HYD 4

HYDRAULICS BRANCH
OFFICIAL FILE COPY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

- - -

HYDRAULIC LABORATORY REPORT NO. 4

- - -

THE HYDRAULIC LABORATORY

OF THE R. ISTITUTO SUPERIORE DI INGEGNERIA DI PADOVA, AND RESEARCH WORK DONE THERE BY DR. ENG. PROF. ETTORE SCIMEMI, DIRECTOR OF THE HYDRAULIC INSTITUTE

By

F. L. PANUZIO, JR. ENGINEER

- - -

Denver, Colorado

U.S.B.R. TRANSLATION No. 128

HYD 4

X

L'ENERGIA ELETTRICA, SEPTEMBER 1935.

HYD4

REVIEW OF:-

THE HYDRAULIC LABORATORY OF THE R. ISTITUTO SUPERIORE DI INGEGNERIA DI PADOVA, AND RESEARCH WORK DONE THERE.

BY

BY DR. ENG. PROF. ETTORE SCIMEMI,
DIRECTOR OF THE HYDRAULIC INSTITUTE.

1. Generalities Concerning the Hydraulic Layout.

An hydraulic laboratory connected to an Engineering Institution must satisfy (as with other subjects of university character) two essential purposes:-- that of instruction and that of research which can be of a scientific, technical, or industrial character.

For instruction purposes a large number of experiments are used to demonstrate clearly to student engineers correct methods of measuring and the principal hydraulic phenomena that are basic in an hydraulic course. The physical meaning of many theoretical relationships is easily understood, yet for other relationships one must call on his experience as a partial or complete substitute for direct observation of the phenomena being studied. Thus it is possible to make courses purely theoretical or purely lectures without recourse to direct experience except for reference to coefficients, since most hydraulic phenomena are generally known.

So hydraulics with its famous traditions, particularly in the experimental field, has only in the past decade been considered indispensible in the experimental plant of an institute of higher education.

Scientific progress can not be otherwise than favorable to laboratories when one realizes that a large number of discoveries have been concieved and developed by experiments in laboratories.

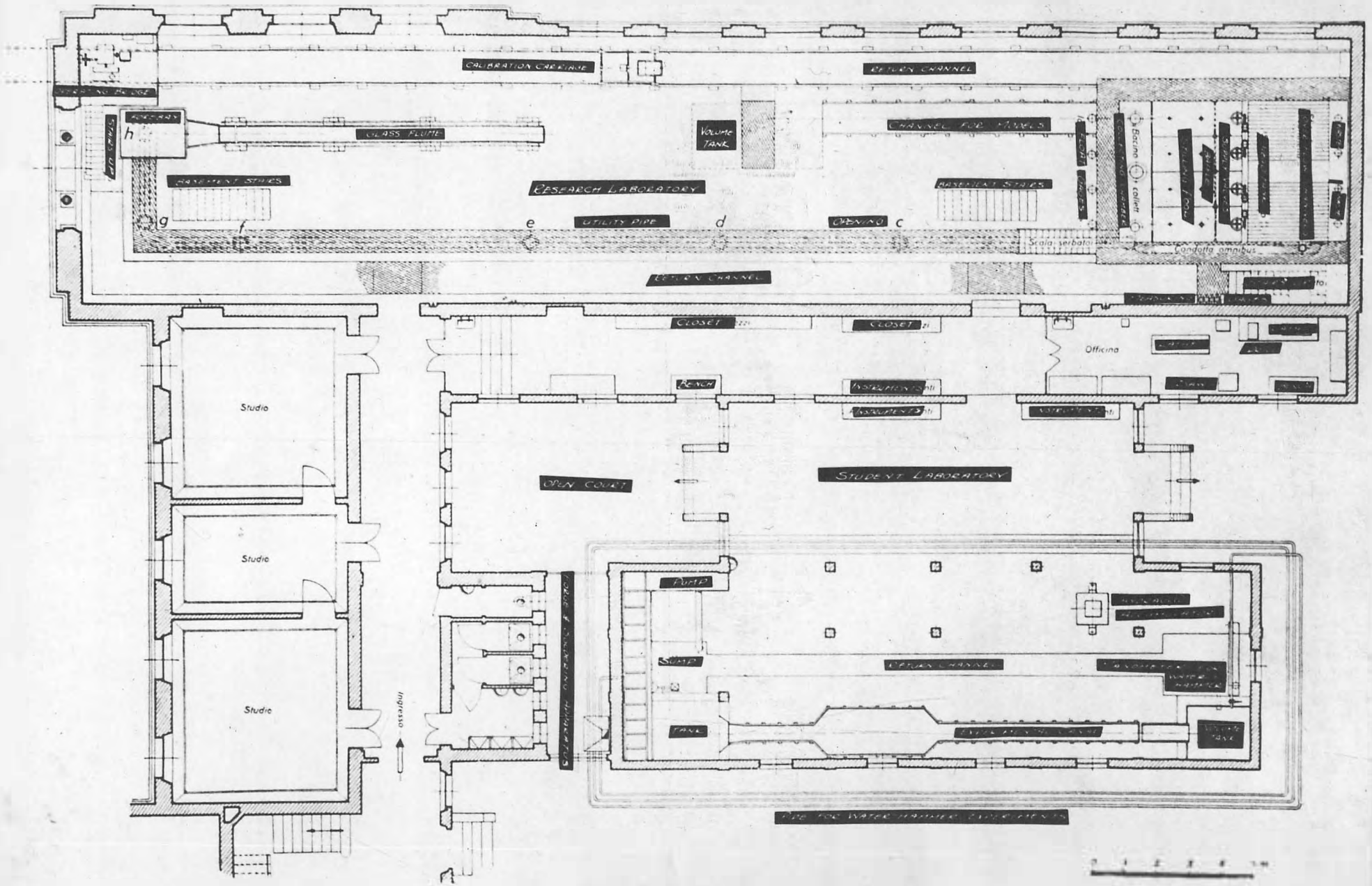
Finally in the field of practical application, one can not be certain of the economics of a plan for a large hydraulic works without the assistance of a laboratory where several solutions can be easily evaluated and compared. Thus the answer of the laboratory is often the deciding factor in the problem.

Before giving a description of the newly constructed buildings, let us review the history of hydraulics at the institute. With the passing of the law 22-XII, 1910, the Water Commissioner of the provinces of Veneta and Mantova authorized the construction of a large university building destined to house the instruction of hydraulics and its specialized fields. A similar 3-story building was constructed in 1914 (Fig. 1, 2, & 3) in which are found instruction in general experimental hydraulics, technical hydraulics, agricultural hydraulics, marine and fluvial construction, and hydro-electric plants.

These buildings house lecture halls, class rooms, a museum of instruments and models. The library, quite large, which was at first the property of the hydraulic institution is to-day incorporated in the central library of the university except for a small part which is constantly used for instruction and in experimental work and which is still housed in the hydraulic school.

The new laboratory was constructed in 1930 (Fig. 4, 5, & 6) with the full approval of the commissioner of the higher institution of engineering. This laboratory, through contributions, was built without any special expense to the state, in a relatively short time, and with proportions which, even though not sumptuous, are larger than those of any other Italian laboratory and larger than most foreign laboratories.

