NUMERICAL SIMULATION OF FREE SURFACE FLOWS AT FISH PASSAGES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

KEREM ÖZKAYA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER SCIENCE
IN
CIVIL ENGINEERING

OCTOBER 2014

Approval of the thesis:

NUMERICAL SIMULATION OF FREE SURFACE FLOWS AT FISH PASSAGES

submitted by **KEREM ÖZKAYA** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Gülbin Dural Ünver ____________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ahmet Cevdet Yalçıner ____________________
Head of Department, **Civil Engineering**

Assoc. Prof. Dr. Mete Köken ____________________
Supervisor, **Civil Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Mustafa Göğüş ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Mete Köken ____________________
Civil Engineering Dept., METU

Prof. Dr. İsmail Aydın ____________________
Civil Engineering Dept., METU

Prof. Dr. Burcu Altan Sakarya ____________________
Civil Engineering Dept., METU

Assoc. Prof. Dr. Mehmet Ali Kökpınar ____________________
DSİ

Date: 23.10.2014

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Kerem ÖZKAYA

Signature:

ABSTRACT

NUMERICAL SIMULATION OF FREE SURFACE FLOWS AT FISH PASSAGES

Özkaya, Kerem
M.S., Department of Civil Engineering
Supervisor: Assoc. Prof. Dr. Mete Köken

October 2014, 102 pages

Hydroelectric dams build on the rivers block most of the flow section and leaves no space for the migrating fish along the rivers. Fish passages are built along the river at those locations to overcome this problem. Understanding the hydrodynamics inside these structures is essential in the design process. Parameters like discharge, velocity, acceleration and turbulence inside the fish passage can be obtained using three dimensional numerical simulations. Change in these parameters is investigated for different fish passage designs within this study. Overall, computational fluid dynamics (CFD) appears to be an effective tool for analyzing free surface flows over technical fish passes for studying of different design scenarios.

Keywords: Brown Trout, Fish Pass, Flow 3D, Numerical Modelling, Open Channel Flow

ÖZ

BALIK GEÇİTLERİNDEKİ SERBEST YÜZEYLİ AKIMIN SAYISAL BENZETİMİ

Özkaya, Kerem
Yüksek Lisans, İnşaat Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Mete Köken

Ekim 2014, 102 sayfa

Nehirlerin üzerine inşa edilen hidroelektrik santraller akım kesitinin büyük bir bölümünü tıkayarak, nehir boyunca göç eden balıkların geçeceği bir boşluğun kalmamasına sebep olur. Bu problemin üstesinden gelmek için nehir boyunca barajların bulunduğu kesitlerde balık geçitleri inşa edilmektedir. Tasarım aşamasında bu yapıların içerisindeki akımın hidrodinamiğini anlamak çok önemlidir. Balık geçitlerindeki debi, hız, ivme ve türbülans karakteristikleri gibi parametreler üç boyutlu sayısal benzetim yöntemleri ile elde edilebilir. Bu çalışmada farklı balık geçidi konfigürasyonları için bu parametrelerin değişimi incelenmiştir. Genel olarak, hesaplamalı akışkanlar dinamiği (HAD) farklı tasarım senaryoları çalışılabildiği için, teknik balık geçitlerindeki serbest yüzeyli akımların incelenmesinde etkili bir araç olarak gözükmektedir.

Anahtar Kelimeler: Açık Kanal Akımı, Balık Geçidi, Flow 3D, Kahverengi Alabalık, Sayısal Modelleme

To the memory of my dear and honored father, İsmail Özkaya

ACKNOWLEDGMENTS

Initially, I would like to express my deepest gratitude to my supervisor, Assoc. Prof. Dr. Mete Köken, for his continuous support, encouragement, determination and belief in me. He took the role of an active guide in this exhausting process and helped me enthusiastically whenever I had difficulty. Without his suggestions, feedback and positive attitude towards me, it wouldn't have been possible to complete this thesis with satisfactory results.

I would like to thank to Assoc. Prof. Dr. Mehmet Ali Kökpınar for providing us the design data and sharing his valuable experience on fish passes. I would also like to render my sincere thanks to the committee members of this thesis Prof. Dr. Mustafa Göğüş, Prof. Dr. İsmail Aydın and Prof. Dr. Burcu Altan Sakarya for their valuable feedback, suggestions and comments throughout the process.

I would also like to express my gratitude to STUCKY Teknik Ltd. for its encouragement to continue my studies in academia. My dear managers Mustafa Aykut and Hacer Erdem have always in there to help me with their suggestions, advise and expertise. Moreover, many thanks go to my colleagues Umut Akın, Koray Kadaş, Çağdaş Şimşek and Eda Fitoz and to other colleagues and friends I cannot name here.

My sincerest thanks go to my parents, İsmail and Füsun Özkaya, for their unconditional love, affection, continuous support and trust in me. My success depends on the way they have brought me up and on their exemplary personalities. In this regard, I owe my diligent and sacrificing personality to my mother who has never been tired of making sacrifices for her family and my strong and determined personality to my incredibly missed father who made me believe in my strength and have a hopeful view of future and life in general: I also feel incredibly lucky to have my brother, Utku Eren Özkaya, who has always been next to me during this process.

Last but not least, I would like to thank my beloved Rana Kahveci, who has made my life more meaningful and whose presence has enabled me to put more dedication to this thesis. Her being in my life makes my success more meaningful and my future more brightful.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF SYMBOLS

$V_{fish,max}$	: Maximum travelling speed (m/s)
$V_{fish,cr}$	: Maximum cruising speed (m/s)
L	: Fish body length (m)
E	: Volumetric dissipated power (watts/m^3)
ρ	: Density of water (1000 kg/m^3)
Δh	: Head difference between pools (m)
$\forall$	: Volume of water in the pool (m^3)
n	: The number of pools
h_{diff}	: Head difference between upstream and downstream (m)
V_{max}	: Maximum velocity in the pool (m/s)
Q	: Discharge passing through fish pass (m^3/s)
h_u	: Water depth at the just downstream of the cross wall (m)
h_0	: Water depth at the just upstream of the cross wall (m)
μ_r	: f(h_u / h_0)
S_l	: Slope of fish pass
s	: Slot width (m)
l_b	: Pool length (m)
c	: Length of projection (m)
a	: Stagger distance (m)
h_{min}	: Minimum depth of water (m)

CHAPTER 1

INTRODUCTION

1.1 General

With the increase in population and developments in industry, many energy production and transformation systems have been established recently. These systems can cause harmful changes in water resources and pose threats to the ecological system in the long run, however.

Dams and weirs which have been established to satisfy the increasing needs change the clarity, quality and amount of water, thereby having a remarkable effect on water resources and leading to changes in ecosystem in general (Schilt, 2007).

Nowadays, a great number of hydroelectric power plants (HEPP) have been built because of the fact that the energy obtained here is renewable, they can serve a long time and the amount of money paid for their maintenance is low. Especially on the Black Sea Region, there have been over 430 planned river type HEPP projects (Aksungur et al., 2011). With the hydroelectric power plants being planned and built now, Turkey ranks as the second country to have the potential of producing the highest energy from hydropower after Norway in Europe (Berkun et al., 2008). Compared to other energy production systems, HEPP projects are considered to be environmentally friendly; however, they also have detrimental effects on the quality of water resources and on the ecosystem. These established structures disturb the natural flow of rivers and pose threats to potamodromous and diadromous fish species as will be explained that migrate for various reasons such as spawning and nutrition.

There has been a considerable amount of decline in population of such potamodromous and diadromous fish species as *Salmo Trutta Labrax* (*Karadeniz Alabalığı*), *chondrostei* (*Mersin Balığı*), and eel *(Yılan Balığı)* since their migration has been hindered with structures such as dams and weirs built on rivers. These structures also prevent the migration of water insects such as *Ephemerttera* and *Trichopteran* which leave their larvas at the upper parts of rivers to prevent them from being dragged and the migration of fresh water mollusks which stick their larvas on migrating fish (Aksungur et al., 2011). Plant communities in rivers are also affected negatively by the low water quality resulting from the construction of dams and weirs (Mitsch et al., 2003).

It is believed that negative effects of such structures on migratory fish can be prevented with the establishment of environmentally friendly fish passes. Only fish passes enable fish to pass through dams when they migrate with the purposes of nutrition and spawning (Erus et al., 2010). With the establishment of such passes, fish species used for trade and recreation will improve their population connections (Lucas et al., 2001), there will be decrease in population loss and harm given to the ecological system in general. Because of these reasons, many organizations work together to build fish passes that will make migration among the habitats easy (Anonim, 2009). Various fish passes have especially been developed to decrease the negative effects of dams and similar structures on diadromous fish species (Larinier, 2002; Croze et al. 2008).

Nowadays, fish passes are of great importance considering the reduced amount of harm given to the ecological system after their increasing establishment and use.

1.2 Conditions of Fish Passes in Turkey

Fish passes are not commonly found in Turkey and the existing ones are not adequate and sufficient for fish species considering the fact that they have not been specifically designed for the migrating fish species as shown in Figure 1.1.

Figure 1.1 An example of inadequate design of fish pass

Seyhan weir on Seyhan River and Çubuk 1 Dam near Ankara were the first to build during the Republican period in 1936. The fish pass which is placed on the left bank of Seyhan Weir and which still works is the first built fish pass of

Turkey (Anonim, 1987). While there are generally Denil type and vertical slot fish pass types and pools and orifices all around the world, fish passes with pools and orifices are more commonly preferred in our country.

There are a great number of planned or built dams, weirs and hydrological structures like HEPP in Turkey and most of these structures (over 430) are planned to be built or being built in the Eastern Black Sea Region (Aksungur et al., 2011). However, fish passes cannot be found in all of these structures. There are also many problems in the Eastern Black Sea Basin as in 26 major basins in Turkey (Ak et al., 2009). Hydroelectric power plants, unplanned infrastructure and unregulated quarries are the major problems of this region (Tabak et al. 2001).

It has been found out that dams without fish passes in our country prevent the migration of sturgeon that are listed as under the risk of extinction in the world list (Berkun et al. 2008). *Salmo trutta labrax* the most important endemic species of Southeastern Black Sea, is also at risk because of reasons such as stream improvement, destruction of river basins resulting from buying supplies for sand and gravel pits and construction of dams and river type hydroelectric power plants (Aksungur, 2009). Furthermore, the study conducted by Alp and Buyukcapar (2006) shows that fish species such as *cyprinus carpio*, *alburnus orontis*, *Salmo trutta macrostigma* and *Anguilla anguillaare* not able to migrate successfully for breeding without fish passes, which results in a decrease in the population of fish that leave eggs in rivers and extinction of fish species in the long run.

The aim of this study is to design a fish pass for target species (Brown trout) to pass over the obstruction in Uzungöl region thus the negative effect of the weir will be eliminated. At the end of the study, the optimal fish pass design will be suggested for Uzungöl Weir-1

CHAPTER 2

DESIGN CRITERIA

2.1 Biological Factors To Be Taken Into Account in the Design of Fish Passes

2.1.1 General

Most fish types have to migrate in order to satisfy their basic needs. Their needs might be looking for food, resting, growing up and spawning. Apart from these needs, fresh water fish types might travel for long distances for the purposes of feeding and shadowing in a day or month.

If usual behavior of fish is restricted with the constructions, migrating fish might be injured or they may die. Fish are more exposed to the threat of getting injured while they are trying to pass structures constructed by human beings. If passing of fish is hindered during the spawning migration, it will cause irreparable damage on the population. The size of eggs and the ability to dig nests might decrease and deaths might occur as well.

Designs of fish passes start with finding out present and past migration patterns of fish types in the project fields. Target fish types are the ones that are under the threat of extinction or that are about to go extinct and there are also other local types and non-native and aggressive kinds as well (United States Department of Agriculture, 2007).

Project designs should be done by taking into consideration the physical features of the weakest kinds. In this regard, sizes of their living spaces and migration routes are of great significance. Furthermore, sufficiency of things to be done is determined by the features and condition of the stream. (Ağıralioğlu, 2012).

While developing design criteria for fish passes, steps given below and characteristics of fish are usually taken into account (Ağıralioğlu, 2012):

Step 1: Determine target species for fish passes.

Step 2: Find out migration periods and phases of fish.

Step 3: Determine the physical restrictions in fish passes (swimming speed, leaping ability).

Step 4: Determine the attractive and repellent characteristics of the environment on the passing route (discharge, flowing velocity, water temperature, seasonal timing).

Step 5: Find out the attitudes of target species that can influence fish passes (like water temperature).

2.1.2 Migration Types of Fish

Fish populations depend on their aquatic habitats which are in line with their biological functions such as nutrition and reproduction. Such dependence is most frequently seen in migrating fish which need differing environments for their main living phases such as spawning, production of juveniles and sexual maturation. Different environments are needed for the species to go on their existence. There are two main groups of migrating species (Larinier, 1992d):

- **Potamodromous** species spend their entire life cycle in freshwater and their reproduction and feeding spaces might be divided by small or big distances. They travel within the river catchment and this migration is necessary for the success of their life cycle. The zones which are required for their life cycle are different and usually separated by large distances in such species as pike (*Esox Lucius*), lake trout (*Salmo trutta lacustris*) and *Salmo trutta fario*. Their migratory needs are quite strong to keep in good health and reproduce healthy populations. Other species such as roach or bleak do not demonstrate so strong needs; however; it is still essential to maintain successful circulation of fish between reaches to prevent reproductive isolation.

- **Diadromous** species make changes in their environments in their life cycle which is partly spent in freshwater and in the sea. Distances between the reproduction and feeding zones might be up to several thousands of kilometers. They have two distinct groups:

Anadromous species such as Atlantic Salmon (*Salmo salar*), sea lamprey (*Petromyzon marinus*), Allis shad (*Alosa alosa*) and sturgeon (*Sturio sturio*) engage in reproduction in freshwater and grow up in the sea. They migrate back to freshwater with the purpose of reproduction. They have the ability to recognize their native river of birth and this phenomenon is based on olfactory recognition of streams. As a consequence, there is a unique unit of stock in each river basin.

Catadromous species such as eel (*Anguilla anguilla*) engage in a reverse life cycle in which they travel back to freshwater for trophic purposes. The broodstock come together in the Sargasso Sea and they do not isolate from any one place or river basin, resulting in one common reserve of eels in the European Atlantic seaboard.

2.1.3 The Different Levels of Swimming Activity

Fish are generally engaged in different swimming styles which are carried out with different types of muscles (Blaxter, 1969; Bell, 1986; Webb, 1975).

- **Cruising activity** can be done for hours and does not lead to major physiological changes in fish. It is an aerobic muscular activity done with "red" muscles.

- **Burst activity** needs intense and continuous effort and it cannot be carried out for very long. It can last from a few seconds to tens of seconds, which depends on the length of the fish and water temperature. It is regarded as excessive acceleration and leaping, namely a violent activity lasting for short time. Anaerobic mechanisms supply all the muscular power by transforming muscular glycogen to create lactic acid. Even though a considerable amount of muscle power is produced quickly, there is still a limited source of energy because of the limited reserves of glycogen and the concentration of lactic acid resulting in preventing muscular contraction.

- **Sustained activity** can last for several minutes but it is quite tiring for fish. It utilizes aerobic and anaerobic mechanisms in various proportions.

2.1.4 Swimming Speed

While designing fish passage facilities, it is quite significant to consider the swimming capacity of the migratory fish, which is described in terms of endurance, swimming speed and time spent for the migration. Even though there is information about swimming and leaping styles of different fish species, various equations and conclusions of different experiments might be utilized as well. However, it is widely accepted that the maximum swimming speed depends on the water temperature and on the length of the fish.

The relationship between endurance, swimming speed, size and temperature has been defined by experimental studies done in Great Britain (Wardle, 1980; Zhou, 1982; Beach, 1984). With the equations obtained from these studies, the maximum swimming speeds and endurance at a particular speed in different lengths and temperatures can be derived. They are presented in Figure 2.1 and Figure 2.2 (Beach, 1984). Videler (1993) came up with an equation derived from a compilation of experimental results (obtained for fish length < 0.50 m) yielding the maximum traveling speed ($V_{fish,max}$) (m/s) in line with body length L (m):

$$V_{fish,max} = 0.4 + 7.4L \tag{2-1}$$

Maximum cruising speed (at which fish continuously swim without demonstrating any signs of exhaustion) rises with the size of the fish. Videler (1993) offered an equation derived from a compilation of experimental results (obtained for fish length < 0.55 m) yielding the maximum cruising speed ($V_{fish,cr}$) (m/s) in line with to body length L (m):

$$V_{fish,cr} = 0.15 + 2.4L \tag{2-2}$$

Furthermore, Katopodis, (1992) summarized the variables and ranges of swimming performance of some fish types listed in Table 2.1.

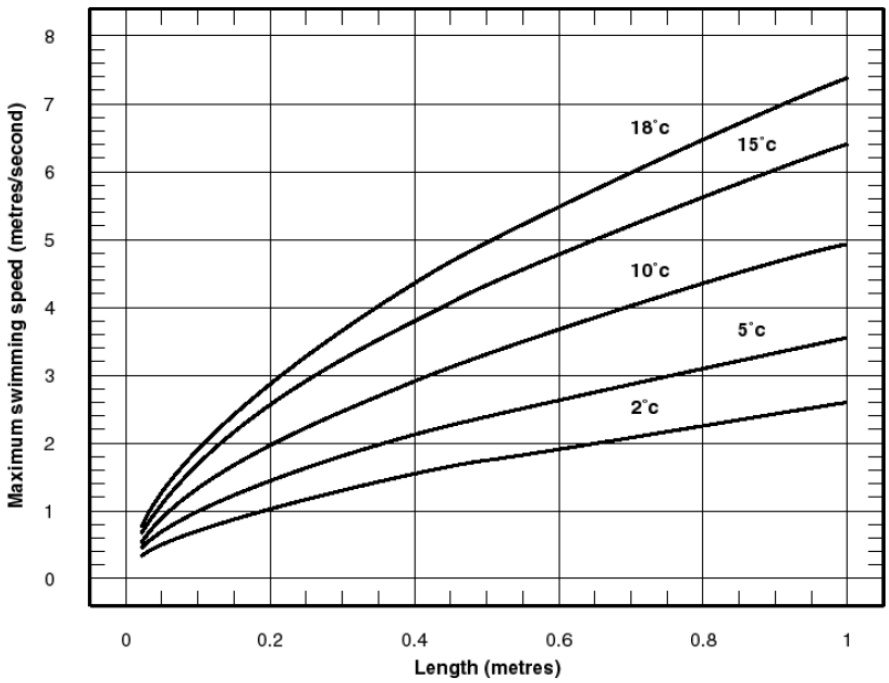


Figure 2.1 Maximum swimming speed for different fish sizes (Beach, 1984)

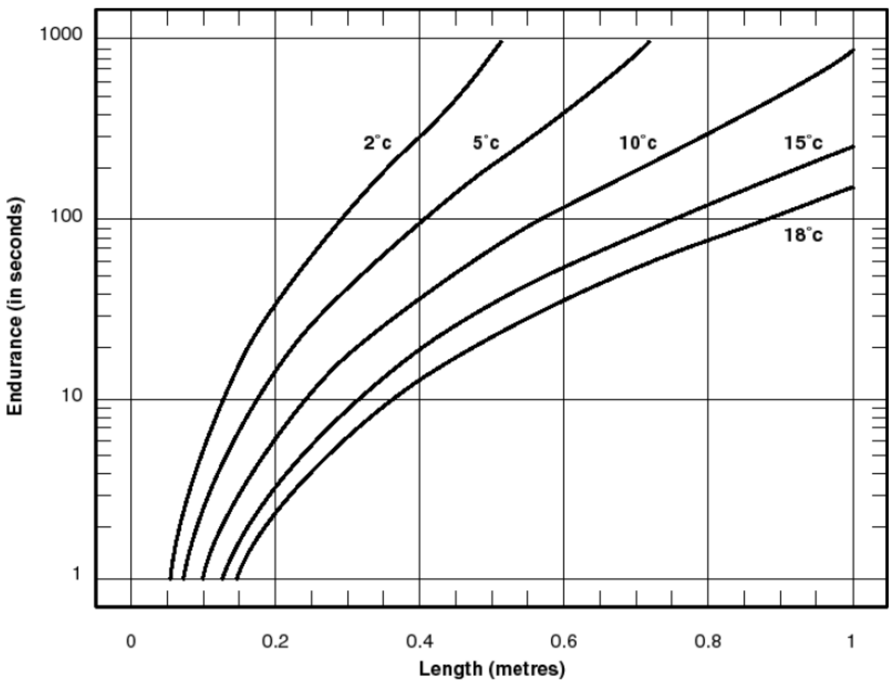


Figure 2.2 Endurance at maximum speeds vs. fish length and temperature (Beach, 1984)

Table 2.1 Variables and ranges of swimming performance data (Katopodis, 1992)

Common Name	Scientific Name	Length Range (mm)	Endurance Time (s)	Swimming Speed (m/s)	Temp. (°C)	No. of Fish	No. of Sources
Anguilliform Swimming Mode							
Burbot	*Lota lota*	120 - 620	600	0.360 - 0.410	7 - 12	56	1
Lamprey	*Petromyzon marinus*	145 - 508	0.8 - 1635	0.300 - 3.960	5 - 23	>75	2
Subcarangiform Swimming Mode							
Arctic char	*Salvelinus alpinus* [A]	80 - 420	6 - 1089	0.411 - 1.300	10 - 13.5	64	3
Arctic grayling	*Thymallus arcticus* [F]	70 - 370	600	0.520 - 0.720	12 - 19	94	1
Atlantic salmon	*Salmo salar* [A]	231	300	0.516	7.0	55	1
Brook trout	*Salvelinus fontinalis* [A]	41 - 172	10 - 1800	0.202 - 0.930	11.5 - 15	42	3
Chum salmon	*Oncorhynchus keta* [A]	38 - 48	300	0.181 - 0.342	10	17	1
Cisco	*Coregonus artedii* [A]	135	433 - 1800	0.458 - 0.630	12	20	1
Coho salmon	*Oncorhynchus kisutch* [A]	51 - 133	534 - 1746	0.343 - 0.701	10 - 20	>100	2
Dace	*Leuciscus leuciscus* [F]	100 - 200	1 - 20	0.430 - 2.400	15	7	1
Flathead chub	*Platygobio gracilus* [F]	170 - 300	600	0.429 - 0.627	12 - 19	28	1
Goldfish	*Carassius auratus* [F]	67 - 213	1 - 20	0.420 - 2.000	15	8	1
Humpback whitefish	*Coregonus clupeaformis* [A/F]	60 -510	72 - 1278	0.341 - 1.021	5 - 19	>200	2
Largemouth bass	*Micropterus salmoides* [F]	81 - 224	300 - 1800	0.340 - 0.589	20 - 30	190	3
Longnose sucker	*Catostomus catostomus* [F]	40 - 530	600	0.230 - 0.910	7 - 19	169	1
Pink salmon	*Oncorhynchus gorbuscha* [A]	465 - 596	72 - 1278	0.780 - 1.740	12 - 20	212	2
Rainbow trout[1]	*Oncorhynchus mykiss* [A/F]	82 - 310	1 - 1800	0.257 - 2.700	7 - 15	78	4
Sockeye salmon	*Oncorhynchus nerka* [A]	126 -621	6 - 1350	0.554 - 1.700	10 - 18	47	3
Walleye	*Stizostedian vitreum* [F]	80 - 380	600	0.380 - 0.840	19	54	1
White sucker	*Catostomus commersoni* [F]	170 - 370	600	0.480 - 0.730	12 - 19	20	1

[1] Former scientific names: Salmo gairdneri; Salmo irideus.

A - Anadromous, F - Freshwater

2.2 General Requirement for Fish Passes

2.2.1 Location of Fish Passes

Effective fish passes enable fish to find the fish entrance as quickly as possible. Compared to the whole width of the obstacle, the width of the entrance remains small and its flow constitutes only a small fraction of the whole flow in the river. Fish are actively directed by the flow at the obstruction towards the entrance.

At hydroelectric power plants, the most convenient place for fish passes is usually on the same side of the river with the power house. The water outlet should be close to the turbine or dam outlet. If the outflow of the fish pass (and its entrance) is situated in the immediate area of the dam, the dead zone between the fish entrance and the obstruction will be reduced, which is quite significant in that fish travelling upstream may miss the entrance and get stuck in the dead zone. Fish passes which extend into the tailwater cause fish to miss the entrance, which is a common error made in construction of many unsuccessful fish passes (Larinier, 1992d).

A fishway on an obstruction which lies on a marked angle to the direction of the water course should be placed at the top upstream point of the barrier as shown in Figure 2.3-a. Therefore, in Figure 2.3-b and Figure 2.3-c, locations of the fishways are inaccurate; the first having an entrance which is too far downstream of the weir, and the second located in the downstream corner of the weir. In the construction of a chevron shared weir, it is the most favorable strategy to place the fishway at the most upstream point, which might be quite challenging to arrange for access, monitor or maintain in some cases as shown in Figure 2.3-d (Larinier, 1992d).

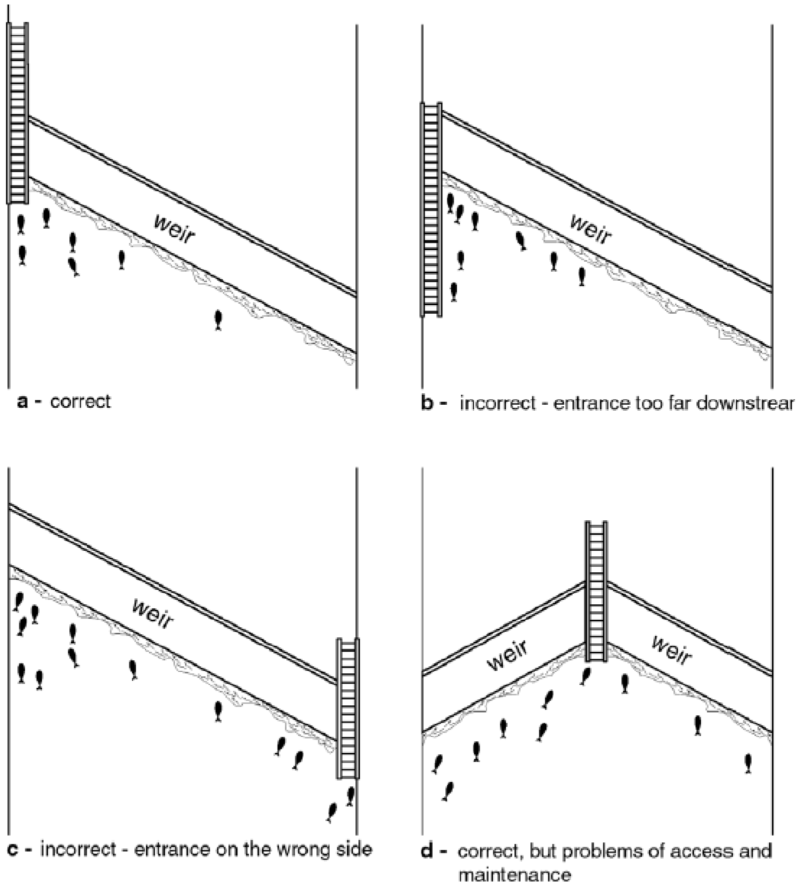


Figure 2.3 Schematic plans of correct location of fishway entrance (Larinier, 1992d)

The fishway should be situated on one side or the other as shown in Figure 2.4-a when the obstruction is at right corners to the banks. In this regard, the flow patterns, the presence of pools, a dominant flow channel and the topography of the bed downwards from the obstruction should be considered. Nevertheless, it is more efficient to build a fish pass on both sides on a wide obstruction as illustrated in Figure 2.4-b (Larinier, 1992d).

The morphology of the riverbed at the downstream of the obstruction might be changed in some occasions to steer fish towards the fishway. High riprap protection can be placed across the central part of the watercourse as well as for a certain way immediately downwards of the installation, while creating two deeper side channels in the meantime. This will direct fish to the fish pass facilities as shown in Figure 2.4-c (Larinier, 1992d).

In some cases as in a long natural bypass channel as shown in Figure 2.4-d, the entrance of the fishway might be situated far downstream of the obstruction. Such cases might require the increase of the flow though the facility so that it will constitute an important part of the discharge of the river during the migration period (Larinier, 1992d).

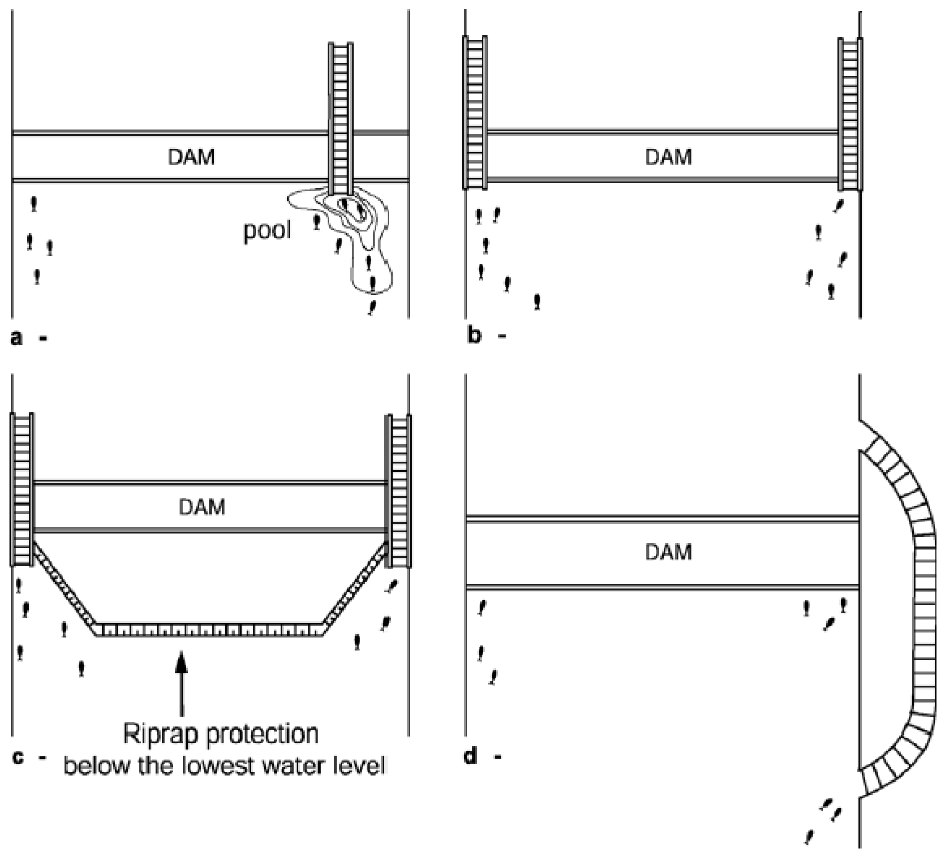


Figure 2.4 Schematic plans of different combination of fishway location (Larinier, 1992d)

In order for fish to swim into the fishway even at low water levels, the construction of the entrance of fish passes is very important. The fish pass might be connected to the natural river bottom with a ramp with a maximum slope of 1:2 as shown in Figure 2.5. Resulting in ease with which even fish species living at the bottom and macrozoonbenthos can enter into the fish pass. For the fish passes which has low tailwater at the entrance, an alternative type of entrance is proposed in the Figure 2.6.

