CHAPTER 85

SOME PROBLEMS CAUSED BY BUILDING THE CROSS DYKE ACROSS TOKYO BAY

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ABSTRACT

Two hydraulic problems anticipated from the construction of a dike across Tokyo Bay, i e water circulation and 'harbor paradox' are discussed from results of numerical experiments

Especially, a new technique has been devised for the investigation of response characteristics of the bay to obtain all the information by only one run

PART I. WATER CIRCULATION

INTRODUCTION

A rapid development of the industrial activities is now going on in the urban districts of Japan, especially in the metropolitan area around Tokyo Bay. The expected increase in the urbanization and industrial activities will ask for improvement of traffic conditions and for remodeling of the metropolitan centre and its through ways

On the other hand, the innermost part of Tokyo Bay which is almost entirely surrounded by coastal line, forming an elliptic basin of water with a narrow passage to the Pacific Ocean, is frequently damaged by severe storm surges.

In order to improve traffic conditions and to reduce storm surges, construction of a dike across the central part of the bay was proposed by the Council for Industry Planning The plan aims at killing two birds with one stone.

The effectiveness of the proposed dike on the reduction of storm surges, together with optimum width of openings for navigation, has already been examined by numerical calculation [1]

In the course of discussion of the plan some problems have been suspected The one is contamination of the inner part of the bay, and the other is anticipation of the so-called harbor paradox. These problems are solved with the same method of approach as the storm surge prediction

The hydrodynamic equations of motion and continuity in two-dimension are represented by

$$\frac{\partial M}{\partial t}+\frac{M}{(h+\zeta)}\frac{\partial M}{\partial x}+\frac{N}{(h+\zeta)}\frac{\partial M}{\partial y}=-g(h+\zeta)\frac{\partial(\zeta-\zeta_0)}{\partial x}+fN-\frac{\tau_b^{(x)}}{\rho_w}+\frac{\tau_s^{(x)}}{\rho_w} \quad (1)$$

$$\frac{\partial N}{\partial t}+\frac{M}{(h+\zeta)}\frac{\partial N}{\partial x}+\frac{N}{(h+\zeta)}\frac{\partial N}{\partial y}=-g(h+\zeta)\frac{\partial(\zeta-\zeta_0)}{\partial y}-fM-\frac{\tau_b^{(x)}}{\rho_w}+\frac{\tau_s^{(x)}}{\rho_w} \quad (2)$$

$$\frac{\partial \zeta}{\partial t}=-\left(\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}\right) \quad (3)$$

where t = time coordinate
x, y = coordinate system (x = east, y = north direction)
U, V = velocity components taken as means in vertical line in x and y direction, respectively
$M = UH$
$N = VH$
$H = h + \zeta$
h = mean water depth
ζ = elevation above mean sea-level
$\zeta_0 = \Delta p/\rho_w g$
f = Coriolis parameter
$\tau_s = \rho_a \gamma^2 |W|W$ (wind stress)
$\tau_b = \rho_w \gamma^2 |V|V - K_s \tau_s$ (bottom friction)

Great care should be taken in the numerical integration because these equations are non-linear to be apt to numerical instability of the finite-difference expression. The problem has already been reported in a previous paper 1)

The net work of computation covered not only Tokyo Bay (about 1000 km^2) with mesh size of 1.5 km but also the outer region connected with the bay (about 9000 km^2) with mesh size of 6 km.

CIRCULATION PATTERN

As shown in Figs 1 and 2 flow patterns for daily tide are quite different from those for the case of storm surge. In the latter case strong counter-clockwise circulation of flow occurs in the inner part of the bay, while in daily tide simple convergent and divergent flows through the central opening are formed.

It has already been pointed out by the authors[1] that in Tokyo Bay storm surges are largely due to the wind forcé acting on sea surface rather than the traveling atmospheric pressure drop. The water depth of the western region of the bay is far shallower than that of the eastern part. As a result, the bottom friction for the eastern part is smaller than the other side giving rise to strong current along the eastern coast

Tidal exchange of water. Discharge of flow through the opening has been calculated. Total amount of water exchange is estimated as 4×10^8 m^3, which amounts to about 10 percent of the water volume of the inner bay.

