DESIGN OF SETTLING BASINS AND RELATED PROBLEMS ENCOUNTERED IN PRACTICE

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

BY

FATMA DENİZ ZALOĞLU

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

SEPTEMBER 2013

Approval of the thesis:

DESIGN OF SETTLING BASINS AND RELATED PROBLEMS ENCOUNTERED IN PRACTICE

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ABSTRACT

DESIGN OF SETTLING BASINS AND RELATED PROBLEMS
ENCOUNTERED IN PRACTICE

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SEPTEMBER 2013, 164 pages

Settling basins are the hydraulic structures used to get sediment-free water from rivers mostly for hydropower systems. Mainly fine sediment is trapped along the settling basins and from time to time the accumulated sediment in the settling basin is flushed away. A wrong design of a settling basin creates lots of problems. In this study based on the hydraulic analysis of a settling basin, the available settling basin design procedures in the literature were reviewed. Some of the settling basins constructed in Turkey were studied and the problems observed in their operations were analyzed. In an experimental setup a series of experiments were conducted at the laboratory with two types of sediments, quartz and silisium , at various size ranges to determine their maximum settling distances as a function of sill height of the model. The related parameters were presented graphically in dimensionless forms.

Keywords: Settling Basins, Hydraulics, Sediment Transport, Hydropower Plants, Flushing Channel.

ÖZ

ÇÖKELTİM HAVUZLARININ PROJELENDİRİLMESİ VE BUNLARLA İLGİLİ OLARAK UYGULAMADA KARŞILAŞILAN PROBLEMLER

ZALOĞLU, FATMA DENİZ

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. Mustafa GÖĞÜŞ

Eylül 2013, 164 sayfa

Çökeltim havuzları, genelde hidroelektrik santrallerde kullanılmak üzere nehirlerden, içinde katı madde bulunmayan suyun elde edilmesi için kullanılan hidrolik yapılardır. Çoğunlukla ince katı malzemeler bu havuzların içinde tutulur ve havuzlarda toplanan bu malzemeler zaman zaman yıkanarak uzaklaştırılır. Bir çökeltim havuzunun yanlış olarak projelendirilmesi durumunda bir çok problem ile karşılaşılır. Çökeltim havuzlarının hidrolik analizi üzerine kurulan bu çalışmada, literatürde mevcut olan çökeltim havuzu projelendirme metotları gözden geçirildi. Türkiye'de inşaa edilmiş olan bazı çökeltim havuzları incelenerek bunların işletmeleri sırasında karşılaşılan problemler tespit edildi. Laboratuvarda imal edilen bir çökeltim havuzu modelinde, iki farklı sediment, kuvars ve silis, farklı çap gruplarında kullanılarak bir seri deneyler yapıldı. Bu deneylerde sedimentlerin maksimum çökelme mesafeleri farklı eşik yüksekliklerinde ölçüldü. İlgili parametreler boyutsuz hale getirilerek aralarındaki ilişkiler grafikler halinde sunuldu.

Anahtar Kelimeler: Çökeltim Havuzları, Hidrolik, Sediment Taşınımı, Hidroelektrik Santraller, Yıkama Kanalı.

To my family and the man of my life…

ACKNOWLEDGEMENTS

Firstly, I would like to express my deepest gratitude to my supervisor Prof. Dr. Mustafa GÖĞÜŞ for his guidance, support, encouragements and trust on me from the first day of this study to the end. I admire him because of his self sacrifice and patience in every circumstances throughout my study.

I would like to thank to Assoc. Prof. Dr. Mehmet Ali KÖKPINAR who supported me with his archieve.

Also, I would like to thank to Middle East Technical University Hydromechanics and Soil Mechanics Laboratory technicians for their help while I performed experiments.

I owe a special thank to my husband Cihan ZALOĞLU who is always with me while writing thesis, performing experiments and when I failed with all my caprices. I am deeply indebted to him for his care on me outside my family since the day we encountered. He is beyond a husband, my life friend who is with me in all activities just like the other half of mine. Perhaps it sounds very classic, but he is always with me in good times and in bad times in sickness and in health. He proves that love always save you when you are in stress.

I would like to appreciate the two main engineering sector firms dealing with Hydropower Plants and Dams, ENSU Eng. Consul. Ltd. and Hidro Dizayn Eng. Consul. and Trade Inc. for their support and consultancy. Especially special thanks for manager of ENSU, Edip ÖZTÜREL who is the instructive to me in the first days I began my first job. Add to these thanks for all companies and representatives gave informations, especially Saygın DENİZ and Süeyla DAŞKIN, at the same time my friends.

Moreover, I want to show my appreciation to my manager at İlbank Inc., Selda GÜRSES for her patience and to my workmates; especially Sefa BOYAR, Ebru BAŞ, Ahmet KUŞYILMAZ, Evrem KİRAZ and Yasin KILIÇ for their supports and friendship during this study.

I would like to thank to Ezgi KÖKER and Ersin DİNÇEL for their supports and friendship in the department. Also special thanks to Halit ŞAHİNER and Ezgi KANLI to show me that kilometers are not an obstacle for the endless friendship. They show me their warm friendship and encouragement even if they are kilometers away, in Australia not only during this study also all the time.

I am very lucky to have the sweetest person in my life, Elif ÇETİN, who I owe a lot of gratitude because of being with me every moment of my life with her goodness and helpfulness.

Also my special thanks go to my dear friend Erdem İSPİR for his valuable presence since the first time I met him.

In addition, my favorite couple Didem, my angel, and Tunç GÜNEL, my dear friend Halil GÜLER with whom we have been together through thick and thinover the years like brothers and sisters.

Furthermore, there is a special person that I owe her a lot thanks being in my life and showing me that friendship is independent of time or anything else, Dila UYKUSUZ, also my colleague. My special thanks go to her to make smile on my face with our endless chit chats, to succor in all the worst times, to consider me as much as my family and to be a soul sister till the end of our lifes. Because it is a very significant thing to have person just like a sister in your life.

Finally if I able to write these lines, of course my sincere thanks must go to my dear mom Hesna ŞEN and my dear dad who is my idol and colleague Muzaffer ŞEN for their endless support during the master study and not only for master study; for my whole lifetime. They are not only just father and mother; more than these, they are friends, teachers of life and mentors to me. Especially my dear mom has been always confidant in all my life when I was in elemantary school, in high school, in university, started to work, I was married and lastly at this moment. Everytime she becomes a shoulder to cry on when I stumble and need her endless mercy and limitless help. Moreover I have to be grateful to her since she is the one in my life who shows the presence of unconditional love and teaches to love as she does. Also lots of thanks for my little brother and at the same time my junior colleague Anıl ŞEN who adds joy to my life. He is very special one in my life that nobody can fill his shoes. I owe to great gratitude to him since he is always with me when I need his help or frienship. I know that my family loves me infinitely which makes me feel strong. Add to my family, a new member of us, I would like to thank to my mother-in-law Nezahat ZALOĞLU who is the second mother for me and promises to be with us at the end of life.

Consequently I realize once more that I am one of the very lucky people because of having a great support and love behind me to handle anything with my family, my husband and my dear friends.

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a	Longest dimension of particle in tridial axes
b	Medium dimension of particle in tridial axes
B_n	Net width of the settling basin
B_s	Width of settling basin
c	Shortest dimension of particle in tridial axes
C_D	Drag coefficient
C_t	Coefficient for transition
d_s	Diameter of sediment particle
E	Total energy
E_W	Water surface elevation
Fr	Froude number
$(Fr)_s$	Densimetric Froude number
g	Gravity acceleration
h	Flow depth
l_s	Maximum settling distance of a sediment particle
Ls	Length of settling basin
n_p	Number of the piers
Q	Discharge in settling basin / design discharge
S_F	Shape factor
$\overline{S_f}$	Average value of the friction slope
t	Thickness of the pier
V	Velocity
V_f	Velocity of flow within the settling basin
V_g	Flow velocity through the gate
V_s	Settling velocity
α	Slope of the cross sectional side edge of the settling basin
ρ	Density of water
ρ_s	Density of sediment
Δz	The height of the downward sill

Δz_u	The height of the upward sill
ΔH_s	Upward sill loss
ΔH_f	Settling basin friction loss
ΔH_g	Gate loss
ΔHt	Transition loss
ΔHz	Downward sill loss
$\Delta\rho$	Ratio between sediment density and water density

CHAPTER 1

INTRODUCTION

1.1. OBJECTIVE OF THE STUDY

In modern world, water demand increases more and more due to exhausting of natural water resources. Consequently, they should be used more carefully and efficiently in order not to meet problems in the future. Since water is transmitted from seas, lakes, rivers or simply reservoirs through intakes to use in power generation, irrigation, domestic and industrial supply, it may carry sediment which is not desired. In order to get sediment-free water through the intake structures, settling basins are widely used. Improvements in the design criteria of the settling basins have a great importance to minimize the cost and use of water quality. It is obvious that the cleaning of the sediment will extend the life time of the settling basin. The cost of settling basins will be reduced by an optimized design of dimensions.

The aim of this study is to summarize the methods used in the design of settling basins and also to investigate the problems encountered in the operation of them.

In addition to these, an experimental work was carried out at the hydraulics laboratory to determine the required settling distances of two different types of sediments having various size ranges, for steady subcritical upstream flow conditions. From the result of this study, the required length and depth of a settling basin can be determined as a function of upstream flow conditions and sediment type.

1.2. OUTLINE OF THE THESIS

There are mainly six chapters in this study apart from the introduction part. These are; literature survey, design of settling basins, operation principles of settling basins, investigation of operational problems for some of the settling basins in Turkey, experimental works, discussion of the results, conclusions and recommendations. At the end of this study, tables of measured and calculated parameters related to the experiments are presented in Appendix A. Moreover, detailed plan, profile and cross sectional projects of settling basins told in this study are presented in Appendix B.

Firstly, in Chapter 2 the literature survey is presented. In this chapter, settling basin is defined and why there is a need for settling basin is briefly explained. Afterwards, types of settling basins according to their shapes are explained with photos in practice.

To succeed this purpose stated in Section 1.1, design criteria of main engineering companies are collected and reviewed. Also by contacting to some hydropower investors, the operational problems are gathered. With respect to these informations, solutions on design criteria are proposed. Design criteria, parameters, assumptions of settling basins and examples in Turkey are given in Chapter 3.

Then, Chapter 4 includes the operation principles of settling basins. How settling basin is cleaned and maintenance concept is associated. In addition to that, another area for usage of settling basin is briefly clarified.

After a brief examine to the settling basins, in Chapter 5 some examples from Turkey are investigated to specify the main problems related to the design of settling basin, or not. A questionnaire is prepared and discussed with some of the companies and project firms. This questionnaire, related problems encountered, some recommendations and informations about settling basins and companies are presented in this chapter with their photographs during operation period.

In Chapter 6, in order to provide some quantitative data related to the settling distances of two types sediments, an experimental study was performed on a model of a settling basin. The experimental set up, flow conditions, the methodology and the results of the experiments are also given in details in this chapter.

Finally the conclusions of the study and some recommendations are given in Chapter 7.

CHAPTER 2

LITERATURE SURVEY

2.1. INTRODUCTION

Water is taken from the rivers for different purposes such as energy, irrigation or domestic usage. In this study only energy purpose of water is concerned. As known modern life is dependent on energy and one of the vital forms of energy is electricity. The need for electricity is growing at a rapid rate due to the increase in industrialization and prosperity of people. As a renewable source, the energy of water became one of the means of electricity production. This process includes the conversion of water energy first to mechanical energy and then to electrical energy.

To produce energy from water, it has to be taken from a reservoir or river. It is a known fact that is impossible to divert water from a river without any sediment. The sediment particles carried by the diverted water can erode and wear off the penstock and turbines or pumps such as runner vanes of them. Moreover, this sediment particles can cause to wear off the lining or the construction materials of the conveyance channels and tunnels. Hence, the sediment particles could reduce the life time period of these expensive structures.

The erosion or the wear-off the materials just mentioned is also known as the *"abrasion"*. The experiences in practice have shown the followings (Yıldırım, 2007):

- The abrasion increases with increasing particle size.
- The angular or sharp-edged particles cause greater abrasion than that of rounded particles.
- The flow parallel to the solid boundary causes less abrasion.
- The particles having high velocity (kinetic energy) or head cause greater abrasion than the slow particles.

There are a lot of examples of ruined turbines and pumps due to the sediment particles in the diverted water. Some of them are exemplified below.

Figure 2.1 shows an example of abrasion caused by silt and fine sand particles which enter the turbine. Abrasion occurs when these particles enter the turbine at high speeds and act like a sandpaper on the runner blades of the turbine. This is why it is essential that the silt and sand be filtered out of the water prior to entering the turbine. This can only be achieved with a settling basin of an appropriate size. Otherwise the turbine output will be reduced and, in the worst case, the turbine might be destroyed.

Figure 2.1 Damaged Pelton buckets caused by silt and sand (Ardüser and Karcheter, 2009)

Figure 2.2 shows that silt and clay particles damage on the trailing edge of a high-head Francis turbine runner occurred after only a few months of operation in a heavily alluvial river in India. Another example to this is given in Figure 2.3 which shows a typical view of runner damage.

Figure 2.2 Damaged Francis runners caused by silt and sand (Gummer, 2009)

Figure 2.3 Abrasion damage to the turbine runners (Khatsuria, 2012)

2.1.1. Permissible Size of Sediments

To determine the dimensions of a settling basin, first the size of the particles to be removed should be decided. For medium head plants the removal of particles larger than 0.2 to 0.5 mm is usually specified. If the particles are sharp-edged quartzite, even 0.25 mm size may seriously damage turbines (Avcı, 1995).

As indicated by experience at high head plants, particle sizes of 0.1 to 0.2 mm and even smaller might be objectionable. For very high heads, of several 100 meters, it may be necessary to remove particles of a size as small as 0.1 to 0.05 mm from the water. The approximate size of the permissible particles varies with the pressure head for the hydropower plant systems as shown in Table 2.1.

Table 2.1 Permissible particle sizes for hydropower plant systems (Çeçen, 1976)

Pressure Head at the Plant (m)	**Permissible Particle Size (mm)**
80~100	settling may be necessary
100~200	0.6
200~300	0.5
300~500	0.3
500~1000	0.1

2.2. DEFINITION OF SETTLING BASIN

As mentioned in "2.1 Introduction Section", in order to take water from a river, it is necessary to construct a water diverting structure which is called the "intake structure" such as "intake weir". Even after some of the sediment runoff has settled in a reservoir, the water still contains suspended solid particles which can not be caught by a water intake. Once they get inside, these particles deposit in the canals and the head pond, there by resulting in the accumulation of mud and excessive wear of the lining and, which is especially dangerous, causing damage to the turbines.

The components of a runoff river type hydropower plant and its 3D view are shown in Figures 2.4-2.5.

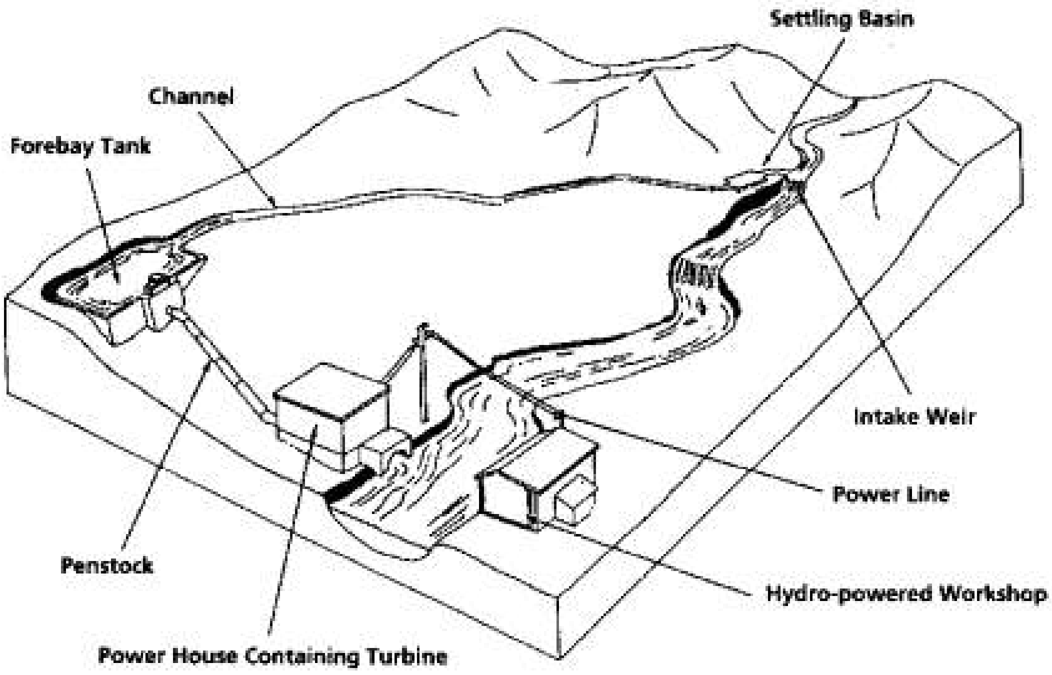


Figure 2.4 Components of a micro hydro scheme (Harvey, 1993)

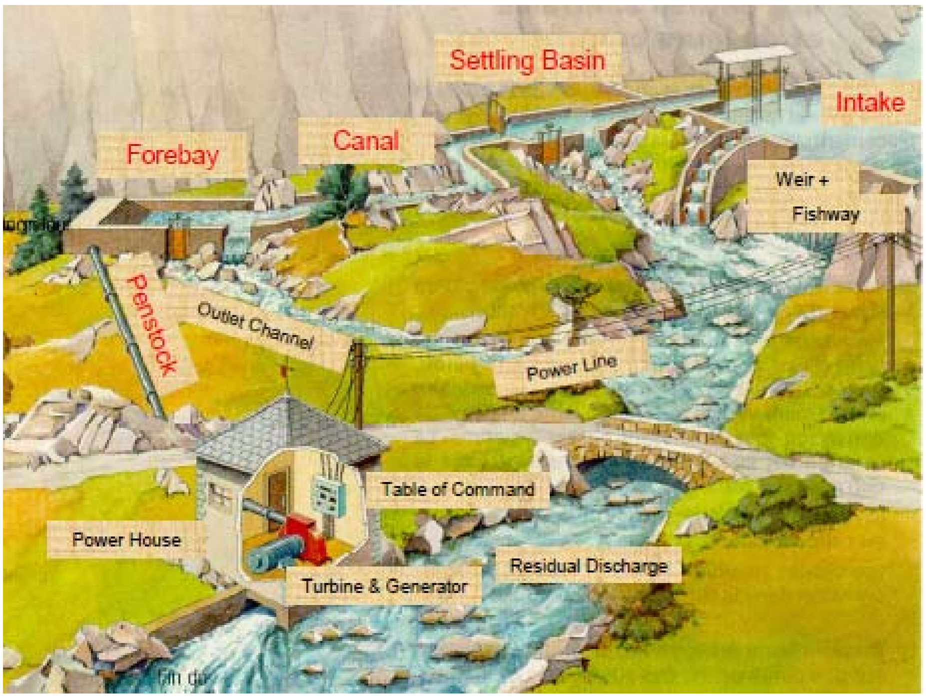


Figure 2.5 Components of a micro hydropower plant in 3D (Andaroodi, 2005)

After diverting and taking the water from a river, intake weir should be connected to another hydraulic structure which is called *"settling basin"* or sometimes *"desilting basin"*. A 3D view of a settling basin is shown in Figure 2.6.

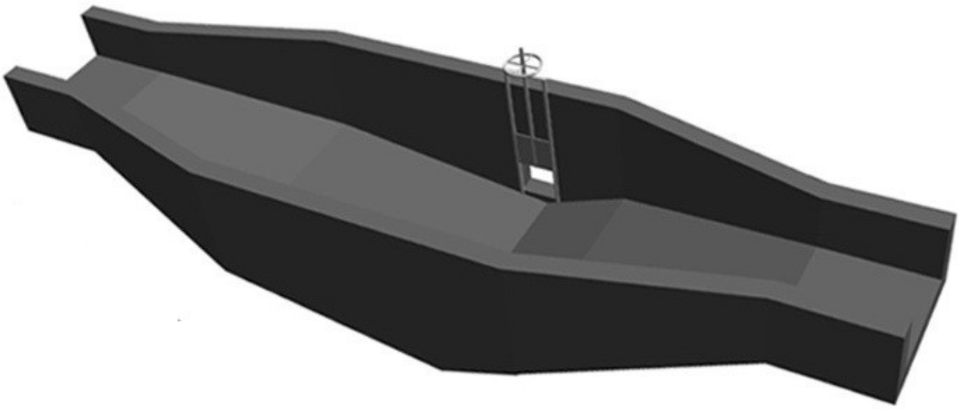


Figure 2.6 Settling basin in 3D view (Ardüser and Karcheter, 2009)

Settling basins are designed to retain water long enough for suspended loads to settle in order to avoid soil particles to enter the penstock and damage the turbine. Settling basins are structures used for removing suspended load from a solid-fluid mixture (in this case sediment-water) and avoiding sediment to enter conveyance structures such as canals and tunnels. They are popularly used for removing excess sediment of specified particle sizes and quantity.

To sum up, the main function of a settling basin is to reduce the velocity of the diverted water and let the sediment particles larger than or equal to the permissible particle size to settle within the basin.

2.3. SECTIONS OF SETTLING BASINS

As it is shown in Figure 2.7, a settling basin consists of the following sections with their main elements basically:

1. Inlet section
    - i. Sill
    - ii. Coarse rack
    - iii. Inlet channel

2. Transition section

    i. Entrance control gate (service gate)

3. Settling basin section

    i. Chambers

    ii. Energy breaking rods for stilling

    iii. Main settling zone

    iv. Flushing channel, header and gates

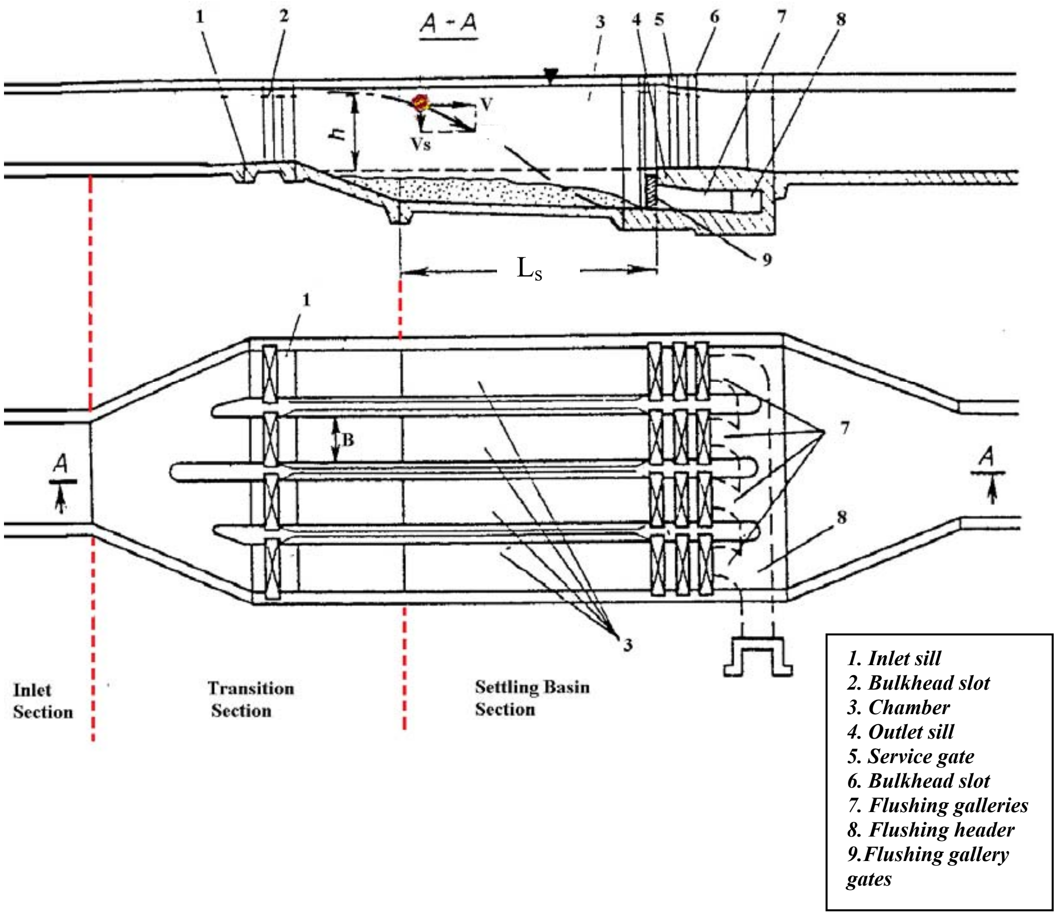


Figure 2.7 Sections of a settling basin

As indicated in Figure 2.7, a settling basin consists of one or more frequently several chambers which are much wider than the diversion channel and the intake spans. The inlet and outlet openings of the chambers are equipped by individually hoisted gates.

The outlet sill is raised above the chamber bottom and gives room to flushing galleries equipped with gates. The flushing galleries are joined by a header discharging into the riverbed.

When it gets into a chamber, water rapidly loses its velocity, so suspended particles have enough time to deposit. The bed sediments accumulating before the outlet sill are washed away from time to time. For this purpose, the outlet opening is closed and the flushing gallery is opened in each chamber in turn. It also exist settling basins where bed sediments are washed away continually.

For the sake of the continuous operation and interrupted service, the chambers are constructed in minimum double number. Because while the half number of the chambers work, the other half of the chambers are being flushed or cleaned.

2.4. TYPES OF SETTLING BASINS

There are two types of settling basins regarding to their shapes;

- Prismatic Tank
- Circular Tank

2.4.1. Prismatic Settling Basins

Figure 2.8 Prismatic settling basin (Birkapılı HEPP, Mersin)

Generally, trapezodial cross-sections are constructed for settling basins (Figure 2.8). In some cases the settling basins of rectangular cross-sections are constructed. Especially there is no different geometry of cross-sections except trapezodial or rectangular cross-section for settling basins of the energy purpose projects.

Conventionally prismatic settling basins include 2 types according to some sources as the following:

- Prismatic Büchi Type
- Prismatic Bieri Type

2.4.1.1. Prismatic Büchi Type

It consists of one or more chambers of sufficient length to let the sediment particles to settle down (Figure 2.9). It is drained almost completely whenever it is needed to be flushed away. This may cause lack of power production for a while. Flushing channel could construct in 2 ways. One of them is constructed vertically along the settling basin basement or the other one is constructed with an angle to the settling basin basement towards to the river bed (Andaroodi, 2005).

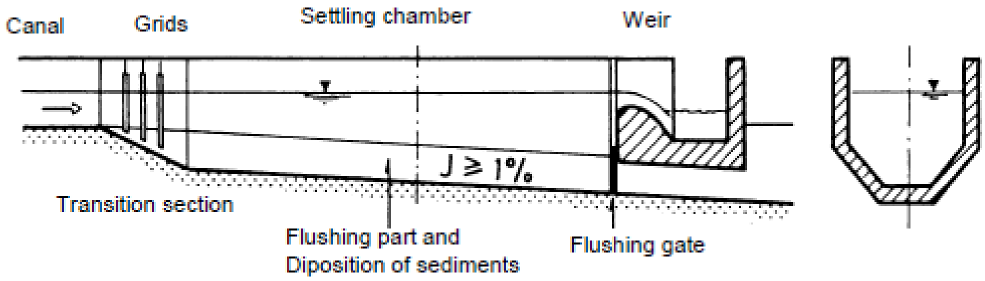


Figure 2.9 Büchi Type settling basin's profile and cross-section view (Andaroodi, 2005)

2.4.1.2. Prismatic Bieri Type

The most important advantage of the Bieri settling basin is that it ensures energy production even during the flushing procedure because of the continuity of the flow. The sediments which settle down within the settling basin are flushed away vertically through the opening into the flushing channel and back to the river. Therefore, the flushing water volume is kept to a minimum amount thanks to sensors permit fully automatic operation (Andaroodi, 2005). Flushing system is shown in Figure 2.10.

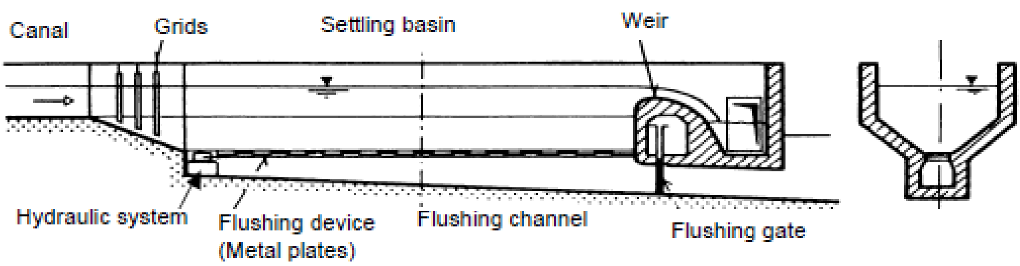
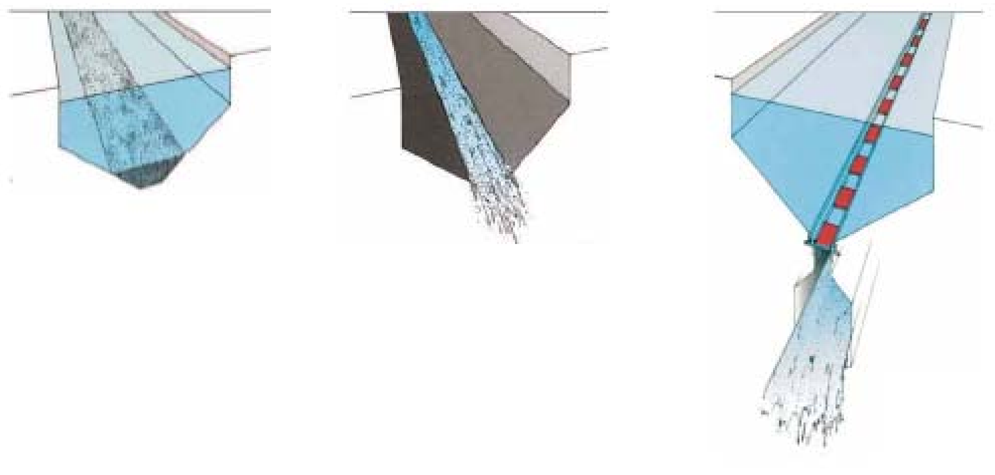


Figure 2.10 Bieri Type settling basin's profile and cross-section view (Andaroodi, 2005)



(a) (b)

Figure 2.11 Comparison of flushing systems a) Cross-section view of Büchi type, b) Cross-section view of Bieri type (Andaroodi, 2005)

2.4.2. Circular Settling Basins

Circular settling basins have the same functional zones as the long rectangular basins, but the flow regime is different. When the flow enters at the center and is baffled to flow radially towards the perimeter, the horizontal velocity of the water continuously decreases as the distance from the center increases (Figure 2.12). Thus, the particle path in a circular basin is a parabola as opposed to the straight line path in the long rectangular tank. Sludge removal mechanisms in circular tanks are simpler and require less maintenance.

Bundesarchiv, Bild 183-1984-1002-002
Foto: Pätzold, Ralf | 2. Oktober 1984

Figure 2.12 Circular settling basin (Patzoid, 1984)

CHAPTER 3

DESIGN OF SETTLING BASINS

3.1. INTRODUCTION

As all the types of other hydraulic structures, a settling basin undergoes the following three basic design steps:

- Hydrological design
- Hydraulic design
- Structural design

In the scope of this study, only hydraulic design of settling basins is discussed. Hydraulic design means that the settling basins should be designed in a such way that they behave hydraulically efficient. The hydraulic efficiency of a settling basin basically involves the following parameters:

- Discharge capacity of the diverted water from the river
- Sediment amount, type and size in the diverted water from the river

Design criterion of the discharge capacity is not concern of this chapter; it deals with experimental works in Chapter 5. In the point of view, Chapter 3 is only about the sediment content criterion.

3.2. HYDRAULIC PRINCIPLES USED IN THE DESIGN OF SETTLING BASINS

To get the sediments entering the settling basin trapped, the velocity of the flow within the settling basin must be reduced. The reduction in velocity is achieved by an increase in width and in depth as shown in Figure 3.1.

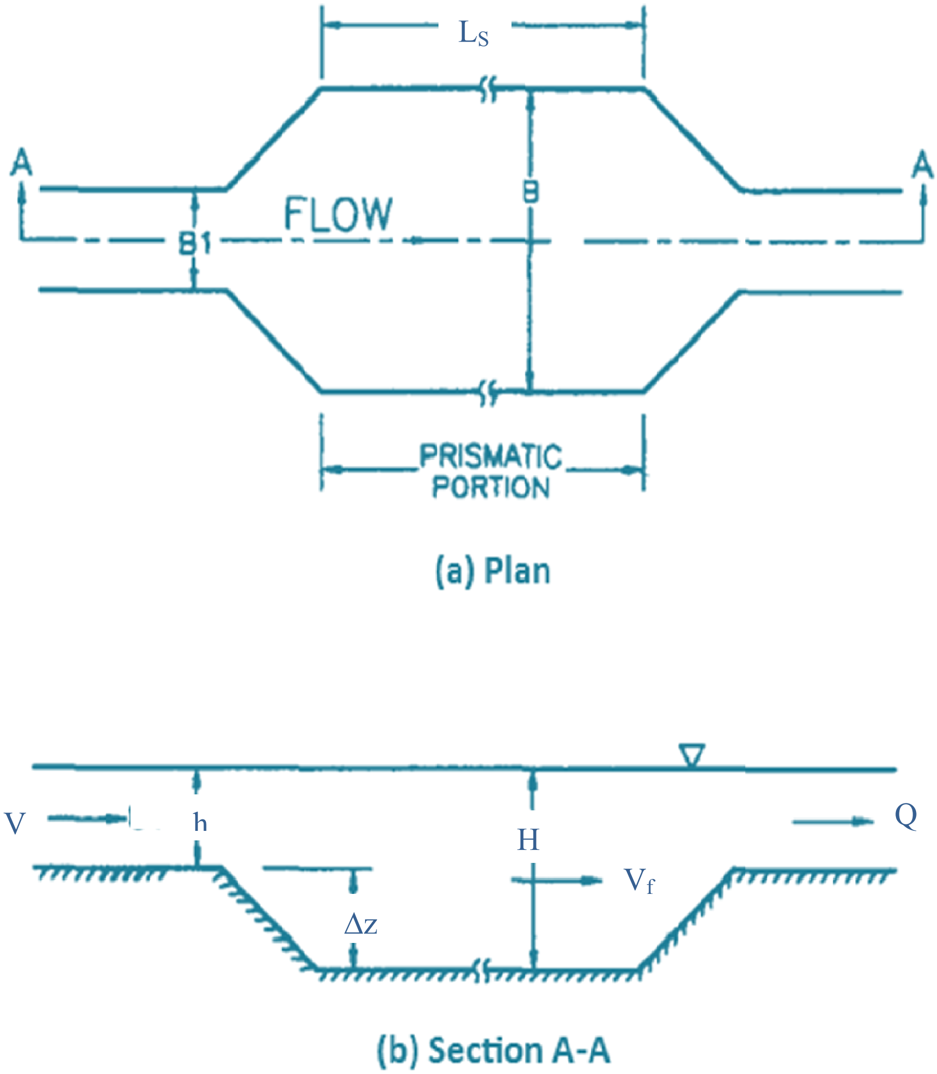


Figure 3.1 Definition sketch of a settling basin (Nandana and Mavendra, 1997)

The correct and proper design of a settling basin significantly extends the lifespan of the hydropower plant. In this particular case, the settling basin is designed to allow sediment particles up to the permissible size in diameter to settle. Specifically, all sediment particles larger than this permissible limit must be removed before the water enters the turbine. To reach the suitable settling result, the flow velocity must be reduced in order to minimize turbulence. Therefore, the cross-section of the basin should be widen gently until the flow is slow enough to let the particles settle down. The flow is quite sensitive to the edges of the structure.

Consequently, according to the hydraulic principles a correct and expected design of the settling basin is sketched in Figure 3.2 with low velocity throughout width and without any turbulence throughout settling basin. High surface velocity and turbulence in corners exist in an incorrect settling basin design shown in Figure 3.3.

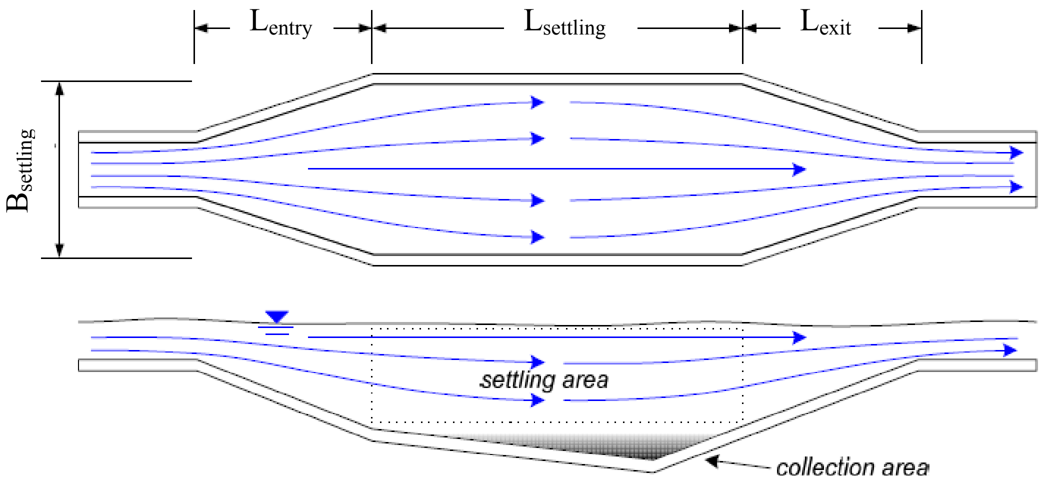


Figure 3.2 A correct design of settling basin (Ardüser and Karcheter, 2009)

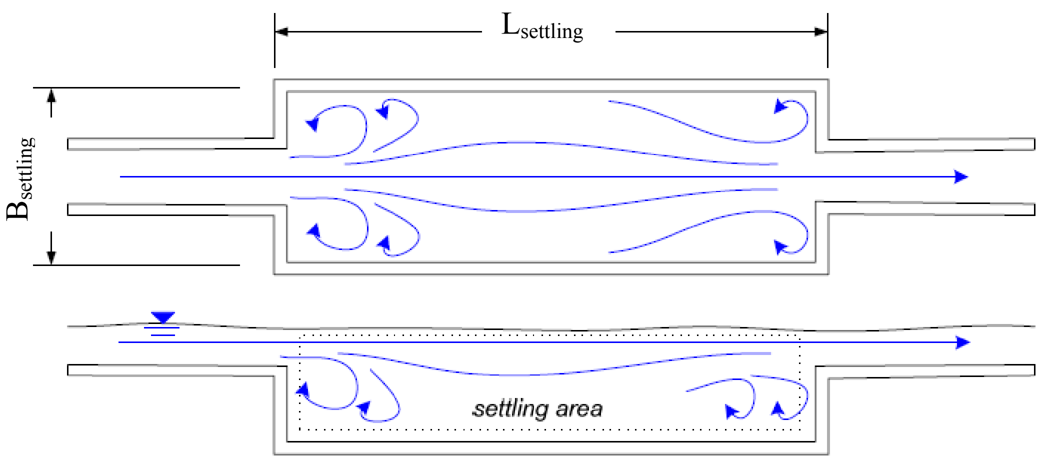


Figure 3.3 An incorrect design of settling basin (Ardüser and Karcheter, 2009)

3.2.1. Design Criteria

In the design of settling basins, also there are some important design criteria to consider which are mentioned below one by one.

3.2.1.1. Sediment Property

It is well known that the sediment is the biggest enemy of the hydraulic structures especially settling basins constructed on the sediment carrying rivers. Therefore, the sediment problem must be solved. For this purpose, the most important design criterion basis on the settling of the sediment.

In line with this objective, the maximum size of the sediment particle allowed to be present in the diverted water must be as small as possible that the flow conditions permit.

So as mentioned, the first design criterion is about sediment properties like sediment particle size and sediment particle shape. Thus the sediment shape factor is calculated by Equation 3.1.

$$S_F = \frac{c}{a+b} \tag{3.1}$$

where a,b and c indicate the longest, medium and shortest lengths of the particle in tridial axes.

3.2.1.2. Sediment Transport Phenomena

When using a turbine or a pump in a system, water quality becomes very important. All types of solid materials can lead to damages to constructions. Figure 3.4 shows the relationship between bed load, floating matters and suspended load.

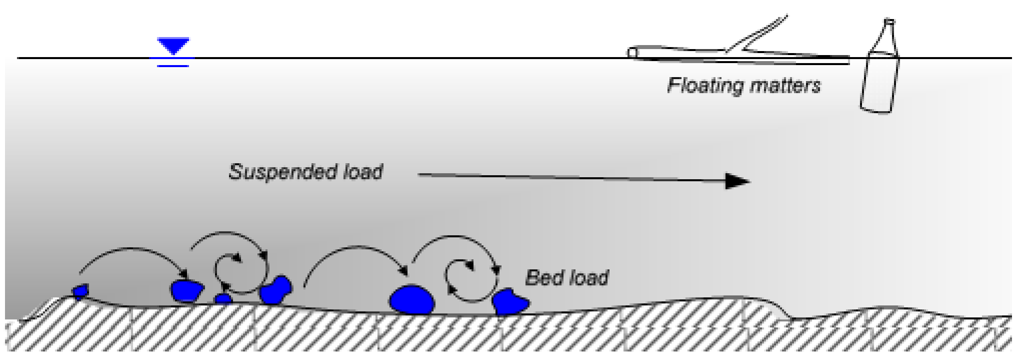


Figure 3.4 Transportation of solid materials (Ardüser and Karcheter, 2009)

Generally, sediment in a river is transported in the following positions (Figure 3.5):

i. Sediment transported in suspension called as *"suspended load"*.

ii. Sediment transported at the bed by sliding and rolling called as "*bed load"*.

iii. Sediment transported in *saltation* moving by jumping at and close to the bed.

Therefore, the saltation occurs across a small height close to the bed, the sediment transported in saltation is merged into the bed load; this position is out of point of view. In other words, suspended load and bed load is just considered in the design criteria concept.

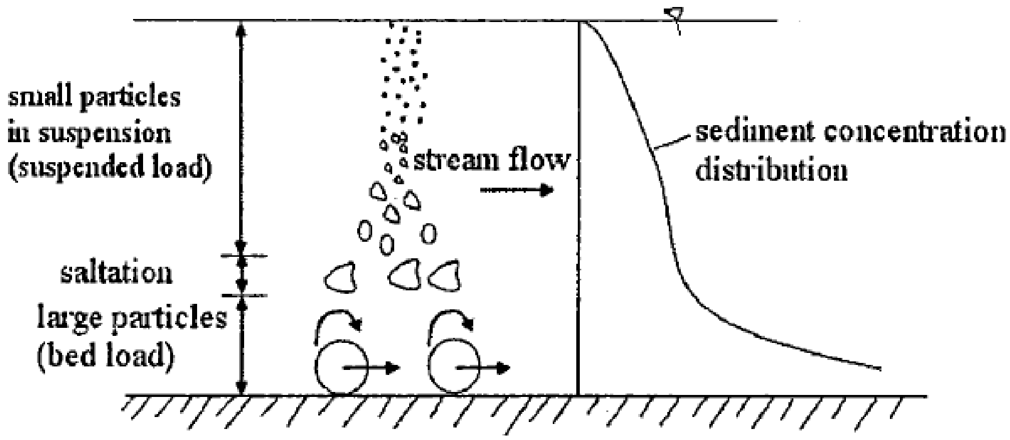


Figure 3.5 Sediment transport in a river (Yıldırım, 2007)

3.2.1.3. Sediment Settling Velocity

Settling velocity is determined by the following equation, derived from Stokes' Law, which is called "*impact law*".

$$V_s = \sqrt{\frac{4 \times \Delta\rho \times g \times d_s}{3 \times C_D}} \tag{3.2}$$

where, Δρ is the ratio of sediment and water densities, $\Delta\rho = (\rho_s - \rho)/\rho$, g is the acceleration of gravity and C_D is the drag coefficient of the sediment (Stokes, 1851).

