NUMERICAL MODELLING OF FREE SURFACE FLOWS ON ROUND VERTICAL SLOT FISH PASSES

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ABSTRACT

NUMERICAL MODELLING OF FREE SURFACE FLOWS ON ROUND VERTICAL SLOT FISH PASSES

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Dams and weirs built on the rivers block the flow and prevent fishes from migrating along the river. To overcome this problem, fish passes can be built at those blocked locations along the river by providing a gently sloped channel with low flow rates and enough water depth to allow fish to ascend. Considering the design process, understanding the hydrodynamics inside fish pass structures is important. By using three dimensional numerical simulations, parameters like flow rates, velocity, turbulence and water depth inside the fish pass can be obtained. In this study, a relatively new type of vertical slot fish pass called round vertical slot fish pass is investigated numerically and adopted to Uzungöl Weir-1. Comparing with the previous study of Özkaya (2014) on conventional vertical slot fish passes, it was observed that round vertical slot fish passes have advantage in terms of lower turbulent kinetic energy values inside the resting pools. It is also shown that with numerical modelling different design alternatives can be tested easily without the need of expensive physical models.

Keywords: Computational Fluid Dynamics, Flow 3D, Numerical Modelling, Round Vertical Slot Fish Pass

ÖZ

YUVARLAK HAVUZ GEÇİDİ TİPİ BALIK GEÇİTLERİNDE SERBEST YÜZEYLİ AKIMIN SAYISAL MODELLEMESİ

Koçal, Çiğdem
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Akarsulara inşa edilen barajlar ve bentler akımın kesilmesine ve balık göçünün engellenmesine sebep olmaktadır. Çözüm olarak nehir boyunca tıkalı yerlere, balıkların yükselmesine izin verecek kadar düşük akış hızlarına ve yeterli su seviyesine sahip hafif eğimli bir kanal sağlayarak balık geçitleri inşa edilmektedir. Dizayn aşamasında bu yapılardaki akımın hidrodinamiğini anlamak önemlidir. Üç boyutlu sayısal benzetim yöntemleri kullanılarak balık geçitlerindeki debi, hız, türbülans ve su seviyesi gibi parametreler elde edilebilir. Bu çalışmada dikey yarıklı balık geçitleri arasında yeni bir tasarım tipi olan yuvarlak havuz geçidi tipi, Uzungöl Bent-1 yapısına uyarlanarak sayısal hesaplamalarla incelenmiştir. Özkaya'nın (2014) klasik dikey yarıklı balık geçidi ile ilgili çalışmasıyla kıyaslandığında, yuvarlak tipteki dinlenme havuzlarında elde edilen daha düşük türbülans kinetik enerji değerleri, bu tipteki balık geçitlerinin daha avantajlı olduğunu göstermiştir. Ayrıca farklı tasarım alternatiflerinin pahalı fiziksel modellere ihtiyaç duyulmadan sayısal modelleme ile kolayca test edilebileceği bu çalışmada gösterilmiştir.

Anahtar Kelimeler: Hesaplamalı Akışkanlar Dinamiği, Flow 3D, Nümerik Modelleme, Yuvarlak Balık Geçidi

To my family

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L_{fish}	: Fish length (m)
D_{fish}	: Fish diameter (m)
Δh_{total}	: Head difference between entrance and exit of fish pass (m)
R_{min}	: Minimum pool radius (m)
D_{pool}	: Diameter of pool (m)
s, s_w	: Slot width (m)
I	: Slope of fish pass
L	: Length of inclined fish channel (m)
$\mathrm{H_{slot}}$	: Water depth in slot (m)
$\mathrm{H_{pool}}$	: Water depth in pool (m)
$\mathrm{h_{ex,min}}$	: Water depth for minimum flow case in exit (m)
$\mathrm{h_{ex,max}}$	: Water depth for maximum flow case in exit (m)
$\mathrm{h_{en,min}}$	: Water depth for minimum flow case in entrance (m)
$\mathrm{h_{en,max}}$	: Water depth for maximum flow case in entrance (m)
Q_{30}	: Discharge below 30 days in a year (m^3/s)
Q_{330}	: Discharge below 330 days in a year (m^3/s)
k	: Turbulent kinetic energy (m^2/s^2)
V_{max}	: Maximum flow velocity (m/s)

CHAPTER 1

INTRODUCTION

1.1. Fish Passes

The structures like dams and weirs built on rivers against flooding, for irrigation purposes and energy requirements block the flow section and do not allow fish migration. The negative effects of such structures on migratory fish can be prevented with properly designed fish passes. Thanks to fish passes, fish can pass through dams and weirs when they migrate with the purposes of nutrition and spawning (Eruz et al., 2010). For that reason, various fish passage types have been developed by considering different types of fish species to decrease the negative effects of the structures constructed on rivers. Herein, it is stated that fish pass design should be done by taking into consideration the physical features of the weakest type or the type which is under the threat of extinction (United States Department of Agriculture, 2007). In this regard, living space area and migration routes of fish species are of great significance.

At present, the most reliable document for design, sizing, monitoring of fish pass structures is DWA-M 509 in which based on the application examples, biological and technical basics are explained and calculation steps and methods are provided for the application and design of fish passages.

1.2. Types of Fish Pass

Unlike previous DWA documents, the recent guideline DWA-M 509 does not classify fish passes as close to nature and technical structure types. According to DWA-M 509, fish passes can be classified into three groups which are pool type fish pass, channel type fish pass and special construction types.

1.2.1. Pool Type Fish Pass

The main principle of a pool pass is dividing a channel from the headwater to the tail water by building cross-walls to create a series of stepped pools where potential energy of the water is gradually reduced in these pools. Fish might face with 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.

DWA-M 509 states that pool passes are one of the oldest types of fish passes and they are appropriate for enabling the migration at dams for both strong fish types and for small and bottom oriented species. An everlasting rough bottom can be built to provide opportunities for ascent to the benthic fauna in pool passes.

Pool type fish passes can also be categorized as classical pool pass, vertical slot pass and rough base channel – pool combination pass.

1.2.1.1. Classical Pool Pass

Classical pool passages are considered to be the oldest fish ways in practice and have proven to be basically suitable for design and installation (DWA-M 509).

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 (Figure 1.1 – Type 1, Type 2 and Type 4). However, pool passes are disadvantageous due to their high maintenance requirements, which result from obstruction of the orifices by debris. Since the orifices can be occasionally clogged by debris, pool passes need regular cleaning at least at weekly intervals.

1.2.1.2. Vertical Slot Pass

Due to rock slides during railway construction in the Fraser River at Hell’s Gate, Canada, the vertical slot pass design was developed to solve passage problems where other fish pass types such as denil, pool and weir fish ways were known but did not work with the hydraulic conditions in that area (Katopodis et al., 2011). Since the mid-1980s, this type of structure has been increasingly used in Europe (DWA-M 509).

The vertical slot passes consist of a sloped rectangular channel with pools divided by concrete or wood. Water flows towards the downstream with passing the vertical slot from one pool to the next pool below (Figure 1.1 – Type 3). 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 direct water into the pool for preventing the short circuit. Fish can pass the slots with burst speed and can rest in the pools. Flow rates up to 100 l / h can be managed with vertical slot passages (DWA-M 509).

There are a lot of advantages of vertical slot passes when compared with the other types. The most important advantage is that it is not sensitive to water level fluctuation of tail water or headwater. It is suitable to be used for both small streams and large rivers. Vertical slots are quite appropriate for bottom living. 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.

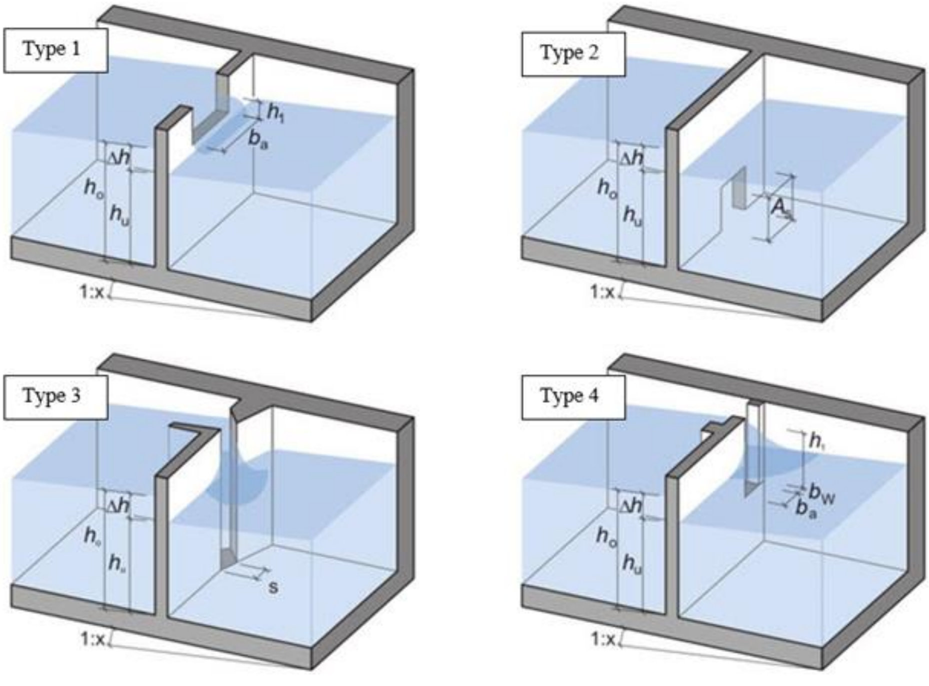


Figure 1.1. Opening types on the cross - walls of pool fish passes (DWA-M 509)

There is another type of vertical slot fish pass named as round vertical slot fish pass described in DWA-M 509. The information about this relatively new type of vertical slot fish pass is given in detail in Chapter 1.3 as the scope of this study.

1.2.1.3. Rough Channel - Pool Pass

Rough channel-pool passages are a combination of a rough channel and a pool-type fish pass where the cross walls are replaced by column-type high-edged stones. In this way, it is possible to select slopes greater than conventional rough channels up to a slope of 1:10. Herein, it is important that the differences in water level between the pools and permissible flow rates should not exceed the relevant design values (DWA-M-509).

Rough channel - pool passages usually require a separation wall made of solid masonry or concrete as shown in Figure 1.2.

Figure 1.2. Rough channel – pool pass at Themar Werra River (DWA-M 509)

1.2.2. Channel Type Fish Pass

1.2.2.1. The Denil Fish Pass

Denil fish way was designed by G. Denil in Belgium at the beginning of the twentieth century. This fish pass consists of a channel in which there are closely located baffles on the floor (Figure 1.3). The reverse currents formed between these baffles generate relatively low flow velocities close to the bottom region of the baffle sections because of the energy dissipation during current interactions.

As an advantage, Denil fish pass can be installed at one time, allowing to reorganize these fish passages cost-effectively under limited spatial conditions. In addition, this type is not affected by the changes in downstream water level.

DWA-M 509 indicates that Denil fish ways have been designed with a slope of 1: 5 to 1: 4 (20 to 25%) and with a channel length of 12 m to 20 m in the past. At present, it is known that, this type does not create a stagnant area within the channel. For this reason, migratory fish must cross the migration corridor quickly. Therefore, in Denil fish pass only the strong fish species with high performances can ascend.

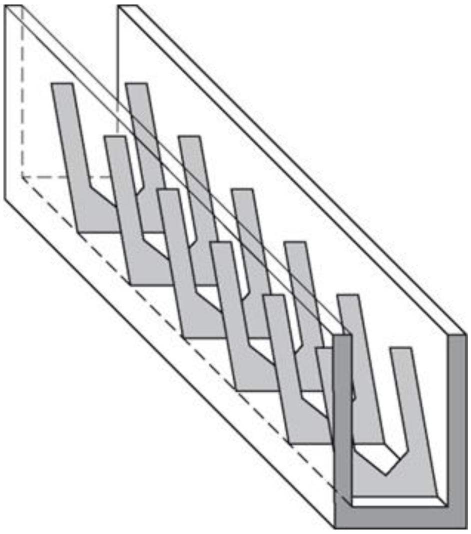


Figure 1.3. Denil pass demonstration (DWA-M 509)

Denil passages have not been built in Germany since the mid-1990s. However, a recent research in Australia has shown that it is possible to enable the week species to migrate with Denil fish ways by adapting the slope of the channel according to these species (Stuart et al., 2007).

1.2.2.2. Brushed Fish Pass

This type of structure was originally developed to be used as a ramp for small boats and as a passage for fish. On the base of rectangular or trapezoidal cross-section, the brush packs are placed as a hydraulically roughness element.

The advantage of brushed fish passes is that if the brushes are elastic and not clogged with the supernatant, a large proportion of the high energy can be dissipated in the brush packs (DWA-M 509).

Past experience shows that a brushed gate with medium hydraulic capacity has an economic life of about 15 years. However, the passage must be covered with a wooden control cover to dry it at a certain distance, and the excessively deformed brushes within the migration corridor should be cut or replaced.

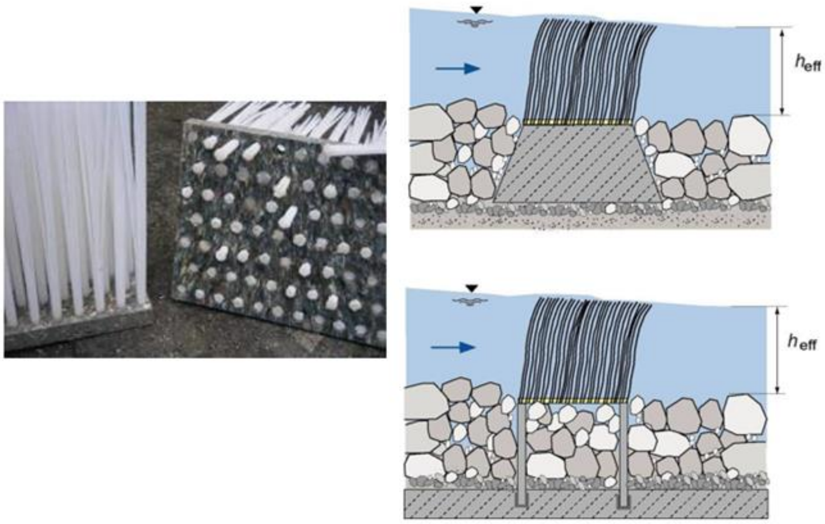


Figure 1.4. Brush package consisting of a carrier plate to which the brush bundle is placed (Left), brush package fixing on concrete foundation and pedestal bearing plate (Right) (DWA-M 509)

1.2.2.3. Eel Ladder

The eel is a migratory fish that grows in rivers then migrates to the sea. Due to the upward migration of the catadrome species of eel (Anguilla anguilla), especially for young ones, some special requirements must be provided for this species. In particular, the glass eel and early elver forms with a body length of 8 cm to 15 cm tends to swim towards the surface of the water rather than the bottom, compared to older eels. At the same time, the swimming capacity of these fish is limited which corresponds to 0.3 m/s to 0.5 m/s and the burst swimming speeds are 0.7 m/s to 0.8 m/s. However, older ones adobt a bottom-oriented lifestyle and at the same time their swimming capacity increase in such a way that they can pass through classical fish passages (DWA-M 509).

An eel ladder illustration is given in Figure 1.5.

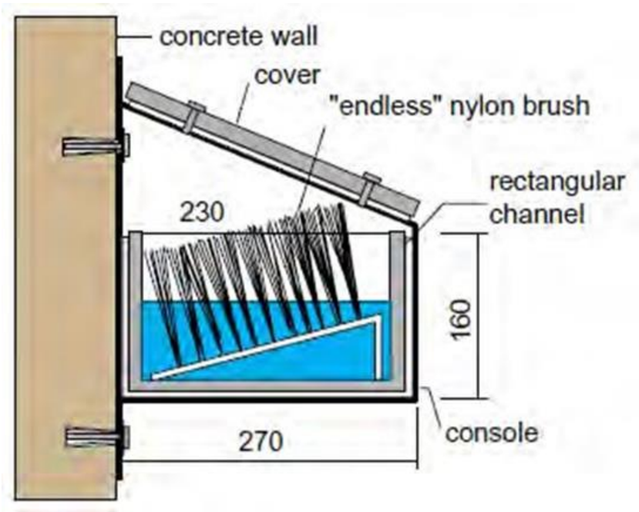


Figure 1.5. The eel ladder at Zeltingen dam on Moselle River (DWA-M 509)

The eel ladders are placed in the mouths of the river and the lower parts of the river to allow upstream migration of glass eel and Anguilla anguilla. These types of structures are not sufficient as a fish passage alone because they eliminate a large number of species. However, these structures play an important role in the upstream migration of young eels (Anguilla anguilla).

1.2.3. Special Types of Fish Passes

The principle of operation in all fish passages and fish migration structures is to establish a migration corridor through which the fish can overcome with its own power through a structure. On the other hand, herein three special fish pass types are given, where the fish are actively transported to the upstream side without using their own power.

- Fish chambers: Fish directed into a room at the downstream level, then that room is filled up with water to the upstream level.

- Fish elevator: It is described as a mechanical transfer device where the fish is transported from downstream to upstream where it will be released.

- Catching gates: They are installed to catch migratory fish in downstream transport systems. The caught fish is then transported to the upstream side by cargo ships.

1.3. Scope of the Study

The scope of this study is to examine a relatively new type of vertical slot fish pass called round vertical slot fish pass which is claimed as the most convenient type to the needs of a fish (DWA-M 509).

At present, there is no detailed information on the construction and hydraulic design of round vertical slot fish way in recent worksheets and standards. There are some manufacturer's specifications about geometrical parameters which can be evaluated only by means of numerical modelling.

Hereby, in order to check the existing information in standards and manufacturer specifications, designing round vertical slot passes with different geometries and finding out the suitability of this type of fish pass for the required hydraulic conditions are studied with numerical analyses.

1.3.1. Literature Review

In DWA-M 509, it is stated that Jens (1995) first described a flow which is guided meanderingly through circular pools with vertical slot passes. Until today, fish passes with different shape of pools and slots, which were called as meander type fish passes, were designed and constructed. However, it is stated that this type of fish passes was designed and constructed mostly in Germany and Switzerland. Besides, the experiences and knowledge of meander-type fish passes published in technical literature are limited and generally only available in German.

At present, there are three types of meander-type fish pass which are C-type, J-type and H-type. Stamm et al. (2015) states that the basic design has a staggered alignment of circular basins for each type of meander fish pass where each pool is connected to its neighbour by an opening (slot). Because of this arrangement, a meandering current can be generated in the pools. Although, these type of fish passes have already been built a lot, hydraulic parameters of basins are not known exactly.

Figure 1.6 shows that the C-type is the most preferred type among meander – type fish passes.

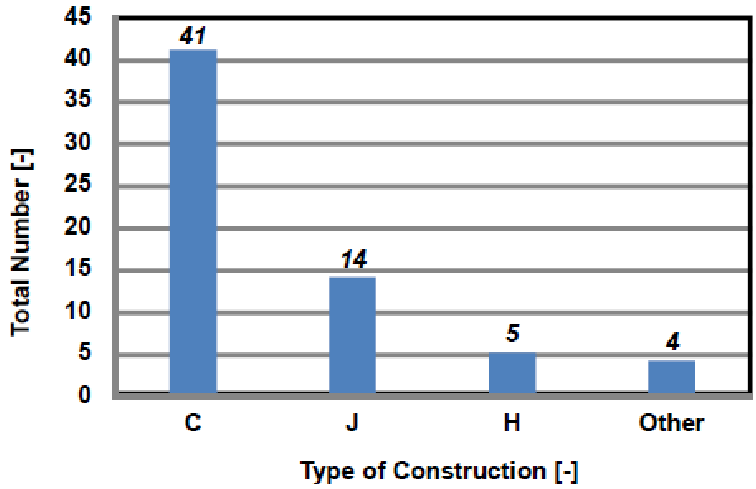


Figure 1.6. Meander type fish ways distribution built in Germany and Switzerland (Stamm et al., IAHR 2015)

The geometry of C-type, J-type and H-type fish passes are illustrated below respectively.

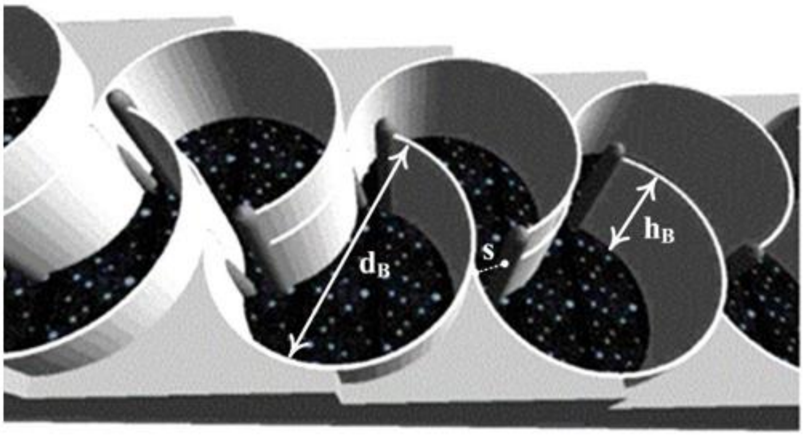


Figure 1.7. C - type fish pass (Peters, 2005; Stamm et al., 2015)

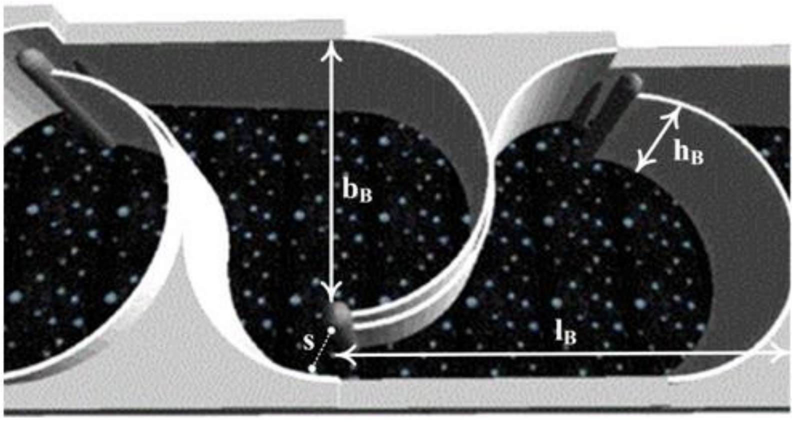


Figure 1.8. J – type fish pass (Peters, 2005; Stamm et al., 2015)

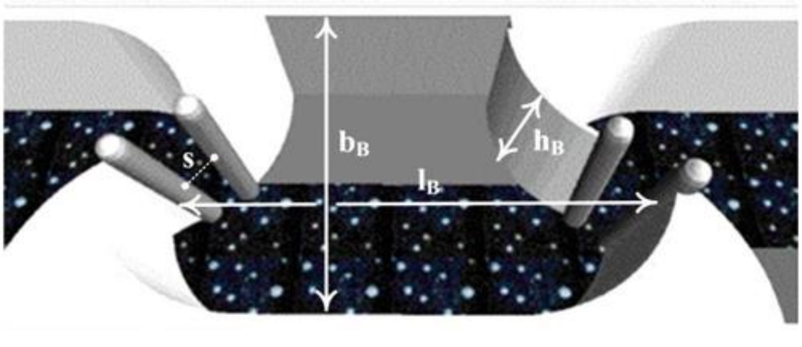


Figure 1.9. J – type fish pass (Peters, 2005; Stamm et al., 2015)

Stamm et al. (2015) give information about appropriate channel slopes for each meander type fish pass. Herein, C – type fish pass which is currently named as "round vertical slot fish pass" in DWA-M 509 can be designed with a slope, I of 17 – 30 %.

Additionally, channel slope for J - type and H type are recommended in order of 8 – 17% and 4 – 8 %. Design and hydraulic criteria for meander types recommended by manufacturers are given in Table 1.1 for these 3 – types of meander pass.

Table 1.1. *Typical design and hydraulic criteria for meander type fish passes (Stamm et al. IAHR 2015)*

CRITERIA	C-TYPE	J-TYPE	H-TYPE
I [%]	17 – 30	8 – 17	4 – 8
d_B [m]	1.0 – 2.4	---	---
l_B [m]	---	1.5 – 3.5	1.5 – 3.5
b_B [m]	---	1.0 – 2.0	1.0 – 2.0
h_B [m]	0.75 – 3.0	0.75 – 3.0	0.75 – 3.0
Q [l/s]	50 – 1000	500 – 1000	500 - 1000
Δh_B	0.14 – 0.2	0.14 – 0.2	0.08 – 0.2
s [m]	0.075 – 0.25	0.1 – 0.25	0.1 – 0.3

DWA-M 509 states that the fish can perform only linear swimming maneuvers without problems due to their rigid body axes and cannot swim at short curves and edges. In particular, migratory fish is adversely affected due to shrinkage of the current generated just after the main current pass the vertical slot (Figure 1.10 – Left). For this reason, minimum pool diameter for the round shape pool should be about $3 \cdot L_{fish}$ where L_{fish} is the length of the largest species on migration corridor. Moreover, the distance, d_f between the theoretical fish migration corridor and outer wall of the pool should be approximately $2 \cdot D_{fish} \sim 3 \cdot D_{fish}$ where D_{fish} is the thickness of the biggest fish species on migration corridor (Figure 1.10 – Right). In addition, the minimum distance between the centre line of opening (slot) and pool's outer wall is recommended as $1 \cdot D_{fish}$. It should be noted that these distances mentioned above are only recommended for C – Type in DWA-M 509.

Figure 1.10. Current shrinkage around vertical slot (DWA-M 509) (Left); Round vertical slot fish pass on Nethe River, df: distance between theoretical fish migration corridor (yellow arrow) and outer wall of the pool (Right)

Although there is no detailed information on hydraulic design of meander-type fish passes in recent worksheets and standards, the manufacturer's specifications (geometrical parameters, hydraulic design) are currently used when building meander-type fish passes (Stamm et al., IAHR 2015). Among these worksheets and standards, DWA-M 509 is the most important regulation which describes a meander-type fish pass which is called as round vertical slot fish pass.

DWA-M 509 sets minimum and maximum design parameters for fish passes facilities that consider sizes of typical fish species in Table 1.2 and Table 1.3. However, it should be noted that these parameters only apply to C-type passes, whereas J- and H-type are not mentioned in this standard.

Table 1.2. *Typical design and hydraulic criteria for round shape type fish passes (DWA-M 509)*

Fish species	Min pool radius R_{min} (m)	Min. Slot width, s (m)	Min. Water depth in slot, H_{slot} (m)
Brown Trout (*Salmo trutta f. fario*)	1.0**	0.3	0.6**
Grayling (*Thymallus thymallus*), Chub (*Squalius cephalus*), Roach (*Rutilus rutilus*)	1.25*	0.45	0.8**
Barbel (*Barbus barbus*), Pikeperch (*Sander lucioperca*), Sea Trout (*Salmo trutta f. trutta*)	1.5*	0.45	0.8**)
Pike (*Esox lucius*), salmon (*Salmo salar*), Hucho (*Hucho hucho*)	1.8*	0.55	0.9**
Carp bream (*Abramis brama*), Carp (*Cyprinus carpio*)	1.8**	0.6	1.0**
*Fish length (L_{fish}), ** Hydraulic condition requirement			

Table 1.3. *Maximum flow velocity (v_{max}) for fish passes depending on fish region and total head (Δh_{total}) including safety factors S_p = 0.9, S_V = 0.9 and S_b = 1.0 (DWA-M 509)*

Total head, Δh_{total} (m)	Upper Trout Region	Lower Trout Region	Grayling Region	Bream Region	Bream Region	Ruffe-Flounder Region
v_{max} (m/s) ($\Delta h_{total} \leq 3.0\ m$)	2.0	1.9	1.8	1.6	1.5	1.4
v_{max} (m/s) ($3.0 < (\Delta h_{total} \leq 6.0\ m$)	1.9	1.8	1.7	1.5	1.4	1.3
v_{max} (m/s) ($6.0 < (\Delta h_{total} \leq 9.0\ m$)	1.8	1.7	1.6	1.4	1.3	1.2
v_{max} (m/s) ($(\Delta h_{total} \geq 9.0\ m$)	1.7	1.6	1.5	Case by case basis		

The same basic geometrical and hydraulic requirements for conventional types of fish passes are also valid for round pool passes. In addition, the basic requirements for the arrangement of the base of the channel and building materials such as precast concrete or plastic materials for the cross walls and main channel are similar to those of other types of construction.

The most important difference between the round vertical slot pass and conventional vertical slot pass with rectangular pools is the current conditions and energy breakage within the pool (DWA-M 509). After the main current pass the slot, the mixture of jets is formed. Herein, according to current jet theory, energy fracture occurs because of the damping of turbulence significantly along the channel wall. It is stated that the flow rate in the middle of the pool is approximately zero.

According to researchers, the most important advantage of round shape fish pass is that lower turbulence occurs in the pools than the other ones. In addition, it is declared that round type of fish passes shows the best adaptation to the needs of fish. However, it is not scientifically confirmed yet.

Based on previous model studies, it was stated that the flow velocities along the pool wall in round pool passages are approximately two times higher than the conventional vertical slot passages with rectangular pools having the same pool number. Stamm et al., 2015 stated that this result was supported by numerical modeling by Haselbauer and Göhl (2010). The main reason for this is that the current approaching the openings has higher current velocities. Therefore, it is stated that in order to provide design values in terms of the number of pools in round vertical slot fish ways, it is necessary to construct significantly more pools compared to the classical application with rectangular pools.

Due to the absence of the appropriate calculation method, the verification of the design values for the flow rates is made through numerical or physical models in case areas and direct measurements in the operational stage.

1.3.2. Research Objectives

In the literature, it is seen that there are some inconsistencies with several hydraulic and geometric parameters regarding round vertical slot fish passes (C – type). DWA-M 509 and manufacturer specifications are not exactly compatible with each other about minimum pool diameter and slot width. Moreover, while manufacturers recommend a slope range for round vertical slot fish ways, there is no information about it in DWA-M 509.

Regarding the vertical slot fish pass design, there is a study prepared by Kerem Özkaya (2014). According to the hydraulic data taken from Özkaya's working area and considering the target fish species, the convenience of the round-type vertical fish pass in this region can be studied and compared with the existing vertical type fish pass. Hereby, it is possible to have an idea about the claim mentioned in DWA-M 509 which is about the round shape fish passes being the best suited type of fish pass for the needs of fish.

In this study, upstream and downstream hydraulic data for the entrance and the exit of the round vertical slot fish pass to be used in the numerical analyses are taken from the case area studied by Özkaya (2014). Then, based on the criteria presented in DWA-M 509 and manufacturer specifications, several variables are taken into account as geometric design factors which are pool diameter and slot width of fish pass. Herein, according to total head difference and pool diameter, pool numbers and the slope of the structure can be directly adjusted.

In Figure 1.11, the image of turbulent kinetic energy, *k* contours in m^2/s^2 at 0.75h fluid depth of the previous study on conventional vertical slot pass prepared by Özkaya, 2014 is given in order to compare the *k* results obtained in conventional and round vertical slot fish passes presented in Chapter 3.3.

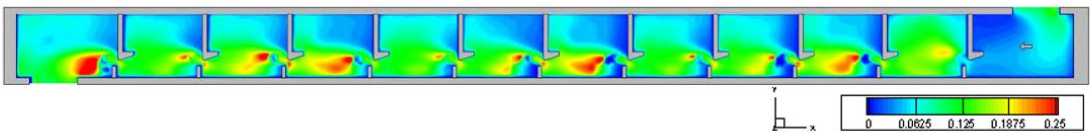


Figure 1.11. Turbulent kinetic energy, *k values in m^2/s^2 at 0.75h fluid depth of the previous study on conventional vertical slot pass by Özkaya, 2014*

In brief, the aim of the study is

- To design a round vertical slot fish pass by referring geometric data given in DWA-M 509 and manufacturer specifications.

- To evaluate the effects of different pool and slot dimensions which are pool diameter, slot width and slope of the channel by means of hydraulic requirements such as velocity, water depth and turbulent kinetic energy.
- To evaluate the suitability of round vertical slot fish pass for the target fish species in study area.
- To compare hydraulic characteristics obtained in the completed fish pass design studied by Özkaya (2014) with the ones obtained in round shape fish pass.

Since there is no method of calculation accepted in the literature for the design of round shape fish pass, performing numerical analyses can be helpful to check the hydraulic requirements in the pools and slots.

CHAPTER 2

DESIGN OF ROUND VERTICAL SLOT FISH PASS

2.1. Previous Study

As mentioned in the section 1.3.2, a previous work on a type of pool fish pass, particularly a conventional vertical slot pass, completed by Özkaya (2014) is used to be able to work on a real case study where hydraulic data readings are available, and where target fish species are known.

In the study of Özkaya (2014), the case area was a weir located on Uzungöl, Solaklı River in Turkey. Also, the target fish species was determined as brown trout.

In Uzungöl region, three types of brown trout exist which are Salmo Trutta Labrax (Karadeniz alabalığı), Salmo trutta fario (Dere alabalığı) and Salmo Trutta Macrostigma (Anadolu alabalığı). Özkaya stated that the average fish length for the case area was taken as 30 cm, and the burst speed of the target species was determined as 2.60 m/s.

Herein, the problem of Uzungöl was specified as the sediment coming with rivers. Cascade weirs were built at the upstream of Solaklı River in order to protect the lake from the risk of sedimentation. In time, these weirs blocked the migration path of fish. Since fish could not reach the spawning area, this situation caused a decrease in number of critically endangered fish species which live in rivers in Black Sea region such as Brown trout. To solve fish migration problem, the optimal fish pass design was suggested by Özkaya for target species brown trout to pass over the obstruction by preparing numerical analyses. Herein, several vertical slot pass types were chosen for the Uzungöl Weir-1 by referring DWVK (1996) and other related referances for dimensioning. Then, 3D solid models of Uzungöl Weir -1 (Figure 2.1) were prepared by Özkaya (2014) to be used in computational fluid dynamics (CFD) analysis.

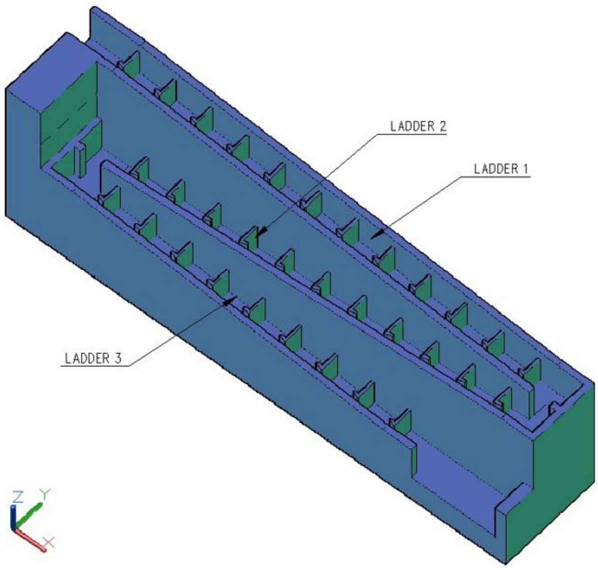


Figure 2.1. 3D solid model of the fish ladder (Özkaya, 2014)

In order to determine the most proper conventional vertical slot geometry, the conclusions were made by comparing velocity magnitudes, streamlines and turbulent kinetic energy (TKE) at different horizontal sections for different geometries.

The chosen type of geometry for conventional vertical slot pass of the study area is given in the Figure 2.2.

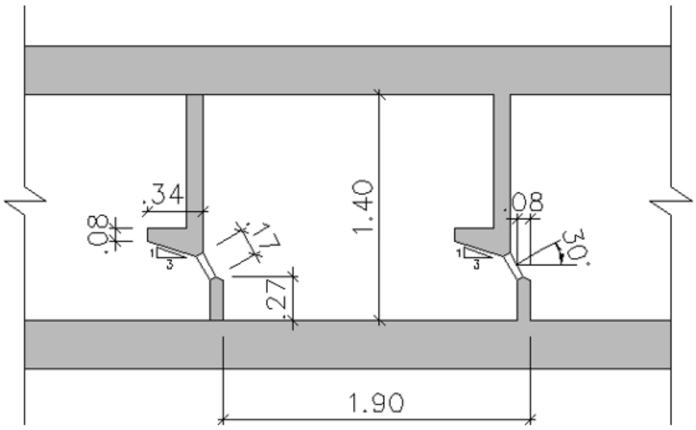


Figure 2.2. Determined conventional vertical slot fish type dimensions (in m) (Özkaya, 2014)

2.1.1. Hydraulic Conditions

For the study area, Özkaya (2014) stated the hydraulic conditions which are the minimum and maximum operating discharges and corresponding water levels at the reservoir.

Herein, for minimum and maximum water levels, the discharge value below 30 days in a year (Q_{30}) and the discharge value below 330 days in a year (Q_{330}) can be used accordingly.

With the data taken from a stream flow station, the minimum and maximum discharge values were found to design the fish pass at the case area which are Q_{30}=0.88 m^3/s and Q_{330}=9.84 m^3/s. Then, Özkaya (2014) calculated the maximum and minimum water levels at the exit and entrance of the fish pass as shown in the Figure 2.3 and Figure 2.4 respectively.

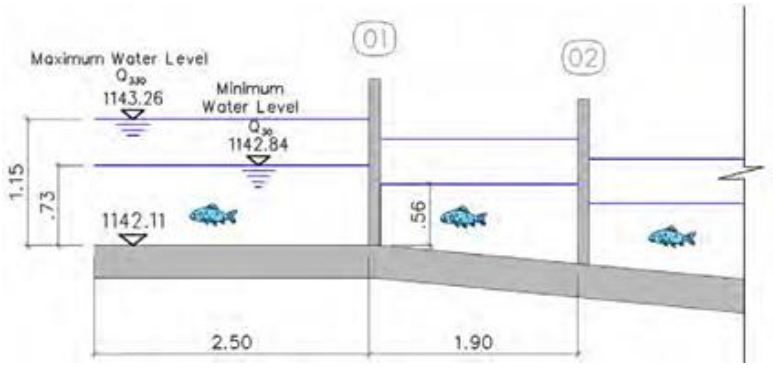


Figure 2.3. Water levels at the conventional vertical slot fish pass exit (Özkaya, 2014)

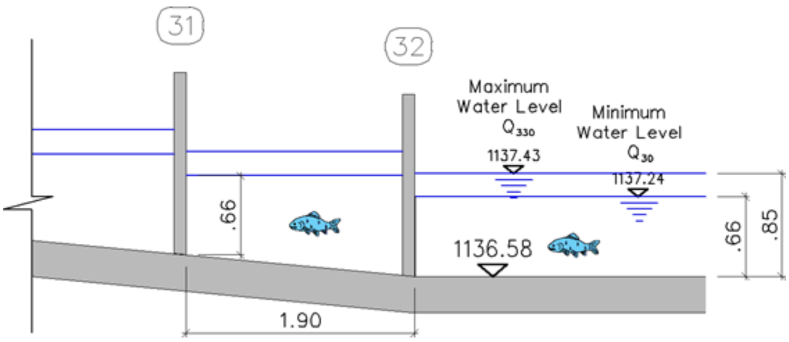


Figure 2.4. Water levels at the conventional vertical slot fish pass entrance (Özkaya, 2014)

Herein, to be used in the design of round vertical slot fish pass, the following hydraulic conditions are taken into account:

- For maximum flow case in exit, water depth, $h_{ex,max}$=1.15 m
- For minimum flow case in exit, water depth, $h_{ex,min}$=0.73 m
- For maximum flow case in entrance, water depth, $h_{en,max}$=0.85 m
- For minimum flow case in entrance, water depth, $h_{en,min}$=0.66 m

2.2. Dimensioning Round Vertical Slot Fish Pass

In section 1.3.1, it is stated that in order to design a round vertical slot fish pass, DWA-M 509 can be considered as the main source for dimensioning of pool diameter and slot width. In Table 1.2, minimum pool diameter for the target fish pass brown trout is given as 2.0 m which is determined regarding the fish length. In this study, pool diameters are taken as 2.0 m, 2.2 m and 2.5 m. Moreover, in Table 1.2, the minimum slot width is given as 0.3 m. In this study, slot width values are taken as 0.2 m, 0.3 m and 0.4 m.

Since there is no information about the slope of the fish pass in DWA-M 509, recommendation of manufacturers about the slope range of meandering type (C – type) fish pass in other words round fish pass is taken into account as a start for design considerations. Herein, in Table 1.1, it is stated that the slope is ranged between the values of 17~30%. Therefore, to be used in design, slope is selected around the value of I=17 %.

In Table 2.1, 27 types of round vertical slot fish pass with different geometries are generated with the combinations of three variables which are pool diameter, slot width and slope. By considering the minimum and maximum flow conditions, 54 models are prepared for the numerical analyses.

A layout plan for entrance and exit of fish pass is not generated in the scope of this study. Herein, the main issue about the design of round vertical slot fish pass is taken as measuring hydraulic characteristics in the pools of the pass. Therefore, each model has one solid shape regardless of geometric details which might be used at the entrance and exit of the pass.

