The most inactive period in fish life is cold wave period from December to January. The life during this period is extremely inactive and the fish are found to be huddled in deeper pools. This lethargic period starts towards the close of October when the temperature of the water falls. The fish then start searching the pools for the winter sojourns. It has been experienced that they collect almost species-wise or with akin species. By the end of November this search is almost complete and in the selection of pools they take the following two precautions :—

(*i*) It should be deep.

(*ii*) It should be free from fish enemies.

Preference is given to places which have either spring or seepage water and have weeds above.

Having selected the places the fish settle down and this inactive life continues for December and January. In February, movement starts which increases in March. By April the fish is again ready for the active life, leave their abodes and begin onward march of migration to repeat the cycle of inactive and passive life.

Pallah fish, being a sea fish, its habits are somewhat different from other species. Instead of hilly tracts it breeds in shallow water near the coast and in the prime of its youth it enters River Indus and goes upstream at a terrific speed, some time 8 miles an hour. Previously it used to travel inland as far as Multan but with the construction of Sukkur Barrage its journey was restricted upto Sukkur and with the completion of Kotri Barrage it has been observed that the crop of this royal fish has dwindled considerably in the area above Kotri Barrage.

Effect of Irrigation Structures on Fish Life.

It has been observed that the mighty Irrigation structures built across the rivers and the canals off-taking from these works are adversely effecting the fish wealth of the country. The fall velocity over these structures is always high enough to allow even the strongest fish to pass. As mentioned above, in June the fish becomes super active and is ready to ascend any fall even at the risk of her life. If she is not allowed or is unable to ascend she probably will not breed which highly affects the future propagation of fish life. In case of structures without efficient fish passes, during breeding period the fish are found striking against the gates and shutters in their attempt to cross the obstacle and it is not some thing less than cruelty to see these animals dying of sheer exhaustion in their attempts to cross the barrier.

Similarly in case of non-perennial canals millions and millions of fish playing in the canal waters get trapped when the canal is closed and are thus put to slow and lingering death. It has been estimated that only in the Lower Sind Barrage area hundreds of maunds of fish are thus destroyed every year.

In view of above, almost all countries in Europe and America have made it a law to provide fish ways in all the structures built across the rivers which hold the water or head it up.

Fish Ladders or Fish Ways.

The fish ladders are channels straight or zigzag, series of pools or small falls or similar Hydraulic Structures constructed to give the fish an easy passage over the impediments like dams, weirs and Headworks.

In West Pakistan as well, fish ladders have been provided in almost all the important Headworks and Barrages, but unfortunately no proper and effective record of the fish movement in the fish ladders has ever been kept from which any definite conclusion about their efficiency could be arrived at. However, from the preliminary data gathered by this Institute, it is concluded that most of the fish ladders in this country are not working satisfactorily, though during the super-active life period of fish we have plenty of discharge to spare for fish ladders.

Before reviewing the design and the working of the fish ladders in this country and their comparison with fish ways used in other countries it is necessary to give brief historical background of the development of the fish ways.

Development of Fish Ways.

In Europe, the construction of fish way in weirs or dams is an old practice. It was Lachanede who described the early fish way in 17th century. But there are still reasons to believe that the fish ways were built in Europe even earlier than 17th century. The earlier fish way design was very primitive and with more modern Irrigation and Power practice the design of fish ways got further stage of perfection.

The designers and authors who stand out among a number of men active at that time, were an American, named, Mecdoneld and a Belgian called Denil. Another French name, Camers, who made an unsuccessful attempt for designing a fish way helped Denil to start his later work on fish ways. It was Denil who made successful and systematic research on fish way problem.

Simultaneously with Mecdoneld, Landmark in Norway found fish ways design which was less radical but was more immediately successful. These four investigators took it for granted that the only determining factor required for the true design of fish way was the effort required by the fish against the velocity that it has to face. But recent work of Denil indicates that it is likely that two fish ways with the same velocity of flow may require a different degree of effort from the same fish depending upon the slopes or if pool fish ways are compared according to the elevation differences between the two consecutive pools. This question is obviously of greater importance, particularly when rules are to be established for rational fish way design.

Characteristics of Fish Ways.

The main requirements in the design of fish way are :—

(1) To provide as much friction as possible so that the velocity in the fish ladder will be the minimum for a given slope.

(2) The hydraulic conditions must be of such nature that the passage of the fish up the fish way does not overtax the energy of any but the weekest individual fish.

(3) The size of the free cross section of the fish way must be sufficient for the unhamperd swiming movements, considering the size and number of fish using the fish way.

(4) The quantity and the characteristics of flow and placement of fish way should be such that the downstream end will be easily accessible and also easily discoverable by the fish.

(5) It should always remain free from debris, excessive silt and trash.

Location or Siting of Fish Way.

The location of fish way requires careful study and planning. The important point in the design of any fish way is the position of its entrance. The habit of fish is to proceed upstream until halted by an obstruction and then nose their way from side to side, searching for the passage always facing upstream. Therefore, entrance on the lower end of the fish way must be placed near the base of the weir, so that there always remains some depth of flow at the entrance even when the river discharge is very low. Similarly in case where the pond level varies, the exit end upstream must also be made to secure reasonable depth of water above it for the easy passage of fish.

Landmark stated many years ago and it is still true today that the majority of unsuccessful fish ways are due to failure to attract the fish. Hence, no generally accepted rule can be given as to exactly where the downstream end of the fish way be placed and it is doubtful whether such a specific rule can be formulated at any stage.

On the contrary almost all experts agree today that the best guide in this respect is the observation of the actual behaviour of the migrants at the particular site. This does not solve the problem, in case of construction of a new structure in the river since the hydrographic and the hydraulic conditions at its foot may be altered to such an extent that the fish may fail to search for passage at the same place as before. For this reason the Norwegian fishery authorities have made it a rule not to design or place a fish way unless the new weir is ready and in operation and actual fish behaviour has been observed for a reasonable period.

Fish Way Designs.

In order to understand the various factors connected with the fish way problems, it is necessary to know the different types of fish ways. Recently a very systematic work has been done by A. M. Mcleod and Neymenyi of the

Iowa Institute of Hydraulic Research to modify the old fish way design. The various important types of fish ways are : —

(1) *Denil or Channel Type Fish Way.*

Denil or channel type fish way consists of straight channel with closely spaced baffles set at an angle with the axis of the channel. The baffles with parts of the channel walls and bottom form "Secondary Channels" while they leave free a relatively large portion of the channel for the straight "main flow" through which the fish pass. The recent Denil designs are perfected in such a manner as to make the entrance of the water into the Secondary Channels more easy for passage through them. The flow re-entering from the Secondary Channels into the main flow meets the latter abruptly *i.e.*, at an angle not far from 90 degrees.

Denil studies, as well as those of the other investigators such as Lachenede in France, Neymenyi and White in London have proved that the Denil system is adaptable to any required shape of cross section and still more important to great headwater fluctations. The oldest fish way design by Denil is reproduced in fig. 1(a) ; and the latest design as modified by Mcleod and Nemenyi in fig. 1(b).

(2) *Pool and Jet Fish Ways.*

The pool and jet fish way consists of series of pools in a stepped arrangement from tail water to headwater. The flow from the pool to pool may be over solid obstacles, or through notches or orifices in the obstacles or a combination of these two. So this type can be sub-divided in the following three types:

(*i*) Pool and Overfall type : the flow takes place over the full width of the solid obstacles.

(*ii*) Pool and Notch type : the flow passes through notches cut in the obstacles and not over the whole of the obstacle.

(*iii*) Pool and Jet type : the flow takes place through the orifices cut in the obstacle near the bed.

This type of fish way in its many variations is probably the oldest and most widely used of all types and is suitable for mild slopes only. A sketch of ordinary overfall type pool fish way is given in fig. 2(a). In this case the fish usually swims up the falling jet and each pool affords a resting place for the migrant. In case when the obstacles are provided with notches or submerged orifices as shown in fig. 2(b) and 2(c) the fish generally prefers to use them to avoid exposure. The most successful design of this type as developed by Neymenyi and White in 1938 is shown in fig. 2(c).

(3) *Alternate Obstacle Fish Ways.*

The alternate baffle fishway consists of a straight rectangular channel with obstacles or baffles placed alternately along the sides producing a jet ... This type of fish way has been built in an almost unlimited variety of baffle shapes, spacings and angles. The flow is confined to a zigzag path which is much longer than the fish way. It is found by recent research that most fish ways of this type are unsatisfactory. It does not provide any resting place for the ascending fish. The velocities are localized and are often in such a direction as to strike the fish from the side. Besides, the fish dislikes the zigzag path created by this type and prefers a straight course even if she has to exert more effort. The design of this type is reproduced in fig. 3.

(4) *Paired Obstacle Fish Way.*

The paired obstacle fish way consists of a sloping rectangular channel with baffles or obstacles in opposed pairs spaced along the channel at intervals about equal to the channel width and with straight free passage between them. The free passage is considerably restricted, one-half to 5/8th of the channel width being taken up by the obstacles. The floor of its free passage is usually flat, although small bottom obstacles may be used.

In effect, the flow in this type is a series of pools and orifices and although the free passage is straight it cannot be considered from the hydraulic point of view true channel type fish way. The effort required by fish varies, being a maximum at the obstacles. This type of fish way adapts itself to a considerable range of headwater elevation with little change in flow characteristics. However, the flow was found to be unstable in full scale fishways. The unstable condition has been noticed in other hydraulic tests where pairs of obstacles were placed symmetrically in a stream. The designs are shown in fig. 4(a) & (b).

