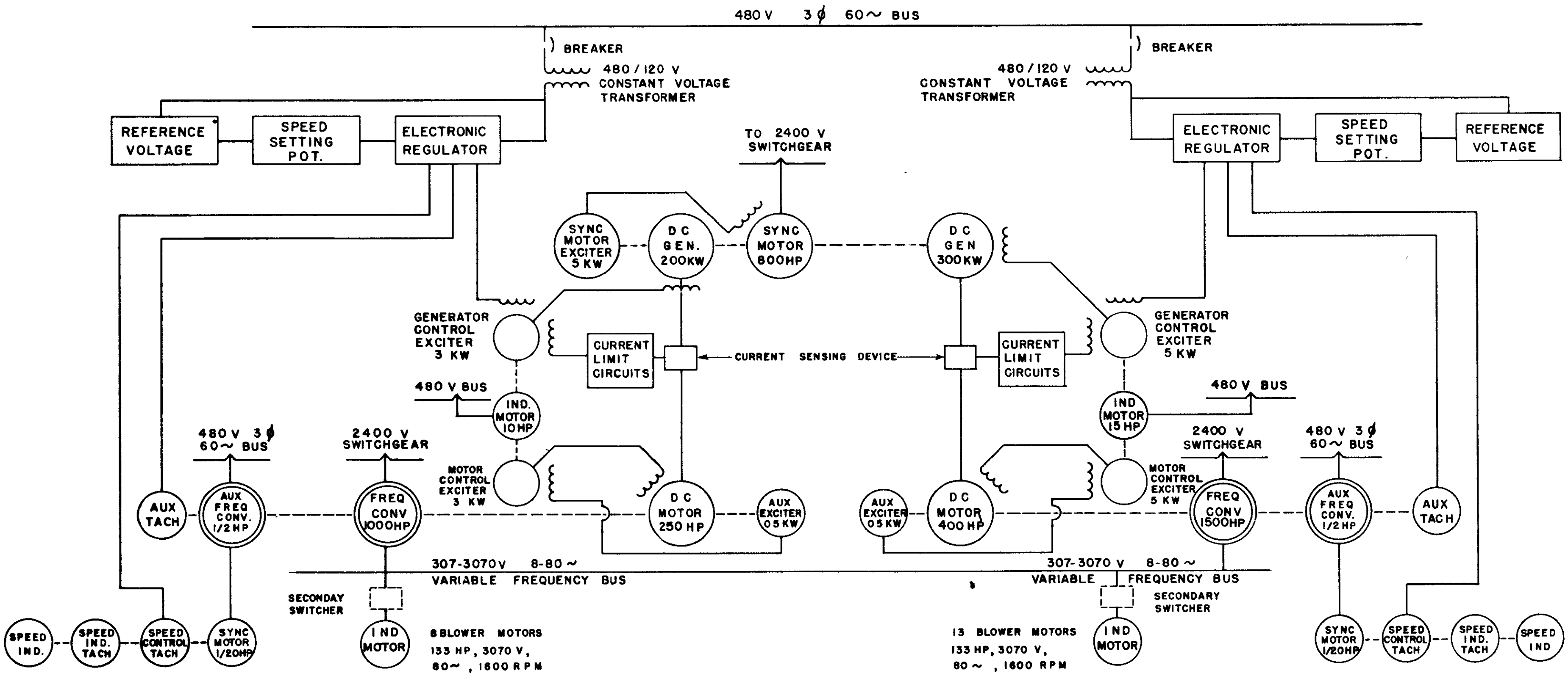


Figure 37 - Block Diagram of Blower Drive System

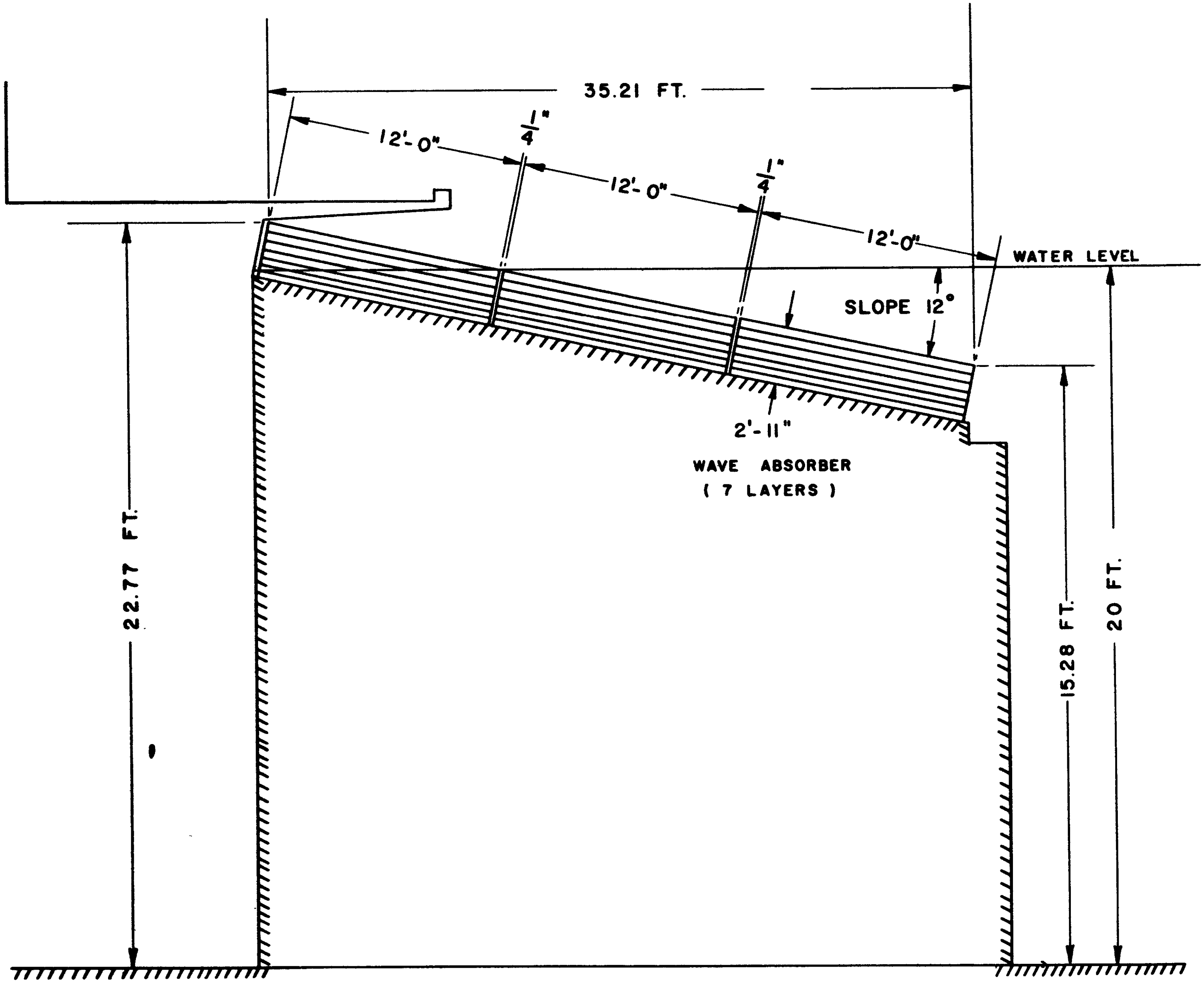


