＜招請講義＞

From Continuous Levees to Emergency Reservoirs

——New concepts and tools for flood prevention——

by Hiroyoshi Shi-igai*

1. Introduction

Flood control has been one of the most important themes of "life or death" for Japanese people, and for the islands of Japan as well, since disasters associated with floods always caused tremendous damages against Japan.

From these reasons, the history of disaster prevention technology was nothing but the history of flood prevention itself until recently. The recent population growth, especially after the 18th century,and the development of technology in a various fields have changed the characteristics and features of disasters disastically, which is followed by the change of people's impression on natural disasters.

Regarding with the loss of life, floods are not dangerous disasters any more. Perhaps traffic accident is one of the most dangerous "disasters" for Japanese people nowadays. This is justified by the fact that the number of death due to traffic accidents reaches ten thousand, or even more, every year. Averaged number of death caused by floods, on the other hand, is 100 or so nowadays, while more than 500 people die during swimming in seas rivers, ponds and even in swimming pools every year. Almost two thousand people also die by the accidents of the minor nature in their own houses. Moreover, twenty thousand people are being killed every year by theirse-

Table 1. Disasters and Accidental Death Related with Them
(Capita/Year; Figures are of scales and not exact ones)

traffic accidents	10,000
floods and tsunamis	100
land slides and mud avaranches	300
fire	500
earthquakes	10
home accidents	2,000
drawned during swimming	500
suiside	20,000
	(Japan 1980〜1985)

* Vice President for Research Development, University of Tsukuba, Japan

lves. Table 1 shows the averaged numbers of accidental death and their reasons.

If we accept this fact, and we have to do so, we reach a conclusion that the natural disasters are not main disasters any more in Japan. This paper analyzes the development of flood prevention technologies and shows a perspective for the future.

2. Historical Views

Irrigation canals have long been considered as one of the most important infrastructures in Japan. Kojiki, the oldest history book written in 712 A.D. (Wado 5) specified that to destroy irrigation canals was one of the heaviest crimes. A lot of storage ponds were constructed in Kinki area, where the old capitals and cities, such as Kyoto, Ohsaka and Nara, exist, at that period. Afforestation in mountaious areas was encouraged by many emperors and gradually some levee construction works were carried out by introducing foreign technologies, mostly from Korea and China in 7th, 8th and 9th centuries. Many engineers came to Japan from those countries and they played very important roles to construct infrastructures for Japan. Many of them became Japanese and we can find their family names even nowadays among present family names in Japan. Their contribution to the construction of levees, reservoirs and canals was tremendous.

In spite of the existence of large forest areas, floods, and very often draughts as well, were causing heavy damages throughout Japan from 7th to 10th centuries. Apparently, large forests and some discontinuous levee works were main flood prevention technologies available at that stage. Since Japanese mountains are of very steep slope, and thus river beds as well, flood duration time was short. Therefore, excessed water flooded through the discontinuous parts of levees whenever a flood took place, and the water went back to river courses when the water levels in rivers went down. This flood control policy was reasonably effective, especially when population of Japan was small. It should be mentioned, however, that the effectiveness of this system is often overestimated nowadays.

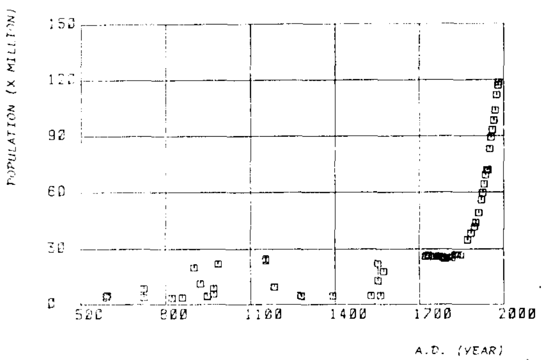

Fig. 1. Population Growth of Japan

Fig. 1 shows the estimated population history of Japan, made by the author and his group. The fact that the population of Japan did not grew until recently made this type of flood control technology more effective, since there weremore spaces availble for flood control at those periods.