Initially, the behaviour of a sediment particle must be known in the settling basin. The sediment particle floats on the water and therefore, we must calculate how long it will take for it to settle to the ground as shown in Figure 3.6. For this reason, we need the flow velocity, V, and the vertical settling velocity,V_s, of the sediment particle.

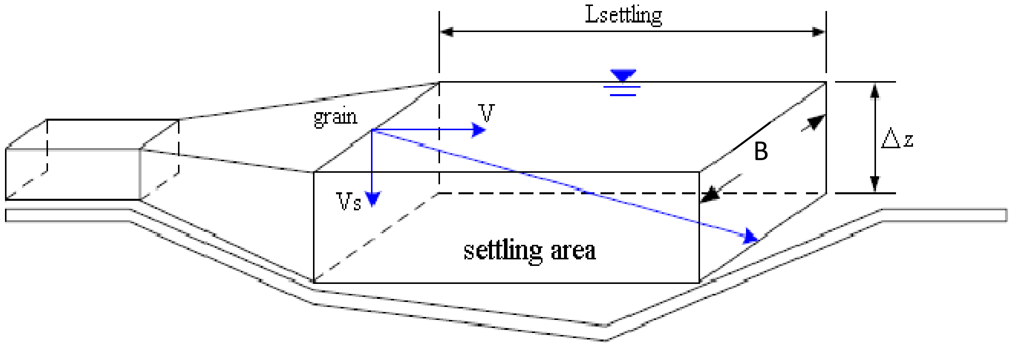


Figure 3.6 Settling behavior of a grain in a settling basin (Ardüser and Karcheter, 2009)

The settling velocity (also called the "fall velocity" or "terminal velocity") is a function of the particle Reynolds number. Generally, for small particles (laminar flow approximation), it can be calculated with Stokes' Law. For larger particles, fall velocity is calculated with the turbulent drag law.

But although the existence of settling velocity equation, since C_D values for natural particles are not available, the settling velocity is preferred to be taken from a curve which is called “Stock Curve” (Sungur, 1988). Stock Curve shows settling velocity versus sediment particle diameter (Figure 3.7). Thus settling velocity is selected from the curve according to the sediment diameters in millimeter.

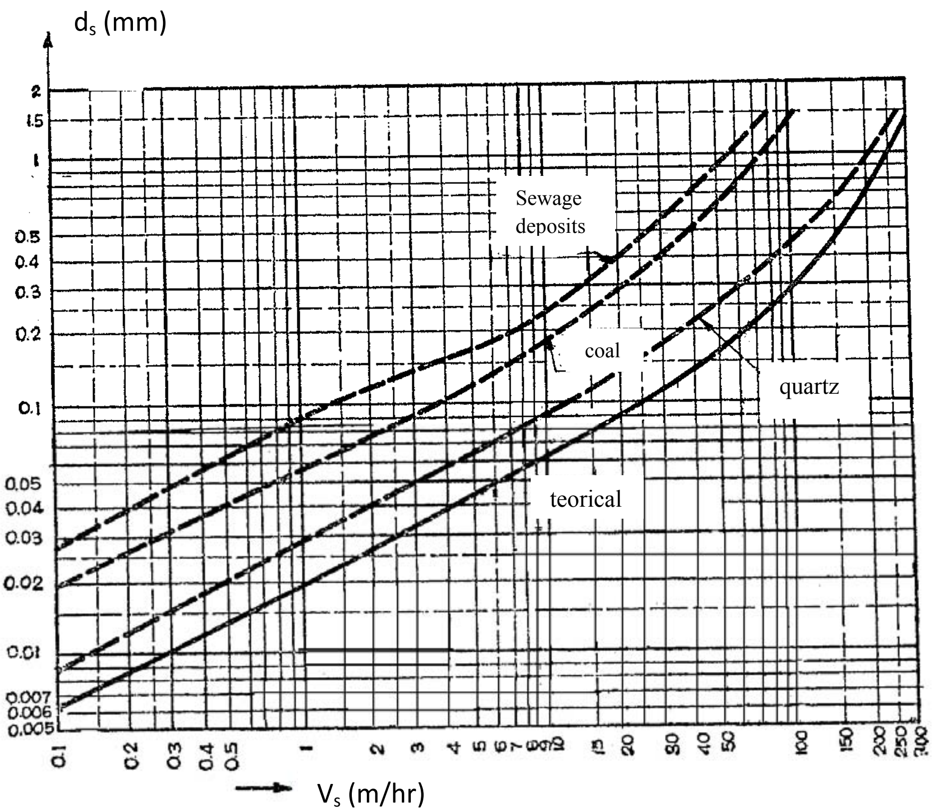


Figure 3.7 Stock Curve (Sungur, 1988)

3.2.2. Design Parameters of Settling Basins

The design parameters of settling basins include the variables such as the properties of the settling basins and the conveyance channels which are shown below one by one.

<u>Settling Basin Variables:</u>

- Length of the settling basin
- Width of the settling basin
- Height of the settling basin

<u>Channel Variables:</u>

- Width of the channel
- Depth of water in the channel

In the scope of this study, the channel variables will not be considered just only the variables of the settling basin will be considered.

3.2.2.1. Width of the Settling Basin

In order to reduce the velocity of the flow in the settling area, first of all, the width of the basin must be chosen. The width of settling basin is usually selected between 2 to 15 times of the width of channel (Ardüser and Karcheter, 2009). In case of a trapezoid channel, the average width is used.

A large settling basin width causes an unequal current in the settling tank which can prevent settling of some sediment particles. To solve this problem, several settling basins must be arranged side by side which is called as *"chamber"*. To generate laminar flow, the width of the settling area should not be very large according to its length. Otherwise, a proper settling could not occur. The exit of a settling basin must be designed similarly to the shape of the entry.

3.2.2.2. Length of the Settling Basin

Another design criterion is the settling basin length. After settling velocity,V_s, is selected from the "Stock Curve" according to the desired particle diameter, the settling basin length, L_s , is calculated by Equation 3.3 (DSİ, 1969).

$$V_s = \frac{3600 \times Q}{L_s \times B_s} \tag{3.3}$$

where Q is the discharge of the settling basin and B_s is the width of the settling basin.

3.2.2.3. Slope of the Settling Basin

Next step of the design is determination of the basement slope of the settling basin. Settling basin should have a slope which is about 0.01 to flush the settling basin effectively by a desilting channel to the river.

3.2.2.4. Side Slope of the Settling Basin

The last design criterion is about the construction property of the settling basin. A settling basin should not be narrow towards to the sill at the end of the basin. Because of the effective settling of sediment is needed towards to the whole basin, contraction should be started after the sills. Therefore, the slope of the side edges (α) of the basement of the settling basin is very important to make small sediment particle go away from the side edges (Figure 3.8).

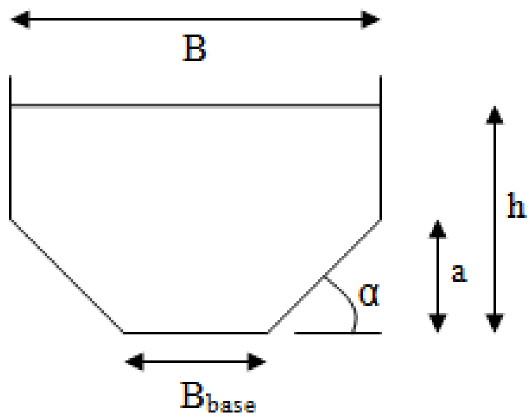


Figure 3.8 Cross-section view of a settling basin

3.2.3. Assumptions

In the design of settling basins there must be some assumptions to make the calculations easier. These assumptions are explained below:

- The direction of the flow within the settling basin is parallel with the slope of the settling basin bottom.
- The flow velocity is uniform within the whole settling basin.
- In first phase approximately the whole amount of suspended material is settled down. In second phase by the drive of flow, a little amount of sediment is resuspended. This resuspended material is neglected in the settling basin design.
- The sediment which is trapped in the settling basin is deposited in the basin uniformly and the bed of the settling basin is linear.
- The effect of turbulent and eddy flow upon settling velocity is neglected in the simple settling theory.

In conclusion, the main purpose of the hydraulic principles used in the design of the settling basin is to settle the smallest diameter of grain sediments in the vertical plane at the bottom of the pool before it reaches the end of the pool.

3.3. DESIGN METHODOLOGY OF SETTLING BASINS

The Froude number, Fr, is a dimensionless parameter that describes different flow regimes of open channel flows. The Froude number is the ratio of inertial and gravitational forces.

Critical flow is the special case where the Froude number is equal to 1. In other words velocity divided by the square root of (gravitational acceleration multiplied by the flow depth) is equal to 1.

Subcritical flow has a Froude number less than 1, and is therefore characterised by slow moving deep water.

Supercritical flow is defined as having a Froude number greater than 1 and is therefore characterised by shallow fast moving flow.

3.3.1. Design Principle

The hydraulic design of the settling basin is presented below in details. The calculations are made for subcritical flow conditions in the settling basin with reference to the plan and profile shown in Figure 3.9.

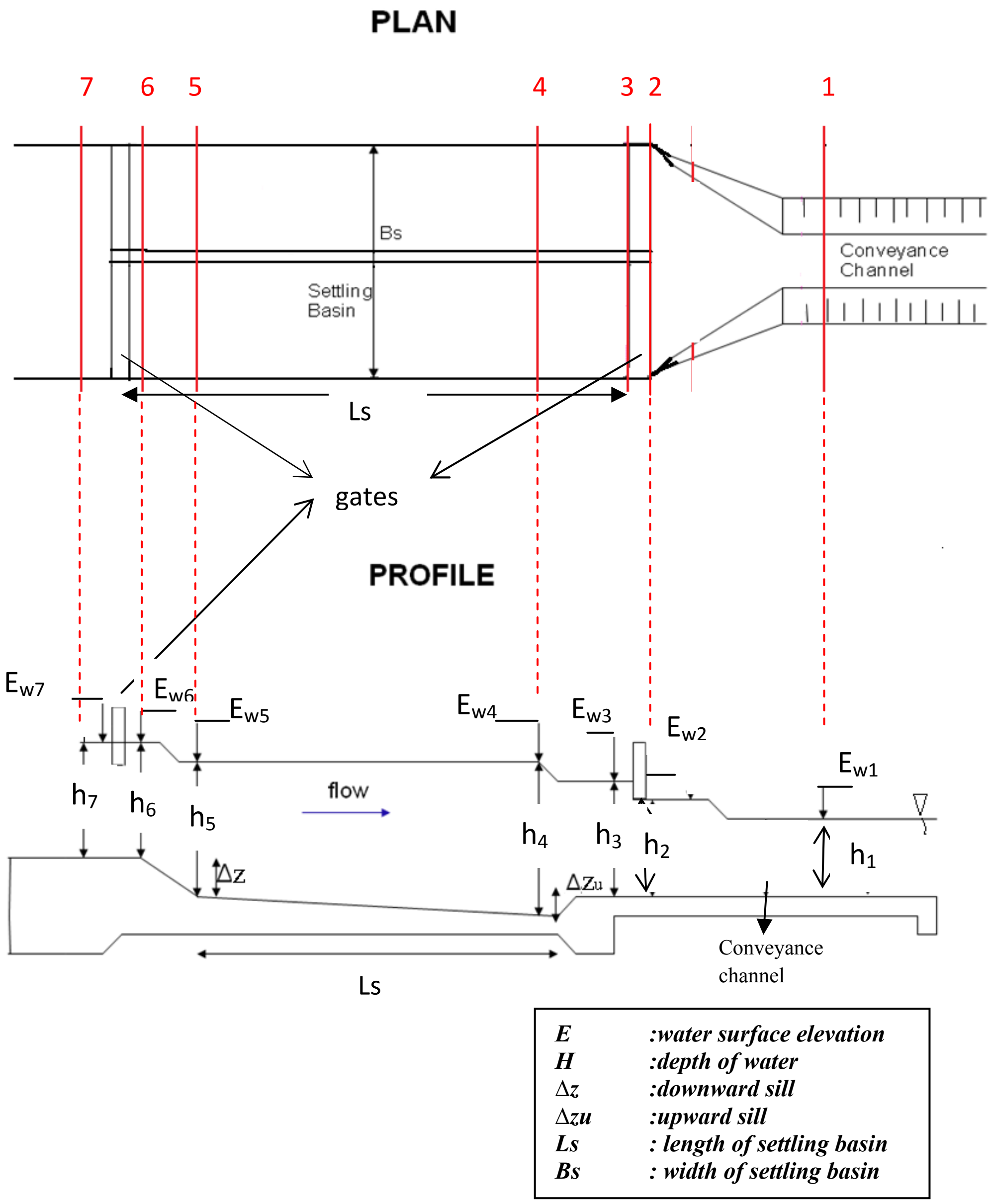


Figure 3.9 Plan and profile views of a settling basin

3.3.2. Design Steps

The computational direction under subcritical flow conditions is from the downstream to the upstream. With the known design discharge, Q, and the known sizes of the conveyance channel, the flow depth, h_1, is computed from the Manning's equation. h_1 is the water depth in the conveyance channel. So water surface elevation at that section, E_{w1} , is determined with known bed elevation of the conveyance channel.

The entrance of the channel and the settling basin are connected to each other by a transition. So the minor loss through transition, ΔH_t, can be computed from Equation 3.4 (Chow, 1959).

$$\Delta H_t = C_t\left(\frac{V_1^2 - V_2^2}{2g}\right) \tag{3.4}$$

where C_t is a coefficient factor of transition, V_1 and V_2 are the velocities at sections 1 and 2, respectively and g is the gravitational acceleration. There are graphs published for transition coefficient according to some authors, but for a straight- line transition this coefficient is taken as C_t=0.3.

After the computation of the head loss of transition, from energy equation between sections 1 and 2:

$$E_1 + \Delta H_t = E_2 \tag{3.5}$$

where E_1 and E_2 are total energy heads of the flow at sections 1 and 2, respectively, and assuming the channel slope between these two sections is negligible; Equation 3.5 can be written as:

$$h_1 + \frac{V_1^2}{2g} + C_t\left(\frac{V_1^2 - V_2^2}{2g}\right) = h_2 + \frac{V_2^2}{2g} \tag{3.6}$$

in which V_2=Q/(Bxh_2) where B is the width at section 2 which can be used minimum width value of the transition section (Note that: V=Q/A). h_2 is computed from Equation 3.6 by iteration, after that E_{w2} which is the water surface elevation at section 2 can be computed by determined value of h_2 .

A gate is placed at the entrance of the channel at section 3 to regulate the flow and to prevent the entrainment of flow into the channel during the flushing of the settling basin. A number of piers are placed at that section to provide insallation of gates. So the minor loss at the gate, ΔH_g , is calculated by Equation 3.7.

$$\Delta H_g = \frac{V_g^2}{0.65^2 \times 2g} \tag{3.7}$$

where 0.65 is an orifice coefficient (Sungur, 1988) and V_g is the velocity at the gate and computed from Equation 3.8.

$$V_g = \frac{Q}{B_n} \tag{3.8}$$

where B_n is the net width at the section of the gate and computed from Equation 3.9.

$$B_n = B_2 - n_p \times t \tag{3.9}$$

in which n_p is the number of piers and t is the thickness of one pier.

Again application of energy equation between sections 2 and 3;

$$E_2 + \Delta H_g = E_3 \tag{3.10}$$

and

$$h_2 + \frac{V_2^2}{2g} + \frac{V_g^2}{0.65^2 \times 2g} = h_3 + \frac{V_3^2}{2g} \tag{3.11}$$

After these computations from Equation 3.11 first h_3 and then E_{w3} are determined.

An upward sill is required at the end of the settling basin to direct the accumulated sediment in the settling basin to the flushing canal in order to prevent the entrainment of sediment into the main channel. The velocity at the end of the settling basin should be small to let the suspended particles at the end of the basin settle down. And according to Sungur (1988), the maximum permissible flow velocity at the end of the pool should be 0.3 m/s.

The height of the upward sill, Δz_u , depends on the project, can be selected at least 80 cm due to exsistence of the flushing channel. If the flushing channel is built at the end of the pool, the upward sill height should be selected according to the height of the gate of the flushing channel.

The minor loss at the sill according to Sungur (1988), ΔH_s , is calculated by;

$$Q = 2.88 \times B_s \left(\frac{2}{3} \Delta H_s^{1.5} + h_3 \sqrt{\Delta H_s} \right) \tag{3.12}$$

From energy equation between section 3 and 4 as shown in Equation 3.13:

$$E_3 + \Delta H_s + \Delta z_u = E_4 \tag{3.13}$$

h_4 is computed from Equations 3.13 and then E_{w4} is calculated using the same procedure stated above.

The length of the settling basin is calculated from Equation 3.14 (DSİ, 1969). The length of the settling basin, L_s, is calculated from Equation 3.14 after selecting the required settling velocity, V_s, of the sediment particle from the "Stock Curve".

$$V_s = \frac{3600 \times Q}{L_s \times B_s} \tag{3.14}$$

The head loss through the settling basin, ΔH_f, is calculated from Equation 3.15.

$$\Delta H_f = \overline{S_f} \times L_s \tag{3.15}$$

where $\overline{S_f}$ is the average value of the friction slopes at sections 4 and 5.

By using "Manning Equation" and from the energy equation between section 4 and 5, Equations 3.16 and 3.17 can be written.

$$E_4 + \Delta H_f = S_0 \times L_s + E_5 \tag{3.16}$$

where S_0 is the slope of the settling basin. Substituting ΔH_f from equation 3.16 after expressing it using the Manning equation and taking $S_0 = 0.01$ (according to DSİ), the following equation is obtained.

$$h_4 + \frac{V_4^2}{2g} + \frac{L_s}{2}\left(\frac{n^2 \times V_4^2}{R_4^{4/3}}\right) = 0.01 \times L_s + h_5 + \frac{V_5^2}{2g} \tag{3.17}$$

where n is the Manning coefficient and R is the hydraulic radius of the section.

(Note that Manning equation: $V = \frac{1}{n} \times R^{2/3} \times \sqrt{S}$)

h_5 and E_{w5} are computed from Equation 3.17.

A downward step, Δz , is placed at the entrance of the settling basin. The minor loss above this sill, ΔH_z , could be taken 0.02 m regarding to Sungur (1988). Energy equation between sections 5 and 6 can be written as:

$$h_5 + \frac{V_5^2}{2g} + \Delta z = \Delta H_z + h_6 + \frac{V_6^2}{2g} \tag{3.18}$$

h_6 and E_{w6} are computed from Equation 3.18.

A gate is placed at the entrance of the settling basin at 7th section to regulate the flow. A number of piers are placed at that section to provide insallation of gates. So the minor loss again at the gate, ΔH_g , is expressed as given in Equation 3.7.

Finally the energy equation between sections 6 and 7 can be written as:

$$h_6 + \frac{V_6^2}{2g} + \frac{V_g^2}{0.65^2 \times 2g} = h_7 + \frac{V_7^2}{2g} \tag{3.19}$$

h_7 and E_{w7} are computed from Equation 3.19.

A settling basin of three chambers which is designed with these hydraulic principles is shown in Figure 3.10. Çamlıca settling basin is a component structure of Çamlıca 1 HEPP which is designed by one of the main project firm called "ENSU Eng. Cons. Ltd.".

Figure 3.10 Çamlıca settling basin (Kayseri, 2009)

Figure 3.11 shows the photograph of Birkapılı settling basin taken in 2003 when it was under construction. It is located in Mut which is the district in the city of Mersin.

Figure 3.11 Birkapılı settling basin under construction (Mersin, March 2003)

Birkapılı settling basin is seen during test of operation in 2003 in Figure 3.12. The system had been tested with its two chambers to examine if the settling basin works efficiently or not. After the successful test, in the beginning of the year 2004, it had been opened officially.

Figure 3.12 Birkapılı settling basin during operation (Mersin, December 2003)

CHAPTER 4

OPERATION PRINCIPLES OF SETTLING BASINS

Settling basins are used for two main operation purposes. The first one is as a flood control structure and the other one is a sediment control structure.

4.1. PREVENTION OF FLOOD

At drainage lands with high slopes and less vegetal cover, soils are subject to erosion almost during each rain. Flows through rivers in such areas can erode their beds, sides and make changes in their bed formation. In the cases of rivers with high regime, sediment load vary from flood to flood.

At the moment of flood or river water level is higher than the desired conditions, the entrance gates of settling basins are closed. So that the system is protected from over load, as turbines are designed only for a specific “design discharge”.

Sometimes during some flood, the high-slope rivers carry large materials like stones, gravels etc. which cause highly nonuniform flow. As the flow passes away, these coarse materials settle at the bed of the intake weirs or structures. Due to the presence of settling basin entrance gates and trush racks, the system could be safe.

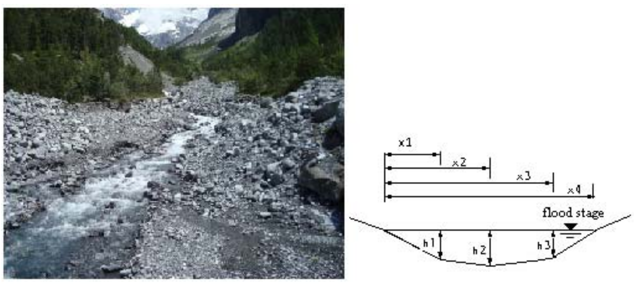


Figure 4.1 Riverbed with flood (Ardüser and Karcheter, 2009)

4.2. CONTROL OF SEDIMENT

A good diversion method and a well designed settling basin could eliminate the sediment-related problems at the beginning of the system; otherwise the maintenance and operation costs will be very expensive. Before construction of the settling basin, the designer must study the problem in detail and design the settling basin carefully to control the sedimentation.

While water is being diverted and taken from the river, some sediment will be present within the diverted water. So, settling basin's main purpose is to control this sediment within the diverted water. Therefore, removing the sediment is the most inexpensive method thanks to the settling basin because despite all the protection taken to avoid the sediment entrainment into the intake structure, still some unwanted sediment will exist in the diverted water.

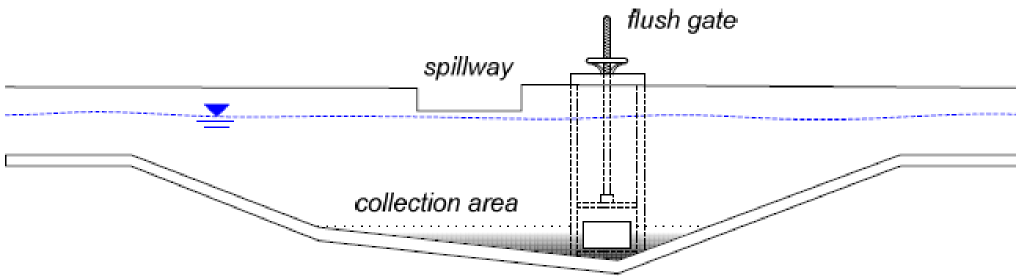


Figure 4.2 Sediment control area of a settling basin (Ardüser and Karcheter, 2009)

The collection area is inside the settling basin exclusively utilized to collect the settled particles to control sedimentation as indicated in Figure 4.2.

Although the diverted water contains a very small amount of sediment, it is still very important problem to deal with in practice. After settling down in the settling basin, the suspended sediment from the diverted water is given back to the downstream of the intake structure by cleaning methods of settling basin such as flushing or hydraulic dredging.

4.3. CLEANING OF SETTLING BASINS

Deposited sediment could be removed from settling basins periodically by hydraulic or mechanical methods. There are two popular practices to clean settling basins. The ways of cleaning are shown below.

- Hydraulic Dredging
- Flushing

By these methods, the capacity of the many settling basins could be restored easily and efficiently.

4.3.1. Hydraulic Dredging

Hydraulic dredging is the most efficient way of cleaning settling basins for fine-grained submerged and deposited materials. Also coarse-grained materials require mechanical equipment for removal from the settling basin. A fronted loader or a power shovel could be used for removal of deposited coarse materials.

A hydraulic dredge floats on the water and excavates and pumps the material through a temporary pipeline to an offsite location, often several thousand feet away. This dredge acts like a floating vacuum cleaner that can remove sediment very precisely. This procedure is shown in Figure 4.3.

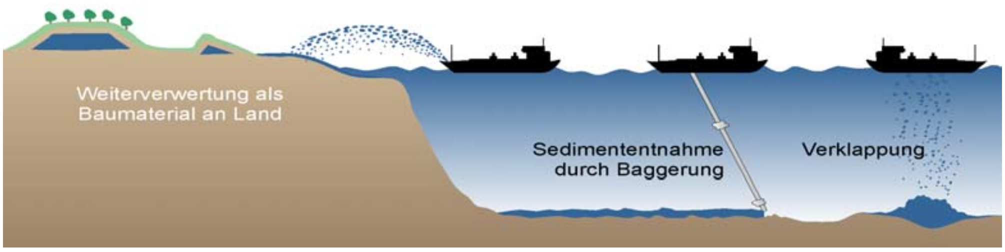


Figure 4.3 Hydraulic dredging (Dredging Company, 2013)

In Figure 4.4, a dredge float is shown in detail with its cleaning equipment. Dredge float cleans sediment-filled base as shown in the figure.

Figure 4.4 Dredge float (Merrell Bros Company, 2013)

The cross section of a settling basin which is cleaned by the method of “hydraulic dredging” is shown in Figure 4.5. Also its equipments are represented in detail in Figure 4.6.

Figure 4.5 Hydraulic dredging in settling basin (Dredging Company, 2013)

As shown below Figure 4.5, the dredge machine averages 80 - 100+ yards of sediment removal per hour; used for sand dredging, river dredging, port dredging, pond, lake and marina dredging.

The dredge machine is highly mobile with its patented Starwheel drive self-propulsion system which allows the dredge to navigate independently and without the need for cables or spuds. Weighing only 17,000 lbs., the dredge machine can be easily highway transported and set up quickly at the job site, keeping mobilization costs to a minumum. As shown in Figure 4.6, it has its own power unit to operate its work.

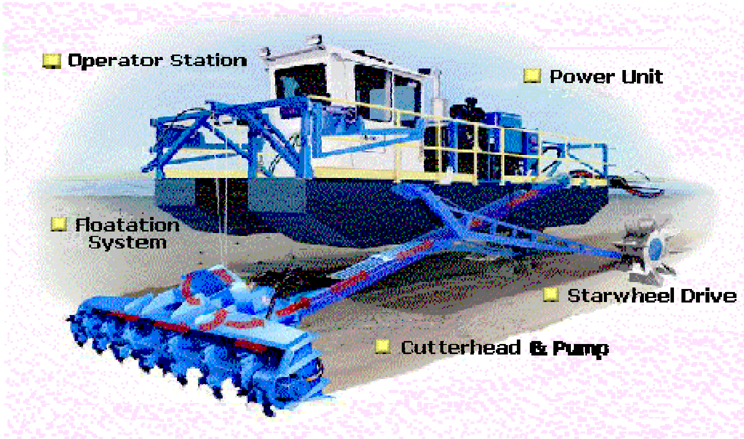


Figure 4.6 Hydraulic dredging equipment (Dredging Company, 2013)

4.3.2. Flushing (Sluicing)

The settling basins are basically designed for the settlement of the fine sediments. A well designed settling basin could be flushed efficiently and in a short period of time. But in the high slope rivers, flushing may not be very easy and efficient because of the coarse materials. A lot of water is needed during their flushing which means a lot of loss of water. In such cases there is a need of power shovel or a digger.

The sediments which settle in the settling basin are flushed vertically through the opening into the flushing channel and back to the downstream of the river. The flushing water volume is therefore kept to a minimum. This flushing system is shown in Figure 4.7 with the flushing tunnels which are connected towards to the river.

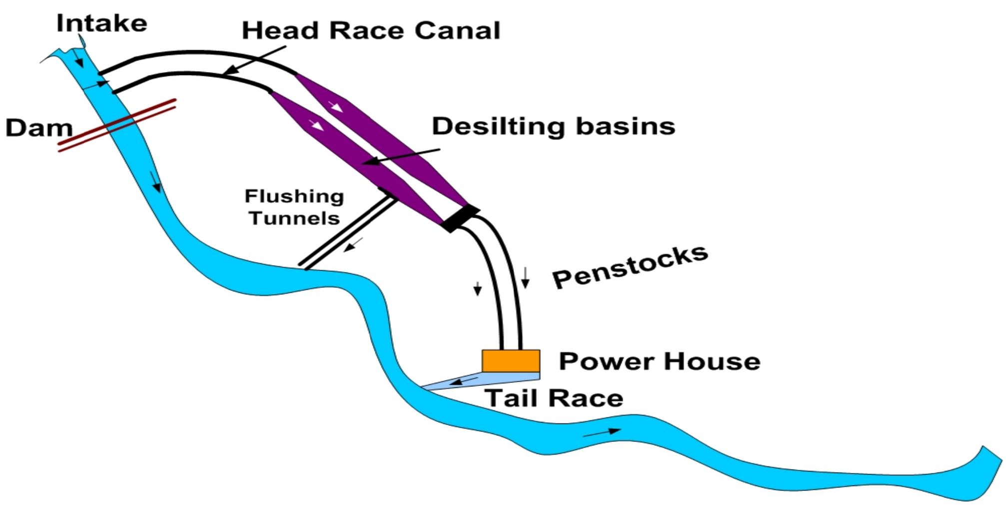


Figure 4.7 Flushing scheme (Khatsuria, 2012)

Flushing system is a highly effective cleaning system which requires no electricity, no maintenance and no fresh water. There is virtually no limit on flushing length as more flush water may be stored without incurring any additional construction or operating costs.

Flushing is a simple method for sediment removal. Flush water is held in reserve in the storage basin. This flush water, released by a patented mechanism, gives rise to a high celerity wave that effectively removes all accumulated debris in basins and interceptors over flushway lengths greater than any other available method.

Flushing is a self contained system. It operates without any external power or water supply and requires no complicated controls. Its success has been proven over the years through hundreds of operating installations.

The flushing system has the following main features (Figure 4.8) :

- The gate which holds back the stored water.

- The float control mechanism for the gate, which is operated by a closed circuit hydraulic system.

- The system may also be operated using electric controls, if desired, with power usage < 1.0 kW.

Figure 4.8 Flushing channel (Gabriel Novac & Assoc. Ltd., 2013)

4.3.2.1. Advantages of Flushing System

Advantages of this method are mentioned below briefly.

- No limitation on flushway length; several devices may be installed in series.
- No external power is required.
- No external water supply is required.
- No maintenance is required.

CHAPTER 5

INVESTIGATION OF OPERATIONAL PROBLEMS FOR SOME OF THE SETTLING BASINS IN TURKEY

5.1. INTRODUCTION

In order to understand the range of problems and needs of private sector, a questionnaire was prepared and given at the next pages. For this purpose, encountered problems related design of the settling basins in practice were investigated and discussed. By contacting some private investors in Turkey, this questionnaire was presented to investigate the operational problems about some of their settling basins. With regard to their answers, some photographs from their archive which show the sedimentation in settling basins were presented in this chapter. Addition to these, some of their settling basin's plan, profile and cross sectional projects were also presented in Appendix B.

When these examples in practice are examined, it is clearly seen that there is no significant problems especially for these settling basins. There isn't any problem for these specified examples; but also there are different kinds of problems related settling basins based on the experiences of the owner's representatives during their business life. In other words, their observations show that the following related problems are encountered in practice as below:

- In some examples of settling basins, an efficient flushing could not be done because of the accumulation of the sediment in the entrance of the settling basin, just near the downward sill.

- Settled sediments became a very tough material as a mud, so presence of another equipment was required like earth digger.

- Especially for some rivers carrying high amount of alluvial, flushing channel dimensions are insufficient so that the deposited particles could choke up the entrance of the flushing channel.

– Trash racks in front of the entrance gates of the settling basins are chocked easily and quickly. It is very difficult to clean them where the system in operation.

Regarding to these problems, the followings are recommended:

❖ Before all the studies, for every projects, a feasibility report is prepared. In this report, there should be more detailed informations about the river in which weir or intake structure is located on. The related informations are the regime of the river, the type of the sediment which river contains at high amount and also its capacity of sediment transport. If such data did not exsist or were inadiquate, the more measurement stations should be established by the government. Such input data let the hydropower systems more safety to the abrasion effects and extend the lifespan of the system.

❖ Flushing system should operate in a specified period of time in such a way that routinely; not only just the presence of the high amount of sediment accumulation. In other words, settling basins should be washed away regularly. Of course this time period of flushing varies due to the characteristics of the river.

❖ The settling basin's cross-sectional side slopes should be as high as possible. Since sedimentation is more intense at the side slopes of the settling basin.

❖ Because of the difficulty of cleaning the chocked trash racks, trash racks could be constructed inclined.

5.2. QUESTIONAIRE

Here below questions and answers:

1) **Was there any problems in settling basin during operation? If it exsists, what kind of problems were faced up?**

PROJECT NAME	**: ÇAMLICA SETTLING BASIN**
PROJECT COMPANY	**: AYEN ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Salih KARADAVUT**
CITY / TOWN	**: Kayseri / Yahyalı**
RIVER / MAIN BRANCH NAME	**: Seyhan /Zamantı**

We have not encountered any problems related with the design of flushing system or settling basin during 15 years of operation period. We have once faced with an operational problem related settling basin and head pond in January. There were frosting problems in settling basin and head pond. Because at the previous night, the plant had been produced at a constant head which caused the settling basin's water surface to decrease. Therefore, settling basin became open fort the frosting.

PROJECT NAME	**: YALNIZCA SETTLING BASIN**
PROJECT COMPANY	**: FİLYOS ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Taha TİRYAKİ, Saygın DENİZ**
CITY / TOWN	**: Karabük / Merkez**
RIVER / MAIN BRANCH NAME	**: Filyos / -**

We have not encountered any problems related with the design of flushing system or settling basin during 4 years of operation period from November 2009.

PROJECT NAME	**: KALE SETTLING BASIN**
PROJECT COMPANY	**: AVKAR ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Hakan YÜCEDAĞ, Saygın DENİZ**
CITY / TOWN	**: Amasya / Taşova**
RIVER / MAIN BRANCH NAME	**: Yeşilırmak / -**

We have not encountered any problems related with the design of flushing system or settling basin from February 2013.

PROJECT NAME	**: BİRKAPILI SETTLING BASIN**
PROJECT COMPANY	**: ENERJİSA ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Harun TAŞ**
CITY / TOWN	**: Mersin / Mut**
RIVER / MAIN BRANCH NAME	**: Değirmen & Söğütözü**

Settling basin is insufficient to settle down the suspended particles in the diverted water within the basin. Due to the escaped sediment particles from settling basin, abrasion occurs which cause the runner of Pelton turbine to be changed once in every three years.

PROJECT NAME	**: Undisclosed**
PROJECT COMPANY	**: SANKO ENERGY CO.**
OWNER'S REPRESENTATIVE	**: Undisclosed**
CITY / TOWN	**: Sakarya**
RIVER / MAIN BRANCH NAME	**: Sakarya**

The biggest problem is about floating materials in the settling basin. We can't cope with these particles because of not settling down. Perhaps overflow weir could be designed to flow away those particles.

2) Does the flushing system of the settling basin work out efficiently? While flushing, was the deposited sediment cleaned away totally from the settling basin? Are you pleased with flushing system?

PROJECT NAME	**: ÇAMLICA SETTLING BASIN**
PROJECT COMPANY	**: AYEN ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Salih KARADAVUT**
CITY / TOWN	**: Kayseri / Yahyalı**
RIVER / MAIN BRANCH NAME	**: Seyhan /Zamantı**

Settling basin is cleaned properly and rapidly. After closing the entrance and exit gates, at each chamber, flushing is done efficiently in half an hour. Once we have just encountered a problem after the flushing that the deposited sediments blurred the downstream of the river. We were fined by "Environmental and Urbanization Ministry".

PROJECT NAME	**: YALNIZCA SETTLING BASIN**
PROJECT COMPANY	**: FİLYOS ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Taha TİRYAKİ, Saygın DENİZ**
CITY / TOWN	**: Karabük / Merkez**
RIVER / MAIN BRANCH NAME	**: Filyos / -**

Settling basin is cleaned properly and rapidly by just opening the flushing gates. Also there is no accumulation of the sediment within the settling basin according to our observations.

PROJECT NAME	**: KALE SETTLING BASIN**
PROJECT COMPANY	**: AVKAR ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Hakan YÜCEDAĞ, Saygın DENİZ**
CITY / TOWN	**: Amasya / Taşova**
RIVER / MAIN BRANCH NAME	**: Yeşilırmak / -**

Settling basin is cleaned properly and rapidly by just opening the flushing gates. Also there is no accumulation of the sediment within the settling basin according to our observations.

PROJECT NAME	**: BİRKAPILI SETTLING BASIN**
PROJECT COMPANY	**: ENERJİSA ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Harun TAŞ**
CITY / TOWN	**: Mersin / Mut**
RIVER / MAIN BRANCH NAME	**: Değirmen & Söğütözü**

Flushing system works properly just only the time when settling basin is emptied completely. In other words, if flushing gates were opened without waiting the basin to be emptied completely, only 3-4 m away deposited sediments from the flushing gates were washed away, not in the entrance of the basin especially as seen in Figure 5.9. So, 3-4 m far away from the gates, there was a cleaning problem related settled particles. In other words, flushing system could not be utilized for the entrance section of the settling basin.

PROJECT NAME	**: Undisclosed**
PROJECT COMPANY	**: SANKO ENERGY CO.**
OWNER'S REPRESENTATIVE	**: Undisclosed**
CITY / TOWN	**: Sakarya**
RIVER / MAIN BRANCH NAME	**: Sakarya**

Length of the settling basin is inadequate. In other words, settling basin's length isn't long enough to prevent sediment particles escaped from the basin and make them settled down within the basin.

3) **In which time period is settling basin needed to be cleaned, of course this depends on the characteristics of the river?**

PROJECT NAME	**: ÇAMLICA SETTLING BASIN**
PROJECT COMPANY	**: AYEN ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Salih KARADAVUT**
CITY / TOWN	**: Kayseri / Yahyalı**
RIVER / MAIN BRANCH NAME	**: Seyhan /Zamantı**

Flushing period is average 6 times in a year due to the amount of deposited sediment. Çamlıca settling basin has 3 chambers. At the same time, just one chamber was flushed away while the other two chambers were operating.

PROJECT NAME	**: YALNIZCA SETTLING BASIN**
PROJECT COMPANY	**: FİLYOS ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Taha TİRYAKİ, Saygın DENİZ**
CITY / TOWN	**: Karabük / Merkez**
RIVER / MAIN BRANCH NAME	**: Filyos / -**

Flushing gates are opened just once in a year for maintenance of the flushing system or for the gates. Since there is no need to flushing due to not existing deposited materials.

PROJECT NAME	**: BİRKAPILI SETTLING BASIN**
PROJECT COMPANY	**: ENERJİSA ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Harun TAŞ**
CITY / TOWN	**: Mersin / Mut**
RIVER / MAIN BRANCH NAME	**: Değirmen & Söğütözü**

As you mentioned it depends to the sediment intensity of the river; but generally time period is once a month.

PROJECT NAME	**: Undisclosed**
PROJECT COMPANY	**: SANKO ENERGY CO.**
OWNER'S REPRESENTATIVE	**: Undisclosed**
CITY / TOWN	**:Sakarya**
RIVER / MAIN BRANCH NAME	**: Sakarya**

Flushing period is about 3-6 months and there isn't any problems in flushing system. But the significant problem is related with the trash racks in the entrance of the settling basin. Because of the tree branches, leafs, wastes of the humans due to the seasonal effects, trash racks could not work efficiently. They were chocked up which reduced settling basin water capacity. Because of this reason, trash racks are cleaned in every 2 or 3 days which causes us a work load.

PROJECT NAME	**: KALE SETTLING BASIN**
PROJECT COMPANY	**: AVKAR ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Hakan YÜCEDAĞ, Saygın DENİZ**
CITY / TOWN	**: Amasya / Taşova**
RIVER / MAIN BRANCH NAME	**: Yeşilırmak / -**

Flushing gates are opened all the time during the all days in operation period. Reason for this, there is a very big problem related deposited sediment in the settling basin of a upstream project of KALE Weir. In this upstream settling basin, 2 chambers of it were filled fully with deposited sediment. According to the such information, river is thought to be very alluvial. Also environmental water for continuation of living species is released from the flushing gate.

4) **Settling basins are designed according to permissible diameter size of sediment. So could you please give some information about the size of settled particles within the settling basin?**

PROJECT NAME	**: ÇAMLICA SETTLING BASIN**
PROJECT COMPANY	**: AYEN ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Salih KARADAVUT**
CITY / TOWN	**: Kayseri / Yahyalı**
RIVER / MAIN BRANCH NAME	**: Seyhan /Zamantı**

Deposited sediments' size are very fine such as mud.

PROJECT NAME	**: YALNIZCA SETTLING BASIN**
PROJECT COMPANY	**: FİLYOS ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Taha TİRYAKİ, Saygın DENİZ**
CITY / TOWN	**: Karabük / Merkez**
RIVER / MAIN BRANCH NAME	**: Filyos / -**

After flushing away at once a year, a little amount of deposited sediments such as mud is observed and also their diameters are smaller than 1 mm. To his opinion, this amount of sediment was deposited during operation because of high velocity in flow and big sizes in settling basin.

PROJECT NAME	**: KALE SETTLING BASIN**
PROJECT COMPANY	**: AVKAR ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Hakan YÜCEDAĞ, Saygın DENİZ**
CITY / TOWN	**: Amasya / Taşova**
RIVER / MAIN BRANCH NAME	**: Yeşilırmak / -**

Deposited sediments' size are very fine such as mud of which diameters are smaller than 1 mm.

PROJECT NAME	**: BİRKAPILI SETTLING BASIN**
PROJECT COMPANY	**: ENERJİSA ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Harun TAŞ**
CITY / TOWN	**: Mersin / Mut**
RIVER / MAIN BRANCH NAME	**: Değirmen & Söğütözü**
Especially diameters are smaller than 1 mm according to petrographical analysis.	

PROJECT NAME	**: Undisclosed**
PROJECT COMPANY	**: SANKO ENERGY CO.**
OWNER'S REPRESENTATIVE	**: Undisclosed**
CITY / TOWN	**: Sakarya**
RIVER / MAIN BRANCH NAME	**: Sakarya**
Settled down materials are very fine, approximately smaller than 1 mm.	

5) **Does the sluice way work properly? If not, what kind of problems related sluice way occur?**

PROJECT NAME	**: ÇAMLICA SETTLING BASIN**
PROJECT COMPANY	**: AYEN ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Salih KARADAVUT**
CITY / TOWN	**: Kayseri / Yahyalı**
RIVER / MAIN BRANCH NAME	**: Seyhan /Zamantı**
Sluice way works properly without any problems in this project.	

PROJECT NAME	**: YALNIZCA SETTLING BASIN**
PROJECT COMPANY	**: FİLYOS ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Taha TİRYAKİ, Saygın DENİZ**
CITY / TOWN	**: Karabük / Merkez**
RIVER / MAIN BRANCH NAME	**: Filyos / -**
Sluice way does not exists in this project. Spillway works as a sluice gate because of having low crest elevation. Deposited materials behind the spillway could easily flushed away from the spillway.	

PROJECT NAME	**: KALE SETTLING BASIN**
PROJECT COMPANY	**: AVKAR ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Hakan YÜCEDAĞ, Saygın DENİZ**
CITY / TOWN	**: Amasya / Taşova**
RIVER / MAIN BRANCH NAME	**: Yeşilırmak / -**
Sluice way does not exist in this project. Spillway works as a sluice gate because of having low crest elevation. Thanks to the wide spillway with 5 spans, there is no problem related deposited materials. Deposited materials behind the spillway could easily flushed away from the spillway.	

PROJECT NAME	**: BİRKAPILI SETTLING BASIN**
PROJECT COMPANY	**: ENERJİSA ENERGY INC.**
OWNER'S REPRESENTATIVE	**: Harun TAŞ**
CITY / TOWN	**: Mersin / Mut**
RIVER / MAIN BRANCH NAME	**: Değirmen & Söğütözü**
There is no important problem in sluice way beside the problem related flushing system.	