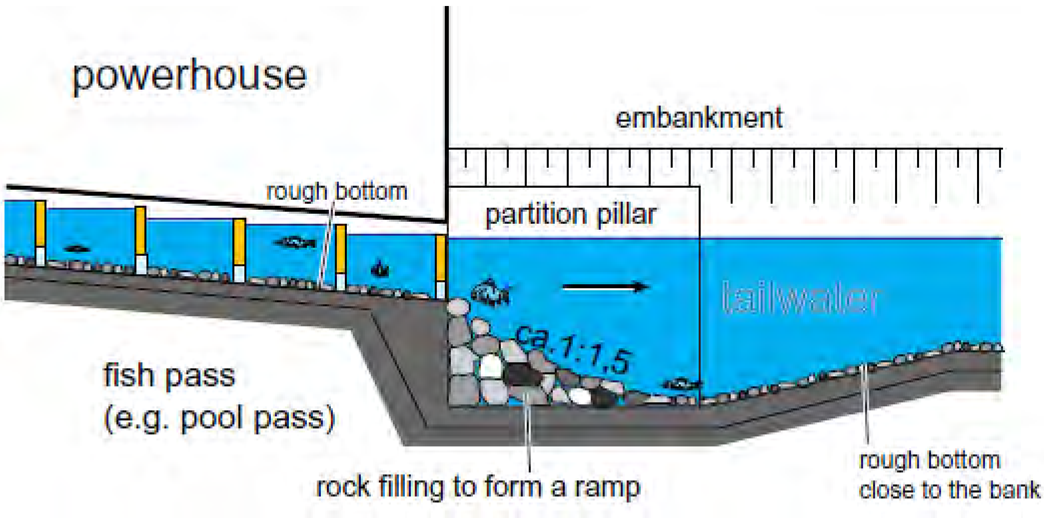


Figure 2.5 Concept of fish passage entrance – 1 (DVWK, 1996)

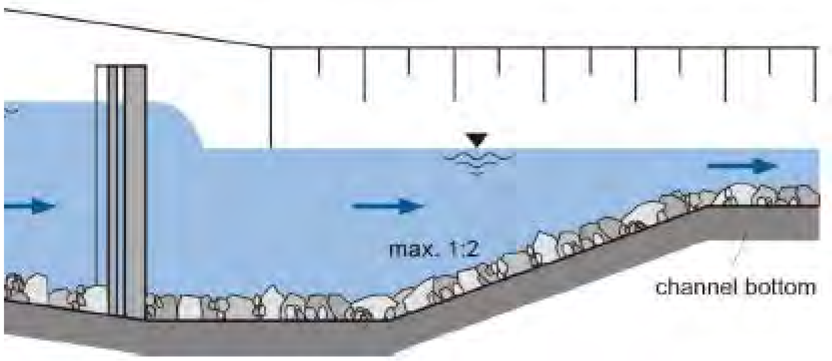


Figure 2.6 Concept of fish passage entrance – 2

2.2.2 The Bottom of Fish Passes

The whole bottom of a fish pass should be covered with a layer having at least 0.2 m thickness of a coarse substrate (Figure 2.7). The material used should be as natural as possible and create a combination of interstices with gaps different in size and gaps due to the differing grain size. Small and young fish and especially benthic invertebrate can rest in such gaps of low current and then go upwards protected from the current. A rough surface can be produced by embedding stones closely together into the concrete before it sets.

Figure 2.7 The bottom of the fish pass (DVWK, 1996)

The rough bottom should be the same upwards, at the exit area of fish, at the slots and orifices. Formation of a rough bottom is not feasible in some technical fish passes such as Denil passes, which indicates that benthic invertebrates cannot run through and such fish passes do not meet one of the significant ecological requirements for fish passes.

2.3 Fish Passes Types

Fish passes can be categorized into two main groups as close-to-nature types of fish passes and technical fish passes (DWVK, 1996). Furthermore, technical fish passes are divided into some subgroups which are given below:

- Vertical Slot Passes
- Pool Passes
- Denil Passes
- Eel Ladders
- Fish Lifts

2.3.1 Close-to-nature Types of Fish Passes

The close-to-nature type of fish passes is a waterway which imitates slope, morphology and hydraulic conditions of the stream as much as possible. The construction materials are chosen from natural materials, therefore, they provide more ecologically sensitive when compared with the other alternative types. While they meet biological requirements of fish adequately, they decrease negative effects of dam or weir constructions.

In terms of construction, DVWK (1996) divided close-to-nature types of fish passes to three groups which are summarized as follows (Figure 2.8).

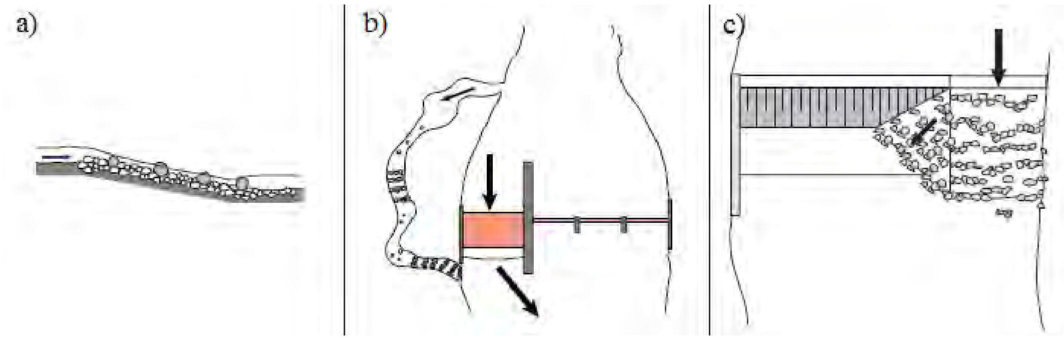


Figure 2.8 The three types of close-to-nature types of fish pass (DVWK, 1996)
(a) Bottom Ramp and Slope (b) Bypass Channel (c) Fish Ramp

a) Bottom Ramp and Slope

The main objective of them is to stabilize the river bottom and overcome the head difference at the river bottom with a mild slope. The watercourses between the big rocks provide shelter area for fish. They are used for substituting weirs which are no longer required from water management point of view.

b) Bypass Channel

When it is not possible to demolish the weir or dam, the obstacle can be passed over with bypass channel for migration of fish which is constructed with natural material and have natural appearance. Bypass channel should be steep and the flow condition should imitate natural river as much as possible. The location of inlet and outlet of the channel should be decided carefully so that migrators can find easily.

c) Fish Ramp

They are combined with the main body of dams or weirs. They are suitable for existing weirs which do not have fish pass. The best hydraulic design is that minimum and mean discharge are passing only from the fish ramp, only flood discharge is passing over crest of the weir. Fish ramp should be gently sloped and boulders should be arranged to provide suitable depth and velocity, however, the boulders should resist bad hydraulic conditions during the flood.

Although, from the ecological point of view, close-to-nature type fish passes present very good solution for problem of migration of fish, there are also some disadvantages. They need considerable surface area and great length and they are very sensitive to the water fluctuation in the upstream water level. Furthermore, bottom ramp and slope cannot be used combined with dams and weirs.

2.3.2 Technical Fish Passes

a) Vertical Slot Passes

The vertical slot passes were developed to solve constriction problems as a result of rock slides during railway construction in the Fraser River at Hell's Gate, British Columbia, Canada. Nowadays, this type of fish passes have been used in Canada, U.S.A., Norway, Australia, France, Germany and many other countries (Katopodis et al., 2011).

The vertical slot passes consist of a sloped rectangular channel with pools divided by concrete or wood successively (Figure 2.9). Water flows towards the downstream with passing the vertical slot from one pool to the next pool below. While the flow is passing through the slot, it forms a jet which dissipates the energy of the flow with mixing in the pool. The number of slot can be one or two according to discharge passing from the channel. After the slot, there is a sill to limiting the flow and to direct water into the pool for preventing the short circuit. That is why, the slots are in the same side in the one-slot type conversely with other type of technical fish passes. Fish can pass the slots with burst speed and can rest in the pools.

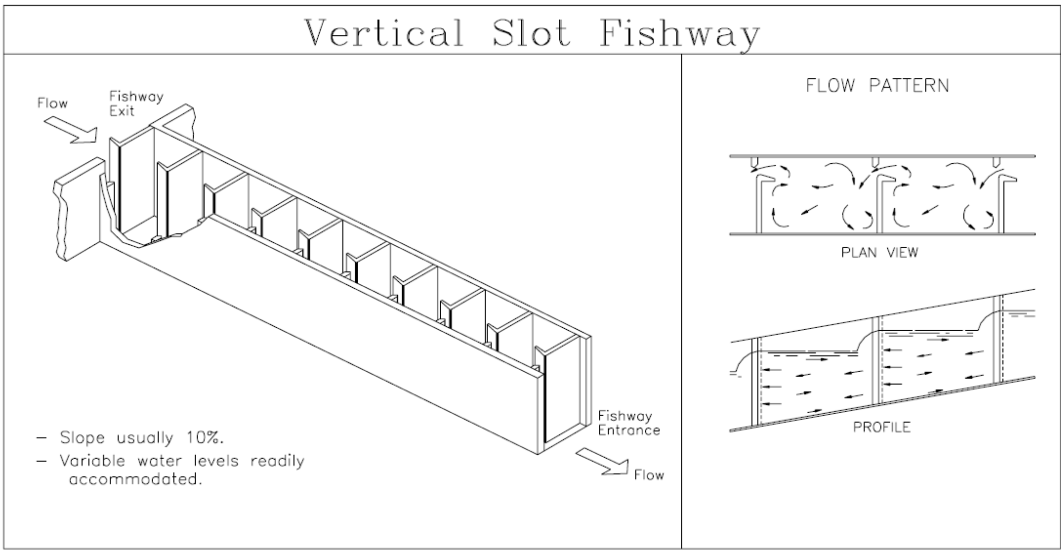


Figure 2.9 Vertical Slot Passes (Katopodis, 1992)

During the determination of size of the pool, the first criterion is volumetric power dissipation in the pools. As turbulence and aeration in the pools increase, the migration of the fish is getting harder. To provide low turbulence current in the pool, the volumetric power dissipation value should not exceed the limit value 200 watts/m^3 (Larinier, 1992a) which can be expressed by the formula:

$$E = \rho g Q \Delta h / \forall \tag{2-3}$$

where,
E: Volumetric dissipated power (watts/m^3)
ρ: Density of water (1000 kg/m^3)

g: Acceleration due to gravity (9.81 m/s^2)

Δh: Head difference between pools (m)

$\forall$: Volume of water in the pool (m^3)

Q: Discharge passing through fish pass (m^3/s)

The next criterion is the phenomenon of short-circuit. The main current should be directed through the middle of the pool so that direct passage will be avoided with high velocity. A hook-shaped projection into the cross-walls assists to deflect the current in the area in front of the slot aperture. Furthermore, the jets should not be sent directly to the walls with high velocity, because this situation may disturb the migrators so that it decreases the efficiency of the fish passes.

The most important dimension of the slot passes is slot width which determines the required pool dimensions. It is generally chosen as three times of diameter of the target species. Then, for the other dimensions, there are some simplifications. To simplify the geometry of the pools, DVWK (1996) defined the minimum dimensions that can be used during designing according to experimental tests and practical solutions. For one-slot passes, the minimum dimension according to different fish fauna is given in Table 2.2 and the terminology for the dimensions is given in Figure 2.10. For two-slot passes, these dimensions should be doubled with using the sidewall as the axis of symmetry. Furthermore, Katopodis (1992) evaluated how hydraulic characteristics change with pool dimension and suggested 18 different versions which are given in Figure 2.11. Lenne (1990) also made some laboratory experiments and defined the dimensions as a function of the slot width which is given by Figure 2.12.

Table 2.2 Minimum dimensions for one-slot passes (DWVK, 1996)

Fish fauna to be considered		Grayling, bream, chub, others		Sturgeon
		Brown trout	Salmon, sea trout, huchen	
Slot width	*s* (m)	0.15 – 0.17	0.30	0.60
Pool width	*b* (m)	1.20	1.80	3.00
Pool length	l_b (m)	1.90	2.75 – 3.00	5.00
Length of projection	*c* (m)	0.16	0.18	0.40
Stagger distance	*a* (m)	0.06 – 0.10	0.14	0.30
Width of deflecting block	*f* (m)	0.16	0.40	0.84
Maximum water level difference	Δh (m)	0.20	0.20	0.20
Minimum depth of water	h_{min} (m)	0.50	0.75	1.30
Required discharge	Q (m^3/s)	0.14 – 0.16	0.41	1.40

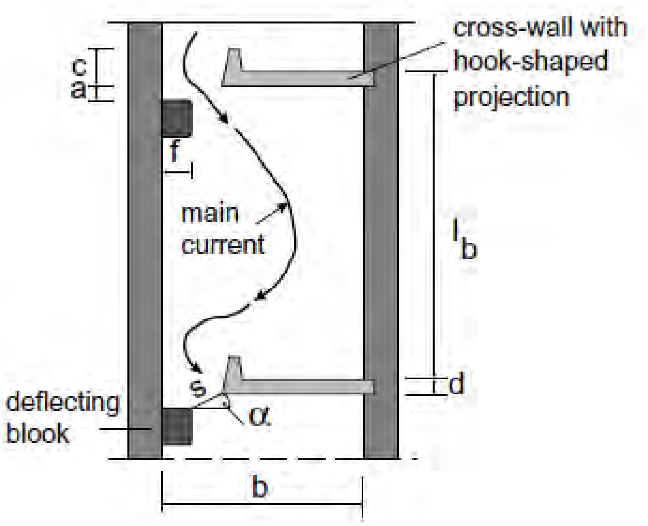


Figure 2.10 Dimensions and terminology for slot passes with one slot only (DWVK, 1996)

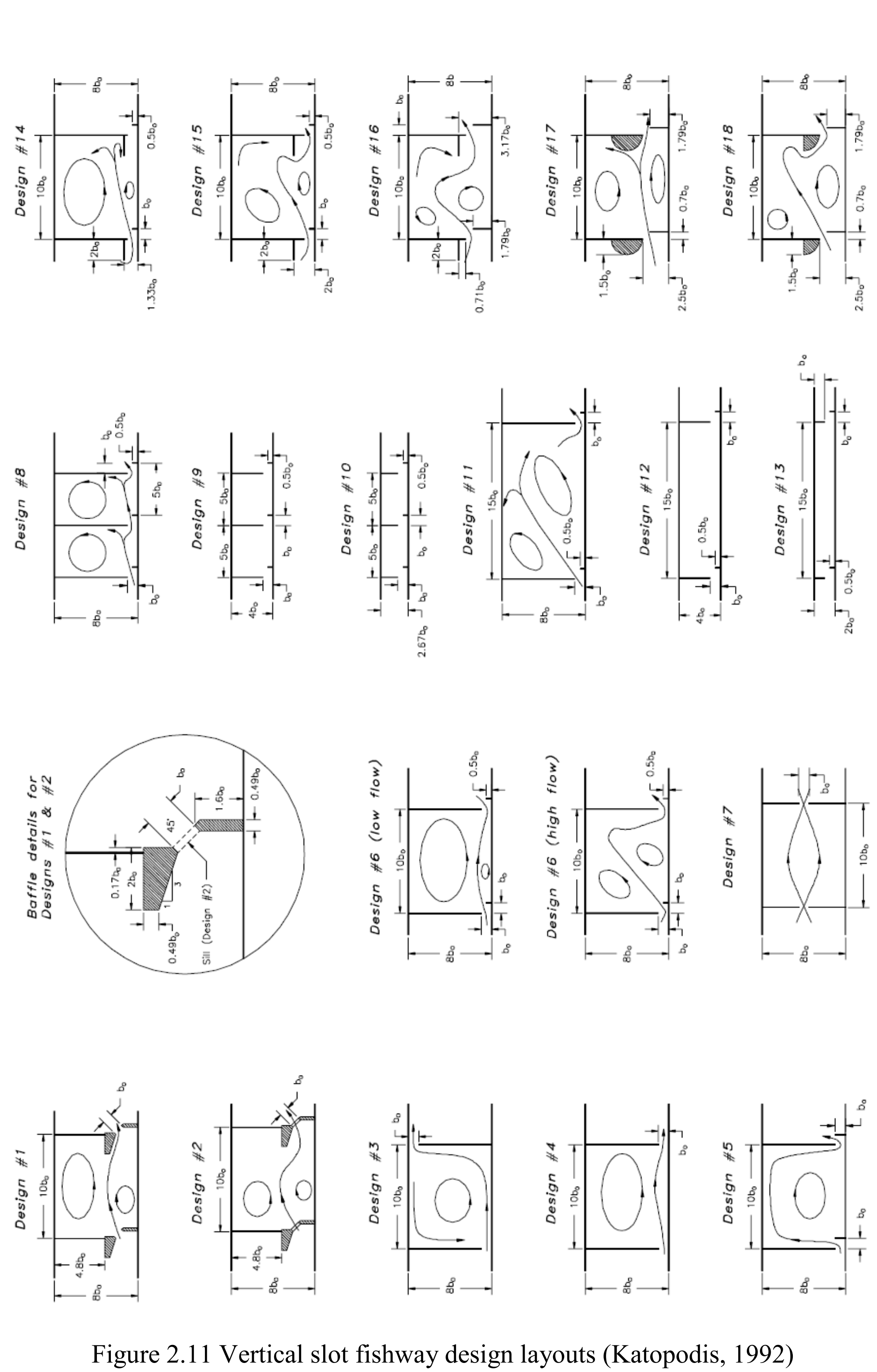


Figure 2.11 Vertical slot fishway design layouts (Katopodis, 1992)

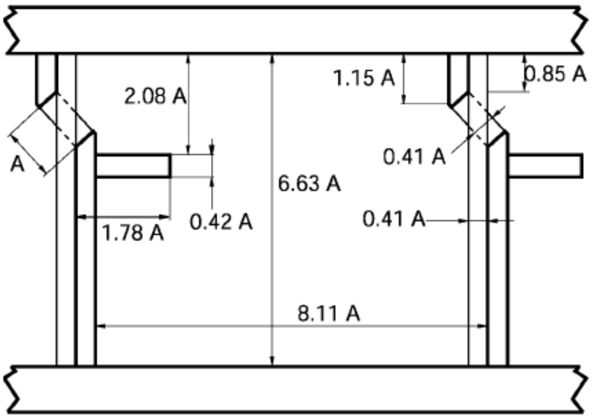


Figure 2.12 Characteristics of a simplified vertical slot fishway (Lenne, 1990)

To evaluate hydraulic condition in the pools, flow velocities in the slot, discharge and water depths in the pools should be calculated. Firstly, the minimum and the maximum water depths at the headwater and tailwater are found. During determination of the minimum water level, the discharge which is below 30 days in a year (Q_{30}) can be used and for the maximum water level, the discharge which is below 330 days in a year (Q_{330}) can be used. The fish pass should work well for a discharge range of $Q_{30} \leq Q \leq Q_{330}$ without any problems, where Q is the discharge passing through the fish pass. This means that a fish pass should be operational for approximately 300 days of a year.

The minimum water depth at the tailwater is the decisive factor in determining the bottom level at the fish passage inlet. Then, the level of the surface of the bottom substrate of fish passage inlet can be found with the minimum water depth at the tailwater minus minimum water level at the fish passage (MW – h_{min}) as can be seen in Figure 2.13. The upstream invert level can be found with the same approach. After that, the number of the pool can be found from the formula given below.

$$n = \frac{h_{diff}}{\Delta h} - 1$$

(2-4)

The maximum velocity depends on head difference between two pools. It is better to provide low velocity for easy migration but it increases the number of pools. The maximum velocity at the slot must be lower than burst speed of target species. The formula which is used to calculate the maximum velocity at the slot is given below.

$$V_{max} = \sqrt{2g\Delta h}$$

(2-5)

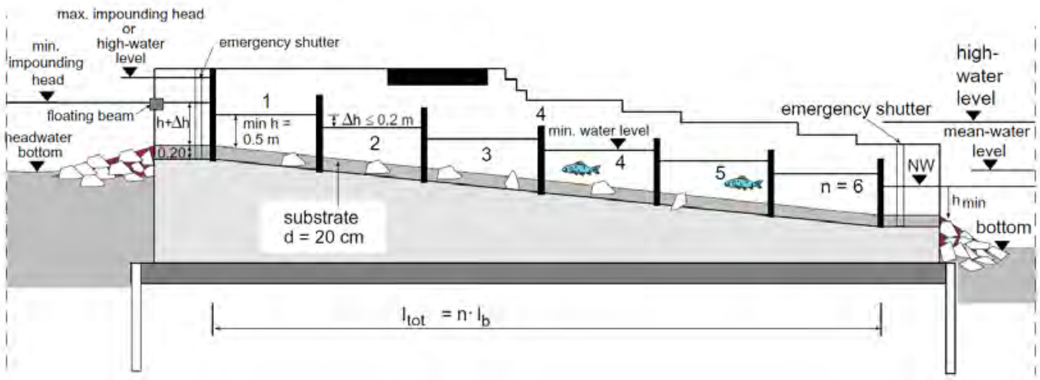


Figure 2.13 Longitudinal section of vertical slot pass (DVWK, 1996)

The discharge in the slot can be found by using the following formula.

$$Q = \frac{2}{3}\mu_r S_l \sqrt{2g} h_0^{3/2}$$

(2-6)

where,

μ_r: discharge coefficient (μ_r = f(h_u / h_o)) as shown in Figure 2.14

h_o: water depth at the just upstream of the cross wall

h_u: water depth at the just downstream of the cross wall

S_l: slope of the fish pass

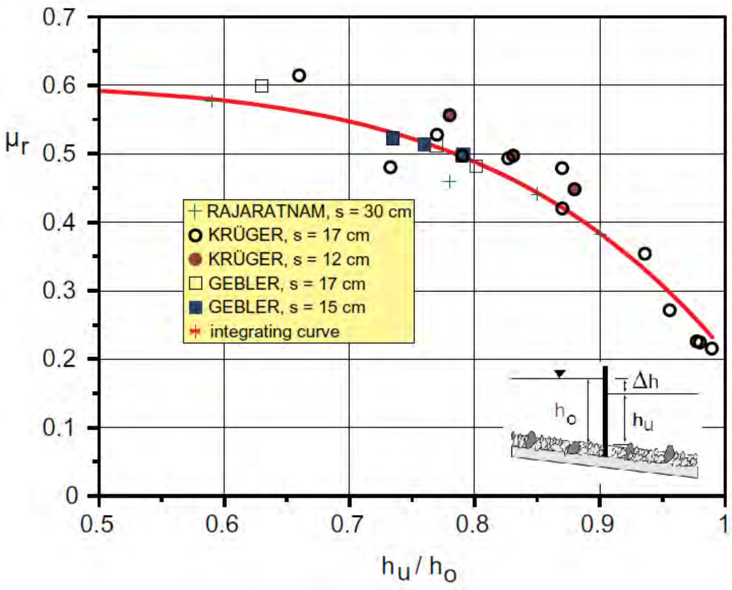


Figure 2.14 Discharge coefficient μ_r = f(h_u / h_o) (DVWK, 1996)

There are a lot of advantages of the vertical slot passes when compared with the other types of technical fish passes. The most important advantage is that it is not sensitive to water level fluctuation of tailwater or headwater. It is suitable to be used for both small streams and large rivers. Vertical slots which rise throughout the whole height of the cross-walls are quite appropriate for bottom living and open water fish and their swimming patterns. Since flow velocities near the bottom of the slots are reduced, fish with low performance can easily ascend. Installing a bottom substrate with some large stones is required to achieve such an aim. Since the orifices lie vertically over the height of cross-walls, slot passes are less vulnerable to blockage than the other types of technical fish passes. Partial blockage at the slot does not lead to a complete functioning.

b) Pool Passes

The main principle of a pool pass is dividing up a channel from the headwater to the tailwater by building in cross-walls to create a series of stepped pools. Discharges are usually found in openings (orifices) in the cross-walls and the potential energy of the water is gradually reduced in the pools as shown in Figure 2.15. Openings in the cross-walls placed at the bottom (submerged orifices) or at the top (notches) enable fish to travel from one pool to the others. Fish might come across high flow velocities only when they are travelling through the cross-walls. Pools with low flow velocities provide shelter and serve as places to rest.

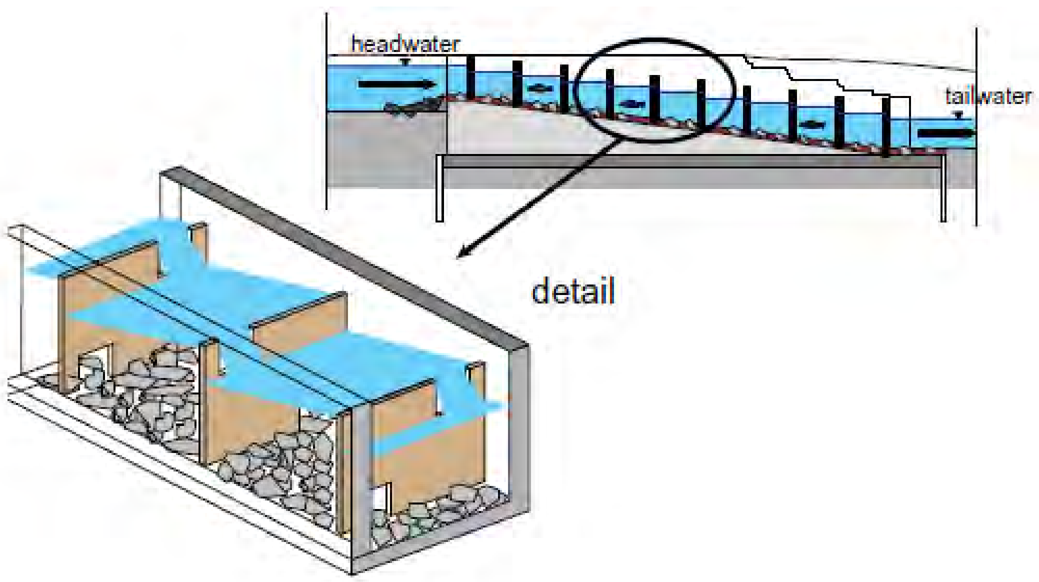


Figure 2.15 A general view of pool passes (DVWK, 1996)

The cross-walls consist of submerged openings which are organized in alternating formation at the bottom of the cross-wall and fish can ascend through them by swimming into the following pool. Reaching to the bottom of the pool, these openings create a rough-surfaced bottom when the substrate is added.

Generally, submergence of cross-walls is to be eluded if it is possible in order for water to pass only through the orifices. Pool passes are one of the oldest types of fish passes and they have been effective whenever their design, maintenance and layout are suitable. They are appropriate for enabling the migration at dams for both strong fish types and for small and bottom oriented fish. An everlasting rough bottom can be built to provide opportunities for ascent to the benthic fauna in pool passes. Relatively low water requirements of between 0.05 and 0.5 m^3/s are advantageous for normal orifice dimensions and differences in water level. However, pool passes are disadvantageous due to their high maintenance requirements, which result from obstruction of the orifices by debris since the orifices are occasionally clogged by debris, pool passes need regular cleaning at least at weekly intervals.

c) Denil Passes

Denil fish passes which were developed in Belgium by the civil engineer, G. Denil at the beginning of the twentieth century include a channel which has symmetrically and closely placed baffles on the floor and sidewall floor as shown in Figure 2.16. These baffles enable the flow to turn and oppose the main stream in the steam in the center of the flume. They direct a part of the energy of the main flow to the walls and the bottom of the channel, leading to energy dissipation and low velocity flow in the center of the fishway. Fish travel upwards in Denil Passes by swimming in the midst of the flume in depths they favor.

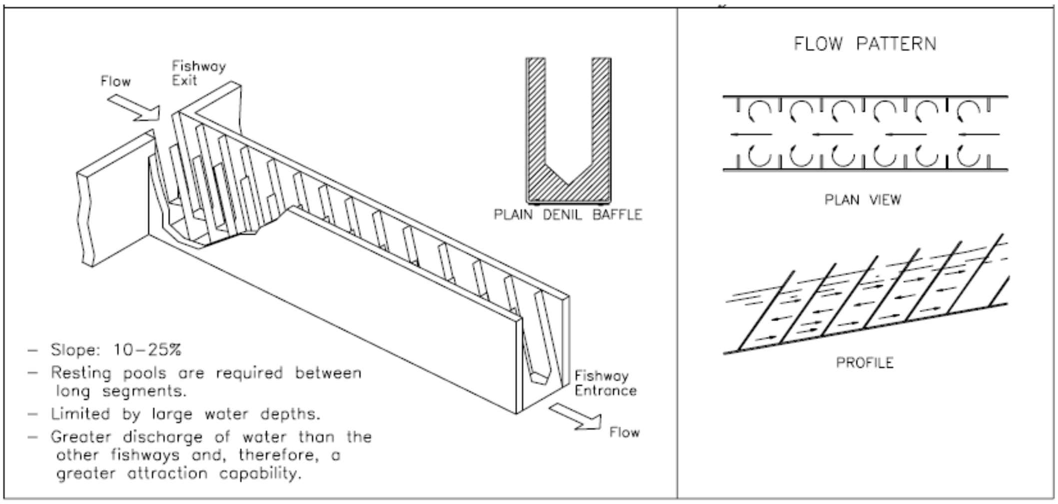


Figure 2.16 Denil passes (Katopodis, 1992)

The flow in a Denil Pass involves two interacting sections, which are the main stream in the center of the channel and a group of systematic lateral streams, all of which corresponds to a side pocket produced by baffles. This interaction between the main stream and he lateral streams creates the main system for transferring momentum and mass, and produces turbulence and energy loss. In this fish pass, the water on the surface moves fast and smoothly (Katopodis et al., 1983).

Denil Passes must have special resting pools every 6-8 meters for cyprinids and brown trout or every 10-12 meters for salmoids, which also serve as energy dissipating pools. Furthermore, the slope of the passes should be chosen between 1:5 (20 %) and 1:10 (10 %).

The Denil pass has several advantages in that it might have steep slopes with low space provision, it is not affected by the variations happening in the level of tailwater and it usually creates a good attraction current in the tailwater. On the other hand, it is highly susceptible to variations in the headwater levels. In reality, only variations of a few centimeters (maximum about 20 cm) are allowed. Another disadvantage is that it needs relatively high discharges compared to other types. Clogging may also disrupt its functioning, resulting in the requirement of continuous maintenance and inspection. Moreover, when its length is too long, small fish and fish with low swimming performance cannot easily pass through, which leads to a preference for bigger and stronger fish species. Considering all of these disadvantages, it can be stated that denil passes should be preferred only if other construction types cannot be built due to the reasons such as lack of space.

d) Eel Fish Passes

The eel is a type of migrant fish that can continue its life in almost all flowing waters connected to the sea. It grows in the rivers until its sexual maturity, and then it migrates to the sea.

There are two common principles in eel fish pass design:

1. Pipes are placed through the body of a weir where combination of brushwood, fascines and other baffles are laid to decrease the flow velocity. These baffles are usually tied to a chain to be pulled out and replaced. The eel travels through these tied devices in order to tackle with the handicaps of migration. This kind of device has not come in handy because of the fact that tubes get clogged with debris, which is difficult to discover and overcome.

2. It is possible to construct relatively small and flat channels passing from tailwater to headwater and made up of steel, concrete or plastic that allows eel to go upwards. As Jens (1982) says, brush-type structures are the most convenient structures of this type. Such channels should include a cover in order to be protected against predators.

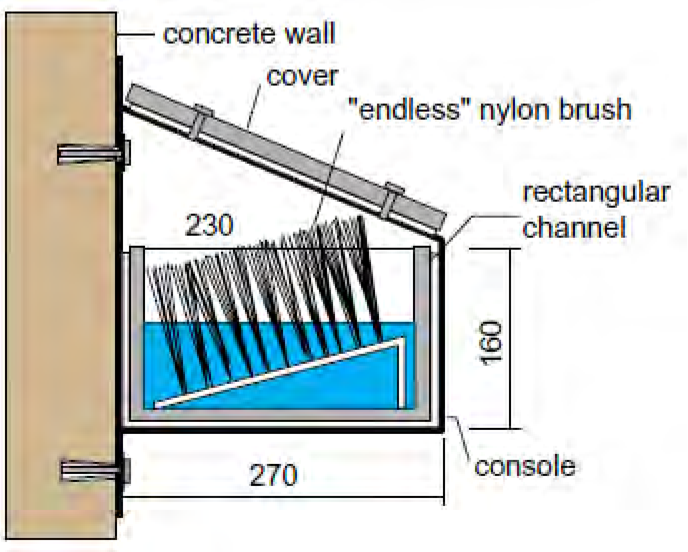


Figure 2.17 The eel ladder at the Zeltingen dam on the Moselle (Rhineland-Palatinate) (DVWK, 1996)

The eel ladders are laid out in a way that makes water trickle through them, allowing moistening, which means that they are not to be used for the ascent of other fish species. An example of eel fish pass is given in Figure 2.17.