The 15th century was a renaissance in Japan regarding with flood control schemes. Ashikaga Government, on Ashikaga Shogun, lost the control and many warlords fought against each other for the final championship in order to obtain the title of Seii-Taishogun whose abbriviation is famous Shogun in the 15th and 16th centuries. Some of them realized that the economical strength was essential for the development of miritalistic power in a long run. Therefore, they encouraged the development of flood prevention technology, since rice production was the main economical source at that period in Japan. Takeda Shingen (1521～1573) was one of the most famous warlords in river control schemes. His base was at Koufu (Yamanashi Prefafacture close to Mt. Fuji) and his cavalry, dressed in red, was so dreadful that he was the largest fear at that time. He spent his much effort in river trainning, neglecting the construction of his own castle. Shingen-tei, or Shingen-levees, constructed by him and his engineers are so famous since a part of his levee is still existing. As a matter of fact, some modification and reignforcement were made during Edo period on Shingen-levees.

After the death of Shingen, his base was taken over by another warlord Oda Nobunaga (1534～1582), though Shingen's red cavalry and his civil engineers were employed by Tokugawa Ieyasu (1542～1616) who became

Shogun later. Ieyasu developed the City of Edo which became Tokyo after 1868.

Shingen is just one of those warlords who spent their much effort to river management. Nobunaga and his successor Toyotomi Hideyoshi (1538~1598) were also strong in river management. The latter was very famous in using flood control technology for military purposes; namely, once he surrounded a castle of one of his opponents by a long levee constructed wiyhin a few weeks, introducing flood water, which lead early surrender of the castle. He and his men used this technique for several times after that. Katoh Kiyomasa (1562~1611) who was one of generals of Hideyoshi worked on river training of Kyushu area with great success.

Tokugawa Ieyasu who was the first Shogun of Tokugawa clan governed Japan quite well. He established a very small government which lasted until 1868. River engineers from Koufu area with their river management technology played important roles for the government. Because of the governmental stability, the production of rice was increased and the population as well. Population explosion is observed at the year 1600 or so (see Fig. 1) and Tokugawa Shoguns maintained the population of Japan as large as thirty million until 1868, the first year of Meiji period.

The increase of population was followed by land development, and though discontinuous levees were frequently used, the introduction of continuous levees was started in the 17th century. The policy that to absorb a large flood in a large area became unpopular among the people of those days to a certain extent. Place which had been used as emergency reservoirs were dwelled by many people already and they hated the inundation like most of people do.

The afforestation was intensive and forest maintenance was continuously well done by the government. "If you cut a twig, you lose one of your fingers" was a part of the law excercised at Owari area governed by one of the cousins of Shogun during Edo period.

Meiji revolution was a large movement for the modernization of Japan. Shogun was ousted, and Meiji Emperor directly governed Japan with his modernized government, and this political change derived another population explosion in Japan (see Fig. 1).

After several political trial, Meiji government employed the policy of "Rich Country with strong militaristic power", which was followed by the policy of better river management and flood control.

Meiji government invited many scholars and engineers in various fields from foreign countries. They were well paid, some of them being paid better than the prime minister. Some Dutch engineers were invited for the technology transfer purposes. They stayed in Japan for comparatively short period, playing extremely important roles for the modernization of Japan.

From technical point of views, as far as the author observes, there was some confusion in the river management policy in Japan at the end of the 19th century, which was resulted by the phylosophical differences between the idea of river management of a very flat country, Holland, and the traditional idea of Japan. However, Japanese Government finally employed the policy established by Naimusho, or Ministory of Interior regarding with the river management of Japan, by, perhaps, early 20th century.

The essential part of the new policy was the intensive construction of continuous levees along rivers with encouraged afforestation. Timbers and woods were considered as important resource for the stronger country. Note that charcoal was one of the main fuel resorces in Japan until recently.

As was mentioned before, islands of Japan extrude sharply from the sea, and the idea to lead flood water to the sea very quickly by constructing continuous levees seems reasonable. The plan might be of great success, if there had been no population explosion in Japan.

However, the rate of population increase in Japan was so intensive that the population reached 120 million in 1986. Since the population at Meiji period was 30 million, population in Japan became four times within 120 years. This rapid increase of population was not anticipated at the beginning of the early 20th century. Almost all the flat areas are now utilized by people, and some philosophical changes in water management policy were inevitable.

Intensive construction of large dams in Japan started after the Second World War, though there had been some exceptional cases before that era. The introduction of larger reservoirs, for irrigation and other water supply purposes and for flood control as well, made total water system in Japan more manageable. The population increase caused more demands for water supply, while yearly precipitation in Japan did not change of course, which means that it was needed to increase reservoir capacity in Japan. Since less space will be utilized for flood control in future, the construction of traditional type of emergency reservoirs and flood control dams will be more difficult in future. Therefore, it is necessary to develop, to introduce and to utilize new type of technologies as much as possible for the better water management in a limited space.

