京都大学防災研究所 年報 第 48 号 C　平成 17 年 4 月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No.48

Research Development for The Risk Assessment Technology of Flood in Urban Area and Its Practical Application

Tomotsuka TAKAYAMA, Kazuya INOUE, Kaoru TAKARA, Keiich TODA,
Hajime MASE, Masaharu FUJITA and Yasuto TACHIKAWA

Synopsis

Last year of 2004 large and various disasters happened due to landing-on of the quite large number of typhoons and the local heavy rainfalls. Thus, our countermeasure against water related disasters is not sufficient even now. The present paper describes following tentative results which have been obtained in our COE project: 1) Quantitative effect of collaborative flood control by a group of dams, 2) Inundation of underground space in urban area, 3) New prediction procedure of suspended load, 4) Storm surge disasters in Korea and 4) Coastal damages of storm barriers and breakwaters.

Keywords: River flood, Collaborative flood control, Inundation in underground space, Numerical model of underground inundation, Suspended load, Coastal disasters, Wave run-up, Wave overtopping rate, Sliding failure of caissons

1. Introduction

. Last year of 2004 Japan quite suffered from the attack of extraordinary number of typhoons, compared to normal year. The number of the typhoons which landed on Japan last year reached ten (10), though the number is two or three in the normal year. Big disasters took place in various places of Japan.

Typhoon 0416 caused large storm surge in Okayama and Kagawa prefectures facing to Seto Inland Sea. The extraordinary sea level rise induced by the storm surge overflowed the seawalls into Takamatsu city and the urban area of the city was flooded. In Okayama Prefecture an old aged female was drowned by the overflowed storm surge. The historically largest sea level rise was caused by the superposition of the two peaks of the spring tide and the storm surge.

Typhoon 0418 attacked almost same area one week later than typhoon 0416. Large disasters happened in Hiroshima Prefecture but not in Okayama area. The main cause of the disasters is judged to be large waves which generated by strong winds of the typhoon. Though the storm surge was also large, the astronomical tide corresponded to the neap one. Therefore, sea level rise was smaller than that of Typhoon 0416 in Okayama coast. On the other hand the sea level rise was large because of large storm surge though the tide was neap. Furthermore, the attack of big waves generated by strong winds enlarged the disasters.

Around middle of last October Typhoon 0423 passed beside Kochi coast and the huge waves generated by the typhoon caused big disasters. The waves broke the parapets of seawalls and overtopped waves collapsed residential houses behind the seawalls. Several persons were sacrificed. The heavy rain accompanied by the typhoon caused severe land slides which much damaged residences.

In addition to the disasters caused by the typhoons local heavy rains occurred in Chuetsu district of Niigata Prefecture and in Fukui city and caused severe river floods in these areas. The disasters due to the river floods were enlarged by the collapses of the river banks.

Thus various disasters happened in different places in Japan. These disasters have revealed the insufficiency of our countermeasures against water-related disasters. Our COE research project started three years before to mitigate water-related disasters or to improve countermeasures against river and coastal inundation. The present paper briefly describes the achieved results in the project, though the project has not been finished yet.

2. River Flood Control (Sayama et al., 2004)

(1) Rainfall-Runoff Prediction

Intensity of rainfall is not spatially uniform but different from place to place even in same river basin. Distributed rainfall in an area flows into a corresponding river basin. To predict the amount of runoff into a river a cell distributed runoff model has been developed.

In the prediction model, the area of interest is covered by grid cells of 10m to 250m in size, and the runoff of the rainfall is numerically traced in each cell. The runoff from every cell forms a river. Consequently not only a hydrograph but also the water level and discharge at a place in the river can be predicted numerically by the runoff model. The model is composed of two systems: One is for execution of numerical computation of runoff under the geographical and topographical information of the area of interest and the other is for the effective expression of computed results.

(2) Construction of the prediction model

A lot of dams have been constructed to secure water resources necessary for human activities and also to control river flood. It is doubtless that the dams have promoted the safety against river flood. However, we have exact information about qualitative but not quantitative promotion of the safety. The effect of the dams at present on the control of the river flood should be estimated accurately. Therefore, a rainfall-runoff prediction system has been developed for the basin of the Yodo River.

