



Research Paper / Makale

The Influence of Bed Material Grain Size on Scouring for Labyrinth Side Weir Flow

Mustafa TUNC, Muhammet Emin EMIROGLU

Civil Engineering Department, Engineering Faculty, Firat University, Elazig, Turkey
mtunc@firat.edu.tr

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Abstract: In an alluvial stream bed, there is a continuous sediment movement depending on the flow. A new type of side weir built in a stream, the labyrinth side weir, can be discharged much more than the conventional weirs. This situation increases the importance of labyrinth weir for flood control. Although the effect of the weir type on the depth of equilibrium scour depth is large, the grain size of the bed material has a large influence on the scouring and the sediment bedform. In this study, it is aimed to investigate how the median grain size of the bed material affects the depth of equilibrium scour depth. For this purpose, the process of reaching equilibrium scour depth around the labyrinth side weir along with the discharge change using bed materials with different median grain sizes has been studied in detail. It has been concluded that the depth of the equilibrium scour depth decreases at different ratios as the median grain size increases with the effect of the flow intensity on the scouring being large.

Key words: labyrinth side weir, equilibrium scour depth, bed material, grain size, hydraulic structure.

Labirent Yan Savak Akımı için Taban Malzemesi Boyutlarının Oyulmaya Etkisi

Öz: Alüvyal tabanlı bir akarsuda akıma bağlı olarak sürekli sediment hareketi söz konusudur. Bir akarsuya inşa edilen yeni bir yan savak tipi olan labirent yan savak ile klasik savağa göre çok daha fazla deşarj yapılabilmektedir. Bu durum taşkın kontrolü için labirent savağın önemini arttırmaktadır. Savak tipinin denge oyulma derinliği üzerine etkisinin büyük olmasıyla birlikte, taban malzemesi medyan dane çapının oyulmaya ve taban şekline etkisi büyüktür. Bu çalışmada, taban malzemesi medyan dane çapının denge oyulma derinliğini nasıl etkilediğinin araştırılması amaçlanmıştır. Bu amaçla, farklı medyan dane çapına sahip taban malzemeleri kullanılarak akım hızı değişimiyle birlikte labirent yan savak etrafındaki denge oyulma derinliği süreci detaylı bir şekilde deneysel olarak incelenmiştir. Akım şiddetinin oyulmaya etkisinin büyük olması ile birlikte medyan dane çapının artmasıyla denge oyulma derinliğinin farklı oranlarda azaldığı sonucuna varılmıştır.

Anahtar kelimeler: labirent yan savak, denge oyulma derinliği, taban malzemesi, dane çapı, hidrolik yapı.

1. Introduction

Side weirs are used in many engineering applications. In the channels passed through the valley slopes, the excess flow that will occur due to the surface flow is also removed with the help of side weirs. It is thought that by using side weirs, it is possible to minimize water losses. The side weirs have different cross-sections such as rectangular, triangular, trapezoidal, and circular side weirs. Side weirs are generally built parallel to the main channel.

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The amount of the discharge from the weir is depends on the side weir type, channel cross-section, and the angle of placement of the weir. The hydraulics of the side weirs, which have been studied theoretically and experimentally since ancient times, still attracts the attention of researchers and many studies are carried out.

Scouring downstream of hydraulic structures is one of the major problems encountered in hydraulic engineering. By examining this phenomenon, scour depth should be minimized. Thus, it will be possible to increase the efficiency and life of hydraulic structures. However, sediment transport is observed in an alluvial river depending on the flow velocity [1]. Bed materials transported may cause scouring and deposit downstream of the hydraulic structure. This is undesirable since it will affect the weir flow and cause damage to the hydraulic structure.

Lateral water intake structures constitute the majority of water intake structures in our country. In these structures, the problem of moving sediment is manifested in a significant way due to the weak vegetation of the land and the slope of the rivers. In order to receive water containing less moving sediment from the lateral water intake structures, factors such as water intake structure type, location, crest height, guide rails, gravel passage, separation wall are of great importance.

The decrease in velocity and shear stresses due to lateral water intake creates a stagnation zone downstream of the side weir, causing the reverse current to occur. Due to changes in shear stress, a scour hole is formed between the main channel axis and the outer shore in the downstream region of the side weir.

Labyrinth side weirs are thought to be preferred more because their discharge capacity is higher than other side weirs [2-4]. Most of the studies in the literature regarding the discharge capacities of labyrinth side weirs have been performed for fixed-bottom channel situations.