As one of the examples of new tools for water management, PAX, the new type of parallel processor, or, in a simpler expression, a super computer, and it's application will be discussed in the next chapter.

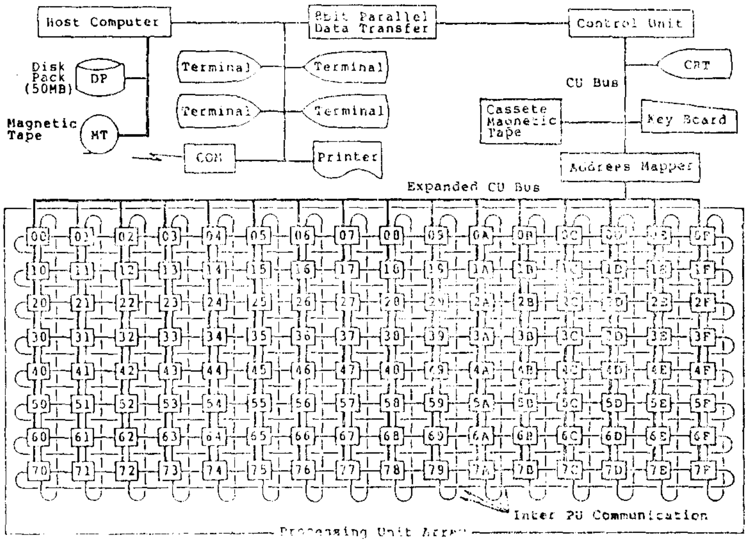

Fig. 2. Architecture of PAX-128 Parallel Computer System

3. PAX, a New Tool for Water Management

PAX series was designed and developed by University of Tsukuba and Kyoto University. PAX-64 and PAX-128 are now being utilized at University of Tsukuba intensively. As a matter of fact, PAX has an architecture convenient for the simulation of hydrodynamical problems and nuclear piles as well. Fig. 2 shows the architecture of PAX-128.

As one may be able to notice from Fig. 2, 128 microprocessors are interconnected in PAX. If any concerning space is devided into 128 subspaces, for example, each precessor takes over the simulation of each subspace. Since information may be exchanged among neighbouring processors automatically with a high speed, computation covering all the space proceeds within a unit computation time. Though the speed of computation of PAX-128 might be 128 times faster than that of each processor superfacially, it is about 100 times in reality because of the comutational overheads.

Though PAX shows a marvelous performance for the computation of hydrodynamical problems because of its nature, it is not a specialized computing machine for those limited purposes only. With the employment of suitable softwares, PAX may be used a series connected computer. In this paper, a new concept of software, Optimum Grid Method or OGM, specially designed for PAX, is discussed.

4. Concept of OGM

In the famous characteristic method for unsteady flow analysis, the process may be summerlized as follows. River section A, river width B and depth h are functions of position x and time t. Therefore,

$$A=A(h,x),\quad B=B(h,x),\quad h=h(x,t) \qquad (1)$$

If we devide a river into many discrete element along x, A, B and h may be written as

$$A=A(h),\quad B=B(h),\quad h=h(t) \qquad (2)$$

In this case, the equation of continuity, eq. (3),

$$\partial A/\partial t+\partial Q/\partial x=q \qquad (3)$$

may be written as,

$$\partial h/\partial t+h\partial u/\partial x=q/B \qquad (4)$$

where Q : discharge, q : side flow, u : mean velocity $(=Q/A)$ and wide river asummption, $A/B=:h$ is employed.

The equation of motion is, on the other hand,

$$\partial u/\partial t+\beta u\partial u/\partial x+g\partial h/\partial x=F \qquad (5)$$

and

$$F=g(i-i_f)-gu/A(1-u_b/u) \qquad (6)$$

(g : gravitational acceleration, i : bottom slope, u_b : side flow velocity in x direction, i_f : friction slope and β : energy coefficient close to unity.)

