SEDIMENT BYPASS MODELLING OF VOLCANIC RIVERS (A CASE STUDY: BOYONG RIVER, MERAPI MOUNT, INDONESIA)

Djoko Legono[1]

ABSTRAK

Sedimen yang diangkut oleh sungai-sungai yang berasal dari gunung berapi sering mempunyai jumlah yang sangat banyak sehingga dapat mengundang permasalahan berupa daya rusak yang ditimbulkan ataupun bahkan dampak negatif lainnya. Penanggulangan yang telah ditempuh selama ini adalah dengan cara membangun bangunan pengendali sediment atau bangunan sabo yang ditujukan untuk mengurangi besarnya daya perusak tersebut dengan cara menahan laju aliran sediment yang mengalir ke hilir. Dalam hal suplai sedimen dari gunung berapi tersebut relative besar maka kehadiran bangunan sabo terlihat nyata manfaatnya. Namun pada saat dimana suplai sedimen berkurang, maka kehadiran bangunan sabo sering dinilai sebagai penyebab utama terjadinya degradasai dasar sungai di ruas-ruas sungai sebelah hilir bangunan sabo. Paper ini membahas hasil studi tentang efektivitas suatu bangunan pengalihan sedimen (sediment bypass), dalam rangka mengurangi besarnya suplai sedimen yang masuk pada suatu sungai, yang kemudian dialihkan pada sungai yang lain. Studi dilakukan dengan mengambil kasus Kali Boyong dan Kali Kuning yang berhulu di puncak Gunung Merapi, Daerah Istimewa Yogyakarta. Teori pendekatan imbangan sedimen diaplikasikan pada suatu geometri bangunan pengalihan, yang selanjutnya diperbandingkan dengan hasil pengujian model fisik. Hasil studi menunjukkan bahwa aplikasi persamaan imbangan air (konservasi massa) pada bangunan pengalihan sedimen mempunyai nilai yang mendekati dengan hasil yang diperoleh dari pengujian model fisik. Hasil studi dapat digunakan untuk menentukan geometri yang sesuai dengan rencana penetapan jumlah pengalihan sedimen dari Kali Boyong ke Kali Kuning.

***Kata kunci** : bangunan pengalihan sedimen, daya perusak, imbangan sedimen.*

INTRODUCTION

Many terms have been used to introduce the hydraulic structures namely sediment bypass. Firstly, the most common term is used in the long shore transport phenomenon of the coastal area where the transport causes the change in shore line formation. In such a case, sediment bypass structure is aimed at maintaining the balance between the deposition and erosion of the coastal line. Secondly, the sediment bypass term is used to divert the sediment flow in a river so that the sedimentation problem of a reservoir is reduced [1]. Asahi dam in Japan is the best illustration for the second type of sediment bypass. At Asahi Dam, the lower pond of Okuyoshino Power Plant (pure pumped storage) in Nara Prefecture, preventive measures against turbidity such as operation of selective intake facilities, installation of a filtering weir immediately downstream of the dam, and protective works against slope collapses around the regulating reservoir had been carried out since completion of construction in 1978. However, due to changes in the watershed caused by activities upstream

[1] Civil Engineering Department, UGM
Jl. Grafika No. 2 Yogyakarta

such as logging, and especially because of mountain side collapses resulting from large-scale floods brought by typhoons in 1989 and 1990, the problem of long-term persistence of turbidity has become prominent. In addition, sedimentation far in excess of original estimates has become a matter of great concern, and radical countermeasures have become necessitated. To cope with the sediment problems of lasting turbidity and sedimentation attributable to Asahi Dam, it was decided to install sediment-bypassing facilities which would take the utmost advantage of the characteristics of operation of the dam and of the dam site. To elaborate, there is no need to store water from the flow of the river since this is a pumped storage facility, while the catchments area is comparatively small. The sediment bypassing facility would consist of a bypass tunnel to route turbid water and sediment load around the reservoir and into the downstream river channel. Construction of the bypass was started in 1994 and its operation in April of 1998.

Merapi is the most active volcano in Indonesia. It has about 7 years return period of eruption which produces relatively large number of sediment. There are many rivers originate from the top of the mountain that carry considerable amount of sediment and its destructive power (Figure 1). Among of those rivers are Boyong and Kuning rivers which flow toward the south part of the mountain. Based on the Review on the Master Plan of Debris Flood Control of Merapi Mount [2], it was stated that the 1994 eruption had produced the potential sediment resources in the form of lava dome at the top of the mountain.