Eel ladders should have their exists at the bank while connection with the bottom is not necessary considering the fact that glass eels travel on the surface of the water. It is important to point out that small discharges in an eel ladder are scarcely efficient to provide enough currents and in the cases of necessity, additional water supply might be utilized for sufficient attraction. Eel ladders are only suitable for the upstream migration of eels, they cannot be effectively used for the mitigation for other fish species.

e) Fish Lift

Restrictions might be put on the use of conventional passes when there are remarkable height differences (>6 to 10 m) and inadequate water. These restrictions might be on the construction costs, the space requirement and on the performance of the fish. In the case of great heights, fish is carried from the tail water to the headwater by means of a lift. In this regard, a trough is used to carry the fish and it can be either with a closable outlet gate or can be tilted. It is sunk to the bottom in the lower position and fish are directed to the fish lift with use of a current. The bottom gate of the lift closes so that the fish collected above the though cannot evade. In this way, fish are lifted to the top, where another connection might be made to the upper water level with the water coming from the through, fish are able to arrive at the upper channel Figure 2.18 shows the model of the fish lift constructed on the east coast of the USA and in France (Larinier, 1992c).

For determination of the position of a fish lift, same principles can be used with conventional fish.

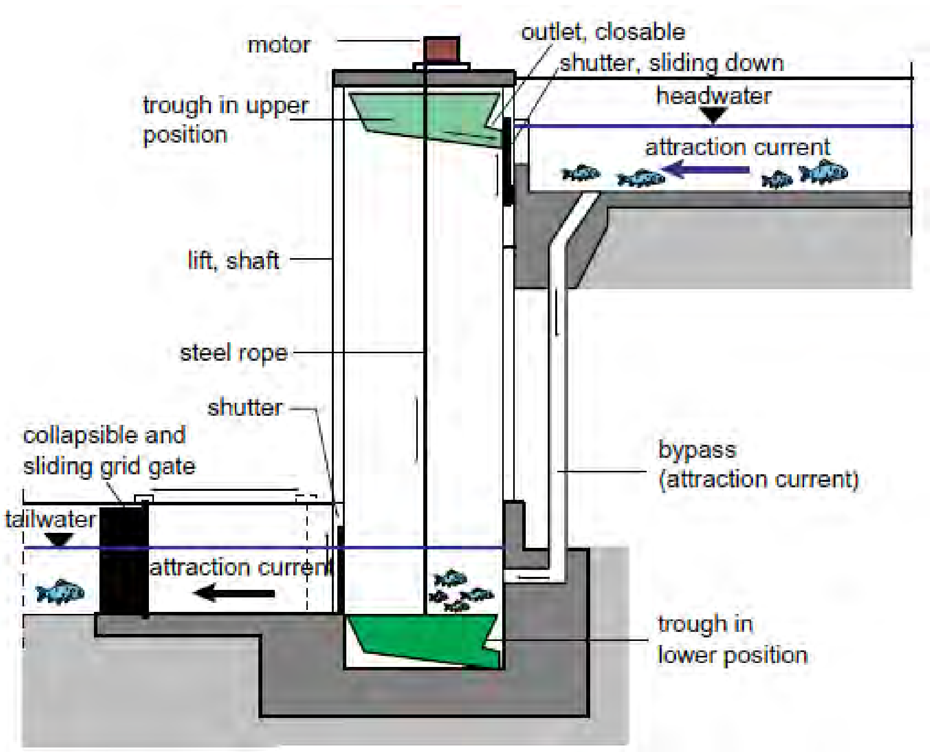


Figure 2.18 Schematic view of the structure of a fish lift (DVWK, 1996)

Overall Assessment:

- Little space is needed for such fish lifts designed to overcome remarkable height differences. Nevertheless, the structural expenditure might be a problem.
- Fish lifts are appropriate for fish with low performance and big fish because the fish are carried upstream passively.
- Fish lifts are not suitable for the upstream migration of invertebrates and the downstream migration of fish.
- An adequate current might not be provided considering large difference in the tailwater.
- This type of fish lifts is more expensive to construct than traditional fish passes types

CHAPTER 3

CASE STUDY

3.1 Project Area: Uzungöl

Being an example of a set silt lake, Uzungöl (Figure 3.1) is located at an altitude of 1090 meters above the sea level. Located between Soğanlı and Kaçkar Mountain Ranges which are known as the rainforests of Turkey, Uzungöl houses more than 60 endemic plant species.

Figure 3.1 A view of Uzungöl

This area gets plenty of rainfall every month of the year with rain in summer and snow in winter, resulting in an evergreen environment. Uzungöl is an example of a natural beauty and protected as a nature park.

Figure 3.2 The weir at the most downstream of the cascade system (Uzungöl Weir-1)

The most important problem of Uzungöl is filling up with sediment which comes with rivers. To protect the lake from the risk of sedimentation, cascade weirs were built at the upstream of Uzungöl, Solaklı River as can be seen in Figure 3.2 which shows the weir at the most downstream of the cascade system. At the reservoir of the weirs, sediments are trapped and purged away from the reservoir periodically. Nevertheless, in time, these weirs block the migration path of fish, and fish cannot reach the spawning area. Therefore, this situation causes the decrease of the number of critically endangered fish species which live in rivers in Black Sea region such as Brown trout. The purpose of this study is to design a fish pass for target species (Brown trout) to pass over the obstructions so that the negative effect of the weir will be eliminated. At the end of the study, the optimal fish pass design will be suggested for Uzungöl Weir-1 at the most downstream of the cascade system in Figure 3.2.

3.2 Criteria for Designing the Fish Pass

3.2.1 Target Species: Brown Trout

Salmonidae family encompasses a large group of fish which can be divided into the categories of *Coregonus*, *Hucho*, *Oncorhynchus*, *Prosofium*, *Salmo*, *Salvelinus*, *Stenodus* and *Thymallus*. Within these groups of fish, *Salmo* is a genus of fish including several kinds: *Salmo salar*, *Salmo ischchan*, *Salmo letnica*, *Salmo penshinensis*, *Salmo platycephalus* and *Salmo trutta* which is known as brown trout. Regarding their life styles, brown trout has been divided into categories of *Salmo Trutta Fraio* (*dere alabalığı*), *Salmo Trutta Lacustris* (*göl alabalığı*) and *Salmo Trutta Labrax* (*deniz formu*) (Ryman, 1983; Hindar et al., 1991) and many subcategories have been determined. The subspecies of brown trout are listed in Table 3.1.

Table 3.1 Subspecies that reported by investigators

Salmo trutta fario Linnaeus, 1758	*Dere Alabalığı*
Salmo trutta macrostigma Dumeril, 1858	*Anadolu Alabalığı*
Salmo trutta labrax Pallas, 1811	*Karadeniz Alabalığı*
Salmo trutta caspius Kessler, 1877	*Aras Alabalığı*
Salmo trutta abanticus Tortonese, 1954	*Abant Alabalığı*
Salmo trutta lacustris Linnaeus	*Göl Alabalığı*
Salmo trutta dentex Heckel, 1851	
Salmo trutta marmoratus Cuvier, 1817	
Salmo trutta letnica Karaman, 1924	
Salmo trutta aralensis Berg, 1908	
Salmo trutta trutta Linnaeus, 1758	
Salmo trutta carpio Linnaeus, 1758	

Brown trout is one of the most known fish types in the world. Compared to other fish species, they live in a wide range of geographical locations and can resist difficult living conditions.

The range of brown trout is mainly European and it extends from the north of Norway to northeast Russia and to Atlas mountains in North Africa. It has been claimed that its natural distribution and types were the results of Ice Age in Europe.

When it comes to its distribution in Turkey, it is a kind of fish that can be naturally found in our country. Figure 3.3 presents its five defined types and their distribution in our country. Furthermore, in Uzungöl region, three types of brown trout live which are *Salmo Trutta Labrax* (*Karadeniz alabalığı*), *Salmo trutta fario* (*Dere alabalığı*) and *Salmo Trutta Macrostigma* (*Anadolu alabalığı*).

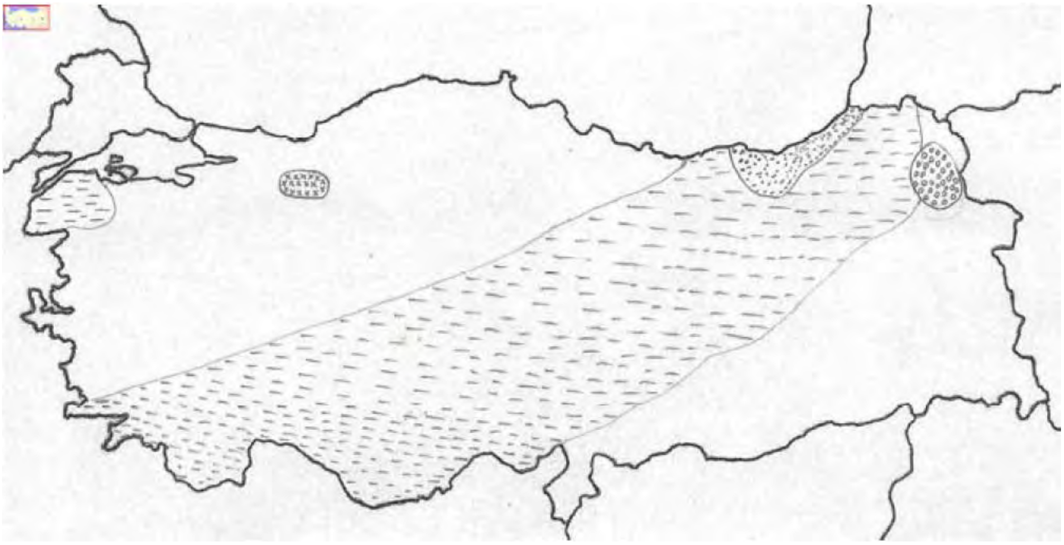


Figure 3.3 Distribution of brown trout in Turkey (Dotted hatched area: *Karadeniz alabalığı* and *dere alabalığı*; Round hatched area: *Aras alabalığı*; Stripped hatched area: *Anadolu alabalığı*; cross hatched area: *Abant alabalığı*) (Kocabas, 2009)

a) *Salmo Trutta Labrax (Karadeniz Alabalığı)*

They can be distinguished from other types of Salmo with a black mark on their gill cover, irregular black dots on their whole bodies and clear/ apparent/ distinct white circles around red spots (Demirsoy, 1988). Their form is given in Figure 3.4.

Figure 3.4 *Salmo Trutta Labrax* (Kocabas, 2009)

They spend most of their life time, especially their feeding period in seas. They mature and grow there. They migrate to freshwater during their breeding period. In the Black Sea, their length can reach 100 cm and their weight up to 26 kg. their distinguishing feature is that their adults return to waters that they spawn in. Influenced by their breeding styles, these ecotypes migrate between the sea and freshwater, resulting in being named as nation marina (Svetovidov, 1984; Geldiay et al., 1996). During the winter time, they travel to freshwater flowing to the Black Sea and leave their eggs in sand in the upper sides of rivers or holes that they dig in pebbles. Their babies can live up to one year in freshwater and then migrate to seas (Tabak et al., 2001). While their males mature at the ages of 2 and 3, females grow fully at the ages of 3 and 4.

b) *Salmo trutta fario (Dere Alabalığı)*

Their living habitat ranges from slopes to fast-flowing streams and the bottom sides of mountainous areas. Their average weight differs from 2.3 to 3.2 kg. Compared to the other types of *Salmo Trutta*, they are smaller and their skin color can change in different parts of their bodies. Their most distinctive characteristic is that red spots on their bodies remain throughout their lives (Slastenenko, 1956; Geldiay et al., 1996; Tabak, 2001). They have less red and black spots on their bodies as well. These spots are placed on their two sides and their gill covers have lots of small spots. Their form is given in Figure 3.5.

Figure 3.5 *Salmo trutta fario* (Kocabas, 2009)

c) Salmo Trutta Macrostigma (*Anadolu Alabalığı)*

Having a large natural distribution in our country, it can be commonly encountered in water sources of all parts of our country. Compared to other ecotypes, it prefers living in upper parts of water resources where water flows fast and in upper parts of mountainous areas. It is commonly observed in areas whose elevation from the sea is between 100- 2300 meter and whose water temperate can rise up to 20 °C. It generally prefers gravelly grounds, cool waters (12-19 °C) and areas near water resources (Balık, 1988; Geldiay et al., 1996; Aras et al., 1997; Teufel et al., 2002). It is claimed to grow up to 35-40 cm in length and 3 kg in weight (Behnke, 1968; Geldiay et al., 1996).

Its body is in the shape of a shuttle, covered with cycloid scales and it has a jaw inside the mouth and teeth in the palate. It has 115-119 scales on its sides and its body color is adapted to its environment, usually in light colors. According to morphological, systematical and phylogenetic researches, its most distinctive characteristics are its large and clear post- orbital spot, less vertebrae and more intense red spots surrounded by white circles. Its form is given in Figure 3.6.

Figure 3.6 *Salmo Trutta Macrostigma* (Kocabas, 2009)

As a result of this information about the target species, the burst speed can be calculated. The burst speed is important while designing fish pass since fish can pass the slots with burst speed. As described in Section 2.1.4 in detail, the maximum traveling speed can be found by using Equation 2.1 or Figure 2.1 according to their length or by using Table 2.1 according to their types. The average temperature of the river can be taken 15°C, since fish live between 12-19°C; furthermore, the average fish length is taken as 30 cm. Thus, the burst speed of the target species is found as 2.6 m/s by using Equation 2.1 and higher than 3.0 m/s by using Figure 2.1. Moreover, the closest species to brown trout is rainbow trout in Table 2.1, and their swimming speed is between 0.26 and 2.70 m/s. To be on the safe side, the burst speed of the target species can be assumed as 2.60 m/s.

3.2.2 Determination of Fish Pass Type

While deciding fish pass type, the first trial should be close-to-nature types since; they imitate slope, morphology and hydraulic conditions of the stream as much as possible and ecological point of view, it offers the best solution as stated in Section 2.3.1. However, as can be seen in Figure 3.2, at the right bank of the weir, there is a very steep mountain and at the left bank, there is a road; so that, there is no space to construct a close to nature type fish pass. Furthermore, there is at least six meters of water head to overcome which it needs a great length and surface area.

If it is not possible to construct close to nature type, technical fish pass will be tried. As advantages stated at the end of vertical slot passes section, vertical slot passes present a lot of advantage while compared with the other technical fish pass types. If the vertical slot passes cannot be constructed, then the other types of the technical passes should be evaluated. Therefore, vertical slot passes were chosen for this study.

At the beginning of the hydraulic calculations, it is necessary to know minimum and maximum operating discharge and corresponding water levels at the reservoir. As stated in vertical slot passes section, during determination of the minimum water level, the discharge which is below 30 days in a year (Q_{30}) can be used and for the maximum water level, the discharge which is below 330 days in a year (Q_{330}) can be used.

3.2.3 Hydrology of Solaklı River

At downstream of Uzungöl, there is a stream flow station 22-07 Haldizen installed by DSI, whose elevation is 1116 meters and coordinates are X: 609060 (m) and Y: 4497459 (m). The monthly average discharge values at this station are listed between years 1982 and 2007 in Table 3.2. With using historical flow data measured at 22-07 Haldizen station, natural streamflows into the weir reservoir is calculated with the following formulae.

$$Q_{Uzungöl} = \left(\frac{A_{Uzungöl}}{A_{22-07}}\right) \times Q_{22-07} \tag{3- 1}$$

The drainage area of 22-07 Haldizen station ($A_{22\text{-}07}$) is 154.7 km^2 and the drainage area of the weir ($A_{Uzungöl}$) is 137.7 km^2. Then, average daily discharges are sorted from minimum to maximum as shown in Figure 3.7 and Figure 3.8 for 22-07 Haldizen and Uzungöl respectively; so that, the minimum and maximum discharge can be found which will be used in designing the fish pass at this location as Q_{30}=0.88 m^3/s and Q_{330}=9.84 m^3/s.

Table 3.2 Haldizen Streamgage observed monthly average discharge at (m3/s)

Year/Month	10	11	12	1	2	3	4	5	6	7	8	9	Average
1982	1.74	1.81	1.47	1.25	1.02	1.81	9.81	11.46	8.56	4.27	1.84	1.40	3.87
1983	1.08	1.22	0.97	0.82	0.95	2.21	5.01	12.42	7.88	3.05	1.56	1.68	3.24
1984	2.43	3.61	1.52	0.79	0.36	1.18	3.22	10.66	9.80	5.58	2.44	1.78	3.61
1985	0.82	0.92	0.90	0.69	0.71	1.11	5.35	11.53	7.19	2.48	1.39	0.96	2.84
1986	2.38	2.00	1.59	1.24	1.46	1.98	5.92	9.23	15.48	6.65	2.01	1.25	4.27
1987	1.65	2.03	1.55	1.57	1.75	1.50	4.52	13.68	11.86	5.97	3.49	1.76	4.28
1988	1.64	2.51	1.56	1.31	1.46	2.35	7.34	14.05	17.60	11.46	5.48	3.05	5.82
1989	4.68	4.29	2.73	1.38	1.49	4.75	14.23	12.55	12.33	5.70	2.24	1.28	5.64
1990	3.28	1.94	1.94	1.10	1.16	2.91	8.99	17.73	13.69	6.64	2.37	1.38	5.26
1991	1.96	3.32	1.63	1.09	1.11	3.23	8.10	12.93	12.30	5.55	2.28	1.18	4.56
1992	1.70	2.15	1.28	1.01	0.98	2.05	6.89	14.85	17.49	7.31	3.30	2.09	5.09
1993	3.53	2.71	1.90	1.38	1.32	2.47	8.35	17.48	17.19	7.77	3.15	1.44	5.72
1994	0.84	1.28	1.40	1.03	1.01	1.98	20.16	12.22	7.28	4.34	2.14	1.29	4.58
1995	1.72	1.83	2.40	2.04	1.87	2.92	6.05	7.50	5.48	4.01	2.16	2.47	3.37
1996	4.14	4.48	2.28	1.57	1.20	1.20	3.41	12.24	8.27	4.81	2.21	2.05	3.99
1997	4.32	2.58	1.77	1.48	1.35	1.55	7.86	13.83	9.82	5.21	2.15	2.22	4.51
1998	3.46	2.80	1.49	1.99	2.71	3.60	6.37	7.70	4.45	2.00	2.44	1.40	3.37
1999	1.31	1.41	2.22	0.83	0.81	1.45	4.66	11.69	9.72	5.03	2.02	1.43	3.55
2000	0.91	1.35	1.47	0.96	0.99	1.60	7.81	6.21	6.44	2.19	1.34	1.10	2.70
2001	2.82	1.57	0.97	0.87	0.88	3.13	5.75	8.87	8.84	3.67	1.26	0.94	3.30
2002	1.24	1.35	0.89	0.85	1.34	2.18	5.37	9.08	14.13	6.83	2.06	2.08	3.95
2003	2.06	1.59	1.12	1.20	0.89	0.91	6.73	10.24	6.88	3.09	2.61	2.93	3.35
2004	2.10	3.24	1.61	1.15	1.30	4.44	5.43	12.68	12.58	5.17	2.18	2.26	4.51
2005	1.36	1.29	1.26	1.30	0.98	1.90	9.01	14.89	12.30	7.88	3.26	2.51	4.83
2006	5.16	4.92	2.63	1.11	1.17	2.65	6.83	11.86	8.27	4.01	1.24	0.56	4.20
2007	1.85	4.25	0.93	0.96	1.20	3.48	2.25	23.34	9.43	3.73	1.49	1.39	4.53
Average	2.31	2.40	1.60	1.19	1.21	2.33	7.13	12.34	10.59	5.17	2.31	1.69	4.19

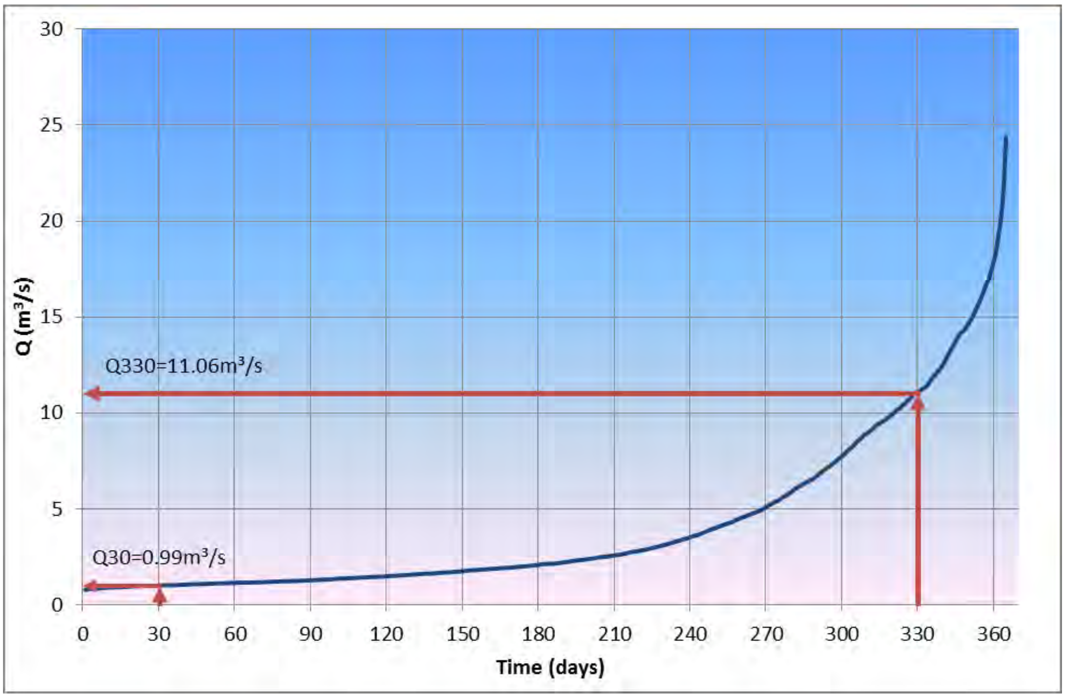


Figure 3.7 Discharge rating curve of 22-07 Haldizen Station

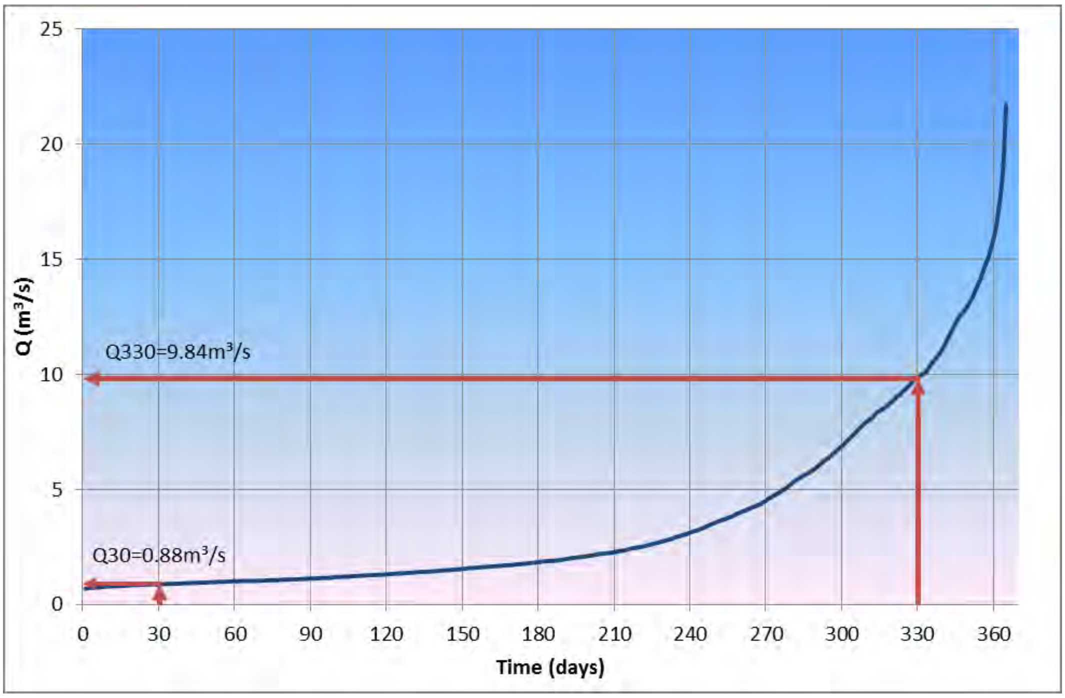


Figure 3.8 Discharge rating curve of Uzungöl

3.2.4 Determination of Dimensions for Cross-walls of the Slot Pass

The first step of the design will be determination of dimensions of the fish pass. With using dimensioning system suggested by DVWK (1996) according to targeted species in Section 2.2.1, the first design is generated as given in Figure 3.9 and it will be called as "Type I" from this point on, throughout the text. All dimensions are taken from Table 2.2 in Brown Trout column, the only difference is the pool width. To decrease the volumetric power dissipation value, it is chosen as 1.40 meters instead of 1.20 meters.

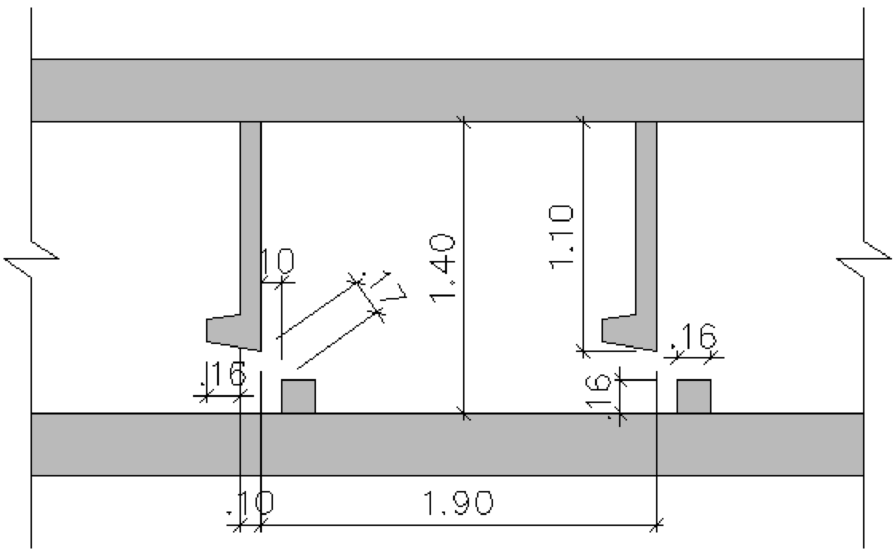


Figure 3.9 The dimensions of "Type I" in meter

In the analyses, different dimensions for hook-shaped projection and sill will be used to see the effects on main current, velocity and the other flow characteristics. Therefore, with using Katopodis (1992) suggestion for hook-shaped projection and sill details which are given in Figure 2.11 (see baffle details for designs #1& #2 in the figure), new type of fish pass is generated as can be seen in Figure 3.10 which will be called as "Type II". In the design of "Type II", 45° angle is used for the slot as suggested. After that, a modified design of "Type II" is generated with using 30° angle for the slot as shown in Figure 3.11 and it will be called as "Type III". At the end of the analyses, the best alternative will be suggested.

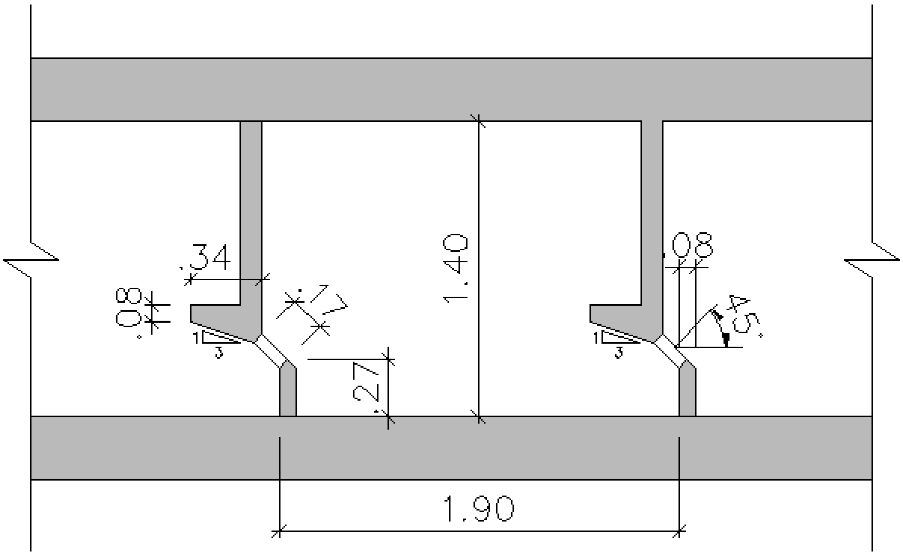


Figure 3.10 The dimensions of "Type II" in meter

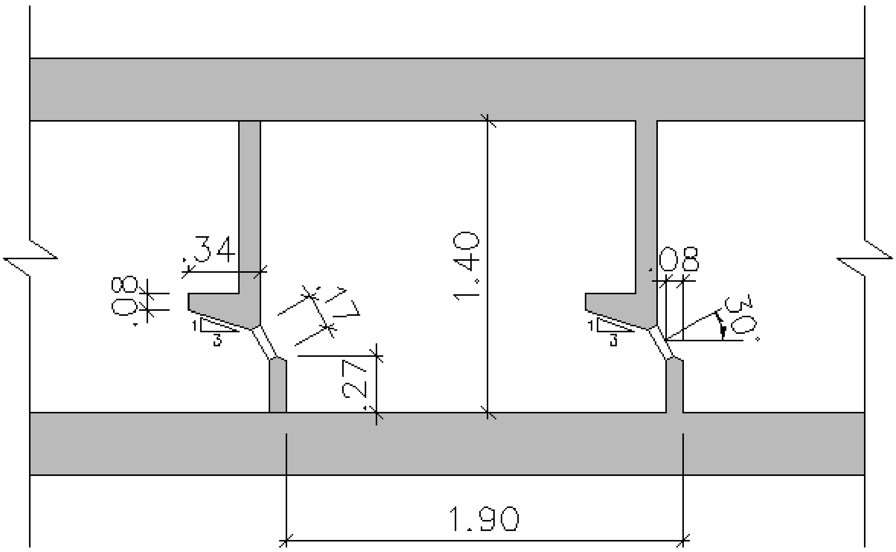


Figure 3.11 The dimensions of "Type III" in meter

3.3 CFD Analyses

In the analyses of the hydraulic characteristics in the fish passes, three different types of fish passes will be modeled numerically using Flow 3D, which is a widely used computational fluid dynamics (CFD) software. All 3D solid models are prepared using Autocad and exported as stl files which are then imported into Flow 3D.

3.3.1 General Description of FLOW 3D

Flow-3D can be described as an influential computational fluid dynamics code, dealing with the Navier Stokes Equations. Analyzing complicated fluid problems, Flow- 3D utilizes definite volume approximations of the energy, mass and momentum equations. It also has different versions designed for moving rigid bodies, sediment transport and flows at porous media.

