Sediment Control at Water Intake Structures in a River

Son, Kwang Ik* / Lee, Jae Joon** / Han, Kun Yeon*** / Lee, Eul Rae****

Abstract: The intake towers of Buyeo W.T.P. in Keum river have being suffered from the sedimentation problems since the beginning of the operation. Impellers of the intake pumps have to be frequently changed due to the serious surface erosion. Thousands tons of sands are entrapped in the intake towers and equalization chambers of W.T.P. every year. Site surveying and numerical analysis were carried out to suggest an appropriate solution by understanding the general sedimentation regime of Keum river and causes of the sedimentation in the intake towers. Origin of the sediment could be found by the desk and site inspections. The validity of the used numerical models was examined by comparisons between the calculated hydraulic values and the measured ones during the specific periods. The design flow rate for the prediction of the future sedimentation regime of the river was studied. The efficiency of the sediment control measures was also examined with the verified numerical models. Finally, it was found that the best solution could be a combination of three sediment control measures: increase the clearance between river bed and inlet, construct jetties at 2 kilometers upstream from the intake towers, and put vanes at the right side of the intake towers.

1. Introduction

Buyeo water treatment plant takes about 300,000 tons/day from Keum River through two intake towers. Diameter and height of the tower above the channel bed are 5 meter and 4.5 meter respectively. The intake towers have being suffered from sedimentation problems since the beginning of the operation. Impellers of the intake pumps are being suffered from the surface erosion. The amount of the entrapped sand was reached up to 3,374 cubic meters and 2,072 cubic meters in 1995 and 1996 respectively. The river-bed around intake towers used to be dredged every year to reduce the entrained sand as a temporary measure. It is strongly recommended that permanent solutions should be studied for the best operation. The permanent solutions could be obtained from the deep understanding of the characteristics of an alluvial channel at intake towers. The best solution might be the provision of measures, which

* Assist. Prof., Dept. of Civil Engrg., Yeungnam Univ., Korea
** Assoc. Prof., Dept. of Civil and Envir. Engrg., Kumoh National Univ. of Technology, Korea
*** Prof., Dept. of Civil Engrg., Kyungpook National Univ., Korea
**** Doctoral Student, Dept. of Civil Engrg., Kyungpook National Univ., Korea

can cease the supply of the sediment from the origin. Therefore, following studies on the sediment behavior of the Keum river was carried out to find out the best measures for relieving the intake towers from the sedimentation problems.

1) stability of the alluvial river at intake towers
2) origin of the entrapped sediment
3) selection of numerical models which can appropriately simulate the Keum river's alluvial characteristics
4) design flow rate for sediment prediction
5) numerical simulation for the proposed measures with the design flow rate

2. Characteristics of Sedimentation in Keum River

2.1 Origin of the Entrapped Sediment

Preliminary review with existing data was carried out to examine the alluvial stability of the Keum river. Depth of thalweg, route of streamline, and the width of channel for the last decades were examined to check the variation degree of channel pattern along the main river. It was found that most of the channel characteristics were generally in stable conditions except some points so that the river could be regarded as stable condition in general. Yu and Woo(1993) also had the same conclusion that the Keum river downstream of the Daechung dam was almost in the stable condition.

The hydraulic surveying of the site and the analysis of the sediment characteristics were also performed to check the alluvial stability of the river near the intake towers. Field inspections were performed to understand the general hydraulic characteristics around the intake towers. Top width of the flood plain, top width of the lower channel, average flow depth, and average flow rate of the river at intake towers are 500 meter, 170 meter, 2.5 meter and 73.8 cubic meter per second (cms) respectively. Fig. 1 shows the plan of the river and the intake towers. Fig. 2 shows the details of intake towers. Kyuam Station locates at 3 kilometers downstream far from the intake towers. The basin area of Kyuam station is 8,273 square kilometers. The design flood flow rate of the river is 11,300 cms (MOC, 1988).

Zee-river, first order tributary of Keum river, enters Keum river from the right-hand side at 2.5 Km upstream from the intake towers. Flow from Jungdong-ditch (storm-water detention basin with drainage area of 18.5 square kilometers) joins to the main river from left-hand side at 30 meter upstream from the intake towers.