Using c for celerity of lone waves, we can obtain eq. (7) and eq. (8) after several steps of calculation.

$$[\partial/\partial t+(u+c)\partial/\partial x](u+2c-m_1t)=0 \qquad (7)$$

$$[\partial/\partial t+(u-c)\partial/\partial x](u-2c-m_2t)=0 \qquad (8)$$

$$[m_1=F+q\sqrt{g/A/B},\quad m_2=F-q\sqrt{g/A/B},\quad F=g(i-i_f)]$$

Therefore, we obtain two characteristics such as

$$dx/dt=u+c(\text{curve } C_1),\quad dx/dt=u-c(\text{curve } C_2) \qquad (9,\ 10)$$

and the following two relations are established on those two curves.

$$d(u+2c)=F\Delta T,\quad d(u-2c)=F\Delta T\ \ (\Delta T:\text{time step}) \qquad (11,\ 12)$$

Eqs. (11), (12) are the famous fundamental equations of the method of characteristics, which should be converted into difference equations. They are,

$$(u+2c)_M-(u+2c)_L=F_{Lm}\Delta T \text{ on } C_1 \qquad (13)$$

$$(u-2c)_M-(u-2c)_L=F_{Rm}\Delta T \text{ on } C_2 \qquad (14)$$

(Meanings of symbols may be read on Fig.3, while $F_{Lm}=(F_L+F_L)/2$ and $F_{Rm}=(F_R+F_L)/2$ respectively.)

If we employ Manning type resistance law, F may be written as,

$$F=g\{i-(n^2/R^{4/3})u|u|\} \qquad (15)$$

(n : Manning's coefficient and R : hydraulic radius.)

The new wave celerity, c, at the point M on Fig. 3, is then written as,

$$c_M=[(u+2c)_L-(u-2c)_R+\Delta T(F_L-F_R)/2]/4 \qquad (16)$$

Adding eq.(13) and (14), we obtain

$$\alpha_M u_M |u_M| + 2u_M - S = 0 \cdots\cdots (17)$$

$$[\alpha_M = g\Delta T(n^2/R^{4/3})_M, \quad S = (u+2c)_L + (u-2c)_R + g\Delta T i_M + (F_L + F_R)]$$

From eq.(17), we obtain the following relations.

$$u_M = S \text{ for } \alpha_M S > 0 \cdots\cdots (18)$$

$$u_M = -S \text{ for } \alpha_M S < 0 \cdots\cdots (19)$$

Thus we can obtain the new velocity, and then the new wave cerelity and finally the new depth.

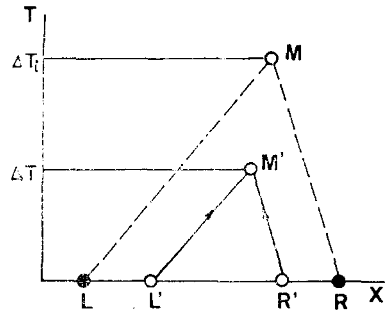

Fig. 3. Concept of OGM, Schematic View

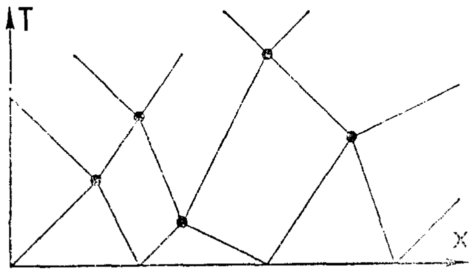

Fig. 4. Deoformed Grid by Conventional Characteristic Scheme

5. Conception of the optimum grid method

The method of characteristics is a strong tool for one-dimensional numerical calculation with a great stability. A weak poit of this computational system is that as time goes, the grids on $x-t$ plane will be deformed, as you may see on Fig. 4. This is caused by the fact that the time step at each pit is decided by computers automatically. To avoid this convenience, a modified mothod of characteristics with a given time step is being used by many people with reasonable success. The optimum grid method or OGM is an improved method of this system where the optimum time step is decided by 128 processors, and the information of the optimum time step may be distributed among processors without going through the conducting processor. Therefore, the length of time step may change time to time satisfying the stability conditions at any time. Since this method is of finite difference type with the explicit procedure, computation speed is amazingly fast, which is accerelated by PAX.

The practical procedure of calculation is as follows.

Each processor calculates the optimum value of time step for which the computation is stable. This time step must satisfy the relation such that

$$(\Delta T)_1 \leqq \Delta K / |(u \pm c)|_i \cdots\cdots (20)$$

where the subscript i means the i th processor. Thus, the universal time step is then determined by

$$\Delta T = \min.[(\Delta T)] \cdots\cdots (21)$$

If we employ the universal time step expressed by eq.(21), it is apparent that each characteristic line does not start from the fixed point. This is ill strated by Fig. 3. Therefore, it is necessary to use the interpolation so as to determine the starting values for each characteristic line, for example the values at L'. This is the essential part of OGM where each time step which is uniform for all the processors may vary according to the hydraulical conditions.