Figure 38 - Maneuvering Basin Wave Absorber

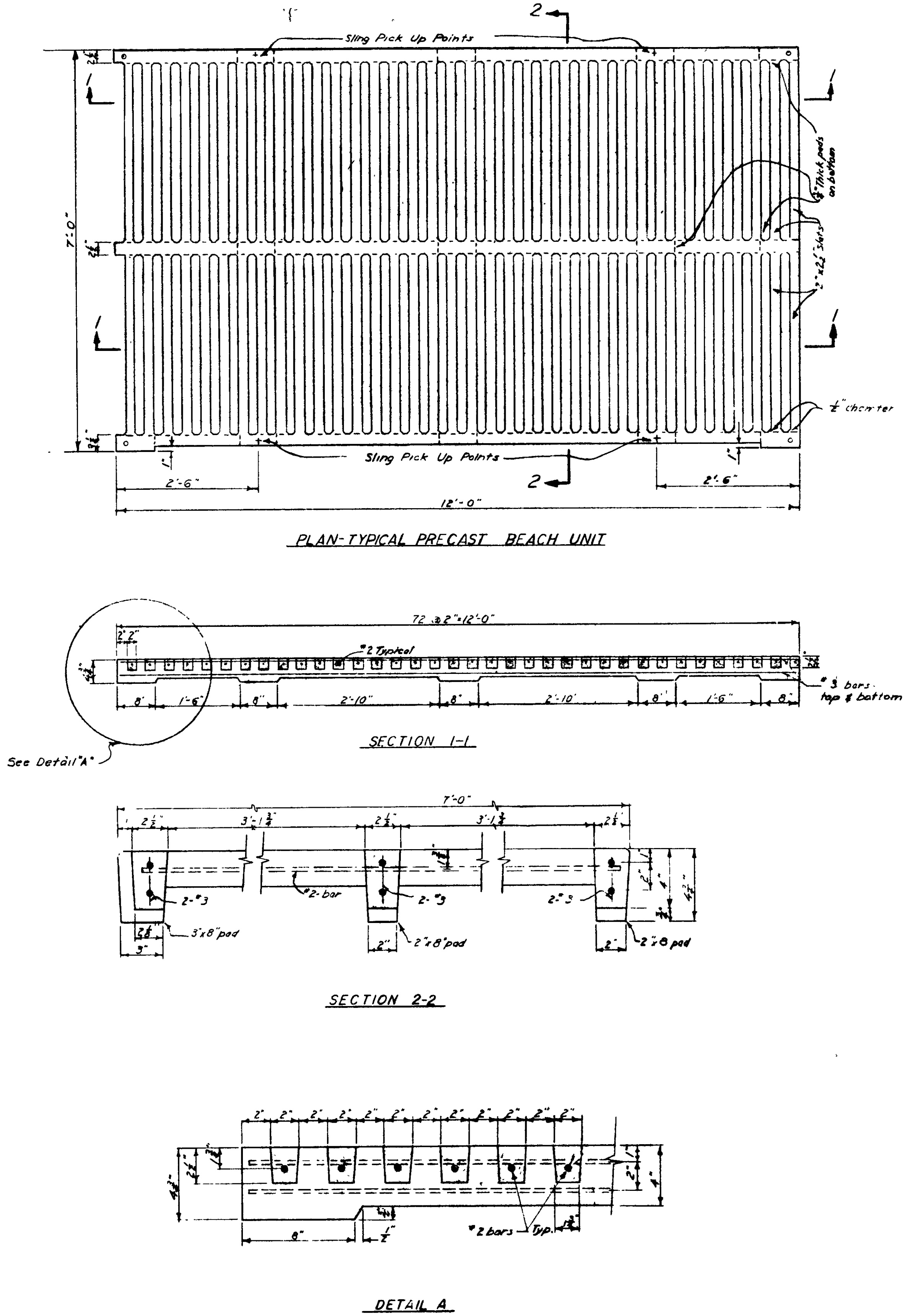


Figure 39 - Details of Typical Precast