The current passing the intake was moderate. The rate was estimated to be 1-1.5m/sec, nearly the same on both sides of the intakes, slightly stronger on the river side. Upstream of the intake towers, the current seemed to attack the bank along the downstream 100-150m of the island. There appeared to be little erosion on the bank upstream of this section. The erosion pattern suggested that a strong current was hitting the bank of the downstream portion of the island at an angle, then was bouncing off the bank and rolling back out into the channel. The flow pattern was quite complex upstream of the intake towers. A notion of the complexity was obtained by letting the survey boat drift. In one area upstream of the

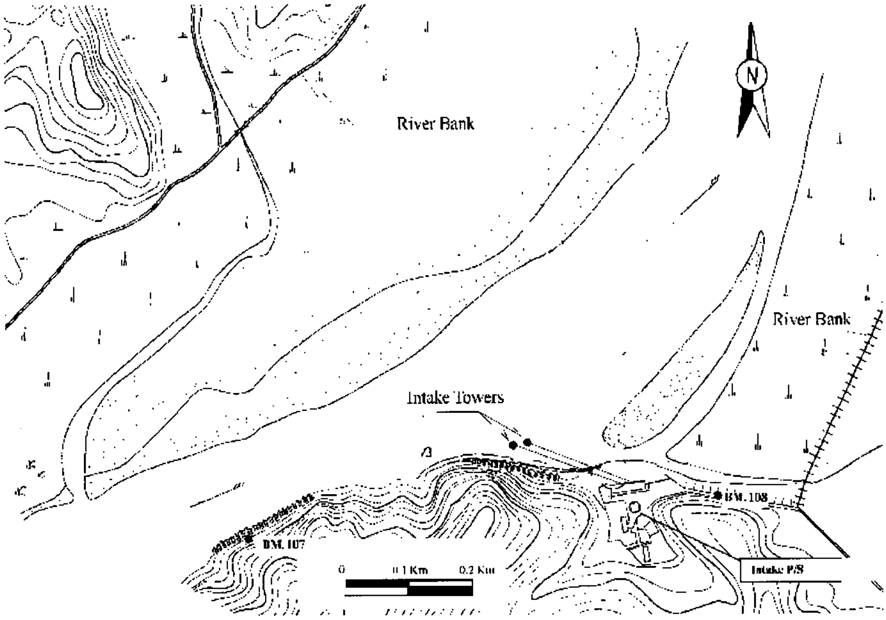


Fig. 1. Buyeo Intake Towers Site Plan

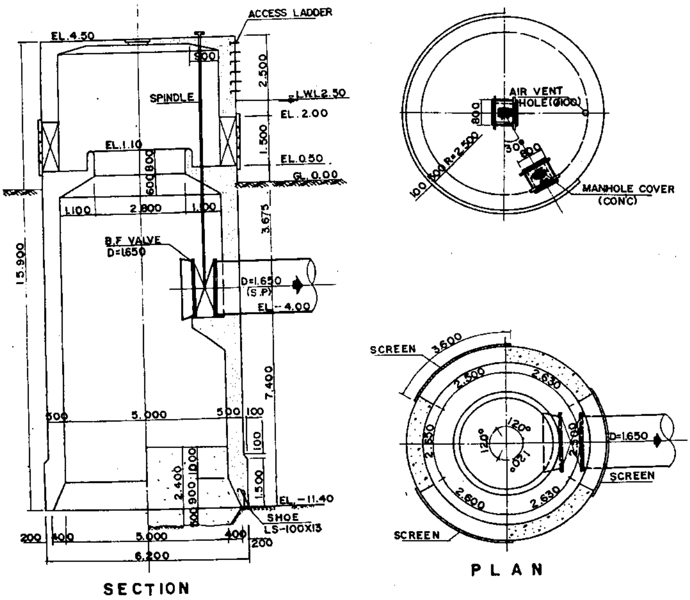


Fig. 2. Details of Buyeo Intake Towers

towers, about 50m off the eroding bank, the boat remained stationary. Closer to the bank, the boat drifted downstream and toward the bank. The flow pattern was probably further complicated by the dredging operation which likely created and uneven bed topography. The

