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COINCIDENT FLOOD FREQUENCY ANALYSIS FOR DESIGN OF CHAO PHRAYA RIVER FLOOD CONTROL SYSTEM FOR BANGKOK

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ABSTRACT: Flood levels of the Chao Phraya river at Bangkok is strongly influenced by the upstream river flood levels at Bangsai and the tide levels at the river mouth at Fort Chula. A flood control system was earlier proposed by the Asian Institute of Technology and the Thai-Austrian Consortium for Bangkok in 1986. However, no coincident flood frequency analysis was done. In this study, a coincident flood frequency analysis is applied to determine the significance of the flood levels at Bangsai and the tide levels at Fort Chula on the flood levels at Bangkok. Also, the change in the return period of flood overtopping the existing river dikes with and without the proposed flood control scheme is determined. It is found that the return period of flood overtopping the river dikes is 2.5 years when there is no flood control scheme and is more than 1000 years when considering the flood control scheme.

INTRODUCTION

Flood overtopping the existing river dikes of the Chao Phraya river often causes severe floodings in Bangkok and its suburban areas. The flood level is excessively high during the simultaneous occurrence of large upstream flood inflow and the downstream high tide at the river mouth. As it is difficult to raise the existing river dike elevation due to socio-economic and environmental problems, it becomes necessary to apply a flood control system to tackle the flooding problems.

In 1986, the Asian Institute of Technology (AIT) and the Thai-Austrian Consortium (TAC) carried out a flood control study for Bangkok and proposed a flood control system in Fig. 1 for the 100 year upstream flood inflow at Bangsai and the 20 year high tide at the river mouth at Fort Chula (AIT and TAC 1986). It is consisted of a diversion dam at Pak Kret (Km 70), a 52 km long and 135 m wide basewidth diversion channel, a sea barrier with a 1,600 m^3/s pumping station near the river mouth (Km 2), a salinity gate at the end of diversion channel near the sea barrier and the surrounding flood embankments on the east and west of Bangkok in Fig. 1. This flood control system can control the river water level within the protected area of 1,400 km^2. below the mean sea level. However, various probabilities of occurrence of flood inflows at Bangsai and high tides at Fort Chula were not considered. Moreover, the previous study did not include the river storage effect between the Pak Kret diversion dam and the sea barrier. Such a design could be too conservative and uneconomical. If the relationship between the capacity of the flood control system and the return period of flood overtopping the existing river dikes is known, a better selection of the capacity of flood control system can be done on probabilistic basis.

Flood records show that annual flood peaks at Bangsai and Fort Chula do not occur at the

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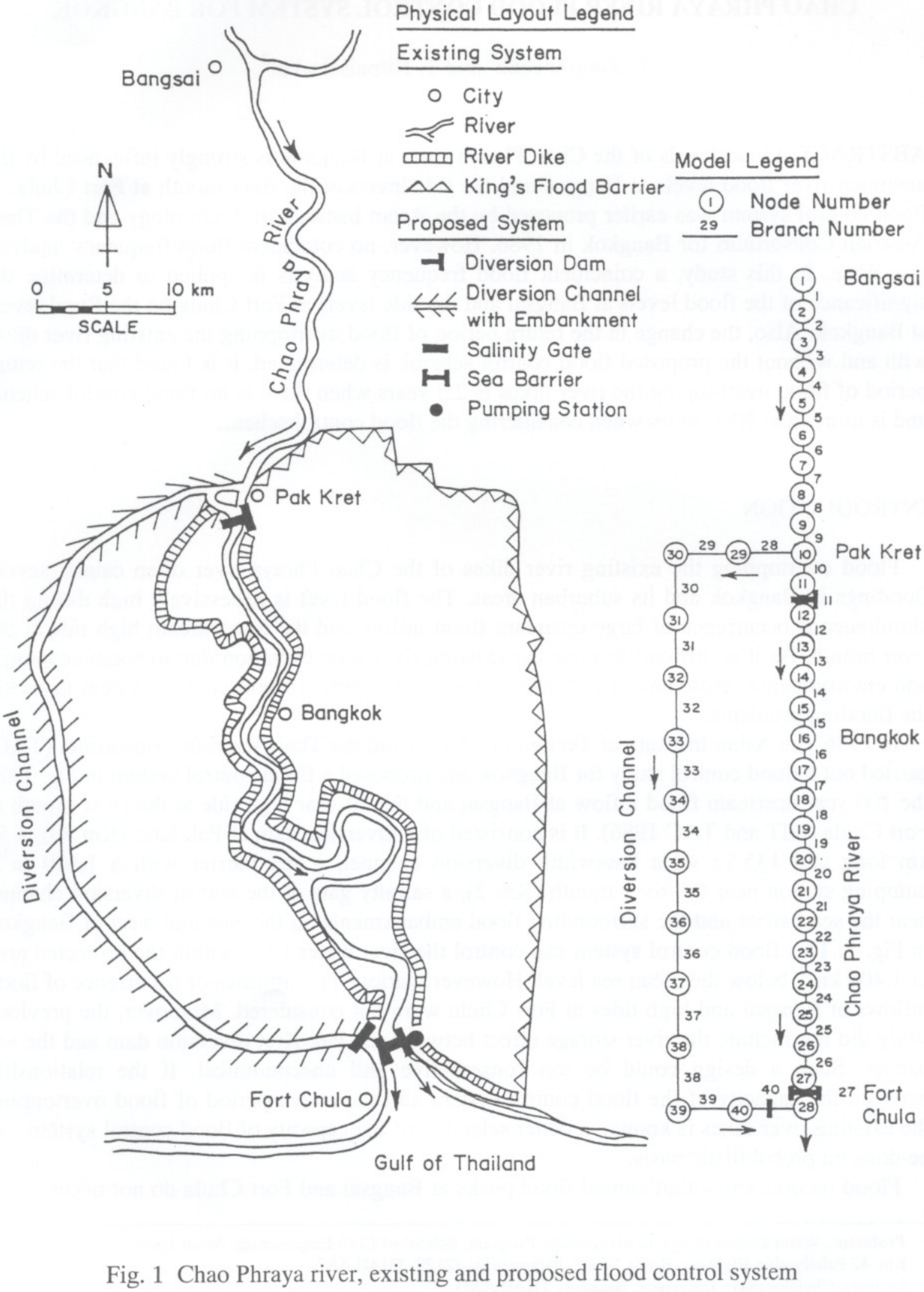


