

Pilot Plant Study on Biological Nutrient Removal of Wastewater

Ahn, Sang-Jin* · Kim, Geon-Heung** · Ahn, Bok-Kyoun***

ABSTRACT / An extensive biological nutrient removal pilot plant study of anoxic/anaerobic/aerobic treatment process was conducted to establish an optimum operational mode using primary effluent. Two operational modes, (1) Q_r/Q was 3.0 and maintaining EMLSS of 3100 mg/L in which the best operational results were obtained from previous bench scale study using synthetic wastewater (2) Q_r/Q was 0.5 and EMLSS of 2200 mg/L which was compatible with the main plant, were compared and evaluated for removal of nitrogen and/or phosphorus under field conditions. The nitrogen removal increased with increasing recycle ratios, but the phosphorous removal revealed more consistent results with 83 percent removal efficiency in the second mode compared with 80 percent in the first mode. Above all, the two modes equally showed good BOD and nitrogen removals by nitrification-denitrification processes. It was also observed that no scum formed in the pilot plant and the sludge exhibited excellent settling characteristic all the time. The modified biological nutrient removal train can be adopted to the main plant without any major changes of their operational modes.

1. Introduction

The need for enhanced nutrient removal in the existing activated sludge plant has been well documented. Several proprietary processes were developed to biologically remove phosphorus from wastewater^{1,2,3}. A program was initiated in 1980 at the University of Texas at Arlington to evaluate a simplified treatment regime that would require minimum unit process addition, and

* Prof., Chungbuk National Univ.

** Assoc. Prof., Inha Univ. Visiting Prof., Univ. of Texas at Arlington

*** Ph. D. Candidate, Univ. of Texas at Arlington

use a single recycle line. An extensive bench scale study was made using combined domestic and synthetic waste water as feed to an anoxic/anaerobic/aerobic reactor sequence with recycle from the settling basin to the anoxic unit. In 1985, a cooperative research program with village Creek Wastewater Treatment Plant of the City of Forth Worth, Texas, USA, was initiated to conduct a pilot plant study of anoxic/anaerobic/aerobic treatment train using raw water after primary settling⁴. Construction of the pilot plant employing the anoxic/anaerobic/aerobic reactor sequence used in bench scale studies was completed in February 1987.

The purpose of the work reported here was to (1) evaluate the modified biological treatment train of anoxic/anaerobic/aerobic sequence under field conditions, (2) establish operational parameters, such as mixed liquor suspended solid (MLSS) and return flow to influent ratio (Q_r/Q), and (3) establish environmental criteria for removal of phosphorus and/or nitrogen.

This paper contains (1) pilot plant description (2) operational parameters and laboratory analysis (3) results and discussion, and (4) conclusions.

2. Pilot Plant Description

The pilot plant system* was designed for maximum flexibility and an influent capacity of up to 81.7 m³/d (21,000 gpd) while independently varying unit detention times, Q_r/Q ratios between 0.5 to 3, and air supply up to 21.2 L/s (945 cfm). A variable time-cycle controller was installed to operate the return sludge pumps, to reduce Q_r/Q ratio to the desired range and to minimize pipe clogging. The pilot plant was fully instrumented to control and record flow and to alert main treatment plant operators of a malfunction at any time. The influent to the pilot plant was primary effluent, pumped from the well located between the primary and secondary treatment units of the main treatment plant. Figures 1 and 2 show the configuration of the pilot plant system and the flow regime.

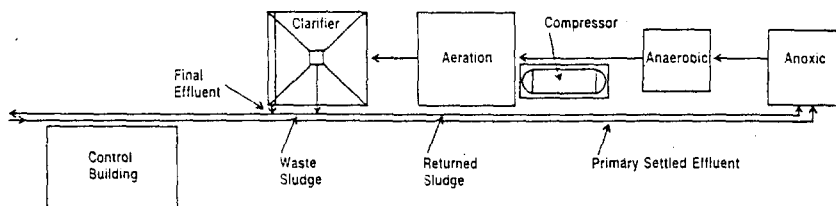


Fig 1. Schematic flow diagram of the pilot plant

* The lengths and widths of various reaction basins were:

anoxic tank 1.83 m × 1.83 m , anaerobic tank 1.52 m × 1.52 m , aerobic tank 2.44 m × 2.24 m and clarifier 2.44 m × 2.24 m . Final clarifier was designed with a hopper with a base 61 cm × 61 cm , and vertical height of 76 cm .

