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HIGH TIDE DISASTER IN THE OHTAGAWA RIVER DELTA IN HIROSHIMA

-Extent of the Disaster and Lessons Learned from Typhoon 9119-

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INTRODUCTION

Hiroshima City, the economic and cultural center of Japan's Chugoku-Shikoku Region, has been developed with reclamation of Hiroshima Bay. Due to the close relationship between the daily lives of the city's inhabitants and the Ohtagawa River, the city has come to be known as "the city of water" and has often suffered water induced disasters. A major portion of the city's functioning is concentrated in the river delta where around half the population, 540 thousand people, live and 70% of the offices, 57% of the factories, and two thirds of the stores are situated (Ministry of Construction et al.(1992)).

The development of the city of Hiroshima began at the end of the 16th century when the daimyo (feudal lord) Mouri constructed Hirosima Castle. The area reclaimed from the middle of the Edo period to the end of the Meiji period is what may be referred to as the "zero meter area", the area being below sea level, and, as Hiroshima Bay opens to the south, the city is topographically susceptible to the influence of high tides. A case in point being Typhoon 9119 of September 27, 1991, a major typhoon which swept violently through Kyusyu Island and caused severe damage in Hiroshima, in which over 1600 homes became submerged in the resulting deluge.

This paper describes the damage caused by Typhoon 9119, and the lessons learned. Also described are the high tide characteristics of Hiroshima, which are to be used in future high tide disaster management

HIGH TIDES IN HIROSHIMA AND TYPHOON 9119

High Tides in Hiroshima

The development of the city of Hiroshima began with the construction of Hirosima Castle at the end of the 16th century by Daimyo Mori.

The area reclaimed from the middle of the Edo period to the end of the Meiji period, referred to as the "zero meter area", is a densely populated area (Fig.1) covering 18.6km ^{2} and lying below T.P (Tokyo Peil) 2m, the average full tide level during the typhoon season The major portion of Hiroshima City's functioning is located within this region. As Hiroshima Bay opens to the south, the city has always been topographically susceptible to the influence of high tides

The city has so far suffered the disastrous effects of Typhoon Suohnada of August 1942, Typhoon Ruth of October 1951, Typhoon Toyamaru of September 1954, Typhoon Louise of October 1995 and so on (Table).

Typhoon 9119 Damage

Typhoon 9119, that crossed Kyusyu Island and swept along the Sea of Japan (Fig 2) , caused wide scale damage throughout its very wide storm area in the Chugoku and Kyusyu regions on September 27, 1991

Recorded wind velocities of 58 9 m/s (maximum instantaneous wind velocity) and 36.0 m/s (maximum wind velocity) were recorded and strong wind over 20m/s had been blown till 21 20. The storm resulted in 6 dead and 49 injured, and destroyed 35,320 homes. Typhoon 9119, however, was a so-called "wind typhoon," the total rainfall being only 86mm in the Ohtagawa River basin.

High tide damage As the typhoon passed through Hiroshima at about the time of astronomical full tide (Fig 3), a new tide level of T.P.2 91m was observed at Eba Station. The typhoon inundated 1,643 houses and submerged 424 ha of Hiroshima City. The maximum deviation of 1 81m was observed at 20:20 about three hours before the astronomical full tide at 23 21. If the typhoon had arrived three hours later, the tide level might have been T.P.3.3m, about 40 cm higher, in which case most of the center of Hiroshima City would have been submerged. Moreover, if it had been a spring-tide, the tide level would have been about T.P 3 75m, some 45cm higher

Power failure Due to electricity transmission pylons and poles being blown down, and salt water damage to transformer substations located several tens of kilometers from the sea coast, a large scale power black out occurred involving 1.1 million houses, about 80% of total households in Hiroshima Prefecture, for as long as 141 hours. As a result, the emergency facilities and operations in hospitals were adversely affected, traffic congestion was caused by inoperative traffic signals, and trouble caused by the on-line systems of banks being down It became apparent to people just how much their daily lives and the functioning of the city depend on the supply of electricity

Tidewater Protection Plans

In the case of flood protection planning, the design scale is determined based on the probability of exceeding a certain rainfall On the other hand, the design scale for high tide protection is usually determined based on high water level records or simulation analyses based on recorded data (Japan River Association (1986)) The tidal water protection plan for the Ohtagawa River region is as follows