Maneuvering Basin Wave Absorber

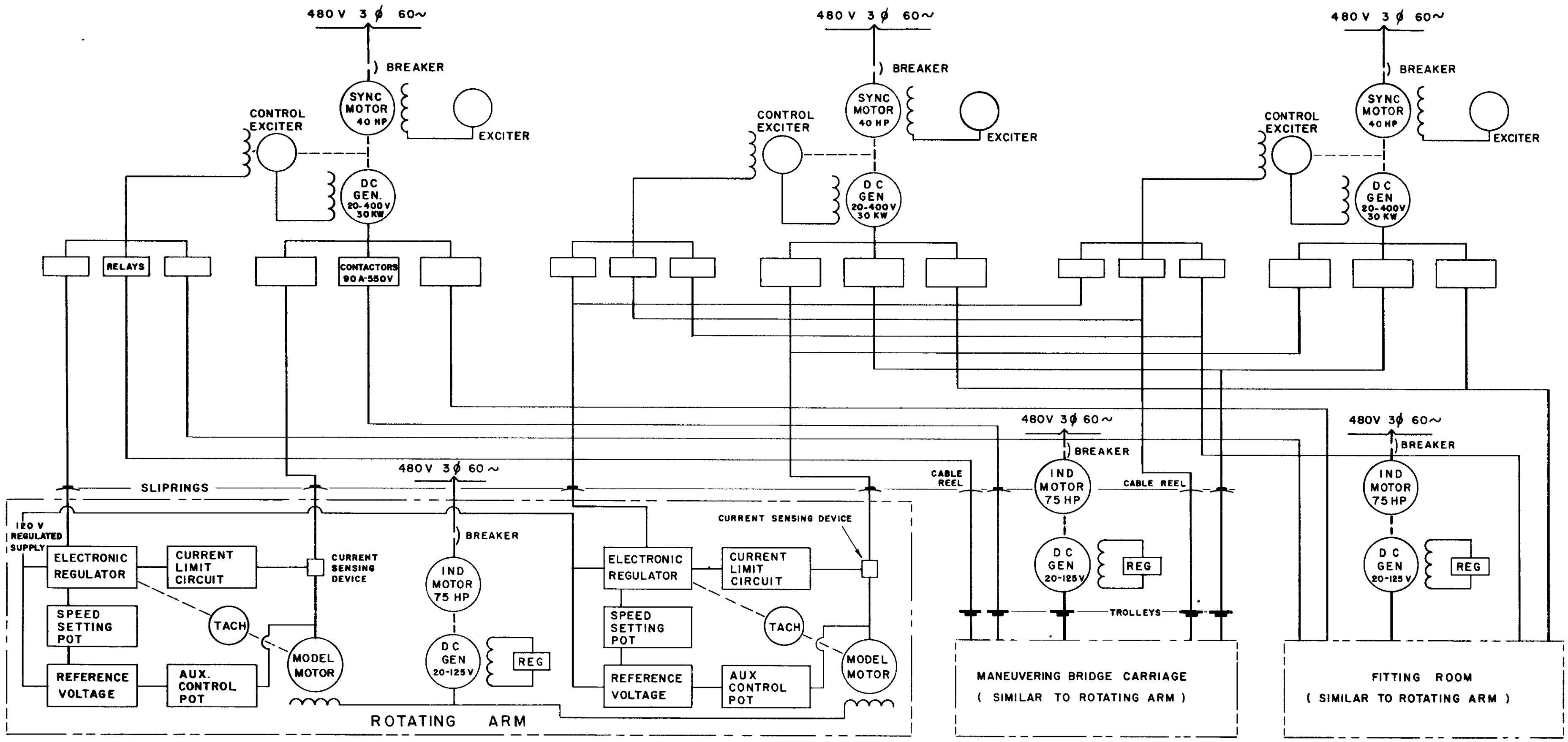


Figure 40 - Block Diagram of the Model Power Supply Systems