Table 2.1. *Model geometries with selected dimensions for the design of round vertical slot pass*

Model No	Type No	Flow Condition	Slope, I (%)	Slot Width, s (m)	Pool Diameter, D_{pool} (m)	Pool Number	Inclined Channel Length, L (m)
1	Type - 1	min	20.95	0.20	2.00	23	26.40
2		max					
3	Type - 2	min	17.95			27	30.80
4		max					
5	Type - 3	min	15.71			31	35.20
6		max					
7	Type - 4	min	20.95	0.30	2.00	23	26.40
8		max					
9	Type - 5	min	17.95			27	30.80
10		max					
11	Type - 6	min	15.71			31	35.20
12		max					
13	Type - 7	min	20.95	0.40	2.00	23	26.40
14		max					
15	Type - 8	min	17.95			27	30.80
16		max					
17	Type - 9	min	15.71			31	35.20
18		max					
19	Type - 10	min	19.20	0.20	2,2	23	28.80
20		max					
21	Type - 11	min	17.72			25	31.20
22		max					
23	Type - 12	min	16.45			27	33.60
24		max					
25	Type - 13	min	19.20	0.30	2,2	23	28.80
26		max					
27	Type - 14	min	17.72			25	31.20
28		max					
29	Type - 15	min	16.45			27	33.60
30		max					

Table 2.2. *Model geometries with selected dimensions for the design of round vertical slot pass (continued)*

Model No	Type No	Flow Condition	Slope, I	Slot Width, s	Pool Diameter, D_{pool}	Pool Number	Inclined Channel Length, L
			(%)	(m)	(m)		(m)
31	Type - 16	min	19.20	0.40	2.2	23	28.80
32		max					
33	Type - 17	min	17.72			25	31.20
34		max					
35	Type - 18	min	16.45			27	33.60
36		max					
37	Type - 19	min	18.62	0.20	2.5	21	29.70
38		max					
39	Type - 20	min	17.07			23	32.40
40		max					
41	Type - 21	min	15.75			25	35.10
42		max					
43	Type - 22	min	18.62	0.30	2.5	21	29.70
44		max					
45	Type - 23	min	17.07			23	32.40
46		max					
47	Type - 24	min	15.75			25	35.10
48		max					
49	Type - 25	min	18.62	0.40	2.5	21	29.70
50		max					
51	Type - 26	min	17.07			23	32.40
52		max					
53	Type - 27	min	15.75			25	35.10
54		max					

CHAPTER 3

NUMERICAL MODELLING

3.1. General Information About Flow 3D

As mentioned in previous sections, a method of calculation for the design of round vertical slot fish pass does not exist. In this regard, performing numerical analyses can provide information about the hydraulic characteristics of the flow in the fish pass structure. For that, 54 models are prepared for numerical analyses to be performed in FLOW 3D which is a computational fluid dynamics (CFD) software. These models are drawn in AutoCAD software as 3D solid models, and then exported to stl. file format to be used in Flow 3D.

FLOW-3D is an accurate and proven CFD software providing highly-efficient, comprehensive solutions for free-surface flow problems.

It uses Volume of Fluid (VOF) technique to model free surfaces. This VOF technique is developed by scientists, including Flow Science's founder, Dr. C. W. Hirt at the Los Alamos National Laboratory.

The industrial fields such as infrastructure, aerospace, automotive etc. can work on dynamic behavior of liquids and gas with CFD simulations of FLOW-3D software.

In FLOW-3D, grids or geometry can be freely changed, meaning they are independent of each other. This approach is named as non-body fitted meshing because this feature eliminates the compelling task of generating body-fitted grids.

It provides a meshing method called FAVOR™ (Fractional Area Volume Obstacle Representation) which improves problem setup by embedding the geometry directly into the mesh, allowing for rapid adjustments.

3.2. Model Setup

In numerical analysis, turbulence model is based on Renormalization-Group (RNG) method which applies statistical methods to the derivation of the averaged equations for turbulence quantities such as turbulent kinetic energy and its dissipation rate. The RNG model uses equations similar to the equations for k-ε model. However, equation constants that are found empirically in the standard k-ε model are derived explicitly in the RNG model. Generally, the RNG model has wider applicability than the standard k-ε model.

The representative RNG k-ε model equations are given below where G_k represents the generation of turbulence kinetic energy because of mean velocity gradients, G_b as the generation of turbulence kinetic energy because of buoyancy, Y_M as the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate, $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$ and R_ε as constants, α_k and α_ε as turbulent Prandtl numbers for k and ε, μ_{eff} as turbulent viscosity, S_k and S_ε as user-defined source terms (Soe and Khaing, 2017).

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\alpha_k \mu_{eff}\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\alpha_\varepsilon \mu_{eff}\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}-R_\varepsilon+S_\varepsilon$$

The bottom of fish pass should be covered with a layer including coarse substrate in order to reduce the flow rate at the bottom and to ease the migration of young fish and for benthic invertebrate to rest in the gaps of that strata. Therefore, in order to represent the real case, different surface roughness values for basin floor and walls of the fish pass are used which are determined as 0.1 m and 0.01 m respectively.

Only one mesh block is created for each model because of the geometry of fish pass models. Also, finish time assigned to each model changes between 200-400 seconds.

Numerical analyses are run until the system is statistically steady which can be checked when volume of flow rate becomes stable at the end of the calculation. For instance, in Figure 3.1, volume flow rate at the boundary (X_{max}) becomes stable in time meaning that the computation time assigned to the analysis was enough to have accurate results.

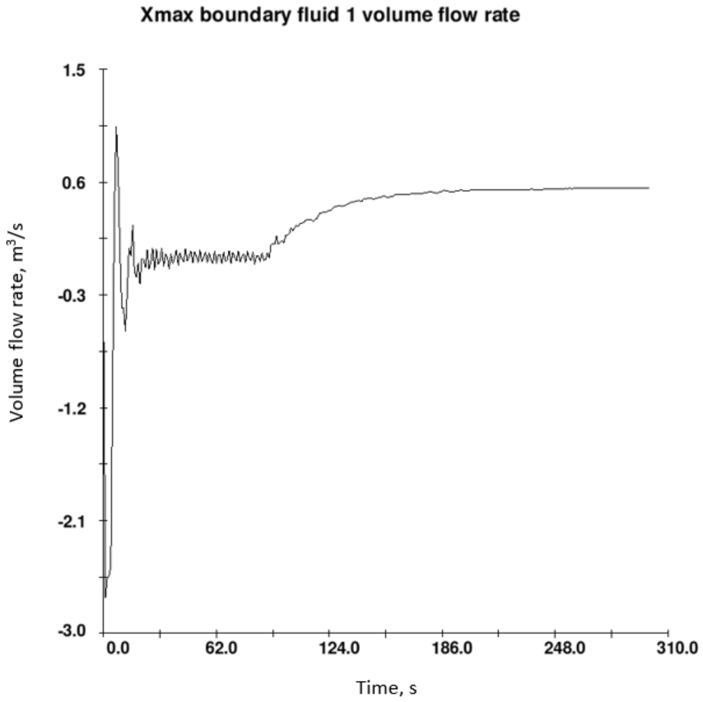


Figure 3.1. Type-1 X_{max} volume flow rate (max flow condition)

3.2.1. Boundary Conditions

In Figure 3.2, typical fish pass section is shown with water levels at the entrance and the exit for minimum and maximum flow cases.

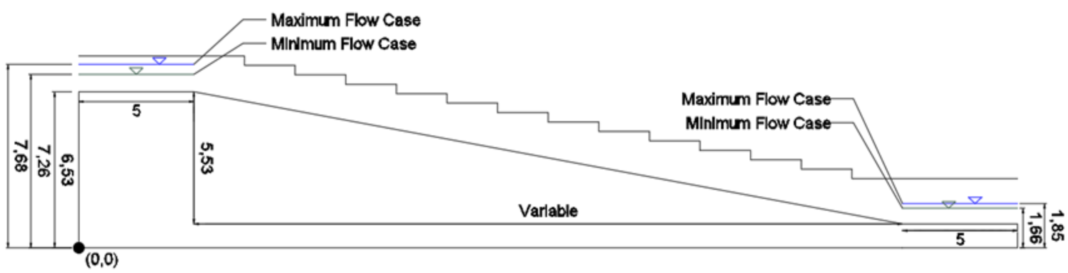


Figure 3.2. Typical fish pass section demonstrating water levels (measurements are in m)

For numerical calculations for each type of round vertical slot fish pass given in Section 2.2, boundary type for entrance and exit is selected as "Specified Pressure" where fluid heights are given as 1.66 m and 7.26 m respectively for minimum flow case, and 1.85 m and 7.68 m for maximum flow case as shown in Figure 3.2. These heights are determined by referring the study of Özkaya (2014) as shown in Figure 2.3 and Figure 2.4.

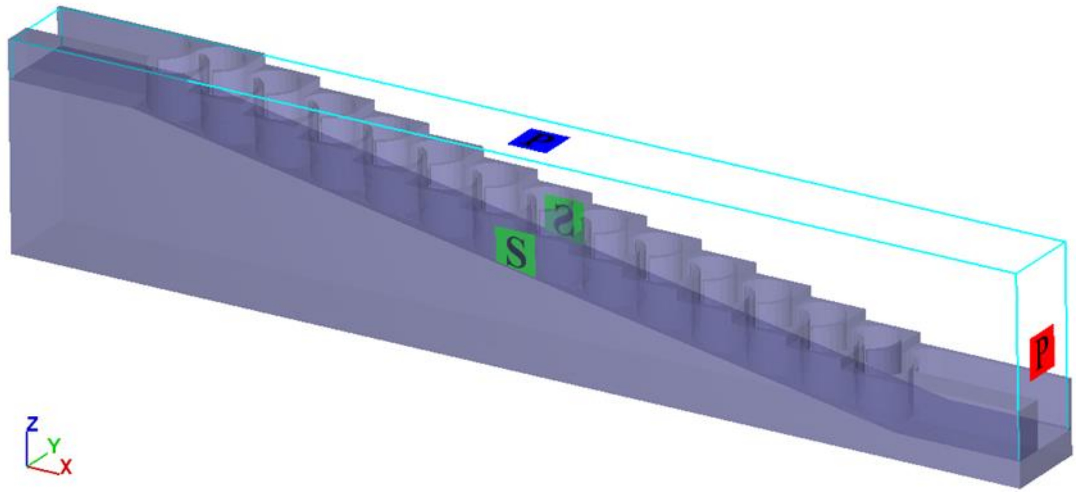


Figure 3.3. Boundary conditions for a typical fish pass

In order to avoid the time-consuming, fill-up process in the channel and to reduce the computation time, initial conditions are applied to each model by generating water volume ready to flow just before entering inclined channel section for minimum and maximum flow cases.

3.2.2. Grid Dependence

Grid dependence check is vital in numerical analysis regarding the computation time and getting accurate results. Although finer mesh can give more accurate results than the coarser one, it takes much more time to complete the analyses and causes larger output file sizes. On the other hand, coarser mesh can cause misleading and inaccurate analysis results.

Before starting numerical calculations of the models given in Table 2.1, grid dependence check is studied for Type – 4 model starting with coarser mesh sizes to finer ones. Herein, volume flow rates at the entrance of fish pass generated with different cell sizes are compared. In Table 3.1 and Table 3.2, the results show that volume flow rates obtained in models with cell sizes of 0.08 m and 0.09 m are similar enough to determine the cell size of all models in this study. Consequently, cell size is taken as 0.09 m for mesh generations of all numerical models.

Table 3.1. *Mesh independency trials for Type – 4 with max. flow conditions*

Cell Size (m.)	Volume Flow Rate (m^3/s) at X_{max}. (at downstream)	Active Cell Number
0.08	0.567	916025
0.09	0.579	658052
0.10	0.471	476207

Table 3.2. *Mesh independency trials for Type – 4 with min. flow conditions*

Cell Size (m.)	Volume Flow Rate (m^3/s) at X_{max}. (at downstream)	Active Cell Number
0.08	0.318	916025
0.09	0.329	658052
0.10	0.263	476207

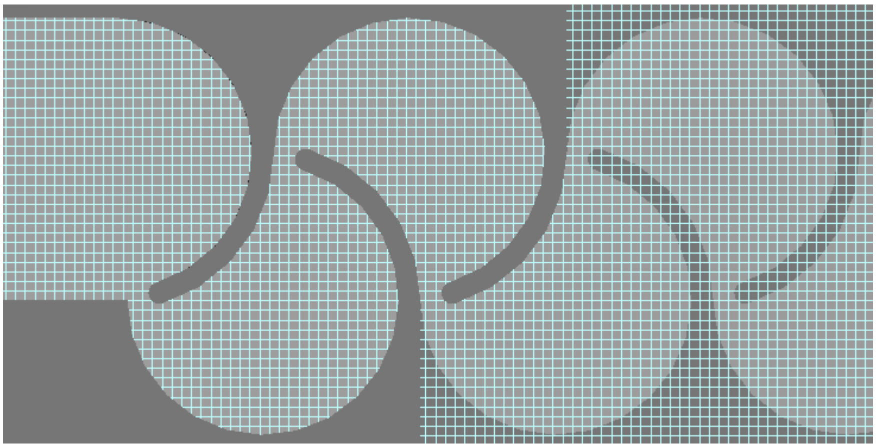


Figure 3.4. Plan view of mesh with 0.09 m cell size

3.3. Evaluation of Numerical Model Results

- Results of Type 1

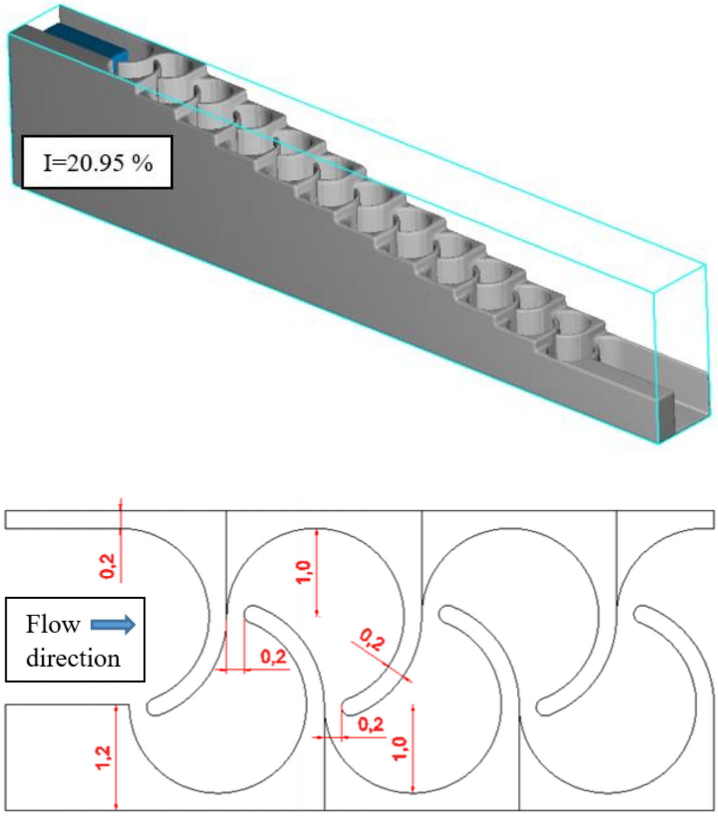


Figure 3.5. Dimensions of Type 1

In Type – 1, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=20.95% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 1 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 1 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.5 and Figure 3.6, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.7 and Figure 3.10, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.9 and Figure 3.12, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.8 and 3.11) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 1 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. In addition, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater than the one considered in Type – 1, Type – 1 geometry is not a proper design for the target fish.

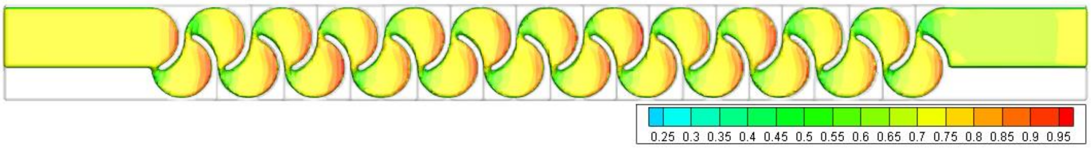


Figure 3.6. Fluid depth of Type 1 considering min. flow rate conditions – Top view

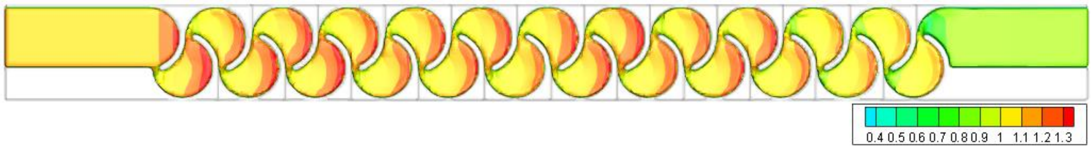


Figure 3.7. Fluid depth of Type 1 considering max. flow rate conditions – Top view

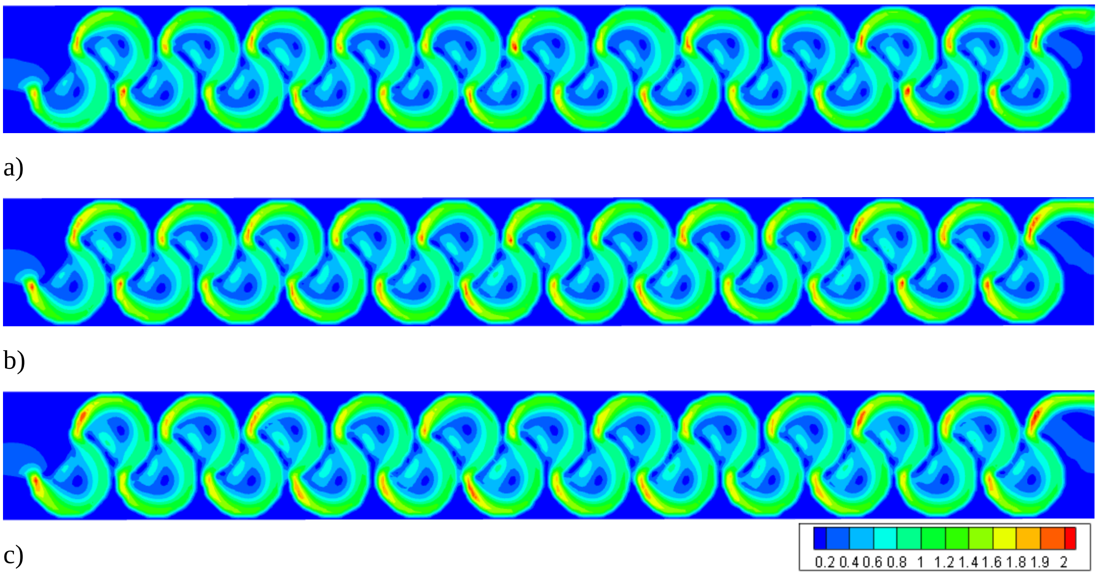


Figure 3.8. Flow velocities of Type 1 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

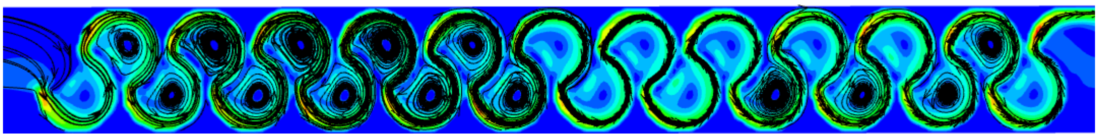


Figure 3.9. Streamlines of Type 1 considering min. flow rate conditions at 0.75h water level

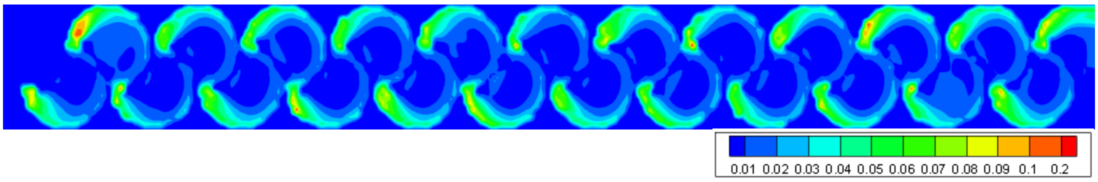
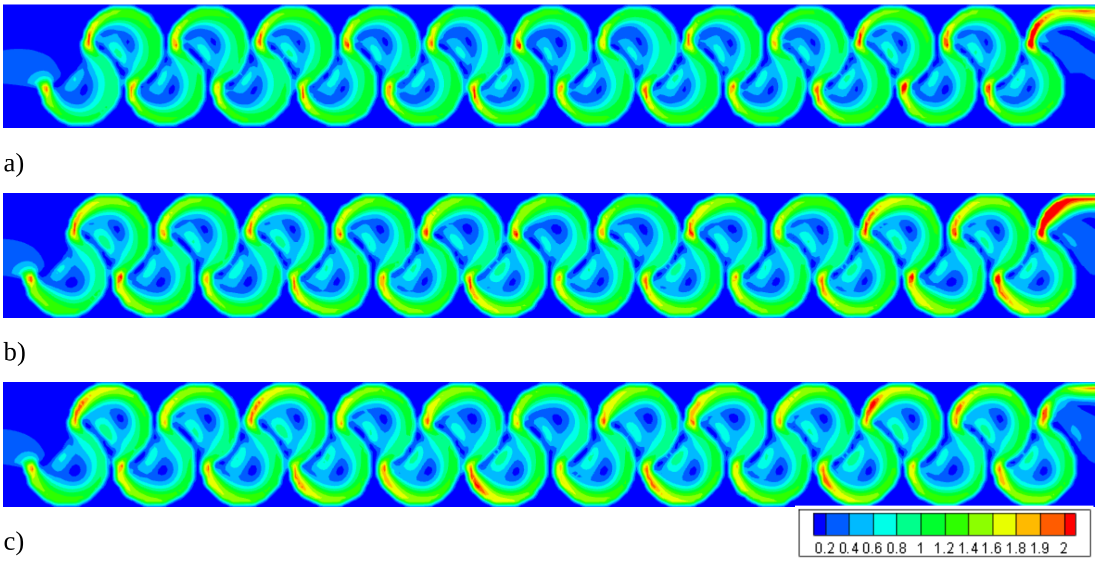


Figure 3.10. TKE of Type 1 considering min. flow rate conditions at 0.75h water level



a)

b)

c)

Figure 3.11. Flow velocities of Type 1 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

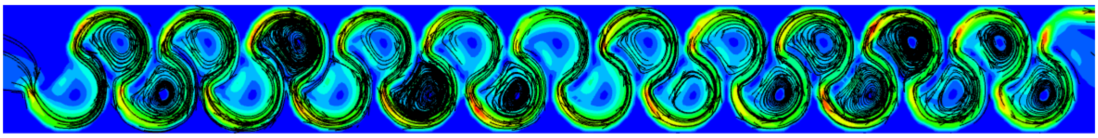


Figure 3.12. Streamlines of Type 1 considering max. flow rate conditions at 0.75h water level

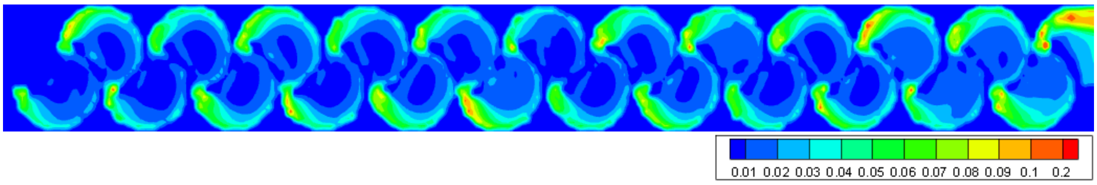
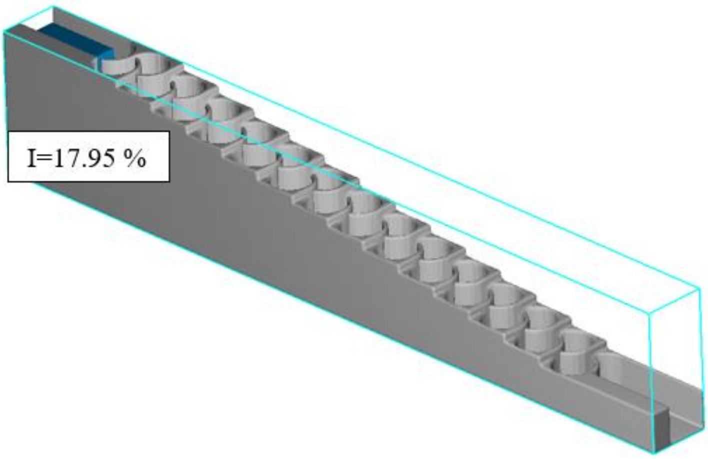


Figure 3.13. TKE of Type 1 considering max. flow rate conditions at 0.75h water level

- Results of Type 2



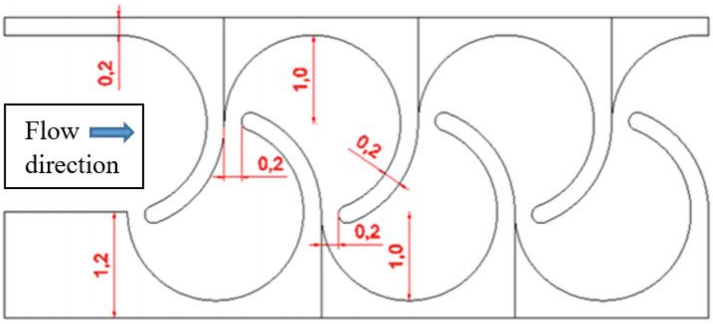


Figure 3.14. Dimensions of Type 2

In Type – 2, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.95% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 2 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 2 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.14 and Figure 3.15, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.16 and Figure 3.19, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.18 and Figure 3.21, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.17 and 3.20) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 2 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. Moreover, the maximum velocity magnitude formed in the pools does not exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. However, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater than the one considered in Type – 2, Type – 2 geometry is not a proper design for the target fish.

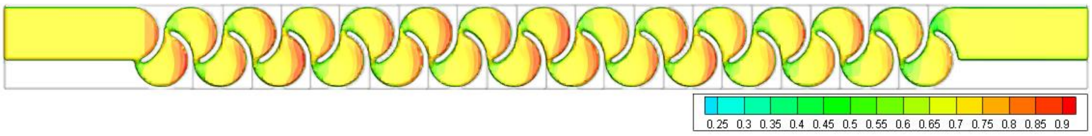


Figure 3.15. Fluid depth of Type 2 considering min. flow rate conditions – Top view

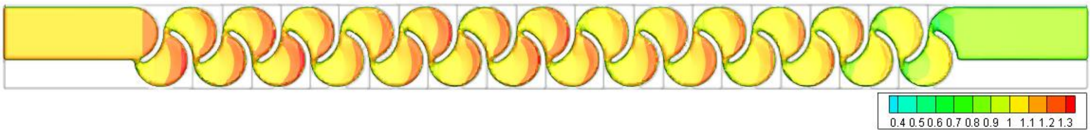


Figure 3.16. Fluid depth of Type 2 considering max. flow rate conditions – Top view

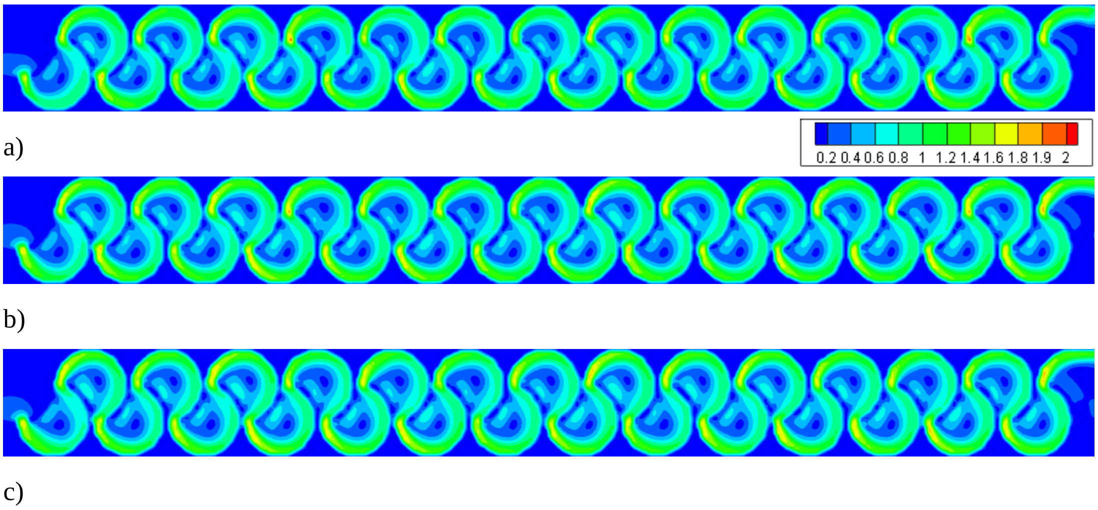


Figure 3.17. Flow velocities of Type 2 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

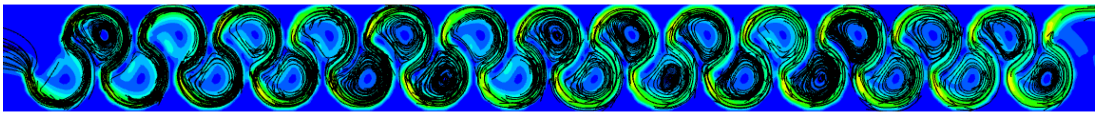


Figure 3.18. Streamlines of Type 2 considering min. flow rate conditions at 0.75h water level

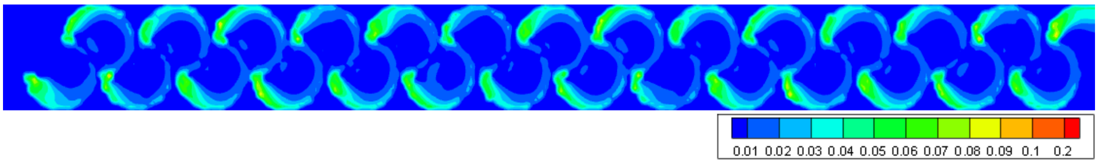
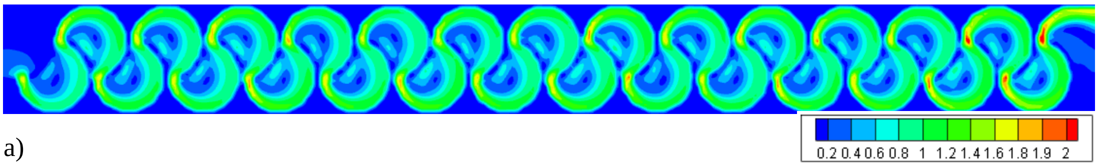
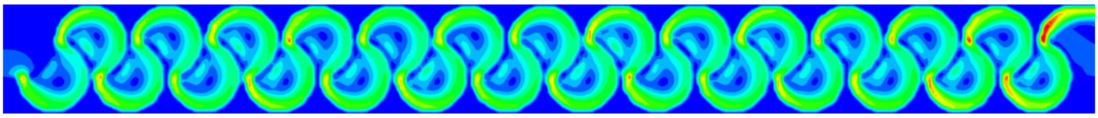


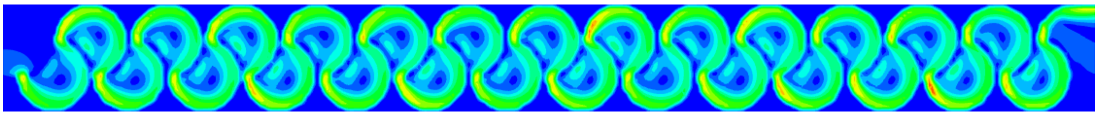
Figure 3.19. TKE of Type 2 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.20. Flow velocities of Type 2 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

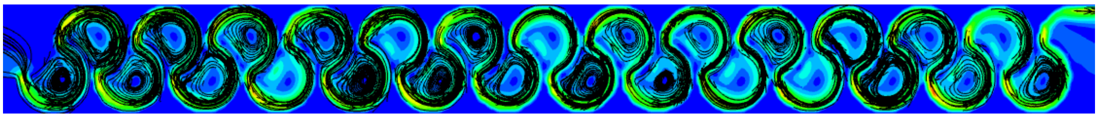


Figure 3.21. Streamlines of Type 2 considering max. flow rate conditions at 0.75h water level

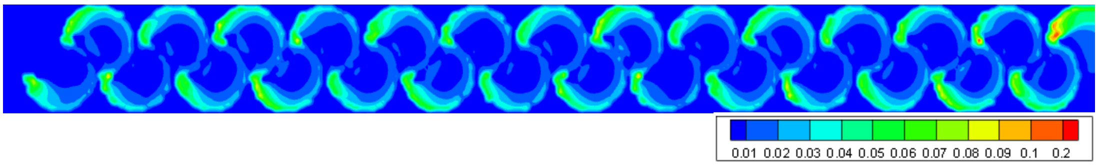


Figure 3.22. TKE of Type 2 considering max. flow rate conditions at 0.75h water level

- Results of Type 3

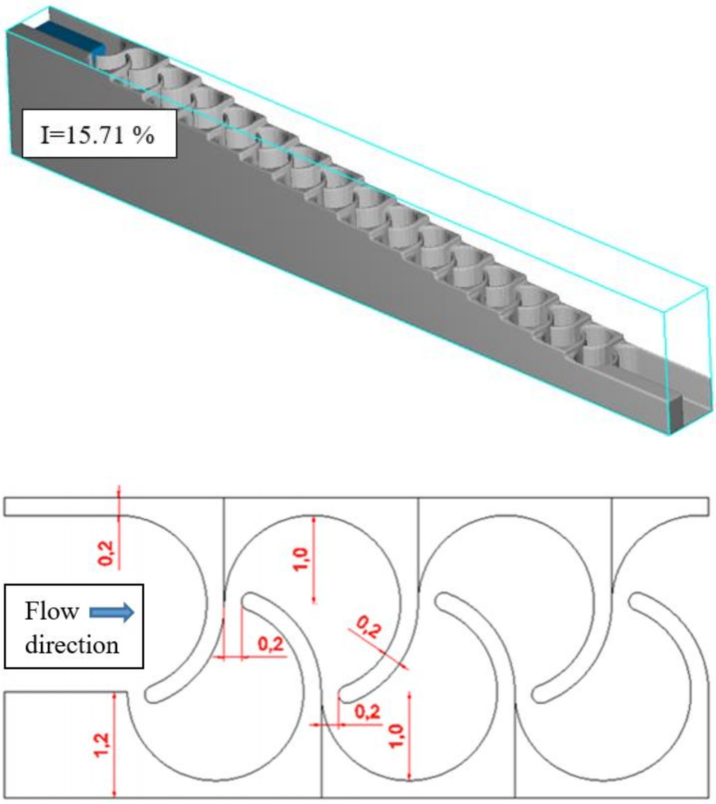


Figure 3.23. Dimensions of Type 3

In Type – 3, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=15.71% which is not in the range of manufacturer recommendations. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 3 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 3 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.23 and Figure 3.24, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.25 and Figure 3.28, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.27 and Figure 3.30, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.26 and 3.29) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 3 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. Moreover, the maximum velocity magnitude formed in the pools does not exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. However, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater

than the one considered in Type – 3, Type – 3 geometry is not a proper design for the target fish.

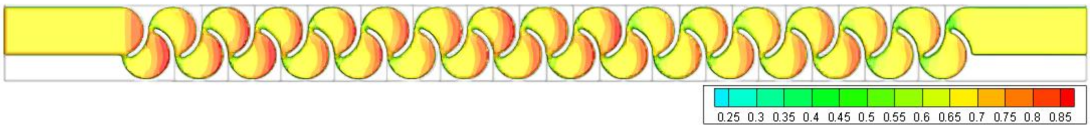


Figure 3.24. Fluid depth of Type 3 considering min. flow rate conditions – Top view

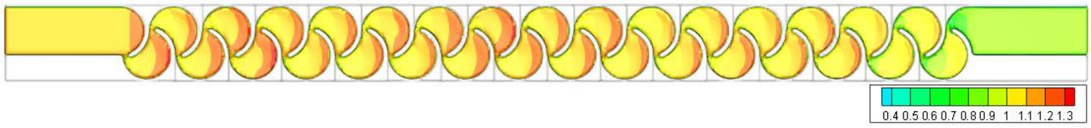


Figure 3.25. Fluid depth of Type 3 considering max. flow rate conditions – Top view

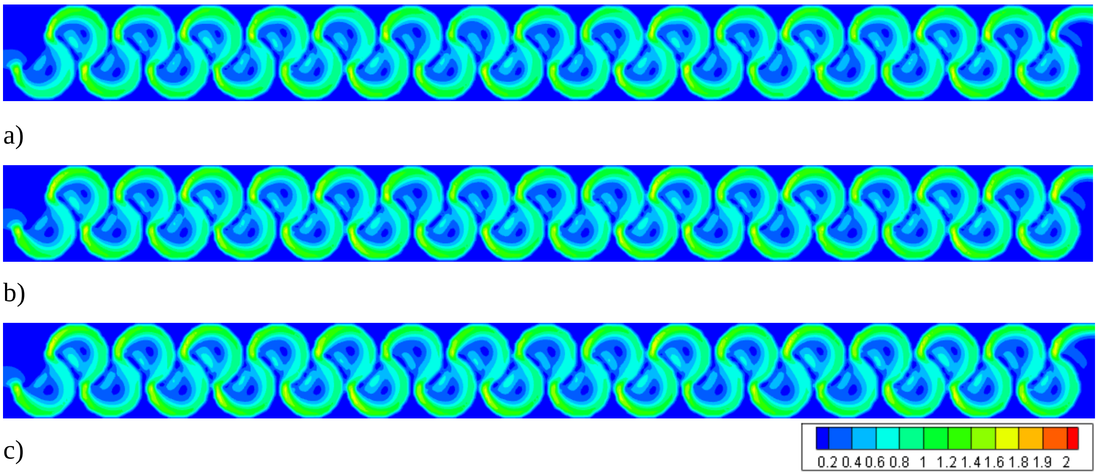


Figure 3.26. Flow velocities of Type 3 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

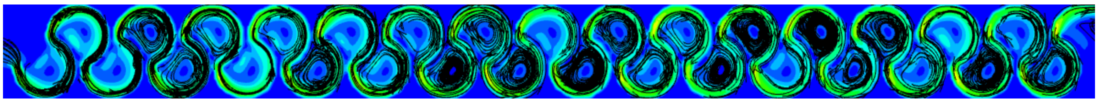


Figure 3.27. Streamlines of Type 3 considering min. flow rate conditions at 0.75h water level

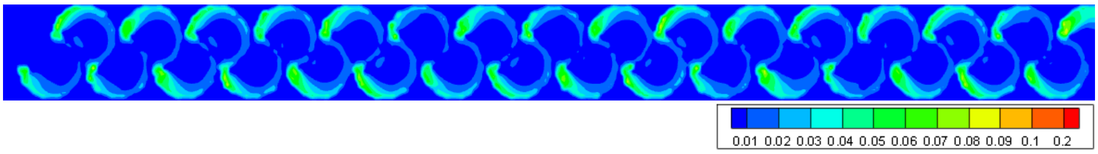
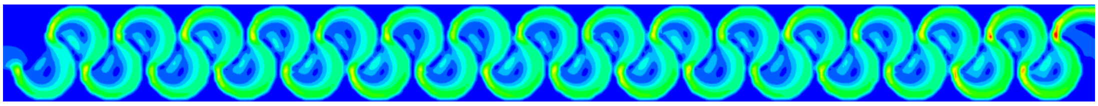
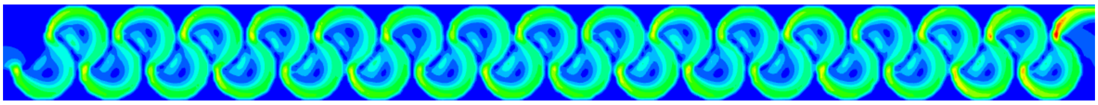


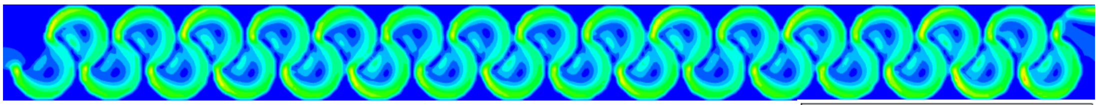
Figure 3.28. TKE of Type 3 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

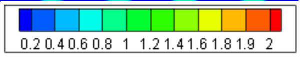


Figure 3.29. Flow velocities of Type 3 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

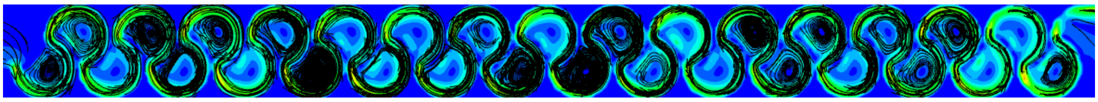


Figure 3.30. Streamlines of Type 3 considering max. flow rate conditions at 0.75h water level

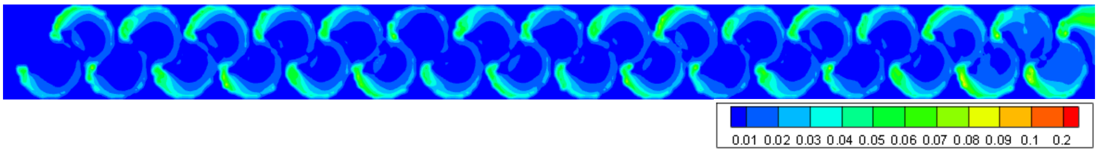


Figure 3.31. TKE of Type 3 considering max. flow rate conditions at 0.75h water level

- Results of Type 4

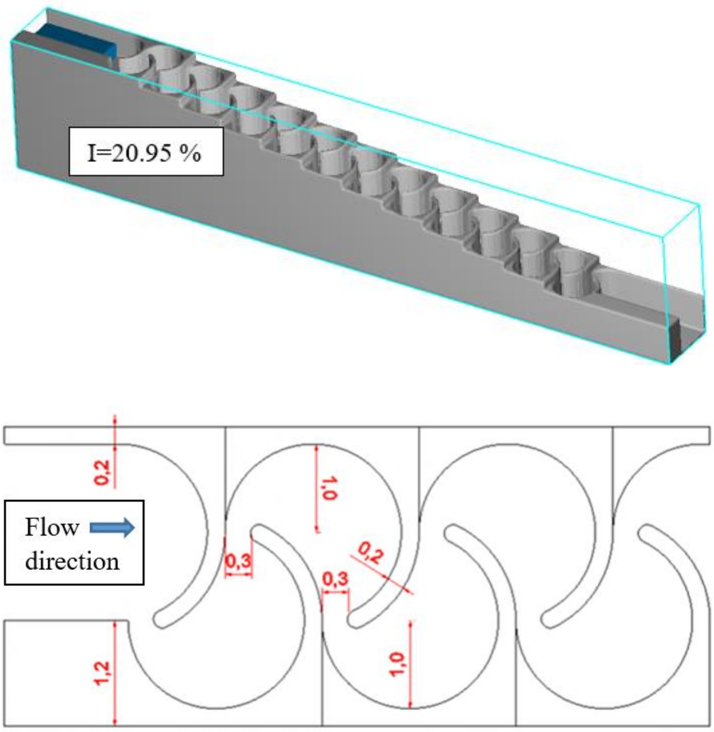


Figure 3.32. Dimensions of Type 4

In Type – 4, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=20.95% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 4 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.32 and Figure 3.33, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.34 and Figure 3.37, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.36 and Figure 3.39, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.35 and 3.38) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 4 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 4 geometry is not a proper design for the target fish.

