Sediment Trap Efficiency and Channel Bed Change Upstream of Sediment Trap Weir

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Abstract

The sediment trap efficiency and the change of channel bed profile upstream of the sediment trap weir were investigated by experiments in a hydraulic laboratory. The study was done using the physical hydraulic models consisting of a flume, a sand feeder, a water supply circulating system and weir models. Along the flume, the water and sediment were feeded to enter the upstream end while the overflow weir was installed at the downstream end. Three factors affecting the sedimentation to be considered were water discharges, mean sediment sizes and weir heights, totaling 45 case studies. Each case study was done in 2 steps, the case without weir and the case with weir, in order to determine the sedimentation upstream of the weir. The data of channel bed levels were measured at every interval of time and distance. Thus, the time series of channel bed profiles were derived and used to determine the channel bed change and the trap efficiency. From the study results, it was found that the change of channel bed profile occurred as a time series of layers of deposited bed sediment. At start, the sediment deposited in a thin layer of definite length in the upper reach extending downstream from the intake point. With more sedimentation on the channel bed, the sediment layer grew up in depth and length extending downstream from the intake to the weir. Eventually, the sediment filled up the channel storage from the intake down to the weir where the bed level equaled the weir crest level. The percentage of length and volume of sedimentation compared with the time percentage during the transient processes were analyzed. The initial and final lengths, times and depths of sedimentation, volumes of sediment inflow and trapped sediments and the sediment trap efficiencies were determined. It was found that the sediment trap efficiency in the channel from the intake point to the weir was averaged about 75%. The sediment trap efficiency varied accordingly with the water discharge and the mean sediment size but inversely with the weir height.

1. Introduction

A sediment trap weir is one type of hydraulic structure constructed in a channel for reducing the sediment amount flowing downstream where the channel storage is important to be preserved for specific purposes. For examples, at the downstream channel, there may be a reservoir for water storage, a river for navigation or a waterway for flood control. If the sediment amount is excessive, the reservoir will lose the storage capacity due to sedimentation and the river becomes shallow and unsuitable for navigation and flood control. In addition, the weir for water diversion unavoidably encounters the same problem of sedimentation in a similar manner as the sediment trap weir. Understanding of the sediment trap efficiency and the change with time of channel bed profile due to the sedimentation upstream of the weir will contribute the solution to the sedimentation problem related with the weir. There will be useful informations in practice for estimating the service life of the channel storage upstream of the weir and the shallowness of the upstream channel bed profile with time such that a good maintenance program such as a channel dredging work can be planned and performed appropriately at time and place.

In practice, the weirs as well as the reservoirs have been widely constructed in a large number for the same purpose of water storage. Similarly, both types of structures have the same problem of sedimentation upstream of the structures. However, the number of studies on the sedimentation between the two structure types are different a lot. In the past, the studies on the sedimentation of reservoirs were widely carried out, yielding a number of standard criteria for estimating the trap efficiency as referred to [1],[2] and the sediment distribution affecting the elevation-area-storage curve of reservoir as referred to [3], being widely used in practice. Oppositely, the studies on the sedimentation of weirs were much less. A few studies on the trap efficiency of weir were done as cited in [4] indicating the mean trap efficiency about 70-80%. Unfortunately, the study on the change with time of the channel bed profile upstream of the weir is scarce and unavailable.

This study had the objectives to investigate the sediment trap efficiency and the change with time of the channel bed profile upstream of the weir. The study was done by experiments in a hydraulic laboratory. Three factors affecting the sedimentation to be considered were water discharges, mean sediment sizes and weir heights. The procedure and results of this study were referred to [5].

2. Experimental Setup

The study was done using the physical hydraulic models at the Laboratory of Hydraulic Research and Coastal Model, Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University. The experimental apparatus were consisted of

1) rectangular flume of 0.60 m. width, 0.75 m. height, 18.0 m. length,
2) motor-driven sand feeder as a container pouring sand into the flume,
3) water supply circulating system and
4) vertical and sharp crest overflow weirs made of plastic plates.