The factors that define the potentialities of an hydraulic laboratory may be summarized in the maximum capacity of water that can be put into circulation and in the available head room and in other factors that are closely connected to the dimensions of the building for it would


CALIBRATION CHANNEL
RETURN CHANNEL
GLASS FLUME
VOLUME TANK
CHANNEL FOR MODELS
BASEMENT STAIRS
RESEARCH LABORATORY
BASEMENT STAIRS
UTILITY PIPE
OPENING
Bacino collett
Condotta omnibus
RETURN CHANNEL
CLOSET
CLOSET
Officina
BENCH
Studio
Studio
Studio
OPEN COURT
STUDENT LABORATORY
PUMP
SUMP
RETURN CHANNEL
TANK
PIPE FOR WATER HAMMER EXPERIMENTS
INGRESSO

TAV. I

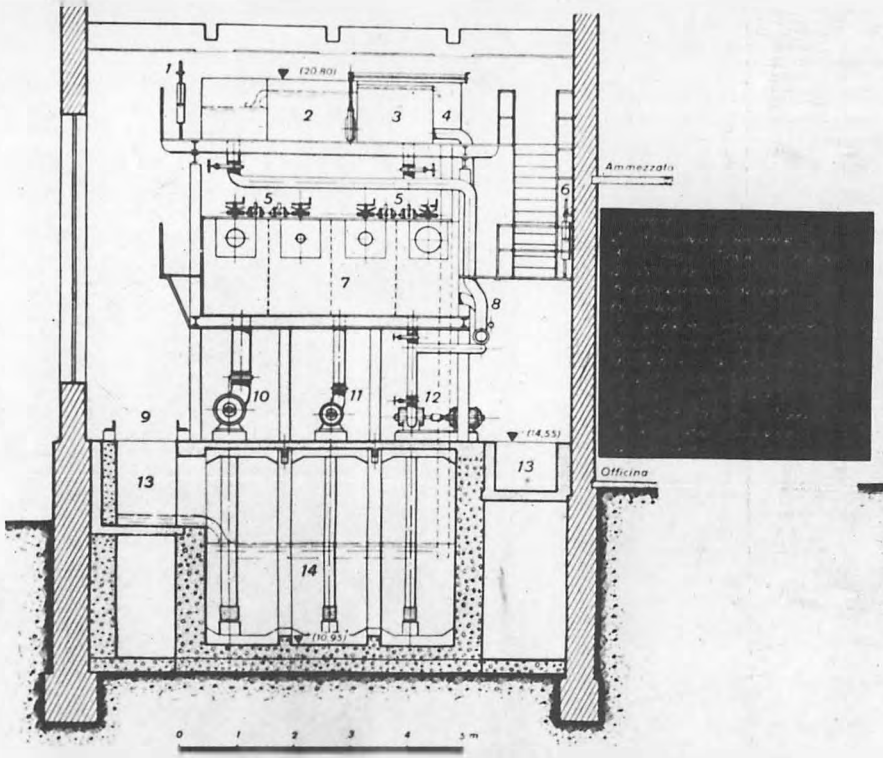


Fig. 4 [redacted]

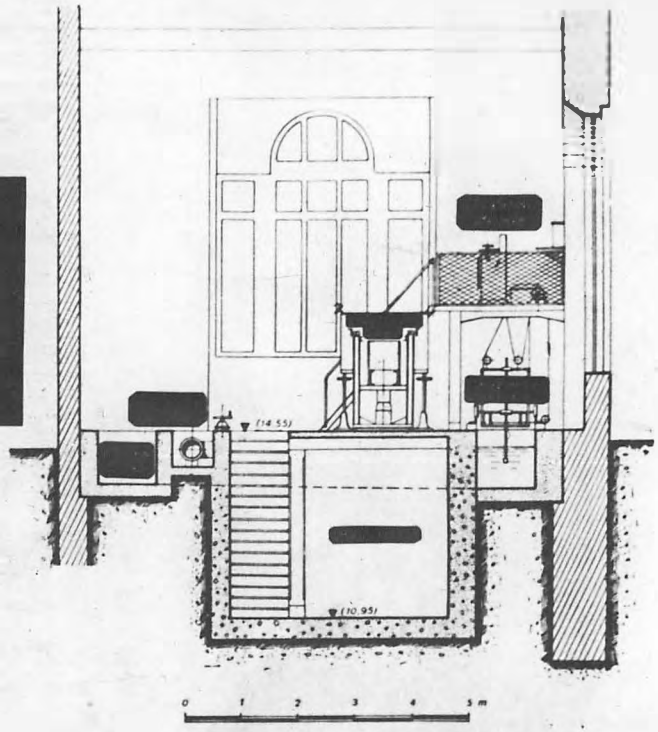


Fig. 2 [redacted]

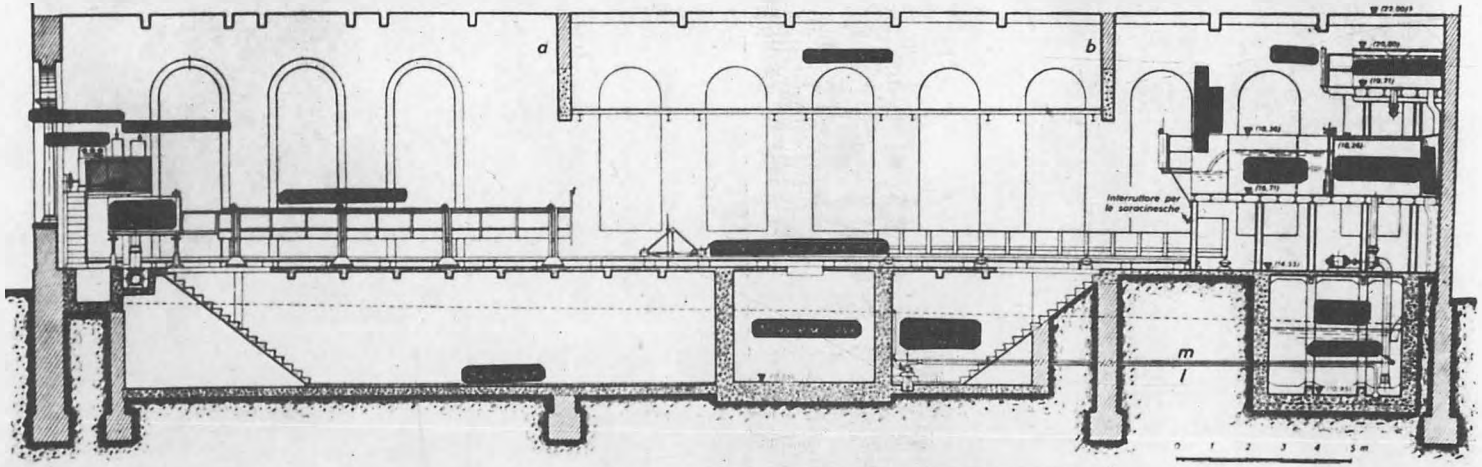


Fig. 5 [redacted]

be impossible to put into circulation a large mass of water unless one has reservoirs and canals of sufficient capacity for the conditions of movement, of measurement, and of storage of this capacity.

The maximum capacity of the laboratory was fixed at 400 liters/sec. (14.1 cfs.) which naturally is not continually renewed but only put into circulation by means of pumps. The maximum free head room in the building is 7 meters (23 ff.) diminished by the necessary heights of head and stilling tanks so the clear heads from the floor of laboratory range between 3.71 to 6.25 meters (12.2 to 20.5 ff.). The proportions of the pumps are such that a flow of 400 liter/sec. (14.1 cfs.) can be circulated against a 3.71 m. (12.2 ft.) head, and of 100 liter/sec. (3.5 cfs.) against a 6.25 M. (20.5 ft.) head. With this set up it is possible to experiment regularly with 400 liter/sec. (14.1 cfs.) (Fig. 5 & 6).

2. <u>The metal tanks.</u>

The storage tanks are built of sheet metal 5 mm (.195 in) thick and electric welded. There are three storage or supply and head tanks - namely the sunken tank in floor with the bottom elevation at 10.95 m. (35.9 ft.) and the top elevation at 14.55 m. (47.7 ft.) (floor level) from which the supply of the other two tanks is obtained by means of one of four sets of pumps; the intermediate tank with the bottom elevation at 16.71 m. (57.8 ft.) and the top elevation at 18.36 m. (60.2 ft.) ; and the ceiling tank with bottom elevation at 19.71 m. (64.6 ft.) and top elevation at 20.80 m. (68.2 ft.). Wasteway channels (skimming weirs) are placed in the intermediate and ceiling tanks at elevations 18.26 and 20.70 m. (59.9 and 67.8 ft.) respectively so that the water surface will under no condition reach the top elevations of 18.36 and 20.80 m. (60.2 and 68.2 ft.) respectively. This safety factor is necessary in a laboratory where a false movement may often happen.

These waste-way channels (skimming weirs) are of the ordinary type consisting of many small channels and these channels are of such capacity that they discharge the maximum quantity to be handled with a head of 2 cm. on the skimming weir crests. In general however, the waste water is limited to a moderate percentage of the quantity in circulation, so that there is a head of only 2 or 3 mm. on the spillway crest of the waste channels. The wasting of water is continued so that the supply taps at the front of the head tank always give a constant discharge. This condition is naturally indispensible to insure that during a run there will be no change in the circulating discharge due to variations in the feed of the pump.