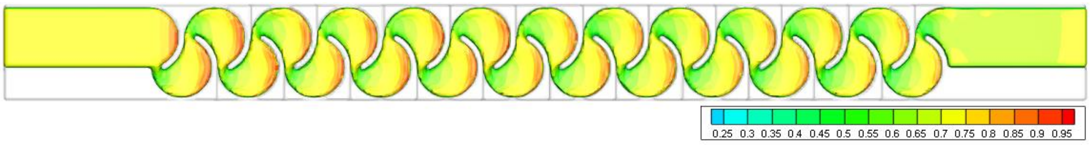


Figure 3.33. Fluid depth of Type 4 considering min. flow rate conditions – Top view

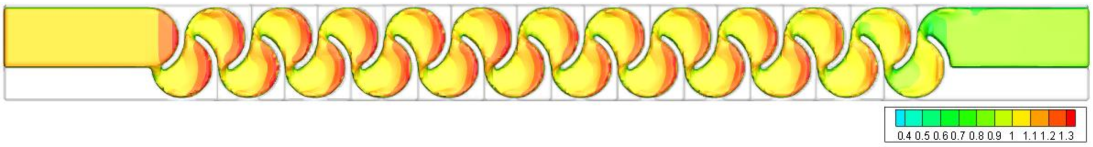
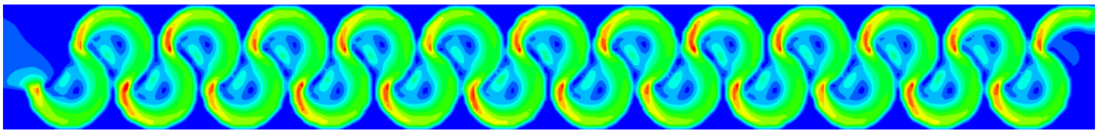
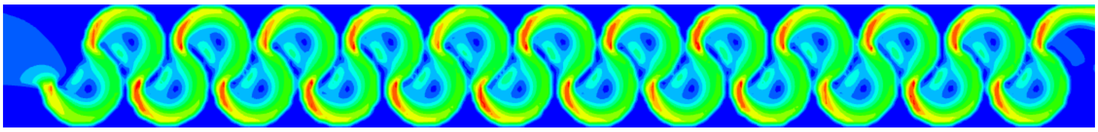


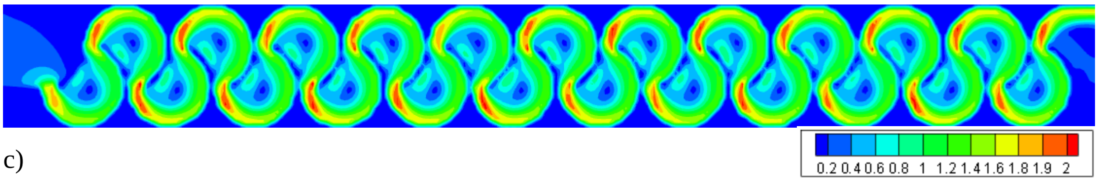
Figure 3.34. Fluid depth of Type 4 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.35. Flow velocities of Type 4 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

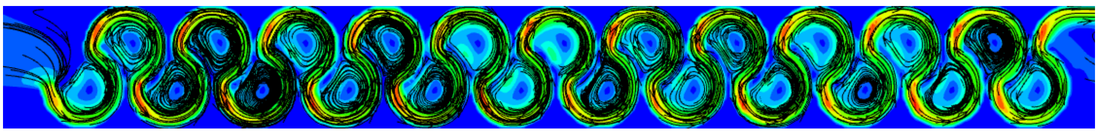


Figure 3.36. Streamlines of Type 4 considering min. flow rate conditions at 0.75h water level

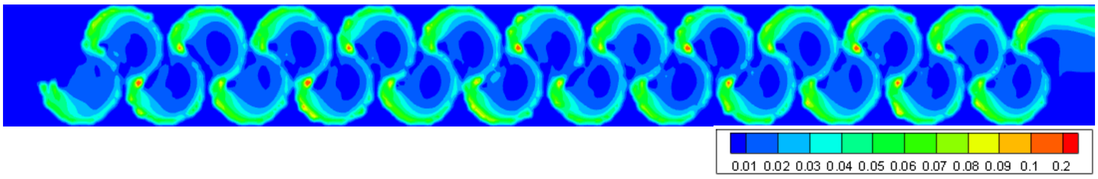
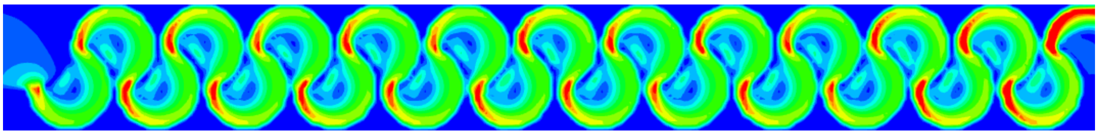
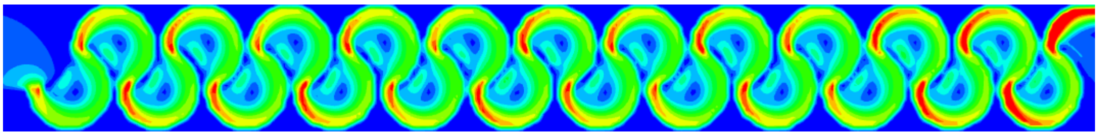


Figure 3.37. TKE of Type 4 considering min. flow rate conditions at 0.75h water level



a)



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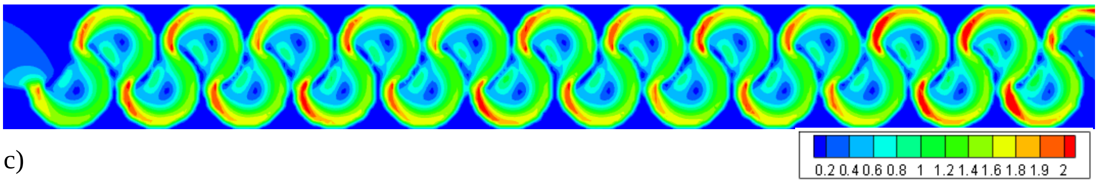


c)

Figure 3.38. Flow velocities of Type 4 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

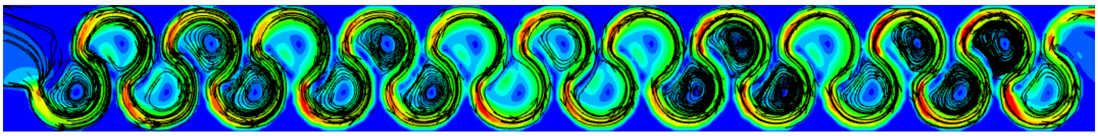


Figure 3.39. Streamlines of Type 4 considering max. flow rate conditions at 0.75h water level

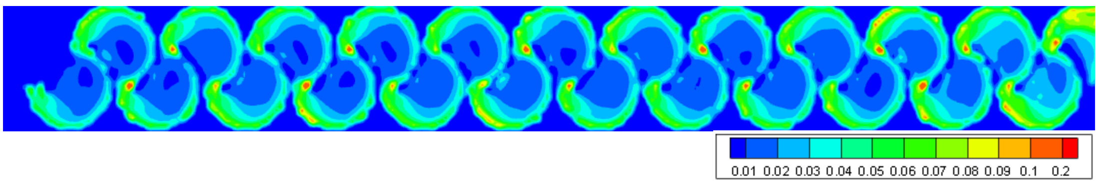


Figure 3.40. TKE of Type 4 considering max. flow rate conditions at 0.75h water level

- Results of Type 5

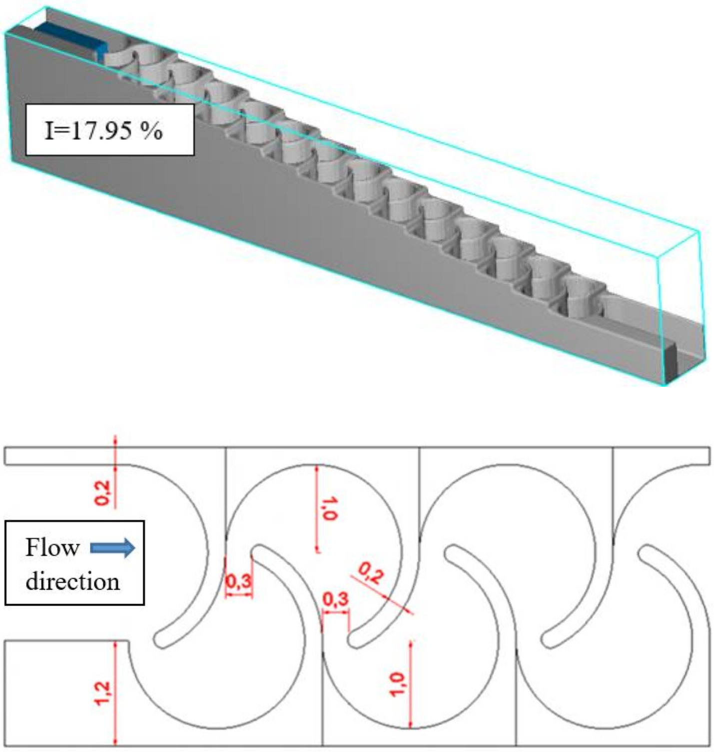


Figure 3.41. Dimensions of Type 5

In Type – 5, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.95% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout.

Herein, numerical simulations are completed for Type – 5 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.41 and Figure 3.42, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.43 and Figure 3.46, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.45 and Figure 3.48, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.44 and 3.47) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 5 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. Therefore, Type – 5 geometry is not a proper design for the target fish.

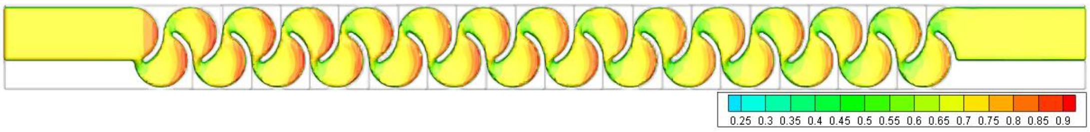


Figure 3.42. Fluid depth of Type 5 considering min. flow rate conditions – Top view

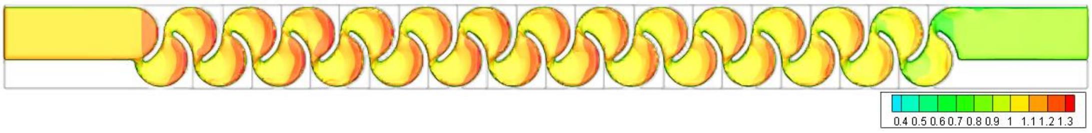


Figure 3.43. Fluid depth of Type 5 considering max. flow rate conditions – Top view

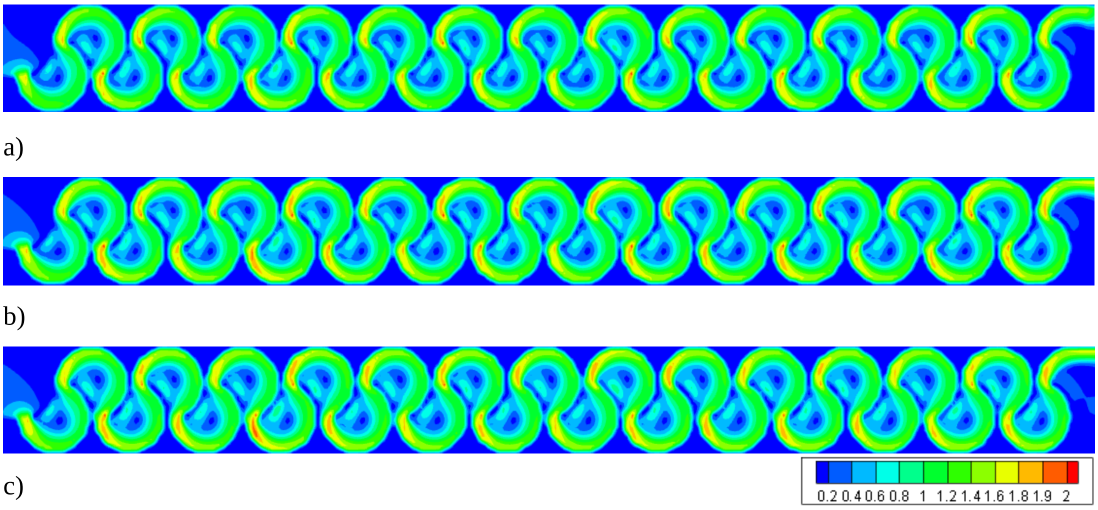


Figure 3.44. Flow velocities of Type 5 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

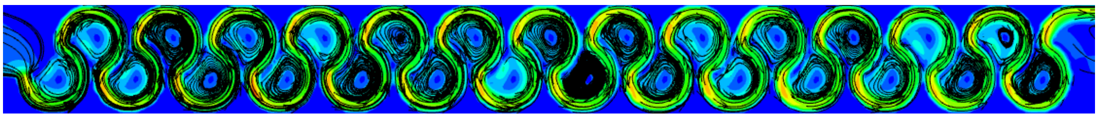


Figure 3.45. Streamlines of Type 5 considering min. flow rate conditions at 0.75h water level

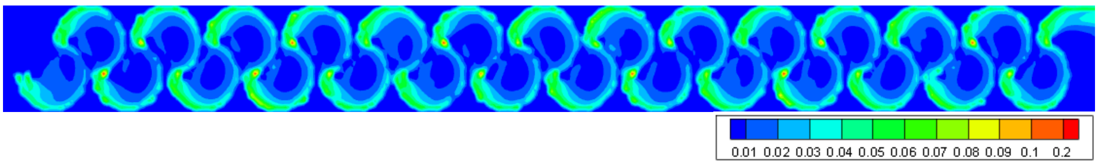
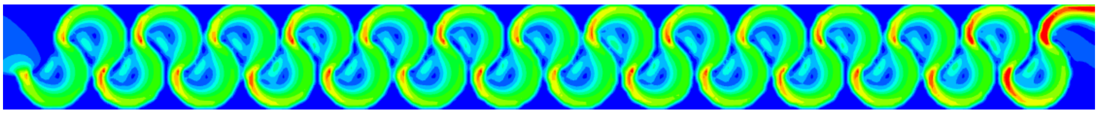
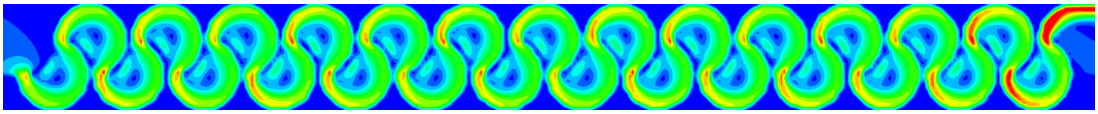


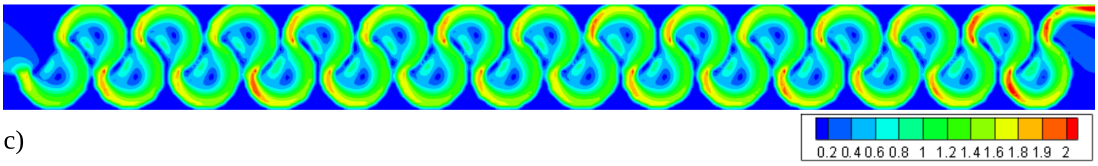
Figure 3.46. TKE of Type 5 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.47. Flow velocities of Type 5 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

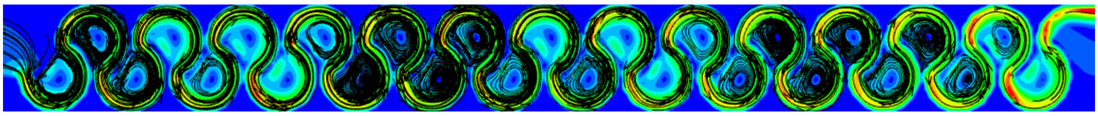


Figure 3.48. Streamlines of Type 5 considering max. flow rate conditions at 0.75h water level

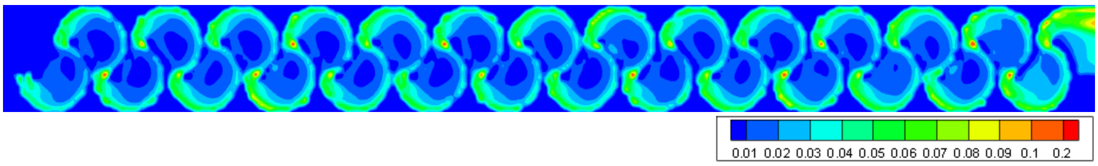


Figure 3.49. TKE of Type 5 considering max. flow rate conditions at 0.75h water level

- Results of Type 6

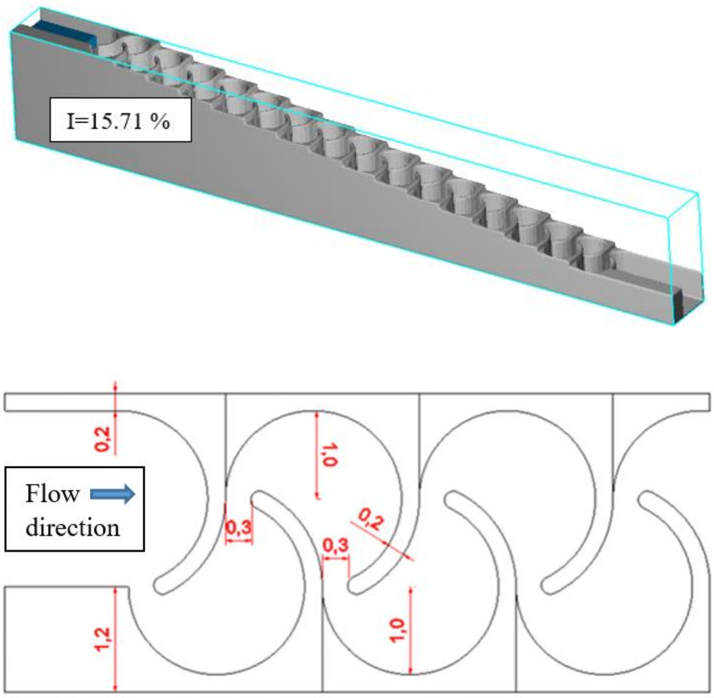


Figure 3.50. Dimensions of Type 6

In Type – 6, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=15.71% which is not in the range of manufacturer recommendations while the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 6 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.50 and Figure 3.51, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.52 and Figure 3.55, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.54 and Figure 3.57, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.53 and 3.56) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 6 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. Moreover, velocity magnitudes formed in the pools does not exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. Therefore, Type – 6 geometry is a proper design for the target fish.

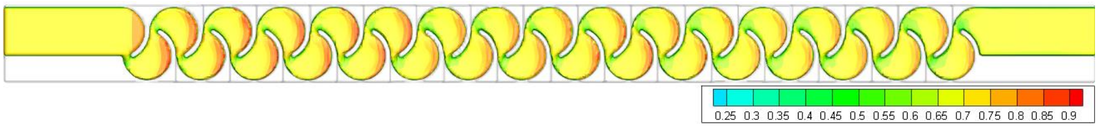


Figure 3.51. Fluid depth of Type 6 considering min. flow rate conditions – Top view

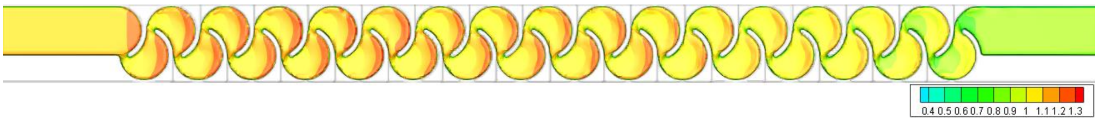
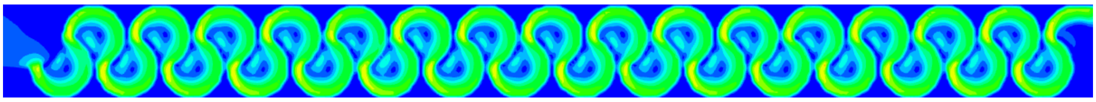
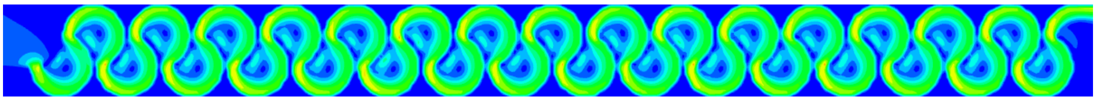


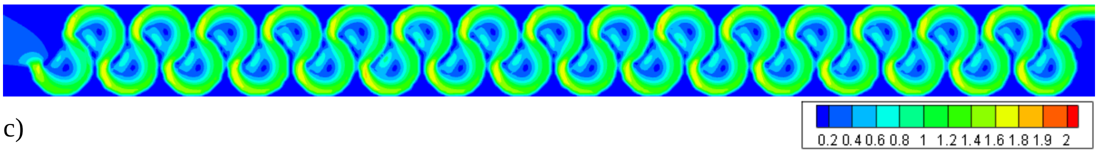
Figure 3.52. Fluid depth of Type 6 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.53. Flow velocities of Type 6 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

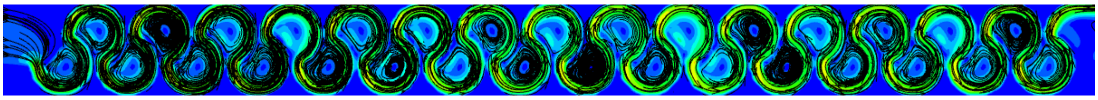


Figure 3.54. Streamlines of Type 6 considering min. flow rate conditions at 0.75h water level

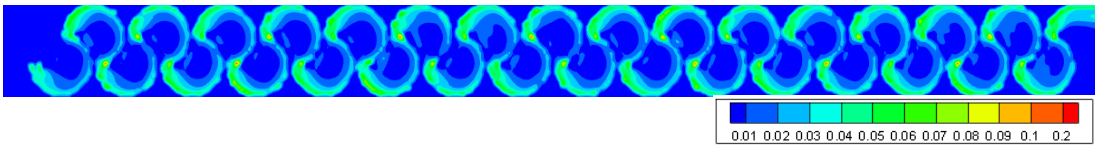
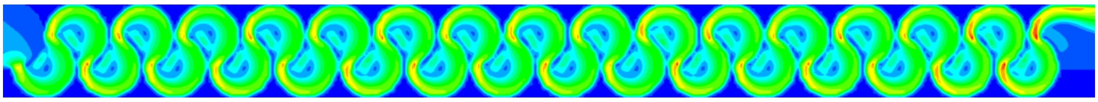
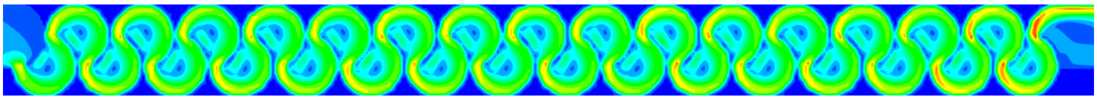


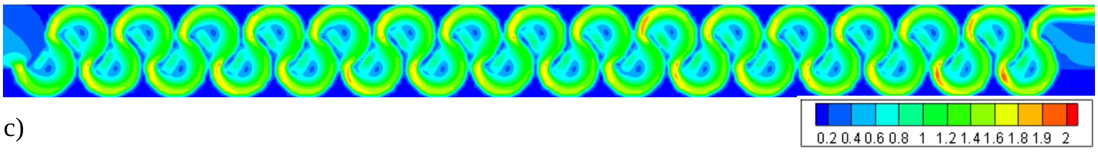
Figure 3.55. TKE of Type 6 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.56. TKE of Type 1 considering max. flow rate conditions at 0.75h water level

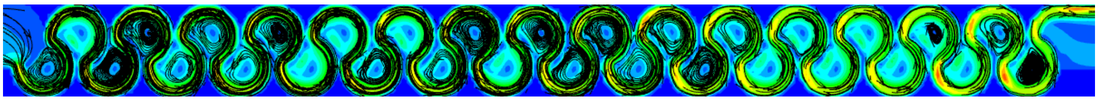


Figure 3.57. Streamlines of Type 6 considering max. flow rate conditions at 0.75h water level

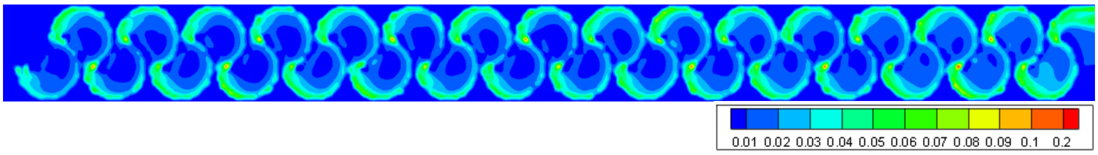


Figure 3.58. TKE of Type 6 considering max. flow rate conditions at 0.75h water level

- Results of Type 7

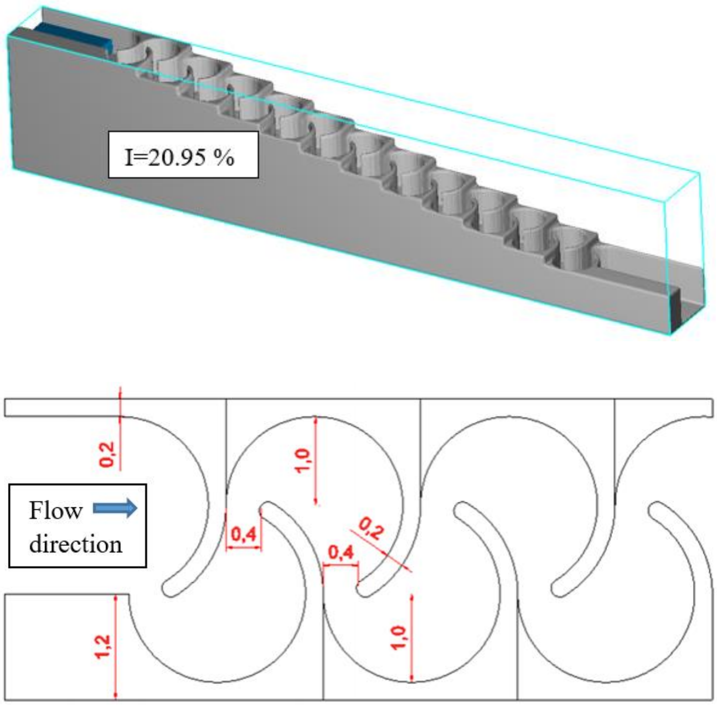


Figure 3.59. Dimensions of Type 7

In Type – 7, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=20.95% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 7 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.59 and Figure 3.60, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.61 and Figure 3.64, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.63 and Figure 3.66, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.62 and 3.65) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 7 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 7 geometry is not a proper design for the target fish.

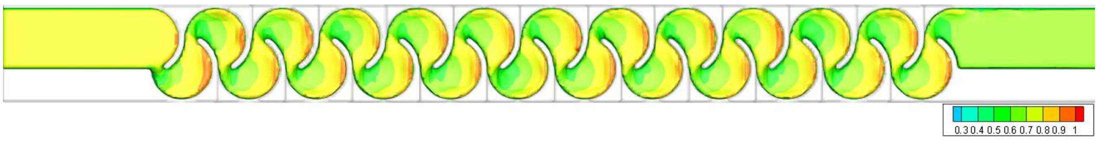


Figure 3.60. Fluid depth of Type 7 considering min. flow rate conditions – Top view

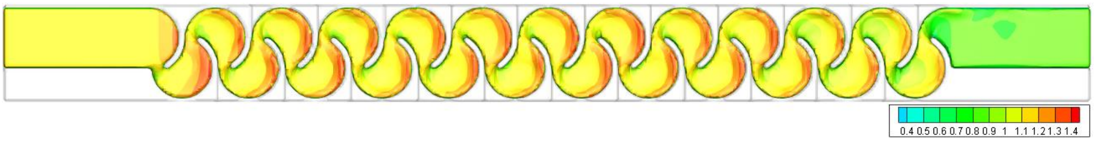
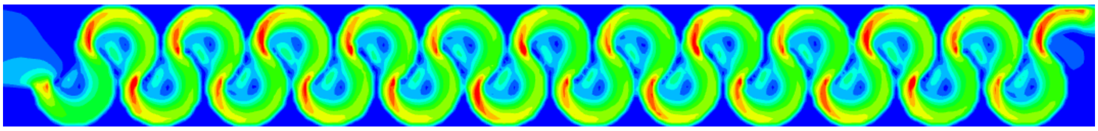
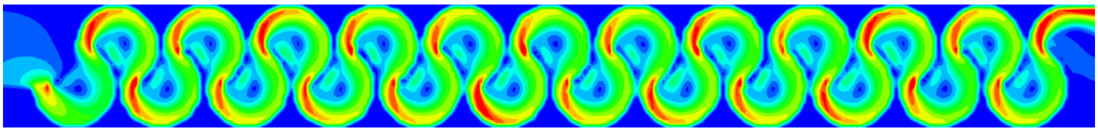


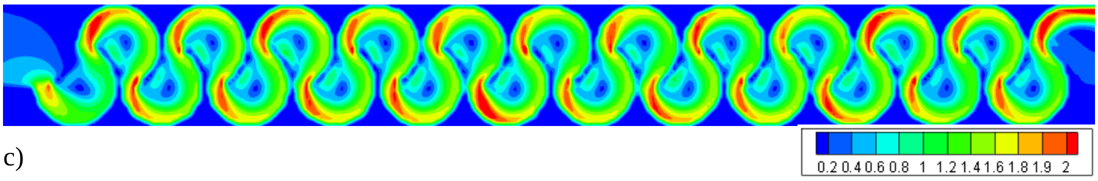
Figure 3.61. Fluid depth of Type 7 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.62. Flow velocities of Type 7 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

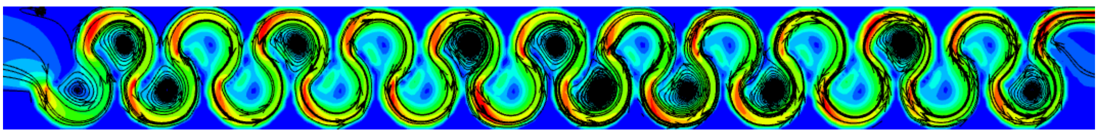


Figure 3.63. Streamlines of Type 7 considering min. flow rate conditions at 0.75h water level

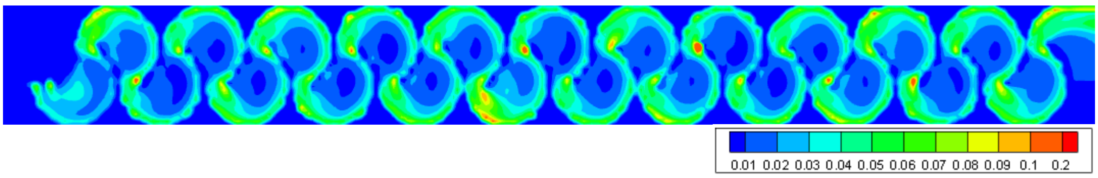


Figure 3.64. TKE of Type 7 considering min. flow rate conditions at 0.75h water level

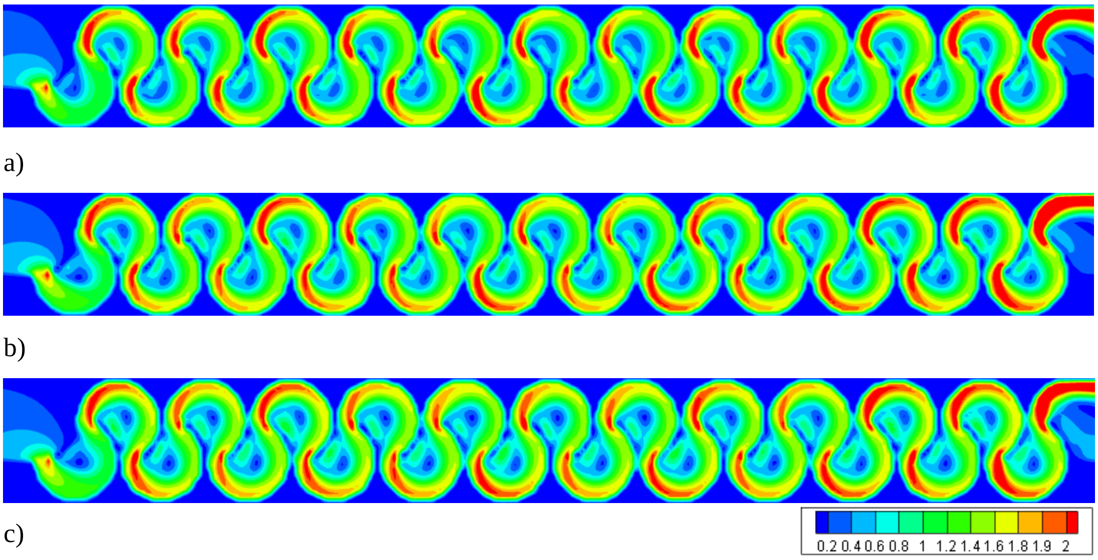


Figure 3.65. Flow velocities of Type 7 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

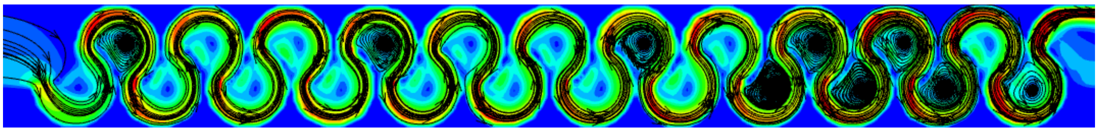


Figure 3.66. Streamlines of Type 7 considering max. flow rate conditions at 0.75h water level

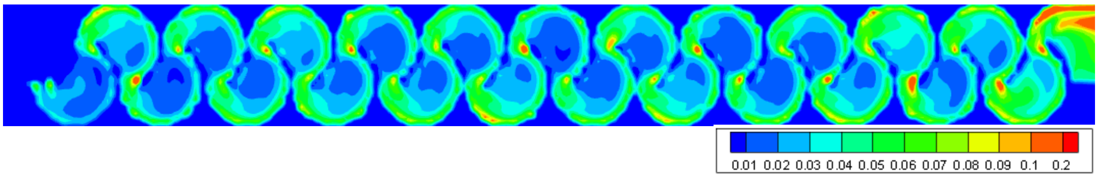


Figure 3.67. TKE of Type 7 considering max. flow rate conditions at 0.75h water level

- Results of Type 8

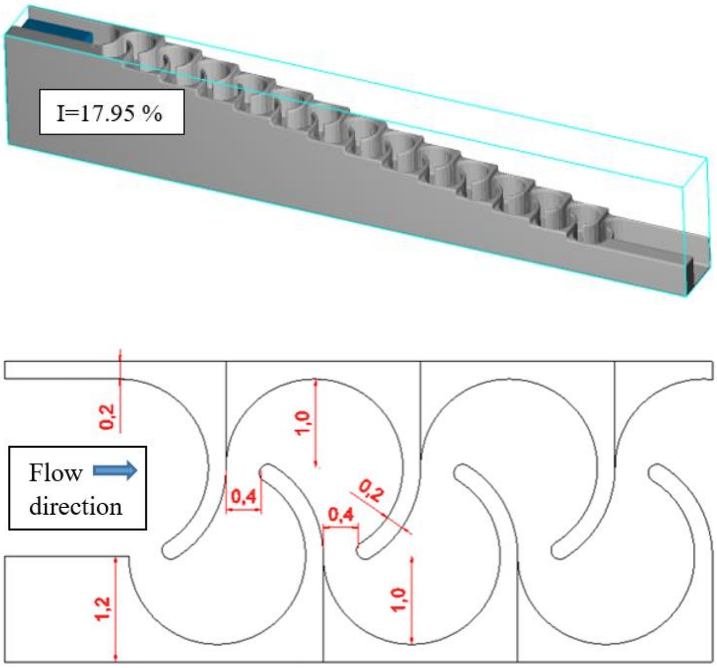


Figure 3.68. Dimensions of Type 8

In Type – 8, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.95% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout.

Herein, numerical simulations are completed for Type – 8 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.68 and Figure 3.69, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.70 and Figure 3.73, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.72 and Figure 3.75, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.71 and 3.74) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 8 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. Therefore, Type – 8 geometry is not a proper design for the target fish.

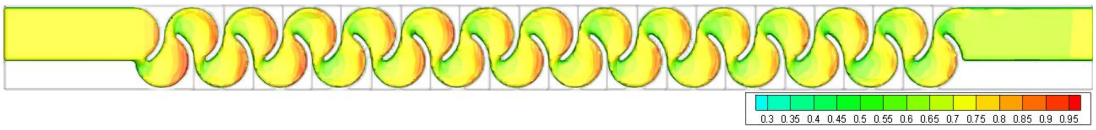


Figure 3.69. Fluid depth of Type 8 considering min. flow rate conditions – Top view

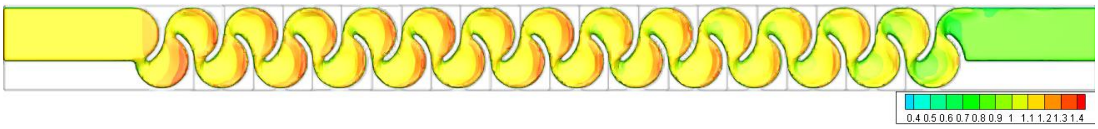


Figure 3.70. Fluid depth of Type 8 considering max. flow rate conditions – Top view

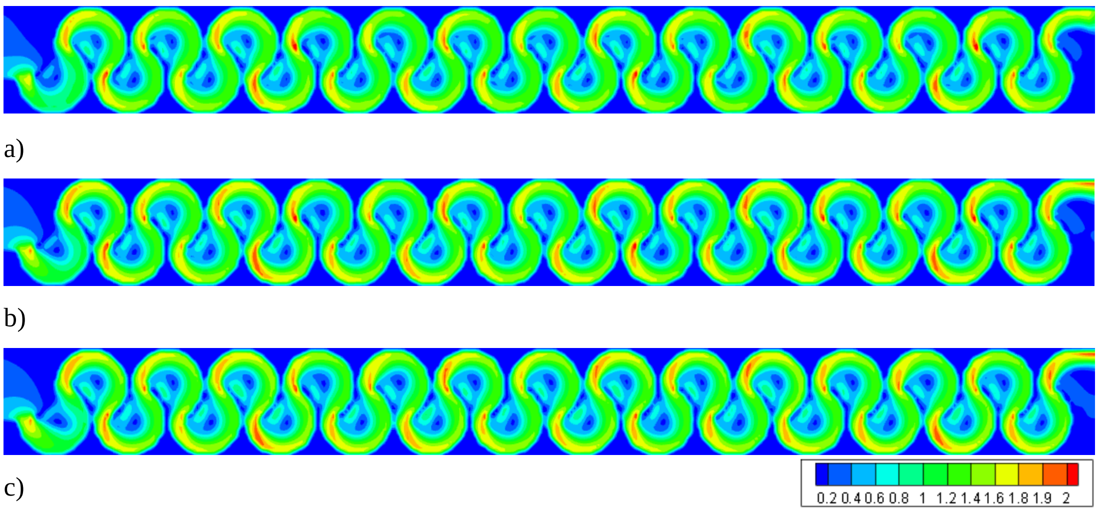


Figure 3.71. Flow velocities of Type 8 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

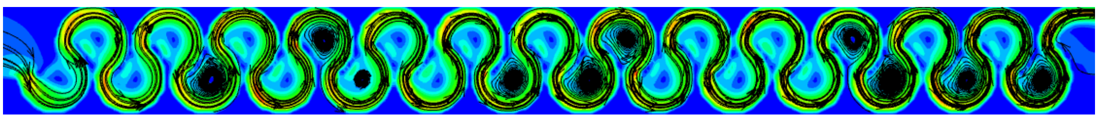


Figure 3.72. Streamlines of Type 8 considering min. flow rate conditions at 0.75h water level

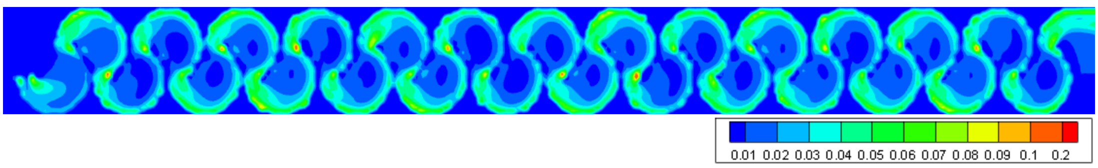
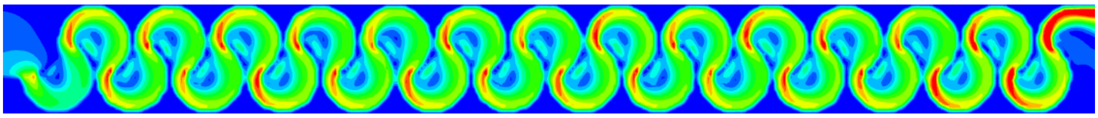
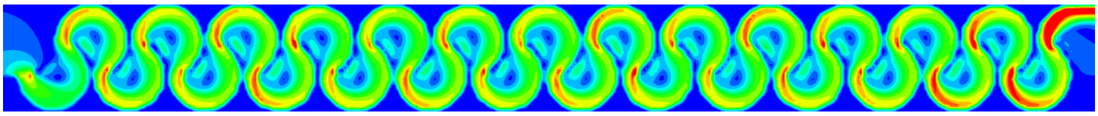


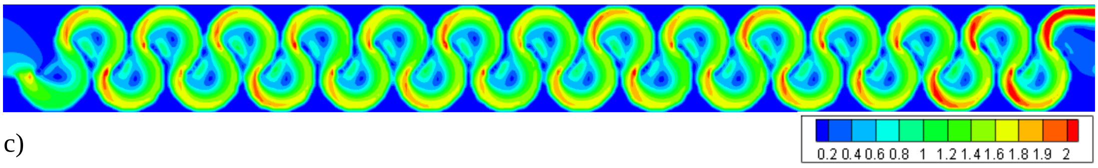
Figure 3.73. TKE of Type 8 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.74. Flow velocities of Type 8 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

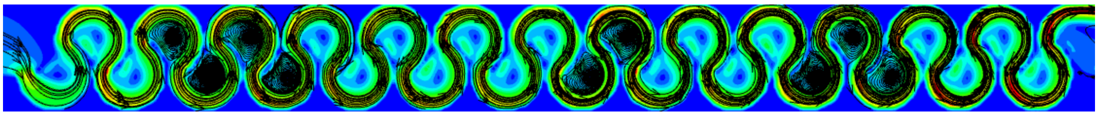


Figure 3.75. Streamlines of Type 8 considering max. flow rate conditions at 0.75h water level

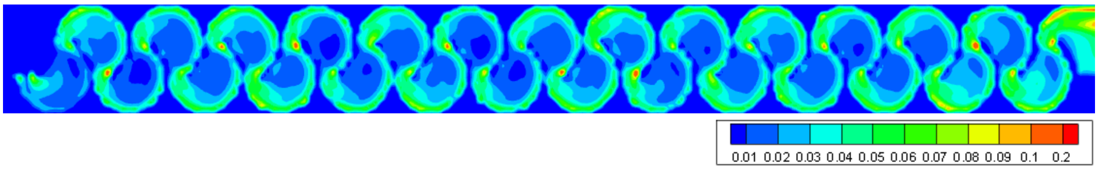


Figure 3.76. TKE of Type 8 considering max. flow rate conditions at 0.75h water level

- Results of Type 9

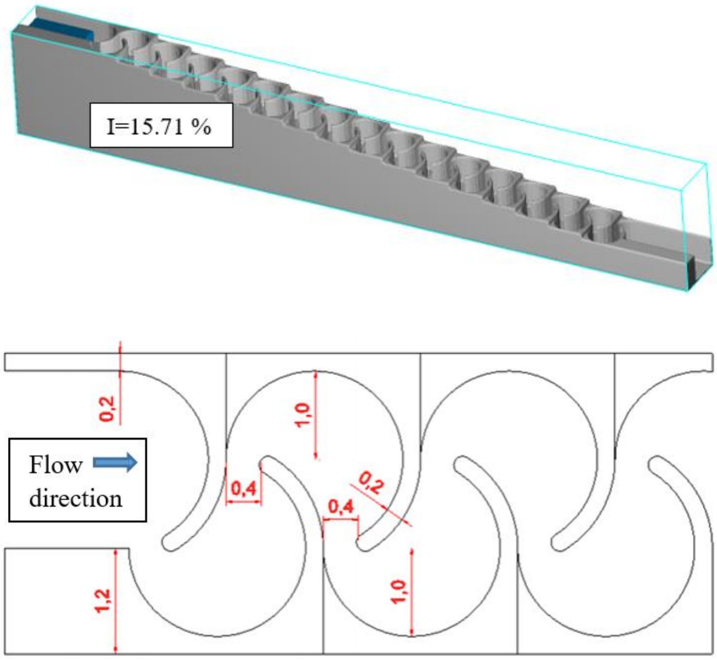


Figure 3.77. Dimensions of Type 9

In Type – 9, pool diameter D_{pool} is taken as 2.0 m which is the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=15.71% which is not in the range of manufacturer recommendations while the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout.