Since free-surfaces often turn out to be problematic, many computer programs have been designed to handle them. Flow- 3D makes use of Volume of Fluid (VOF) technique, first noted by Hirt et al. (1975) and by Hirt and Nichols (1981). VOF is quite powerful in tracking sharp interfaces. While gas and liquid usually engage in independent movements, the interface creates a thin viscous boundary layer. It is possible to solve only the water phase together with the interface in Flow 3D which is computationally less expensive than solving a second set of equations for the air phase as well.

3.3.2 Determination of Stage-Discharge Relationship of the Weir

To determine the water level at the upstream of the weir, it is necessary to define the stage-discharge formula of the weir. While determining bottom elevation of the passes, this formula will be used. Geometric details of the weir is given as technical drawings in the Appendix. Using these drawings, 3D model of the weir is prepared and imported to Flow 3D. To decrease analyses time, half of the weir is modeled and symmetry boundary condition of Flow 3D is used at the centerline of the weir. One mesh block is enough to solve the model and mesh size is chosen as 0.05 meter. The mesh block extends 5 meters upstream and 5 meters downstream of the weir and a baffle is defined as flux surface at the middle of the weir to record the discharge (Figure 3.12). Discharges at seven different water elevations are simulated and calculated beginning from the top level of the spillway (1142.77 m). The water levels and corresponding discharges are listed in Table 3.3 from which a stage-discharge curve is obtained (Figure 3.13).

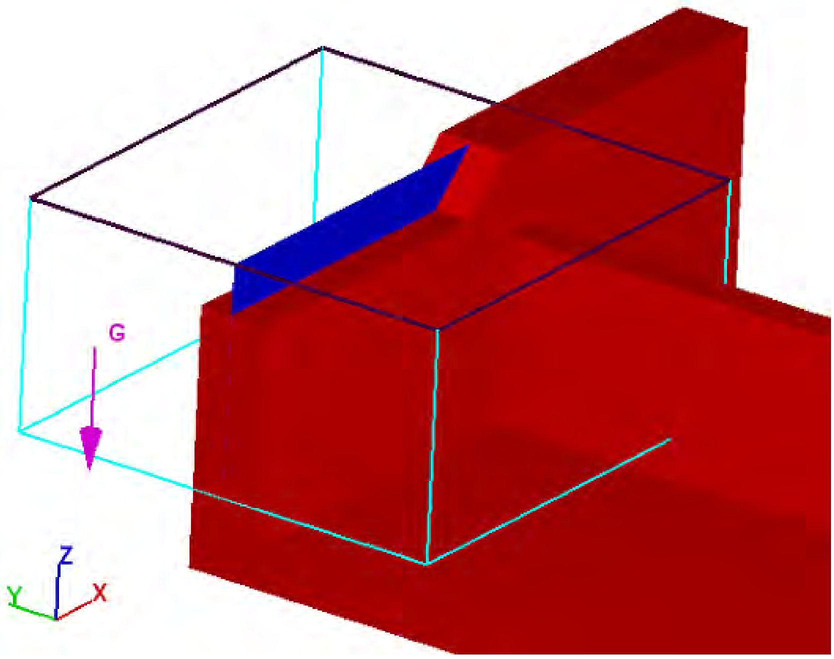


Figure 3.12 Computational domain of the weir

Table 3.3 Stage-Discharge relationship for the weir

Water Head (m)	1142.80	1142.90	1143.00	1143.10	1143.20	1143.26	1143.30
Calculated Discharge (m^3/s)	0.16	1.22	3.04	5.20	7.70	9.42	10.60

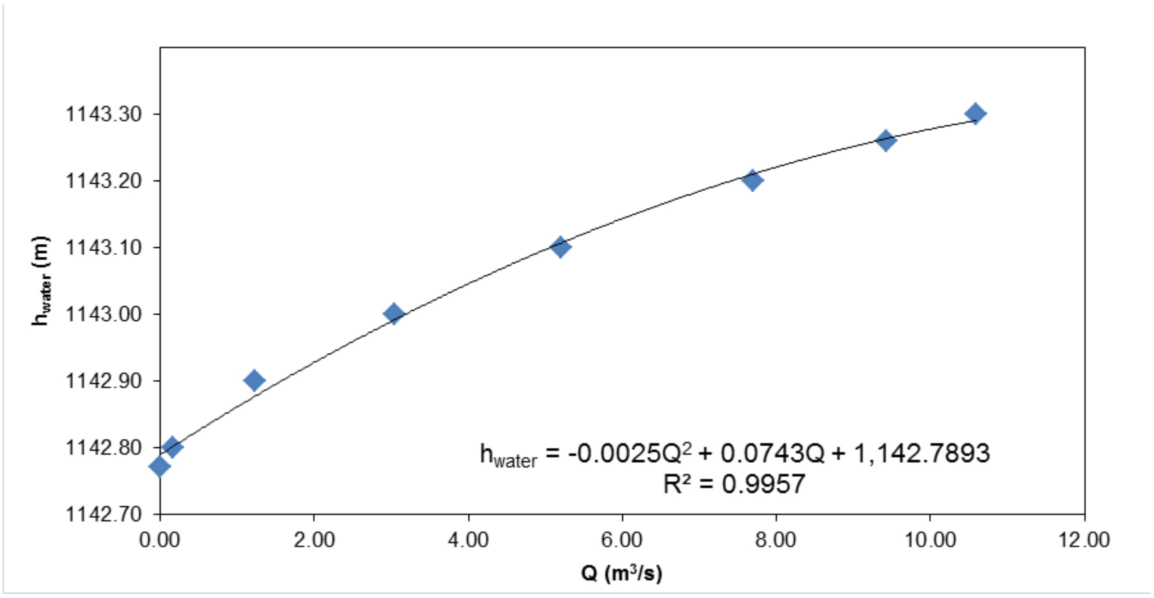


Figure 3.13 Stage - Discharge curve for the weir

3.3.3 Preliminary Hydraulic Calculations

Herein, Q_{30} and Q_{330}, stage-discharge curve and formula for the weir are known and 3 different types of fish passes are generated according to the target species, so the internal dimensions of the fish passes are found. However, the general dimensions which are slope, number of pools, upstream and downstream bottom elevations are not decided at this point. Therefore, before the hydraulic condition are monitored in the fish pass in detail with CFD analyses, preliminary calculations are done with using the given formula in Section 2.3.2 and general dimensions are defined by satisfying the conditions discussed in Section 2.3.2.

The conditions to be satisfied are:

- The maximum water level difference should be lower than 0.20 meter (Table 2.2).
- The critical water level at the entrance and exit of the fish pass as shown in Figure 2.13 should not be lower than 0.50 m.
- Volumetric dissipated power should be lower than 200 watts/m^3 (Eq 2-3).

- Since at this stage the maximum velocity can be calculated by using equation 2-5, the maximum velocity should be lower than 2.0 m/s suggested by DVWK (1996) for brown trout instead of the burst speed of the target species.

The problem is that while satisfying these conditions, the discharge in the fish pass changes with the change in slope; therefore, it causes a change in the upstream water level especially in the minimum flow case. For this reason, the upstream water level is calculated iteratively in which the discharge passing from the weir is calculated by using the formula given in Figure 3.13 and the discharge passing from the fish pass is calculated with the process described in Section 2.3.2.

Before giving how to find the general dimensions, after several iterations, it is seen that, for the minimum flow case, when the upstream water level is 1142.84 meters, the total discharge found by using procedure given in previous paragraph gives Q_{30}.

$$Q_{30} = Q_{30,fishpass} + Q_{30,weir} = 0.20 + 0.68 = 0.88\ m^3/s \tag{3-2}$$

where, $Q_{30,fishpass}$ is the discharge passing through the fish pass at minimum flow conditions whereas $Q_{30,weir}$ is the discharge passing through the weir at minimum flow conditions. After that with using same procedure, the upstream water level for the maximum flow case is found as 1143.26 m. The discharge in the fish pass will be almost 0.35 m^3/s and the discharge over the weir will be 9.42 m^3/s. Therefore, it is seen that the maximum upstream water level with 1143.26 m. is very close to the discharge value found as Q_{330} in Section 3.2.3, 1143.26 m. can be assumed for the maximum flow case.

$$Q_{330} = Q_{330,fishpass} + Q_{330,weir} = 0.35 + 9.42 = 9.77\ m^3/s \tag{3-3}$$

where, $Q_{330,fishpass}$ is the discharge passing through the fish pass at maximum flow conditions whereas $Q_{330,weir}$ is the discharge passing through the weir at maximum flow conditions. Downstream water levels are calculated as 1137.24 m and 1137.43 m for the minimum and maximum flow cases, respectively. The maximum head difference between upstream and downstream occurs at maximum flow case being h_{dif} = 1143.26 – 1137.43 = 5.83 meters and the permissible water level difference is Δh = 0.2 meter as given in Table 2.2. Then, the number of the pools, n, can be found from equation (2-4);

$$n = \frac{h_{diff}}{\Delta h} - 1 = \frac{5.83}{0.2} - 1 = 28.15 \cong 29\, pools \tag{3-4}$$

However, providing optimal position of the fish pass entrance and minimum slope, 31 pools are created. Therefore, the length of the fish pass is 58.90 meters and the slope is I = 1:10.65. With this number of pools, the water level difference in each pool will be Δh = 5.83 / 31 = 0.188 meter. Thus, the maximum velocity at the slot can be approximately calculated as follow;

$$V_{max} = \sqrt{2g\Delta h} = \sqrt{2 \times 9.81 \times 0.188} = 1.92\, m/s \tag{3-5}$$

As show in Figure 2.13 the minimum water level at the upstream and downstream of the fish pass should be at least 0.50 meters. As a result of preliminary hydraulic calculation, it is found that, the minimum upstream water level is 0.56 m. and the minimum downstream water level is 0.66 m. The sketch of the entrance and the exit of the fish pass are given in Figure 3.14 and Figure 3.15.

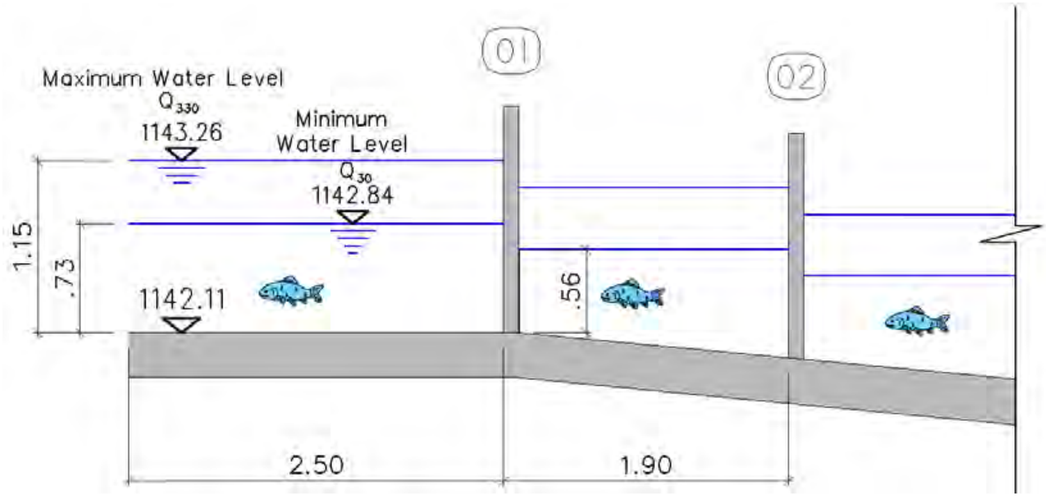


Figure 3.14 The sketch of the exit of the fish pass

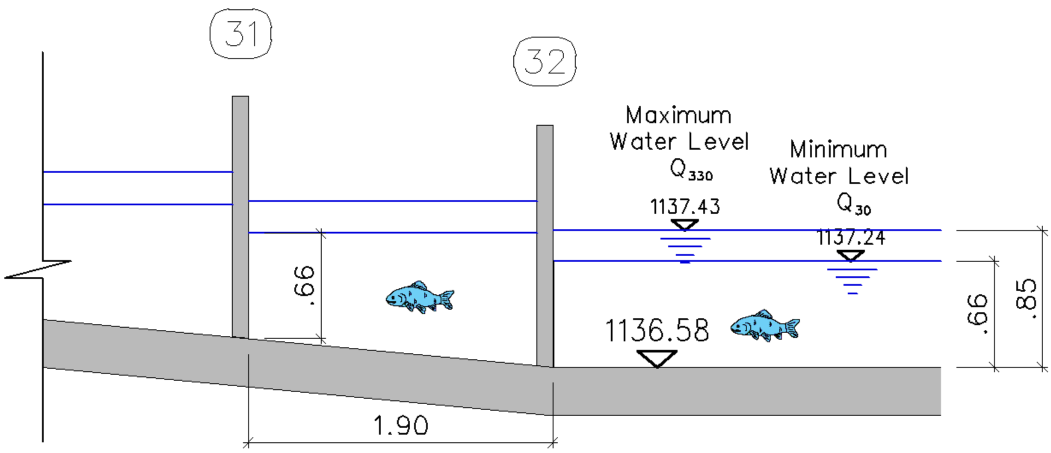


Figure 3.15 The sketch of the entrance of the fish pass

In Table 3.4 and Table 3.5, the flow characteristics are summarized for each pool for the minimum flow case and maximum flow case, respectively. Firstly, numbers are given to cross-walls starting from upstream; then, the elevation of the bottom of each cross-wall is given in the second column. By using Δh, water level at the upstream of the each cross-wall is calculated and given in the third column. To find the discharge, h_u and h_0 are found then by using Figure 2.14 μ_r is calculated. Finally, the discharge and the volumetric power dissipation which is lower than 200 watts/m^3 for each pool at minimum and maximum flow cases are listed at the end of the columns by using Equations 2-6 and 2-3 respectively.

Table 3.4 The flow characteristics for each pool for minimum flow case

Cross-wall no.	Elevation of the bottom above sea level (m)	Water level in the pool (m)	h_o (m)	h_u (m)	Δh (m)	V_s (m/s)	h_u / h_0	μ_r (from the Figure 15)	E (watts / m^3)
2	1141.93	1142.67	0.73	0.56	0.17	1.85	0.76	0.50	166.71
3	1141.75	1142.49	0.74	0.56	0.17	1.85	0.76	0.50	166.99
4	1141.57	1142.32	0.74	0.56	0.17	1.85	0.76	0.50	167.27
5	1141.40	1142.14	0.74	0.57	0.17	1.85	0.76	0.50	167.55
6	1141.22	1141.97	0.75	0.57	0.17	1.85	0.76	0.50	167.82
7	1141.04	1141.79	0.75	0.57	0.17	1.85	0.76	0.50	168.10
8	1140.86	1141.62	0.75	0.58	0.17	1.85	0.76	0.50	168.38
9	1140.68	1141.44	0.76	0.58	0.17	1.85	0.76	0.50	168.65
10	1140.50	1141.27	0.76	0.58	0.17	1.85	0.77	0.50	168.93
11	1140.33	1141.09	0.76	0.59	0.17	1.85	0.77	0.50	169.21
12	1140.15	1140.92	0.77	0.59	0.17	1.85	0.77	0.50	169.48
13	1139.97	1140.74	0.77	0.59	0.17	1.85	0.77	0.50	169.76
14	1139.79	1140.57	0.77	0.60	0.17	1.85	0.77	0.50	170.03
15	1139.61	1140.39	0.78	0.60	0.17	1.85	0.77	0.50	170.31
16	1139.43	1140.22	0.78	0.60	0.17	1.85	0.77	0.50	170.58
17	1139.26	1140.04	0.78	0.61	0.17	1.85	0.77	0.50	170.86
18	1139.08	1139.87	0.79	0.61	0.17	1.85	0.77	0.50	171.13
19	1138.90	1139.69	0.79	0.61	0.17	1.85	0.77	0.50	171.41
20	1138.72	1139.52	0.79	0.62	0.17	1.85	0.78	0.50	171.68
21	1138.54	1139.34	0.80	0.62	0.17	1.85	0.78	0.50	171.95
22	1138.36	1139.17	0.80	0.62	0.17	1.85	0.78	0.50	172.23
23	1138.19	1138.99	0.80	0.63	0.17	1.85	0.78	0.50	172.50
24	1138.01	1138.82	0.81	0.63	0.17	1.85	0.78	0.50	172.77
25	1137.83	1138.64	0.81	0.63	0.17	1.85	0.78	0.50	173.04
26	1137.65	1138.47	0.81	0.64	0.17	1.85	0.78	0.50	173.31
27	1137.47	1138.29	0.82	0.64	0.17	1.85	0.78	0.50	173.59
28	1137.29	1138.12	0.82	0.64	0.17	1.85	0.78	0.50	173.86
29	1137.12	1137.94	0.82	0.65	0.17	1.85	0.78	0.50	174.13
30	1136.94	1137.77	0.83	0.65	0.17	1.85	0.78	0.50	174.40
31	1136.76	1137.59	0.83	0.65	0.17	1.85	0.79	0.50	174.67
32	1136.58	1137.42	0.84	0.66	0.17	1.85	0.79	0.50	174.94

Table 3.5 The flow characteristics for each pool for maximum flow case

Cross-wall no.	Elevation of the bottom above sea level (m)	Water level in the pool (m)	h_o (m)	h_u (m)	Δh (m)	V_s (m/s)	h_u / h_0	μ_r (from the Figure 15)	E (watts / m^3)
2	1141.93	1143.08	1.15	0.97	0.18	1.89	0.84	0.45	186.00
3	1141.75	1142.90	1.14	0.96	0.18	1.89	0.84	0.45	185.75
4	1141.57	1142.71	1.14	0.96	0.18	1.89	0.84	0.45	185.49
5	1141.40	1142.53	1.13	0.96	0.18	1.89	0.84	0.45	185.23
6	1141.22	1142.35	1.13	0.95	0.18	1.89	0.84	0.45	184.98
7	1141.04	1142.17	1.13	0.95	0.18	1.89	0.84	0.45	184.72
8	1140.86	1141.98	1.12	0.95	0.18	1.89	0.84	0.45	184.46
9	1140.68	1141.80	1.12	0.94	0.18	1.89	0.84	0.45	184.20
10	1140.50	1141.62	1.12	0.94	0.18	1.89	0.84	0.45	183.94
11	1140.33	1141.44	1.11	0.93	0.18	1.89	0.84	0.45	183.68
12	1140.15	1141.26	1.11	0.93	0.18	1.89	0.84	0.45	183.42
13	1139.97	1141.07	1.10	0.93	0.18	1.89	0.84	0.45	183.16
14	1139.79	1140.89	1.10	0.92	0.18	1.89	0.84	0.45	182.90
15	1139.61	1140.71	1.10	0.92	0.18	1.89	0.84	0.45	182.64
16	1139.43	1140.53	1.09	0.91	0.18	1.89	0.84	0.45	182.38
17	1139.26	1140.35	1.09	0.91	0.18	1.89	0.84	0.45	182.12
18	1139.08	1140.16	1.09	0.91	0.18	1.89	0.84	0.45	181.86
19	1138.90	1139.98	1.08	0.90	0.18	1.89	0.84	0.45	181.60
20	1138.72	1139.80	1.08	0.90	0.18	1.89	0.83	0.45	181.34
21	1138.54	1139.62	1.07	0.90	0.18	1.89	0.83	0.45	181.08
22	1138.36	1139.43	1.07	0.89	0.18	1.89	0.83	0.45	180.81
23	1138.19	1139.25	1.07	0.89	0.18	1.89	0.83	0.45	180.55
24	1138.01	1139.07	1.06	0.88	0.18	1.89	0.83	0.45	180.29
25	1137.83	1138.89	1.06	0.88	0.18	1.89	0.83	0.45	180.02
26	1137.65	1138.71	1.05	0.88	0.18	1.89	0.83	0.45	179.76
27	1137.47	1138.52	1.05	0.87	0.18	1.89	0.83	0.45	179.50
28	1137.29	1138.34	1.05	0.87	0.18	1.89	0.83	0.45	179.23
29	1137.12	1138.16	1.04	0.87	0.18	1.89	0.83	0.45	178.97
30	1136.94	1137.98	1.04	0.86	0.18	1.89	0.83	0.45	178.70
31	1136.76	1137.79	1.04	0.86	0.18	1.89	0.83	0.45	178.44
32	1136.58	1137.61	1.03	0.85	0.18	1.89	0.83	0.45	178.17

3.3.4 Preparation of CFD Analyses of the Fish Pass

To be used in CFD analyses, 3D solid model of Uzungöl Weir-1 is prepared using Autocad which is composed of reservoir topography, the weir, the fish pass at the right bank of the weir and downstream part of the river as shown in Figure 3.16. Solving this large model requires special hardware (with high speed processors and high capacity memory) and lots of time, during the design process. To save time, a separate 3D model of the fish pass is used which is composed of three ladders as shown in Figure 3.17.

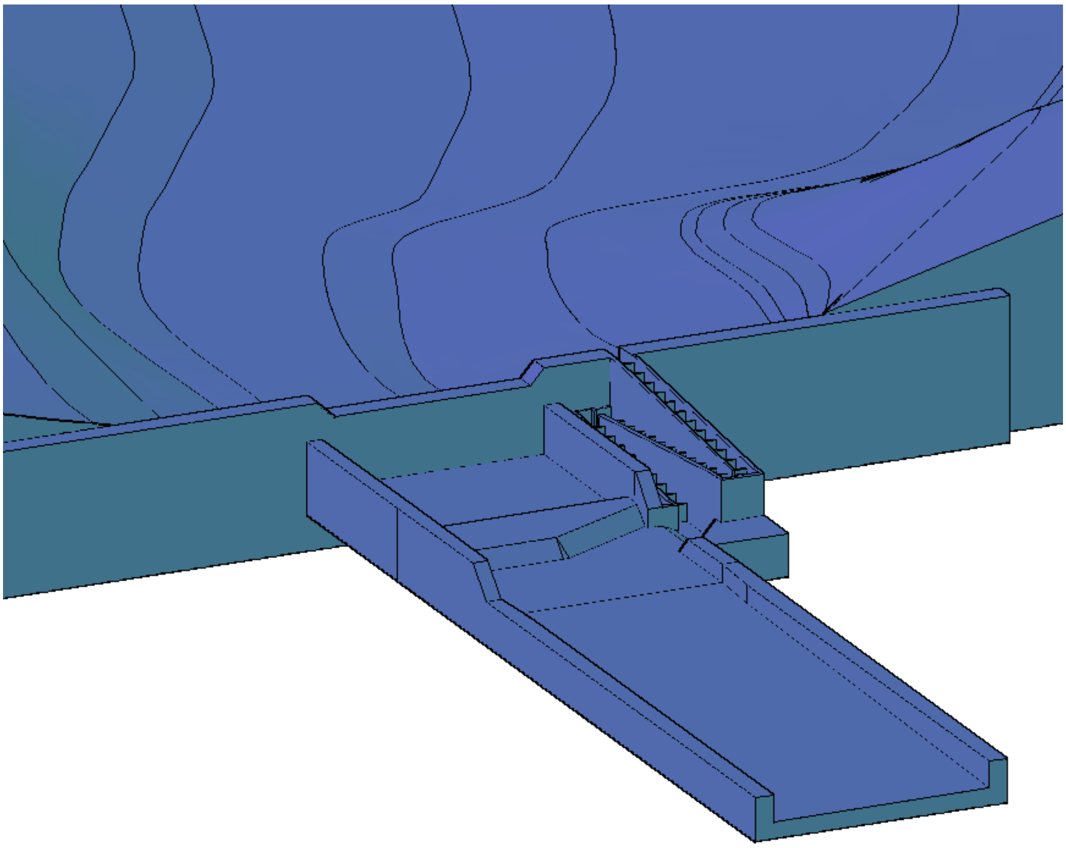


Figure 3.16 3D model of Uzungöl Weir-1

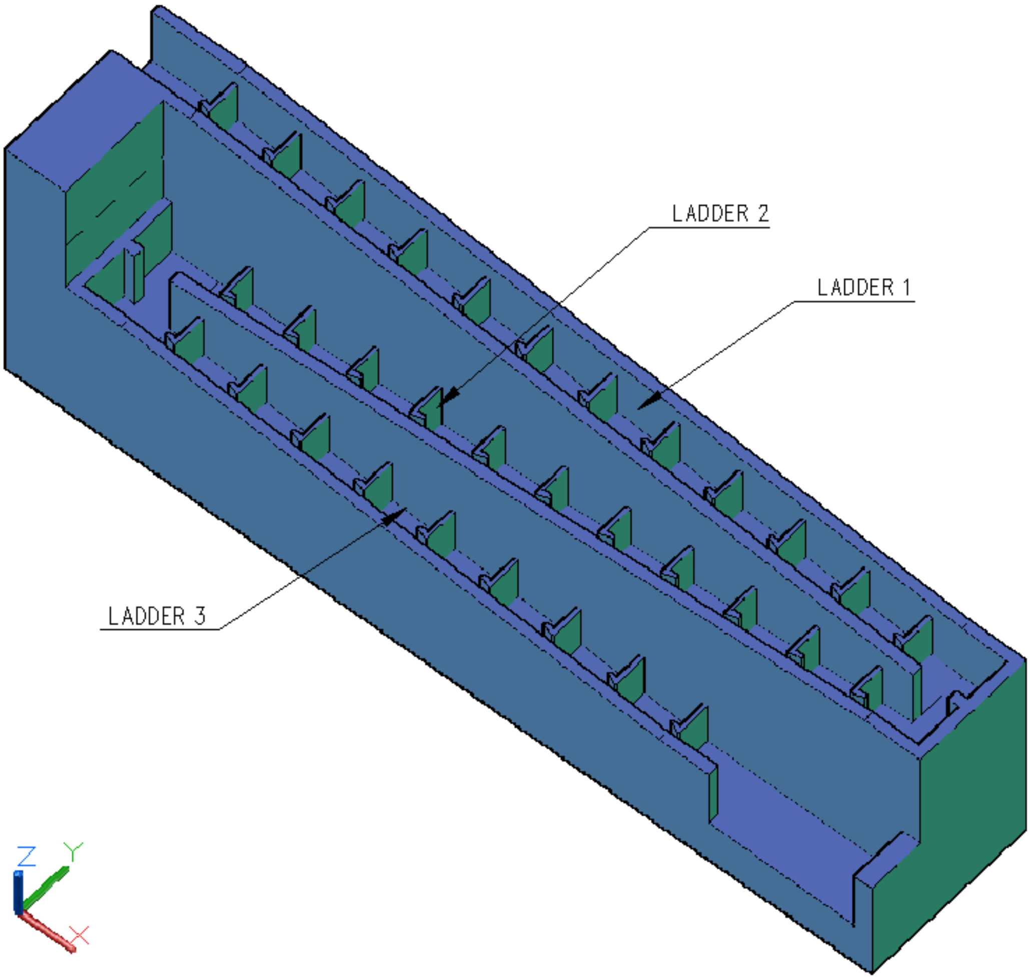


Figure 3.17 3D model of the fish pass

The first step of the analyses is to determine the appropriate cell size in the mesh. Determination of accurate cell size is a very critical issue, because inadequate grid resolution can cause misleading results. On the other hand, too fine grid resolution causes time loss and ends up with larger output files. Mesh independency studies start with using mesh from courser to finer until the results of different mesh sizes are in good agreement. For modeling the fish pass, simulating only Ladder 1 is enough to decide on the cell size. After some iteration, it is seen that solving Type-II and Type-III fish pass requires finer cell size, since they have smaller dimensions. To be on the safe side, mesh independency studies is done on Type-II, and then the cell size found here is used for all other models. The number of total active cells and the corresponding cell sizes in the grid dependence study used are given in Table 3.1.

Table 3.1 Cell data for mesh independency studies

Cell Size (m)	Total Active Cells
0.050	589,727
0.048	694,213
0.045	835,532
0.040	1,183,516
0.035	1,747,973
0.030	2,712,514

Each size given in Table 3.1 is solved up to steady case, and it is seen that after cell size of 0.035 meters, the results were in good agreement with each other. The velocity magnitude contours, streamlines and turbulent kinetic energy contours at mid-flow depth are given for mesh sizes of 0.030 m. and 0.035 m. in Figure 3.18 and Figure 3.19, respectively. As can be seen from these figures, the results are almost same for both mesh sizes; thus, for analyses of all types of fish pass, the mesh size is chosen as 0.030 m

3D model of the fish pass shown in Figure 3.17 is imported to Flow 3D as a stl file and one mesh block with a cell size of 0.030 m. is used to solve the geometry. Water depth at the upstream is defined as 1142.84 m. for minimum flow case and 1143.26 m for maximum flow case. Water depth at the downstream is defined as 1137.24 m. for minimum flow case and 1137.43 m. maximum flow case.