There are four taps from the intermediate tank. The control valves are of the cast iron-brass, low pressure type of 300 mm. (11.8 in.) in diameter. They are installed on the front wall of the supply tank with the bottom of the valves at bottom of the tank. They discharge into four stilling reservoirs which are identical in dimension, and which are adjacent to each other but which are not interconnected; for each channel there is a measuring weir. Dividing the source of supply into four parts has the big advantage of permitting the use of only one division for experiments needing a small discharge, and further has the advantage that when needing greater discharge, its measurement is divided among the four measuring weirs that are rated independently of one another. The discharge measured over each weir falls into the collecting channel from the bottom of which the discharge is carried directly through the experiment. In this channel the head varies from elevation 17.78 m. to 16.71 m. (58.3 to 54.8 ft.) for minimum to maximum discharges. In the stilling basin (Fig. 4) there are placed baffles, upstream from the rated weirs, and the piezometer connections in the floor, which are connected to the gage wells in which are measured the head of water on the weirs. Another row of piezometer connections (1" diameter) make

possible a reading of the head on the weirs with a float gage that is visible from any point in the laboratory.

Some of the gages are attached to small glass wells that are attached to the wall of the building. The water readings are free of oscillations, in any case such oscillations can be dampened by a by-pass that restricts the passage to the gage wells.

In the ceiling tank (Fig. 5 & 6) the wastewsy and measuring weir are similar to those of the intermediate tank, although its capacity is only 100 liter/sec. (3.5 c.f.s.); it was not necessary to divide the stilling reservoir, although the flow from the supply tank is through four valves of 225 mm. (8.85 in.) diameters. The measuring weir is connected to a gage well.

Therefore the intermediate tank is the one most frequently used. A word should be said concerning the movement of the pressure valves which are controlled electrically from a position on the lower floor. From the position of the pumps, it is possible to manipulate the pressure valves while observing the head on the weir by means of the float gages (Fig. 5-8). A large number of experiments have thus been made without going to the balcony around the intermediate tank. But it is not possible to get data from the float gage-- the determination of the head on the weir always has to be made with the point gages on the wall of the balcony. Balconies surround both the intermediate and the ceiling tanks and are reached by stairways.

3. <u>The utility supply pipe.</u>

Not only the intermediate but also the ceiling reservoirs furnish water to experiments only as measured by the rated weirs, but to furnish contemporaneously various discharges or else discharges at other points not in the near vicinity of the elevated reservoirs, a utility conduit is used. The conduit starts at the supply reservoir of the intermediate tank and after a short horizontal stretch drops into and travels in a rectangular channel flush with the floor, which extends the full length

of the laboratory. The conduit, 300 mm. (11.8 in.) diameter, is of metal and is provided with many outlets that are closed off with blind flanges or valves. Thus it is possible to supply any point in the laboratory with a maximum head corresponding to the elevation of the wasteway of the intermediate channel. Furthermore the utility conduit has a valve at its entrance to the intermediate tank, while just below this point is connected a vertical conduit leading to the supply chamber of the ceiling reservoir so that closing the valve at the intermediate tank and opening that at the ceiling reservoir, the utility conduit furnishes the laboratory with a head corresponding to the head in the ceiling reservoir.

Measurement of the flow through the utility conduit is not generally required because usually it is desirable to measure the discharge through each experiment, but since the flow is equally constant along the hanging horizontal stretch, there are installed, under pressure, a Venturi tube and a pilot tube. The former, of 90 mm. (3.5 in.) diameter is installed in a conduit by-pass and measures flows up to 15 liters/sec. (.5 c.f.s.); the latter is placed in the conduit proper and measures flows up to 350 liters/sec. (12.3 c.f.s.).

4. Pumping equipment.

The laboratory pumps (Fig. 6-8) are able to deliver 400 liters/sec. (14.1 c.f.s.) to the intermediate reservoir and 100 liters/sec. (3.5 c.f.s.) to the ceiling reservoir, these flows to be obtained by a combination of pumps divided as follows:

1 pump 25 l/s at 8 m head - 7 HP - .9 c.f.s. at 26 ft. hd.

1 pump 75 l/s at 8 m head - 16 HP - 2.6 c.f.s. at 26 ft. hd.

1 pump 100 l/s at 5 m head - 16 HP - 3.5 c.f.s. at 16 ft. hd.

1 pump 200 l/s at 5 m head - 25 HP - 7.1 c.f.s. at 16 ft. hd.

While all pumps are of the proper capacity to function for the intermediate reservoir, only the first two are of the proper capacity to pump

to the ceiling reservoir. On the other hand all the pumps drawing from the reservoir below the floor level are able to pump water directly into the intermediate reservoir, thereby discharging together 400 liters/sec. (14.1 c.f.s.). The discharge pipes of the first two pumps form a "V" with valves, the operation of which sends the flow to the ceiling reservoir instead of to the intermediate reservoir.

The division of the discharge for the pumps were so proportioned for maximum usefulness, because while an installation of such completeness is used in relatively rare cases, nevertheless it is essential. At least 50% of the experiments happen in a range of 25 to 50 liters per sec.(.9 to 1.8 c.f.s.).

The pumps are of the centrifugal type and were given to the laboratory by Societa Costruzioni Meccaniche Riva di Milano. The assembled motors are Pellizzari of three phase 220 volt BEW type with automatic starters.

There is also another group of electric pumps at the research laboratory; one is fixed and will be explained in the following paragraph, and the other is mounted on a two wheeled carriage, and has flexible rubber suction and discharge pipes and is used for supplying discharges up to 10 liters per sec. (.35 c.f.s.) with a 10 meter (33 ft.) head for experiments in special cases.

5. <u>The supply and circulation of water (Fig. 1-5).</u>

The water supply comes from the city accueducts through the medium of ordinary stop cocks that discharge into the lower, middle, and upper tanks. In 12 hours there is obtained a sufficient supply of water in the three tanks so that the laboratory is ready to function. Both upper tanks empty into the tank below the floor level, but this tank can not be emptied directly through the waste channel, which is at an elevation higher than the bottom of the lower tank. Therefore it is necessary to do some pumping; this pumping is done with a motor pump installed below the floor of the laboratory.

6. Calibration of weirs and measurement of discharges (Fig. 4,5,&11).

A complicated problem that is encountered in the functioning of a laboratory is the measurement of discharges; some times this measurement may be made only approximately which in the majority of cases is sufficiently accurate for industrial use, and yet often one is confronted with the need for measurements of the greatest precision. The laboratory as described, insures the constancy of the discharge for when the head chambers are full to the elevation of the waste weirs and the gates are open, the waste weirs waste excess water over the top into the collecting waste channels, for a constant discharge cannot be obtained if the head on the supply weir varies. As to the type of weir, we have finally adopted some triangular weirs having an opening of 90° and some circular weirs of diameters 400, 300, 200, and 100 mm. (15.7, 11.8, 7.9 and 3.9 in.). The triangular weirs, as noted, give measure of small discharges with sufficient accuracy but with increase of head the discharge increase to such an extent that small errors in reading the head give appreciable error in the discharge. The same defect exists in the rectangular weirs. The circular weirs give the best measure for a limited range from not too small heads to heads equal to the diameter of the weir. A circular weir of 400 mm. (15.7 in.) with a head equal to the diameter gives a discharge of about 100 liters/sec. (3.5 c.f.s.). Four weirs of 400 mm. (15.7") diameter placed respectively in the four stilling channels of the intermediate reservoir give therefore at our laboratory the maximum discharge of 400 liters/sec. (14.1 c.f.s.). Further the plates from which all the measuring weirs of the laboratory are cut are also interchangeable and therefore give all the desired possibilities for combining changes in the diameter of the weir with the discharge. The plates for all the weirs are pieces of brass (.75 x .75 m., 30 x 30 in.) and 5 mm. (.195 in.) thick; the circular weirs are turned out on a lathe in order to obtain the maximum precision of shape for each weir, and a sharp upstream edge of the crest, which is difficult to obtain in other

types of weir. Since the four stilling basins of the intermediate tank are exactly similar with respect to the supply basin one will find the same calibration for weirs similarly placed in the stilling basin, so that it is sufficient to calibrate only one series of weirs to obtain the calibrations for all the others similarly located.