Herein, numerical simulations are completed for Type – 9 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.77 and Figure 3.78, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.79 and Figure 3.82, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.81 and Figure 3.84, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.80 and 3.83) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 9 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. Therefore, Type – 9 geometry is not a proper design for the target fish.

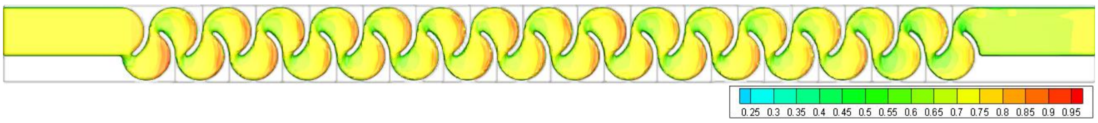


Figure 3.78. Fluid depth of Type 9 considering min. flow rate conditions – Top view

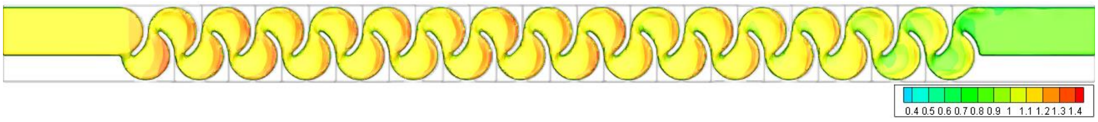
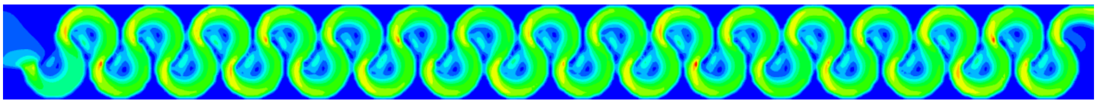
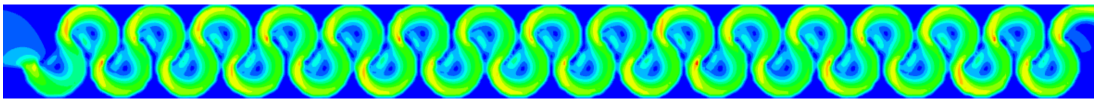


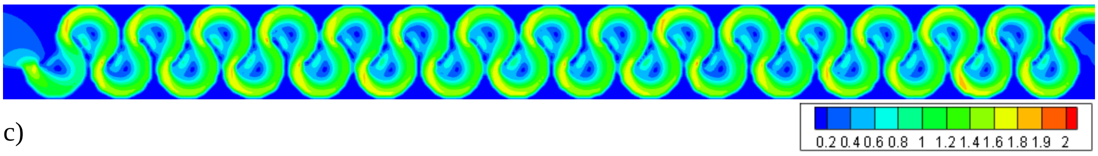
Figure 3.79. Fluid depth of Type 9 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.80. Flow velocities of Type 9 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

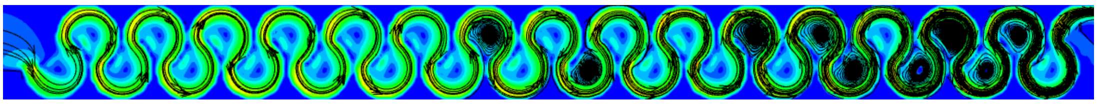


Figure 3.81. Streamlines of Type 9 considering min. flow rate conditions at 0.75h water level

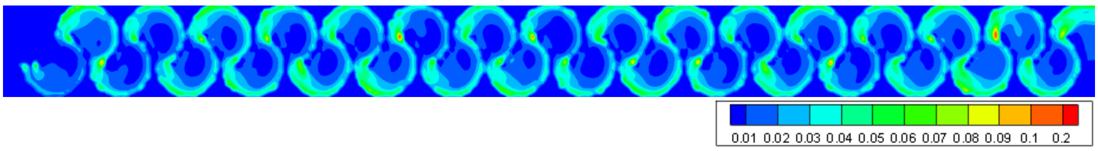
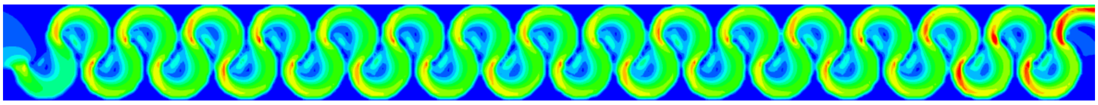
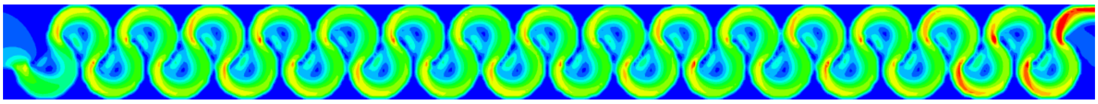


Figure 3.82. TKE of Type 9 considering min. flow rate conditions at 0.75h water level



a)



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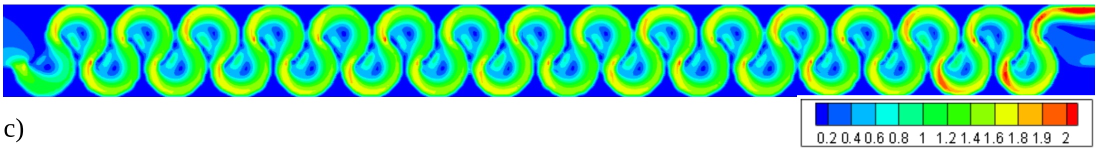


c)

Figure 3.83. Flow velocities of Type 9 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

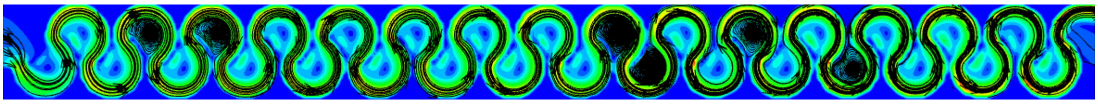


Figure 3.84. Streamlines of Type 9 considering max. flow rate conditions at 0.75h water level

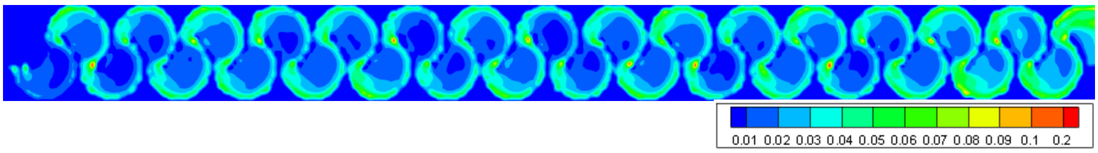
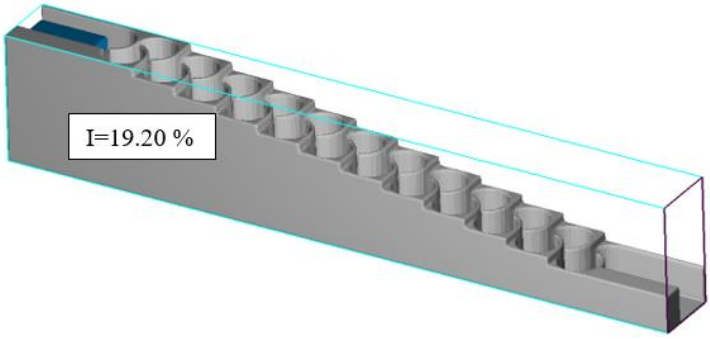


Figure 3.85. TKE of Type 9 considering max. flow rate conditions at 0.75h water level

- Results of Type 10



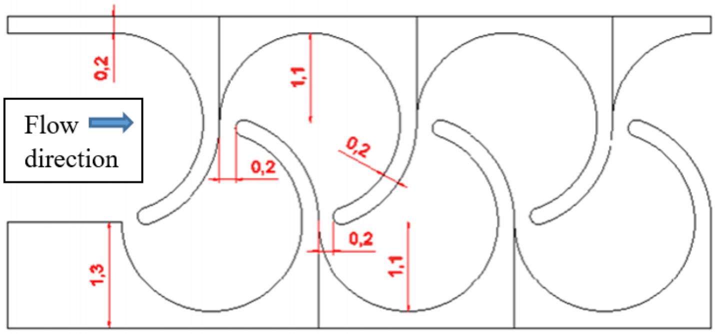


Figure 3.86. Dimensions of Type 10

In Type – 10, pool diameter D_{pool} is taken as 2.2 m which is greater than minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=19.20% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 10 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 10 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish

pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.86 and Figure 3.87, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.88 and Figure 3.91, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.90 and Figure 3.93, turbulent kinetic energy (k) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, k value varies between the values of 0 – 0.09 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.89 and 3.92) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, k contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, k values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 10 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. In addition, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater

than the one considered in Type – 10, Type – 10 geometry is not a proper design for the target fish.

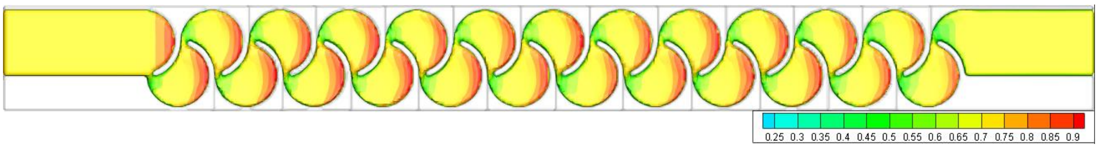


Figure 3.87. Fluid depth of Type 10 considering min. flow rate conditions – Top view

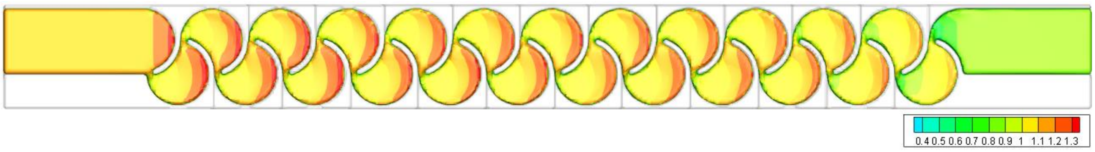
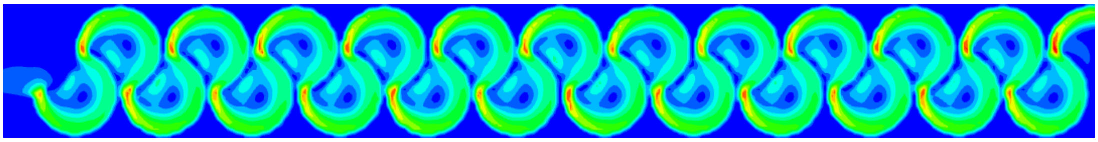


Figure 3.88. Fluid depth of Type 10 considering max. flow rate conditions – Top view



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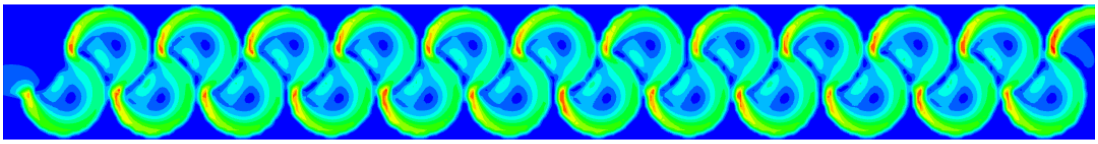
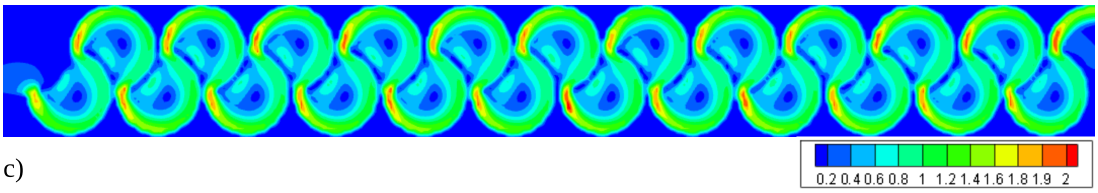


b)



c)

Figure 3.89. Flow velocities of Type 10 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

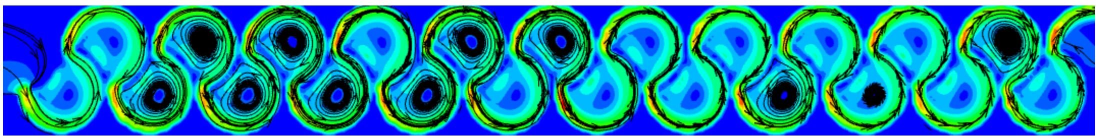


Figure 3.90. Streamlines of Type 10 considering min. flow rate conditions at 0.75h water level

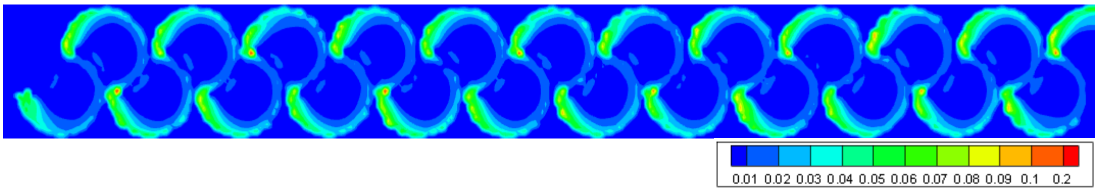
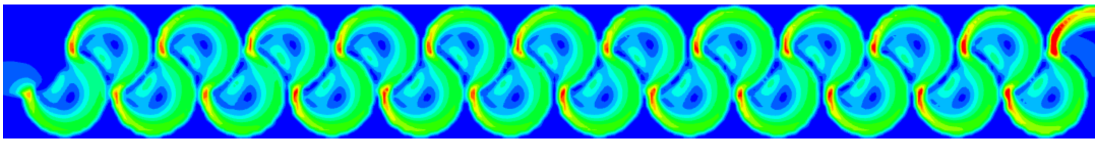
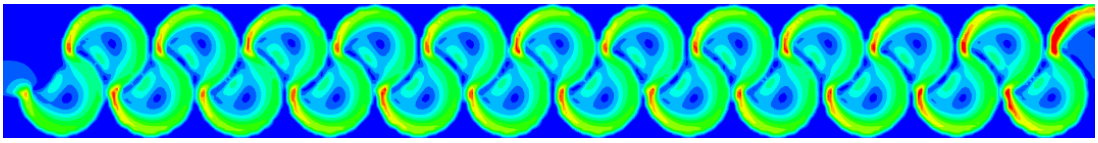


Figure 3.91. TKE of Type 10 considering min. flow rate conditions at 0.75h water level



a)



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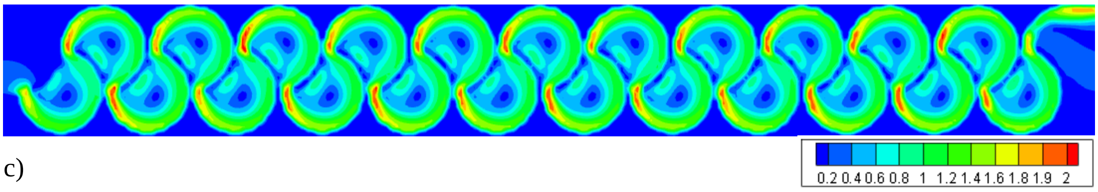


c)

Figure 3.92. Flow velocities of Type 10 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

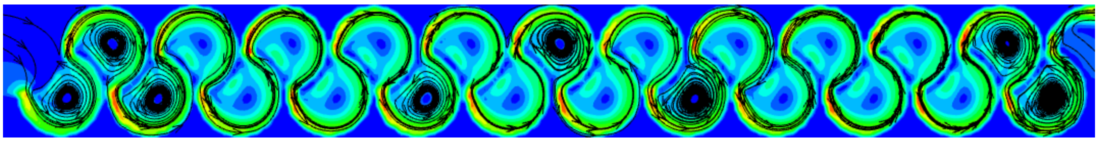


Figure 3.93. Streamlines of Type 10 considering max. flow rate conditions at 0.75h water level

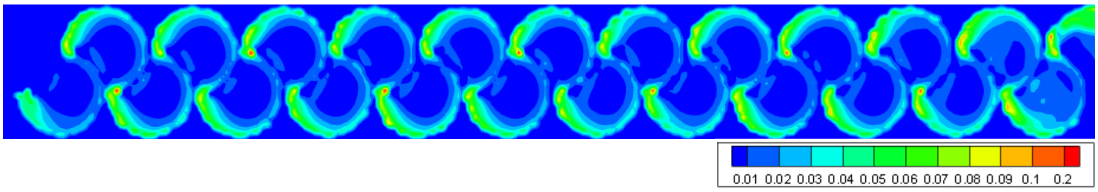


Figure 3.94. TKE of Type 10 considering max. flow rate conditions at 0.75h water level

- Results of Type 11

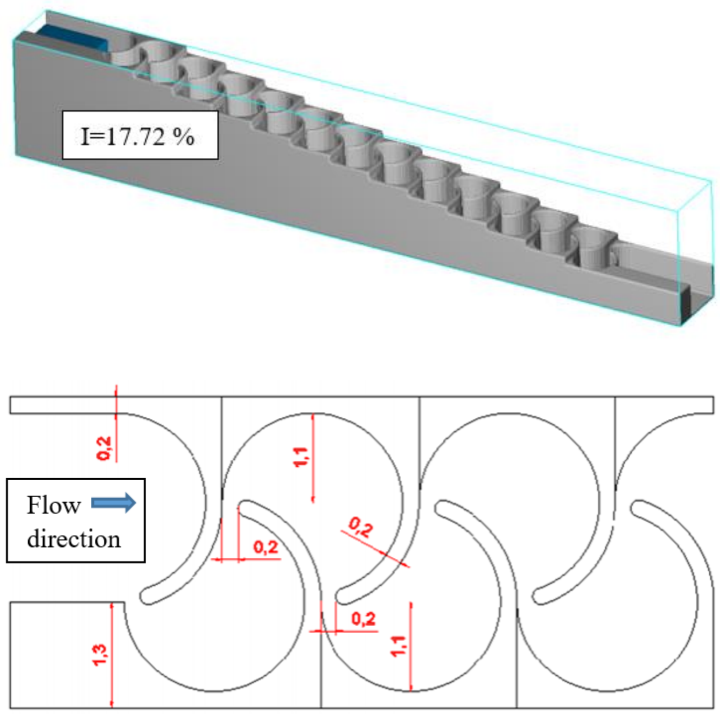


Figure 3.95. Dimensions of Type 11

In Type – 11, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.72% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 11 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 11 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish

pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.95 and Figure 3.96, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.97 and Figure 3.100, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.99 and Figure 3.102, turbulent kinetic energy (k) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, k value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.98 and 3.101) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, k contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, k values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 11 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. In addition, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater than the one considered in Type – 11, Type – 11 geometry is not a proper design for the target fish.

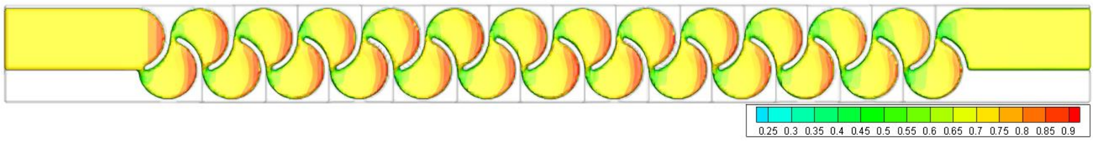


Figure 3.96. Fluid depth of Type 11 considering min. flow rate conditions – Top view

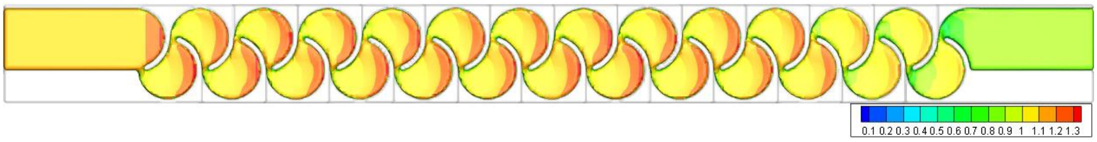
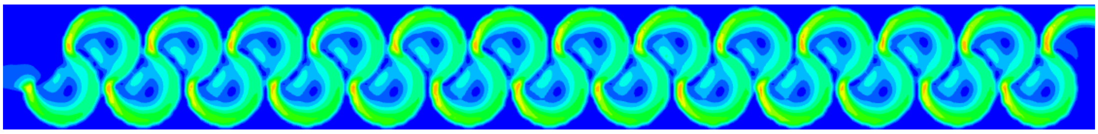
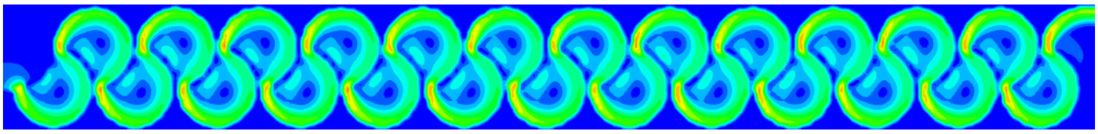


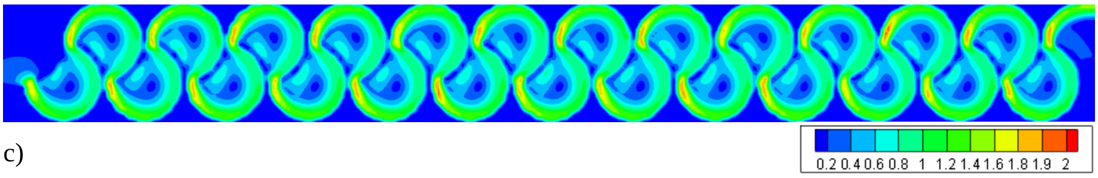
Figure 3.97. Fluid depth of Type 11 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.98. Flow velocities of Type 11 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

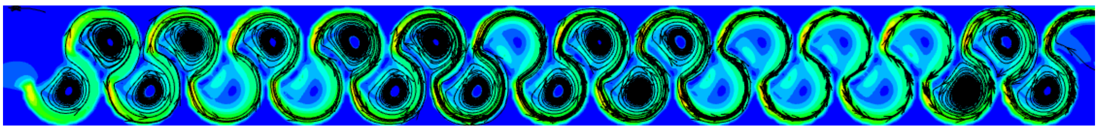


Figure 3.99. Streamlines of Type 11 considering min. flow rate conditions at 0.75h water level

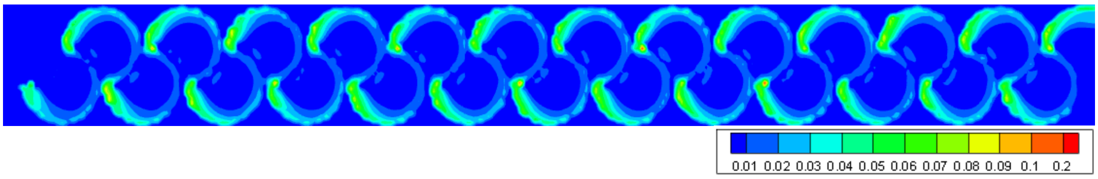
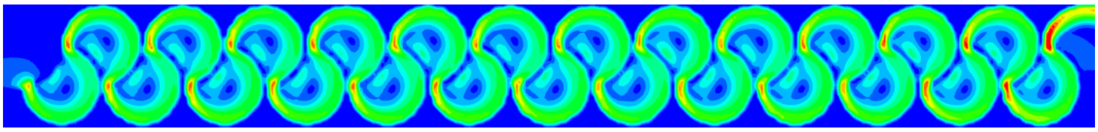
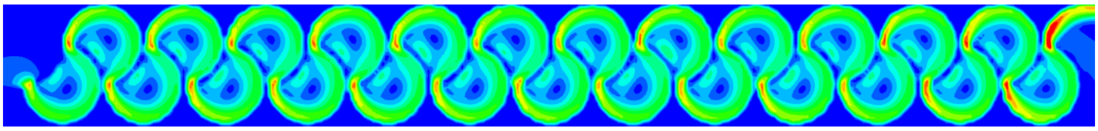


Figure 3.100. TKE of Type 11 considering min. flow rate conditions at 0.75h water level



a)



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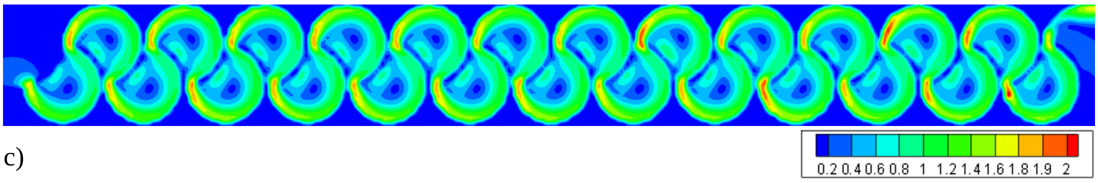


c)

Figure 3.101. Flow velocities of Type 11 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

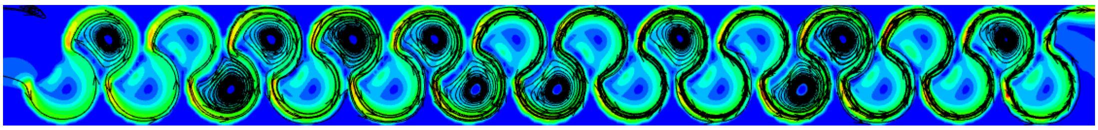


Figure 3.102. Streamlines of Type 11 considering max. flow rate conditions at 0.75h water level

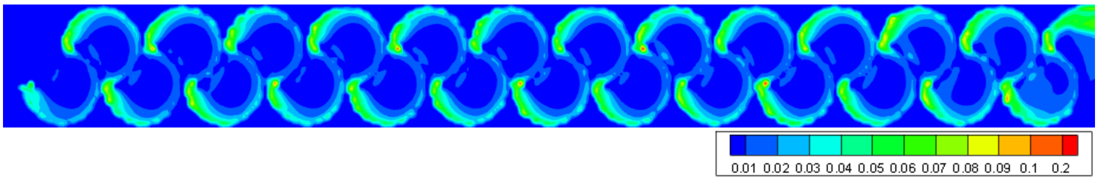


Figure 3.103. TKE of Type 11 considering max. flow rate conditions at 0.75h water level

- Results of Type 12

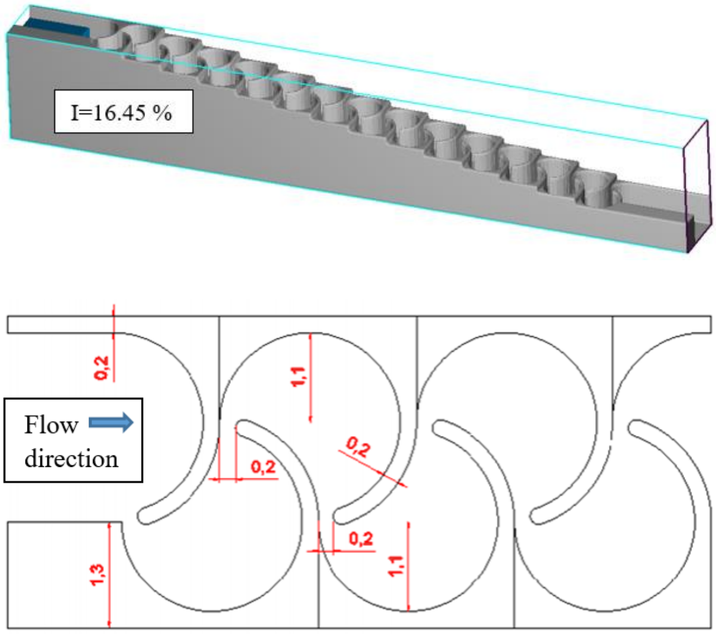


Figure 3.104. Dimensions of Type 12

In Type – 12, pool diameter D_{pool} is taken as 2.2 m which is greater the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=16.45% which is not in the range of manufacturer recommendations. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 12 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 12 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.104 and Figure 3.105, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.106 and Figure 3.109, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.108 and Figure 3.111, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.109 and 3.110) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 12 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. Moreover, the maximum velocity magnitude formed in the pools does not exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. However, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater than the one considered in Type – 12, Type – 12 geometry is not a proper design for the target fish.

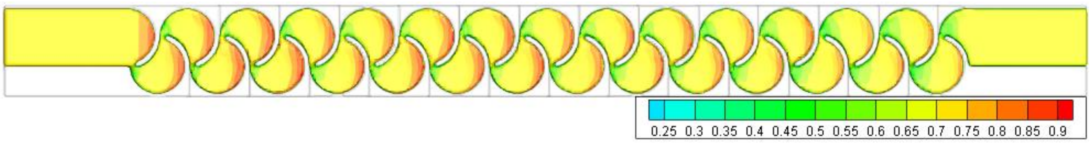


Figure 3.105. Fluid depth of Type 12 considering min. flow rate conditions – Top view

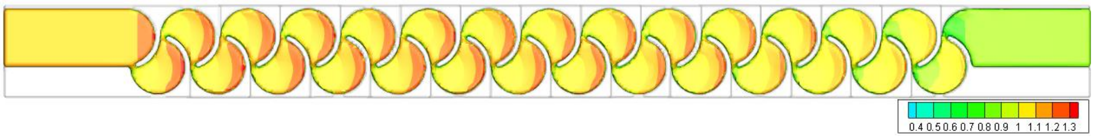
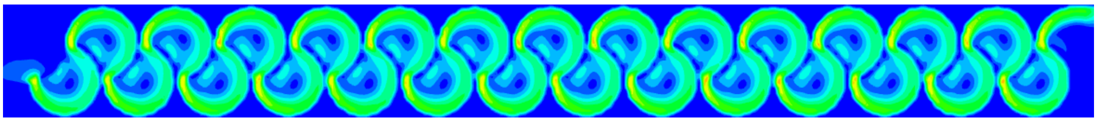
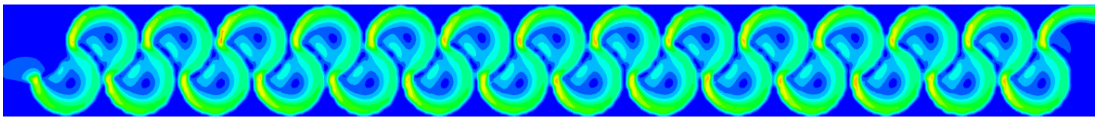


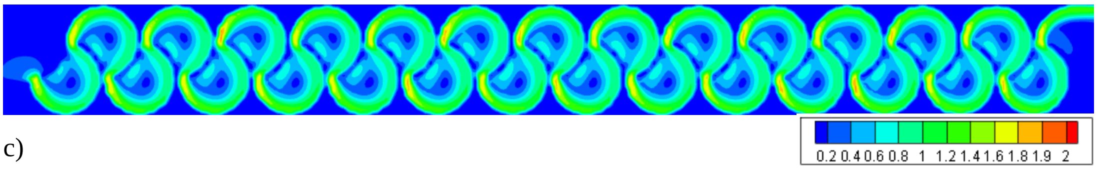
Figure 3.106. Fluid depth of Type 12 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.107. Flow velocities of Type 12 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

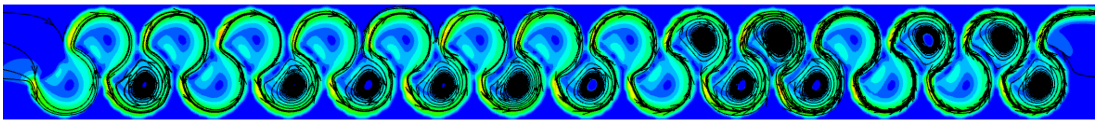


Figure 3.108. Streamlines of Type 12 considering min. flow rate conditions at 0.75h water level

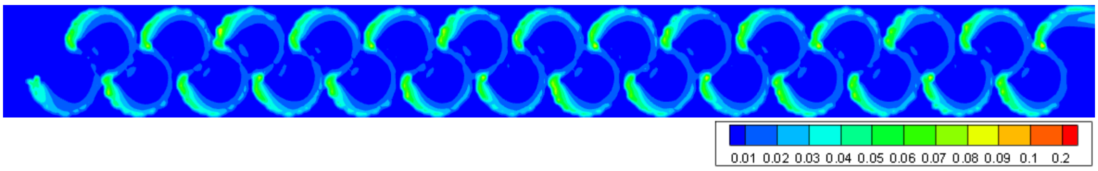
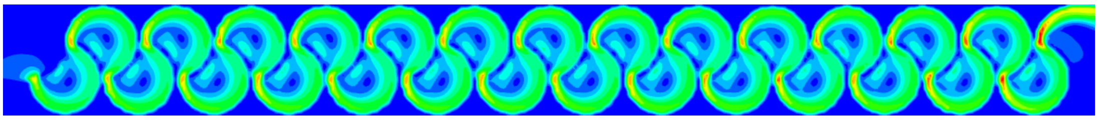
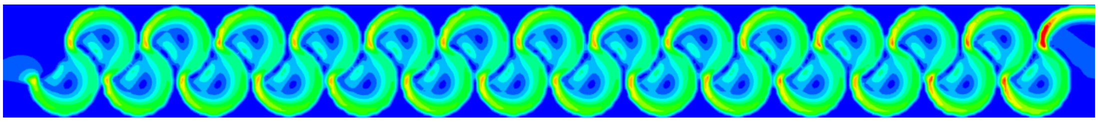


Figure 3.109. TKE of Type 12 considering min. flow rate conditions at 0.75h water level



a)



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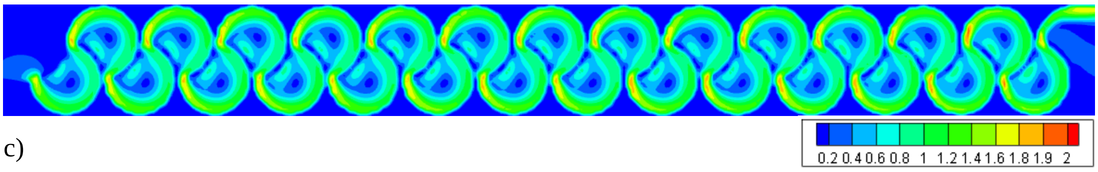


c)

Figure 3.110. Flow velocities of Type 12 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

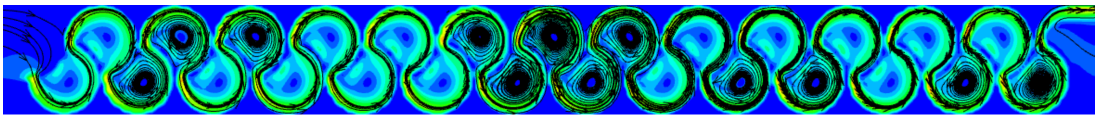


Figure 3.111. Streamlines of Type 12 considering max. flow rate conditions at 0.75h water level

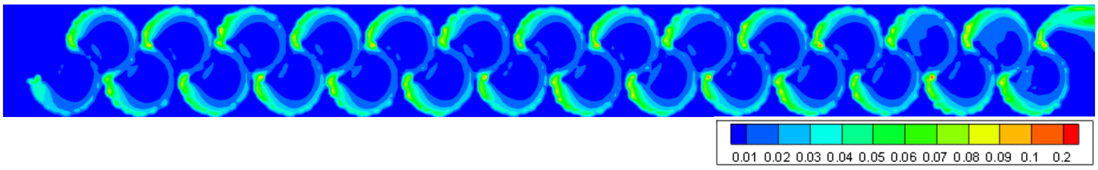


Figure 3.112. TKE of Type 12 considering max. flow rate conditions at 0.75h water level

- Results of Type 13

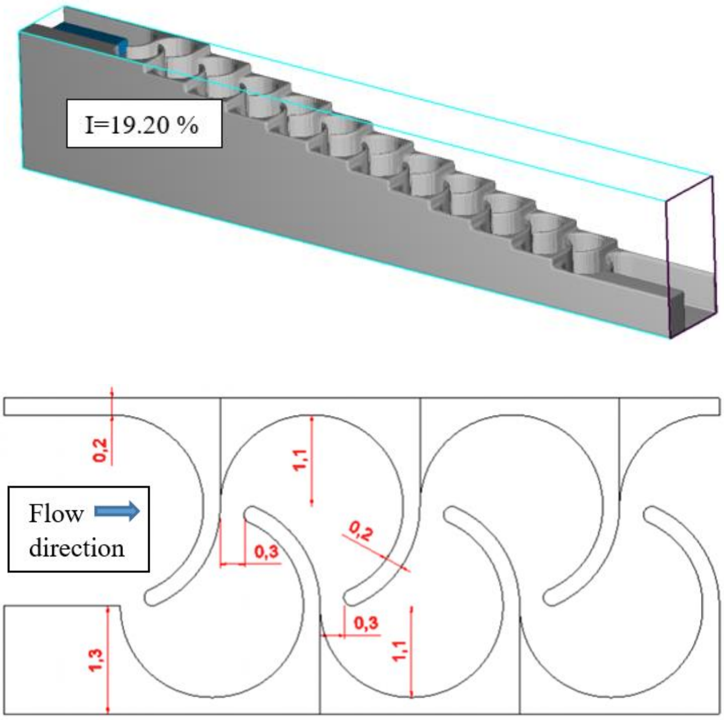


Figure 3.113. Dimensions of Type 13

In Type – 13, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=19.20% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 13 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.113 and Figure 3.114, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.115 and Figure 3.118, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.117 and Figure 3.120, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.116 and 3.119) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 13 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 13 geometry is not a proper design for the target fish.