PART II. HARBOR PARADOX*)

PRELIMINARY REMARK

Recently, a very interesting phenomenon has been pointed out by Miles and Munk[3] that a response of water level oscillations to incident waves from open sea would not necessarily be reduced even if the opening width of a port or harbor is decreased. This is the so-called "Harbor Paradox" phenomenon.

From this point of view, a suspicion is anticipated that the construction of a dike across the central part of Tokyo Bay may increase the amplitude of periodic water level oscillation (seiche) superposed on storm surge, giving rise to the reduction of the benefits of the dike.

In fact, seiches with period about 60 to 90 minutes are frequently observed in Tokyo Bay

Although for regular basins analytical discussion has been given by Ippen and Goda[4] and others, boundaries and water depths are so irregular for natural basins that the problem cannot almost be feasiable to purely mathematical treatments On the contrary, numerical integration of the hydrodynamic equations has been shown very reliable and effective for storm surge prediction. However, even if recourses were made to mathematical model (numerical solution), it is not advantageous means to calculate independently amplitude responses to every simple harmonic incident oscillations with differing periodicty, because of the enormous expenditure. It is better to obtain all informations of response characteristics by only one numerical experiment. The authors attempted to solve this difficulty by applying the statistical technique

METHOD OF ANALYSIS

Irregular oscillations with broad spectral band were applied at the

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*) For details, the readers are referred to the paper (2).

entrance of the bay That is water-level fluctuation at the entrance is written, in terms of stochastic Fourier-Stieltjes integrals, as

$$\zeta_e(t) = \int_{-\infty}^{\infty} e^{i\omega t}\, dZ(\omega) \tag{4}$$

in which ω is a circular frequency variable, and increments in the random function $Z(\omega)$ has the property

$$\left.\begin{aligned} &\lim_{d\omega_1 = d\omega_2 = d\omega \to 0} \frac{\overline{dZ^*(\omega_1)\, dZ(\omega_2)}}{d\omega} = 0 \qquad (\omega_1 \neq \omega_2) \\ &\lim_{d\omega \to 0} \frac{\overline{dZ^*(\omega)\, dZ(\omega)}}{d\omega} = F_e(\omega) \end{aligned}\right\} \tag{5}$$

in which $dZ^*(\omega)$ means conjugate of $dZ(\omega)$.

In order to realize numerically these random water-level fluctuations at the entrance, the TURBULON model of turbulence theory was applied. The model is composed of sum of weighted 6 groups of random number series of period ranging from 4 to 128 minutes (Model I nominated by one of the authors)(Fig.3)

$$\zeta_e(t) = \sum_{i=1}^{6} A_i R_i(N_i) \tag{6}$$

where $R_i(N_i)$ means N_ith member of a random number series of life time $\tau = 2^{1+i}$

$$N_i = [\, 2 + 2^{-i-1}(t + t_c - 1) \,] \quad \text{and} \quad A_i / A_6 = (i/6)^p \; .$$

Of course, the generation of the incident waves has also been performed by electronic digital computer IBM 7090 as one of the boundary conditions, simultaneously in course of numerical calculation of eqs. (1), (2) and (3).

The fundamental ideas and details of the random wave generation are reported elsewhere[5),6)]. Figure 4 shows the spectrum of incident long waves thus produced. It is not necessarily equivalent to the wave spectrum to be expected actually, but it needs only to decrease smoothly and gradually covering anticipated resonance frequencies of the bay.