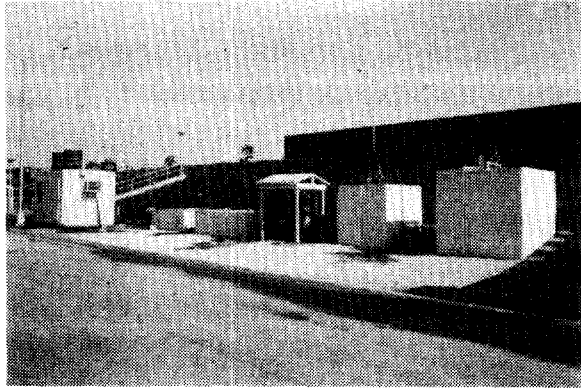


Fig2. Photograph of pilot plant facility

3. Operational Parameters and Laboratory analysis

The system was operated in two modes. In the first mode, Q_r/Q ratio was maintained at 3.0 and the EMLSS * concentration at 3100 mg/L in anoxic/anaerobic/aerobic sequence from March 1987 to May 1988. In the second mode, Q_r/Q ratio was 0.5 and the EMLSS concentration around 2200 mg/L in the anoxic/anaerobic/aerobic sequence from June 1988 to September 1989. The second operation mode was intended to be compatible with the Village Creek WWTP. The average detention time for these two modes are given in Table 1.

All laboratory analysis were conducted in accordance with the Standard Methods⁵. Routine monitoring includes those measurements that were monitored on daily or weekly basis. Non-routine monitoring involved spot checks and infrequent measurements. The routine parameters measured included; flow temperature, DO, TSS, COD, BOD₅, nitrogen and phosphorus. Table 2

Table 1. Detention Times in Modes I and 2

$Q_r(Q)^{a,b}$ L/min	Q_r/Q	Detention Times based on $(Q_r + Q)$ and Q , min.			
		Anoxic reactor	Anaerobic reactor	Aerobic reactor	Clarifier
95.7 (31.9)	3.0	46 (176)	26 (100)	93 (366)	74 (256)
19.7 (40.5)	0.5	96 (144)	54 (78)	192 (288)	168 (252)

Total detention times at $Q_r/Q=0.5$ are 4 and 8.5 hours based on Q_r+Q , and 15 and 12.7 hours based on Q respectively.

* Effective mixed liquor suspended solids (EMLSS) represents the weighted average of the individual MLSS concentrations in three reactors.

^a Values in parenthesis are based on influent flow only.

^b L/min = 0.2642 gpm

Table 2. Data Collection Matrix

Parameter	Influent	Effluent	Aerobic reactor	Anoxic reactor	Anaerobic reactor	Frequency ^a
Flow	x	x				c
Recycle flow			x	x	x	c
COD	x	x		x	x	w
BOD ^b	x	x	x	x	x	w
TSS		x	x	x	x	w
MLSS			x	x	x	w
MLVSS			x	x	x	w
Settleable solids			x	x	x	w
NO ₃ -N		x		x	x	w
NH ₃ -N	x	x				w
TKN	x	x				w
Ortho-P (asP)	x	x		x	x	w
Total-P (asP)	x	x				w
DO			x			d
Temperature		x	x	x	x	d