Along the flume, the water and sediment were feeded to enter the upstream end (at station 14.25 m.) while the weir was installed at the downstream end (at station 0.0 m.). The water discharge was feeded by the water supply circulating system. The sediment transport was feeded by the sand feeder. The bed of the flume was laid with the same sand material with the initial thickness of 20 cm. Both side walls of the flume were transparent glass plates.

Three factors affecting the sedimentation to be considered were water discharges, mean sediment sizes and weir heights. The total number of experiments were 45 case studies, each of which was specified with the values of each factor as follows

1) water discharges : Q1=14 l/s, Q2=16 l/s, Q3=20 l/s, Q4=24 l/s, Q5=28 l/s,
2) mean sediment sizes : D1= 0.33 mm, D2= 1.40 mm, D3= 2.00 mm and
3) weir heights : W1=5 cm, W2=7.5 cm, W3=10 cm.

Experiments of each case study was done in 2 steps and it is described as follow.

1) The case without weir was done first to set up the equilibrium condition to balance the sediment transport rate with the water flow discharge and the mean sediment size. To set the sediment transport rate close to the equilibrium value, it was initially calculated using the formulas of [6-7]. The rate of sand feeding or the sediment rate was adjusted until the equilibrium condition was achieved as no change of channel bed profile with time was observed.
2) The case with weir was done later using the equilibrium condition from the case without weir as the initial condition. The experiment was run until the sediment filled up the flume down to the weir.

The data of the channel bed levels were measured at every cross section with distance interval of 0.25 m and every hour. Thus, the time series of the channel bed profiles were derived and used to determine the channel bed change and the trap efficiency.

Of the 45 case studies, only the 26 case studies were completed with full sedimentation down to the weir while the 19 case studies were not completed due to the sand shortage causing not yet full sedimentation. Thus the data of only the 26 complete case studies were further analyzed for the study results.

3. Study Results

3.1 Change of Channel Bed Profile

All case studies had the change of channel bed profile from the initial through the transient until the final conditions in a similar pattern. Fig.1 shows the hourly time series of channel bed profiles for the case study W3-D2-Q5. As seen, the change of channel bed profile occurred as a time series of layers of deposited bed sediment. At start, the sediment deposited as a thin layer with definite depth and length in the upper reach, extending from the intake point down to an intermediate point between the intake point and the weir. The deposited sediment layer had a bed wave front with steep slope on the downstream side. With more sedimentation on the channel bed, the sediment layer grew up in depth and length extending downstream from the intake to the weir. Evidently, the bed wave front of the sediment layer moved downstream with increasing size until reaching the weir. Eventually, the sediment filled up the channel storage from the intake down to the weir where the bed level equaled the weir crest level.

Fig.2 shows the percentage of sedimentation length with respect to the time percentage. The sedimentation length was measured downstream from the intake to the bed wave front. The length of deposited sediment increased with time but with decreasing speed. The effects of water discharge, mean sediment size and weir height on the increase of percentages of the sedimentation length with time were not significant as the graphs were little different.

Fig.3 shows the percentage of sedimentation volume with respect to the time percentage. The volume of deposited sediment increased with time at rather constant rate. The effects of water discharge, mean sediment size and weir height on the increase of percentages of the sedimentation volume with time were little as the graphs were close to each other.

3.2 Initial Length of Sedimentation

The upper reach had an initial length of deposited bed sediment with the length measured downstream from the intake to the initial bed wave front. The lower reach had initially no sedimentation with the initial length measured upstream from the weir to the initial bed wave front. Table 1 shows the lengths of the upper and lower reaches for all case studies. The lengths of the upper reach were in the range of 6.75-11.25 m with the mean of 8.92 m. The lengths of the lower reach were in the range of 3.00-7.50 m with the mean of 5.33 m. The initial length of sedimentation varied accordingly with the mean sediment size, but inversely with the weir height and negligibly with the water discharge.