The calculation was performed with the time increment Δt = 30 sec, for time duration corresponding to 21 hours of actual phenomenon from which 3 hours of initial record before reaching a stationary motion were discarded from statistical data processing. These long records of water-level variations are requested from mathematical conditions on stability, resolution and maximum frequency of information by the procedure of Blackman and Tukey[7] Also, the statistical analyses such as correlation function $C_{ij}(\tau)$ and spectra $F_{ij}(f)$ are due to this method.

$$C_{ij}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} \zeta_{ij}(t)\zeta_{ij}(t+\tau)dt \tag{7}$$

$$F_{ij}(f) = \int_{-\infty}^{\infty} C_{ij}(\tau)e^{-2i\pi f\tau}d\tau \tag{8}$$

where subscripts i and j refer to mesh point ($x = i\Delta d$, $y = j\Delta d$).

The energy amplification factor $A^2(f)$ is obtained from

$$A^2(f) = F_{ij}(f)/F_e(f) \tag{9}$$

where $F_e(f)$ denotes the energy spectrum of incident random wave at the entrance.

An alternative way of investigation is to make use of the concept of unit-impulse response-system function[8], i.e. the power amplification function $A^2(f)$ is obtained by the multiplication of the Fourier transform of the water level response $\zeta_*(t)$ to a unit-step impulse by its conjugate,

$$\left.\begin{aligned} &A^2(f) = H(f)\overline{H(f)}\ , \quad H(f) = \int_{-\infty}^{\infty} \zeta_*(t)e^{-2\pi ift}dt\ , \\ &\overline{H}(f) = \int_{-\infty}^{\infty} \zeta_*(t)e^{2\pi ift}dt \end{aligned}\right\} \tag{10}$$

However, the latter method was discarded for reasons among other that the unit step impulse was anticipated to cause instability of numerical calculations and that the computational time and procedures were not saved, becoming rather complicated.

RESULTS

Results and conclusions are summarized as follows:

1) Although the incident waves seem to propagate towards innermost coast as if there were no boundaries[9], the correlation function show that waves with long period are almost completely reflected at the innermost coast of the bay As already Isozaki and Unoki[9] pointed out, the apparent wave velocity is considerably lower than $\sqrt{gh}$ as it proceeds inward

2) The dike which is planned at the central portion for storm surge protection reduces greatly (about one hour) the arrival time of wave front (Figs. 6 and 7).

3) The predominent resonant periodicity is found to be about from 60 min to 90 min. and its harmonics. The periodicity coincides with the field observation. Consequently, it is anticipated and, in fact, sometimes experienced that extraneous high water levels occur, especially superposed on storm surges, by resonant action with breathing of winds or pressure fluctuations and incident waves such as "Tsunami". The construction of the dike will not change considerably the response characteristics That is, the "harbor paradox" is scarcely expected (Figs. 8 and 9)

4) Waves with longer periodicities transport the energy from the entrance inwards, while waves with shorter periodicities play a role to dissipate the energy by the frictional force The nonlinear terms (inertial and non-linear friction term) act to transfer the energy of waves with lower frequency to waves with higher frequency. The process is the same as the mechanism of turbulent shear flow field.

5) Further calculations are needed by inserting a "mathematical wave filter" at the entrance of the bay to exclude the effect of re-reflection of waves.

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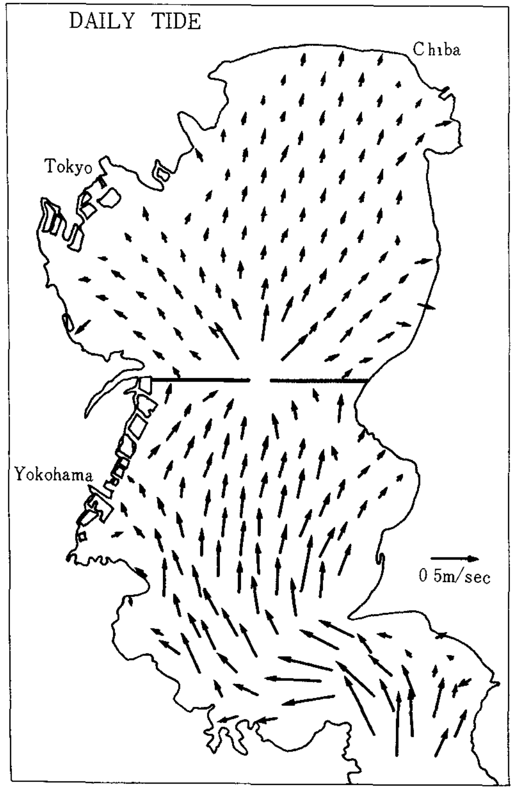

Fig. 1. Typical flow pattern of daily tide.