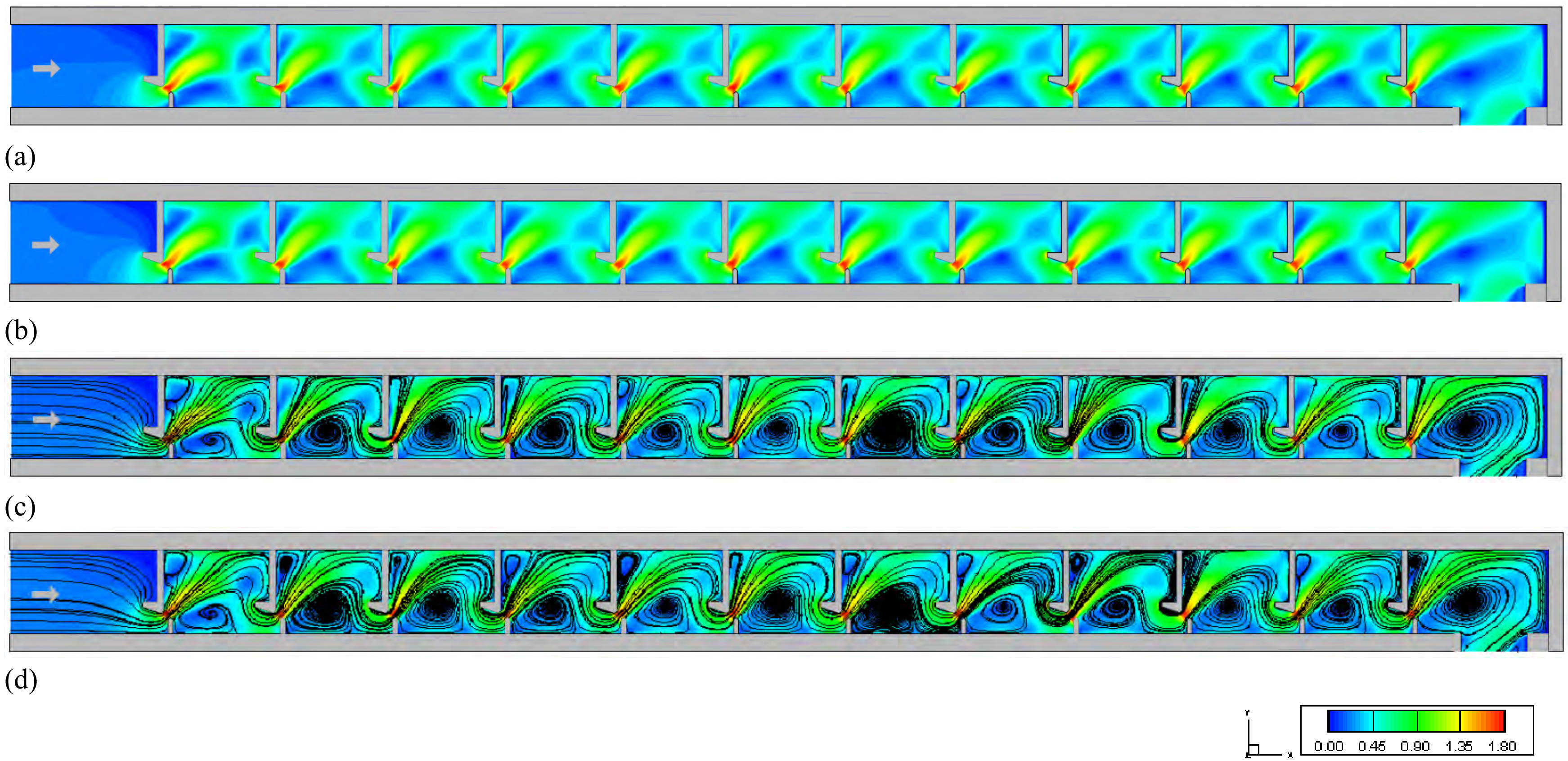


Figure 3.18 (a) Velocity contours (mesh size 0.03 m.) (b) Velocity contours (mesh size 0.035 m.) (c) Velocity streamlines (mesh size 0.03 m.) (d) Velocity streamlines (mesh size 0.035 m.) (all sections are taken from the middle of the water depth)

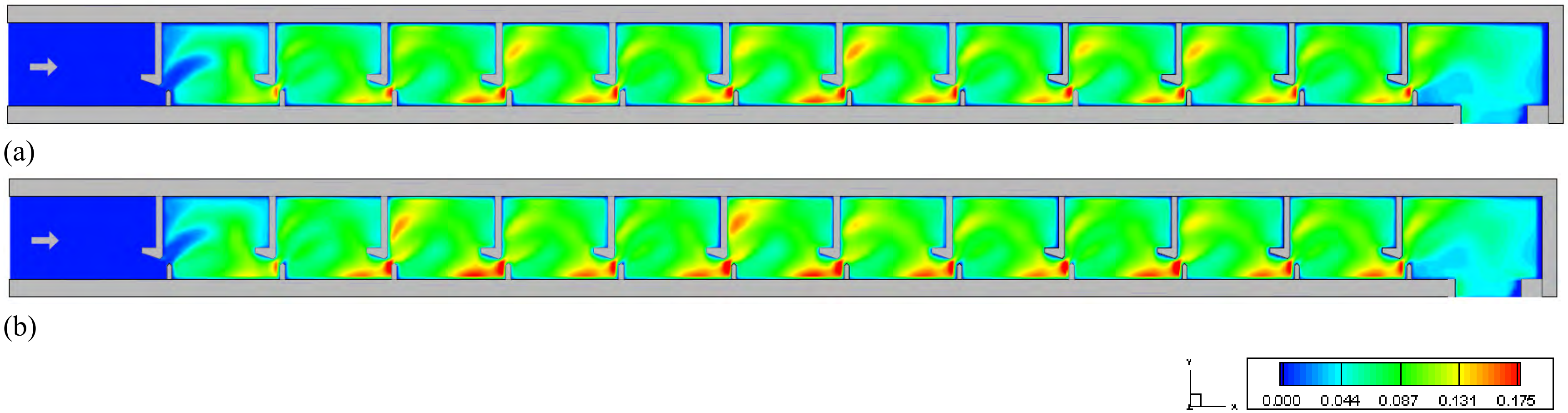


Figure 3.19 (a) Turbulent kinetic energy contours (mesh size 0.03 m.) (b) Turbulent kinetic energy contours (mesh size 0.035 m.) (all sections are taken from the middle of the water depth)

3.3.5 Results of CFD Analyses of the Fish Pass

CFD analyses of three different types of the fish pass are done for minimum and maximum flow case. Velocity magnitude, streamlines and turbulent kinetic energy contours are compared at different horizontal sections (Figure 3.20 - Figure 3.44). Since the results on all three ladders (Figure 3.17) are similar only the results of Ladder-2 are given here.

Figure 3.20 and Figure 3.21 give the velocity magnitude and streamline patterns, respectively, at flow depths of 0.1 h_u, 0.25 h_u, 0.50 h_r, 0.75 h_u at minimum flow conditions for Type I fish pass. Flow magnitude is amplified at the openings of the fish pass where maximum velocity is observed to be almost 2.40 m/s. A large recirculating flow is observed inside the pools where velocity magnitudes are smaller whereas a second small recirculating flow occurs behind the gate slot notch.

Figure 3.22 gives the turbulent kinetic energy contours at the same horizontal planes as the previous figure for minimum flow case for Type I fish pass. It is observed that turbulent kinetic energy values are amplified around the fish slots. One has to note that the amplification around the fish slot is approximately four times larger close to the free surface compared to that close to the channel bed.

Figure 3.23 and Figure 3.24 gives the velocity magnitude and streamline patterns, respectively, at flow depths of 0.1 h_u, 0.25 h_u, 0.50 h_u, 0.75 h_u at maximum flow conditions for Type I fish pass. The results are very similar to the minimum flow case except that the velocity magnitudes are significantly larger (approximately 10 times) along the fish slot.

Figure 3.25 gives the turbulent kinetic energy contours at the same horizontal planes as the previous figure for maximum flow case for Type I fish pass. Similar to the minimum flow case, turbulent kinetic energy values are amplified around the fish slots. Interestingly the turbulence intensity close to the free surface (Figure 3.25c and Figure 3.25d) is not as large as the one that was observed in the minimum flow case. This might be related to the shallowness of the flow in the minimum flow case where larger oscillations are observed compared to the maximum flow case.

In Type I fish pass, short circuits have occurred between the pools for both minimum and maximum flow cases where the main current is not directed through the middle of the pools, as shown in Figure 3.21 and Figure 3.24. This increases the length of the region with high velocity (>2.4 m/s). To overcome this region with high velocity, fish have to use the burst speed longer.

Figure 3.26 and Figure 3.27 give the velocity magnitude and streamline patterns, respectively, at flow depths of 0.1 h_u, 0.25 h_u, 0.50 h_u, 0.75 h_u at minimum flow conditions for Type II fish pass. Velocity magnitudes are amplified close to the fish pass opening and follow a diagonal pattern which hits the side wall of the fish pass. Checking the streamline patterns one can see that the large recirculating cells observed in Type I inside the pools are vanished whereas the small recirculating cells behind the notches are increased in size. The velocity magnitudes are not as large as the ones observed in Type I however the main current is directed directly to the walls. Furthermore, in the pools there is no region with low velocity to give fish an opportunity to rest. The situation may disturb the migrators and it decreases the efficiency of the fish pass.

Figure 3.28 gives the turbulent kinetic energy contours at the same horizontal planes as the previous figure for minimum flow case for Type II fish pass. It is observed that turbulent kinetic energy values are amplified almost uniformly all over the fish pass pools confirming that there is no calm resting place for fish inside the pools.

Figure 3.29 and Figure 3.30 give the velocity magnitude and streamline patterns, respectively, at flow depths of 0.1 h_u, 0.25 h_u, 0.50 h_u, 0.75 h_u at maximum flow conditions for Type II fish pass. Unlike the minimum flow case this time the recirculating flows inside the pools exist and the main flow is not directed towards the wall. The turbulent kinetic energy values are amplified almost uniformly all over the fish pass pools similar to the minimum flow case (Figure 3.31). Although the maximum flow conditions look reasonable it is not possible to accept this fish pass type as it failed in the minimum flow conditions as explained above.

Figure 3.32 and Figure 3.33 give the velocity magnitude and streamline patterns, respectively, at flow depths of 0.1 h_u, 0.25 h_u, 0.50 h_u, 0.75 h_u at minimum flow conditions for Type III fish pass. In the results of Type III, the directions of main current have occurred in the optimal position. It has been found out that there are currents which resemble current direction which is offered by Katopodis(1992) in the Figure 2.11 #design 1 and #design 2. The problem of short circuit is prevented by using 30° angle in slot; thus, the region with high velocity is reduced to a great extent. Although high turbulent kinetic energy values are observed along the main flow and behind the notch there are regions inside the pool where turbulent kinetic energy values are relatively small (Figure 3.34). Furthermore, circulation regions emerge and these regions give fish an opportunity to rest. Same kind of flow conditions are observed in the maximum flow case (Figure 3.35 - Figure 3.37). Therefore for migration of fish, Type III presents the most efficient flow conditions.

In addition to completed analyses, to understand the efficiency of the hook shape on the slot, a new type is generated by only deleting hooks of Type III. The dimensions of the new type are given in Figure 3.38 and it will be called as "Type IV". The same analyses are done with Type IV and the results are given between Figure 3.39 and Figure 3.44. The results of Type IV show that it has almost the same flow conditions with Type III except in some pools the main flow is hitting the wall like in Type II. At minimum flow conditions this condition is observed in the first pool (Figure 3.26 and Figure 3.27) whereas in the maximum flow conditions it is observed in pools 3 and 5 (Figure 3.42 and Figure 3.43). Therefore it is not proper to design this fish pass without the hook shaped part.

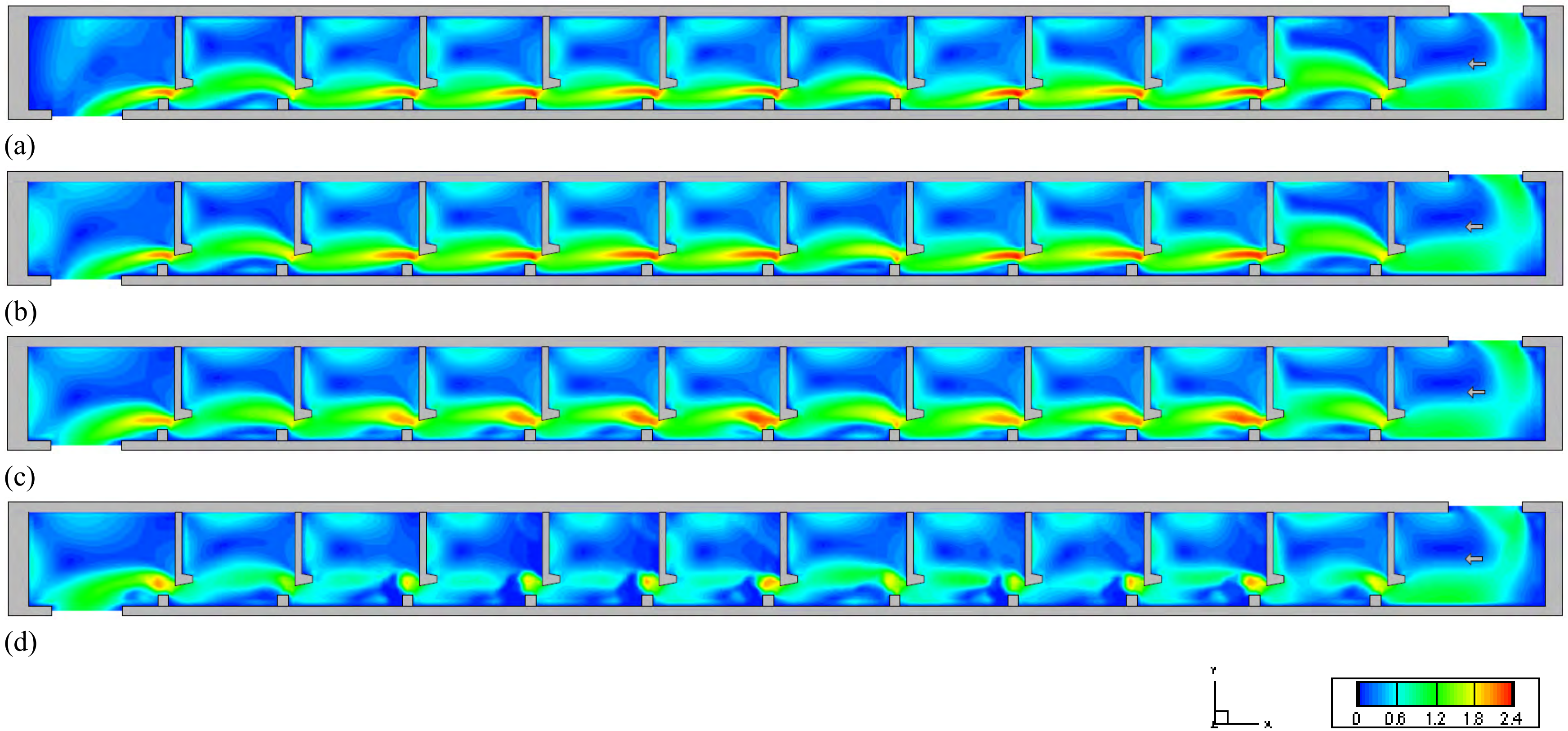


Figure 3.20 Velocity magnitude contours of Type I for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

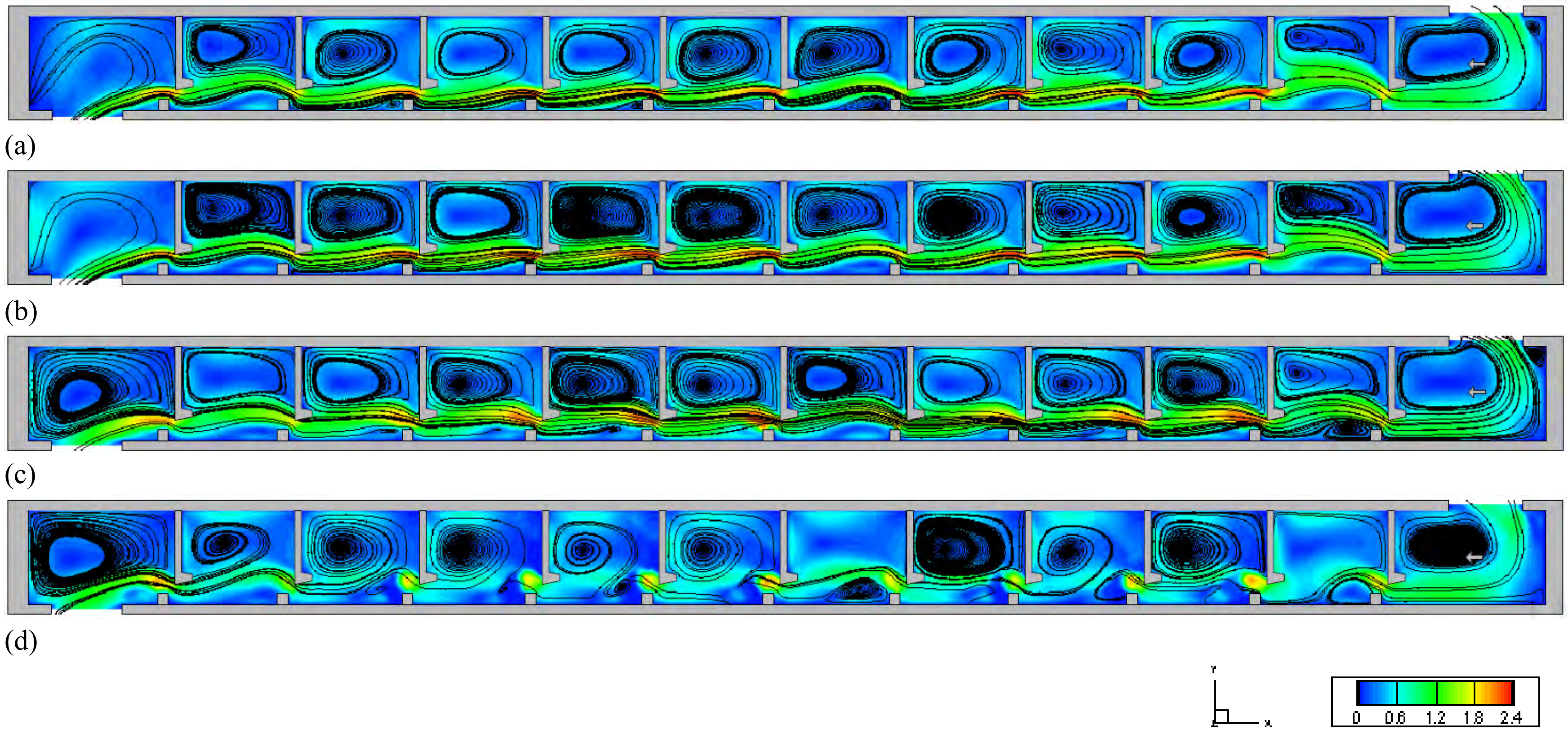


Figure 3.21 Velocity magnitude contours and streamlines of Type I for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

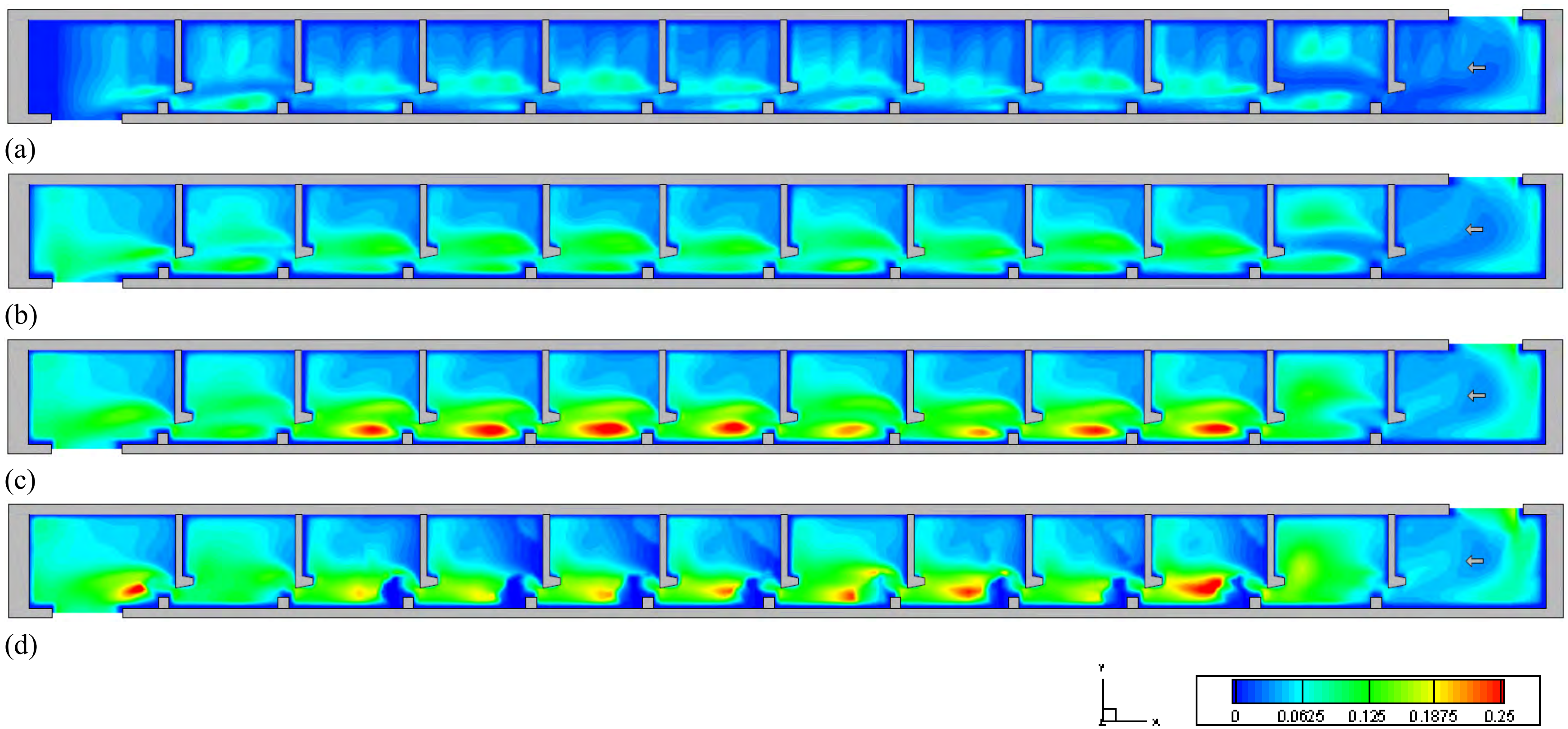


Figure 3.22 Turbulent kinetic energy contours of Type I for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

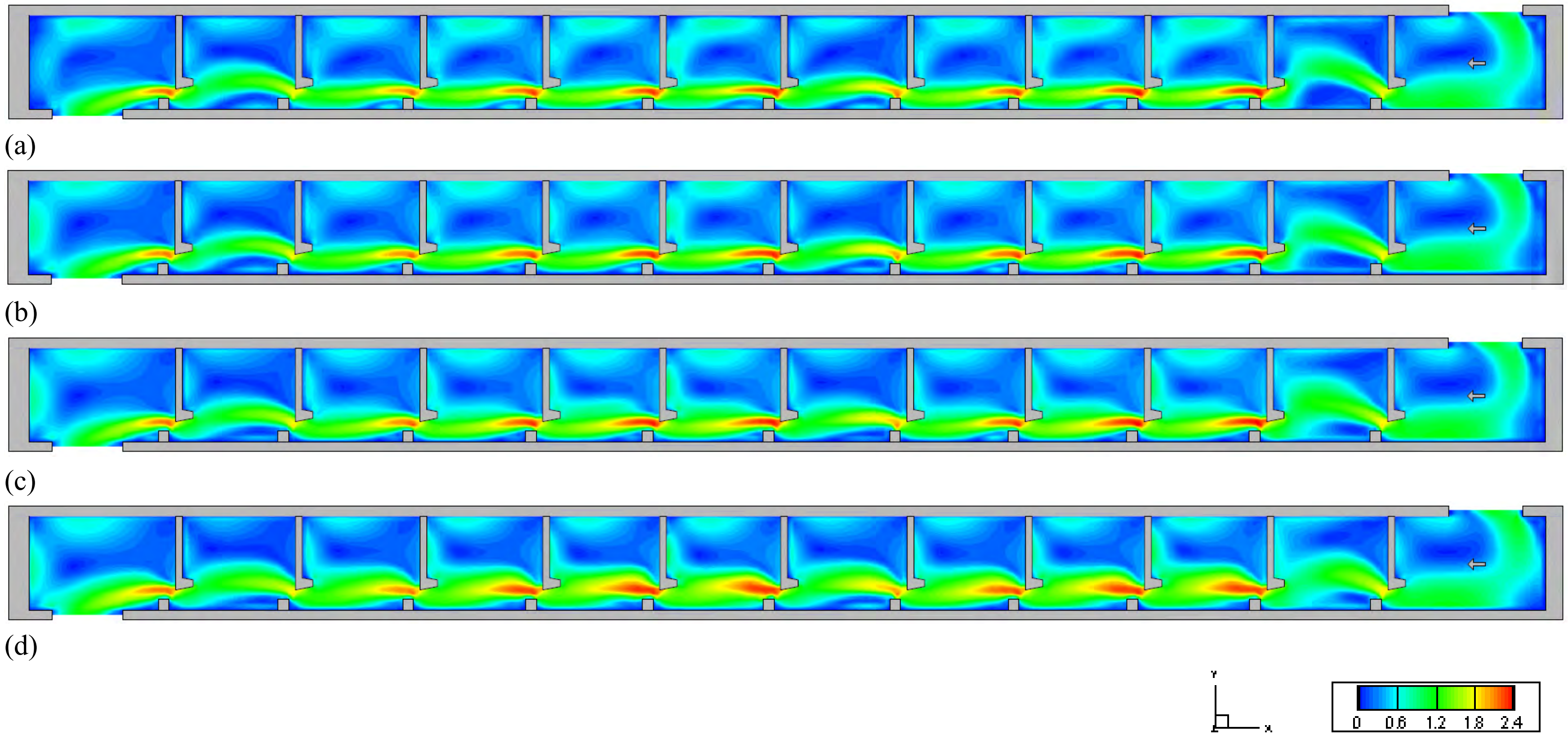


Figure 3.23 Velocity magnitude contours of Type I for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

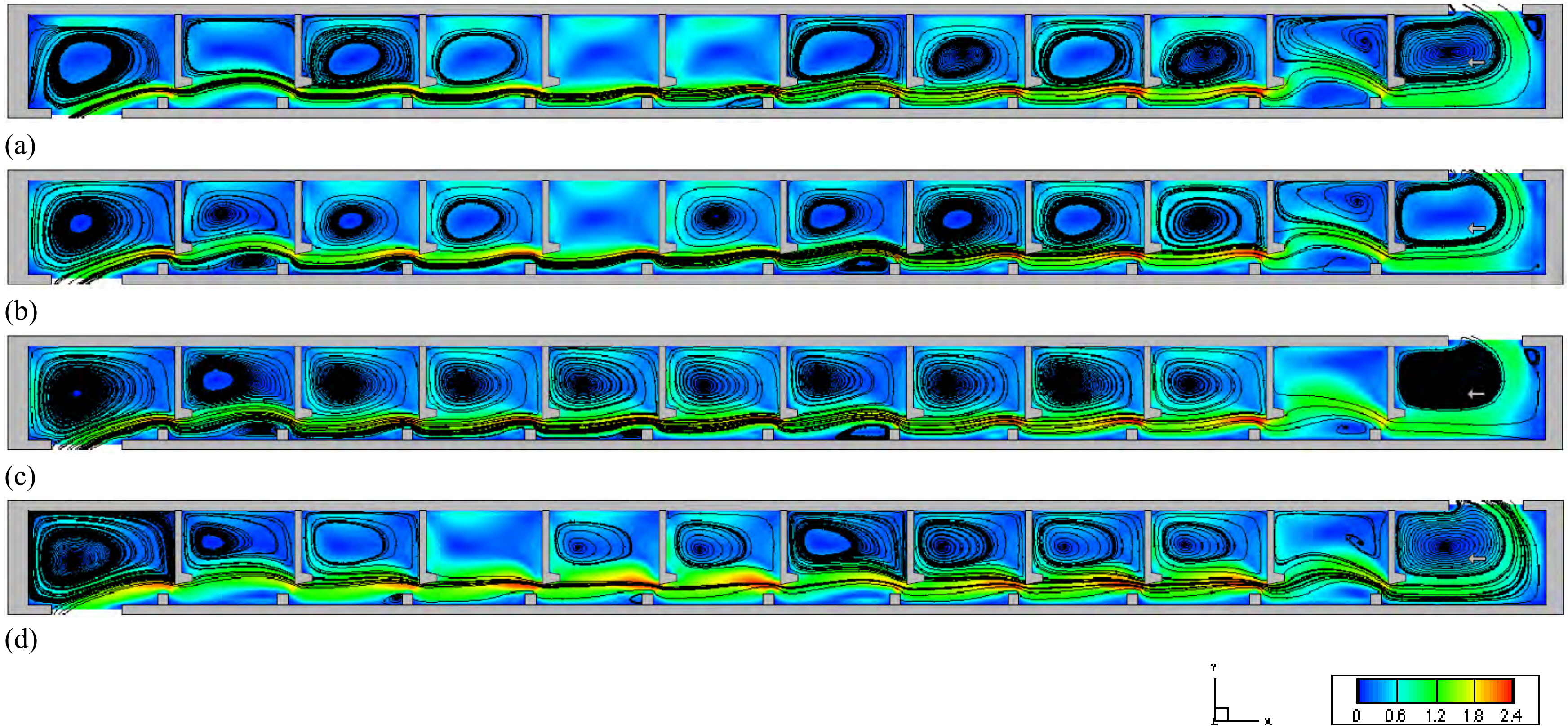


Figure 3.24 Velocity magnitude contours and streamlines of Type I for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

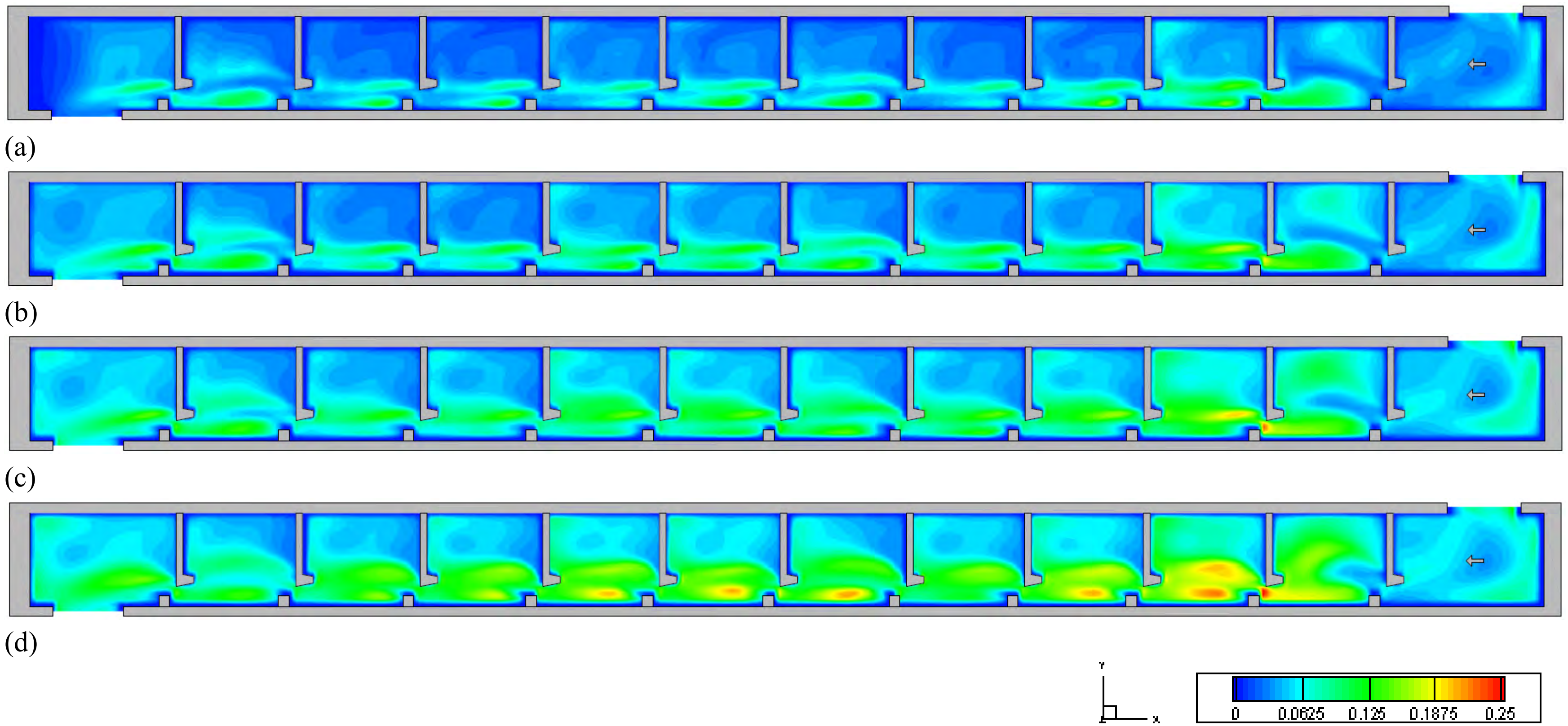


Figure 3.25 Turbulent kinetic energy contours of Type I for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