There are a limited number of studies investigating the scouring around the labyrinth side weir in alluvial channels. Emiroglu et al. (2017) aimed to reduce the scour by preventing the vortex by using plates in the labyrinth side weir flow [5]. In Tunc and Emiroglu (2018a), the effect of labyrinth side weirs reflected on the bed topography for live bed scour was investigated experimentally [6]. In addition, the bed geometry around classical rectangular weirs has been investigated experimentally in the literature [7,8]. The relationship between bed morphology and discharge from the weir is determined in the literature [9].

When the literature was researched, the papers in which different shaped labyrinth weirs were analyzed were found. [10,11]. Different scour depths have been obtained for different labyrinth weir types. However, it has been observed that the equilibrium scour depth formed around the labyrinth weirs, in general, is quite low compared to the conventional weirs. Trapezoidal labyrinth weirs have reduced the scour depth by up to 19% compared to conventional weirs, while rectangular labyrinth weirs have reduced the scour depth by up to 10% compared to conventional weirs [12]. When the different apex angles of the triangular labyrinth weir are tested, it is determined that the weir giving the least depth of scouring is the labyrinth weir with a 60° apex angle [13].

The use of labyrinth side weirs is expected to increase due to the high discharge capacity. There are many hydraulic structures in our country which is rich in rivers. It should be ensured that excess water is safely removed from these hydraulic structures. In particular, it is thought that examining the scouring problem for labyrinth side weirs will contribute to the literature. The aim of this study is to investigate the effect of the use of labyrinth side weir, which is a new type of weir, for different flow intensities and different sediment grain sizes and the bedform in an alluvial channel.

2. Experimental Methods

In order to carry out this study, the present experimental setup as shown in Figure 1 was used. This test system consists of the main channel with a labyrinth side weir and a collection channel where the water is discharged.

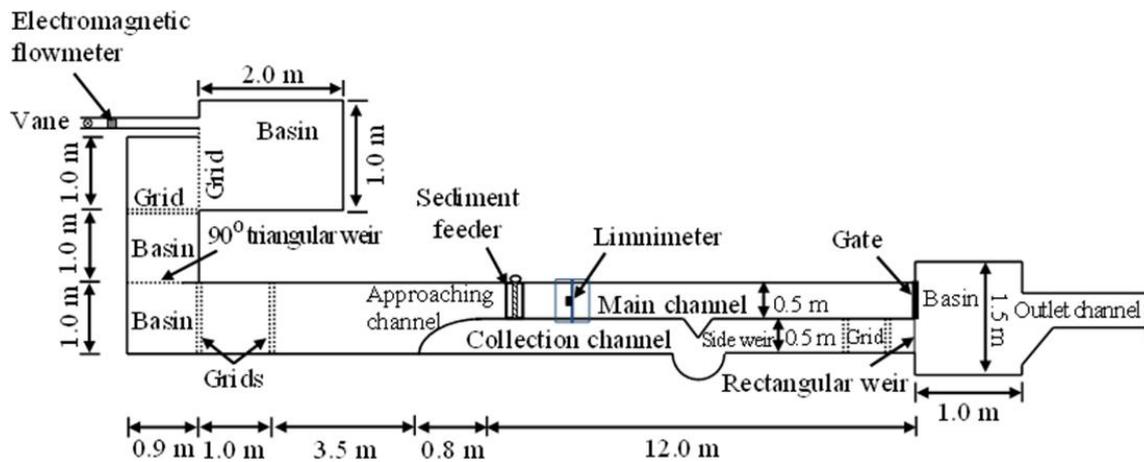


Figure 1. Plan view of the experimental setup.

In the experiments, the discharge of water entering the main channel was determined using an electromagnetic flow meter (Figure 2a). Discharges are measured in “L/s”. Level measurements on the main channel and side weir were measured by electronic limnimeter (± 0.01 mm accuracy) (Figure 2b). With this limnimeter the measurement can be taken in both x and y directions.