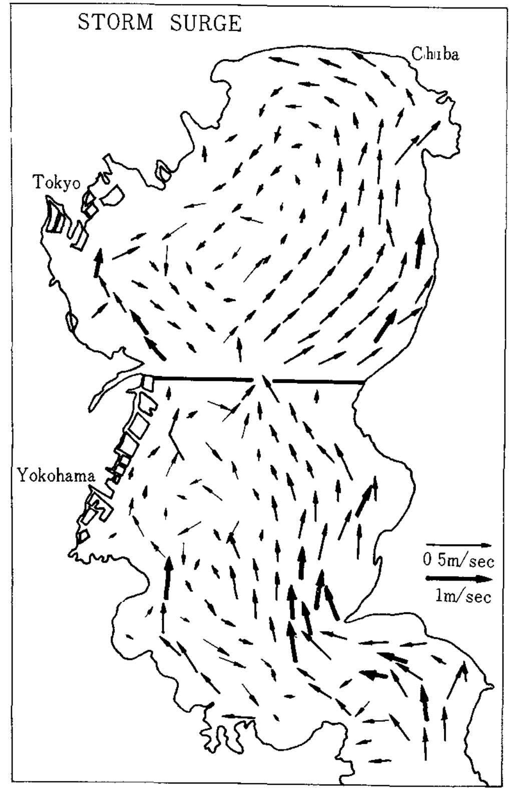

Fig. 2. Typical flow pattern for the case of storm surge.

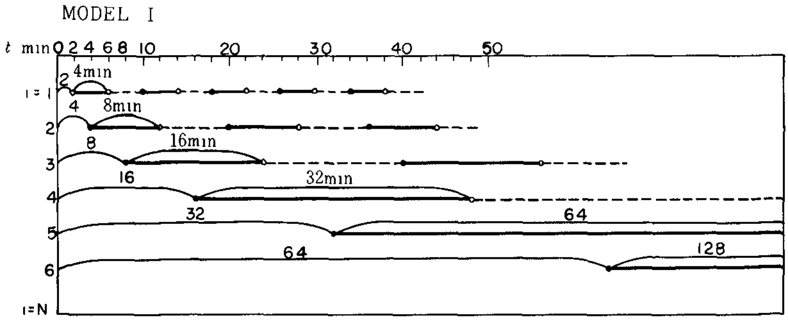

Fig 3. Schematic diagram of random wave generation.

