

## DESIGN OF STILLING BASIN FOR DECREASING BACK WATER IN THE DAM FOOT

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**ABSTRACT:** This research studies the hydraulic behavior and the problem solving alternatives of original until final design, and the most effective stilling basin and downstream regulator channel for decreasing back water from the upstream water level in the dam foot. The methodology consists of physical modeling in the Laboratory of River and Swamp, Department of Water Resources, Faculty of Engineering, University of Brawijaya. The methods include the USBR for the hydraulic analysis, the Hind's formulation for the side channel analysis, the energy equation by analyzing the standard step for the transition and the chute way analysis, and the USBR type III for designing the stilling basin. A square cross-section with the Manning coefficient of 0.40 is used for determining the control of the Tail Water Level (TWL) and a trapezoidal cross-section with the Manning coefficient of 0.39 is used for the final design. However, the equation of Schotlisch and Veronise is used for the local scouring analysis. The result of Model Test and analysis indicates that there are some differences among the analysis in every point of the building. Therefore, the relative error is needed to know how big the error in the comparison result.

*Keywords: stilling basin, regulator channel, hydraulic, dam*

### 1. INTRODUCTION

The project of water resources development often faces the complex problem, so it has to be handled specifically [1]. Therefore, in the water usage, there is needed an accurate regulation to obtain the maximum result. One of the efforts to solve the problems is by building the dam. Dam is a river transversal building which has the function to hold water and to be formed as a water storage such as reservoir. Reservoir is functioned for fulfilling irrigation, hydro electrical power, fresh water, recreation, etc. Dam has some parts of components such as dam body, intake, spillway, and the other complement building. The flow condition in the spillway construction until the upstream regulator channel which is designed, is often not identified by the analytical approach and the mathematical modeling. Therefore, it is needed to evaluate the dimension of building which has been designed by using the hydraulics physical model test for looking the building from the hydraulic side and it is hoped to obtain the high significance of success, strength, and safety in design, remembering that the dam construction is as a very important building and has the high risk in financial as well as social aspect [2]-[3].

Indonesian President Rule No 5, 2010 about National Secondary Period Development Plan (RPJMN) mentions that the fifth national priority is food security. Therefore, the development of Gongseng Reservoir is important to be carried out for implementing that the reservoir is as the irrigation infra-structure for

supporting the food security [4]. Besides it, the development of Gongseng Reservoir is also prioritized for fulfilling the society demand such as the domestic water supply. As the evaluation of original design, there is happened the back water with high condition in the dam foot because the design of stilling basin, the downstream regulator channel, and the existing river condition are not too perfect. Based on the description as above, the improvement can be carried out due to the result such as the safety of hydraulics side to the construction and the dam function itself. Result of the physical model test on the Gongseng Dam with the scale of 1 : 50 indicates that there is the hydraulic jump which is not effective on the stilling basin and not effective in design of the downstream regulator channel cross section that influences the function of V-notch at the elevation of +66.00 in the dam foot. Therefore, the height of the back water has to be  $\leq 1$  m from +65.00 on the elevation of the dodged channel bed.

This study intends to carry out the physical model test on the Gongseng Dam which is located in the Bojonegoro Regency, East Java Province of Indonesia. The dam is hoped to be able to overcome the flood which is often happened in the Bengawan Solo river. Regarding to the Laws No 7, 2004 about the water destructive force controlling which is overall carried out that involves the efforts of the prevention, countermeasures, and the recovery, some items which is wanted to be studied are as follow: 1) to analyze the flow condition from the spillway until the chute way; 2) to analyze the flow condition

from the stilling basin until the downstream regulator channel; and 3) to describe the effort for decreasing the back water which is happened in the dam foot.

## 2. MATERIALS AND METHODS

Gongseng Dam is located in the Bengawan Solo sub-watershed in Bojonegoro Regency, East Java Province of Indonesia. Map of the location is presented as in Fig. 1. The physical model test study of Gongseng Dam in the Bojonegoro Regency, East Java Province of Indonesia is conducted on the Laboratory of River and Swamp, Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, East Java Province of Indonesia. The dimension

conversion of the prototype to model is as in Table 1.