Fig. 1 Chao Phraya river, existing and proposed flood control system for Bangkok and mathematical model configuration

same time due to their independent sources. The annual peak of upstream floods at Bangsai usually occurs in October while the annual peak of the downstream tides at Fort Chula usually occurs in December. This implies that the annual flood peak at Bangkok which usually occurs in November is not influenced by the flood peaks at Bangsai and at Fort Chula at the same time but dominated by one of the two. To determine which one of the two is the dominant one, two techniques are used namely goodness of fit test and sensitivity analysis.

This paper presents the applications of a coincident flood frequency analysis to verify the true dominant and non-dominant boundary conditions affecting the river flood level at Bangkok and to determine the exceedence probability distribution of the river water level at Bangkok and the return period of flood overtopping the existing river dikes at Bangkok for various capacities of the flood control system.

THEORETICAL CONSIDERATIONS

The theoretical part involves two steps. The first step is the flood flow simulation to develop the flooding relationships of the river flood levels at Bangkok and at two flood boundary stations namely Bangsai and Fort Chula for various capacities of the flood control system. The second step is the coincident flood frequency analysis using the simulation results in step 1 to analyze the exceedence probability distribution of river flood level at Bangkok. The dominant and non-dominant boundary conditions must be determined before using with the flooding relationship in the coincident flood frequency analysis. This can be determined using the goodness of fit test between the computed and observed water levels at Bangkok or by using sensitivity analysis to determine which of the two boundary conditions namely Bangsai or Fort Chula has more effect on the variation of flood level at Bangkok. With proper selection of the dominant and non-dominant boundary conditions, the computed exceedence probability distribution of flood level at Bangkok will closely fit the observed data and will not change significantly with the change of the time duration distribution curve of the non-dominant boundary condition.

Flood Flow Simulation Analysis

A one-dimensional flow model using a finite difference of implicit scheme together with a node and branch schematization (Tingsanchali 1974; Tingsanchali and Ackermann 1976) is applied. The model is used to compute flood flow in the Chao Phraya river and the diversion channel. The Chao Phraya river reach considered is from Bangsai to Fort Chula, a distance of 112 km. The river reach is schematized into 40 nodes and 40 branches. The node is assigned to take in to account storage effects as well as inflows to and outflows from the node. The branch connects the flow between the two nodes and it is assigned to take into account the frictional effects and the inertia effects of flow between the two nodes. The water level in each node is considered to be horizontal while a uniform discharge is considered to exist in the branch connecting the two nodes. The water surface is assumed to vary linearly along the branch. The governing equations and the finite difference of implicit scheme used to transform the governing equations to the finite difference equations are described as follows:

Continuity equation for a node :

$$F\frac{dH}{dt} = \sum_{i=1}^{m} Q_{in,i} - \sum_{j=1}^{n} Q_{out,j} + Q_l \qquad (1)$$

Momentum equation for a branch:

$$\frac{\partial Q}{\partial t} + \frac{2Q}{A}\frac{\partial Q}{\partial x} - \frac{Q^2}{A^2}\frac{\partial A}{\partial x} + gA\frac{\partial H}{\partial x} + \frac{gn^2 Q|Q|}{A^2 R^{4/3}} = 0 \qquad (2)$$

where A = flow cross-sectional area of a branch, F = water surface area of a node, g = gravitational acceleration, H = water level of the node, n = Manning's roughness coefficient, Q = discharge of the branch, $Q_{in,i}$ = i^{th} inflow to node, $Q_{out,j}$ = j^{th} outflow from the node, Q_l = lateral inflow to the node, R = hydraulic radius of the branch, t = time, x = distance.