^aC-continous ; W-4 to 5 times weekly ; d-twice daily

^bCalculated from routine correlation with COD

provides a list of various parameters measured, their points of measurement, and frequency of analysis. Due to the time factor in the analysis of 5-day BOD, a correlation between BOD₅ and COD was made. The linear regression equations derived from the statistical analysis with 45 samples of the influent and effluent are as follows:

$$\text{Influent BOD}_5 = 0.48(\text{Influent COD}) + 0.72$$

$$\text{Effluent Soluble BOD}_5 = 0.069(\text{Effluent soluble COD}) + 7.24$$

These calculated BOD values were used for the day that BOD test did no run. Also the quantity of waste sludge from clarifier was determined based on a designed EMLSS. The sludge age, of Mean Cell Residence Time(MCRT), was calculated from the sludge wasting data. The F/M(Food to Microorganism Ratio) and SVI(Sludge Volume Index) was also obtained to understand the environmental criteria on each modes.

4. Results and Discussion

Dissolved oxygen in the aeration basin was maintained above 2.0 mg/L and averaged 4.0 mg/L

during the research period. Morning DO values were consistently higher than afternoon values due to reduced bacterial activity and higher level of saturation for DO at low temperatures. Average monthly temperatures were almost same in all the three reactors. The final clarifier temperature was one to two degrees lower than the reactors because of open contact with atmosphere. Average seasonal temperature, °C, of the reactors for the study period: winter, summer, and fall/spring months were 13.4, 26.4 and 21.2, respectively. Essentially no scum formed in the pilot plant. The assessment of biomass was done by measuring the Mixed Liquor volatile Suspended Solids (MLVSS) in each reactor. The MLVSS/MLSS ratio averaged 0.72 for the first mode and 0.75 for the second mode for the three reactors. The Q_r/Q ratio, EMLSS concentration maintained, sludge age, F/M ratio, and SVI are detailed in Table 3.

Table 3. The Summary Data of Q_r/Q , EMLSS, MCRT, F/M and SVI

Operational	Recycle ratio Q_r/Q					
	3.0			0.5		
Parameter	Max	Min	Ave	Max	Min	Ave
Q_r/Q	6.5	0.5	3.0	6.6	0.3	0.5
EMLSS, mg/L	4800	1200	3457	5400	760	2427
MCRT, days	70	2	14.8	26	7	13.1
F/M*, d ⁻¹	0.4	0.05	0.12	0.75	0.08	0.24
SVI	280	80	91	240	30	90

* F/M = Influent BOD₅ (lbs/d) / MLVSS maintained (lbs)

Influent and effluent summary data for BOD, COD, Phosphorus, and nitrogen are presented in Table 4.

An intensive sampling and analysis program was carried out to establish mass balances for both nitrogen and phosphorus between January 17 and March 31, 1988 for first mode and June 24 and August 30, 1989 for the second mode. Total nitrogen and total phosphorus mass balance data are presented in Table 5.

Recycle ratio, maintenance of anoxic/anaerobic conditions and BOD concentration were believed to be the significant factor in enhancing nutrient removal efficiency. The nitrogen removal increased with an increase in recycle ratio⁷. This was expected since increase in recycle ratio increases the nitrate loading on the anoxic reactor. Average nitrogen and phosphorous removals in the pilot plant were 80% and 44% for Q_r/Q of 3.0, and 40% and 83% for Q_r/Q of 0.5, respectively. Average total nitrogen concentrations in the effluent were 4.0 mg/L and 10.8 mg/L for Q_r/Q of 3.0 and 0.5, respectively. Second mode ($Q_r/Q = 0.5$) provided excellent nitrification giving an average ammonia nitrogen concentration of 2.3 mg/L and NO₃-N concentration of 6.9 mg/L in the effluent. However, a higher percentage of total nitrogen (28.3%) was removed in the anoxic reactor as N₂ at Q_r/Q ratio of 3.0 (due to denitrification). Only 13.5%