3.3 Final Length of Sedimentation

The final length of sedimentation was investigated. From all case studies, it was found that the sediment ultimately deposited along the overall channel length from the weir up to the intake. Consider the channel length of 14.25 m. and the weir height of 5-10 cm. Therefore, the channel length affected by the sedimentation was at least about 143-285 times of the weir height.

3.4 Time of Sedimentation

Table 1 shows the times of sediment filling up the channel storage for all case studies. The times of sedimentation were in the range of 90-660 minutes with the mean of 370 minutes. The time of sedimentation varied accordingly with the weir height, but inversely with the water discharge and the mean sediment size.

3.5 Depth of Sedimentation

Table 1 shows the final depths of deposited sediment at the intake and the weir. The depths of deposited sediment were least at the intake in the range of 1.1-5.9 cm. with the mean of 3.5 cm. and varied accordingly with the weir height, but negligibly with the water discharge and the mean sediment size. The depths of deposited sediment were most at the weir and almost equaled the weir height.

3.6 Volume of Trapped Sediment

Fig.4 and Table 1 show the volumes of sediment deposited fully in the channel in the range of 0.122-0.529 m^3 with the mean of 0.363

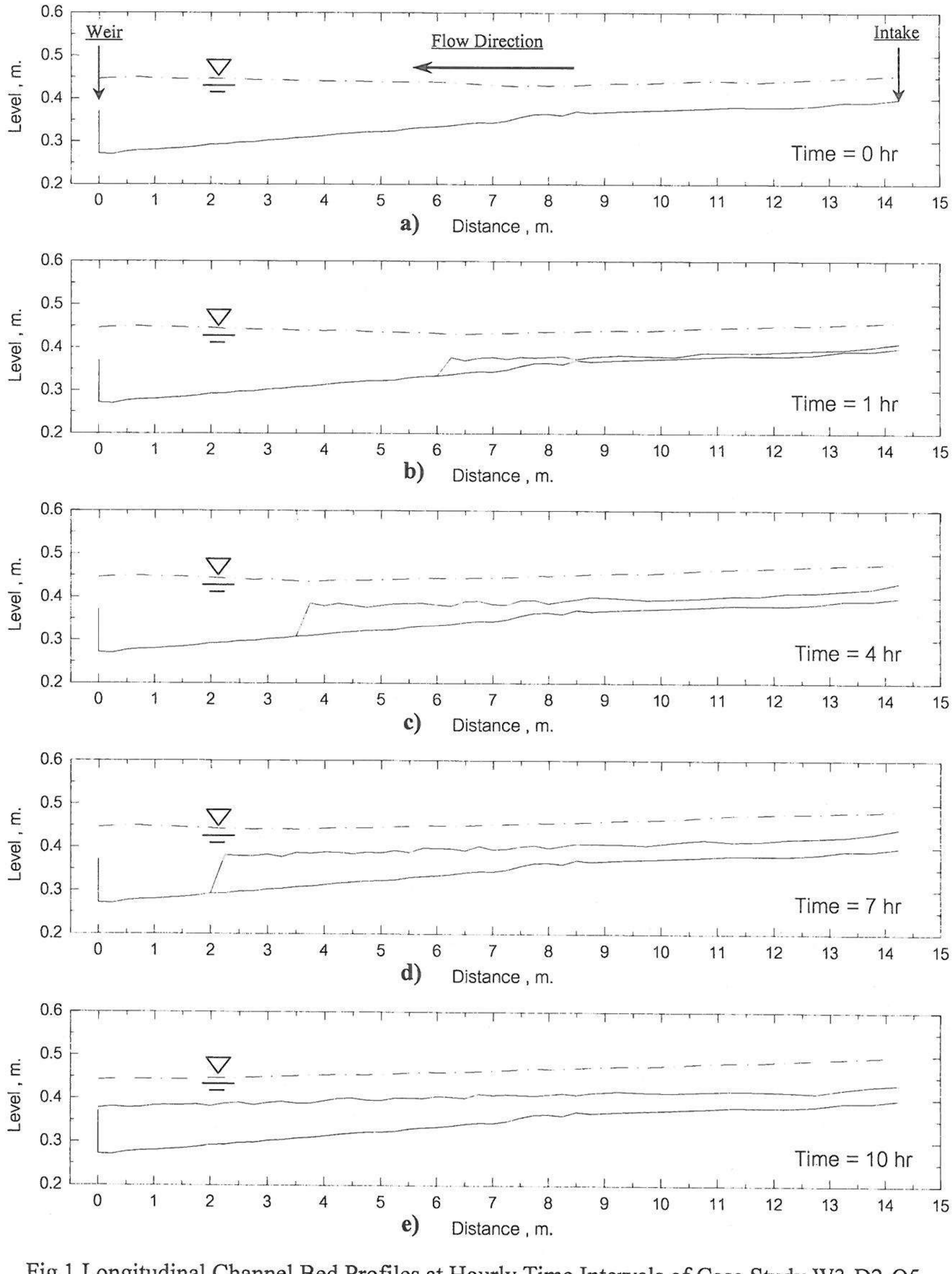

Fig.1 Longitudinal Channel Bed Profiles at Hourly Time Intervals of Case Study W3-D2-Q5

