Effect of sediment roughness on surface aeration around boulders in an open channel flow

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Abstract: In the present study the role of boulders placed in a laboratory flume in enhancing the flow Dissolved Oxygen levels was examined for various boulder arrangements and different bed roughness. Various flow depths and bottom roughness were performed at defining configuration for understanding effect of flow depth on DO efficiency.

Key words: open channel flow, Dissolved Oxygen (DO), bottom roughness

Introduction

Dissolved oxygen (DO) efficiency is one of the most important parameters affecting environmental aspects of stream behavior. For example, enhancing dissolved oxygen in streams contributes to the improvement of the quality of aquatic habitat. Nowadays, the condition of aquatic resources is deteriorating due to a variety of human activities that have an adverse effect on the environment. Boulders and other meso-scale obstructions to flow tend to increase significantly the complexity of the local flow patterns in their vicinity. Some of these patterns, such as vortex formation, higher turbulence intensity and local transitions from subcritical to supercritical and back to subcritical flow may contribute to increased activity in terms of air entrainment, especially in the wake region of the obstruction. The number of boulders, their location and arrangement within the stream, as well as their height in relation to the flow depth, i.e. submerged versus the case of protruding through the free surface, and bed roughness are expected to influence the ability of the flow to increase DO levels, (Cokgor and Kucukali, 2004). In the literature numerous contractual arrangements such as weirs, gates, cascades and chutes were designated for water re-aeration (Avery and Novak, 1978; Nakasone, 1987; Kim and Walters, 2001).

Experimental Study

Experiments were performed in a recirculating flume 0.5 m wide, 0.5 m deep and 18 m long. DO measurements were generated by an oxygen probe (WTW OXI DIGI 539 oxygen meter and recorder), and flow velocity was measured using Nortek 10 MHz acoustic doppler. The oxygen probe was also able to given water temperature at the measurement point in the flow. Concrete cubes with 15x15x15cm dimensions and in four different sizes were used to represent boulders in the flume. In the experiments, stones were placed tangent to the sidewalls. The reference measurement points for determining DO efficiency of the boulder arrangements

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were 100 cm upstream and 300 cm downstream from the beginning point of the boulders. Oxygen measurements were also conducted around the boulders systemically at the mesh with a 110 cm x 50 cm plan area around the stones.

RESULTS AND DISCUSSION

The present work was focused on two main objects; 1) oxygen transfer between upstream and downstream that explains the efficiency of boulder configuration, 2) oxygen quantity and distribution around boulder(s) at different bottom roughness. The experimental study was carried out at various flow depths and tested at two identical cube tests because the water level is not the same in natural streams due to hydrological events. Experimental results for oxygen efficiency for various boulder configurations, flow quantities and height of the roughness are given in Table 1. In the Table, q, U and h are the flow parameters, discharge per unit width, mean velocity and water depth respectively. Time average air temperature, T_a, and water temperature, T_w, were measured during the experiments. C_S, C_U, and C_D are the saturation, upstream and downstream oxygen concentrations (mg/L), respectively. From the table, low flow depths are always given high DO efficiency. When the boulder(s) submerge into the water, DO efficiency was determined as 0 which means no oxygen gained in that condition. The table also indicates the importance of bottom roughness on DO efficiency. When bottom roughness increases, E values also increase. DO distribution around the boulders is presented in Figure 1 for smooth and medium roughness. From the figure, oxygen reach zones are shown between the stones at the downstream of the boulders. On the wake side of the boulders untreated zones are shown. Figure 1 indicates the untreated zone at the wake side of the boulders reducing because turbulence intensities were increased by bottom roughness.