Table 4. Influent and Effluent Summary Data

Parameter ^a	Operating Condition					
	Recycle ratio, Q _r / Q					
	3.0			0.5		
	Max	Min	Ave	Max	Min	Ave
TSS	120	3	10	150	2	7
BOD						
Influent	381	47	136	183	93	140
Effluent soluble	3	2	2	15	0.6	7.4
Removal			99			95
COD						
Influent	864	71	284	371	147	268
Effluent	143	16	31	120	20	51
Removal			89			81
Total phosphorus ^b						
Influent	9.0	5.8	7.6	18	0	11.1
Effluent	7.4	2.3	4.3	9.5	0	1.9
Removal			44			83
Orthophosphate ^b						
Influent	8.8	5.4	6.8	9.5	0.5	5.0
Effluent	7.3	1.0	4.0	7.3	0.0	1.0
Removal			39			80
Ammonia ^c						
Influent	23.5	9.7	13.8	34	9.5	15.1
Effluent	0.5	0.0	0.1	4.1	0.0	2.3
Removal			99.8			85
Total nitrogen ^c						
Influent	40.6	16	19.9	30	14	18
Effluent	9.9	2.8	4.0	13	3.3	10.8
Removal			79.7			40
Nitrate ^c						
Effluent	8.7	1.6	2.9	14.2	2.5	6.9

^aParameter in mg / L ; Removal efficiency in percent

^bAs phosphorous

^cAs nitrogen

removal of total nitrogen through denitrification was achieved at Q_r/Q of 0.5.

Phosphorous removal was more consistent in the second mode than that in the first mode. Average overall phosphorous removal during the study period was 83 percent in the second mode. Phosphorus removal depended greatly upon the BOD₅ concentration in the influent. Individual measurements showed high phosphorous removal at high BOD₅ concentration in the feed. It is well known that in the anoxic and anaerobic zones, phosphorous release from microorganisms occurs⁸.

Table 5. Nitrogen and Phosphorus Mass Balance

Parameter	Sampling Location		
	Influent	Effluent	Solid Wasted
Qr / Q=3.0			
Total nitrogen, gm/d ^a	876.4	226.7	402.6
Nitrogen fraction, %		25.9	45.9
Total phosphorous, gm/d	273.7	123.6	150.1
Phosphorous fraction, %		45.0	55.0
Qr/Q=0.5			
Total nitrogen, gm/d ^b	1071.0	543.0	383.0
Nitrogen fraction, %		50.7	35.8
Total phosphorous, gm/d	359	82.0	277.0
Phosphorous fraction, %		23.0	77.0

a 409.9 g / d $\text{NO}_3\text{-N}$ returned to anoxic reactor ; 247.1 g / d $\text{NO}_3\text{-N}$, 28.3% of total nitrogen was removed in anoxic reactor as N_2

b 210.0 g / d $\text{NO}_3\text{-N}$ returned to anoxic reactor ; 145.0 g / d $\text{NO}_3\text{-N}$, 13.5% of total nitrogen was removed in anoxic reactor as N_2

This release is essential for phosphorous uptake in the aerobic reactor and provides high overall phosphorous removal. It was found in the first mode that when the influent BOD_5 concentration was low, there was hardly any release of phosphorous in the anoxic and anaerobic tanks. It is generally accepted that a carbon source, and anaerobic conditions are essential to achieve phosphorous release and a period of aerobic condition must follow to promote enhanced phosphorous uptake⁸. At higher concentration of BOD_5 in the mixture, the microorganisms are able to utilize the carbon source more effectively for phosphorous release². If influent flow to the system cannot be arranged to obtain a flow stream high in BOD, a supplemental carbon must be added to either the anoxic or anaerobic reactors.

Both modes had good settling characteristics with about 90 of SVI. The microaerophilic/fast growing filaments that adversely effect sludge settling characteristics would not proliferate in the anoxic/anaerobic sequence.

5. Conclusions

A pilot plant study of anoxic/anaerobic/aerobic treatment train using primary effluent of the village Creek Wastewater Treatment Plant, City of Forth Worth, Texas, USA, was performed to evaluate the modified biological treatment train underfield conditions.

Based on the results of pilot plant study, the followings are concluded:

1. The pilot plant had a good BOD removals, and produced a high quality effluent, producing average BOD_5 and TSS concentrations below the state limits of 10/10 mg/L each in the both modes.