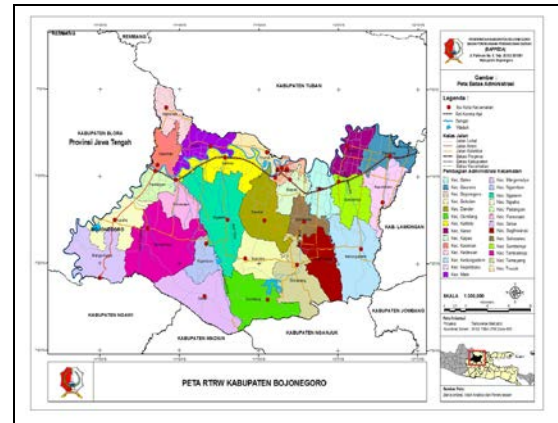


Fig. 1 Map of the study location

Table 1 Dimension conversion of the prototype to model

| Description                            | Prototype (m) | Ratio | Model (cm) |
|----------------------------------------|---------------|-------|------------|
| I. Main Dam                            |               |       |            |
| • Height                               | 30.00         | 0.02  | 60.00      |
| • The width of the peak                | 9.00          | 0.02  | 18.00      |
| II. Spillway                           |               |       |            |
| • The height of the spillway threshold | 4.00          | 0.02  | 5.00       |
| • The width of the spillway            | 55.00         | 0.02  | 110.00     |
| III. Side channel                      |               |       |            |
| • The width of the upstream channel    | 10.00         | 0.02  | 20.00      |
| • The width of the downstream channel  | 16.00         | 0.02  | 32.00      |
| IV. Transition channel                 |               |       |            |
| • Length of the channel                | 148.73        | 0.02  | 297.46     |
| • The width of the upstream channel    | 16.00         | 0.02  | 32.00      |
| V. Chute way                           |               |       |            |
| • Length of the channel                | 89.51         | 0.02  | 179.02     |
| • The width of the upstream channel    | 16.00         | 0.02  | 32.00      |
| • The width of the downstream channel  | 16.00         | 0.02  | 32.00      |
| VI. Stilling basin                     |               |       |            |
| • Length of the channel                | 30.00         | 0.02  | 60.00      |
| • The width of the channel             | 16.00         | 0.02  | 32.00      |

Source: own study (the result of analysis)

### 2.1. Scale of model

This test uses the scale of the model and based on some considerations as follow [2]: 1) The aim of the test and the accuracy that is hoped, and 2) The facility which is available in the laboratory as well as available time and cost. However, the determination of minimum scale is due to the minimum water height over the spillway such as 0.821 m (based on the analysis of spillway design with  $Q_{2\text{ year}} = 90.46 \text{ m}^3/\text{s}$ ). The formula is as follow (De Vries, 1997):

$$\frac{\Delta q}{q} = 1 - \left\{ \frac{H_e}{H} \right\}^{3/2} \quad (1)$$

$$5\% = 1 - \left\{ \frac{H - 0.457}{H} \right\}^{3/2} \quad (2)$$

$$H = 13.326 \text{ mm}$$

$$\text{Scale of model: } L_r = 13.326/821 = 1/61.61$$

### 2.2. Discharge Coefficient of Spillway

To analyze the discharge over the spillway is used the formula as follow [5]-[6]:

$$Q = C.L.H^{3/2} \quad (3)$$

However, the overflow discharge coefficient (C) of standard type on a weir can be obtained by using the formula of Iwasaki as follow [7]:

$$C_d = 2,200 - 0,0416(H_d / W)^{0,9900} \quad (4)$$

$$C = 1,60 \frac{1 + 2\alpha(h / H_d)}{1 + \alpha(h / H_d)} \quad (5)$$

Where:  $C$  = coefficient of overflow discharge,  $C_d$  = coefficient of overflow discharge when  $h = H_d$ ,  $h$  = water height over the weir mercu (m),  $H_d$  = design head over weir mercu (m), and  $W$  = height of weir (m)

### 2.3. The effective width of the weir

The effective length of the weir is analyzed by using the formula as follow [8]:

$$L = L' - 2(N.K_p + K_a).H \quad (6)$$

Where:  $L$  = effective width of spillway (m),  $L'$  = real width of spillway (m),  $N$  = number of pillar over the mercu,  $K_p$  = contraction coefficient of the pillar,  $K_a$  = contraction coefficient of the side wall, and  $H$  = total head over the spillway mercu (m)

### 2.4. Transition channel

Hydraulics analysis of the transition channel end conditions is sub-critic and in the upstream is critic due to the Bernoulli formula as follow [9]:

$$d_e + \frac{v_e^2}{2g} = d_c + \frac{v_c^2}{2g} + \frac{K(v_e^2 - v_c^2)}{2g} + h_m \quad (7)$$