(5) *Lock Chamber Type Fish Way.*

One of the most successful mechanical devices for lifting fish over obstructions is the fish lock, which incorporates the essential features of a navigation lock. That is, it consists of a lock chamber, a gate-controlled entrance by which the fish enter the chamber at the lower level, a similar means of permitting the fish to leave the chamber at the higher level, and a system of valves for alternately filling and draining the chamber.

Comparison of Fish Ways.

A comparison of fish ways was made by Mcleod and Neymenyi of Iowa Institute with the latest modified design of Denil fish way shown in fig. 1(b). The comparison was made using the full size fish ways constructed on Iow River, 70 miles above Mississippi. As a result of this comparison, the fish showed a preference ratio for the modified Denil type of about 7 to 1 when compared with the straight overfall fish way and when compared with the paired obstacle fish way, the preference for the Denil modified type was about 4·5 to 1. The pool and submerged orifices type as shown in fig. 2(c) when compared with Denil modified type gave equal results.

General Conclusions of Fish Way Type.

(*i*) No single fish way is complete to cover all aspects of fish way problem.

(*ii*) The idea of energy dissipation which was first incorporated in the design by Denil is the most efficient so far known and is generally adaptable in most conditions.

(*iii*) The modified Denil type shown in fig. 1(b), pool and jet type as shown in fig. 2(c), have shown the best results and may be useful for slopes upto 25%.

Fish Ladders in West Pakistan.

Out of 13 major Headworks in West Pakistan, 11 Headworks, *i.e.*, Balloki, Suleimanki, Islam, Marala, Khanki, Trimmu, Panjnad, Rasul, Kalabagh, Taunsa and Kotri have been provided with fish ladders. The only two exceptions are Sidhnai and Sukkur. These fish ladders have generally been placed along the divide walls constructed to separate the main weir from the undersluice pocket. The Headworks having off-take on one side are provided with one divide wall and have got one fish ladder only, while in case of Headworks having off-takes on either sides, fish ladders have generally been provided on both sides along the right and left divide walls.

Location of Fish Ladder.

Most of the fish ladders have been placed on the main weir side of the divide wall with downstream opening on the pocket side and the upstream opening on the weir side as shown in fig. 5. The utility of this arrangement is obvious, on the weir side there is always much turbulance and great agitation and the conditions are deterrent for the attraction of the fish. Whereas on the pocket side the conditions are relatively calm and the fish ladder is easily accessible by the migrating fish. However, Marala, Khanki, Kotri, Rasul and Islam are exceptions to this general practice. Fish ladders at Marala, Khanki and Kotri have been placed on the main weir side with both ends opening on the weir side. In case of Rasul, fish ladder has been located in the undersluice pocket with its entrance and exit lying in the pocket. In case of Islam, fish ladder has been located in the divide wall with both the openings falling in between the weir and the pocket.

Design of Fish Ladders.

Almost all the fish ladders in West Pakistan are of pool and jet type. A typical fish ladder is shown in fig. 6. It consists of consecutive pools or compartments placed in a stepped arrangement, rising from the downstream bed level in lifts of one foot to the crest level or higher above in some cases. The pools have been formed by R.C.C. baffles placed transverse to the side walls at an angle varying from 60° to 90° as shown in fig. 6 & 7. In some cases, the pools have been formed by merely placing the baffles on the downstream glacis slope of the weir as shown in fig. 8. The flow discharges through the deep notches or slits placed on the alternate sides of the baffles. Grooves have been provided in the baffles to regulate the flow by wooden karries to create small drop at each step. At the upstream inlet the discharge is generally controlled by a vertical gate operated by a valve.

To understand the deign features of the fish ladder, the hydraulic data and the velocity calculations for the most recently constructed fish ladder at Taunsa Barrage are given below. This fish ladder is the outcome of the combined efforts of the design engineers of the Irrigation Department and the fish experts of the Fisheries Department and is supposed to contain all the essential requisites of a good fish ladder. The salient features of the barrage design are as below :

Summer pond level	= R. L. 446
Winter pond level	= R. L. 443·4
U/S floor level of the Barrage	= R. L. 421
Crest level of the Barrage	= R. L. 428
D/S floor level of the Barrage	= R. L. 415
Lowest water level D/S of Barrage assumed without retrogression.	= R. L. 425
Lowest possible water level D/S of Barrage with retrogression.	= R. L. 421

From the discharge gauge curves for the years 1936 to 1952 it is revealed that during the migration period from April to October the tail level is not likely to fall below R. L. 426 and similarly it was also pointed out that during winter when the canals will be closed the pond level may fall as low as R. L. 440. The problem, therefore, was to fix a fish ladder to cater for U/S levels from R. L. 446 to 440 and D/S level from R. L. 421 to 426 and higher up. The design, as finally approved and constructed, is shown in fig. 9. The bed level of the first compartment was fixed at R. L. 438 with water level at R. L. 442 and in steps of 1 foot it was brought down to R. L. 423 and water level 427 at the D/S exit.

The maximum velocity at each step was calculated as below :—

Fall $= 1.0$ ft.

$$\text{Drowning ratio} = \frac{4-1}{4} = 0.75$$

This being less than 80% critical velocity will occur :

$$Dc = \frac{2}{3}\ H = \frac{2}{3} \times 4 = 2.67'$$

$$Q = CBH^{3/2} = 3 \times 3 \times 4^{3/2} = 72 \text{ cusecs.}$$

Now $Q = BDc\ Vc$

$$Vc = \frac{Q}{BDc} = \frac{72}{3 \times 6.27} = 9 \text{ ft./sec.}$$

which is less than the limit to which a fish can easily travel. To have an idea of the working efficiency of the fish ladders found in this country a brief detail of different fish ladders and their working conditions as reported by the executive engineers are given below.

Balloki Headworks.

(a) The fish ladder is situated in the main weir in Bay No. 20. It is 6 feet wide and about 130 feet in length, rising from R. L. 614.5 to R. L. 628.4 in 17 steps of 0.8 feet each. The discharge passes through the staggered notches 2′ × 3′ provided in the baffles.

(b) Since the construction of pitched island above the headworks, connected with weir by an earthen shank the fish ladder is not working altogether.

Suleimanki Headworks.

(a) Suleimanki headworks has been provided with two fish ladders. A fish ladder has been constructed along each divide wall, situated on the weir side with the exit and entrance, both lying on the weir side. The fish ladder on the right is 12 feet wide while on the left 10 feet wide. The floor level at the D/S entry is at R. L. 549 and U/S exit at R. L. 552, the drop has been created in a length of 270·5 feet divided in 18 compartments.

(b) No report is available about the working of the fish ladders.

Islam Headworks.

(a) A fish ladder is situated in the right divide wall. It rises from R. L. 435 to R. L. 445.2 in a length of about 365 feet, in steps of .75 feet to ·25 feet height. It is 8 feet wide provided with deep notches placed on the alternate sides in the baffles. The exit and entrance lies between the weir and the pocket.

(b) No observations have ever been made about the working of fish ladder.

Marala Headworks.

(a) Fish ladder at Marala is situated in Bay No. 1, along the divide wall with opening on the both ends lying on the weir sides. It rises from R. L. 793.83 to R. L. 800 in a length of about 116 ft. The pools have been formed by R.C.C. baffles placed on the downstream glacis slope. Each pool is 12′ × 10′ with flow discharging through staggered notches 2 feet wide, provided with grooves to regulate the flow by wooden karries.

(b) Fish ladder at Marala is working partially as under the present system of regulation it remains closed during winter and is worked in summer only. The main defects in this fish ladder are :

(*i*) While the width of the notches or the slits in the baffles is two feet the gate at the U/S opening is 12 feet wide. When the fish ladder is worked only a small opening of few inches at the bottom of this gate supplies the required discharge. The velocity through this small opening is too high to allow the fish to pass.

(*ii*) The side walls of the last compartment are at R. L. 796.0 and when a discharge of about 8,000 cusecs is passing down, the tail level rises above R. L. 796, submerging the last compartment and shifting the fall within the confinement of high side walls. Under these conditions the fish ladder works as under shot instead of over shot and is difficult for the fish to locate.

Khanki Headworks.

(a) When the Headwork was originally constructed a fish ladder was provided in Bay No. 1 of the weir along the divide wall but it was damaged and in 1912 and a new fish ladder was constructed on the left flank of Bay No, 8 of the weir. In this case also like Marala, pools have been formed by baffles placed on the downstream glacis slope of the weir. It rises from R. L. 715 to R. L. 723 in a length of 118′. The flow discharges through 2 feet wide slits placed on alternate sides of the baffles. It is also provided with grooves for karri regulation.

(b) The fish ladder is not functioning properly ever since its construction; the main defect lies with outlet which is untracable by the fish.

Trimmu Headworks.

(a) Trimmu Headwork is also provided with two fish ladders. A fish ladder is located on weir side along each of the divide wall. The one on right is 11 feet wide while the other on left is 10 ft. wide. The floor level at entry on the downstream is at R. L. 465 which rises to R. L. 481 at the exit. It is 256 feet in length divided in 17 compartments each provided with one foot fall. The flow discharges through 2 feet wide notches for the full depth of the baffle and the grooves are provided in the baffles so that the karries can be put to create regular small drops in water level. The opening on the downstream is towards pocket and on the upstream to weir side.