2. Nitrogen removal by nitrification–denitrification was successfully achieved with this reactor sequence of anoxic/anaerobic/aerobic condition.
3. Phosphorus removal without additional carbon source was performed by phosphorus release–uptake reaction by incorporating anoxic/anaerobic reactors.
4. The sludge exhibited excellent settling characteristic in both modes as evident from the SVI measurements.
5. It was observed that essentially no scum formed in the pilot plant whereas a high scum formation was reported at the aeration basin of the main plant.
6. The conventional activated sludge plant can be modified to remove nitrogen and phosphorus effectively by adding anoxic/anaerobic reactors prior to the aerobic treatment. The operational parameters can be chosen based upon individual requirements of removing nitrogen or phosphorus or both.

6. Reference

1. Arvin, E. (1985) Research advances in the understanding of biological phosphorus removal. Paper presented at International Conference on New Directions and Research in Wastewater Treatment and Residual Management, University of British Columbia, Vancouver, Canada.
2. Qasim, S. R. and K. Udomsinrot, (1985) Biological Nutrient removal in Anoxic–Anaerobic–Aerobic Treatment Process, International Journal of Environmental Studies, 30, 357.
3. Qasim, S. R., et al. (1986) Bench Scale Studies on Biological Nutrient Removal Using Primary Effluent from the Village Creek Wastewater Treatment Plant, Report CE–FW–1–86, Dept. of Civil Engineering, University of Texas at Arlington, Arlington, Texas, USA..
4. Qasim S. R., et al. (1988) Pilot Plant study on Biological Nutrient Removal at Village Creek WWTP, report CE–FW–1–87, Dept. of Civil Engineering, University of Texas at Arlington, Arlington, TX.
5. Standard Methods for the Examination of Water and Wastewater. (1985) 16th Ed. Am. Public Health Assoc., Am. Water Works Assoc. and WPCF, Washington, D. C..
6. Qasim, S. R., C. E. Parker, and Bok K, Ahn, (1989) Biological Nutrient Removal Phase II Pilot Plant Operation at Village Creek WWTP, report CE–FW–1–88, Dept. of Civil Engineering, University of Texas at Arlington, Arlington, TX.
7. Parker, C. E, et al. (1989) Enhanced Nutrient Removal by biological Treatment Systems, International J. Environmental Studies, Vol 33, pp.275–284.
8. Davelaar, D., R. T. Davis and G. S. Wiechers. (1978) The significance of an anaerobic zone for the Biological Removal of Phosphorus from Wastewater, Water SA 4, April, 54.

Abstracts of Papers in the Journals of the KAHS (March 1989 ~ December 1989)

Vol. 22, No. 1

Groundwater Flow Analysis using a Steady State Three-dimensional Model in an Upland Area

Bae, Sang Keun, Assist. Prof., Keimyung Univ.

A numerical simulation technique of three-dimensional finite difference model is developed to study the groundwater flow system in Dejima, an upland area which faces Kasumigaura Lake. For general perspectives of the groundwater flow system, a steady state three-dimensional model is simulated. For the sedimentary mud formations which are found in the representative formation, three situations of hydraulic conductivity are considered, representing an isotropic condition and situations where the horizontal permeability is equal to 10 times and 100 times of the vertical one. The finite difference grid used in the simulation has $60 \times 50 \times 30 = 90,000$ nodes. A converged solution with a tolerance of 0.001 meter of hydraulic head is set. Having determined the flow net by using a steady state three-dimensional model, the results for the three cases of hydraulic conductivity are compared with the results of the tracer methods(Bae and Kayane, 1987). With the aid of four representative vertical cross-sections, groundwater flow systems in the study area are assumed. The results of these are reasonably good comparable with the results of the basin yield and the recharge-discharge distribution.

Discharge Coefficient of Flow through Gate Piers

Kim, Chae Soo, Graduate Student, · Nahm, Sun Woo, Prof., Dept. of Civil Eng. Dongkuk Univ.