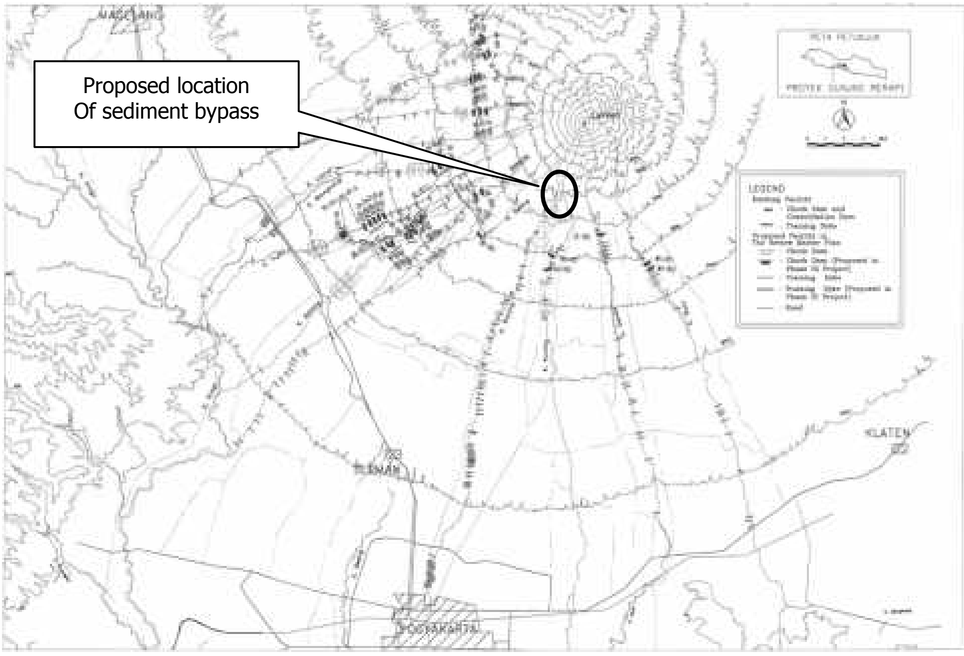

Figure 1. River system from Merapi Mount

The 1994 erruption contributed 2.19 MCM (Million Cubic Meter) and 1.94 MCM that may flow downstream through the Boyong and Kuning river respectively. At the elevation of 1,250.00 m those two rivers are situated very close as less than 100m, separated by relatively narrow bank. Boyong river flows pass through high dense populated area such as the downtown of capital city of Yogyakarta Province, whereas Kuning River, although flows pass through low dense populated area, it flows through the runway of the international airport of Yogyakarta. Kuning River crosses the runway by means of culvert. Bearing in mind that during 1994 thru 1996 the debris flow at Boyong River occurred more frequent rather than that at Kuning River, some idea came up in the form of reducing the sediment flow at Boyong River. This is done by introducing the sediment bypass structure which is aimed at diverting a certain amount sediment flow from Boyong to Kuning River.

SIMPLIFIED SEDIMENT FLOW MODEL

The governing equation for the hydraulic model simulation of the sediment bypass was developed utilizing the mass balance of the sediment flow. The simplification is made by assuming that the sediment flow would behave as ordinary water flow, except the flow density is assumed to be slightly higher than water. The hydraulic simulation was carried out in order to study the performance of the sediment bypass structure from Boyong to Kuning River, and its corresponding checkdam in Boyong River. The condition of the Boyong River indicates that the longitudinal bed slope of the river around the sediment bypass location is approximately 0.1 with the average width of 0.70m. The mechanism of the sediment flow diversion from Boyong to Kuning river could be anticipated possible through the development of the sediment bypass, which is a side spillway structure and a slit type checkdam as sketched in Figure 2, with the crossectional shape sketched in Figure 3. The slit type checkdam is selected to allow sediment remains flowing even in relatively small flow of water.

It is unlikely ordinary side spillway; the hydraulic performance of the river bifurcation to divert the sediment flow may be uncertainly simulated. This is due to the complex characteristic of the sediment flow, such as the non-uniformity of the sediment size distribution [3]. A sediment flow routing through such structure is really multi dimensional that simulation technique may present results with considerable errors. A very basic but conceptual approach is introduced to contribute the sediment distribution strategy of the allowable amount of sediment to be diverted from Boyong to Kuning River.