Where:  $d_e$  = flow depth into transition channel,  $v_e$  = flow velocity into transition channel,  $d_c$  = critical depth in the transition channel end.  $v_c$  = critical flow velocity in the upstream end of transition channel,  $K$  = coefficient of pressure head loss

### 2.5. Stilling basin

Before the water flow flows to the river, it has to be slow down and it is changed as the sub-critic condition, so there does not happen the scouring which endangers river geometric on the bed and edge river [10]-[11]. The hydraulic formula which is used as the design base of stilling basin comes from the principal of energy eternity law by the phenomena that the forces which are worked on the channel section for the flow condition has changed from super-critic to the sub-critic flow [9].

## 3. RESULTS AND DISCUSSION

Based on the analysis of overflow coefficient, it is made the comparison between the USBR method and the physical model test and the result is presented as in Table 2.

Table 2 Recapitulation of overflow coefficient value (C) of USBR method and physical model test

| No | Return period | Q Outflow           | Water level over spillway(Hd) |       | Overflow coefficient (C) |                       |
|----|---------------|---------------------|-------------------------------|-------|--------------------------|-----------------------|
|    |               |                     | USBR                          | Model | USBR                     | Model                 |
|    | (year)        | (m <sup>3</sup> /s) | (m)                           | (m)   | (m <sup>0.5</sup> /s)    | (m <sup>0.5</sup> /s) |
| 1. | 2             | 90.46               | 0.884                         | 0.900 | 1.979                    | 1.926                 |
| 2. | 100           | 258.00              | 1.698                         | 1.700 | 2.120                    | 2.116                 |
| 3. | 1,000         | 368.56              | 2.118                         | 2.150 | 2.175                    | 2.126                 |
| 4. | PMF           | 786.15              | 3.359                         | 3.400 | 2.327                    | 2.280                 |

Source: own study (the result of analysis)

By using the formula as above, it can be analyzed the profile of water level over the spillway. The shape of transition channel on the Gongseng Dam is not constriction but there is a turn (R) with the slope of 1 : 2 and the length channel is 148.73 m. The side channel on the model test of Gongseng Dam is happening the change on the stilling basin and in upstream part. Before the flow traverses the spillway again into the river, so flow with high velocity in super-critic condition has to slow down and it is changed on the sub-critic flow condition. Therefore, energy content from there is very strong scouring that is appeared in the flow has to

be reduced until reaching the normal level again, so the flow is back into the river without endangering the stability of river plot [15].

### 3.1. Model of Seri-0 (original design)

The original design uses the stilling basin of USBR-III. Design flood for the stilling basin design of USBR-III is  $Q_{100 \text{ years}}$  with the data as follow:  $h_1 = 1.170$  m,  $h_2$  (height after jump) = 9.047 m,  $V$  (velocity) = 19.683 m/s, and Froude = 5.809. The analysis result of water level height is presented as in Table 3 for  $Q_{100}$ .

Table 3 Result of the water level height on the stilling basin due to the original design with  $Q_{100}$  years

| Section | Analysis result |          |                        |            |       | Note         |
|---------|-----------------|----------|------------------------|------------|-------|--------------|
|         | B<br>(m)        | H<br>(m) | A<br>(m <sup>2</sup> ) | V<br>(m/s) | Fr    |              |
| 29      | 16              | 0.96     | 15.360                 | 16.797     | 5.473 | Super-critic |
| 30      | 16              | 2.00     | 32.000                 | 8.063      | 1.820 | Super-critic |
| 31      | 16              | 5.94     | 95.040                 | 2.715      | 0.356 | Sub-critic   |
| 32      | 16              | 5.95     | 95.200                 | 2.710      | 0.355 | Sub-critic   |

Source: own study (the result of analysis)

Based on the measuring result of original design by using USBR-III,  $V_{theoretic} \geq V_{measuring}$  such as 32.925 m/s with the Froude number is 10.729. However, the measuring result for velocity is 16.797 m/s with the Froude number is 5.473. Based on the measuring as above, it can be seen that the flow condition on the stilling basin is still in super-critic condition.