This study was aimed to determine a discharge coefficient of flow through gate piers. The

coefficient was calibrated with water stage data observed during 1984 to 1987 at the Young San Estuary Dam. The coefficient is the function of the dimensionless parameters combined with the difference between up and down stream water level to down stream water depth ratio and water surface draw-down ratio. From the verification with existing methods and actual drainages, drainages predicted by the relationship have the most consistency with the actual drainages, also Matthai's method can be used within the proposed condition originally.

Unsteady Flow Analysis on Flood Characteristics in KEUM River Downstream.

Kim, Hyun Yong, Ph. D, Agricultural Development Corporation. · Park, Seung Woo, Assist. Prof., Dept of Agricultural Eng. Seoul Nat'l Univ.

KEUM River downstream has some characteristics in which the downstream is affected with tidal motion. the several tributaries are forming a dendritic river system, and the channel cross-sections are irregular. The flood in this downstream can not be analyzed by the hydrological flood routing methods and under the assumption regarding the dendritic river system as a single reach. In this study the river system was modeled as a dendritic system and the unsteady flow analysis i.e. explicit finite difference scheme was used for the flood routing. The flood records which were measured in 1978 and 1987 were applied for calibration and verification of the unsteady flow model respectively. The results show that the flood at KANG-KYONG station was not affected with the tidal motion when the discharge at KONG-JU station exceeded about 5,000 m³/sec, and that the bottle neck at IP-PO station intercepted the tidal influences.

Watershed Runoff Analysis by SSARR Model

Ahn, Sang Jin, Prof., · Lee, Yong Soo, M. E., Chungbuk National Univ.

An attempt is made to describe the theory and computer algorithm of the SSARR model, and to try it's application to the small watershed, by using the estimation of the model parameters with the data of Bochong stream basin. The selected period of the hydrological data is from 1982 to 1988 for the modeling. The selected basin is the Bochong stream basin which is one of the tributaries of Geum river. The estimation of model parameters and sensitivity test are carried out for the analysis of the characteristics of model parameters.

An Experimental Study on Wastewater Treatment by Modified Activated Sludge Process

Chea, Soo Kwen, Graduate Student, Inha Univ. · Yeon, Ki Suck, Assist. Prof., Daijeon Eng. College · Kim, Kun Heung, Assoc. Prof., Inha Univ. · Ahn, Sang Jin, Prof., Chungbuk National Univ.

This study deals with the performance of an activated sludge system which is modified by the researcher to function without any additional chemical or internal recycle in removing organics, nitrogen, and phosphorus from synthetic wastewater. To improve the nutrient removal efficiency, the researcher utilized the anoxic, anaerobic, and aerobic reactor sequences with a single sludge return, which led to nitrification/denitrification and phosphorus release/overplus accumulation. A bench scale system was operated with a view to investigating the reaction characteristics of each reactor, and to measuring the biological kinetic coefficients (Y , K_d , k , K_s) for the removal of COD in relation to the mean cell residence time at five different MLSS concentrations, 5000, 4200, 3300, 2600, and 1900 mg/l. The results of the research showed that organic substance and nutrient were removed simultaneously by this modified activated sludge process. And the process had 66%-99% Ortho-P removal efficiency.

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A Study on the Bed-Load Transport Rate

Kang, Ju Bok, Prof., · Jeong, Yeon Tae, Graduate Student · Kim, Won Gyu, Graduate Student, Pusan Univ.

A method is presented which enables the computation of the bed-load transport rate as the product of particle velocity and bed-load concentration. In this study, it is assumed that particle velocity is proportional to the flow velocity near the particle and the appearance frequency of the component of the fluctuating velocity of turbulent flow close to bed is normally distributed, and the particle velocity is expressed by mean flow velocity near the particle and the function of bed shear stress. Engelund formula, which is checked indirectly to be proper to use in this study, is employed to estimate the effective shear velocity. And the effective bed shear stress acting on particle is obtained by that shear velocity. Ashida-Michiue's formula is used to get the concentration of bed-load. Experimental data for bed-load is compared with the results of other studies and the transport formula suggested in this paper gives results which are in good accordance with other's experimental data excepting the results obtained the case of comparatively small bed shear stress.