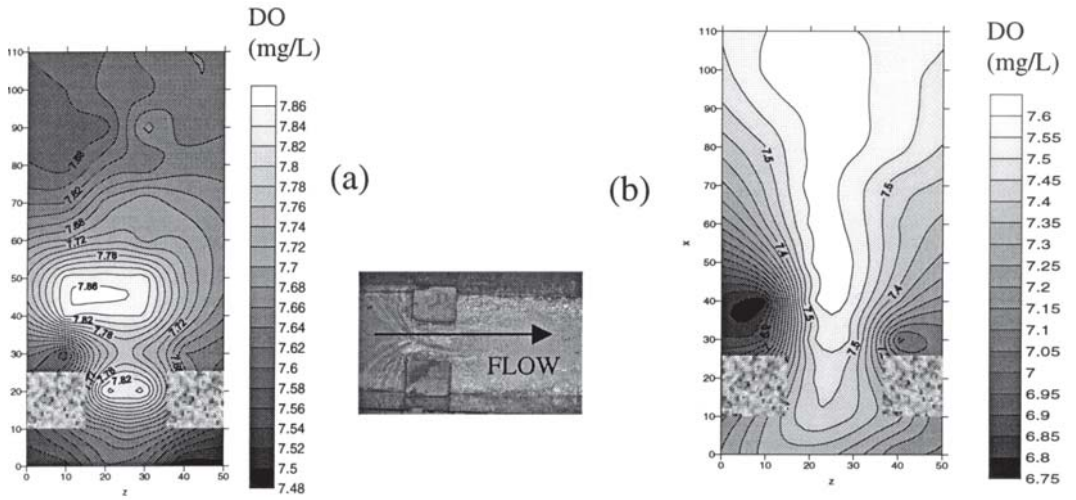

Figure 1. DO concentrations around two identical cubes for h=10cm (a) smooth bed, (b) rough bed (k=1.38cm).

Table 1. Flow conditions and test results

Run No	Boulder Arrangements	h (cm)	a (cm)	k	q (m^2/s)	U (cm/s)	T_a (^oC)	T_w (^oC)	C_S (mg/L)	C_U (mg/L)	C_D (mg/L)	E	E_{20}	r	r_{20}
1	Double cubes	5.24	2.14	0	0.005	9.16	25.1	25	7.98	7.45	7.62	0.32	0.29	1.47	1.42
2	Double cubes	10.1	5.52	0	0.013	12.72	25	26	7.94	7.56	7.62	0.16	0.14	1.19	1.17
3	Double cubes	15.1	7.82	0	0.026	17.26	25.3	26	8.16	7.81	7.84	0.09	0.07	1.09	1.08
4	Stone No2 (single)	9.66	4.87	0	0.0268	27.74	24.9	25.2	7.81	7.62	7.65	0.16	0.14	1.19	1.17
5	Stone No3 (single)	9.66	4.72	0	0.0122	12.63	25.6	26.5	7.86	7.60	7.61	0.04	0.03	1.04	1.03
6	Stone No2 and3	9.86	5.47	0	0.0144	14.60	26.0	25.6	8.08	7.64	7.79	0.34	0.31	1.52	1.45
7	Stone No2 and 5	9.10	5.16	0	0.0204	22.42	22.5	23	8.52	8.23	8.27	0.14	0.13	1.16	1.15
8	Double cubes	10.4	5.12	13.8	0.018	17.31	26.6	25.2	8.43	8.06	8.19	0.35	0.32	1.54	1.47
9	Stone No2 and 3	10.3	4.87	13.8	0.018	17.48	26.6	25.2	8.43	8.06	8.22	0.44	0.40	1.76	1.66
10	Stone No2 and 3	9.96	2.47	30.9	0.0072	7.23	25.6	24.6	8.35	7.58	7.82	0.31	0.29	1.45	1.40
11	Double cubes	10.35	2.59	30.9	0.018	17.39	25.6	24.6	8.35	7.69	7.81	0.18	0.11	1.22	1.12

Conclusions

Results indicated that DO configurations increase by placing boulders in streams with correct installation. Results may be summarized as follows;

- Water depth was an important parameter for oxygen efficiency and distribution around the boulders. When the boulders got submerged, there was no oxygen gain in the system (h = 20cm test results).
- Bottom roughness played an important role in the DO efficiency and increasing the roughness showed a better DO distribution downstream of the boulders.
- Two boulder configurations in the flume resulted in sufficient DO ratios. But these configurations were very important to uniform oxygen distribution on the wake side.
- Placing boulders in the stream could be of use in river reclamation projects because they increase DO efficiency in the stream in a friendly and natural manner in contrast to human made structures such as weirs cascades and chutes.

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