The changes of water level and discharge in each time step are based on the derivatives of water levels and discharges at time t and $t+\Delta t$ as:

$$\frac{\Delta H}{\Delta t} = (1-\theta)\left.\frac{dH}{dt}\right|_t + \theta\left.\frac{dH}{dt}\right|_{t+\Delta t} \qquad (3)$$

$$\frac{\Delta Q}{\Delta t} = (1-\theta)\left.\frac{dQ}{dt}\right|_t + \theta\left.\frac{dQ}{dt}\right|_{t+\Delta t} \qquad (4)$$

where ΔH = change in water level of a node, ΔQ = change in discharge of a branch, Δt = time step, θ = time weighting coefficient

Substituting Eqs. (3) and (4) into Eqs. (1) and (2), the finite difference continuity equation for a node and the finite difference momentum equation for a branch are obtained. The continuity and momentum finite difference equations of all nodes and branches are solved simultaneously with Gaussian Elimination Method to determine ΔH for every node and ΔQ for every branch.

Coincident Flood Frequency Analysis

Coincident flood frequency analysis is applicable for determining an exceedence probability distribution of a dependent variable such as the river flood level at Bangkok which is a function of two or more causative factors with known statistics of occurrence such as the river flood level at Bangsai and the tidal level at the Chao Phraya river mouth (Dyhouse 1985). The procedure uses two theorems which are described as below.

Coincident Probability Theorem

Consider A be a function of B and C which are mutually independent. It is assumed that A is more influenced by C than B, that is C is the dominant boundary condition . From their relationship, for given B_j, if A_i is exceeded, C_k will also be exceeded. Therefore,

$$P(A > A_i | B_j) = P(C > C_k) \qquad (5)$$

Total Probability Theorem

The conditional exceedence probability distribution expresses a set of exceedence probability distributions of A conditional on B in which there is a number of possible events to occur. B_1, B_2,..., B_m represents a set of mutually exclusive and collectively exhaustive events for B. By the total probability theorem, the exceedence probability of A_i is determined as:

$$P(A > A_i) = \sum_{j=1}^{j=m} P(A > A_i | B_j) * D(B_j) \quad (6)$$

where $P(A>A_i)$ = probability that event A_i is exceeded for a total time span m, $P(A>A_i|B_j)$ = conditional probability that event A_i is exceeded given event B_j occurred, $D(B_j)$ = increment of time span that B_j represents, and $P(C>C_k)$ = probability that event C_k is exceeded.

Knowing the relationship between A, B and C, the exceedence probability distribution of dominant causative factor C and the time duration distribution of non-dominant causative factor B, the exceedence probability distribution of A can be developed as shown in Fig. 2.