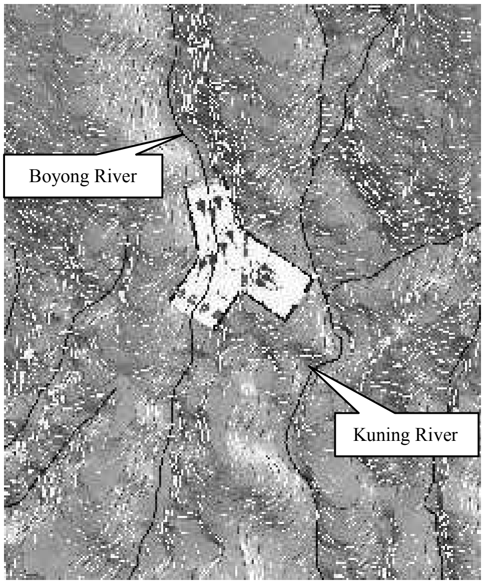

Figure 2. Layout of proposed sediment bypass

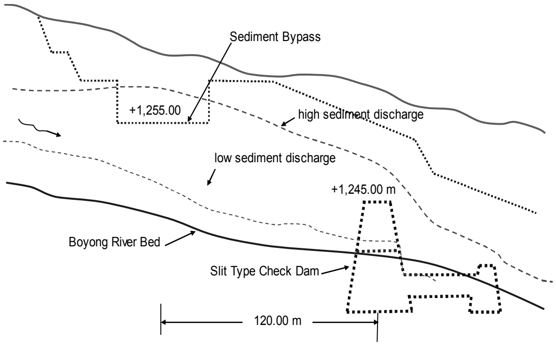

Figure 3. Sketched of sediment bypass system

The solution of equation was utilized to estimate the overflow of sediment through the sediment bypass structure [4].

$$\left(\frac{I_1 + I_2}{2}\right)\Delta t - \left(\frac{O_1 + O_2}{2}\right)\Delta t = S_2 - S_1 \text{ .... (1)}$$

where:

I : sediment inflow towards the system (m3/sec),
O : sediment outflow living from system (m3/sec),
Δt : time descrete (hours),
S : storage volumeupstream of system (m3).

Based on the agreement among boards within the local government of the Yogyakarta provincial city, only the peak sediment inflow is distributed over the Boyong and Kuning river. The volume of the sediment inflows being simulated were then approximated at 150 - 700 m3. The sediment outflows may be possible occurred through the slit type checkdam. In case where the surface elevation of the sediment flow located beneath the sediment bypass crest, no flow of sediment passes through the sediment bypass and vice versa. The amount of the sediment which flows through either the sediment bypass and the slit type checkdam may be calculated utilizing the overflow formula.

$$Q = CBH^{3/2} \text{ ....(2)}$$

where:

Q : sediment outflow from either sediment bypass or slit type checkdam (m3/sec),
C : over flow coefficient of sediment bypass and slit type checkdam,
B : width of crest of sediment by pass or slit type checkdam (m),
H : depth of flow near upstream of crest (m).

The hydraulical geometry of the sediment bypass and the slit type checkdam would give specific characteristic of the flow distribution over the sediment inflow being introduced. The slit type checkdam is introduced to allow sediment remain flowing even at a relatively low induced of water. As a result, the sediment bypass structure may only function when the high sediment discharge enters the system. When high sediment discharge comes, the sediment volume distribution over both Boyong and Kuning River is quite depend upon the river bed condition as the starting time of the hydraulic routing. At a certain condition when the river bed is very low, i.e. due to the presence of slit, only a relatively high sediment discharge would contribute the mechanism of the sediment distribution. On the other hand, at a condition when the river bed is very high, i.e. after the previous debris flood occurrence, even a small sediment discharge would contribute the mechanism of the sediment distribution. This dynamic behavior is very complex in nature and only an ideal situation may be solved by the used of Equation (1) and (2).

The formation of the river bed slope due to the presence of the checkdam is simplified in Figure 5. It is seen from the figure that h is the dam hight (m), Io is the initial river bed slope, Is is the static river bed slope (assumed to be 0.50 Io), and Id is the dynamic river bed slope (assumed to be 0.67 to 0.75 Io). The storage characteristic of the river upstream of the checkdam may contribute the mechanism of the distribution of the sediment volume. A relationship among the elevation, the surface area, and the the volume of the storage of the river upstream of the checkdam is identified during the routing period.