PROJECT NAME	**: Undisclosed**
PROJECT COMPANY	**: SANKO ENERGY CO.**
OWNER'S REPRESENTATIVE	**: Undisclosed**
CITY / TOWN	**: Sakarya**
RIVER / MAIN BRANCH NAME	**: Sakarya**
In general, sluice gates could not secure exact impermeability because of the settlement of accumulated materials just before the gates of sluice gates.	

5.3. PHOTOGRAPHS OF SOME OF THE SETTLING BASINS IN PRACTICE

5.3.1. Çamlıca Settling Basin

Referring Section 5.2; flushing period of Çamlıca settling basin is generally 6 times per year and during flushing of one chamber, the other two chambers operate as shown in Figure 5.1 which shows a view of upstream of the basin. As it is clearly seen in Figure 5.1, the one chamber of the settling basin is washed away and becomes clean without sediment particles. In Figure 5.2 ,the basement of the basin is very muddy with full of fine sediment particles. After a while flushing procedure starts towards downstream of the settling basin, then settled particles are carried to the river bed by flushing channel as shown in Figure 5.3.

Figure 5.1 Flushing of one chamber of Çamlıca settling basin

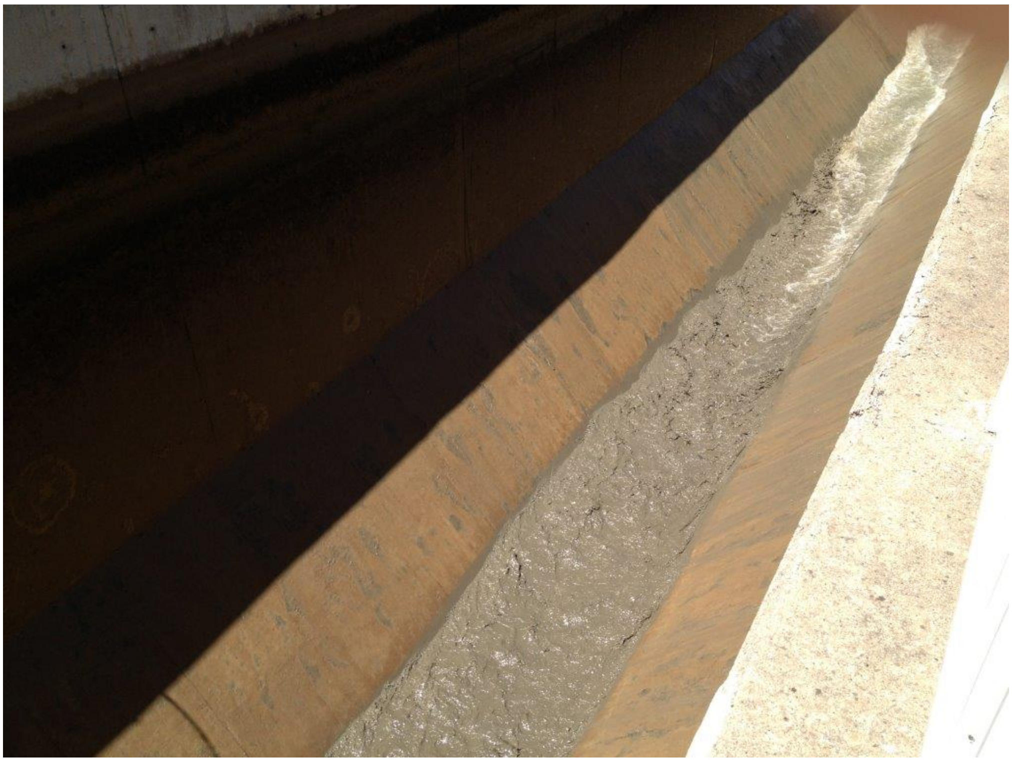


Figure 5.2 Before the flushing of Çamlıca settling basin

Figure 5.3 Çamlıca settling basin during flushing

5.3.2. Kale Settling Basin

In Figure 5.4 Kale settling basin is seen with its 3 chambers during the flushing. As stated in Section 5.2, an efficient flushing seems to be occurred. The close view of the basement of the settling basin is shown in Figure 5.5. Settling basin's basement seems very clear due to the succesfull operation of the flushing system. The flushing channel is connected to the river bed downstream of the weir as seen in Figure 5.6. As a result in this settling basin the flushing system utilizes properly and rapidly as mentioned.

Figure 5.4 Kale settling basin

Figure 5.5 The basement of Kale settling basin

Figure 5.6 Flushing channel

5.3.3. Birkapılı Settling Basin

In Figure 5.7, a photograph of Birkapılı settling basin is shown during its flushing time. The flushing procedure of Birkapılı settling basin starts with draining away one of the chamber of its as seen in Figure 5.7. After washing away the first chamber, the second chamber is washed away while the other chamber continues to operate as seen in Figure 5.8. After flushing, it is clearly seen that there is a cleaning problem in the flushing system because the entrance of the basin is full of the sediment particles, especially coarser particles as seen in Figure 5.9. When Figure 5.9 is looked carefully, water is blurred and slimy because of settled particles and the gates at the entrance of the settling basin and the bottom of the side walls are muddy. Consequently the flushing system isn't utilized properly in Birkapılı settling basin.

Figure 5.7 Flushing of the left chamber of Birkapılı settling basin

Figure 5.8 Flushing of the right chamber of Birkapılı settling basin

Figure 5.9 The entrance of Birkapılı settling basin after flushing

CHAPTER 6

EXPERIMENTAL STUDY

Model studies permit visual observation of the flow and make it possible to obtain certain numerical data such as optimum dimensions of hydraulic structures before construction. Also thanks to model studies, costly mistakes in practice can be avoided.

To obtain some quantitative data related to the optimum length of a settling basin a series of experiments were conducted at the laboratory with two types of sediment having various grain sizes. In this chapter, detailed information regarding the experimental setup and procedure is presented.

6.1. DIMENSIONAL ANALYSIS

In the scope of this thesis, dimensional analysis was applied to the problem of settling of sediments in a settling basin referring to Figure 6.1 as a definition sketch. Assuming that a sediment particle of known diameter, d_s, and density, ρ_s, is being carried by the flow along the approach channel of the settling basin of which the depth is Δz, one can write the following equation for the settling distance of the particle, l_s, within the settling basin.

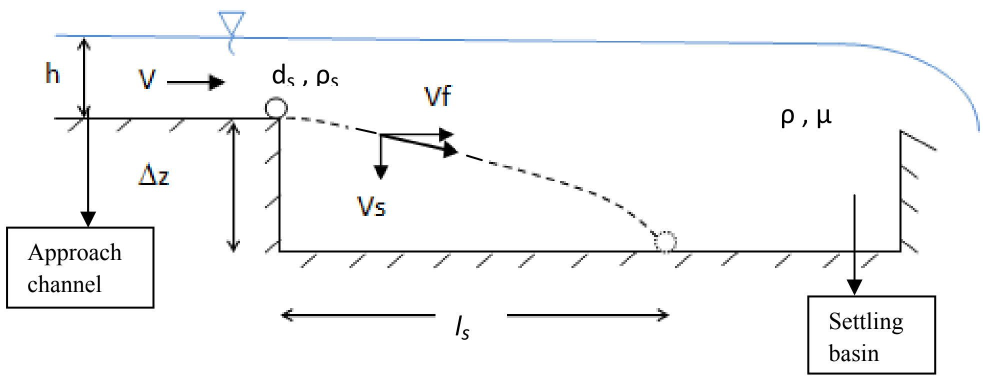


Figure 6.1 Definition Sketch

$$l_s = f\left(V, \rho, \mu, d_S, \rho_s, g, h, \Delta z\right) \tag{6.1}$$

In this formula, l_s, is the *dependent term* and the other terms in the parenthesis are *independent terms* where V and h are approach flow velocity and depth, respectively, ρ and μ are density and dynamic viscosity of water, respectively.

By selecting V, ρ and d_s as the repeating parameters and applying the *"Buckingham's π Theorem"*, Equation 6.1 can be written into dimensionless terms as stated in Equation 6.2.

$$\frac{l_s}{d_S} = f\left(\frac{\rho_s}{\rho}, \frac{g \times d_S}{V^2}, \frac{\mu}{\rho \times V \times d_S}, \frac{h}{d_S}, \frac{\Delta z}{d_S}\right) \tag{6.2}$$

The meanings of the dimensionless parameters given in Equation 6.2 are as follow:

- $\frac{l_s}{d_s}$ is the relative settling distance of the sediment with respect to the sediment diameter, d_s.
- $\frac{\rho_s}{\rho}$ is the relative density of the sediment with respect to the density of water.
- $\frac{g \times d_s}{V^2} = \frac{1}{Fr^2}$ is the inverse of the Froude number, Fr , based on approach flow velocity, V, and sediment diameter, d_s.
- $\frac{\mu}{\rho \times V \times d_s} = \frac{1}{\mathrm{Re}}$ is the inverse of the Reynolds number, Re , based on approach flow velocity and sediment diameter.
- $\frac{h}{d_s}$ is the relative approach flow depth with respect to the sediment diameter.
- $\frac{\Delta z}{d_s}$ is the relative settling basin depth with respect to the sediment diameter.

In open channel flows the Froude number is more dominant than the Reynolds number. Therefore the Reynolds number can be removed from Equation 6.2. In addition to this, combining the second dimesionless parameter, ρ_s/ρ, with the Froude number one can form a new Froude number named as "densimetric Froude number" as;

$$\left(Fr\right)_s = \frac{V}{\sqrt{\frac{\Delta\rho}{\rho} \times g \times d_s}} \tag{6.3}$$

where $\Delta\rho = \rho_s - \rho$.

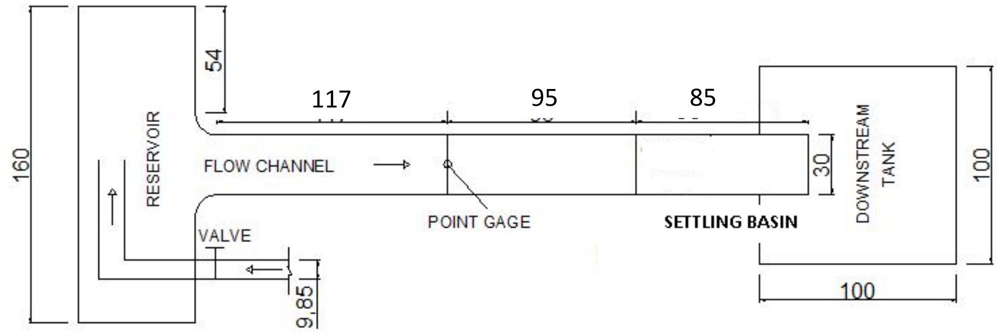
Hence, Equation 6.4 can be stated as;

$$\frac{l_s}{d_s} = f\left[\left(Fr\right)_s, \frac{h}{d_s}, \frac{\Delta z}{d_s}\right] \tag{6.4}$$

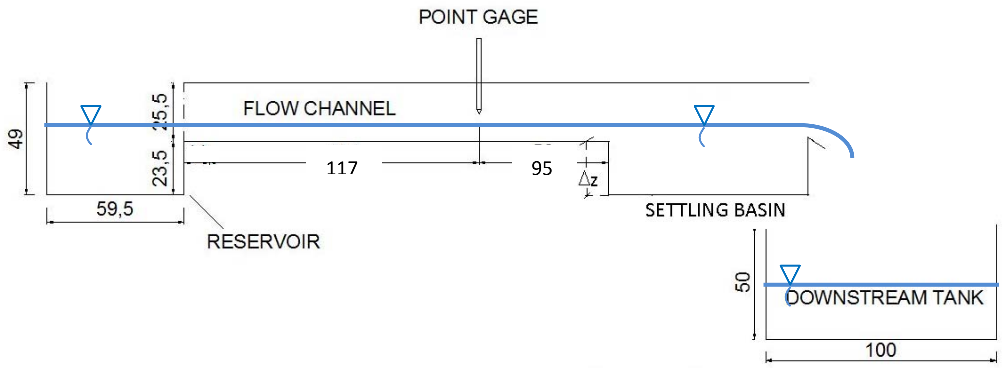
Based on the above relationship, from the measured and calculated experimental data the dimensionless parameters given in Equation 6.4 were determined and tabulated in Appendix A. The variation of l_s/d_s with those terms in Equation 6.4 were graphically presented in the following sections.

6.2. EXPERIMENTAL SETUP

A settling basin model was constructed at the hydromechanics laboratory to investigate the minimum lengths of settling basins with 3 selected heights of sills (Figures 6.2-6.5). The model of settling basin consists of a reservoir at the upstream, an open channel 0.30 m wide and 3 m long, a point gauge for measurement of the water surface elevation in the open channel and a tank at the downstream which is 1 m in length, 1 m in width and 0.50 m in depth. Water is taken from the upstream reservoir by an open channel in 30 cm width and the discharge was controlled with a manuel valve.



(a) Plan view



(b) Longitudinal profile

Figure 6.2 Plan view and longitudinal profile of the experimental setup (all dimensions are in cm)

The settling basin 85 cm in length and 30 cm in width was made of plexi-glass and supported by a steel framework. In addition, a drainage pipe with a manuel valve, to empty the settling basin, was connected to the bottom of the basin. This pipe is also connected to the downstream tank. The discharged water from the settling basin and the drainage pipe is transported to the main water storage below the hydromechanics laboratory. Water in the main water storage is pumped by another pump to the elevated constant-head water tank from which water is supplied to the upstream reservoir of the model.

Figure 6.3 General view of the experimental setup

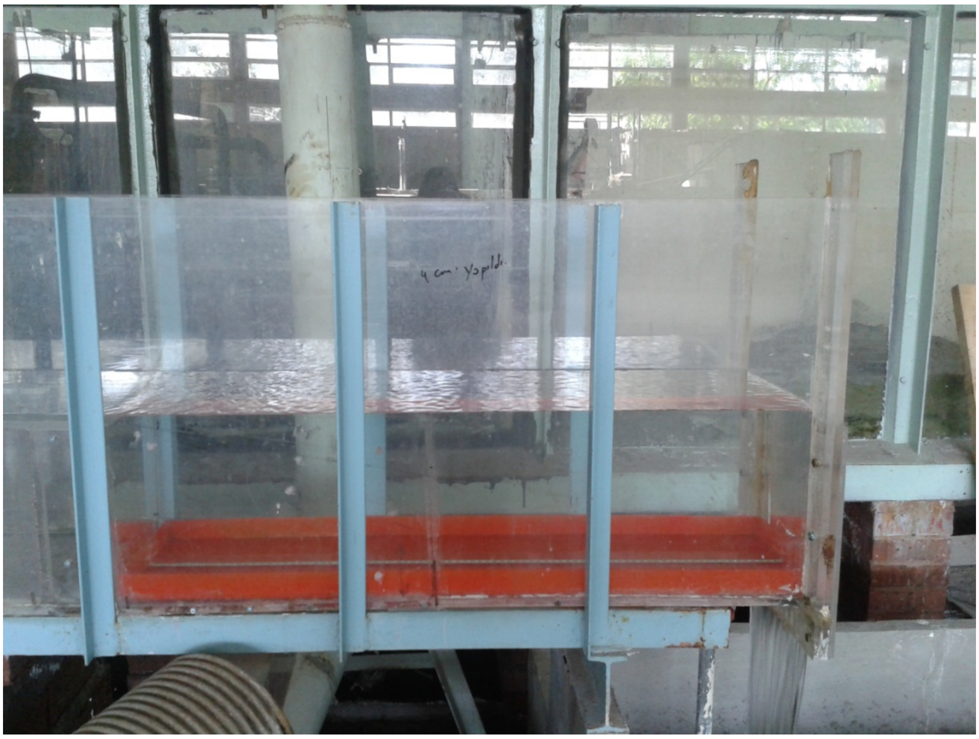


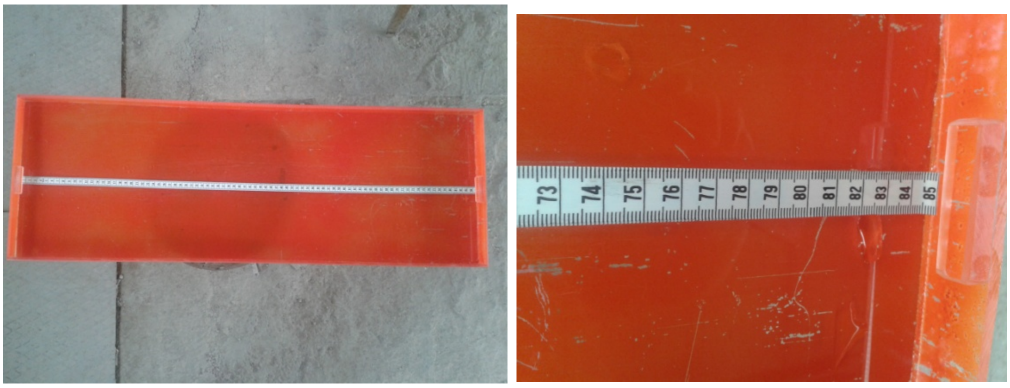
Figure 6.4 Side view of the settling basin

Figure 6.5 Cross sectional view of the settling basin

To check the effect of settling basin sill height on the performance of the settling basin, the bottom of the original settling basin was raised twice by using the portable plexiglass supports having different heights (Figure 6.6). Hence it was possible to investigate the performance of the settling basins having depths of Δz=23 cm, 18 cm, 13 cm.

Figure 6.6 Portable plexiglass supports for the settling basin

In all experiments a portable pan covering the whole bottom area of the settling basin was used with a ruler glued along the centerline of it to measure the distances travelled by sediment particles (Figure 6.7).



(a) (b)

Figure 6.7 Portable pan for the settling basin a) top view b) close view

Quartz and silisium obtained from a firm located in İzmir, at various size ranges were used in the experiment as the sediment. Sediment types used in the experiments and their size ranges are presented in Table 6.1. Sediments in the first five groups in Table 6.1 were provided by applying sieve analysis at the laboratory to the sediment received in the size range of 1.00~3.00 mm. Figures 6.8-6.9 show the photographs of the sediment groups tested in the experiments. Densities of quartz and silisium are 2.65 gr/cm^3 and 2.33 gr/cm^3, respectively.

Table 6.1 Sediment types tested and their size ranges

Sediment Type	Diameter (mm)
	3.00~2.00
	2.00~1.68
	1.68~1.41
Quartz & Silisium	1.41~1.19
	1.19~1.00
	0.50~1.00
	0~0.40

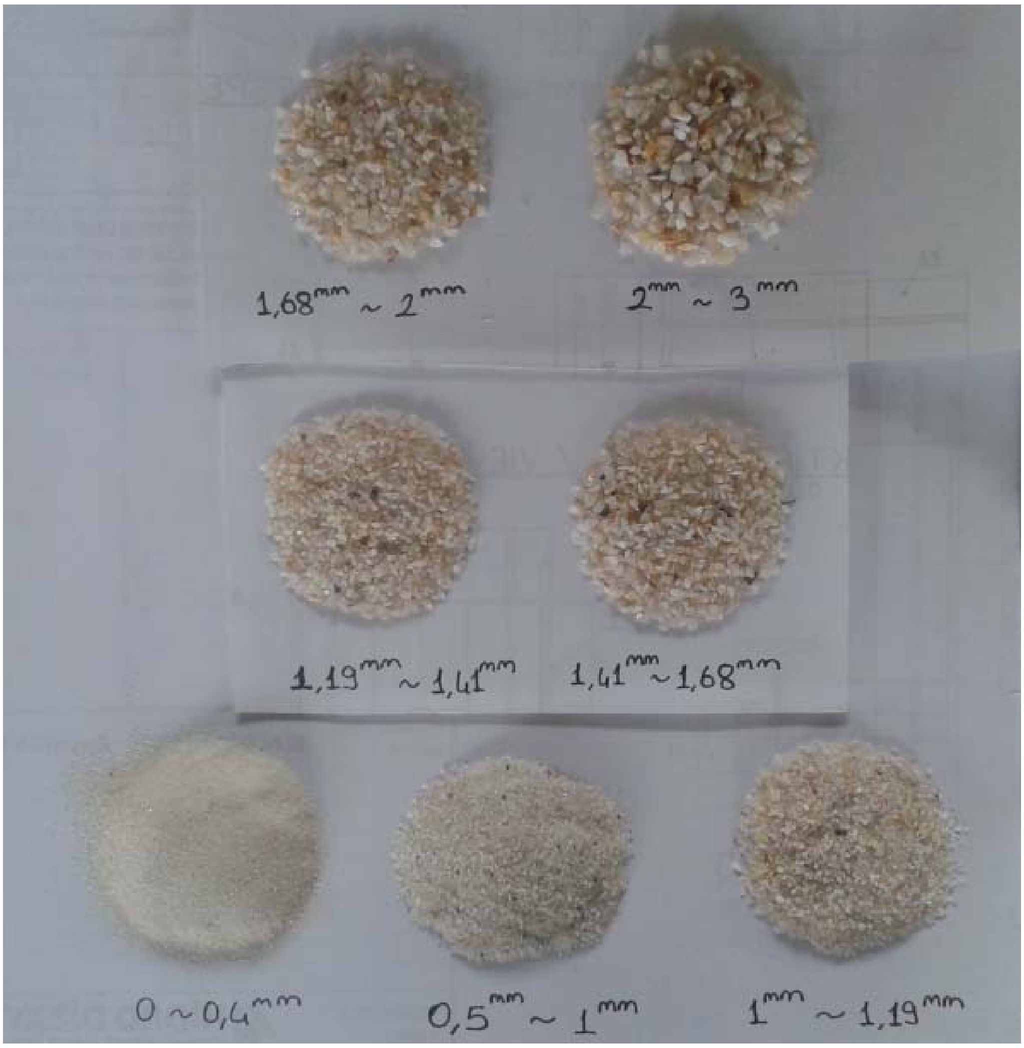


Figure 6.8 Sediments tested (quartz) with their size ranges

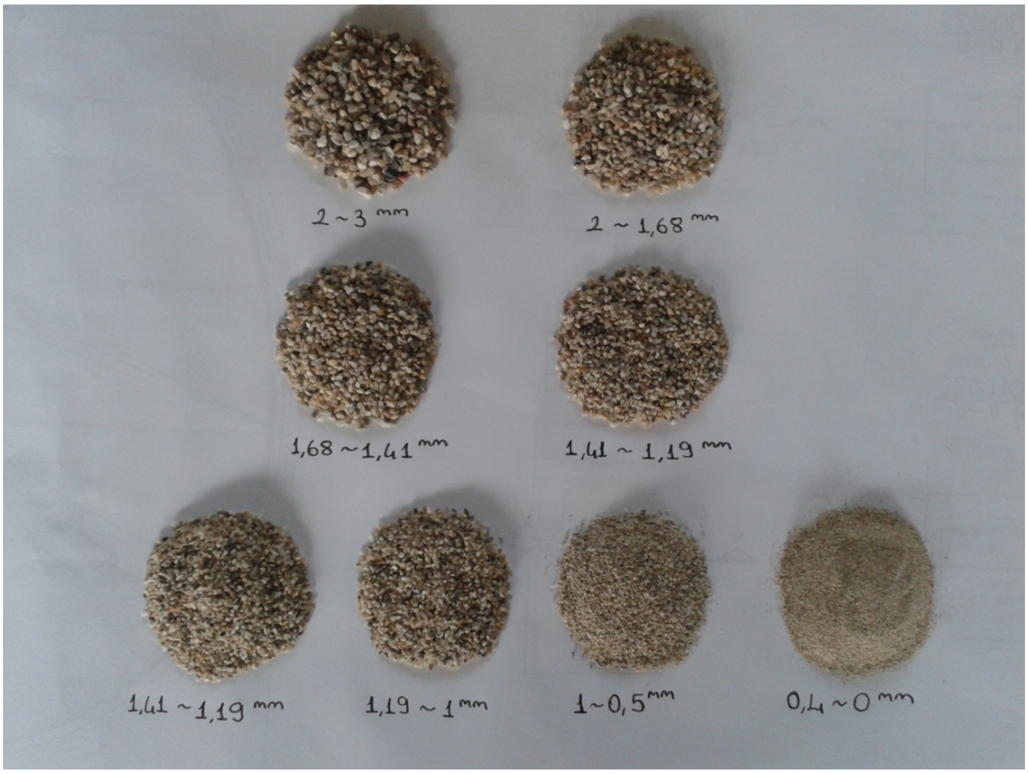


Figure 6.9 Sediments tested (silisium) with their size ranges

6.3. EXPERIMENTAL PROCEDURE

6.3.1. Discharge Measurements in the Settling Basin

At first a series of experiments were performed to find the discharge calibration curve of the settling basin with respect to the flow depth in the channel. In the first step, a low level of water was given to the system from the water intake pipe by opening the manual valve. After waiting for about approximately 10 minutes to get the flow stabilized in the channel, the flow depth at the depth measurement section was recorded by a point gage. The discharge of the flow was measured volumetrically by collecting the incoming water into the downstream tank during a certain time period.

After that, the discharge was increased gradually with the manual valve and the other measurements were taken for a wide range of discharges with the same procedure mentioned above. The measured discharges, Q, and the corresponding flow depths, h, were presented in Table 6.2. Afterwards, the polynomial curve given by Equation 6.5 was driven with a correlation coefficient of R^2=0.996 (Figure 6.10).

$$Q=0.182h^2+0.448h-0.371 \tag{6.5}$$

which is valid for 1.0 cm ≤ h ≤ 7.3 cm.

Table 6.2 Measured Q and h values used in forming the discharge rating curve of the experimental setup

Test No	**Flow Height (h)**	**Discharge in the Settling Basin (Q)**
	cm	**lt/s**
1	1.0	0.28
2	1.3	0.41
3	1.5	0.73
4	1.9	1.13
5	2.6	2.00
6	3.3	3.03
7	3.8	4.09
8	4.1	4.69
9	4.6	5.89
10	5.0	6.48
11	5.5	7.35
12	6.0	8.56
13	6.3	9.63
14	6.8	10.65
15	7.3	13.17

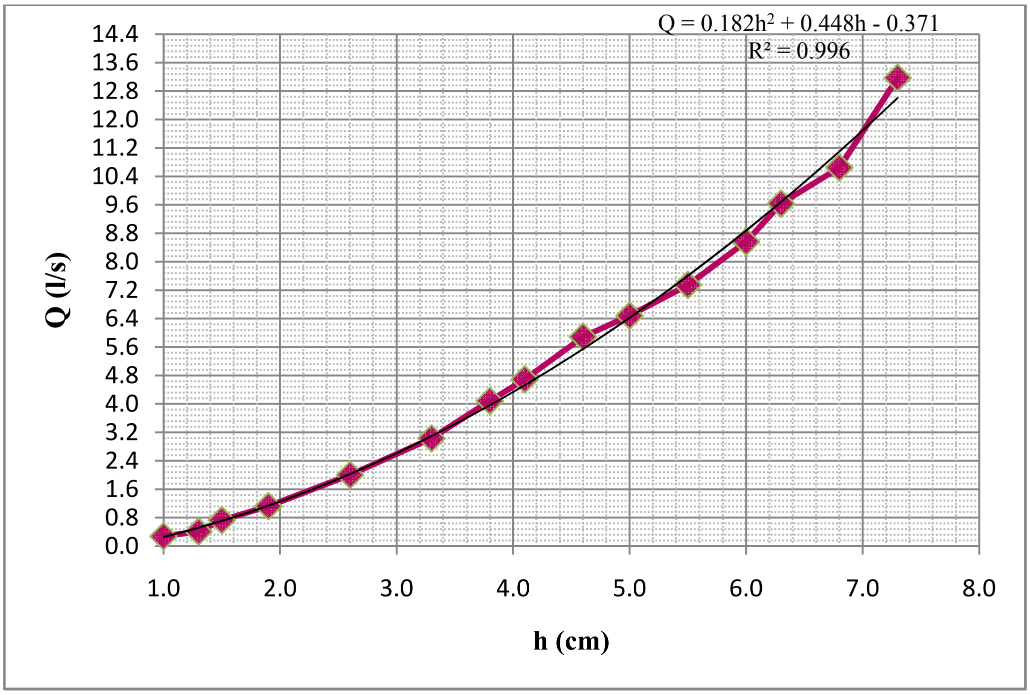


Figure 6.10 Discharge rating curve for the settling basin

Flow velocity, V, and the corresponding Froude number, $Fr = V / \sqrt{g \times h}$, of the flow in the approach channel upstream of the settling basin for these measured h and Q values (Table 6.1) were calculated and presented in Table 6.3. As it is seen from this table, the flow approaching to the settling basin is always subcritical, Fr<1.

Table 6.3 Hydraulic parameters of the flow in the approach channel

Test No	h	Q	V	Fr
	(cm)	lt/s	m/s	
1	1.0	0.28	0.09	0.30
2	1.3	0.41	0.11	0.30
3	1.5	0.73	0.16	0.42
4	1.9	1.12	0.20	0.46
5	2.6	2.00	0.26	0.51
6	3.3	3.03	0.31	0.54
7	3.8	4.09	0.36	0.59
8	4.1	4.69	0.38	0.60
9	4.6	5.89	0.43	0.64
10	5.0	6.48	0.43	0.62
11	5.5	7.35	0.45	0.61
12	6.0	8.56	0.48	0.62
13	6.3	9.63	0.51	0.65
14	6.8	10.65	0.52	0.64
15	7.3	13.17	0.60	0.71

6.3.2. Measurements of Particle Settling Distances

The experimental procedure is as summarized below:

The experiments were started with adjusting the minimum discharge of the model. After setting the stabilized flow depth at the depth measurement section corresponding to the minimum selected discharge, the desired sediment group of 50~60 gr was almost uniformly poured to the bottom of the channel about 20 cm upstream of the entrance of the settling basin (Figure 6.11). These sediment particles were swept down towards the settling basin by the flow. When the particles were coarse and the flow discharge was minimum, some of the particles placed on the channel bottom did not move. Then the maximum distance travelled by one of the particles within the pan placed on the bottom of the settling basin was measured and recorded. The same experiment was repeated one more time with the same group of the same sediment under the same flow conditions and the maximum settling length of the sediment was determined. This procedure was applied to all of the sediment groups for 15 different discharges for the settling basins of 3 different depths. Some of the photographs taken during the experiments of various sediment groups are shown in Figures 6.11-6.22. The data of all these experiments were presented in Appendix A in Tables A1-A16.

Figure 6.11 Quartz in 2~3 mm diameter

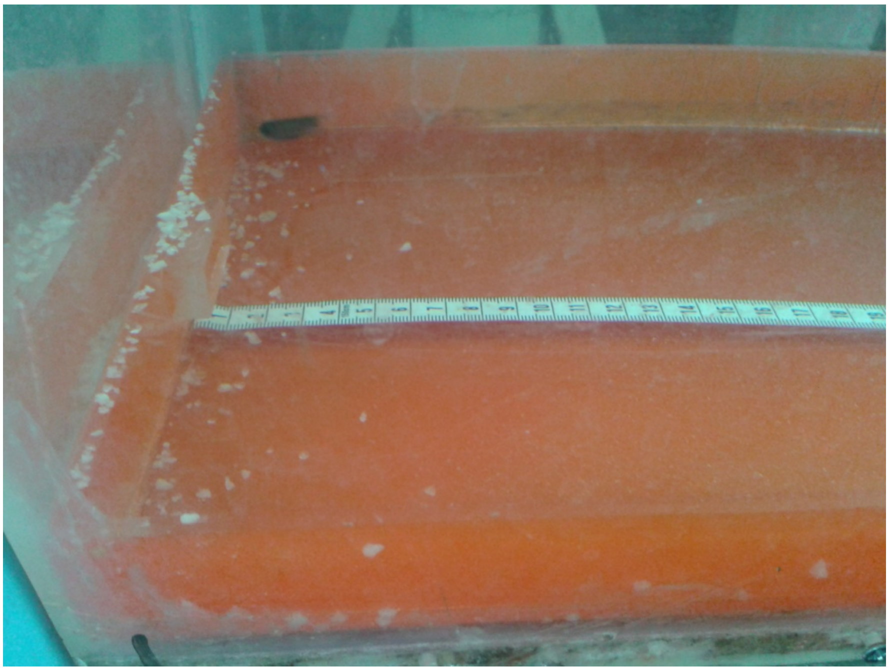


Figure 6.12 Settled quartz in 2~3 mm diameter

Figure 6.13 Quartz in 0.5~1 mm diameter

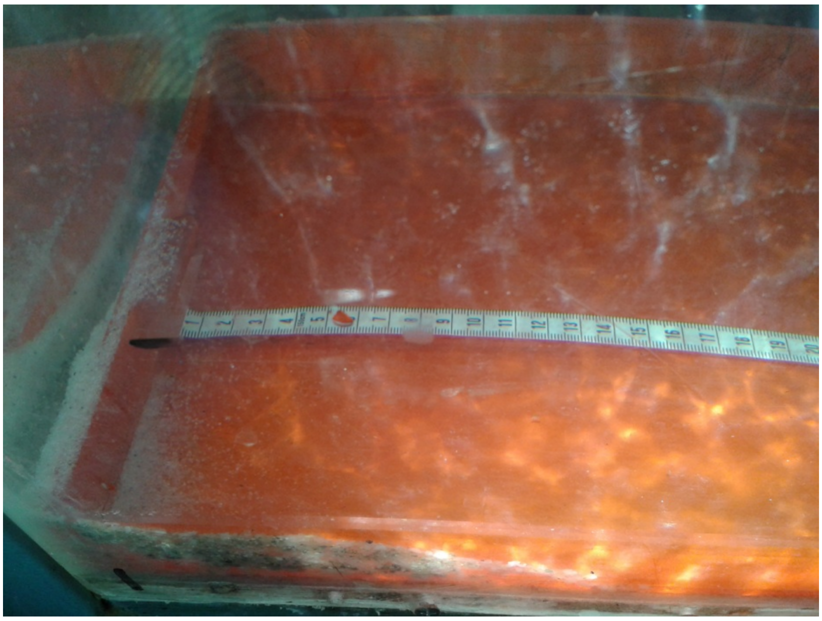


Figure 6.14 Settled quartz in 0.5~1 mm diameter

Figure 6.15 Quartz in 0~0.4 mm diameter

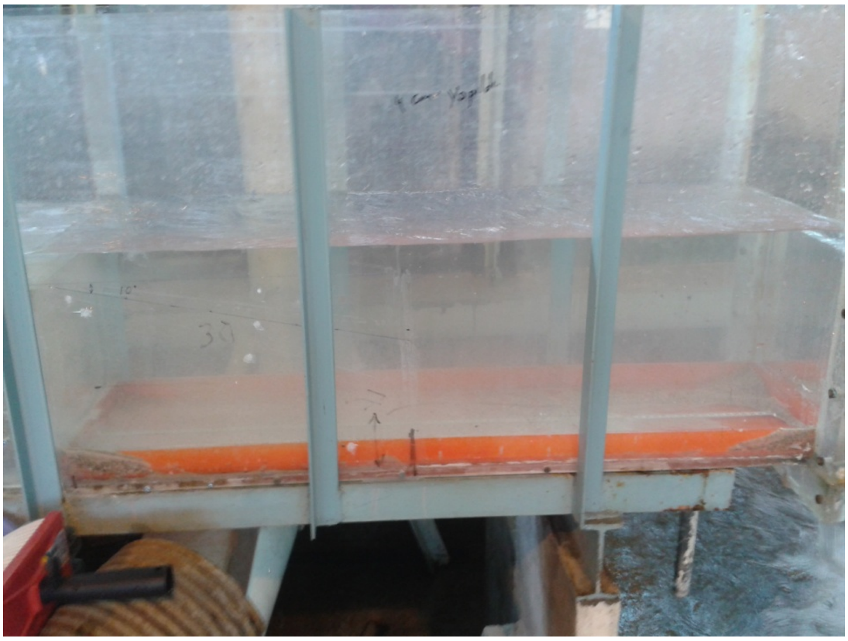


Figure 6.16 Settled quartz in 0~0.4 mm diameter

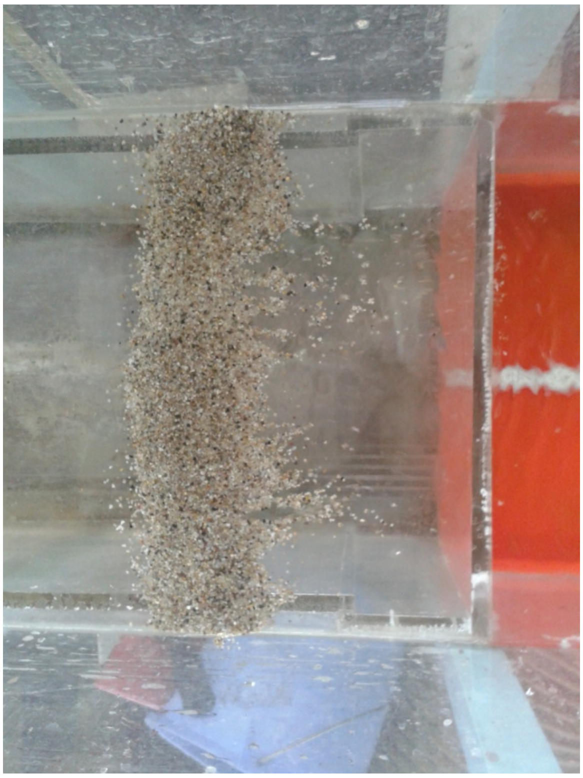


Figure 6.17 Silisium in 2~3 mm diameter

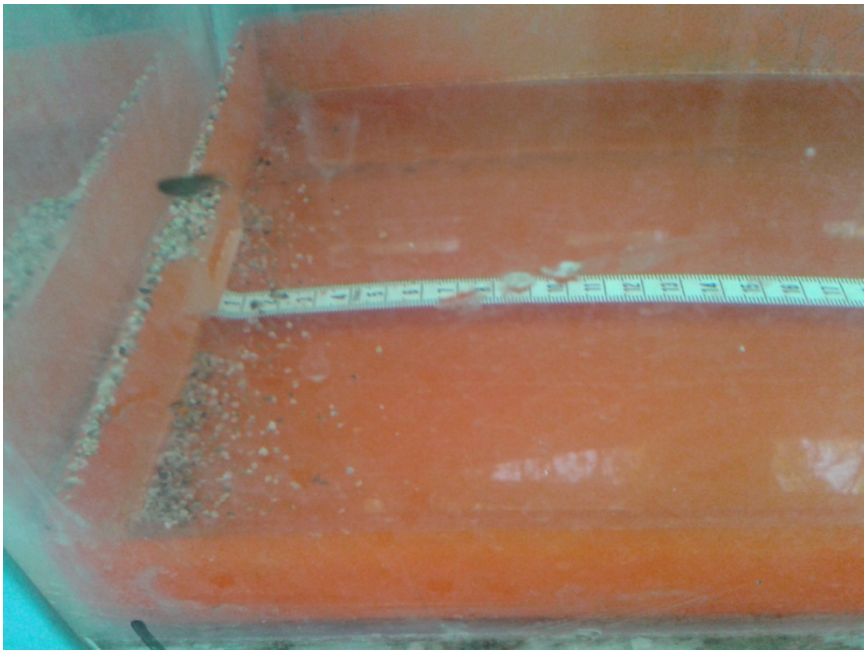


Figure 6.18 Settled silisum in 2~3 mm diameter

Figure 6.19 Silisium in 0.5~1 mm diameter

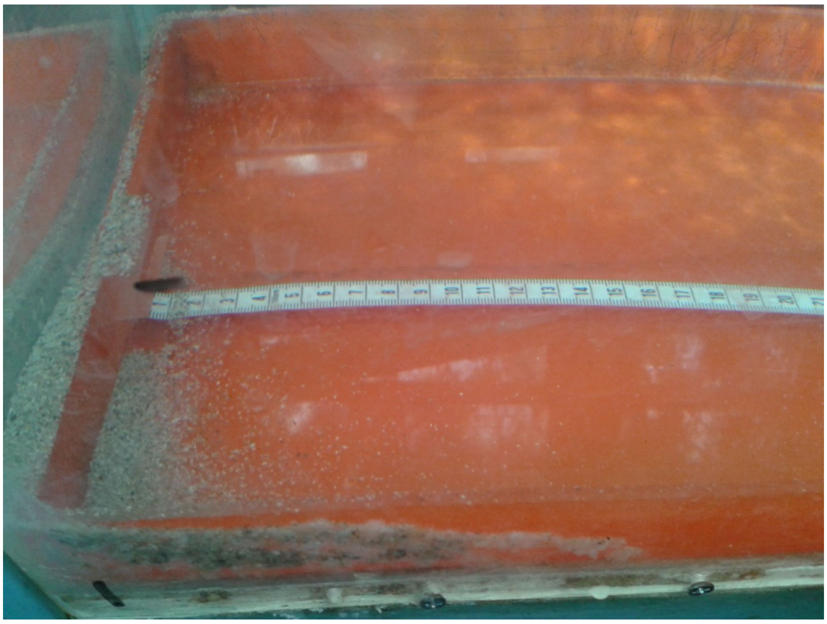


Figure 6.20 Settled silisium in 0.5~1 mm diameter

Figure 6.21 Silisium in 0~0.4 mm diameter

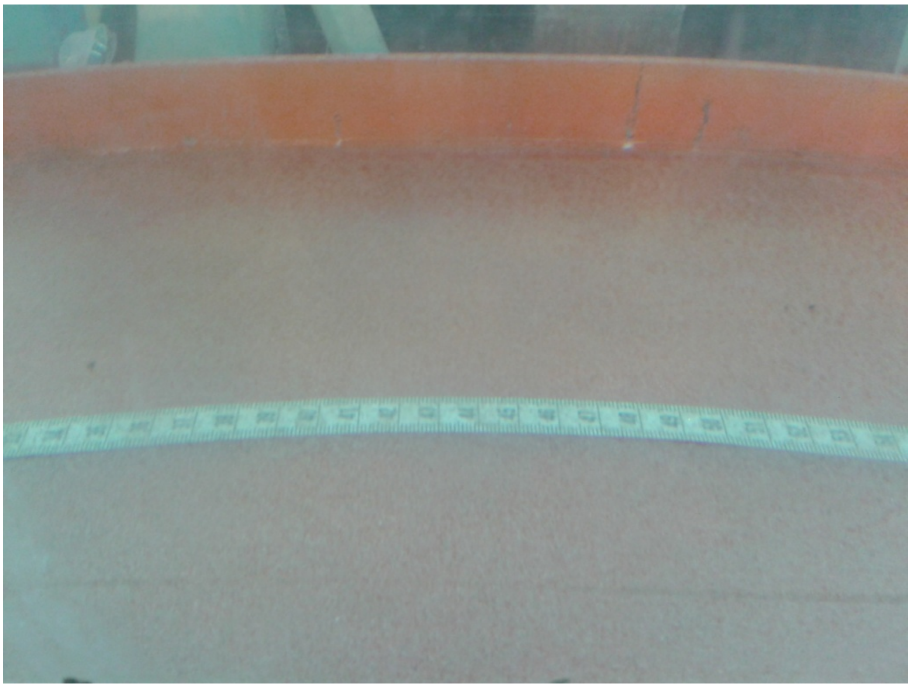


Figure 6.22 Settled silisium in 0~0.4 mm diameter

6.4. ANALYSIS AND DISCUSSION OF THE EXPERIMENTAL RESULTS

6.4.1. Observations

During experiments the following observations were made within the settling basins of depths Δz=23 cm, 18 cm and 13 cm. As it is seen in Tables A1-A2, in the settling basin of Δz=23 cm, all of the particles tested were trapped within the settling basin. As the flow discharge increased and the sediment size was reduced, the settling distances of the particles increased and finally reached the total length of the settling basin. But they could not pass over the downstream sill of the settling basin. Even some of them attempted to escape from the settling basin, by the effect of the reverse flow at just upstream of the end sill they turned back and remain settled in the basin. In these cases the maximum settling distances of the particles were assumed to be equal to the total length of the settling basin.

Similar observations were made for the second type of settling basin of Δz=18 cm (Tables A3-A4). The situation was a little bit different for the last settling basin of Δz=13 cm, in which the depth of the basin was not high enough to hold all of the especially fine particles. At high flow rates some of the fine particles escaped from the settling basin. Only for these particles it can be stated that the available length of the settling basin was not enough to hold them within the basin (Tables A5-A6).