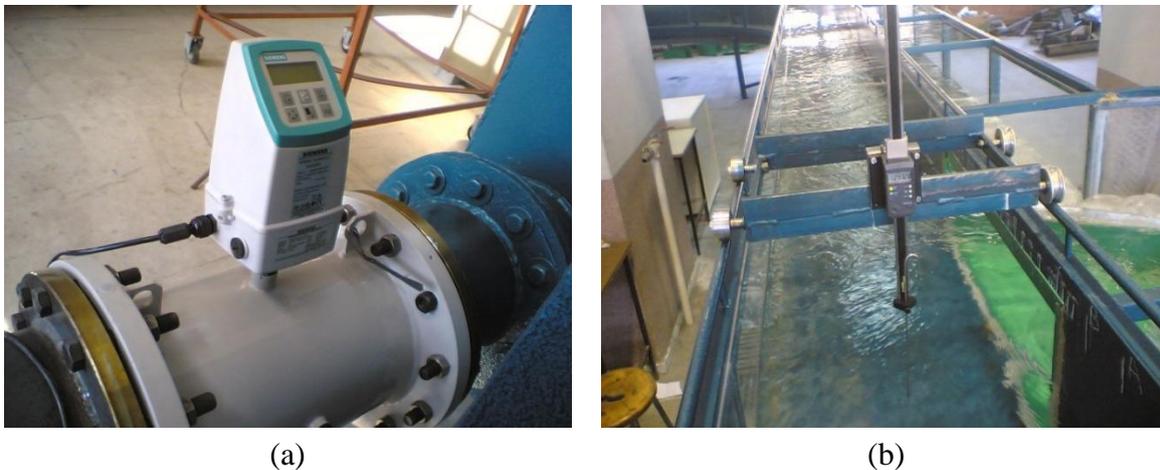


Figure 2. Testing devices used in experiments: a) Electromagnetic flowmeter, b) Digital limnimeter.

The experiments were conducted using a triangular labyrinth side weir with weir opening length of $L=25$ cm, crest height of $p=16$ cm from the sediment bed, and an apex angle $\theta=90^\circ$ in a straight channel with a rectangular cross-section. A view of the labyrinth side weir flow is presented in Figure 3. The experiments were carried out under stable flow conditions, in the case of a free flow state of the live bed scour conditions ($V_1/V_c > 1$). Bricks are placed at certain points of the channel to ensure a stable flow condition. In order to provide free flow and prevent any interference to the flow, the part that passes from the side weir to the collection channel is circular enough outward in

size (Figure 3). In order to minimize the surface tensile effect, the minimum nappe height was taken as 3 cm [14-16].

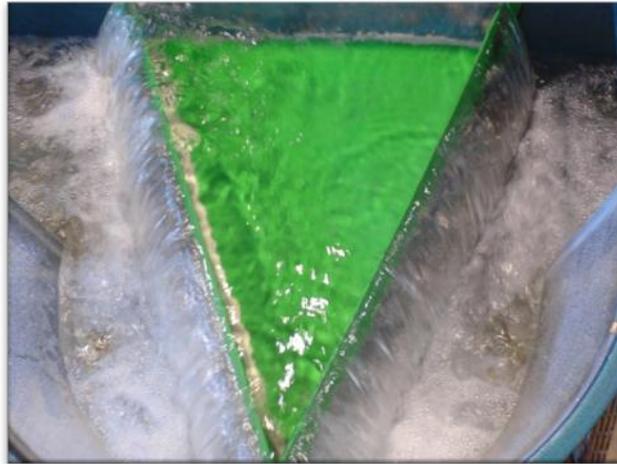


Figure 3. Labyrinth side weir flow.

Quartz sand with different grain sizes ($d_{50} \approx 1.2$ mm, $d_{50} \approx 1.5$ mm, and $d_{50} \approx 1.8$ mm) was placed in the main channel. The sediment bed, 20 cm high, was leveled on each side of the channel and made ready for testing (Figure 4a). Water was slowly introduced into the channel to prevent distortion of the flat sediment bed. After a certain discharge was set, the experiment was started. It is known that 9 hours is sufficient for reaching the equilibrium scouring depth [17]. After the experiment, the view of the sediment bed in the main channel is presented in Figure 4b.



Figure 4. Sediment bed: a) Before the start of the experiment, b) After the end of the experiment.

After the end of the experiment, the maximum scour depth around the side weir area was measured with the digital limniimeter (Fig. 2b).

In this study, grain sizes and specific gravities of quartzitic sands were determined by experiments carried out in the Hydraulic Laboratory of Firat University Civil Engineering Department. The specific gravity of the bed materials used is approximately $\gamma_s = 2.65$ g/cm³. Grain-size curves of the bed materials used in the experiments are given in Figure 5(a-c). According to Figure 5, uniform material is used.