The planned tide level The planned tide level is T P 4 4m, being a total of the astronomical tide level plus the deviation caused by typhoons

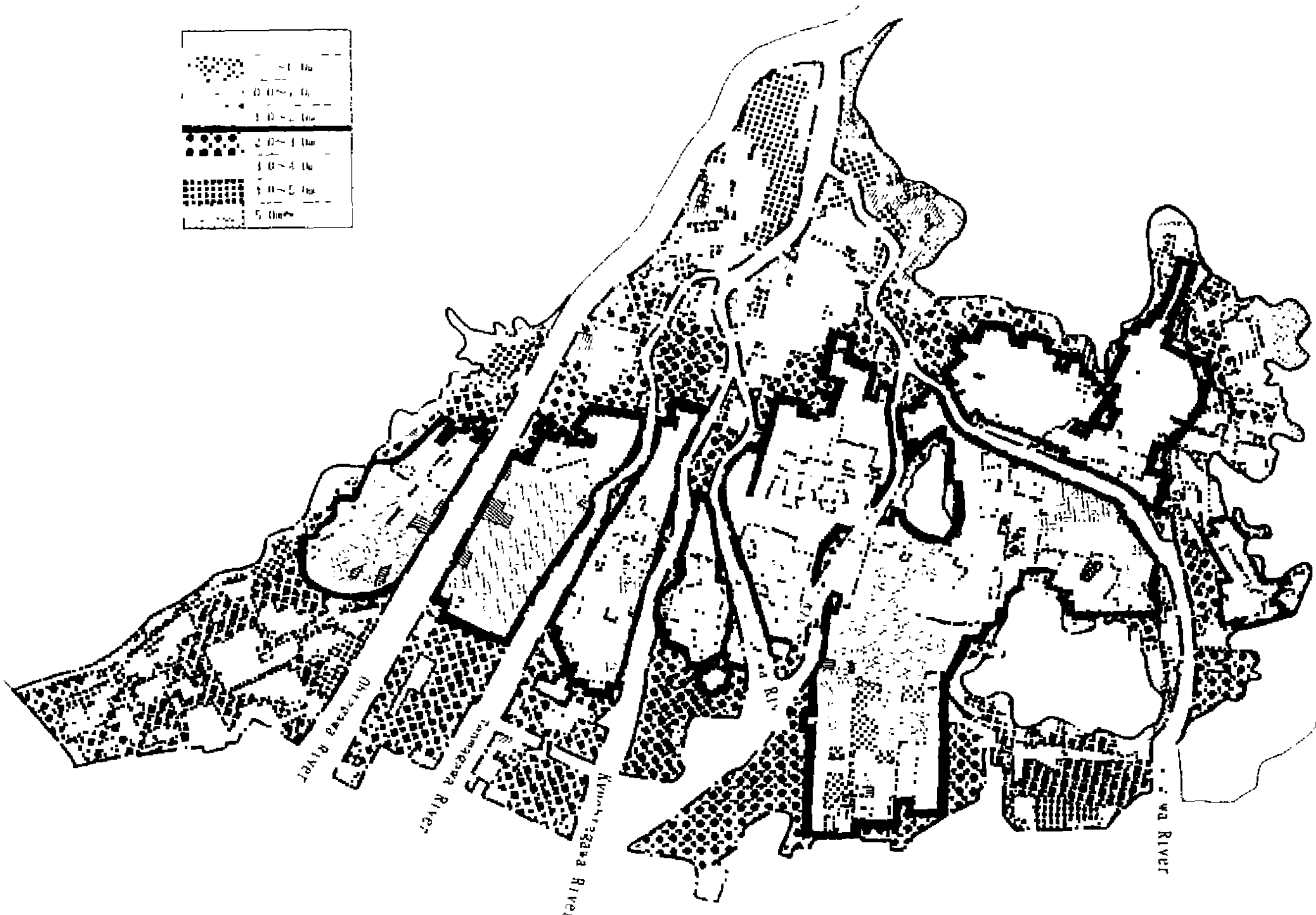

Fig. 1 Ground Hight of Hiroshoma City

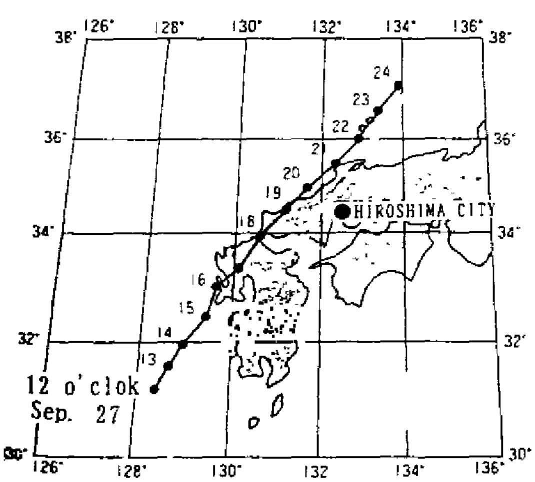

Fig. 2 course of Typhoon 9119

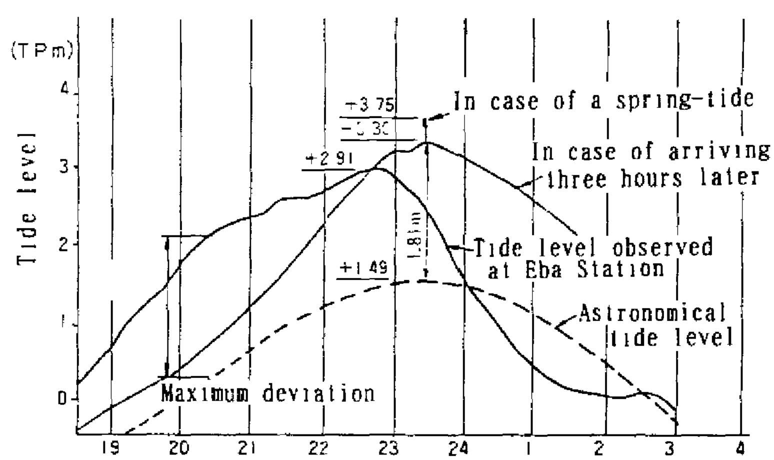

Fig. 3 Tide level

	date	Name	Maximum Tide Level (T. P. m)	Deviation (m)	Damage
①	20Oct. 1933		2. 58	NA	
②	9Sep. 1934		NA	NA	Destroyed Houses.690 Inundated Houses.234
③	27Aug 1942	Suohnada	3 30	1. 00	Destroyed Houses 1, 159 Inundated Houses·21
④	20Sep. 1943	No. 26	2 30	NA	Destroyed houses:471 Inundated houses:574
⑤	13Sep. 1950	Kijia	2. 33	NA	Inundated Houses Above Floorboards:410 Inundated houses Below Floorboards:2, 804
⑥	15Oct. 1951	Ruth	1. 78	1. 90	Destroyed Houses:226 Inundated Houses:4, 540
⑦	26Sep. 1954	Toyamaru	2. 70	1. 30	Inundated Houses Above Floorboards.256 Inundated Houses Below Floorboards.2, 953
⑧	1Oct. 1955	Louise	2. 69	1 00	Inundated Hoses Above Floorboards:361 Inundated Houses Below Floorboards:2, 633
⑨	13Sep. 1976	No. 17	2 38	1. 00	Inundated Houses Below Floorboards:66
⑩	15Sep. 1978	No. 18	2 78	0. 9	Inundated Houses Below Floorboards:16
⑪	27Sep1991	No. 19	2. 91	1. 81	Inundated Houses Above Floorboards.423 Inundated Houses Below Floorboards:1220

