EFFECT OF COMPRESSED AIR ON MORTALITY OF FISH PASSING THROUGH A MODEL TURBINE

by

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ABSTRACT

Rates of mortality among young salmon passing through a high speed model propeller turbine operating under a 50 ft hydraulic head but under various draft tube suctions are given. Effects, on both fish mortality and turbine performance, of admission of compressed air into the turbine at various locations to reduce the effect of cavitation (believed to be the major cause of fish mortality in the turbine) are discussed. At low turbine speed and low efficiency, admission of air immediately downstream from the blades reduced the mortality of fish substantially but at high turbine speed and high efficiency, the reduction was insignificant. At high turbine speed, the effect, on fish mortality, of admitting compressed air into the penstock and atmospheric air into the turbine draft tube through a 3" diameter steel pipe installed about 1 ft downstream of the blades are shown to be beneficial. Records of biological examination from some of the tests to determine the apparent type of injuries are included. An attempt has been made to correlate the turbine speed with the number of injuries likely to be caused by fish being hit by the blades. The effect of partial vacuum on fish is also given.

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INTRODUCTION

Each year a large quantity of Pacific salmon is caught by both commercial fisheries and sport fishermen off the west coast of the North American continent and in numerous rivers and streams on the same coast. These valuable fish spend part of their early life as well as the final period of their mature life in fresh water. They spend the remainder of their life span in sea water, feeding on marine plankton, and there grow to a considerable size; but in order to propagate their race, adult salmon must return to their native streams to deposit their spawn. The eggs are deposited in a nest which the female prepares on a gravel bed, in the cold clear water which is normally found near the head waters of larger tributary streams where the current is strong enough to carry away most of the fine sediments. The eggs are laid in the river at a depth varying from a few inches to several feet and are covered with two to eighteen inches of gravel to protect the eggs during the incubation period. Unlike the Atlantic salmon, the completion of the deposition of the eggs and their fertilization is followed by the death of the parent leaving the future of the species entirely dependent on the survival of the eggs and the young. Adult fish normally return to spawn during the summer and fall months, and in the spring the eggs are hatched and become free swimming fry. The fry of some species then spend a year feeding in fresh water whereas others migrate directly to the sea in their first year. The period they spend at sea also varies from species to species but when they reach maturity, they must return to spawn in their native streams, thus completing their life cycle.

Because of the population and industrial growth of the communities on the west coast of North America, multi-use of the rivers is essential, so that maximum benefits can be realised from all resources. The dependence of salmon on a suitable fresh water environment during their migration and early stage of development has placed them in direct competition with the other fresh water users.

Through water developments for power, water storage and irrigation, dams are constructed across some rivers inhabited by salmon. This results in a barrier to migration of adult and young fish. Passage of large numbers of adult fish over dams is usually accomplished by means of fish ladders or fish elevators. If the number of fish to be passed over the dam is small, they may be trapped downstream from the dam and transported up to the reservoir in specially designed trucks. The primary problem associated with by-passing of adult fish over the dam is the ability to attract the migrants to the entrance of the by-pass system without delay, injuries or mortality.

There are many problems of adult fish migration other than the problem of passing them successfully over the dam. The discussion of these problems is beyond the scope of this thesis.

The interested reader is referred to the Nov. 1956 Progress Report on Fisheries - Engineering Research Program of the U.S. Corps of Army Engineers(14)[1].

At a typical power dam, young fish migrating seaward are swept into the turbines or over the spillway. The percentages of fish utilizing the spillway or turbine exits are not well defined at present. For example, at a typical dam on the Columbia river, if it is assumed that fish are distributed in proportion to the rates of flow, then about one-half of the fish pass over the spillway.

Recent experiments have shown that mortality rates among fish passing over the spillway ranged from 37% at lower Elwha river (7) to 2% at McNary(7) and Big Cliff(7) depending on the type and length of the spillway. For high free-fall spillways discharging into a plunge pool, no significant mortality was reported and a relatively safe passage of young fish over the spillway can be assured.

Recent tests have shown that mortality among young fish passing through turbines can occur. The rate of mortality ranged from an insignificant amount at the Lower Elwha dam(7), 11% at McNary(7) to 30% at Glines Canyon dam(7). The major causes of mortality among young fish passing through turbines are believed to be (a) exposure to cavitation(8) and (b) collision with turbine blades. Turbine intake screens have been used at a few dams to prevent young fish from entering the turbines. Because the size

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1. Numbers in the parenthesis refer to the Bibliography.

of young fish of certain species is very small at the time of migration, the screen openings must also be small. Debris caught on the screen may block the flow. The necessity of frequent cleaning makes the screen impractical as a means of preventing fish from passing through a turbine.

Numerous guiding systems have been invented to guide fish away from the turbine intakes and the spillway entrance into a safe by-pass. Some have met with limited success. Because of the high initial and maintenance cost, they are not likely to be used extensively.

In the future, with optimum control at storage dams, more fish would pass through the turbines and fewer fish over the spillway. To date no attempt has been made to make the passage through the turbines safer for fish migration, although the tests at the Lower Elwha dam have shown that safe passage of fish through a turbine is possible.

The purpose of this investigation is to ascertain the effects of adding air into a turbine on the mortality of young fish passing through the turbine. Air has been admitted into turbines previously to reduce the effect of cavitation. It is believed that the same technique can be used as a means of reducing fish mortality and of improving the turbine performance.

It is thought that tests carried out in a model propeller turbine will accomplish the aim set out above. It is recognised that fish mortality depends on many variables. To keep the number of these variables small, the test is limited to one position of the wicket gate and to one value of the total head. The draft tube suction head is limited to two values only.

CHAPTER I

REVIEW OF PREVIOUS RESEARCH

1.1 Passage of Young Fish Through Turbines

Soon after fish enter a turbine intake they will experience a gradual increase in hydrostatic pressure until they approach the leading edge of a turbine blade. After a brief time interval of the order of a fraction of a second, the pressure decreases to atmospheric pressure or to a partial vacuum. Once fish have passed the blade, they may be exposed to cavitation if the draft tube suction reaches the vapour pressure of the water. Vapour pockets form in the region of this low pressure. When they are carried into regions of higher pressure, they collapse. Local pressure intensities of high magnitude then occur. High pressure intensity waves are transmitted to various parts of the water passages. If fish pass through the cavitation region, they will be subjected to this high pressure wave which may cause injury or mortality. In the draft tube, fish are also subjected to partial vacuum and turbulence.

By chance some fish may collide with the turbine blades and be killed or injured.

1.2 Turbine Fish Mortality Studies

Several studies have been made to date on problems of fish passage through hydraulic turbines. The most notable tests were made by the Corps of Engineers of the United States.

In 1959, a series of tests were conducted in a low head model test stand at the Allis Chalmers Hydraulic Turbine Laboratory in York, Pensylvania. Fish were passed through a model Kaplan turbine with 12" diameter runner and through another 12" model Francis turbine with a 15 bladed runner. The hydraulic head varied from 5 ft to 45 ft and the speed from 95 rpm to 1400 rpm. The tests were performed with a given net head and turbine speed and with the runner set at various elevations above tail water elevation.

Cramer(3) reported that the Kaplan and Francis model runner gave similar results. Wide variation of fish survival rate (from 96% to 1%) could be achieved, dependent on speed and tail water elevation. He also reported increased mortality where adverse hydraulic conditions resulted in cavitation and lower efficiency.

Further tests were conducted on the same model Francis Turbine but with a slightly modified runner. Cramer and Oligher(4) reported that the most desirable characteristics of a Francis runner to provide maximum survival for fish are (a) relatively low runner speed, high efficiency, (b) relatively deep setting of the turbine so that the runner is submerged below the tail water level, (c) maximum clearance between blades and between the wicket gates and the intake edges of the blades.

These model tests were followed by full scale tests in which fish were passed through a Francis turbine operating under a 470 ft head at the Cushman II dam in Washington and through another Francis turbine operating under a 420 ft head at Shasta dam in California, in 1961 and 1962 respectively. Results (4,5) from both test series confirmed the results of the model tests. In the prototype, operating conditions such as the gate opening, plant sigma and tail water level had the greatest influence on fish mortality.

The mortality rate of young fish passing through the turbine at Cushman II ranged from 23% to 55% depending on gate opening and tail water elevation. There was a wide variation of the tail water (0.5 ft to 12.5 ft) at Cushman because it was influenced by the tidal action in the tail race. The mortality rate of young fish passing through the turbine at Shasta ranged from 10.7% at 0.65 gate opening to 24.6% at 0.50 gate opening. The improved fish survival rate at Shasta as compared to Cushman is attributed to a greater blade clearance at Shasta. The peripheral velocity of the runner was almost the same for both runners.

In all tests conducted by the Corps of Engineers, where dead fish were captured, the type of apparent injuries likely to cause mortality was usually recorded. There were four major factors considered responsible for death and these were classified as follows.

1. Mechanical - i.e. fish killed by collision with a solid object such as a turbine blade
    - (a) Abrasion - rubbing or scraping off skin
    - (b) Contusion - bruising of the body
    - (c) Decapitation - severing of the body
    - (d) Laceration - ripping, tearing or cutting of tissue.

2. Pressure Change

(a) Eye damages - hemorrhaging, missing or otherwise damaged eyes

(b) Collapsed or damaged air bladder.

3. Shearing Action

Caused by two forces of water going in opposite directions. The damage suffered by fish is normally a torn operculum.

4. Cavitation

Characterized by hemorrhage of internal organs and/or body rupture

Some fish had no visible injuries; hence they were assumed to be suffering from stress and handling.

More tests have been performed by other agencies in the U.S.A. and in Canada to determine the overall mortality rates of fish passing through turbines. Lucas(7) has conveniently summarized and tabulated all these results.

1.3 Effects of Cavitation, Pressure Change and Vacuum on Young Fish

Rowley(13) showed that fish can withstand pressure changes of substantial amounts, providing the pressure does not decrease below atmospheric.

Muir(8) developed a hypothesis that mortality among young fish passing through turbines is caused mainly by exposure to cavitation. He performed experiments on coho fingerling using a long pipe rack normally used for water hammer experiments in the Hydraulic laboratory at U.B.C. Coho fingerling when exposed to cavitation showed a mortality rate of 60%. The experiment demonstrated the possibility of fish being killed by cavitation in a turbine.

Partial vacuum affects fish by changing the concentration and state of dissolved gases in the fish vascular system. Bishai (12) showed that formation of gas bubbles in the heart and blood vessels and the bulging of the eyes may result if fish are decompressed from a high positive pressure to partial vacuum. Fish are said to suffer from "gas disease" or "bends". Muir(8) showed that the bends in fish depend mainly on the degree of vacuum and the length of time that the fish are exposed to it.

Further effect of partial vacuum is felt through the changing of volume of the fish's swim bladder. A salmon has an open swim bladder, i.e. it has a duct leading from the esophagus to the swim bladder. An increase in pressure in the water will cause a reduction in the bladder volume. If the pressure is suddenly reduced to atmospheric, the bladder returns to its original size but if the pressure is reduced substantially below atmospheric, the fish must release gas from the bladder through the esophagus; otherwise the bladder wall may be ruptured.

A salmon, given sufficient time to become conscious of the pressure reduction, can release the excess air. In this case if the pressure later returns to atmospheric, the bladder remains collapsed. The fish can reinflate its bladder by rising to the water surface and gulping air from the atmosphere. If a fish is weakened, it may not rise to the surface. Mortality can result but may not necessarily be due to a deflated swim bladder. Muir(8) showed that few fish died as a result of a deflated swim bladder. He claimed that stresses resulting from collapse of the fish's swim bladder are not likely to be a significant cause of mortality among young fish passing through turbines(8,9). Tests at Cultus Lake(7), B.C. have shown that sockeye salmon when exposed to pressure reduction from high positive pressure to high vacuum sometimes suffered rupture of the swim bladder.

1.4 Mechanical Type of Injuries Suffered by Fish Passing Through Turbines

When fish enter the turbine intake, they may come in contact with the edges of the wicket gates or other solid objects. They may suffer bruises and possibly laceration but severance of their bodies is not believed to be likely.

Some evidence has been found that mortality as a result of impact between fish and a solid object is possible. At Bonneville Laboratory in 1955, salmon fingerlings were placed in an injector connected to a 20" pipe from which water issued through a nozzle at a velocity of 45.6 f.p.s.(14). A steel plate was placed so that the 8" jet impinged directly on it at 45° and at a 90° angle. The mortality rate for the 45° impact test was 1.7% while the corresponding mortality rate for the 90° test was 3%.

When fish reach the turbine runner, they may be struck by the blades. The usual injuries suffered by fish are laceration, severance of the body or crushed head.

For fish, the time available for avoidance of collision with the blades is the time required for a leading edge of the next blade to hit any part of that fish; therefore the longer the fish, the higher the possibility of contact between the blade and the fish.

Von Raben(10) derived a formula for the prediction of fish mutilation in a propeller turbine as follows:

The time taken by the blade to take up the position of the preceding blade

$$T_r = \frac{60}{nN}$$

in which n = number of blades on the runner

N = turbine speed in rpm

The axial component V_N of the absolute velocity V of the water is

$$V_N = \frac{4\,Q}{\pi\,(D^2 - d^2)}$$

in which Q = turbine discharge

D = Diameter at the tip of the blade

d = hub diameter

The length of water section (W) flowing through the space between the runner blades during the time T_r is

$$W = T_r\ V_n$$

The possibility of contact (c) between fish and blade is given by:

$$c = \frac{L}{W} = \frac{L\pi \ (D^2 - d^2) \ . \ (n) \ . \ (N)}{240 \ Q}$$

in which L = the length of the fish.

Water flowing towards the leading edge of the blades possesses a whirl component V_T; hence the flow is at an angle α to the assumed direction of V_N

$$\therefore \quad C = \frac{L\pi \ (D^2 - d^2) \ n.N.\cos\alpha}{240 \ Q}$$

in which α = the angle between the absolute velocity (V) and the velocity V_N

The Impact Velocity

Von Raben claims that the velocity at which fish strike the leading edge of the blade must exceed a critical value before decapitation of the body is possible. If the fish is assumed to move with the current in the turbine, then it will move at the same velocity as that of the water relative to the leading edge of the blade, i.e. at a relative velocity v (fig.1).

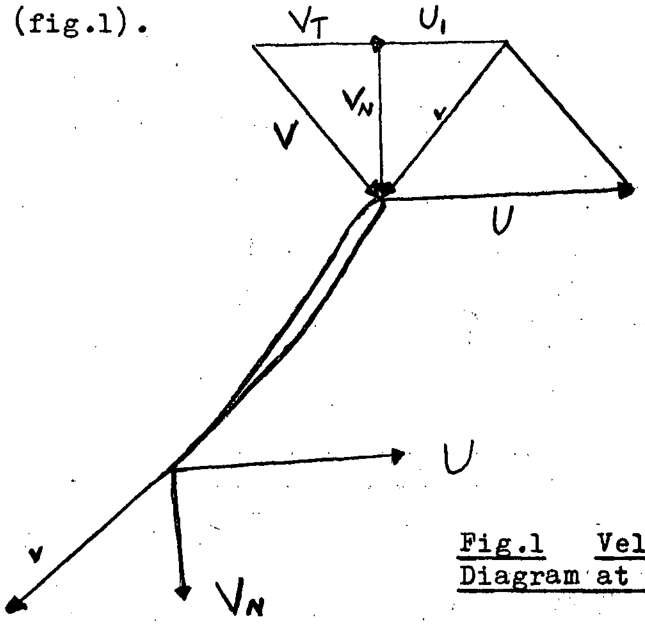

Fig.1 Velocity Vector Diagram at a Turbine Blade

Consider a velocity vector diagram at a point A along the leading edge of the blade. The axial component of velocity V_n is

$$V_N = \frac{4\,Q}{\pi\,(D^2 - d^2)}$$

The circumferential velocity (U) of the point A on the leading edge of the blade is

$$U = \frac{N\pi R}{60}$$

in which R = distance from the centre line of the shaft to A.

If V_T is the whirl component of the velocity of water approaching the leading edge of the blade, then

$$v = \sqrt{V_N^{\,2} + U_1^{\,2}}$$

in which $U_1 = U - V_T$

v = velocity of water relative to the leading edge of the blade

But $V_T = V_n \tan \alpha$

$$\therefore \quad v = \sqrt{U^2 - 2U.V_n.\tan + \frac{V_n^{\,2}}{\cos^2\alpha}}$$

The circumferential velocity U for points on the leading edge of the blade varies from the minimum value of $\frac{N\pi d}{60}$ to $\frac{N\pi D}{60}$ at the periphery of the blade. The impact velocity also varies depending on the distance from the centre-line of the runner to to fish.

Von Raben claims that fish decapitation resulting from collision with the blade of a propeller turbine occurs only if the impact velocity between the fish and the blade exceeds a critical value: that the possibility of contact depends upon the diameter of the turbine runner and the hub, the number of the blades on the runner, the speed and the discharge of the turbine, the length of the fish, and the direction the fish is moving relative to the leading edge of the blade.

1.5 Cavitation in a Propeller Turbine

When the pressure in the moving water is reduced to its vapour pressure, the water ruptures and vapour pockets form. When the vapour pockets move into a higher pressure zone, they collapse. Because of the low compressibility of water, the collapse of vapour pockets sets up a very high localized pressure intensity. This dynamic phenomenon is called cavitation.

In a propeller turbine, cavitation can occur at no less than three locations depending on the location of the pressure reduction zone:

(a) Blade profile cavitation. Because of the nature of the flow around the turbine blades, a low pressure zone exists on one side of the blade; if the maximum suction reaches the vapour pressure of water, cavitation can occur.

(b) Blade clearance and blade tip cavitation. In the tip region of the blades, leakage of flow from the pressure side is always possible because the blade span is finite. To reduce this leakage, the wall of the runner casing is built as close to the tip of the blades as possible. A flow of high velocity exists at the clearance zone. Cavitation may occur at the region of the tip of the blades.

(c) Hub or blade shoulder cavitation. Roughness on the hub or an unsatisfactorily-designed junction between the blade and the hub can cause vortex motion around the hub. The low pressure zone occurring at the centre of the vortex can result in a stationary vapour pocket. The collapse of the cavity at the downstream end of the vapour pocket results in hub cavitation.

Cavitation in a turbine is not a uniform process nor does it occur at any definite pressure. Water can resist a certain amount of tensile stress before it starts to rupture. If it contains some dissolved gases, the water will rupture more readily. It is therefore possible for water to rupture at different pressures, depending on the size and number of gas nuclei present. Cavitation inception then depends on the total air or gas content of the water. At low air content, a pressure below the vapour pressure of the water is required to trigger off cavitation.

The Thoma criterion ratio of cavitation, sigma (σ), has been used as an indication of cavitation. Sigma is expressed by means of the formula:

$$\sigma = \frac{H_b - H_s}{H}$$

in which H_b is the height of the barometric water column in ft;

H_s is the elevation in ft at which the turbine is placed above the tail water level; and H is the net head in ft under which the turbine operates.

For a turbine set at a moderate elevation above sea level and for the usual temperature range, $80^{\circ}F \pm$

$$H_b = 34 - 1.2$$
$$= 32.8 \text{ ft of water and}$$
$$\sigma = \frac{32.8 - H_s}{H}$$

Effects of Cavitation

Soon after cavitation takes place in a turbine, the efficiency decreases. Noise and vibration of the turbine increase.

Objectionable noise due to cavitation is related to a fairly well developed stage of cavitation. Advantage may be taken of the noise as a means of measurement of cavitation. Noise analysis has been used to obtain information on incipient cavitation and to indicate its development. The noise level increases sharply at the cavitation inception point. However, efforts to use the overall noise level as an indication of the degree of cavitation have failed because at certain stages of cavitation, the noise level may even be reduced.

Vibration of the turbine may result from runner hub cavitation and may cause load instability in the turbine. Draft tube surge is considered to be the result of hub cavitation.

Cavitation damage is due largely to mechanical action. The collapse of vapour pockets sets up a high pressure intensity sufficient to cause localized fatigue failure of the metal. The damage usually takes the form of pitting on the runner blades and on the draft tube wall.

The Effect of Compressed Air on Cavitation

When compressed air is admitted into a turbine operating under cavitating conditions, it has been observed that the noise and vibration levels are reduced as well as the extent of pitting of the runner blades and draft tube wall. Compressed air, when allowed to mix with the water, increases the compressibility of the mixture enormously; thus the pressure intensity set up by cavitation is reduced.

CHAPTER II

DETAILS OF TEST ARRANGEMENTS

2.1 Turbine Test Stand

The hydraulic turbine test stand normally used for the undergraduate instruction in U.B.C. Hydraulic Laboratory is used in this test programme. It is a closed system consisting of an overhead tank, a turbine and a sump. Water is pumped from the sump located in the basement up into the overhead tank and is allowed to flow through a 14" diameter steel penstock to the turbine, through the turbine and the draft tube and back to the sump. (See figs. 1 to 10).

The control gate is installed upstream from the turbine to control the amount of flow and the pressure in the penstock. Water from the penstock enters the scrollcase of the turbine and is admitted to the turbine runner through manually operated wicket gates. The pressure in the penstock and the suction in the draft tube are indicated on Bourdon gauges. A downstream control gate is used to vary the draft tube suction.

The diameter of the penstock and the draft tube are equal; therefore the velocity heads in the penstock and the draft tube are also equal. The total dynamic head of the turbine is then equal to the sum of the penstock pressure head and the draft tube suction head.

The turbine is a propeller type. The 10" diameter runner, mounted on a horizontal shaft, has 4 blades with a minimum blade clearance of 1-1/4". The turbine is connected to a hydraulic dynamometer. The turbine out-put torque in lbs. ft is measured on a weighing beam scale of the dynamometer. The turbine speed in rpm is obtained from the tachometer reading on the control panel of the dynamometer and can be adjusted by means of two small valves controlling the amount of water supplied to and drained from the dynamometer. The turbine speed can be set at any desired figure up to 2800 rpm.

The water leaving the runner flows along a 15 ft straight vertical draft tube and then along another 8 ft of horizontal section of the draft tube before discharging in air into the sump.

2.2 The Fish Injector

An acrylic pipe, $2\frac{1}{2}$" diameter, fitted with a ring-C follower gate is used as a fish introduction device. It is installed in a horizontal position making an angle 45° with the centre line of the penstock. The injector is bolted to a 3" diameter steel pipe with a square flange, which is welded to the penstock wall. For the details of the fish injector see fig. 11.

Fish are placed in the fish chamber through a 5" x $2\frac{1}{2}$" rectangular opening fitted with a removable cover which when in place forms a complete pipe section. The plunger is fitted with an O-ring so that it is water-tight as well as fish-tight. For manual operation, a 24" brass rod is attached to the plunger. A plastic screw cap with a small air valve is used to cover the end of the fish injector. Copper drains (see fig. 11) fitted with two-way valves are used to drain the chamber and the spacing behind the plunger. One end of the drains is attached to a small plastic tube leading to the turbine penstock while the other end is attached to the city water supply pipe. Fish are led to the releasing point at the centre of the penstock through a leading pipe of the same size as that of the fish chamber, extending from the gate to the releasing point. The action of the injector is as follows.

The gate is first closed and the cover on the top of the fish chamber removed. A known number of fish is placed in the chamber and the lid replaced. The two-way valve connecting the penstock and the injector is opened to allow the high pressure water in the penstock to flow into the chamber. At the same time all air in the chamber is carefully eliminated through a valve at the top of the chamber and through another valve on the screw cap. This is done to prevent the fish coming in contact with free air-water surface during the fish injection period. When the pressure in the chamber equals that of the penstock, the gate is quickly opened. The valve connecting the injector with the city water is opened to admit city water which presses the plunger slowly forward to force fish into the penstock. When the plunger has travelled the full length of the pipe, and fish have been introduced into the penstock, the city water supply is shut off. The drain is opened to allow the water in the chamber to escape while the penstock pressure forces the plunger back to its original position. The gate is finally closed to complete the injector operation.

Visual observation of fish introduced into a fast moving stream is possible by means of a plastic window provided at the point immediately downstream from the fish releasing point, (Fig.12). Small plastic windows are provided, one at the runner casing to permit visual observation of cavitation of the turbine and another one about 1 ft downstream from the blades to observe fish after they have passed through the runner space and the cavitation zone.

2.3 Fish Recovery Gear
Draft Tube Extension

The draft tube is extended through a specially designed extension, a 14" square section, the top and bottom walls of which are made of 3/4" thick plywood and the two side-walls lined with No. 30 gauge metal strip. For details of the extension, see fig. 13 to 18. Four 3" x 3" x $\frac{1}{2}$" angles are welded to the existing end of the draft tube and are bolted to the wooden flange of the extension. Care was exercised throughout the construction of the extension of the draft tube to avoid any sharp protrusion from its inside walls, to prevent fish being damaged by them. The extension is supported by a series of wooden beams and columns to resist forces induced by the flow of water around the 90° bend and any vibration set up by the flow in the extension.

The Wooden Transition

Because of the fluctuation of the sump water level, a wooden transition is provided to direct the flow from the draft tube extension to the water surface of the sump. One end of the transition is a 14" square section hinged to the top end of the draft tube extension. A piece of canvas wrapped around the gap created by the joining of the two sections acts as a flexible joint so that the transition can pivot about the hinge. Rubber sheets are used to bridge the inside gap. The transition is made of 3/4" plywood and its section gradually changes from 14" square to 24" x 6". It is suspended from the ceiling of the sump.

The Trap

After the flow from the draft tube has passed through the extension, it is passed on to the trap, a device developed to skim the fish from the discharge. The principal feature of the trap is an adjustable inclined screen through which most of the water flows leaving the fish and a comparatively small amount of water to pass over and into a specially provided collection pool at the end of the trap. The screen used in this trap is a Monel stainless steel no. 14 constructed of 0.009" diameter wire, occupying 24% of the area. The screen is placed on top of a Pedlar grating No. 10-1½-60 which is supported by a wooden frame constructed from 2" x 4" timber. The frame is hung at the ends of four 5/8" diameter steel rods suspended from the sump ceiling.

The collection compartment at the end of the trap is divided into three sections. (See fig. 16). A special collection box is fitted into the central portion to collect fish at the end of their journey through the turbine. The collection section of the trap is screened so that fish or parts of fish are all collected. On the two side-sections, the screen slopes slightly toward the central portion. Any fish caught on these two screens are placed in the collection box.

A training wall of ½" plywood is provided around the screen and the collection compartment to prevent any escape of fish into the sump.

The flow of water through the screen is regulated by means of a 3/4" thick regulating board installed beneath the screen. It is hung at the end of four brass rods fitted with screw threads and wing nuts. By raising or lowering the board, the flow can be adjusted. The flow can be further adjusted by changing the slope of the screen. This is done by adjusting the position of the rods from which the screen is suspended. The current created by the flow of water from the top side of the regulating board flows upward through the side screen of the collection compartment and keeps the fish off the screen. The transition and the trap can be set in any desired position by adjusting the length of the various rods from which the system is suspended.

<u>The Fish Collection Box</u>

The fish collection box is a 12" x 9" x 6" brass box with an open top. The top half of its walls is screened to allow the excess water to flow through (see fig. 27a). A brass plate bent to fit the outside corner of the box is used to transfer fish from the box to the other container. The box fits the central portion of the collection compartment in such a manner that its top comes up to the elevation of the side screens on both sides of the central portion.

2.4 Arrangements for the Supply of Compressed Air

Air injected into the turbine is drawn from an air compressor through an air duct one inch in diameter. A nozzle, machined according to the A.S.M.E. standard dimensions, with an inside diameter equal to one-half the diameter of the air pipe, is installed as an air meter. A straight brass pipe 4' long and 1.06" diameter precedes the nozzle to ensure uniformity of the approaching air flow at the nozzle. The reading of the water manometer, connected across the nozzle, is taken as the nozzle pressure drop, from which the mass flow of air across the nozzle is calculated using the flow coefficient from published data.

The flow of air depends on the absolute temperature, the density of the air and the pressure drop across the nozzle. The air temperature used in the calculations is based on 50°F, the mean temperature of the air outside the laboratory where the air supply of the compressor was drawn. The range of the air temperature during the experimental period was 40°F to 65°F. Variations of the air temperature up to 25°F will change the mass density of air by less than 5%.

A pressure gauge is installed about 1 ft downstream from the nozzle to indicate the air pressure. The reading can be taken as sufficiently accurate to represent the pressure of the air upstream from the nozzle because the pressure drop across the nozzle is very small.

Because the nozzle was designed for a higher anticipated air flow, the manometer readings were usually small. The quantity of air as calculated, while not precise, is sufficiently accurate for purposes of comparison.

From the nozzle, four plastic tubes convey the air to two injection points - in the penstock upstream from the turbine and in the draft tube immediately downstream from the blades. Four holes drilled at equal distances from each other in the penstock and in the draft tube ensures that air is uniformly mixed with the water. Air valves are installed at each injection point to control the quantity of air going into the turbine at each entry.

Air pressure in the air compressor tank is kept above 96 psi. By using a pressure regulator in the air supply system, the air pressure is regulated down to any desirable value. No fluctuation of air pressure during the entire experimental period was observed.

For one series of tests, a 3" diameter steel pipe with valve is installed as a vent in the draft tube of the turbine 1 ft downstream from the blades (see fig.4). Atmospheric air is sucked into the draft tube. Flow of air used in these tests was not measured.