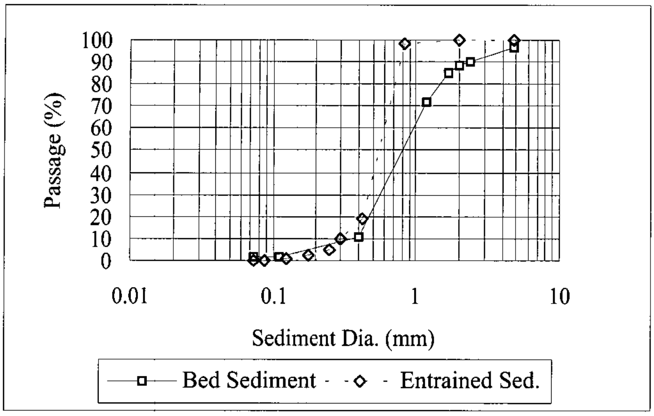


Fig. 3. Comparison of Grain Size Distribution between Entrained Sediment and Bed Sediment

average bed at the tower is at El. 0.00, and the intake opening is from El. 0.50 to El. 2.00. With only 0.50 elevation difference between bed and bottom of intake opening, one can expect that a significant amount of bed load will be entrained. The solution measures depend on the main causes of the sedimentation. But, it was not clear which load is entrained. To determine, following data were collected and examined: (1) grain size distribution of the entrained sediment; and (2) grain size distribution of bed sediment in the river at the intake.

It would be good to know the relationship between the ratio of suspended load and bed load which are entrained into intake towers and depth. To obtain this relationship the vertical distribution of sediment concentration in the river at the various flow rates and stages are necessary. The problem is not only that the bed elevation varies with time but also that the measurement in impossible during floods.

A better way to determine the causes of the sediment is that the examination of the particle size of the river bed and the particle size of the sediment deposited in the sedimentation basin within the plant and in the towers. Based on the data it would appear that the medium size of the entrained sediment is about the same as that of the river bed material. (refer to Fig. 3). Less than 1% of the sample from the intake towers has a grain size of 0.15 mm or less, and only about 5% have a size of less than 0.25 mm. This suggests that by far the most sand that accumulates in the towers and sedimentation basin is bed load. That is the origin of the sediment is the bed load. It means that the increasing the clearance between the inlet of the intake towers and the bed-level is the only way to reduce or prevent the sediment entrapping. The distance from the river bed to the opening of intake towers would be increased so the opening could be above the possible maximum bed level during flood season unless the rivers are naturally degraded.

2.2 River Bed Simulation Models

Prediction of hydraulic behavior of a river is essential for the effective control and management of the river. Especially, the importance of the sedimentation behavior in a river cannot be over emphasized. Some numerical models, which seemed to be the most appropriate for the Keum river, were adopted among many sediment simulating numerical models. HEC-6 (COE, 1991), GSTARS (Molinas and Yang, 1986) and RMA (King, 1995) models were chosen and examined to confirm the appropriateness of model application for the prediction of the Keum river sedimentation behaviors. HEC-6 is one-dimensional model. GSTARS model and RMA model are quasi-two and two-dimensional model, respectively. The validity of numerical models was examined by comparisons between the estimated probable maximum river depths and the measured maximum river depths for two periods (1984-1988, 1988-1996) with actual flow records. Thirty-four kilometers -long reach in the midstream of Keum river was selected for the simulation. The Kyuam stage station has 13 years-long (1984-1996) automatic stage records. The cross sections of the river were measured every 500 meters in 1984 and 1988 along the whole section. Another measurement of cross sections every 500 meters for eighteen kilometers-long distance was carried out in 1996.