After completing the experiments of sediment groups of quartz with three different settling basin depths, in the second part of the study, the above mentioned experiments were repeated with the sediment groups of silisium, for 15 different discharges.

6.4.2. Variation of Dimensionless Settling Length with Related Parameters

Based on the theoretical derivation of the particle settling length discussed in Section 6.1, the experimental data presented in Tables A1-A6 in Appendix A were analyzed and Tables A7-A12 were prepared. From two measurements conducted for a given sediment group and flow conditions at two times particle settling lengths had been determined. Among them the larger one was selected as the minimum required settling length for the tested sediment group. Using this value as the l_s value of the given sediment group, some other measured and calculated dimensional and dimensionless parameters were determined and presented in Tables A7-A12 in Appendix A. Referring these tables the variation of the dimensionless settling length, l_s/d_s , with those dimensionless parameters given in Equation 6.4 were investigated and presented in the following sections.

6.4.2.1. Variation of l_s /d_s with $(Fr)_s$

Figures 6.23-6.25 and Figures 6.26-6.28 show the variation of l_s/d_s with $(Fr)_s$ for quartz and silisium, respectively, for the settling basins of Δz=23 cm, 18 cm and 13 cm. All of these figures reveal that as the sediment diameter gets smaller, the maximum l_s values measured increase, and for a given sediment diameter l_s/d_s increases as $(Fr)_s$ increases. For the finest sediment group of d_s=0.2 mm, if $(Fr)_s$ gets greater than about 4.51, most of the sediment particles in the group reach to the exit sections of the settling basins. However all of them remain trapped within the settling basins of Δz=23 cm as it was discussed in the "6.4.1 Observations" section. When the sediment diameter gets larger, the limit value of $(Fr)_s$ after which l_s/d_s becomes constant gets smaller. These limit values of $(Fr)_s$ for the sediment groups of d_s=0.75 mm and 1.10 mm are 3.25 and 3.56 regardless of the sediment type and settling basin depth. Since the densities of quartz and silisium are close to each other, the related figures of these sediments show almost the same trends with very close numerical values. The required minimum l_s/d_s values can be provided from Figures 6.23-6.28 as a function of sediment type and settling basin depth, Δz, for a given value of $(Fr)_s$.

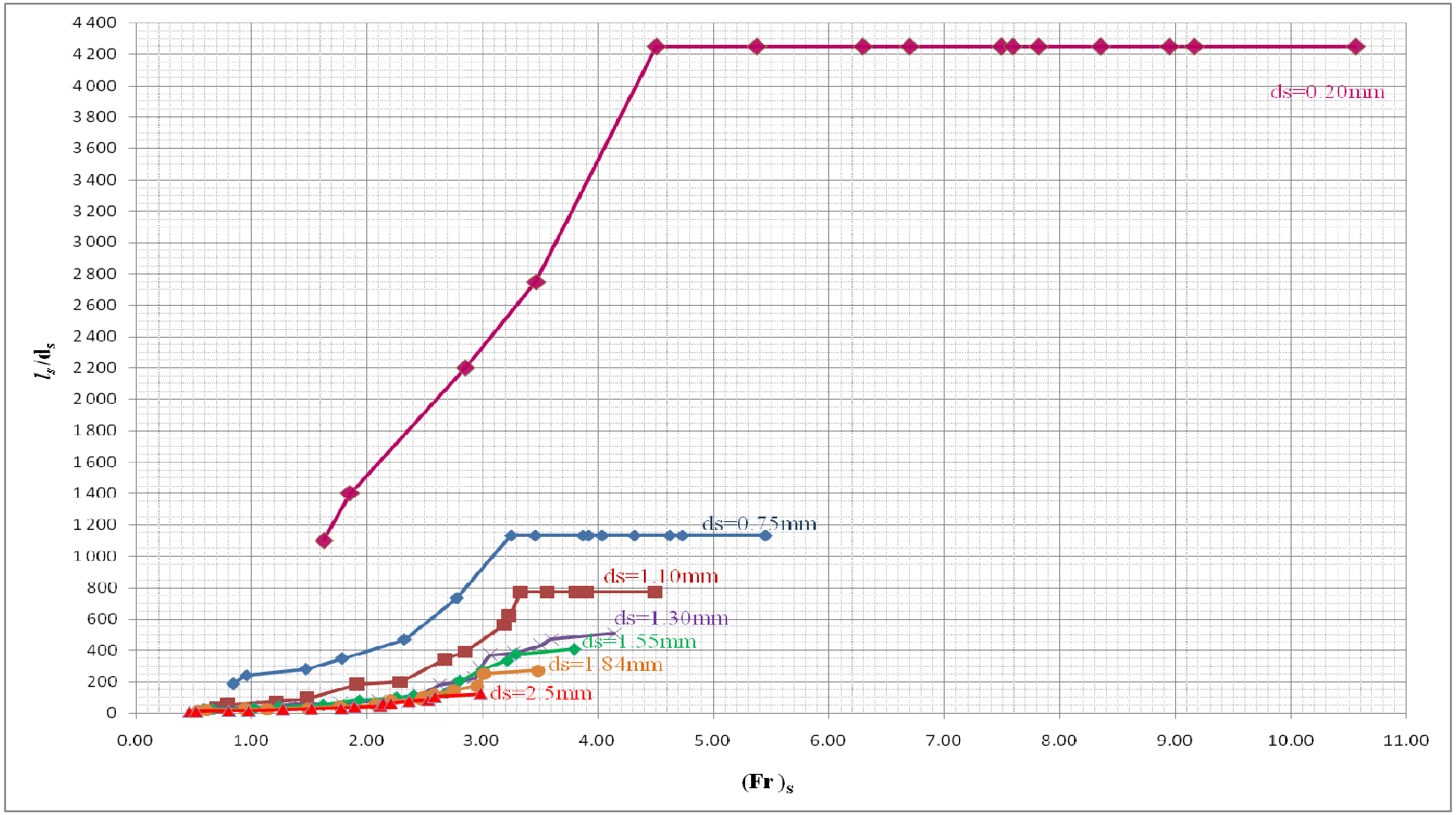


Figure 6.23 Variation of l_s/d_s with $(Fr)_s$ for quartz for the settling basin of Δz=23 cm

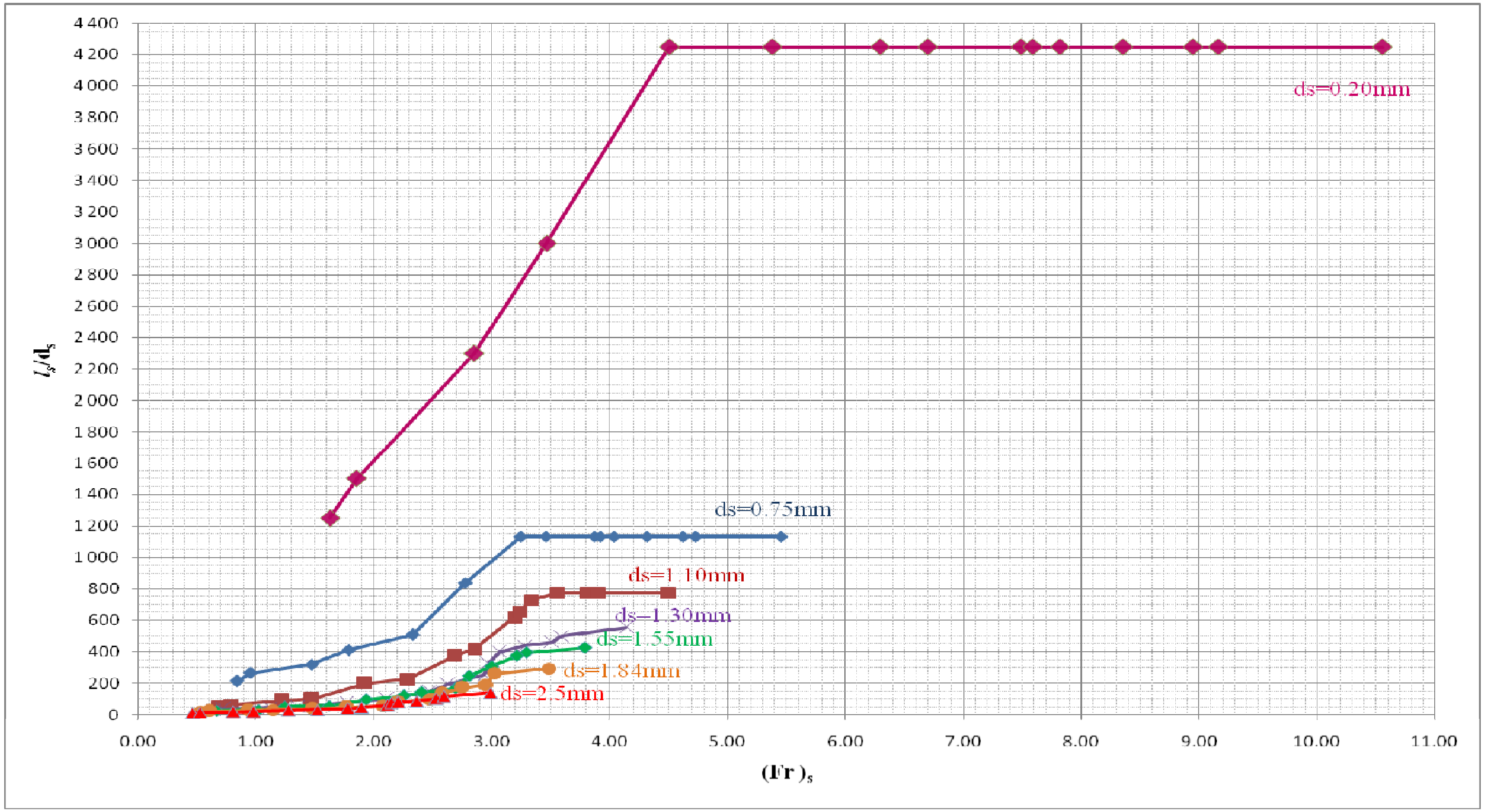


Figure 6.24 Variation of l_s/d_s with $(Fr)_s$ for quartz for the settling basin of Δz=18 cm

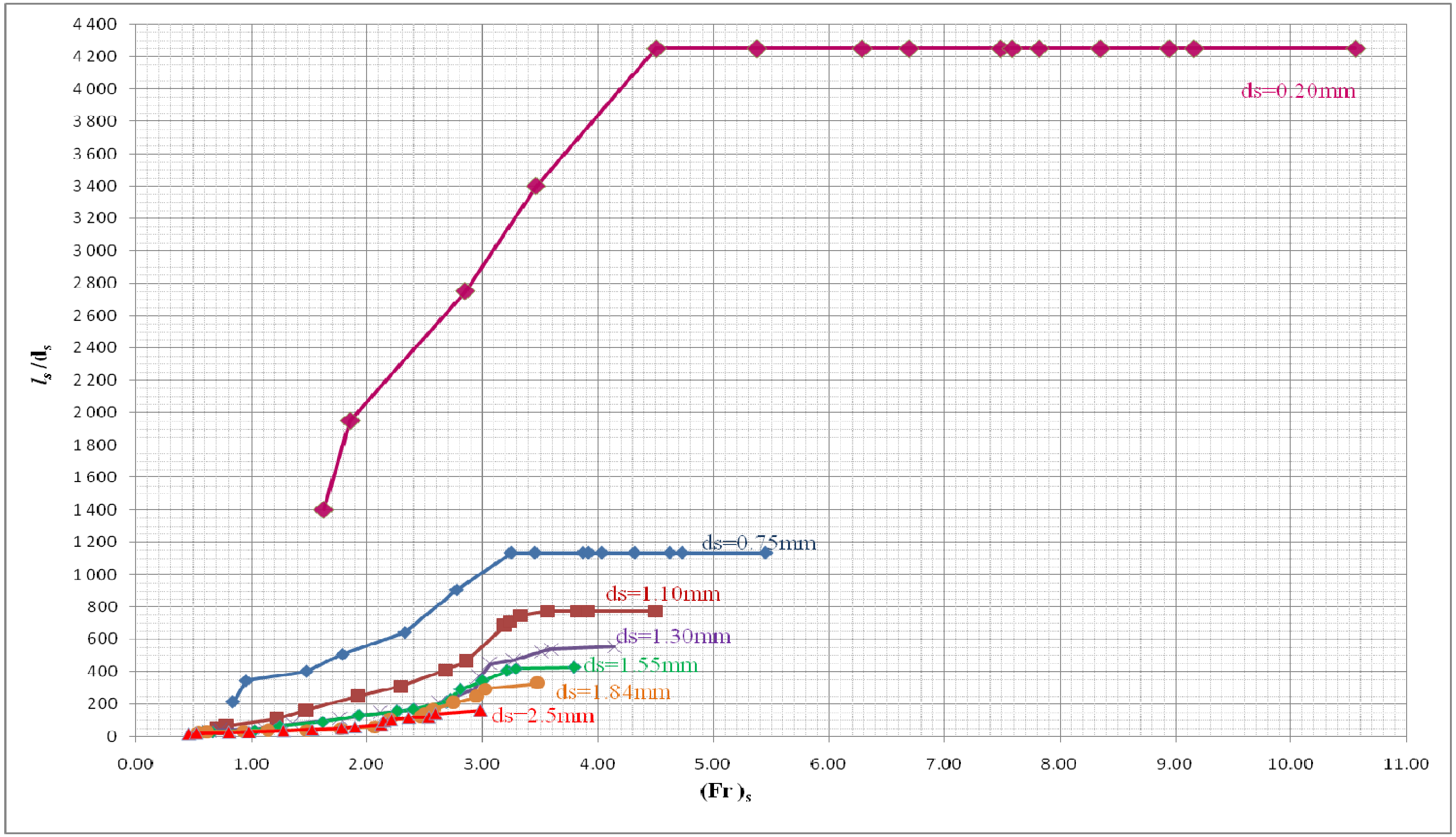


Figure 6.25 Variation of l_s/d_s with $(Fr)_s$ for quartz for the settling basin of Δz=13 cm

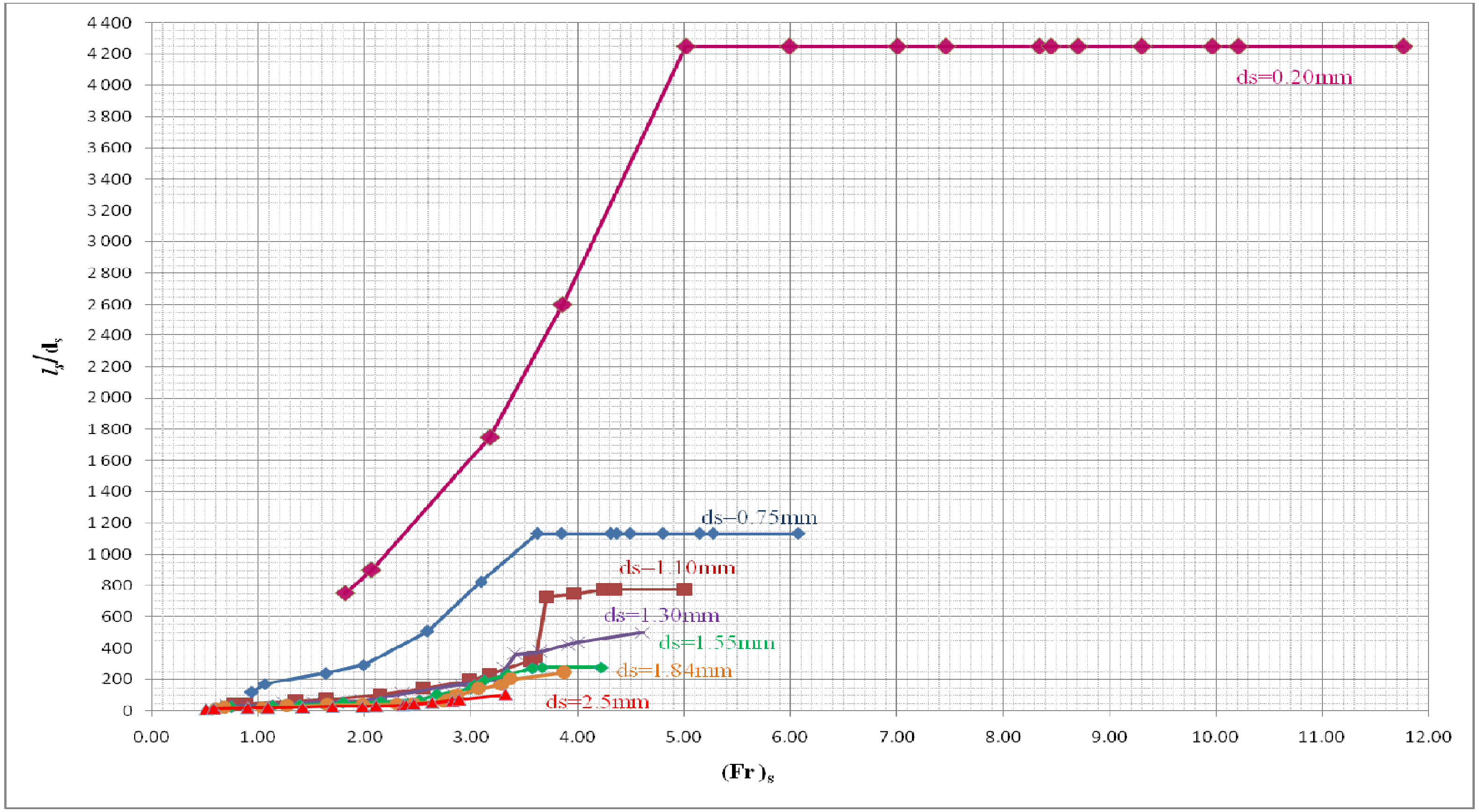


Figure 6.26 Variation of l_s/d_s with $(Fr)_s$ for silisium for the settling basin of Δz=23 cm

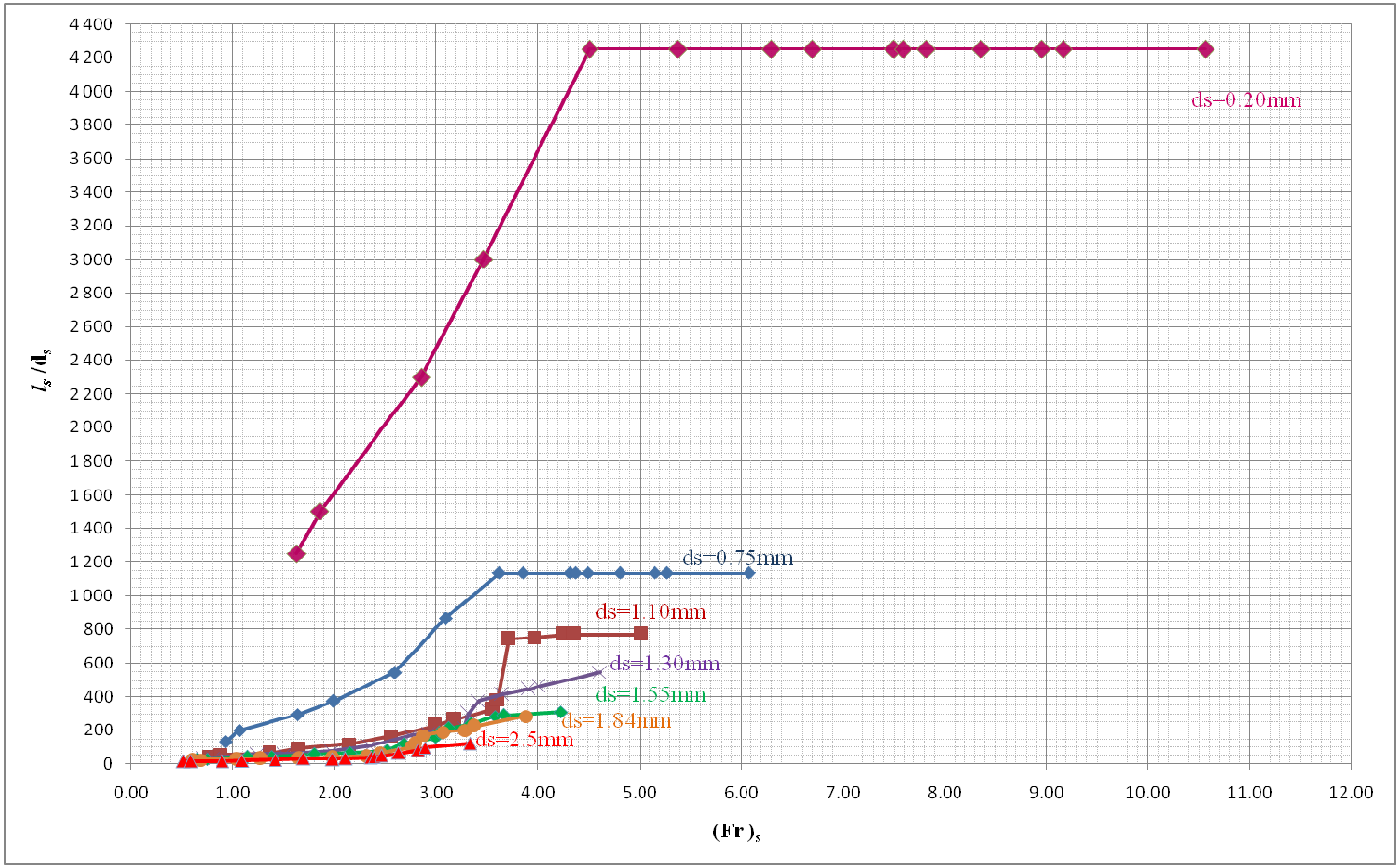


Figure 6.27 Variation of l_s/d_s with $(Fr)_s$ for silisium for the settling basin of Δz=18 cm

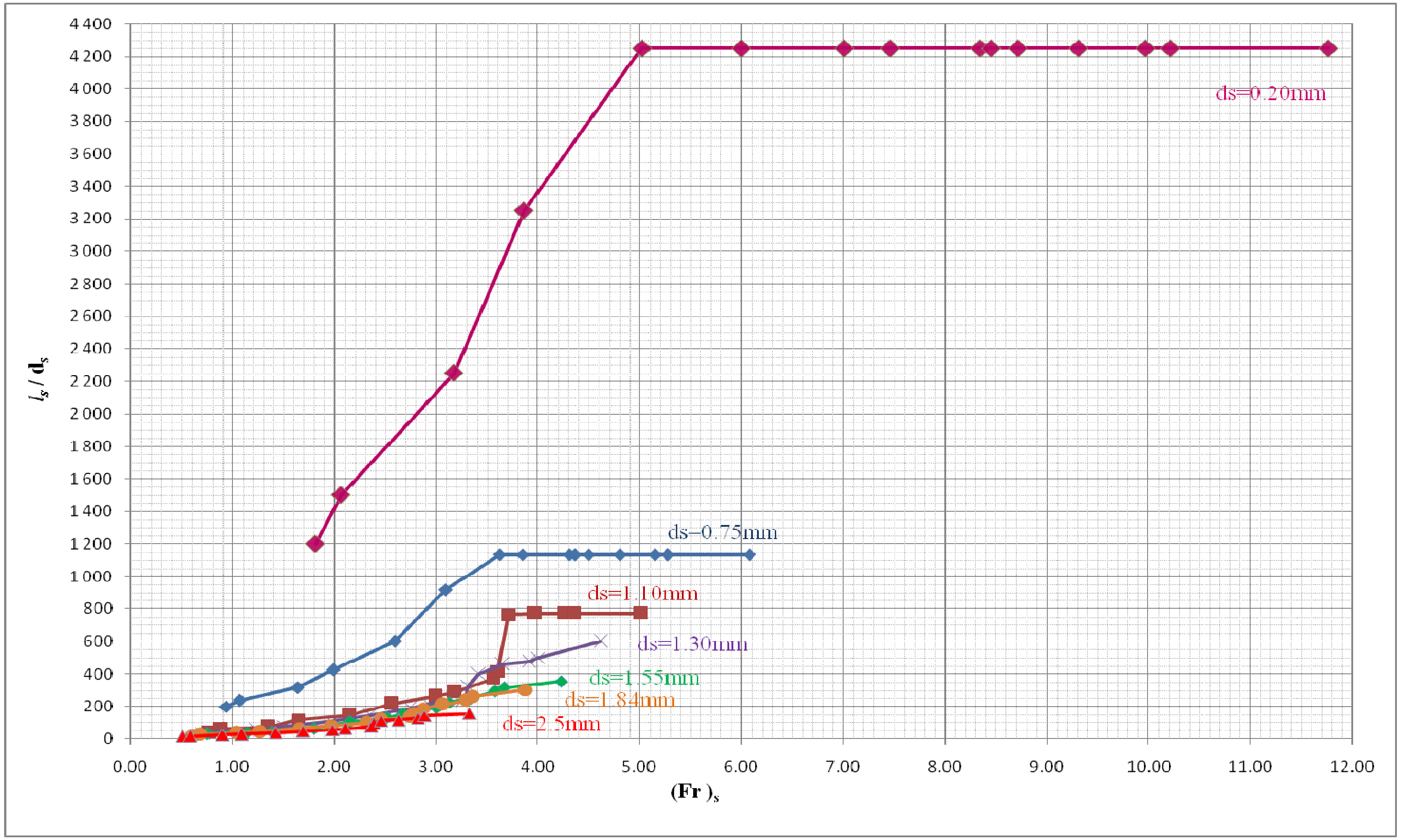


Figure 6.28 Variation of l_s/d_s with $(Fr)_s$ for silisium for the settling basin of Δz=13 cm

6.4.2.2. Variation of l_s /d_s with h/d_s

The general trends of the curves given in Figures 6.29-6.31 and Figures 6.32-6.34, which show the data of l_s/d_s versus h/d_s for quartz and silisium, respectively, are very similar to those of l_s/d_s versus $(Fr)_s$ shown in Figures 6.23-6.28. Actually the only different parameter in these figures is h/d_s instead of $(Fr)_s$. Since h is related to velocity V in the approach channel, which is one of the parameters used in the expression of $(Fr)_s$, the similarity observed between the figures stated above is normal. By means of these figures, one can determine l_s/d_s values for known h/d_s, sediment type and Δz.

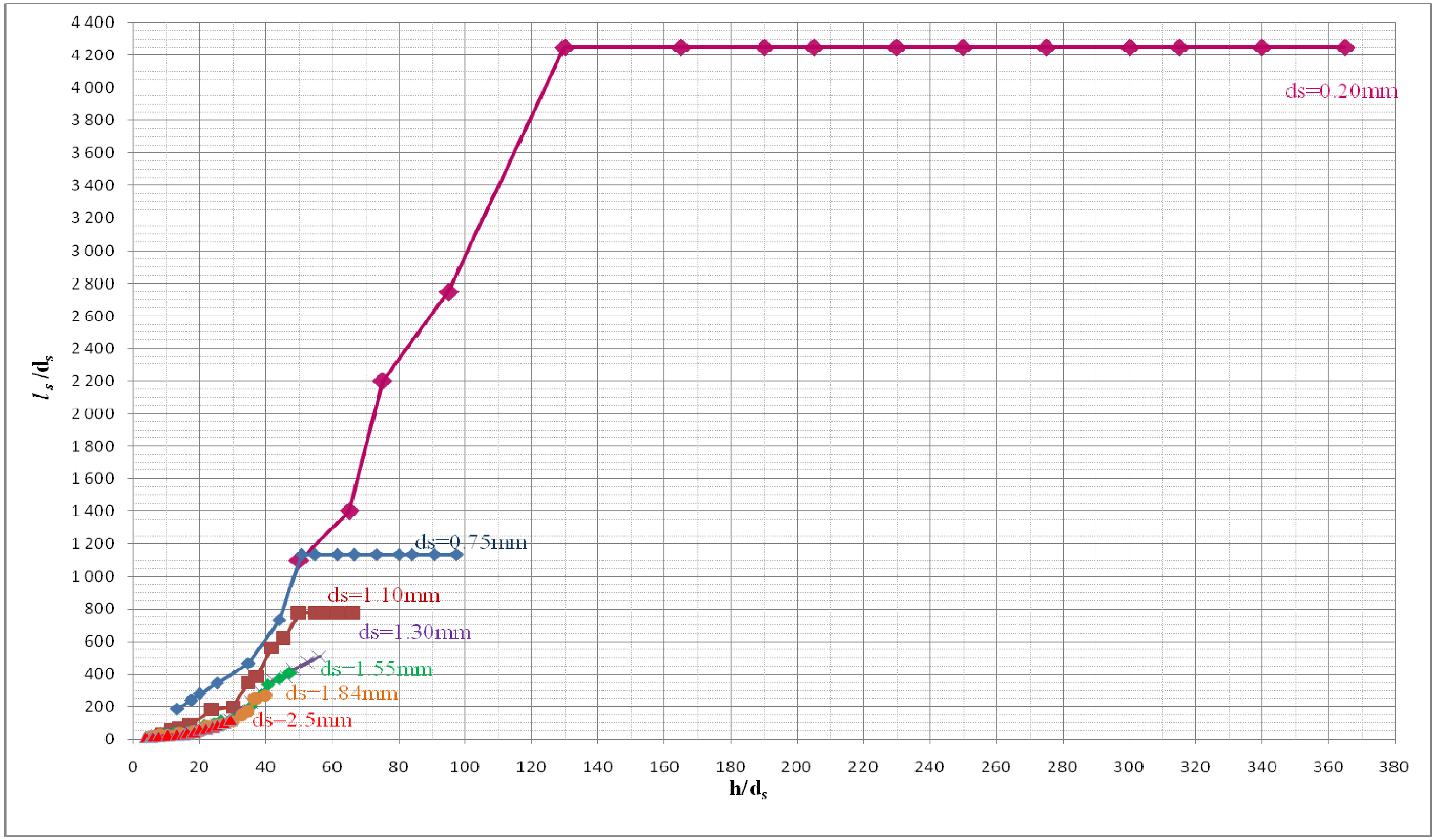


Figure 6.29 Variation of l_s/d_s with h/d_s for quartz for the settling basin of Δz=23 cm

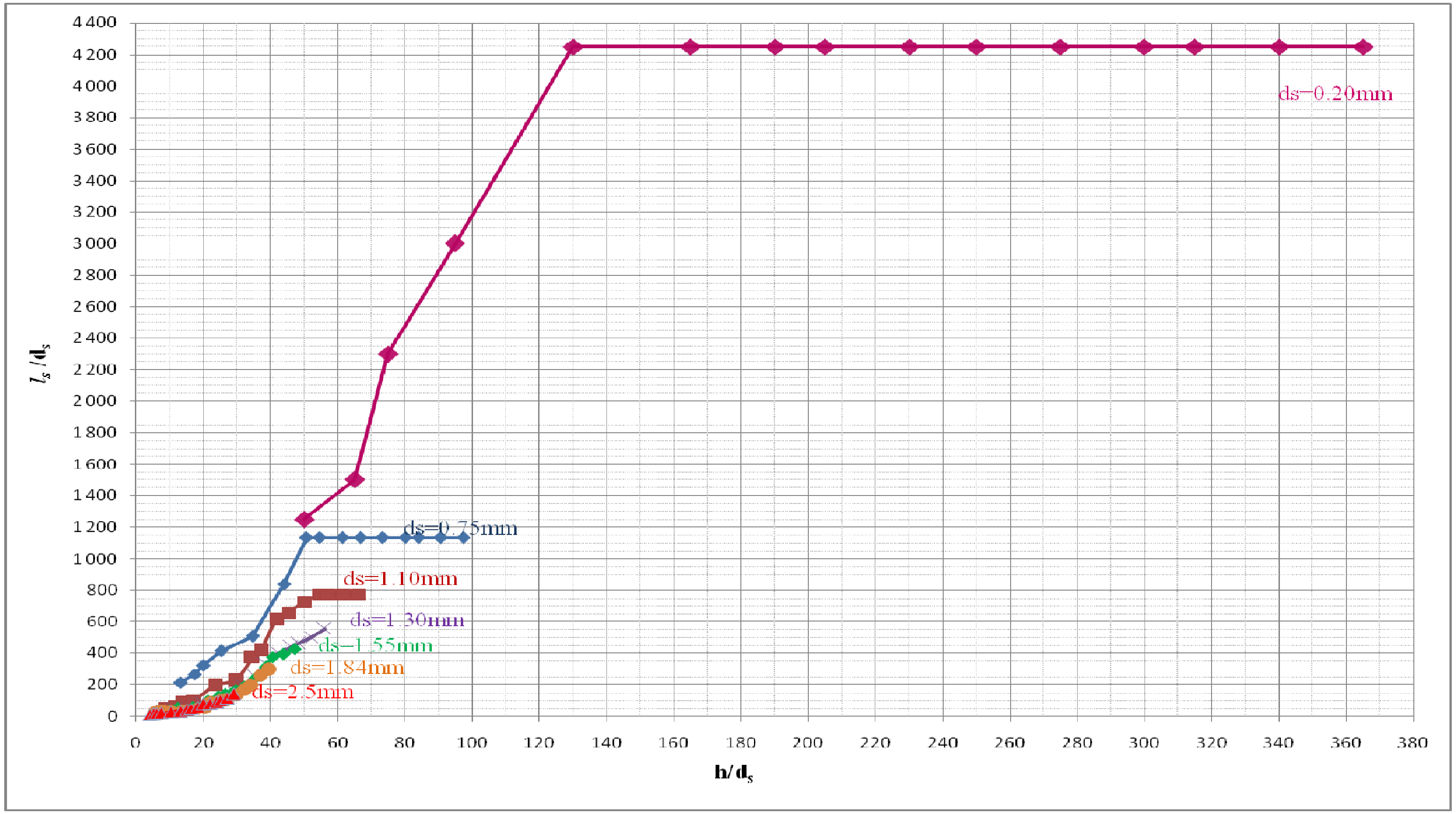


Figure 6.30 Variation of l_s/d_s with h/d_s for quartz for the settling basin of Δz=18 cm

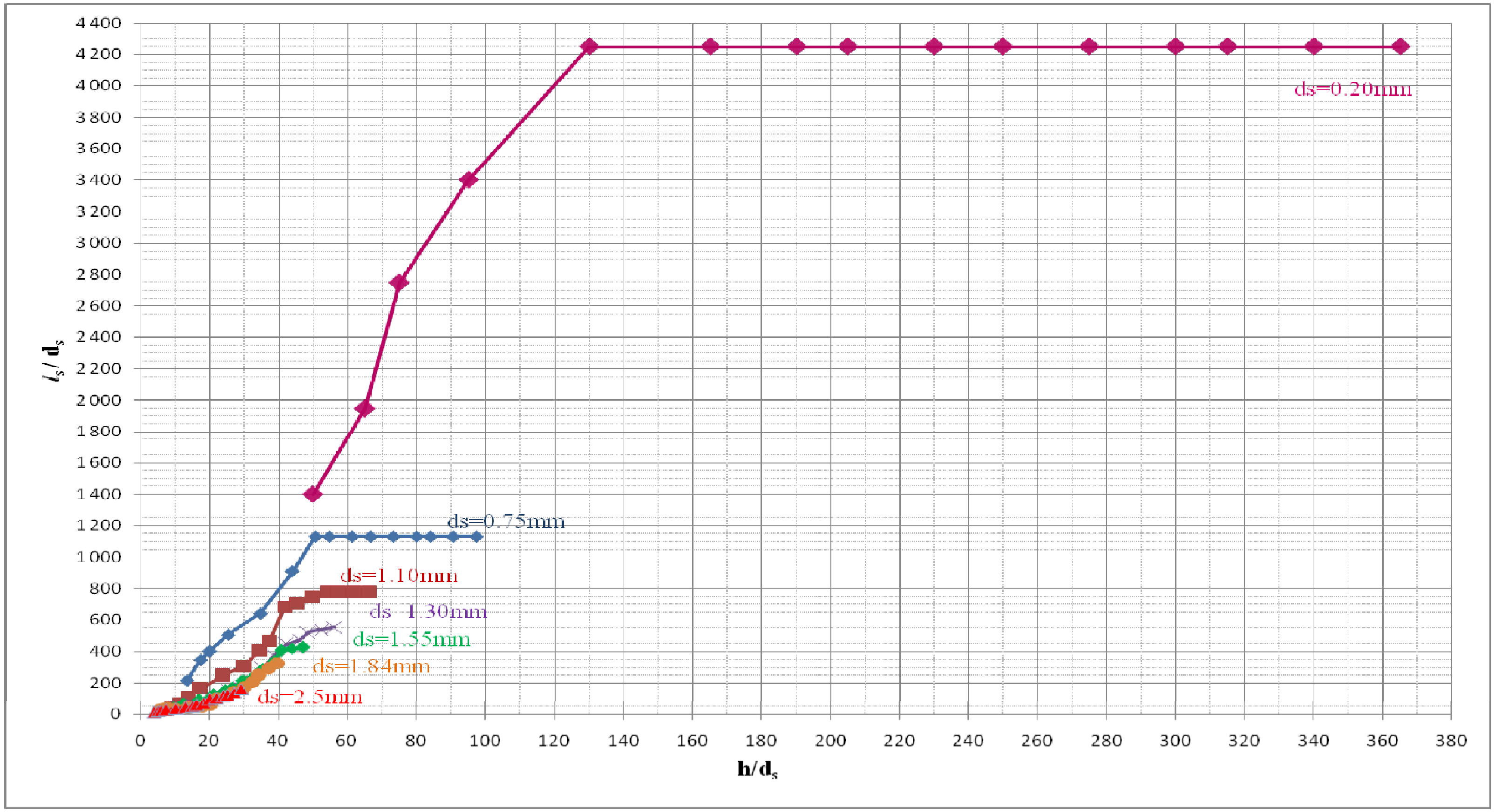


Figure 6.31 Variation of l_s/d_s with h/d_s for quartz for the settling basin of Δz=13 cm

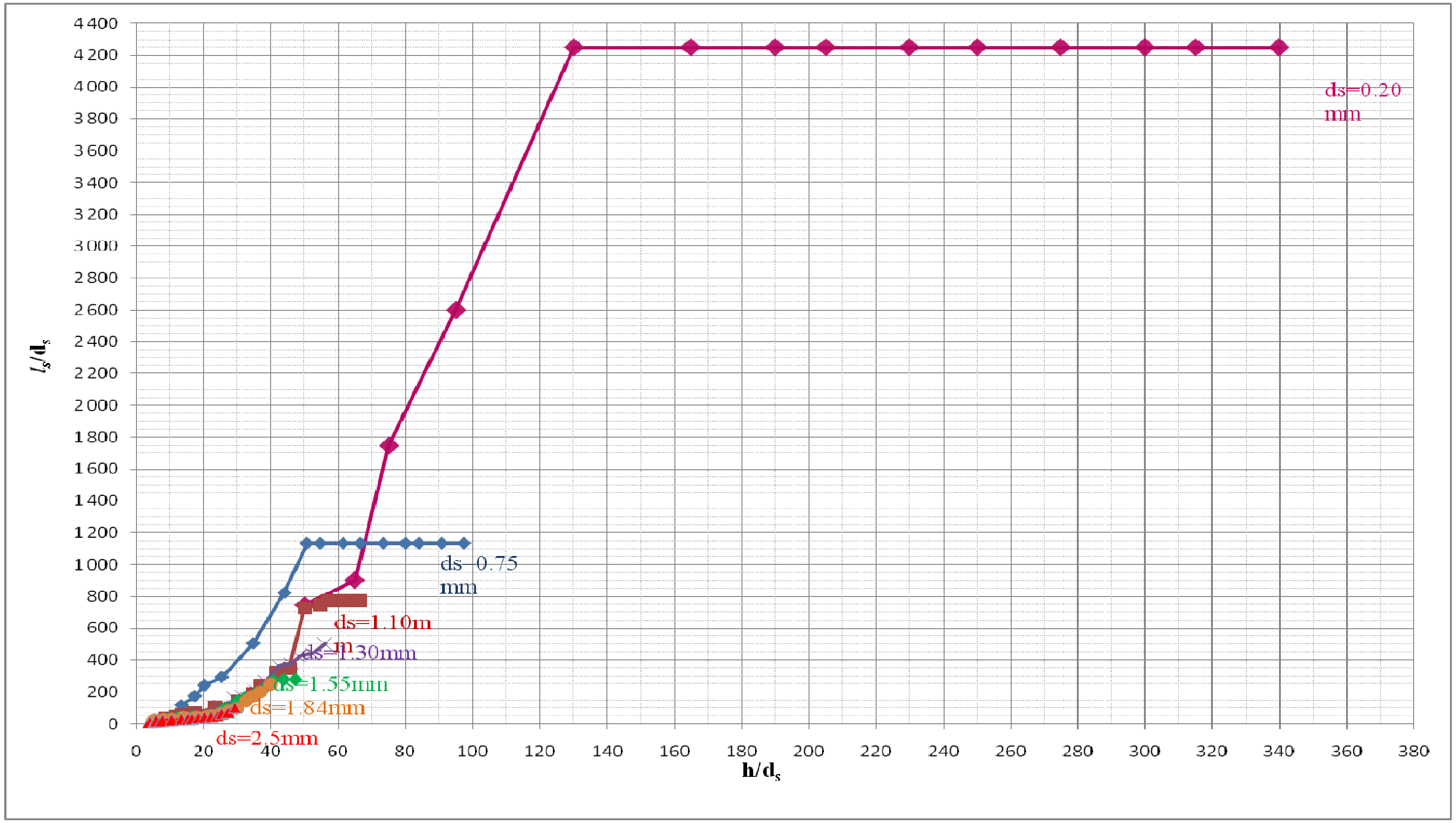


Figure 6.32 Variation of l_s/d_s with h/d_s for silisium for the settling basin of Δz=23 cm

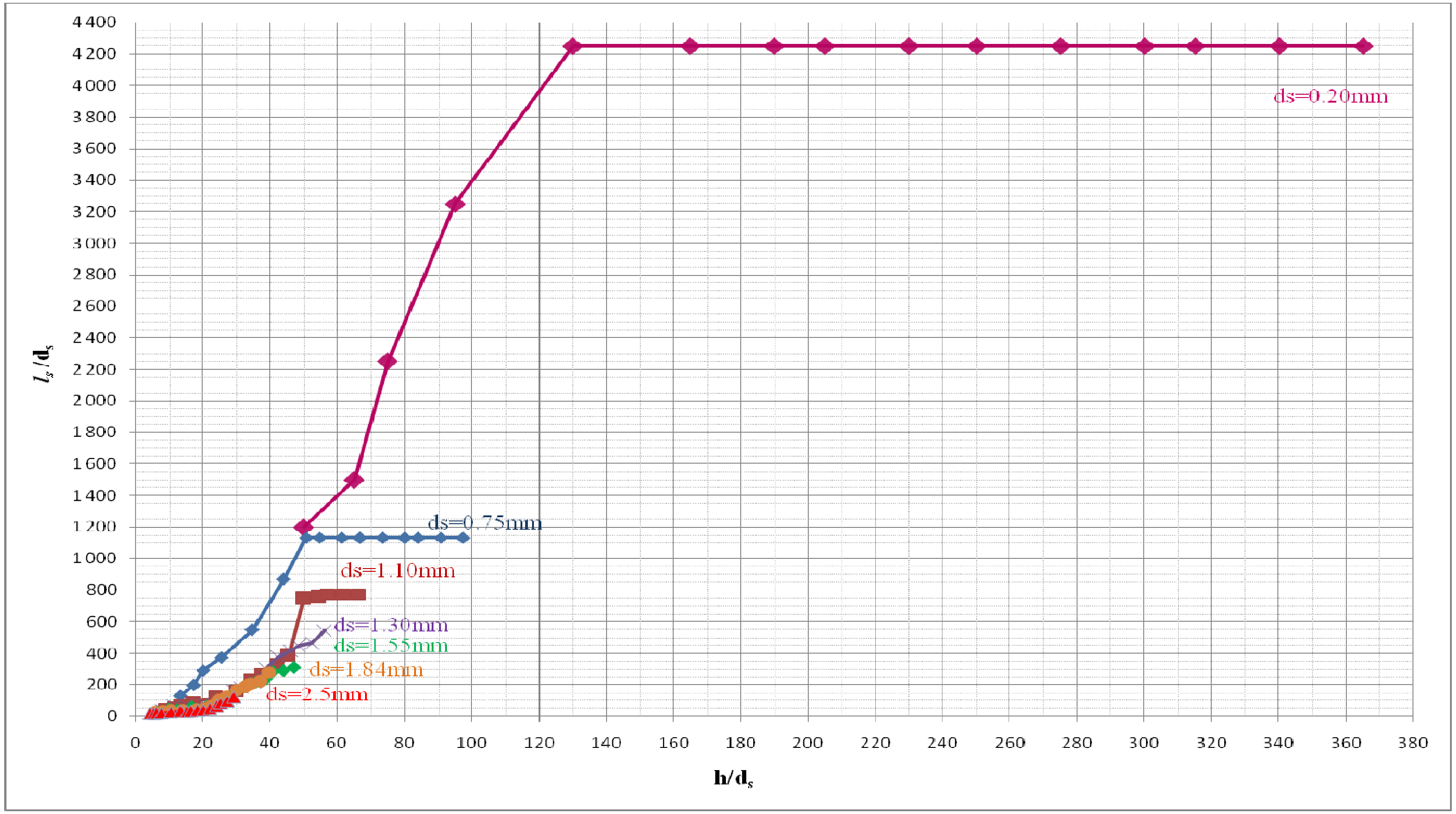


Figure 6.33 Variation of l_s/d_s with h/d_s for silisium for the settling basin of Δz=18 cm

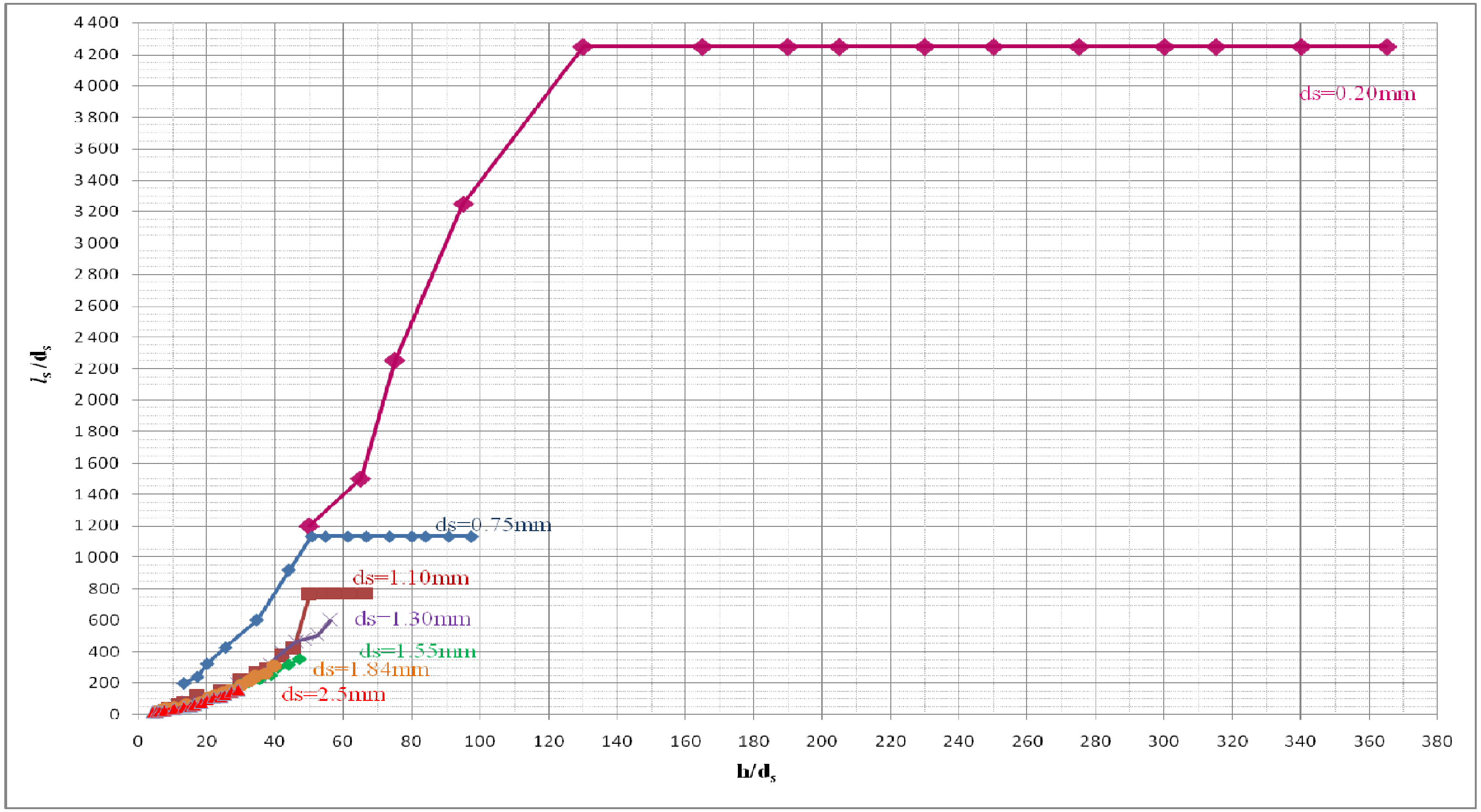


Figure 6.34 Variation of l_s/d_s with h/d_s for silisium for the settling basin of Δz=13 cm

6.4.2.3. Variation of l_s /d_s with $\Delta z/d_s$

Variation of l_s/d_s with $\Delta z/d_s$ are shown in Figures 6.35-6.41 and Figures 6.42-6.48 in two graphs for quartz and silisium as a function of particle diameter, d_s, and densimetric Froude number, $(Fr)_s$. From the analysis of these figures it can be concluded that for fine particles of diameters , ds<1.10 mm, l_s/d_s almost does not change with increasing settling basin sill height, $\Delta z/d_{s,}$ at maximum $(Fr)_s$ tested. Since the particles are quite fine and the approach flow velocities and therefore the Froude numbers are large, the settling distances of the sediments are almost equal to the total length of the settling basins of different depths used in the experiments. The same situation is observed at coarse particles, $d_s \geq 1.10$ mm, for the minimum $(Fr)_s$ values tested; l_s/d_s does not change with increasing $\Delta z/d_s$. At small aproach velocities coarse particles have almost the same settling distances regardless of the settling basin depth. At intermediate $(Fr)_s$ values, l_s/d_s always show a decreasing trend with increasing $\Delta z/d_s$ for a given particle. It means that the settling basin having the maximum sill height shows the best performance by yielding the minimum settling distance for the particles tested. Referring to Figures 6.35-6.48 one can determine the maximum settling distances of a given sediment type and group as a function of $(Fr)_s$ and $\Delta z/d_s$.