1) River channel model

Combining river channel data in land numerical information and data of lakes and marshes, river channel network has been prepared. The river channel network is divided into another size of segments at river junctions, river discharge observation stations and dam sites, and river channel of more than 3km long is divided into other segments in every 3km. The shore line of the lake of Biwa is also divided at river inlets and the shore line of more than 3km is divided in every 3km. The river channel width is determined by an empirical formula which was derived from the field relation between river channel widths and basin areas at 22 points. However, the empirical formula is not valid for the estimation of the channel widths in Yodo main river, Seta river and Uji river because of the existence of the lake of Biwa in their upper reach. Their channel widths are given as the average values of surveyed channel widths.

2) Segmented river basin model

Under the assumption that the rainfall flows down in the steepest slope direction in every rectangular segment, the subcatchment is determined as the area on which the rainfall discharge flows into a segmented river channel. The subcatchment is expressed as an assemble of rectangular segments with the information of slope and area. Considering the state of soil like saturate and unsaturated, runoff discharge is estimated. The runoff discharge is given as shown in **Fig.1**.

3)Lake and marsh model

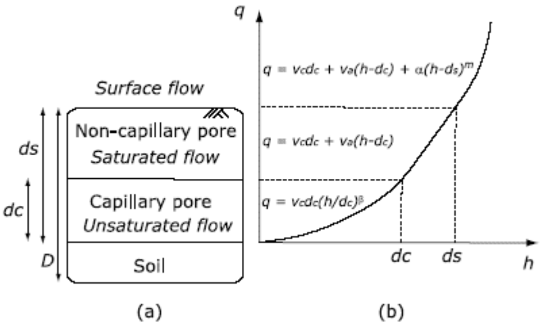
The water level of the lake of Biwa is computed through the mass conservation equation by giving the data of inflow from rivers, outflow form Seta river sluice and rainfall on the lake.

4) Dam control model

The flow control process by dams is modeled through the formulation of dam operation manual and decision making. The present model can predict the amount of outflow from the dam and water level under the input information of amount of inflow, mean rainfall intensity in the upper reach and operational process of the dams for collaboration.

(3)Application and Results

The models described above are combined to predict the effect of a group of dams on the control of river flood. The model was applied to flood control in the Yodo river system to numerically evaluate the significance of the construction of dams.



(a) Concept of soil layer (b)Relation of discharge and water depth

Fig. 1 Runoff model

The large amount of flow discharge occurred twice in 1959 and 1961 of a short period. Therefore, the master plan of Yodo river system was revised in 1965. According to the master plan Amagase dam was first completed in 1965, and many dams had been constructed for 30 years until the completion of Hinachi dam. The model has taken main 8 multi-purpose dams into account to control river flood in Yodo river system.

Only dams which were already completed at the beginnings of the years of 1960, 1970, 1980, 1990 and 2000 were considered in flood control. Peak discharge sat Hirakata were computed for different extreme rainfall intensities on two days average. The computation results of the peak discharge at Hirakata are shown in **Fig.2**, where the vertical and horizontal axes represent the peak discharge and return period of extreme rainfall. In the figure only 4 lines are shown because of the coincidence of the results between 1980 and 1990. That is caused by the fact that no new dams were completed in the period from 1980 to 1990.

Figure 2 draws the following conclusions: At the year of 1960 only Setagawa dam was available for flood control. Consequently the peak discharge goes over the design high water discharge at Hirakata, if the return period of the extreme rainfall reaches over 30 years. It is clear that flood control of dam group becomes more effective as the number of completed dams increases. At the year of 2000 the peak discharge can be kept under the design high water discharge even if the extreme rainfall of 100 years return period happens.

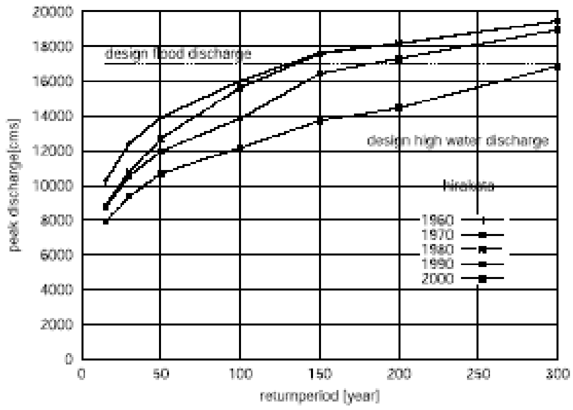


Fig.2 Simulated peak discharges at Hirakata considering dams completed in the selected years, and different scale of rainfall as input data

3. Flood in urban area

(1) Aims

Recent urban floods such as Fukuoka flood in Japan in 1999 and Seoul flood in Korea in 2001 have induced inundations in underground space and have caused heavy damages. Furthermore, in the central district of large cities, a number of buildings stand close together on the ground surface, under which underground space facilities such as underground mall and subway are developed. Populations and properties are densely concentrated there. If flood flow attacks this area, the flow would extend to underground space and the damage would be serious. Therefore, it is very significant to study the inundation flow behavior in underground space from the hydraulic and disaster preventive aspects.