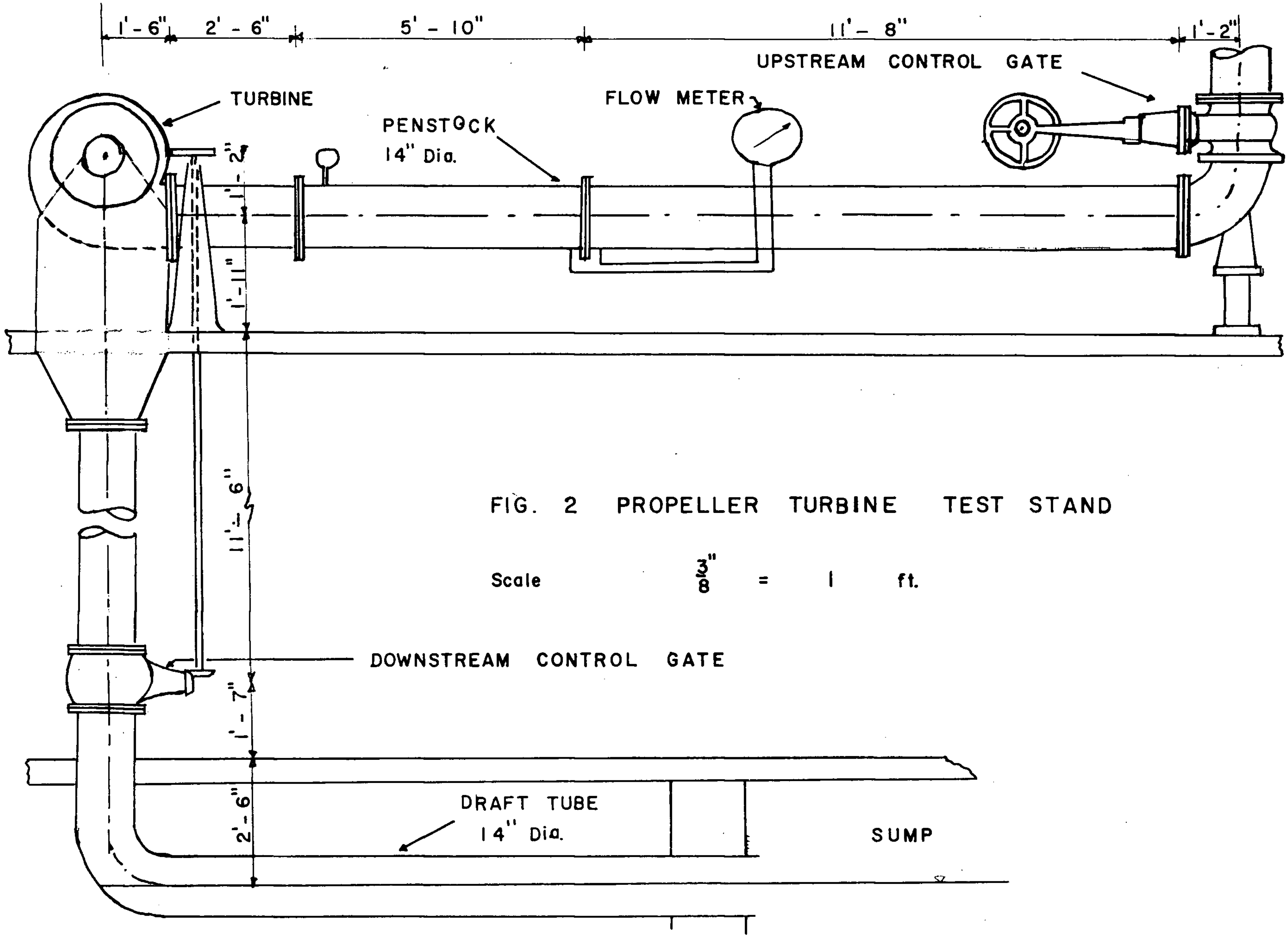

FIG. 2 PROPELLER TURBINE TEST STAND

Scale $\frac{3}{8}$" = 1 ft.

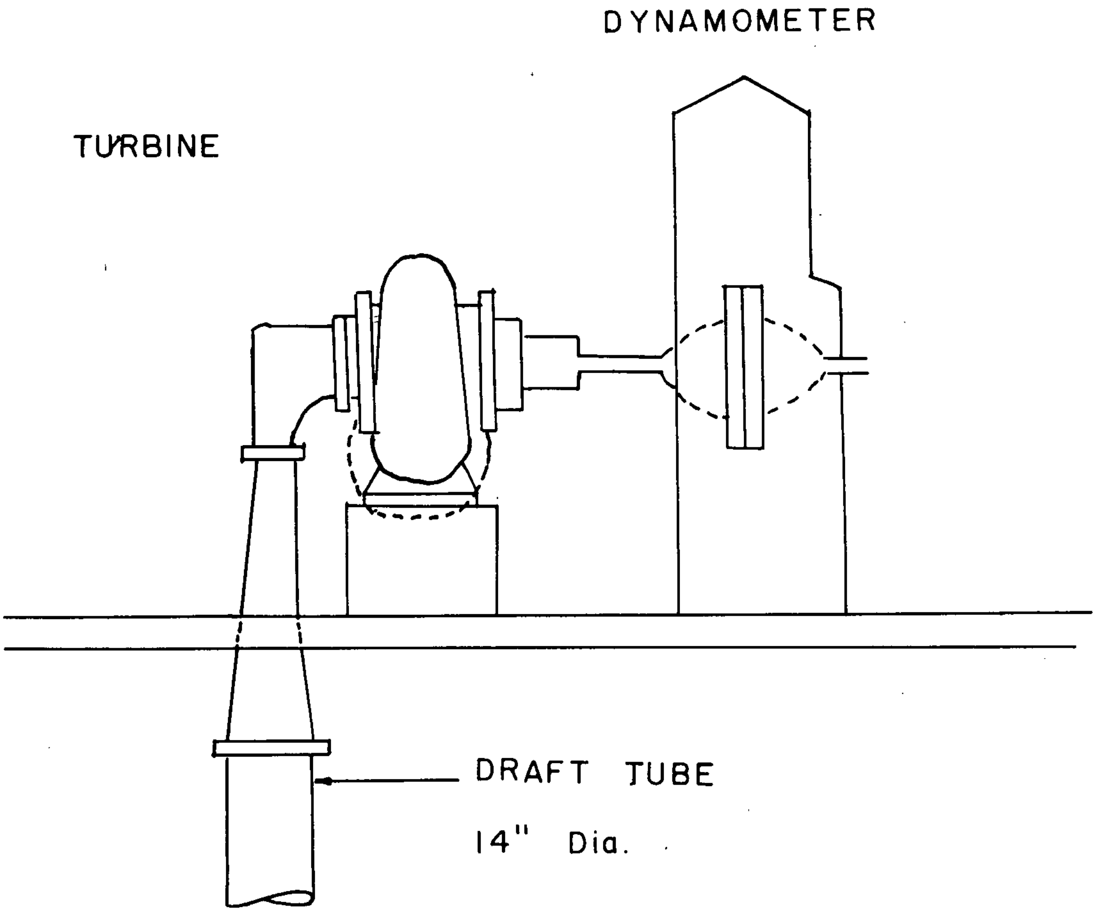

FIG. 3 PROPELLER TURBINE AND DYNAMOMETER

Not to scale

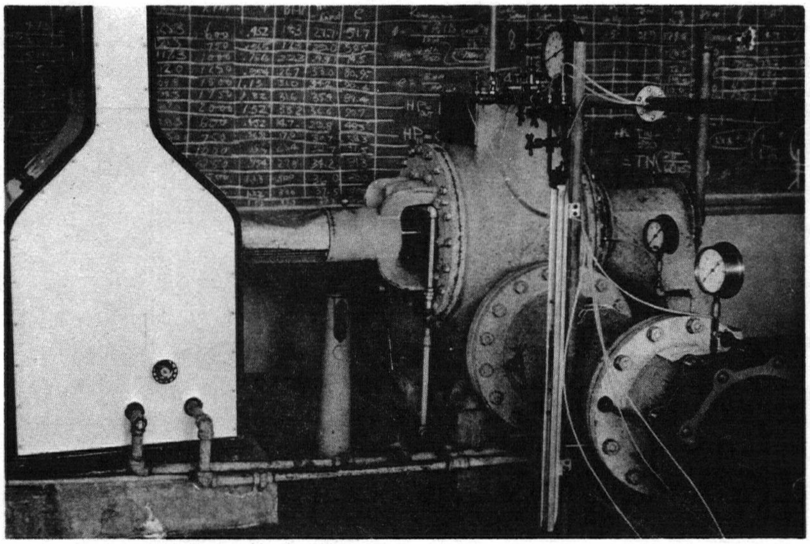

FIG. 4 GENERAL VIEW OF THE TESTSTAND

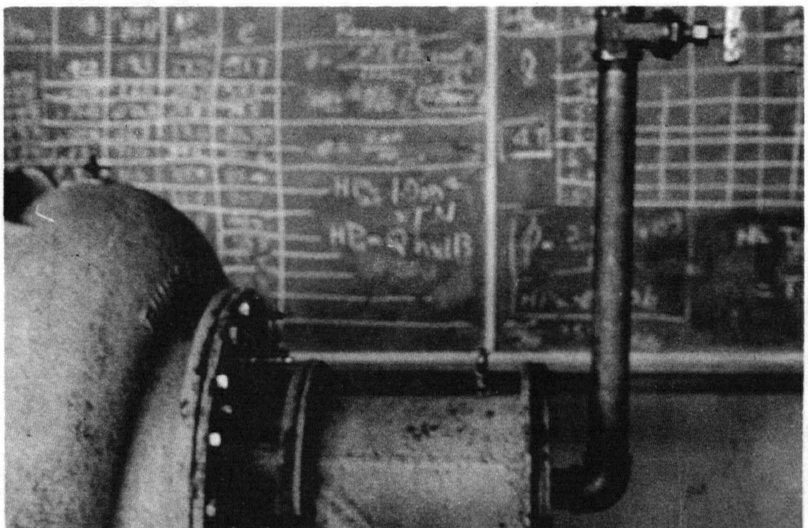

FIG. 5 LARGE AIR VENT IN THE DRAFT TUBE

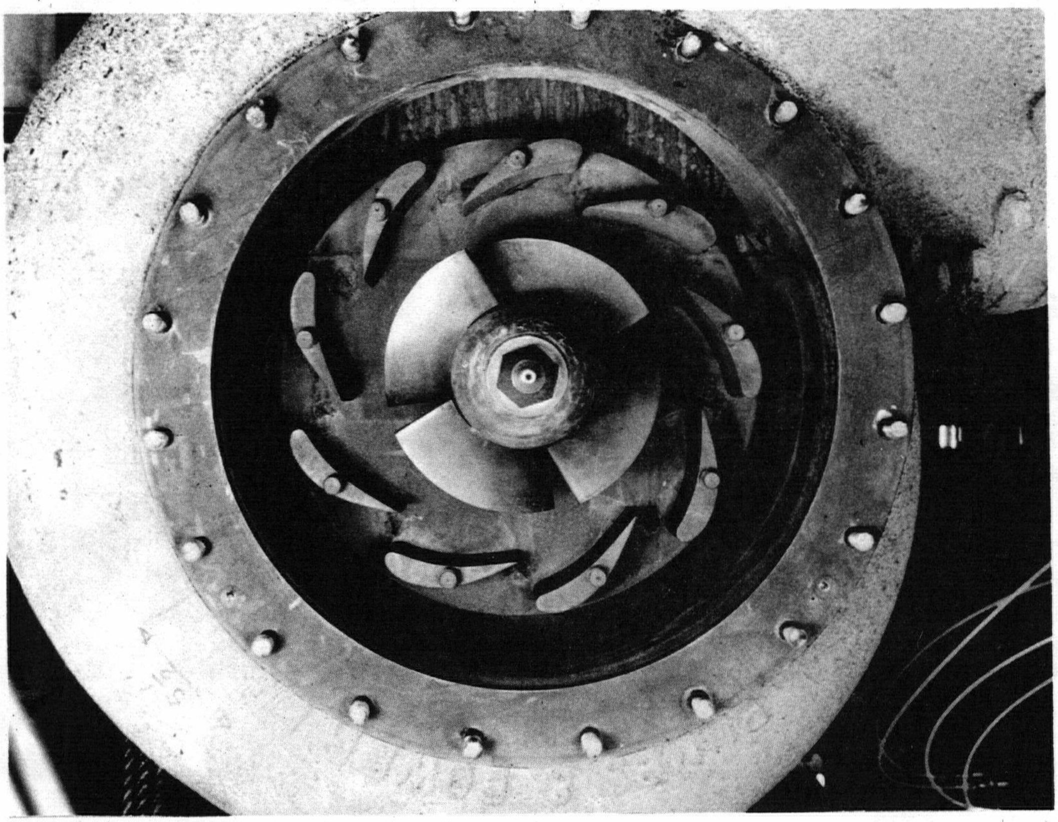

FIG. 6a WICKET GATES AT POSITION NO. 6

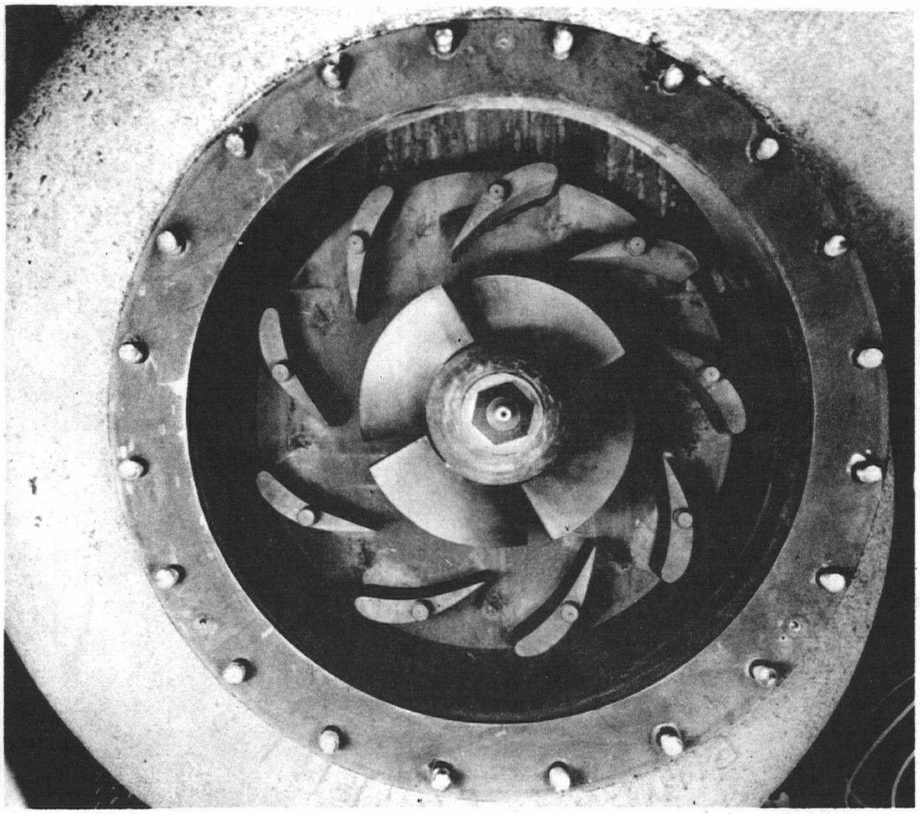

FIG. 6b WICKET GATE AT POSITION NO. 9

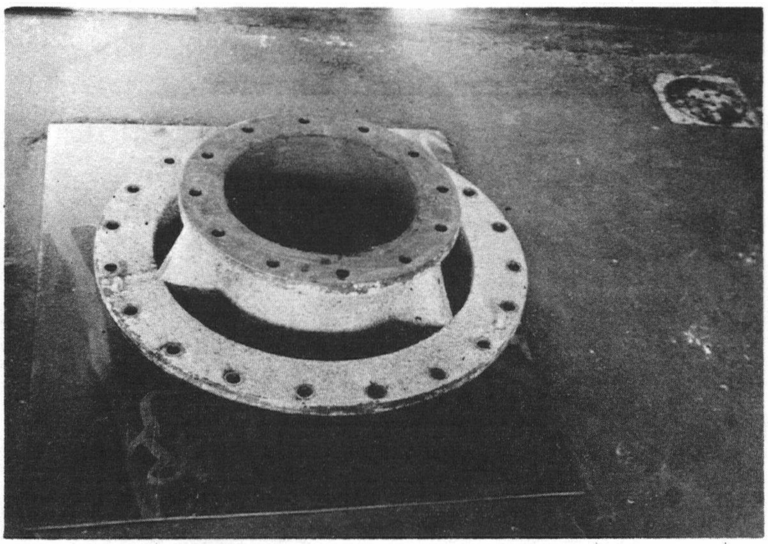

FIG. 7 DRAFT TUBE IMMEDIATELY DOWNSTREAM OF THE RUNNER

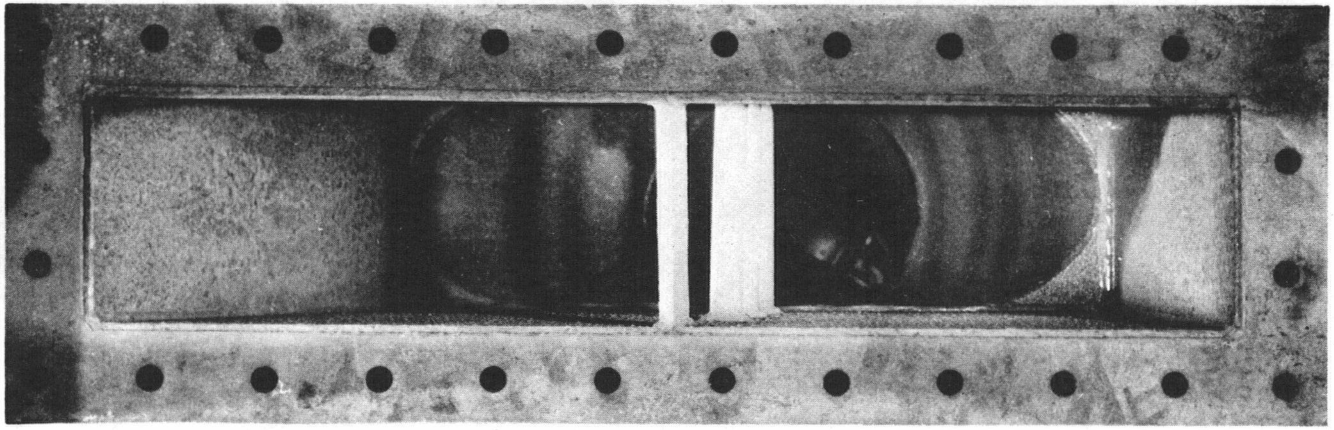

FIG. 8 TOP VIEW OF DRAFT TUBE SHOWING FISH OBSTACLES

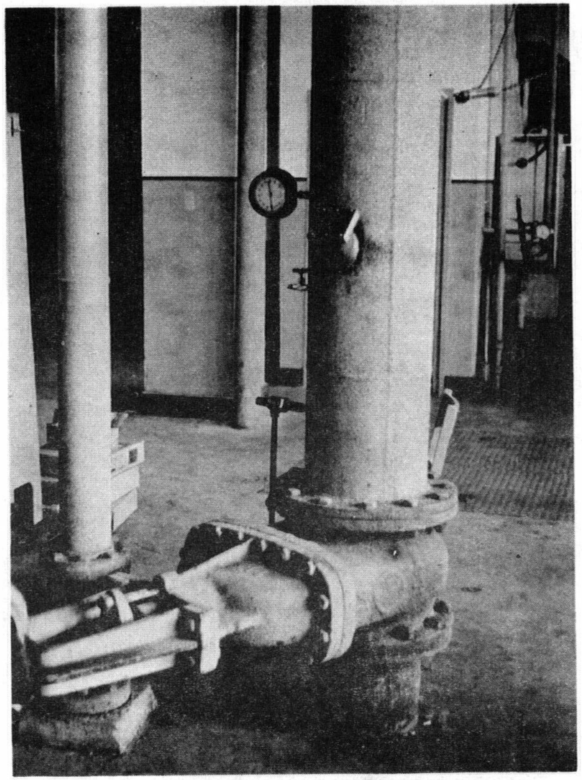

FIG. 9 FISH INJECTION POINT BELOW THE CONTROL GATE

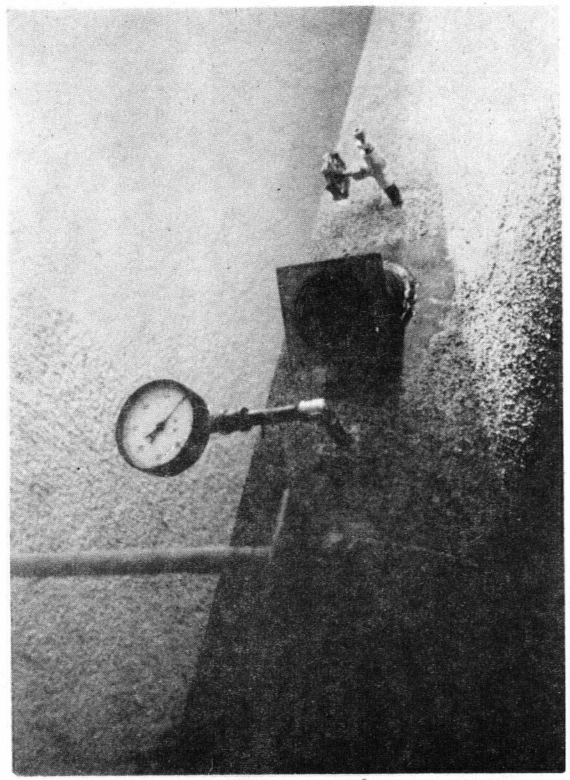

FIG.10 FISH INJECTION POINT ABOVE THE DOWNSTREAM CONTROL GATE

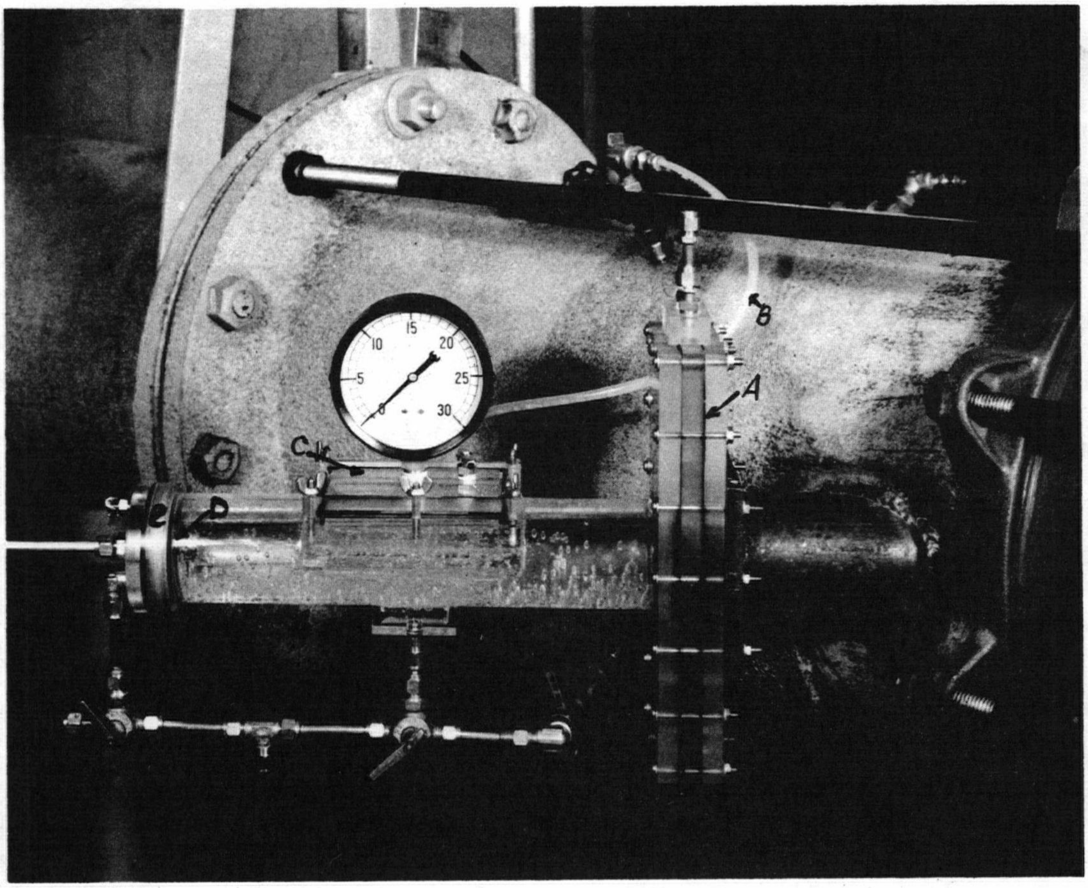

FIG.11 THE FISH INJECTOR

a. Ring-C Follower Gate

b. Pressure equalising connection

c. Fish chamber lid with pressure gauge and air escaping valve

d. Plunger and rod

e. Screw cap and air escaping valve

f. City water entrance

g. Fish chamber drainage system.

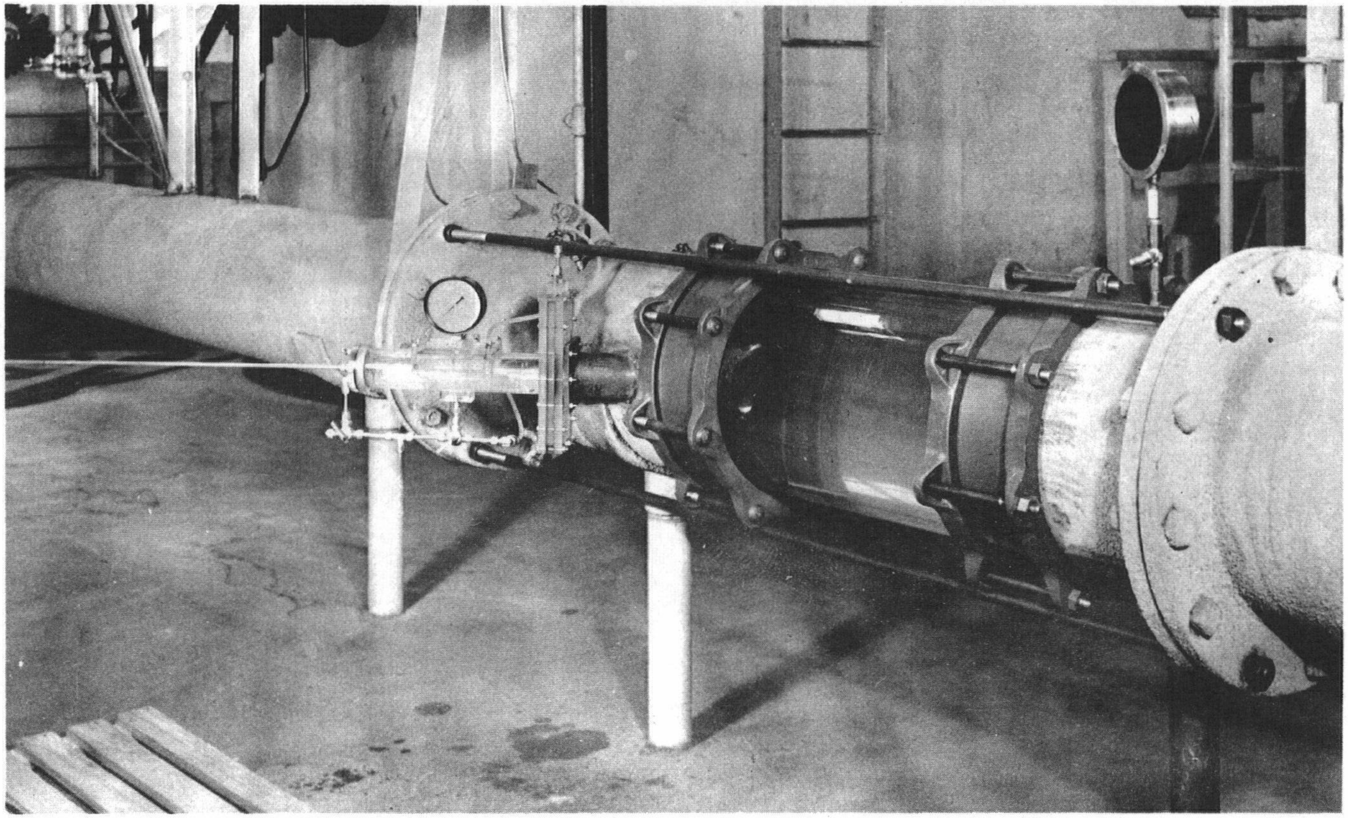

FIG.12 FISH INJECTOR AND THE PLASTIC SECTION OF THE PENSTOCK

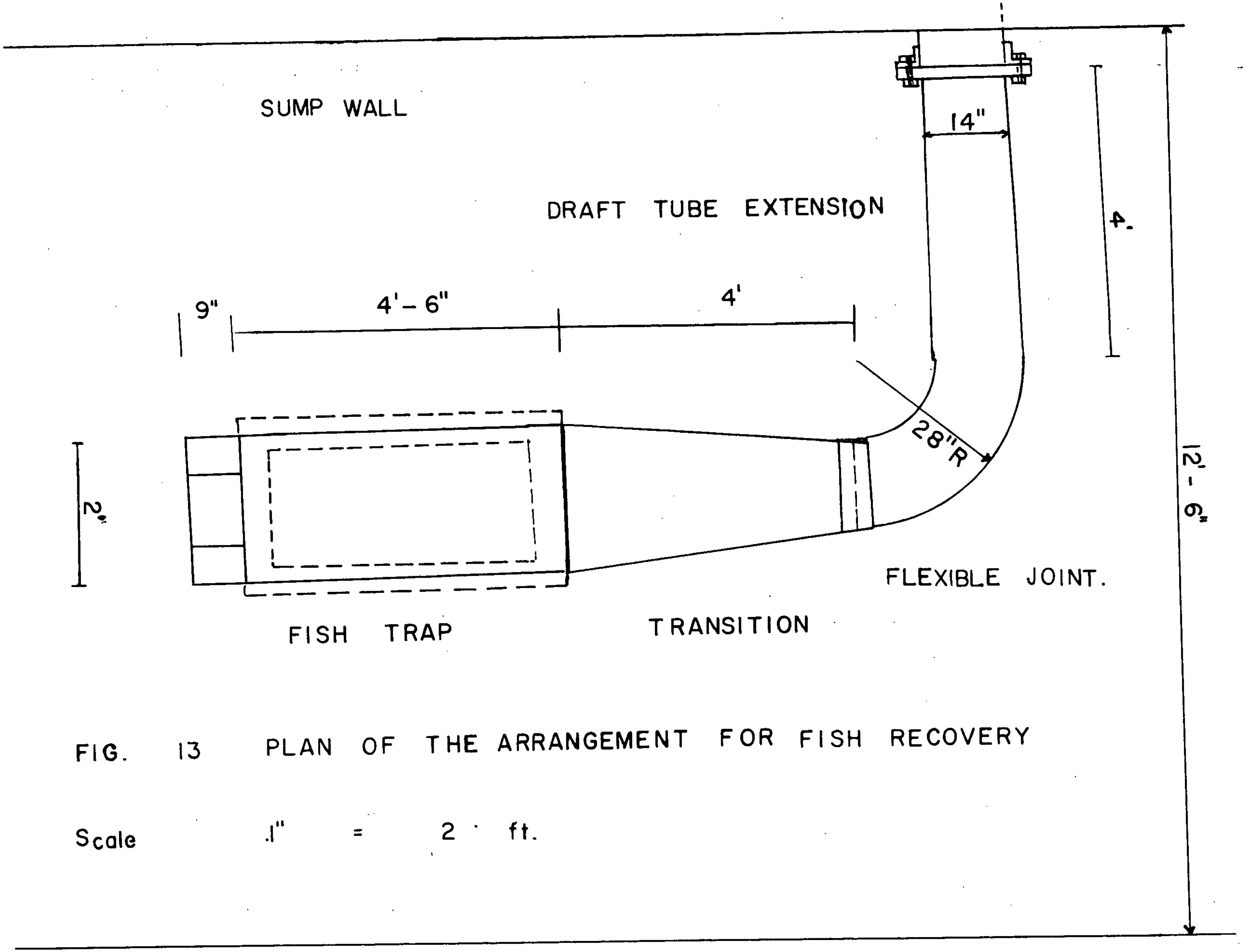

FIG. 13 PLAN OF THE ARRANGEMENT FOR FISH RECOVERY

Scale .1" = 2 ft.