In calibrations, besides the accurate reading of the head, which will be discussed under the heading of instruments, the measure of discharge is wanted, for which purpose there is the large measuring tank below the floor level of the laboratory.

This tank, which is of concrete, was built exactly rectangular (4 x 2 m) (13.2 x 6.6 ft.) and has a useful depth of 3 m (9.9 ft.), the capacity is therefore 24 m^3 (850 cu. ft.). Since the maximum discharge to be measured for each weir to be calibrated is 100 liters/sec. (3.5 c.f.s.) it is apparent that 240 seconds are necessary in order to completely fill the subterranean tank. Therefore, since the reading of time can be obtained to 1/5 of second, the measure of the discharge can be determined within approximately 0.1% when the period, recorded almost instantaneously, from the start to the end of the filling is used. In order to make the cross-section of the tank uniform and easy to measure, eight exactly rectilinear bars were fixed and bolted to the walls before the placing of the internal plaster so as to make the horizontal sections of the tank perfectly regular and at right angles. These strips made the plastering between them accurate

The measurement of the section of the tank was made with millimeter rules held horizontally and movable vertically inside the tank, the maximum difference in the measurements of the tank from top to bottom was 1/3 millimeter, which could be easily removed, but the area of the sections did not depart more than .05% from the mean value of 8.19 m^2. The reading of the depth of water in the tank is made in a water well that is outside of tank and with a depth gage that is supported on a millimeter

Fig. 10. UTILITY PIPE & MEASURING DETAILS

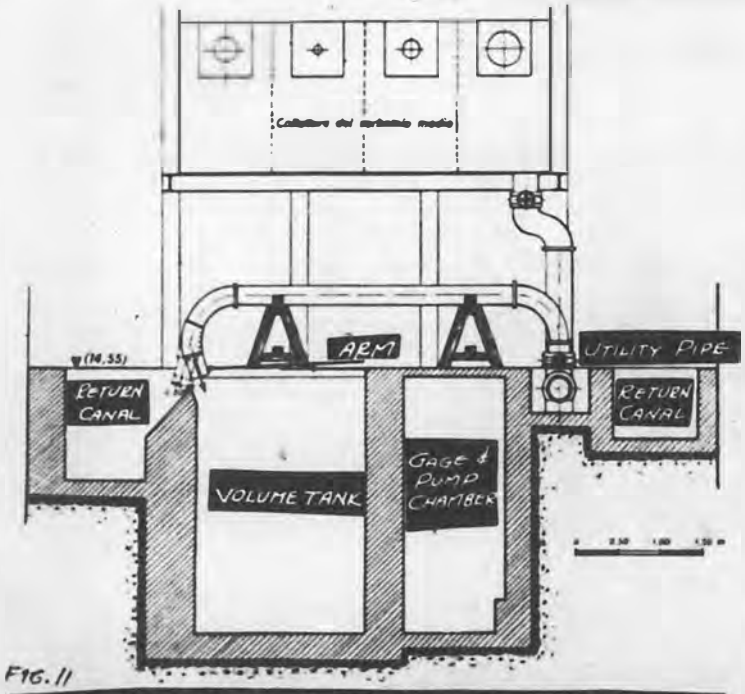


FIG. 11

MEASURING TANK & UTILITY PIPE WITH MOVABLE SPOUT

Sezione A-A

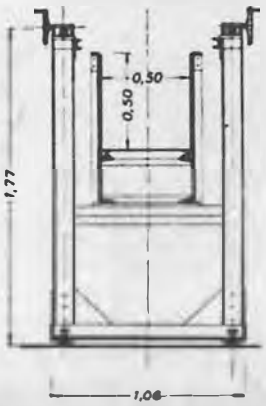


Fig. 13. TRANSVERSE SECTION OF GLASS-IRON FLUME

scale with a vernier reading to 1/10 millimeter and with a magnifying glass.

A check of the volume of the tank, other than by the geometrical relations, was made by volume and by weight.

In the first method a 250 litre (9 c.f.s.) metallic tank with a very narrow neck was used, the accurate capacity of which was checked with a calibrated litre. One then proceeded to weigh the same tank and, knowing the specific weight of the water, one obtained a volume that checked with that first obtained with the calibrated litre. Then one starts to fill the 24 m^3 (850 cu. ft.) tank, reading the depth gage for each emptying of the tank.

After having made several trials with this method with inevitable small losses, the difference in volume of the tank between the geometeric method and the method of volume and weight was found to be of the order of .125%.

At the bottom of the measuring tank there is a common sump from which a 3 in. pipe goes to a pump as previously noted, situated below the floor level; it also serves when emptying the measuring tank to dump the water into the return channel. (Fig. 5).

For filling the tank during a calibration, the utility supply pipe is used, to which, at opening "d" (Fig. 4) is attached for the occasion a horizontal tube which is furnished at its extremity with a right angle bend with a hinged spout. (Fig. 11).

This wall of the calibration tank is made at the top with a sharp metal corner so that if the movable spout is turned towards the inside the pipe discharges into the measuring tank and if turned towards the outside the pipe discharges into the return channel. Although the distance that is moved between the two extreme positions of the hinged spout is 0.3 meter (1 ft.), it is possible to make the movement in a fraction of a second, in spite of which, it is certain that between the start and end of the movement some flow enters the tank.

In this operation, the 24 m^3 (850 cr. ft.) capacity of the measuring tank has demonstrated its adequacy in relation to the proportions of the rest of the laboratory. If it had been desired to calibrate accurately weirs of 400 liters/sec. (14.1 c.f.s.) rather than those of 100 liter/sec. (3.5 c.f.s.), the capacity of the tank would be reached in only 60 seconds, a period too short to keep the error of measuring the time less than 1%, on the other hand if it was desired to assign a greater capacity to the tank for a suitable period of filling, i.e., 100 m^3 (353 cu. ft.), one would have the problem of the greater difficulty in the movement of the swing spout, and, in addition one would encounter another grave inconvenience, that is to say that in order to refill the tank one would have to completely empty all receivers, canals, and pump sumps with grave trouble to the regular functioning of the pump, which would be obliged to pump an almost constant, maximum quantity under markedly variable head.

At all times to keep the reading of discharge within 1% it is necessary that during calibrations one never reads a depth of water less than 0.1 m (4 in.) in the measuring tank, although even for small discharges it is well to use quantities of at least 50 cm (20 in.) for the duration of the calibration.

The calibration of the venturi and of the pilot tube, always attached to the utility supply conduit, has a procedure analagous to that used for the weir.

7. <u>The flume of steel and glass. (Fig. 12,13,14).</u>

For a gre t number of experiments both scientific and industrial, it is necessary to get direct vision of the type of flow and in some cases if possible to give color to the lines of flow and record them with an ordinary, or a moving picture camera. In general it is possible to experiment on modest scales, but tests must sometimes be carried out with a large variety of sections and of slopes. To cover such a wide scope one wants a flume of glass with great mobility. The flume of the

