Discussion of "Discharge through a Permeable Rubble Mound Weir" by Kohji Michioku, Shiro Maeno, Takaaki Furusawa, and Masanori Haneda

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The discusser congratulates the writers for their valuable contribution to flow through permeable weirs, including rubble mound weir, rockfill structures, and some timber weirs. Their combined theoretical and physical modeling approach yields convincing results, and prototype tests could be a nice complement. The following comments are aimed to complement the findings.

Related applications of rubble mound weir include the in-built spillway dam and the stepped weir. The former design has been used in Australia since the 1950s (Fig. 1). Lawson (1987) described several prototype experiences. The latter design is commonly used for soil retention, storm-water system, and irrigation structures (e.g., Fig. 2). Chanson (2001) presented a wide range of applications. With both in-built spillway embankment and stepped weir, the shape of the downstream embankment face may have some influence on the seepage discharge. For example, in Fig. 2(b), the seepage outflow increases toward the downstream weir toe. It would be valuable if the authors could comment on the effect of the weir shape and the implications.

While the authors focused their study on seepage flow, the interactions between seepage and overflow cannot be ignored in many applications, and practicing engineers do need some expert guidance. A number of researchers discussed the interactions between the seepage flow through the rockfill and the overflow for in-built spillway structures (e.g., Parkin et al. 1966; Curtis and Lawson 1967; Olivier 1967; Fenton 1968; Kells 1993; Chanson 1996). Recently, a 200-m-long rockfill cascade was built for the diversion of Oaky Creek, Australia (Macintosh 2004), and physical tests showed significant interaction between seepage and overflow particularly for small to medium floods. With the stepped weir design, these interactions are further complicated by the stepped flow patterns and associated flow regimes (Peyras et al. 1991, 1992). Although there has been some discussion on the influence of step face roughness on the overflow, the interactions seepage/overflow have received little attention to date with the exception of one study (Kells 1995). This is a topic worthwhile for further studies.

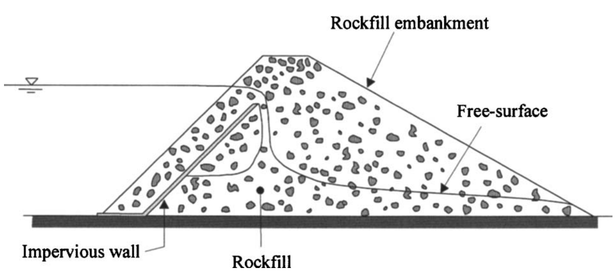

Fig. 1. In-built spillway rockfill embankment

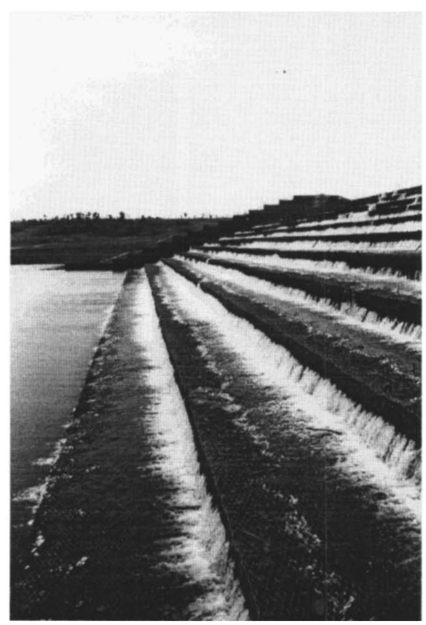

Fig. 2. Rockfill stepped weirs: (a) Rockfill stepped weir made of Reno mattresses in Robina, Gold Coast, Australia; and (b) Gabion stepped weir at Guaribraba, Capo Grande, Brazil (Courtesy of Officine Maccaferri)—note the seepage flow, the absence of overflow, and the increasing seepage with downstream distance from the crest

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Closure to "Discharge through a Permeable Rubble Mound Weir" by Kohji Michioku, Shiro Maeno, Takaaki Furusawa, and Masanori Haneda

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The writers would like to express their appreciation to the discusser for his valuable comments and advice on rubble mound weir from various engineering points of view. The writers were able to learn that such various types of rubble mound structures are in practical use for a wide spectrum of engineering purposes in Australia, while the writers' interest was limited to the problem of rubble mound weirs that are lower than rockfill dams. On the other hand, the writers were encouraged through the discussion to learn that their study may provide fundamental information on rubble mound structures and that the study could be further extended in different directions.