Fig. 4 shows that the comparison between the actual deepest bed-level variation and the calculated one by using actual flow rate for eight years. It tells us that qualitative predictions are possible with 75% confidence but the quantitative predictions are not satisfactory. The comparisons among actual and calculated the deepest bed-level by using the HEC-6 and GSTARS models are shown in Fig. 5. It also indicates some discrepancies in quantitative predictions. But the qualitative prediction with both models could be possible with some degree of confidence. Therefore two models will be used for the analysis of the alluvial channel

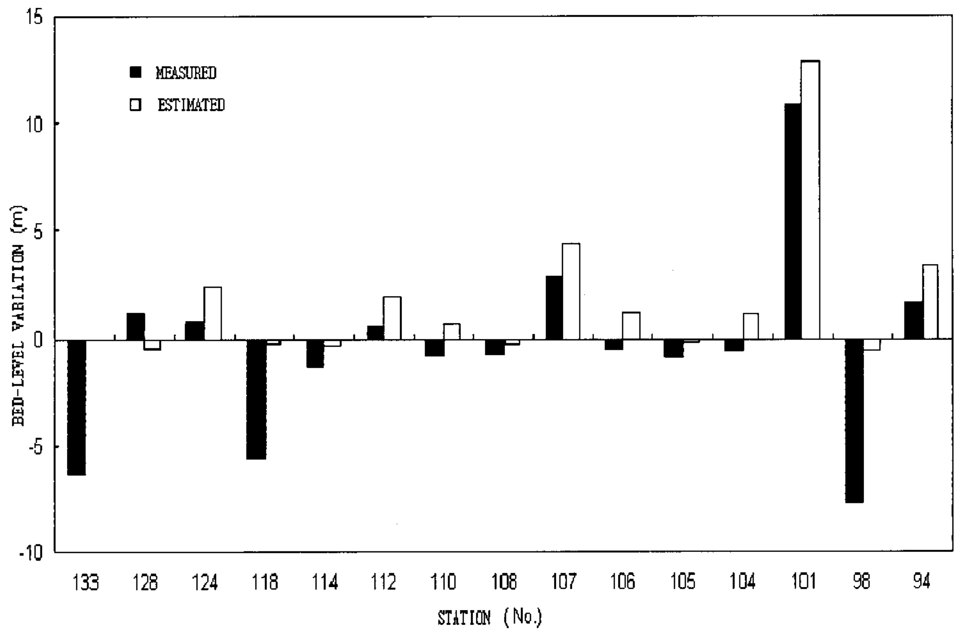


Fig. 4. Comparison between Estimated and Measured Thalweg Depth with HEC-6

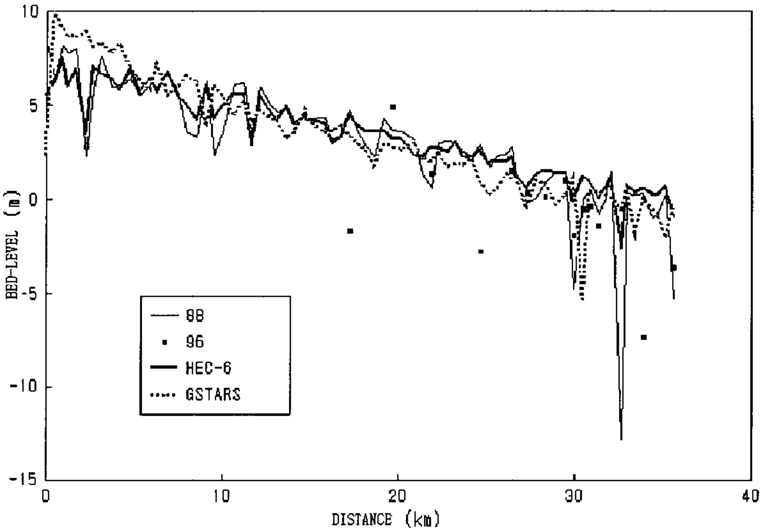


Fig. 5. Comparison between Estimated and Measured Thalweg Depth with HEC-6 and GSTARS

characteristics of Keum river.

2.3 Design Flow Rate for an Analysis of Alluvial Channel

Most of the previous researches on sedimentation focused on understanding the sedimentation mechanism or developing the numerical simulation techniques. But the final purpose of the research on sedimentation is to predict a sediment movement reacting to the hydrological variation of the river, such as flow rates and flow patterns. Therefore, the design flow rate should be reasonably decided for the reliable prediction of a river sedimentation behavior.