(b) Both the fish ladders are functioning satisfactorily. It is always possible to reduce head across at each step to 1 foot or less by karri regulation to give easy passage to fish. During summer all types of fish are invariably found playing in the fish ladders.

Punjnad Headworks.

(a) The fish ladder is incorporated in the divide wall. It comprises of 19 compartments in stepped arrangement with 1 foot fall at each step. The size of each compartment is 7′×8′. The opening on the upstream is on the weir as well as on the pocket side, and on the downstream the opening lies in the centre of the divide wall. The floor level at the entrance is at R. L. 315 and at U/S exit at R. L. 334.5. This drop of 19.5 feet is attained in a length of about 190 feet.

(b) The fish ladder is working quite satisfactorily. It affords easy passage for the fish to move up and down the weir and all indigenous varieties are found playing in the fish ladder during migration period.

Rasul Headworks.

(a) The fish ladder is situated in the undersluice pocket along the divide wall. It is 150 feet long and steps from R. L. 707.94 to R. L. 702 in 10 compartments. Each compartment is $10' \times 13'$ with baffles having 3 feet wide staggerd slits provided with grooves to create small falls by wooden karries.

(b) The record shows that the fish ladder is not functioning properly since long. It was re-modelled some time back but with no improvement. The main defects in this fish ladder are :

(*i*) The location of fish ladder is as such that it is not self advertising. It is completely masked by the divide groyne No. 1 which disconnects it from the main weir and so it is untracable by the fish approaching from the main weir side.

(*ii*) With rise in D/S level when the lower compartments get submerged, the fall shifts to the upper compartments and the high side walls of the lower compartments obstruct the fish to reach the fall.

Kalabagh Headworks.

(a) Kalabagh Headwork is also provided with two fish ladders. The fish ladders are located on the weir side of each divide wall with downstream entrance in the pocket and upstream exit on the weir side. The fish ladders rise from R. L. 667 to 684 in a length of 233 feet, divided in 18 steps of one foot each. The baffles have got two feet wide notches to the full depth, provided with groove for karri regulation.

(b) The fish ladders are not functioning properly. The velocity in the chambers is supposed to be too high to permit the passage of the fish through the ladders. Attempts were made by the field engineers to check the excessive velocity by putting Karries, but the compartments got silted up to the karries level. At present, no fish is ever found playing in the fish ladders.

Kotri Barrage.

(a) Kotri Barrage is also equipped with two fish ladders situated on the main weir side along each divide wall. The entry and fish approaching the fish ladder and thus provides no resting place for the migrants.

(*iii*) The entrance on the D/S side is located on the main side where there is always much turbulance and is not easily accessible by the fish.

Taunsa Barrage.

Taunsa Barrage is also equipped with a fish ladder situated on the main weir side of the left divide wall, with its inlet on the main weir side and outlet on the pocket side. It consists of 16 compartments with 1 foot fall at each step. The downstream exit is at R. L. 723 which rises to R. L. 438 in a length of 262 feet.

It is the first fish ladder which has been evolved jointly by the engineers and the fisheries experts after a study of existing fish ladders and behaviour of the fish found in this country. Some improvements upon the old design made in this fish ladder are :—

(*i*) The width of U/S inlet and the opening of the baffle have been kept the same to secure equal intensity of flow at all steps.

(*ii*) The length of compartments have been increased to 15 feet against 10 ft. in old designs to provide resting places for the negotiating fish.

(*iii*) A pool of 32.5′ × 11′ has been provided at the downstream entrance for accumulation of fish at the tail.

(*iv*) To keep the fish ladder self-advertising at all stages of flow, the side walls of the last four compartments have been kept as high as the maximum tail level to ensure free fall at the outlet upto a discharge of 5 lakh cusecs.

(b) As the barrage has come into operation most recently no detailed report about its working is available.

Gudu Barrage

The Barrage is still under construction; however, it is claimed by the Chief Engineer (Water) WAPDA that a very efficient design of fish ladder has been selected for Gudu Barrage. The main feature of design as stated by the Chief Engineer will be the presence of fall at the outlet at all stages of flow to attract fish to the fish ladder.

scussions of Fish Ladder in West Pakistan

rom the details of the design and the working conditions of the rs, as given above, it is evident that :—

Almost all the fish ladders in West Pakistan are pool and otch type, with flow discharging through deep notches or slits provided on the alternate sides of the baffles, generally creating one foot drop at each step.

(*ii*) Most of the fish ladders have been placed on the main weir side of the divide wall with downstream opening in the pocket and upstream opening on the weir side.

(*iii*) Out of the sixteen fish ladders provided in all headworks, only three or four are working properly, the one at Panjnad, two at Trimmu and the 4th may be at Taunsa. The rest are either functioning unsatisfactorily, or not functioning altogether.

As already mentioned no record of the fish movement in the fish ladders have ever been kept from which any definite conclusion about the efficiency of the existing fish ladder could be made However from the above information and the reports of different investigators it is concluded that :—

(*i*) Though the design of the fish ladders commonly used in West Pakistan is of an old type and is, no doubt, inferior to the recent modified design yet it has got a reasonable efficiency and suits well to the varieties of fish found in this country, as is evident from the working of the fish ladders at Trimmu and Panjnad. The best feature of its design is the fall created at its outlet which makes it self-advertising. This type of fish ladder is also in use in some places in United States. But its efficiency mainly depends upon the species of fish found in the vicinity. According to Mcleod:

"In negotiating an ordinary overfall the fish usually swims up the falling jet. The tendency to jump from pool to pool is limited in certain species of fish and is caused by inadequate conditions for swimming such as exist when the overfall jet is too shallow". According to Denil "Passing from pool to pool the fish must work against two forces ; first, against the velocity of the jet or overfall; second, against a threshold resistance encountered in entering an orifice or passing over an obstacle. In the case of an overfall the fish must raise itself from one pool elevation to next and in case of an orifice the fish must work against the difference in the static pressure on the two sides of the orifice."

The experiments conducted by Mcleod, and Nemenyi by the full scale fish ladders on Iowa River showed that in case of overfall type pool fish way only carp fish used it. In c of deep notch type pool fish way when the fal reduced Cat fish and Quillback fish also used t way along the Carp fish, while in case of orifice fish way where there was no fall almost all spec fish way. This shows that the type of fish way West Pakistan are unattractive for some spec perhaps the'case with Palla fish at Kotri Barrage.

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In our opinion it needs a detailed full scale study by the Research Institute in colaboration with the Fisheries Department to evolve a design most suitable for Palla, to be fitted at Kotri, Sukkur and Gudd Barrage for the easy passage of Palla fish. The mere remodelling of existing fishways or provision of new fish ways of the same type perhaps may not do the job.

(*ii*) From the above information it is also revealed that the outlets or the downstream entrance of the most of the fish ladders are defective; either they have been wrongly located as in case of Kotri Barrage or they do not keep self-advertising at all stages of flow. In most cases, with the rise in the tail level, the lower compartments get submerged as shown in Appendix I and the end fall from the river shifts into the confinement of high side walls. The outlet in this case works as under shot which the fish cannot discover. This defect has been avoided in the design of Taunsa Barrage fish ladder where the side walls of the last four compartments have been kept as high as the maximum tail level and a free fall in the river is ensured upto a discharge of 5 lakh cusecs.

(*iii*) Another defect in some of the fish ladders is the faulty inlets. The width of the inlet in these cases have been kept much greater than the opening in the baffle. To work the fish ladder a very small opening at the inlet supplies the required discharge and the velocity of the jet issuing from the orifice is too high for the easy passage of the fish. This defect has also been given due consideration in the design of Taunsa fish ladder where the width of the inlet has been kept the same as the opening in baffle.

(*iv*) Another drawback as inferred from the above informations is the wrong location of fish ladders as is the case with fish ladders at Marala and Balloki, Khanki and Rasul.

(*v*) The most interesting is the case of fish ladders at Kalabagh Headworks. The design and location of the fish ladders is exactly similar to Trimmu which is working very effectively. But the fish ladders at Kalabagh are reported to be not functioning at all. The probable reason is the U/S approach conditions which throw excessive silt in the fish ladder and thus hinder the passage of fish.

(*vi*) Another defect in the fish ladders is the size of the compartments. Generally, the size of the compartments is too small to provide any resting place for the migrant fish. The length of the compartments of Taunsa Barrage fish ladder was increased from 10 to 15 feet on recommendation of Fisheries Department; and it has got the biggest compartments as compared to other fish ladders found in this country. A comparison of the dimensions of Taunsa fish ladder is made with fish ladders at Benneville Dam and McNary Dams of U.S.A. in Appendix II.

Fish in Canals

Besides the irrigation structures, the irrigation channels are also playing havoc with the fish culture. In canals as big as found in this country millions and millions of fish find their way and when the canal supply is closed, they get trapped and are put to wholesale destruction. In case of perennial canals, since the closures are generally of small duration the loss of fish life is not so substantial. The seepage flow, scour pits and cisterns below falls give timely refuge to fish. But in case of non-perennial canals where the closures are of six months duration, the canal proves to be a slaughter house for the fish. The appalling condition can be well imagined from a note of the Chairman WAPDA, which he submitted to the Government after his visit to a canal taking off from Kotri Barrage.

> "At one regulator, there were hundreds of maunds of fish collected in a small pool and this was inspite of fish contractor removing fish at the rate of a hundred maunds a day. It was not possible for the contractor to cope with any more."