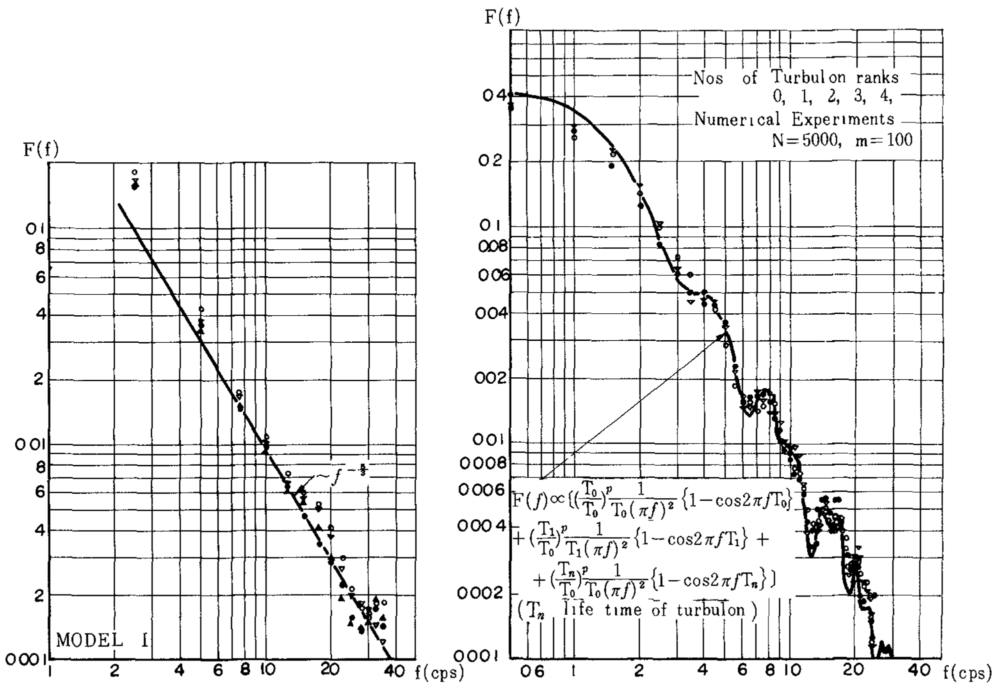

Fig. 4. Spectra of random waves simulated by the sum of weighted random number series.

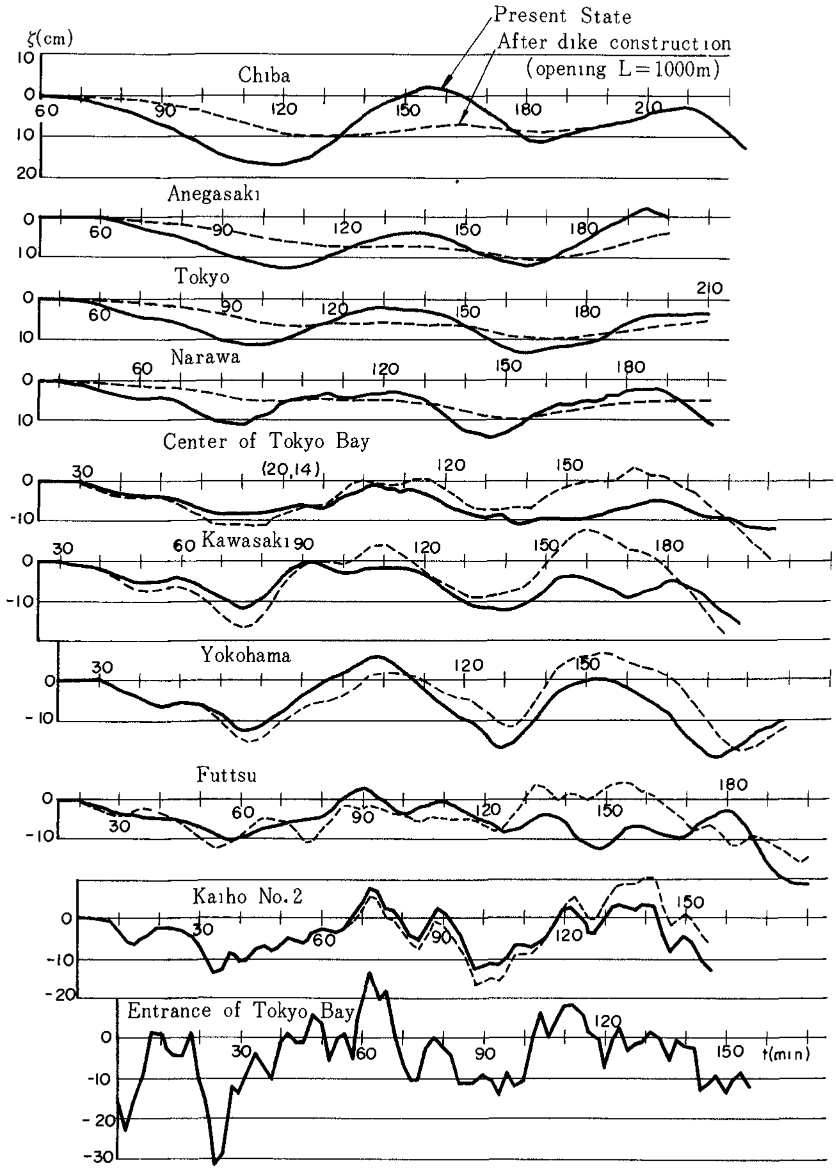

Fig. 5. Propagation and deformation of incident wave.