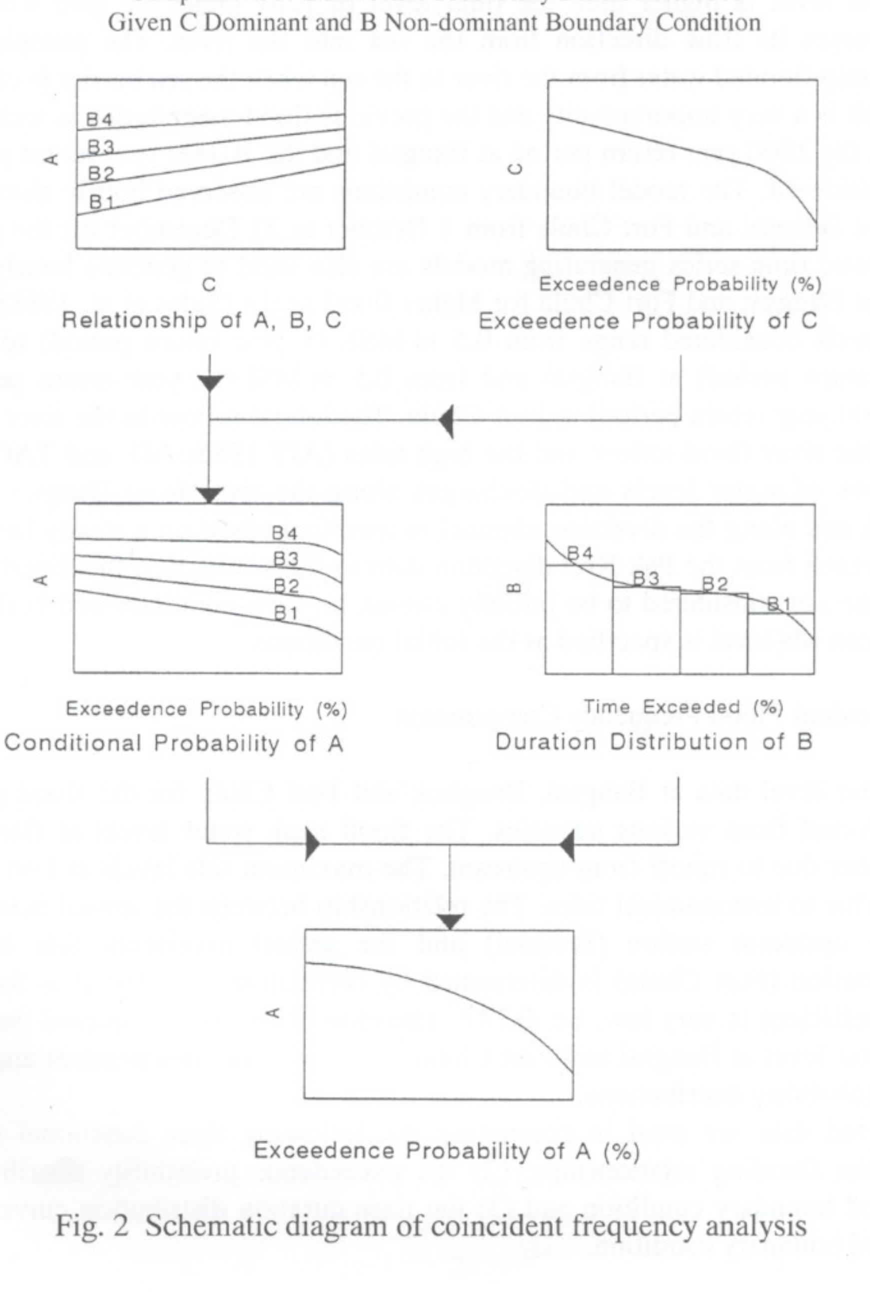


Fig. 2 Schematic diagram of coincident frequency analysis

DATA USED

Data for Flood Flow Simulation

The Chao Phraya river from Bangsai to the river mouth at Fort Chula is schematized into 40 nodes and 40 branches with distance interval about 4 km in Fig. 1. The time step of 1,200 sec and the time weighting coefficient (θ) of 0.55 are used in the computation. The Manning's roughness coefficients of the Chao Phraya river and the diversion channel obtained from calibration are 0.028 and 0.018 respectively (AIT and TAC 1986). The capacity of the flood control system depends on the diversion channel in which its basewidth varies from 20 to 80 m and the sea barrier pumping capacity from 0 to 2,000 m^3/s. For the operation of the flood control system (Tingsanchali and Kitpaisalsakul 1995), it is intended to utilize the maximum capacity of the diversion channel in which the maximum water level at its entrance is limited up to the channel embankment crest level, at Pak Kret diversion dam, i.e., 3.00 m.MSL. The operating rule of the sea barrier, same as that of the salinity gate, is to fully open the gate when the river level is higher than the tidal level or fully close the gate when the flood discharge reverses its flow direction from the sea into the river. The pumping station is operated to pump flooded water from the river to the sea when the sea barrier is closed.

As Bangkok is a very important city and the previous flood magnitudes as well as damages are very high, the 1000 year return period at Bangsai and the 10,000 year return period at Fort Chula are considered. The model boundary conditions are observed hourly river water level hydrographs at Bangsai and Fort Chula from 1 October to 31 December for the period 1971-1993 . Stochastic time series generating models are also used to generate hourly water level hydrographs at Bangsai and Fort Chula for higher flood peaks (Salas et al. 1988). The annual peak water levels considered range from 0.5 m.MSL (1 year return period) to 5.0 m.MSL (1,000 year return period) at Bangsai and from 0.5 m.MSL (1 year return period) to 2.2 m.MSL (10,000 year return period) at Fort Chula. The lateral inflow to the river is negligible compared to the river flood inflow and the high tides (AIT 1985; AIT and TAC 1986). The initial condition of water levels and discharges along the river from Bangsai to Pak Kret diversion dam and along the diversion channel is specified based on a steady flow condition. For the river reach from the Pak Kret diversion dam to the sea barrier, the diversion dam and the salinity gate are considered to be initially closed, no flow condition and horizontal water level at the mean sea level is specified as the initial conditions.