The modified stilling basin type-III which has the length of stilling basin is 30 m and the height of chute block is 0.7 m, the height of baffle block is 1.5 m, and the head of the end sill is 1 m is carried out for controlling the PMF outflow discharge. For the flow design of  $Q_{1,000}$  years, there is happened the hydraulic jump in outside of the stilling channel with the shape of downstream regulator channel is square. There is happened the back water which is still high such as 1.35 m. The test result shows that the stilling basin is not maximal in controlling the water jump and the flow condition in the upstream can cause the happening of the depth scouring.

### 3.2. Design alternative of model

Based on the series-0 model test result, there is not optimal by the unsuitability with a hydraulic aspect, so it is needed the design alternative of the model. The design alternatives are as follow:

#### 3.2.1. Model of Seri-I

The dimension of Seri-0 model is not normative, so it is carried out the change on the downstream regulator channel by increasing the end sill elevation to the channel bed elevation with the slope is 1 : 2, the length is 60 m, the height is 1 m, and it is added the mix of sand and coal each of 50% with the diameter of 0.5 m. In addition, there is opened the downstream regulator channel becoming as the trapezoidal shape. However, the back water is still high such as 1.05 m. To improve the flow condition on the original design, there is carried out some changes as follow: a) To add the end sill height of 1 m becoming to the elevation of +62.50 m, and b) To add the rip rap for terminal channel

The change of cross-section shape on the downstream regulator channel of the square section is the width of 16 m becoming to the

trapezoidal shape with the width of 24 m and the slope of 1: 0.6, and the length of 27 m. Sketch of Seri-I dimension on the stilling basin can be seen as in Fig. 2. The test result by changing the shape and the dimension of downstream regulator channel indicates that it has the ability to control the flow until  $Q_{PMF}$ , but it happens the cross flow on the outlet of stilling basin (the channel width change from 16 m becomes as 24 m).

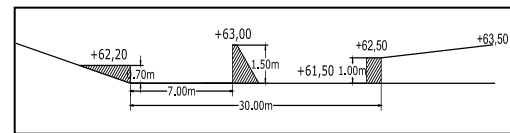


Fig. 2 Seri-I dimension of basin basin

#### 3.2.2. Model of Seri II

By the dimension change on the Seri-I, it has the muffling possibility for  $Q_{1000}$  years and outflow. discharge of PMF cannot be controlled, so there is added on the downstream regulator channel by making a trapezoidal shape with the width of 24 m, the length of 27 m from end sill by adding gravel and with the slope (S) of 0.005. To get rid of the cross flow on the downstream regulator channel, there is made the width change from 16 m into 24 m on the terminal channel and the result can be seen as in Fig. 3. The test result indicates that by the change, it is able to get rid of the cross flow on the downstream regulator channel and to be able to muffle flow in the downstream.



Fig. 3 The addition of rip-rap on the terminal channel

### 3.2.2. Model of Seri-III

On the Seri-III, as the Seri-II, muffling for  $Q_{1,000}$  years and the outflow discharge of PMF cannot be controlled, so it is made the increasing end sill elevation to the channel with the height of 2.5 m. There is made the bed elevation from the beginning downstream regulator channel of +65.00 m until end downstream regulator channel. In the Seri-III, there is added the rip=rap for terminal channel and the change in the elevation of downstream regulator channel from +63.50 m is increased 1.50 m becoming as +65.00 m. However, by the elevation increasing, it does not decrease the backwater such as about 2.375 m and the condition can be seen as in Fig. 4. The test result indicates that by the change, the flow on the downstream regulator channel is more and better. However, there is dead flow on the outlet of downstream regulator channel.



Fig. 4. Sketch of water level height with  $Q_{100}$  years on the stilling basin Seri-IV

### 3.2.3. Model of Seri IV

For the Seri-IV, because of the water height on back water is still high, so the dimension of stilling basin is modified such as the distance between chute block and baffle block from 7 m into 4 m, and the baffle block is made as the trapezoidal shape. The modification on the baffle block dimension is carried which the height of baffle block is decreased from 1.5 m to 1 m. On the downstream regulator channel which is added the gravel at first, now it is made the brick, sand, cement and over it is added wood. However, the downstream regulator channel from the elevation of +65.00 m is made as the hard soil. The back water is still high such as 1.20 m. The analysis result of water level height is presented as in Table 4 and Fig. 5. Sketch of dimension on the stilling basin Seri-IV is as in Fig. 6.