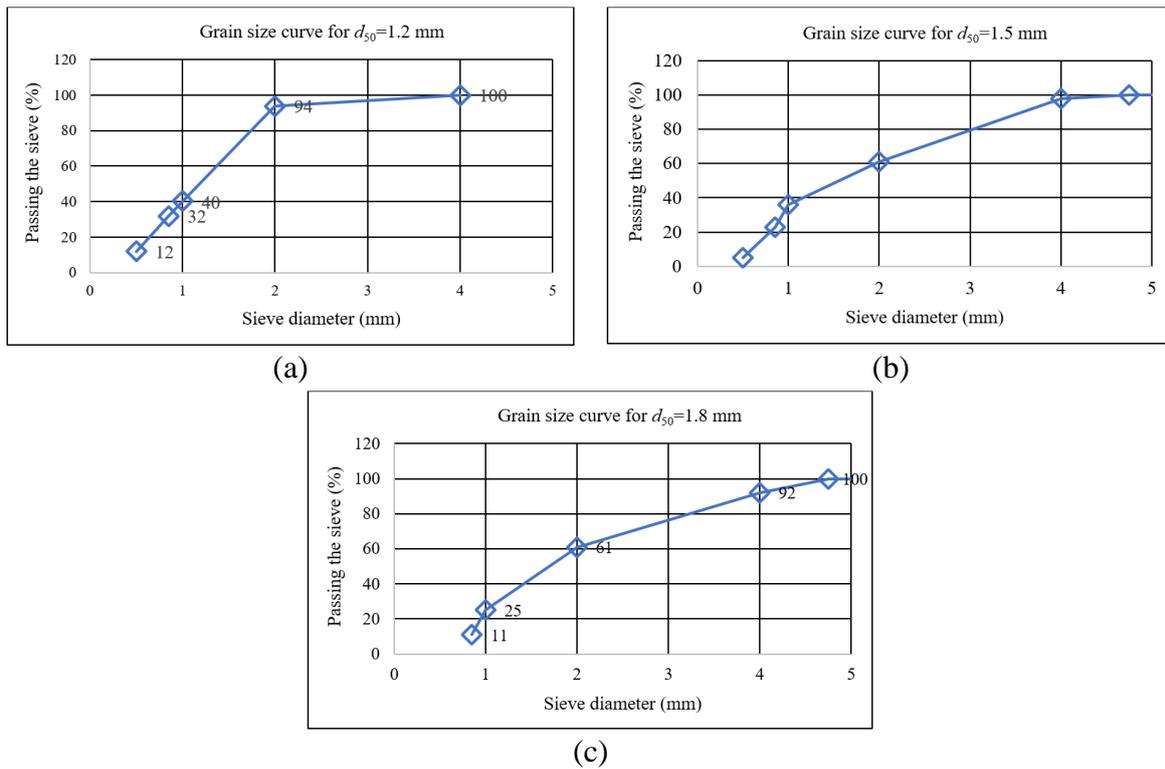


Figure 5. Grain-size curves of quartzitic sediment: a) for $d_{50}\approx 1.2$ mm, b) for $d_{50}\approx 1.5$ mm, c) for $d_{50}\approx 1.8$ mm.

3. Experimental Results and Discussion

As a result of this study, the relationship between the flow intensity (V_1/V_c) and the equilibrium scour depth (d_{se}) was observed in a rectangular cross-section straight channel for $L=25$ cm weir opening length and $p=16$ cm crest height at the triangular labyrinth side weir flow with different discharge values and live bed scour conditions. In the case of live bed scour condition ($V_1/V_c > 1$), it was observed that the sediment transport occurred at a very high level as the dunes were formed in a short time and the bed was constantly in motion (Figure 4b). Therefore, the amount of spilled sediment from the weir increased continuously with the increase of " V_1/V_c " value. It was assumed that the equilibrium scour depth was reached when there was less than 1% change for the scour depth at a successive hour. The equilibrium scour depth generally occurred at the downstream end of the triangular labyrinth side weir (Figure 6).



Figure 6. Location of equilibrium scour depth.

The critical flow velocities (V_c) that will mobilize the bed material were calculated by Equation (1) [14,15].

$$\frac{V_c}{u_{*cr}} = 5.75 \log\left(5.53 \frac{y}{d_{50}}\right) \tag{1}$$

where u_{*c} =critical shear velocity (m/s), y =flow depth in the main channel (m), d_{50} =median grain size.