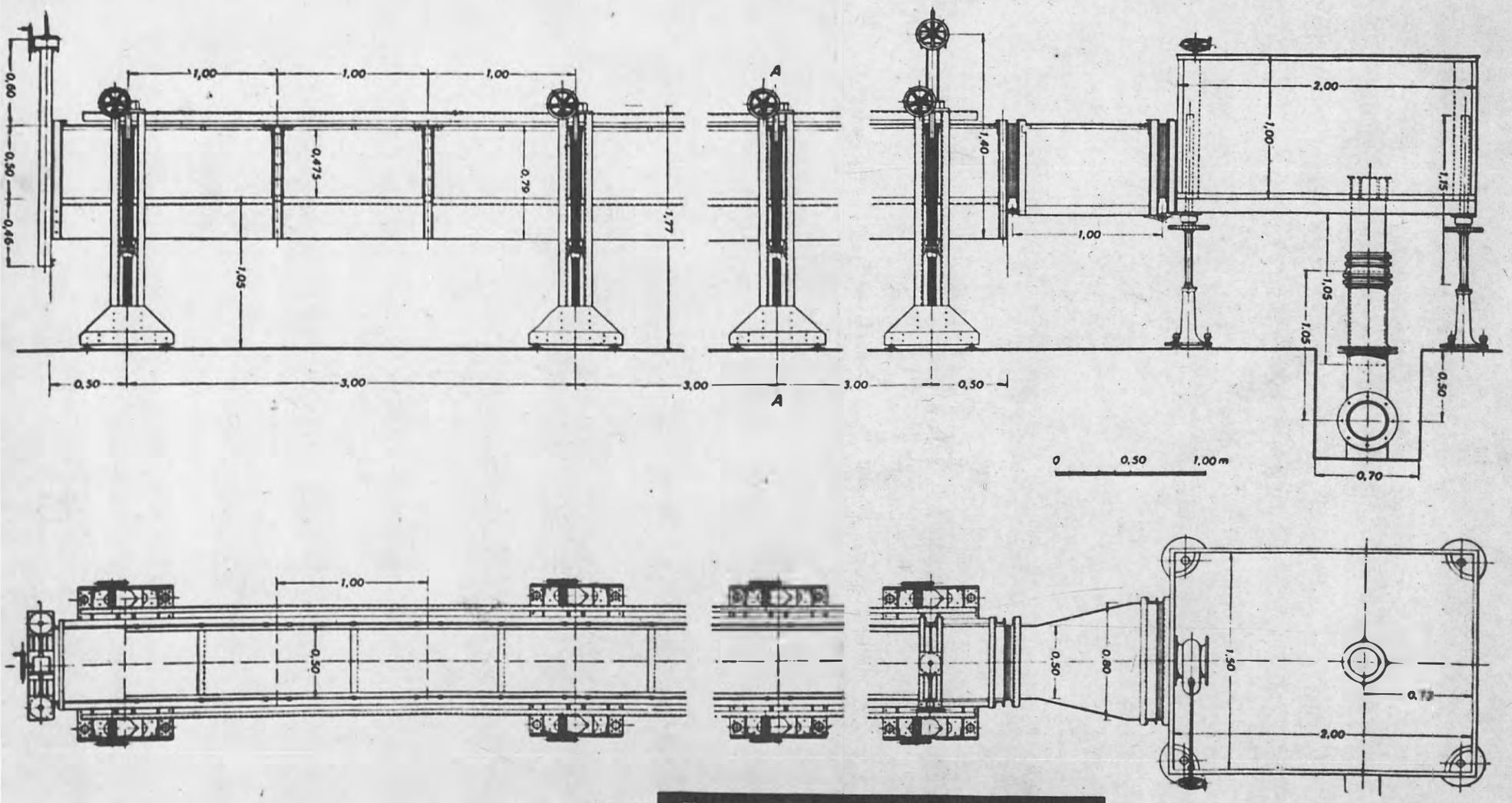


Fig. 12. FLUME OF STEEL AND GLASS

laboratory has a framework 10 meters (33 ft.) long and a maximum cross section of .5 x .5 meters (20 x 20 in.). The walls are of glass, each pane of glass equal to 0.5 x 1.0 meters (20 x 40 in.) and a 8 mm. (.3 in.) thick. The framework is so built that steel and glass panels are interchangeable the full length of the flume. Due to its large size, the flume is assembled on longitudinal vertical beams that extend the full length of the flume. In order to vary the slope of the channel the flume is supported on longitudinal beams which in turn are supported in cradles. These cradles are adjustable in height by means of screws that permit the channel to assume slopes from 0 to 14%.

The cradle supports uphold two guides that are independent of the flume. These are adjusted exactly horizontal and serve as rails for a carriage with a pantograph system for measuring relief in the section. At the upstream and downstream end are installed two plank bulkheads. The one downstream allows some discharge below it and some above it, and is under perfect control; to that end are provided three movable horizontal planks for the bulkhead, controlled by an eccentric wheel, capable of fixing the bulkhead in any position (Fig. 14). The water supply for the flume comes from the utility supply pipe through opening "h" (Fig. 4) which opens into a stilling tank provided with a low sliding gate connecting the tank with the flume. Because it was desired to leave to the flume full freedom to assume any position in elevation or slope, it was not possible to arrange a rigid joint from the opening "h" to the stilling pool, therefore the joint was a small telescope with rubber joints; for the same reason the connecting channel from the stilling pool with horizontal bottom to the tilting flume is furnished with two vertical rubber joints.

The measurement of the water that flows through the flume can be made directly at the mouth, entering the measuring tank, or else through the medium of a triangular weir that is installed at the front of the