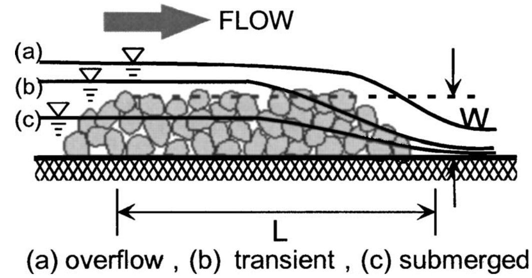

Fig. 1. Flow around a rubble mound weir: (a) overflow; (b) transient; and (c) submerged

The writers' understanding is that the discussion consists of two parts. The first is the problem of rubble mound weirs with different types of internal and external structures, such as the in-built spillway dam and the stepped weir. The second is with respect to a hydrodynamics in the case of rubble mound weir with overflow.

Rubble Mound Weirs with Different Types of Internal and External Structures

From an engineering point of view, it is a useful method for controlling through-flow discharge to partially install an in-built spillway or less permeable materials in a rubble mound structure (e.g., Parkin et al. 1966; Curtis and Lawson 1967). One of the problems with this type of structure, however, is the supposed difficulty in maintenance and repair work. The rubble mound weir must be designed under a concept that the structure could fail with severe flood flows. The basic idea is that the structure must be repaired and overhauled with a certain frequency. This is completely different from the design concept of conventional solid structures of concrete and steel. In the old ages, local inhabitants used to cooperate with each other to repair the weir after heavy stormwater. The repair work had a function to tighten the local community (Michioku 2003). In this sense, inhomogeneous structures are not suitable to the rubble mound weir, since complicated and special techniques are needed to repair the failed structure. An additional problem from an analytical point of view is that the one-dimensional flow analysis is no more applicable in the case of inhomogeneous rubble mound weir. A two- or three-dimensional analysis for the porous media flow is necessary, which is itself a fascinating scientific topic and worthwhile to be investigated but is beyond the writers' scope.

As was pointed out in the discussion, the writers did not mention a rubble mound weir with complicated external profile such

Fig. 2. Side view of the laboratory experiment

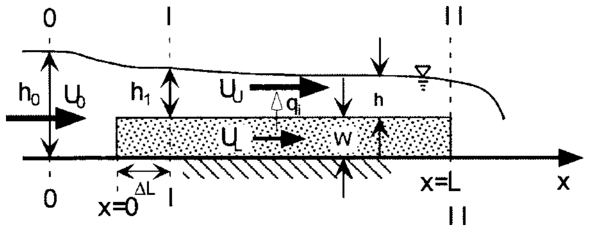

Fig. 3. Flow system

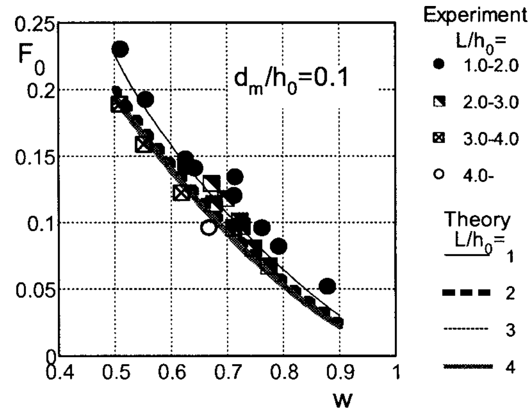

Fig. 4. Dimensionless discharge F_0 plotted against dimensionless weir height $w=W/h_0$