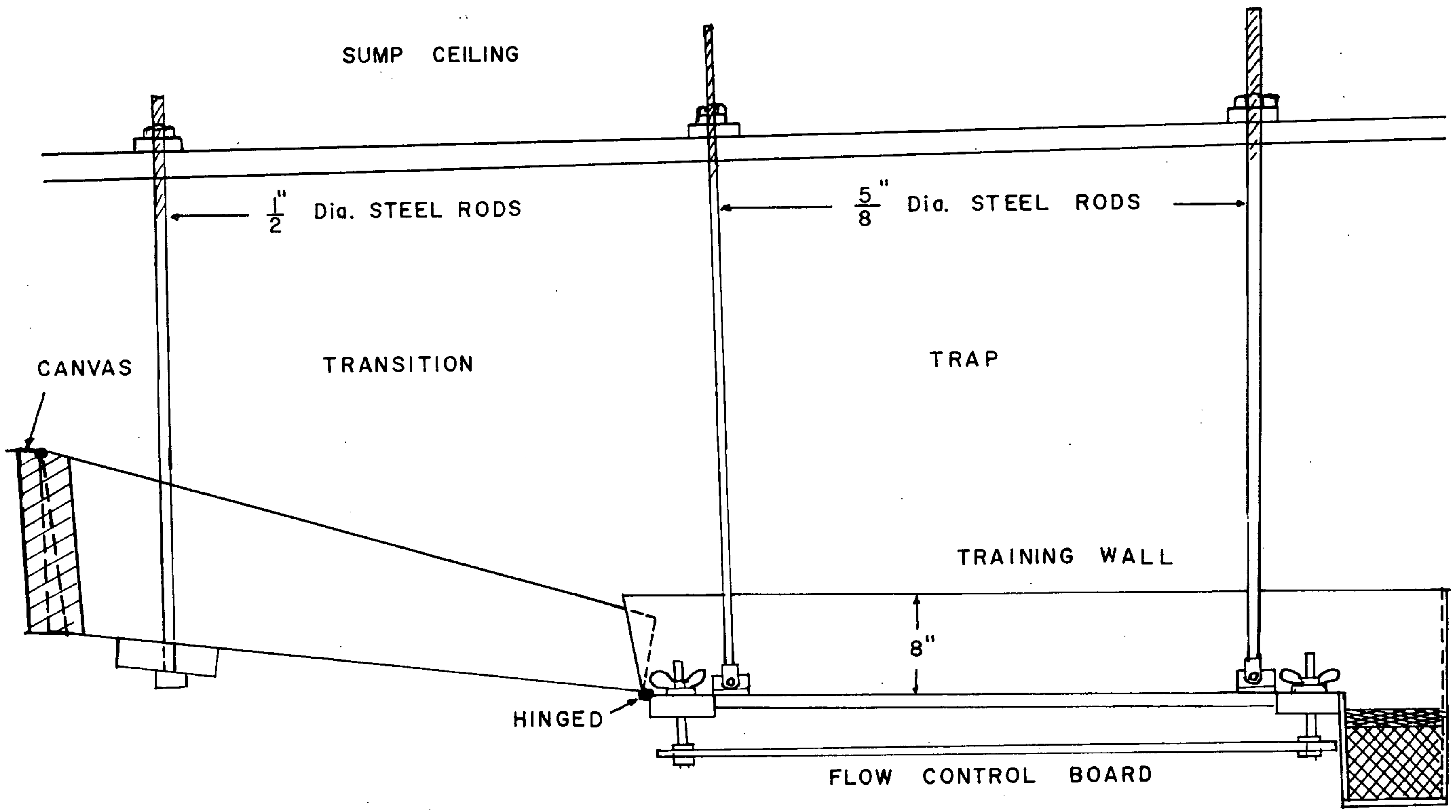

FIG. 14 SIDE VIEW OF THE ARRANGEMENT FOR FISH RECOVERY

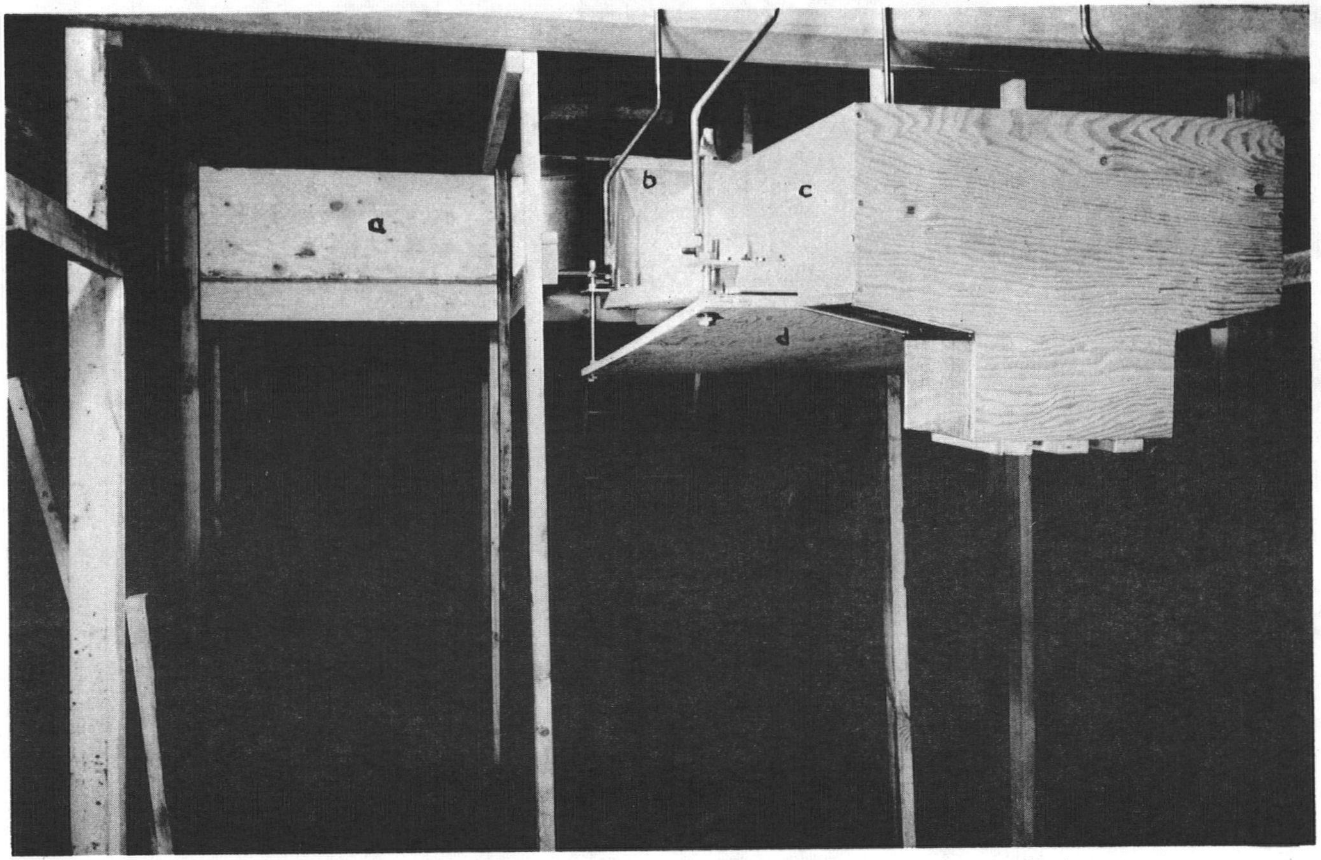

FIG.15 FISH RECOVERY GEARS

a. Draft tube extension c. Trap

b. Transition d. Flow control board

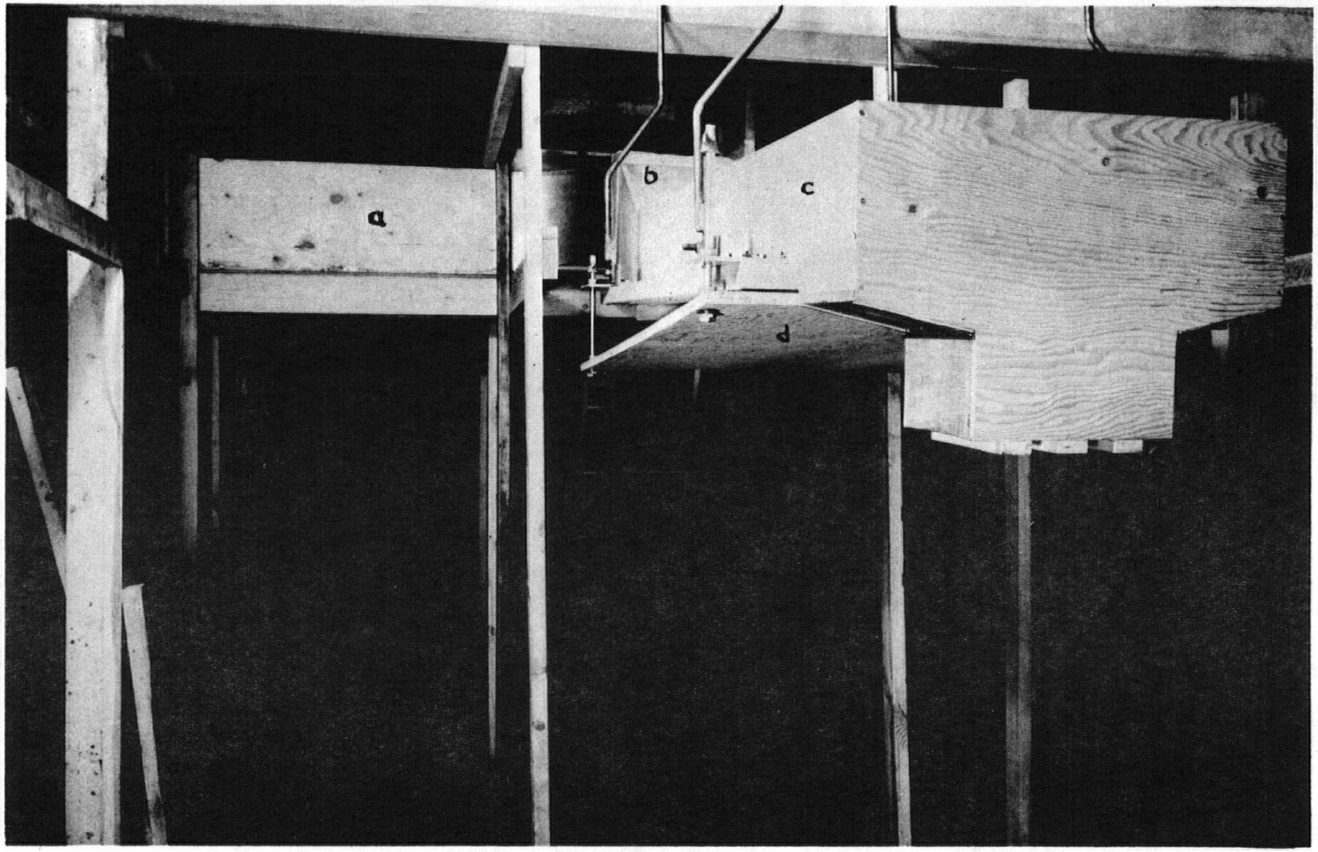

FIG.15 FISH RECOVERY GEARS

a. Draft tube extension

b. Transition

c. Trap

d. Flow control board

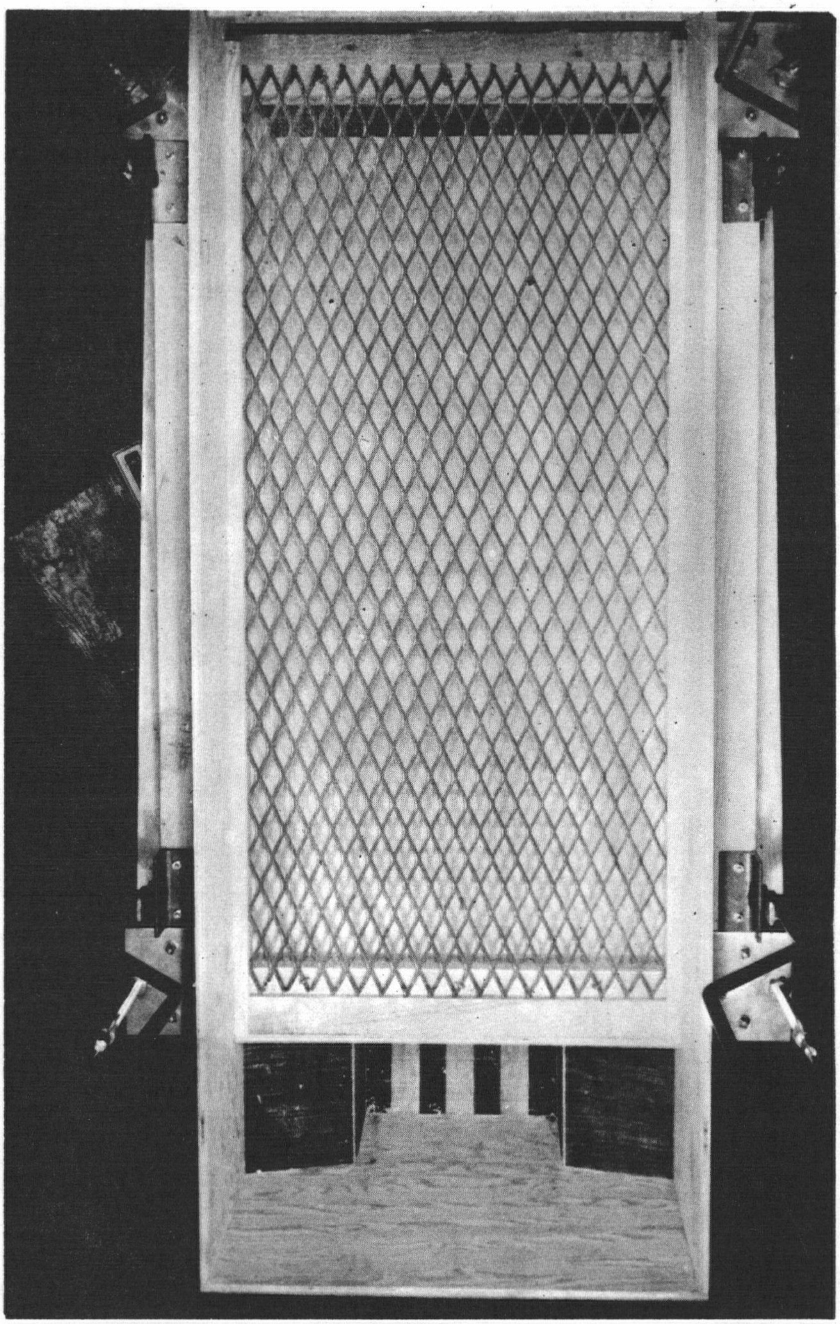

FIG.16 TOP VIEW OF THE TRAP

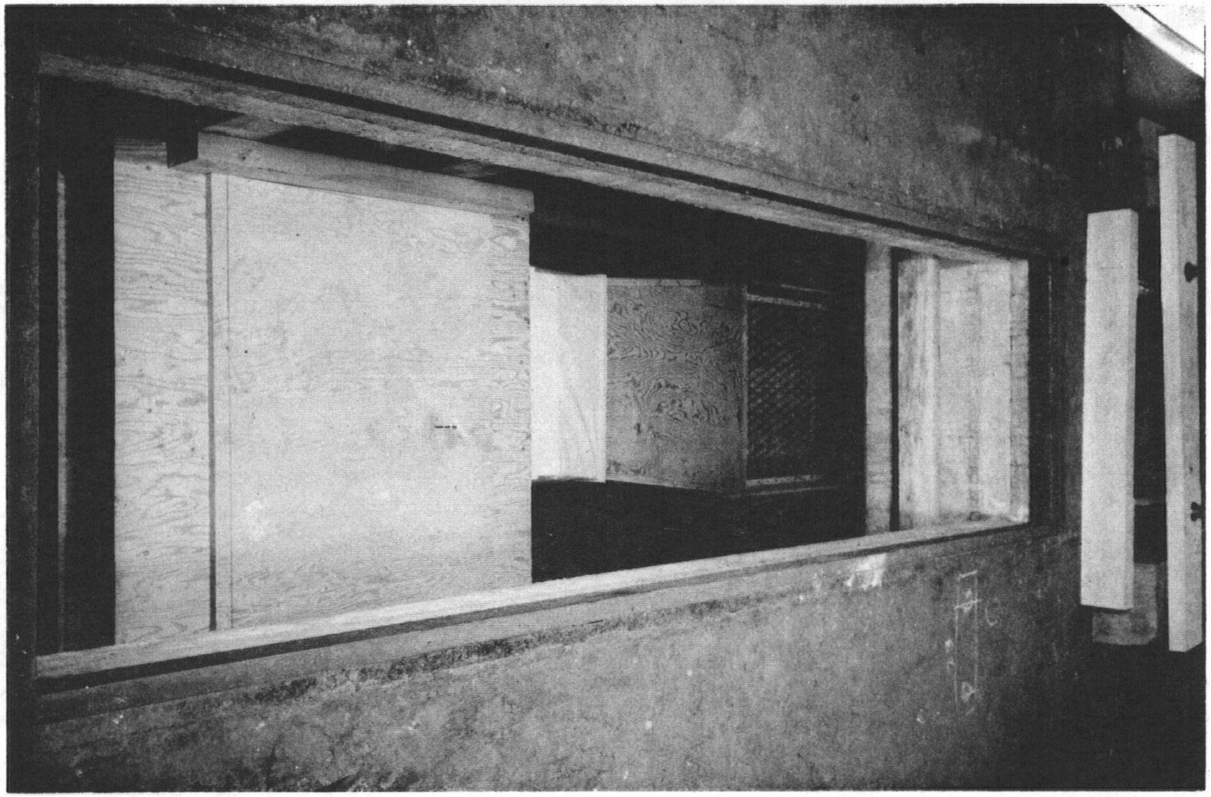

FIG.17 FLEXIBLE JOINT AT DRAFT TUBE EXTENSION AND THE TRANSITION

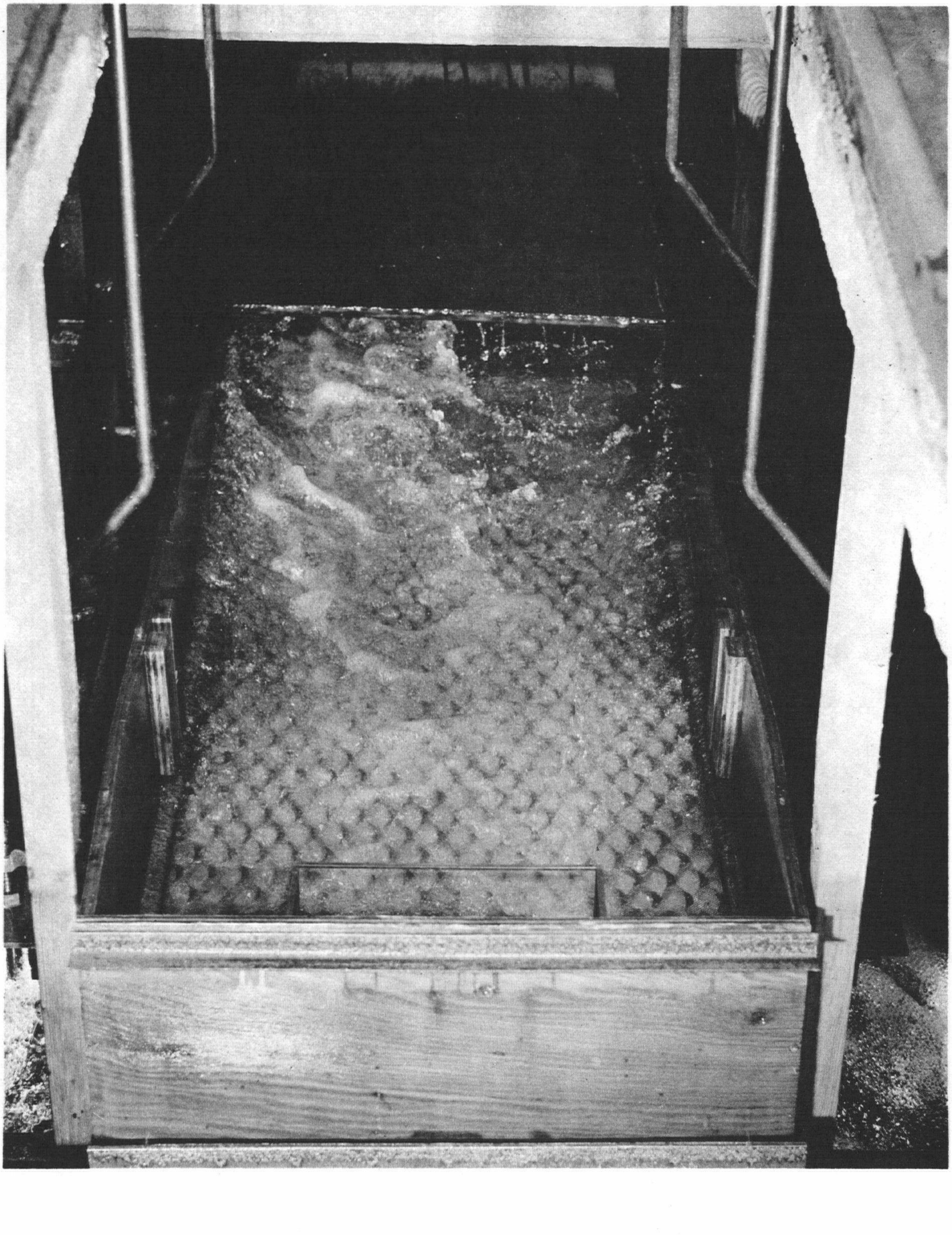

FIG 18 FISH TRAP DURING TEST

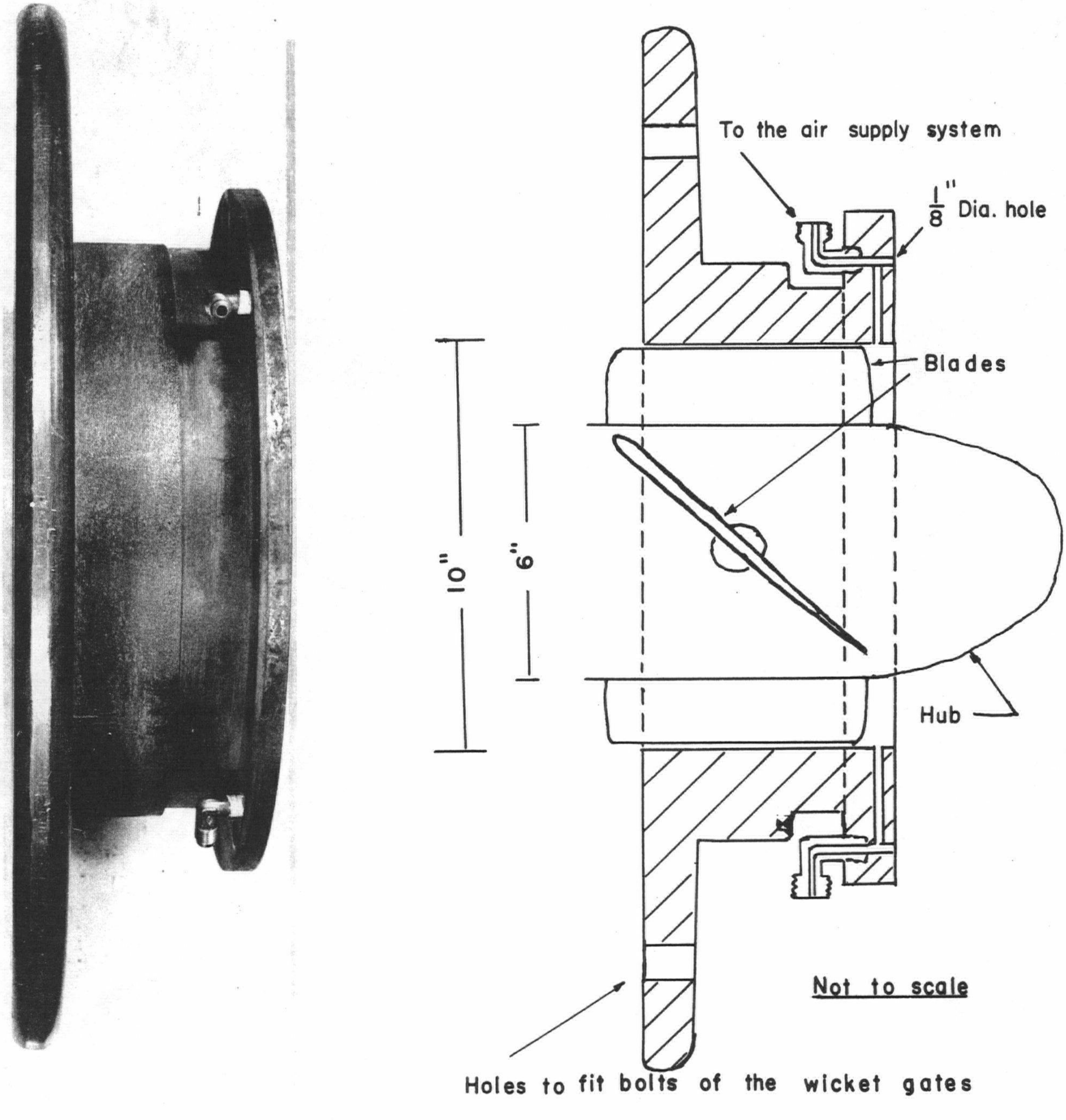

FIG. 19 AIR INJECTION POINTS IMMEDIATELY DOWNSTREAM FROM THE BLADES

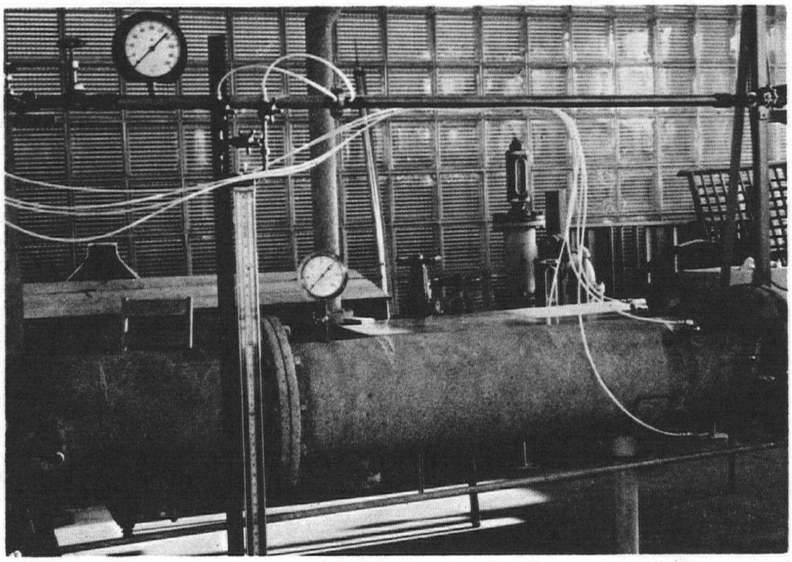

FIG.20a ARRANGEMENT OF AIR SUPPLY SYSTEM

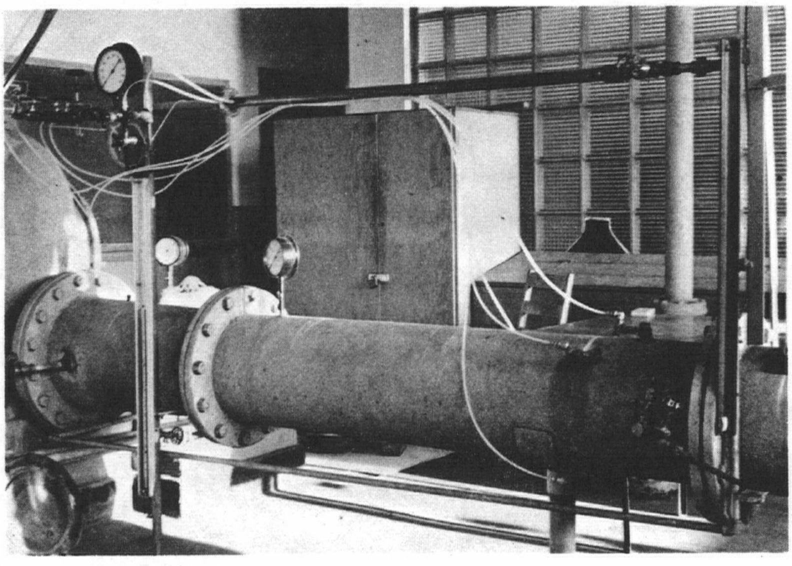

FIG.20b LOCATIONS OF INJECTION OF AIR INTO THE PENSTOCK

CHAPTER III

TEST PROCEDURE

3.1 Test Specimens

Laboratory Survival Test

Pink salmon fry about one month old from Harrison Lake, B.C., were used in a survival test to determine the mortality in the laboratory throughout the period of testing. It was found that these fish could be kept alive in the laboratory with negligible mortality, providing that they were fed regularly and that the temperature of the water in their tank was kept at approximately $47^{\circ}F$.