The variation of the sedimentation behavior for the design period was predicted by using the verified numerical models and lots of synthesized hydrological data. The synthetic hydrological data was generated from the statistical combination of the daily stage records for the last 13 years. Not only the daily flow rate but also the average flow rates for different duration were also examined. Four synthetic hydrological data were used to decide the best appropriate design flow rate for the prediction of a river sedimentation behavior. Mean flow rates(μ_d) and standard deviations(σ_d) for every Eulerian calendar dates were estimated. Mean flow rates (μ_{2w}) of an average flow rate for every two weeks and their standard deviation (σ_{2w}) were also estimated. Then the synthetic flow rate μ_d, $\mu_d+2\sigma_d$, μ_{2w}, and $\mu_{2w}+2\sigma_{2w}$ were estimated. The flow rate of μ_d, $\mu_d+2\sigma_d$, μ_{2w}, and $\mu_{2w}+2\sigma_{2w}$ are shown in Fig. 6 and 7.

Simulation of the response of the alluvial river to the variation of design flow rate was performed by comparison of the deviation between the measured bed-level caused by the actual flow and the estimated bed-level caused by synthetic flow rates. The deviation was quantified by the mean square error (MSE : ratio of the summation of the squared error to the number

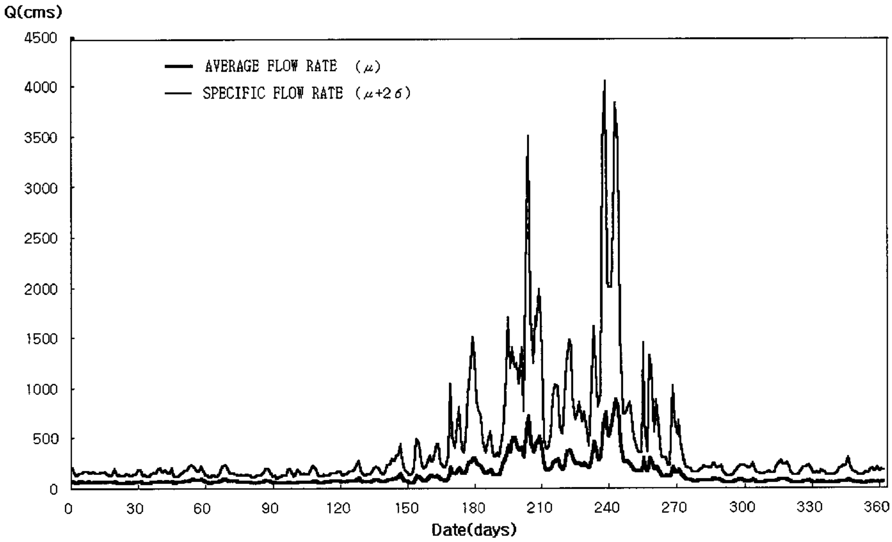


Fig. 6. Flow rate of μ_d, $\mu_d+2\sigma_d$, μ_{2w} at Kyuam station

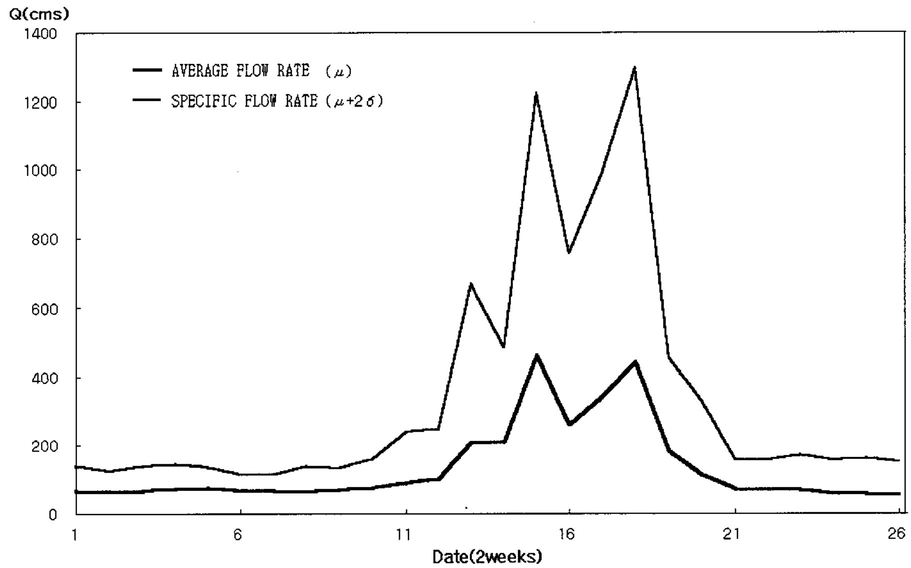


Fig. 7. Flow rate of μ_{2w}, and $\mu_{2w}+2\sigma_{2w}$ at Kyuam station

of cross-section.) for every cross section. Table 1 shows an error estimation example with the synthetic flow rate μ_d and μ_{2w}. The estimated bed-levels in Table 1 were simulated under the assumption that the synthetic flow rate μ_d, shown in Fig. 6, repeated eight times during the eight years. It was found that the most appropriate flow rate was μ_d when the HEC-6 simulation model was applied. In case of the GSTARS model, μ_{2w} showed the best result.

Table 1. Error Estimation for Flow Rate of μ_d and μ_{2w}

Sect'n No.	Acc. dist. (km)	thalweg depth(m)				calculation error			