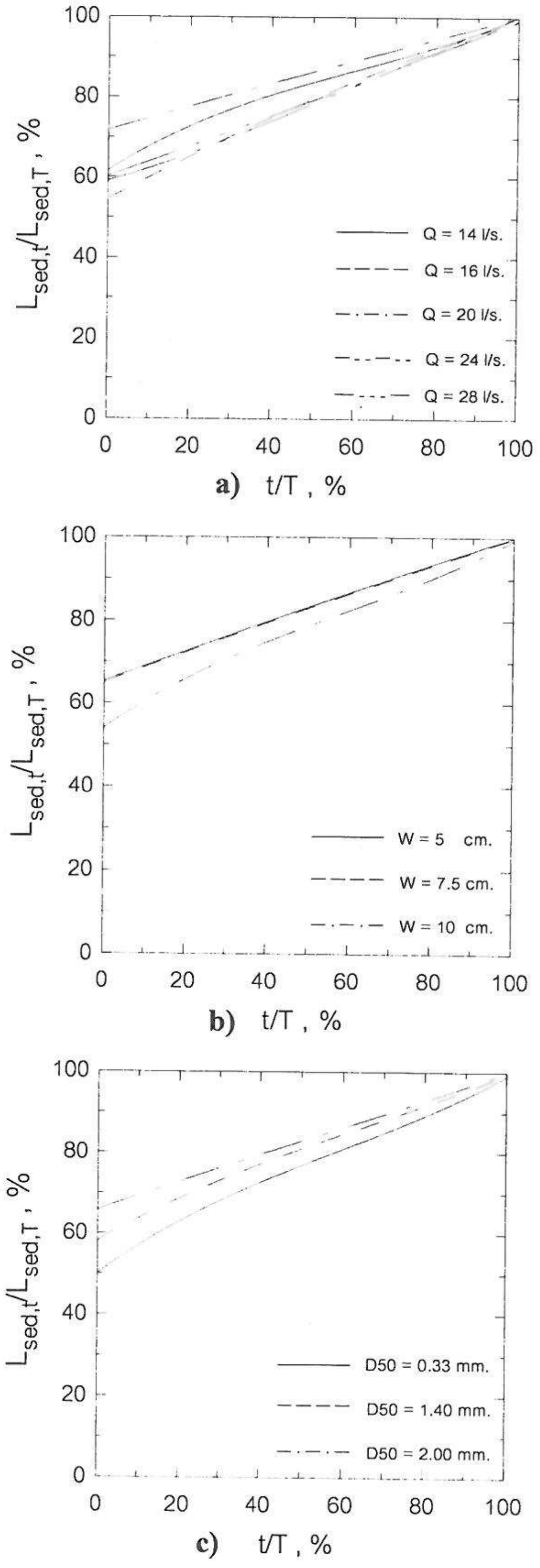

Fig. 2 Sedimentation Length VS Time Percentage

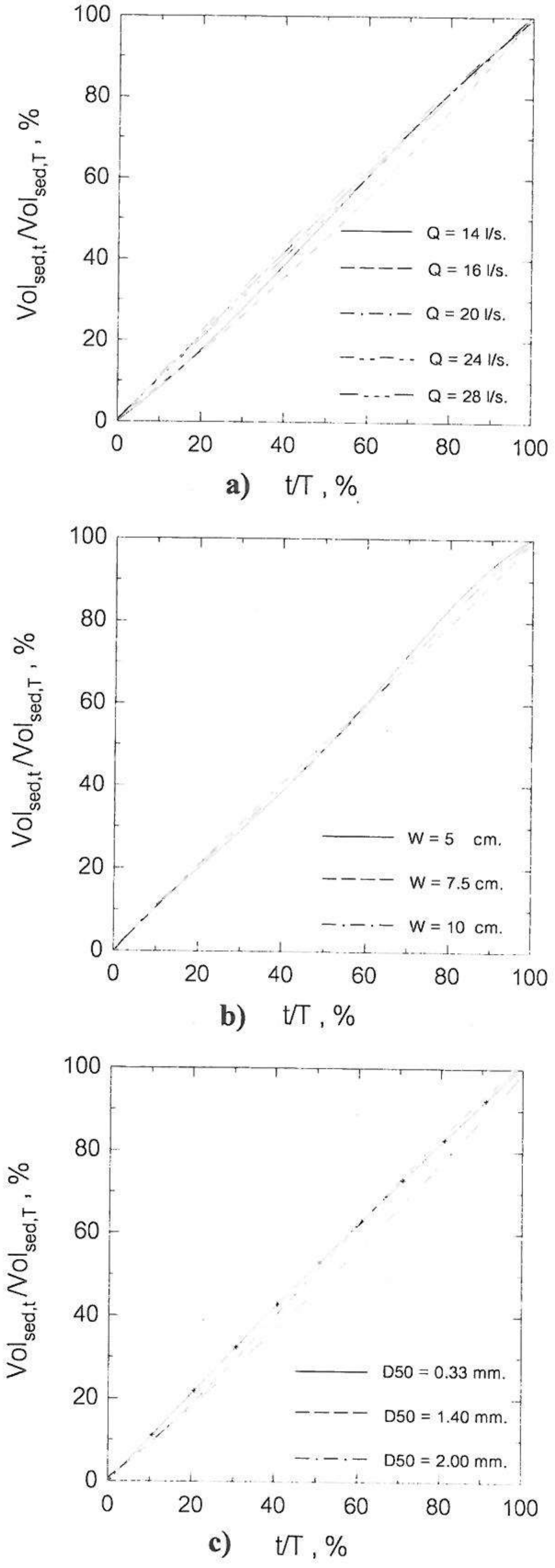

Fig. 3 Sedimentation Volume VS Time Percentage

Table 1 Lengths, Times, Depths, Volume of Sedimentation and Trap Efficiencies

Case Study	Lower Reach Length (m)	Upper Reach Length (m)	Sed. Time (min)	Sed. Depth at weir (m)	Sed. Depth at intake (m)	Trap sed. Vol. (m^3)	Inflow sed. Vol. (m^3)	Trap eff. %
W1-D1-Q1	4.00	10.25	300	0.042	0.024	0.284	0.359	66
W1-D1-Q2	3.00	11.25	385	0.044	0.025	0.346	0.5	68
W1-D1-Q3	7.00	7.25	270	0.031	0.02	0.39	0.394	99
W1-D1-Q4	6.00	8.25	270	0.035	0.02	0.299	0.419	71
W1-D1-Q5	7.00	7.25	213	0.026	0.02	0.298	0.358	83
W2-D1-Q1	5.75	8.50	633	0.072	0.052	0.474	0.747	63
W2-D1-Q2	7.50	6.75	445	0.073	0.056	0.437	0.61	72
W2-D1-Q3	6.00	8.25	396	0.070	0.039	0.437	0.576	76
W2-D1-Q4	4.00	10.25	300	0.067	0.041	0.360	0.481	75