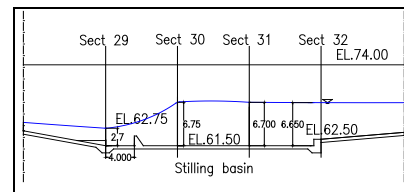


Fig. 5 Sketch of water level head to  $Q_{100}$  year on stilling basin Seri-IV

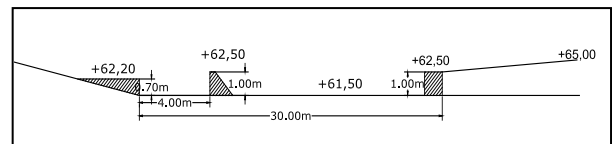


Fig. 6 Sketch of dimension on stilling basin Seri-IV

Table 4. The result of water level head on the stilling basin Seri-IV with  $Q_{100}$  years

| Section | Analysis result |          |                        |             |       | Note         |
|---------|-----------------|----------|------------------------|-------------|-------|--------------|
|         | B<br>(m)        | H<br>(m) | A<br>(m <sup>2</sup> ) | V<br>(m/dt) | Fr    |              |
| 29      | 16              | 2.7      | 43.200                 | 5.972       | 1.160 | Super-critic |
| 30      | 16              | 6.75     | 108.000                | 2.389       | 0.294 | Sub-critic   |
| 31      | 16              | 6.70     | 107.200                | 2.407       | 0.297 | Sub-critic   |
| 32      | 16              | 6.65     | 106.400                | 2.425       | 0.300 | Sub-critic   |

Source: own study (the result of analysis)

On this series, it is also carried out the normalization of the river by opening the river cliff on the downstream regulator channel. By the normalization, it is hoped to more expedite the water flow towards the natural river so there does not happen the cumulation flow in downstream

regulator channel which causes the effect of highback water on the river in the dam foot. Fig. 7 presents the dimension change on the chute block and baffle block and Fig. 8 shows the normalization in the downstream river.



Fig. 7. Dimension change in chute block and baffle block

The running result indicates that opening of river cliff can be more decreasing the back water. However, the result has not been optimal, it is proved by the height of back water is still about 1.2 m.

### 3.2.4. Model of Seri-V (Final Design)

By the change on the seri-IV, the water head on the back water has not been decreasing. By the same distance, it is made the change of baffle block into a square shape with the height of



Fig. 8. Normalization of the downstream river

1.25 m. The flow condition on the stilling basin is sub-critic. On this seri, it is possible to be as the final design which is applied in the field. However, due to the four series before, the alternative of Seri-V is as the seri with not too high back water such as 0.25 m or  $\leq 1$  m. It is as the safe condition on the downstream and does not disturb the V-notch in the dam foot on the elevation of +66.00 m. Table 5 presents the water level on the stilling basin Seri-V due to the  $Q_{100}$  years. Fig. 10 presents the sketch of water level head with  $Q_{100}$  years on the stilling basin Seri-V

Table 5. The result of water level height on the stilling basin seri-V with  $Q_{100}$  years

| Section | Analysis result |          |                        |                           |       | Note         |
|---------|-----------------|----------|------------------------|---------------------------|-------|--------------|
|         | B<br>(m)        | H<br>(m) | A<br>(m <sup>2</sup> ) | V<br>(m <sup>3</sup> /dt) | Fr    |              |
| 29      | 16              | 1.04     | 16.667                 | 15.480                    | 4.843 | Super-critic |
| 30      | 16              | 5.80     | 92.800                 | 2.780                     | 0.369 | Sub-critic   |
| 31      | 16              | 6.42     | 102.667                | 2.513                     | 0.317 | Sub-critic   |
| 32      | 16              | 6.43     | 102.933                | 2.506                     | 0.316 | Sub-critic   |

Source: own study

In this seri, there is carried out to modify the baffle block shape which at first it is regarding to the standard of USBR type-III and then it is changed to the square shape with the length of 1.25 m. The modification is carried out in order to get the more effective muffling pattern mainly for  $Q_{1,000}$  years dan  $Q_{PMF}$ . Fig. 9 presents the water level head and Fig. 10 presents the sketch of dimension on the final design stilling basin.