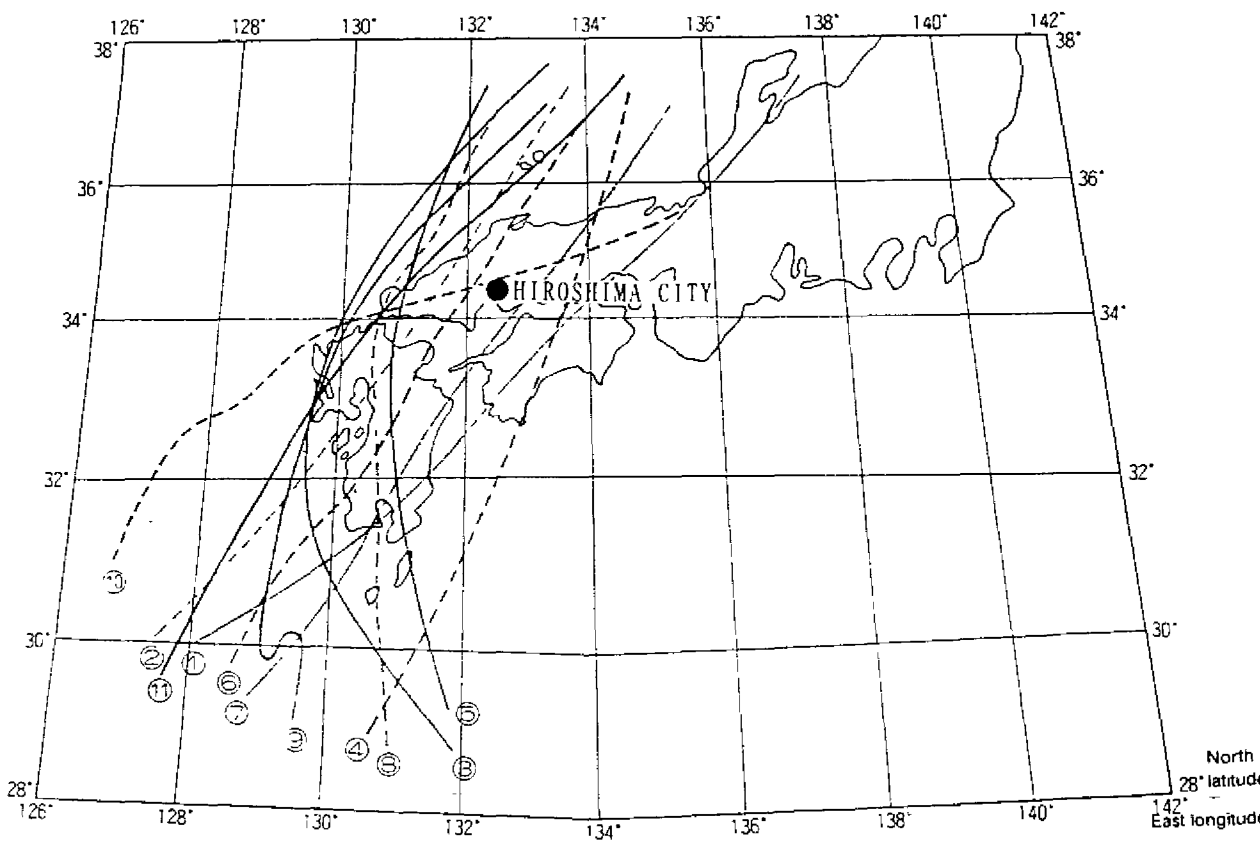

Table Tide level and courses of recent typhoons

The astronomical tide level is set at T.P.2.0m, based on the average full tide level during the typhoon season recorded at Eba and Ujina observation stations during the period from 1954 to 1965.

For the deviation, the value was calculated on the assumption of a model typhoon of intensity equal to the Isewan Typhoon and with directions the same as the previously recorded typhoons Suonada, Ruth, Toyamaru, and Louise that caused significantly high tides in the past. For the model typhoon of intensity equal to the Isewan Typhoon, the largest calculated deviation occurred in the direction of Typhoon Ruth, and the maximum deviation was set at 2.40m.

The planned wave height: The planned wave height was calculated using the S.M.B. method under the wind conditions for the planned deviation. The planned wave height was set at 2.50 m, and the recession of the wave taken into consideration for the Ohtagawa River water way.

LESSONS LEARNED FROM TYPHOON 9119

After the Typhoon 9119 disaster, various measures have been taken based on lessons learned from the disaster (Sumi and Kadoma (1992)).

High Tide Protection Works

High tide prevention works have been developed for the Ohtagawa River Delta from 1980, and to match the scale of this typhoon, prevention works have been started in the aftermath of Typhoon 9119. The height of the bank is T.P.3.4m, and the works are scheduled for completion by the year 2001. In the meantime, works are underway to revive the "city of water" and to characterize the waterfront along the Ohtagawa River in accordance with the "Master Plan for the Development of the City of water", jointly formulated by the Ministry of Construction, Hiroshima City Government, and Hiroshima Prefecture Government.