		'88 actual	'96 actual	estimation('96)		absolute (m)		relative (%)	
				1day	14days	1day	14days	1day	14days
No.133	17.23	4.70	-1.70	4.51	4.55	6.21	6.25	97	98
No.128	19.65	3.70	4.90	3.33	3.44	-1.57	-1.46	131	121
No.124	21.90	0.60	1.38	2.78	3.01	1.40	1.63	180	209
No.118	24.67	2.85	-2.80	2.56	2.72	5.36	5.52	95	98
No.114	26.42	2.80	1.50	2.25	2.32	0.75	0.82	57	63
No.112	27.33	-0.25	0.32	0.57	0.44	0.25	0.12	44	22
No.110	28.36	0.90	0.11	1.56	1.56	1.45	1.45	183	183
No.108	29.47	1.40	1.00	1.51	1.48	0.51	0.48	127	120
No.107	29.94	-4.80	-1.94	-0.10	-0.24	1.84	1.70	64	59
No.106	30.50	0.00	-0.53	1.17	1.26	1.70	1.79	321	338
No.105	30.88	0.50	-0.37	0.98	0.86	1.35	1.23	155	141
No.104	31.35	-0.80	-1.43	0.09	0.21	1.52	1.64	241	160
No.101	32.65	-12.80	-1.93	-2.43	-0.96	-0.50	0.97	5	9
No.98	33.92	0.30	-7.37	0.56	0.44	7.93	7.81	103	102
No.94	35.62	-5.28	-3.65	-0.97	-0.98	2.68	2.67	164	164

From the results of this comparisons, it could be concluded that worst flow condition did not always give us the best simulation results. GSTARS model with flow rate μ_{2w} would give us the best prediction results especially for Keum river. Therefore, the bed-level in 2001 was predicted by HEC-6 with flow rate of μ_d and GSTARS with flow rate of μ_{2w}. Both simulations indicate that the bed-level at intake towers will be raised a little bit or will stay with the same level. It means that the clearance between the opening of intake towers and the bed-level would not be naturally increased. So, it should be artificially raised by construction of hydraulic structures.

3. Measures of Sediment Control

Part of the problem is undoubtedly that the intake is located in a relatively wide section of the channel compare to the other channel section. Some sections have a significant flow area below El. 2.0 m. Another section has hardly any flow area below 2.0 m. Numerical analysis indicated the intake towers are located in slightly deposit area. Expected bed form at the intake towers is anti-dune or plane during the flood season. The distance from the river bed to the opening would be increased so the intake tower opening could be above the possible maximum bed level during flood season.