Shear velocities are determined with the help of Shields Diagram. For quartz sand at 20 °C, Equation (2) was obtained using the Shields Diagram [18,19].

$$u_{*c} = 0.0305d_{50}^{0.5} - 0.0065d_{50}^{-1} \ ; \ 1 \text{ mm} < d_{50} < 100 \text{ mm} \tag{2}$$

For d_{50} =1.2 mm, equations (1) and (2) were used to obtain Equation (3) for critical velocities at various depths of the flow that could mobilize the bed material.

$$V_c = 0.1610 \times \log(4608 \times y) \tag{3}$$

For d_{50} =1.5 mm, equations (1) and (2) were used to obtain Equation (4) for critical velocities at various depths of the flow that could mobilize the bed material.

$$V_c = 0.1899 \times \log(3687 \times y) \tag{4}$$

For d_{50} =1.8 mm, equations (1) and (2) were used to obtain Equation (5) for critical velocities at various depths of the flow that could mobilize the bed material.

$$V_c = 0.2145 \times \log(3072 \times y) \tag{5}$$

The dimensions of the weir, flow characteristics, grain sizes of bed materials, the experimental results from this study are presented in Table 1.

Table 1. Flow conditions and test results.

Exp. No	p (cm)	L (cm)	Q_1 (L/s)	y (cm)	B (cm)	d_{50} (mm)	V_1 (m/s)	V_c (m/s)	V_1/V_c (-)	d_{se} (cm)	d_{se}/p (-)
1	16	25	65	21	50	1.2	0.62	0.48	1.29	5.1	0.32
2	16	25	75	20	50	1.2	0.75	0.48	1.56	5.6	0.35
3	16	25	80	19	50	1.2	0.84	0.47	1.79	6.4	0.40
4	16	25	90	19	50	1.2	0.95	0.47	2.02	9.2	0.58
5	16	25	110	19	50	1.2	1.16	0.47	2.47	11.5	0.72
6	16	25	65	21	50	1.5	0.62	0.55	1.13	4.7	0.29
7	16	25	75	20	50	1.5	0.75	0.54	1.39	5.3	0.33
8	16	25	80	19	50	1.5	0.84	0.54	1.56	6.0	0.38
9	16	25	90	19	50	1.5	0.95	0.54	1.76	8.5	0.53
10	16	25	110	19	50	1.5	1.16	0.54	2.15	10.2	0.64
11	16	25	65	21	50	1.8	0.62	0.60	1.03	4.2	0.26
12	16	25	75	20	50	1.8	0.75	0.60	1.25	4.5	0.28
13	16	25	80	19	50	1.8	0.84	0.59	1.42	5.3	0.33
14	16	25	90	19	50	1.8	0.95	0.59	1.61	7.4	0.46
15	16	25	110	19	50	1.8	1.16	0.59	1.97	9.2	0.58