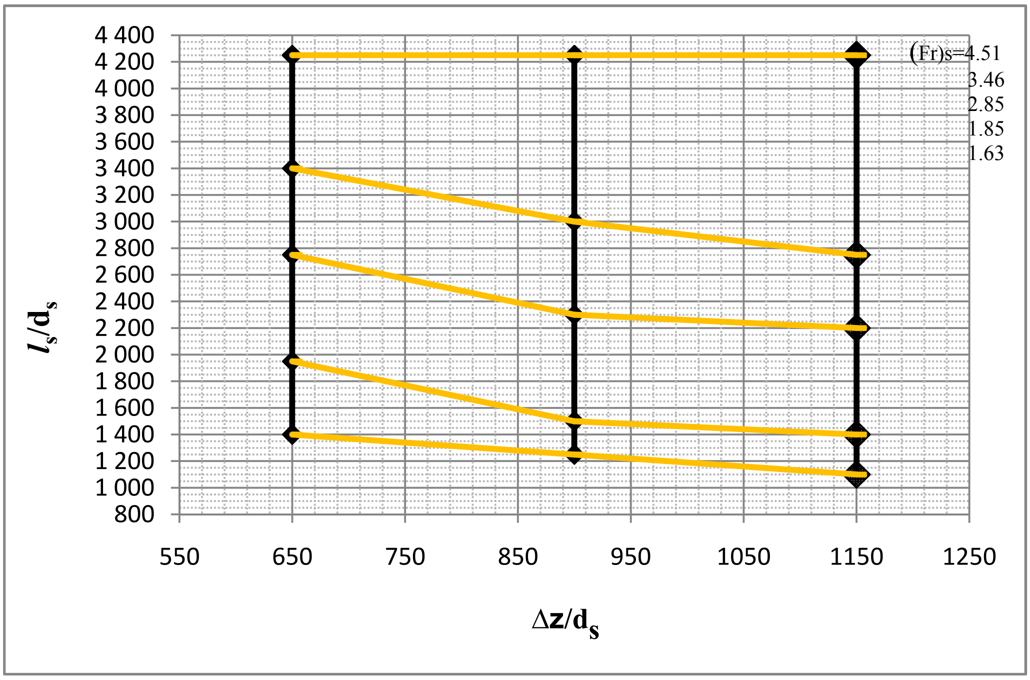


Figure 6.35 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =0.2 mm

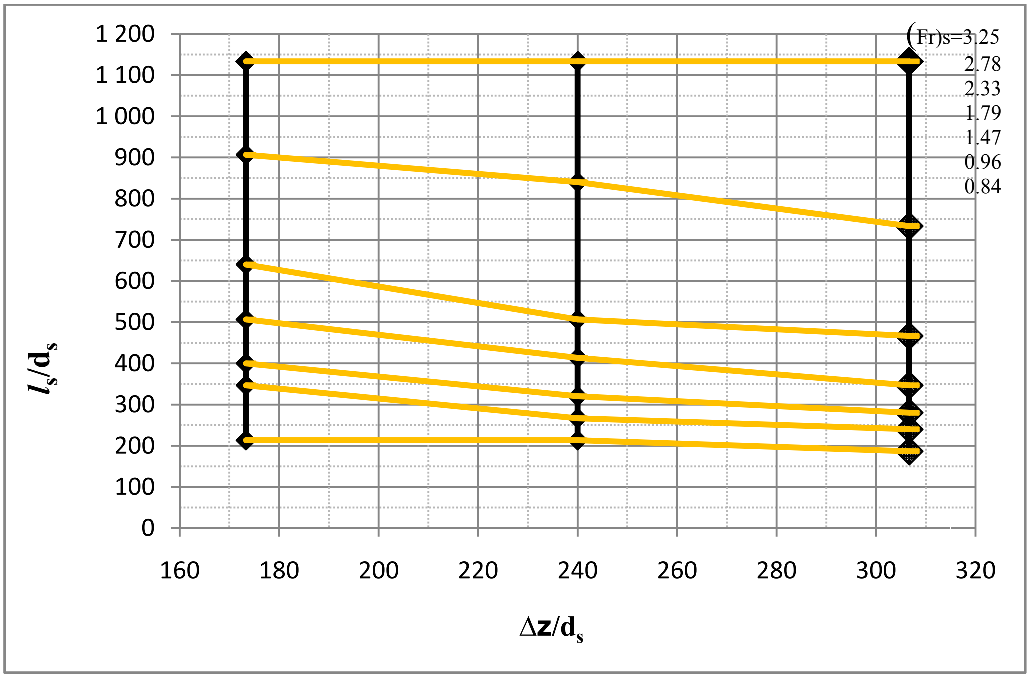


Figure 6.36 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =0.75 mm

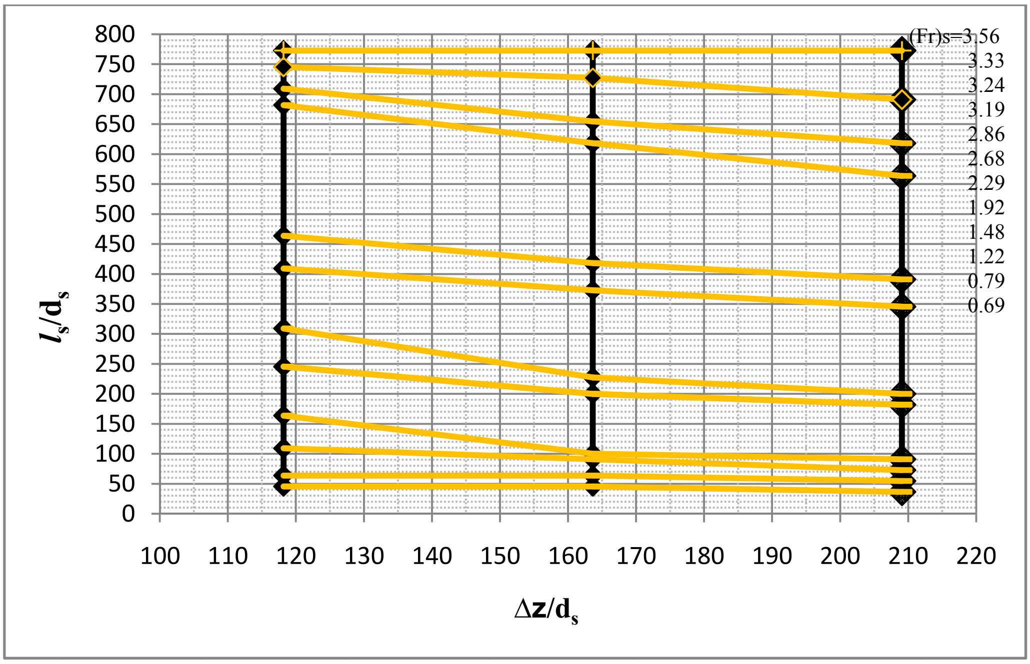


Figure 6.37 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =1.10 mm

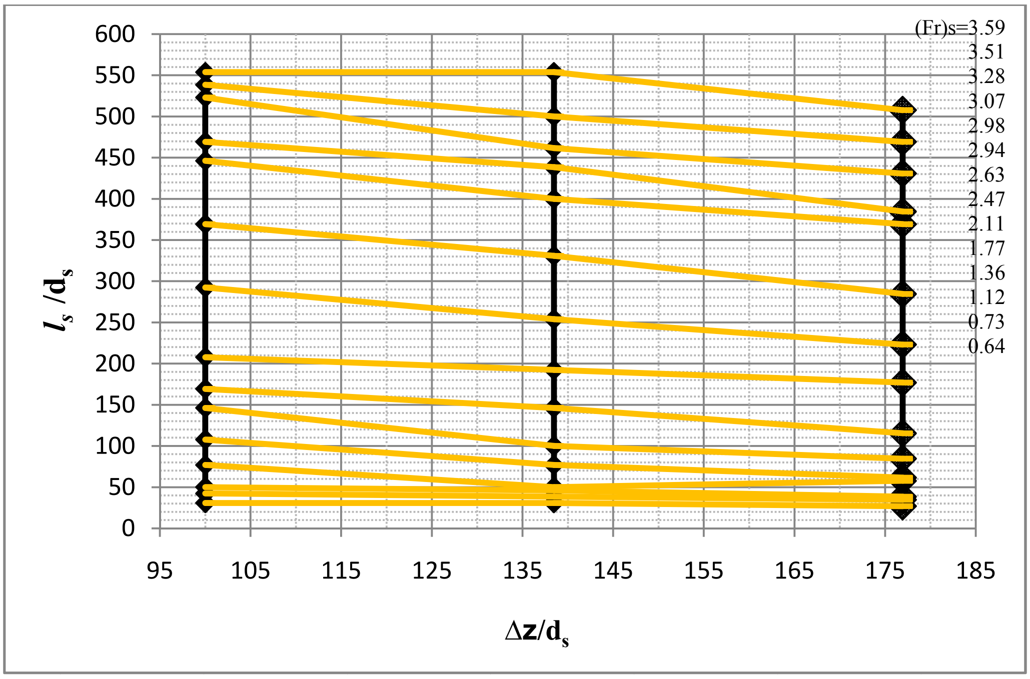


Figure 6.38 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =1.30 mm

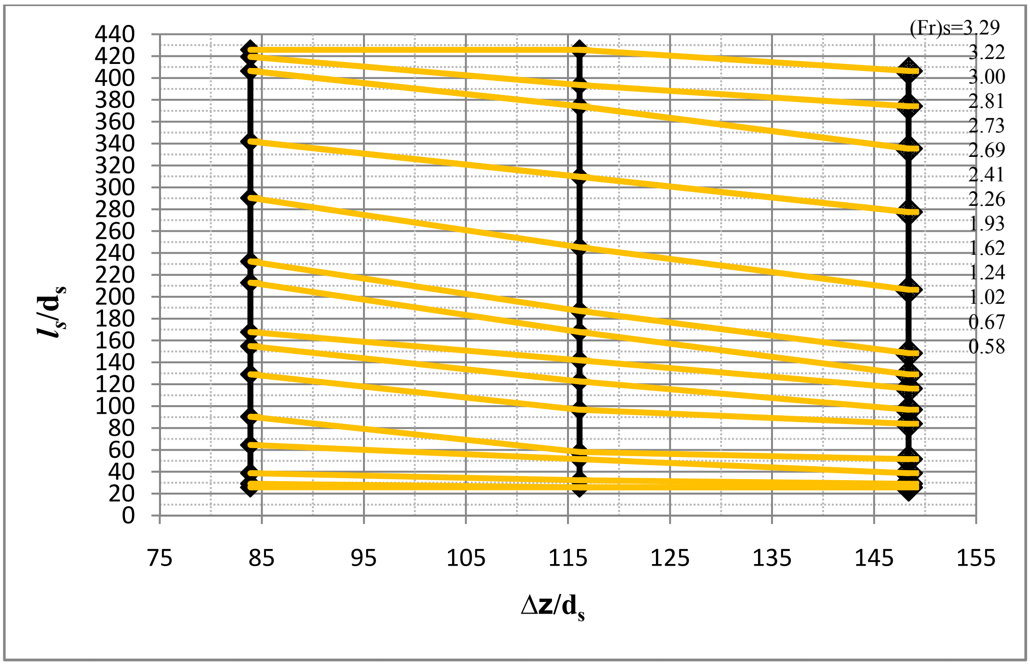


Figure 6.39 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =1.55 mm

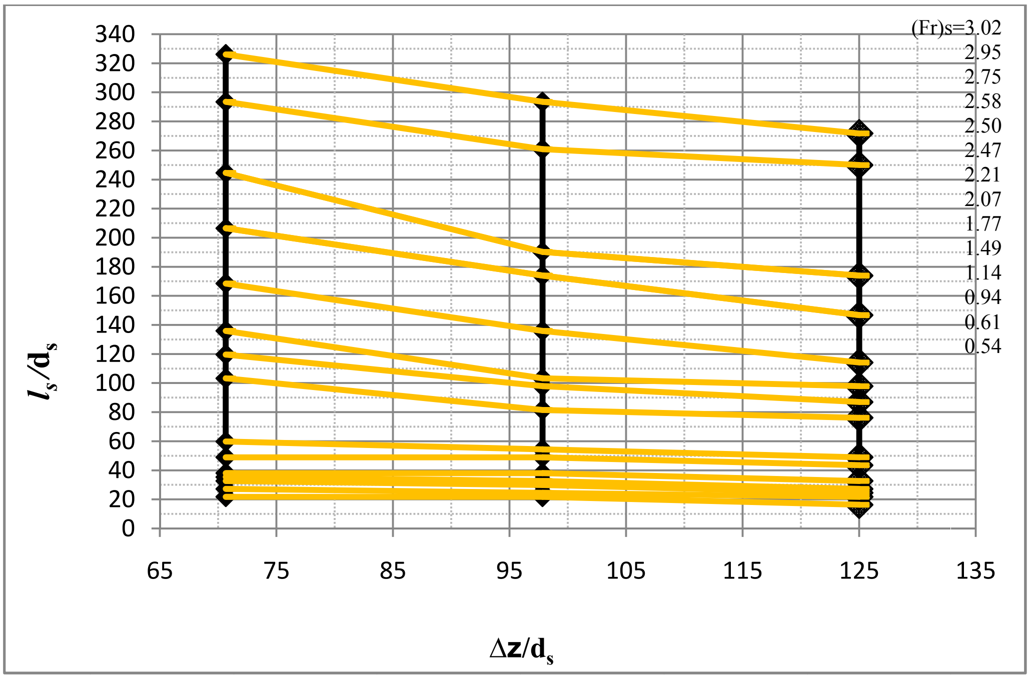


Figure 6.40 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =1.84 mm

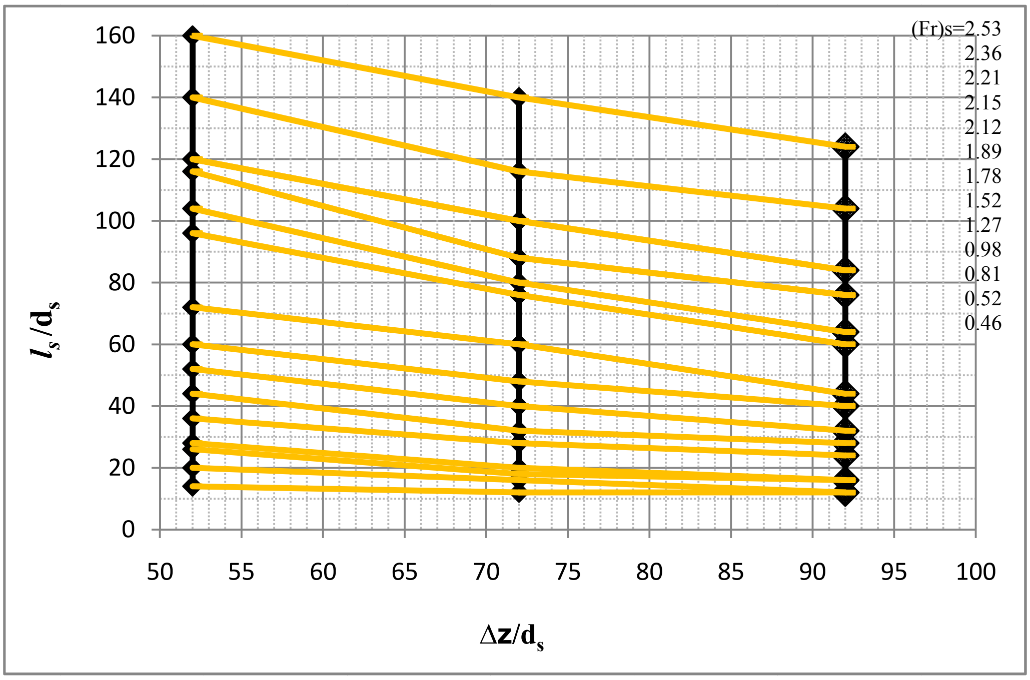


Figure 6.41 Variation of l_s/d_s with $\Delta z/d_s$ for quartz of d_s =2.5 mm

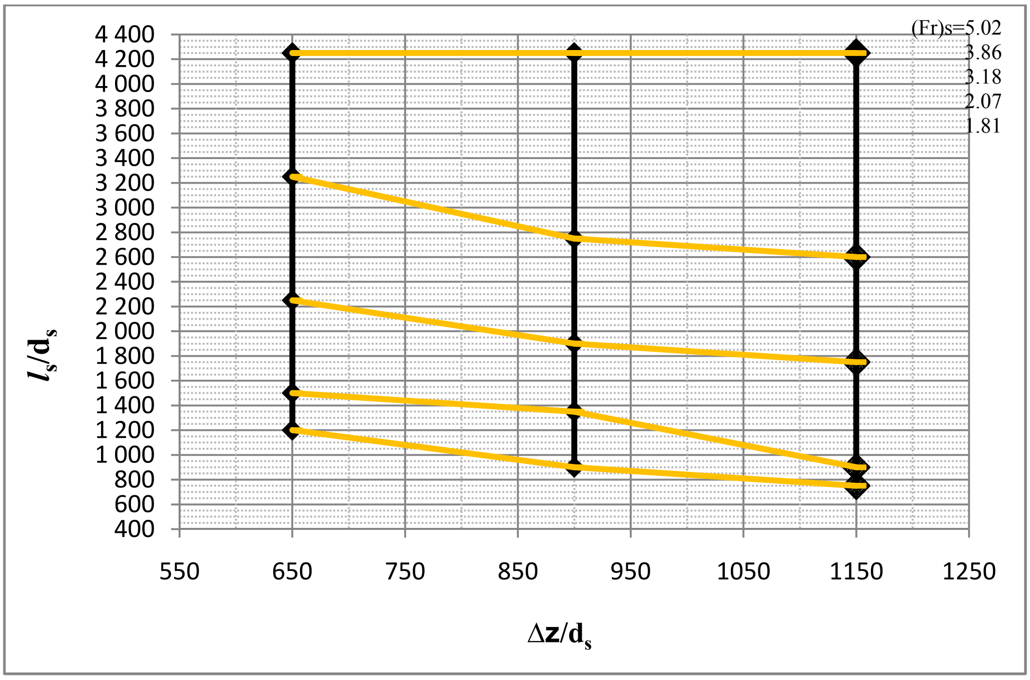


Figure 6.42 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =0.2 mm

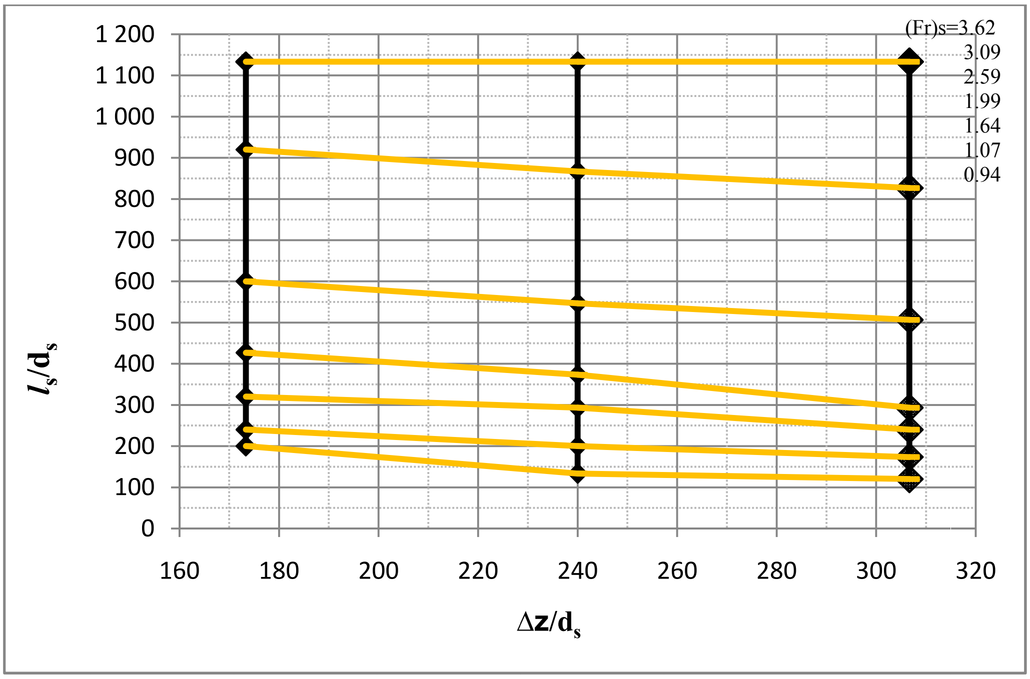


Figure 6.43 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =0.75 mm

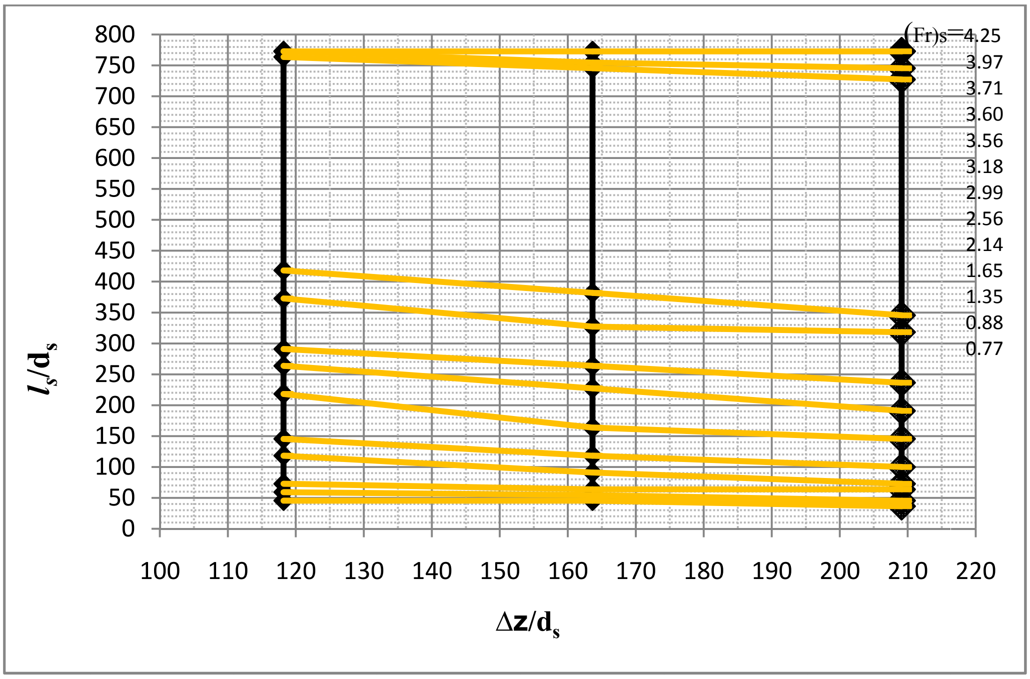


Figure 6.44 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =1.10 mm

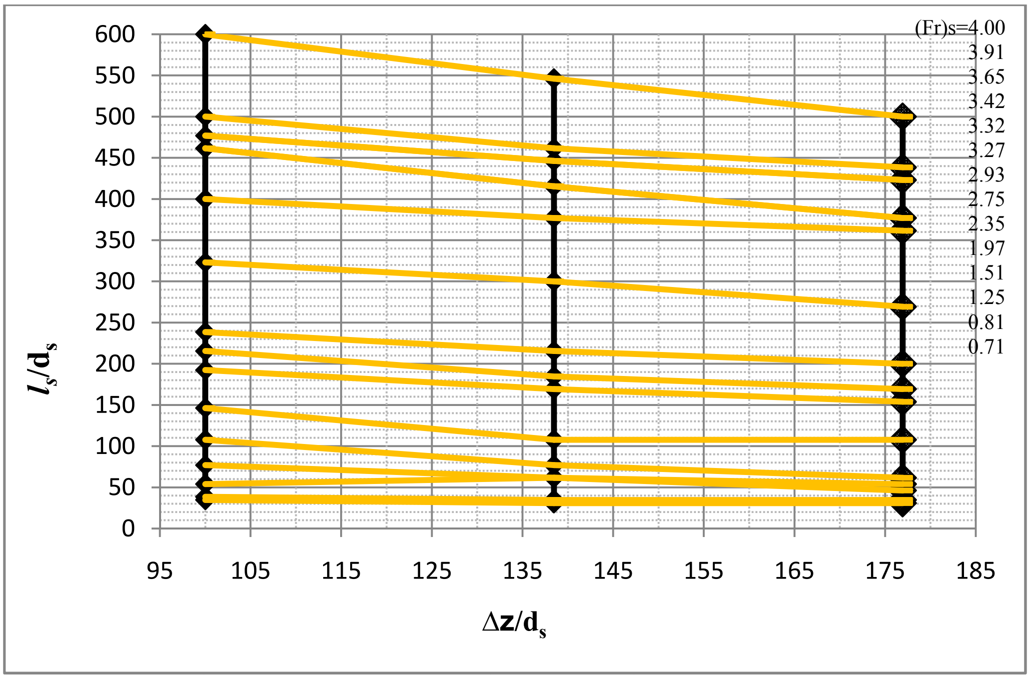


Figure 6.45 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =1.30 mm

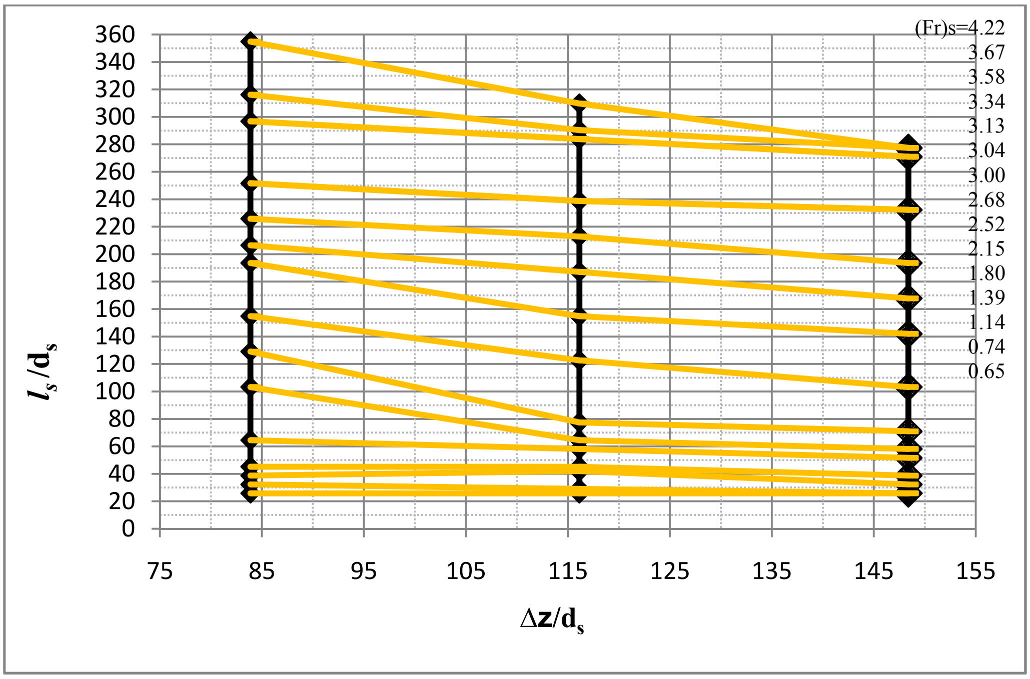


Figure 6.46 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =1.55 mm

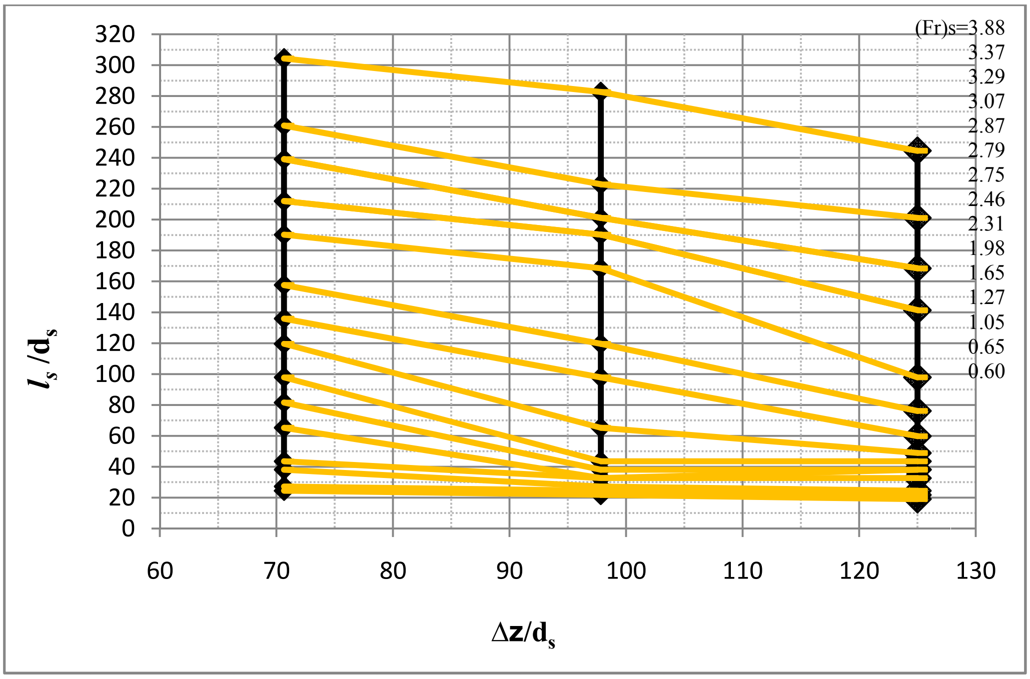


Figure 6.47 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =1.84 mm

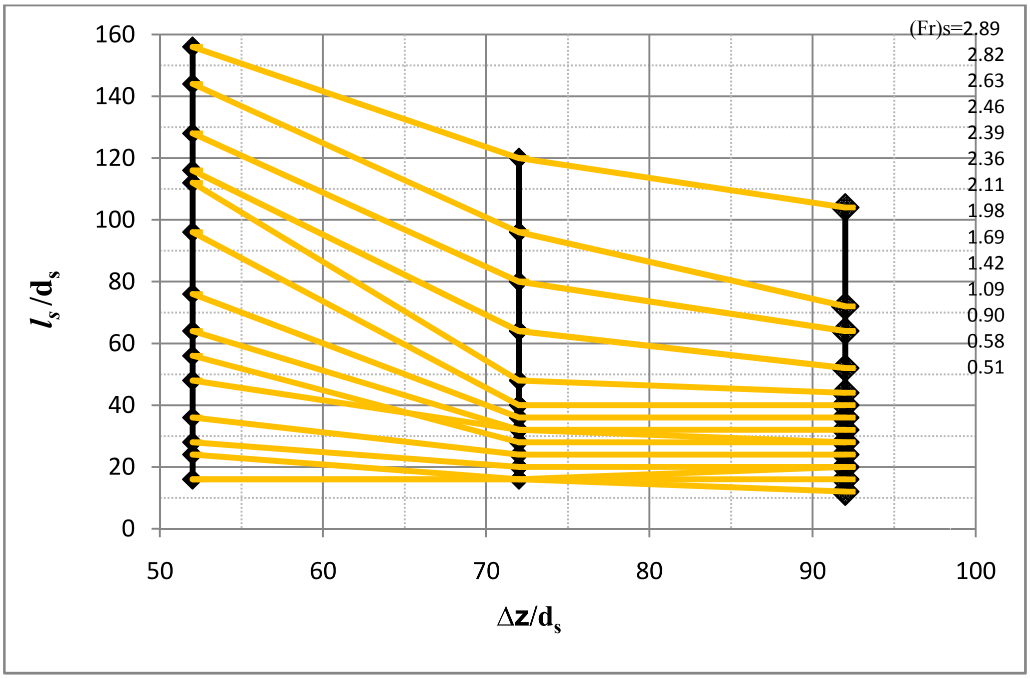


Figure 6.48 Variation of l_s/d_s with $\Delta z/d_s$ for silisium of d_s =2.5 mm

6.4.2.4. Effect of Particle Density and Shape on l_s/d_s

To show the effect of particle density and shape on l_s/d_s, the variation of l_s/d_s with only $(Fr)_s$ as a function of particle diameter was plotted and presented in Figures 6.49-6.54 for the model settling basins of Δz=23 cm,18 cm and 13 cm. These figures reveal that at almost each size range tested for a given $(Fr)_s$, quartz particles have about 0-100 % larger l_s/d_s values than those of silisium particles. This is due to the more rounded shape of the silisium particles than quartz particles which have sharp edges. Therefore, the quartz particles can remain in suspension longer than silisium particles of the same diameter for the same $(Fr)_s$ although they have larger densities than silisium particles. Because of these differences in l_s/d_s values of the two types of sediments tested, the related figures of these sediments were not combined and presented together in this study.