The time step may be small whenever careful computation is necessary and large whe the computation is reasonably stable. The largest virtue of OGM is that the computation is always stable in spite of the employment of the explicit method, which means the computation time is extremely fast.

6. Brief Discription of PAX

As was illustrated on Fig. 2, PAX-128 is consisted of 8×16, two dimensionally connected Processing Units (PU) and Control Unit(PU) which controls PU and Host Computer which supervises CU and PU. It should be noted that PAX is a parallel super processor for general use.

Categolically, PAX has some ancestors like Illiac and Clay, though the architecture of PAX is completely different from those of them. By means of the appropriate softwares, PAX may work as a series computers which is good for the computation of Pipeline system.

It is natural that PAX shows its strength most when a large amount of parallel computation is necessary. For example, the author et al used PAX for three dimensional simulation of a large lake where each processor carried out the computation of each grid point from the bottom to the surface of the lake.

The commercial price of PAX is approximately 40 million yen, though the prototype made by university of Tsukuba costed only 6 million yen. Since the cost of hardwares, and thus the cost of computation as well, are extremely low, PAX may be used as one of the peripherals of a large processing unit when it deals with the simulation for months and years with negligible cost. PAX can of course carry out the conventional computation as well with the help of some optional subroutines added to FORTRAN, for example. At this moment, PAX is employing SPLM which is very similar to PASCAL.

7. Computational Results

Fig. 5 shows a perspective presentation of a imaginary flood wave generated in a straight channel whose length is 19km and width is 100m. The bottom slope of this imaginary channel is 0.001 and the normal depth is 4m. The most downstream depth is controled as 4m.

Since computer chooses the optimum time step all the time, computation was smooth and very stable. It shouble be emphasized that any artificial smoothing was not introduced for this computation. Fig. 6 shows the variation of time step regarding with physical time. It is observed that the time steps became shorter when the flood peak was approached and longer when the peak passed.

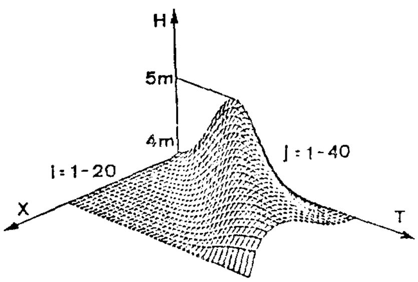

Fig. 5. Flood in a Uniform Channel

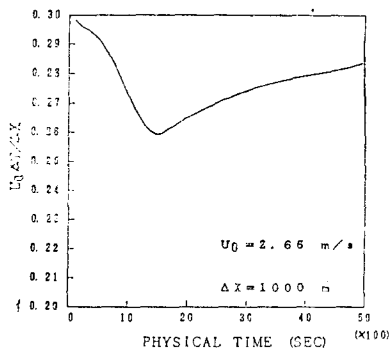

Fig. 6. Variation of Time Step for a Uniform Channel

Fig. 7 shows the computation time of a flood for PAX-128 and for FACOM M-380 using OGM designed for FORTRAN. If we know the prices of two computers, 40 million yen for PAX and 2200 million yen for FACOM approximately: PAX showed a tremendous performance regarding with computational speed, though FACOM's computation speed was 5 times faster. Please note that if we have a hundred of FACOMS, a group of FACOMS can work as a PAX. PAX is not the name for a special computer but for a computational architecture.

Fig. 8 shows the variation of time steps in OGM for the case of an actual river in Japan. Since the configulation of the natural river is not uniform, and the flood hydrograph is of more complicated snape, the variation of time steps is more complicated, which is difficult to predict.

The author et al have published a paper on flood computation using an explicit method with a mathematical stabilizer designed for PAX-64. Since this method needs a given time step, a reasonable care is necessary to select a time step. From Fig. 8 we know the maximum of the time steps which is 52. 649s and the minimum, 32. 293s, in a comparison was made by using these time steps.