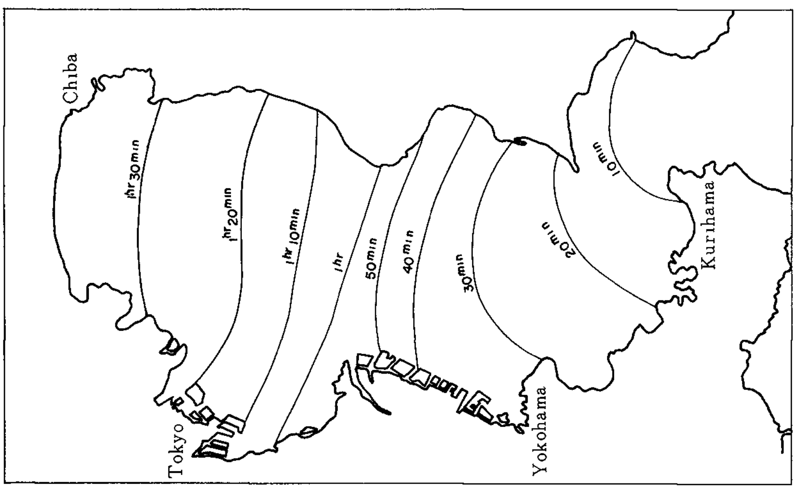

Fig. 6 (a). Contour lines of the time when the maximum correlation occurs (Present state).

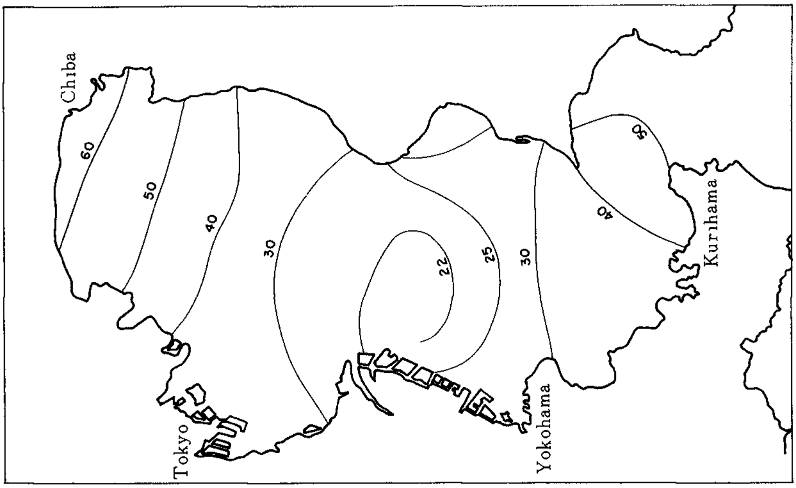

Fig 6 (b). Contour lines of the maximum correlation (cm^2) (Present state)