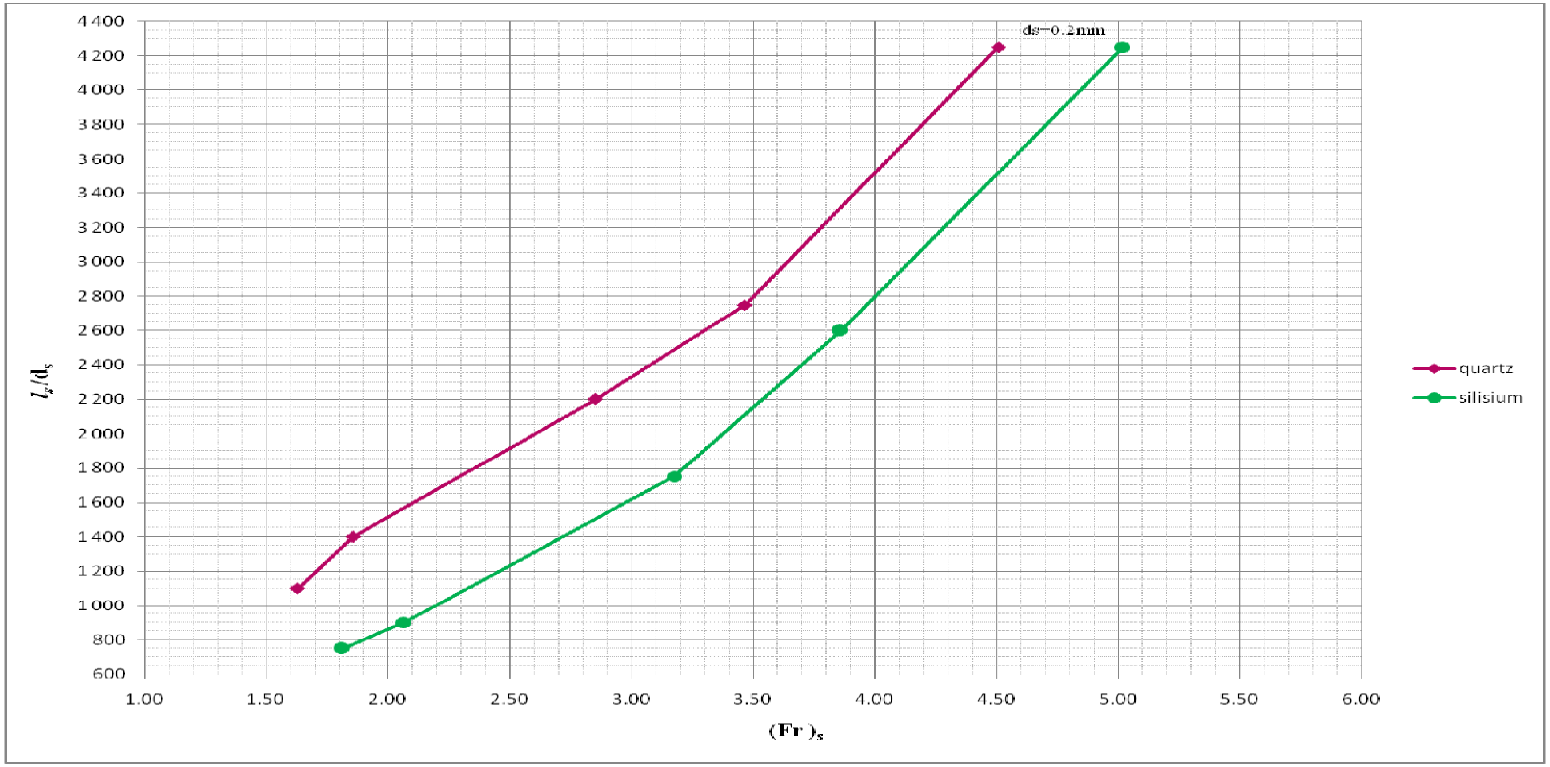


Figure 6.49 Variation of l_s/d_s with $(Fr)_s$ for quartz and silisium for the settling basin of Δz =23 cm for ds=0.2 mm

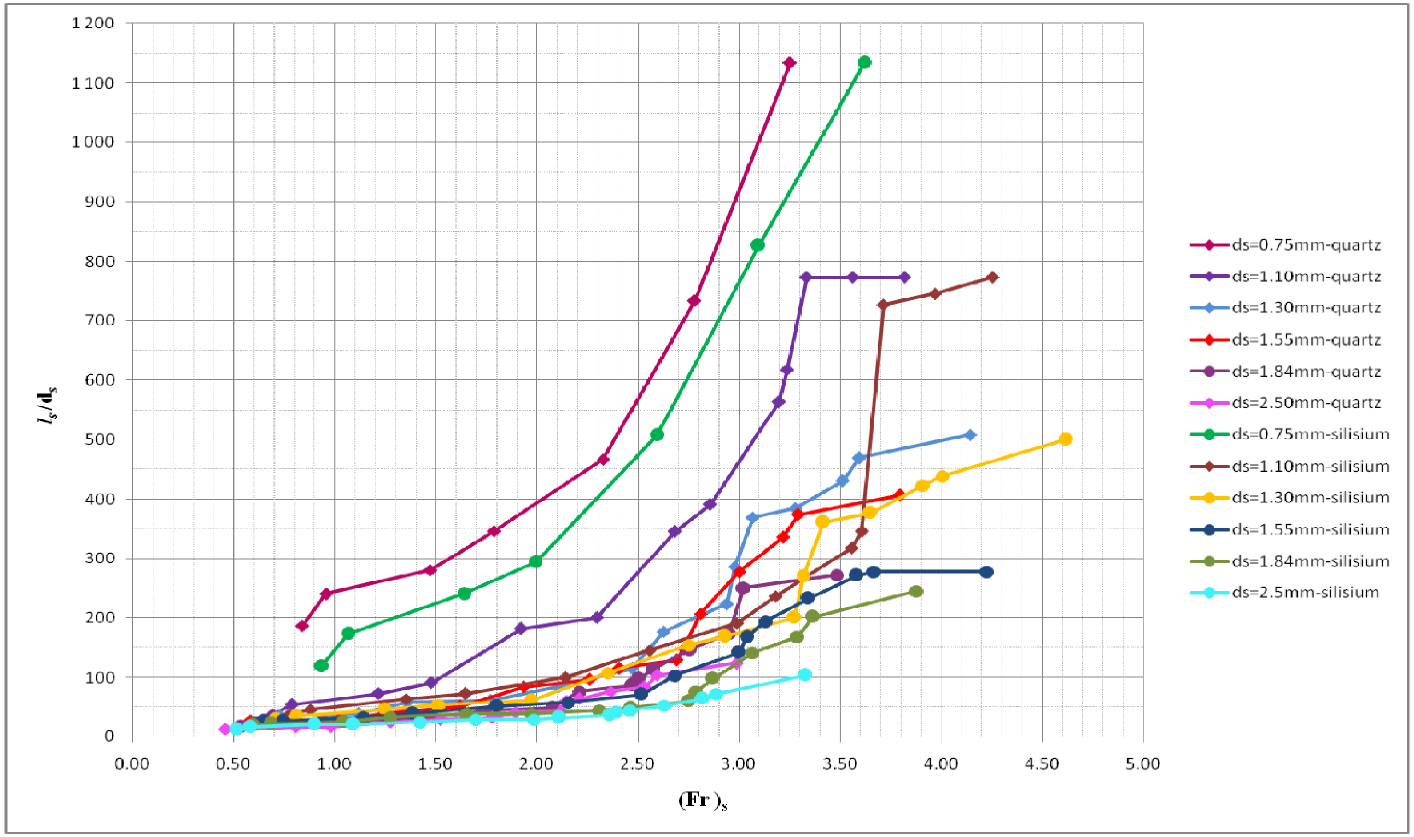


Figure 6.50 Variation l_s/d_s with $(Fr)_s$ for quartz and silisium for the settling basin of Δz =23 cm

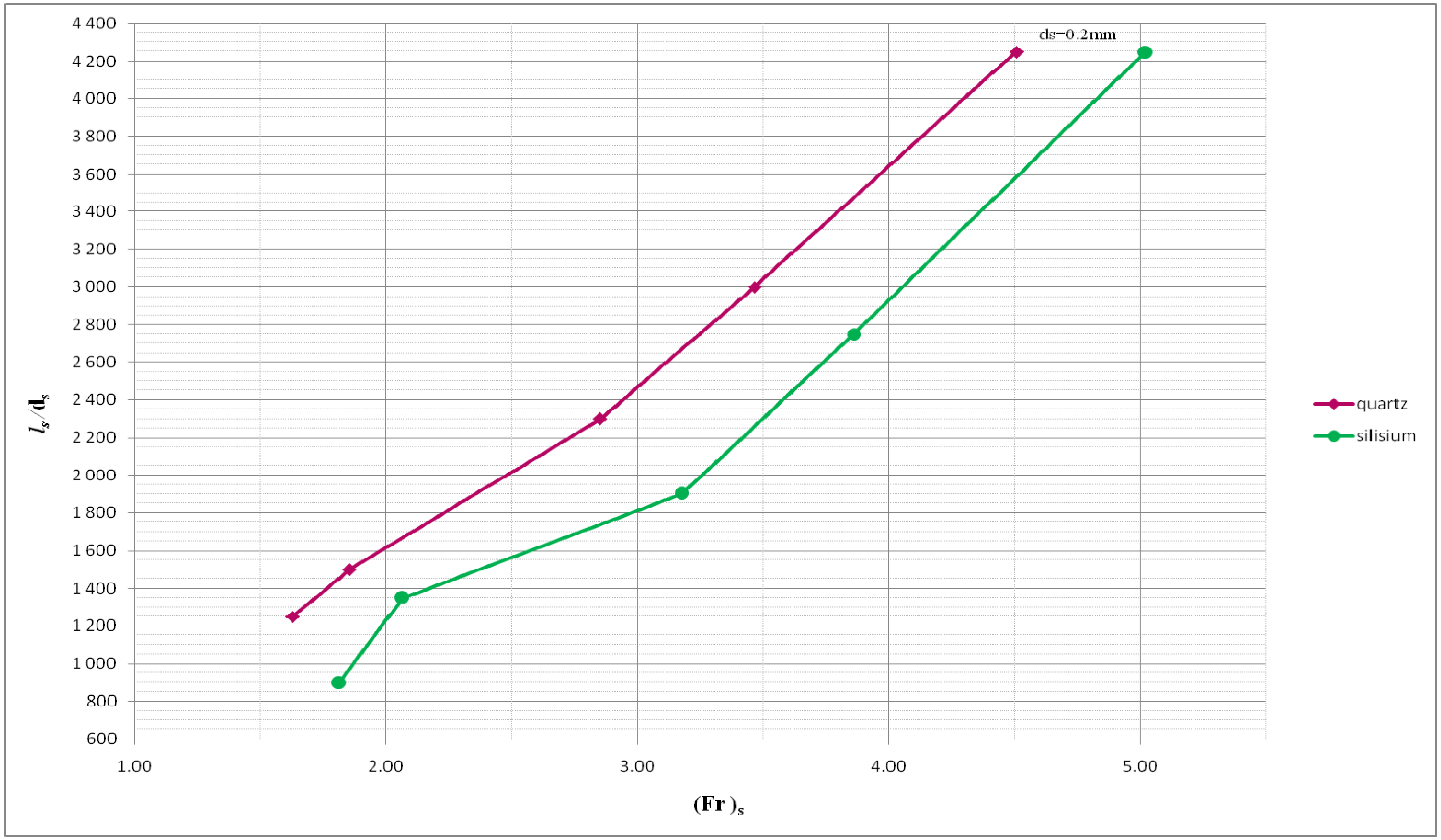


Figure 6.51 Variation of l_s/d_s with $(Fr)_s$ for quartz and silisium for the settling basin of Δz =18 cm for ds=0.2 mm

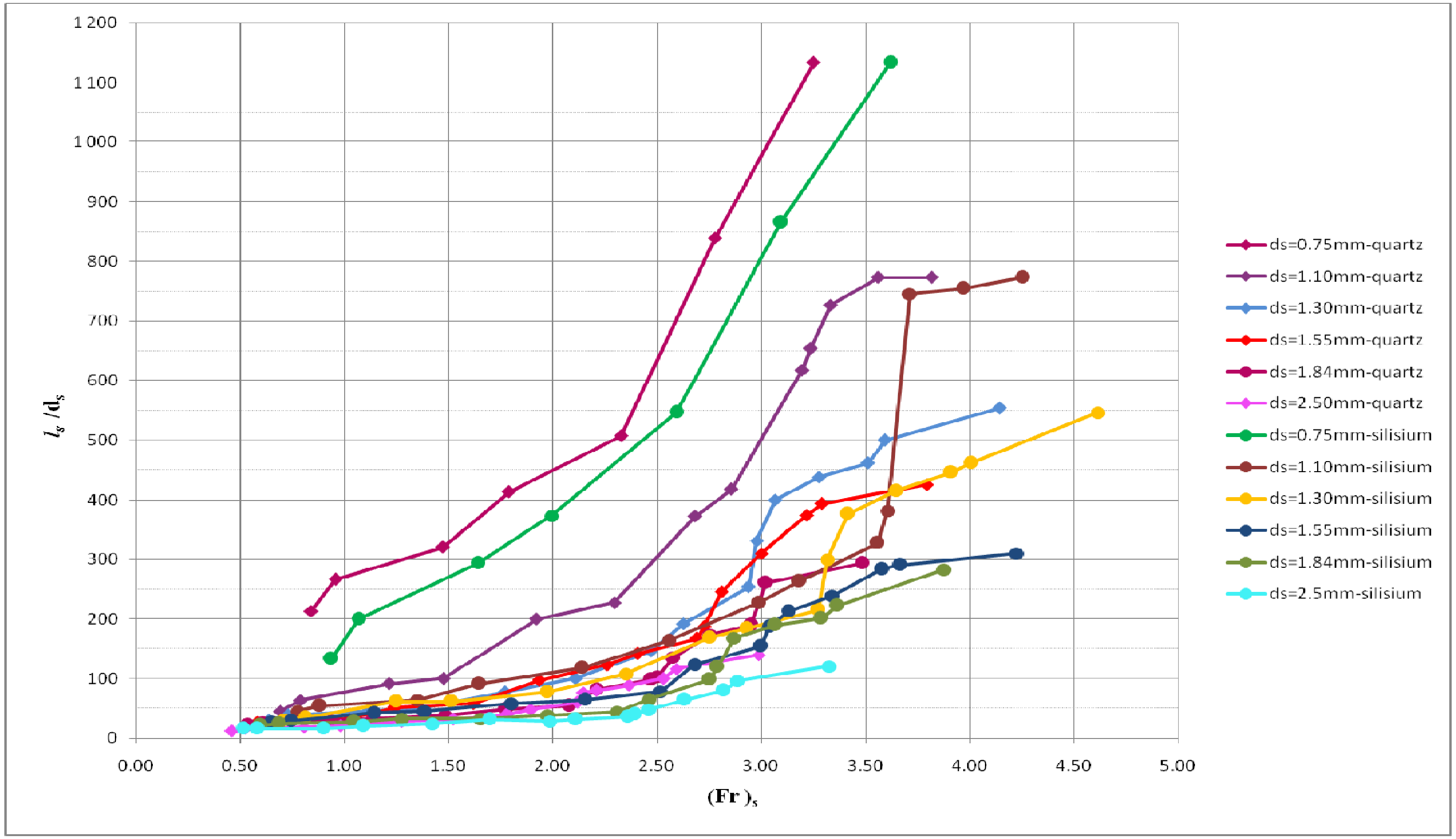


Figure 6.52 Variation of l_s/d_s with $(Fr)_s$ for quartz and silisium for the settling basin of Δz =18 cm

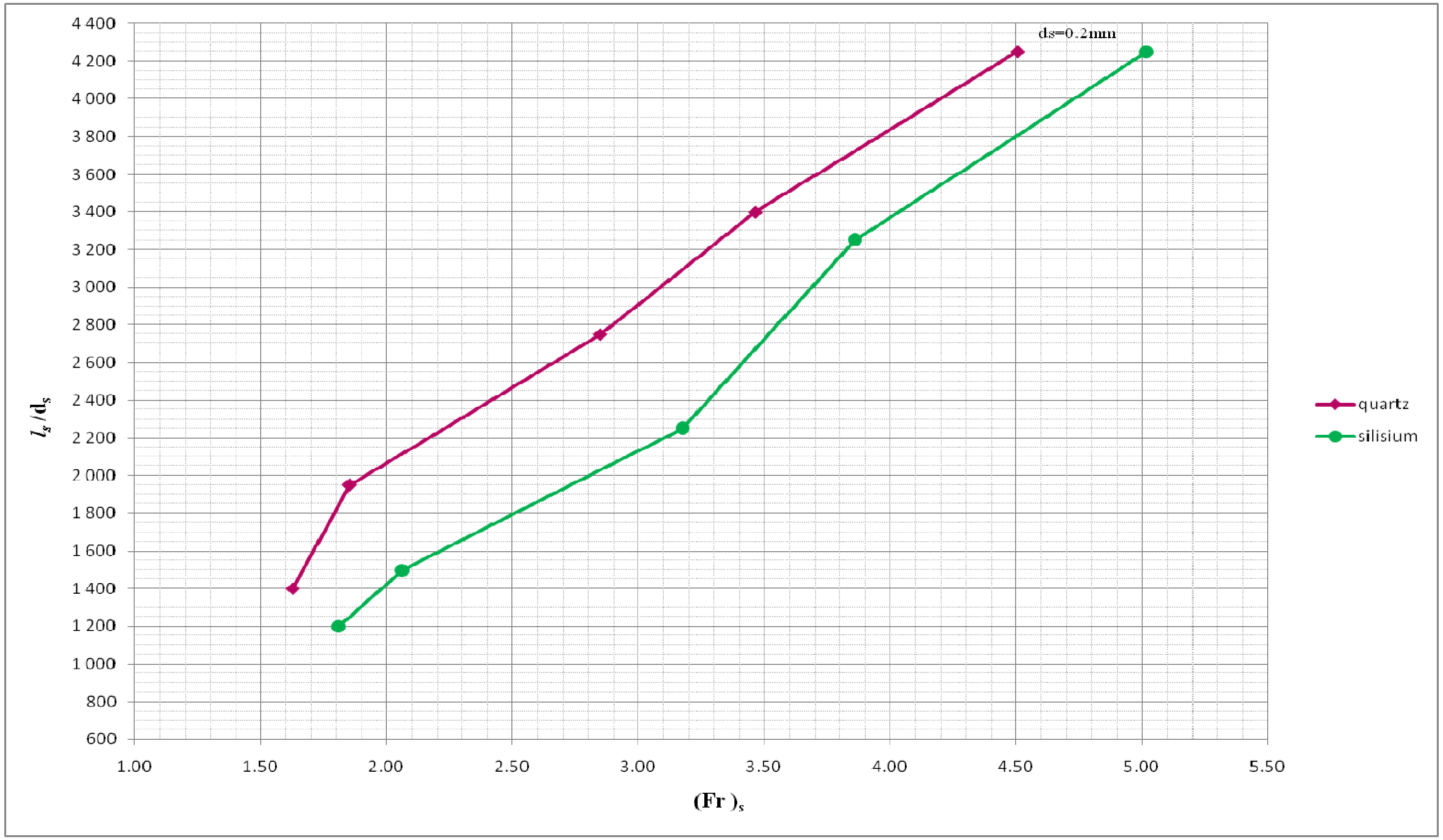


Figure 6.53 Variation of l_s/d_s with $(Fr)_s$ for quartz and silisium for the settling basin of Δz =13 cm for ds=0.2 mm

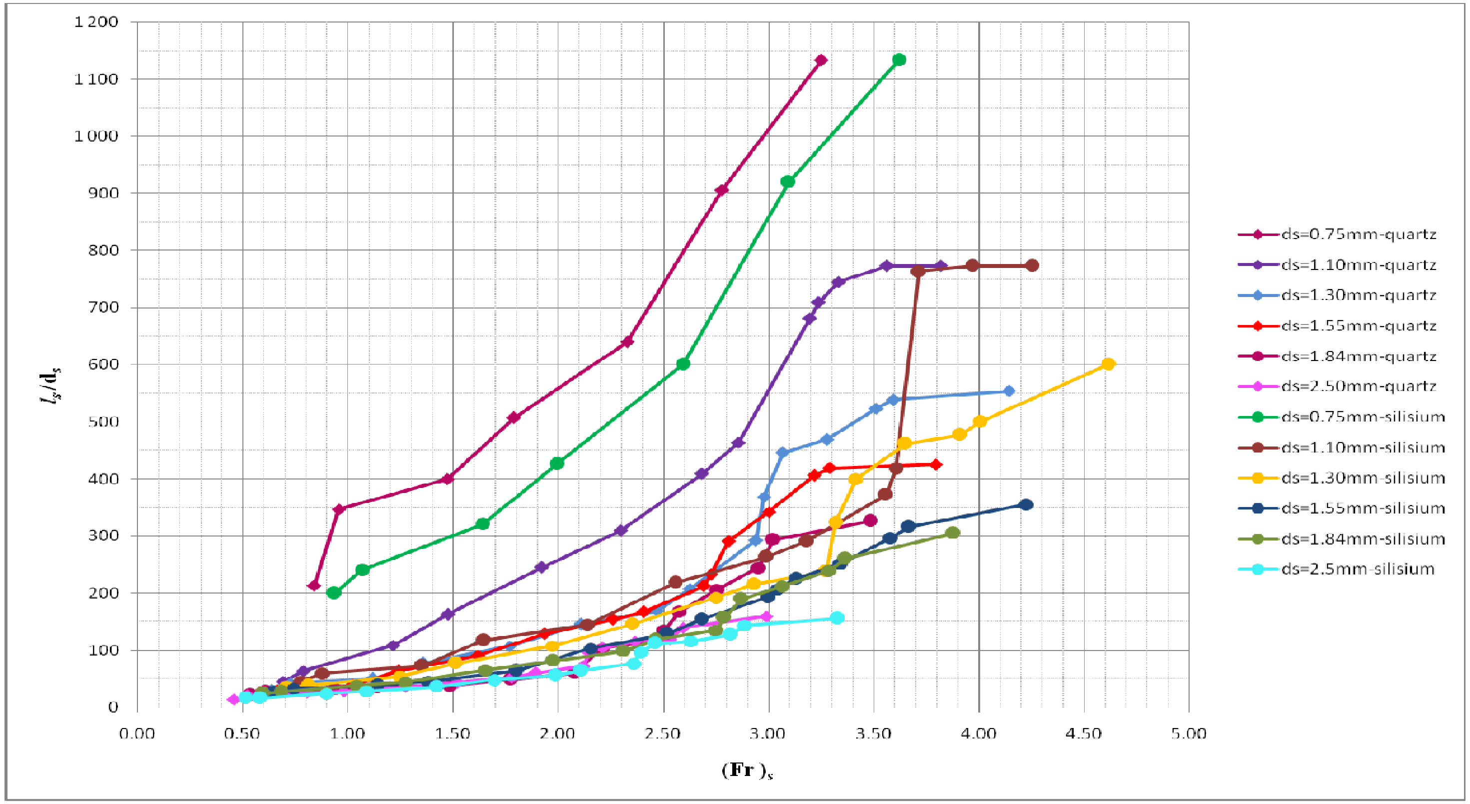


Figure 6.54 Variation of l_s/d_s with $(Fr)_s$ for quartz and silisium for the settling basin of Δz =13 cm

6.4.3. Numerical Examples

To compare the results of settling basin lengths to be dertermined from the findings of this study with those of Stock curve within the limits of parameters of this study, a series of numeric examples were presented below with 2 different discharges tested in the model for the settling basins of 3 different depths. The other input data were shown below and the results were presented in Tables 6.4 -6.9.

INPUT DATA:

B=	0.3	m
$(\rho_s)_{q=}$	2.65	m/s
$(\rho_s)_s$=	2.33	gr/m^3
ρ_w=	1.00	gr/m^3
$(\Delta\rho)_q$=	1.65	gr/m^3
$(\Delta\rho)_s$=	1.33	gr/m^3
g=	9.81	m/s^2

The calculations was started with reading the settling velocities, V_S, from the "Stock Curve (Figure 3.7)" according to the corresponding sediment diameters and the determined V_S values were shown in "column 2". In "column 3" the values of the required settling basin length calculated from Equation 3.3 was given. Then, the densimetric Froude numbers, $(Fr)_S$, were calculated from Equation 6.3 for each sediment diameter value and shown in "columns 5 and 6". After that l_S /d_S values were read from Figures 6.23-6.28 for quartz and silisium, respectively, for the calculated values of $(Fr)_S$ and stated in "columns 7 and 8". Lastly, the minimum required settling distances, $(l_S)_{exp}$, were deternined by multiplying d_S by l_S/d_S values written in "columns 7-8".

The analysis of Tables 6.4-6.9 shows that l_S values obtain from the Stock curve and the findings of this experimental study are compatable with each others. In Table 6.4, it is seen that while l_S values obtained from Stock curve vary between 0.06-0.35 m for the finest sediment group of 0.1mm≤d_S≤0.4mm, the corresponding l_S values calculated from the results of this study are 0.44 m for quartz and 0.35 m for silisium for which the average sediment diameter used is 0.2 mm. From this table and the others it is clearly seen that l_S values obtained from Stock curve for d_S=0.1 mm is very close to those of this study for d_S =0.2 mm for quartz and silisium used in the examples.

Table 6.4 Comparison of l_s values determined from the Stock curve and the results of the present study for Q=0.73 l/s at Δz=23cm

d_s (mm)	V_s (m/hr)	$(l_s)_{stock}$ (m)	d_s (mm)	$(Fr)_s$ for quartz	$(Fr)_s$ for silisium	l_s/d_s for quartz	l_s/d_s for silisium	$(l_s)_{exp}$ for quartz (m)	$(l_s)_{exp}$ for silisium (m)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0.1	25	0.35	0.2	2.85	3.18	2200	1750	0.44	0.35
0.2	65	0.13							
0.3	100	0.09							
0.4	135	0.06							
0.5	150	0.06	0.75	1.47	1.64	280.00	240.00	0.21	0.18
0.6	180	0.05							
0.7	200	0.04							
0.8	220	0.04							
0.9	240	0.04							
1	250	0.04							
1.1	255	0.03	1.1	1.22	1.35	72.73	63.64	0.08	0.07
1.3	290	0.03	1.3	1.12	1.25	38.46	46.15	0.05	0.06
1.55	300	0.03	1.55	1.02	1.14	29.03	32.26	0.05	0.05

Table 6.5 Comparison of l_s values determined from the Stock curve and the results of the present study for Q=1.13 l/s at Δz=23cm

d_s (mm)	V_s (m/hr)	$(l_s)_{stock}$ (m)	d_s (mm)	$(Fr)_s$ for quartz	$(Fr)_s$ for silisium	l_s/d_s for quartz	l_s/d_s for silisium	$(l_s)_{exp}$ for quartz (m)	$(l_s)_{exp}$ for silisium (m)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0.1	25	0.54	0.2	3.46	3.86	2750	2600	0.55	0.52
0.2	65	0.21							
0.3	100	0.13							
0.4	135	0.10							
0.5	150	0.09	0.75	1.79	1.99	346.67	293.33	0.26	0.22
0.6	180	0.07							
0.7	200	0.07							
0.8	220	0.06							
0.9	240	0.06							
1	250	0.05							
1.1	255	0.05	1.1	1.48	1.65	90.91	72.73	0.10	0.08
1.3	290	0.05	1.3	1.36	1.51	57.69	53.85	0.08	0.07
1.55	300	0.04	1.55	1.24	1.39	38.71	38.71	0.06	0.06

Table 6.6 Comparison of l_s values determined from the Stock curve and the results of the present study for Q=0.73 l/s at Δz=18cm

d_s (mm)	V_s (m/hr)	$(l_s)_{stock}$ (m)	d_s (mm)	$(Fr)_s$ for quartz	$(Fr)_s$ for silisium	l_s/d_s for quartz	l_s/d_s for silisium	$(l_s)_{exp}$ for quartz (m)	$(l_s)_{exp}$ for silisium (m)
1	2	3	4	5	6	7	8	9	10
0.1	25	0.35	0.2	2.85	3.18	2300	1900	0.46	0.38
0.2	65	0.13							
0.3	100	0.09							
0.4	135	0.06							
0.5	150	0.06	0.75	1.47	1.64	320.00	293.33	0.24	0.22
0.6	180	0.05							
0.7	200	0.04							
0.8	220	0.04							
0.9	240	0.04							
1	250	0.04							
1.1	255	0.03	1.1	1.22	1.35	90.91	63.64	0.10	0.07
1.3	290	0.03	1.3	1.12	1.25	46.15	61.54	0.06	0.08
1.55	300	0.03	1.55	1.02	1.14	32.26	41.94	0.05	0.07

Table 6.7 Comparison of l_s values determined from the Stock curve and the results of the present study for Q=1.13 l/s at Δz=18cm

d_s (mm)	V_s (m/hr)	$(l_s)_{stock}$ (m)	d_s (mm)	$(Fr)_s$ for quartz	$(Fr)_s$ for silisium	l_s/d_s for quartz	l_s/d_s for silisium	$(l_s)_{exp}$ for quartz (m)	$(l_s)_{exp}$ for silisium (m)
1	2	3	4	5	6	7	8	9	10
0.1	25	0.54	0.2	3.46	3.86	3000	2750	0.60	0.55
0.2	65	0.21							
0.3	100	0.13							
0.4	135	0.10							
0.5	150	0.09	0.75	1.79	1.99	413.33	373.33	0.31	0.28
0.6	180	0.07							
0.7	200	0.07							
0.8	220	0.06							
0.9	240	0.06							
1	250	0.05							
1.1	255	0.05	1.1	1.48	1.65	100.00	90.91	0.11	0.10
1.3	290	0.05	1.3	1.36	1.51	50.00	61.54	0.07	0.08
1.55	300	0.04	1.55	1.24	1.39	51.61	45.16	0.08	0.07

Table 6.8 Comparison of l_s values determined from the Stock curve and the results of the present study for Q=0.73 l/s at Δz=13cm

d_s (mm)	V_s (m/hr)	$(l_s)_{stock}$ (m)	d_s (mm)	$(Fr)_s$ for quartz	$(Fr)_s$ for silisium	l_s/d_s for quartz	l_s/d_s for silisium	$(l_s)_{exp}$ for quartz (m)	$(l_s)_{exp}$ for silisium (m)
1	2	3	4	5	6	7	8	9	10
0.1	25	0.35	0.2	2.85	3.18	2750	2250	0.55	0.45
0.2	65	0.13							
0.3	100	0.09							
0.4	135	0.06							
0.5	150	0.06	0.75	1.47	1.64	400.00	320.00	0.30	0.24
0.6	180	0.05							
0.7	200	0.04							
0.8	220	0.04							
0.9	240	0.04							
1	250	0.04							
1.1	255	0.03	1.1	1.22	1.35	109.09	72.73	0.12	0.08
1.3	290	0.03	1.3	1.12	1.25	50.00	53.85	0.07	0.07
1.55	300	0.03	1.55	1.02	1.14	38.71	38.71	0.06	0.06

Table 6.9 Comparison of l_s values determined from the Stock curve and the results of the present study for Q=1.13 l/s at Δz=13cm

d_s (mm)	V_s (m/hr)	$(l_s)_{stock}$ (m)	d_s (mm)	$(Fr)_s$ for quartz	$(Fr)_s$ for silisium	l_s/d_s for quartz	l_s/d_s for silisium	$(l_s)_{exp}$ for quartz (m)	$(l_s)_{exp}$ for silisium (m)
1	2	3	4	5	6	7	8	9	10
0.1	25	0.54	0.2	3.46	3.86	3400	3250	0.68	0.65
0.2	65	0.21							
0.3	100	0.13							
0.4	135	0.10							
0.5	150	0.09	0.75	1.79	1.99	506.67	426.67	0.38	0.32
0.6	180	0.07							
0.7	200	0.07							
0.8	220	0.06							
0.9	240	0.06							
1	250	0.05							
1.1	255	0.05	1.1	1.48	1.65	163.64	118.18	0.18	0.13
1.3	290	0.05	1.3	1.36	1.51	76.92	76.92	0.10	0.10
1.55	300	0.04	1.55	1.24	1.39	64.52	45.16	0.10	0.07

CHAPTER 7

CONCLUSIONS AND RECCOMENDATIONS

7.1. SUMMARY AND CONCLUSIONS

Within the scope of this study based on the hydraulic analysis of a settling basin, the available settling basin design procedures in the literature were reviewed. Some of the settling basins constructed in Turkey were studied and the problems observed in their operations were analyzed. In a model of a settling basin having constant width and variable depths a series of experiments were carried out with various sediment groups of quartz and silisium. These sediment groups were tested in the settling basin model over a wide range of discharges to measure the maximum settling distances of the sediment particles. From the measured and calculated hydraulic parameters some important dimensionless parameters describing the particle settling process were calculated and related with each others. From the results of this experimental study the following conclusions can be drawn:

1) In the design of settling basins prismatic Bieri type basins can be preferred since it ensures energy production even during the flushing procedure.

2) The cross section of the basin should be widen gently until the flow is slow enough to let the particles settle down. The flow is quite sensitive to the edges of the structure.

3) A large settling basin width causes an unequal current in the settling tank which can prevent settling of some sediment particles. To solve this problem, several settling basins must be arranged side by side which is called as "chamber".

4) The slope of the side edges (α) of the basement of the settling basin is very important to make small sediment particles go away from the side edges.

5) Based on the interview performed with some authorized engineers who are in charge of operation of some settling basins in Turkey, the following conclusions can be stated:

– Before designing the water intake structure, the type and size ranges of the sediments which will come from upstream of the hydraulic system should be investigated carefully.

– The water intake structure should be designed in such a way that most of the incoming sediment, especially during flood times, should be diverted downstream of the structure so that only fine particles are allowed to enter the settling basin.

– The bottom and side slopes of the settling basin should be large enough so that the flushing operation can easily be performed.

– The deposition rates of the settling basins with sediment should be observed carefully and the flushing process should be applied before the settled sediment gets firm. Otherwise, an efficient flushing can not be applied and dredging is needed.

6) Under given flow and settling basin conditions; h, V, Δz known, as the sediment diameter gets smaller, the settling distance of the particle increases.

7) For a given diameter of sediment, the dimensionless particle settling distance, l_s/d_s, increases as the densimetric Froude number, $(Fr)_s$, increases. The rate of increase of l_s/d_s with $(Fr)_s$ decreases as the sediment particles get coarser.

8) The variation of l_s/d_s with h/d_s is very similar to that of l_s/d_s with $(Fr)_s$.

9) For particles of diameters $d_s \leq 1.10$ mm, l_s/d_s almost does not change with increasing sill height, $\Delta z/d_s$, at maximum $(Fr)_s$ tested; $3.25 \leq (Fr)_s \leq 5.02$ for quartz and silisium. Because, under these flow condition, the total length of the settling basin used in the experiments was not long enough.

10) For particles of $d_s > 1.10$ mm, for the minimum $(Fr)_s$ values tested; $0.46 \leq (Fr)_s \leq 0.71$, l_s/d_s does not change with increasing $\Delta z/d_s$.

11) At intermediate $(Fr)_s$ values l_s/d_s decreases with increasing $\Delta z/d_s$. The settling basins having the maximum depth show the best performances by yielding the minimum settling distances for the particles tested.

12) Due to more rounded shape of silisium particles than quartz particles, although the density of quartz particles are larger than silisium particles, their l_s/d_s values are less than those of quartz particles.

7.2. RECOMMENDATIONS

The similar experiments to those carried out in this study should be repeated with much larger settling basin models. In this case, it will be possible to convey very high flow rates through the settling basins from which more data for l_s/d_s can be provided at much larger $(Fr)_s$ than those obtained in this study. The possibility of measuring the sediment concentration entering and leaving the settling basin will enable to get very important information about the efficiency of the settling basins.

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APPENDIX A

MEASURED AND CALCULATED EXPERIMENTAL PARAMETERS

Table A1 Maximum settling distances of quartz particles at 23 cm sill height

l_s (cm) for Quartz																
d_s (mm) \ h (cm)		1	1.3	1.5	1.9	2.6	3.3	3.8	4.1	4.6	5	5.5	6	6.3	6.8	7.3
0~0.4	test-1	22	26	44	53	85	85	85	85	85	85	85	85	85	85	85
	test-2	20	28	42	55	85	85	85	85	85	85	85	85	85	85	85
0.5~1	test-1	13	16	20	26	35	55	85	85	85	85	85	85	85	85	85
	test-2	14	18	21	25	33	52	85	85	85	85	85	85	85	85	85
1~1.19	test-1	4	6	8	9	18	19	35	41	60	68	76	85	85	85	85
	test-2	4	5	8	10	20	22	38	43	62	66	72	85	85	85	85
1.19~1.41	test-1	3	4	5	7.5	8	11	15	22	29	37	48	50	56	61	66
	test-2	3.5	4.5	5	6	8	10	14	23	28	36	45	48	55	59	65
1.41~1.68	test-1	4	4	4.5	6	8	9	15	16	20	23	32	43	52	58	63
	test-2	4	4	4	6	7	13	14	18	18	22	29	42	49	55	61
1.68~2	test-1	3	4	4	5	6	7	7	12	15	16	18	27	30	44	48
	test-2	3	4	4.5	5	6	8	9	14	16	18	21	25	32	46	50
2~3	test-1	3	3	4	4	5	7	8	9	11	15	15	18	21	24	31
	test-2	3	3	4	4	6	5	6	10	10	13	16	19	20	26	27

Table A2 Maximum settling distances of sillisium particles at 23 cm sill height

d_s (mm)	h (cm)	l_s (cm) for Silisium: 1	1.3	1.5	1.9	2.6	3.3	3.8	4.1	4.6	5	5.5	6	6.3	6.8	7.3
0~0.4	test-1	15	18	32	45	85	85	85	85	85	85	85	85	85	85	85
	test-2	13	16	35	52	85	85	85	85	85	85	85	85	85	85	85
0.5~1	test-1	8	10	16	22	35	58	85	85	85	85	85	85	85	85	85
	test-2	9	13	18	20	38	62	85	85	85	85	85	85	85	85	85
1~1.19	test-1	4	4	6	8	11	16	21	25	31	36	75	80	85	85	85
	test-2	4	5	7	8	10	15	18	26	35	38	80	82	85	85	85
1.19~1.41	test-1	4	4.5	6	6	7	12	18	21	26	35	47	49	52	57	65
	test-2	4	4	5	7	8	14	20	22	25	33	45	47	55	56	62
1.41~1.68	test-1	4	4	5	5	8	9	9	14	19	24	30	36	38	41	43
	test-2	4	4	5	6	7	9	11	16	22	26	29	35	42	43	41
1.68~2	test-1	3.5	4	4.5	6	6	6	8	9	10	14	18	24	31	37	43
	test-2	3	4	4	5	7	7	6	8	11	12	16	26	29	35	45
2~3	test-1	3	4	5	4	6	6	6	7	7	10	11	13	16	17	25
	test-2	3	4	4	5	5	7	7	8	9	9	10	12	15	18	26

Table A3 Maximum settling distances of quartz particles at 18 cm sill height

		l_s (cm) for Quartz														
d_s (mm)	h (cm)	**1**	**1.3**	**1.5**	**1.9**	**2.6**	**3.3**	**3.8**	**4.1**	**4.6**	**5**	**5.5**	**6**	**6.3**	**6.8**	**7.3**
0~0.4	test-1	22	30	46	58	85	85	85	85	85	85	85	85	85	85	85
	test-2	25	28	43	60	85	85	85	85	85	85	85	85	85	85	85
0.5~1	test-1	16	18	24	29	38	60	85	85	85	85	85	85	85	85	85
	test-2	15	20	22	31	35	63	85	85	85	85	85	85	85	85	85
1~1.19	test-1	5	6	8	11	22	25	41	44	65	72	76	85	85	85	85
	test-2	4	7	10	10	20	22	38	46	68	70	80	85	85	85	85
1.19~1.41	test-1	4	5	6	6.5	10	11	18	22	31	41	50	55	60	65	72
	test-2	4	5	6	6	9	13	19	25	33	43	52	57	58	62	69
1.41~1.68	test-1	4	4	5	8	7	15	19	21	25	28	36	48	56	61	64
	test-2	4	4	5	7	9	13	16	22	26	29	38	46	58	59	66
1.68~2	test-1	4	4	5	6	6	7	7	15	18	19	23	32	33	48	52
	test-2	4	4.5	5.5	6	7	9	10	14	17	18	25	29	35	44	54
2~3	test-1	3	3	4	4	7	8	10	11	13	19	20	22	25	29	32
	test-2	2.5	4	4.5	5	6	7.5	9	12	15	17	18	20	24	27	35

Table A4 Maximum settling distances of silisium particles at 18 cm sill height

d_s (mm)	h (cm)	l_s (cm) for Silisium														
		1	**1.3**	**1.5**	**1.9**	**2.6**	**3.3**	**3.8**	**4.1**	**4.6**	**5**	**5.5**	**6**	**6.3**	**6.8**	**7.3**
0~0.4	test-1	15	26	35	48	85	85	85	85	85	85	85	85	85	85	85
	test-2	18	27	38	55	85	85	85	85	85	85	85	85	85	85	85
0.5~1	test-1	10	11	22	28	41	60	85	85	85	85	85	85	85	85	85
	test-2	9	15	20	26	39	65	85	85	85	85	85	85	85	85	85
1~1.19	test-1	4	6	6	9	12	18	21	29	34	40	82	83	85	85	85
	test-2	5	5	7	10	13	16	25	28	36	42	78	78	85	85	85
1.19~1.41	test-1	4	4.5	8	8	9	14	18	20	28	36	46	51	58	60	69
	test-2	4	4	7	8	10	14	22	24	25	39	49	54	55	55	71
1.41~1.68	test-1	4	4	6	5	8	9	9	19	22	28	33	33	40	43	48
	test-2	4	4.5	6.5	7	9	10	12	18	24	29	31	37	44	45	45
1.68~2	test-1	4	4.5	4.5	6	6	5	6	12	16	22	31	35	37	41	49
	test-2	3	4	5	5	6	7	8	11	18	21	28	33	35	38	52
2~3	test-1	3	4	4	4	6	8	6	8	9	11	12	15	18	22	28
	test-2	4	4	4	5	5	7	7	6	8	9	11	16	20	24	30

Table A5 Maximum settling distances of quartz particles at 13 cm sill height

		l_s (cm) for Quartz														
d_s (mm)	h (cm)	**1**	**1.3**	**1.5**	**1.9**	**2.6**	**3.3**	**3.8**	**4.1**	**4.6**	**5**	**5.5**	**6**	**6.3**	**6.8**	**7.3**
0~0.4	test-1	28	35	50	66	85	85	85	85	85	passed away	passed away	passed away	passed away	passed away	passed away
	test-2	26	39	55	68	85	85	85	85	85	passed away	passed away	passed away	passed away	passed away	passed away
0.5~1	test-1	20	26	30	36	48	68	85	85	85	85	passed away	passed away	passed away	passed away	passed away
	test-2	18	24	28	38	45	60	85	85	85	85	passed away	passed away	passed away	passed away	passed away
1~1.19	test-1	4.5	6	12	18	26	34	45	51	70	78	82	85	85	85	85
	test-2	5	7	11	15	27	32	43	48	75	75	79	85	85	85	85
1.19~1.41	test-1	4	5	6.5	8	14	16	22	25	35	48	55	58	68	70	78
	test-2	4.5	5.5	6	10	10	19	18	27	38	45	58	61	64	68	75
1.41~1.68	test-1	4	4	6	10	12	20	24	26	33	36	45	51	63	65	68
	test-2	3.5	4.5	6	9	14	18	18	25	31	35	43	53	61	64	72
1.68~2	test-1	4	5	6	6.5	6	8	11	19	22	25	28	36	45	54	60
	test-2	4	4	5.5	6	7	9	9	18	19	24	31	38	42	52	58
2~3	test-1	3	4.5	5	7	8	10	13	15	16	24	26	26	30	33	38
	test-2	3.5	5	6.5	6	9	11	11	14	18	23	22	29	28	35	40

Table A6 Maximum settling distances of sillisium particles at 13 cm sill height

l_s (cm) for Silisium																
d_s (mm) \ h (cm)		1	1.3	1.5	1.9	2.6	3.3	3.8	4.1	4.6	5	5.5	6	6.3	6.8	7.3
0~0.4	test-1	20	30	45	65	85	85	85	85	85	passed away	passed away	passed away	passed away	passed away	passed away
	test-2	24	29	41	60	85	85	85	85	85	passed away	passed away	passed away	passed away	passed away	passed away
0.5~1	test-1	15	18	18	29	45	58	85	85	85	85	passed away	passed away	passed away	passed away	passed away
	test-2	13	13	24	32	42	69	85	85	85	85	passed away	passed away	passed away	passed away	passed away
1~1.19	test-1	4.5	5	8	11	16	23	28	30	38	44	78	85	85	85	85
	test-2	5	6.5	7	13	15	24	29	32	41	46	84	85	85	85	85
1.19~1.41	test-1	4.5	5	6	10	14	19	25	25	31	42	51	58	62	63	78
	test-2	4.5	4	7	8	13	18	22	28	28	39	52	60	59	65	75
1.41~1.68	test-1	4	5	5.5	6.5	10	16	20	24	30	32	33	39	46	45	55
	test-2	4	4.5	6	7	9	14	18	22	28	30	35	37	44	49	52
1.68~2	test-1	4.5	4	6	8	12	14	18	20	24	26	34	39	42	48	55
	test-2	4	5	7	7	10	15	15	22	25	29	35	38	44	46	56
2~3	test-1	4	4	5	7	8	10	14	15	19	24	26	27	32	33	39
	test-2	3	3.5	6	6	9	12	12	16	18	22	28	29	30	36	35

Table A7 Measured and calculated experimental parameters for quartz and the setlling basin of Δz=23 cm

QUARTZ , Δz=23 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
0.20	1	0.09	22	1100	1.63	50	1150
	1.3	0.11	28	1400	1.85	65	1150
	1.5	0.16	44	2200	2.85	75	1150
	1.9	0.20	55	2750	3.46	95	1150
	2.6	0.26	85	4250	4.51	130	1150
	3.3	0.31	85	4250	5.38	165	1150
	3.8	0.36	85	4250	6.29	190	1150
	4.1	0.38	85	4250	6.70	205	1150
	4.6	0.43	85	4250	7.49	230	1150
	5	0.43	85	4250	7.59	250	1150
	5.5	0.44	85	4250	7.82	275	1150
	6	0.48	85	4250	8.35	300	1150
	6.3	0.51	85	4250	8.95	315	1150
	6.8	0.52	85	4250	9.17	340	1150
	7.3	0.60	85	4250	10.56	365	1150
0.75	1	0.09	14	186.67	0.84	13.33	306.67
	1.3	0.11	18	240.00	0.96	17.33	306.67
	1.5	0.16	21	280.00	1.47	20.00	306.67
	1.9	0.20	26	346.67	1.79	25.33	306.67
	2.6	0.26	35	466.67	2.33	34.67	306.67
	3.3	0.31	55	733.33	2.78	44.00	306.67
	3.8	0.36	85	1133.33	3.25	50.67	306.67
	4.1	0.38	85	1133.33	3.46	54.67	306.67
	4.6	0.43	85	1133.33	3.87	61.33	306.67
	5	0.43	85	1133.33	3.92	66.67	306.67
	5.5	0.44	85	1133.33	4.04	73.33	306.67
	6	0.48	85	1133.33	4.31	80.00	306.67
	6.3	0.51	85	1133.33	4.62	84.00	306.67
	6.8	0.52	85	1133.33	4.73	90.67	306.67
	7.3	0.60	85	1133.33	5.45	97.33	306.67

Table A7 Continued

QUARTZ , Δz=23 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
1.10	1	0.09	4	36.36	0.69	9.09	209.09
	1.3	0.11	6	54.55	0.79	11.82	209.09
	1.5	0.16	8	72.73	1.22	13.64	209.09
	1.9	0.20	10	90.91	1.48	17.27	209.09
	2.6	0.26	20	181.82	1.92	23.64	209.09
	3.3	0.31	22	200.00	2.29	30.00	209.09
	3.8	0.36	38	345.45	2.68	34.55	209.09
	4.1	0.38	43	390.91	2.86	37.27	209.09
	4.6	0.43	62	563.64	3.19	41.82	209.09
	5	0.43	68	618.18	3.24	45.45	209.09
	5.5	0.44	76	690.91	3.33	50.00	209.09
	6	0.48	85	772.73	3.56	54.55	209.09
	6.3	0.51	85	772.73	3.82	57.27	209.09
	6.8	0.52	85	772.73	3.91	61.82	209.09
	7.3	0.60	85	772.73	4.50	66.36	209.09
1.30	1	0.09	3.5	26.92	0.64	7.69	176.92
	1.3	0.11	4.5	34.62	0.73	10.00	176.92
	1.5	0.16	5	38.46	1.12	11.54	176.92
	1.9	0.20	7.5	57.69	1.36	14.62	176.92
	2.6	0.26	8	61.54	1.77	20.00	176.92
	3.3	0.31	11	84.62	2.11	25.38	176.92
	3.8	0.36	15	115.38	2.47	29.23	176.92
	4.1	0.38	23	176.92	2.63	31.54	176.92
	4.6	0.43	29	223.08	2.94	35.38	176.92
	5	0.43	37	284.62	2.98	38.46	176.92
	5.5	0.44	48	369.23	3.07	42.31	176.92
	6	0.48	50	384.62	3.28	46.15	176.92
	6.3	0.51	56	430.77	3.51	48.46	176.92
	6.8	0.52	61	469.23	3.59	52.31	176.92
	7.3	0.60	66	507.69	4.14	56.15	176.92