High Tide Prediction System

Before the Typhoon 9119 disaster, the Meteorological Agency announced that the level of the coming high tide might exceed 2.5 m. It was impossible at that time, however, to make a more accurate prediction.

After the disaster, a high tide level prediction system was developed. The method takes into consideration the effects of wind-drift and drop in atmospheric pressure caused by a typhoon. The maximum deviation is expressed as.

$$\zeta_{max} = a(1010-P) + bW^2 \cos\theta$$

where,

ζ_{max} maximum deviation

P lowest atmospheric pressure

W maximum wind velocity

θ : angle between the maximum wind velocity and the main direction of Hiroshima Bay

a,b. coefficients

The coefficients are calculated by multiple regression from the data obtained from previous typhoons Input data is based on real-time predictions released by the Meteorological Agency. This system is currently being used for incoming typhoons .

photo. sunk pleasure crafts

Action Against Pleasure Craft Illegally Moored in the River

There were over 2200 boats illegally moored in the Ohtagawa River at the time of the typhoon, over 100 boats of which were sunk, swept out in to the bay, or thrown up onto the shore (photo). There was also the problem of oil pollution caused by oil leakage from sunken or damaged boats. However, a quick response to these problems was impossible due to the fact that the owners of the vessels could not be contacted.

Coping with these boats is of vital importance as they are also a source of damage to the river bank at the time of a flood. Measures being taken to deal with the problem include river marina projects, and the formulating of a master plan for the utilization of the surface of the Ohtagawa River, the purpose of which is to set up a code to make rules for the various river users providing them with a guide to the manners of river use

Communication System for Mobile Stations

Seven land vehicles were patrolling during the disaster but wireless communications became congested and were not effective The vehicles have now been equipped with a new mobile telephone type communications system.

Publication of Flood Map

An area map indicating areas susceptible to high tides and flooding and which shows the recorded locations of broken embankments has been published to increase local public awareness of disaster prevention.

HIGH TIDE CHARACTERISTICS IN HIROSHIMA

The data from eleven typhoons having a deviation of over 1 m at Eba Station were analyzed to determine the high tide characteristics, and the results are summarized below.

Probability of Concurrence of Flood and High Tide

The worst case scenario for a tide damage prone area during a major typhoon is the simultaneous occurrence of flood and high tide

Previous records show that the peaks of floods occurred at least three hours after the peaks of hgh tides in the Ohtagawa River. It was therefore considered unnecessary to formulate a protection plan under the assumption of concurrent floods and high tide and the conventional design policy of designing for floods and high tide protection separately was supported.

The Time of Maximum Deviation

Maximum deviation took place when the typhoons had reached the positions shown in Figure 4, showing that this maximum deviation occurred as the typhoon left Chougoku Region, 1 to 3 hours after the minimum pressure was observed at the Hiroshima Meteorological Office. Accordingly, it is possible to predict the peak time and level of deviation several hours before, if the course and pressure are observed at Hiroshima. This data can therefore be effectively used for formulating warning announcements and evacuation plans

The Course Causing High Tides

As shown in Figure 1, high tides are caused by typhoons travelling across the west side of Hiroshima City in a north easterly direction. It is therefore necessary to take the utmost care when typhoons approach from this direction.

Hydrograhic Model of Deviation

For the simulation, it is necessary to make a hydrograhic model of the deviation. A cosine curve can be used to approximate the deviation using average period of duration (Fig. 5).