Experts' Report

The matter was hotly persued by the Government as well as by WAPDA and a fish ladder expert, Mr. W.R. Martin, was deputed by the Chairman WAPDA to investigate and to suggest necessary measures to save the fish from this mass destruction. He after inspection of differnt sites and holding meetings with the officers of the Fisheries and Irrigation Departments, put forth the following suggestions :---

(*i*) Just prior to the closure of canals a mobile sweeping device be carried along the canals to force the fish back into the main river.

(*ii*) Provide side reservoirs with closing structures to hold the fish during the closure period. In this case, it would also be necessary to utilise a sweep system for forcing fish into the reservoir.

(*iii*) Provide sections of canals deeper than the normal depth to hold fish during closure period.

In the opinion of Mr. Martin himself the first and the second proposals were too expensive as they will require a considerable amount of road work along the canal banks to drive the sweeping screens along the canals and will necessitate building of a large number of fish ladders also. According to him, the third proposal was the most desirable. He recommended the investigation tests to be performed on some canals by providing pits 200 feet long and 5 feet deep, 3 pockets at 1-mile intervals, 2 at 2-mile intervals and 2 at 5-mile intervals. This proposal, though too simple and economical but with the amount of silt comming in our canals the silting of these pockets will be a matter of few days even though they are provided with sloping upstream and downstream faces.

Fisheries Department's Suggestions

The Director of Fisheries gave the following three suggestions to preserve the fish life during canal closures :

(*i*) Fishing auctions to private enterprise may be stopped. Instead, the Fisheries Department should come in and at the time of closure the fishery officials with vehicles might market the adults and salvage and stock useful varieties of fry and fingerlings into perennial waters to provide more span of life to fish.

(*ii*) Deep reservoirs of about 20 acres may be provided in the canals every fifteen miles so that the fish may collect and pass off with ease during the closure periods. Such reservoirs may be opened to anglers for fishing. It might help in breeding of fish and providing young ones for stocking operations.

(*iii*) Some type of fish passes could be designed in the canal at its source so that fish could go upstream from canal as and when she so desires.

Out of the above three measures proposed by the Direcetor of Fisheries the feasibility of the (*i*) can be better judged by the Fishries Department; about the (*iii*) suggestion, that is, to provide fish ladders or fish passes at the canal falls and regulators, the method can be of some help on canals of smaller lengths but in case of canals as long as 200 miles there is no possibility of the fish to reach the main river at the time of closure.

Side Reserviors

The only feasible alternative is the provision of side reservoirs at suitable intervals. But in this case a detailed study of behaviour of fish at the time of closure shall have to be made by the Zoloogists of the Fisheries Department in order to devise some method to attract fish to reservoirs at the time of closure. Mr. W. R. Martin is of the opinion that mobile sweeping will be needed to push the fish into the reservior. But it has generally been observed that when the canal supply falls very low the fish run in search of safer places and at the time of closure they are found huddled in pools or scour pits below falls and regulators. This leads to the credence the nature has bestowed the creature with a sense to research for safer places at the time of closure and if the reservoirs are placed at reasonable intervals there is a likelihood of fish to accumulate in the reservoir on its own accord or by directing the flow through reservoirs with fish screens at the outlet of the reservoir. However, this aspect needs a thorough investigation and a detailed study with particular reference to the following points:

(*i*) The direction of movement of the fish at the falling supply. This is to study whether the fish moves along the flow, against the flow or in a haphazard direction during canal closur.

(*ii*) The length to which the fish normally travels in search of pools during falling supply.

This study will give valuable information about the utility of reservoirs, necessity of mobile sweeping, the location and realative distance of the reservoirs. The details of the inlet and outlet structures can only be worked after the comprehensive knowledge of fish habits during canals closure. If the fish are found to swim along the flow, the reservoirs can be located upstream of the falls with a fish screen at the downstream outlet. The fish can be collected in the reservoir by diverting the flow to the reservoir during falling discharge by means of gates or karries placed at the crest of the fall. In case of fish found flowing against the flow the fish screen shall have to be placed at the inlet to allow the fish to enter from the downstream outlet. But if their movement is found to be in a haphazard direction there can be no alternative except the mobile sweeping before closure.

Lock Channels.

The provision of a fish ladder or a lock channel at the head regulator can help a lot in saving the fish trapped in the head reach of the canal as is at present practised at Sirhind Canal offtaking from Ropur HeadWorks (Bharat).

As shown in fig. 10 the lock channel directly connects the canal with the main river and when the cannal is closed the fish are invariably found crowding in the lower chamber of the lock channel which are safely allowed to escape into the river by operation of the gates and thus thousands of fish trapped in the head reach are saved from being destroyed without reproduction.

Scope of Work on Fish Ladders

As already mentioned, out of 16 fish ladders provided in 11 major Headworks of West Pakistan only 4 are supposed to be working properly. This state of affairs is rather alarming for the fish wealth of the country and needs a serious consideration. So far as our knowledge is concerned no detailed research in this connection has ever been carried out in this sub-continent since the inception of the present irrigation system. The existing fish ladders have been designed on the only information that a fish can travel upto a velocity of 10 ft/sec and can jump to 2 ft. height, without having any detailed knowledge of the fish habits of the different species found in different regions. Similarly, a good deal of fish is being destroyed due to inadequate arrangement for the protection of fish life in our canals. It is a subject which has actually been ignored in the past but with interest of preserving fish, an important food commodity for the growing population of the country, the matter needs a thorough study and detailed investigations. It is a problem which requires combined efforts of the zoologists of Fisheries Department, engineers of the Irrigation Department and scientists of the Research Institute. Broadly speaking the study can be divided in the following three stages :

(*i*) To collect a reliable data about the efficiency of the existing fish ladders. This is to roughly estimate the number of fish approaching the headworks, percentage of fish succeeding in tracing the fish ladder, and percentage of fish actually passing the fish ladder. These ohservations can be taken by the site engineers with the help and guidance of the Fisheries Department.

(*ii*) To acquire a detailed knowledge of the habits and behaviour of different important species of the fish found in different regions of West Pakistan and also the behaviour of the fish during canals closure. This is to know the zone of their movement, limit of efforts they can exert in overcoming an obstacle and direction of movements during canals closure. This aspect of the problem is to be studied by the zoologist of the Fisheries Department exclusively.

(*iii*) To study the hydraulic properties of different types of fish ladders, to design fish ladders most suitable for different important species keeping in view their habits and behaviour as studied by the Fisheries Department. This part of the study is to be conducted by the design office of the Irrigation Department and Hydraulic Laboratories of the Research Institute. The selected designs can be checked at the Hydraulic Field Research Station, Nandipur, on full scale fish ladders using different species of fish found in this country.

The authors acknowledge, with thanks, the help they have received in preparing this paper from a Note by Mr. Ahmad Hasan, Additional Chief Engineer (Operation). They are also idebted to Mr. Mohy-ud-Din Khan, Director, Design & Research, for the typical designs of existing fish ladders in use. They also thank executive engineers incharge of different headworks who have supplied information about the working of different fish ladders in their charge. The list of literature from which help has been taken to prepare this note is given in the bibliography at the end.

APPENDIX I.

Statement Showing the R. L. of the Side Walls of the Last Compartment as Compared with the D/S Water levels during Migration Period.

S. No.	Name of Headworks	R. L. of the side wall of the last compartment	Mean of the D/S water level during			
			June 1957	July 1957	August 1957	September 1957
		RL	RL	RL	RL	RL
1.	Balloki	621.25	620.9	624.2	624.2	628.0
2.	Islam	429.5	432.6	441.75	443.8	443.1
3.	Marala	802.0	795.0	802.3	800.2	797.9
4.	Khanki	724.0	726.5	730.5	729.5	725.0
5.	Trimmu	477.0	483.5	482.2	486.0	482.2
6.	Panjnad	321.25	329.7	331.5	332.0	328.1
7.	Rasul	706.24	712.75	712.7	711.75	708.7
8.	Kalabagh	675.0	683.0	685.7	683.2	678.9

APPENDIX II.

Statement Showing Comparison of Taunsa Fish Ladder with Fish Ladder at Benneville and McNary Dams.

S. No.	Fish Ladders	Taunsa Barrage	Benneville Dam	Mc Nary Dam
1.	Number	2	3	2
2.	Width	11 feet	One 37 feet & two 40 ft.	30 feet each
3.	Length	262 feet	1,310 feet	21,00 feet
4.	Gradient	1:17.5	1:16	1:20
5.	Velocity	9 fps	1 fps	2 fps
6.	Discharge	72 Cs	160 Cs	180 Cs
7.	Dimension of resting pools	15′×11′	16′×40′	20′×30′
8.	Depth of pools	4 feet	6 feet	6 feet
9.	Overflow depth	1 foot	1—1.5 ft.	1—1.5 ft.

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The question to be answered is : which is most favourable cross section to be given initially and how much time will the scouring process take ?

The slope of the link in the first twenty miles will be 1:10,000 and in the remaining 20 miles 1:4,000.