(2) Experimental investigation (Toda et al., 2004)

The studied underground space of Kyoto Oike is located in the central area of Kyoto in Japan. The Kamo river runs in the near east side. This underground space has the multiple stories as shown in **Fig.3**.

A hydraulic model of the underground space is furnished which is made of acryl. The model is undistorted with the scale of 1/30. The model has three basement floors, but the second basement is horizontally shifted slightly for the flow pattern observation and measurement. The water is supplied from the head tank to each enterance on the ground. The condition is assumed that an inundation flow caused by overflow of the Kamo river invades the underground space nearby.

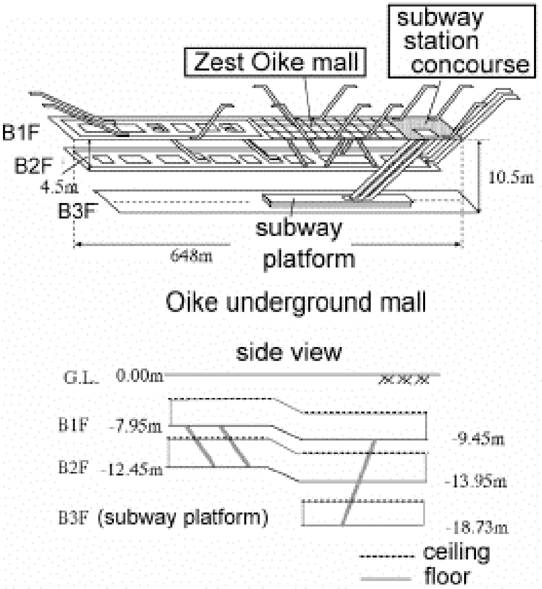


Fig.3 Structure of Kyoto Oike underground space

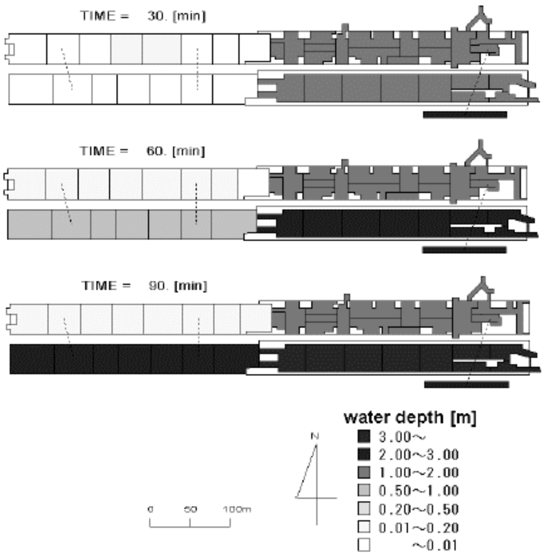


Fig.4 Distribution of inundation water depth

In the model tests which were carried out under the condition that the discharge of 100m^3/s overflows from this Kamo river at the upstream site of Oike Bridge. The inflow condition to each underground entrance is applied as the boundary condition of the underground inundation experiment.

The inundating water disperses in the shopping mall and subway concourse of B1F, where the water depth rises. The water on B1F immediately flows down through the wicket to the subway platform on B3F in less than 20min. If all doors for passengers are kept closed in inundating, the platform is submerged in about 20min. while, the inundation water also invades B2F parking lot independently of B1F, and as time goes on, the water continues to rise because there are no outlets below. **Figure 4** shows the distribution of inundation water depth on each basement floor at t=30, 60, and 90 min. It is found that the whole B3F is inundated to 2-3m deep within 90min. after the occurrence of inundation on the ground. It was found that if the inundation flow invades the studied underground space, the inundation area expands rapidly and the water depth rises very quickly.