W2-D1-Q5	3.00	11.25	253	0.068	0.042	0.366	0.425	86
W3-D1-Q1	7.50	6.75	N/A	N/A	N/A	N/A	N/A	N/A
W3-D1-Q2	8.00	6.25	N/A	N/A	N/A	N/A	N/A	N/A
W3-D1-Q3	8.00	6.25	N/A	N/A	N/A	N/A	N/A	N/A
W3-D1-Q4	7.50	6.75	N/A	N/A	N/A	N/A	N/A	N/A
W3-D1-Q5	7.00	7.25	610	0.096	0.027	0.519	1.025	51
W1-D2-Q1	6.00	8.25	566	0.056	0.052	0.362	0.577	63
W1-D2-Q2	6.00	8.25	485	0.048	0.052	0.401	0.536	75
W1-D2-Q3	4.50	9.75	360	0.061	0.024	0.256	0.395	54
W1-D2-Q4	3.25	11.00	180	0.062	0.015	0.242	0.459	88
W1-D2-Q5	6.50	7.75	N/A	N/A	N/A	N/A	N/A	N/A
W2-D2-Q1	7.50	6.75	N/A	N/A	N/A	N/A	N/A	N/A
W2-D2-Q2	7.00	7.25	N/A	N/A	N/A	N/A	N/A	N/A
W2-D2-Q3	7.25	7.00	N/A	N/A	N/A	N/A	N/A	N/A
W2-D2-Q4	7.50	6.75	N/A	N/A	N/A	N/A	N/A	N/A
W2-D2-Q5	7.25	7.00	N/A	N/A	N/A	N/A	N/A	N/A
W3-D2-Q1	6.50	7.75	N/A	N/A	N/A	N/A	N/A	N/A
W3-D2-Q2	8.00	6.25	N/A	N/A	N/A	N/A	N/A	N/A
W3-D2-Q3	7.75	6.50	N/A	N/A	N/A	N/A	N/A	N/A
W3-D2-Q4	7.50	6.75	600	0.096	0.035	0.521	0.739	71