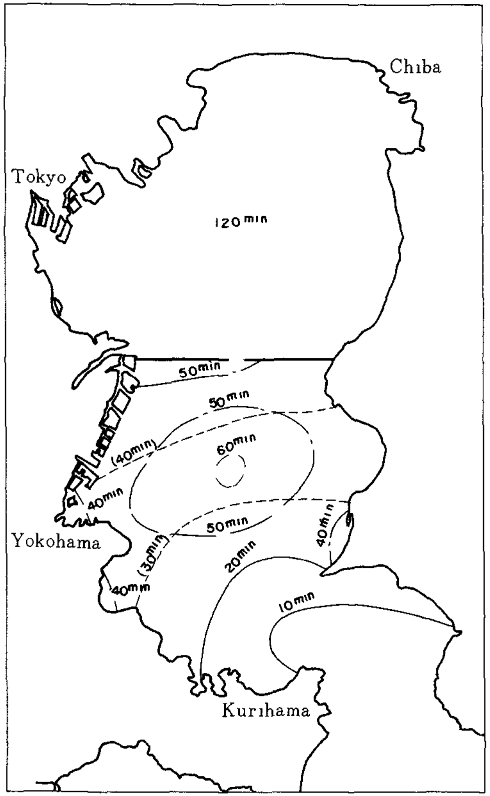

Fig. 7 (a). Contour lines of the time when the maximum correlation occurs
(After dike construction, opening L=1000m).

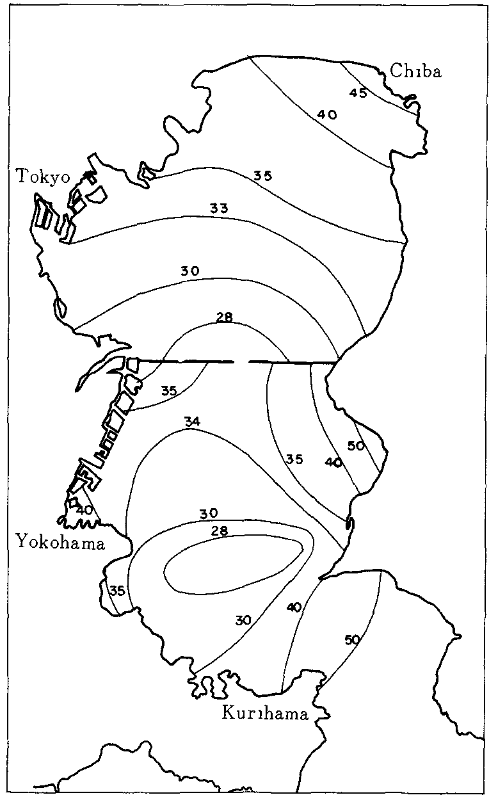

Fig. 7 (b). Contour lines of the maximum correlation (cm²)
(After dike construction, opening L=1000m).