Estimation of Radial Spectrum for Rainfall

Lee, Jae Hyeong, Assoc. Prof., Chonbuk National Univ. · Lee, Dong Joo, Assoc. Prof., Kunsan Junior College. · Park, Young Ki, Graduate Student, Chonbuk National Univ.

Using the storm data which was augmented by the stochastic correlation with its neighbors, the multiquadric equation of random surface of total storm depth is constructed. And to separate the local components from its regionals and find the regional characteristics, a double Fourier analysis was applied to the total depths of storm data. The local components, storm residuals of each storm was assumed to be an homogeneous random field and investigated with its autocorrelation function. For the practical application, isotropic was assumed and that was identified with empirical data. Coefficients of normalized autocorrelation for all storms showed similar appearance. Using this empirical result, an example of the radial spectral distribution function which represents the spatial characteristics of rainfall over Han River Basin during 1975-1983 is presented.

A Study on the Gradual Breach of Earth Dam

Oh, Nam Seon, Graduate Student · Sonu, Jung Ho, Prof., Seoul National Univ.

Gradual failure of an earth dam is caused by piping or overtopping. In this gradual failure, a breach will form and grow gradually under the erosive action of the waters. The process involved during an earth dam failure is very dynamic and complicated. The physical model of Fread and mathematical model of Singh and Scarlatos are verified and compared in this study. Fread's model(BREACH) simulates dam failure well when sufficient data are given, and Singh and Scarlatos' model simulates it approximately with a few simple data.

A Forecasting Model for the Flooded Area Resulting from Breached Levee

Lee, Jong Tae, Prof., Kyonggi Univ. · Han, Kun Yeun, Prof., Kyungbuk National Univ.

A dynamic levee breach model is demonstrated which can be applied to various types of breach such as overtopping, breaking, and piping. Through a hypothetical simulation the sensitivity of breach width and duration in the result are discussed. The breach width has more important effect than the failure duration upon the side discharge owing to levee breach.

Unsteady Groundwater Flow in Aquifer

Lee, Jong Kyu, Prof., Hanyang Univ.

The partial differential equation of the unsteady groundwater flow was reduced to an ordinary differential equation by the Boltzmann transformation. Its numerical solutions were obtained by the finite difference method and the new method to get the initial missing slope using the Richardson method and the finite difference equation was proposed. The solutions computed by the newly proposed method were compared with other investigator's computations and they showed a satisfactory agreement and that the proposed method is easy and simple to get solutions.

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Development of the Daily Runoff Simulation Model

Kim, Yang Su, Researcher ·Seoh, Byung Ha, Director, Water Resources Eng. Div., KICT ·Kang, Kwan Weon, Prof., Inha Univ.

This study is aimed to develop a long-term daily runoff simulation model. The model is theoretically constructed and is applied to the practical problems to verify its reasonableness. A lumped, nonlinear model is proposed and is calibrated as quasilinearization procedures. The hydrological data used in this study are precipitation, runoff, and evaporation records in the Bochong Stream which is one of the tributaries of the Geum River.

Comparison of Radiating Ocean Boundary Conditions by Error Analysis

Suh, Seung Won, Fulltime Instructor, Kunsan National College ·Yoon, Tae Hoon, Prof., Hanyang Univ.

The effects of open boundary conditions including the radiating condition are compared by utilizing the L^2 -norm and RMS error in the numerical modeling of ocean problem. In numerical tests of M_2 tide, grid size and bed roughness are considered and analyzed. For the M_2 tide test in a simplified bay where the analytical solutions are available, it is found that improved radiating boundary condition(IMPSON) may increase the reliability of computed results by 40% of L^2 -norm and 96% of RMS error than the pen boundary condition without radiating effect. In case of using the half-size grids, better results are obtained. It is also found that the

IMPSOM is applicable with satisfaction when the bottom friction is included.