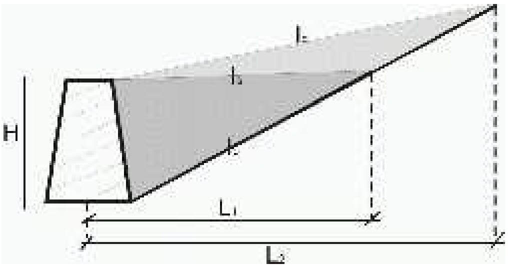

Figure 4. Longitudinal section of the checkdam

$$L_1 = \frac{H}{(I_0 - I_s)} \quad \text{..................................(3)}$$

$$L_2 = \frac{H}{(I_0 - I_d)} \quad \text{..................................(4)}$$

PHYSICAL MODEL DEVELOPMENT

A physical model was established to investigate the distribution mechanism of the sediment discharge passes through the sediment bypass and slit type checkdam. The model was non-distorded and rigid boundary, at a certain geometry of sediment bypass and slit type checkdam various runs were introduced. The sediment volume passes through both sediment bypass and slit type checkdam were measured. The scale of the physical model was 1 : 100, giving the model parameters as shown in Table 1. The geometry of the slit type checkdam and the lay out of the physical model are shown in Figure 5 and 6 respectivelly. The sediment discharge entering the system was introduced through the sediment feeder which enables supplying the sediment up to 0.700 m3.

Table 1. Parameter ratio of prototype and model

Parameter	Unit	Scale	Prototype	Model
Boyong River Length	m	100	400	4.00
Boyong River Width	m	100	90	0.90
Checkdam width	m	100	33	0.33
Sediment Bypass Width	m	100	41	0.41
Checkdam height	m	100	3	0.30
Width of slit	m	100	2	0.20
Volume of sediment disacharge	m^3	1000	700	0.70

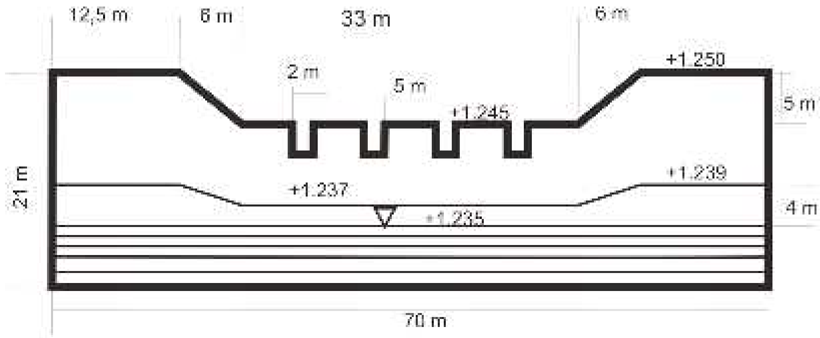

Figure 5. Longitudinal section of the checkdam

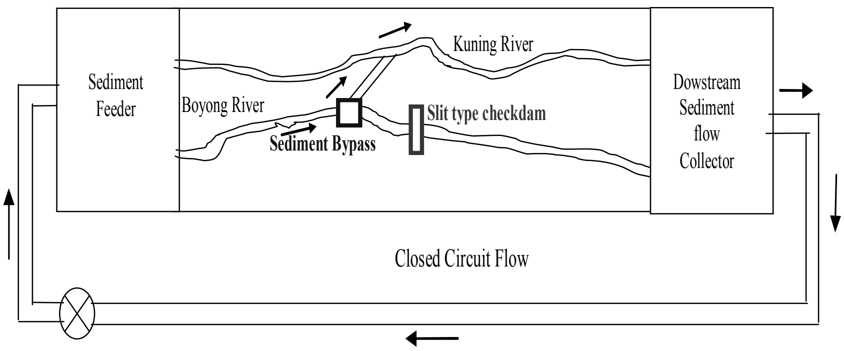

Figure 6. Layout of the physical model

The running of the physical model was carried out by assuming that at certain rainfall intensity, the accumulation of sediment at the upstream Boyong River would move downstream as a relatively short period hydrograph. This sediment flow hydrograph would create sediment volume transfer within short period of time under investigation. For the purpose of the varying the model running, the sediment inflow hydrographs were then categorized into five different magnitudes, i.e. 375,000 m3, 472,500 m^3, 562,500 m3, 640,000 m3, and 750,000 m3. The model running was carried out based on various sediment inflow hydrographs and the hydraulic structures' (sediment bypass and slit type checkdam) geometry.