There are many options for alleviating the problem. Somehow we need to lower the bed at intake towers, and that may require some channel adjustment. One way to stabilize the flow in this area is to construct submerged wing dams on the opposite bank as indicated in Fig. 10. These wing dams would divert the flow toward the left bank and create a main channel at about the same width throughout the area. The wing dams would create sediment deposits on the right side of the river downstream from the dams as indicated in figure. This might be beneficial to the dredging business. Creating a well defined, relatively deep channel down past the intake towers with no intermittent sand bar also would be beneficial to navigation.

While the submerged wing dams would stabilize the flow in a global sense, submerged vanes located along and immediately upstream from the towers would be a means of stabilizing the flow in the immediate vicinity of the towers. The submerged vanes would create a local lowering of the bed level. This would make it more difficult for bed load to be entrained into the intakes. While there would probably be some local scour around the towers due to the bridge pier effect, the vanes would expand the area of local scour to cover a larger area around the towers. Design of the Submerged vanes was designed with Odgaard and Wang's program (Odgaard and Wang, 1995) The design results and the effects of the vanes are shown in Figs. 8~9.

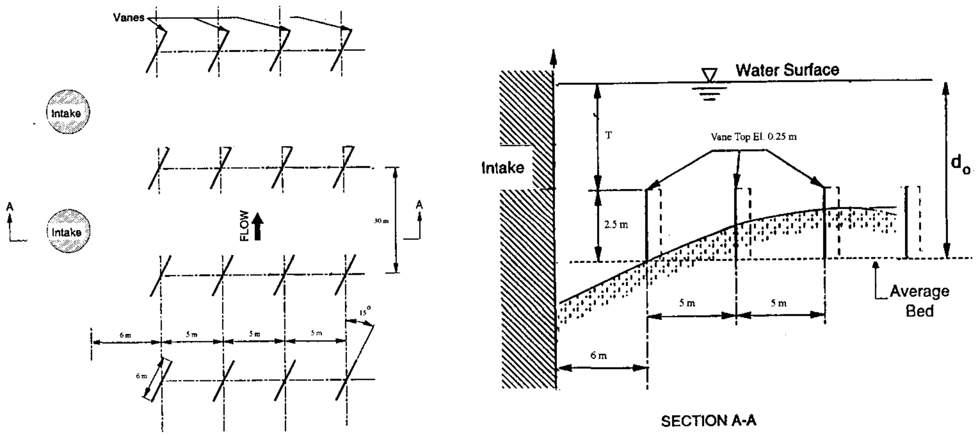


Fig. 8. Submerged Vane Plan and Section

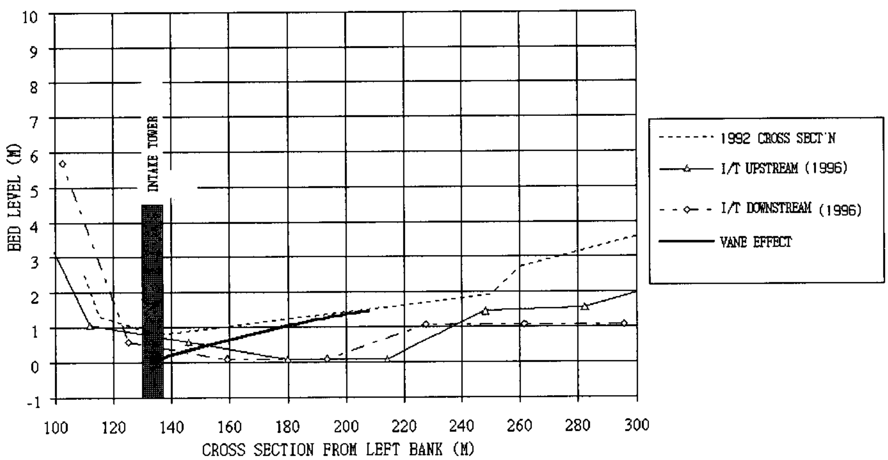
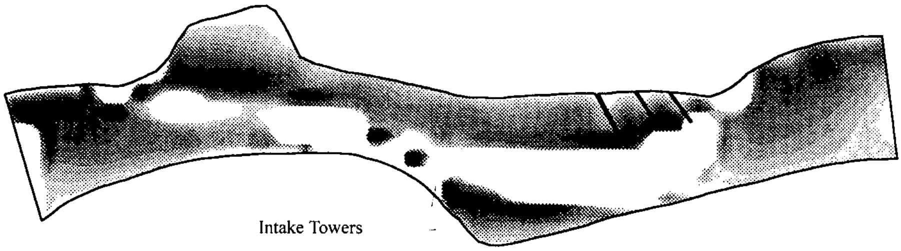
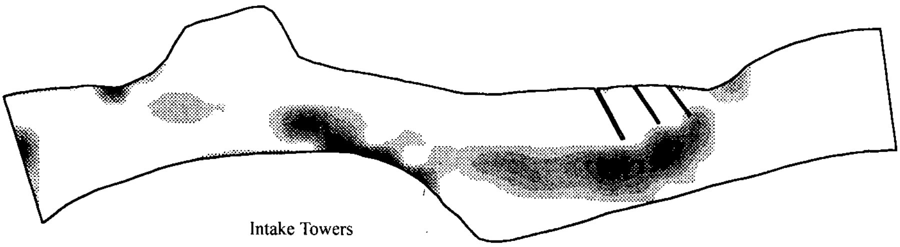