Comparative Evaluation of Dam-Break Models

Lee, Changhoon, Researcher, KICT · Lee, Kil Seong, Assoc. Prof., Seoul National Univ.

Three representative dam-break models, HEC - 1, DAMBRK, and SMPDBK were analyzed respectively in their theories and then applied to the failure of Teton Dam for which some observed data exist.

From the results of this study, it can be concluded that:(1) HEC - 1, which uses the hydrologic routing method, produces stable solutions for almost all the cases that were tested in this study ; (2)DAMBRK, which uses the dynamic routing method, is most accurate among the three models ; (3)SMPDBK, which uses the generalized dynamic routing relationships, is most economical and easily applicable.

Stochastic Forecasting of Monthly River Flows by Multiplicative ARIMA Model

Park, Moo Jong, Graduate Student · Yoon, Yong Nam, Prof., Korea Univ.

The monthly flows with periodicity and trend were forecasted by multiplicative ARIMA model and then the applicability of the model was tested based on 23 years of the historical monthly flow data at Jindong river stage gauging station in the Nakdong River Basin. The parameter estimation was made with 21 years of data and the remaining two years of monthly data were used to compare the forecated flows by $ARIMA(2, 0, 0) \times (0, 1, 1)_{12}$ with the observed, The results of forecast showed a good agreement with the observed, implying the applicability of multiplicative ARIMA model for forecating monthly river flows at the Jindong site.

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Development of Synthetic Unit Hydrograph for Estimation of Design Flood

Lee, Hong Rae, Researcher · Lee, Chong Kuk, Researcher · Seoh, Byung Ha, Director Water Resources Eng. Div., KICT

In this study, more exact runoff phenomena of the watersheds were comprehended and the

relationships between geographical factors of the selected watershed and the unit hydrograph characteristic variables representing runoff processes, were also established. The estimation method of the adequate design flood was presented, which is needed for the design of the hydraulic structures in the ungauged watersheds. Using these results, it is considered to be possible to execute the effective flood control projects of the river and the efficient water resources management.

Mathematical Analysis of Water Hammer Generated an Initially Empty Piping with a Sudden Contraction Subject to Rapid Filling

Woo, Hyo Seop, Senior Research Fellow · Lee, Sam Hee, Researcher, KICT

An analytical equation was formulated using the continuity, momentum, and energy equations for the transients generated in an initially empty piping with a sudden contraction subject to rapid filling with liquid. Also, two mathematical models, MOC and RCT were applied to this particular piping to reveal that the rigid column method is less applicable than the method of characteristics to the piping.

On Spectral and Statistical Characteristics of Sea Waves by the Typhoons

Shim, Jae Seol, Researcher · Oh, Byung Chul, Researcher · Kim, Sang Ik, Researcher, KORDI

Using the wave by typhoons LEE, VERA, THELMA which gave great damages in the Korean peninsula, the significant waves based on zero-up & down crossing and Tucker-Draper method are compared with those from the wave energy spectrum. And the histograms of individual waves obtained from zero-up crossing method are presented and compared with the Rayleigh, Weibull, Gluhovski, Ibrageemov and Goda distributions, and also the Chi-square goodness of fit test is applied to each theoretical distributions. It is shown that the significant wave heights by zero-up crossing method are very well agreed to those by energy spectrum method. The wave heights are found to well follow the Rayleigh and Goda distributions by the Chi-square test.

A Channel Flood Routing by the Analytical Diffusion Model

Yoo, Chul Sang, Graduate Student · Yoon, Yong Nam, Prof., Korea Univ.

The analytical diffusion model is first formulated and its characteristics are critically

reviewed. The flood events during the 1985-1986 flood seasons in the IHP Pyungchang Representative Basin are routed by this model and are compared with those by the kinematic wave model. The results showed that the analytical diffusion model simulates the observed flood events much better than the analytical kinematic wave model. The presented model is proven to be an excellent means of taking the backwater effects due to lateral inflow or downstream river stage variations into consideration in channel routing of flood flows. It also requires much less effort and computing time at a desired station compared to any other reliable flood routing methods.