Fish Used for Low Turbine Speed Fish Mortality Test

For a mortality test at a turbine speed of 600 rpm, the specimens used were Chum fry hatched at the University Hatchery, U.B.C. They were approximately 1½" long and were from four to seven weeks old at the time of the tests. Fish were fed regularly throughout the test period.

Fish Used for High Turbine Speed Fish Mortality Test

For a mortality test at a turbine speed of 1800 rpm, the specimens used were Coho fry from Robertson Creek, Vancouver Island, B.C. Fish were approximatley 1½" long and were from one to two months old at the time of the test. The feeding of fish was stopped at the start of the testing period in an effort to keep the length and size of the fish the same throughout the testing period. (Fish were not fed for 13 days.)

3.2 Test Procedure

The procedure generally followed in making a test is described in the following paragraphs. The results are tabulated in the Appendix III and the general discussion of the results is made in Chapter IV.

Turbine Fish Mortality Test

The overhead tank was first filled up and the turbine started. The turbine operating conditions were set at a predetermined value. The penstock and draft tube pressure was adjusted so that the total effective head of the turbine was 50 ft of water. The draft tube suction was set at a specified value. Pressure control was achieved by manipulating the upstream and downstream control gates. The rpm of the turbine was kept constant at a desirable value by manipulating two control valves of the dynamometer. The fish trap was then arranged so that the optimum amount of water flowed into the collection compartment at the end of the trap. The fish collection box was placed in the central portion of the collection compartment. Packing compound was used to seal off all cracks and openings around the rim of the box so that fish did not escape from the box. Readings of the turbine discharge, penstock pressure, out-put torque, rpm and draft tube suction were recorded.

Fish, 80 in number, which had been previously counted and kept in a holding tank, were transferred to the fish injector. Fish were placed in the injector chamber and the lid replaced.

By using the equalizing valve, the pressure in the fish chamber was increased to the same value as that in the penstock. The pressure equalizing process took 10 to 30 seconds to complete; simultaneously all air inside the fish chamber was carefully removed to ensure that no fish came in contact with free air during the process of pressurization. The injector gate was quickly opened so that the city water pressure slowly pushed the plunger forward, forcing the fish into the penstock. When the plunger had travelled the whole length of the leading pipe and all fish were in the penstock, the city water valve was shut off. The penstock pressure then returned the plunger to its original position. The injector gate was closed to complete the injector cycle.

A time of 60 seconds was allowed to elapse from the moment the plunger had forced all fish into the penstock to the time they were removed from the trap. An assistant was stationed at the trap to place any fish caught on the side screens in the fish collection box and then to remove the collection box from the trap. The contents of the box were poured into a basin where the live fish were separated from the dead and placed in a nylon net. After counting the number of immediate survivors, the assistant transferred fish back to the holding tank for a delayed mortality observation. At no time during the test were live fish allowed to be out of water. Dead fish from the test were counted and the decapitated parts matched as far as possible to form complete bodies. In the case of missing fish, the turbine was stopped and the whole system drained to see if they could be recovered. All dead fish were examined by a biologist to determine and record the types of apparent injuries and to measure the length of those that were measurable. The delayed mortality was recorded and fish bodies examined each day. At the end of a three day holding period, all surviving fish were anaesthetized and their length measured.

To eliminate the possibility of fish getting a temperature shock when introduced into a warmer water, the water in the sump was drained each evening prior to the testing day and fresh cold city water taken in so that the temperature of water in the system was close to that in the fish holding tank. The temperature of the water in the holding tank was kept at about 47°F.

In tests in which compressed air was injected into the turbine, the air was admitted before the fish were introduced into the penstock and before the readings of air meter and air pressure were recorded. The only deviation from this procedure occurred when atmospheric air was introduced through a vent in the turbine draft tube. Although no air meter was installed to measure the air flow through the vent, it was observed that the draft tube suction gauge reading decreased directly with the valve opening; wherefore the reading on the draft tube suction gauge was used as an indication of the amount of air being admitted into the turbine draft tube.

Test series to investigate the fish mortality with and without the admission of air were carried out at turbine speeds of 600 rpm and 1800 rpm. Tests on turbine fish mortality without the admission of air were carried out at 300, 900 and 1200 rpm.

3.3 Fish Mortality Test with the Turbine Runner Removed

The turbine runner was first removed and the draft tube gate set at a wide open position so as not to interfere with the passage of fish in the draft tube. The upstream control gate was partially opened so that the discharge was approximately equal to the discharge normally obtained in the tests at turbine speed of 600 rpm as previously described. The procedure followed thereafter was the same as that described in the preceding section. The test was then repeated for a discharge approximately equal to that in the 1800 rpm test series. The reason for doing this was to keep the degree of turbulence in the system at approximately the same level as in the test with the turbine runner.

3.4 Test for Fish Mortality in the Draft Tube

In order to check the mortality of fish in the draft tube and the possibility of the downstream control gate interfering with the passage of fish in the draft tube, two fish injection points are provided for in the draft tube, one upstream (fig.10) and one downstream from the control gate (fig.9). At the opening above the control gate, fish were poured into the draft tube, otherwise the procedure followed was the same as in 3.2. The introduction of fish into the opening downstream from the control gate was through the injector and the same procedure as in 3.2 was followed.

3.5 Preliminary Test to Observe Extent of Delayed Mortality

Five preliminary turbine fish mortality tests were carried out using the same pink fry mentioned in 3.1 as test speciments. The results are tabulated in Table VIII and in Table X (P-series). The primary object of the test was to check the functioning of the equipment. It was observed that the delayed mortality occurred within two days after the test. The period of observation for the delayed mortality for the subsequent tests was limited to three days.

3.6 Fish Mortality Rate at the Trap

When fish were dumped into the water in the trap operating under the same condition as in the turbine fish mortality test and held for one minute, no immediate mortality was observed. The delayed mortality was less than 2%; hence the mortality rate of fish at the trap alone was negligible.

Biological Examination of Dead Fish

The results of the biological examinations of all dead fish are presented in Table IV. The classification of types of injury was based on those used by the U.S.Army Corps of Engineers. In each set of tests under identical turbine operating conditions, the number of occurrences of the apparent type of injury likely to cause death are summed and expressed as a percentage of the number of dead fish examined. The results appear in Table II.

The total percentage of occurrence of every type of injury in Table II exceeds 100% because more than one injury is often found in one dead fish. Figures appearing in the columns headed "Decapitation and Laceration" and "non apparent injury" represent the true percentage of occurrences. In the case of "decapitated fish", no further attempt is made to identify the types of injury. In the case of "non apparent injury", dead fish showed no visible sign of injury; hence the number of this occurrence appears in one column only.

3.7 Effect of the Admission of Air on the Turbine Performance

The turbine was set at 50 ft hydraulic head and operated at 600 rpm with the wicket gate set at position No. 6. Air was admitted into the draft tube immediately downstream from the blades. Air pressure and air meter reading were recorded. The test was repeated using various amounts of air. The draft tube suction was reset but the total head was maintained at 50 ft; the tests were repeated for six values of the draft tube suction. The whole procedure was repeated for the machine speeds of 1200 and 1800 rpm. The wicket gate setting was then altered to No. 9 position and the entire programme repeated.

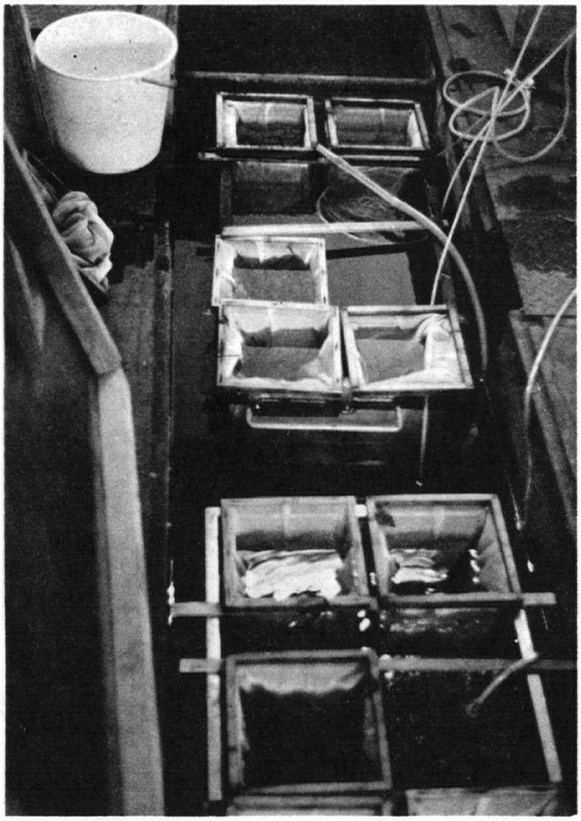

FIG.21a FISH HOLDING TANKS

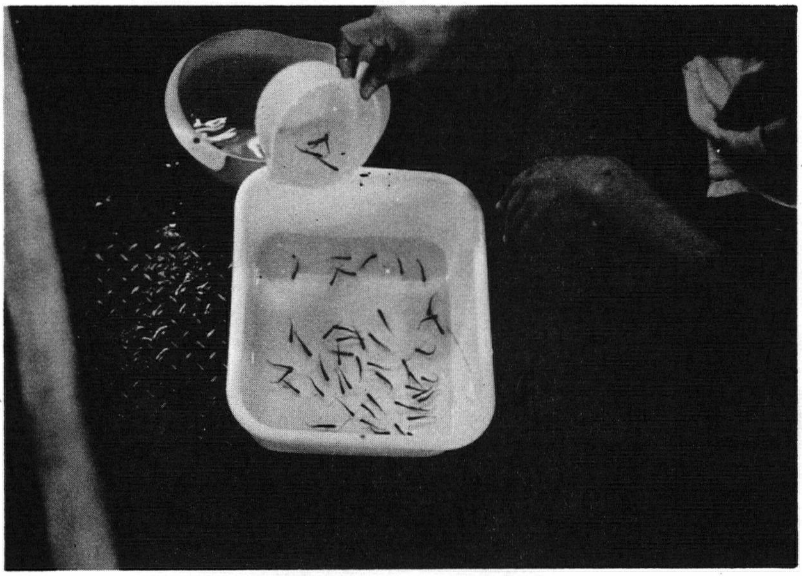

FIG.21b COUNTING OF FISH

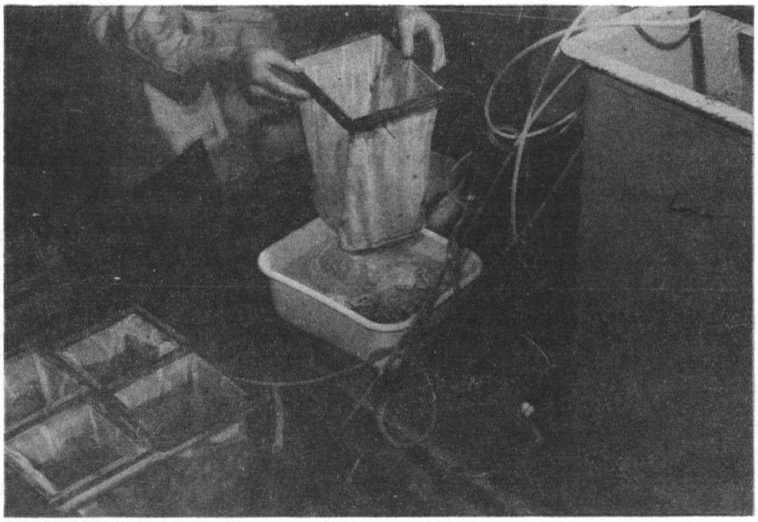

FIG.22 TRANSFERRING OF FISH TO BASIN COMPLETED

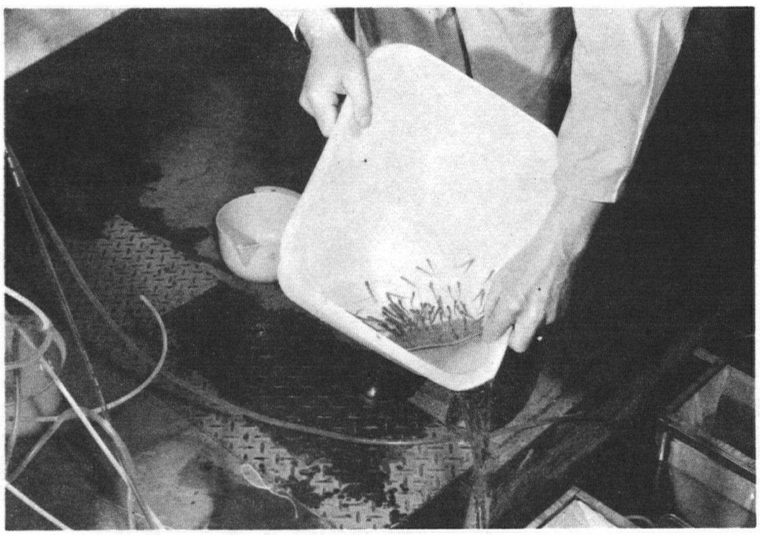

FIG.23 GETTING RID OF EXCESS WATER

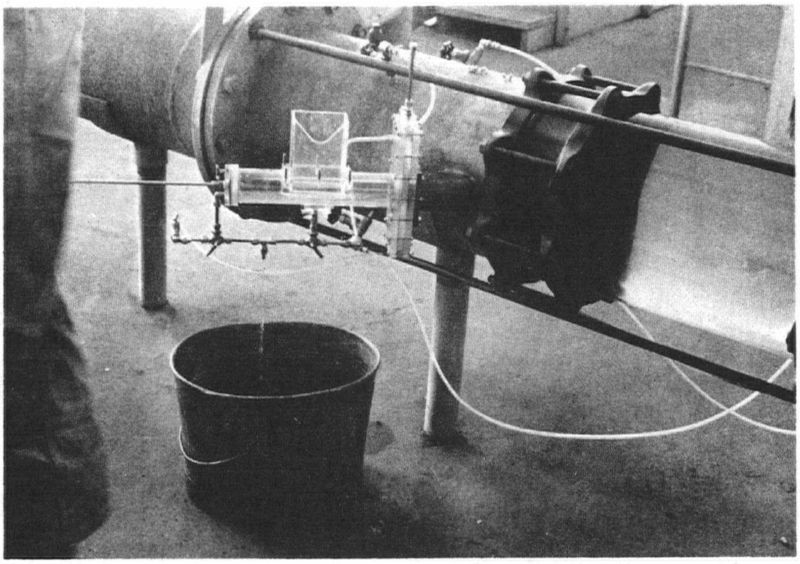

FIG 24a THE INJECTOR AND EXTENSION

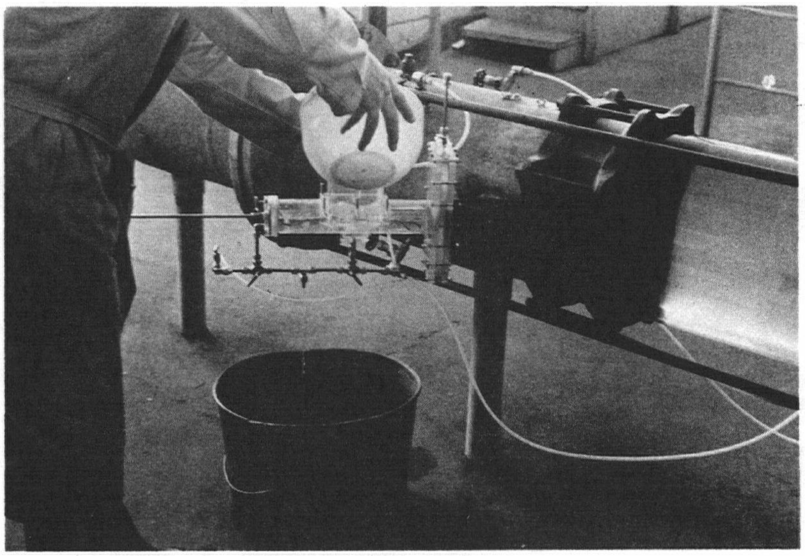

FIG.24b FISH BEING POURED INTO THE INJECTOR

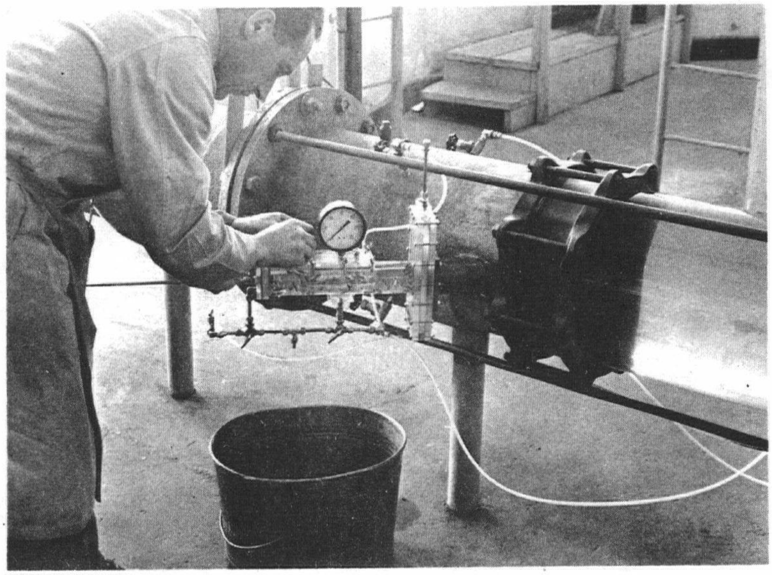

FIG 24c CLOSING THE INJECTOR LID

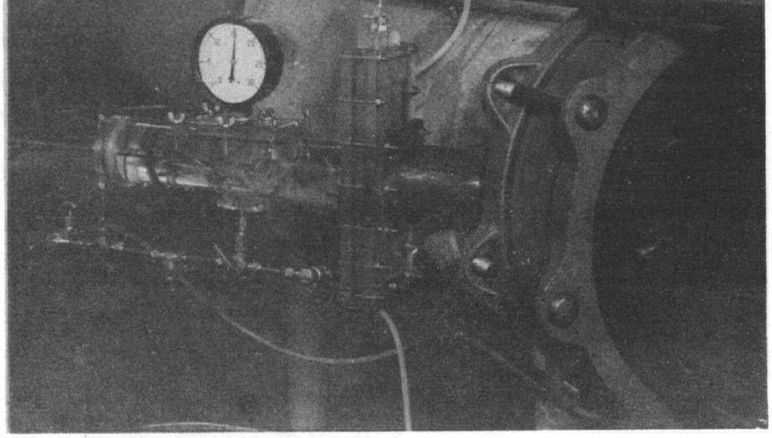

FIG 24d FISH BEING INTRODUCED INTO THE PENSTOCK

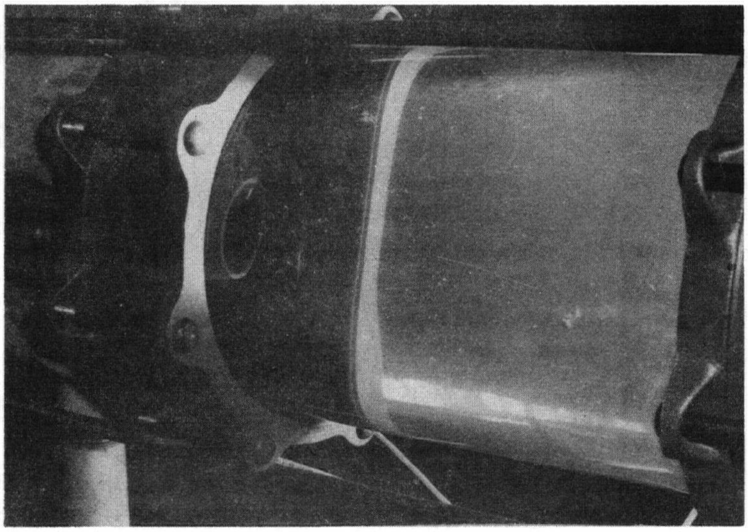

FIG. 25 FISH IN THE PENSTOCK

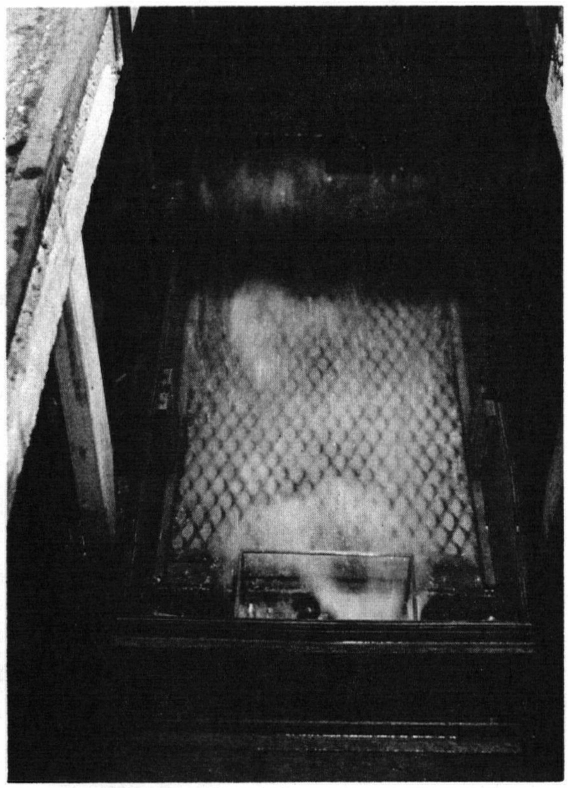

FIG. 26 FISH TRAP

FIG. 27a REMOVAL OF FISH COLLECTION BOX FROM THE TRAP

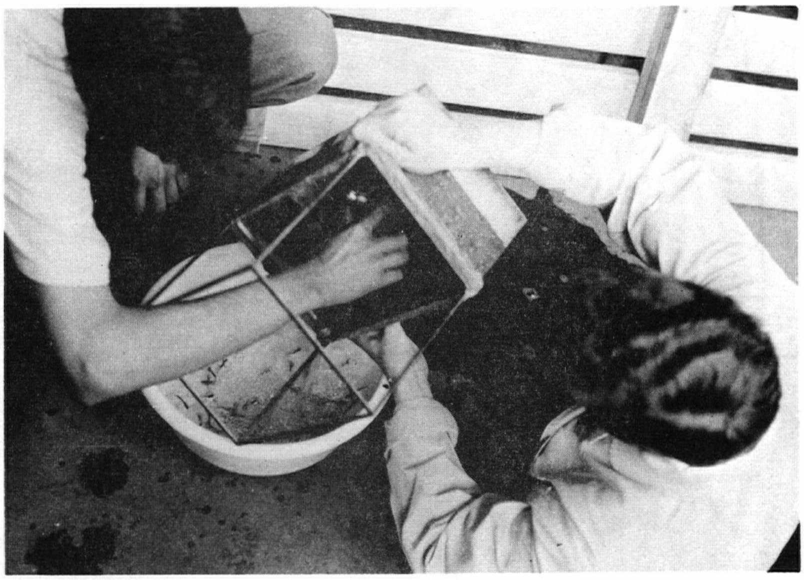

FIG. 27b FISH BEING TRANSFERRED INTO A BASIN

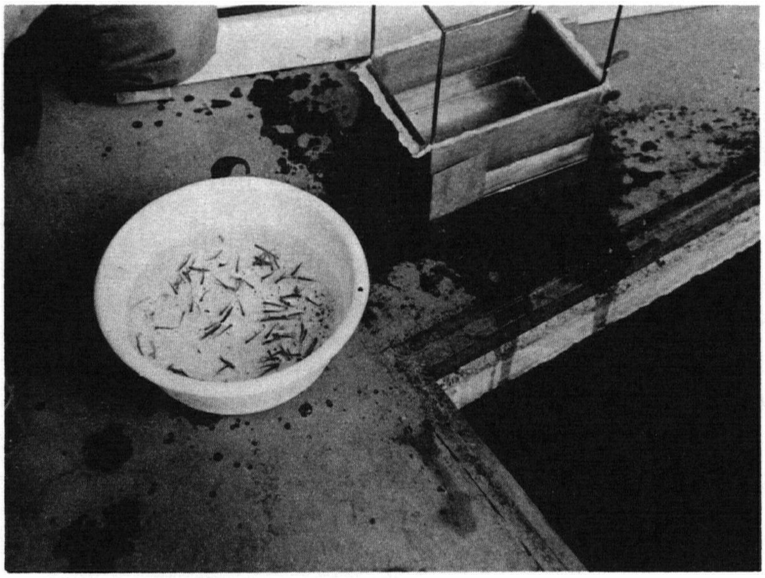

FIG.27c TEST FISH READY FOR SEPARATION

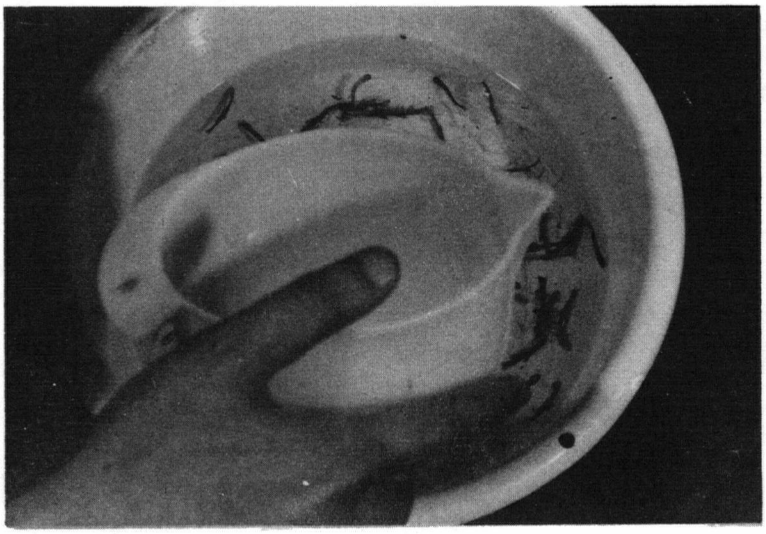

FIG. 27d SEPARATION OF LIVE FISH FROM DEAD FISH

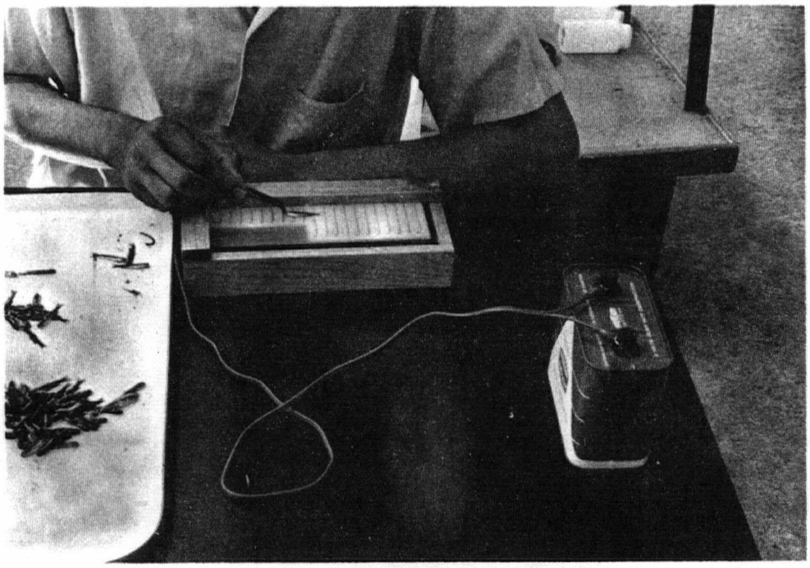

FIG. 28 FISH LENGTH MEASUREMENT

CHAPTER IV

DISCUSSION OF EXPERIMENTAL RESULTS

4.1 Effect of Turbine Operating Conditions on Fish Mortality Rate Effect of Turbine Speed on Mortality

As indicated in fig. 29 and Table I, the mortality rate of fish passing through the turbine operating under approximately the same head and sigma and variable speed are as follows:

Speed rpm	Efficiency %	Sigma	Head ft	Mortality Rate %
600	52	0.41	45.4	40
1200	81	0.39	50.5	42
1800	86	0.39	50	34

Although it appears that an increase in mortality rate accompanies the reduction in turbine speed, the results are inconclusive. The turbine speed is not the only variable in these tests. At 1800 rpm, the efficiency of the turbine is almost at the maximum possible for the 50 ft head (fig.29). At lower speed, the efficiency is less than 86%. Previous research (3,9) indicates that higher mortality rate is associated with low efficiency. It is then possible for the mortality rate of fish passing through the turbine operating at lower speed and lower efficiency to be higher than that at higher speed and higher sigma.