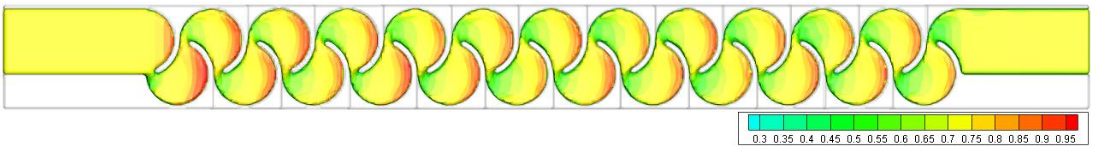


Figure 3.114. Fluid depth of Type 13 considering min. flow rate conditions – Top view

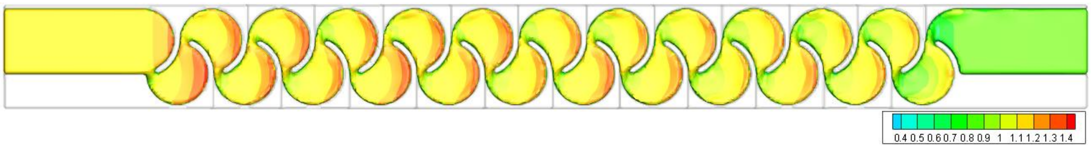
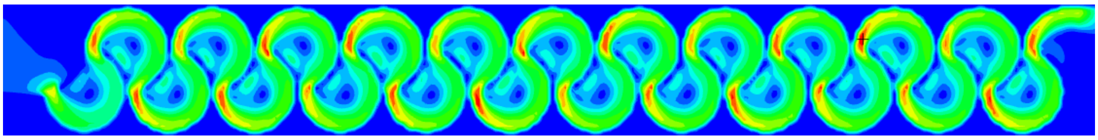
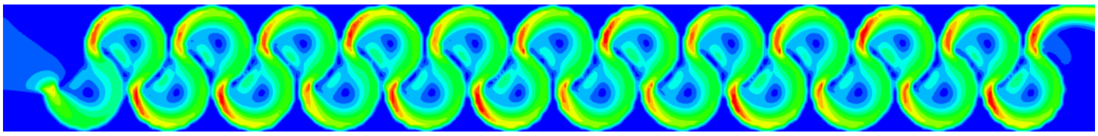


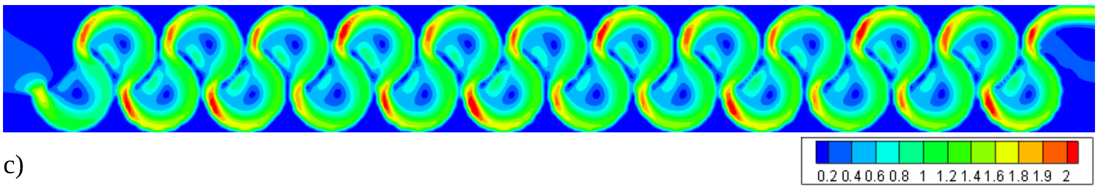
Figure 3.115. Fluid depth of Type 13 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.116. Flow velocities of Type 13 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

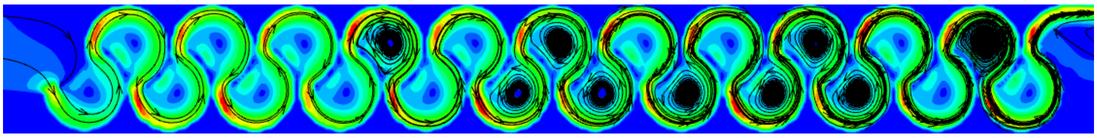


Figure 3.117. Streamlines of Type 13 considering min. flow rate conditions at 0.75h water level

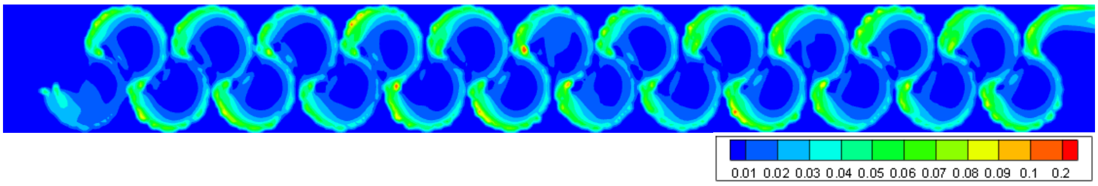
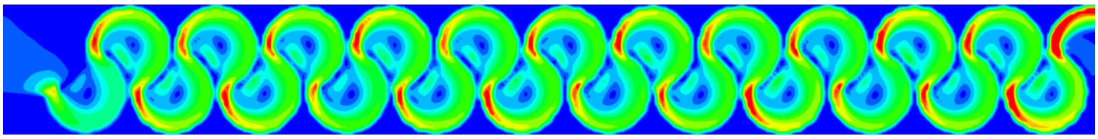
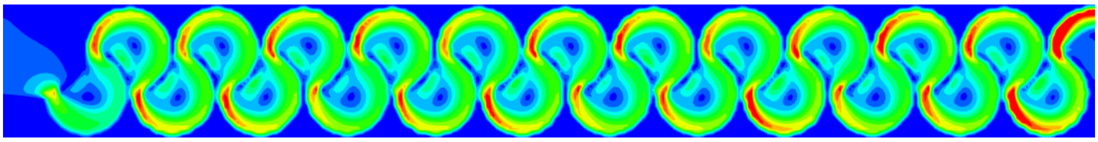


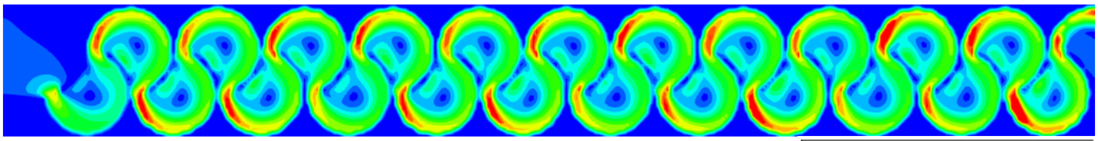
Figure 3.118. TKE of Type 13 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

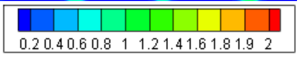


Figure 3.119. Flow velocities of Type 13 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

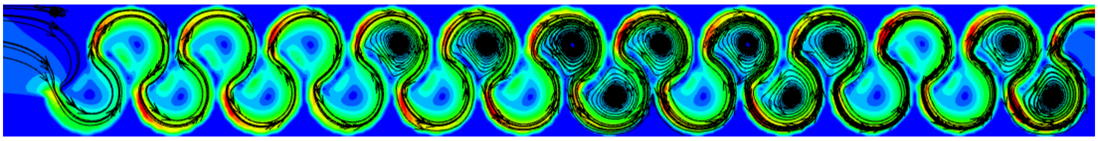


Figure 3.120. Streamlines of Type 13 considering max. flow rate conditions at 0.75h water level

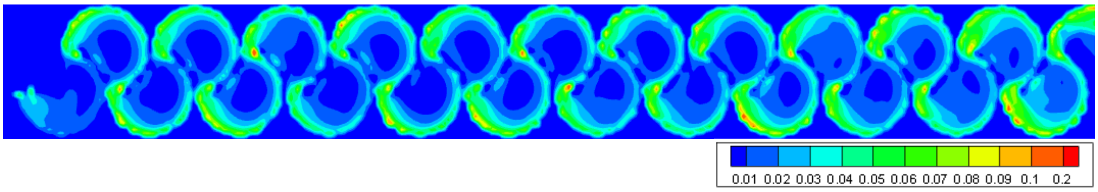


Figure 3.121. TKE of Type 13 considering max. flow rate conditions at 0.75h water level

- Results of Type 14

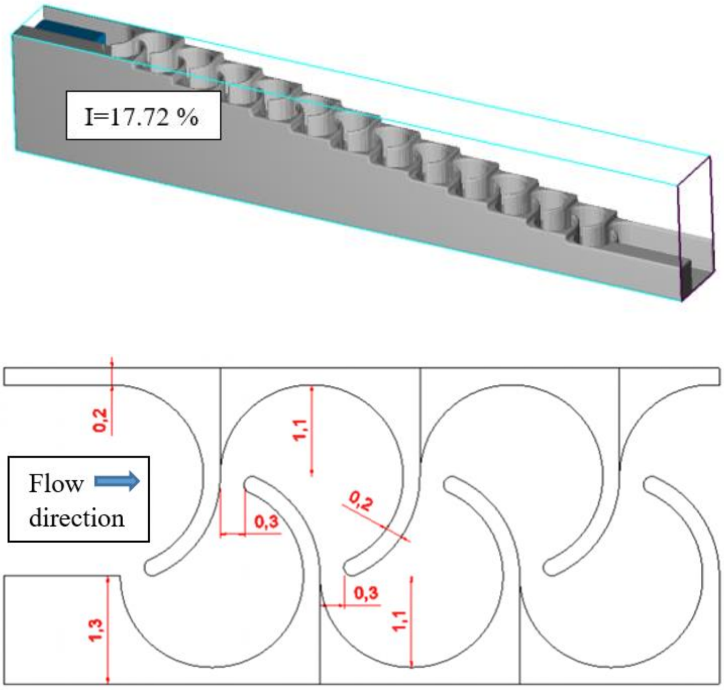


Figure 3.122. Dimensions of Type 14

In Type – 14, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.72% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout.

Herein, numerical simulations are completed for Type – 14 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.122 and Figure 3.123, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.124 and Figure 3.127, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.126 and Figure 3.129, turbulent kinetic energy (k) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, k value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.125 and 3.128) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, k contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, k values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 14 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. Therefore, Type – 14 geometry is not a proper design for the target fish.

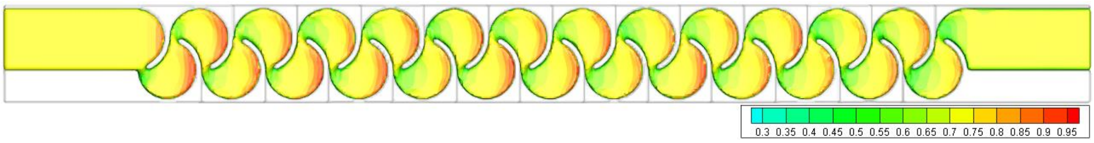


Figure 3.123. Fluid depth of Type 14 considering min. flow rate conditions – Top view

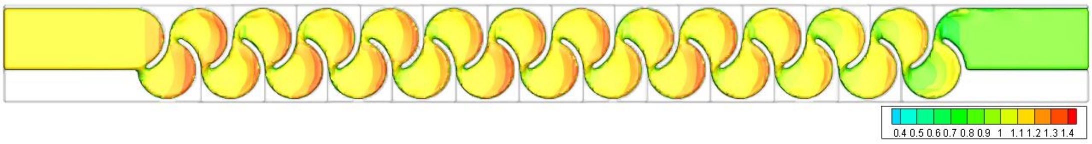
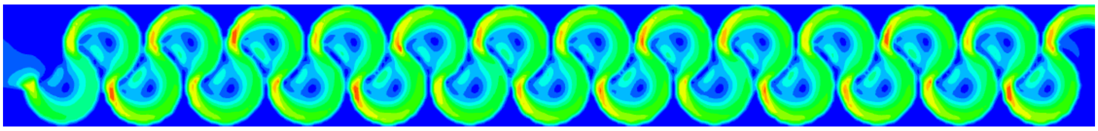
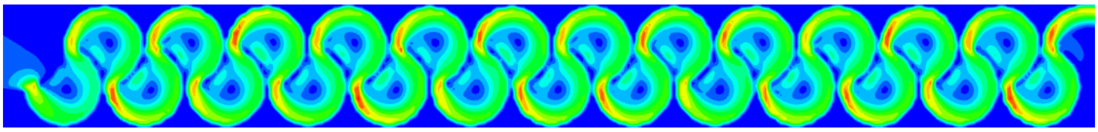


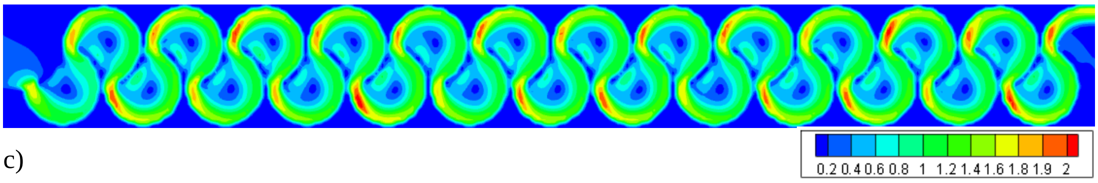
Figure 3.124. Fluid depth of Type 14 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.125. Flow velocities of Type 14 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

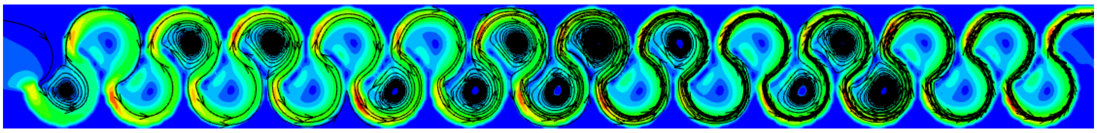


Figure 3.126. Streamlines of Type 14 considering min. flow rate conditions at 0.75h water level

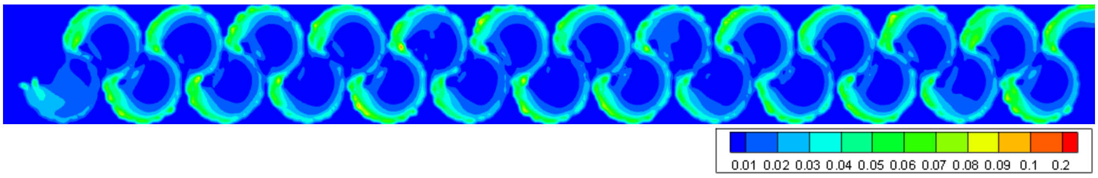
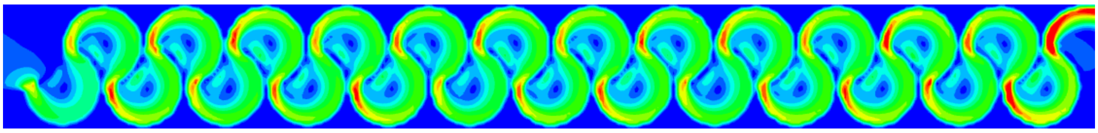
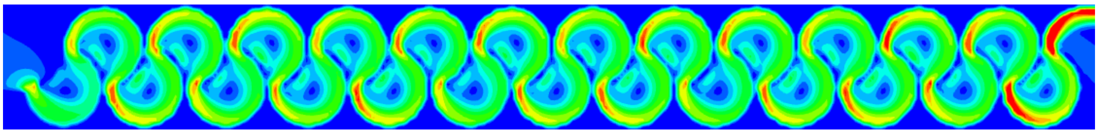


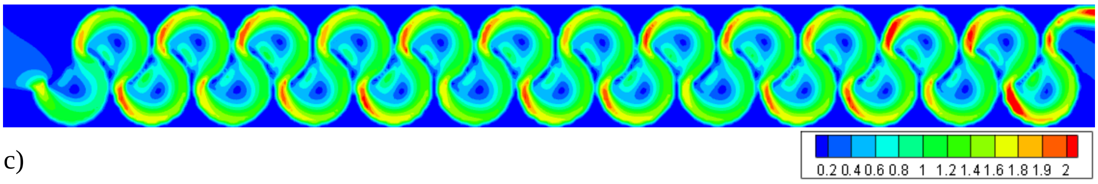
Figure 3.127. TKE of Type 14 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.128. Flow velocities of Type 14 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

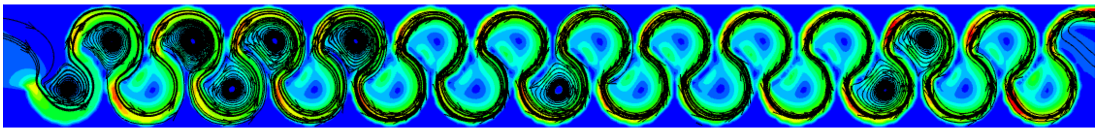


Figure 3.129. Streamlines of Type 14 considering max. flow rate conditions at 0.75h water level

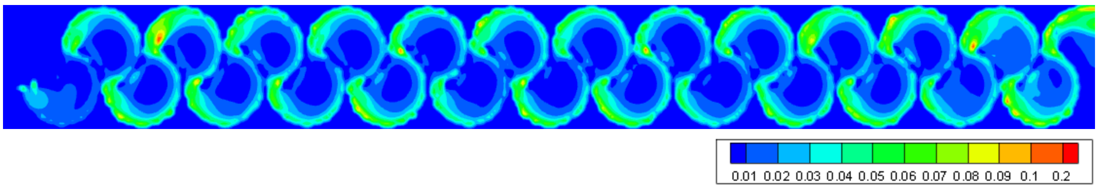


Figure 3.130. TKE of Type 14 considering max. flow rate conditions at 0.75h water level

- Results of Type 15

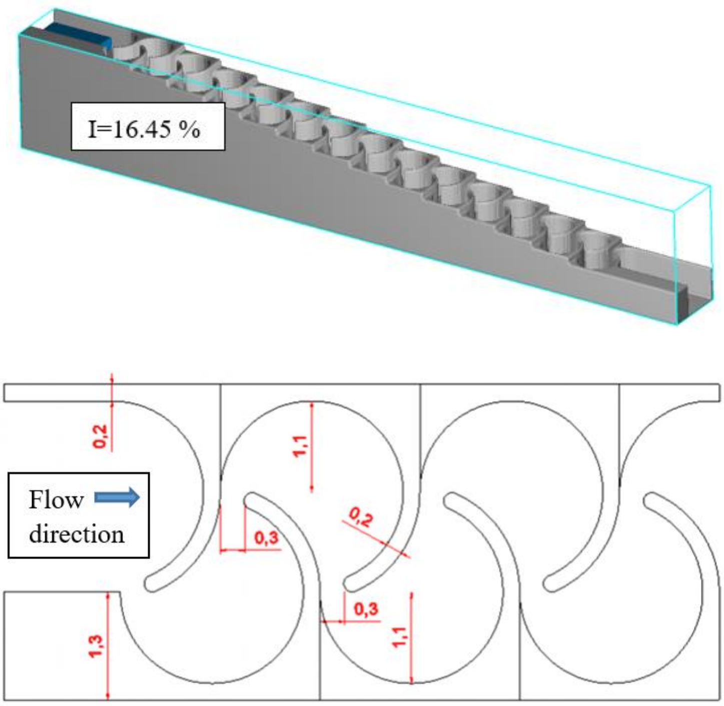


Figure 3.131. Dimensions of Type 15

In Type – 15, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=16.45% which is not in the range of manufacturer recommendations while the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout.

Herein, numerical simulations are completed for Type – 15 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.131 and Figure 3.132, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.133 and Figure 3.136, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, while the velocity magnitude in slots for min. flow rate condition is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3, the one for max. flow rate conditions is greater than 1.9 m/s. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.135 and Figure 3.138, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.134 and 3.137) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 15 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, for maximum flow conditions, the maximum velocity magnitude formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout. Therefore, Type – 15 geometry is not a proper design for the target fish.

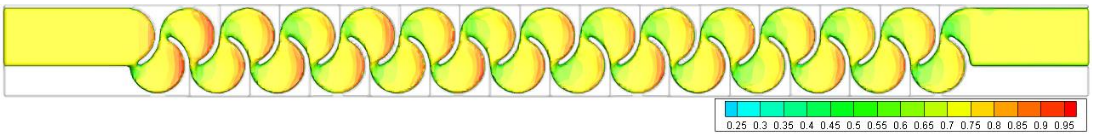


Figure 3.132. Fluid depth of Type 15 considering min. flow rate conditions – Top view

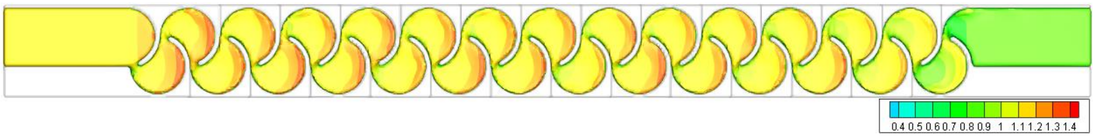


Figure 3.133. Fluid depth of Type 15 considering max. flow rate conditions – Top view

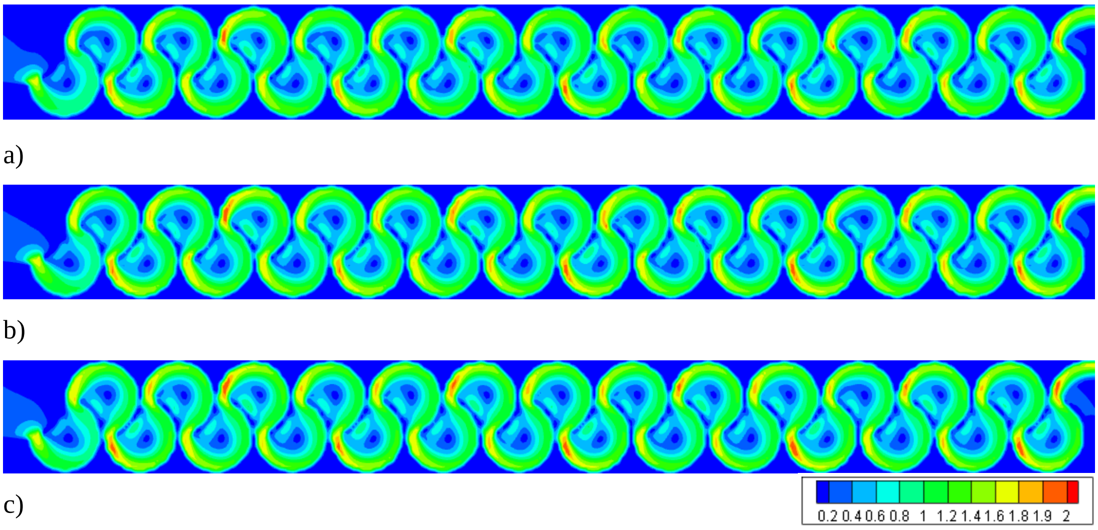


Figure 3.134. Flow velocities of Type 15 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

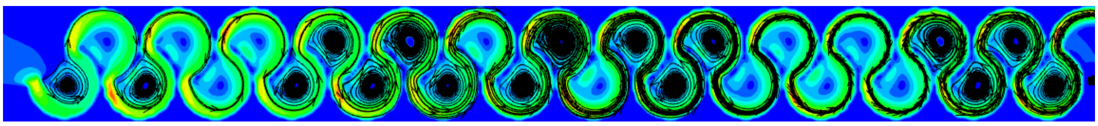


Figure 3.135. Streamlines of Type 15 considering min. flow rate conditions at 0.75h water level

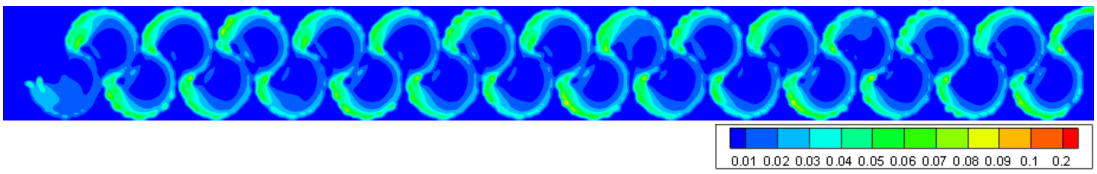


Figure 3.136. TKE of Type 15 considering min. flow rate conditions at 0.75h water level

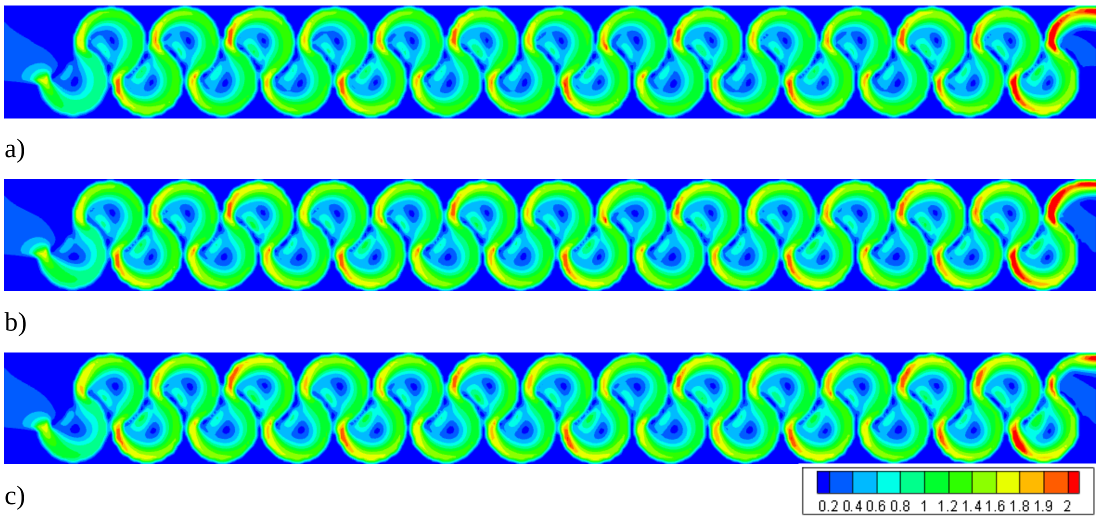


Figure 3.137. Flow velocities of Type 15 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

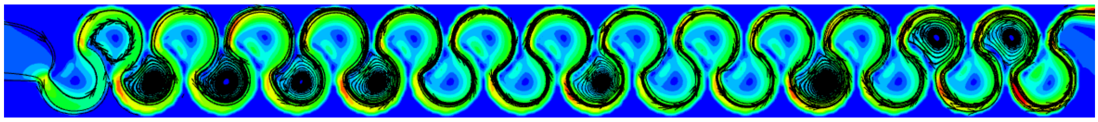


Figure 3.138. Streamlines of Type 15 considering max. flow rate conditions at 0.75h water level

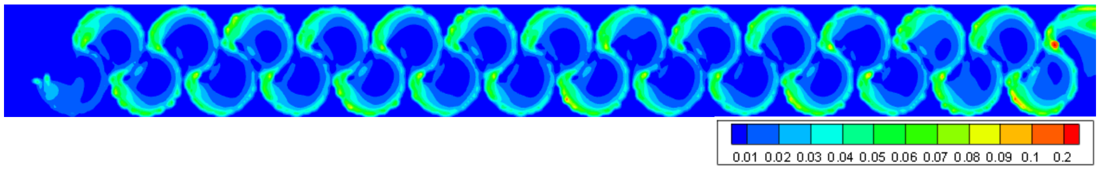


Figure 3.139. TKE of Type 15 considering max. flow rate conditions at 0.75h water level

- Results of Type 16

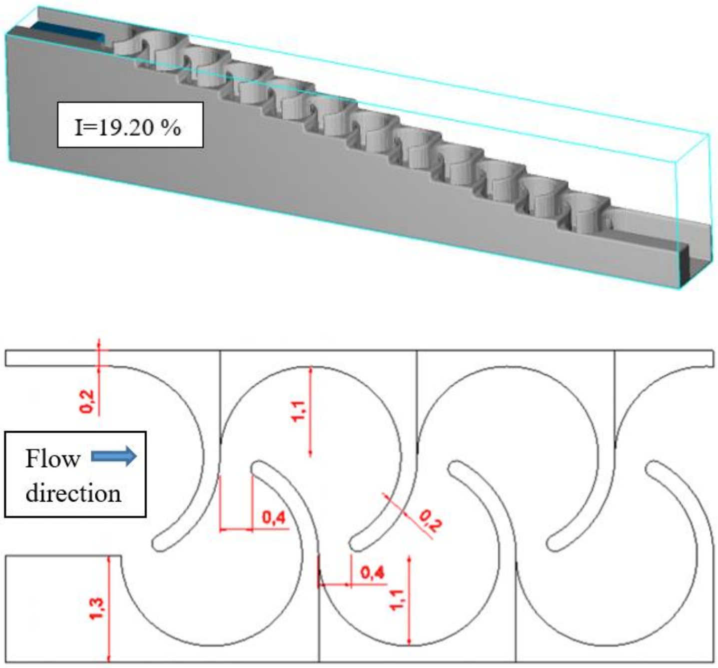


Figure 3.140. Dimensions of Type 16

In Type – 16, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=19.20% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 16 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.140 and Figure 3.141, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.142 and Figure 3.145, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.144 and Figure 3.147, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.143 and 3.146) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 16 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 16 geometry is not a proper design for the target fish.

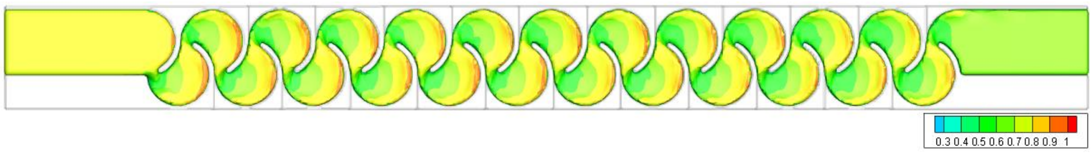


Figure 3.141. Fluid depth of Type 16 considering min. flow rate conditions – Top view

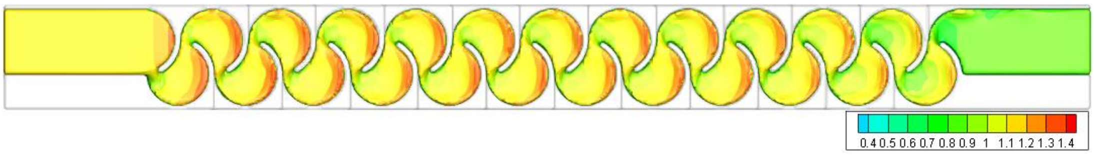


Figure 3.142. Fluid depth of Type 16 considering max. flow rate conditions – Top view

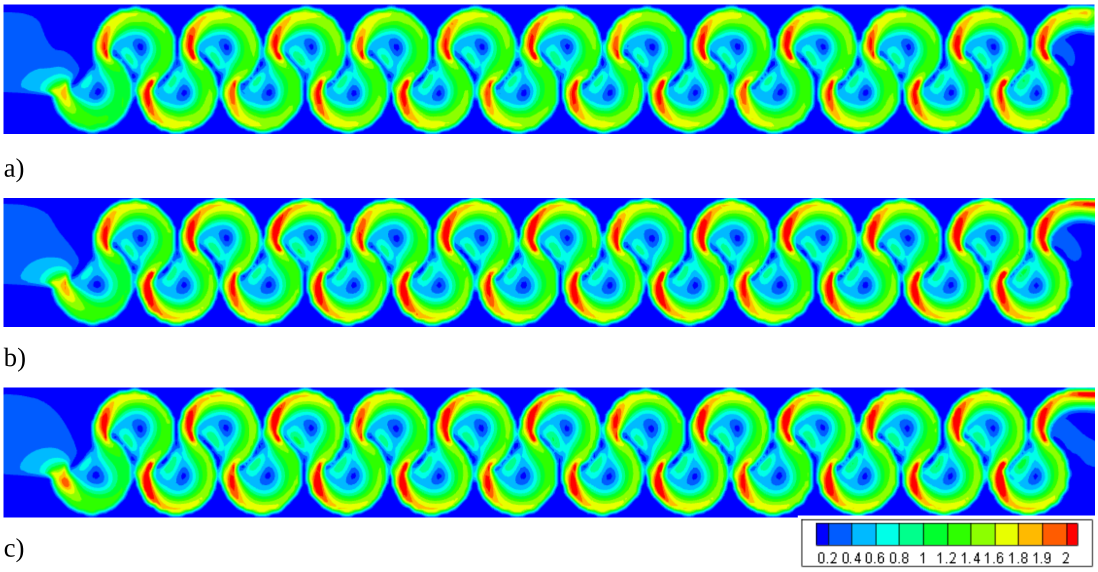


Figure 3.143. Flow velocities of Type 16 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

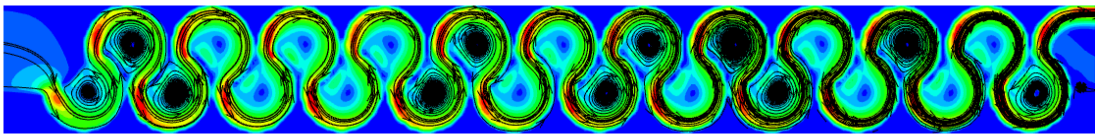


Figure 3.144. Streamlines of Type 16 considering min. flow rate conditions at 0.75h water level

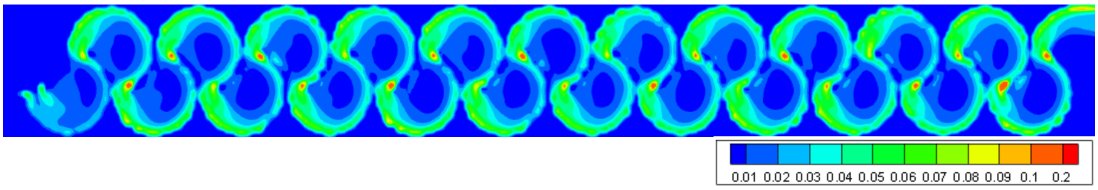
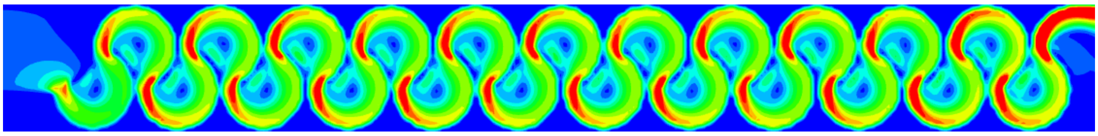
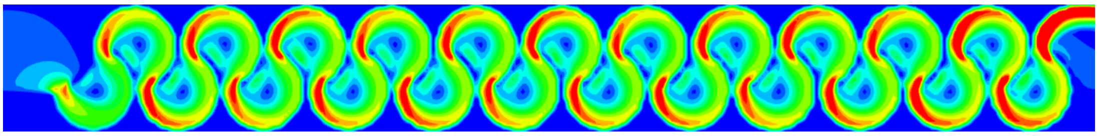


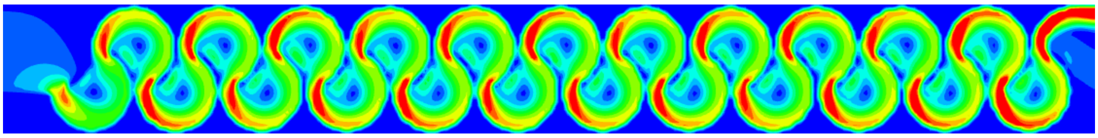
Figure 3.145. TKE of Type 16 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

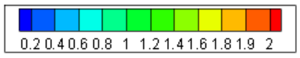


Figure 3.146. Flow velocities of Type 16 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

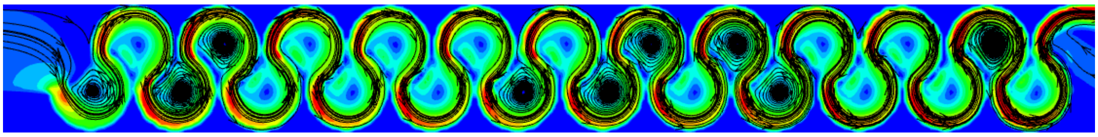


Figure 3.147. Streamlines of Type 16 considering max. flow rate conditions at 0.75h water level

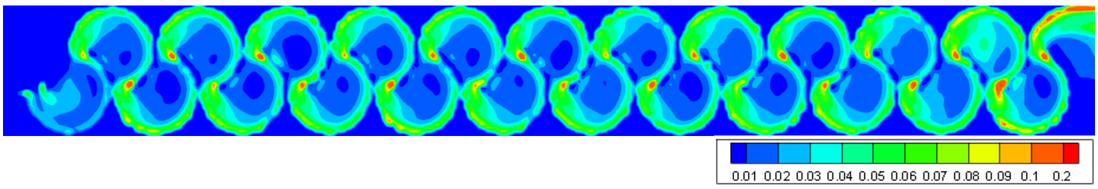
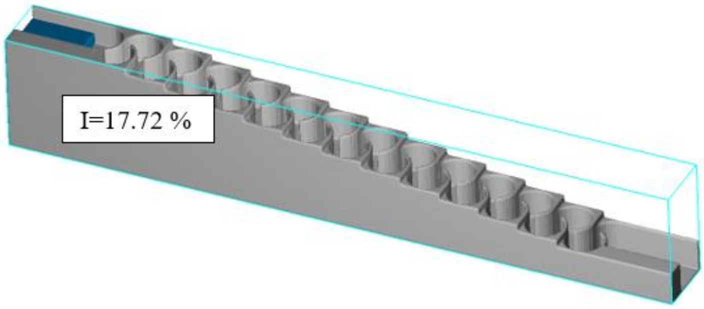


Figure 3.148. TKE of Type 16 considering max. flow rate conditions at 0.75h water level

- Results of Type 17



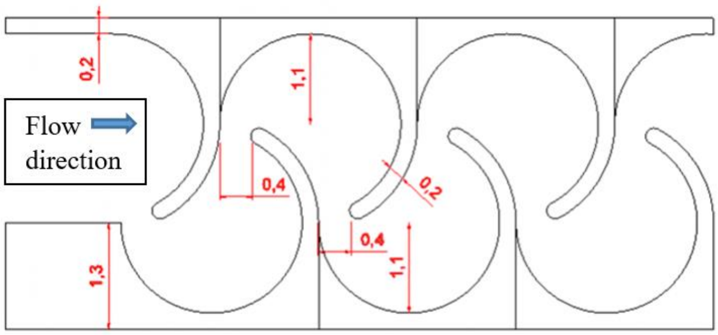


Figure 3.149. Dimensions of Type 17

In Type – 17, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.72% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 17 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.149 and Figure 3.150, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.151 and Figure 3.154, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.153 and Figure 3.156, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.152 and 3.155) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 17 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 17 geometry is not a proper design for the target fish.

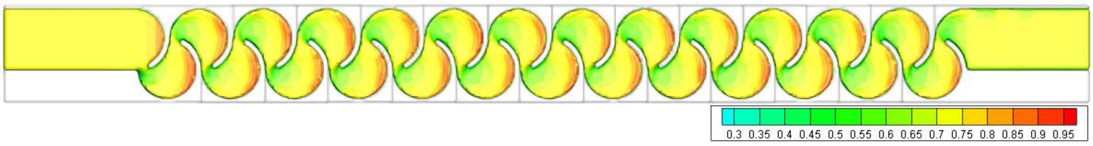


Figure 3.150. Fluid depth of Type 17 considering min. flow rate conditions – Top view

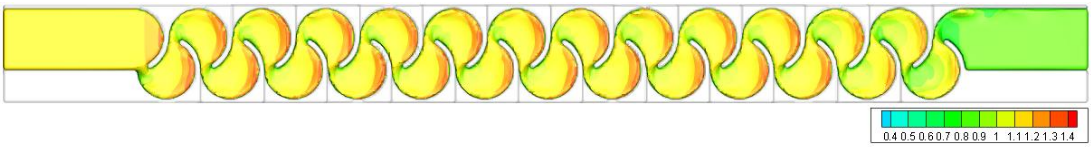
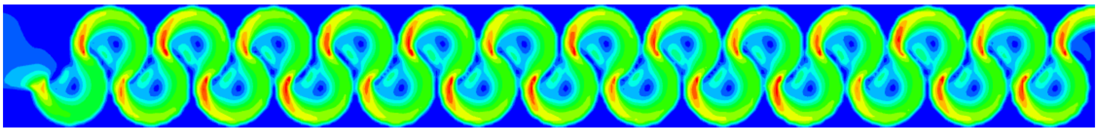
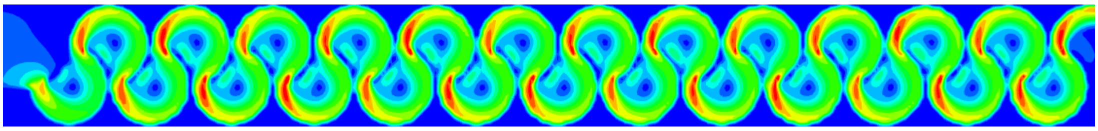


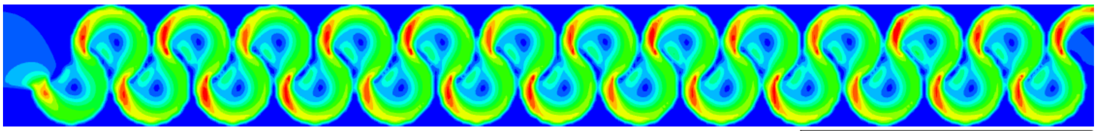
Figure 3.151. Fluid depth of Type 17 considering max. flow rate conditions – Top view



a)



b)



c)

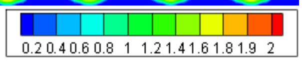


Figure 3.152. Flow velocities of Type 17 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

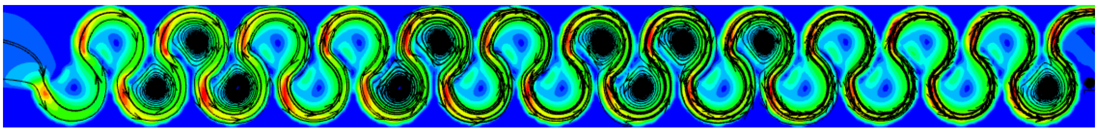


Figure 3.153. Streamlines of Type 17 considering min. flow rate conditions at 0.75h water level

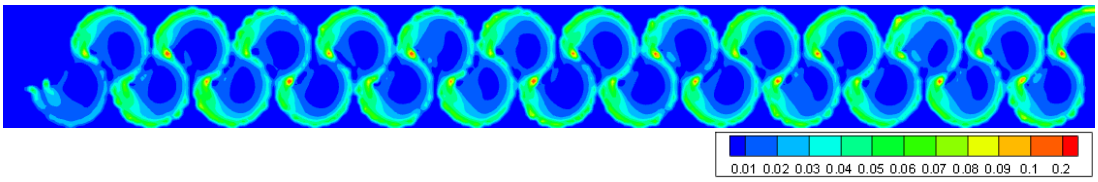
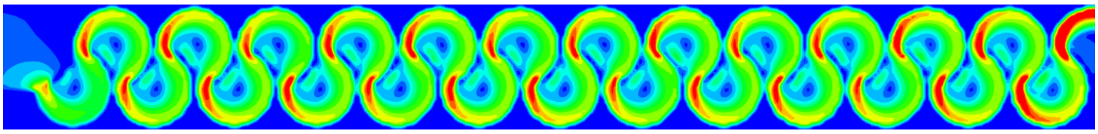
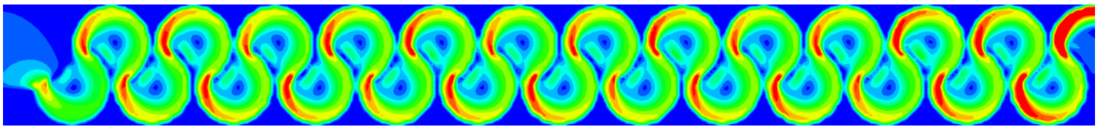


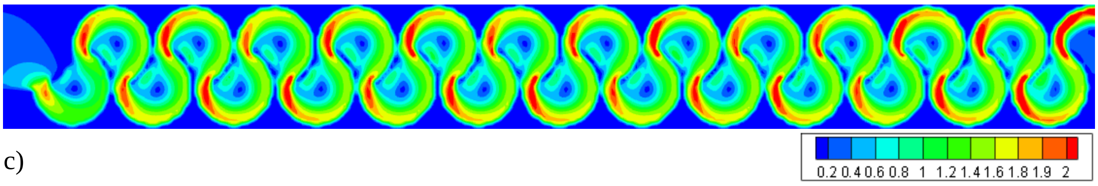
Figure 3.154. TKE of Type 17 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.155. Flow velocities of Type 17 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

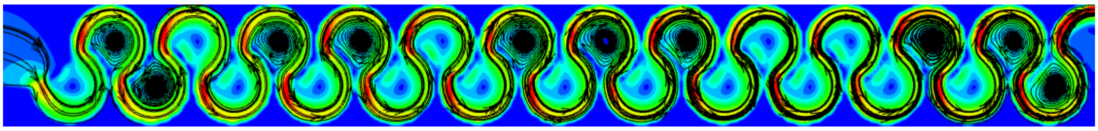


Figure 3.156. Streamlines of Type 17 considering max. flow rate conditions at 0.75h water level

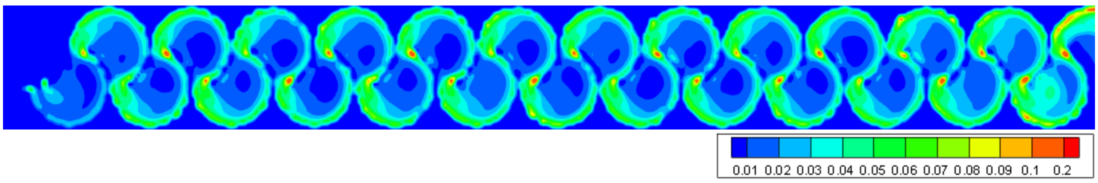


Figure 3.157. TKE of Type 17 considering max. flow rate conditions at 0.75h water level

- Results of Type 18

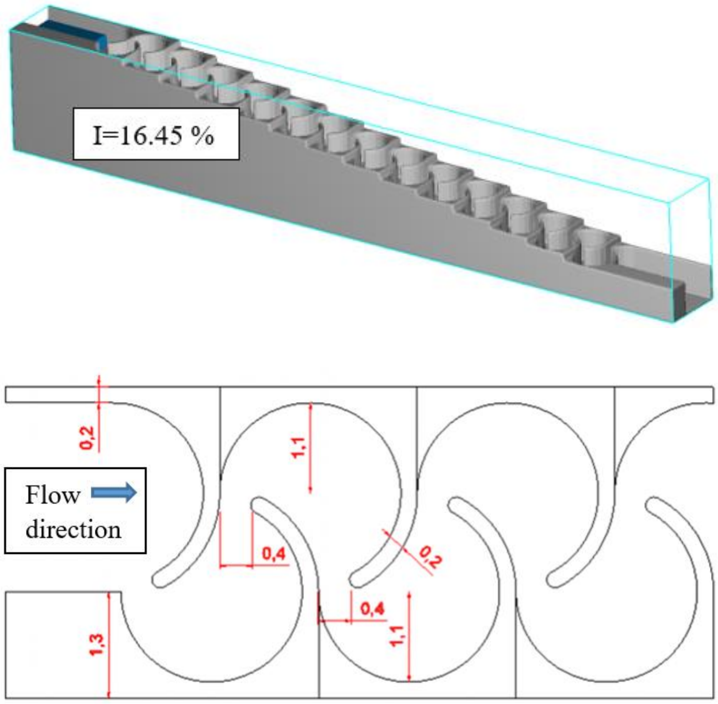


Figure 3.158. Dimensions of Type 18

In Type – 18, pool diameter D_{pool} is taken as 2.2 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), and also in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=16.45% which is not in the range of manufacturer recommendations while the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 18 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.158 and Figure 3.159, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.160 and Figure 3.163, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.162 and Figure 3.165, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.161 and 3.164) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 18 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 18 geometry is not a proper design for the target fish.