W3-D2-Q5	7.50	6.75	610	0.106	0.035	0.523	0.7	75
W1-D3-Q1	5.25	9.00	N/A	N/A	N/A	N/A	N/A	N/A
W1-D3-Q2	7.50	6.75	180	0.043	0.024	0.122	0.139	51
W1-D3-Q3	6.25	8.00	N/A	N/A	N/A	N/A	N/A	N/A
W1-D3-Q4	3.75	10.50	103	0.016	0.014	0.201	0.206	87
W1-D3-Q5	3.00	11.25	90	0.043	0.011	0.136	0.147	97
W2-D3-Q1	5.25	9.00	660	0.048	0.059	0.446	0.646	76
W2-D3-Q2	6.25	8.00	N/A	N/A	N/A	N/A	N/A	N/A
W2-D3-Q3	3.50	10.75	180	0.063	0.015	0.226	0.271	83
W2-D3-Q4	6.25	8.00	360	0.076	0.058	0.529	0.631	84
W2-D3-Q5	4.75	9.50	180	0.074	0.029	0.346	0.374	92
W3-D3-Q1	5.25	9.00	660	0.049	0.059	0.452	0.699	65
W3-D3-Q2	8.00	6.25	N/A	N/A	N/A	N/A	N/A	N/A
W3-D3-Q3	7.75	6.50	N/A	N/A	N/A	N/A	N/A	N/A
W3-D3-Q4	7.00	7.25	N/A	N/A	N/A	N/A	N/A	N/A
W3-D3-Q5	7.00	7.25	330	0.053	0.053	0.475	0.565	93
Min	3.00	6.25	90	0.016	0.011	0.122	0.139	51
Max	8.00	11.25	660	0.106	0.059	0.529	1.025	99
Mean	6.18	8.07	370	0.058	0.035	0.363	0.499	75