It is significant to know the possibility of evacuation through stairs connecting the underground inundations. For five different types of stairs of 1/30scaled underground model, the water depth and the flow velocity were measured by point gages and video camera. The experimental results are plotted in **Fig.5**, where the solid line indicates the critical line for evacuation proposed by Takedomi et al. (2001). **Figure 6** shows the temporal

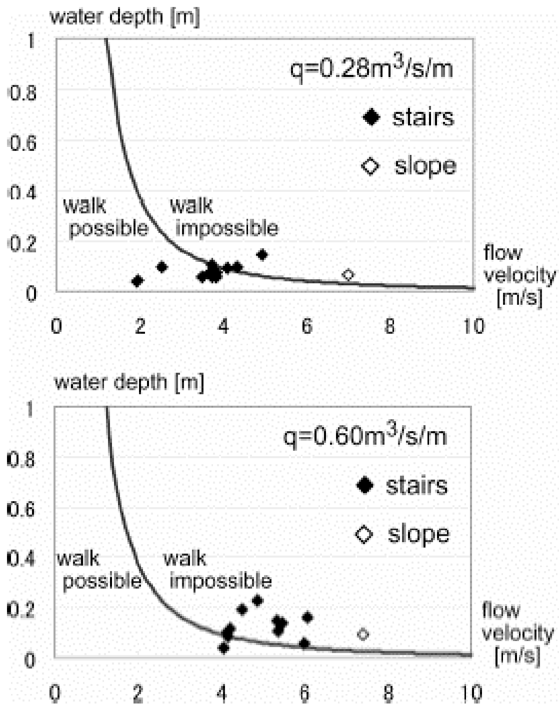


Fig.5 Evacuation possibility at stairs

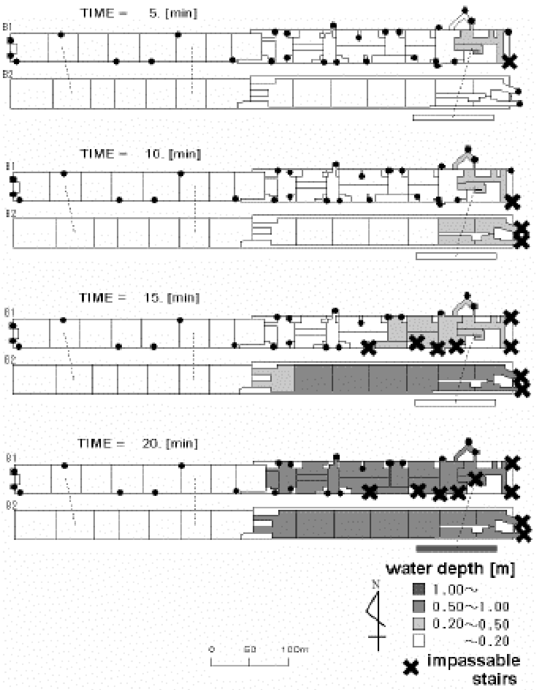


Fig.6 Evacuation possibility

change of water depths each 5 min. after inundation water intrusion starts. The figure points out that unless people staying in underground go out to the ground proptly within 20 min. after the water intrusion starts, they may have much danger of being drowned and losing their lives.

(3) Inundation analysis of underground space (Toda et al., 2004)

A solid numerical simulation is developed based on a pond (tank) model that is one of the ground surface inundation models. This model is simpler and in addition, adjacent subway can be easily incorporated as the part of underground space. The data required for the model is also reduced. This model is applied to Umeda underground mall and adjacent subway lines and the inundation flow behavior there is studied in detail.

The inundation by overflow from the large river is assumed. The condition is supposed that the constant inundation water flows into underground space through some entrances. **Figure 7** shows the inundation water behavior for the inflow of $15m^3/s$ into the underground space. In the figure the time historical expansion of inundation in the mall is indicated at every 1hour after the inflow start. At 1 hour later, the inundation water flows

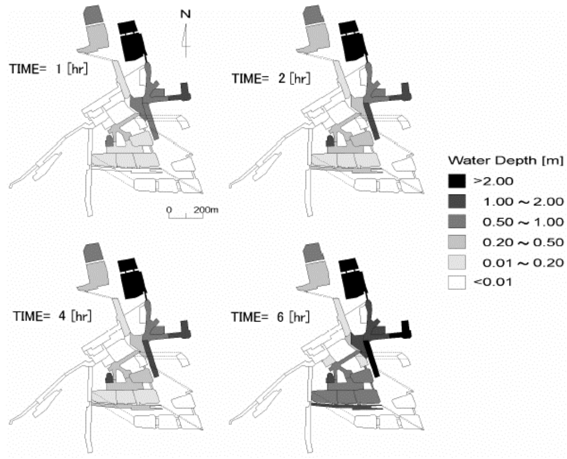


Fig.7 Inundation in underground mall

down to the low elevation area, and the inundation area expands widely to Hankyu-Sanbangai, whity Umeda, Diamor Osaka and B2F of Osaka Station Building. On B2F of Hankyu-Sanbangai, the inundation depth exceeds 2m.