Table A7 Continued

QUARTZ , Δz=23 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
1.55	1	0.09	4	25.81	0.58	6.45	148.39
	1.3	0.11	4	25.81	0.67	8.39	148.39
	1.5	0.16	4.5	29.03	1.02	9.68	148.39
	1.9	0.20	6	38.71	1.24	12.26	148.39
	2.6	0.26	8	51.61	1.62	16.77	148.39
	3.3	0.31	13	83.87	1.93	21.29	148.39
	3.8	0.36	15	96.77	2.26	24.52	148.39
	4.1	0.38	18	116.13	2.41	26.45	148.39
	4.6	0.43	20	129.03	2.69	29.68	148.39
	5	0.43	23	148.39	2.73	32.26	148.39
	5.5	0.44	32	206.45	2.81	35.48	148.39
	6	0.48	43	277.42	3.00	38.71	148.39
	6.3	0.51	52	335.48	3.22	40.65	148.39
	6.8	0.52	58	374.19	3.29	43.87	148.39
	7.3	0.60	63	406.45	3.79	47.10	148.39
1.84	1	0.09	3	16.30	0.54	5.43	125.00
	1.3	0.11	4	21.74	0.61	7.07	125.00
	1.5	0.16	4.5	24.46	0.94	8.15	125.00
	1.9	0.20	5	27.17	1.14	10.33	125.00
	2.6	0.26	6	32.61	1.49	14.13	125.00
	3.3	0.31	8	43.48	1.77	17.93	125.00
	3.8	0.36	9	48.91	2.07	20.65	125.00
	4.1	0.38	14	76.09	2.21	22.28	125.00
	4.6	0.43	16	86.96	2.47	25.00	125.00
	5	0.43	18	97.83	2.50	27.17	125.00
	5.5	0.44	21	114.13	2.58	29.89	125.00
	6	0.48	27	146.74	2.75	32.61	125.00
	6.3	0.51	32	173.91	2.95	34.24	125.00
	6.8	0.52	46	250.00	3.02	36.96	125.00
	7.3	0.60	50	271.74	3.48	39.67	125.00

Table A7 Continued

QUARTZ , Δz=23 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	***l_s*** (cm)	***l_s*/d_s**	**$(Fr)_s$**	**h/d_s**	**Δz/d_s**
2.50	1	0.09	3	12.00	0.46	4.00	92.00
	1.3	0.11	3	12.00	0.52	5.20	92.00
	1.5	0.16	4	16.00	0.81	6.00	92.00
	1.9	0.20	4	16.00	0.98	7.60	92.00
	2.6	0.26	6	24.00	1.27	10.40	92.00
	3.3	0.31	7	28.00	1.52	13.20	92.00
	3.8	0.36	8	32.00	1.78	15.20	92.00
	4.1	0.38	10	40.00	1.89	16.40	92.00
	4.6	0.43	11	44.00	2.12	18.40	92.00
	5	0.43	15	60.00	2.15	20.00	92.00
	5.5	0.44	16	64.00	2.21	22.00	92.00
	6	0.48	19	76.00	2.36	24.00	92.00
	6.3	0.51	21	84.00	2.53	25.20	92.00
	6.8	0.52	26	104.00	2.59	27.20	92.00
	7.3	0.60	31	124.00	2.99	29.20	92.00

Table A8 Measured and calculated experimental parameters for silisium and the setlling basin of Δz=23 cm

SILISIUM , Δz=23 cm , ρ_s=2.33 gr/cm³							
d_s (mm)	**h** (cm)	**V** (m/s)	l_s (cm)	l_s/d_s	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
0.20	1	0.09	15	750	1.81	50	1150
	1.3	0.11	18	900	2.07	65	1150
	1.5	0.16	35	1750	3.18	75	1150
	1.9	0.20	52	2600	3.86	95	1150
	2.6	0.26	85	4250	5.02	130	1150
	3.3	0.31	85	4250	5.99	165	1150
	3.8	0.36	85	4250	7.01	190	1150
	4.1	0.38	85	4250	7.46	205	1150
	4.6	0.43	85	4250	8.34	230	1150
	5	0.43	85	4250	8.45	250	1150
	5.5	0.44	85	4250	8.71	275	1150
	6	0.48	85	4250	9.31	300	1150
	6.3	0.51	85	4250	9.97	315	1150
	6.8	0.52	85	4250	10.21	340	1150
	7.3	0.60	85	4250	11.76	365	1150
0.75	1	0.09	9	120.00	0.94	13.33	306.67
	1.3	0.11	13	173.33	1.07	17.33	306.67
	1.5	0.16	18	240.00	1.64	20.00	306.67
	1.9	0.20	22	293.33	1.99	25.33	306.67
	2.6	0.26	38	506.67	2.59	34.67	306.67
	3.3	0.31	62	826.67	3.09	44.00	306.67
	3.8	0.36	85	1133.33	3.62	50.67	306.67
	4.1	0.38	85	1133.33	3.85	54.67	306.67
	4.6	0.43	85	1133.33	4.31	61.33	306.67
	5	0.43	85	1133.33	4.37	66.67	306.67
	5.5	0.44	85	1133.33	4.50	73.33	306.67
	6	0.48	85	1133.33	4.81	80.00	306.67
	6.3	0.51	85	1133.33	5.15	84.00	306.67
	6.8	0.52	85	1133.33	5.27	90.67	306.67
	7.3	0.60	85	1133.33	6.07	97.33	306.67

Table A8 Continued

SILISIUM , Δz=23 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	***l_s*** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
1.10	1	0.09	4	36.36	0.77	9.09	209.09
	1.3	0.11	5	45.45	0.88	11.82	209.09
	1.5	0.16	7	63.64	1.35	13.64	209.09
	1.9	0.20	8	72.73	1.65	17.27	209.09
	2.6	0.26	11	100.00	2.14	23.64	209.09
	3.3	0.31	16	145.45	2.56	30.00	209.09
	3.8	0.36	21	190.91	2.99	34.55	209.09
	4.1	0.38	26	236.36	3.18	37.27	209.09
	4.6	0.43	35	318.18	3.56	41.82	209.09
	5	0.43	38	345.45	3.60	45.45	209.09
	5.5	0.44	80	727.27	3.71	50.00	209.09
	6	0.48	82	745.45	3.97	54.55	209.09
	6.3	0.51	85	772.73	4.25	57.27	209.09
	6.8	0.52	85	772.73	4.35	61.82	209.09
	7.3	0.60	85	772.73	5.02	66.36	209.09
1.30	1	0.09	4	30.77	0.71	7.69	176.92
	1.3	0.11	4.5	34.62	0.81	10.00	176.92
	1.5	0.16	6	46.15	1.25	11.54	176.92
	1.9	0.20	7	53.85	1.51	14.62	176.92
	2.6	0.26	8	61.54	1.97	20.00	176.92
	3.3	0.31	14	107.69	2.35	25.38	176.92
	3.8	0.36	20	153.85	2.75	29.23	176.92
	4.1	0.38	22	169.23	2.93	31.54	176.92
	4.6	0.43	26	200.00	3.27	35.38	176.92
	5	0.43	35	269.23	3.32	38.46	176.92
	5.5	0.44	47	361.54	3.42	42.31	176.92
	6	0.48	49	376.92	3.65	46.15	176.92
	6.3	0.51	55	423.08	3.91	48.46	176.92
	6.8	0.52	57	438.46	4.00	52.31	176.92
	7.3	0.60	65	500.00	4.61	56.15	176.92

Table A8 Continued

SILISIUM , Δz=23 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
1.55	1	0.09	4	25.81	0.65	6.45	148.39
	1.3	0.11	4	25.81	0.74	8.39	148.39
	1.5	0.16	5	32.26	1.14	9.68	148.39
	1.9	0.20	6	38.71	1.39	12.26	148.39
	2.6	0.26	8	51.61	1.80	16.77	148.39
	3.3	0.31	9	58.06	2.15	21.29	148.39
	3.8	0.36	11	70.97	2.52	24.52	148.39
	4.1	0.38	16	103.23	2.68	26.45	148.39
	4.6	0.43	22	141.94	3.00	29.68	148.39
	5	0.43	26	167.74	3.04	32.26	148.39
	5.5	0.44	30	193.55	3.13	35.48	148.39
	6	0.48	36	232.26	3.34	38.71	148.39
	6.3	0.51	42	270.97	3.58	40.65	148.39
	6.8	0.52	43	277.42	3.67	43.87	148.39
	7.3	0.60	43	277.42	4.22	47.10	148.39
1.84	1	0.09	3.5	19.02	0.60	5.43	125.00
	1.3	0.11	4	21.74	0.68	7.07	125.00
	1.5	0.16	4.5	24.46	1.05	8.15	125.00
	1.9	0.20	6	32.61	1.27	10.33	125.00
	2.6	0.26	7	38.04	1.65	14.13	125.00
	3.3	0.31	7	38.04	1.98	17.93	125.00
	3.8	0.36	8	43.48	2.31	20.65	125.00
	4.1	0.38	9	48.91	2.46	22.28	125.00
	4.6	0.43	11	59.78	2.75	25.00	125.00
	5	0.43	14	76.09	2.79	27.17	125.00
	5.5	0.44	18	97.83	2.87	29.89	125.00
	6	0.48	26	141.30	3.07	32.61	125.00
	6.3	0.51	31	168.48	3.29	34.24	125.00
	6.8	0.52	37	201.09	3.37	36.96	125.00
	7.3	0.60	45	244.57	3.88	39.67	125.00

Table A8 Continued

SILISIUM , Δz=23 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
2.50	1	0.09	3	12.00	0.51	4.00	92.00
	1.3	0.11	4	16.00	0.58	5.20	92.00
	1.5	0.16	5	20.00	0.90	6.00	92.00
	1.9	0.20	5	20.00	1.09	7.60	92.00
	2.6	0.26	6	24.00	1.42	10.40	92.00
	3.3	0.31	7	28.00	1.69	13.20	92.00
	3.8	0.36	7	28.00	1.98	15.20	92.00
	4.1	0.38	8	32.00	2.11	16.40	92.00
	4.6	0.43	9	36.00	2.36	18.40	92.00
	5	0.43	10	40.00	2.39	20.00	92.00
	5.5	0.44	11	44.00	2.46	22.00	92.00
	6	0.48	13	52.00	2.63	24.00	92.00
	6.3	0.51	16	64.00	2.82	25.20	92.00
	6.8	0.52	18	72.00	2.89	27.20	92.00
	7.3	0.60	26	104.00	3.33	29.20	92.00

Table A9 Measured and calculated experimental parameters for quartz and the setlling basin of Δz=18 cm

QUARTZ , Δz=18 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	***l_s*** (cm)	***l_s*/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
0.20	1	0.09	25	1250	1.63	50	900
	1.3	0.11	30	1500	1.85	65	900
	1.5	0.16	46	2300	2.85	75	900
	1.9	0.20	60	3000	3.46	95	900
	2.6	0.26	85	4250	4.51	130	900
	3.3	0.31	85	4250	5.38	165	900
	3.8	0.36	85	4250	6.29	190	900
	4.1	0.38	85	4250	6.70	205	900
	4.6	0.43	85	4250	7.49	230	900
	5	0.43	85	4250	7.59	250	900
	5.5	0.44	85	4250	7.82	275	900
	6	0.48	85	4250	8.35	300	900
	6.3	0.51	85	4250	8.95	315	900
	6.8	0.52	85	4250	9.17	340	900
	7.3	0.60	85	4250	10.56	365	900
0.75	1	0.09	16	213.33	0.84	13.33	240.00
	1.3	0.11	20	266.67	0.96	17.33	240.00
	1.5	0.16	24	320.00	1.47	20.00	240.00
	1.9	0.20	31	413.33	1.79	25.33	240.00
	2.6	0.26	38	506.67	2.33	34.67	240.00
	3.3	0.31	63	840.00	2.78	44.00	240.00
	3.8	0.36	85	1133.33	3.25	50.67	240.00
	4.1	0.38	85	1133.33	3.46	54.67	240.00
	4.6	0.43	85	1133.33	3.87	61.33	240.00
	5	0.43	85	1133.33	3.92	66.67	240.00
	5.5	0.44	85	1133.33	4.04	73.33	240.00
	6	0.48	85	1133.33	4.31	80.00	240.00
	6.3	0.51	85	1133.33	4.62	84.00	240.00
	6.8	0.52	85	1133.33	4.73	90.67	240.00
	7.3	0.60	85	1133.33	5.45	97.33	240.00

Table A9 Continued

QUARTZ , Δz=18 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	***l_s*** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
1.10	1	0.09	5	45.45	0.69	9.09	163.64
	1.3	0.11	7	63.64	0.79	11.82	163.64
	1.5	0.16	10	90.91	1.22	13.64	163.64
	1.9	0.20	11	100.00	1.48	17.27	163.64
	2.6	0.26	22	200.00	1.92	23.64	163.64
	3.3	0.31	25	227.27	2.29	30.00	163.64
	3.8	0.36	41	372.73	2.68	34.55	163.64
	4.1	0.38	46	418.18	2.86	37.27	163.64
	4.6	0.43	68	618.18	3.19	41.82	163.64
	5	0.43	72	654.55	3.24	45.45	163.64
	5.5	0.44	80	727.27	3.33	50.00	163.64
	6	0.48	85	772.73	3.56	54.55	163.64
	6.3	0.51	85	772.73	3.82	57.27	163.64
	6.8	0.52	85	772.73	3.91	61.82	163.64
	7.3	0.60	85	772.73	4.50	66.36	163.64
1.30	1	0.09	4	30.77	0.64	7.69	138.46
	1.3	0.11	5	38.46	0.73	10.00	138.46
	1.5	0.16	6	46.15	1.12	11.54	138.46
	1.9	0.20	6.5	50.00	1.36	14.62	138.46
	2.6	0.26	10	76.92	1.77	20.00	138.46
	3.3	0.31	13	100.00	2.11	25.38	138.46
	3.8	0.36	19	146.15	2.47	29.23	138.46
	4.1	0.38	25	192.31	2.63	31.54	138.46
	4.6	0.43	33	253.85	2.94	35.38	138.46
	5	0.43	43	330.77	2.98	38.46	138.46
	5.5	0.44	52	400.00	3.07	42.31	138.46
	6	0.48	57	438.46	3.28	46.15	138.46
	6.3	0.51	60	461.54	3.51	48.46	138.46
	6.8	0.52	65	500.00	3.59	52.31	138.46
	7.3	0.60	72	553.85	4.14	56.15	138.46

Table A9 Continued

QUARTZ , Δz=18 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
1.55	1	0.09	4	25.81	0.58	6.45	116.13
	1.3	0.11	4	25.81	0.67	8.39	116.13
	1.5	0.16	5	32.26	1.02	9.68	116.13
	1.9	0.20	8	51.61	1.24	12.26	116.13
	2.6	0.26	9	58.06	1.62	16.77	116.13
	3.3	0.31	15	96.77	1.93	21.29	116.13
	3.8	0.36	19	122.58	2.26	24.52	116.13
	4.1	0.38	22	141.94	2.41	26.45	116.13
	4.6	0.43	26	167.74	2.69	29.68	116.13
	5	0.43	29	187.10	2.73	32.26	116.13
	5.5	0.44	38	245.16	2.81	35.48	116.13
	6	0.48	48	309.68	3.00	38.71	116.13
	6.3	0.51	58	374.19	3.22	40.65	116.13
	6.8	0.52	61	393.55	3.29	43.87	116.13
	7.3	0.60	66	425.81	3.79	47.10	116.13
1.84	1	0.09	4	21.74	0.54	5.43	97.83
	1.3	0.11	4.5	24.46	0.61	7.07	97.83
	1.5	0.16	5.5	29.89	0.94	8.15	97.83
	1.9	0.20	6	32.61	1.14	10.33	97.83
	2.6	0.26	7	38.04	1.49	14.13	97.83
	3.3	0.31	9	48.91	1.77	17.93	97.83
	3.8	0.36	10	54.35	2.07	20.65	97.83
	4.1	0.38	15	81.52	2.21	22.28	97.83
	4.6	0.43	18	97.83	2.47	25.00	97.83
	5	0.43	19	103.26	2.50	27.17	97.83
	5.5	0.44	25	135.87	2.58	29.89	97.83
	6	0.48	32	173.91	2.75	32.61	97.83
	6.3	0.51	35	190.22	2.95	34.24	97.83
	6.8	0.52	48	260.87	3.02	36.96	97.83
	7.3	0.60	54	293.48	3.48	39.67	97.83

Table A9 Continued

QUARTZ , Δz=18 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
2.50	1	0.09	3	12.00	0.46	4.00	72.00
	1.3	0.11	4	16.00	0.52	5.20	72.00
	1.5	0.16	4.5	18.00	0.81	6.00	72.00
	1.9	0.20	5	20.00	0.98	7.60	72.00
	2.6	0.26	7	28.00	1.27	10.40	72.00
	3.3	0.31	8	32.00	1.52	13.20	72.00
	3.8	0.36	10	40.00	1.78	15.20	72.00
	4.1	0.38	12	48.00	1.89	16.40	72.00
	4.6	0.43	15	60.00	2.12	18.40	72.00
	5	0.43	19	76.00	2.15	20.00	72.00
	5.5	0.44	20	80.00	2.21	22.00	72.00
	6	0.48	22	88.00	2.36	24.00	72.00
	6.3	0.51	25	100.00	2.53	25.20	72.00
	6.8	0.52	29	116.00	2.59	27.20	72.00
	7.3	0.60	35	140.00	2.99	29.20	72.00

Table A10 Measured and calculated experimental parameters for silisium and the setlling basin of Δz=18 cm

SILISIUM , Δz=18 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
0.20	1	0.09	18	900	1.81	50	900
	1.3	0.11	27	1350	2.07	65	900
	1.5	0.16	38	1900	3.18	75	900
	1.9	0.20	55	2750	3.86	95	900
	2.6	0.26	85	4250	5.02	130	900
	3.3	0.31	85	4250	5.99	165	900
	3.8	0.36	85	4250	7.01	190	900
	4.1	0.38	85	4250	7.46	205	900
	4.6	0.43	85	4250	8.34	230	900
	5	0.43	85	4250	8.45	250	900
	5.5	0.44	85	4250	8.71	275	900
	6	0.48	85	4250	9.31	300	900
	6.3	0.51	85	4250	9.97	315	900
	6.8	0.52	85	4250	10.21	340	900
	7.3	0.60	85	4250	11.76	365	900
0.75	1	0.09	10	133.33	0.94	13.33	240.00
	1.3	0.11	15	200.00	1.07	17.33	240.00
	1.5	0.16	22	293.33	1.64	20.00	240.00
	1.9	0.20	28	373.33	1.99	25.33	240.00
	2.6	0.26	41	546.67	2.59	34.67	240.00
	3.3	0.31	65	866.67	3.09	44.00	240.00
	3.8	0.36	85	1133.33	3.62	50.67	240.00
	4.1	0.38	85	1133.33	3.85	54.67	240.00
	4.6	0.43	85	1133.33	4.31	61.33	240.00
	5	0.43	85	1133.33	4.37	66.67	240.00
	5.5	0.44	85	1133.33	4.50	73.33	240.00
	6	0.48	85	1133.33	4.81	80.00	240.00
	6.3	0.51	85	1133.33	5.15	84.00	240.00
	6.8	0.52	85	1133.33	5.27	90.67	240.00
	7.3	0.60	85	1133.33	6.07	97.33	240.00

Table A10 Continued

SILISIUM , Δz=18 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
1.10	1	0.09	5	45.45	0.77	9.09	163.64
	1.3	0.11	6	54.55	0.88	11.82	163.64
	1.5	0.16	7	63.64	1.35	13.64	163.64
	1.9	0.20	10	90.91	1.65	17.27	163.64
	2.6	0.26	13	118.18	2.14	23.64	163.64
	3.3	0.31	18	163.64	2.56	30.00	163.64
	3.8	0.36	25	227.27	2.99	34.55	163.64
	4.1	0.38	29	263.64	3.18	37.27	163.64
	4.6	0.43	36	327.27	3.56	41.82	163.64
	5	0.43	42	381.82	3.60	45.45	163.64
	5.5	0.44	82	745.45	3.71	50.00	163.64
	6	0.48	83	754.55	3.97	54.55	163.64
	6.3	0.51	85	772.73	4.25	57.27	163.64
	6.8	0.52	85	772.73	4.35	61.82	163.64
	7.3	0.60	85	772.73	5.02	66.36	163.64
1.30	1	0.09	4	30.77	0.71	7.69	138.46
	1.3	0.11	4.5	34.62	0.81	10.00	138.46
	1.5	0.16	8	61.54	1.25	11.54	138.46
	1.9	0.20	8	61.54	1.51	14.62	138.46
	2.6	0.26	10	76.92	1.97	20.00	138.46
	3.3	0.31	14	107.69	2.35	25.38	138.46
	3.8	0.36	22	169.23	2.75	29.23	138.46
	4.1	0.38	24	184.62	2.93	31.54	138.46
	4.6	0.43	28	215.38	3.27	35.38	138.46
	5	0.43	39	300.00	3.32	38.46	138.46
	5.5	0.44	49	376.92	3.42	42.31	138.46
	6	0.48	54	415.38	3.65	46.15	138.46
	6.3	0.51	58	446.15	3.91	48.46	138.46
	6.8	0.52	60	461.54	4.00	52.31	138.46
	7.3	0.60	71	546.15	4.61	56.15	138.46

Table A10 Continued

SILISIUM , Δz=18 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
1.55	1	0.09	4	25.81	0.65	6.45	116.13
	1.3	0.11	4.5	29.03	0.74	8.39	116.13
	1.5	0.16	6.5	41.94	1.14	9.68	116.13
	1.9	0.20	7	45.16	1.39	12.26	116.13
	2.6	0.26	9	58.06	1.80	16.77	116.13
	3.3	0.31	10	64.52	2.15	21.29	116.13
	3.8	0.36	12	77.42	2.52	24.52	116.13
	4.1	0.38	19	122.58	2.68	26.45	116.13
	4.6	0.43	24	154.84	3.00	29.68	116.13
	5	0.43	29	187.10	3.04	32.26	116.13
	5.5	0.44	33	212.90	3.13	35.48	116.13
	6	0.48	37	238.71	3.34	38.71	116.13
	6.3	0.51	44	283.87	3.58	40.65	116.13
	6.8	0.52	45	290.32	3.67	43.87	116.13
	7.3	0.60	48	309.68	4.22	47.10	116.13
1.84	1	0.09	4	21.74	0.60	5.43	97.83
	1.3	0.11	4.5	24.46	0.68	7.07	97.83
	1.5	0.16	5	27.17	1.05	8.15	97.83
	1.9	0.20	6	32.61	1.27	10.33	97.83
	2.6	0.26	6	32.61	1.65	14.13	97.83
	3.3	0.31	7	38.04	1.98	17.93	97.83
	3.8	0.36	8	43.48	2.31	20.65	97.83
	4.1	0.38	12	65.22	2.46	22.28	97.83
	4.6	0.43	18	97.83	2.75	25.00	97.83
	5	0.43	22	119.57	2.79	27.17	97.83
	5.5	0.44	31	168.48	2.87	29.89	97.83
	6	0.48	35	190.22	3.07	32.61	97.83
	6.3	0.51	37	201.09	3.29	34.24	97.83
	6.8	0.52	41	222.83	3.37	36.96	97.83
	7.3	0.60	52	282.61	3.88	39.67	97.83

Table A10 Continued

SILISIUM , Δz=18 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	***l_s*** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
2.50	1	0.09	4	16.00	0.51	4.00	72.00
	1.3	0.11	4	16.00	0.58	5.20	72.00
	1.5	0.16	4	16.00	0.90	6.00	72.00
	1.9	0.20	5	20.00	1.09	7.60	72.00
	2.6	0.26	6	24.00	1.42	10.40	72.00
	3.3	0.31	8	32.00	1.69	13.20	72.00
	3.8	0.36	7	28.00	1.98	15.20	72.00
	4.1	0.38	8	32.00	2.11	16.40	72.00
	4.6	0.43	9	36.00	2.36	18.40	72.00
	5	0.43	10	40.00	2.39	20.00	72.00
	5.5	0.44	12	48.00	2.46	22.00	72.00
	6	0.48	16	64.00	2.63	24.00	72.00
	6.3	0.51	20	80.00	2.82	25.20	72.00
	6.8	0.52	24	96.00	2.89	27.20	72.00
	7.3	0.60	30	120.00	3.33	29.20	72.00

Table A11 Measured and calculated experimental parameters for quartz and the setlling basin of Δz=13 cm

QUARTZ , Δz=13 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
0.20	1	0.09	28	1400	1.63	50	650
	1.3	0.11	39	1950	1.85	65	650
	1.5	0.16	55	2750	2.85	75	650
	1.9	0.20	68	3400	3.46	95	650
	2.6	0.26	85	4250	4.51	130	650
	3.3	0.31	85	4250	5.38	165	650
	3.8	0.36	85	4250	6.29	190	650
	4.1	0.38	85	4250	6.70	205	650
	4.6	0.43	85	4250	7.49	230	650
	5	0.43	85	4250	7.59	250	650
	5.5	0.44	85	4250	7.82	275	650
	6	0.48	85	4250	8.35	300	650
	6.3	0.51	85	4250	8.95	315	650
	6.8	0.52	85	4250	9.17	340	650
	7.3	0.60	85	4250	10.56	365	650
0.75	1	0.09	16	213.33	0.84	13.33	173.33
	1.3	0.11	26	346.67	0.96	17.33	173.33
	1.5	0.16	30	400.00	1.47	20.00	173.33
	1.9	0.20	38	506.67	1.79	25.33	173.33
	2.6	0.26	48	640.00	2.33	34.67	173.33
	3.3	0.31	68	906.67	2.78	44.00	173.33
	3.8	0.36	85	1133.33	3.25	50.67	173.33
	4.1	0.38	85	1133.33	3.46	54.67	173.33
	4.6	0.43	85	1133.33	3.87	61.33	173.33
	5	0.43	85	1133.33	3.92	66.67	173.33
	5.5	0.44	85	1133.33	4.04	73.33	173.33
	6	0.48	85	1133.33	4.31	80.00	173.33
	6.3	0.51	85	1133.33	4.62	84.00	173.33
	6.8	0.52	85	1133.33	4.73	90.67	173.33
	7.3	0.60	85	1133.33	5.45	97.33	173.33

Table A11 Continued

QUARTZ , Δz=13 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
1.10	1	0.09	5	45.45	0.69	9.09	118.18
	1.3	0.11	7	63.64	0.79	11.82	118.18
	1.5	0.16	12	109.09	1.22	13.64	118.18
	1.9	0.20	18	163.64	1.48	17.27	118.18
	2.6	0.26	27	245.45	1.92	23.64	118.18
	3.3	0.31	34	309.09	2.29	30.00	118.18
	3.8	0.36	45	409.09	2.68	34.55	118.18
	4.1	0.38	51	463.64	2.86	37.27	118.18
	4.6	0.43	75	681.82	3.19	41.82	118.18
	5	0.43	78	709.09	3.24	45.45	118.18
	5.5	0.44	82	745.45	3.33	50.00	118.18
	6	0.48	85	772.73	3.56	54.55	118.18
	6.3	0.51	85	772.73	3.82	57.27	118.18
	6.8	0.52	85	772.73	3.91	61.82	118.18
	7.3	0.60	85	772.73	4.50	66.36	118.18
1.30	1	0.09	4	30.77	0.64	7.69	100.00
	1.3	0.11	5.5	42.31	0.73	10.00	100.00
	1.5	0.16	6.5	50.00	1.12	11.54	100.00
	1.9	0.20	10	76.92	1.36	14.62	100.00
	2.6	0.26	14	107.69	1.77	20.00	100.00
	3.3	0.31	19	146.15	2.11	25.38	100.00
	3.8	0.36	22	169.23	2.47	29.23	100.00
	4.1	0.38	27	207.69	2.63	31.54	100.00
	4.6	0.43	38	292.31	2.94	35.38	100.00
	5	0.43	48	369.23	2.98	38.46	100.00
	5.5	0.44	58	446.15	3.07	42.31	100.00
	6	0.48	61	469.23	3.28	46.15	100.00
	6.3	0.51	68	523.08	3.51	48.46	100.00
	6.8	0.52	70	538.46	3.59	52.31	100.00
	7.3	0.60	72	553.85	4.14	56.15	100.00

Table A11 Continued

QUARTZ , Δz=13 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
1.55	1	0.09	4	25.81	0.58	6.45	83.87
	1.3	0.11	4.5	29.03	0.67	8.39	83.87
	1.5	0.16	6	38.71	1.02	9.68	83.87
	1.9	0.20	10	64.52	1.24	12.26	83.87
	2.6	0.26	14	90.32	1.62	16.77	83.87
	3.3	0.31	20	129.03	1.93	21.29	83.87
	3.8	0.36	24	154.84	2.26	24.52	83.87
	4.1	0.38	26	167.74	2.41	26.45	83.87
	4.6	0.43	33	212.90	2.69	29.68	83.87
	5	0.43	36	232.26	2.73	32.26	83.87
	5.5	0.44	45	290.32	2.81	35.48	83.87
	6	0.48	53	341.94	3.00	38.71	83.87
	6.3	0.51	63	406.45	3.22	40.65	83.87
	6.8	0.52	65	419.35	3.29	43.87	83.87
	7.3	0.60	66	425.81	3.79	47.10	83.87
1.84	1	0.09	4	21.74	0.54	5.43	70.65
	1.3	0.11	5	27.17	0.61	7.07	70.65
	1.5	0.16	6	32.61	0.94	8.15	70.65
	1.9	0.20	6.5	35.33	1.14	10.33	70.65
	2.6	0.26	7	38.04	1.49	14.13	70.65
	3.3	0.31	9	48.91	1.77	17.93	70.65
	3.8	0.36	11	59.78	2.07	20.65	70.65
	4.1	0.38	19	103.26	2.21	22.28	70.65
	4.6	0.43	22	119.57	2.47	25.00	70.65
	5	0.43	25	135.87	2.50	27.17	70.65
	5.5	0.44	31	168.48	2.58	29.89	70.65
	6	0.48	38	206.52	2.75	32.61	70.65
	6.3	0.51	45	244.57	2.95	34.24	70.65
	6.8	0.52	54	293.48	3.02	36.96	70.65
	7.3	0.60	60	326.09	3.48	39.67	70.65

Table A11 Continued

QUARTZ , Δz=13 cm , ρ_s=2.65 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
2.50	1	0.09	3.5	14.00	0.46	4.00	52.00
	1.3	0.11	5	20.00	0.52	5.20	52.00
	1.5	0.16	6.5	26.00	0.81	6.00	52.00
	1.9	0.20	7	28.00	0.98	7.60	52.00
	2.6	0.26	9	36.00	1.27	10.40	52.00
	3.3	0.31	11	44.00	1.52	13.20	52.00
	3.8	0.36	13	52.00	1.78	15.20	52.00
	4.1	0.38	15	60.00	1.89	16.40	52.00
	4.6	0.43	18	72.00	2.12	18.40	52.00
	5	0.43	24	96.00	2.15	20.00	52.00
	5.5	0.44	26	104.00	2.21	22.00	52.00
	6	0.48	29	116.00	2.36	24.00	52.00
	6.3	0.51	30	120.00	2.53	25.20	52.00
	6.8	0.52	35	140.00	2.59	27.20	52.00
	7.3	0.60	40	160.00	2.99	29.20	52.00

Table A12 Measured and calculated experimental parameters for silisium and the setlling basin of Δz=13 cm

SILISIUM , Δz=13 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	h (cm)	V (m/s)	l_s (cm)	l_s/d_s	$(Fr)_s$	h/d_s	$\Delta z/d_s$
0.20	1	0.09	24	1200	1.81	50	650
	1.3	0.11	30	1500	2.07	65	650
	1.5	0.16	45	2250	3.18	75	650
	1.9	0.20	65	3250	3.86	95	650
	2.6	0.26	85	4250	5.02	130	650
	3.3	0.31	85	4250	5.99	165	650
	3.8	0.36	85	4250	7.01	190	650
	4.1	0.38	85	4250	7.46	205	650
	4.6	0.43	85	4250	8.34	230	650
	5	0.43	85	4250	8.45	250	650
	5.5	0.44	85	4250	8.71	275	650
	6	0.48	85	4250	9.31	300	650
	6.3	0.51	85	4250	9.97	315	650
	6.8	0.52	85	4250	10.21	340	650
	7.3	0.60	85	4250	11.76	365	650
0.75	1	0.09	15	200.00	0.94	13.33	173.33
	1.3	0.11	18	240.00	1.07	17.33	173.33
	1.5	0.16	24	320.00	1.64	20.00	173.33
	1.9	0.20	32	426.67	1.99	25.33	173.33
	2.6	0.26	45	600.00	2.59	34.67	173.33
	3.3	0.31	69	920.00	3.09	44.00	173.33
	3.8	0.36	85	1133.33	3.62	50.67	173.33
	4.1	0.38	85	1133.33	3.85	54.67	173.33
	4.6	0.43	85	1133.33	4.31	61.33	173.33
	5	0.43	85	1133.33	4.37	66.67	173.33
	5.5	0.44	85	1133.33	4.50	73.33	173.33
	6	0.48	85	1133.33	4.81	80.00	173.33
	6.3	0.51	85	1133.33	5.15	84.00	173.33
	6.8	0.52	85	1133.33	5.27	90.67	173.33
	7.3	0.60	85	1133.33	6.07	97.33	173.33

Table A12 Continued

SILISIUM , Δz=13 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
1.10	1	0.09	5	45.45	0.77	9.09	118.18
	1.3	0.11	6.5	59.09	0.88	11.82	118.18
	1.5	0.16	8	72.73	1.35	13.64	118.18
	1.9	0.20	13	118.18	1.65	17.27	118.18
	2.6	0.26	16	145.45	2.14	23.64	118.18
	3.3	0.31	24	218.18	2.56	30.00	118.18
	3.8	0.36	29	263.64	2.99	34.55	118.18
	4.1	0.38	32	290.91	3.18	37.27	118.18
	4.6	0.43	41	372.73	3.56	41.82	118.18
	5	0.43	46	418.18	3.60	45.45	118.18
	5.5	0.44	84	763.64	3.71	50.00	118.18
	6	0.48	85	772.73	3.97	54.55	118.18
	6.3	0.51	85	772.73	4.25	57.27	118.18
	6.8	0.52	85	772.73	4.35	61.82	118.18
	7.3	0.60	85	772.73	5.02	66.36	118.18
1.30	1	0.09	4.5	34.62	0.71	7.69	100.00
	1.3	0.11	5	38.46	0.81	10.00	100.00
	1.5	0.16	7	53.85	1.25	11.54	100.00
	1.9	0.20	10	76.92	1.51	14.62	100.00
	2.6	0.26	14	107.69	1.97	20.00	100.00
	3.3	0.31	19	146.15	2.35	25.38	100.00
	3.8	0.36	25	192.31	2.75	29.23	100.00
	4.1	0.38	28	215.38	2.93	31.54	100.00
	4.6	0.43	31	238.46	3.27	35.38	100.00
	5	0.43	42	323.08	3.32	38.46	100.00
	5.5	0.44	52	400.00	3.42	42.31	100.00
	6	0.48	60	461.54	3.65	46.15	100.00
	6.3	0.51	62	476.92	3.91	48.46	100.00
	6.8	0.52	65	500.00	4.00	52.31	100.00
	7.3	0.60	78	600.00	4.61	56.15	100.00

Table A12 Continued

SILISIUM , Δz=13 cm , ρ_s=2.33gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	l_s (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
1.55	1	0.09	4	25.81	0.65	6.45	83.87
	1.3	0.11	5	32.26	0.74	8.39	83.87
	1.5	0.16	6	38.71	1.14	9.68	83.87
	1.9	0.20	7	45.16	1.39	12.26	83.87
	2.6	0.26	10	64.52	1.80	16.77	83.87
	3.3	0.31	16	103.23	2.15	21.29	83.87
	3.8	0.36	20	129.03	2.52	24.52	83.87
	4.1	0.38	24	154.84	2.68	26.45	83.87
	4.6	0.43	30	193.55	3.00	29.68	83.87
	5	0.43	32	206.45	3.04	32.26	83.87
	5.5	0.44	35	225.81	3.13	35.48	83.87
	6	0.48	39	251.61	3.34	38.71	83.87
	6.3	0.51	46	296.77	3.58	40.65	83.87
	6.8	0.52	49	316.13	3.67	43.87	83.87
	7.3	0.60	55	354.84	4.22	47.10	83.87
1.84	1	0.09	4.5	24.46	0.60	5.43	70.65
	1.3	0.11	5	27.17	0.68	7.07	70.65
	1.5	0.16	7	38.04	1.05	8.15	70.65
	1.9	0.20	8	43.48	1.27	10.33	70.65
	2.6	0.26	12	65.22	1.65	14.13	70.65
	3.3	0.31	15	81.52	1.98	17.93	70.65
	3.8	0.36	18	97.83	2.31	20.65	70.65
	4.1	0.38	22	119.57	2.46	22.28	70.65
	4.6	0.43	25	135.87	2.75	25.00	70.65
	5	0.43	29	157.61	2.79	27.17	70.65
	5.5	0.44	35	190.22	2.87	29.89	70.65
	6	0.48	39	211.96	3.07	32.61	70.65
	6.3	0.51	44	239.13	3.29	34.24	70.65
	6.8	0.52	48	260.87	3.37	36.96	70.65
	7.3	0.60	56	304.35	3.88	39.67	70.65

Table A12 Continued

SILISIUM , Δz=13 cm , ρ_s=2.33 gr/cm^3							
d_s (mm)	**h** (cm)	**V** (m/s)	**l_s** (cm)	**l_s/d_s**	**$(Fr)_s$**	**h/d_s**	**$\Delta z/d_s$**
2.50	1	0.09	4	16.00	0.51	4.00	52.00
	1.3	0.11	4	16.00	0.58	5.20	52.00
	1.5	0.16	6	24.00	0.90	6.00	52.00
	1.9	0.20	7	28.00	1.09	7.60	52.00
	2.6	0.26	9	36.00	1.42	10.40	52.00
	3.3	0.31	12	48.00	1.69	13.20	52.00
	3.8	0.36	14	56.00	1.98	15.20	52.00
	4.1	0.38	16	64.00	2.11	16.40	52.00
	4.6	0.43	19	76.00	2.36	18.40	52.00
	5	0.43	24	96.00	2.39	20.00	52.00
	5.5	0.44	28	112.00	2.46	22.00	52.00
	6	0.48	29	116.00	2.63	24.00	52.00
	6.3	0.51	32	128.00	2.82	25.20	52.00
	6.8	0.52	36	144.00	2.89	27.20	52.00
	7.3	0.60	39	156.00	3.33	29.20	52.00