Two significant results of the tests are that (1) no decapitation of fish occurs at a turbine speed of 600 rpm or less, (2) decapitation increases progressively as the speed increases.

If it is assumed that fish travel at the same velocity as that of the water, then the impact velocity of fish at the leading edge of the blades is the same as the velocity of water relative to the leading edge of the blades. The relative velocities corresponding to various turbine speeds are as follows:

Speed rpm	Velocity of Water Relative to the Leading Edge of Blades ft/sec		Decapitation %
	At the Hub	At the periphery	
600	19	29	0
900	26.5	41.5	3.6
1200	36	54.5	9.1
1800	51	80	14.3

The tests show that if by chance fish collide with a blade, decapitation does not occur if the velocity relative to the blade is less than 29 ft/sec. The critical impact velocity between fish and the leading edge of the blades resulting in decapitation of the fish appears to be between 29 ft/sec and 41.5 ft/sec. Some fish obviously travel through the runner spaces without colliding with the turbine blades.

As indicated in fig. 30, the percent decapitation increases proportionally with the turbine speed-discharge ratio. In Von Raben's formula(10), for fish of the same length, the possibility of contact between fish and the blades is also proportional to the turbine speed-discharge ratio. Von Raben admits that the calculated possibility of contact is higher than the observed fish decapitation and suggests that a factor K be applied to the calculated value to bring it closer to the observed results. For the results in these tests, K is approximately 0.15.

Effect of Operating Sigma on Fish Mortality

In tests at a turbine speed of 600 rpm, Table VIII shows that the mortality rate of fish increases from 34% to 40% when sigma is reduced from 0.65 to 0.41. From the findings of previous research(3,9) this result is expected.

In tests at a turbine speed of 1800 rpm and efficiency of 86%, the mortality rate of fish reduces from 38% to 34% when the sigma is reduced from 0.59 to 0.39. An inconsistency of the results is thought to be due to the interference of the draft tube control gate with the passage of fish in the draft tube. At low sigma, the gate is left in a wide open position, whereas at the higher sigma, it is only partially opened. Fish could come in contact with the partially opened gate.

4.2 Effect of the Turbine Blades on the Mechanical Injuries of Fish

When fish were injected into the penstock with the turbine runner removed, some mortality occurred. The biological examination of all dead fish appears in Table II and Table IV, parts of which are shown on the following page.

It can be seen that the majority of the mechanical injuries suffered by fish passing through the turbine occurs as a result of collision with turbine blades. Fish colliding with other solid objects such as the wicket gates receive negligible mechanical injuries.

Test Conditions	Q cfs	Number of fish Injected	Number of dead Fish Examined	Cases of Mechanical Injuries			
				Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	Damage to Liver & Viscera
1. Runner removed	4.4	160	11	1	1	0	2
2. Runner removed	6.0	160	43	3	2	0	3
3. Runner in place	5.95	479	170	35	24	71	16

4.3 Effect of Adding Air into the Turbine on the Fish Mortality Air Added in the Draft Tube Immediately Downstream from the Blades

The mortality rate of fish passing through the turbine with and without the admission of air into the draft tube immediately downstream from the blades appears in Table VIII and Table IX. In order to illustrate the effect of air on fish mortality, parts of the Table VIII and Table IX are reproduced below.

Test Series No.	N rpm	H ft	Sigma	Q_a lb/min	Mortality Rate % Without air	With air
1	600	45.4	0.64	0.22	34	27
2	600	45.4	0.41	0.22	40	28
3	1800	50	0.59	0.16	38	36
4	1800	50	0.39	0.16	34	30
5	1800	50	0.39	0.32	34	40

From the results above, it is concluded that, in general, at all speeds admission of air is beneficial. At lower values of sigma, i.e., when the cavitation increases, benefits of adding air to the turbine are progressively greater. Test results in the series No.5 are an exception. It appears that a large quantity of air increases the fish mortality rate. Test results from this particular series are however inconclusive because they contain a wide variation in the number of the delayed mortality.

As pointed out in discussion in 4.5, a large quantity of air added to the turbine at low sigma can seriously effect the turbine performance. More tests should be conducted in the future to ascertain the effect of a large quantity of air on the fish mortality rate.

Air Added in the Penstock and Through the Draft Tube Vent

The mortality rate of fish passing through the turbine with air added in the penstock and in the draft tube through a 3" diameter steel vent, are given in Table IX, parts of which appear below.

Test Series	Air Data	H ft	Sigma	Efficiency %	Mortality Rate %
1	No air	50	0.39	86	34
2	Air in penstock	50	0.39	85	39
3	Air through vent	44	0.65	75	34

The operating conditions during all three test series were identical. In the series No.1, no air was added. In series No.2, air was added into the penstock; hence a slight change in the operating condition occurred. In series No.3, when air was added to the draft tube through the vent, the draft tube suction was reduced from 11.5 inches of Hg to 4 inches of Hg; hence the sigma and the efficiency changes to the recorded values. The speed in all three sets was 1800 rpm.

Test results were inconclusive because the test series 2 and 3 were conducted 10 to 13 days after test series 1. During this time, fish were not fed and might have been in a weakened condition at the time of testing.

Biological records show that addition of air into the penstock had some benefits. The percentage of dead fish that had decapitated bodies decreased from 42% in tests in which no air was added to 23% in tests in which air was added into the penstock. (Table II).

Biological records also show that addition of air into the draft tube through the vent was beneficial. The cases of collapsed air bladders in dead fish were reduced from 38% in tests in which air was not added to 17% in tests in which air was added. The reduction in the cases of collapsed air bladders was attributed to the reduction of the draft tube suction.

4.4 Effect of Partial Vacuum on Fish

When fish were injected into the penstock with the turbine runner removed, some mortality occurred. The biological examination record of dead fish appears in Table II and Table IV, part of which is as follows:

Q cfs	Hs in.Hg	Number of fish injected	Number of dead fish	Injuries due to Exposure to partial Vacuum	
				Eye Damage	Collapsed air Bladder
4.4	5	160	11	1	7
6	8	160	43	3	40

The majority of dead fish suffered from collapsed air bladder which is considered to be caused by exposure to partial vacuum. The number of cases of collapsed air bladders increases with the increase in the degree of partial vacuum. Other types of injury of dead fish from the same tests are discussed in 4.2.

With the turbine runner removed, most of the energy of the water was extracted by the upstream control gate alone because the downstream gate was left in a wide open position so that it did not interfere with the passage of fish. The penstock pressure was maintained at slightly above atmospheric pressure. Hydraulic losses due to friction and turbulence in the scrollcase were sufficient to induce a partial vacuum in the top part of the draft tube.

When fish were injected into the draft tube at the openings above and below the downstream gate, mortality occurred. The mortality rate is given in Table VII and the record of biological examination of dead fish in Table V. Unfortunately the biological record was incomplete; therefore an attempt to interprete the result is not possible.

4.5 Effect of the Addition of Air on the Turbine Performance

The level of the turbine noise and vibration is observed to be reduced when air is admitted into the draft tube immediately downstream from the blades. This is especially noticeable when the turbine is operating under severe cavitating conditions. The relationship between the turbine power output, efficiency, discharge and the air discharge is shown in Figs. 31a to 32c. The figures show that the turbine out-put is reduced when air is admitted into the draft tube. The efficiency, except in a very few instances is also reduced. The reduction of both the efficiency and the power output of the turbine, in which an air volume up to 1% of the discharge* is added, is less than 2%.

Fig.32b shows that the quantity of air admitted into the draft tube at high draft tube suction, i.e., at low sigma, has important effects on the turbine performance. As the amount of air admitted into the draft tube increases beyond a certain critical value, the turbine out-put decreased and the discharge increases abruptly, resulting in a large decrease in turbine efficiency. The noise level in the turbine during the period that this phenomenon takes place is also increased but the noise does not resemble that normally encountered in the turbine operating under cavitating condition. Figs. 31a and 31b show that when air equivalent to 3% of the discharge is added to the draft tube at low sigma, a reduction in efficiency up to 6% and in power out-put up to 7% can be expected.

4.6 Some Shortcomings of the Tests

1. The interpretation of the results in the preceding discussions are based on the average value of the mortality rate of fish. The number of tests carried out is thought to be too few for a satisfactory application of the theory of statistics; therefore no statistical analysis of the results is given.

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* Stated value of air volume is the equivalent volume at atmospheric pressure.

2. The time that fish are exposed to the partial vacuum in the draft tube in the present set up is longer than in a prototype installation. The average discharge during the tests was about 6 cfs. The average cross-sectional area of the draft tube is about 1 sq. ft; therefore the velocity of water in the draft tube is about 6 ft/sec. The length of the draft tube including the extension is about 35 ft. Fish are exposed to varying degree of partial vacuum for about 6 seconds. Muir(8) showed that exposure of fish to severe partial vacuum over one second can result in mortality. At McNary, the time fish are exposed to partial vacuum is estimated at about 2 seconds.

3. During the first three tests in the Co-series, no packing compound was used to seal cracks and small openings around the rim of the fish collection box. Some live and dead fish were found underneath the box. Extra stress might have been imposed on these live fish. During the same three tests, a few fish stayed within the system, an unexpected occurrence which was not often experienced in the preceding low speed tests. The procedure subsequently adopted - of stopping the turbine and draining the whole system after each test - resulted in great improvement. Thereafter the number of fish missing after any one test was either very small or nil.

4. It was observed that during the delayed mortality observation period, Coho fry did not hesitate to attack the weaker members of their group. Some delayed mortality may have resulted

from the combination of stresses imposed on the fish in the passage through the turbine and the attack by stronger members of the group.

5. Fish when placed close to the source of air supply during the holding period for delayed mortality observation often showed a higher rate of delayed mortality than those placed further away from the air source. A possible explanation is that the outlet of the air supply was placed at the bottom of the tank. Air bubbles rose to the water surface and created a water current away from that point. In order to maintain their positions, fish would have to swim and exert themselves. Harvey(7) in his study of the effect of pressure on Sockeye salmon at Cultus Lake, B.C., expressed an opinion that after decompression, some fish could rest quietly but gas emboli and death could be precipitated in the same fish if they were stressed or exercised.

Table I FISH MORTALITY AND TURBINE OPERATING CONDITIONS

Wicket Gate Position No.6

Speed rpm	Head ft of water	Efficiency %	Sigma	Speed-Discharge Ratio	Total Mortality %	Decapitation %	Contact Possibility %
300	8.3	70	3.1	14.3	19	0	42
600	45.4	52	0.41	13.6	40	0	41
900	52.5	71	0.37	18.7	46	3.6	56
1200	50.5	80.5	0.39	23.2	42	9.1	68
1800	50.0	86	0.39	31.1	34	14.3	86

TABLE II COMPARISON OF TYPE OF INJURIES AND THEIR FREQUENCY OF OCCURRENCE

Test conditions	Discharge cfs	Penstock pressure	Draft tube pressure in of Hg	Total number of Dead fish examined	Injuries in percent of cases examined								REMARKS
					Operculum damage	Eye Damage	Collapse air bladder	Damaged liver and viscera	Abrasion and Contusion	Ventral rupture	Decapitation and Laceration	None apparent	
High suction													
1. No air	5.93	16	11.5	170	3.5	7.6	38	9	20.5	14.1	42	6.5	N = 1800 rpm
2. Small air behind blades	6.14	16	11.5	141	6.8	17	47	14	23.4	10.5	33	5.1	
3. Large air behind blades	6.21	15.8	11.4	220	3.2	12.7	54	17	20.0	8.6	35.4	5.5	
4. Air in draft tube through vent	5.51	17.2	4	139	0.6	11.5	17	6.5	26.6	21	36	11.5	
5. Air in penstock	5.97	16.2	11	125	0	8	40	4	18.4	17.5	23	10.4	
Low suction													
1. No air	5.83	20.2	3	204	6.9	18	36	13.7	19.6	10.8	38	9.3	N = 1800 rpm
2. With air behind blades	5.84	20.2	3	167	3	19.7	32.3	21	19.7	16.7	43.7	8.4	
No Blades													
1. Low discharge	4.4	1.25	5	11	0	9	64	18	9	9	0	0	
2. High discharge	5.8	1.25	8	43	2	7	98	7	7	5	0	4	