Data for Coincident Flood Frequency Computation

Hourly water level data at Bangsai, Bangkok and Fort Chula for the flood period 1971-1993 are collected from various agencies. The flood peak water levels at Bangsai usually occur in October due to runoff from upstream. The maximum tide levels at Fort Chula occur in December due to astronomical tides. The relationship between the annual maximum water levels at the upstream station (Bangsai) and the annual maximum tide levels at the downstream station (Fort Chula) is determined by correlation analysis. It is found that the correlation coefficient is very low, i.e. 0.142. Therefore it can be considered that the annual maximum water level at Bangsai and Fort Chula are statistically independent and hence their exceedence probability distributions.

The collected data are used in computing the following three functional relationships namely: (1) the flooding relationships, (2) the exceedence probability distribution of the dominant flood boundary condition and (3) the time duration distribution curve of the non-dominant flood boundary condition.

RESULTS AND DISCUSSIONS

Identification of Dominant and Non-dominant Boundary Conditions

Two exceedence probability distributions of the annual maximum hourly flood levels at Bangkok are computed without the flood control scheme considering Bangsai as dominant and Fort Chula as non-dominant. Two time duration distribution curves at Fort Chula for daily maximum hourly tide levels at Fort Chula are developed; one based on long term average data from 1971 to 1993 and another based on the 100 year tidal level hydrograph. The two computed exceedence probability distributions agree closely with that computed from the observed annual maximum hourly flood levels at Bangkok in Fig. 3. Moreover, these two computed exceedence probability distributions of the flood levels at Bangkok are also very close to each other, indicating insignificant influence of the non-dominant boundary condition, i.e., Fort Chula. Opposite results are obtained when considering Fort Chula as dominant and Bangsai as non-dominant. The two computed exceedence probabilities also are much different from each other in Fig. 4. This indicates the significance of the dominant boundary condition at Bangsai. Therefore, the flood levels at Bangsai and Fort Chula are selected to be the dominant and non-dominant boundary conditions, respectively.

Relationships of River Flood Levels at Bangkok, Bangsai and Fort Chula

The flood peak level relationships of the computed peak levels at Bangkok and those of boundary conditions at Bangsai and Fort Chula for various capacities of the flood control system and without flood control system are shown in Fig. 5. Under the flood control system, when the water level at Bangsai is equal to or less than 3 m MSL, the flood level at Bangkok will be regulated equal to or lower than the mean sea level (0 m MSL). It is found that a diversion dam and a diversion channel can significantly divert the excessive flood inflow to the sea while a sea barrier at the river mouth can effectively reduce the backwater effect of high tides on the river water level at Bangkok. This flow regulation effectively lowers the river flood level at Bangkok despite coincidence of large upstream flood from Bangsai and high tides at Fort Chula. When the diversion channel basewidth is larger, the river water level at Bangkok is more lowered. On the other hand, the pumping station can only slightly reduce the river flood level at Bangkok.

Exceedence Probability Distributions of Flood Levels at Bangkok for Various Capacities of Flood Control System

The exceedence probability distributions of river flood levels at Bangkok for various capacities of the flood control system including that without flood control system are shown in Fig. 6 (Kitpaisalsakul 1996). It is found that the return period of flood overtopping the river dikes at Bangkok is significantly increased by the proposed flood control system. When there is no flood control system, the return period of flood overtopping the river dikes at Bangkok is about 2.5 years. The flood control system with a 20 m basewidth diversion channel and a pumping capacity of 0 to 2,000 m^3/s at sea barrier can increase the return period of flood overtopping the river dikes at Bangkok up to 80 years without pumping station and to 460 years with a 2,000 m^3/s pumping station. The flood control system with a 40 basewidth diversion channel without pumping station can increase the return period of flood overtopping the river dikes at Bangkok to more than 1,000 years. It indicates that the flow regulation using both the river storage between the diversion dam and the sea barrier and the proposed flood control system to discharge flood water by gravity to the sea can protect flood overtopping the river dikes at Bangkok given the maximum flood boundary conditions of 1,000 years at Bangsai and 10,000 years at Fort Chula.