The following results are drawn through the application to Umeda underground mall. A mathematical model based on the storage pond model is developed and applied to actual underground moll and adjacent subway. The model can be applicable to real complicated underground space without much difficulty of data set preparation. The location and elevation of subway station and the volume of subway space have major influence on the inundation water behavior in complicated underground mall connected with subways lines.

4. Suspended Load (Fujita and Mizuyama, 2004)

(1) Background of the research

There are two important parameters governing suspended load concentration distribution: One is the ratio of a shear velocity to falling velocity of sand particles. As the distribution proposed by Rouse (1937) shows, it is only a parameter included in the previous diffusion theory. The other is the distribution of source points of suspended particles. Higher source points result in a large concentration. A sediment supply on the whole water surface produce the uniform concentration distribution. Previous diffusion theory has not contained the parameter concerning source points because it has been developed only for the sand particles already being in suspension. It has been found that the Rouse's distribution does not agree with the concentration distribution measured in a steep channel with large roughness. One of the reasons is that the diffusivity is much higher than that in the case mild slope channels, but another seem to be the lack of a concept of source points.

(2) Diffusion equation of suspended load

The paper has pointed out the necessity and importance of source term in the diffusion equation. Then it has developed a new framework of analysis of suspended load concentration distribution and presented a diffusion equation with a source term as a more general form for suspended load. This framework can remove the ambiguous points from the previous diffusion theory. A method for calculating the vertical distribution of source points of suspended load was also presented considering the sheltering effect of bed gravels. The calculation results on source points and sediments concentration have indicated that the presented model could express the effect of bed gravels on their distributions as well as their experimental ones , as shown in **Fig.8** of the comparison between the experimenta and calculated results.

5. Coastal Disasters

(1) Recent big disasters in coastal area

Since the storm surge disaster caused by Second Muroto Typhoon in 1961, Japan had suffered from no disasters induced by storm surges, but in 1999 twelve (12) persons were drowned in Matsuai district of Kumamoto prefecture by the direct cause of the storm surge induced by Typhoon 9918. In 2003 several Koreans were drowned by the inundation of building basement caused by the storm surge due to Typhoon 0314. In 2004 a lot of typhoons actually landed on Japan and they caused various disasters in coastal areas of Seto Inland Sea, Kochi Prefecture and others.

Several researchers were dispatched for field surveys to the disastrous sites to investigate direct physical causes and disaster occurrence process. The results of the field investigations are described hereafter.

(2) Coastal disaster in Busan and Masan in Korea (Takayama et al., 2004)

Typhoon 0314 was born in the eastside sea of the Philippine Islands on Sept. 6, 2003 and moved in the direction of NW. As shown in **Fig.9**, the typhoon changed the moving direction to NNE at the west of Miyako Island on Sept. 11and landed on the south of Korea. When the typhoon was at the vicinity of Miyako Island, the central atmospheric pressure sank down to 910hPa and the strong wind of more than 70m/s blew in Miyako Island. The typhoon landed on Korea around 20:00 on Sept. 12 with the atmospheric pressure of 950hPa and wind speed of 40m/s. At 3:00 on Sept. 13 it moved out from Korea and entered the Japan Sea.