N/A : incomplete full sedimentation

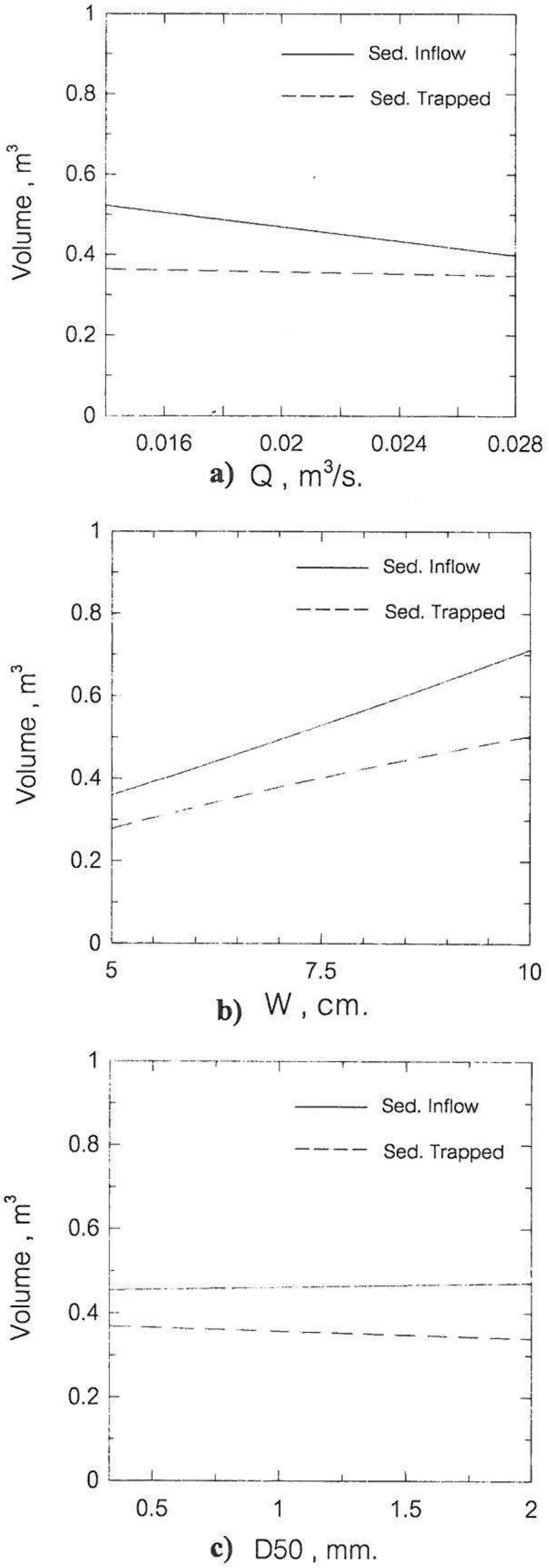

Fig. 4 Volume of Trapped Sediment and Sediment Inflow

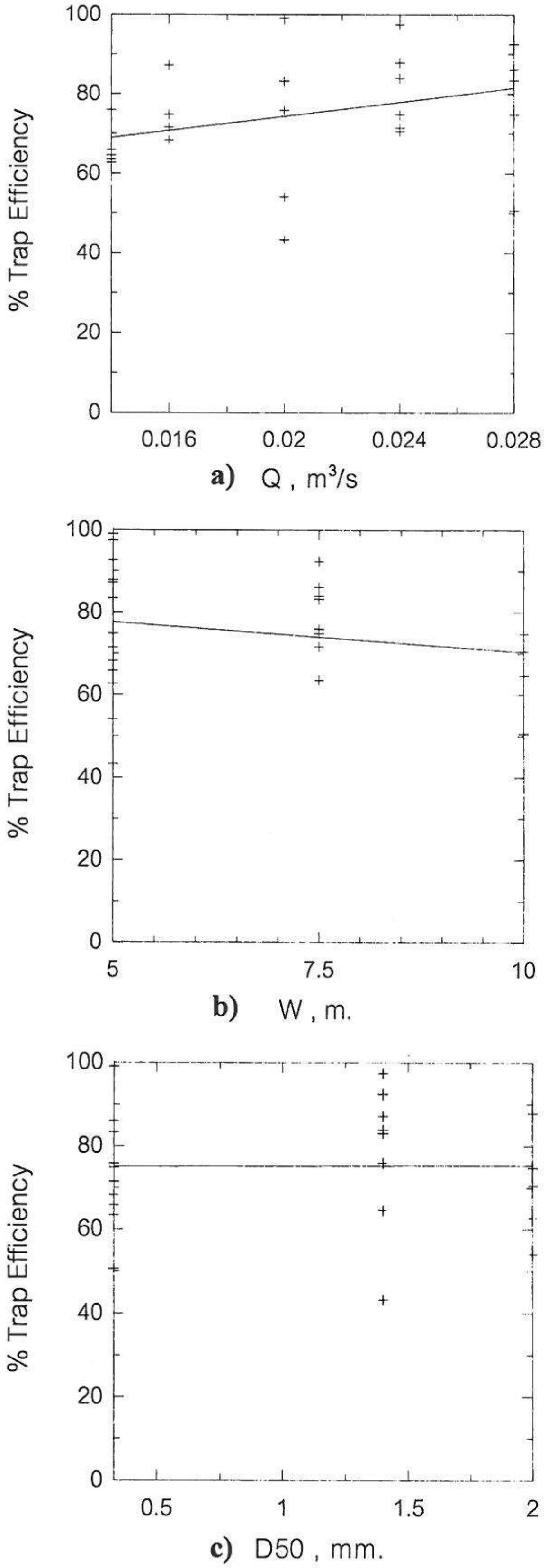

Fig. 5 Sediment Trap Efficiencies

m^3. The volume of trapped sediment varied accordingly with the weir height, but negligibly with the water discharge and the mean sediment size. It was found that more sediment was deposited in the lower reach than the upper reach.

3.7 Volume of Sediment Inflow

Fig.4 and Table 1 show the volumes of sediment inflow within the time of sedimentation. The volumes of sediment inflow were in the range of 0.139-1.025 m^3 with the mean of 0.499 m^3. The volume of sediment inflow varied accordingly with the weir height, but inversely with the water discharge and negligibly with the mean sediment size.

3.8 Sediment Trap Efficiency

The sediment trap efficiency was defined as the ratio of the trapped sediment volume to the inflow sediment volume within the same time period, in this study using the time of sedimentation. Fig.5 and Table 1 show the sediment trap efficiencies in the overall channel in the range of 51-99 %.with the mean of 75 %. The sediment trap efficiency varied accordingly with the water discharge, but inversely with the weir height and negligibly with the mean sediment size

Conclusion

1. The changes of the channel bed profiles with respect to time upstream of the weir were investigated by the experiments. The study was done to determine the effects on the change of the channel bed profile due to the 3 factors such as water discharges, mean sediment sizes and weir heights, totaling 45 case studies. As the results, the time series of channel bed profiles were derived.
2. The patterns of the changes of channel bed profiles were discussed. All case studies had the changes of channel bed profiles in a similar pattern as a time series of layers of deposited bed sediment. At start, the sediment deposited in a thin layer in the upper reach. With more sedimentation, the sediment layer grew up extending downstream to the weir. Eventually, the sediment filled up the channel storage.
3. The sediment ultimately deposited along the overall channel length from the weir up to the intake. At the intake, the sediment deposited increasingly such that the sedimentation and the backwater effect were likely to continue to extend upstream further above the intake point until the new equilibrium of steady and uniform flow would occur again.
4. The characteristics of sedimentation were determined. The percentage of length and volume of sedimentation with respect to the time percentage during the transient processes were analyzed. The initial and final lengths, times and depths of sedimentation, volumes of sediment inflow and trapped sediments and the sediment trap efficiencies were determined. In addition, the effects of the three factors on such sedimentation characteristics were discussed

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