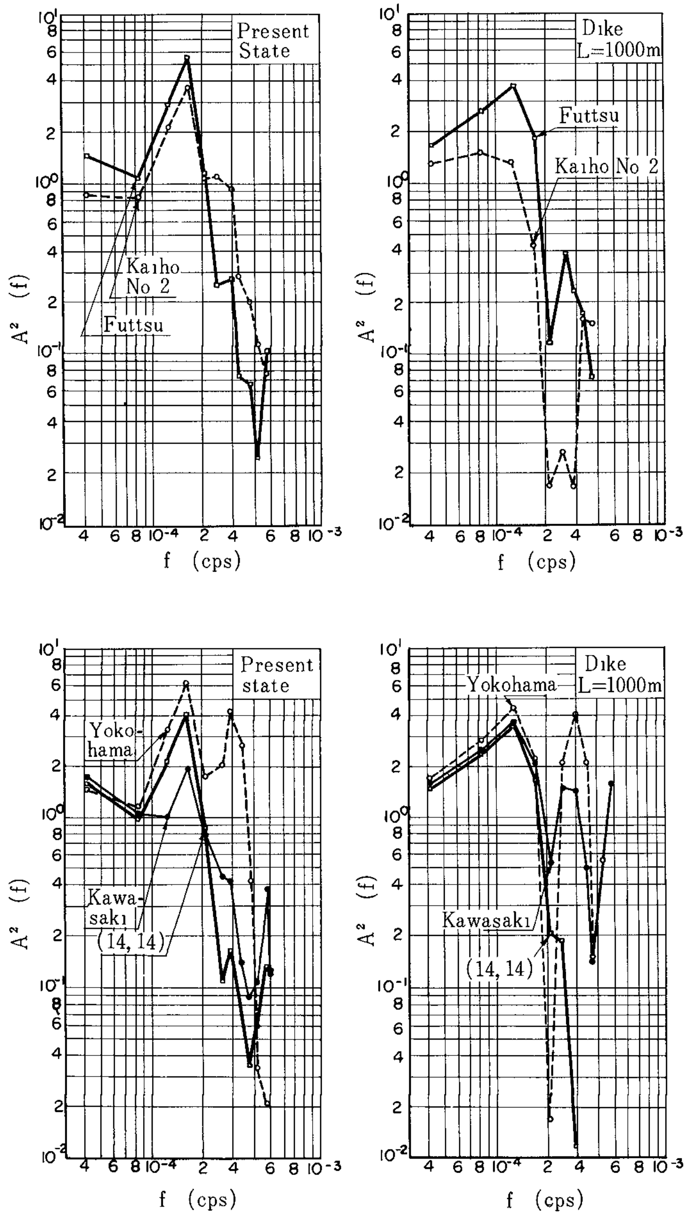

Fig. 8. Energy amplification factor at seveal location (Resoution of spectra is increased)
L means the opening width at the center of dike.

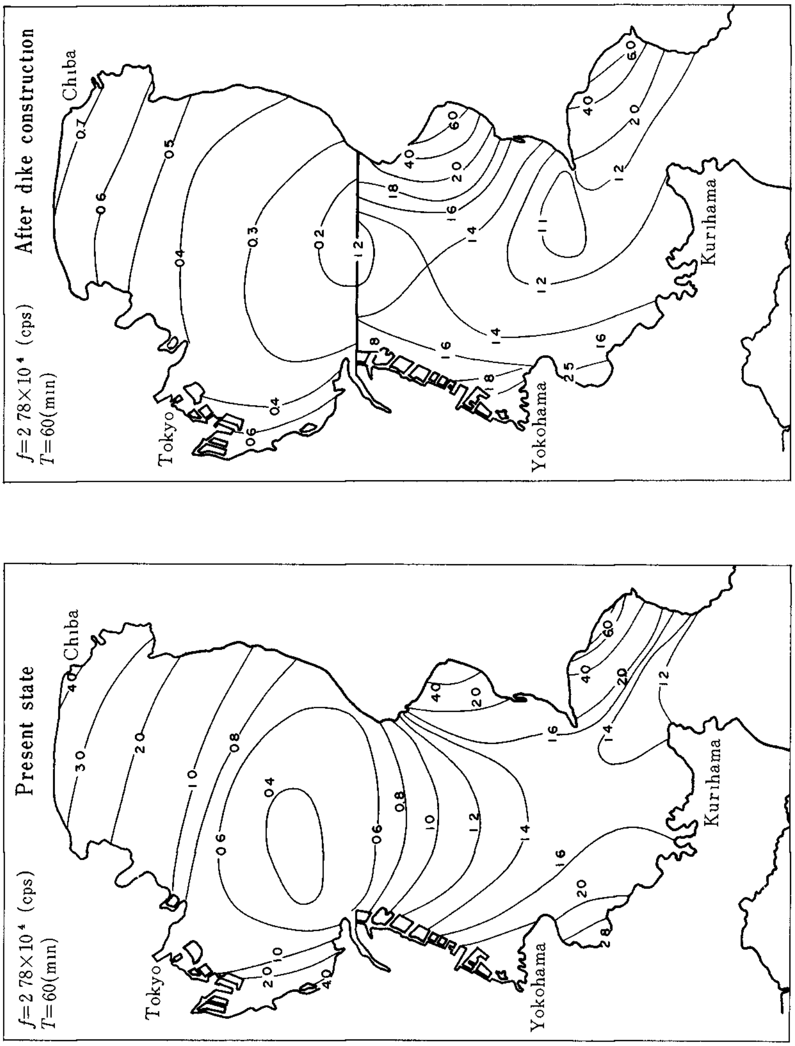

Fig. 9 Contour lines of the equi-energy amplification factor for periodicity T=60min