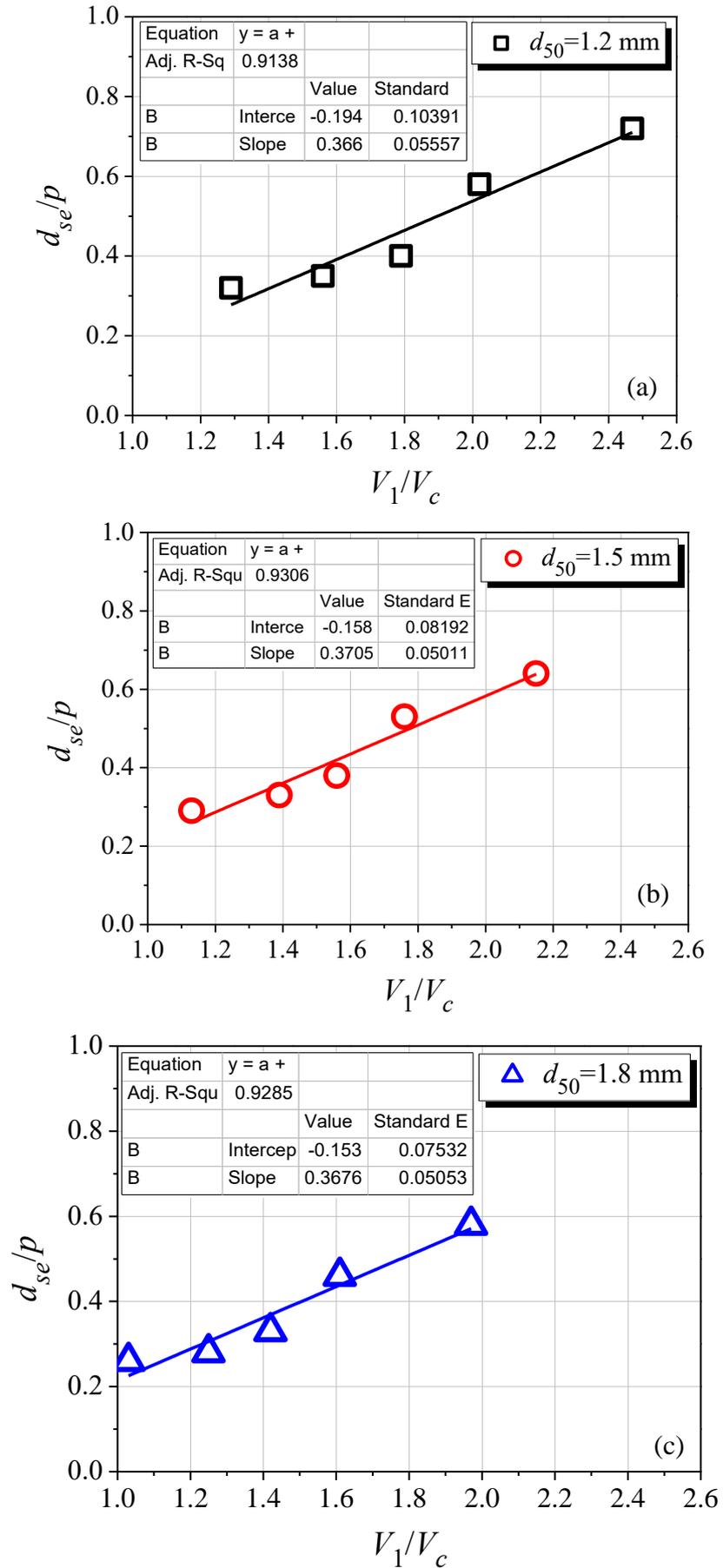


Figure 7. Variation of d_{se}/p with V_1/V_c : a) $d_{50}=1.2$ mm, b) $d_{50}=1.5$ mm, c) $d_{50}=1.8$ mm.

In this section, the variation of dimensionless equilibrium scour depth (d_{se}/p) with flow intensity (V_1/V_c) under different flow conditions is examined and given in Figure 7(a-c). In Figure 7(a-c), it is seen that is occurred scour for all V_1/V_c values, constant side weir opening length ($L=25$ cm), and constant crest height ($p=16$ cm). As the median grain diameter (d_{50}) increased, it was determined that flow intensity and equilibrium scour depth decreased. It has been determined that with the increase of flow intensity (V_1/V_c) by about 90-92%, the dimensionless equilibrium scour depth (d_{se}/p) increases by about 120-125%. Moreover, it was determined that the median grain diameter d_{50} increased by 25%, the equilibrium scour depth d_{se}/p decreased by about 5-11%. Similarly, it was determined that the median grain diameter d_{50} increased by 50%, the equilibrium scour depth d_{se}/p decreased by about 8-20%.

4. Conclusions

The conclusions of the present experimental study are summarized below:

- In this study, equilibrium scour depths were measured for labyrinth side weir flow in an open channel where bed material of different grain sizes was placed.
- The experiments were performed for different discharges.
- As the effective crest lengths are high, it is thought that the labyrinth weirs will distribute the water to a larger area than the conventional weirs and take place a smaller scour depth at the downstream.
- Since the experiments were carried out for high flow intensities ($V_1/V_c > 1$), scour and dunes were observed in all experiments.
- In case of live bed scour conditions ($V_1/V_c > 1$), it was observed that the scours and dunes were formed in a short time.
- It has been determined that the flow intensity (V_1/V_c) decreases by increasing the median grain diameter (d_{50}) of the bed material.
- It has been determined that the equilibrium scour depth (d_{se}) decreases by increasing the median grain diameter (d_{50}) of the bed material.
- It has been determined that with the increase in flow intensity (V_1/V_c), the dimensionless equilibrium scour depth (d_{se}/p) increases.
- The amount of bed material spilled from the labyrinth side weir increased with increasing flow intensity (V_1/V_c).
- The location of the equilibrium scour depth is generally observed as the downstream end of the triangular labyrinth side weir.
- It is thought that examining the scouring problem for labyrinth side weirs will contribute to the literature and the related engineers.
- It is recommended that this study be conducted for larger sediment median grain diameters, different side weir types, and sizes.

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