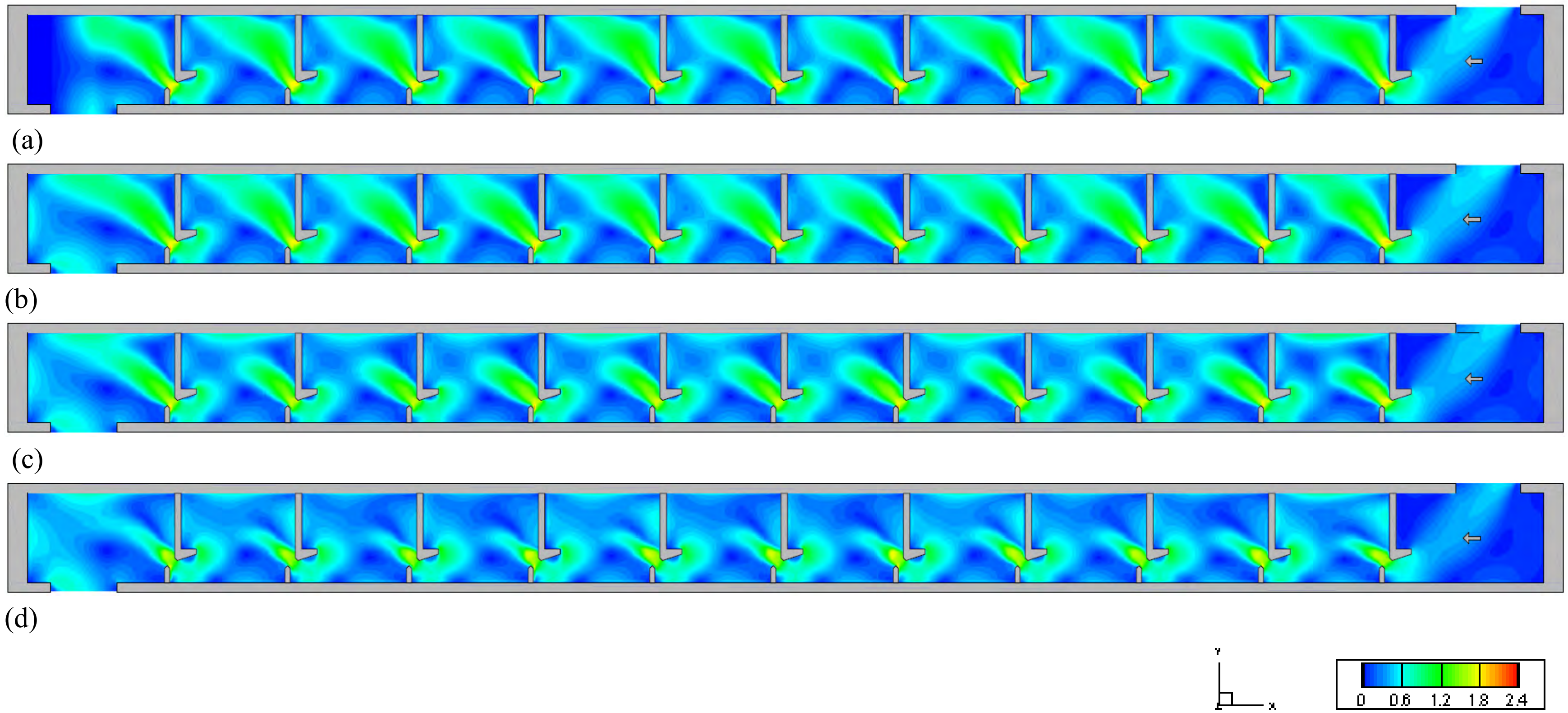


Figure 3.26 Velocity magnitude contours of Type II for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

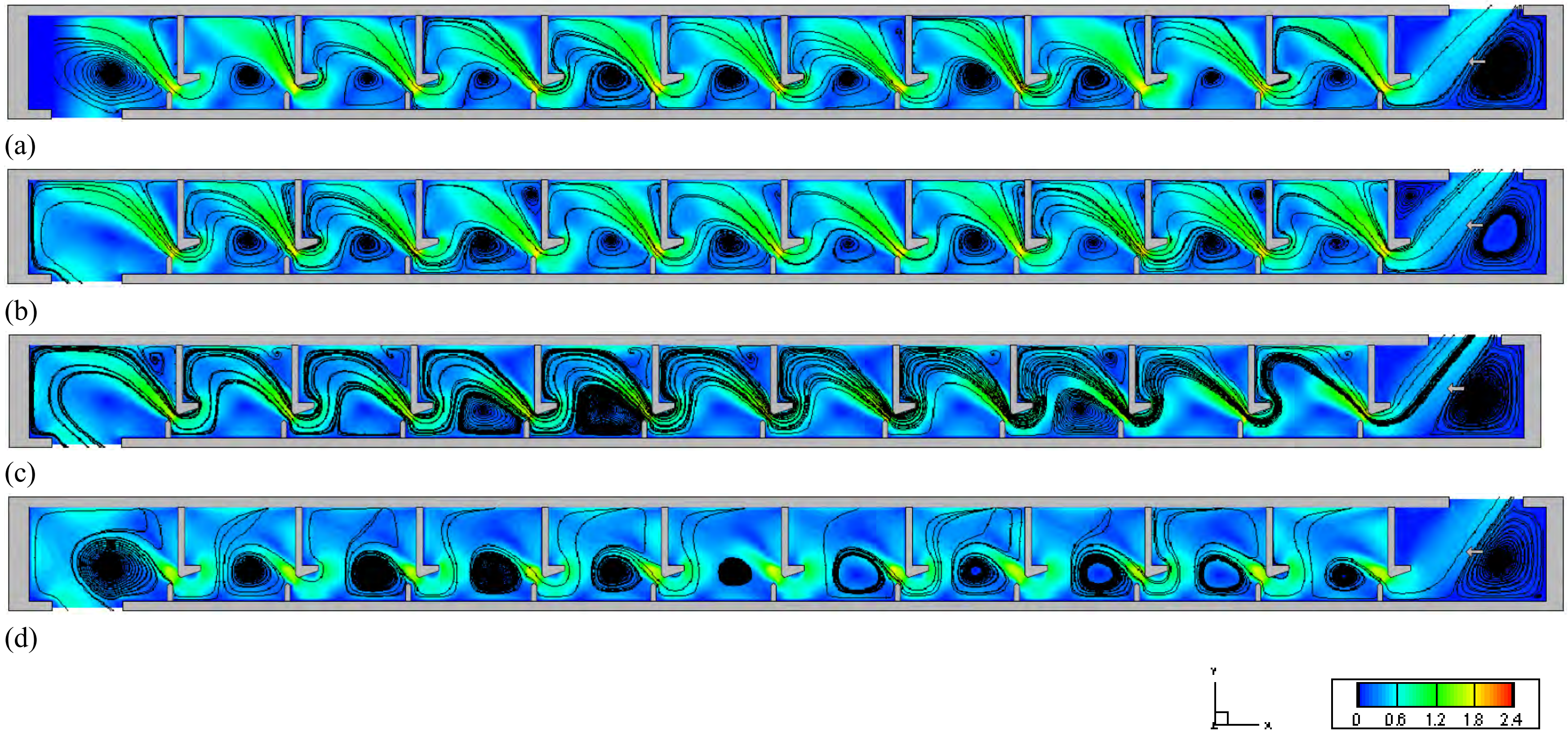


Figure 3.27 Velocity magnitude contours and streamlines of Type II for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

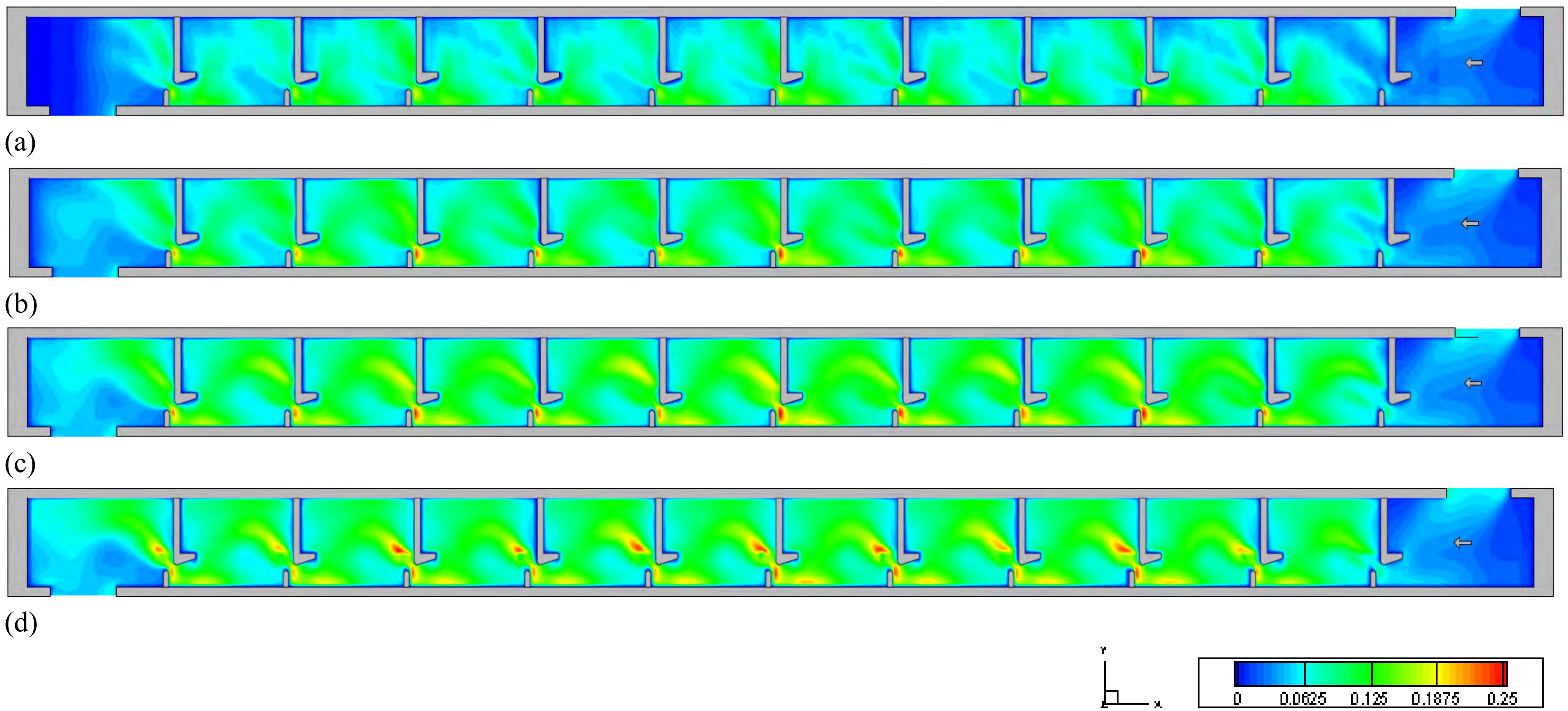


Figure 3.28 Turbulent kinetic energy contours of Type II for the minimum flow case at flow depths of: (a) 0.10h_u; (b) 0.25h_u; (c) 0.50h_u; (d) 0.75h_u

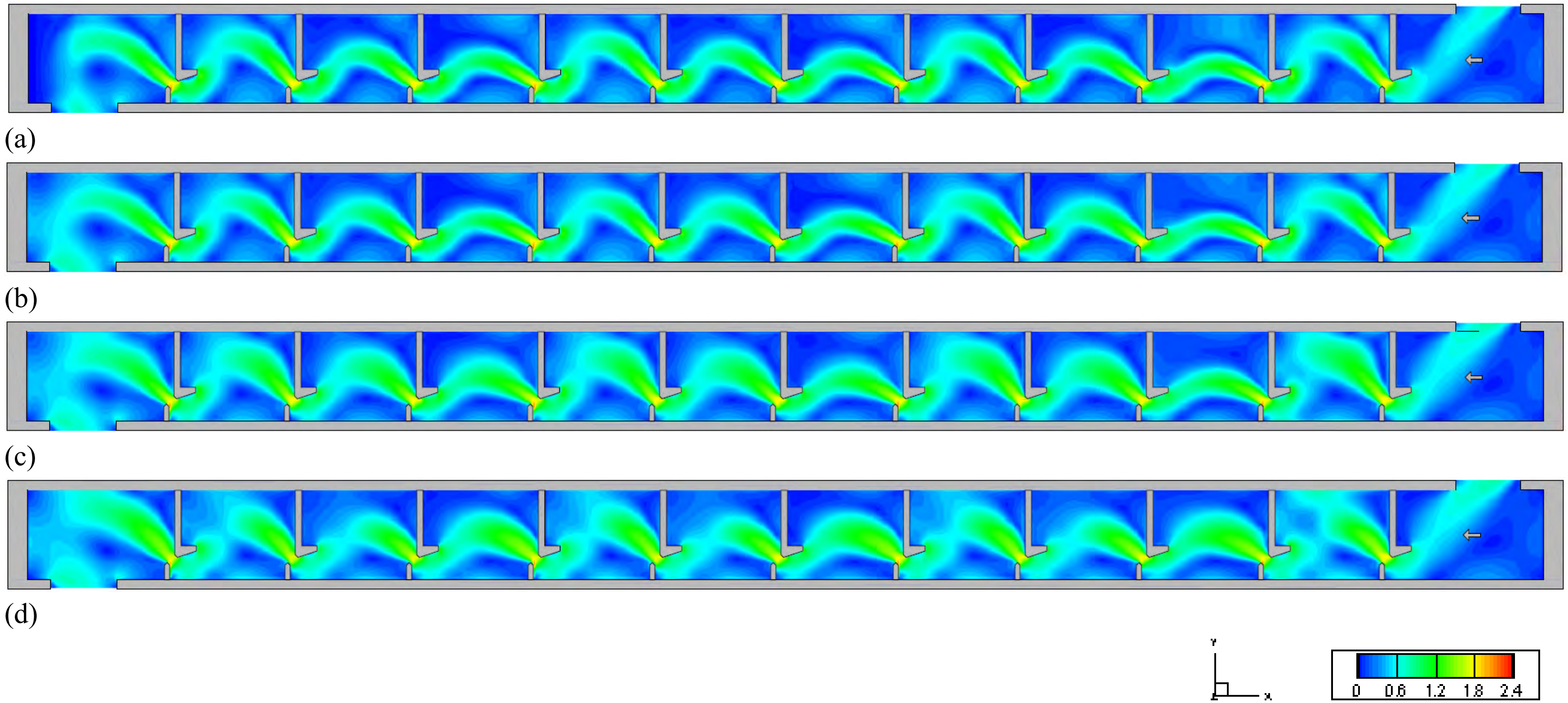


Figure 3.29 Velocity magnitude contours of Type II for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

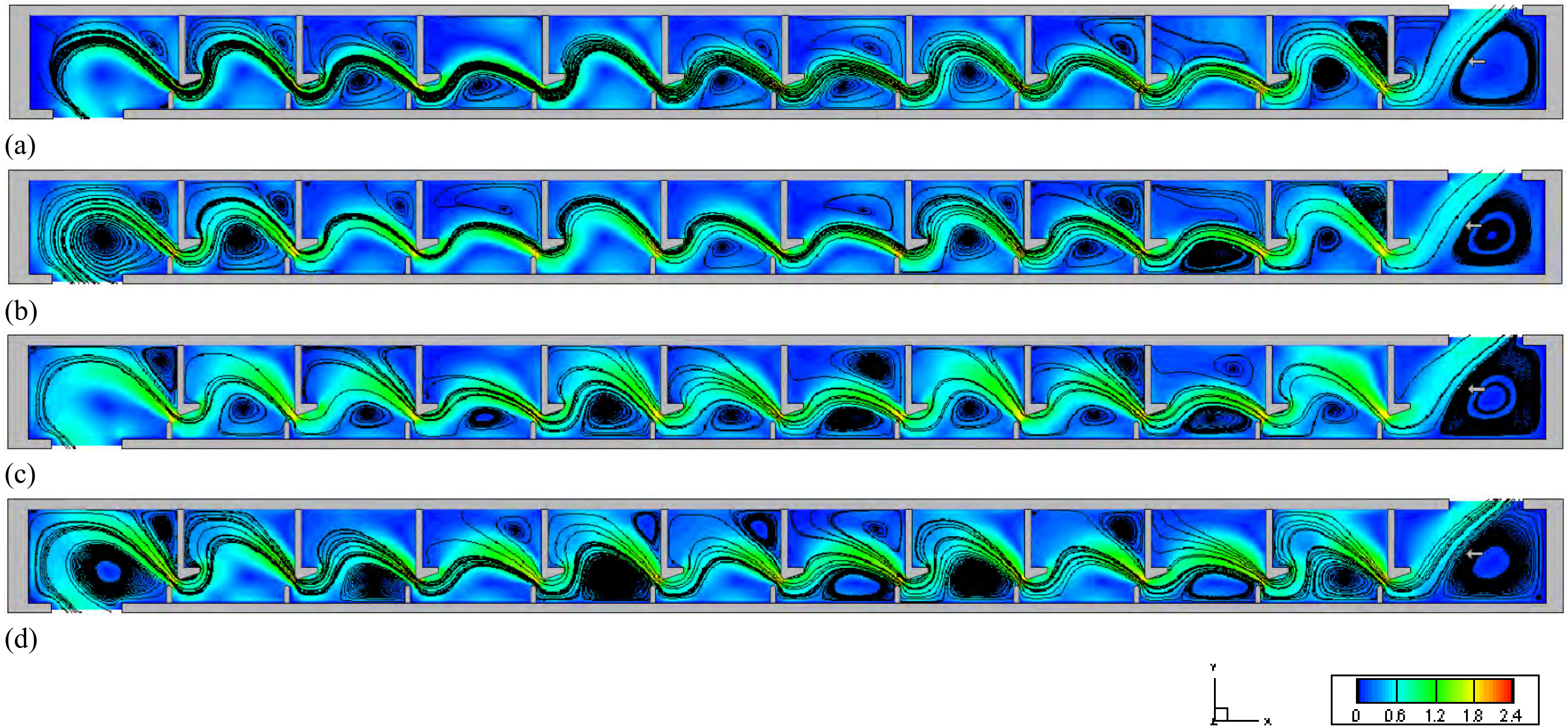


Figure 3.30 Velocity magnitude contours and streamlines of Type II for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

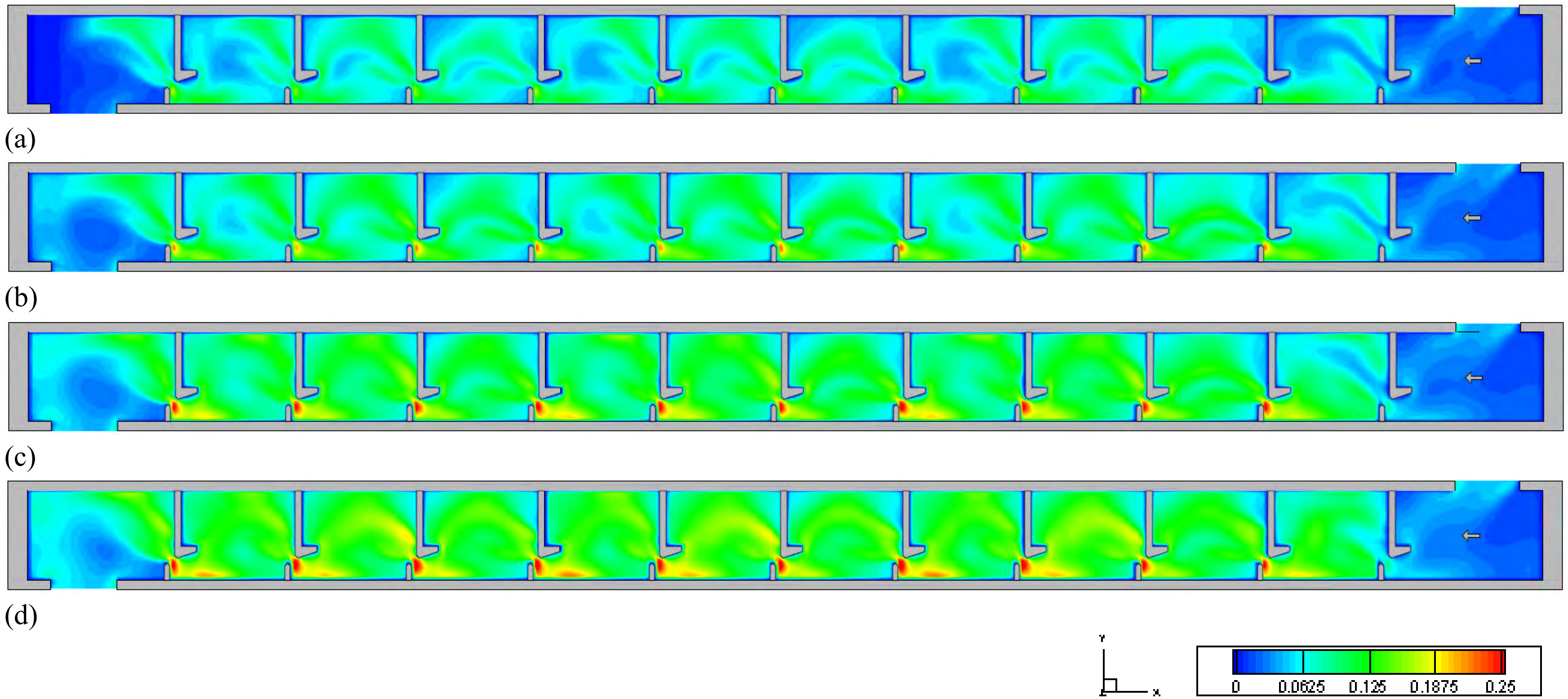


Figure 3.31 Turbulent kinetic energy contours of Type II for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

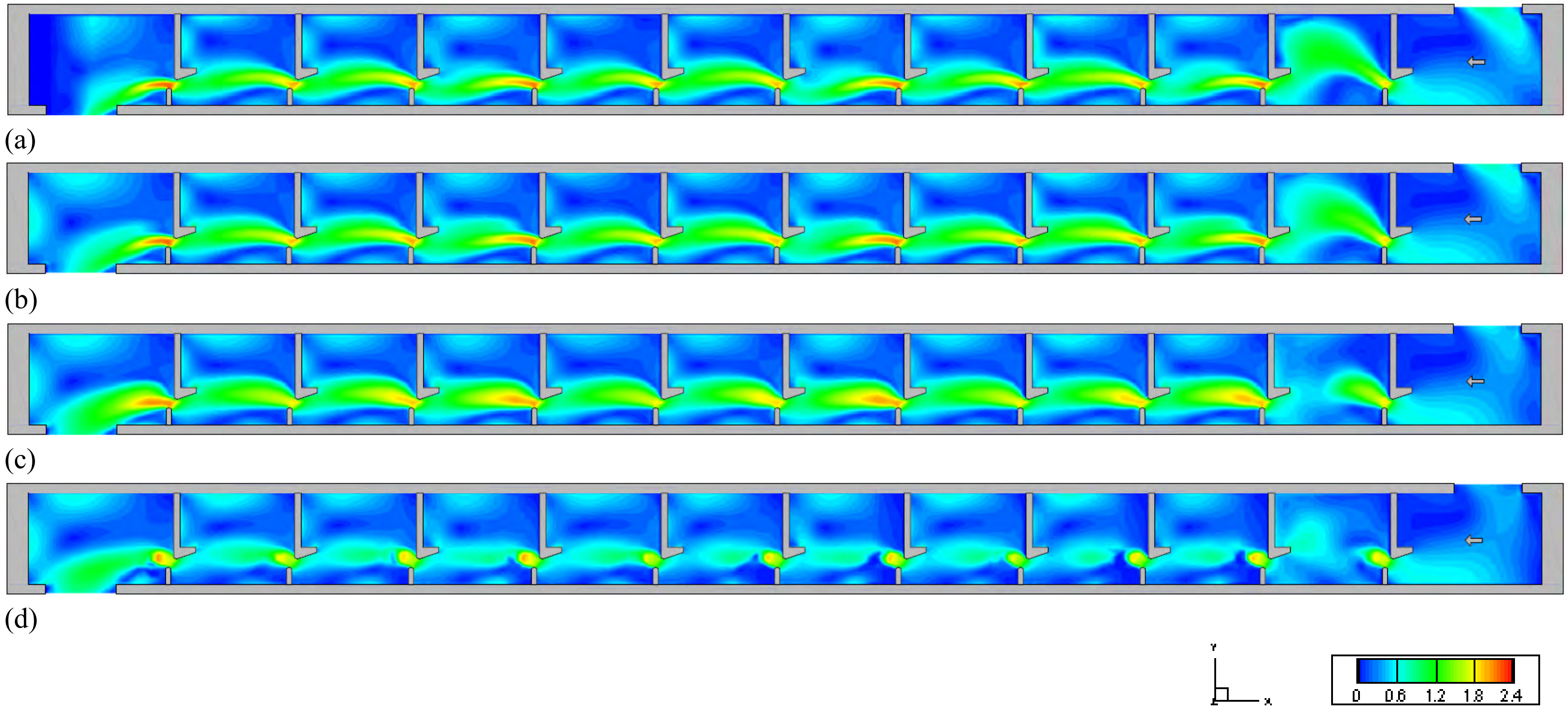


Figure 3.32 Velocity magnitude contours of Type III for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

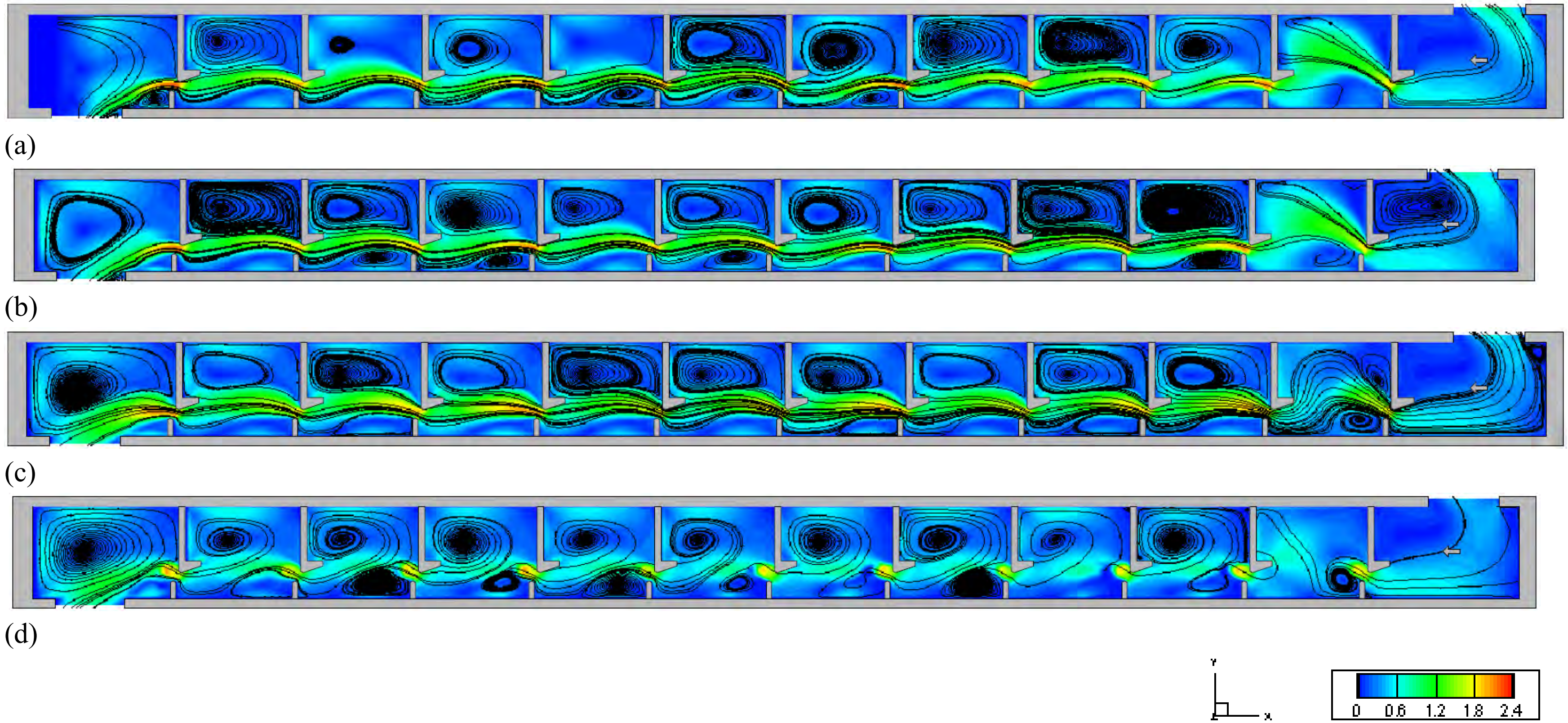


Figure 3.33 Velocity magnitude contours and streamlines of Type III for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

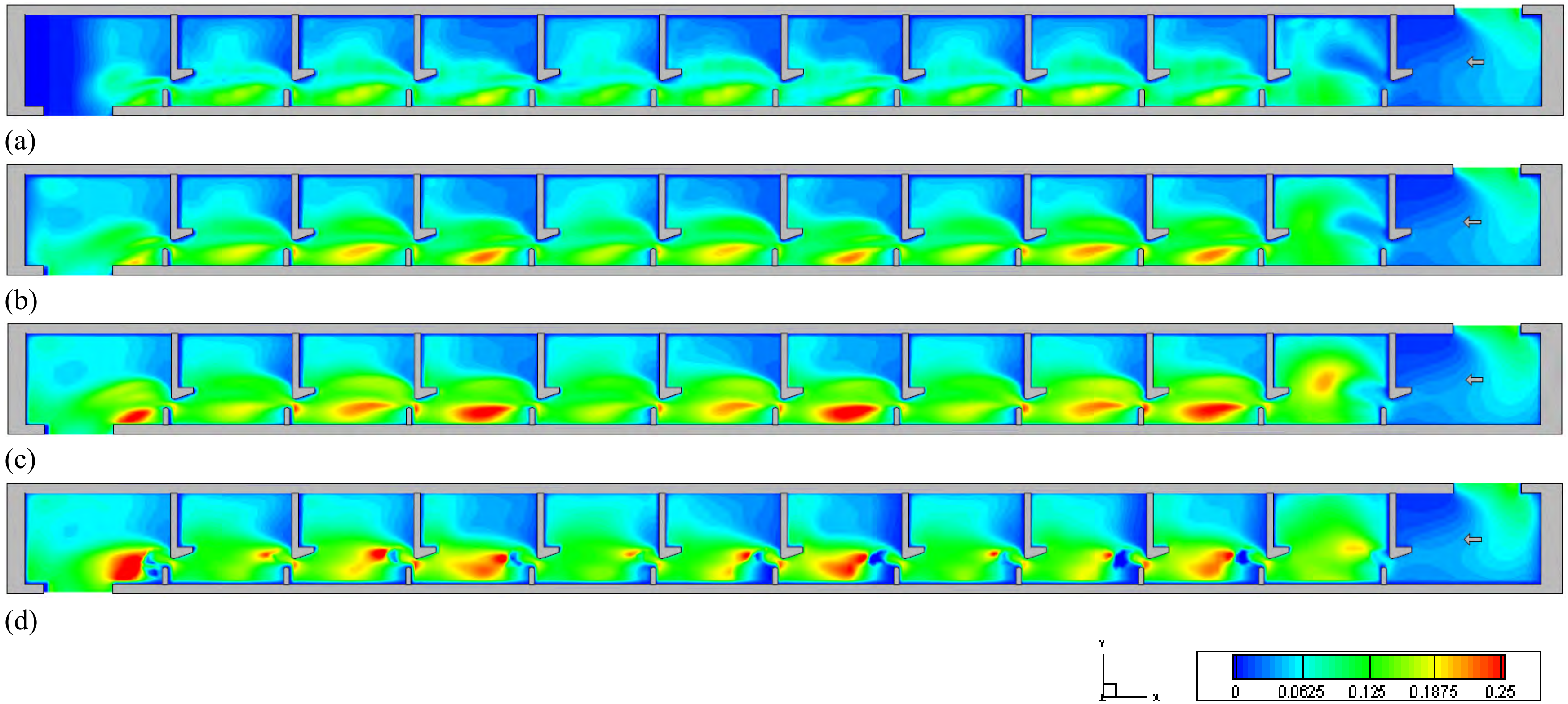


Figure 3.34 Turbulent kinetic energy contours of Type III for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