The typhoon caused coastal disasters in Busan such as damages of seawalls and breakwaters, overturning failure of the floating hotel **(Photo.1**), and inundation due to overtopped waves. **Figure 10** shows the observed and predicted storm tides at Busan Port. The observation and prediction are represented by the solid and dash lines, respectively, and they agree quite well. The storm tide

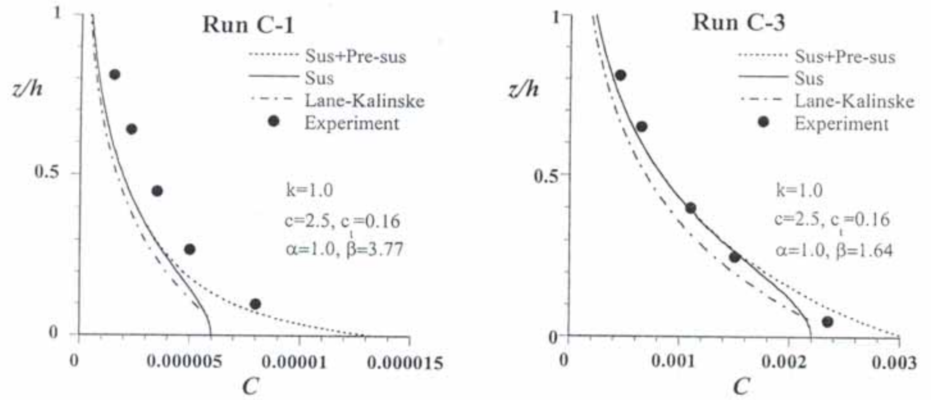


Fig.8 Comparison between the experiments and computations on suspended load concentration

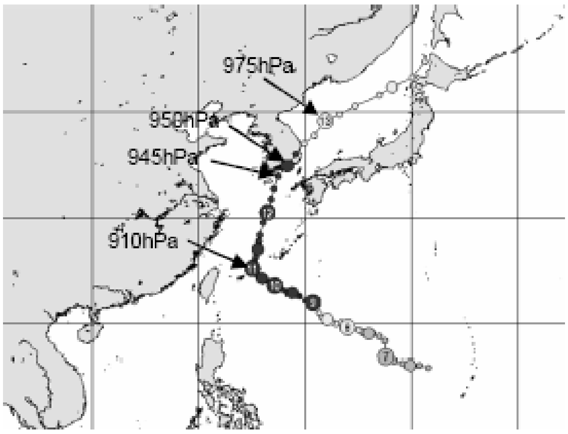


Fig.9 Track of Typhoon 0314

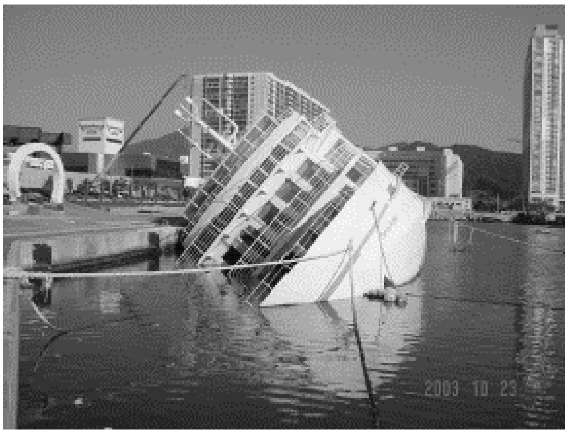


Photo.1 Madamge of a floating hotel

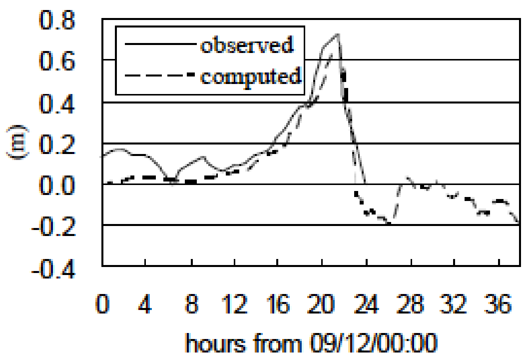


Fig.10 Time history of storm surge at Busan Port

was as high as 0.7m and not so high. On the other hand, the predicted wave height reached 6m, as shown in Fig.11.

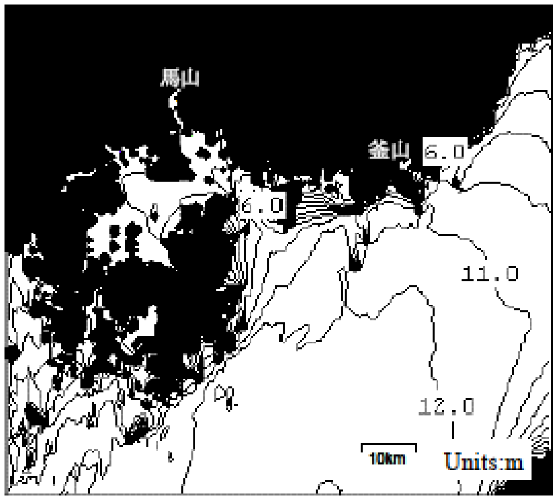


Fig.11 Distribution of maximum wave height around Busan

Therefore, it can be concluded that the disasters in Busan were mainly caused by big waves rather than by the storm surge.