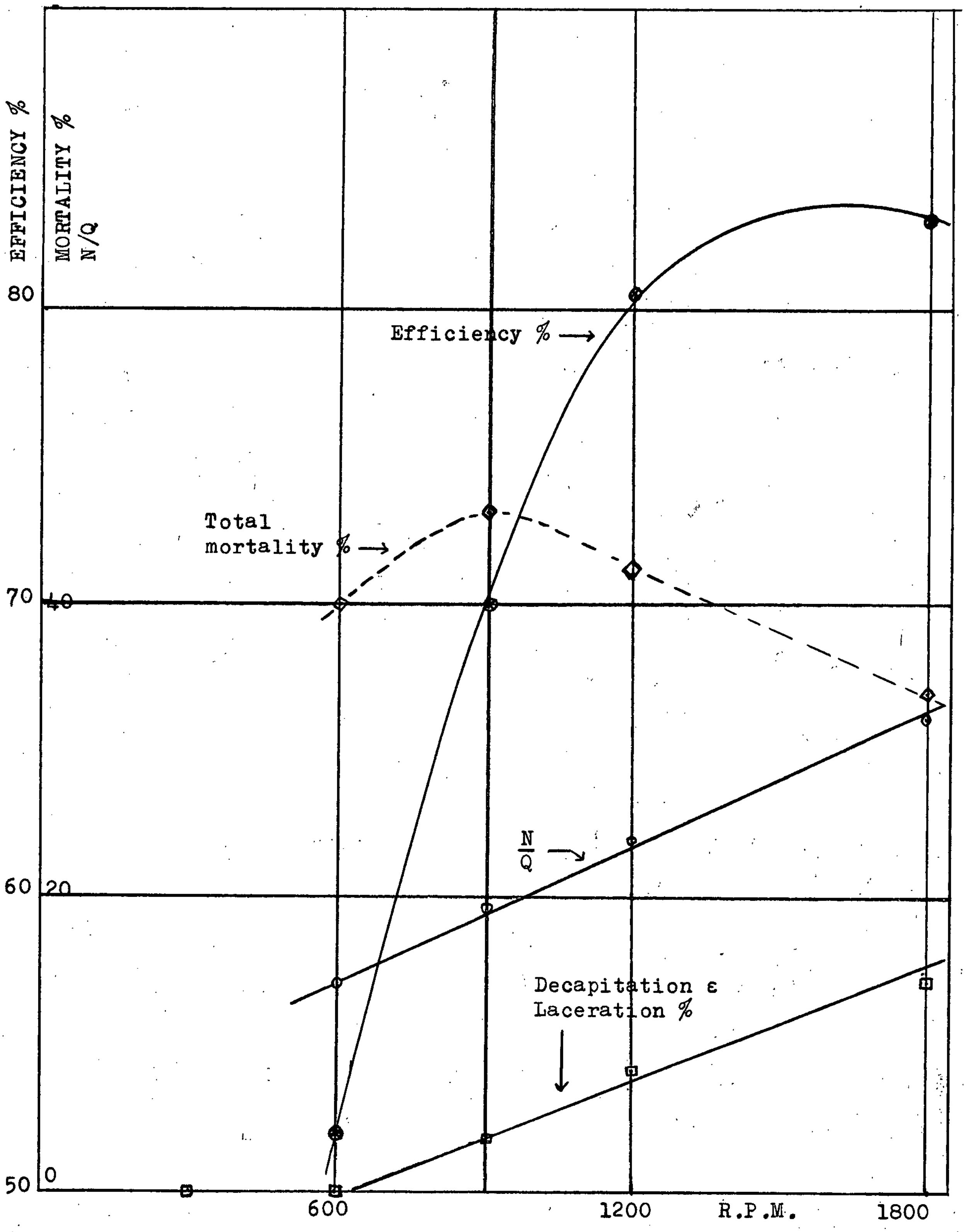

FIG.29 FISH MORTALITY v OPERATING CONDITION

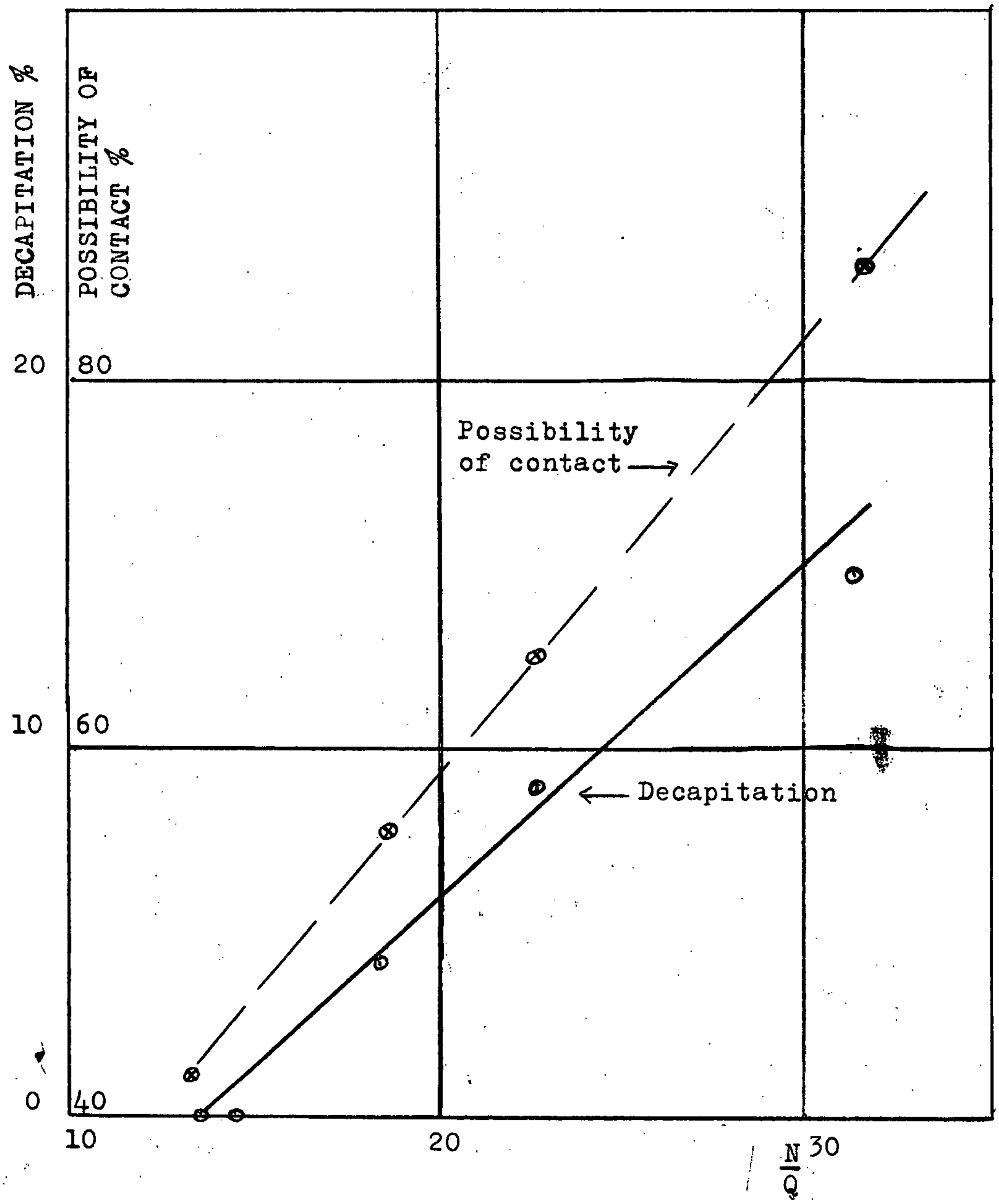

FIG. 30 DECAPITATION v N/Q

H = 50 ft

Wicket Gate Position No. 6

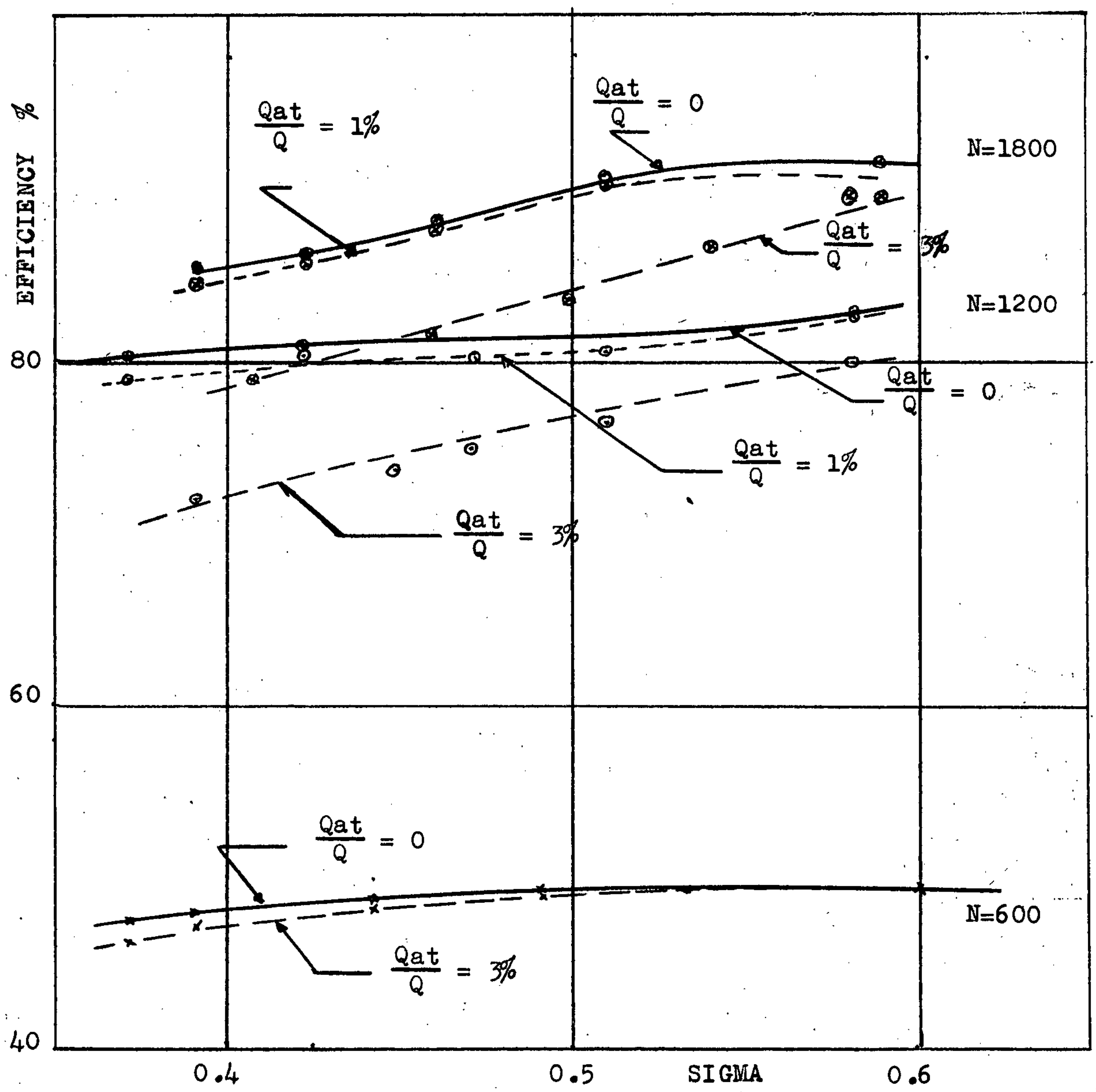

FIG.31a EFFECT OF AIR ON THE TURBINE EFFICIENCY

H = 50 ft

Wicket Gate Position No.9

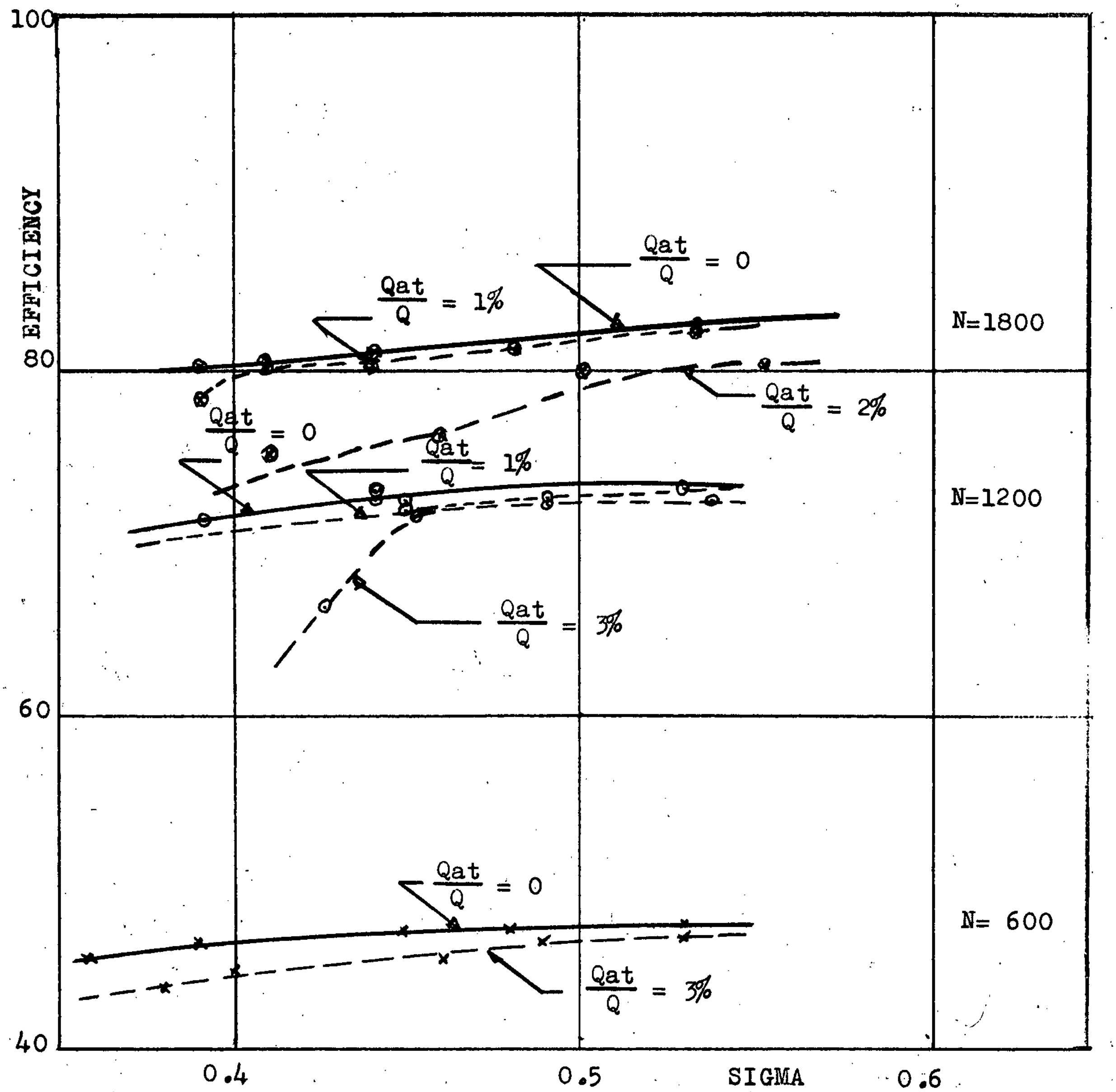

FIG.31b EFFECT OF AIR ON TURBINE EFFICIENCY

H = 50, Gate Position No. 9, N = 590 RPM

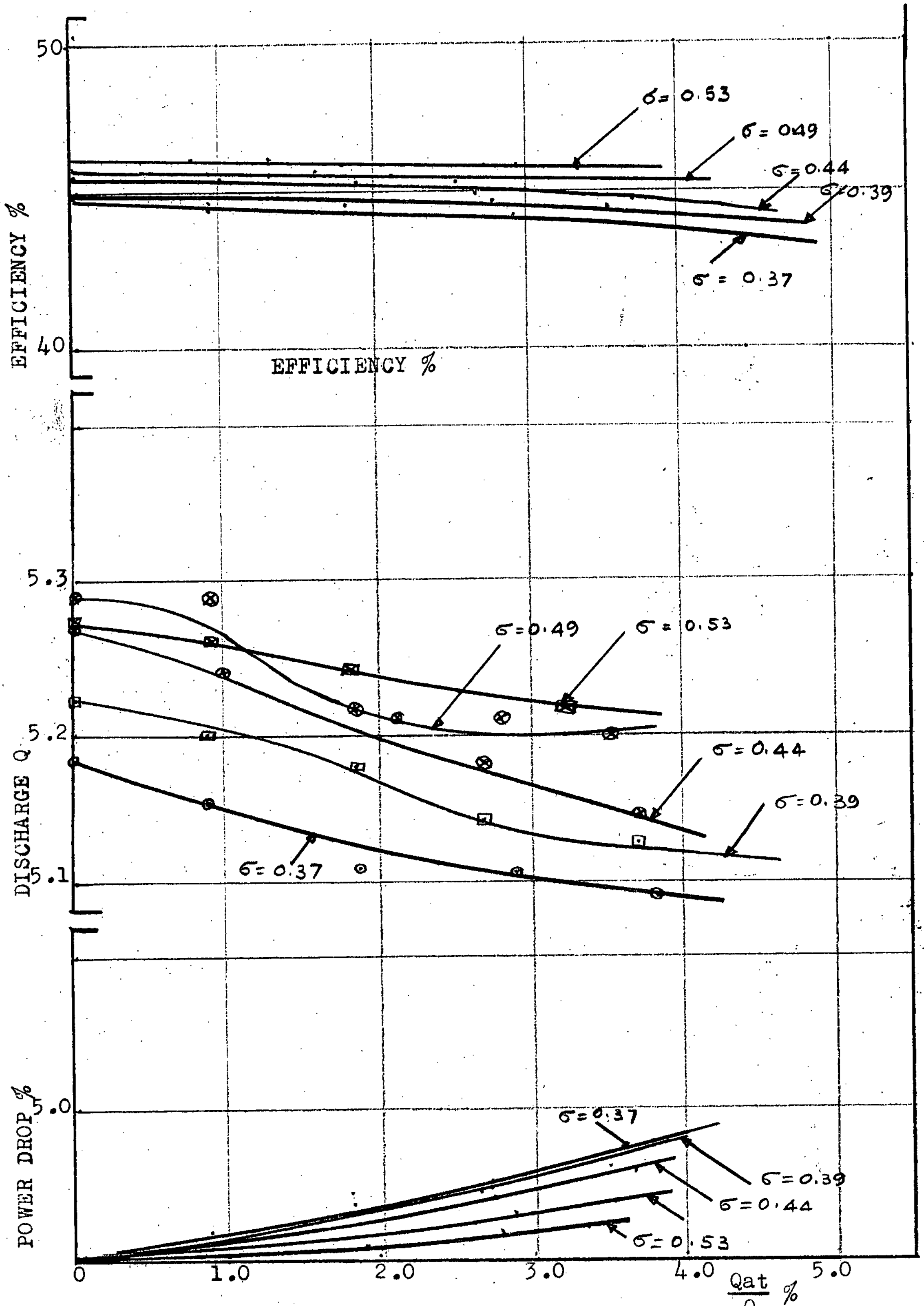

Fig.32a AIR v TURBINE PERFORMANCE

H = 50, Gate No. 9, N = 1200 RPM

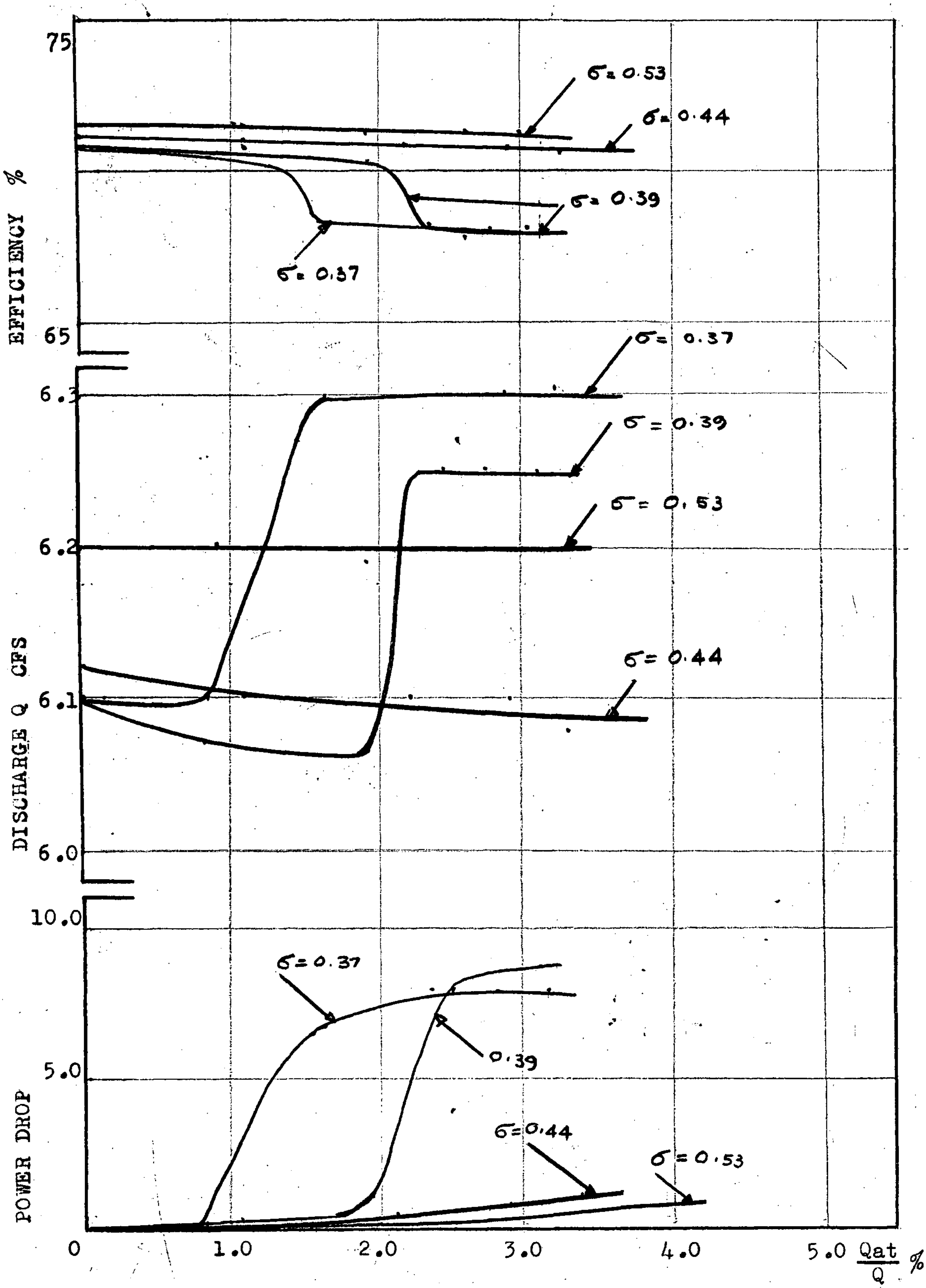

FIG.32b AIR v TURBINE PERFORMANCE

H = 50 ft, Gate Position 6, N = 1800

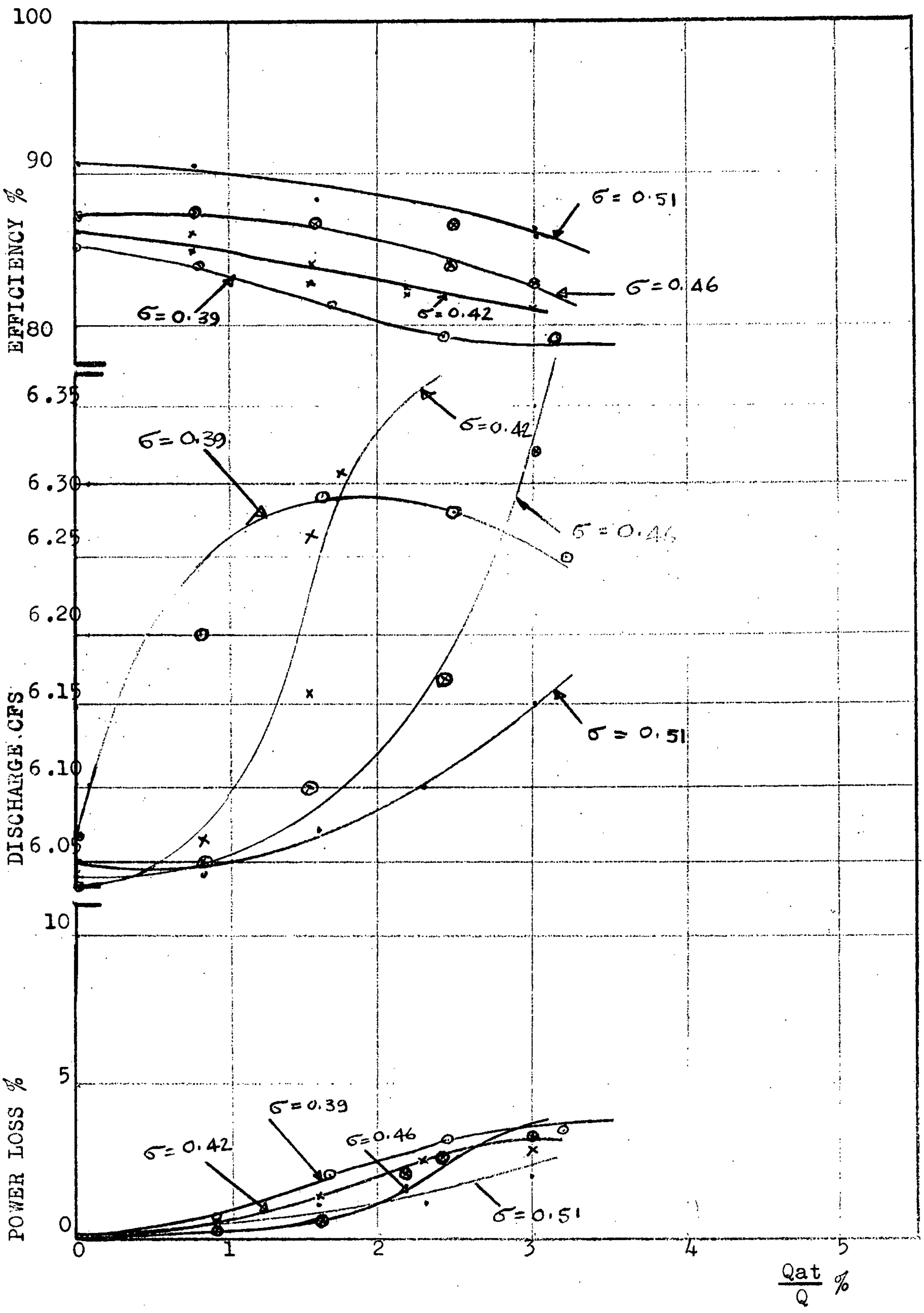

FIG.32 C AIR v TURBINE PERFORMANCE

CHAPTER V

CONCLUSIONS

As indicated in the available but limited number of test results, it is concluded that the addition of compressed air into the model propeller turbine reduces the mortality rate of fish passing through the turbine substantially if the turbine is operating at low efficiency and low sigma. The admission of air into the turbine does not significantly reduce the mortality rate when the turbine is operating at high efficiency.

In general, the addition of air into the turbine reduces the turbine output and efficiency as well as reducing the noise and vibration level. Small quantities of air (of an order of 1% of the discharge) do not reduce the efficiency nor the output by a significant amount. A larger quantity of air beyond a critical value (of the order of 3% of the discharge) when admitted into the turbine operating at low sigma results in an abrupt increase in discharge and a reduction in output and efficiency.

The turbine blades are the largest single source of mechanical injury suffered by fish passing through the turbine. The fish decapitation appears only after a certain impact velocity between fish and the blade has been exceeded and thereafter increases with the turbine speed-discharge ratio.

Mortality of fish exposed to partial vacuum in the draft tube of the turbine is possible.

The above conclusions are based on average values of a few test results. A statistical approach to the interpretation of the results is a superior way to deal with test results of this nature. Unfortunately, the number of tests carried out is thought to be too few for satisfactory application of statistical theory. More tests should be conducted, preferably in a turbine prototype, in a further study of the benefits of adding air to the turbine to reduce the mortality rate of fish passing through the turbine.

Should more tests be conducted in the same model turbine, the shortcomings listed in Chapter IV should be avoided as far as possible.

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APPENDIX I

SYMBOLS, ABBREVIATIONS AND UNITS

The following is a list of symbols and abbreviations used throughout the text. The units refer to the values as specified in the tables of data and results in Appendix III.

A_1 - Area of the air pipe preceding the nozzle

A_2 - Area of the nozzle

BHP - Horsepower output of the turbine

HP_{in} - Horsepower input of the turbine

C - The possibility of contact between fish and the blades

C_d - Flow coefficient of the air nozzle

D - Blade tip diameter of the turbine

d - Hub diameter of the turbine

H - Total effective head across the runner of the turbine in ft of water

Δh - Air meter reading in inch of water

H_b - Barometric head of water in ft of water

H_s - Draft tube suction head in ft of water

K - Constant of proportionality

L - Length of fish

N - Turbine speed in rpm

n - Number of blades on the turbine runner

P_a - Air gauge pressure in psi

P_{a1} - Air pressure in front of the nozzle in psi

P_1 - Penstock pressure in psi

APPENDIX I (Cont'd)

P_{a2} - Air pressure behind the nozzle

P_2 - Draft tube suction gauge reading in inch of Hg

Q - Turbine discharge in cfs

Qa - The discharge of air through the nozzle

Q_{at} - The discharge of air at atmospheric pressure

T - Turbine output torque in lbs. ft.

T_r - Time taken by the blade to take up the position of the preceding blade

T_a - Absolute temperature of the air

t_a - Air temperature in ^oF

U - Circumferencial velocity of a point on the leading edge of the blade

V_T - Whirl component of the water approaching the leading edge of the blade

V - Absolute velocity of water approaching the blade

V_N - Axial component of the velocity of water approaching the leading edge of the blade

v - Velocity of water relative to the leading edge of the blade

W - Water section through the runner during the time T_r

w_a - Specific weight of the air lb/ft^3

σ - Turbine sigma

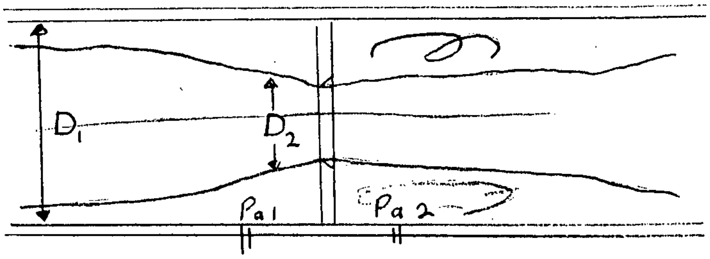
η - Turbine efficiency %

α - Angle between V_N and V

APPENDIX II

SAMPLE OF CALCULATION

1. Flow of air through a nozzle



$$Q = \frac{A_2 \, C_d}{\sqrt{\left(1 - \frac{A_2}{A_1}\right)^2}} \cdot \sqrt{\frac{2g.\,(P_{a1} - P_{a2})}{w_a}}$$

$$= \frac{\frac{\pi}{4} \cdot D_2^2 \cdot C_d}{\sqrt{1 - \left(\frac{D_2^2}{D_1^2}\right)^2}} \cdot \sqrt{\frac{2g.\,(P_{a1} - P_{a2})}{w_a}}$$

For $D_2 = D_1/2 = 0.53$ inch

Air meter reading $\Delta h = h_1 - h_2$ ft of water

$$= \frac{P_{a1} - P_{a2}}{34} .14.7$$

w_a = specific weight of air in lb/ft^3

C_d = Coefficient of discharge of the nozzle

$$Q = 0.1085 \; C_d \sqrt{\frac{\Delta h}{w_a}}$$

APPENDIX II (Cont'd)

Specific weight of air w_a

From $pv_a = RT_a$

p = air absolute pressure lb/ft^2

v_a = specific volume of air ft^3/lb

R = gas constant

= 53.3 ft/ degree of absolute temperature

T_a = absolute temperature of air

= $460 + t^oF$

t_a = Air temperature in degrees F

P_a = Air gauge pressure in psi

$w_a = 1/v_a$

$$= \frac{144(P_a + 14.7)}{53.3\ (460 + t)} \quad 16/ft^3$$

It is assumed that the air temperature is equal to 50^{o}F, the mean temperature of air outside the Laboratory, where the supply of the compressor is drawn.

In the test No. C 10

Data

Draft tube suction (P_2) 12.5 in of Hg

Turbine discharge Q 4.22 cfs

Air pressure 14 psi

Air meter reading Δh 0.4 in. of water

Coefficient of discharge C_d 0.63

Calculation

$$w_a = \frac{144(14 + 14.7)}{53.3(460 + 50)}$$

$$= 0.15 \quad lb/ft^3$$

APPENDIX II (Cont'd)

Discharge of air through air meter

$$Q_a = 0.1085 \times 0.63 \sqrt{\frac{0.4}{12 \times 0.151}}$$

$$= 0.0322 \quad ft^3/sec.$$

Weight of air being admitted into the draft tube

$$= 0.0322 \times 0.15 \times 60 \quad lb/min$$

$$= 0.29 \ lb/min$$

Discharge of air corrected to the pressure in the draft tube

$$= \frac{0.0322 \times 28.7}{14.7 - 0.49 \times 12.5}$$

$$Q_a = 0.108 \ cfs$$

$$Q_a/Q = \frac{0.108}{4.22} \times 100$$

$$= 2.54 \ \%$$

To change the discharge Q_a to the discharge at atmospheric pressure Q_{at}

$$Q_{at} \doteq Q_a \times \frac{(14.7 - P_2 \times 0.49)}{14.7}$$

2. Contact possibility of fish with turbine blades.

Data Tests of fish mortality in the turbine operated at high speed but with no admission of air.

Average turbine discharge	5.93 cfs
Average turbine speed	1800 rpm
Average length of fish	37 mm
Tip diameter of the blades	10 inches
Runner hub diameter	6 inches
Number of blades on the runner	4

APPENDIX II (Cont'd)

From Von Raben formula

$$\text{Contact possibility} = \frac{37 \times \pi \times (100-36) \times 4 \times 1800}{25.4 \times 12 \times 240 \times 5.95 \times 144}$$

$$= 0.86$$

$$= 86\%$$

TABLE OF OBSERVED RESULTS

TABLE III EFFECT OF ADDITION OF COMPRESSED AIR ON TURBINE PERFORMANCE

WICKET GATE POSITION NO. 6

Q	P_1	P_2	H	N	T	H_a	P_a	$\frac{Q_{at}}{Q}$	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in.	psi	%				%
4.77	20.0	3.5	50.0	580	120.4	-	-	-	13.3	27.2	0.6	48.9
4.77	20.0	3.5	50.0	580	120.0	0.1	9	1.0	13.2	27.2	0.6	48.7
4.70	20.0	3.5	50.0	577	119.2	0.4	8	1.9	13.1	26.8	0.6	48.9
4.66	20.0	3.5	50.0	575	118.0	1.0	7.5	3.2	13.0	26.5	0.6	48.9
4.66	20.0	3.5	50.0	570	118.5	1.2	7.5	3.4	12.9	26.5	0.6	48.5
4.67	20.0	3.5	50.0	577	118.0	0.9	7.5	3.0	13.0	26.6	0.6	48.8
4.69	20.0	3.5	50.0	581	119.5	0.4	8	1.9	13.2	26.6	0.6	49.5
4.74	20.0	3.5	50.0	582	120.4	0.1	10	1.0	13.3	27.0	0.6	49.5
4.75	20.0	3.5	50.0	585	120.4	-	-	-	13.4	27.4	0.6	49.5
4.72	19.0	5.5	50.0	580	119.7	-	-	-	13.2	26.9	0.53	49.3
4.69	19.0	5.5	50.0	580	119.0	0.1	9	1.0	13.2	26.7	0.53	49.3
4.66	19.0	5.5	50.0	580	118.5	0.4	8	2.0	13.1	26.5	0.53	49.5
4.63	19.0	5.5	50.0	580	117.7	0.8	7.5	2.8	13.0	26.4	0.53	49.3
4.63	19.0	5.5	50.0	580	117.2	1.3	7.5	3.5	13.0	26.4	0.53	49.3
4.63	19.0	5.5	50.0	575	118.0	0.8	7.5	2.8	12.9	26.4	0.53	49.1
4.65	19.0	5.5	50.0	580	118.7	0.4	8	2.0	13.1	26.5	0.53	49.5
4.68	19.0	5.5	50.0	580	119.7	0.1	9	1.0	13.2	26.6	0.53	49.6
4.71	19.0	5.5	50.0	585	119.9	-	-	-	13.4	26.8	0.53	49.8
4.67	18.0	7.6	50.1	575	118.5	-	-	-	13.0	26.6	0.48	49.0
4.66	18.1	7.5	50.2	575	118.0	0.1	9	1.0	12.9	26.5	0.48	48.7
4.62	18.1	7.4	50.1	575	117.0	0.4	8	2.0	12.8	26.2	0.49	48.8
4.60	18.2	7.3	50.3	575	116.6	0.9	7.5	3.0	12.8	26.2	0.49	48.7
4.58	18.2	7.2	50.1	575	115.7	1.4	7	3.6	12.7	26.0	0.49	48.7
4.58	18.2	7.3	50.3	575	116.5	0.9	7.5	3.0	12.8	26.1	0.49	48.8
4.62	18.1	7.3	50.0	575	117.2	0.4	8	2.0	13.1	26.5	0.49	48.9
4.64	18.1	7.5	50.2	575	118.2	0.1	9	1.0	13.0	26.4	0.49	49.1
4.65	18.0	7.5	50.0	575	118.5	-	-	-	13.0	26.4		49.1
4.62	17.0	9.5	50.0	575	117.2	-	-	-	12.8	26.2	0.44	49.0
4.60	17.0	9.4	49.9	573	116.8	0.1	9	1.0	12.7	26.0	0.44	49.0
4.57	17.1	9.3	50.0	575	115.7	0.4	8	1.9	12.6	25.9	0.44	48.9
4.55	17.1	9.3	50.0	570	114.6	0.9	7.5	3.1	12.4	25.8	0.44	48.2
4.55	17.2	9.1	50.0	565	114.2	1.5	7	3.8	12.3	25.8	0.45	47.7
4.55	17.2	9.2	50.1	570	115.0	0.9	7.5	3.0	12.5	25.9	0.45	48.2
4.58	17.1	9.3	50.0	575	116.0	0.4	8	1.9	12.7	25.9	0.44	49.0
4.59	17.1	9.4	50.1	575	116.5	0.1	9	1.0	12.8	26.0	0.44	49.2
4.60	17.0	9.5	50.0	575	117.5	-	-	-	12.9	26.1	0.44	49.4

WICKET GATE POSITION NO.6

Q	P_1	P_2	H	N	T	H_a	P_a	$\frac{Q_{at}}{Q}$	BHP	HP_{in}	σ	η
cfs.	psi	in.Hg	ft	rpm	lb.ft	in.	psi	%				%
4.56	16.0	11.5	50.1	570	115.7	-	-	-	12.6	26.0	0.39	48.4
4.52	16.1	11.5	50.3	570	114.2	0.1	9	1.1	12.4	25.8	0.39	48.1
4.50	16.1	11.3	50.1	570	114.0	0.4	8	2.0	12.3	25.6	0.40	48.3
4.50	16.2	11.2	50.1	565	112.6	1.0	7.5	3.2	12.1	25.6	0.40	47.3
4.47	16.2	11.1	50.0	565	111.7	1.6	7	4.0	12.0	25.4	0.40	47.3
4.50	16.2	11.2	50.1	565	112.5	1.0	7.5	3.1	12.1	25.6	0.40	47.3
4.52	16.1	11.4	50.2	570	113.9	0.4	9	2.0	12.4	25.7	0.39	48.1
4.55	16.1	11.4	50.2	570	114.7	0.1	9	1.1	12.5	25.9	0.39	48.1
4.57	16.0	11.5	50.1	565	115.7	-	-	-	12.5	26.0	0.39	48.1
4.53	15.4	12.7	50.0	565	112.7	-	-	-	12.1	25.7	0.37	47.2
4.52	15.3	12.6	49.7	565	113.0	0.1	10	1.1	12.2	25.5	0.37	47.6
4.47	15.4	12.5	49.8	565	111.4	0.4	8	2.1	12.0	25.2	0.37	47.5
4.47	15.5	12.5	50.0	560	110.7	0.9	7.5	3.0	11.8	25.4	0.37	46.5
4.44	15.5	12.4	49.9	560	108.8	1.7	7	4.1	11.6	25.1	0.38	46.3
4.46	15.5	12.5	50.0	560	110.7	0.9	7.5	3.0	11.8	25.3	0.37	46.5
4.49	15.5	12.5	50.0	565	111.2	0.4	8	2.0	12.0	25.5	0.37	46.9
4.51	15.4	12.6	49.9	565	112.7	0.1	9	1.1	12.1	25.5	0.37	47.7
4.53	15.3	12.6	49.7	565	113.0	-	-	-	12.2	25.5	0.37	47.7
5.42	19.9	3.5	50.0	1220	110.2	-	-	-	25.7	30.7	0.58	83.3
5.42	19.9	3.3	49.8	1210	110.0	0.1	9	0.8	25.4	30.7	0.58	82.7
5.40	19.9	3.1	49.5	1200	108.7	0.4	8	1.6	24.9	30.4	0.59	81.8
5.37	19.9	3.2	49.7	1190	107.0	0.9	7.5	2.3	24.3	30.3	0.59	80.4
5.35	20.0	3.3	49.9	1190	106.8	1.3	7.5	2.9	24.2	30.3	0.58	79.8
5.36	20.0	3.2	49.8	1185	107.5	0.9	7.5	2.3	24.3	30.3	0.58	80.2
5.37	20.0	3.3	49.9	1185	109.2	0.4	8	1.6	24.6	30.4	0.58	81.0
5.39	20.0	3.4	50.0	1185	110.5	0.1	9	0.8	24.9	30.6	0.58	81.5
5.39	19.9	3.5	50.0	1190	111.2	-	-	-	25.3	30.6	0.58	82.8
5.40	19.0	6.0	50.7	1180	111.2	-	-	-	24.9	31.0	0.51	80.2
5.39	19.0	6.0	50.7	1175	111.5	0.1	9	0.9	24.9	31.0	0.51	80.4
5.37	19.0	6.0	50.7	1160	109.5	0.4	8	1.7	24.2	30.8	0.51	79.8
5.33	19.1	5.8	50.6	1155	107.7	0.9	7.5	2.6	23.7	30.6	0.51	77.4
5.31	19.1	5.8	50.6	1145	106.6	1.4	7	3.1	23.2	30.5	0.52	76.6
5.33	19.1	5.9	50.8	1150	107.7	0.9	7.5	2.6	23.6	30.7	0.51	76.9
5.35	19.1	5.9	50.8	1160	110.0	0.4	8	1.7	24.3	30.8	0.51	78.9
5.37	19.0	6.0	50.7	1165	111.7	0.1	9	0.9	24.8	30.8	0.51	80.5

TABLE III (Cont'd)

WICKET GATE POSITION NO.6

Q	P_1	P_2	H	N	T	H_a	P_a	$\frac{Q_{at}}{Q}$	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in.	psi	%				%
5.35	17.5	8.3	49.8	1190	107.5	-	-	-	24.3	30.2	0.47	80.5
5.35	17.5	8.3	49.8	1200	107.0	0.1	9	0.9	24.5	30.2	0.47	81.1
5.31	17.6	8.2	50.0	1185	104.2	0.4	8	1.7	23.5	30.1	0.47	78.0
5.32	17.6	8.0	49.8	1170	101.6	0.9	7.5	2.6	22.7	30.0	0.48	75.9
5.34	17.6	7.8	49.6	1165	100.5	1.6	7	3.4	22.3	30.0	0.48	74.4
5.30	17.6	8.1	49.9	1170	102.5	0.9	7.5	2.6	22.8	30.0	0.47	76.0
5.30	17.5	8.2	49.7	1175	104.5	0.4	8	1.7	23.4	29.9	0.47	78.9
5.33	17.5	8.3	49.8	1185	107.2	0.1	9	0.9	24.2	30.1	0.47	80.3
5.35	17.5	8.3	49.8	1185	108.0	-	-	-	24.4	30.2	0.47	80.2
5.34	16.5	10.4	49.9	1215	105.5	-	-	-	24.4	30.1	0.42	81.0
5.33	16.5	10.4	49.9	1220	105.5	0.1	9.5	0.9	24.3	30.1	0.42	80.7
5.31	16.5	10.2	49.6	1195	101.1	0.4	8	1.7	23.0	29.9	0.43	77.0
5.42	16.3	9.9	48.9	1180	99.2	0.9	7.5	2.5	22.3	30.0	0.44	74.4
5.42	16.2	9.5	48.2	1175	98.2	1.8	7	3.5	22.0	29.6	0.46	74.2
5.41	16.2	9.8	48.5	1175	99.2	0.9	7.5	2.5	22.2	29.8	0.45	74.6
5.32	16.5	10.2	49.6	1195	102.5	0.4	8	1.7	23.2	29.9	0.43	75.2
5.31	16.5	10.3	49.7	1205	105.0	0.1	9	0.9	24.1	30.0	0.43	80.7
5.33	16.4	10.4	49.9	1210	105.7	-	-	-	24.6	30.1	0.42	81.7
5.30	15.6	12.4	50.0	1205	105.2	-	-	-	24.2	30.0	0.37	80.5
5.30	15.6	12.4	50.0	1195	104.0	0.1	9	0.9	23.6	30.0	0.37	78.8
5.44	15.3	12.0	49.0	1165	99.8	0.4	8	1.7	22.1	30.2	0.39	73.2
5.43	15.2	11.9	48.6	1160	98.0	0.9	7.5	2.5	21.7	30.0	0.40	72.2
5.40	15.3	11.8	48.8	1145	97.2	1.6	7	3.3	21.2	30.1	0.40	71.0
5.42	15.3	12.0	49.0	1155	98.5	0.9	7.5	2.5	21.7	30.0	0.39	72.3
5.42	15.3	12.0	49.0	1165	100.00	0.4	8	1.7	22.2	30.1	0.39	73.8
5.29	15.6	12.4	50.0	1180	103.2	0.1	9	0.9	23.3	30.1	0.38	77.4
5.30	15.6	12.5	50.2	1195	106.0	-	-	-	24.0	30.1	0.37	80.3
6.00	20.0	3.4	50.0	1790	90.0	-	-	-	30.7	34.1	0.58	89.9
6.02	20.0	3.3	49.9	1800	89.5	0.1	11	0.8	30.6	34.1	0.58	89.7
5.98	19.9	3.1	49.5	1785	88.5	0.4	10	1.6	30.1	33.6	0.59	89.7
5.95	19.9	3.2	49.6	1760	89.7	0.9	9	2.5	30.1	33.5	0.59	89.9
5.95	20.0	3.0	49.6	1735	91.8	1.6	9	3.2	30.3	33.5	0.59	90.2
5.96	20.0	3.0	49.6	1745	90.00	0.9	10	2.5	30.0	33.5	0.59	89.5
5.96	20.0	3.1	49.7	1800	87.2	0.4	10	1.6	29.9	33.6	0.59	89.0
6.02	20.0	3.2	49.8	1865	85.1	0.1	11	0.8	30.2	34.0	0.58	88.9