Assuming for the second stretch of the canal a depth of 10 ft. a bed-width of 40 ft. and side slopes of 1:1·5 then : the cross section, $A=550$ sq. ft. the wetted perimeter, $P=76'$ the hydraulic radius, $R=7,24'=2,20$ m, the mean velocity, $V=KR^{2/3} S^{1/2}$, $K=25/E^{1/6}$ $E=0,04$ m, or in f.p.s. units $K=43/0,304^{1/3}=64,5$

Thus, $1,486/n=64,5$ $n=0,023$. $V=1,13$ m/Sec $=3,7$ ft./Sec.
The discharge $Q=2035$ Cs. and the concentration of sinking material G_s/G_w $=V^4/800\ R^{4/3}=0·7$ g/l

Now in case other hydraulic characteristics are given, *i.e.*,

$D=14'$ $B=20'$ with side slopes 1:1 then :

$A=476$ sq. ft.

$P=56'$

$R=8,5'=2,69$ m

$V=1,29$ m/Sec $=4,23$ ft./Sec.

$Q=2014$ Cs. $=57·5\ m^3$/Sec.

$G_s/G_w=0,91$ g/l

It appears that the most favourable hydraulic section is the one which has the highest sediment carrying capacity. This is in accordance with the law of the conservation of energy for the less energy is spent on friction, the more will be available for the transportation of solid material. The first part of the Taunsa-Panjnad Link will have a slope of only 1:10,000. Therefore, its silt transporting capacity will be rather low.

Assuming $R=10'=3$ m, then $V=43·3^{2/3}/100=0,90$ m/Sec and the concentration of sinking material $G_s/G_w=V^4/800\ R^{4/3}=0,19$g/1. The difference of 0,91 and 0,19 or approximately 0,7 g/1 will be the amount of particles with size bigger than 0,07 mm that will remove from the bed and the sides of the second part of the link. Therefore the scouring will be :—

$0,7 \times 57500$ gram per sec

$= 0,7 \times 57,500 \times 86,400$ gram per day

$= 0,7 \times 57,5 \times 86,4$ ton per day

$= 0,7 \times 57,5 \times 86,4/1,4\ m^3$ per day

$=0{,}7 \times 57{,}5 \times 86{,}4 \times 30/1{,}4 m^3$ per 30 days

$=74{,}750\ m^3$ for the first month

Apart from this quantity all the particles with a diameter less than 0,07 mm will be washed out.

Of course in the Thal desert the percentage of this silt is low, probably not exceeding 20%. Thus the total amount of material taken in suspension during 30 days will be 75,000 + 20% = about 90,000 m^3. Supposing further that the sand of the Thal desert does not contain particles bigger than 1 mm which could be carried along the bottom as bed-load, then about 300,000 cub. feet will be taken up along the 20 miles during the first month of operation. This will result in an enlargement of the cross section up to 30 sq. ft. As the original wetted perimeter was 56′ it may be expected that the depth of the canal will increase with about half a foot and the width with one foot during the first month of exploitation.

Example 5: Cut-offs.

Sometimes very small cut-offs are made with the intention to let them develop on their own by the running water. In such cases the experience mostly has not been satisfactory.

Assuming the river has a slope of 0,00010 and a hydraulic mean depth of 4 m (13 ft.)

Supposing a cut-off is constructed with a slope equal to 0,00030 and a hydraulic radius of R = 1 m only. The mean velocity of the river will be 1,25 m/Sec and that of the cut-off about 0,85 m/Sec.

The concentration of sinking material in the river is $G_s / G_w = V^{4/} 800\ S^{4/3} = 0{\cdot}5$ g/1.

The water flowing through the cut-off can carry a concentration $G_s / G_w = 0{\cdot}80^4 / 800.1^{4/3} = 0{\cdot}63$ g/1. Therefore no appreciable amount of scouring will occur.

However, when the cut-off is started with a hydraulic radius of 2 m, then the water velocity will amount to 1,35 m/Sec and the sediment concentration will be $1{,}35^4 / 1000 = 1{,}65$ g/1. The process of scouring in this case will proceed with 1,15 g/1 under the condition that the soil consists of fine sandy material.

Example 6. Bi- Tri- or Multi- furcations.

Suppose investigations in soil mechanics laboratory have indicated thete the banks of a canal in a certain soil are stable if its side slopes are constructed 1:2 over the upper 10 ft. below the water surface, 1:3 over the

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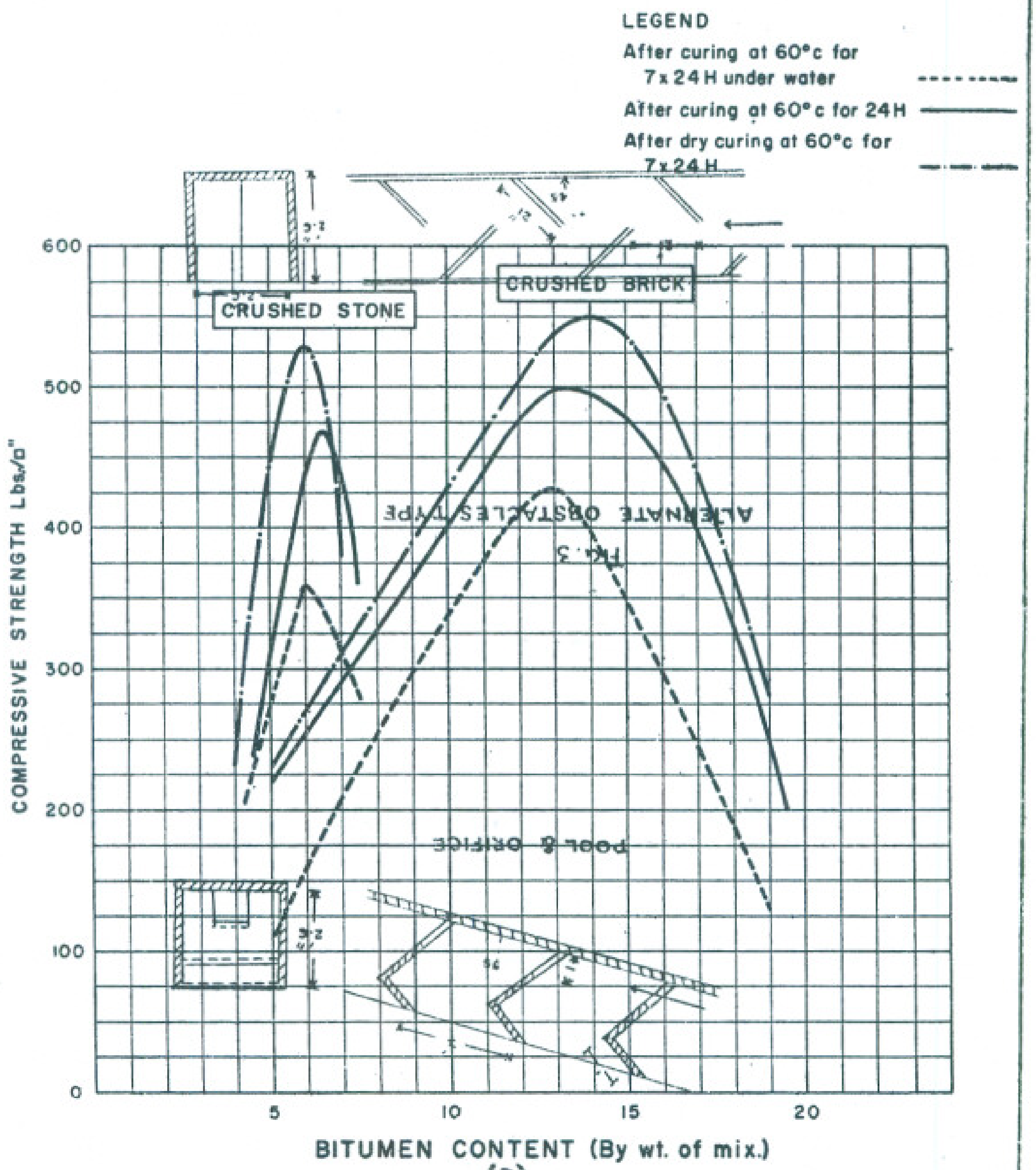
FIG – 2

COMPRESSIVE STRENGTH
OF BRICK & STONE AGGREGATES



(C)