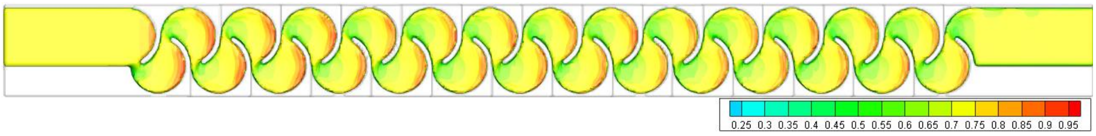


Figure 3.159. Fluid depth of Type 18 considering min. flow rate conditions – Top view

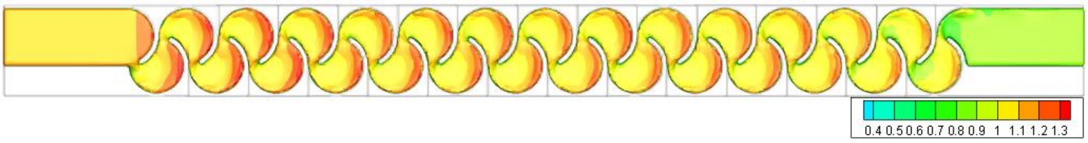
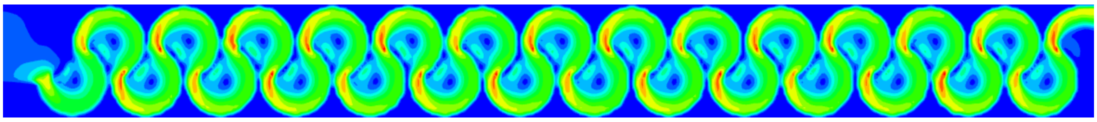
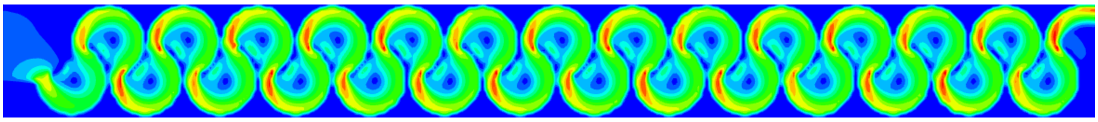


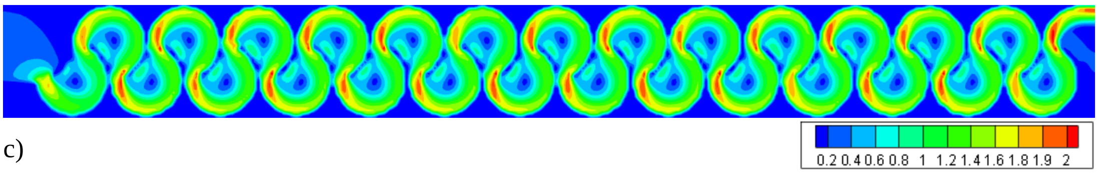
Figure 3.160. Fluid depth of Type 18 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.161. Flow velocities of Type 18 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

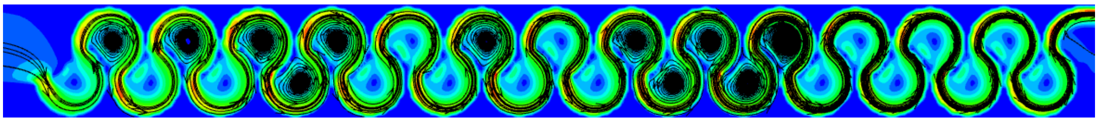


Figure 3.162. Streamlines of Type 18 considering min. flow rate conditions at 0.75h water level

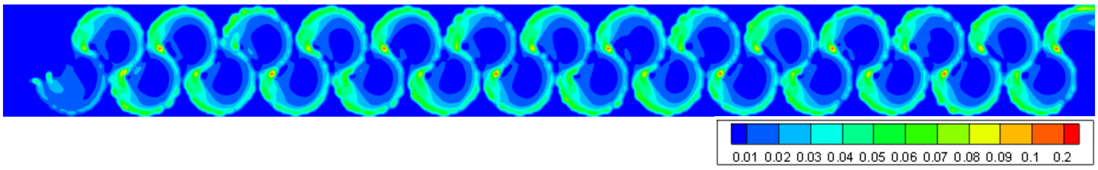


Figure 3.163. TKE of Type 18 considering min. flow rate conditions at 0.75h water level

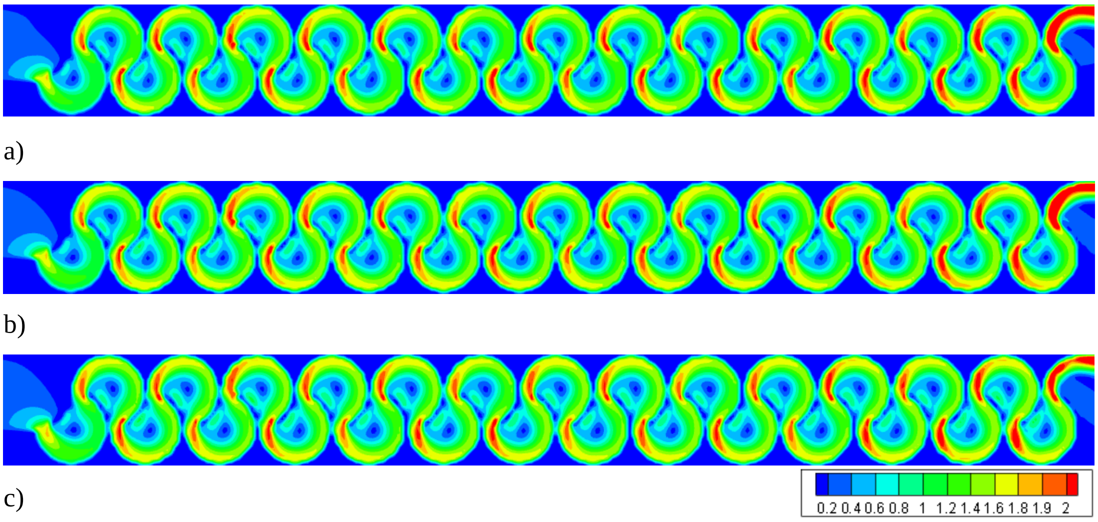


Figure 3.164. Flow velocities of Type 18 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

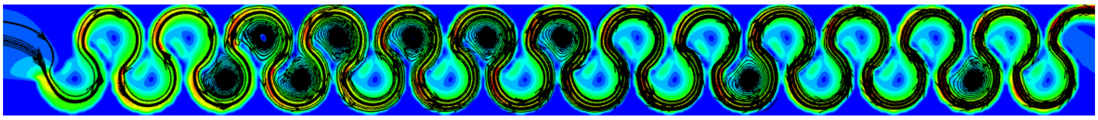


Figure 3.165. Streamlines of Type 18 considering max. flow rate conditions at 0.75h water level

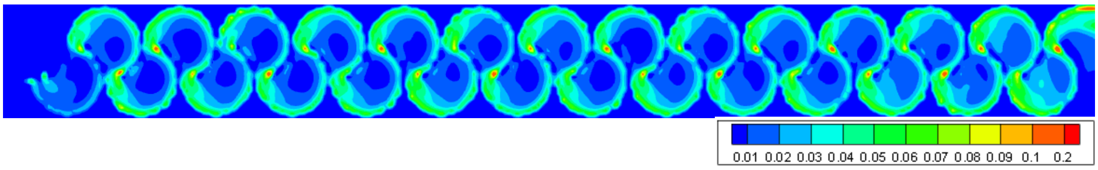


Figure 3.166. TKE of Type 18 considering max. flow rate conditions at 0.75h water level

- Results of Type 19

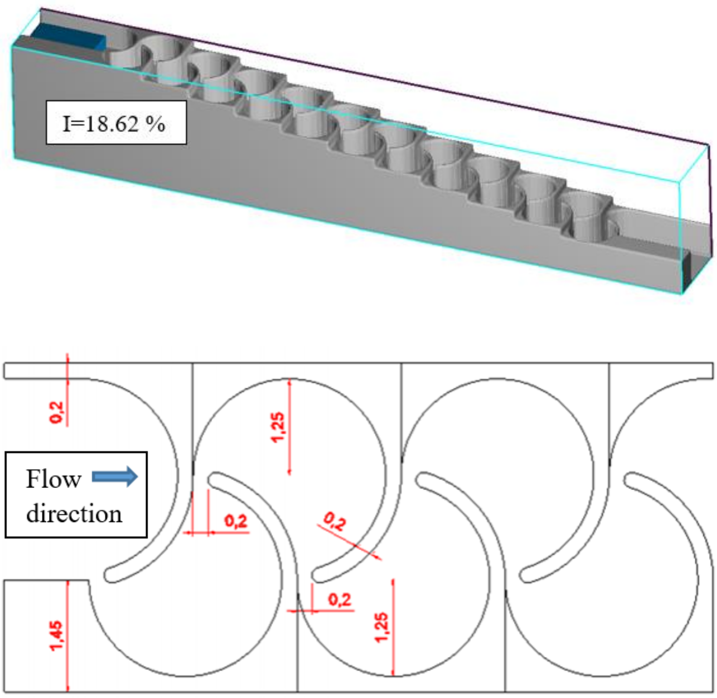


Figure 3.167. Dimensions of Type 19

In Type – 19, pool diameter D_{pool} is taken as 2.5 m which is greater than minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but not in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=18.62% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 19 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 19 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish

pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.167 and Figure 3.168, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.169 and Figure 3.172, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.171 and Figure 3.174, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.09 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.170 and 3.173) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 19 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. In addition, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater

than the one considered in Type – 19, Type – 19 geometry is not a proper design for the target fish.

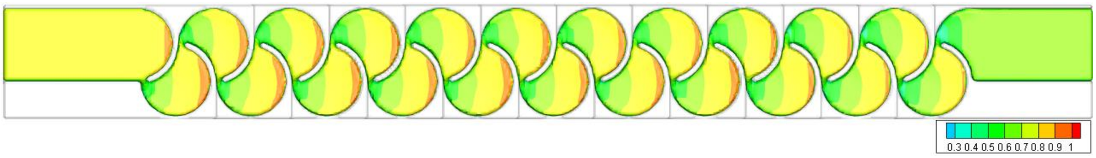


Figure 3.168. Fluid depth of Type 19 considering min. flow rate conditions – Top view

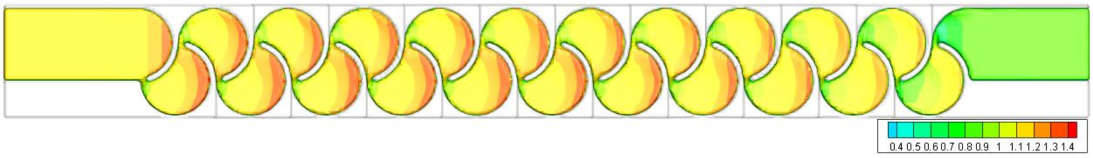


Figure 3.169. Fluid depth of Type 19 considering max. flow rate conditions – Top view

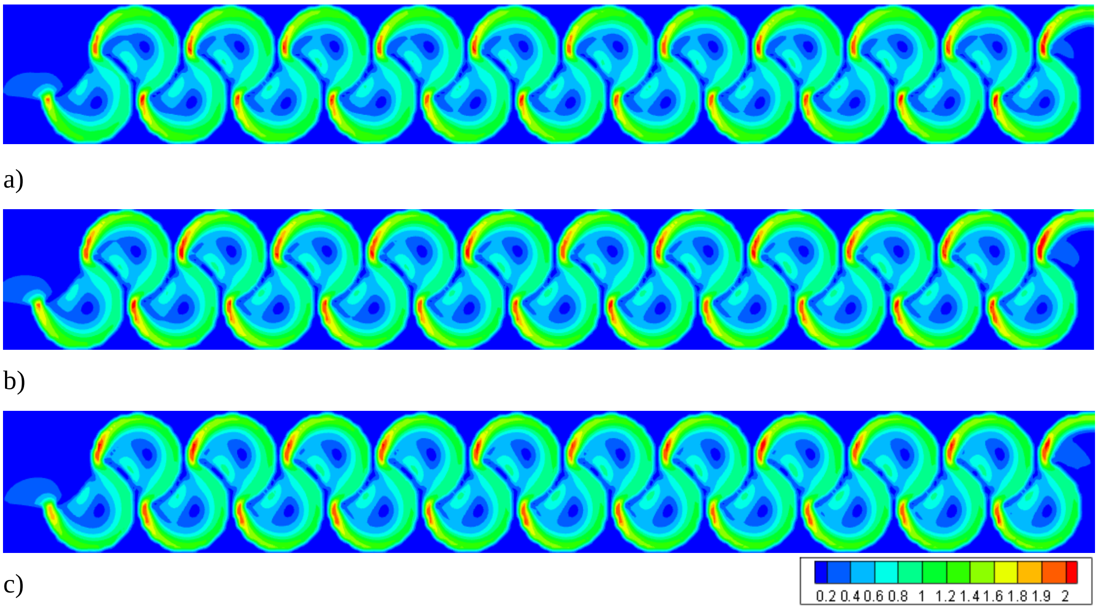


Figure 3.170. Flow velocities of Type 19 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

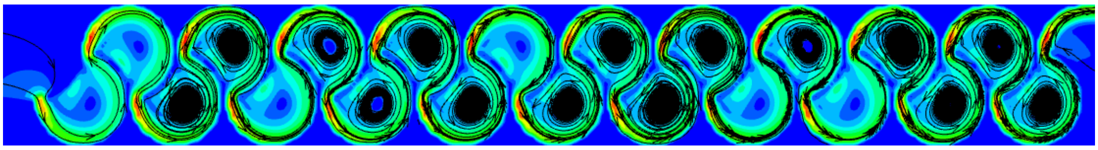


Figure 3.171. Streamlines of Type 19 considering min. flow rate conditions at 0.75h water level

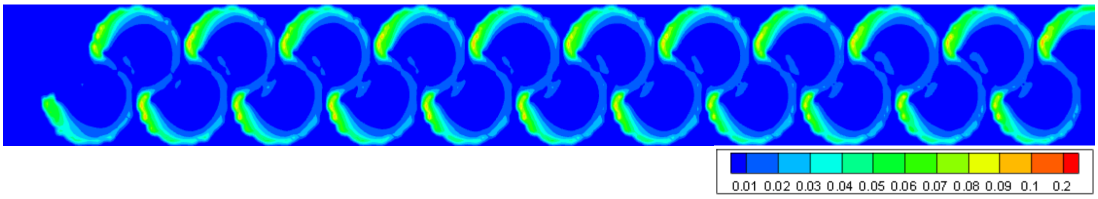


Figure 3.172. TKE of Type 19 considering min. flow rate conditions at 0.75h water level

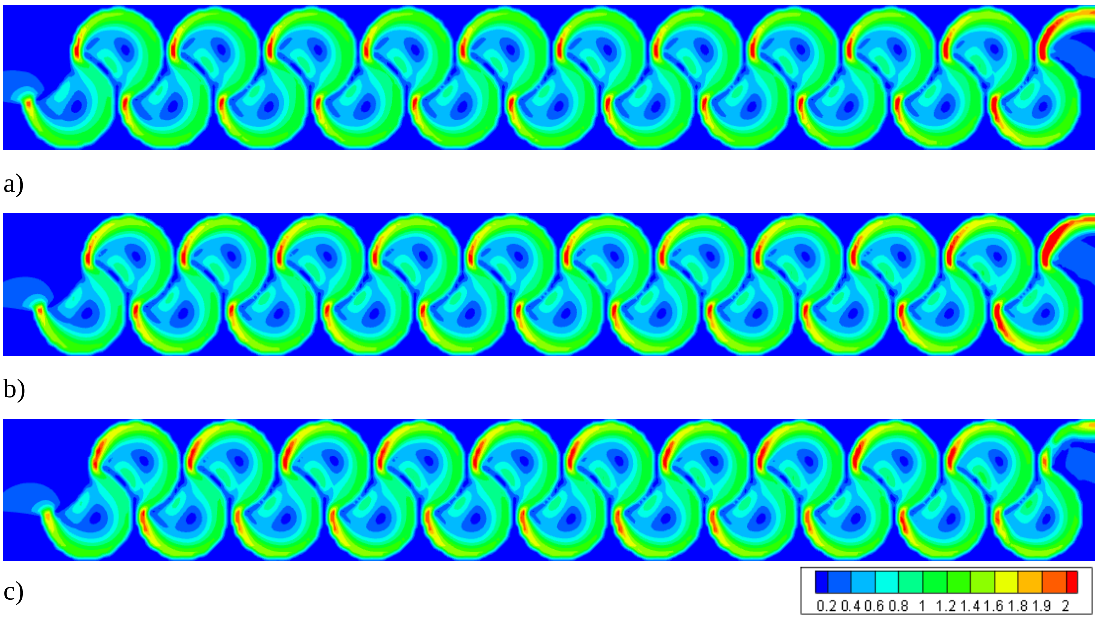


Figure 3.173. Flow velocities of Type 19 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

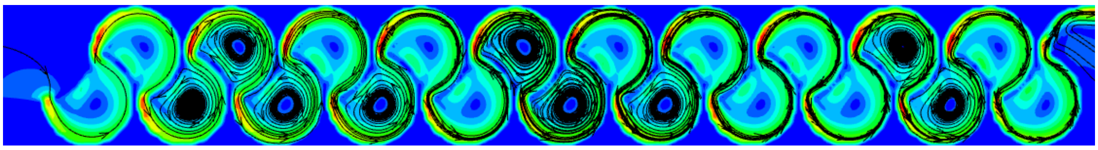


Figure 3.174. Streamlines of Type 19 considering max. flow rate conditions at 0.75h water level

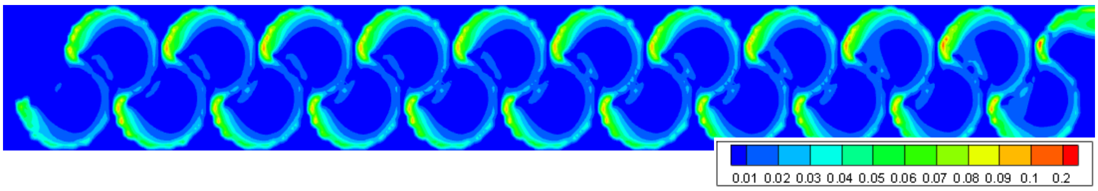


Figure 3.175. TKE of Type 19 considering max. flow rate conditions at 0.75h water level

- Results of Type 20

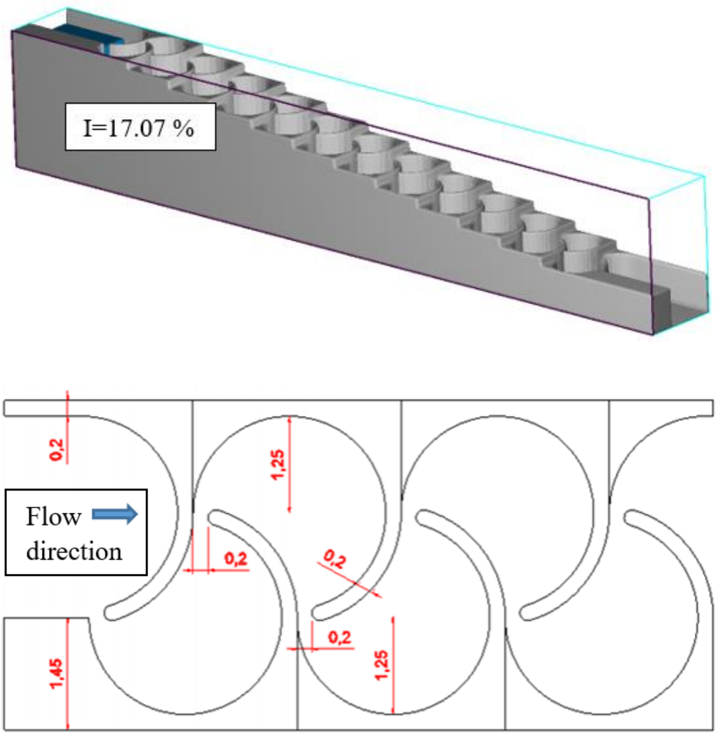


Figure 3.176. Dimensions of Type 20

In Type – 20, pool diameter D_{pool} is taken as 2.5 m which is greater than minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but not in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.07% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 20 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 20 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish

pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.176 and Figure 3.177, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.178 and Figure 3.181, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.180 and Figure 3.183, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.179 and 3.182) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 20 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. In addition, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater

than the one considered in Type – 20, Type – 20 geometry is not a proper design for the target fish.

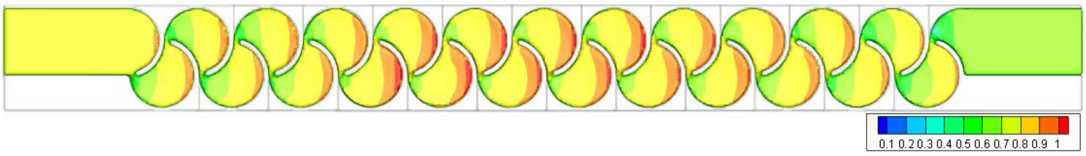


Figure 3.177. Fluid depth of Type 20 considering min. flow rate conditions – Top view

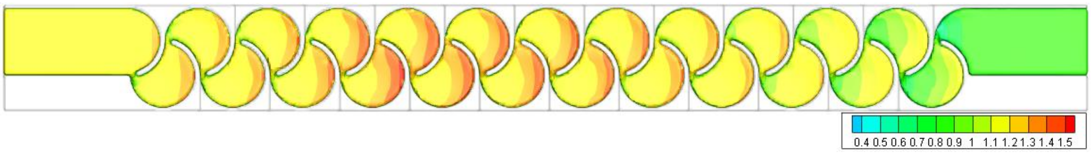
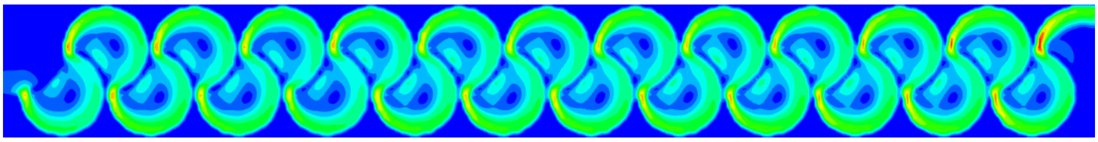
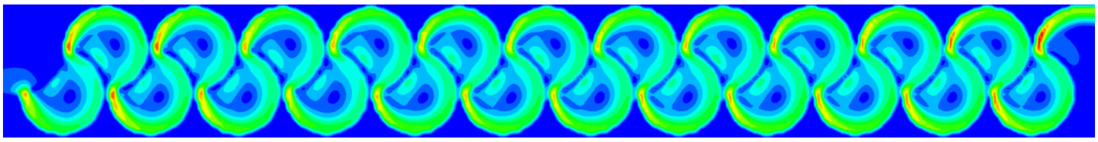


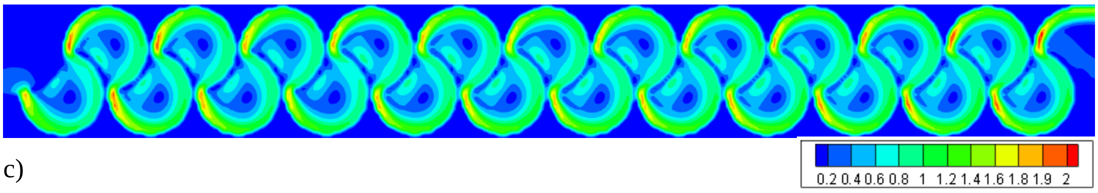
Figure 3.178. Fluid depth of Type 20 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.179. Flow velocities of Type 20 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

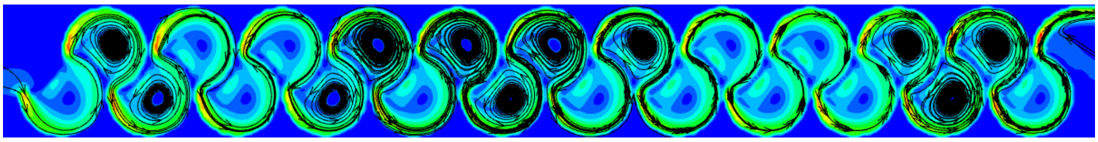


Figure 3.180. Streamlines of Type 20 considering min. flow rate conditions at 0.75h water level

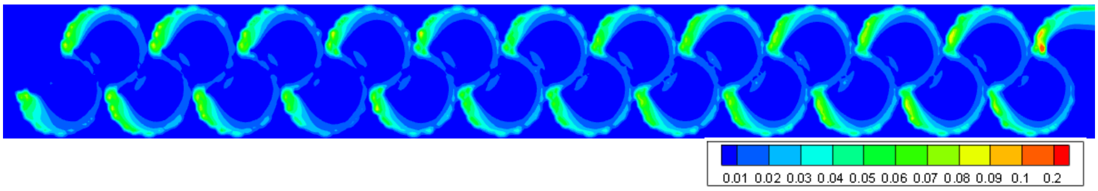
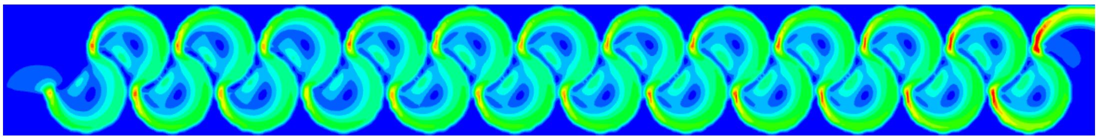
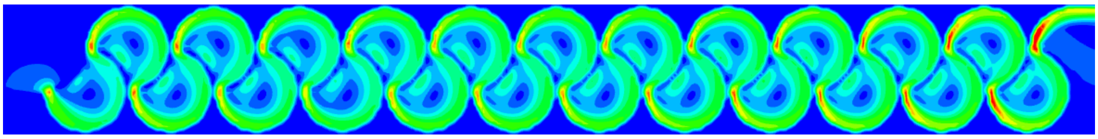


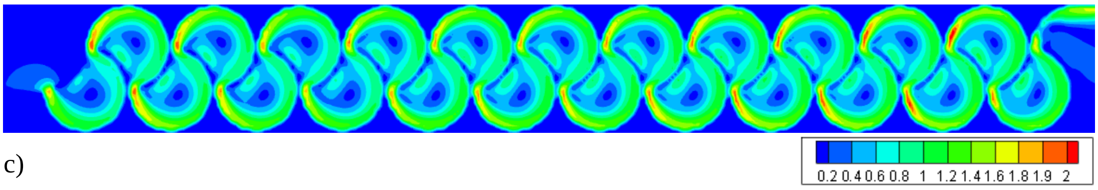
Figure 3.181. TKE of Type 20 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.182. Flow velocities of Type 20 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

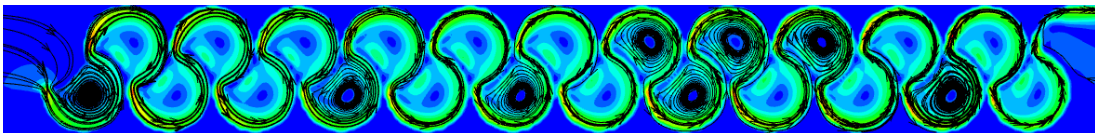


Figure 3.183. Streamlines of Type 20 considering max. flow rate conditions at 0.75h water level

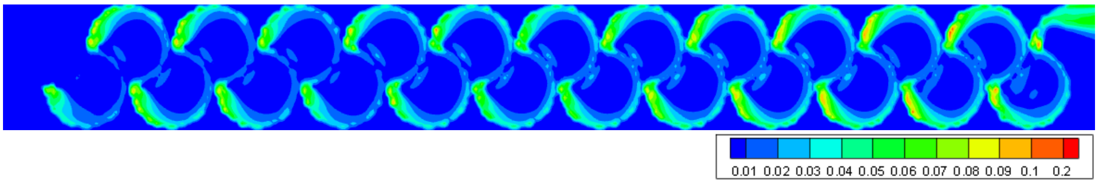


Figure 3.184. TKE of Type 20 considering max. flow rate conditions at 0.75h water level

- Results of Type 21

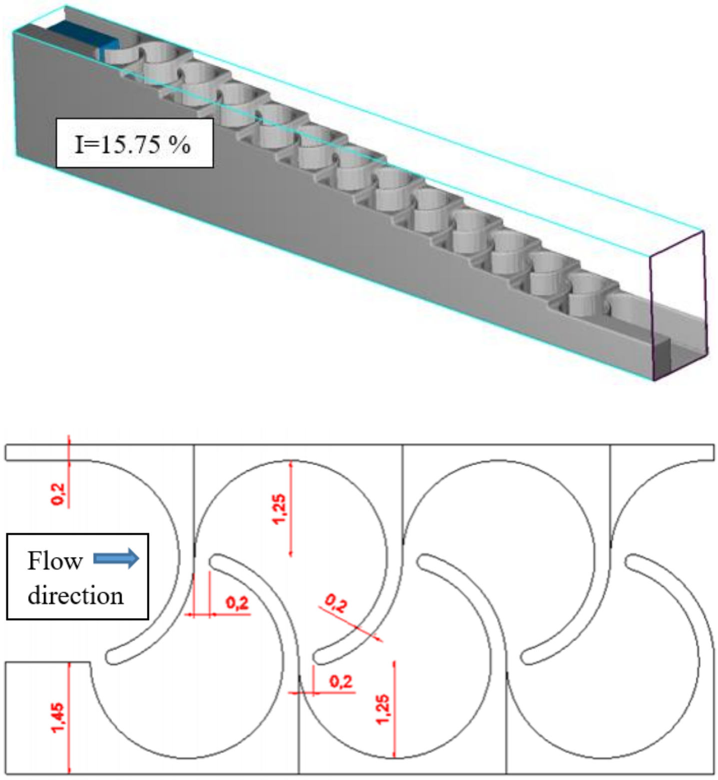


Figure 3.185. Dimensions of Type 21

In Type – 21, pool diameter D_{pool} is taken as 2.5 m which is greater the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but not in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=15.75% which is not in the range of manufacturer recommendations. Regarding the target fish species, selected slot width, s_w=0.2 m does not match with the requirements of DWA where minimum s_w=0.3 m is recommended for brown trout. This subject about proper slot width for various fish species is not mentioned in manufacturer specifications. Although the chosen slot width in Type – 21 is not recommended for the target fish, numerical analyses were completed with this width in order to compare hydraulic characteristics of flow in other types of models and to evaluate the effect of slot width.

Herein, numerical simulations are completed for Type – 21 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.185 and Figure 3.186, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.187 and Figure 3.190, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions is less than 1.9 m/s which is proper for the target fish as indicated in Table 1.3. Moreover, velocity magnitude at the middle of pools varies between the values of 0.0 – 0.8 m/s which provides a resting area for fish.

In Figure 3.189 and Figure 3.192, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.188 and 3.191) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 21 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. Moreover, the maximum velocity magnitude formed in the pools does not exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions. However, since the minimum permissible slot width for brown trout in round vertical slot fish pass is recommended as 0.3 m, which is greater than the one considered in Type – 21, Type – 21 geometry is not a proper design for the target fish.

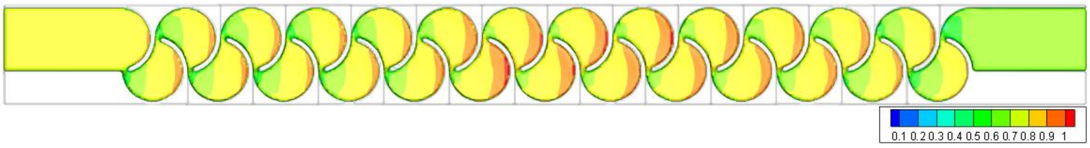


Figure 3.186. Fluid depth of Type 21 considering min. flow rate conditions – Top view

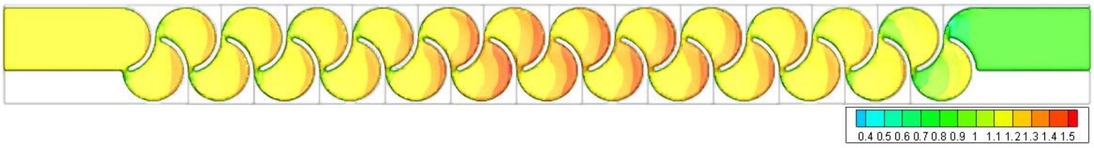
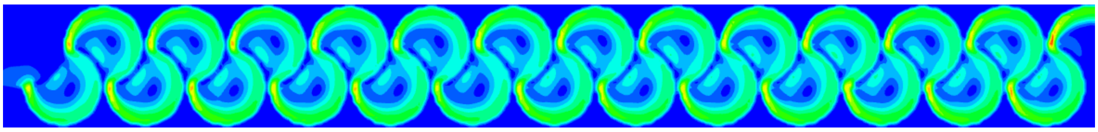
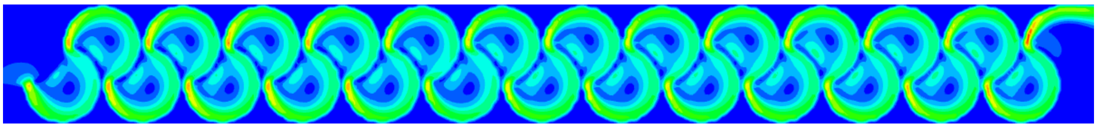


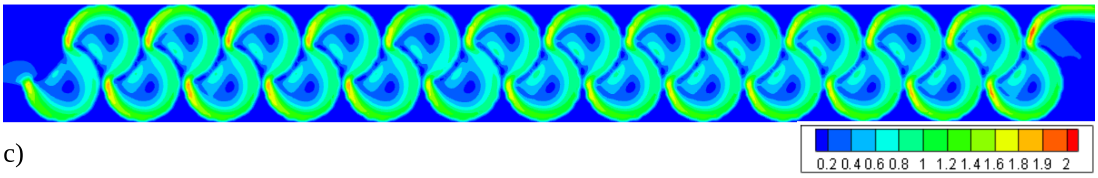
Figure 3.187. Fluid depth of Type 21 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.188. Flow velocities of Type 21 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

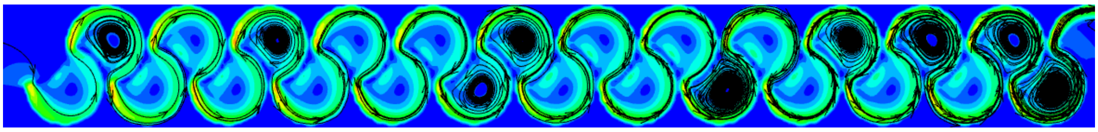


Figure 3.189. Streamlines of Type 21 considering min. flow rate conditions at 0.75h water level

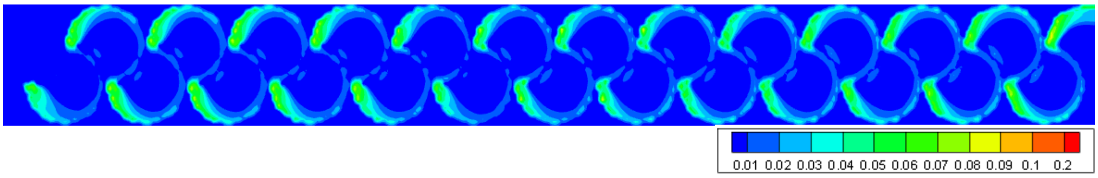


Figure 3.190. TKE of Type 21 considering min. flow rate conditions at 0.75h water level

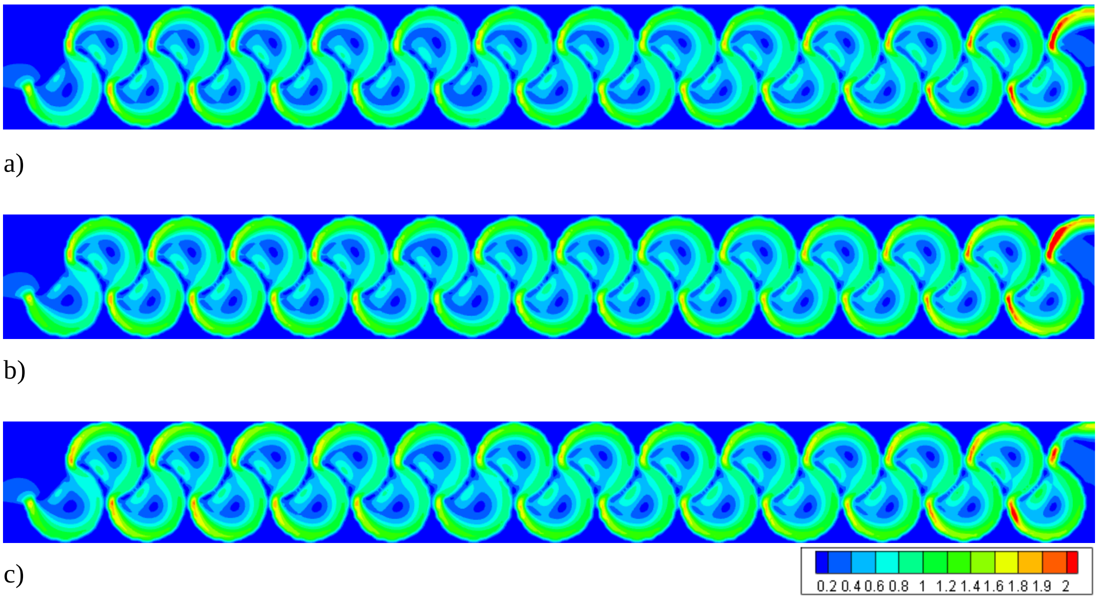


Figure 3.191. Flow velocities of Type 21 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

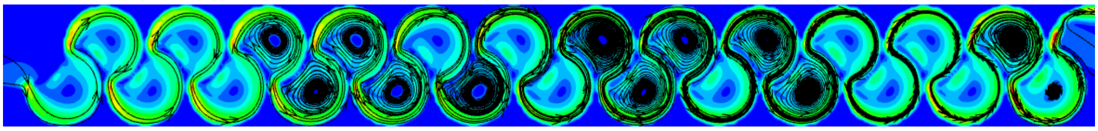


Figure 3.192. Streamlines of Type 21 considering max. flow rate conditions at 0.75h water level

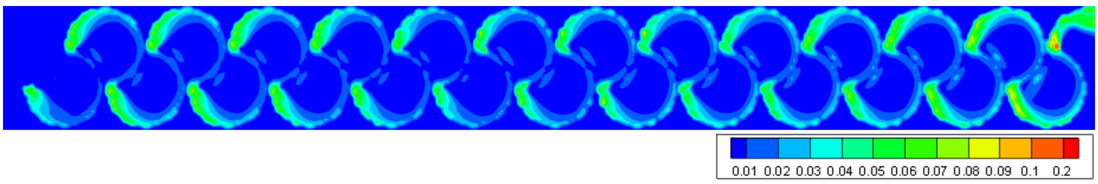


Figure 3.193. TKE of Type 21 considering max. flow rate conditions at 0.75h water level

- Results of Type 22

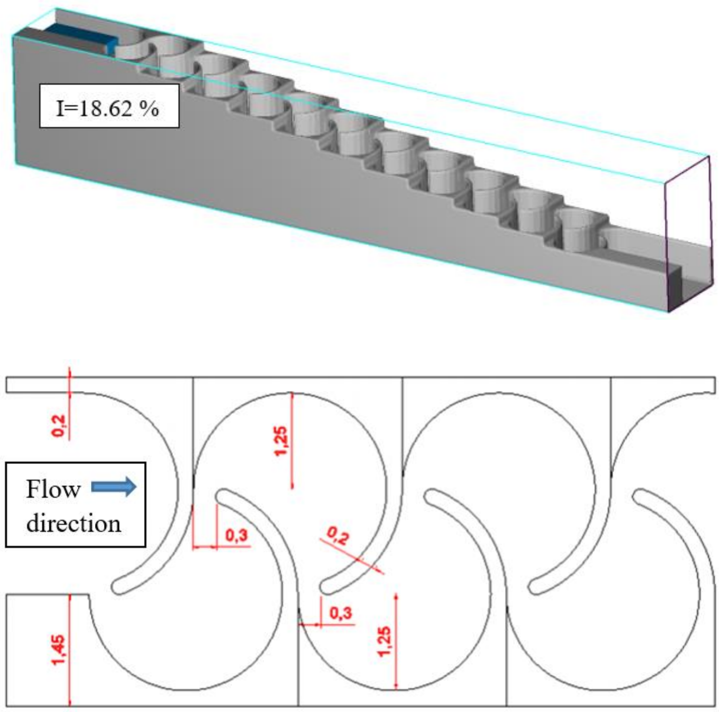


Figure 3.194. Dimensions of Type 22

In Type – 22, pool diameter D_{pool} is taken as 2.5 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=18.62% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 22 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.194 and Figure 3.195, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.196 and Figure 3.199, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish.