TABLE III (Cont'd)

WICKET GATE POSITION NO.6

Q	P_1	P_2	H	N	T	H_a	P_a	$\frac{Q_{at}}{Q}$	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in.	psi	%				%
6.05	19.1	5.9	50.8	1800	91.7	-	-	-	31.4	34.8	0.51	90.4
6.04	19.1	5.8	50.7	1800	91.5	0.1	11	0.8	31.4	34.7	0.52	90.5
6.07	19.1	5.6	50.5	1800	89.5	0.4	10	1.6	30.7	34.7	0.52	88.3
6.10	19.1	5.5	50.3	1800	89.7	0.9	9	2.3	30.8	34.8	0.53	88.4
6.15	19.1	5.0	49.8	1800	87.7	1.7	8	3.0	30.1	34.7	0.54	86.8
6.10	19.1	5.5	50.3	1800	90.0	0.9	10	2.4	31.2	34.8	0.53	88.8
6.07	19.1	5.5	50.3	1800	89.7	0.4	10	1.6	30.8	34.8	0.53	88.6
6.07	19.1	5.9	50.8	1800	91.1	0.1	11	0.8	31.2	34.9	0.52	89.3
6.06	19.1	5.9	50.8	1800	91.3	-	-	-	31.3	34.9	0.51	89.7
6.04	17.5	8.5	50.0	1800	87.2	-	-	-	29.9	34.3	0.46	87.4
6.05	17.4	8.5	49.8	1800	87.1	0.1	11	0.8	29.9	34.2	0.46	87.3
6.10	17.3	8.1	49.2	1800	86.0	0.4	10	1.5	29.5	34.0	0.48	86.7
6.17	17.0	7.8	48.2	1800	82.7	1.0	10	2.4	28.3	33.7	0.50	84.0
6.35	17.0	7.6	47.9	1800	82.0	1.8	8	3.0	28.1	34.7	0.50	83.6
6.30	17.1	7.8	48.4	1800	83.8	0.9	9	2.2	28.7	34.5	0.50	83.3
6.22	17.1	8.0	48.6	1800	85.7	0.4	10	1.5	29.4	34.3	0.49	85.7
6.08	17.2	8.1	48.9	1800	87.0	0.1	11	0.8	29.8	33.7	0.48	88.4
6.05	17.3	8.5	49.6	1800	87.7	-	-	-	30.1	34.1	0.47	88.4
6.03	16.7	10.4	50.2	1800	86.5	-	-	-	29.7	34.4	0.42	86.2
6.07	16.6	10.4	50.0	1800	86.3	0.1	11	0.8	29.6	34.4	0.42	86.0
6.27	16.1	10.1	49.0	1800	84.2	0.4	10	1.5	28.9	34.4	0.44	84.0
6.36	16.0	9.5	47.8	1800	82.2	1.0	9	2.3	28.2	34.4	0.46	82.0
6.32	16.0	9.6	47.9	1800	81.6	1.8	8	3.0	28.0	34.3	0.46	81.7
6.37	16.0	9.6	47.9	1800	83.5	0.8	10	2.1	28.6	34.6	0.46	82.4
6.31	16.1	9.9	48.4	1800	84.2	0.5	10	1.7	28.9	34.6	0.45	83.3
6.15	16.5	10.2	49.6	1800	86.7	0.1	11	0.8	29.7	34.6	0.43	85.8
6.09	16.5	10.3	49.7	1800	87.0	-	-	-	29.8	34.4	0.42	86.7
6.07	15.5	12.0	49.4	1800	84.7	-	-	-	29.0	34.0	0.39	85.2
6.20	15.2	11.8	48.5	1800	83.7	0.1	11	0.8	28.7	34.1	0.40	84.2
6.29	15.1	11.5	47.9	1800	81.2	0.5	10	1.7	27.8	34.2	0.41	81.3
6.25	15.1	11.5	47.9	1800	78.7	2.0	8	3.2	27.0	33.9	0.41	79.4
6.28	15.1	11.6	48.0	1800	79.0	1.0	10	2.4	27.1	34.2	0.41	79.4
6.37	14.9	11.6	47.8	1800	81.2	0.4	10	1.5	27.8	34.5	0.41	80.8
6.23	15.1	11.6	48.0	1800	83.5	0.1	11	0.8	28.6	34.0	0.41	84.2
6.10	15.5	12.0	49.4	1800	85.5	-	-	-	29.3	34.2	0.39	85.5

TABLE III (Cont'd)

WICKET GATE POSITION NO. 9

Q	P_1	P_2	H	N	T	H_a	P_a	Qat/Q	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in	psi	%				%
5.27	19.0	5.4	50.0	590	125.0	-	-	-	14.1	29.9	0.53	47.0
5.26	19.0	5.5	50.1	590	125.0	0.1	10	0.9	14.1	29.9	0.53	47.0
5.25	19.0	5.5	50.1	590	124.8	1.2	10	1.3	14.0	29.9	0.53	46.9
5.24	19.0	5.5	50.1	585	124.0	0.4	10	1.8	13.9	29.9	0.53	46.6
5.23	19.0	5.4	50.0	585	123.0	0.9	9	2.7	13.8	29.8	0.53	46.3
5.22	19.0	5.4	50.0	585	122.2	1.4	8	3.3	13.7	29.8	0.53	46.1
5.23	19.0	5.5	50.1	590	123.2	1.0	9	2.9	13.8	29.8	0.53	46.5
5.25	19.0	5.5	50.1	590	124.3	0.4	10	1.8	13.9	29.8	0.53	46.7
5.27	19.0	5.5	50.1	590	125.5	0.1	10	0.9	14.1	30.0	0.53	46.9
5.29	19.0	5.5	50.1	590	125.2	-	-	-	14.0	30.0	0.53	46.9
5.29	18.0	7.5	50.1	590	124.5	-	-	-	14.0	30.0	0.48	46.6
5.29	18.0	7.5	50.1	590	124.4	0.1	11	0.9	13.9	30.0	0.48	46.3
5.25	18.0	7.4	50.0	585	123.5	0.2	10	1.3	13.8	29.8	0.49	46.1
5.23	18.0	7.4	50.0	585	122.0	0.8	9	2.5	13.6	29.7	0.49	45.8
5.21	18.0	7.4	50.0	585	121.7	1.0	9	2.8	13.5	29.6	0.49	45.8
5.20	18.0	7.4	50.0	585	121.0	1.6	8	3.5	13.5	29.5	0.49	45.8
5.20	18.0	7.4	50.0	585	121.2	1.2	9	3.2	13.5	29.5	0.49	45.8
5.21	18.0	7.4	50.0	585	122.1	0.7	9	2.1	13.6	29.6	0.49	46.0
5.25	18.0	7.4	50.0	590	123.5	0.3	10	1.6	13.9	29.8	0.49	46.5
5.27	18.0	7.4	50.0	585	124.2	0.1	10	0.9	13.8	29.9	0.49	46.2
5.28	18.0	7.5	50.1	590	124.5	-	-	-	14.0	30.0	048	46.7
5.27	17.0	9.5	50.1	590	123.7	-	-	-	13.9	29.9	0.44	46.3
5.25	17.0	9.5	50.1	585	123.2	0.1	10	1.0	13.7	29.8	0.44	46.1
5.22	17.1	9.5	50.3	580	121.5	0.3	10	1.8	13.4	29.7	0.44	45.2
5.18	17.1	9.4	50.1	580	119.9	0.9	9	2.6	13.2	29.5	0.44	44.9
5.14	17.2	9.2	50.2	575	119.0	1.6	8	3.6	13.0	29.3	0.45	44.5
5.18	17.2	9.2	50.2	580	120.1	0.9	9	2.7	13.3	29.5	0.45	45.0
5.20	17.1	9.4	50.1	585	121.7	0.3	10	1.8	13.5	29.6	0.44	45.7
5.24	17.0	9.5	50.1	590	122.7	0.1	10	1.0	13.7	29.8	0.44	45.8
5.23	17.0	9.5	50.1	590	123.7	-	-	-	13.8	29.8	0.44	46.6
5.23	16.1	11.5	50.3	585	122.5	-	-	-	13.7	29.5	0.39	45.8
5.20	16.1	11.5	50.3	580	121.0	0.1	10	0.9	13.4	29.7	0.39	45.2
5.17	16.2	11.3	50.2	570	119.5	0.4	10	1.8	13.0	29.5	0.40	44.1
5.14	16.2	11.1	50.0	575	118.5	1.0	9	2.7	13.0	29.2	0.40	44.6
5.13	16.4	11.0	50.5	575	117.7	1.6	8	3.5	12.9	29.4	0.40	43.9
5.14	16.4	11.1	50.6	575	118.7	1.0	9	2.7	13.1	29.4	0.40	44.1
5.17	16.2	11.3	50.2	580	121.0	0.2	10	1.3	13.4	29.4	0.40	45.5
5.19	16.1	11.4	50.1	585	121.7	0.1	11	0.9	13.5	29.5	0.39	45.9
5.20	16.1	11.5	50.3	585	122.5	-	-	-	13.7	29.7	0.39	45.9

TABLE III (Cont'd)

WICKET GATE POSITION NO. 9

Q	P_1	P_2	H	N	T	H_a	P_a	Qat/Q	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in	psi	%				%
5.18	15.5	12.7	50.2	580	119.8	-	-	-	13.2	29.5	0.36	44.9
5.15	15.5	12.7	50.2	575	118.6	0.1	11	0.9	13.0	29.3	0.36	44.4
5.11	15.6	12.5	50.2	575	117.0	0.4	10	1.8	12.8	29.1	0.37	44.0
5.11	15.7	12.2	50.1	570	116.0	1.0	9	2.9	12.6	29.0	0.38	43.5
5.09	15.7	12.2	50.1	570	115.5	1.8	8	3.8	12.5	28.9	0.38	43.5
5.11	15.6	12.5	50.2	570	116.8	0.8	9	2.5	12.7	29.1	0.37	43.6
5.10	15.6	12.5	50.2	570	117.1	0.5	10	2.1	12.7	29.1	0.37	43.7
5.12	15.6	12.6	50.3	575	118.0	0.2	10	1.3	12.9	29.2	0.37	44.2
5.15	15.4	12.7	50.0	585	120.1	-	-	-	13.4	29.3	0.37	45.8
6.20	19.0	5.5	50.1	1185	114.5	-	-	-	25.8	35.3	0.53	73.1
6.20	19.0	5.5	50.1	1160	116.5	0.2	10	1.1	25.8	35.3	0.53	73.1
6.19	19.0	5.5	50.1	1155	116.0	0.6	10	1.9	25.5	35.2	0.53	72.4
6.20	19.0	5.3	49.9	1150	116.2	1.2	9	2.6	25.5	35.1	0.54	72.6
6.19	19.1	5.3	49.9	1145	116.6	1.6	8	3.0	25.4	35.1	0.54	72.4
6.19	19.1	5.2	49.8	1140	117.0	1.2	9	2.6	25.5	35.0	0.54	72.8
6.17	19.1	5.3	49.9	1135	117.5	0.5	10	1.7	25.4	35.1	0.54	72.6
6.16	19.1	5.5	50.1	1135	118.2	0.1	11	0.8	25.6	35.1	0.53	73.0
6.18	19.0	5.5	50.1	1160	116.0	-	-	-	25.7	35.2	0.53	73.1
6.16	18.0	7.5	50.1	1160	115.0	-	-	-	25.4	35.0	0.49	72.7
6.17	18.0	7.5	50.1	1160	115.5	0.1	11	0.8	25.5	35.1	0.49	72.7
6.15	18.0	7.5	50.1	1155	115.2	0.4	10	1.6	25.4	35.0	0.49	72.6
6.14	18.0	7.3	49.9	1155	114.2	0.9	9	2.3	25.2	34.7	0.49	72.6
6.15	18.0	7.3	49.9	1160	114.0	1.3	8	2.8	25.2	34.8	0.49	72.4
6.15	18.0	7.3	49.9	1165	114.2	1.0	10	2.4	25.3	34.8	0.49	72.8
6.15	18.0	7.4	50.0	1170	114.7	0.4	10	1.6	25.5	34.9	0.49	73.1
6.16	18.0	7.5	50.1	1170	115.2	0.1	11	0.8	25.6	35.0	0.49	73.1
6.16	18.0	7.5	50.1	1170	114.5	-	-	-	25.5	35.0	0.49	73.0
6.12	17.0	9.6	50.2	1165	113.4	-	-	-	25.2	34.8	0.44	72.4
6.10	17.0	9.6	50.2	1165	113.1	0.2	10	1.1	25.1	34.7	0.44	72.3
6.10	17.0	9.5	50.1	1165	112.0	0.8	9	2.2	24.9	34.6	0.44	72.0
6.10	17.0	9.3	49.8	1160	111.5	1.2	9	2.9	24.7	34.5	0.45	71.8
6.07	17.0	9.3	49.8	1155	110.8	1.6	8	3.3	24.4	34.3	0.45	71.2
6.12	17.0	9.3	49.8	1160	111.7	0.8	9	2.2	24.7	34.5	0.45	71.5
6.11	17.0	9.4	50.0	1170	112.5	0.4	10	1.6	25.0	34.7	0.44	72.2
6.10	17.0	9.5	50.1	1165	113.0	0.1	10	0.8	25.0	34.6	0.44	72.3
6.10	17.0	9.6	50.2	1165	113.1	-	-	-	25.1	34.7	0.44	72.4

TABLE III (Cont'd)

WICKET GATE POSITION NO. 9

Q	P_1	P_2	H	N	T	H_a	P_a	$\frac{Q_{at}}{Q}$	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in	psi	%				%
6.10	16.0	11.5	50.1	1170	111.7	-	-	-	24.8	34.7	0.39	71.5
6.07	16.0	11.4	50.0	1170	111.0	0.1	11	0.8	24.7	34.7	0.40	71.7
6.06	16.0	11.4	50.0	1160	109.4	0.6	10	1.9	24.2	34.3	0.40	70.6
6.25	15.7	11.0	48.8	1140	104.7	1.2	9	2.5	22.8	34.6	0.42	66.0
6.25	15.5	10.8	48.2	1135	104.3	1.8	8	3.1	22.6	34.2	0.43	66.2
6.24	15.6	10.8	48.3	1145	104.6	1.4	8	2.7	22.7	34.2	0.43	66.4
6.25	15.7	11.0	48.8	1145	105.2	1.0	9	2.3	22.9	34.6	0.42	66.3
6.06	16.0	11.3	49.8	1165	109.9	0.5	10	1.7	24.4	34.2	0.40	71.4
6.06	16.0	11.3	49.8	1170	110.5	0.2	10	1.1	24.6	34.2	0.40	71.9
6.10	16.0	11.4	50.0	1170	111.5	-	-	-	24.8	34.6	0.40	71.8
6.10	15.6	12.4	50.2	1175	112.0	-	-	-	25.1	34.8	0.37	72.1
6.10	15.6	12.4	50.2	1180	111.4	0.1	11	0.8	25.1	34.8	0.37	72.1
6.27	15.2	12.1	48.9	1155	106.0	0.4	10	1.5	23.3	34.8	0.39	67.1
6.27	15.2	12.1	48.9	1150	105.5	1.2	8	2.5	23.1	34.8	0.39	66.5
6.31	15.2	11.9	48.8	1150	105.7	1.8	8	3.2	23.1	34.9	0.39	66.4
6.30	15.2	12.0	48.9	1150	105.7	1.6	8	2δ9	23.1	34.9	0.39	66.4
6.30	15.3	12.1	49.1	1155	106.2	0.5	10	1.6	23.4	35.1	0.38	66.7
6.10	15.7	12.2	50.2	1175	110.7	0.2	10	1.1	24.8	34.8	0.38	71.4
6.11	15.7	12.4	50.4	1180	112.0	-	-	-	25.2	34.9	0.37	72.2
7.30	15.8	11.6	49.7	1810	96.0	-	-	-	32.9	41.1	0.39	80.0
7.50	15.5	11.5	49.0	1785	95.5	0.1	11	0.7	32.4	41.6	0.40	78.0
7.42	15.5	11.4	48.9	1750	93.2	0.6	10	1.5	31.0	41.1	0.41	75.6
7.30	15.7	11.4	49.2	1720	92.7	1.4	8	2.4	30.4	40.7	0.40	74.6
7.25	15.8	11.4	49.5	1690	92.7	1.9	7.5	2.8	29.8	40.7	0.40	73.2
7.23	15.8	11.4	49.5	1680	93.7	1.6	8	2.5	30.0	40.5	0.40	74.1
7.28	15.8	11.4	49.5	1675	96.5	0.6	10	1.5	30.8	40.9	0.40	75.4
7.35	15.8	11.7	49.8	1675	99.2	0.1	11	0.6	31.6	41.1	0.39	76.5
6.90	16.3	12.0	51.3	1670	100.2	-	-	-	31.7	40.2	0.37	79.1
7.00	16.5	10.5	50.0	1760	95.0	-	-	-	31.8	39.7	0.41	80.0
7.14	16.1	10.5	49.0	1760	95.0	0.1	11	0.6	31.8	39.7	0.43	80.4
7.40	16.1	10.4	48.9	1740	93.5	0.6	10	1.6	31.0	41.0	0.43	75.6
7.35	16.0	10.0	48.3	1730	92.5	1.2	9	2.2	30.4	41.0	0.43	75.6
7.30	16.0	10.0	48.3	1720	91.5	1.8	8	2.7	30.0	40.0	0.44	75.0
7.31	16.0	10.1	48.4	1710	93.2	1.4	8	2.3	30.4	40.1	0.44	76.0
7.30	16.1	10.5	49.0	1705	94.6	0.7	10	1.7	30.8	40.2	0.44	76.8
7.05	16.1	10.5	49.0	1705	96.5	0.4	10	1.3	31.3	39.1	0.43	80.1
7.00	16.5	10.5	50.0	1695	97.2	0.1	11	0.7	31.4	39.7	0.42	79.1

TABLE III (Cont'd)

WICKET GATE POSITION NO.9

Q	P_1	P_2	H	N	T	H_a	P_a	$\frac{Qat}{Q}$	BHP	HP_{in}	σ	η
cfs	psi	in.Hg	ft	rpm	lb.ft	in	psi	%				%
7.18	16.8	9.7	49.9	1780	95.1	-	-	-	32.3	40.6	0.44	79.6
7.24	16.6	9.4	49.0	1805	95.1	0.2	11	1.0	32.7	40.7	0.45	81.2
7.50	16.0	9.0	47.2	1805	92.5	0.6	10	1.5	31.8	40.2	0.48	79.1
7.51	16.1	9.1	47.5	1800	92.0	0.9	9	1.9	31.6	40.4	0.47	78.1
7.45	16.1	9.1	47.5	1805	90.2	1.2	9	2.2	31.0	40.1	0.47	76.4
7.55	16.1	9.1	47.5	1820	92.0	0.8	10	1.8	31.9	40.6	0.47	78.7
7.48	16.1	9.1	47.5	1835	93.5	0.4	10	1.3	32.7	40.3	0.47	81.3
7.28	16.5	9.1	48.1	1835	93.5	0.1	11	0.7	32.7	39.7	0.47	82.7
7.15	16.9	9.5	49.8	1830	93.5	-	-	-	32.6	40.4	0.44	80.7
7.00	18.0	7.6	50.2	1795	95.1	-	-	-	32.5	39.9	0.48	81.4
7.07	17.9	7.4	49.8	1790	94.6	0.1	11	0.7	32.3	39.9	0.49	81.0
7.18	17.9	7.1	49.5	1770	95.5	0.5	10	1.5	32.2	40.3	0.49	79.8
7.16	17.9	7.0	49.4	1760	95.5	0.9	9	2.1	32.0	40.0	0.50	80.0
7.30	17.8	6.7	48.7	1795	94.5	1.3	8	2.3	32.1	40.3	0.52	79.8
7.51	17.5	6.5	47.9	1780	92.2	1.6	8	2.4	31.4	40.8	0.53	78.0
7.28	17.5	6.7	48.1	1800	94.2	1.0	9	2.0	32.3	39.7	0.52	81.4
7.28	17.7	6.8	48.6	1805	94.5	0.5	10	1.5	32.4	40.1	0.51	80.8
7.14	17.7	7.2	49.0	1800	94.5	0.7	11	0.1	32.4	39.7	0.50	81.4
7.00	18.0	7.6	50.2	1800	94.7	-	-	-	32.4	39.9	0.48	81.2
6.97	19.0	5.5	50.1	1800	95.4	-	-	-	32.7	39.6	0.53	82.6
6.97	19.0	5.5	50.1	1790	94.5	0.1	11	0.7	32.3	39.6	0.53	81.6
7.08	18.9	5.1	49.6	1785	95.2	0.6	10	1.6	32.4	39.8	0.55	81.4
7.15	18.9	5.1	49.6	1775	95.2	1.1	9	2.2	32.2	40.2	0.55	80.2
7.08	18.8	4.9	49.0	1760	95.5	1.6	9	2.6	32.0	39.4	0.56	81.2
7.04	18.9	5.0	49.4	1760	95.5	1.2	9	2.2	32.0	39.5	0.55	81.0
7.08	18.9	5.0	49.4	1770	95.2	0.8	10	1.9	32.1	39.7	0.55	80.9
7.06	19.0	5.1	49.7	1780	95.7	0.2	10	1.0	32.4	39.8	0.54	81.4
6.94	19.0	5.5	50.1	1780	96.7	-	-	-	32.8	39.4	0.53	83.2

TABLE IV TYPES OF INJURIES OF DEAD FISH.

Test number	Mortality	Number of dead fish examined	Types of Injuries: Operculum Damage	Eye Damage	Deflated Bladder	Damaged liver	Abrasion & Contusion	Ventral rupture	Decapitation & Laceration	None apparent	Remarks
C04.1	Immediate	20	2	0	10	2	0	0	6	3	
	1st day	6	1	0	5	3	2	1	0	0	
	2nd day	3	1	0	1	1	2	0	0	0	
	3rd day	2	0	1	0	0	1	0	0	0	
C05.5	Immediate	13	0	1	3	0	2	0	8	1	
	1st day	8	0	3	5	2	5	2	0	2	
	2nd day	1	1	0	0	0	0	0	0	0	
	3rd day	1	1	1	1	1	1	0	0	0	
C06.3	Immediate	26	0	5	4	0	3	3	14	3	
	1st day	10	1	6	7	8	4	5	0	2	
	2nd day	6	0	4	3	3	3	1	0	1	
	3rd day	5	0	2	4	2	1	0	0	1	
C08.1	Immediate	23	0	0	6	1	3	2	13	3	
	1st day	4	0	1	2	2	0	2	1	0	
	2nd day	2	-	-	-	-	-	-	-	-	
	3rd day	1	0	0	1	0	0	0	0	0	
C08.2	Immediate	21	2	2	8	0	2	2	10	2	
	1st day	5	1	2	3	1	3	1	0	1	a) N = 1800 rpm, σ = 0.64, Qa = 0
	2nd day	1	-	-	-	-	-	-	-	-	
	3rd day	1	0	1	1	0	0	0	0	0	
C08.3	Immediate	17	1	2	4	1	2	1	13	0	
	1st day	1	0	0	1	0	1	0	0	0	
	2nd day	1	-	-	-	-	-	-	-	-	
	3rd day	0	0	0	0	0	0	0	0	0	
C08.4	Immediate	19	2	3	4	0	3	1	12	0	
	1st day	2	1	2	1	1	2	1	0	0	
	2nd day	5	-	-	-	-	-	-	-	-	
	3rd day	0	0	0	0	0	0	0	0	0	

TABLE IV (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None apparent	
CO4.2	Immediate	21	2	2	5	1	2	3	10	0	b) N = 1800 rpm, Qa = 0.22 lb/min, σ = 0.64
	1st day	0	0	0	0	0	0	0	0	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	3	0	1	1	1	1	2	0	0	
CO5.6	Immediate	11	0	1	1	0	0	1	8	1	
	1st day	5	1	1	2	2	1	1	0	2	
	2nd day	3	0	1	2	2	1	1	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO6.4	Immediate	26	0	3	4	0	5	1	15	3	
	1st day	12	0	5	7	8	5	7	0	1	
	2nd day	5	0	2	3	4	4	1	0	1	
	3rd day	6	0	4	3	4	3	1	0	1	
CO11.1	Immediate	19	1	2	5	0	2	1	13	0	
	1st day	4	0	1	2	4	2	1	1	0	
	2nd day	3	0	1	2	2	2	0	0	0	
	3rd day	2	0	1	1	0	0	0	0	1	
CO11.2	Immediate	19	0	5	3	1	0	1	12	2	
	1st day	2	0	1	2	2	1	2	1	0	
	2nd day	1	0	0	1	0	0	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO11.3	Immediate	18	0	1	5	1	1	2	12	1	
	1st day	5	1	1	4	3	2	2	1	0	
	2nd day	1	0	0	1	0	1	0	0	0	
	3rd day	1	0	0	0	0	0	0	0	1	

TABLE IV (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None Apparent	
CO 4.3	Immediate	30	4	2	6	1	6	2	18	1	
	1st day	1	0	0	1	1	0	0	0	0	
	2nd day	1	1	0	1	1	0	0	0	0	
	3rd day	1	0	0	0	0	1	0	0	0	
CO 5.1	Immediate	24	1	2	5	0	3	2	16	0	
	1st day	1	0	0	1	1	1	1	0	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	1	0	1	1	1	1	0	0	0	
CO 20.1	Immediate	14	0	0	3	1	1	2	9	1	
	1st day	8	0	0	6	0	3	4	0	1	
	2nd day	3	0	0	1	0	2	0	0	0	
	3rd day	1	0	0	0	0	1	0	0	0	
CO 6.5	Immediate	20	0	2	7	0	1	1	11	1	c) N = 1800, σ = 0.39, Qa = 0
	1st day	6	0	2	5	4	0	1	0	0	
	2nd day	1	0	0	0	0	1	1	0	0	
	3rd day	2	0	1	1	0	2	0	0	0	
CO 19.3	Immediate	12	0	0	5	1	1	2	5	2	
	1st day	6	0	1	4	0	2	0	0	1	
	2nd day	2	0	0	1	1	0	1	0	0	
	3rd day	1	0	0	1	0	1	0	0	0	
CO 19.6	Immediate	20	0	2	7	2	3	2	12	2	
	1st day	11	0	0	6	2	4	4	0	2	
	2nd day	2	0	0	2	0	0	1	0	0	
	3rd day	2	0	0	1	0	1	0	0	0	

TABLE IV (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None apparent	
CO 4.4	Immediate	19	1	2	8	1	4	0	7	1	d) N = 1800, σ = 0.39, Qa = 0.16 lb/min.
	1st day	4	0	1	2	0	2	0	0	0	
	2nd day	1	0	0	1	1	0	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO 4.5	Immediate	17	1	2	7	0	1	0	8	1	
	1st day	2	0	0	2	2	0	0	0	0	
	2nd day	1	0	1	1	1	0	1	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO 5.2	Immediate	21	3	2	16	0	6	2	5	1	
	1st day	1	0	1	1	1	0	1	0	0	
	2nd day	1	0	0	1	0	0	0	0	0	
	3rd day	2	0	0	2	1	1	0	0	0	
CO 5.3	Immediate	17	1	2	6	1	4	2	8	0	
	1st day	1	0	0	1	0	0	0	0	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO 5.1	Immediate	19	1	3	5	0	4	2	10	2	
	1st day	7	0	2	4	5	1	4	0	0	
	2nd day	2	0	2	2	1	2	1	0	0	
	3rd day	2	0	0	2	0	1	0	0	0	
CO 6.6	Immediate	16	1	2	5	1	2	0	8	2	
	1st day	3	1	2	3	2	1	2	0	0	
	2nd day	2	0	1	2	1	2	0	0	0	
	3rd day	3	0	1	1	2	2	0	0	0	