POOL AND JET TYPE

FIG. 2

97.60.2

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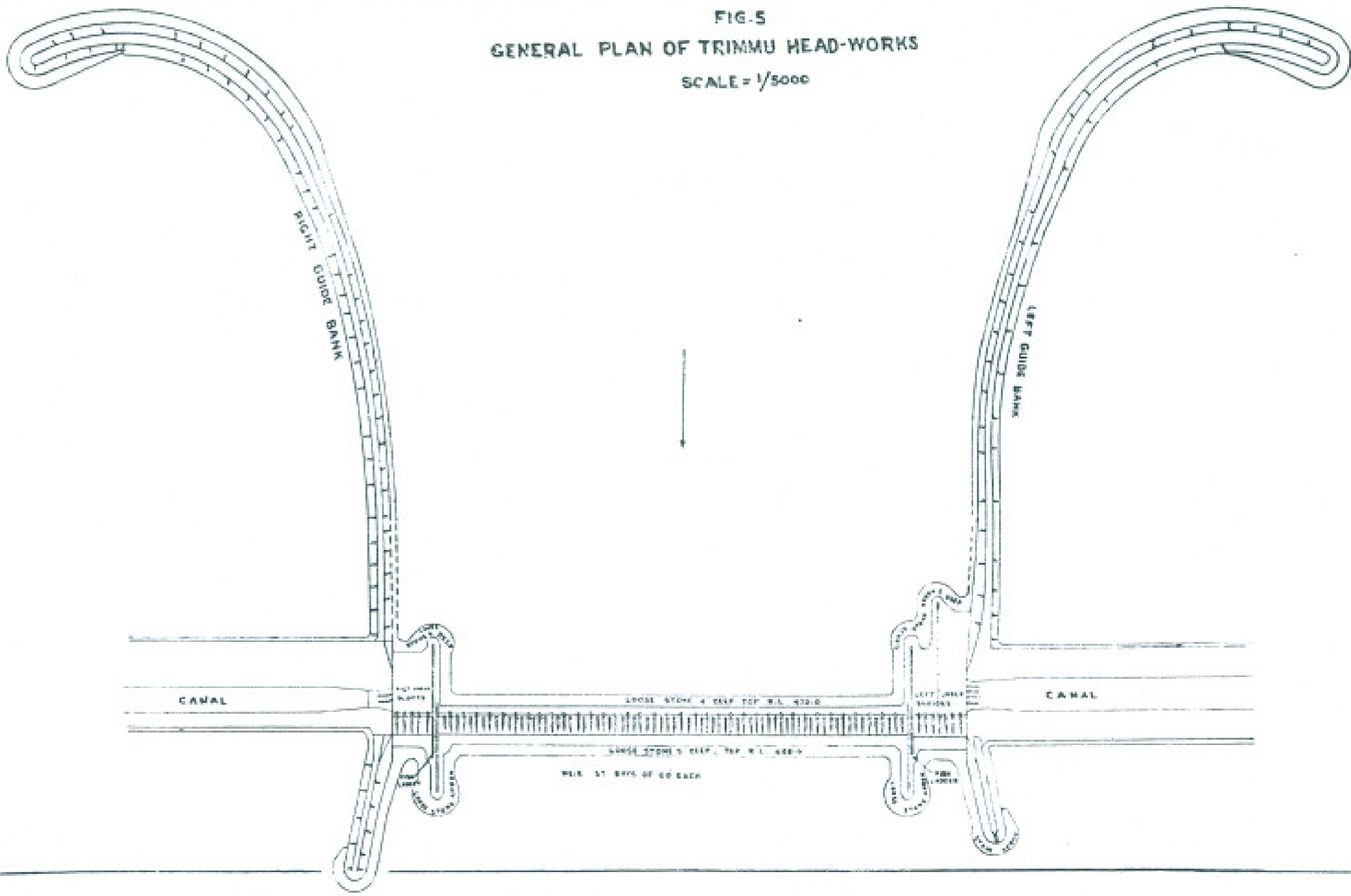
of economics, structural stability, ease of construction etc., it was decided to provide a normal crossing between the two channels, with the LCC Upper passing through a RCC trough aqueduct over the link canal. The bed width of the aqueduct was maintained as 110 feet against the channel bed width of 240 feet. For providing a normal crossing, LCC Upper was relocated from R.D. 131 to Sagar Regulator, with two curves : one preceding the aqueduct with a radius of 5,000 feet and a deflection angle of about 45°, the other following the aqueduct with a centre line radius of 1,150 feet and a deflection angle of about 85°. The latter curve was made contiguous with the expansion transition downstream of the aqueduct.

The design of LCC Complex, which includes the relocation of LCC Upper from R.D. 131 to Sagar Regulator was referred to the Irrigation Research Institute for model studies on the aspects of silt charge distribution in the off-takes at Sagar Regulator and the hydraulic performance of the channel transitions downstream of the Aqueduct. These were studied on two different models at the Nandipur Field Research Station. The study of the hydraulic performance of the channel transition downstream of the Aqueduct showed that the design was inadequate as the flow through the curve suffered separation on both the banks in a major position of the 1150 feet radius curve. A number of devices were tried to improve the performance. These included longer expansion transitions, splitter vanes etc.; but were found inadequate. Finally, an equiangular spiral curve was designed between the end of the aqueduct and the relocated approach channel to Sagar Regulator. This combined expansion-*cum*-turning transition was found efficient, as it obviated separation from the solid boundaries and also ensured an even velocity distribution in the flow approaching Sagar Regulator.

This paper briefly describes the LCC Complex, the proposed design of the transitions downstream of the Aqueduct, their hydraulic behaviour as verified on the model and corrective devices tried on the model. It then gives the theoretical derivation of equiangular spiral as ideal fluid streamlines and some properties of the spiral. The method of fitting such a spiral to an actual problem is first discussed generally and is then followed by the design calculations adopted for the LCC Complex. The model and prototype performance of the spiral curve are also discussed. A brief discussion of the characteristics of open channel flow in bends is also included alongwith the limitations of theoretical analysis of this commonly experienced flow. It is hoped that this type of transition, which has proved successful, in the extremely critical imposed hydraulic conditions, will find use, when similar limitations are experienced elsewhere and the expansion and curve transitions are to be made contiguous.

FIG. 5
GENERAL PLAN OF TRIMMU HEAD-WORKS
SCALE = 1/5000



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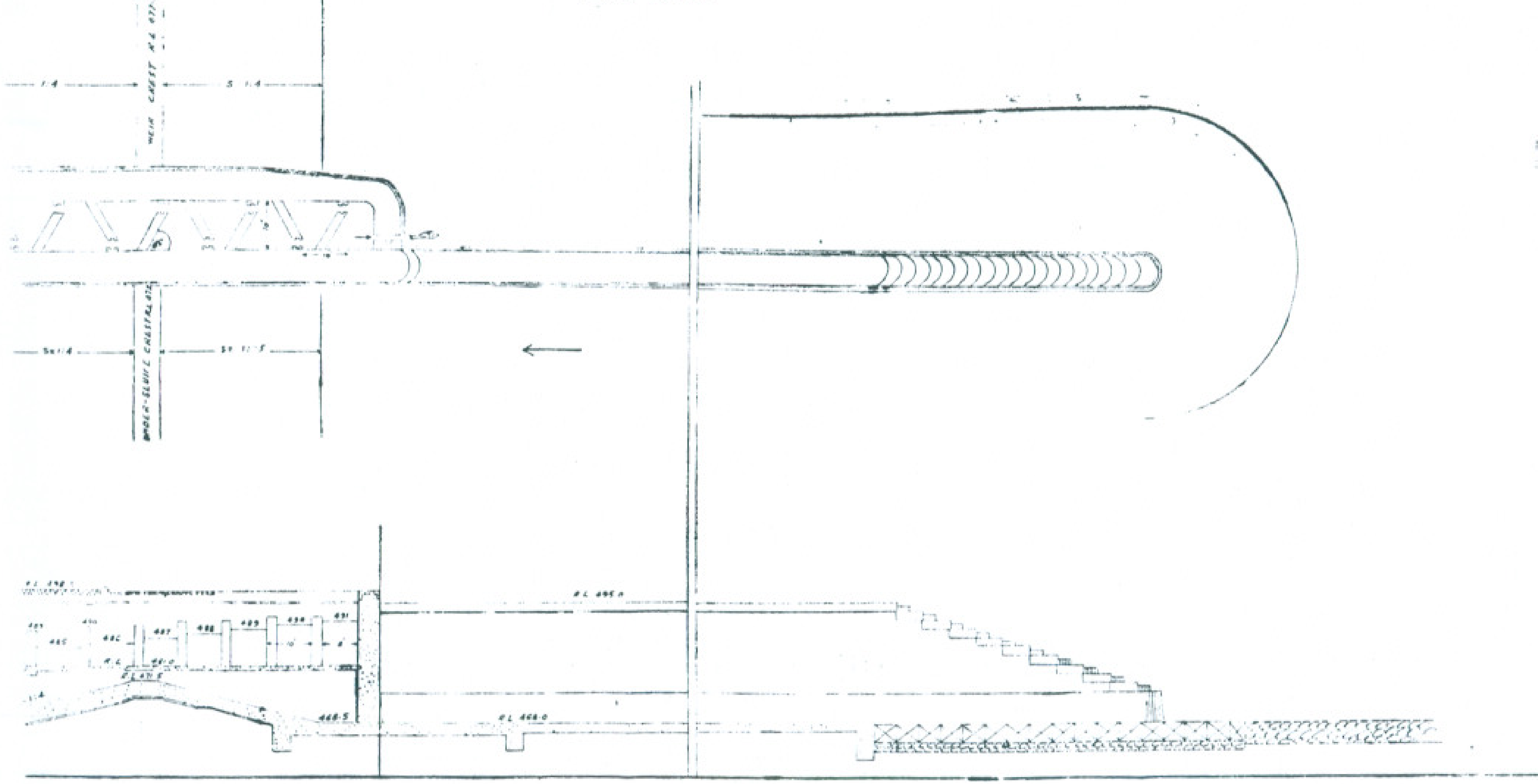