as stepped weir. The writers partially agree with the discusser on this point, because the rubble mound weir, strictly speaking, should have slopes at both the up- and downstream ends for stabilizing the structure. The writers, however, consider that their analysis for the rectangular weir is still useful because weirs used for irrigation are usually lower than a rockfill dam and thus the depth-to-length ratio is quite small. This means that even the trapezoidal weir can be well approximated by an equivalent rectangular weir, and a one-dimensional flow analysis is expected to give a good solution for the flow through rubble mound weir.

Interactions between Seepage and Overflow

The analysis and experiment in this paper was limited to a case in which the water surface is submerged in the rubble mound [see (c) in Fig. 1]. The writers agree with the discusser on the point that it is necessary to further investigate the situation in which flow runs over the weir, as shown in Fig. 1(a), although little literature is found in this field. Michioku and Maeno (2004) and Maeno and Michioku (2004) have already extended the study to this situation, carried out an experiment as shown in Fig. 2, and developed a one-dimensional model for analyzing flow discharge and water surface profile. Although the results are contained in the conference proceedings, the writers are not yet ready to submit a paper to a journal. Here, the concept of the model and a part of the results are shown in brief.

Interaction between the seepage and overflow is a key to the flow analysis. As illustrated in Fig. 3, the flow is assumed to be a two-layer structure consisting of a free-surface flow over the weir and a turbulent seepage flow in the weir. One-dimensional continuity equations were formulated as follows:

$$\frac{d}{dx}(U_U h) = q_i = -\frac{d}{dx}(U_L n W) = -\frac{d}{dx}(U_S W) \tag{1}$$

U_U is the velocity in the upper layer, and U_L is the seepage fluid velocity in the weir. U_L is related to apparent velocity U_s as $U_s=nU_L$ in terms of porosity n; q_i is the exchange rate or entrainment velocity between the upper and lower layers.

Momentum balances in the two layers are written as follows:

$$\underbrace{\frac{d}{dx}\left(\frac{U_{\mathrm{U}}^2}{2g}\right)}_{\text{(I)}} + \underbrace{\frac{dh}{dx}}_{\text{(II)}} - \underbrace{i}_{\text{(III)}} + \underbrace{\frac{\tau_w P}{\rho g A}}_{\text{(IV)}} + \underbrace{E\frac{q_i}{gh}(U_{\mathrm{U}} - U_s)}_{\text{(V)}} = 0 \tag{2}$$

$$\underbrace{\frac{d}{dx}\left(\frac{U_{\mathrm{L}}^2}{2g}\right)}_{\text{(I)}} + \underbrace{\frac{dh}{dx}}_{\text{(II)}} - \underbrace{i}_{\text{(III)}} - \underbrace{E\frac{q_i}{gW}(U_{\mathrm{U}} - U_{\mathrm{S}})}_{\text{(IV)}} + \underbrace{C_1 U_s + C_2 U_s^2}_{\text{(V)}} = 0 \tag{3}$$

In the equations, τ_w is wall friction, and (A, P) are the cross-section area and wetted perimeter in the upper layer. Refer to Fig. 3 for the other variables. E=entrainment coefficient in respect to mass and momentum exchange between the two-layer's interface. Drag force in the rubble mound or the term (V) in Eq. (3) is formulated by using the flow resistance law as mentioned in the paper, where the coefficients C_1 and C_2 are given as functions of porous body's parameters such as porosity, grain diameter, etc.

A solution for a water surface profile is obtained by integrating the set of equations under a given discharge. As recognized in Fig. 2, a control section appears at the downstream end of the weir. Then a singular point condition is applied in order to obtain a solution for discharge. An example of the solutions for normalized discharge F_0 is plotted as a function of dimensionless weir height w, which is compared with the laboratory data in Fig. 4. Good agreement between the theory and experiment is confirmed.

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