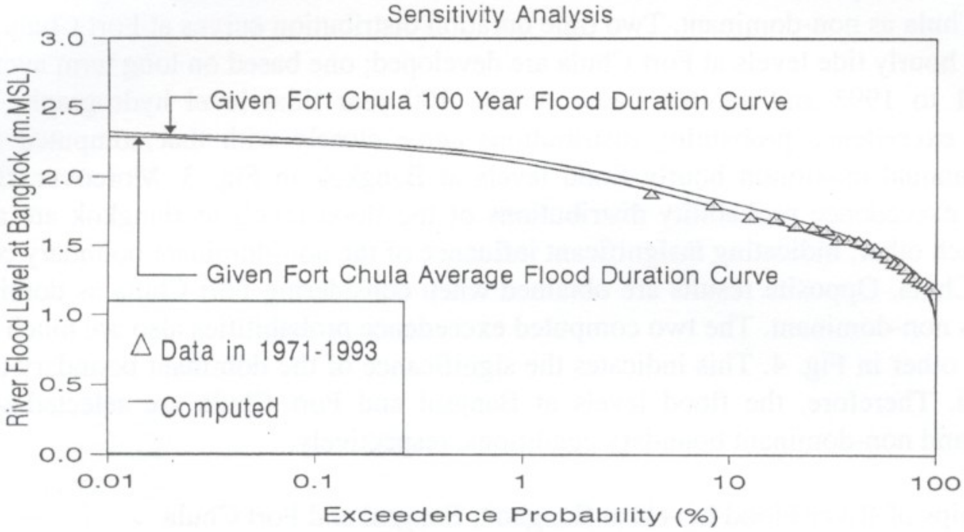


Fig. 3 Exceedence probability of annual maximum river flood levels at Bangkok without flood control system given Bangsai dominant and Fort Chula non-dominant

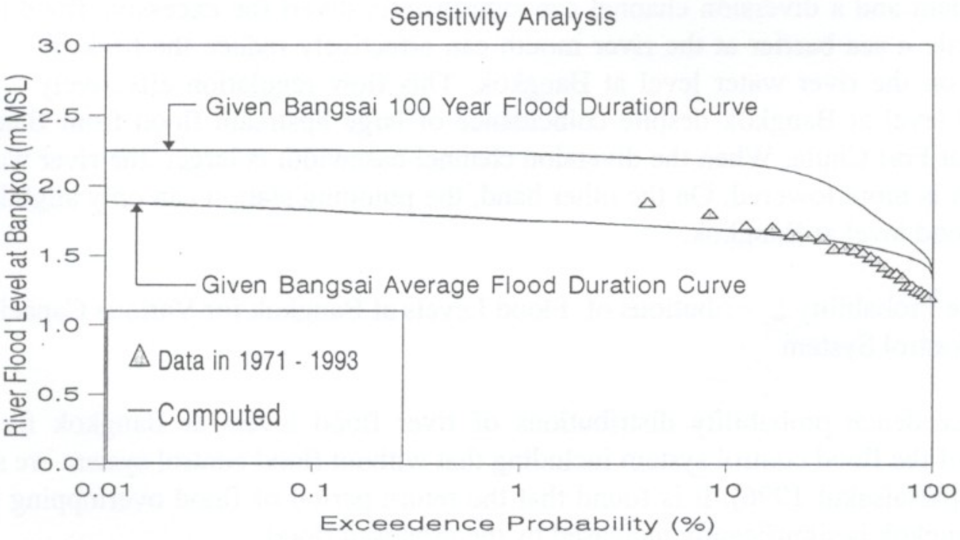


Fig. 4 Exceedence probability of annual maximum river flood levels at Bangkok without flood control system given Fort Chula dominant and Bangsai non-dominant