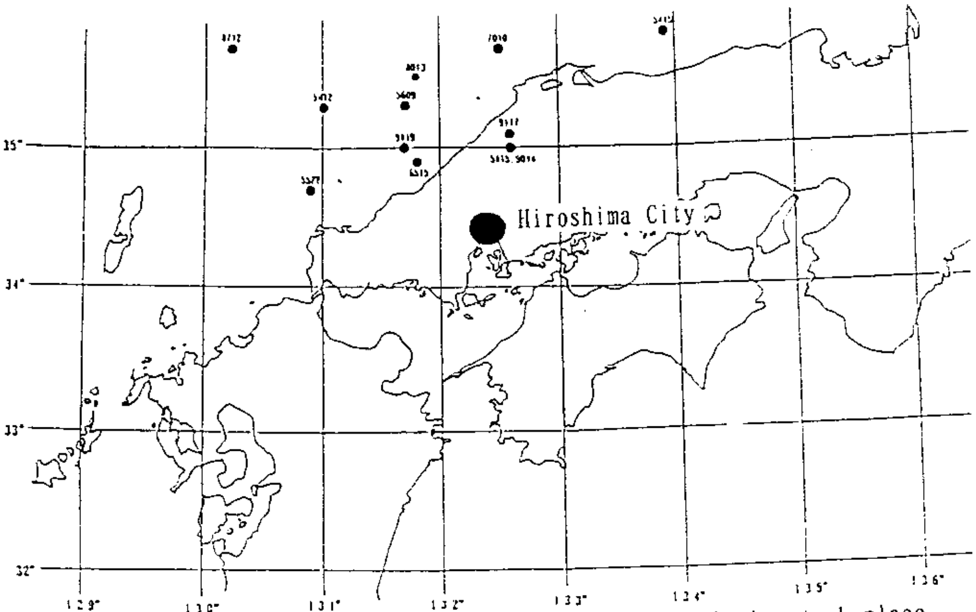

Fig. 4 The positions of the typhoons when maxmum deviation took place

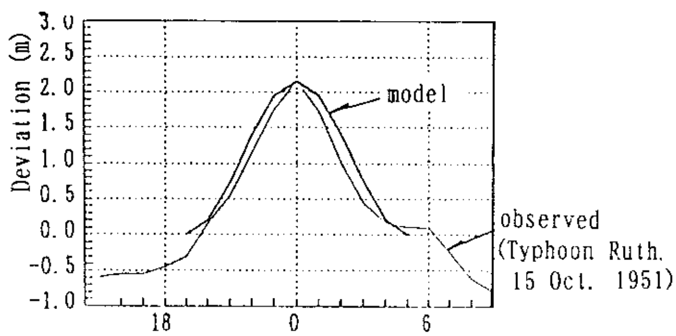

Fig. 5 Hydrographic model of deviation

FORESEEABLE HIGH TIDE DAMAGE

For the formulation of evacuation plans as part of the risk management. an accurate simulation model is necessary for the prediction of flood depth and area caused by high tides. It is also necessary for calculating the speed and direction of floodwater flow when considering methods of flood flow control in the city (Fukuoka and Matunaga (1992)). For this reason, a two-dimensional numerical model with a general non-orthogonal coordinate system was introduced.

Simulation Model

Previous methods of calculation used for the Ohtagawa River Delta made use of an orthogonal coordinate system with a mesh size of 250m × 250m. Using this system. however. presented difficulties in the simulation of floodwater blocked by buildings and liner structures such as roads. railways. and channels. and the floodwater flows on roads. An improved two-dimensional numerical model with a general non-orthogonal coordinate system having a much smaller mesh size of 50m × 50m and less. about the size of a residential block. was introduced to provide more accurate simulation of flood flows. for example. on roads in crowded urban districts. This system incorporates a high degree of topographical detail and land usage (Aoto and Ichihara (1996)).