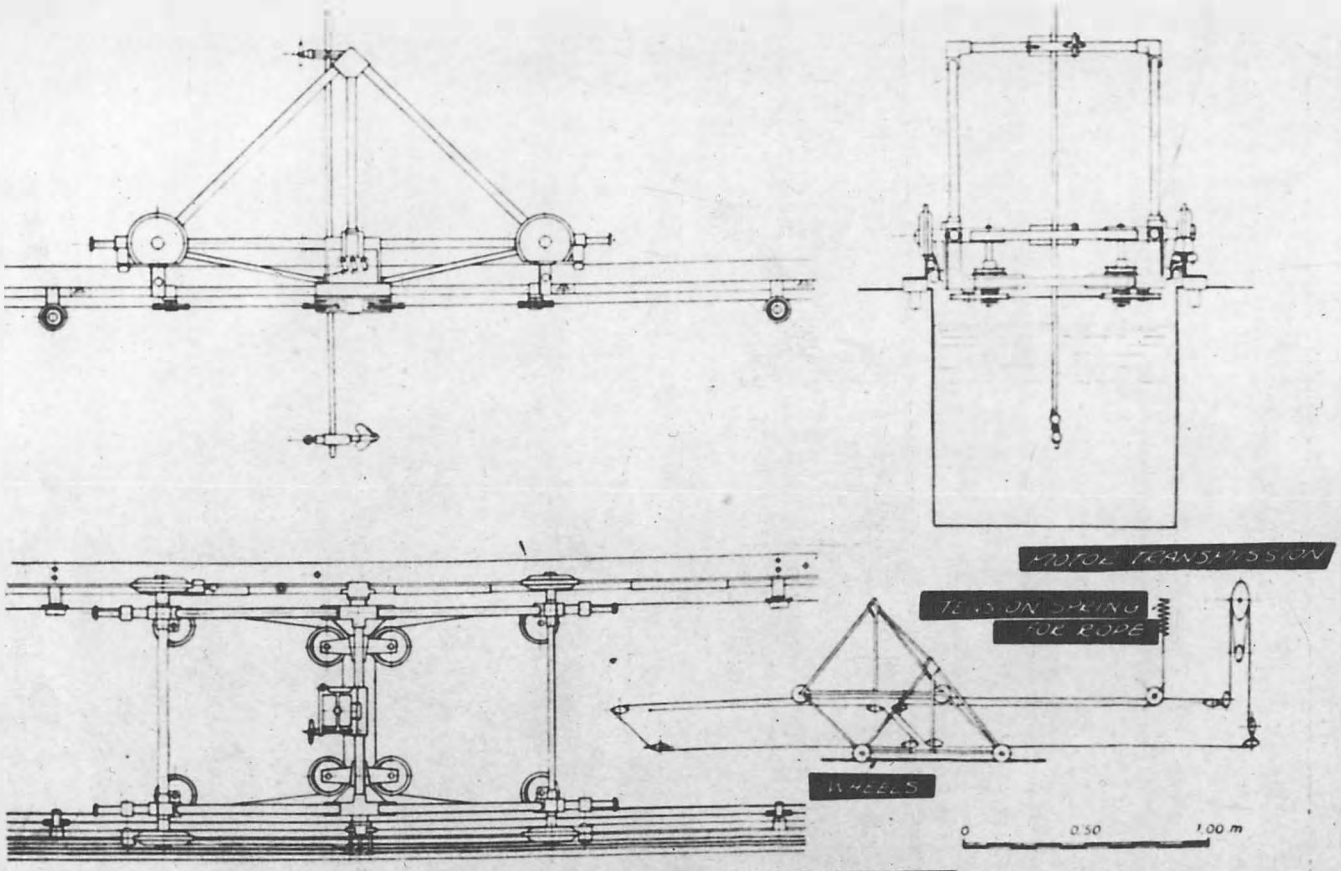


Fig. 15. CALIBRATION CARRIAGE

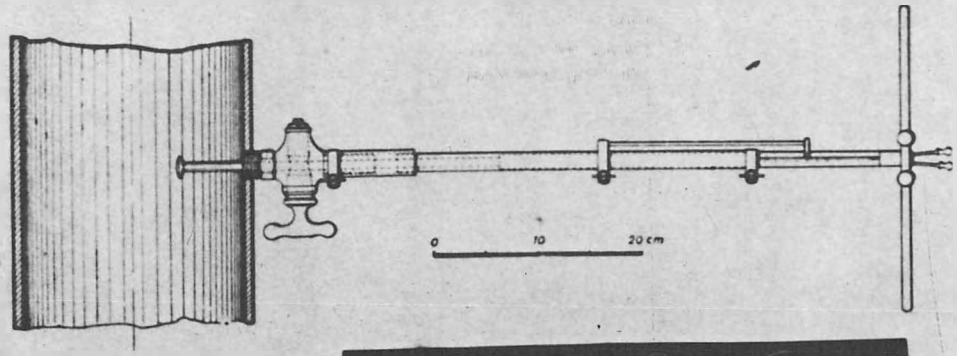


Fig. 28. PITOT TUBE FOR SMALL CONDUIT

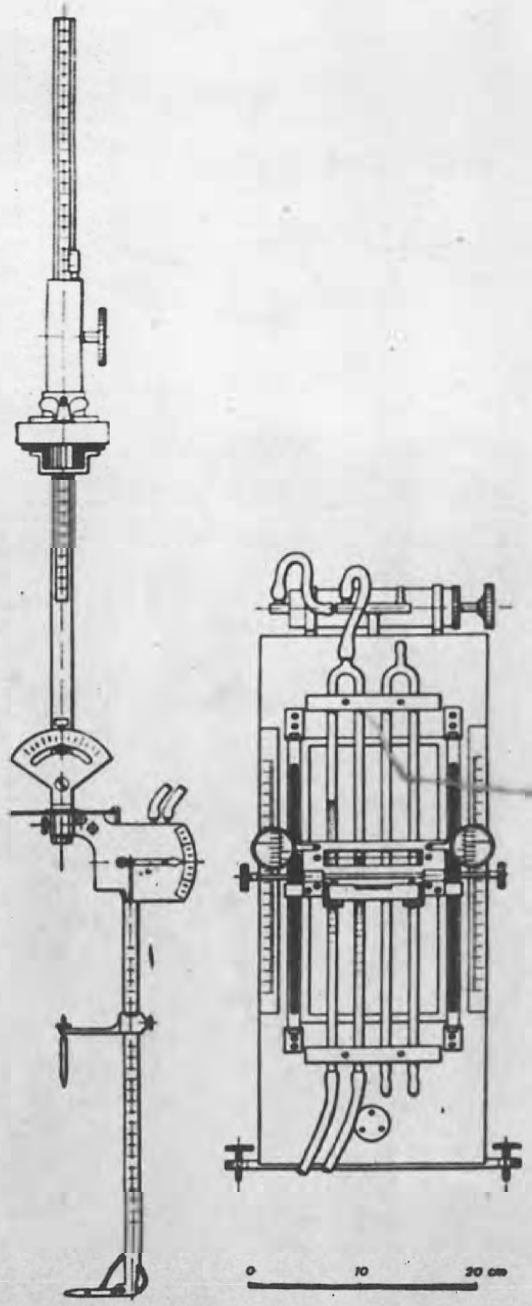


FIG 27 REHBOCK'S UNIVERSAL TUBE

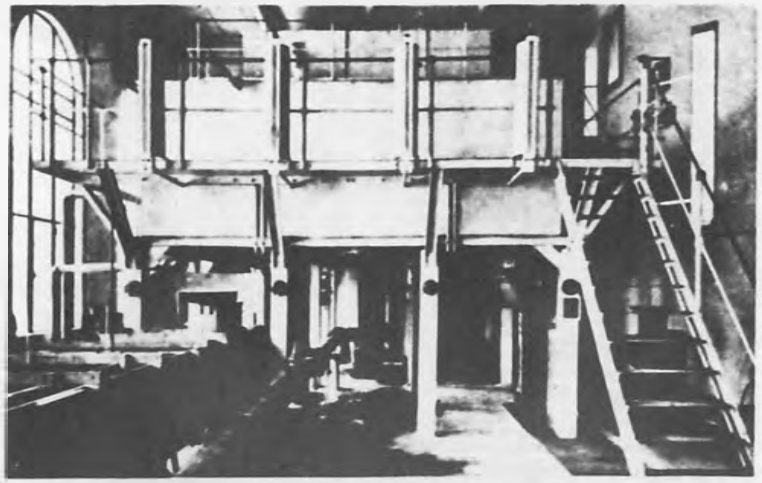


Fig. 8. - INTERMEDIATE METAL TANK & VIEW OF PUMPS

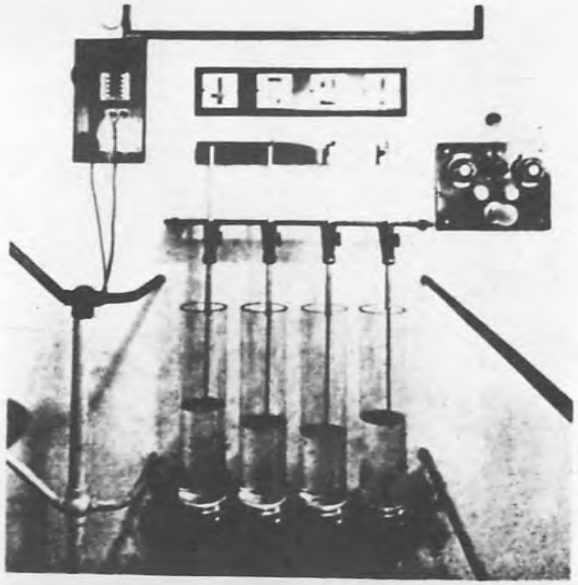


Fig. 9 ELECTRIFIED VERNIER POINT GAGE

Fig. 16. CALIBRATION CARRIAGE

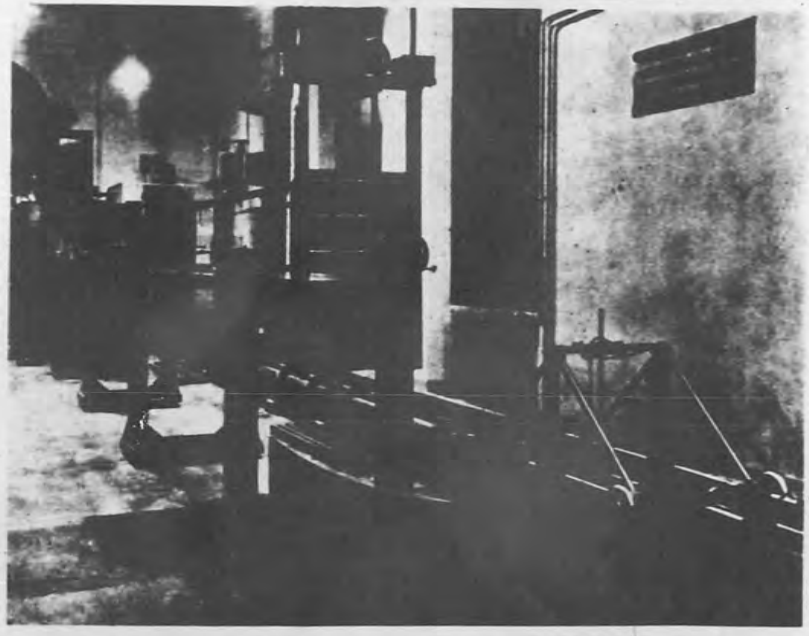


Fig. 14 - IRON-GLASS FLUME ON MOVABLE SUPPORTS-D.S. VIEW

stilling pool when closing the low sliding gate which connects the stilling pool and the flume.

8. The hydrometric carriage (Fig. 15 to 20).

Although the matter of calibrating hydrometric instruments is entrusted in this day of specialization to special stations, it seemed equally necessary to furnish our laboratory with a car for precision, which, other than permitting calibration work, would likewise serve for the study of the drag of totally or partially immersed bodies, with respect to hychodynamic equipment, leaving vortices about the object, etc.

The construction of such apparatus was entrusted to a very specialized concern, namely F. A. Ott of Kemptin, (Bavaria). This concern has also recently furnished complete carriage equipment to Germany, also to Russia (Tiflis) and to France (Beauvert).