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None Apparent	
CO 4.6	Immediate	16	2	1	6	1	2	1	6	2	e) N = 1800, $\sigma = 0.39$, $Qa = 0.32$ lb/min.
	1st day	10	0	0	10	4	1	1	0	0	
	2nd day	6	0	2	5	4	3	0	0	0	
	3rd day	1	0	0	0	1	0	0	0	0	
CO 5.4	Immediate	18	0	1	2	0	0	0	15	1	
	1st day	15	0	4	13	7	9	2	0	1	
	2nd day	4	0	0	3	4	4	0	0	0	
	3rd day	5	0	2	3	3	3	1	0	1	
CO 6.2	Immediate	17	1	1	4	0	0	1	9	2	
	1st day	3	0	1	2	2	1	0	0	1	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	3	0	2	3	3	3	1	0	0	
CO12.5	Immediate	22	0	1	8	0	3	1	13	1	
	1st day	2	0	0	2	2	2	2	1	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO12.6	Immediate	38	1	2	19	0	2	0	16	1	
	1st day	2	0	0	2	1	1	1	0	0	
	2nd day	2	0	0	2	1	1	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	
CO12.7	Immediate	23	2	6	11	0	3	2	8	1	
	1st day	2	0	1	2	1	1	0	0	0	
	2nd day	1	0	0	1	0	0	0	0	0	
	3rd day	1	0	0	1	1	1	1	0	0	
CO12.8	Immediate	22	0	3	10	1	1	3	10	1	
	1st day	5	0	1	4	0	2	1	0	0	
	2nd day	1	0	0	1	0	0	0	0	0	
	3rd day	1	1	0	1	1	1	1	0	0	

TABLE IV (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries: Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None Apparent	Remarks
C019.1	Immediate	21	0	1	8	1	2	4	6	1	f) Air in Penstock
	1st day	3	0	0	2	0	0	1	0	1	
	2nd day	3	0	0	2	0	1	1	0	0	
	3rd day	2	0	0	2	0	1	1	0	0	
C019.5	Immediate	19	0	1	7	1	4	3	7	1	
	1st day	17	0	1	9	1	1	2	0	5	
	2nd day	3	0	0	1	0	0	0	0	0	
	3rd day	1	0	0	1	0	0	0	0	0	
C020.3	Immediate	11	0	1	4	1	1	2	2	2	
	1st day	2	0	0	1	0	1	0	0	0	
	2nd day	2	0	0	1	0	1	0	0	1	
	3rd day	5	0	0	2	0	4	2	0	0	
C020.5	Immediate	27	0	4	9	1	5	3	14	1	
	1st day	6	0	2	2	0	2	1	0	1	
	2nd day	1	0	0	0	0	1	1	0	0	
	3rd day	2	0	0	0	0	1	1	0	0	
C012.1	Immediate	2	0	0	2	0	0	0	0	0	g) No blade, Q = 4.4
	1st day	2	0	0	2	1	0	0	0	0	
	2nd day	1	0	0	0	0	0	0	0	1	
	3rd day	1	0	0	0	0	0	0	0	1	
C012.2	Immediate	1	0	0	1	0	0	0	0	0	
	1st day	4	0	1	2	1	1	1	0	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	

TABLE IV (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion ε Contusion	Ventral Rupture	Decapitation ε Laceration	None Apparent	
C016.2	Immediate	15	1	3	1	1	1	1	9	2	h) Air through vent
	1st day	5	0	1	2	1	1	1	0	0	
	2nd day	1	0	0	1	0	0	1	0	0	
	3rd day	1	0	0	0	0	0	1	0	0	
C019.4	Immediate	16	0	2	4	2	4	3	10	3	
	1st day	20	0	3	3	1	5	4	0	7	
	2nd day	3	0	0	1	0	1	1	0	0	
	3rd day	4	0	0	2	0	2	1	0	1	
C020.2	Immediate	17	0	1	0	0	1	2	12	1	
	1st day	6	0	1	1	1	2	2	0	1	
	2nd day	2	0	1	0	0	1	0	0	0	
	3rd day	4	0	0	0	0	3	0	0	1	
C020.4	Immediate	12	0	2	0	0	0	1	9	0	
	1st day	4	0	1	3	1	1	3	0	0	
	2nd day	3	0	0	1	0	2	2	0	0	
	3rd day	3	0	0	1	0	2	2	0	0	
C020.6	Immediate	18	0	1	4	2	5	2	10	0	
	1st day	0	0	0	0	0	0	0	0	0	
	2nd day	2	0	0	0	0	2	1	0	0	
	3rd day	3	0	0	0	0	3	1	0	0	
C012.3	Immediate	16	0	0	16	0	0	0	0	0	j) No blades, Q =6
	1st day	3	0	1	2	1	1	1	0	1	
	2nd day	3	1	1	2	1	1	1	0	1	
	3rd day	1	0	0	0	0	1	0	0	0	
C012.4	Immediate	18	0	0	18	0	0	0	0	0	
	1st day	1	0	0	1	0	0	0	0	0	
	2nd day	1	0	1	1	1	0	0	0	0	
	3rd day	0	0	0	0	0	0	0	0	0	

TABLE IV (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None Apparent	
C022.1	Immediate	25	0	2	12	2	6	4	11	2	N = 1200
	1st day	4	0	0	1	1	3	1	0	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	2	0	0	0	0	0	0	0	2	
C023.2	Immediate	30	0	6	20	3	18	9	3	0	
	1st day	5	1	1	0	0	0	0	1	2	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	2	0	0	0	0	0	0	0	2	
C022.2	Immediate	31	0	5	25	2	7	7	4	1	k) N = 900
	1st day	8	0	0	8	0	7	2	0	0	
	2nd day	1	0	0	0	0	0	0	0	1	
	3rd day	2	0	0	1	0	0	0	0	1	
C023.1	Immediate	26	0	3	20	3	11	7	2	0	
	1st day	3	0	2	1	0	0	0	0	0	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	3	0	0	2	0	0	0	0	1	

TABLE V TYPES OF INJURIES OF DEAD FISH

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None Apparent	
C07.1	Immediate	0	0	0	0	0	0	0	0	0	Fish were introduced below control gate
	1st day	1	0	0	0	0	0	0	0	1	
	2nd day	3	0	0	1	0	0	0	0	2	
	3rd day	7	-	-	-	-	-	-	-	-	
C07.2	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	2	0	0	2	0	0	0	0	0	
	2nd day	3	0	0	0	0	1	0	0	2	
	3rd day	3	-	-	-	-	-	-	-	-	
C013.1	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	3	0	1	1	2	1	0	0	0	
	2nd day	3	0	0	0	0	0	0	0	3	
	3rd day	2	0	1	1	0	0	1	0	1	
C026.1	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	7	-	-	-	-	-	-	-	-	
	2nd day	2	-	-	-	-	-	-	-	-	
	3rd day	3	-	-	-	-	-	-	-	-	
C026.2	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	6	-	-	-	-	-	-	-	-	
	2nd day	4	-	-	-	-	-	-	-	-	
	3rd day	1	-	-	-	-	-	-	-	-	

TABLE V (Cont'd)

Test number	Mortality	Number of dead fish examined	Types of Injuries								Remarks
			Operculum Damage	Eye Damage	Deflated Bladder	Damaged Liver	Abrasion & Contusion	Ventral Rupture	Decapitation & Laceration	None Apparent	
CO13.2	Immediate	1	0	0	0	0	1	0	0	0	Fish introduced below Control gate
	1st day	2	0	2	1	1	1	0	0	0	
	2nd day	4	1	2	2	0	1	0	0	1	
	3rd day	5	1	0	2	0	1	0	0	2	
CO13.3	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	3	1	1	2	1	0	0	0	1	
	2nd day	5	0	1	3	0	1	1	0	1	
	3rd day	2	1	2	2	1	2	1	0	0	
CO26.3	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	3	-	-	-	-	-	-	-	-	
	2nd day	0	0	0	0	0	0	0	0	0	
	3rd day	1	-	-	-	-	-	-	-	-	
CO7.3	Immediate	1	0	0	1	0	0	0	0	0	Fish introduced above gate
	1st day	3	0	2	0	0	2	0	0	1	
	2nd day	5	0	1	2	1	3	0	0	1	
	3rd day	10	-	-	-	-	-	-	-	-	
CO7.4	Immediate	0	0	0	0	0	0	0	0	0	
	1st day	1	0	0	1	0	0	0	0	0	
	2nd day	7	1	5	6	2	5	1	0	0	
	3rd day	12	-	-	-	-	-	-	-	-	

TABLE VI CONTROL FISH

Date set up	No of fish set up	Total mortality during 3 days observation
May 7, 1964	80	1
May 8, 1964	80	1
May 11, 1964	80	2
May 12, 1964	80	1
May 13, 1964	80	2
May 19, 1964	80	1
May 20, 1964	80	2
May 22, 1964	80	2
May 23, 1964	80	4
May 26, 1964	80	3

No control fish were set up for the test on May 4, 5 and 6.
Fish to be tested on May 4 were separated and set up in 6 nylon nets 4 days before the testing day. Total mortality was 1.
Fish to be tested on May 5, were set up in 6 baskets 4 days before the testing days. Total mortality was 1.
Fish to be tested on May 6, were set up 2 days before the testing day. No mortality was observed. In addition, fish in one tank had not been used. Negligible mortality was observed in that tank.

TABLE VII FISH MORTALITY IN THE PASSAGE DOWNSTREAM FROM THE RUNNER.

TEST CONDITIONS					FISH MORTALITY											REMARKS
										DELAYED MORTALITY						
TEST NUMBER	DATE	TIME	DISCHARGE cfs	SUCTION AT ENTRY in.Hg	AVERAGE LENGTH OF FISH mm	NUMBER OF FISH INJECTED	ALIVE	DEAD	MISSING	1st DAY	2nd DAY	3rd DAY	TOTAL MORTALITY	PERCENTAGE	AVERAGE	
C07.3	7.5.64	11.30	5.84	5	38	80	79	1	0	3	5	10	19	24	25	Fish sucked in above Control Gate.
C07.4	7.5.64	11.40	5.84	5	38	80	80	0	0	1	7	12	20	25		
C06.1	7.5.64	10.20	5.83	slight	38	80	80	0	0	1	3	7	11	14	13	Fish injected into draft tube below Control Gate with slight suction at entry.
C07.2	7.5.64	10.40	5.84	slight	38	80	80	0	0	2	3	3	8	10		
C013.1	13.5.64	13.30	5.85	slight	38	80	80	0	0	3	3	2	8	10		
C026.1	26.5.64	10.25	5.50	slight	38	79	79	0	0	7	2	3	12	15		
C026.2	26.5.64	10.45	5.50	slight	38	79	78	0	1	6	4	1	12	15		
C013.2	13.5.64	15.45	5.85	-	38	80	77	1	2	2	4	5	14	17	11	Fish injected at same location but with slight pressure at entry.
C013.3	13.5.64	16.00	5.85	-	38	79	79	0	0	3	5	2	10	12		
C026.3	26.5.64	11.15	5.50	-	38	80	80	0	0	3	0	1	4	5		
C15	3.5.64	16.00	4.25	-	37	80	80	0	0	0	1	0	1	1	2	Fish dumped on trap.
C16	3.5.64	16.10	4.25	-	37	80	80	0	0	0	0	0	0	0		
C026	26.5.64	10.05	5.50	-	38	80	80	0	0	0	1	2	3	4		

TABLE VIII FISH MORTALITY DUE TO TURBINE AT LOW SPEED

Test number	Date	Time	HYDRAULIC CONDITIONS															FISH MORTALITY											REMARKS
			Discharge cfs	Penstock pressure psi	Draft tube pressure in. of Hg	Suction head ft. of water	Total head ft. of water	Torque lb-ft	R.P.M.	Air meter reading in. of water	Air pressure psi	Air quantity lb/min	Air in percent of discharge	Horse power output	Horse power input	Efficiency %	Sigma σ	Average length m.m	Number of fish injected	Alive	Dead	Missing	Delay mortality 1st day	Delay mortality 2nd day	Delay mortality 3rd day	Total mortality	Percentage	Average	
C-1	25.4.64	14.00	4.3	18.1	3.2	3.6	45.4	104.7	600	—	—	—	—	11.9	22.2	53.3	0.64	3.7	80	55	24	1	0	0	0	25	31	34	Low suction
C-2	25.4.64	14.30	4.3	18.1	3.2	3.6	45.4	105.2	600	—	—	—	—	12.2	22.2	54.4	0.64	3.76	80	51	28	1	1	0	0	30	37		No air
C-3	28.4.64	9.40	4.37	18.1	3.2	3.6	45.4	105.5	600	0.4	14	0.29	2.5	12.1	22.5	53.8	0.64	3.75	80	60	19	1	2	0	0	22	27	27	Low suction,
C-4	28.4.64	10.00	4.37	18.1	3.2	3.6	45.4	105.5	600	0.4	14	0.29	2.5	12.1	22.5	53.8	0.64	37.5	80	62	19	+1	3	1	0	22	27		with air in draft tube
C-5	28.4.64	10.40	4.3	13.6	12.5	14.2	45.4	101.5	600	—	—	—	—	11.5	22.1	52.0	0.41	37.6	80	62	17	1	2	1	0	21	26	40	High suction,
C-6	1.5.64	10.30	4.25	13.6	12.5	14.2	45.4	101.5	600	—	—	—	—	11.4	21.9	52.0	0.41	37.6	105	72	28	5	7	2	0	42	40		no air.
C-7	1.5.64	11.20	4.25	13.6	12.5	14.2	45.4	101.5	600	—	—	—	—	11.5	21.9	52.0	0.41	37.5	101	72	28	1	17	4	0	50	49		
C-8	1.5.64	14.30	4.23	13.6	12.5	14.2	45.4	101.5	600	—	—	—	—	11.5	21.9	52.0	0.41	37.5	103	76	35	2	11	5	1	54	48		
C-9	1.5.64	14.25	4.24	13.6	12.5	14.2	45.4	101.5	600	—	—	—	—	11.5	21.9	52.0	0.41	37.5	100	77	23	0	10	3	0	36	36		
C-10	28.4.64	11.10	4.25	13.6	12.5	14.2	45.4	100	600	0.4	14	0.29	2.5	11.4	21.9	52.0	0.41	37.5	80	67	16	+3	6	1	0	20	25	28	High suction,
C-11	3.5.64	14.00	4.22	13.6	12.5	14.2	45.4	100	600	0.4	14	0.29	2.5	11.4	21.8	52.0	0.41	37.5	98	65	33	0	0	1	0	34	35		with air,
C-12	3.5.64	14.20	4.22	13.6	12.5	14.2	45.4	100	600	0.4	12	0.28	2.5	11.4	21.8	52.0	0.41	37.5	106	78	27	1	3	0	0	31	29		in draft
C-13	3.5.64	14.50	4.22	13.6	12.5	14.2	45.4	100	600	0.4	10	0.27	2.4	11.4	21.8	52.0	0.41	37.5	98	80	16	2	1	0	0	19	20		tube.
C-14	3.5.64	15.30	4.22	13.6	12.5	14.2	45.4	100	600	0.4	16	0.30	2.62	11.4	21.8	52.0	0.41	37.5	100	78	27	+3	3	0	0	30	30		
P 4	1.4.64	10.00	2.1	0.5	6.5	7.15	8.3	25.0	300	—	—	—	—	1.4	2.0	70	3.1	3.7	30	27	3	0	0	0	0	3	10	19	Pink fry
P 5	1.4.64	10.30	2.1	0.5	6.5	7.15	8.3	25.0	300	—	—	—	—	1.4	2.0	70	3.1	3.7	20	15	3	0	2	0	0	5	25		Preliminary test.

TABLE IX FISH MORTALITY DUE TO TURBINE OPERATING AT NORMAL SPEED.

Test number	Date	Time	HYDRAULIC CONDITIONS: Discharge cfs	Penstock pressure psi	Draft tube pressure in. of Hg	Suction head ft. of water	Total head ft. of water	Torque lb.ft.	R.P.M.	Air meter reading in. of water	Air quantity lb/min	Air pressure psi	Air in percent of discharge	Horse power output	Horse power input	Efficiency %	Sigma	FISH MORTALITY: Average length m.m	Number of fish injected	Alive	Dead	Missing	Delay mortality: 1st day	2nd day	3rd day	Total mortality	Percentage	Average	REMARKS
CO4·1	4·5.64	10·10	5.83	20.2	3.0	3.4	50.0	85.2	1800	—	—	—	—	28.7	33.1	86.7	0.59	36	80	54	20	6	6	3	2	37	46		Low suction,
CO5·5	5.5.64	14.30	5.84	20.2	3.0	34	50.0	85·1	1800	—	—	—	—	29.0	33.2	87.4	0.59	37	80	65	13	2	8	1	1	25	31		no air.
CO6·3	6.5.64	13.40	5.83	20.2	3.0	3.4	50.0	84.5	1800	—	—	—	—	28.8	33.2	87.0	0.59	37	80	56	26	+2	10	6	5	45	56		
CO8·1	8.5.64	10.20	5.83	20.2	3.0	3.4	50.0	84·1	1800	—	—	—	—	28.7	33.2	86.8	0.59	35.5	79	56	23	0	4	2	1	30	38	38	
CO8·2	8.5·64	10.45	5.83	20·2	3.0	3.4	50.0	84.2	1800	—	—	—	—	28.7	33.2	86.8	0.59	37	80	59	21	0	5	1	1	28	35		
CO8·3	8.5.64	13.40	5.84	20.2	3.0	3.4	50.0	84.3	1800	—	—	—	—	28.9	33.2	87.0	0.59	38	80	63	17	0	1	1	0	19	24		
CO8·4	8.5.64	14.00	5.85	20.2	3.0	3.4	50.0	84.8	1800	—	—	—	—	29.0	33.2	87.4	0.59	37	80	61	19	0	2	5	0	26	32		
CO4·2	4·5.64	10.50	5.82	20.2	3.0	3.4	50.0	82.7	1800	0.2	0.22	18	1.3	28.3	33.0	85.8	0.59	37	80	51	21	8	0	0	3	32	40		Low suction,
CO5·6	5.5.64	15.00	5.81	20.2	3.0	3.4	50.0	84.2	1800	0.2	0.22	18	1.3	28.7	33.0	87.0	0.59	36	80	70	11	+1	5	3	0	18	22		with air
CO6·4	6.5.64	14.20	5.83	20.2	3.0	3.4	50.0	84.2	1800	0.2	0.22	18	1.3	28.8	33.4	86.8	0.59	37	80	54	26	0	12	5	6	49	61		in draft
CO11·1	11.5.64	9.45	5.89	20.2	3.0	3.4	50.0	84.5	1800	0.2	0.22	16	1.26	29.0	33.4	86.9	0.59	37	80	61	19	0	4	3	2	28	35	36	tube.
CO11·2	11.5.64	10.10	5.87	20.2	3.0	3.4	50.0	84.5	1800	0.2	0.22	17	1.3	29.0	33.4	86.9	0.59	38	80	61	19	0	2	1	0	22	27		
CO11·3	11.5.64	10.35	5.86	20.2	3.0	3.4	50.0	84.5	1800	0.2	0.22	17	13	29.0	33.3	87.1	0.59	37.5	80	62	18	0	5	1	1	25	31		

TABLE IX FISH MORTALITY DUE TO TURBINE OPERATING AT NORMAL SPEED.

Test number	Date	Time	HYDRAULIC CONDITIONS: Discharge cfs	Penstock pressure psi	Draft tube pressure in. of Hg	Suction head ft. of water	Total head ft. of water	Torque lb.ft.	R.P.M.	Air meterreading in. of water	Air pressure psi	Air quantity lb / min.	Air in percent of discharge	Horse power output	Horse power input	Efficiency %	Sigma σ	FISH MORTALITY: Average length mm	Number of fish injected	Alive	Dead	Missing	Delay mortality: 1st day	2nd day	3rd day	Total mortality	Percentage	Average	REMARKS
C04.3	4.5.64	13.30	5.91	16.0	11.5	50	50	85.7	1800	—	—	—	—	28.9	33.6	85.8	0.39	35	79	55	30	+6	1	1	1	27	34		High suction,
C05.1	5.5.64	9.45	5.95	16.0	11.5	13	50	85.7	1800	—	—	—	—	29.0	33.8	86	0.39	36	80	57	24	+1	1	0	1	25	31		no air.
C06.5	6.5.64	14.55	5.95	16.0	11.5	13	50	86	1800	—	—	—	—	29.5	33.7	87.6	0.39	36.5	80	60	20	0	6	1	2	29	36	34	
C0193	19.5.64	13.45	5.92	16.1	11.1	12.6	49.8	86	1800	—	—	—	—	29.5	33.5	87.8	0.4	38	80	68	12	0	6	2	1	21	26		
C0196	19.5.64	15.15	5.95	16.5	11.0	12.3	50.3	86	1800	—	—	—	—	29.5	33.7	87.5	0.39	38	80	62	20	+2	11	2	2	33	41		
C020.1	20.5.64	10.30	5.90	16.1	11	12.3	49.5	84.5	1800	—	—	—	—	29.0	33.3	86.8	0.39	38	80	65	14	-1	8	3	1	27	34		
C04.4	4.5.64	14.00	6.11	16.0	11.5	13	50	82.1	1800	0.2	17	0.22	1.2	27.9	34.6	81	0.39	36	80	60	19	-1	4	1	0	25	31		High suction,
C04.5	4.5.64	14.25	6.09	16.0	11.5	13	50	84.5	1800	0.1	20	0.16	0.9	28.8	34.5	83.3	0.39	35.5	79	60	17	-2	2	1	0	22	27		with small
C05.2	5.5.64	10.20	6.18	15.7	11.5	13	49.3	82.7	1800	0.2	17	0.22	1.2	28.0	34.7	80.8	0.4	36	80	62	21	+3	1	1	2	22	27	30	quantity
C05.3	5.5.64	11.00	6.18	15.7	11.5	13	49.3	82.7	1800	0.2	17	0.22	1.2	28.0	34.7	80.8	0.4	36	80	62	17	-1	1	6	0	19	24		of air. in the draft
C06.1	6.5.64	18.30	6.10	16.1	11.5	13	50.3	85.5	1800	0.2	17	0.22	1.2	29.3	34.6	85.0	0.39	37	80	60	19	-1	7	2	2	31	39		tube.
C06.6	6.5.64	15.30	6.18	15.9	11.5	13	49.8	84.1	1800	0.2	17	0.22	1.2	28.8	34.9	82.6	0.39	37	80	63	16	-1	3	2	3	25	31		

TABLE IX FISH MORTALITY DUE TO TURBINE OPERATING AT NORMAL SPEED.

Test number	Date	Time	HYDRAULIC CONDITIONS: Discharge cfs	Penstock pressure psi	Draft tube pressure in. of Hg	Suction head ft. of water	Total head ft. of water	Torque lb.ft.	R. P. M.	Air meterreading in. of water	Air pressure psi	Air quantity lb / min.	Air in percent of discharge	Horsepower output	Horse power input	Efficiency %	Sigma σ	FISH MORTALITY: Average length mm	Number of fish injected	Alive	Dead	Missing	Delay mortality: 1st day	2nd day	3rd day	Total mortality	Percentage	Average	REMARKS
CO4.6	4.5.64	15.00	6.18	15.5	11.5	13	49	82.0	1800	0.6	7	0.31	1.75	28	35.1	80	0.4	35	80	64	16	0	10	6	1	32	40		High suction,
CO5.4	5.5.64	13.45	6.15	15.6	11.4	12.9	49.1	81.5	1800	0.6	11	0.34	2.0	27.6	34.3	80.5	0.4	35.5	80	59	18	-3	15	4	5	45	56		large
CO6.2	6.5.64	11.10	6.21	15.8	11.5	13	49.6	82	1800	0.6	12	0.35	2.0	28	35	80	0.39	36.5	80	63	17	0	3	0	3	23	29		quantity of
CO12.5	12.5.64	14.15	6.2	16	11.5	13	50	81	1800	0.6	7	0.31	1.75	27.8	35.2	79.5	0.39	37	80	57	22	-1	2	0	0	25	32	40	air.
CO12.6	12.5.64	14.45	6.2	16	11.5	13	50	84	1800	0.6	8	0.32	1.8	28.8	35.4	81.8	0.39	38	80	44	38	+2	2	2	0	40	50		
CO12.7	12.5.64	15.15	6.27	16	11.3	12.8	49.8	84	1800	0.6	9	0.32	1.8	28.8	35.4	81.4	0.4	38	80	56	23	-1	2	1	1	28	35		
CO12.8	12.5.64	15.45	6.27	16	11.4	12.9	49.9	84	1800	0.6	8	0.32	1.8	28.8	35.4	81.4	0.4	37.5	80	58	22	0	5	1	1	29	36		
CO19.2	19.5.64	11.10	5.56	17.2	4	4.5	44.3	61.5	1800		atm.			21.5	28.0	76.7	0.64	38	74	60	16	+2	5	1	1	21	28		Large
CO19.4	19.5.64	14.25	5.5	17.2	4	4.5	43.7	60	1800		atm.			20.6	27.3	73.6	0.65	38.5	80	64	16	0	20	3	4	43	54		quantity of
CO20.2	20.5.64	11.00	5.5	17	4	4.5	43.7	58.7	1800		atm.	–		20.1	27.3	73.6	0.65	38	80	63	17	0	6	2	4	29	36	34	air in the
CO20.4	20.5.64	14.15	5.49	17.1	4	4.5	44	59.5	1800		atm			20.4	27.4	74.5	0.64	37	80	70	12	+2	4	3	3	20	25		draft tube-
CO20.6	20.5.64	15.05	5.51	17.2	4	4.5	44	59.6	1800		atm			20.5	27.5	74.2	0.64	38	80	64	18	+2	0	2	3	21	26		through vent.
CO19.1	19.5.64	10.40	5.97	16.1	11	12.4	49.6	83.7	1800	0.1	17	0.16	0.7	28.7	33.9	84.7	0.4	39	80	57	21	-2	3	3	2	31	39		Air in
CO19.5	19.5.64	14.45	5.97	16.3	11	12.4	50	84.1	1800	0.1	17	0.16	0.7	28.9	34	85.2	0.4	38	80	63	19	+2	17	3	1	38	47		penstock
CO20.3	20.5.64	13.45	5.98	16.2	11	12.4	49.8	83.4	1800	0.1	17	0.16	0.7	28.6	33.9	84.2	0.4	38.5	80	68	11	-1	2	2	5	21	26	39	
CO20.5	20.5.64	14.30	5.96	16.2	11	12.4	49.8	83.7	1800	0.1	17	0.16	0.7	28.7	33.8	85.2	0.4	38	80	53	27	0	6	1	2	36	45		

TABLE IX FISH MORTALITY DUE TO TURBINE OPERATING AT NORMAL SPEED.

Test number	Date	Time	HYDRAULIC CONDITIONS: Discharge cfs	Penstock pressure psi	Draft tube pressure in. of Hg	Suction head ft. of water	Total head ft. of water	Torque lb.ft.	R.P.M.	Air meterreading in. of water	Air pressure psi	Air quantity lb / min.	Air in percent of discharge	Horsepower output	Horse power input	Efficiency %	Sigma σ	FISH MORTALITY: Average length mm	Number of fish injected	Alive	Dead	Missing	Delay mortality: 1st day	2nd day	3rd day	Total mortality	Percentage	Average	REMARKS
P-1	193.64	14.30	6.3	19.0	5.5	6.2	50.0	89.7	1800	—	—	—	—	30.7	35.4	86.9	0.53	—	20	14	4	1	1	0	0	6	30	30	
P-2	243.64	15.00	6.1	17.0	11.5	13.0	52.1	88.5	1800	—	—	—	—	30.4	36.2	84.0	0.38	—	20	14	5	1	0	0	0	6	30		
P-3	243.64	15.30	6.3	17.0	11.5	13.0	52.1	87.5	1800	0.1	20	0.22	1.2	30.0	37.3	81.0	0.38	—	20	13	5	2	1	0	0	8	40		
CO22.2	225.64	15.00	4.8	16.7	12.0	13.6	52.2	116.7	900	—	—	—	—	20.1	28.2	71.4	0.37	38	80	49	31	0	8	1	2	42	52	46	
CO23.1	235.64	10.45	4.84	17.1	11.8	13.3	52.5	119.0	900	—	—	—	—	20.4	29.0	70.4	0.37	39	80	54	26	0	3	0	3	32	40		
CO22.1	225.64	14.30	5.18	16.0	11.5	13.0	50.0	103.7	1200	—	—	—	—	23.7	29.4	80.6	0.39	38	80	54	25	1	4	0	2	32	40	43	
CO23.2	235.64	11.10	5.14	16.5	11.5	13.0	51.1	107.9	1200	—	—	—	—	24.5	29.7	82.0	0.39	38.5	80	52	29	+1	5	0	2	36	45		
CO12.1	125.64	10.00	4.4	1.25	5.0	5.7	—	—	—	—	—	—	—	—	—	—	—	37.5	80	78	2	0	2	1	1	6	8	7	No
CO12.2	125.64	10.10	4.4	1.25	5.0	5.7	—	—	—	—	—	—	—	—	—	—	—	37.5	80	79	1	0	4	0	0	5	6		runner.
CO12.3	125.64	10.25	6.0	1.25	8.0	9.1	—	—	—	—	—	—	—	—	—	—	—	37.5	80	64	16	0	3	3	1	23	29	27	No
CO12.4	125.64	10.35	6.0	1.25	8.0	9.1	—	—	—	—	—	—	—	—	—	—	—	37.5	80	62	18	0	1	1	0	20	25		runner.