In Figure 3.198 and Figure 3.201, turbulent kinetic energy (k) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, k value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.197 and 3.200) where turbulence damping occurs along the wall. At the middle of pools k value is obtained as ~0.0 m^2/s^2. As a comparison, k contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, k values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 22 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 22 geometry is not a proper design for the target fish.

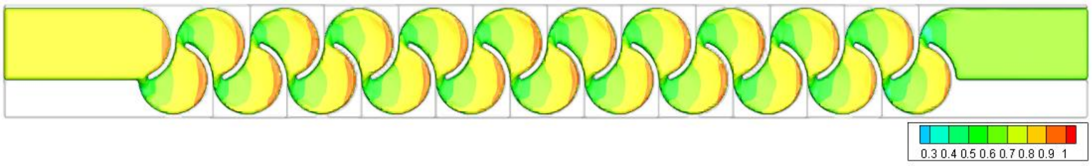


Figure 3.195. Fluid depth of Type 22 considering min. flow rate conditions – Top view

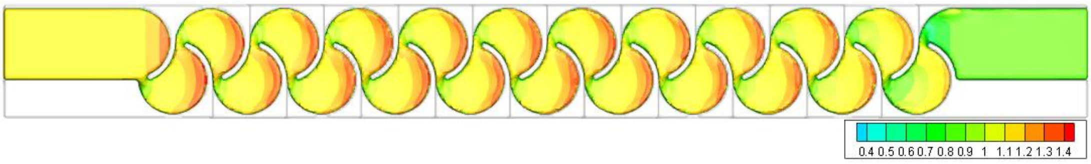


Figure 3.196. Fluid depth of Type 22 considering max. flow rate conditions – Top view

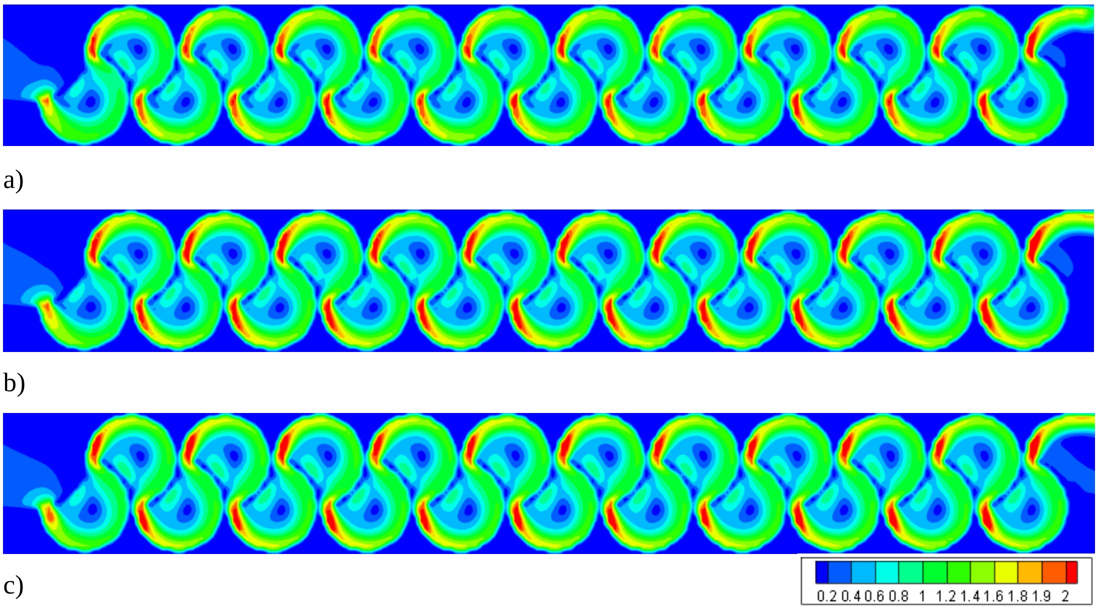


Figure 3.197. Flow velocities of Type 22 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

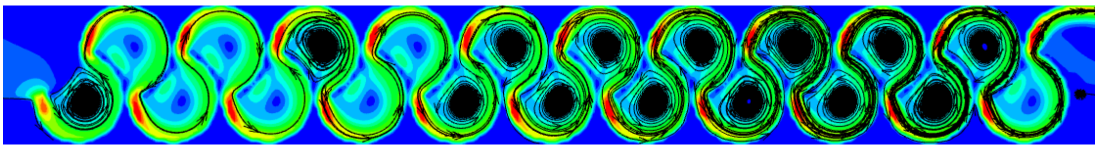


Figure 3.198. Streamlines of Type 22 considering min. flow rate conditions at 0.75h water level

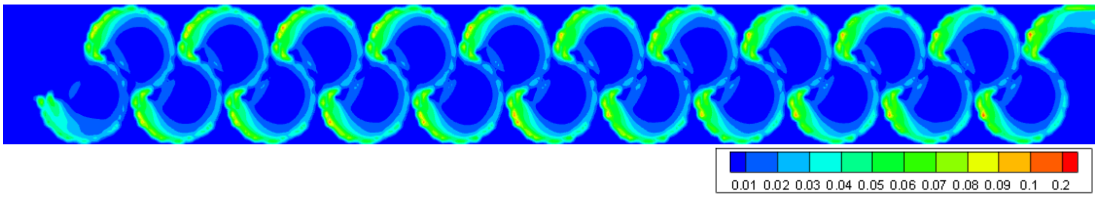
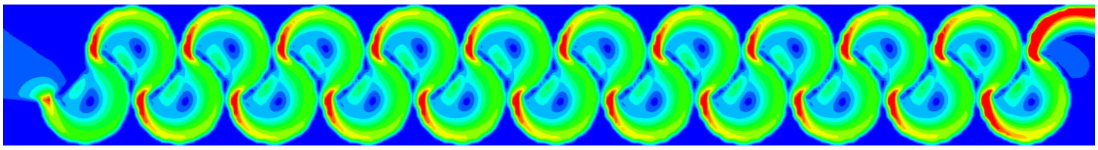
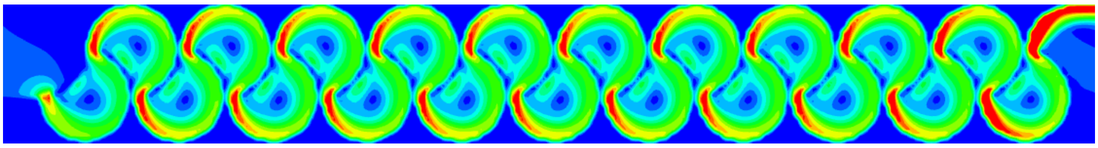


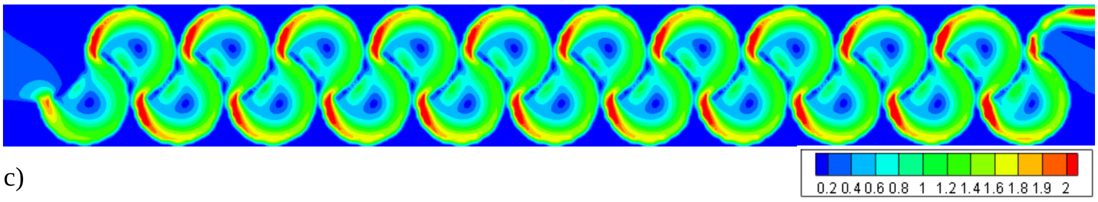
Figure 3.199. TKE of Type 22 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.200. Flow velocities of Type 22 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

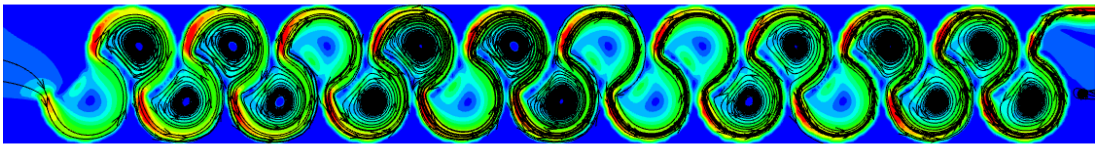


Figure 3.201. Streamlines of Type 22 considering max. flow rate conditions at 0.75h water level

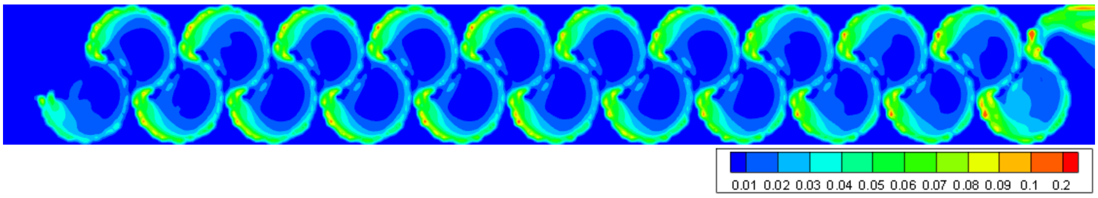


Figure 3.202. TKE of Type 22 considering max. flow rate conditions at 0.75h water level

- Results of Type 23

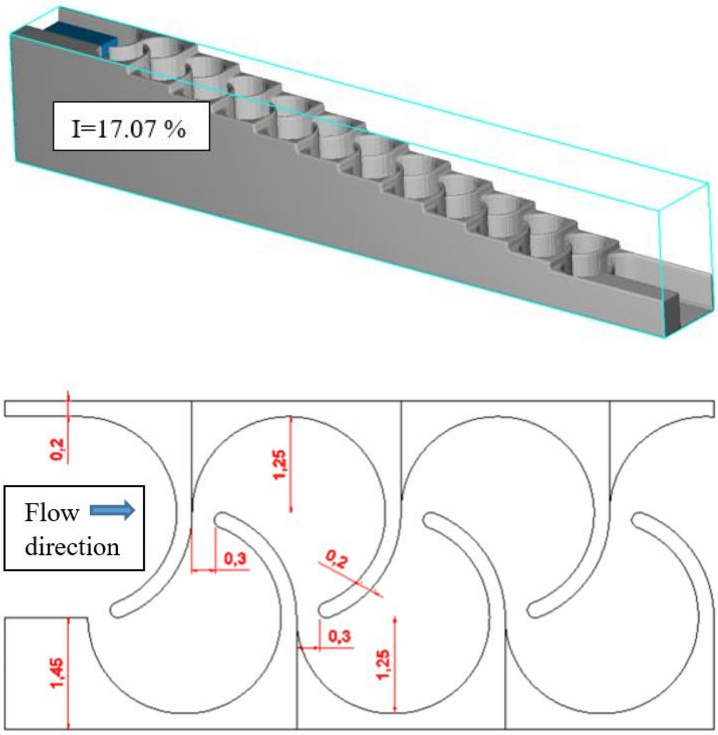


Figure 3.203. Dimensions of Type 23

In Type – 23, pool diameter D_{pool} is taken as 2.5 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.07% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 23 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.203 and Figure 3.204, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.205 and Figure 3.208, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish.

In Figure 3.207 and Figure 3.210, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.206 and 3.209) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 23 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 23 geometry is not a proper design for the target fish.

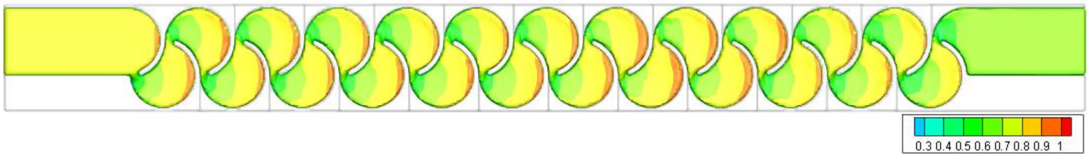


Figure 3.204. Fluid depth of Type 23 considering min. flow rate conditions – Top view

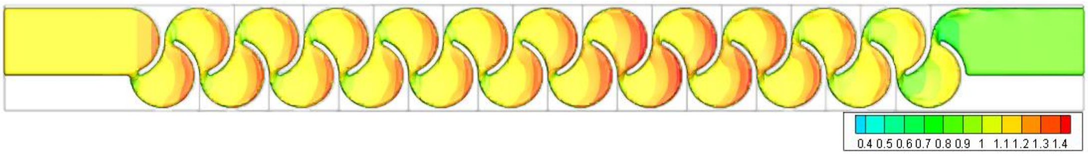
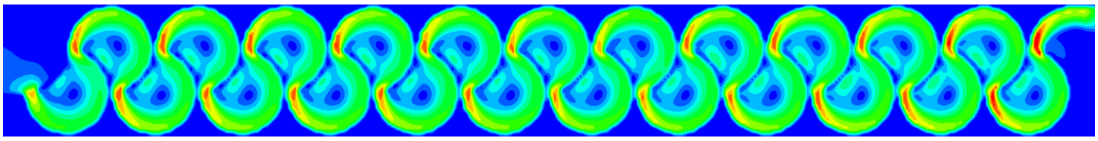
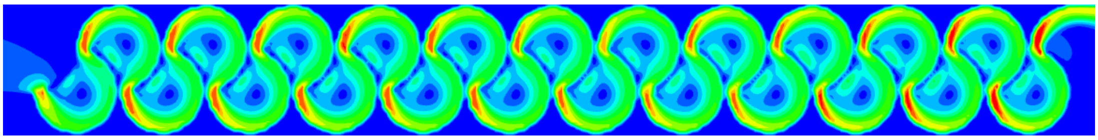


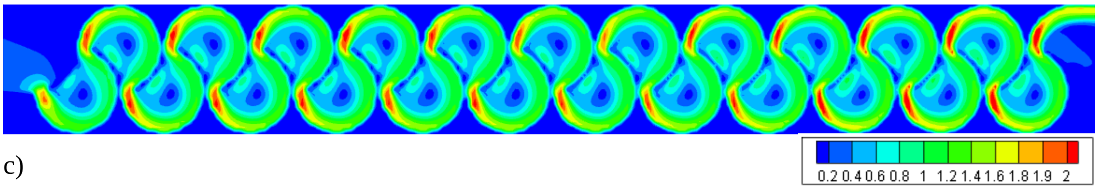
Figure 3.205. Fluid depth of Type 23 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.206. Flow velocities of Type 23 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

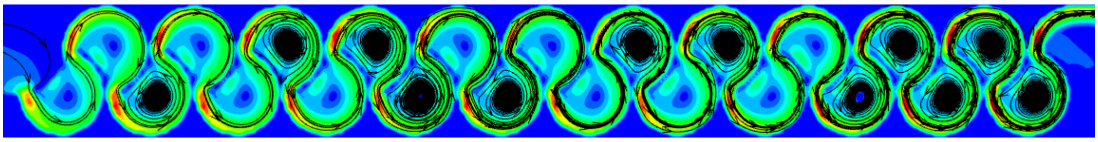


Figure 3.207. TKE of Type 23 considering min. flow rate conditions at 0.75h water level

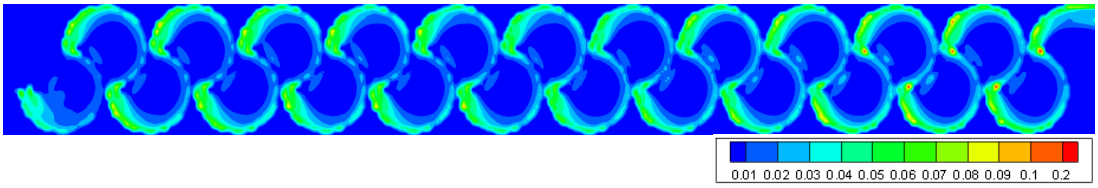
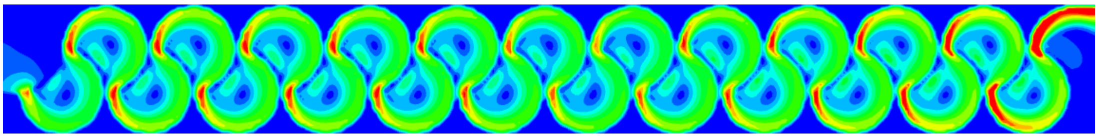
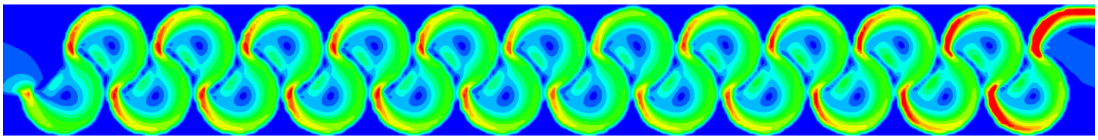


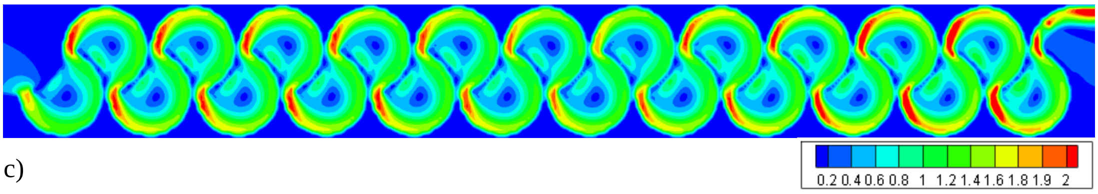
Figure 3.208. TKE of Type 23 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.209. Flow velocities of Type 23 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

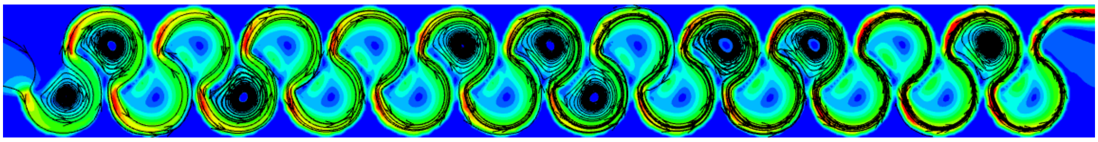


Figure 3.210. Streamlines of Type 23 considering max. flow rate conditions at 0.75h water level

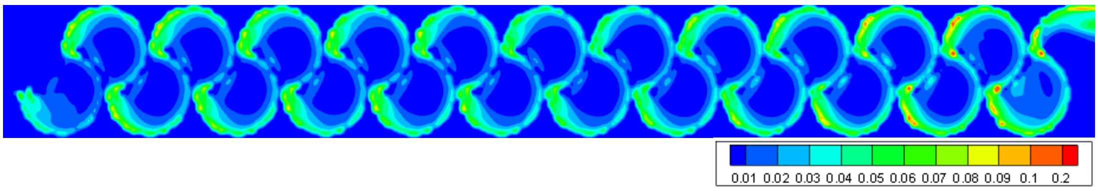


Figure 3.211. TKE of Type 23 considering max. flow rate conditions at 0.75h water level

- Results of Type 24

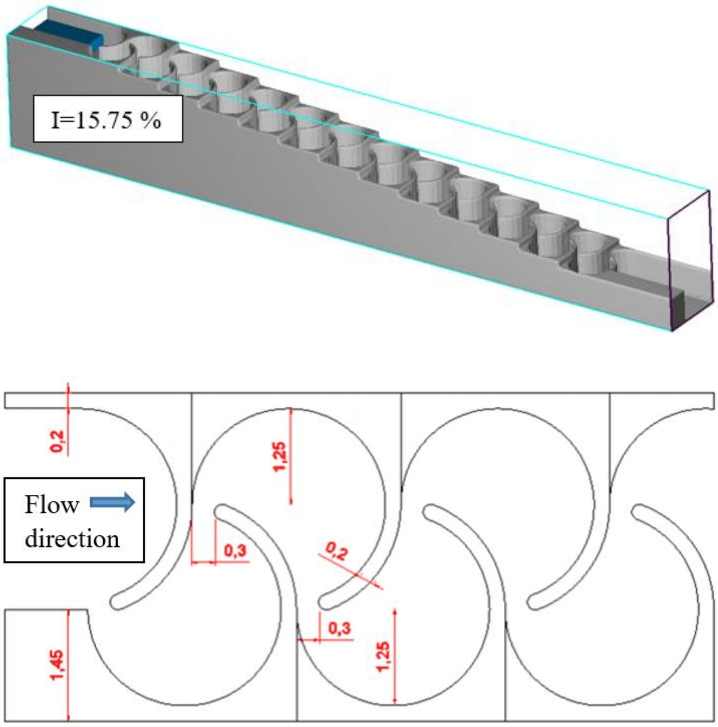


Figure 3.212. Dimensions of Type 24

In Type – 24, pool diameter D_{pool} is taken as 2.5 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=15.75% which is not in the range of manufacturer recommendations while the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.3 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 24 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.212 and Figure 3.213, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.214 and Figure 3.217, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish.

In Figure 3.216 and Figure 3.219, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.08 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.215 and 3.218) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 24 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceed the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 24 geometry is not a proper design for the target fish.

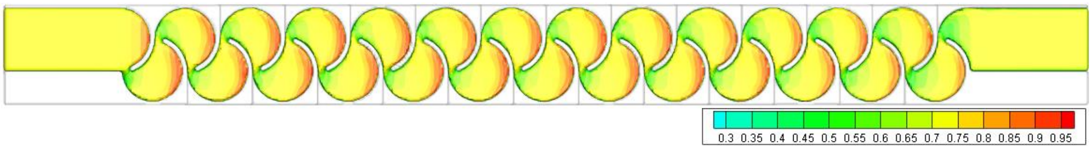


Figure 3.213. Fluid depth of Type 24 considering min. flow rate conditions – Top view

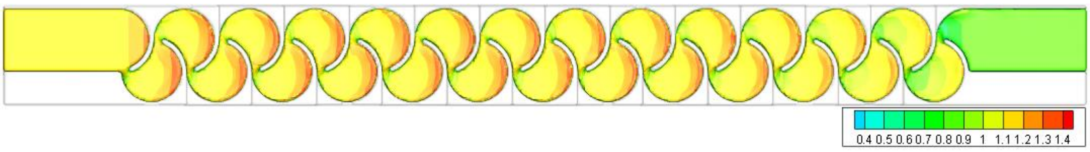


Figure 3.214. Fluid depth of Type 24 considering max. flow rate conditions – Top view

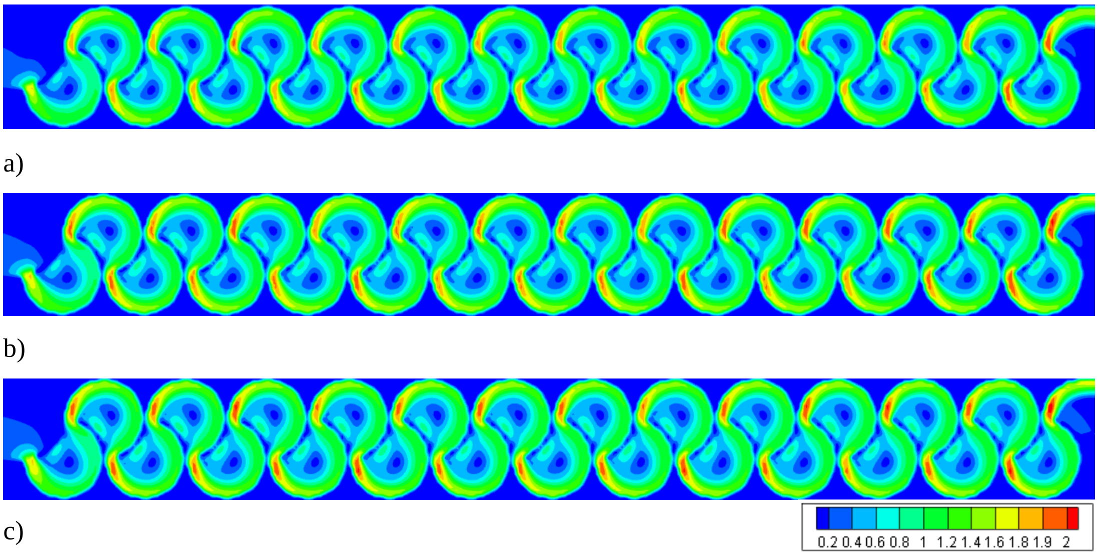


Figure 3.215. Flow velocities of Type 24 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

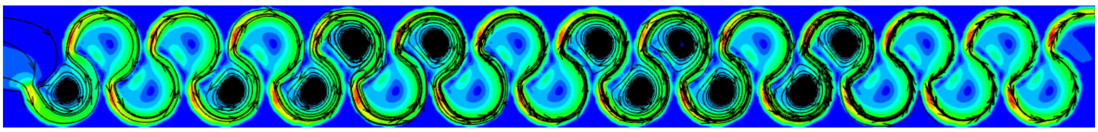


Figure 3.216. Streamlines of Type 24 considering min. flow rate conditions at 0.75h water level

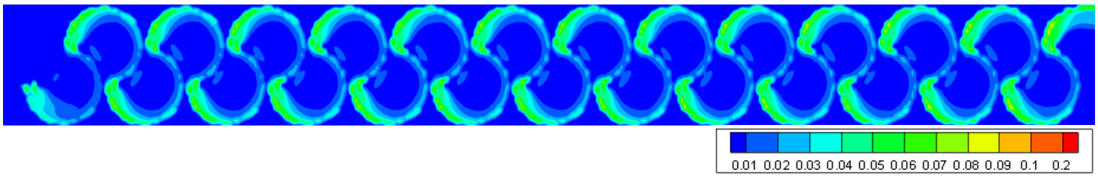
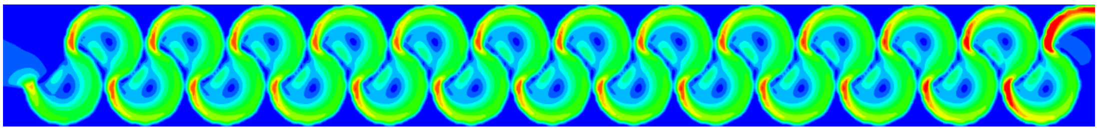
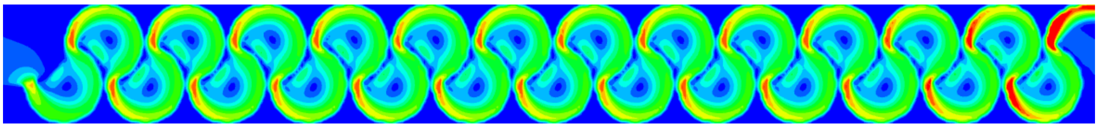


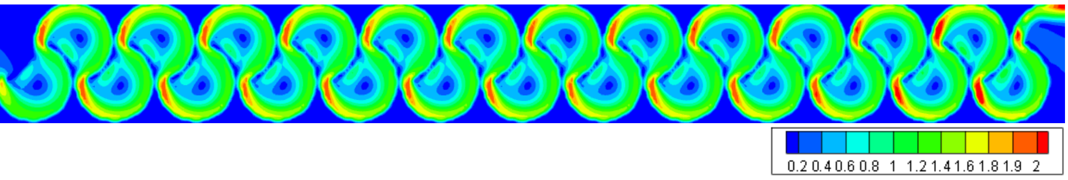
Figure 3.217. TKE of Type 24 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.218. Flow velocities of Type 24 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

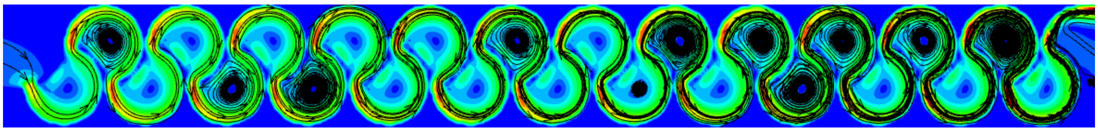


Figure 3.219. Streamlines of Type 24 considering max. flow rate conditions at 0.75h water level

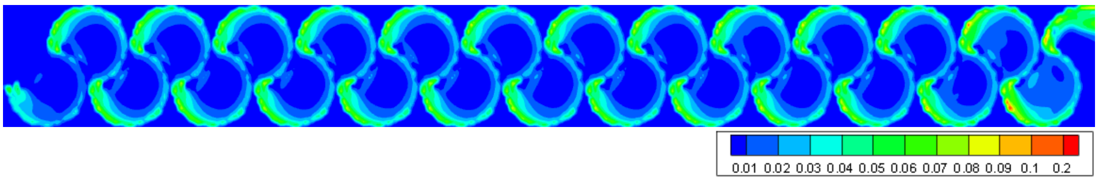


Figure 3.220. TKE of Type 24 considering max. flow rate conditions at 0.75h water level

- Results of Type 25

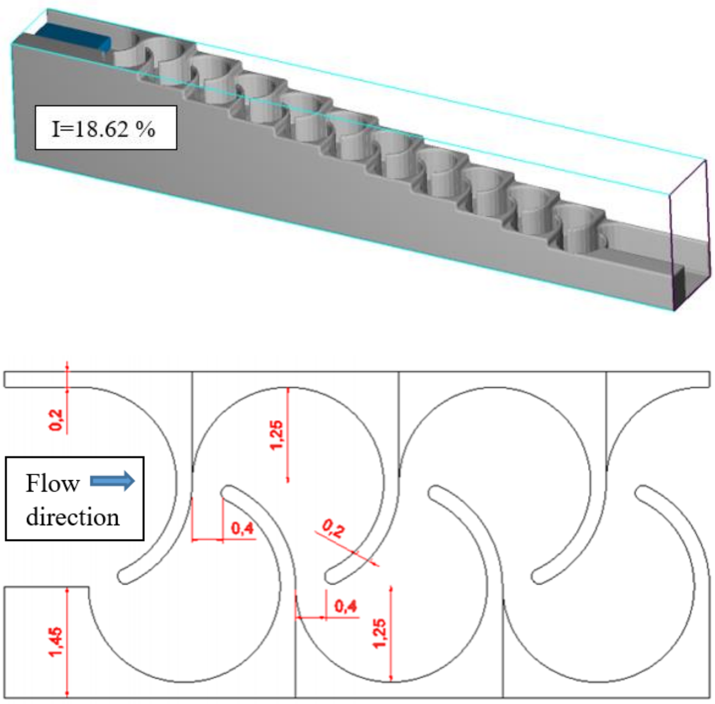


Figure 3.221. Dimensions of Type 25

In Type – 25, pool diameter D_{pool} is taken as 2.5 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but not in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=18.62% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 25 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.221 and Figure 3.222, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.223 and Figure 3.226, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.225 and Figure 3.228, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.224 and 3.227) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 25 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 25 geometry is not a proper design for the target fish.

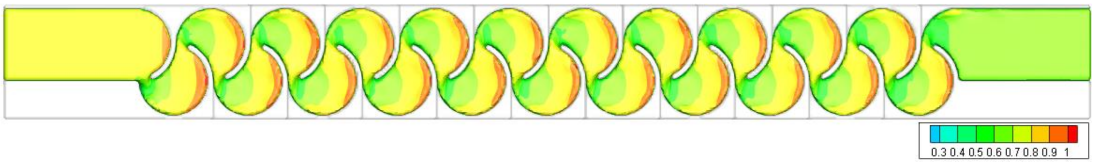


Figure 3.222. Fluid depth of Type 25 considering min. flow rate conditions – Top view

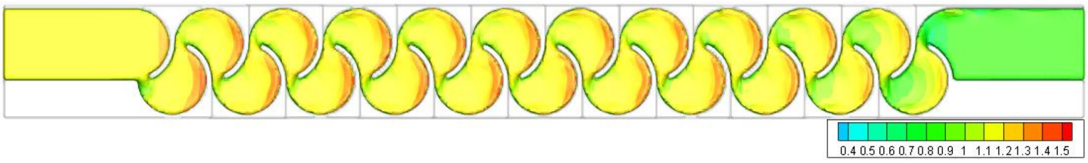
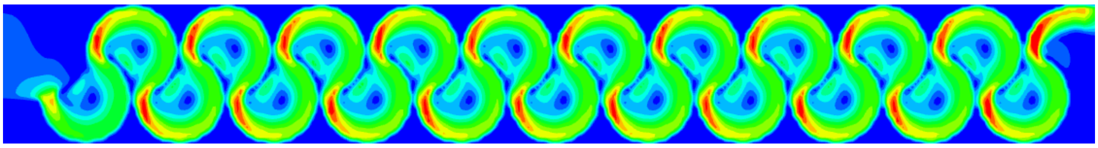
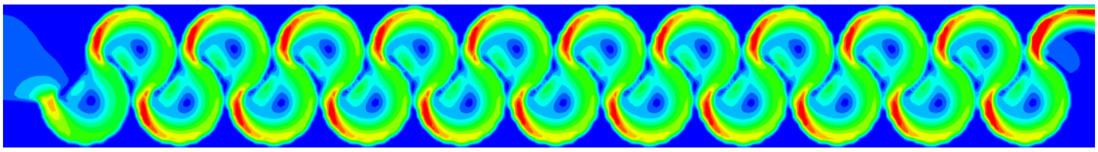


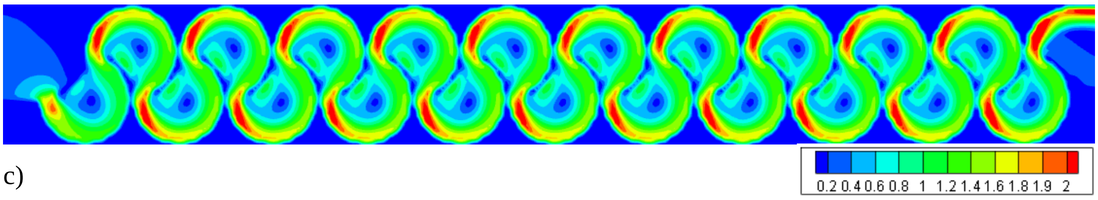
Figure 3.223. Fluid depth of Type 25 considering max. flow rate conditions – Top view



a)



b)



c)

Figure 3.224. Flow velocities of Type 25 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

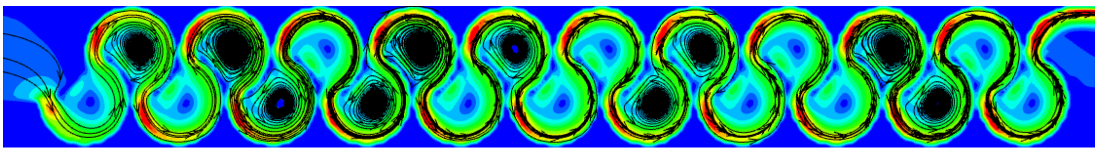


Figure 3.225. Streamlines of Type 25 considering min. flow rate conditions at 0.75h water level

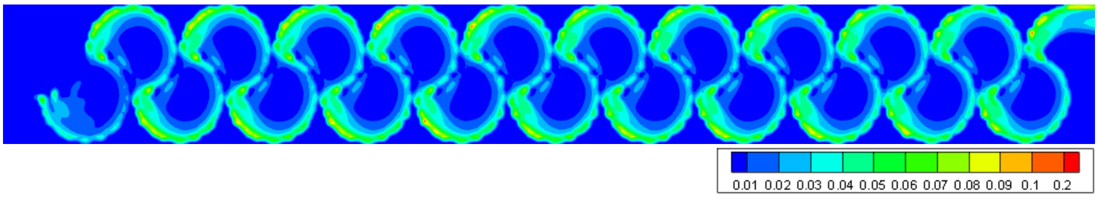
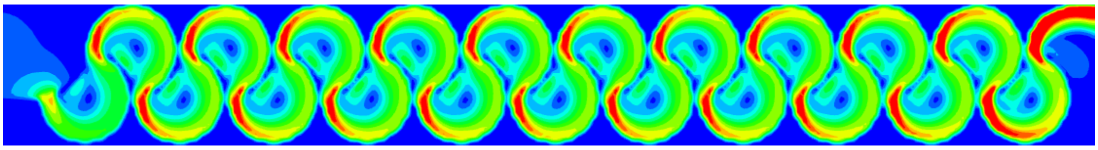
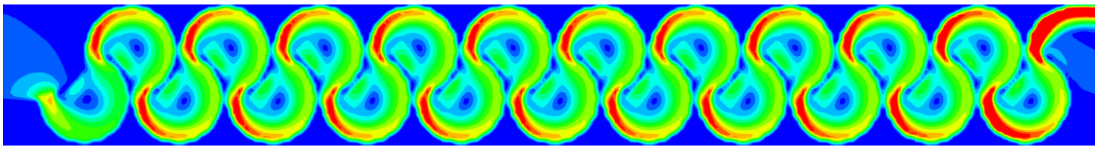


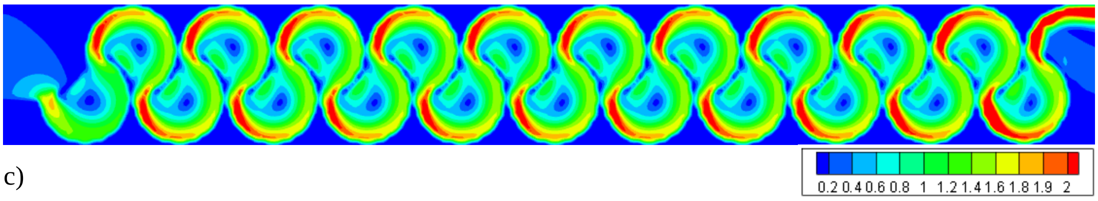
Figure 3.226. TKE of Type 25 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.227. Flow velocities of Type 25 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

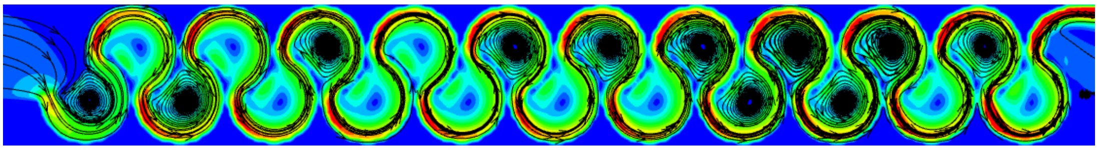


Figure 3.228. Streamlines of Type 25 considering max. flow rate conditions at 0.75h water level

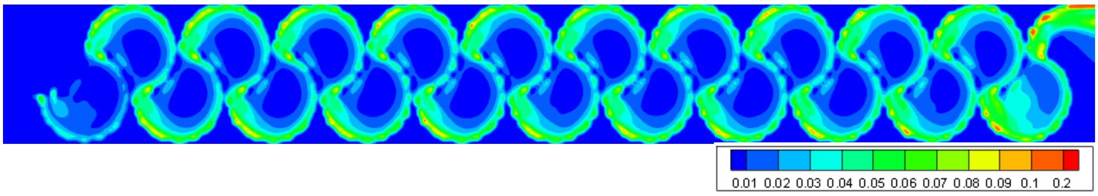


Figure 3.229. TKE of Type 25 considering max. flow rate conditions at 0.75h water level

- Results of Type 26

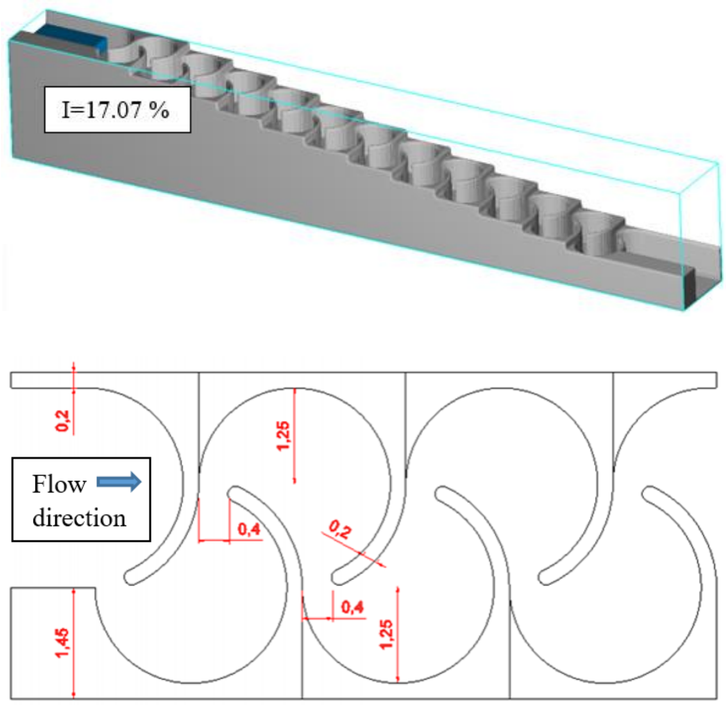


Figure 3.230. Dimensions of Type 26

In Type – 26, pool diameter D_{pool} is taken as 2.5 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but not in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=17.07% which is in the range of manufacturer recommendations as well, however the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 26 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.230 and Figure 3.231, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.232 and Figure 3.235, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.234 and Figure 3.237, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.233 and 3.236) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 26 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 26 geometry is not a proper design for the target fish.