The requisites that must be fulfilled by an hydrometric carriage are the following:--A large gamut of velocities, maximum regulation of movement for the greatest part possible of the available length of travel. Such results are obtained when the carriage moves on perfectly rectilinear, parallel and horizontal rails without any bumps, however small, or disturbances of a trembling nature. The carriage must be light to acquire or lose the required velocity in the shortest possible time. For obtaining this velocity one is able to use two solutions:-- either the motor installed on the carriage or the carriage pulled by a rope which is moved by a fixed independent installation on a platform at the opposite end. The first solution can be used either for large carriages, for the weight of the motors (or several motors with respect to the desirable changes for having a large range of velocities on hand) is not a useful part of the whole weight, or when one has at his disposal an unlimited length of path for the carriage so that one can spare a long stretch for starting and stopping. In our case the maximum length obtainable within the laboratory is 38.85 meters (127 ft.), therefore it was necessary to

accept the second system which is more generally used in small laboratories. The span of the carriage was designed for the large return channel, the rails were installed along the edge of the channel with a distance of 1.05 meters (3.45 ft.) between them. The rails are perfectly rectilinear, made from steel angles, accurately planed and aligned along the edge on which the wheels of the carriage rest. The points of support along the canal are on small concrete posts furnished with metal adjusting plates for small horizontal and vertical movement of the rails.

As for the carriage it was believed necessary to have recourse directly to the Ott firm, which was furnished one entirely of aluminum, capable of supporting, eventually, more than the apparatus and one person, and equipped with all the necessary articles for the recording of the path (Fig. 15 & 16). This electrical wiring is laid along four guides of brass that are fixed permanently to the rail and on which run four brushes for three electric circuits; the first marks the rapid movement of the carriage by making a contact every 50 cm (20 in.), the second carries the signals of the current meters corresponding to the contacts, and the third serves as a service telephone between the carriage and the operating platform from which proceed all movements. Fixing the scheme of movement with ropes as indicated in Fig. 15, the most delicate part is found in the method of pulling, through the medium of pulleys, grooved to minimize slip.

For the movement of the pulleys various systems were proposed, including those providing electric motors run by direct current, or by alternating current with variation of velocities. However, these complications were all unsuited, because a quick stopping action was desired. Therefore, a hydraulic drive system was chosen. Its good points, besides the large range of velocities obtainable, are the quick stopping and starting action.

The scale of velocities ranges from 0.01 m/sec. to 5.00 m.sec. (4 in. to 16.4 ft. per sec.) and is controlled by the hydraulic transmission with a three speed gear-box of the firm of A. Calzoni of Bologna. The functioning of this hydraulic transmission, ordinary yet unique for an installation of its kind, needs to be illustrated with greater detail as per figure 17, 18, & 19.

The apparatus consists namely of:

(a) gear pump

(b) a rotating servo-motor

(c) a counter-pressure valve

(d) two chamber valves

(e) main chamber

(f) safety valve

(g) a velocity transmission with gears

(h) a control board

(1) Lever control with three control points A. B. & C. give the carriage velocities varying respectively - 1 cm/sec to 10 cm/sec; 7 cm/sec to 70 cm/sec; 60 cm/sec to 500 cm/sec (.4 to 4 in/sec; 2.8 to 28 in/sec; 2 to 16.4 ft/sec).

(2) Voltmeters. For a check on the manufacturer's statements, immediately following the final installation, it was found that the transmission designed by Calzoni responded smoothly to all conditions imposed on it, that is to say that it had a distance of stopping and starting not greater than 5 meters (16.4 ft.) for the maximum velocity of the carriage of 5 m/sec (16.4 ft/sec) and that the variation of the velocity, during the run, with respect to the mean, at any time, was not greater than 0.3%. The diagram (Fig. 20) represents a calibration obtained with an Ott current meter belonging to the laboratory.

9. <u>The instruction laboratory and the circular calibration tank.</u>

As early as 1922, at the suggestion of Prof. G. Turazza, it was

hoped to furnish a small laboratory in the institution, devoted to instruction. Such a laboratory was started and completed in 1925 and it is totally devoted to demonstration experiments and to such as are necessary for tests in experimental hydraulics by candidates for degrees in engineering.

The laboratory consists of :--

(a) Two tanks below the floor, (Fig. 4) connected by a deep channel of trapezoidal section (Fig. 21).

(b) Two groups of electric pumps of 10 & 60 liters/sec (.35 and 2.1 c.f.s.) for heads up to 5 m (16.4 ft.) that are illustrated in (Fig. 22).

(c) Two metal elevated tanks, with constant level weirs, similar to those of the research laboratory.

(d) A stilling basin, with a calibrated weir, at the discharge end of the preceding tank.

(e) A movable experimental flume.

(f) A calibration tank of 3 m^3 (106 cu. ft.) capacity.

(g) An hydraulic accumulator of 150 atmospheres and 10 liters (.35 cu. ft.) capacity.

(h) Annexed to the instruction laboratory is a circular tank (Fig. 1 & 23) of 10 meter (33 ft.) diameter and 1 meter (3.3 ft.) deep. At present this tank is abandoned for the calibration of instruments used in measuring velocities because of various parsitic phenomena that are difficult to eliminate during the experiment.

On the other hand, as we have discussed, we have provided a moving carriage on the rectilinear canal. For instruction purposes, nevertheless, the circular tank is very useful, and therefore we have kept in good repair the tank and the rotating bridge, constructed before the world war. The bridge, moved by a three phase electric motor, with three

speed changes, can assume three angular speeds, in the proportion 1:3:9 so that the drag velocities in the tank range from 0.10 to 3.5 meters per second (4" to 11.5' per sec.).

The tank is equally useful for small instruments whose calibration need prolonged immersions.

10. The machine shop.

The majority of the apparatus and instruments for measurement in the laboratory are of special construction and therefore the general market is not prepared to furnish them. L' Istituto Superiore di Ingegneria di Padova has formed a central office that, on a par with the library, provides this general service. But the central office is not provided with machines and tools that are necessary for our work of precision, therefore it was necessary to provide a certain number of machine tools, lathes, shapers, drills, forges, etc., that were placed in room on the first floor of the laboratory and where two mechanics are employed.

11. Instruments.

(a) Gages. The greater part of the depth gages are staffs marked in millimeters and sliding in a sleeve provided with a vernier. The type that we have adopted is that of Rehbock (Kneller) with rack and pinion that we have built and had built in Italy in many styles. The reading of the contact is made visually with the straight as well as the hook point. The verniers are marked to read to the nearest 1/10 millimeter.

But in cases where the motion of the water level in the point gage well is not uniform, it is not possible to read the contact visually and with the same accuracy for all positions of the water level, therefore we have resorted to electrical contacts. Many systems are known in this field, but the majority lack the proper sensitiveness, because before the voltmeter records the signal of immersion there occurs an appreciable current which corresponds to the capillary rise on the

point; meanwhile the variation in water surface changes the point of contact. We have adopted as an element of contact a platinum wire and as an indicator of the current a neon lamp of 130 volts. This lamp indicates very feeble currents and therefore a contact of a fraction of a tenth of a millimeter of immersion is sufficient to light it. The voltage is rather high and therefore the apparatus must be kept well insulated but the sensitiveness of the apparatus has been demonstrated with great satisfaction.

The float gages that we have in use were furnished by the firms, namely (Ott, Kneller, Officina Magistrato alle Acque) and from our own shop; each one being furnished with a multiplying quadrant. Yet difficulties are encountered in making them as precise as those of the staff and vernier type, therefore till now they have served only for indicative values of the head on the weirs.

(b) Hydrometrographs (water stage recorders) are of the type of Salmoiraghe, Ott, or Officina del Magistrato alle Acque. They record the hydrometric movement of the water in full scale or in reduced scales up to 1:50 with periods of revolution of the drum from 6 hours to a month. They also can record by electrical transmission from a distance.

(c) Manometers - Differential Manometers. Besides a group of manometers of the Bourdon type mostly used for industrial applications, the laboratory has liquid manometers of the simple and differential type. These were adopted by us at small intervals for multiplications (up to 50 times) of the difference of pressure in water between two points. Ethyl Alcohol, Nitrobenzine, and Aniline are used for this purpose, used because of their specific gravity in water at the surrounding temperature (Fig. 10).