FIG. 6

FISH LADDER

TRIMMU HEAD-WORKS

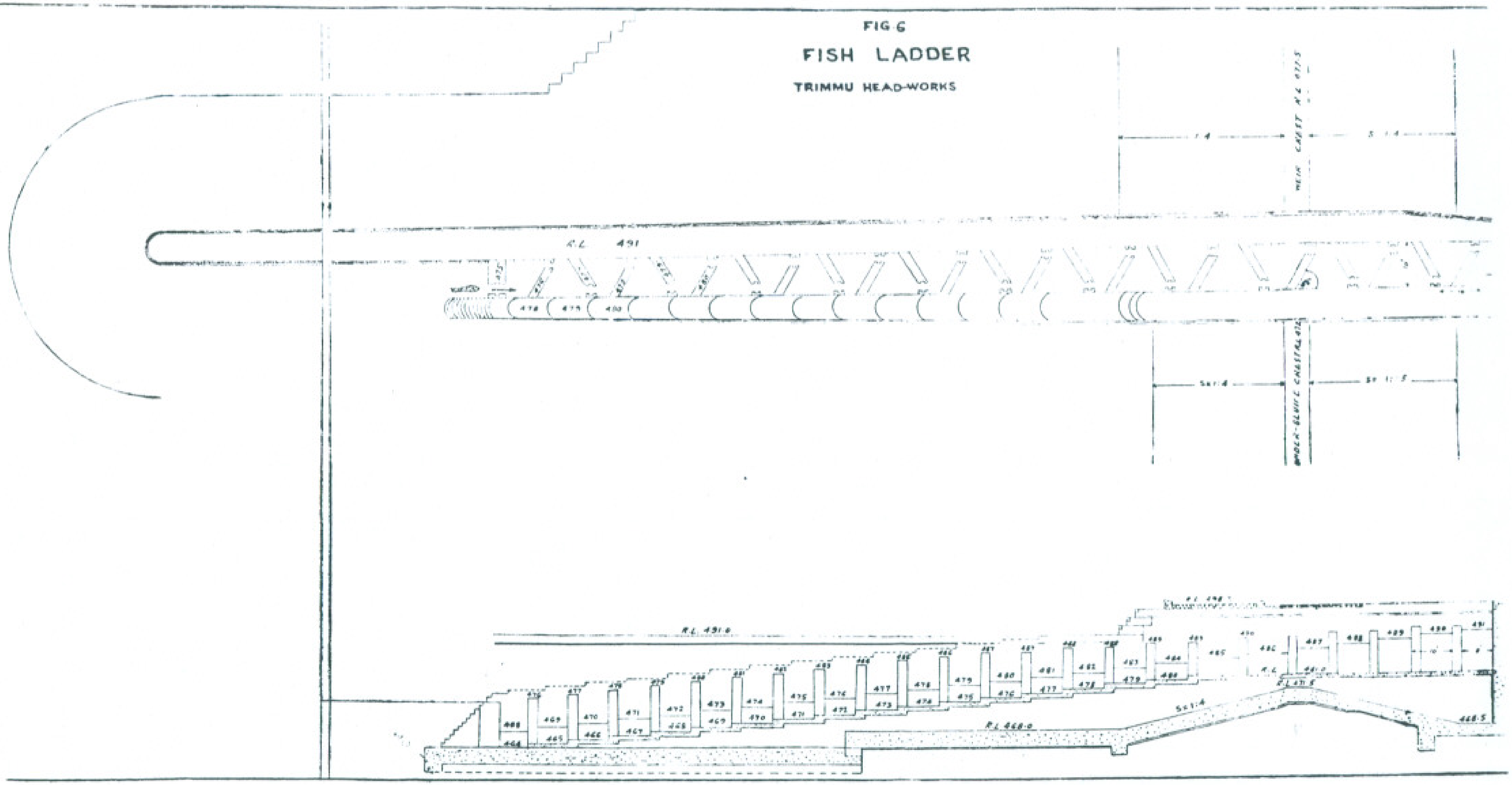

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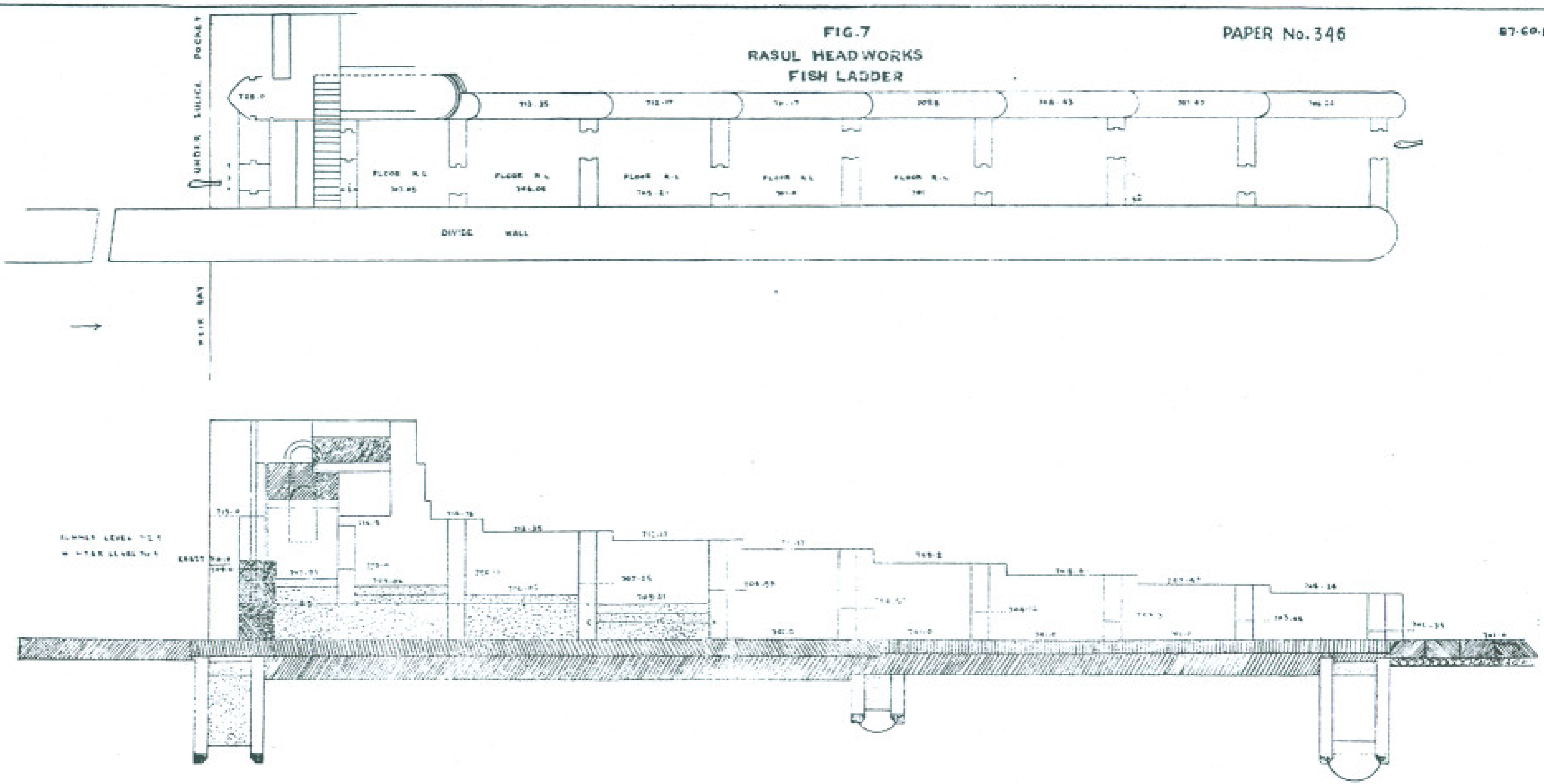
FIG. 7
RASUL HEAD WORKS
FISH LADDER