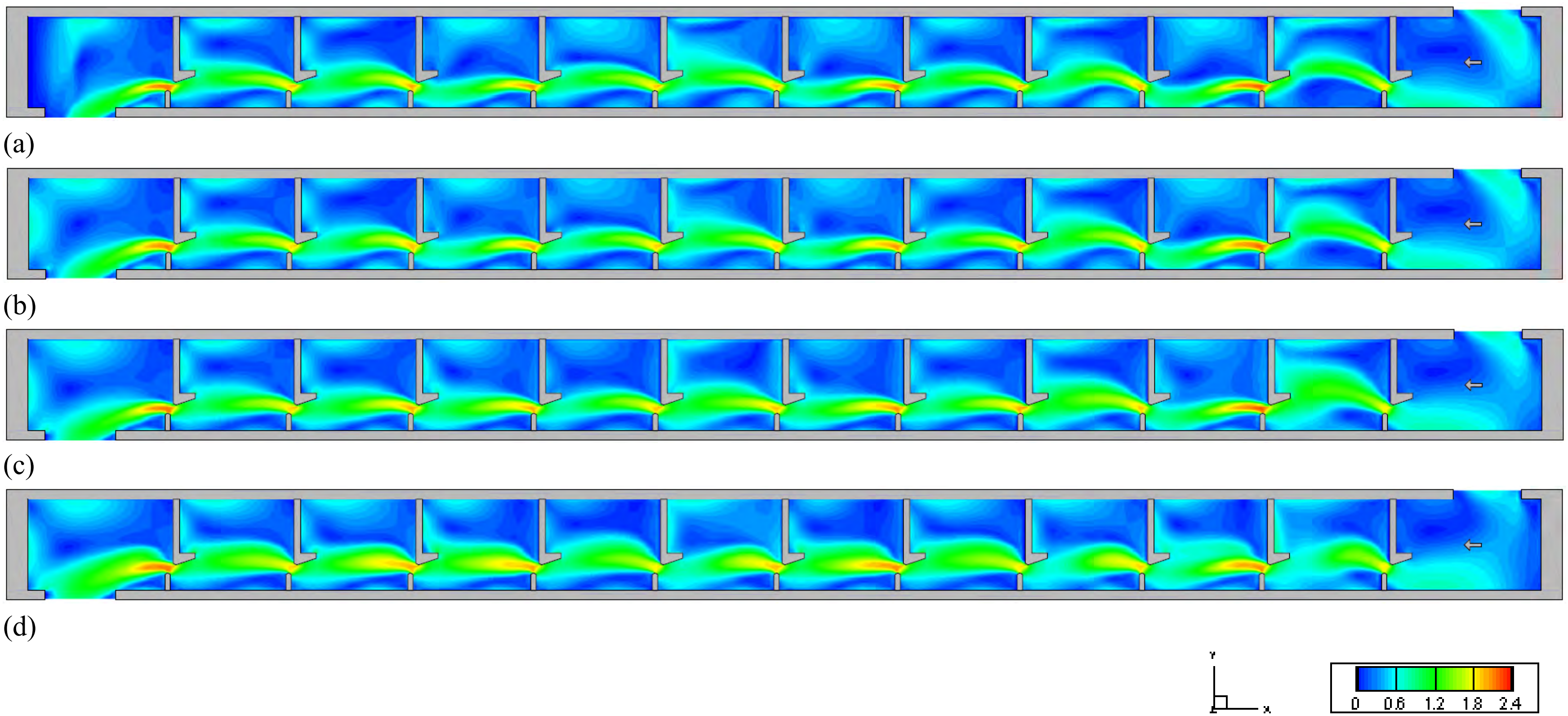


Figure 3.35 Velocity magnitude contours of Type III for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

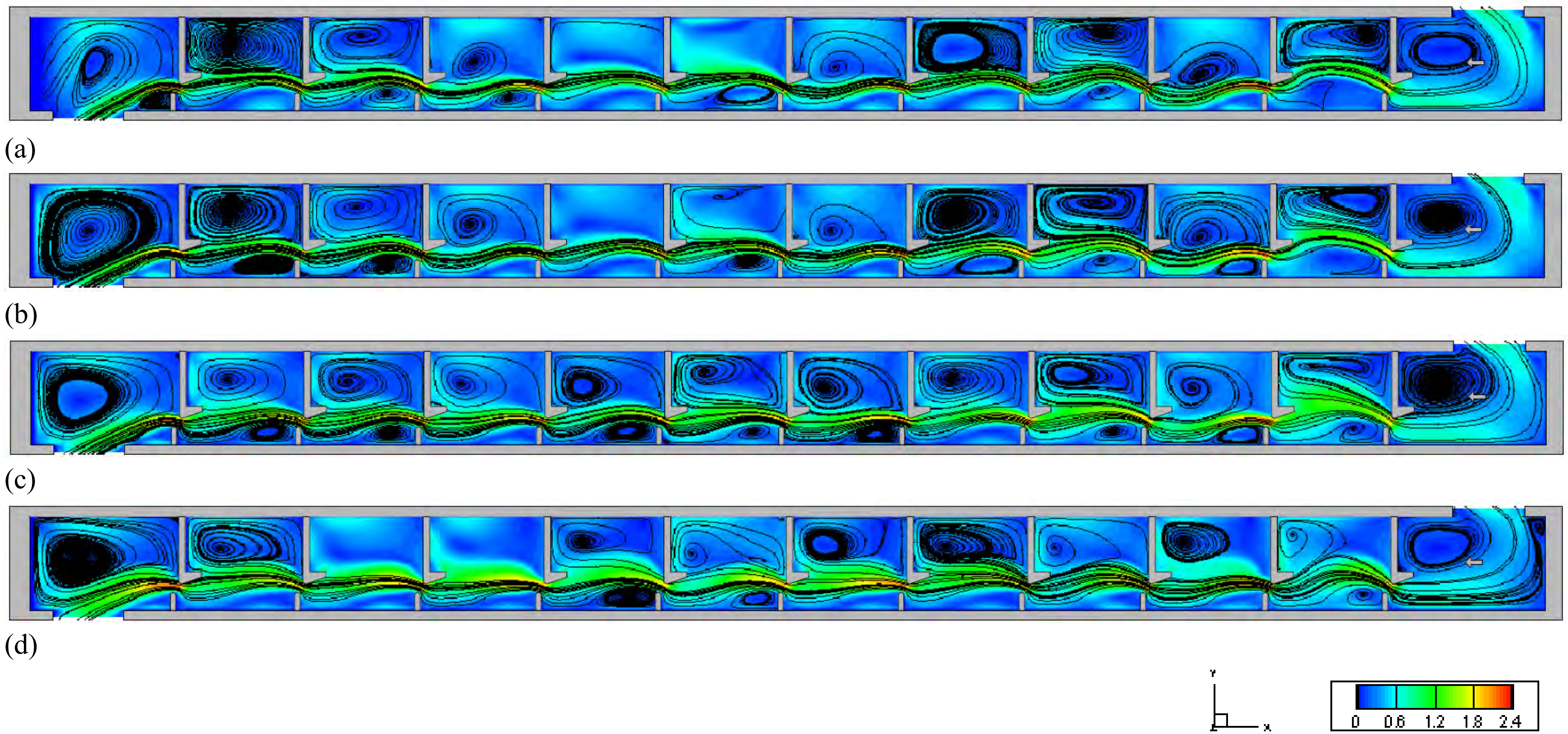


Figure 3.36 Velocity magnitude contours and streamlines of Type III for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$;(c) $0.50h_u$; (d) $0.75h_u$

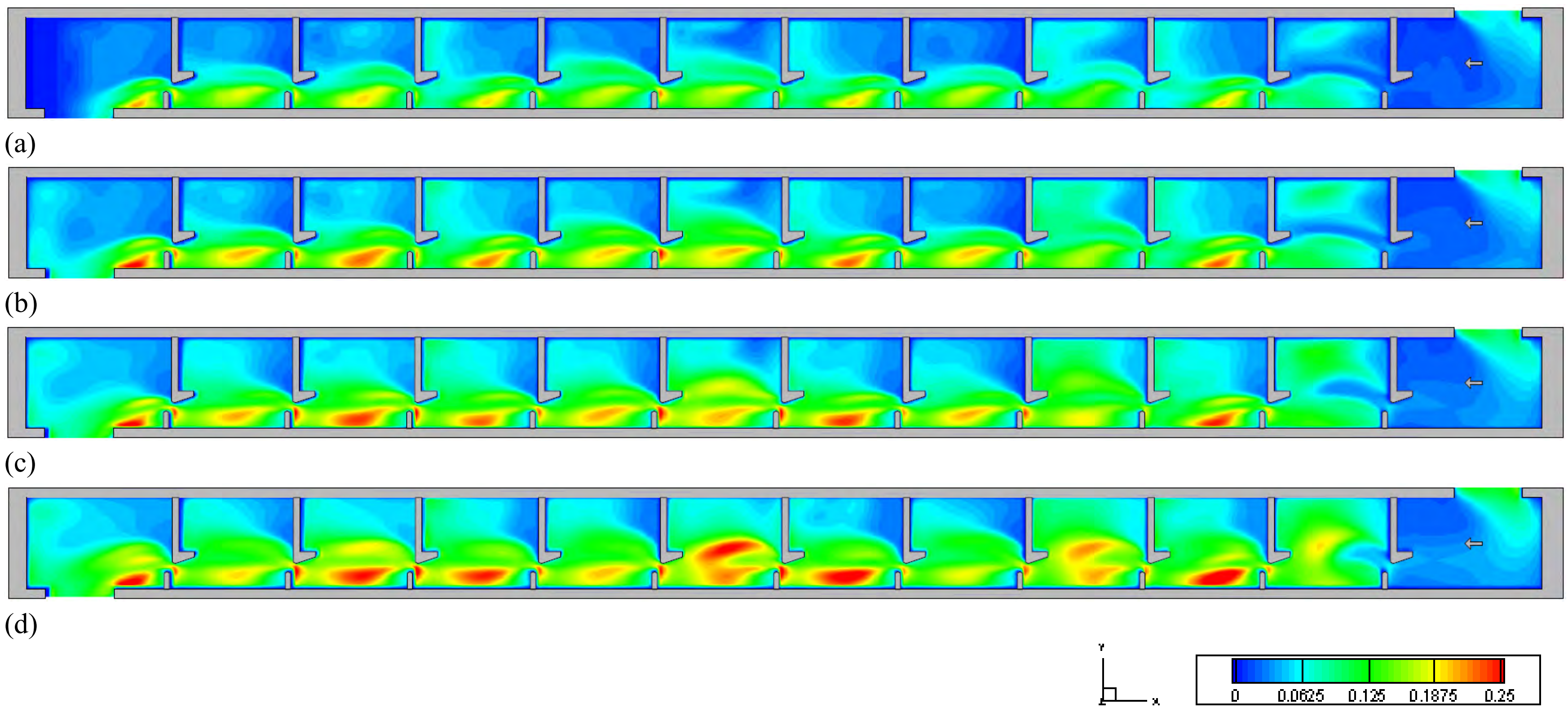


Figure 3.37 Turbulent kinetic energy contours of Type III for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

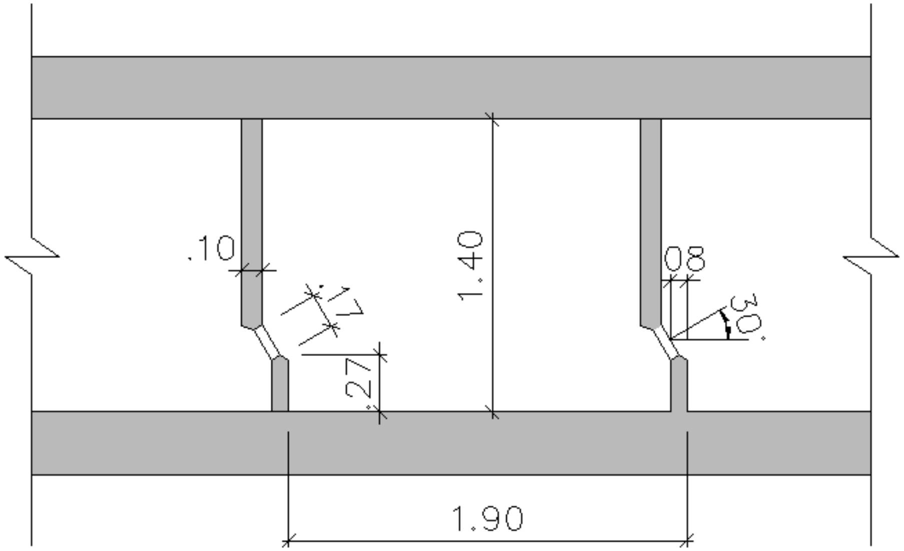


Figure 3.38 The dimensions of “Type IV” in meter

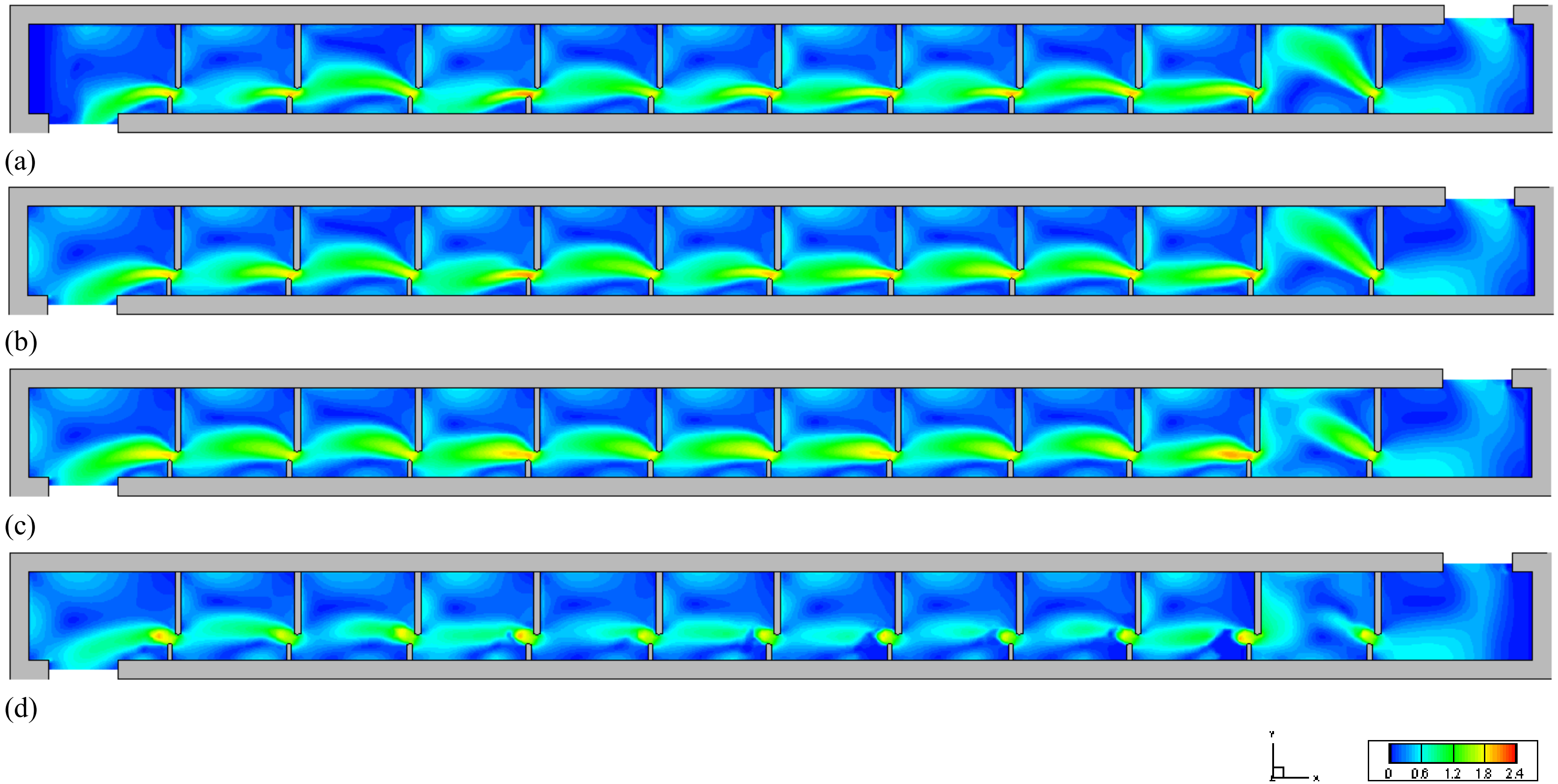


Figure 3.39 Velocity magnitude contours of Type IV for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

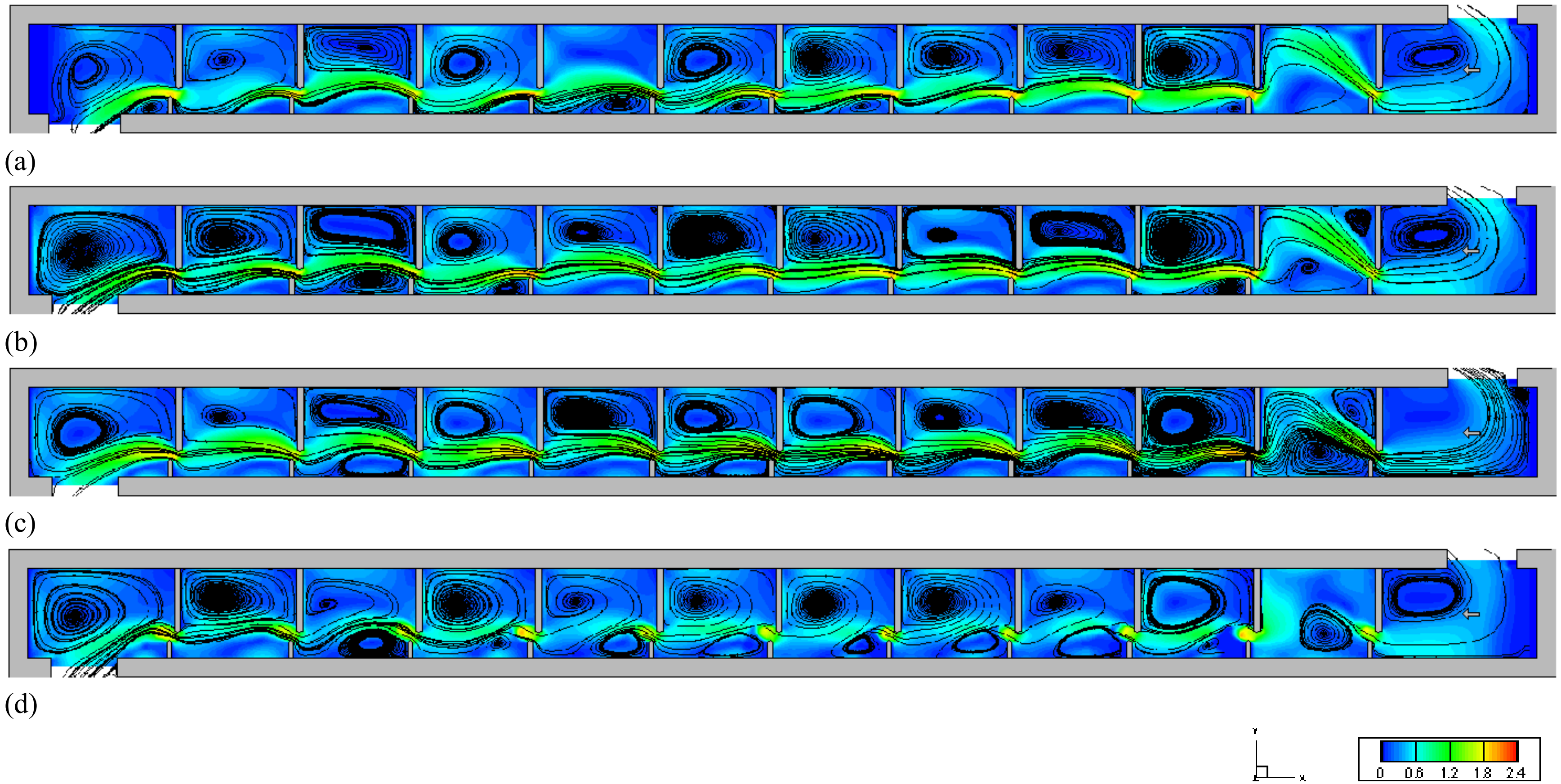


Figure 3.40 Velocity magnitude contours and streamlines of Type IV for the minimum flow case at flow depths of: (a) 0.10h_u; (b) 0.25h_u; (c) 0.50h_u; (d) 0.75h_u

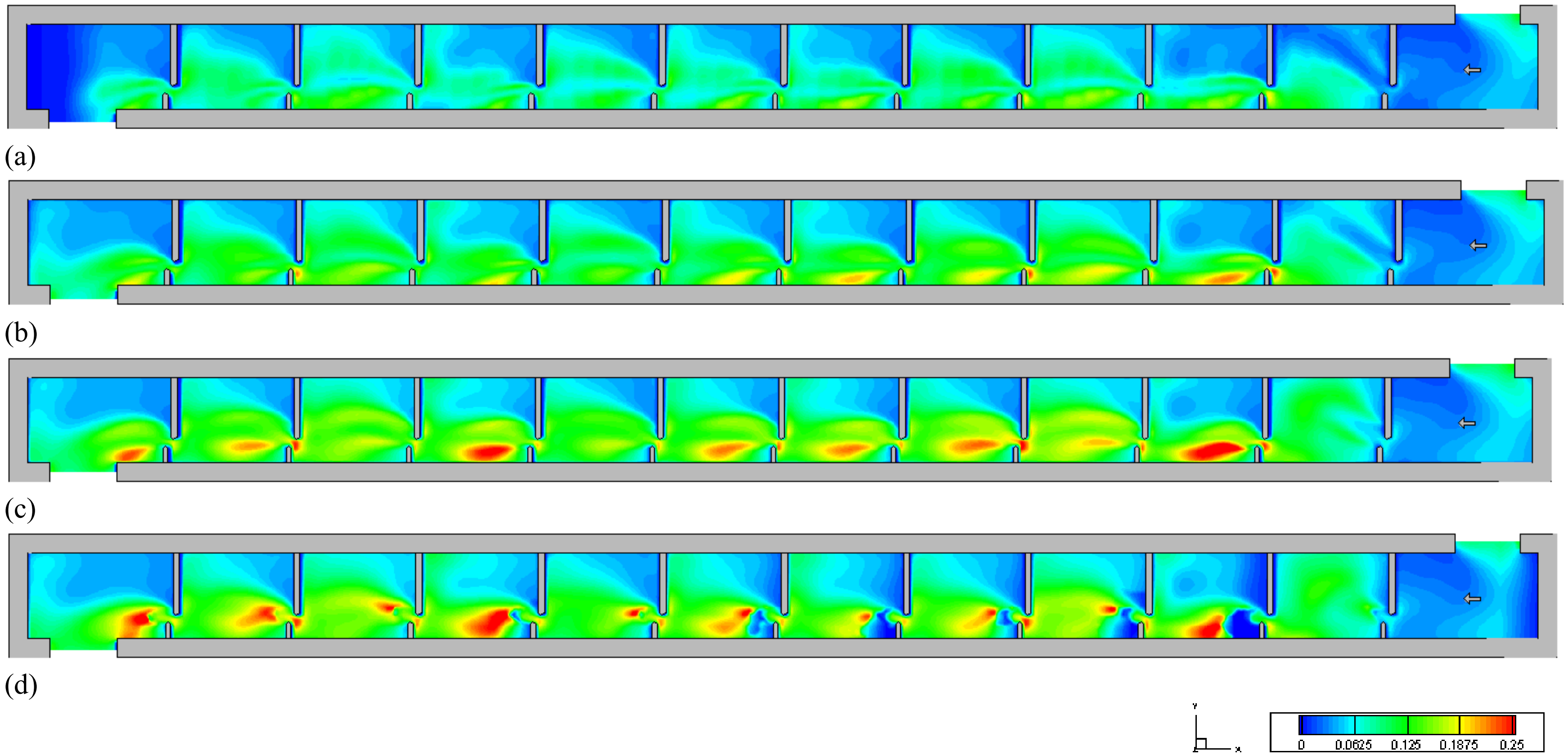


Figure 3.41 Turbulent kinetic energy contours of Type IV for the minimum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

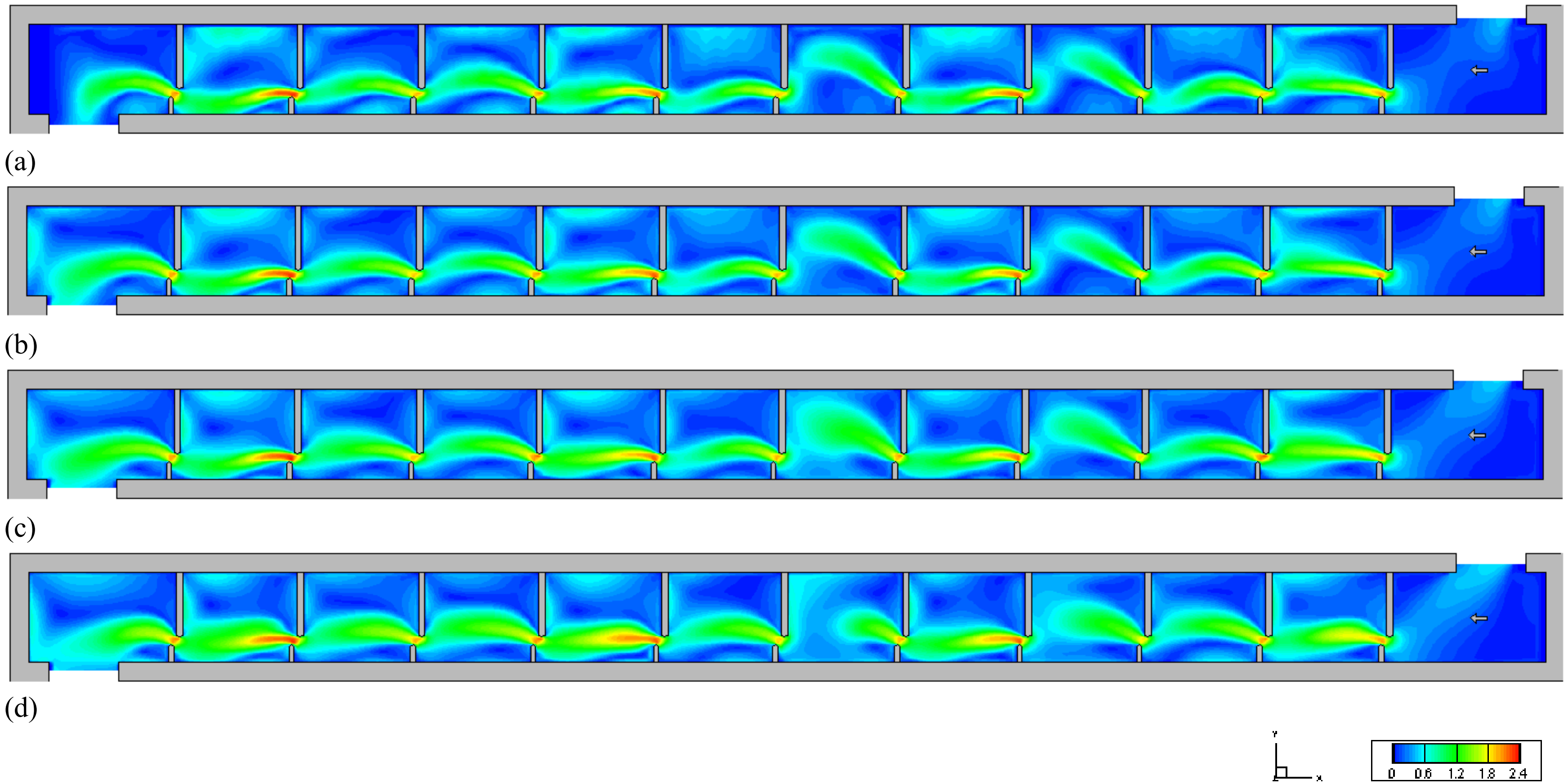


Figure 3.42 Velocity magnitude contours of Type IV for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

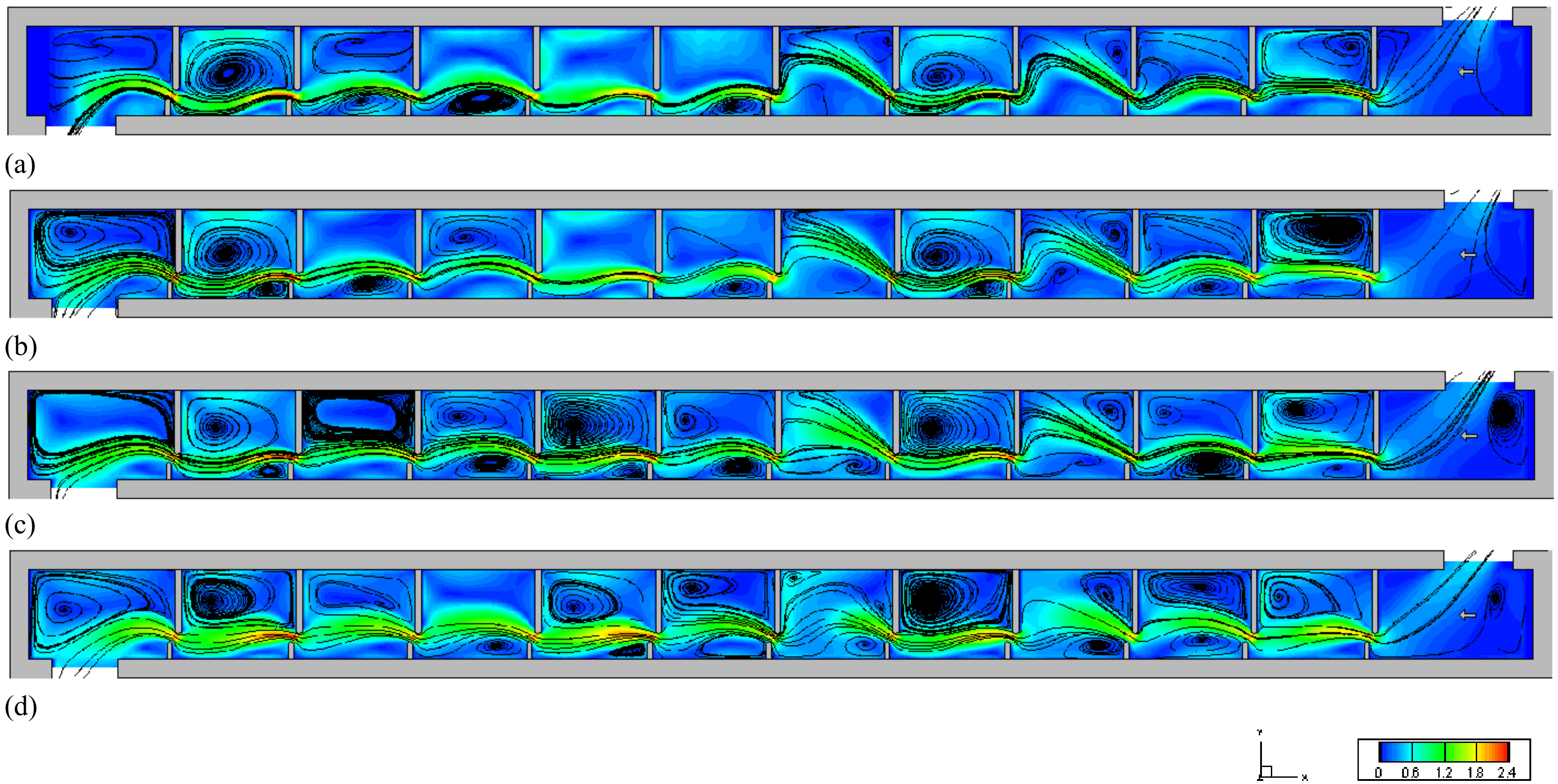


Figure 3.43 Velocity magnitude contours and streamlines of Type IV for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

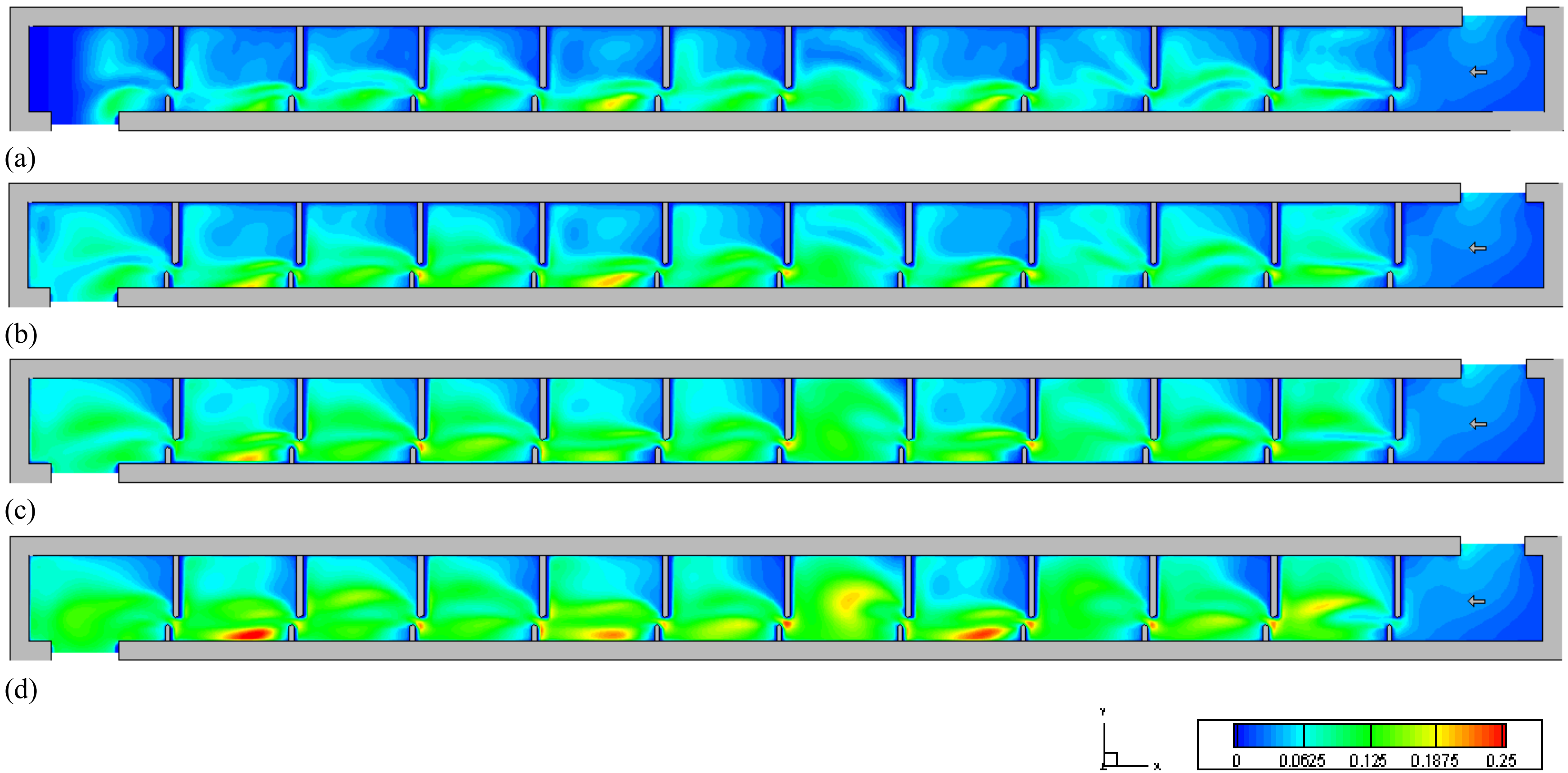


Figure 3.44 Turbulent kinetic energy contours of Type IV for the maximum flow case at flow depths of: (a) $0.10h_u$; (b) $0.25h_u$; (c) $0.50h_u$; (d) $0.75h_u$

CHAPTER 4

CONCLUSION

To solve fish migration problem of Uzungöl, by using Flow 3D, the optimal fish pass design is suggested for target species (Brown Trout) to pass over the obstruction. Firstly, close-to-nature type of fish pass is suggested; however, there is no space to construct in the project area. After that, since the vertical slot passes present a lot of advantages while compared with the other technical fish pass types, the vertical slot passes were chosen as the best alternative for the Uzungöl Weir-1. By using dimensioning system suggested by DWVK (1996) and by Katopodis (1992), three different types are generated. Then, to be used in CFD analysis 3D solid model of Uzungöl Weir -1 is prepared and by using Flow 3D, CFD analyses are done. The conclusions of this numerical study are listed as follows:

1) Numerical simulations provide cost effective solutions. CFD analyses have flexibility and many scenarios can be tested easily by making minor changes in the model. Despite the fact that CFD analyses have some limitations such as long run times and numerical instabilities, they are preferred because of providing economical solutions and giving an opportunity in investigating the hydraulic characteristics in detail in three dimensions.