Other types are recorders, of the Bourdon-glycerine type or of the spring and piston type with an indicator (Fig. 25).

The speed of response of the latter type is remarkable, its sensitiveness can be depended on to pick up reading with the necessary accuracy.

(d) Pilot Tubes. Of these instruments we adopted for the industrial plants the Salmoiraghi type for canals, or the British-Pilot Meter Co. type for conduits; for the research laboratory our institute owns a universal Rehbock type very useful for all measurements in canals, and a receptacle type, of our own construction for measuring in conduits (Fig. 28). This last one is applicable to determine flow through small mouth orifices, provided by slide gates, in such a way that the Pilot tube is introduced in the conduit to examine without interrupting the outflow.

One of these pilot tubes is inserted permanently in the utility supply pipe (Fig. 10) and it has been calibrated so that by obtaining the indicated velocity at the center of the conduit, the discharge is determined. In order to make the reading of the corresponding piezometer differentials more sensitive, aniline and nitrobenzine are used. The discharge that this pilot can measure ranges from 15 to 350 liters/sec. (.5 to 12.2 c.f.s.).

(e) Venturi tubes are of the common type. One of these furnished by the firm, Astra di Milano, was permanently installed in a 90 mm by-pass of the utility supply pipe (Fig. 10). The discharge to be measured varies up to 15 liters/sec. (.5 c.f.s.), the readings are made coarsely on an ordinary dial, with more exact determinations through the medium of a differential manometer of mitrobenzine and analine.

Current meters are all of the European contact type of Kern, Salmoiraghi, Amsler, Ott, Officina Magistrato alle Acque, D. D. B. This last one has a volumetric indicator of the velocity. Some are of the small type and others of the large type for measuring in large canals, being suspended by a rope and having a direction indicator.

(g) Chronometers and chronographs. Ordinary chronometers reading to 1/5 second serve in almost all cases. For special research we adopted those reading to 1/10 second, and for measure of shorter intervals of time a chronoscope of which we possess a make furnished by the

firm of Zimmermann (Leipzig) and with which, through the medium of electrical contact through a pool of mercury, we read intervals of time of 1/50 of a second for 8 minute durations.

Other chronometers (type Ott, Mioni, Favarger) can give electrical contacts for each second or 1/2 second and are used mostly for calibration of current meters and of pipes.

A chronometer of this type and of this precision is that with a pendulum, furnished by the firm of Ott, installed on the control platform of the hydrometric carriage (Fig. 19).

The chronographs of the laboratory have points perforating ordinary paper, moved by a spring or by a counterweight, others have writing pens. Among these the very best is equipped with eight pens.

(h) In addition to instruments used in hydraulic experimentation the Institute owns many other instruments of a general character, such as planimeters (Salmoiraghi, Ott, Coradi), calculating machines (Monroe, Mercedes-Euklid), levels, tachometer, theodolites, dynamometers, thermometers, barometers, rain gages, pantographs, etc.

12. Some experiments completed and in progress.

(a) "Research on self priming siphons". The results can be summarized so:--To determine the height of fall of a siphon it is generally necessary to have three models of different scales, in case this is not possible, the maximum height of fall may be determined through the medium of one model, provided the time of fall in the model is taken into consideration.

(b) An interesting set of experiments have been started on the "Project of a canal system from Noce to Rocchetta" under the direction of the Commissioner of Water Ways. Two models 1:50 and 1:100 of the general works to study the control and functioning of spillways.

(c) Another problem under the direction of the Commissioner of Water Ways is concerned with the "Hydraulic details for plans of storage on the River Avisi". This problem has the virtue of not only storing

its own muddy waters but also of receiving the water of the Adige River and thereby diminishes floods at Trento. This problem was studied in two models of the following scales:--

Lateral	1:1000	1:500
Vertical	1:200	1:100

(d) Research for an industrial society was made "to determine the point of stabilization of a deposit in a branch of the canal that discharges flood waters of 900 mc/sec." The model was constructed to 1:50 scale with obstacles corresponding to various irregularities in the prototype canal.

(e) At the suggestion of the International Commission of the Adriatic there were made experiments on a "Model of the shallow port of Lido, Lido-Venice, Venezia". The principal characteristics of this experiment were as follows:--The reproduction of the combined action of the currents of the sea at the mouth of the port and of waves on the transportation of gravel formation and modification of barriers at the mouth of the port. The model was constructed 1:2000 laterally and 1:200 vertically. The results of the model have reproduced with sufficient approximation the modifications already noted between the years 1872-1882-1892.

(f) "Studies are being made on the movement of bed material to confirm data on the transportation of material, and to examine the new practical details of the problem". The latest research of this kind is the study of transportation of material in the Talfera River from its source to the cultivated fields of Bolzano at its mouth.

(g) A problem of marked practical interest, carried out partly in the field and partly in the laboratory for the office of Hydrology of the Commissioner of Water Ways is that of "the operation of irrigation siphons that are placed at top of dykes". The results are extremely satisfactory and will allow calculations of sufficient accuracy for the waste of water from the source to the mouth, which loss each year is of

marked importance to the agricultural economics of the Veneta Region. These tests are made on metallic siphons of diameters 450-600-1000 mm., 350-400 mm. in the field, and 200-300 mm. diameter in the laboratory.

(h) Of a purely scientific character were the studies relative to the formation of vortices about bodies fully immersed in flowing liquids, those concerning the phenomena of turbulence in flow over side channel weirs, and those handling the measurement of discharge by chemical and electro-chemical methods.

(i) A set up of pipes was made to purposely study and experiment with the water hammer. The length of pipe was 165 meters (540 ft.) long and 80 mm. (3.15 in.) in diameter with one end at the constant level tank and the other at the measuring tank of the instruction laboratory. The hammer was caused by a lever gate at the discharge end, which could be closed instantaneously or very rapidly compared to the length of pipe. Just upstream from the gate was inserted a Maihak pressure indicator of the spring and piston type, for recording quick changes the moment the action started. The time of closing the gate was determined by a cronoscope with an electric contact which recorded intervals of time from 1/50 second to 8 minutes. The pressure indicator had a writing pen with light contact on a rotating cylinder covered with smoked paper which was fixed with a gummed alcohol solution. Other indicators could be inserted at other points of the pipe, thereby picking up the pressure diagrams at such other points simultaneously or in a differential course. Although the experiments were primarily of an instructive nature, most interesting were the results concerned with the Gibson method of measuring the discharge and with the action of the pipe as a penstock from pump to reservoir.

(j) At the suggestion of the National Research Council there have been undertaken in our laboratory and those of R. R. Politecnici di Milano e Torrino research (on a comparative scale) on the measurement of flowing liquids through diaphram orifices and notches.

(k) Time is also given to research in loss of head in canals and pressure conduits, partly studied for laboratory use and partly for industrial use. The first study of the laboratory was carried out with old conduits of Casal Monferrato with diameters of 50, 150, 300, and 400 mm. The results led to the determination of the law $V=165\left(\frac{D}{4}\right)^{68} i + 56$ with almost exact agreement, this law was checked seven years later by A. Ludin of the Poletecnico di Berlino with pipes of 50, 100, 150, 200, and 250 mm. in diameter. To speak of an analagous subject, experiments on new seamless steel pipe internally coated with tar of 40, 60, 80, 100, 150, 200, 250, 300, 350, and 400 mm determined the law $V=105\left(\frac{D}{4}\right)^{59} i^{.55}$.

The work of the new Hydraulic laboratory of the Hydraulic Institute has given a marked impulse to agricultural hydraulic research.

13. Cost of the plant and of research.

The project of the laboratory was approved 1930, and constructed in three years 1930-1932. The plant was dedicated on the 16th of April, 1932.

The cost of the Hydraulic Research laboratory including some special apparatus was 370,000.00 L. which conforms to the estimated cost for the project in 1930. Cost was subdivided so -

(a)	Cost of building	72,109
(b)	Metal tanks	60,364
(c)	Various conduits	42,490
(d)	Motors, pumps and electrical plant	18,470
(e)	Canal of metal and glass	25,300
(f)	Depth measuring carriage	46,109
(g)	Laboratory instruments	73,724
(h)	Incidentals	29,160
	TOTAL COST--	367,726 L.

The operating cost in the first five years amounts to 30,000 L. annually excluding the wages to personnel and the cost of special research carried on by the head of the department.