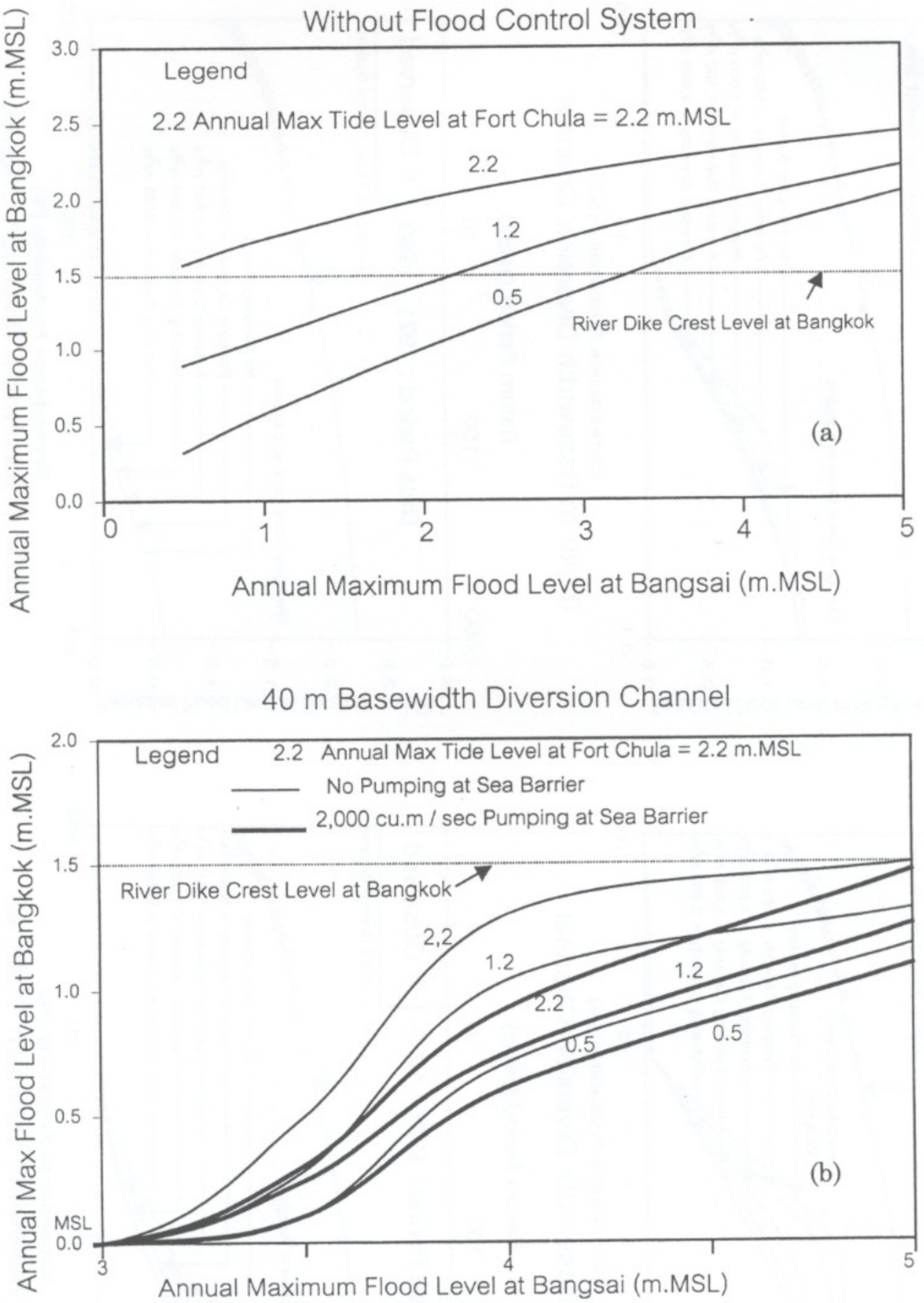
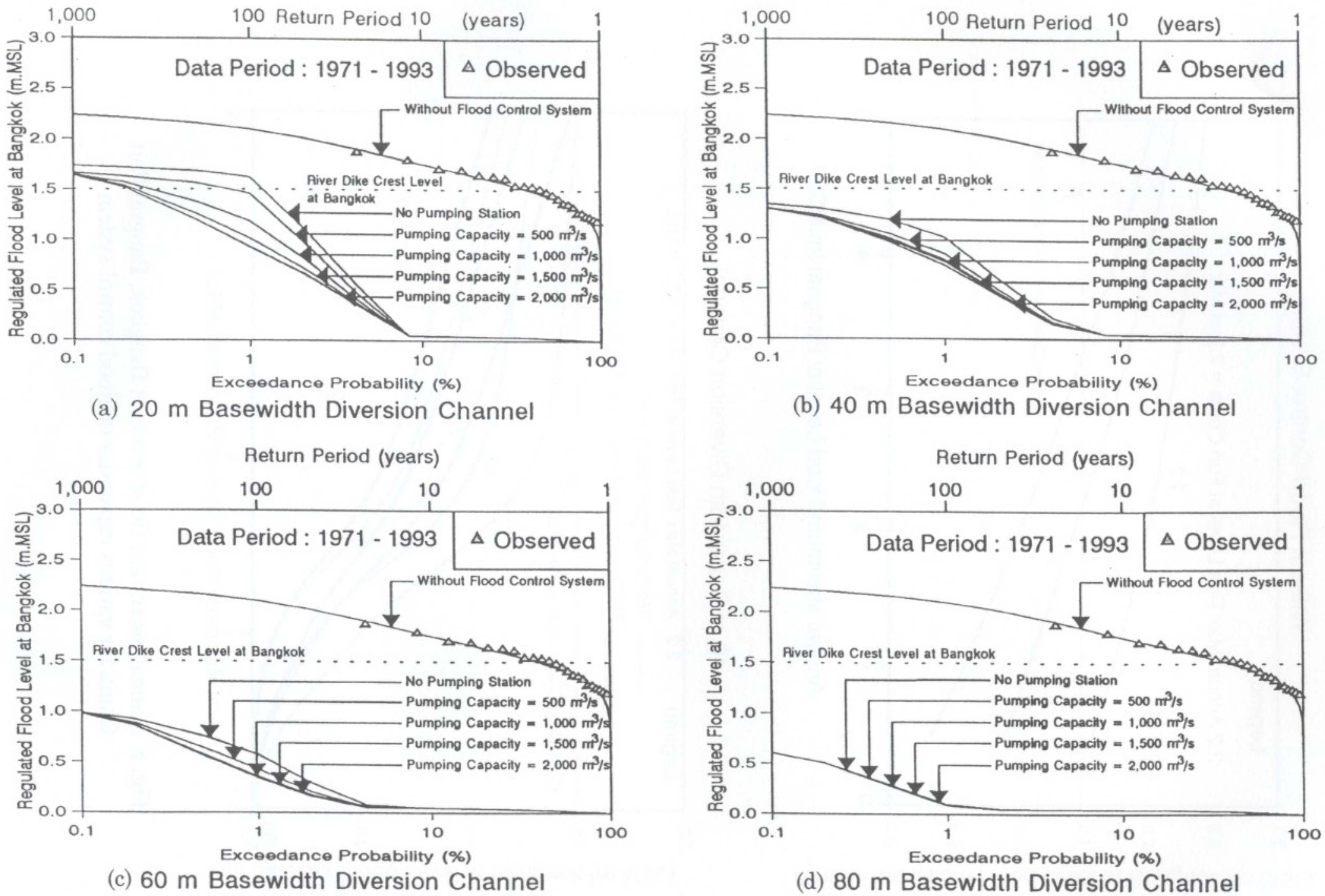