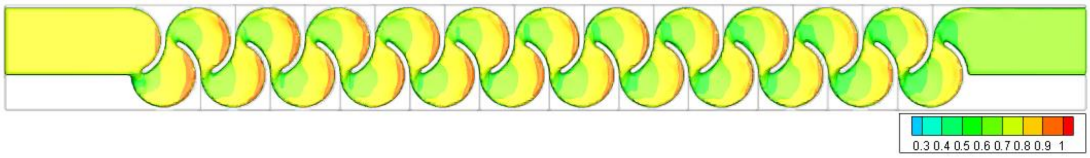


Figure 3.231. Fluid depth of Type 26 considering min. flow rate conditions – Top view

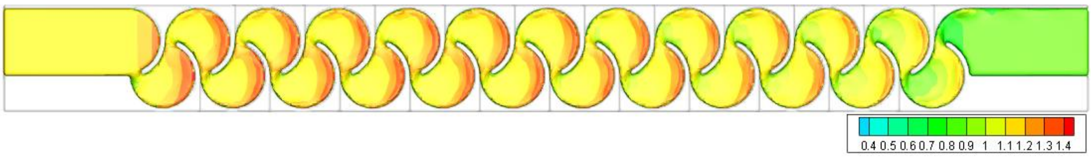


Figure 3.232. Fluid depth of Type 26 considering max. flow rate conditions – Top view

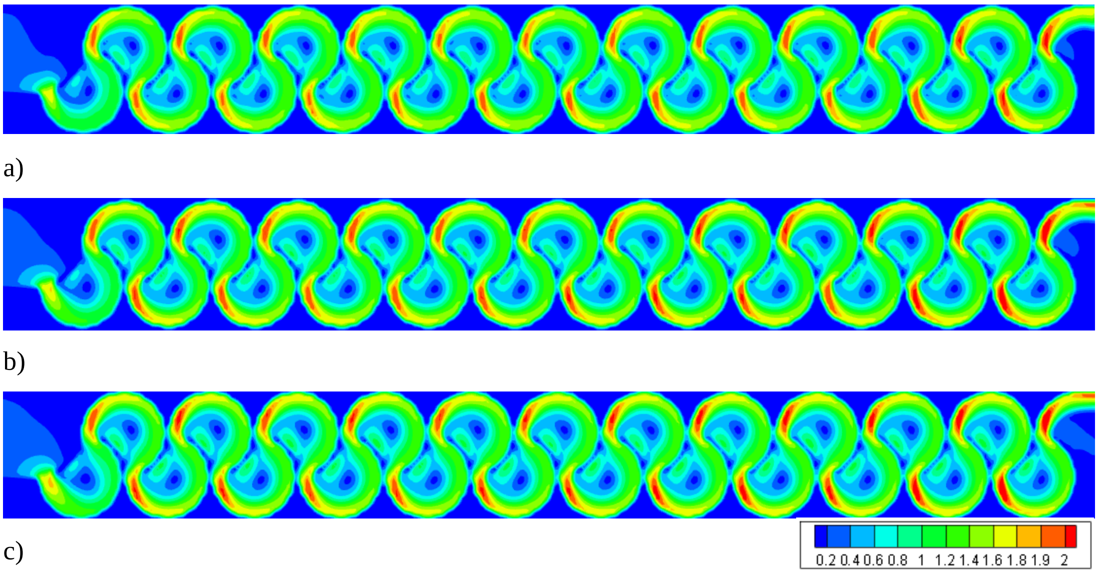


Figure 3.233. Flow velocities of Type 26 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

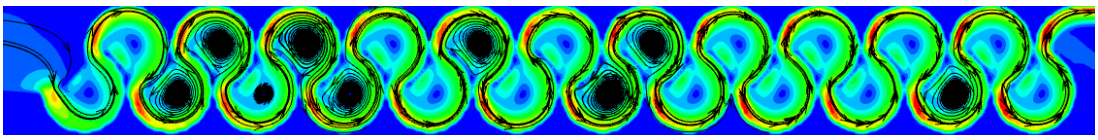


Figure 3.234. Streamlines of Type 26 considering min. flow rate conditions at 0.75h water level

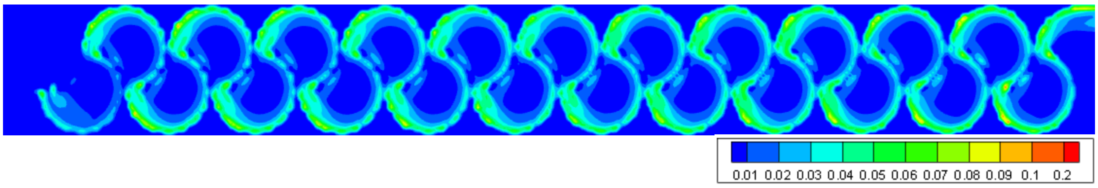
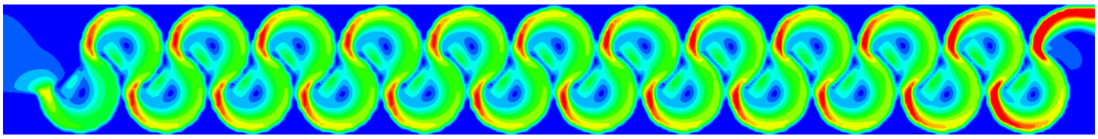
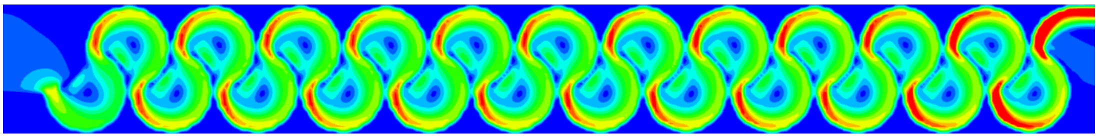


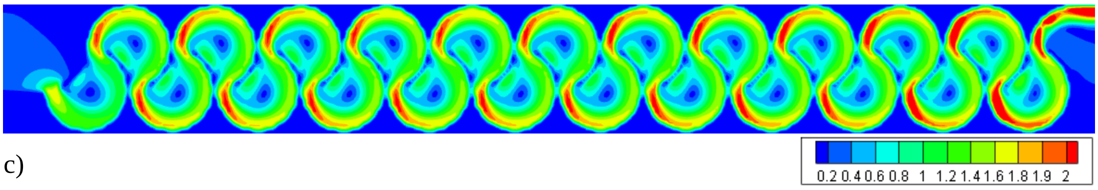
Figure 3.235. TKE of Type 26 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.236. Flow velocities of Type 26 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

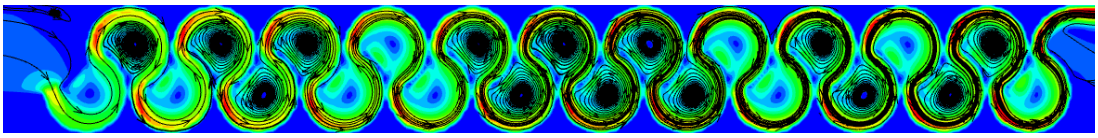


Figure 3.237. Streamlines of Type 26 considering max. flow rate conditions at 0.75h water level

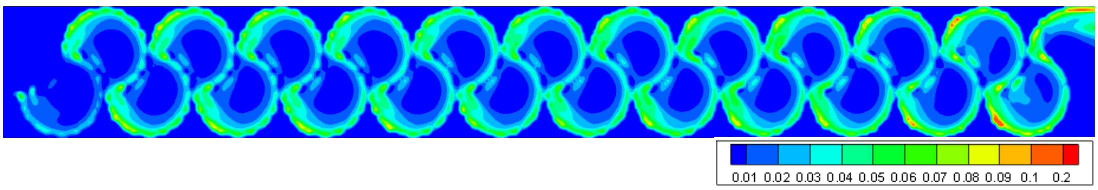


Figure 3.238. TKE of Type 26 considering max. flow rate conditions at 0.75h water level

- Results of Type 27

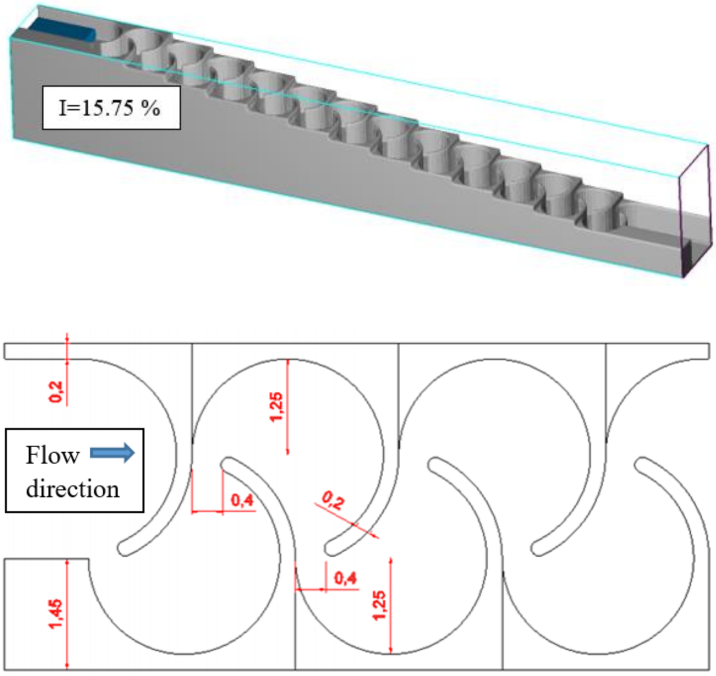


Figure 3.239. Dimensions of Type 27

In Type – 27, pool diameter D_{pool} is taken as 2.5 m which is greater than the minimum allowable diameter value suggested in DWA-M 509 (Table 1.2), but not in the range of manufacturer recommendations (Table 1.1). Moreover, the slope of the channel is I=15.75% which is not in the range of manufacturer recommendations while the standards in current use do not give information about it. Regarding the target fish species, selected slot width, s_w=0.4 m matches with the requirements of DWA where minimum s_w=0.3 m is recommended as well for brown trout.

Herein, numerical simulations are completed for Type – 27 geometry for min. and max. flow rate conditions to evaluate water depth in the slot and in the pools of fish pass, velocity magnitude in slot and turbulent kinetic energy to be compared with the previous conventional vertical slot type results.

In Figure 3.239 and Figure 3.240, fluid depths are shown for min. and max. flow rate conditions. Here, for each case fluid depth is greater than 0.6 m at slots meaning that this type is suitable for target fish species (Table 1.2).

In Figure 3.241 and Figure 3.244, velocity magnitudes at different fluid depths are given for min. and max. flow rate conditions. Here, the velocity magnitude in slots for both min. and max. flow rate conditions are greater than 1.9 m/s which is not proper for the target fish as indicated in Table 1.3. On the other hand, velocity magnitude at the middle of pools varies between the values of 0.0 – 1.0 m/s which provides a resting area for fish. As a comparison with previous types, while the slot width increases, the resting place for fish with low velocity is getting smaller.

In Figure 3.243 and Figure 3.246, turbulent kinetic energy (*k*) values at 0.75h fluid depth are given for min. and max. flow rate conditions. For both flow cases, *k* value varies between the values of 0 – 0.1 m^2/s^2. Here, max. values are obtained just after the flow pass the slots. Here, because of the geometry, the current is directed to the side wall of the pool (Figure 3.242 and 3.245) where turbulence damping occurs along the wall. At the middle of pools *k* value is obtained as ~0.0 m^2/s^2. As a comparison, *k* contours of the previous study on conventional vertical slot pass studied by Özkaya (2014) shown in Figure 1.11 indicates that there is a relatively smaller area without turbulence in the pools. Also, *k* values obtained in pools that varies between the values of 0 – 0.25 m^2/s^2 are greater than the turbulent kinetic energy obtained in round shape one.

In brief, the results of numerical analyses of Type – 27 indicate that fluid depth obtained in slots are proper for the target fish regarding both minimum and maximum flow conditions. However, since the maximum velocity magnitudes formed in the pools exceeds the permissible value which is stated as 1.9 m/s for brown trout for both min. and max. flow conditions, Type – 27 geometry is not a proper design for the target fish.

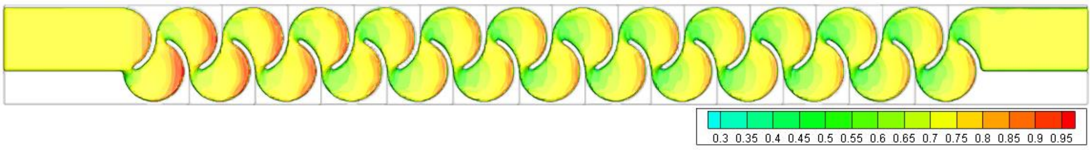


Figure 3.240. Fluid depth of Type 27 considering min. flow rate conditions – Top view

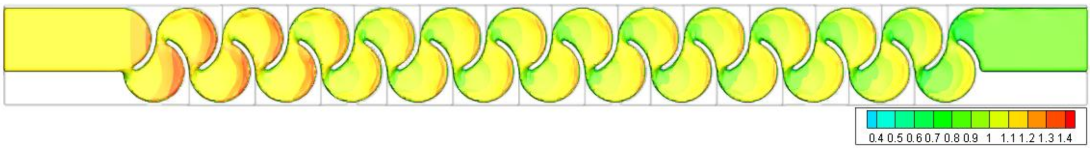


Figure 3.241. Fluid depth of Type 27 considering max. flow rate conditions – Top view

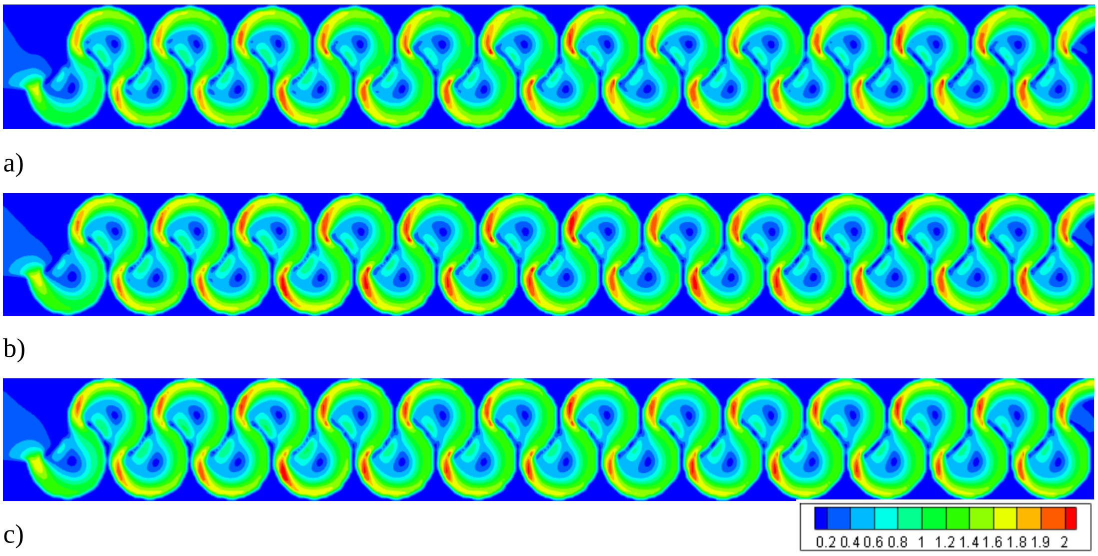


Figure 3.242. Flow velocities of Type 27 considering min. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

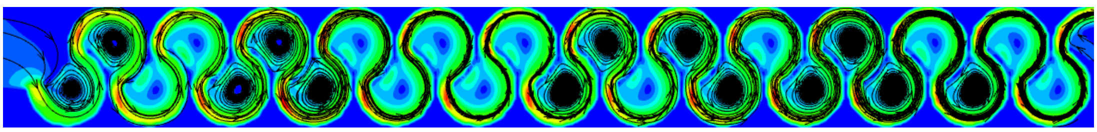


Figure 3.243. Streamlines of Type 27 considering min. flow rate conditions at 0.75h water level

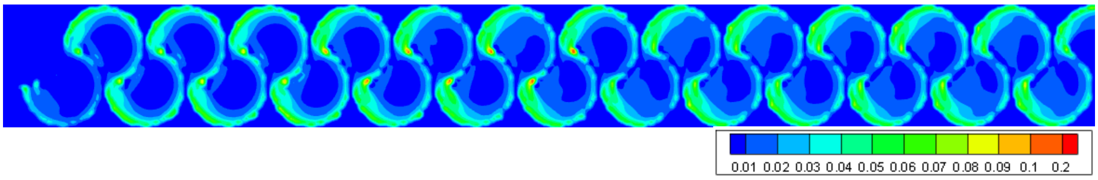
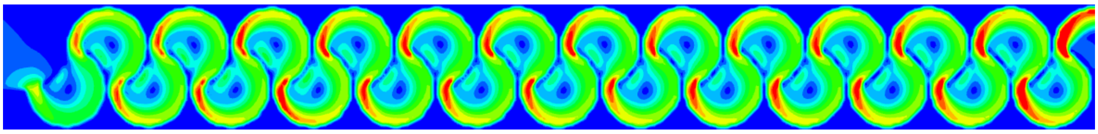
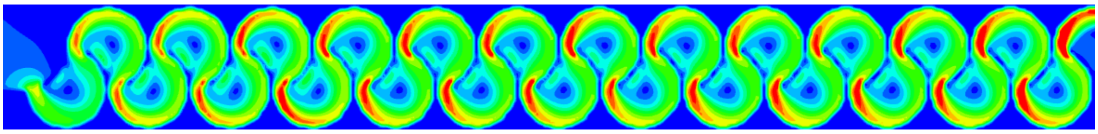


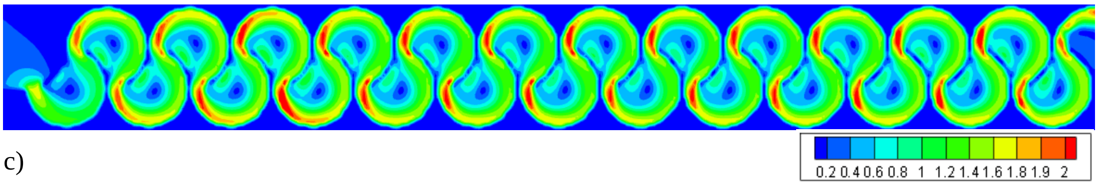
Figure 3.244. TKE of Type 27 considering min. flow rate conditions at 0.75h water level



a)



b)



c)

Figure 3.245. Flow velocities of Type 27 considering max. flow rate conditions at water levels of: a) 0.25h, b) 0.50h, c) 0.75h

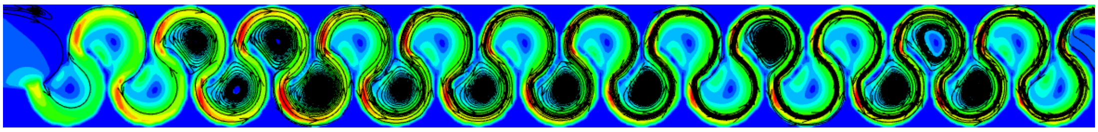


Figure 3.246. Streamlines of Type 27 considering max. flow rate conditions at 0.75h water level

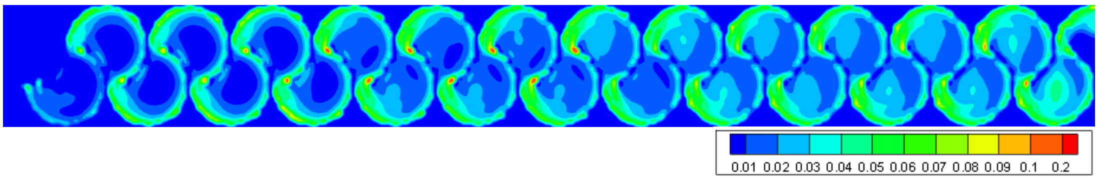


Figure 3.247. TKE of Type 27 considering max. flow rate conditions at 0.75h water level

3.3.1. Discussion of Results

The summary of the round vertical slot fish pass geometries and the numerical simulation results of the hydraulic characteristics is given in Table 3.3 below.

Table 3.3. *Summary of the round vertical slot fish way geometries and the numerical simulation results of the hydraulic characteristics*

Type No	Flow Cond.	Slope, I (%)	Slot Width, s (m)	Pool Dia., D_{pool} (m)	Pool #	Length, L (m)	Max. Velocity, V_{max} (m/s)	Min. Water Depth in Slot, H_{slot} (m)	Min. Water Depth in Pool, H_{pool} (m)	Suitability for target fish species
Type - 1	min	20,95	0,20	2,00	23	26,40	<1.9	>0,6	>0,5	OK*
	max	20,95	0,20	2,00	23	26,40	>1.9	>0,6	>0,6	X
Type - 2	min	17,95	0,20	2,00	27	30,80	<1.9	>0,6	>0,5	OK*
	max	17,95	0,20	2,00	27	30,80	<1.9	>0,6	>0,6	OK*
Type - 3	min	15,71	0,20	2,00	31	35,20	<1.9	>0,6	>0,5	OK*
	max	15,71	0,20	2,00	31	35,20	<1.9	>0,6	>0,6	OK*
Type - 4	min	20,95	0,30	2,00	23	26,40	>1.9	>0,6	>0,5	X
	max	20,95	0,30	2,00	23	26,40	>1.9	>0,6	>0,6	X
Type - 5	min	17,95	0,30	2,00	27	30,80	<1.9	>0,6	>0,5	OK
	max	17,95	0,30	2,00	27	30,80	>1.9	>0,6	>0,6	X
Type - 6	min	15,71	0,30	2,00	31	35,20	<1.9	>0,6	>0,5	OK
	max	15,71	0,30	2,00	31	35,20	<1.9	>0,6	>0,6	OK
Type - 7	min	20,95	0,40	2,00	23	26,40	>1.9	>0,6	>0,5	X
	max	20,95	0,40	2,00	23	26,40	>1.9	>0,6	>0,6	X
Type - 8	min	17,95	0,40	2,00	27	30,80	<1.9	>0,6	>0,5	OK
	max	17,95	0,40	2,00	27	30,80	>1.9	>0,6	>0,6	X
Type - 9	min	15,71	0,40	2,00	31	35,20	<1.9	>0,6	>0,5	OK
	max	15,71	0,40	2,00	31	35,20	<1.9	>0,6	>0,6	X
Type - 10	min	19,20	0,20	2,20	23	28,80	<1.9	>0,6	>0,5	X
	max	19,20	0,20	2,20	23	28,80	>1.9	>0,6	>0,6	X
Type - 11	min	17,72	0,20	2,20	25	31,20	<1.9	>0,6	>0,5	OK*
	max	17,72	0,20	2,20	25	31,20	<1.9	>0,6	>0,6	X
Type - 12	min	16,45	0,20	2,20	27	33,60	<1.9	>0,6	>0,5	OK*
	max	16,45	0,20	2,20	27	33,60	<1.9	>0,6	>0,6	OK*
Type - 13	min	19,20	0,30	2,20	23	28,80	>1.9	>0,6	>0,5	X
	max	19,20	0,30	2,20	23	28,80	>1.9	>0,6	>0,6	X
Type - 14	min	17,72	0,30	2,20	25	31,20	>1.9	>0,6	>0,5	OK
	max	17,72	0,30	2,20	25	31,20	>1.9	>0,6	>0,6	X
Type - 15	min	16,45	0,30	2,20	27	33,60	<1.9	>0,6	>0,5	OK
	max	16,45	0,30	2,20	27	33,60	>1.9	>0,6	>0,6	X
Type - 16	min	19,20	0,40	2,20	23	28,80	>1.9	>0,6	>0,5	X
	max	19,20	0,40	2,20	23	28,80	>1.9	>0,6	>0,6	X
Type - 17	min	17,72	0,40	2,20	25	31,20	>1.9	>0,6	>0,5	X
	max	17,72	0,40	2,20	25	31,20	>1.9	>0,6	>0,6	X
Type - 18	min	16,45	0,40	2,20	27	33,60	>1.9	>0,6	>0,5	X
	max	16,45	0,40	2,20	27	33,60	>1.9	>0,6	>0,6	X
*Inconvenient design because of the slot width										

Type No	Flow Cond.	Slope, I	Slot Width, s	Pool Dia., D_{pool}	Pool #	Length, L	Max. Velocity, V_{max}	Min. Water Depth in Slot, H_{slot}	Min. Water Depth in Pool, H_{pool}	Suitability for target fish species
		(%)	(m)	(m)		(m)	(m/s)	(m)	(m)	
Type - 19	min	18,62	0,20	2,50	21	29,70	>1.9	>0,6	>0,5	X
	max	18,62	0,20	2,50	21	29,70	>1.9	>0,6	>0,6	X
Type - 20	min	17,07	0,20	2,50	23	32,40	>1.9	>0,6	>0,5	X
	max	17,07	0,20	2,50	23	32,40	>1.9	>0,6	>0,6	X
Type - 21	min	15,75	0,20	2,50	25	35,10	<1.9	>0,6	>0,5	OK*
	max	15,75	0,20	2,50	25	35,10	<1.9	>0,6	>0,6	OK*
Type - 22	min	18,62	0,30	2,50	21	29,70	>1.9	>0,6	>0,5	X
	max	18,62	0,30	2,50	21	29,70	>1.9	>0,6	>0,6	X
Type - 23	min	17,07	0,30	2,50	23	32,40	>1.9	>0,6	>0,5	X
	max	17,07	0,30	2,50	23	32,40	>1.9	>0,6	>0,6	X
Type - 24	min	15,75	0,30	2,50	25	35,10	>1.9	>0,6	>0,5	X
	max	15,75	0,30	2,50	25	35,10	>1.9	>0,6	>0,6	X
Type - 25	min	18,62	0,40	2,50	21	29,70	>1.9	>0,6	>0,5	X
	max	18,62	0,40	2,50	21	29,70	>1.9	>0,6	>0,6	X
Type - 26	min	17,07	0,40	2,50	23	32,40	>1.9	>0,6	>0,5	X
	max	17,07	0,40	2,50	23	32,40	>1.9	>0,6	>0,6	X
Type - 27	min	15,75	0,40	2,50	25	35,10	>1.9	>0,6	>0,5	X
	max	15,75	0,40	2,50	25	35,10	>1.9	>0,6	>0,6	X
*Inconvenient design because of the slot width										

Hydraulic results of Type 1~9 in which the diameter of the pools is 2.0 m indicate that as the slot width increases, maximum velocity read in slots increases as well. For instance, if Type – 3, Type – 6 and Type – 9 are compared where the slope of the channel and the diameter values are the same, it is shown that while the velocity magnitude in slots is less than 1.9 m/s in Type – 3 and 6, it is greater than 1.9 m/s in Type – 9 where slot width is 0.4 m.

Moreover, while the slope of the channel is getting steeper, the velocity magnitude read in slot increases. For example, hydraulic parameters of flow in Type – 4 where the slope is 20.95% are not suitable for both minimum and maximum flow conditions. Also, in Type – 5, where the channel slope is 17.95%, only the flow conditions of minimum flow case are proper for the target fish species. Finally, the hydraulic parameters of both flow conditions read in slots are suitable in Type – 6 where the channel slope is 15.71%. Apart from the figures 3.53 and 3.56 in which velocity magnitudes are shown with horizontal sections, additional flow sections that are taken from the entrance region of the Type – 6 (for maximum flow conditions) are presented below to examine the change in velocity magnitude with depth in vertical direction.

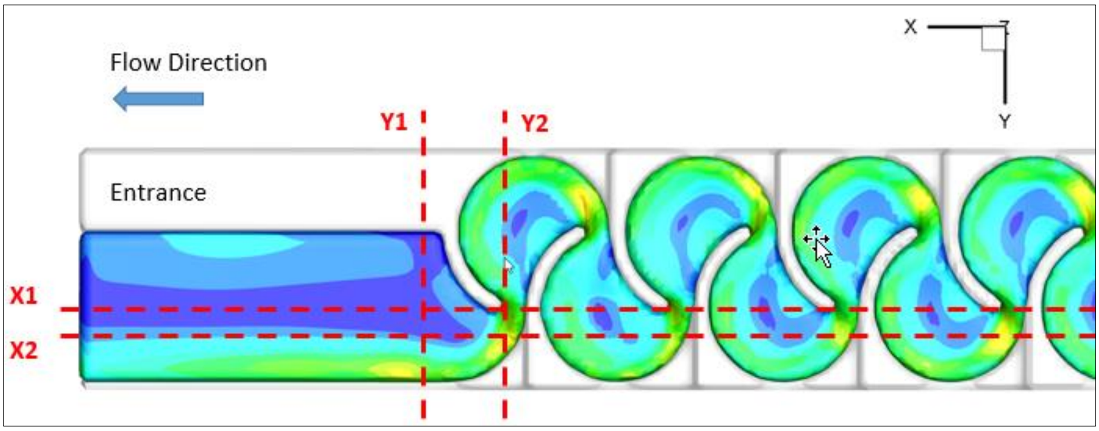


Figure 3.248. Sections taken form entrance of fish pass

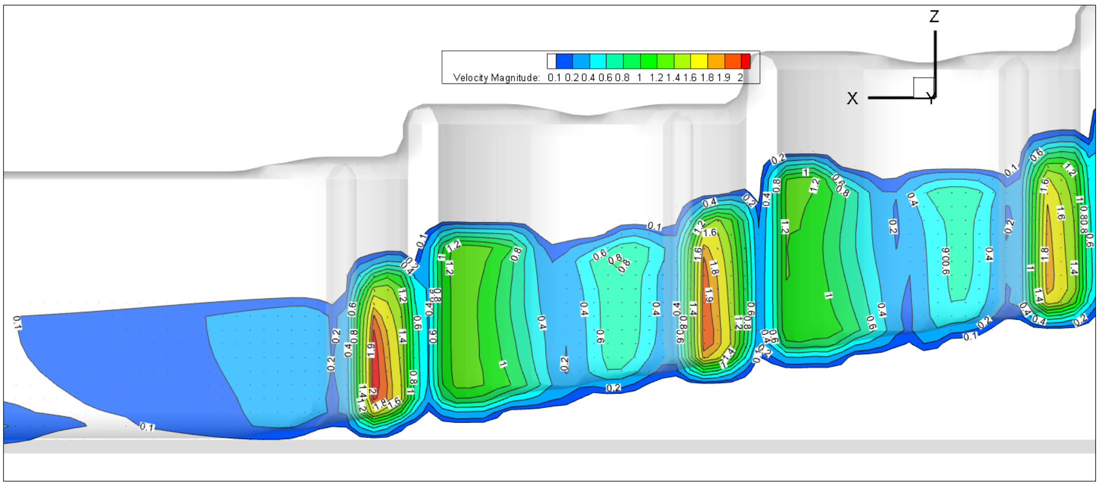


Figure 3.249. Velocity magnitude contours (xy plane) of section x_1

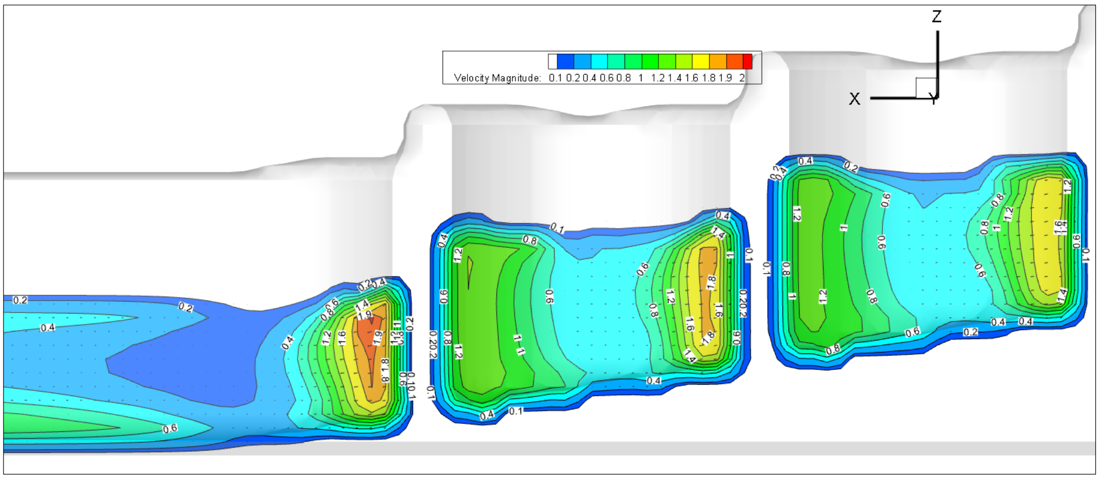


Figure 3.250. Velocity magnitude contours (xy plane) of section x_2

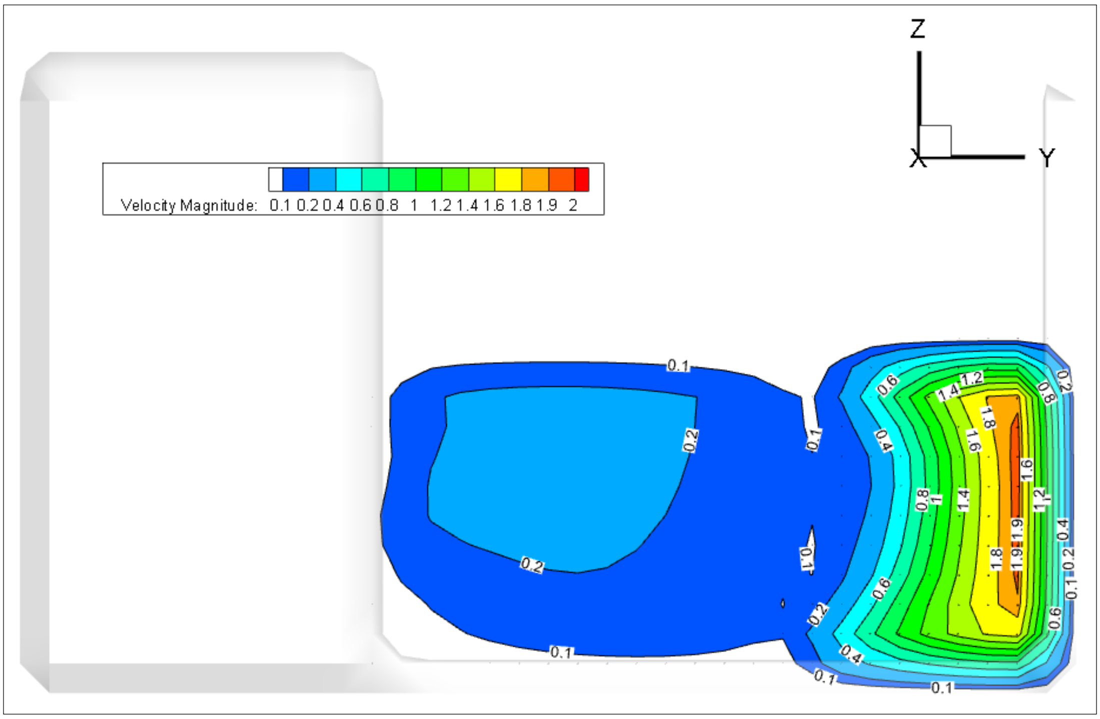


Figure 3.251. Velocity magnitude (xy plane) of section y_1

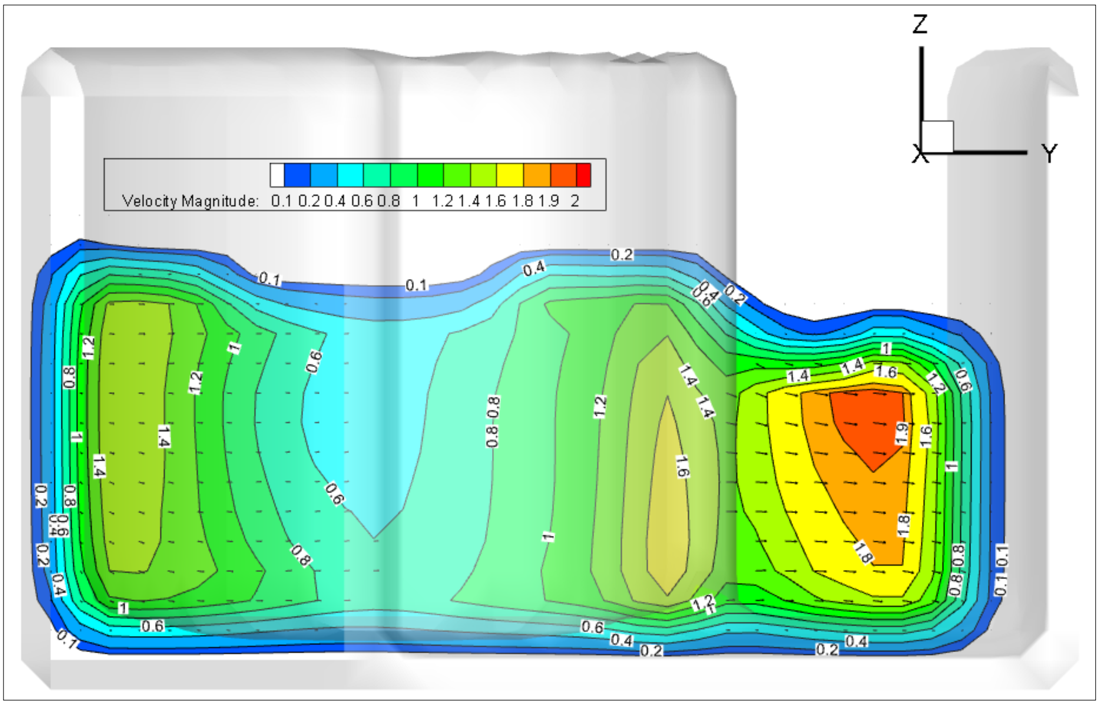


Figure 3.252. Velocity magnitude (xy plane) of section y_2

The similar assessments about the effects of slot width and the channel slope to the hydraulic parameters of the flow can be applied to Type 10~18 as well where the diameter of the pools is 2.2 m. However, while there is a type which is Type – 6 that is suitable for the target fish for both minimum and maximum flow conditions among Type 1~9, there is no type of geometry that is applicable for both flow conditions among Type 10~18.

Hydraulic results of Type 19~27 in which the diameter of the pools is 2.5 m indicate that these types are not suitable for the target fish brown trout. Herein, the effect of the change in the slot width cannot be investigated with the selected channel slopes which are approximately between 16% and 19%. Therefore, channel slopes less than 16% should be studied for these types in order to detect the effects of the slot width.

In general, Table 3.3 indicates that the increase in pool diameter influences the suitability of the fish pass for brown trout negatively by means of the increase of maximum velocity limit in slots. Moreover, as the slot width increases, the velocity magnitude generated in slot becomes greater, and the area in pools for fish to rest where flow velocity and turbulence kinetic energy values are very low is getting narrower. In such regions in pools where flow velocity is very low, sediment accumulation can be a long term problem. Herein, regular cleaning or flushing can be a solution to overcome that problem.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

In this study, numerical simulations are generated with FLOW 3D software in order to design a pool type of fish pass called round vertical slot fish pass which is claimed that it possesses the best suited geometry for fish migration especially considering the low turbulent kinetic energy values formed in the pools.

According to recent standard DWA-M 509 and manufacturer specifications about round vertical slot fish pass, solid models are created with different dimensions that can affect the flow hydraulic properties in order to evaluate the effects of dimensions of the passage and to determine the proper geometry for a target fish species, which is brown trout in this case, with hydraulic data taken from a previous study where conventional vertical type of fish pass was studied. The study is summarized in Table 3.3.

Firstly, although the types with the slot width, s_w equals to 0.2 m are not suitable for the target fish where the min. slot width should be 0.3 m because of the current shrinkage in openings as stated in DWA-M 509, numerical analyses were completed with this slot width to compare hydraulic characteristics of the flow with other types and to evaluate the effect of slot width.

Secondly, while taking the pool diameter as a constant value which is selected as 2.0 m, the effects of other variables which are slot width and slope are evaluated. In this case, decreasing the slope influences the velocity criteria positively where velocity magnitude in slots decreases. Moreover, regarding the effect of slot width, it is observed that as the slot width increases, velocity magnitude in slots increases as well. Also, resting area in pools for fish where velocity and turbulence values are very low is getting narrower as the slot width increases. Herein, only Type – 6 with the slot width which equals to 0.3 m provides the required hydraulic conditions for the target fish species in both minimum and maximum flow conditions.

Thirdly, as the pool diameter increases, it is observed that for all types with different slot width and slope values given in Table 3.3 does not meet the needs of hydraulic requirements for the target species. In other words, the types with pool diameter which equals to 2.2 m and 2.5 m are unsuitable with all the dimensions of slot width and slope chosen in this study.

According to the results represented in Table 3.3, it can be stated that the dimensions recommended in DWA-M 509 are suitable for the hydraulic conditions studied in this study meaning that the recommended pool diameter and slot width dimensions which are 2.0 m and 0.3 m respectively are convenient. In addition, about the slope of the channel, numerical simulations indicate that the steepest slope for round vertical slot fish pass can be recommended as ~16% for the case studied.

In the previous study about conventional vertical slot fish pass design completed by Özkaya (2014), total number of pools and slots were 31 and 32 respectively, and the slope of the channel was selected as 10.65 %. Moreover, slot width, pool width and pool length were chosen as 0.17 m, 1.4 m and 1.9 m respectively.

Herein, the total pool and slot numbers are equal in both designs interestingly. However, it should be noted that in this study a layout plan for round vertical slot fish pass is not prepared for the case area meaning that the entrance and exit part of the channel are not designed. Therefore, these numbers can be different after preparing the exact layout plan. In addition, regarding the slope of the fish passes, round shape vertical slot pass can provide a steeper fish way than conventional one, however the pool area and slot width dimensions of conventional type are smaller than the ones in round shape one.

Herein, it can be stated that for both fish pass design, hydraulic requirements for target species can be provided. However, regarding the turbulent kinetic energy, k generated in the pools of both designs, it can be stated that k in the round vertical slot fish pass is prominently less than the one generated in conventional type. Moreover, while turbulence in the pools of conventional type expands inside the pools, large turbulence values occur only along the side walls of the pools in round fish passes. Therefore, the resting area for migratory fish with very low velocity and turbulence is wider in the round shape pools than the ones in conventional type.

Overall, in this study, a round vertical slot fish pass is designed with numerical analyses completed in Flow 3D software for a specific area in which the hydraulic conditions are taken from a previous study where a conventional vertical slot pass was designed.

Herein, studies are completed for a target fish species and for a certain total head difference, Δh_{total}. Therefore, the dimensions and hydraulic properties given in Table 1.2 for different types of fish, and different Δh_{total} conditions given in Table 1.3 can be studied for future studies in order to increase the knowledge about the round vertical slot fish ways in which the experience of designers and manufacturers and the current knowledge in literature are not sufficient.

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