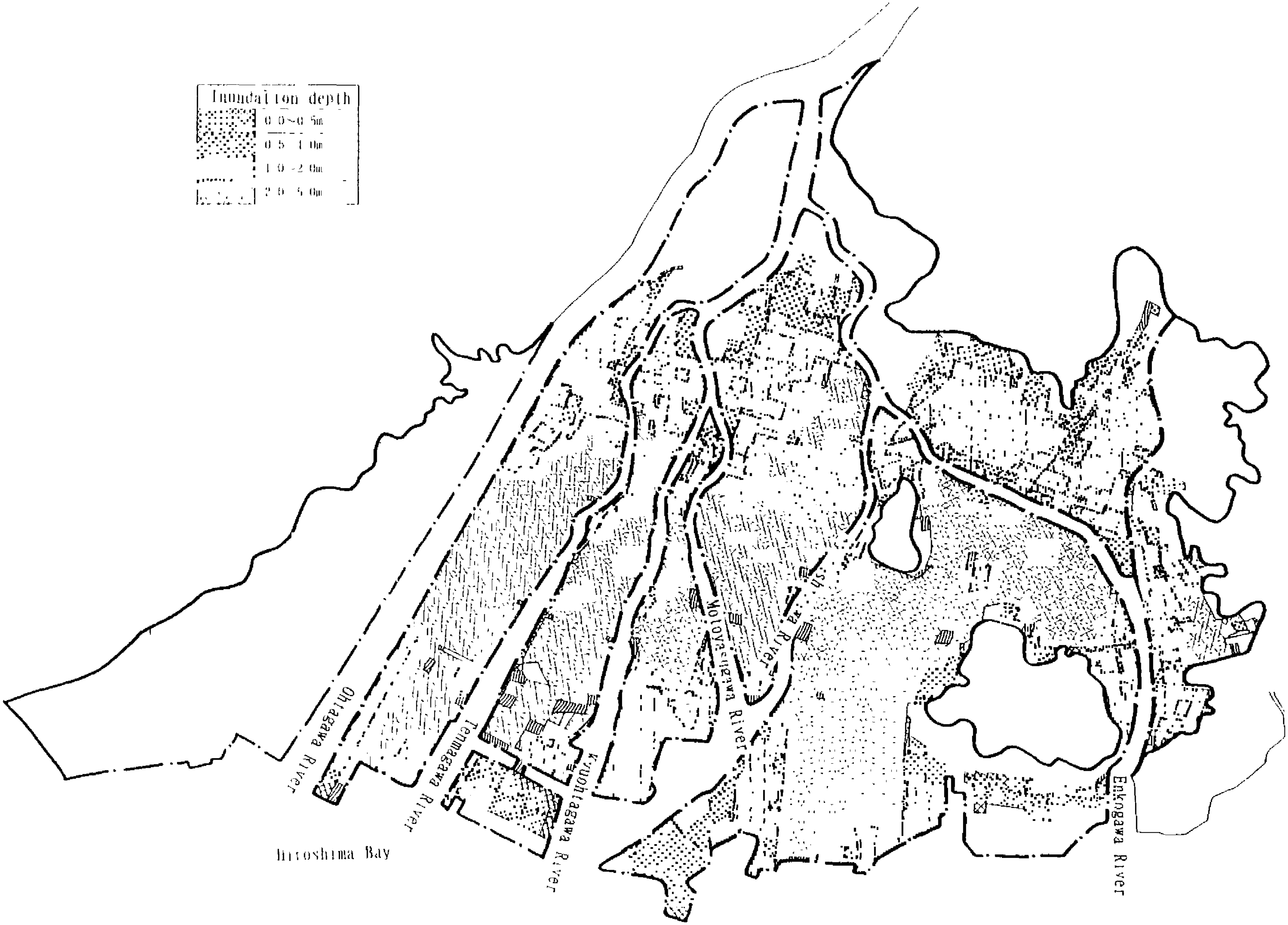

Fig 6 Calculation results of floods caused by planned high tide

Previous methods also used a single value of Manning roughness coefficients for urban areas without regard to the land usage For the new model, this coefficient was taken to be 0.043 for roads, and between 0 056-1 000 for residential areas, based on hydraulic model test of a crowded urban district (Fukuoka and Kawashima (1994))

River flood volumes were not taken into consideration.

It was assumed that embankments without any kind of protection works would be destroyed when floodwaters overflowed the embankment crown

Results of Calculations

The results of calculation for a flood caused by the planned high tide are shown in Figure 6 The planned high tide would result in inundation of most of the center of Hiroshima City, and some 300,000 people would directly suffer as a consequence of such a high tide. It was found that there were some points where the maximum velocity of the floodwater was around 4 m/s, so evacuation plans should be formulated taking due consideration of this high velocity.

CONCLUSIONS

Various measures have been taken in the aftermath of Typhoon 9119, in the Ohtagawa River Delta that is often subject to high tide disasters. Analysis has been used to obtain a clear understanding of the high tide characteristics of the region, and an improved model was used to more accurately simulate the flood flows caused by high tides.

This data is to be utilized in the high tide disaster risk management for the Ohtagawa River Delta

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