2) In a numerical study determination of accurate cell size, choosing correct initial and boundary conditions are very critical issues; because use of

improper mesh size and wrong boundary conditions can cause misleading results.

3) In the results of Type I, the short circuit problem is occurred between the pools. Since the main flow is not directed through the middle of the pools, the region with high velocity is very large. To overcome this region with high velocity, fish have to use the burst speed longer.

4) In the results of Type II, although the velocity magnitudes are not as large as observed in Type I, the main current has been sent towards the walls and there is no region with low velocity to give fish an opportunity to rest. The situation may disturb the migrators and it decreases the efficiency of the fish pass.

5) In the results of Type III, it has been found out that there are currents which resemble current direction which is offered by Katopodis (1992). The problem of short circuit is prevented by using 30° angle in slot; thus, the region with high velocity is reduced to a great extent. It is seen that Type III presents the most efficient stream conditions to the migrators.

6) In addition to these three types, Type IV is generated only deleting the hooks of Type III to understand the efficiency. Although it shows generally same hydraulic conditions with Type III, in some pools, the main current is hitting the walls. Therefore, it is seen that the hooks assist to deflect the main current.

7) Overall, CFD appears to be an effective tool for analyzing free surface flows over technical fish passes for testing different design scenarios.

REFERENCES

Ağıralioğlu, N. (2012). “Balık Geçitleri ve Tasarım Esasları.”

Alp, A., Buyukcapar, H.M. (2006). “Kahramanmaraş’ta Su Urunleri Sektorunun Gelişimi ve Balıkcılığa Uygun Su Kaynakları.” KSU. Fen ve Muhendislik Dergisi, 9(1): 104-110.

Aksungur, M. (2009). “Deniz Alabalıklarında Stok Yonetimi ve Koruma Stratejileri.” Doğal Alabalık Calıştayı: Surdurulebilir Yetiştiricilik, Koruma ve Balıklandırma. 22-23 Ekim 2009. Trabzon.

Ak, O., Aksungur, M., Özdemir, A. (2009). “Nehir Tipi Hidroelektrik Santrallerinde Çed Süreci ve Sucul Ekosisteme Etkide Doğal Alabalıkların Yeri.” Doğal Alabalık Çalıştayı: Sürdürülebilir Yetiştiricilik, Koruma ve Balıklandırma. 22-23 Ekim 2009. Trabzon.

Aksungur, M., Ak, O., Ozdemir, A. (2011). “Nehir Tipi Hidroelektrik Santrallerinin Sucul Ekosisteme Etkisi: Trabzon Orneği.” Journal of Fisheries Sciences.com, 5(1): 79-92.

Anonim, (1987). “Balık gecitleri.” T.C Bayındırlık ve İskan Bakanlığı Devlet Su İşleri Genel Mudurluğu İşletme ve Bakım Dairesi Başkanlığı, DSİ yayını, 97s. Ankara.

Anonim, (2009). “Balık Gecitleri Tasarım, Boyutlandırma ve İzleme”, DSİ yayını, 118s., Ankara.

Aras, M.,S., Çetinkaya, O. ve Karataş, M. (1997). "Anadolu Alabalığı (Salmo trutta macrostigma, Dum., 1858)'in Türkiye'deki Bugünkü Durumu. Akdeniz Balıkçılık Kongresi", Nisan, İzmir.

Balık, S. (1988). "Türkiyenin Akdeniz Bölgesi İçsu Balıkları Üzerinde Sistematik ve Zoocoğrafik Araştırmalar." Doğa Turkish Journal of Zooloji D., 12, 2, 156-179.

Barrett, J., Mallen-Cooper, M. (2006). "The Murray River's 'Sea to Hume Dam' Fish Passage program: Progress to Date and Lessons Learned. Ecological Management & Restoration", 7 (3): 173–183.

Beach, M.H., (1984). "Fish pass design - criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fishes in rivers." Ministry of Agriculture, Fisheries and Food, Lowestoft, Fish. Res. Tech. Rep. 78, 45 p.

Behnke, R., J. (1968). "A new subgenus and species of trout Salmo (Platysalmo) platycephalus, from southcentral Turkey, with comments on the classification of the sub family Salmoninae." Mitt. Hamburg. Zool. Mus. Inst., 66, 1-15.

Bell, M.C., (1986). "Fisheries handbook of engineering requirements and biological criteria." Fish. Eng. Res. Prog., U.S. Army Corps of Eng., North Pacific Div., Portland, Oregon, 290 p.

Berkun, M., Aras, E., Koc, T. (2008). "Barajların ve Hidroelektrik Santrallerin Nehir Ekolojisi Uzerinde Oluşturduğu Etkiler." Turkiye Muhendislik Haberleri, 452: 41-48.

Blaxter, J.H.S., (1969). "Swimming speeds of fish." FAO Fish. Rep., 62 (1): 69-100.

Croze, O., Bau, F., Delmouly, L. (2008). "Efficiency of A Fish Lift for Returning Atlantic Salmon at A Large- Scale Hydroelectric Complex in France. Fisheries Management and Ecology", 15:467–476.

Demirsoy, A. (1988). "Yaşamın Temel Kuralları." Cilt, 3, kısım 1, Hacettepe Üni. Yay. No: A/55, Ankara, 684 s.

DVWK,(1996). "Fish passes – Design, dimensions and monitoring",117 pages.

Eruz, C., Duzgunes, E. (2010). "Ecological Impacts of Hydro Electrical Power Stations on Mountain Stream Ecosystems in South West Caucasus. Energyonline", 1(2) : 1-8.

Geldiay, R. ve Balık, S. (1996). "Türkiye Tatlı Su Balıkları." Ege Üniversitesi, Su ÜrünleriFakültesi Yayın No: 46. Ders Kitabı. Dizin No: 16, Ege Üniversitesi Basımevi, Bornova, İzmir.

Hindar, K., Jonsson, B., Ryman, N. ve Ståhl, G. (1991). "Genetic relationships among landlocked, resident, and anadromous brown trout, Salmo trutta L., Heredity", 83-91.

Hirt, C.W., Nichols, B.D. (1981). "Volume of fluid (VOF) method for the dynamics of free boundaries", Journal of Computational Physics, Volume 39, Issue 1: 201–225.

Jens, G. (1982). "Der Bau von Fischwegen", Hamburg, Berlin (Verlag Paul Parey), 93.

Katopodis, C. (1992). "Introduction to Fishway Design, Working Document", 68 pages.

Katopodis, C., Rajaratnam N. (1983). “A Review and Lab Study of Hydraulics of Denil Fishways, Can. Tech. Rep. Fish.” Aquatic Sci., 1145, 181.

Kocabaş, M. (2009). “Türkiye Doğal Alabalık (Salmo trutta) Ekotiplerinin Kültür Şartlarında Büyüme Performansı Ve Morfolojik Özelliklerinin Karşılaştırılması.”

Larinier, M. (1992a). “Passes à bassins successifs, prébarrages et rivières artificielles.” Bull. Fr. Pêche Piscic. 326/327, 45-72.

Larinier, M. (1992b). “Les passes à ralentisseurs.” Bull. Fr. Pêche Piscic. 326/327, 73-94.

Larinier, M. (1992c). “Ecluses et ascenseur à poisson.” Bull. Fr. Pêche Piscic. 326/327, 95-110.

Larinier, M. (1992d). “Implantation des passes àpoissons.” Bull. Fr. Pêche Piscic. 326/327, 30 - 44.

Larinier, M. (2002). “Fishways–General considerations. Bulletin Francais De La Peche Et De La Pisciculture”, 364: 21–27.

Lenne, D. (1990). “Circulation des poissons migrateurs: franchissement des buses et étude hydraulique des passes à bassins successifs (Movement of migratory fish: passage through culverts, and hydraulic study of pool passes.)” ENITRS-CEMAGREF Rep., 70 p.

Lucas, M.C., Baras, E. (2001). “Migration of Freshwater Fishes. Oxford: Blackwell Science”, pp. 420.

Mitsch, W. J., Jorgensen, S.E., (2003). “Ecological Engineering: A field Whose Time Has Come. Ecological Engineering”, 20: 363–377.

Ryman, N. (1983). “Patterns of distribution of biochemical genetic variation in salmonids: differences between species, Aquaculture”, 33, 1–21.

Schilt, C.R. (2007). “Developing Fish Passage and Protection at Hydropower Dams.” Applied Animal Behaviour Science, 104: 295-325.

Slastenenko, E. (1956). “Karadeniz Havzası Balıkları.” Çeviri: H.E Altan, Et ve Balık Kurumu Umum Müdürlüğü, İstanbul. 711 s.

Svetovidov, A., N. (1984). “Salmonidae.” In P.J.P. Whitehead, M.–L.Bauchot, J.-C. Hureau, J. Nielsen and E. Tortonese (eds.), 1984. Fishes of the North-Eastern Atlantic and the Mediterranean, Unesco, Paris, 1, 373–385.

Tabak, İ., Aksungur, M., Zengin, M., Yılmaz, C., Aksungur, N., Alkan, A., Zengin, B., Mısır, D.S. (2001). “Karadeniz Alabalığının Biyoekolojik Ozelliklerinin Tespiti ve kulture alınabilirliliğinin araştırılması projesi.” TAGEM/HAYSUD/98/12/01/2007. Sonuc Raporu. 193s. Trabzon.

Teufel, J., Pätzold, F. ve Potthof, C. (2002). “Scientific research on transgenic fish with special focus on the biology of trout and salmon.” Research Report, 360, 05, 023, Federal Environmental Agency (Umweltbundesamt), Berlin, 175 p.

United States Department of Agriculture, (2007). “Natural Resources Conservation Service, Stream Restoration Design, Part 654, Fish Passage and Screening Design, Technical Supplement 14N”, National Engineering Handbook, 47 p.

Videler, J., (1993). “Fish swimming.” Chapman & Hall, Fish and fisheries series 10, 260 p.

Wardle, C.S., (1980). “Effects of temperature on the maximum swimming speed of fishes.” Environmental Physiology of Fishes, Plenum Press (ed.), New York and London, 723 p.

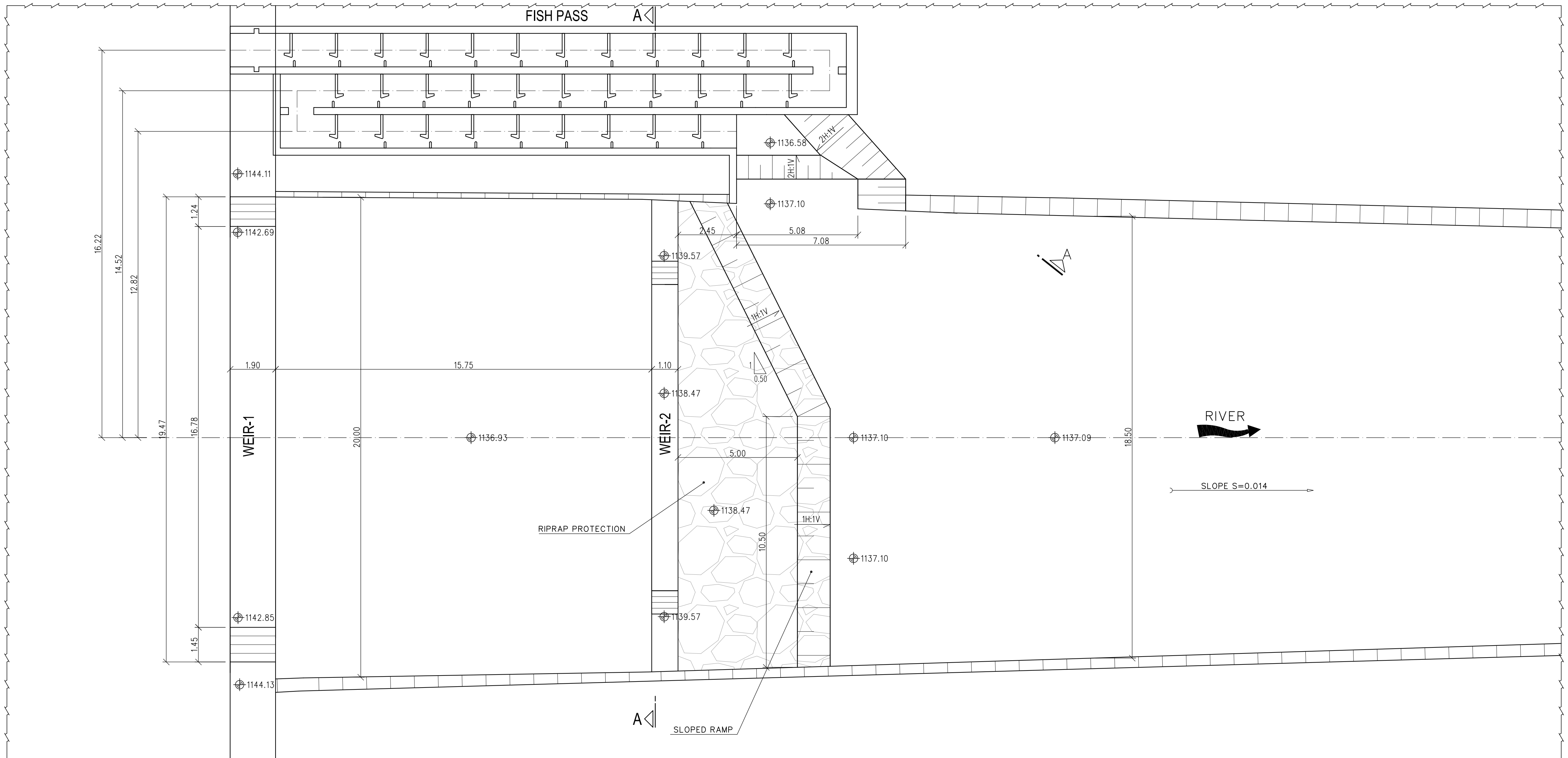
Webb, P.W., (1975). “Hydrodynamics and energetics of fish propulsion.” Bull. Fish. Res. Bd. Can., 190, 158 p.

Williams, J. G. (2011). “The development of fish passage research in a historical context Christos Katopodisa.”

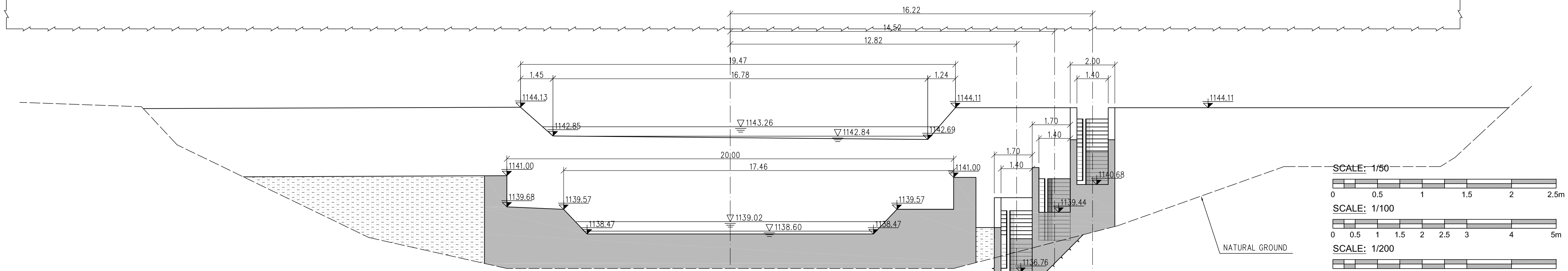
Zhou, Y., (1982). “The swimming speed of fish in towed gears, a reexamination of the principles.” Dept. of Agriculture and Fisheries for Scotland, Work. Pap. 4, 55 p.

APPENDIX

Three technical drawings are given on the following pages.

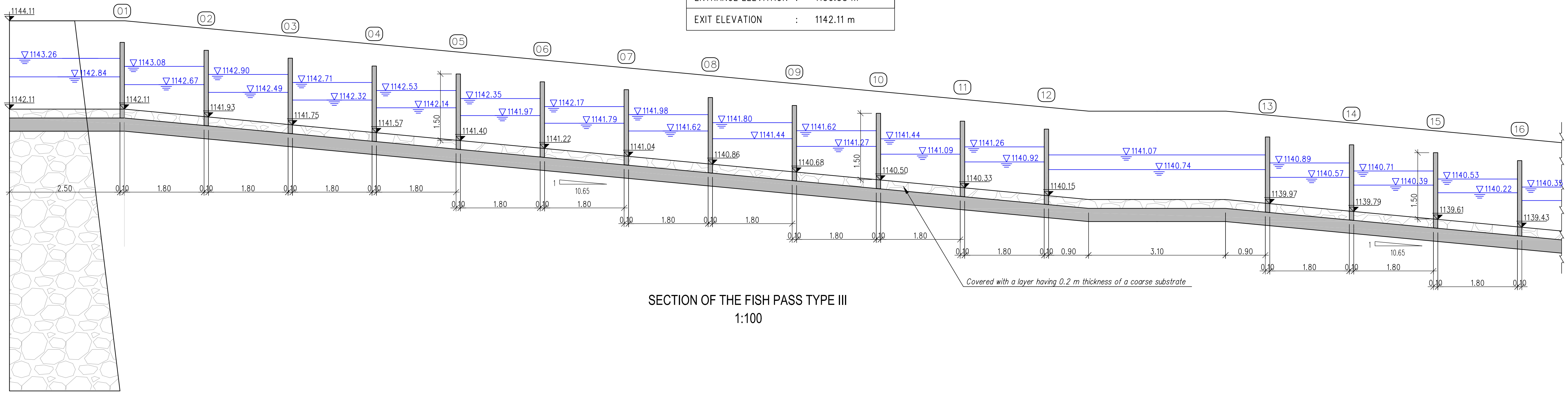


GENERAL LAYOUT OF UZUNGÖL WEIR 1
1:200

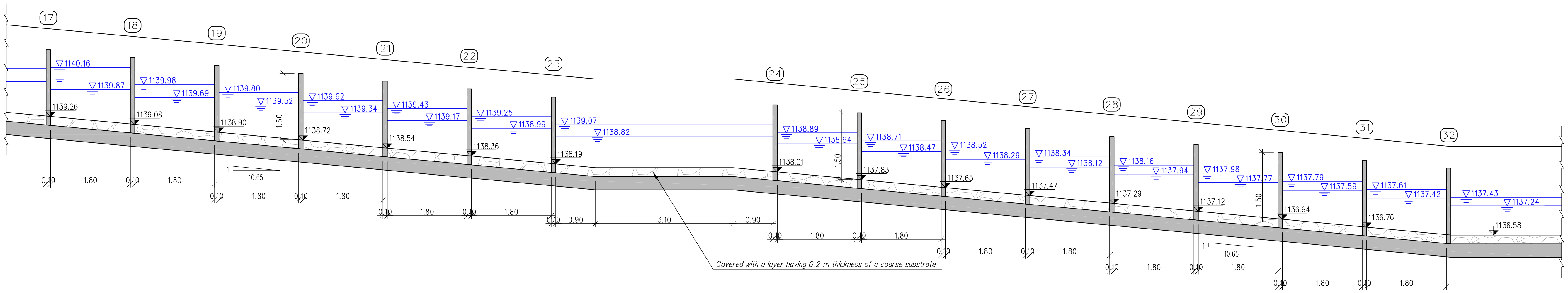


SECTION A-A
1:200

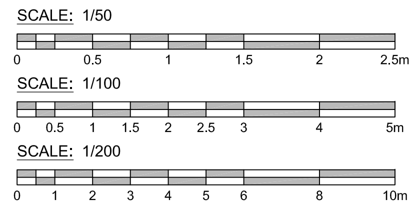
FISH PASS CHARACTERISTICS		
NUMBER OF POOLS	:	n = 31 pools
POOL WIDTH	:	b = 1.40 m
SLOT WIDTH	:	s = 0.17 m
POOL LENGTH	:	l = 1.90 m
SLOPE	:	S = 1 : 10.65
ENTRANCE ELEVATION	:	1136.58 m
EXIT ELEVATION	:	1142.11 m

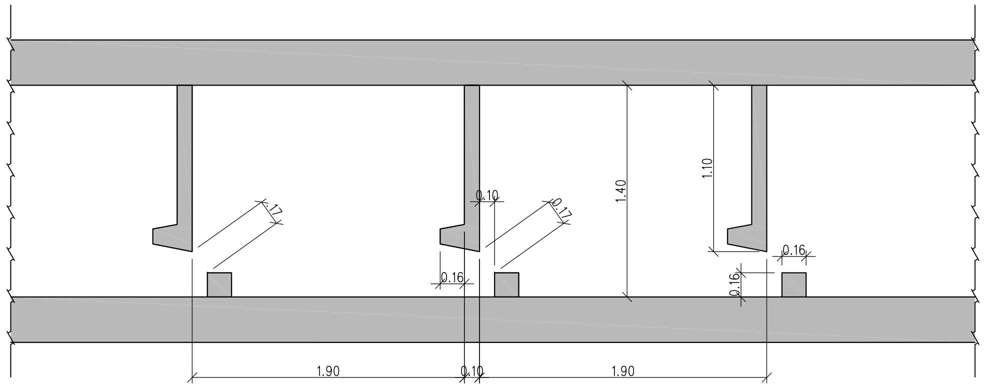


SECTION OF THE FISH PASS TYPE III
1:100

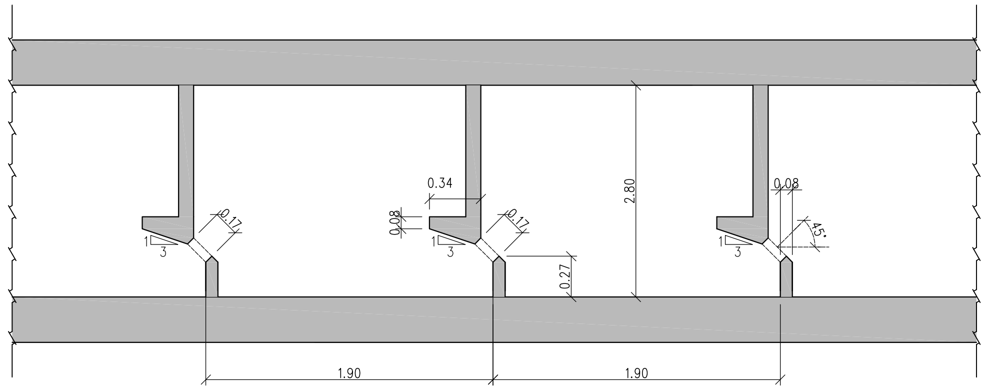


SECTION OF THE FISH PASS TYPE III
1:100

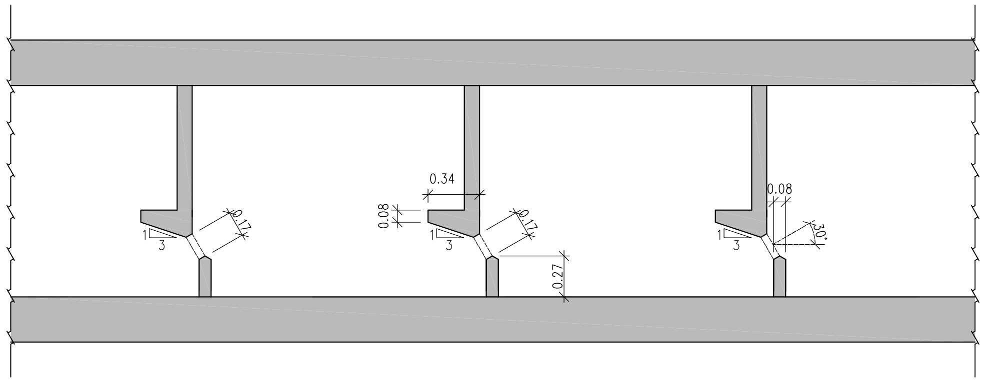




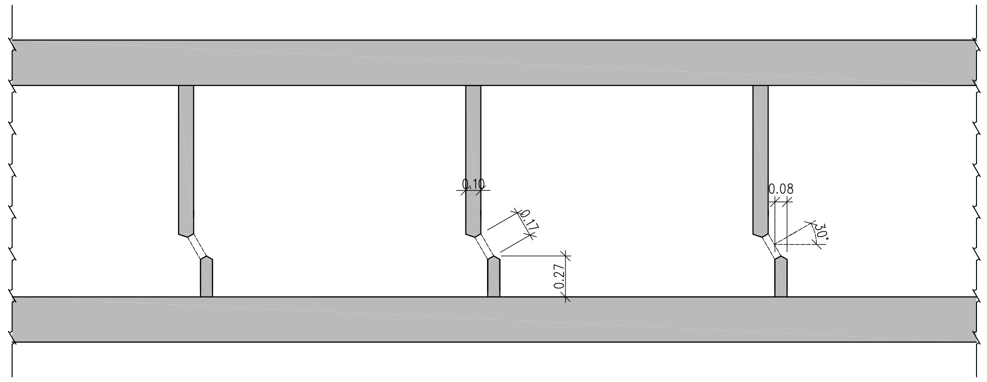
FISH PASS TYPE I
1:50



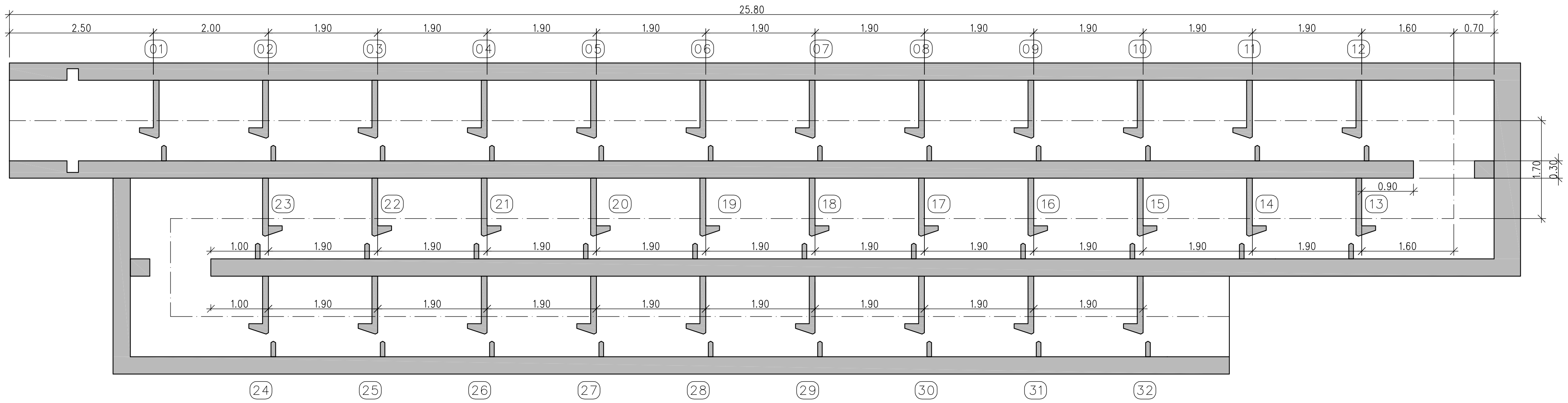
FISH PASS TYPE II
1:50



FISH PASS TYPE III (Suggested Type)
1:50



FISH PASS TYPE IV
1:50



PLAN VIEW OF THE FISH PASS TYPE III
1:100