Fig. 5 Annual maximum flood levels at Bangkok, Bangsai Fort Chula for various capacities of flood control system



(a) 20 m Basewidth Diversion Channel

(b) 40 m Basewidth Diversion Channel

(c) 60 m Basewidth Diversion Channel

(d) 80 m Basewidth Diversion Channel

Fig. 6 Exceedence probability distributions of annual maximum river flood levels at Bangkok with and without flood control sysyem

CONCLUSIONS

A proposed flood control system is consisted of a diversion dam across the Chao Phraya river at Pak Kret, a 52 km long flood diversion channel from the diversion dam to the sea, a salinity gate at the outlet of the diversion channel and a sea barrier with a pumping station at the Chao Phraya river mouth. The capacity of the flood control system depends on the diversion channel in which its basewidth varies from 20 to 80 m and a pumping capacity at the sea barrier from 0 to 2,000 m^3/s. The river flood level at Bangkok is considered as a function of river flood levels at Bangsai and high tides at Fort Chula.

Coincident frequency analysis is applied to determine the exceedence probability distribution of the river flood level at Bangkok which depends on flood levels at Bangsai and at Fort Chula. Prior to the application of the coincident frequency analysis, it is necessary to determine the dominant and non-dominant boundary conditions affecting the river flood level at Bangkok. It is found that the probability distribution of maximum river flood levels at Bangkok is more influenced by maximum inflow at Bangsai than high tide at Fort Chula (Kitpaisalsakul 1996).Then the dominant boundary condition is the exceedence probability distribution of river flood levels at Bangsai while the non-dominant boundary condition is the average duration distribution of daily maximum hourly tide levels at Fort Chula. The change of the exceedence probability distribution of the river flood level at Bangkok due to the proposed flood control system and the return period of flood overtopping the river dikes at Bangkok without and with each capacity of flood control system can be determined.

As the results of the flooding relationships, the proposed flood control system is found to be very effective in lowering river water level below the river dikes at Bangkok. The diversion scheme can divert a significant portion of incoming flood through a diversion channel and releasing an amount of flow through a diversion dam to the Chao Phraya river in city. The sea barrier can significantly reduce the backwater effect of high tides on the river water level and consequently provide more river storages to accommodate the flood discharge released through the diversion dam. It is found that the pumping can only slightly lower the river flood level at Bangkok.

From the results of the exceedence probability distributions, the proposed flood control system can significantly increase the return period of river flood overtopping the river dikes at Bangkok. It is found that the flood control system with a 20 m basewidth diversion channel without pumping station can protect flood overtopping the river dikes with a return period of at least 80 years while the 40 m basewidth diversion channel can protect flood overtopping the river dikes with a return period of more than 1,000 years.

In conclusion, the coincident flood frequency analysis is a very useful technique for determining the change of the exceedence probability distribution of river water level and the change of return period of river flood overtopping the river dikes at Bangkok due to the regulation of the flood control system. From the results of study, it is found that the proposed flood control system is very effective in protecting the flood overtopping the existing river dikes at Bangkok under the coincidence of the upstream flood flow from Bangsai of a maximum return period of 1,000 years and the high tides at Fort Chula of a maximum return period of 10,000 years.

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