Fig. 9. Degrading Effects of the Submerged Vane for Q = 200cms



a) Deposition pattern around intake towers



b) Erosion pattern around intake towers

Fig. 10. Effects of the Submerged Wing Dams under Design Flood Condition

As an alternative to channel modification and resulting bed lowering, the intake towers could be modified. By blocking the lower portion of the intake openings and widening the top portion, the distance from the river bed to the opening would be increased making it more difficult for bed load to be entrained

4. Conclusions

The intake towers of Buyeo W.T.P. in Keum river have being suffered from the sedimentation problems since the beginning of the operation. The following studies on the sediment behavior of the Keum river was carried out to find out the best permanent measures for relieving the intake towers from the sedimentation problems. 1) stability of the alluvial river at intake towers, 2) origin of the entrapped sediment, 3) selection of numerical models which can appropriately simulate the Keum river's alluvial characteristics, 4) design flow rate for sediment prediction, and 5) numerical simulation for the proposed measures with the design flow rate.

Causes of sedimentation could not be found with measurement of the sediment concentration but with the comparison of the sediment distribution between the river bed and intake towers. The validity of HEC-6, and GSTARS numerical models were examined by comparisons between the estimated probable maximum river depths and the measured maximum river depths with actual flow records. The comparisons indicate some discrepancies in quantitative predictions. But the qualitative prediction with both models could be possible with some degree of confidence.

Evaluation method of the design flow rates for the prediction of the river sedimentation was developed. It was found that the most appropriate flow rate was μ_d for the HEC-6 simulation model and μ_{2w} for GSTARS model.

There are many options for alleviating the problem. Somehow we need to lower the bed at intake towers, and that may require some channel adjustment. While the submerged wing dams would stabilize the flow in a global sense, submerged vanes located along and immediately upstream from the towers would be a means of stabilizing the flow in the immediate vicinity of the towers.

Due to the limitation of the 2-D model, it is strongly recommended that physical model should be used to confirm the unpredicted problems in 3-D flow.

References

Army Corps of Engineers (1991). *Scour and deposition in rivers and reservoir*, HEC-6 user's manual, Hydrologic Engineering Center, U.S. Army Corps of Engineers

King, I.P. (1996). *RMA(Resources Management Associates) users instruction manuals*, U.C. Davis

Ministry of Construction (1988). *Keum river basin improvement plan report*, Ministry of Construction, South Korea

Odgaard, A.J., and Y. Wang (1995). "Sediment management in rivers using submerged vanes." HYDRA2000, IAHR Annuak Conference Vol. 4: 60-65

Molinas, A., and C.T. Yang (1986). *Computer program user's manual for Generalized stream tube model for alluvial river simulation*, Bureau of Reclamation Engineering and Research Center, U.S. Dept. of the Interior

Yu, K.K. and H.S. Woo (1993). Prediction of river profile changes downstream of the Daechung *dam by using the computer program HEC-6, Proceedings of the Korean Society of Civil Engineers*, Vol. 13, No. 5, p. 157-163