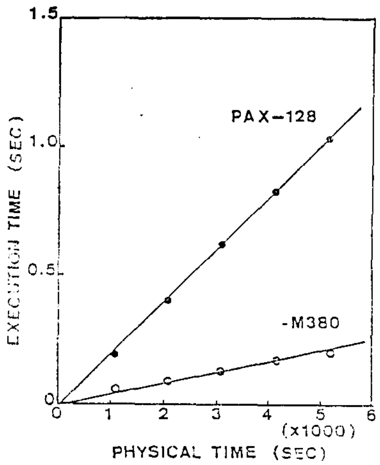

Fig. 7. Comparison of Computational Speeds

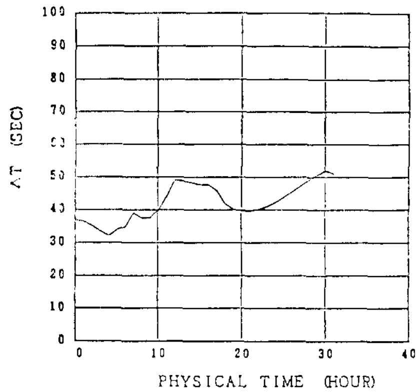

Fig. 8. Variation of Time Step for a Natural River

Table 2 shows the result of this comparison. Three methods showed almost the same results, while the method adopting the possible maximum time step showed the least computational time steps, which means the least computational time. Though some symptoms of instability in computation were observed, the modified up-wind stabilizer suppressed them. The computation using longer time steps than the possible maximum became more unstable. Since we do not know the possible maximum time step in advance, we have to use the possible minimum time step which may be predicted only by a careful theoretical consideration. Therefore, the advantage of OGM, and thus of PAX, is apparent.

Some may wonder why theauthor is seriously concerning about the computational time less than one second, which may be seen from Fig. 7. The present large computer is already fast enough for computations and simulations of which physical time, or real time, is of fifty, seventy, or even several hundred hours may be carried out wiyhin a few seconds. However, how about the simulation for one year, then years or hundred years? If we use a large computer like FACOM-380 for two hours the computational cost is already enormous, while PAX can compute the same simulation with ten hours whose computational cost is about 500 yen. Since we will need more detailed simulations in three dimensions with a long range in near future, PAX and other super computers, faster and cheaper, will be strong tools for disaster prevention technology.

Table 2. Comparison of OGM and Upwind Explicit Method

	Max. disch. m^3/s	Max. level m	Peak time hour	Step numb.	Total step 31 hours
$(\Delta T)_{min}$: 32. 293s	4974. 9	11. 278	20. 001	2230	3458
OGM	5047. 5	11. 295	20. 006	1798	2682
$(\Delta T)_{max}$: 52. 649s	5094. 2	11. 303	20. 006	1368	2121

8. Conclusion

Disaster prevention technology is a combination of a vast range of software and hardware technologies. It includes a varaiety of human knowledges, past and present, and from the south, north, east and west.

Flood prevention technology is, perhaps, one of the oldest disaster prevention technologies. Though three will be no success in flood prevention technology, many people in Japan think that we are now in partial success. This may be justified if I point out the fact that many consider flooding is not a natural disaster but the result of poor water management of Government of Japan.

Though I cannot share this type of optimism, it is true that the better flood control has derived more responsibility of the Government. It is also true that more and more people are forgetting the danger of flood, since fewer and fewer people are now having flood experience every year.

therefore, it is urgently necessary to adopt new ideas, unique systems and modern technologies to prevent flood disasters in Japan. PAX is just one of such examples and many geneous trials are being carried out in many institutes.

9. Acknowledgement

The design and prototype production of PAX were carried out by Professor T. Hoshino and Dr. T. Shirakawa, Institute of Engineering Mechanics of University of Tsukuba. A part of the fund was supported by Ministry of Education, Science and Culture through Scientific Research Fund, No.58850117, in 1983. Deep appreciation be expressed to the people and organization mentioned above by the author.

10. Bibliography

1) T. Kikkawa and H. Shi-igai: On the characteristics of floods at estuary, UNESCO, International symposium on floods and Their Computation, pp. 15～22, August 1967.

2) H. Shi-igai, T. Hoshino and T. Miyake: Application of PAX-128 to unsteady flow computation (Japanese), Proceedings of JSCE, No.349/6～1, pp. 26～33, 1984.

3) H. Shi-igai, T. Miyake and Y. Higashi: Unsteady flow analysis by means of optimum grid method (Japanese), Proceedings of JSCE, No.369/Ⅱ-5, pp. 71～78, 1985.