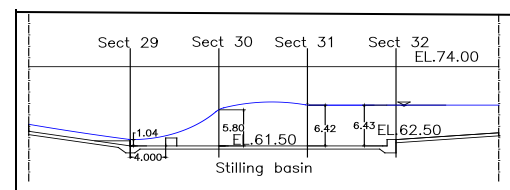


Fig. 9 Skech of water level head with  $Q_{100}$  years on the stilling basin Serri-V

Besides the change of baffle block shape, on this seri is also carried out the change in the channel bed material from the terminal channel which is used rip-rap before and as the protection into by the structure strengthening to be able to

more protecting the channel bed if compared only by using the rip-rap. Fig. 11 presents the dimension change of baffle block and Fig. 12 presents the dimension change of terminal channel.

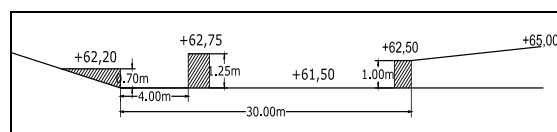


Fig. 10 Sketch of dimension on the final of the stilling basin Seri-V



Fig. 11 Change dimension of baffle block

Flow condition: a) On the spillway of Gongseng Dam, it indicates that it is able to flow the discharge condition of  $Q_{2\text{years}}$  until  $Q_{\text{PMF}}$  and safe to the overtopping danger; b) On the side channel for the flow condition does not cause the back water effect over the spillway and it is able to traverse all of the design flood without happening the submerged flow and the caused energy can be muffled; c) On the transition channel, the flow is uniform from the beginning of transition channel until end channel. The channel slope is 0.0005, the happening flow is sub-critic ( $Fr < 1$ ) along all channel, and it is almost equally until critic towards the chute way ( $Fr = 1$ ); d) The chute way with slope of 1 : 5 is able to store every design flood and it does not cause the trill flow and cross flow, it is marked by the equally flow formation. It is safe to the cavitation danger for the super-critic flow condition ( $Fr > 1$ ).

Flow condition on the stilling basin and downstream regulator channel: a) The test results shows that flow condition of the stilling basin can cause the depth scouring. However, the flow condition on the stilling basin is the cross-section shape is square which is the velocity and the water height has not still able to push the flow to downstream, so the influence of water level height on the back water is also high such as about 1.32 m; b) On the stilling basin seri-I, it still refers to the seri-0. However, the flow is still in super-critic condition. There is happened the cross flow on the outlet of stilling basin (the change of channel width is from 16 m into 24 m). For the  $Q_{100\text{ year}}$ , the flow condition in downstream regulator channel is able to decrease the water level height on back water becoming as 1.1 m; c) On the stilling basin seri-II uses the same as original design. However, on the terminal channel, there is made a trapezoidal shape in the beginning channel with the width of 16 m and in the end channel with the width of 24 m. The flow condition is super-critic, but on the  $Q_{1,000\text{ year}}$ , there



Fig. 12 Change dimension of terminal channel

is happened hydraulic jump out of the muffler. On the downstream regulator channel, the flow is uniform and water level height in the back water itself has not able to be decreased such as about 1.465 m; d) On the stilling basin seri-III by using USBR-III for  $Q_{1,000\text{ year}}$  and  $Q_{\text{PMF}}$ , the hydraulic jump cannot be controlled. Dimension change of end sill which is increased becoming as 2.5 m is influencing the downstream condition and water level height on the back water such as about 2.375 m. On the downstream regulator channel, the flow condition is uniform but there is dead flow on the outlet of downstream regulator flow; e) On the seri-IV, there is carried out the modification of stilling basin such as the distance inter-block is changed from 7 m becoming as 4 m and the height of baffle block is 0.3 m. The flow condition on the stilling basin is sub-critic. On the downstream cliff is opened and the river is normalized. It is hoped to be going to expedite the flow in downstream regulator channel and the happened local scouring is not too deep. However, the happened back water has still not less than 1 m such as 1.2 m.

#### 4. CONCLUSION

The efforts to decrease back water in the dam foot: Final design (Seri-V) on the model test of Gongseng Dam gives the illustration as follow: a) On the stilling basin, baffle block is changed into square with the height of 1.25 m (sub-critic flow); b) On the terminal channel, bed material which uses rip-rap before is changed; c) On the modification of stilling basin, there is giving the effective result in muffling energy; e) By changing the cross section, the plural trapezoidal cross section has ability to the flowing water until river part without causing the deep local scouring. Based on the cross-section test, it shows that  $H_{\text{trapezoidal}} < H_{\text{square}}$ ; f) The elevation change on the regulator channel becoming to +65.00 m for  $Q_{1,000\text{ years}}$  and the back water is 0.75 m, it proves

that the decreasing of water level head is less than 1 m.

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