APPENDIX B

PROJECT DETAILS OF ENSAMPLED SETTLING BASINS

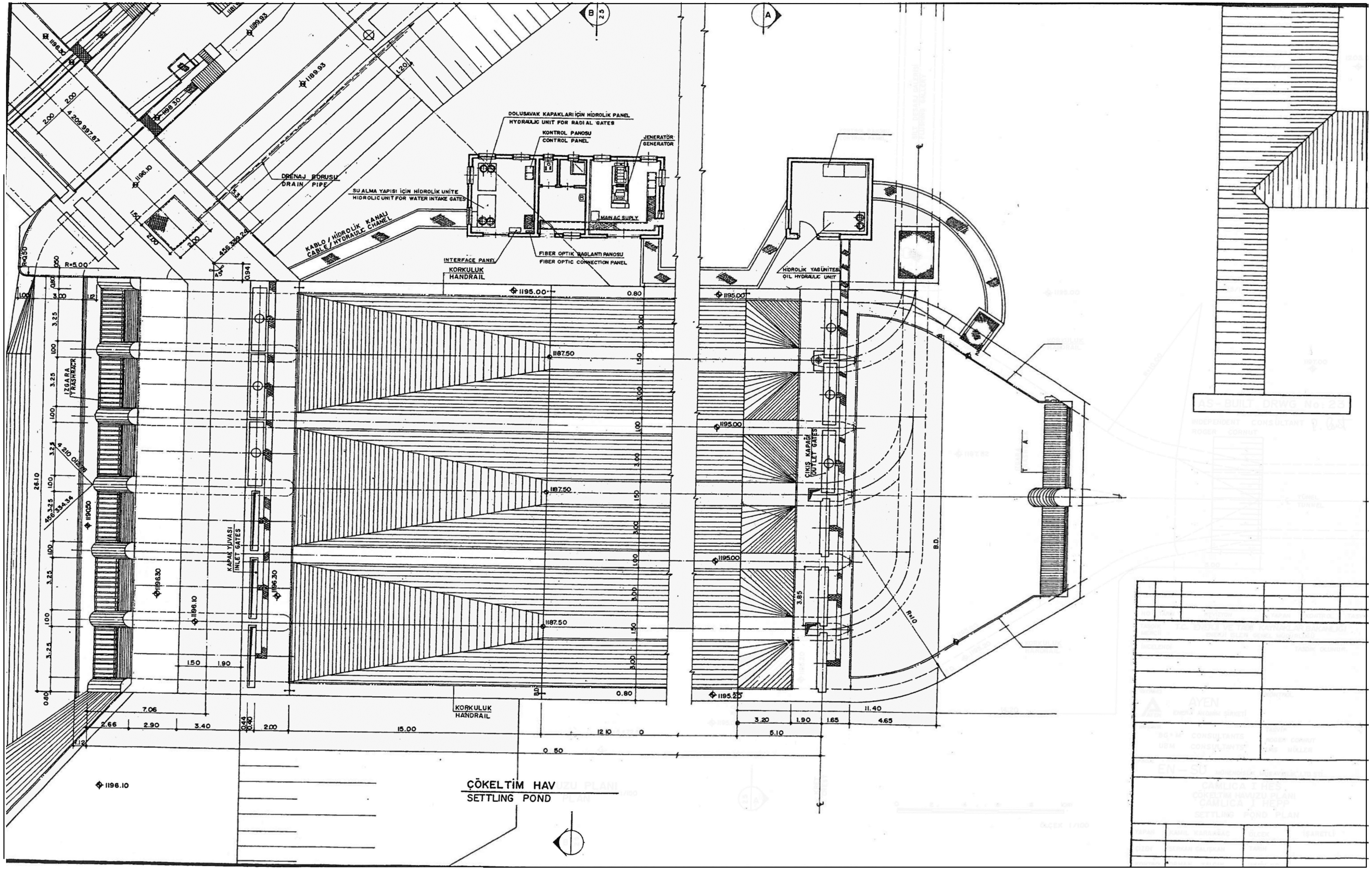

Figure B1 Plan view of Çamlıca settling basin

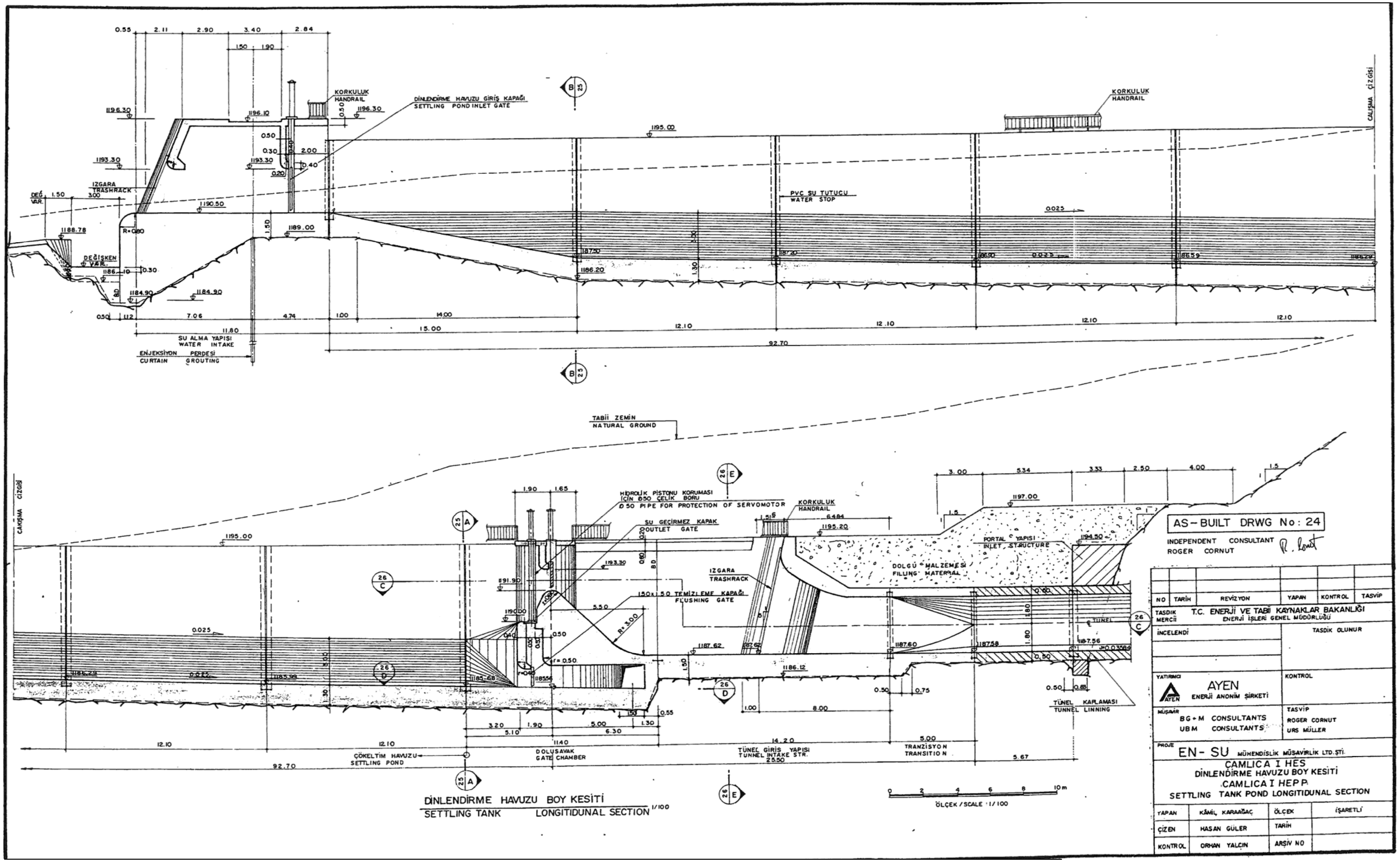

Figure B2 Longitudinal view of Çamlıca settling basin

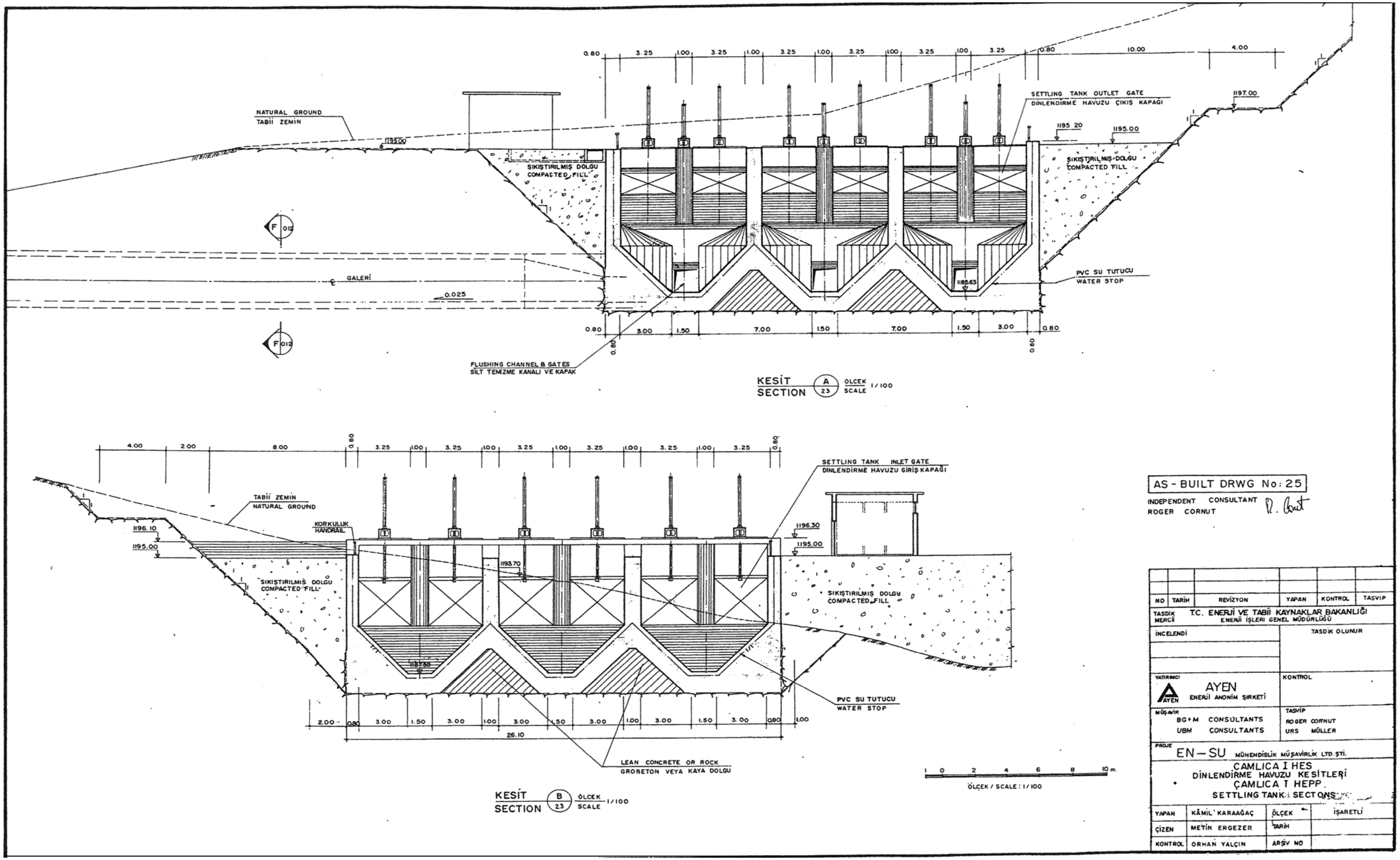

Figure B3 Cross sections of Çamlıca settling basin

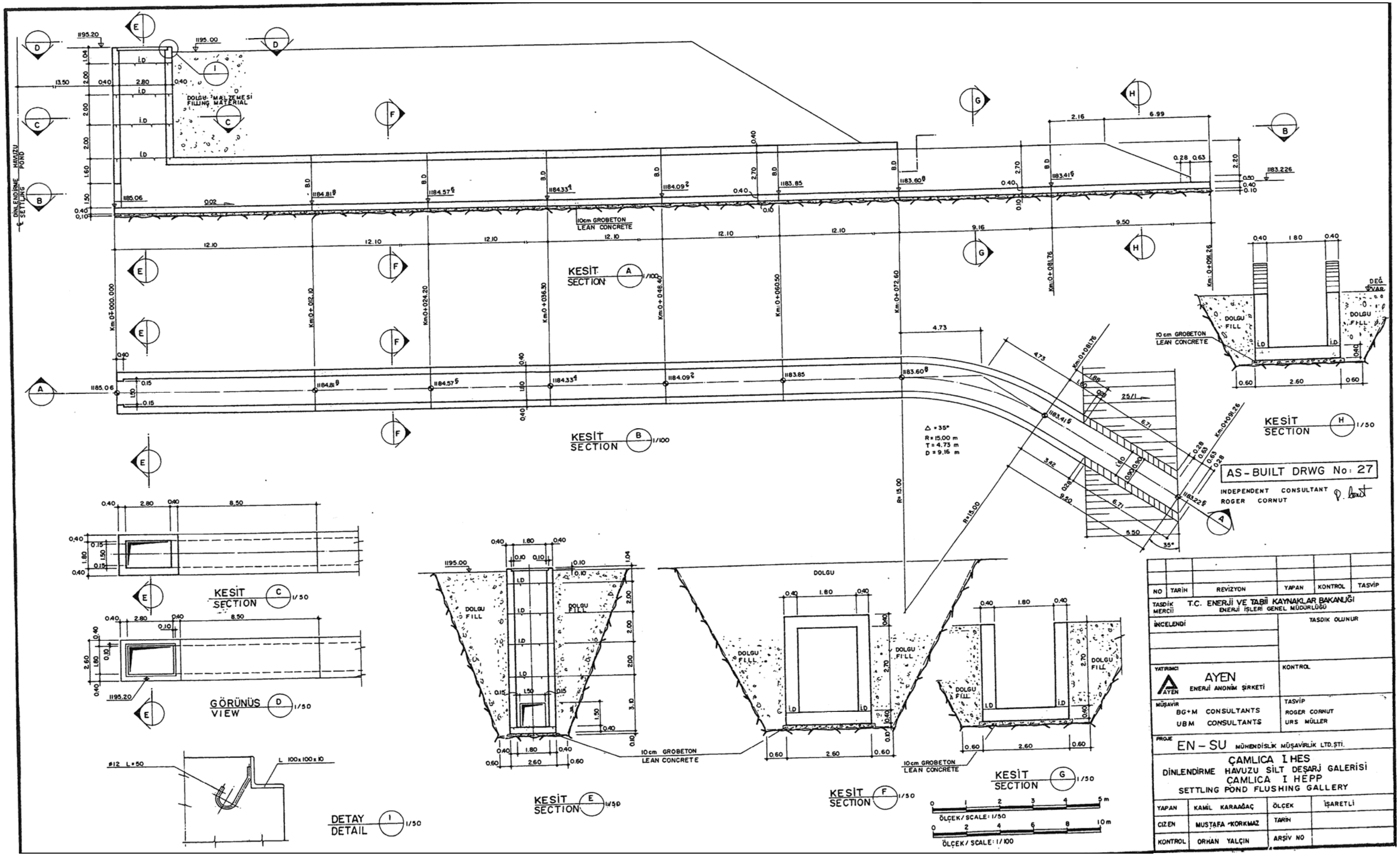

Figure B4 Flushing channel of Çamlıca settling basin

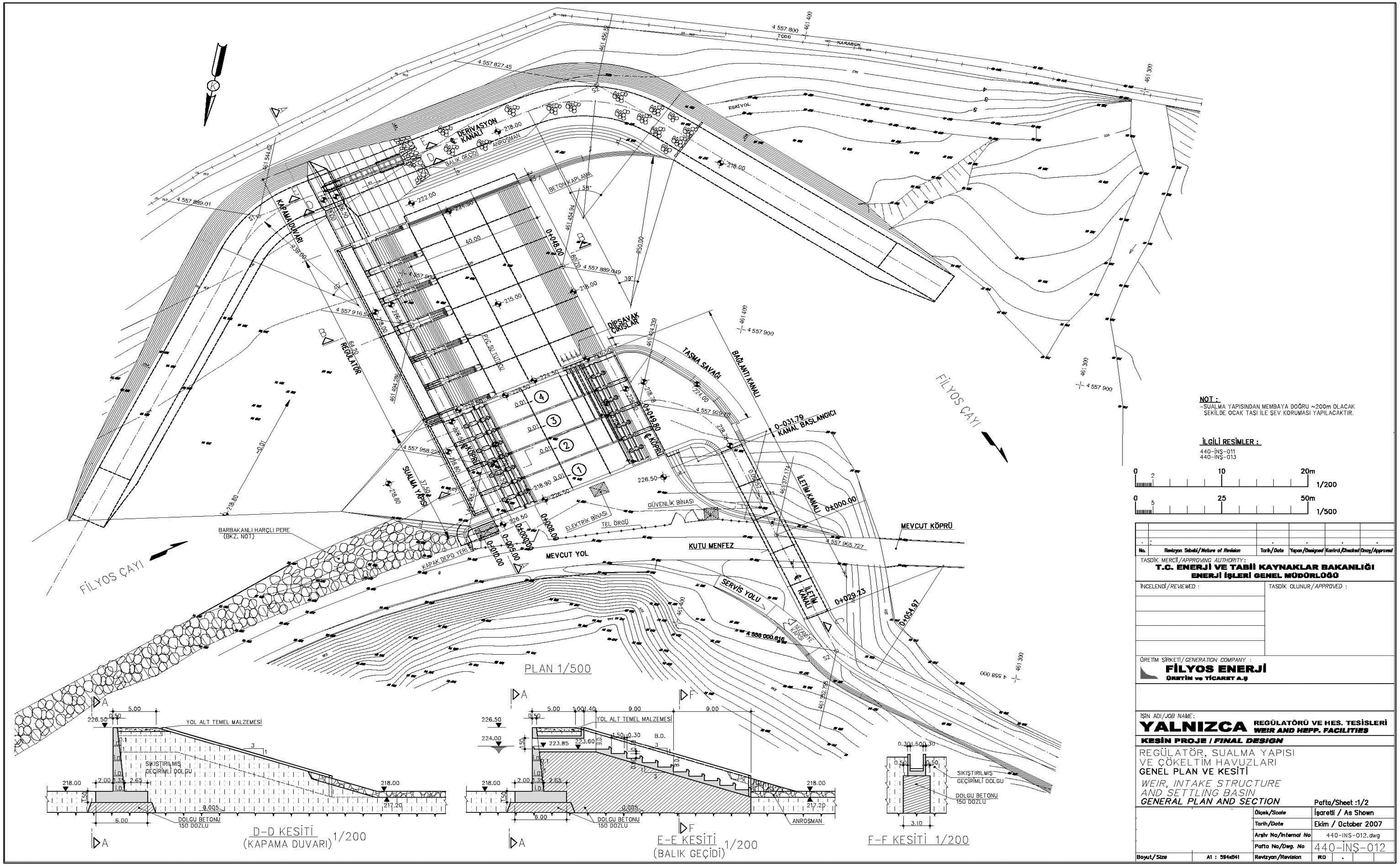

Figure B5 Plan view of Yalnızca settling basin

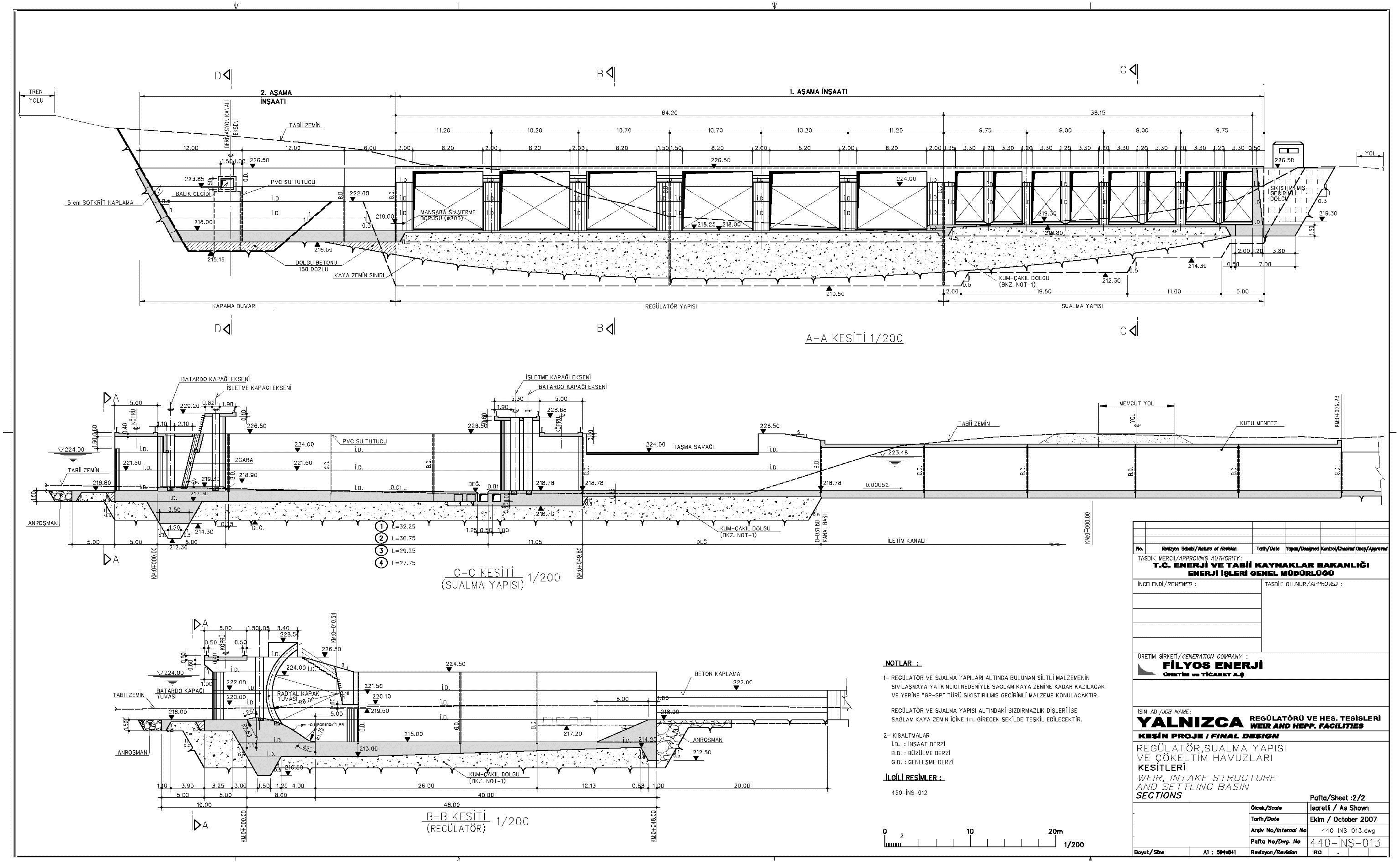

Figure B6 Longitudinal view and cross sections of Yalnızca settling basin

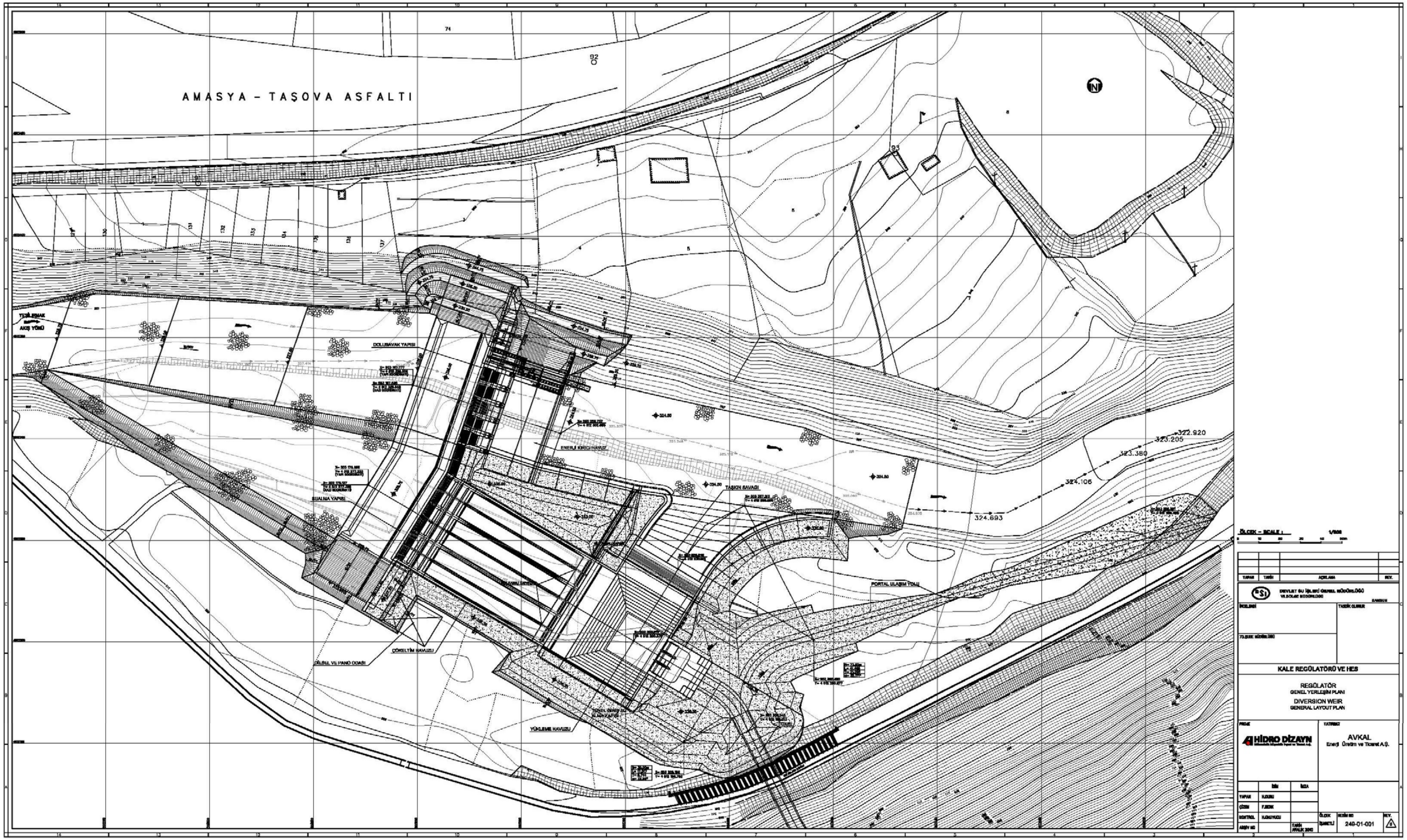

Figure B7 General layout of Kale weir and settling basin

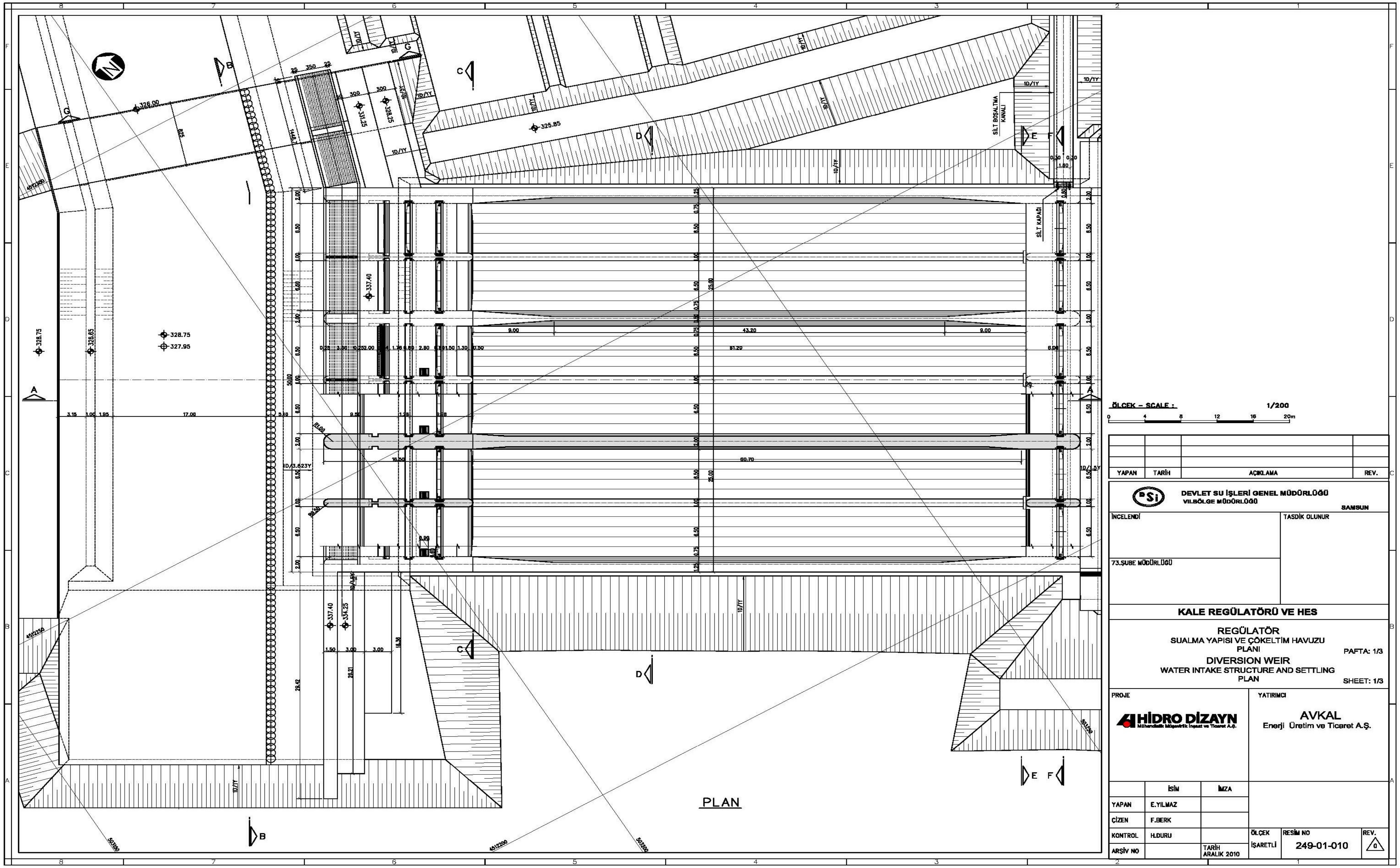

Figure B8 Plan view of Kale settling basin

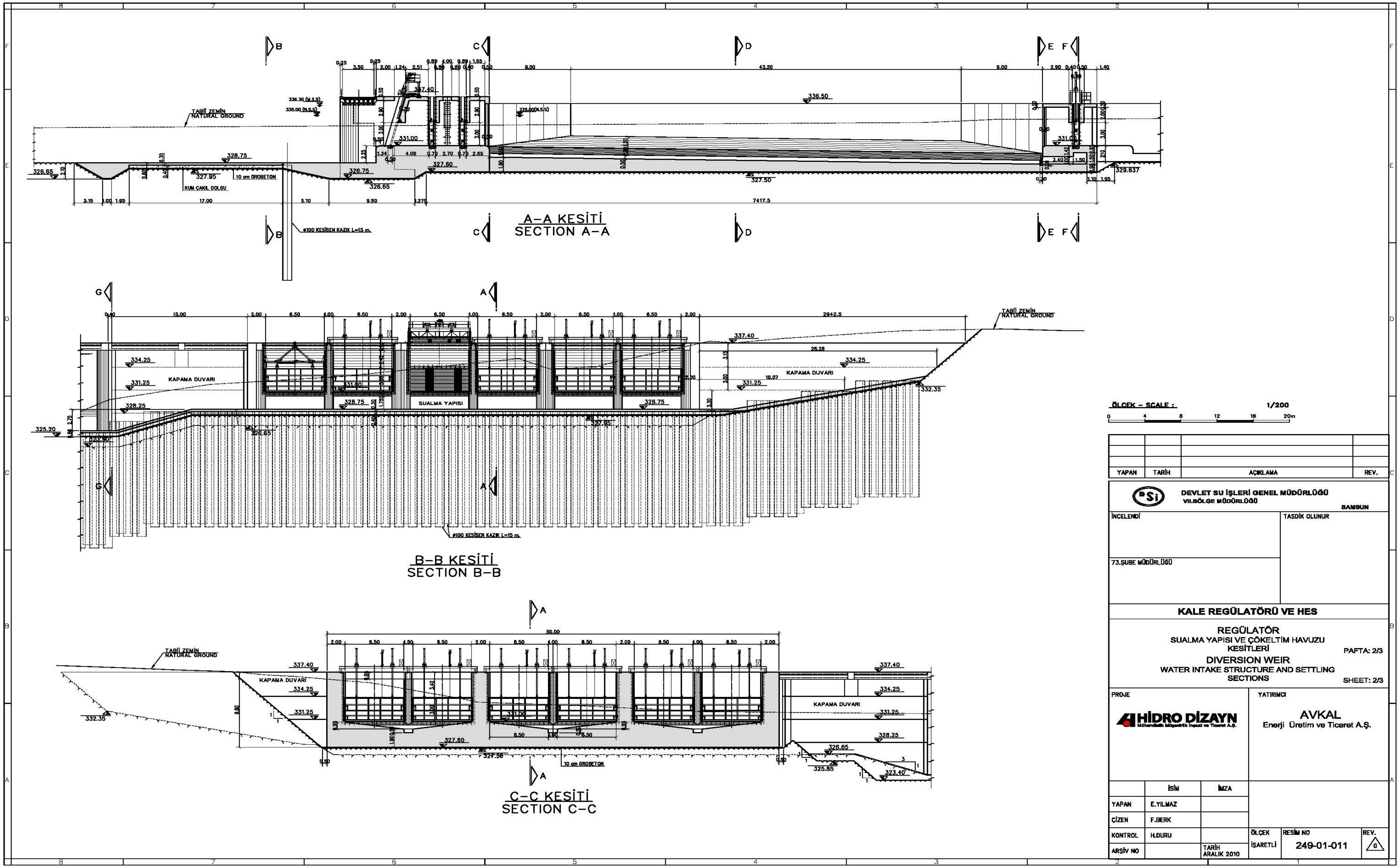

Figure B9 Cross sections of Kale settling basin

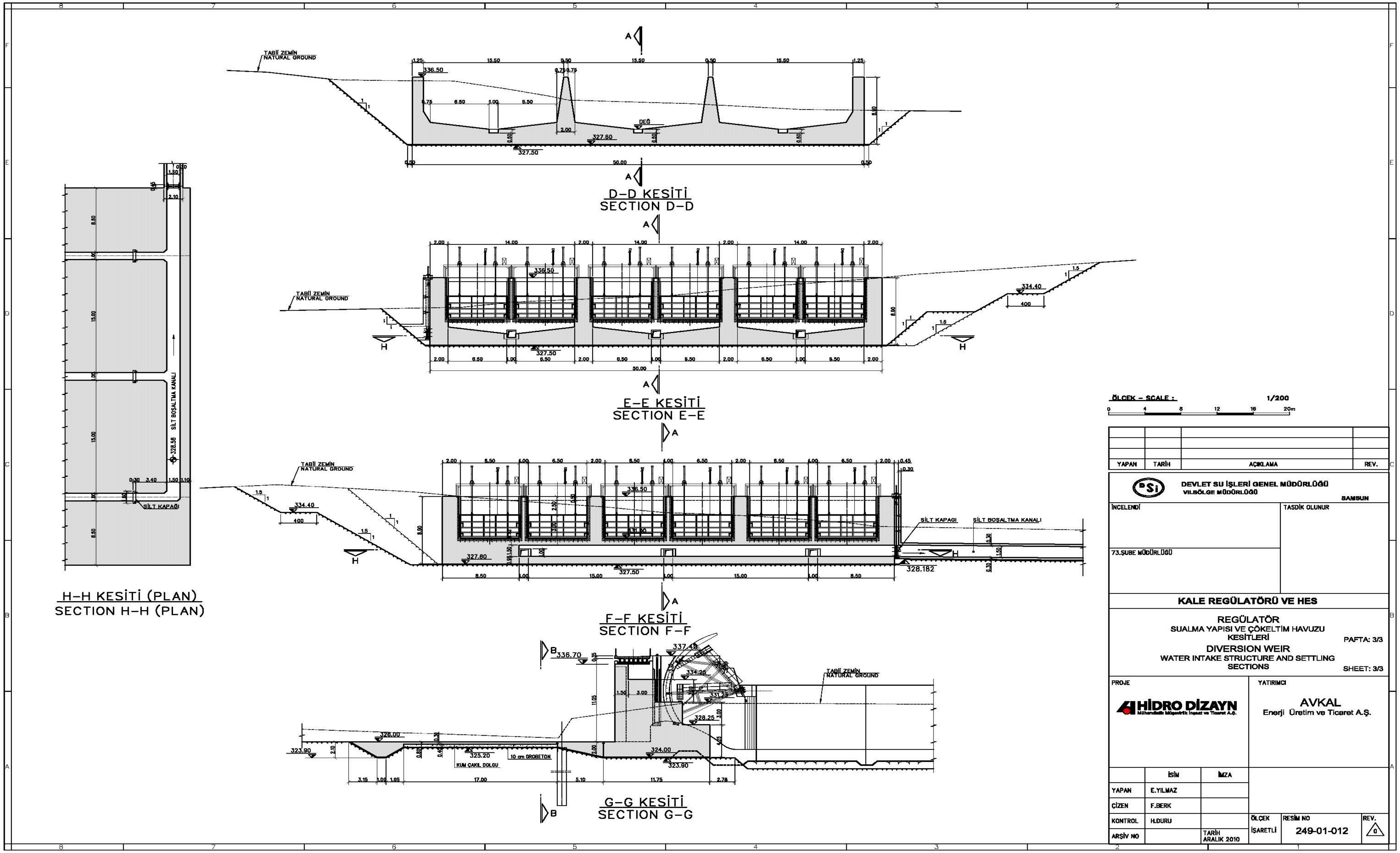

Figure B10 Cross sections-2 of Kale settling basin

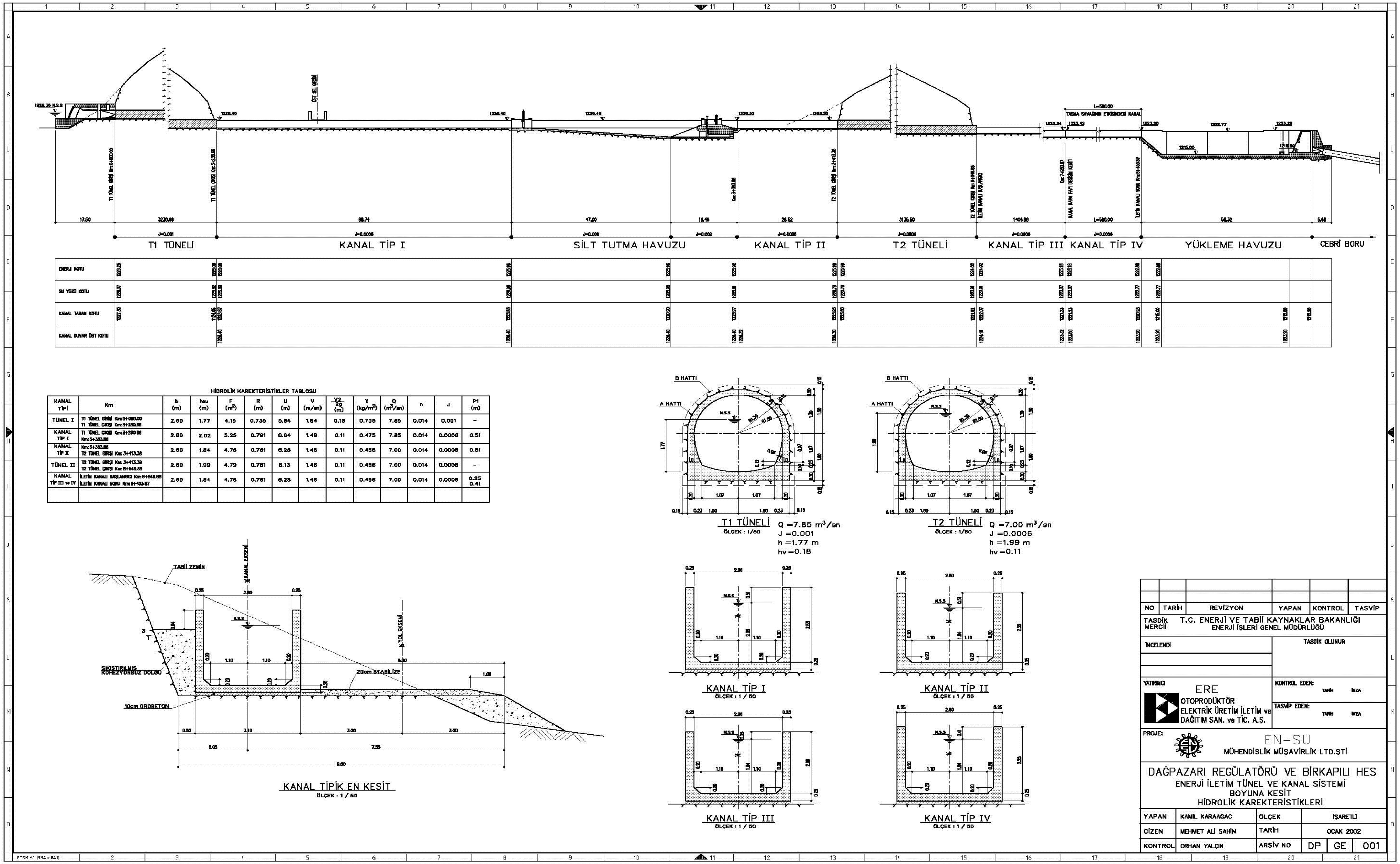

Figure B11 General profile view of Birkapılı HEPP

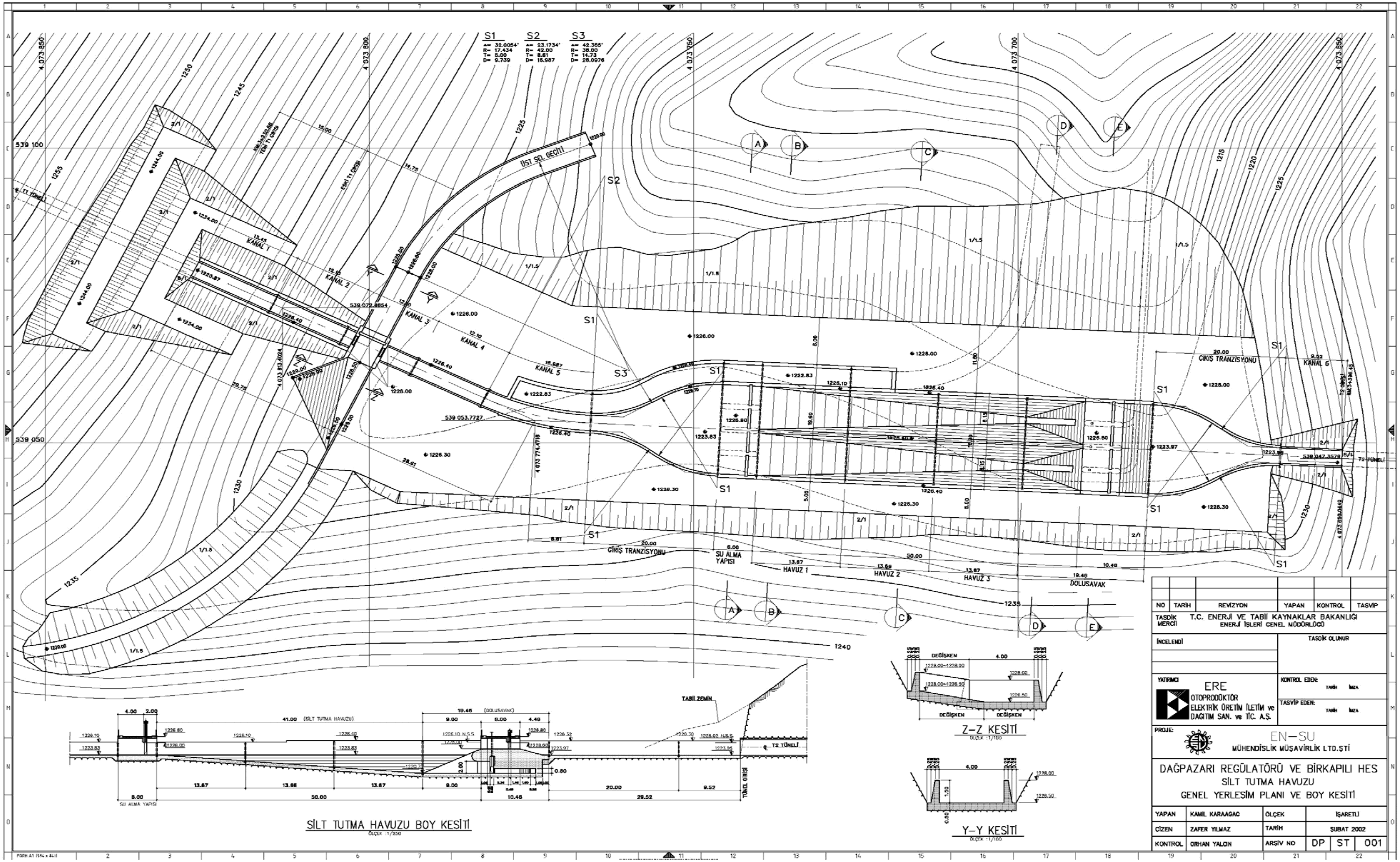

Figure B12 Plan view of Birkapılı settling basin

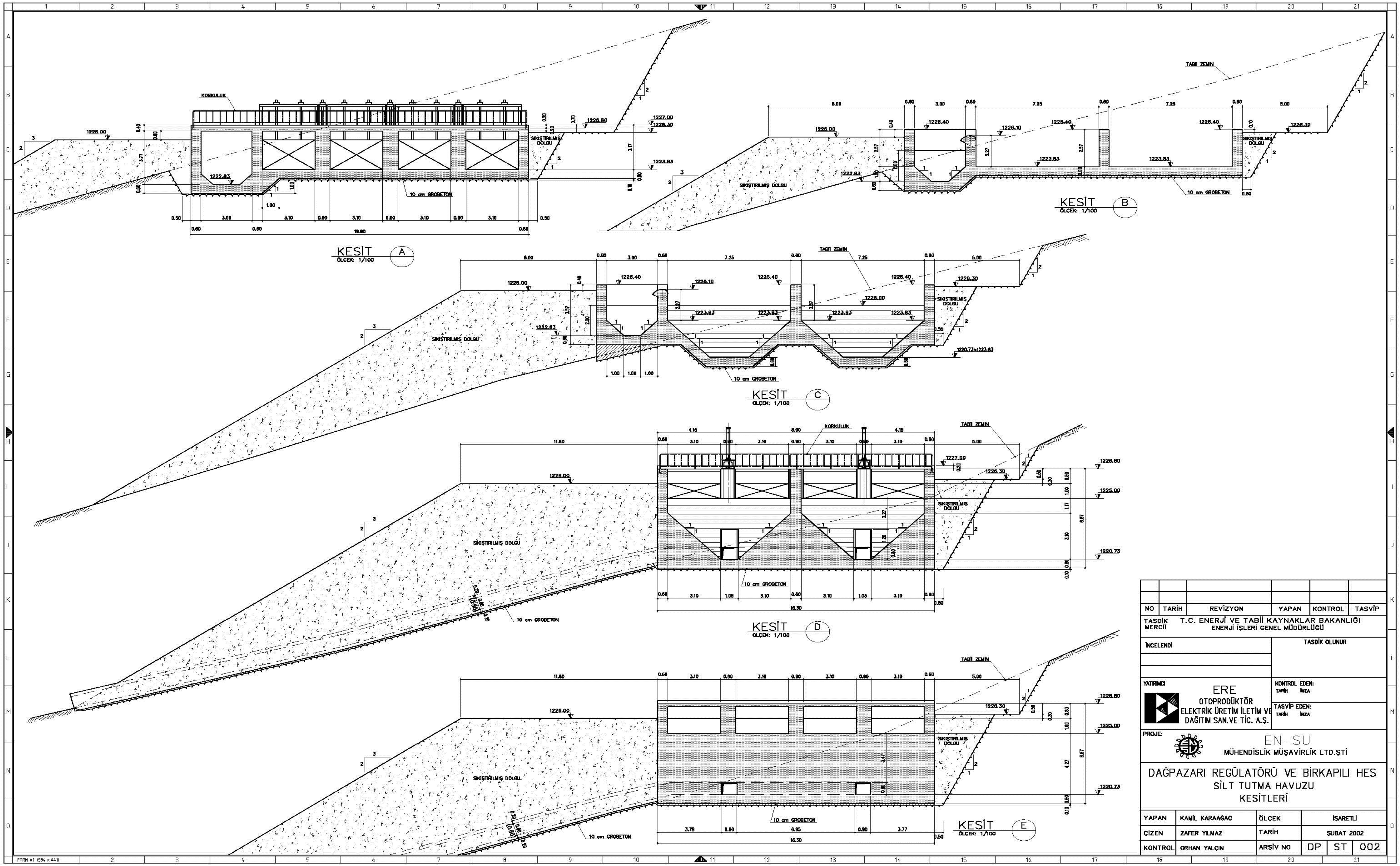

Figure B13 Cross sections of Birkapılı settling basin