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FISH LADDER AT MARALA H/W

FIG. 8

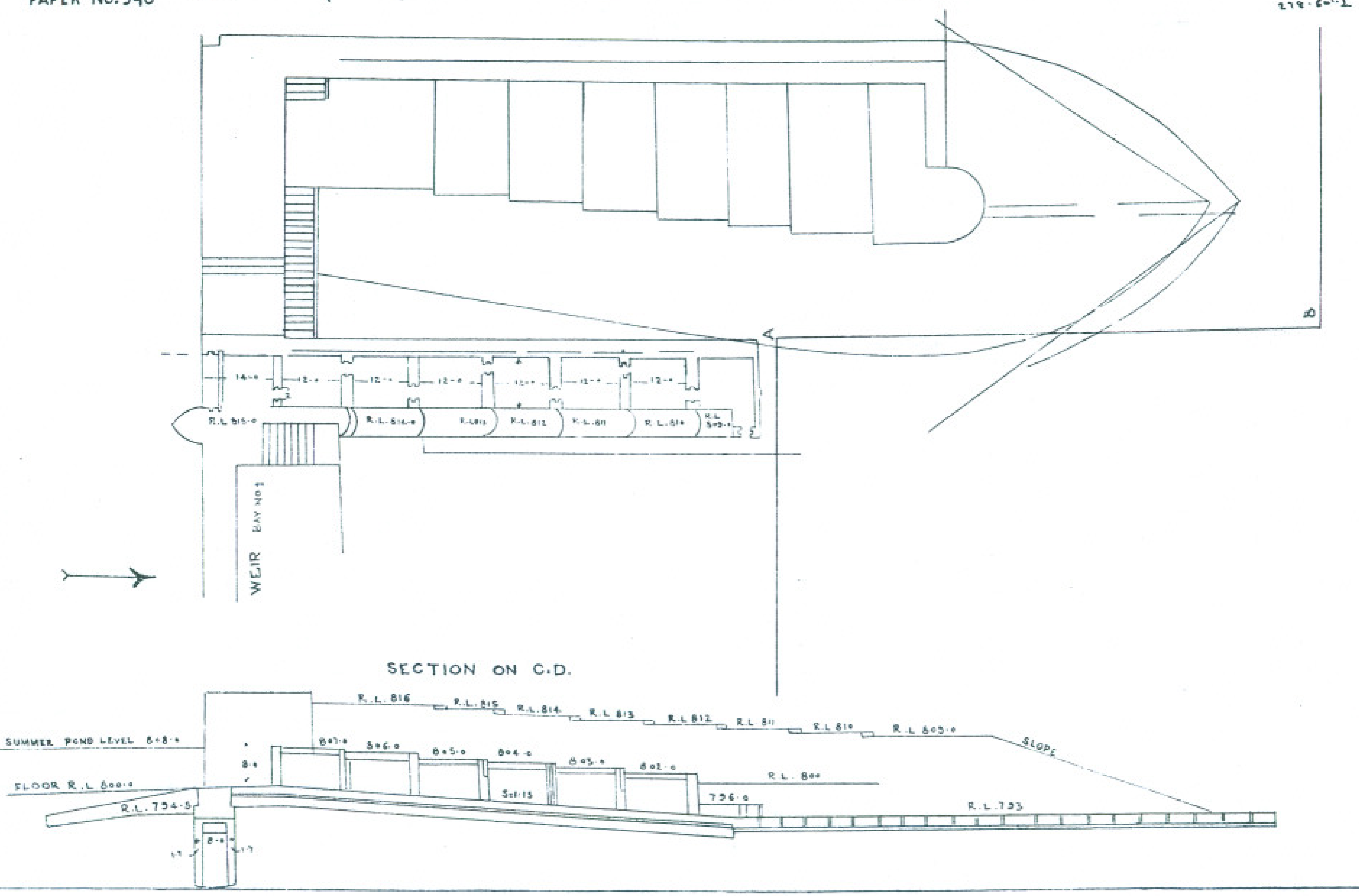

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FIG. 9.

TAUNSA BARRAGE FISH LADDER

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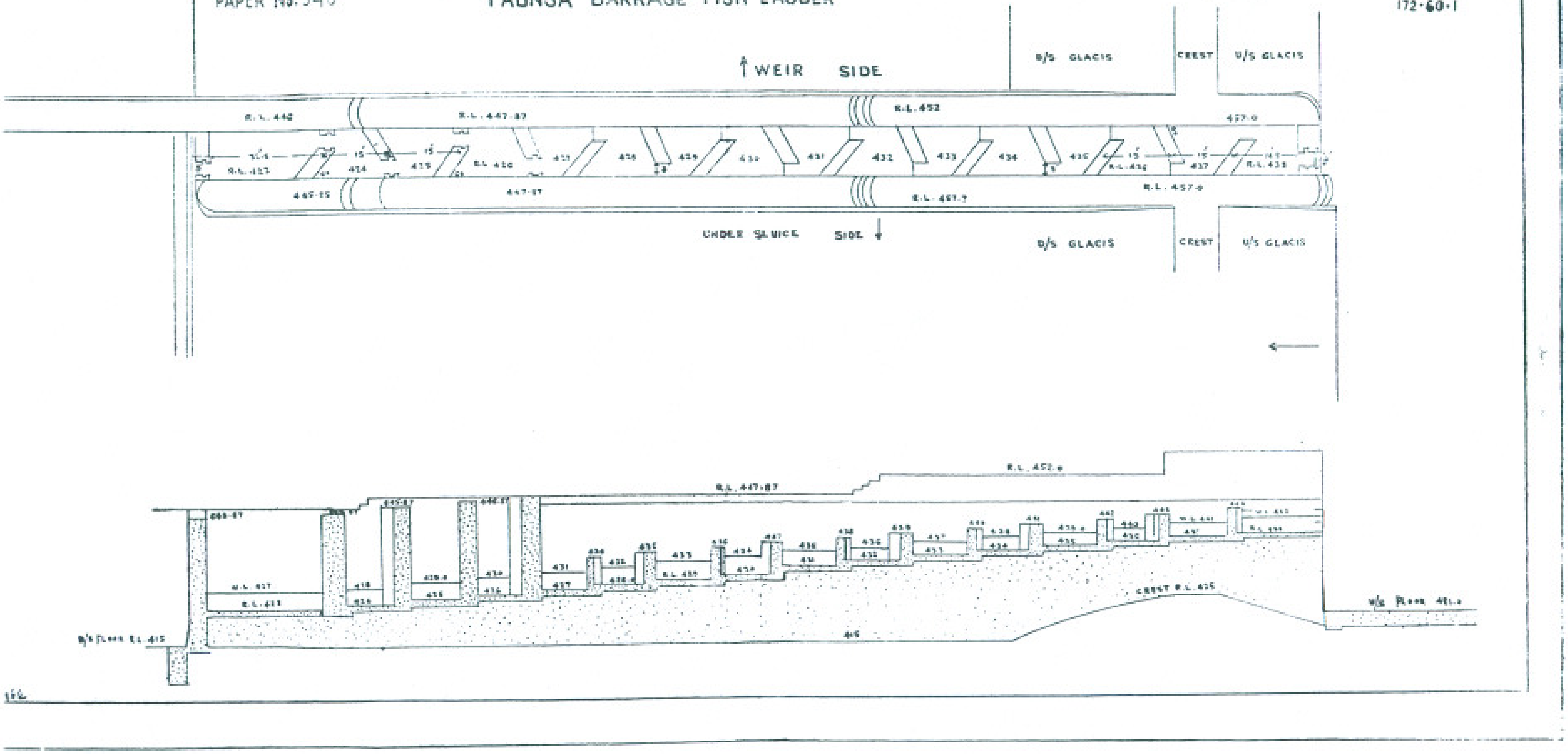

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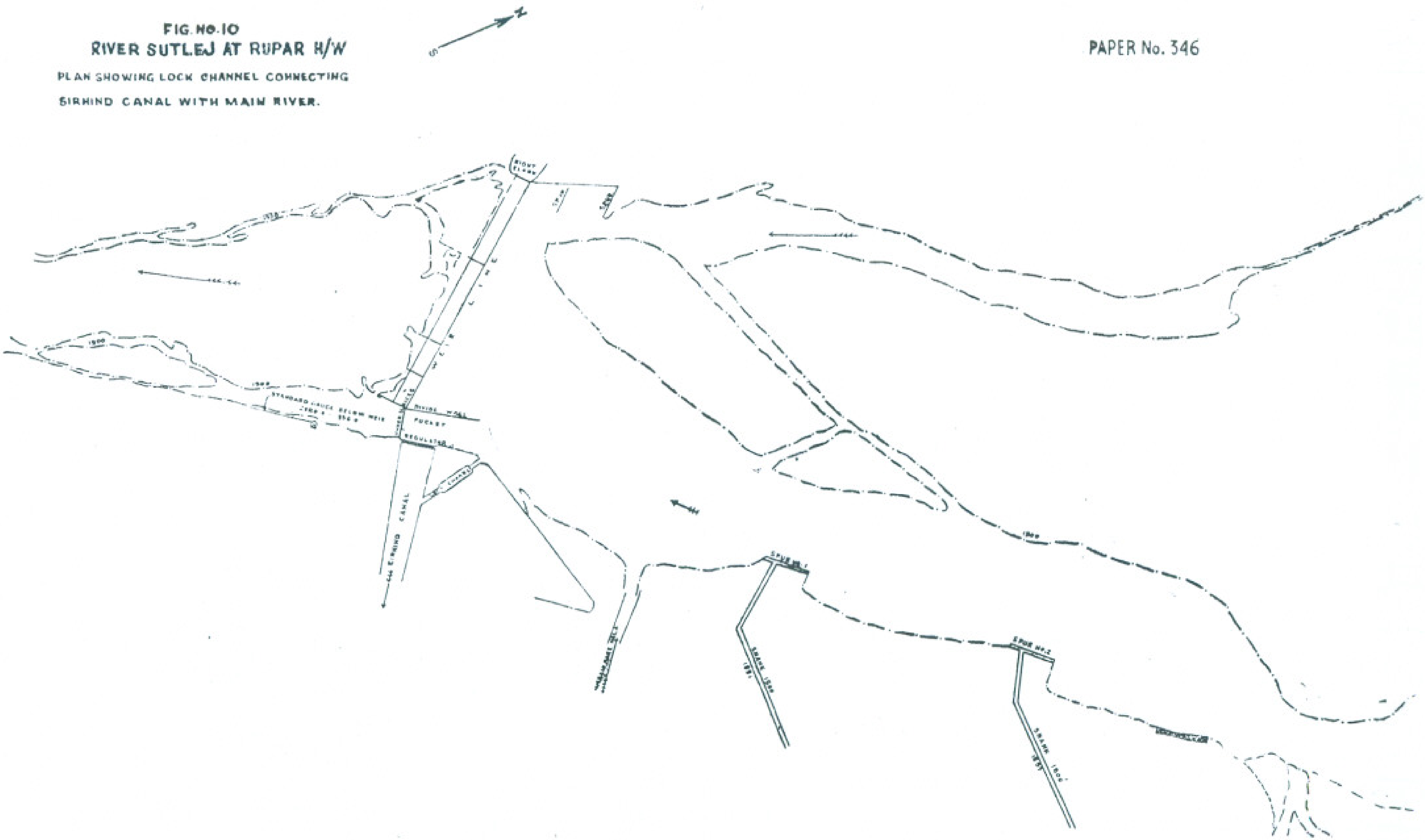
FIG. No. 10

RIVER SUTLEJ AT RUPAR H/W

PLAN SHOWING LOCK CHANNEL CONNECTING SIRHIND CANAL WITH MAIN RIVER.



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