RESULTS AND CONCLUSION

The systems of Equation (1) and (2) are solved by inputting the various sediment inflows similar to those for physical model running. The investigation on the sediment flows over the crest elevation was carried out into five different crest elevation, i.e., + 1,254.00 m; + 1,254.50 m; 1,255.00 m; + 1,255.50 m; and 1,256.00 m. Results of the physical model running and analytical solution of those equations were then compared and their discrepancies were studied. The analytical simulation requires the storage characteristic as well as initial river bed of Boyong River. The storage characteristic of the Boyong River is assumed to be the average longitudinal crossection of the river (a function of Io, Is, and Id of Figure 4), times the average width of the river at the upper part of the slit type checkdam. The following magnitudes were used to solve the system of Equation (1) and (2). Initial river bed of Boyong River prior to the hydraulic sediment routing is assumed to have the following figures;

$I_0 = 0.100$
$I_s = 0.068$
$I_d = 0.050$

The time step being used for the hydraulic sediment routing is 0.005 hour; with the period time of routing is 15 hours. Similar treatment was applied to run the physical model in such that the total sediment volume relatively closes to the corresponding sediment volume design. It was found in the analytical simulation that the model was very sensitive in the variation on the crest elevation of either sediment bypass or the slit type checkdam. A relatively slight change in the crest elevation of the sediment bypass may result a significant change in sediment volume overflowing from its crest. This probably due to the assumption of the sediment flow behavior which assumed to be nearly the same as ordinary water flow is far rather than ideal. However, the presence of results obtained from the physical model might be used as to introduce some important factors on the analytical simulation.

The storage characteristic of Boyong River upstream of sediment bypass was calculated by applying the average width of the river at 39.00m width and longitudinal slope of 0.100 obtained from the topographical survey. The coefficient of sediment flow over the sediment bypass crest and the slit type checkdam was assumed to be 0.6. At every simulation, the sediment amount passes through sediment bypass was evaluated, the percentage over the incoming sediment flow hydrograph was calculated.

It is seen from Figure 5 that the analytical simulation of the system of Equation (1) and (2) presents the sensitivity of the results on the 0.50 m different in the elevation of the sediment bypass crest. Due some difficulty in introducing the sediment flow characteristic to be similar with those run in the analytical simulation, only one condition of the sediment bypass and slit type dam geometry was studied. The sediment bypass crest elevation was set at + 1,255 m, whereas the slit type checdam crest was set at + 1.245. There was limited chance to vary the geometrical condition on either sediment bypass crest elevation as well as slit type checkdam crest elevation. Figure 7 shows the results of the distribution of sediment volume for various runnings of the analytical simulation, compared with those obtained from the physical model investigation.

The results obtained from analytical simulation of system of Equation (1) and (2) and the physical model runnings are showing good aggrement, particularly at the sediment bypass crest elevation of + 1,255.00 m. Some significant discrepancies are found in the condition where the sediment bypass crest is at + 1,256.00 m. However, for the initial approach, the application of system of Equation 1) and (2) tends to be promossing, subject to some necessary correction factor being introduced, based on the study on more physical model running. Specific information obtained from the current model development is the condition where the maximum number of sediment volume has been distributed over the crest of the sediment bypass was 7% of total sediment volume entering the system.

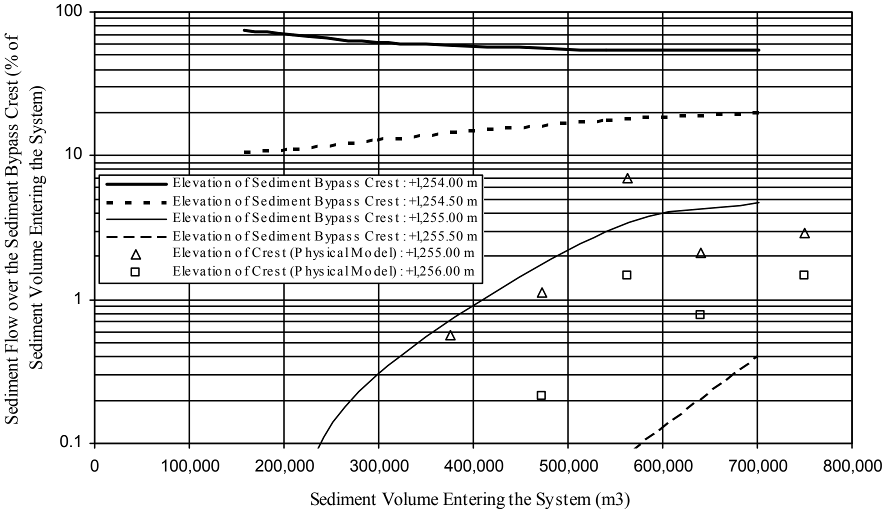

Figure 7. Sediment volume distributions over the sediment bypass system

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