In Masan where several Koreans were drowned in the underground spaces in buildings, the storm tide is shown in Fig.12 as time historical variation. The highest storm surge occurred at about 22:00 on Sept. 12 and reached more than 2.5m. Masan is located at the innermost place of Masan bay, which is relatively narrow and long. Therefore, waves generated in the bay can be supposed to be as small as about 1m. Therefore, it would be right that the disasters in Masan were mainly caused by the storm surge.

(3) High wave disasters in Murotsu (Mase et at., 2005)

High waves generated by Typhoon 0423 broke the

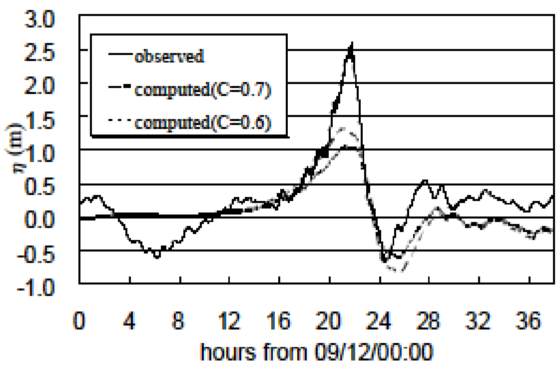


Fig.12 Time history of storm surge at Masan

parapets of storm barriers along Nabae Coast of Murotsu city in Kochi Prefecture and sacrificed three residents. The historically highest wave of 13.55m was observed off Murotsu. The analyzed results on the wave run-up height and overtopping rate in Murotsu are described in some details.

Assuming that the high wave of 13.55m observed off Murotsu attacked the damaged coast, the run-up height of the wave was estimated by using the method of the revised imaginary slope which is indicated in **Fig.13**. The correspondence of the run-up calculated by the revised method to the experimentally measured run-up is shown in **Fig.14**. The calculated 1/3 max. run-ups corresponds to the lowest ones of the experiments. The run-up of 1.25 times higher than calculated one agrees

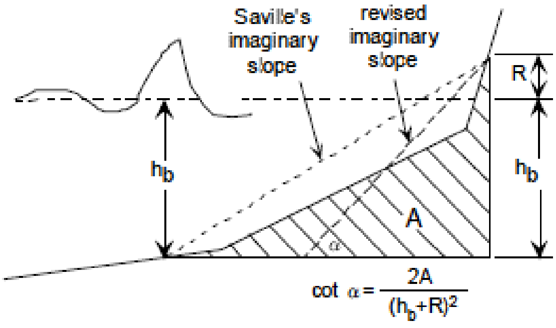


Fig.13 Imaginary slope

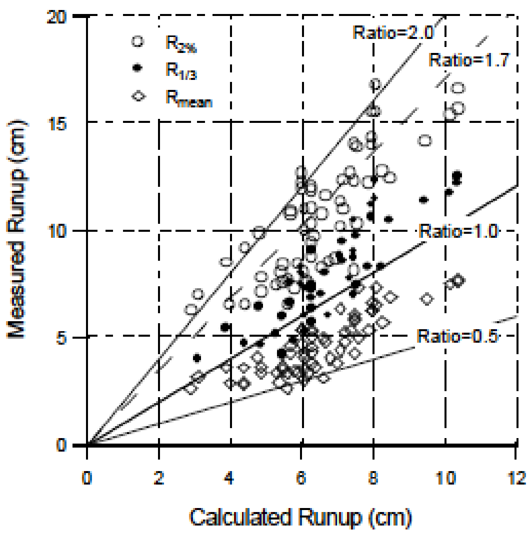


Fig.14 Comparison between measured and estimated runup heights

with the experimental 1/3 run-up on average. The 1/50 max. run-up height of 2% excessive probability becomes 1.7 times larger than calculated 1/3 max. run-up height. If the figure is applied for the estimation of the run-up at the damaged site, the 1/3 max. run-up height is estimated to be 7.1m, which corresponds to the crown level of the storm barrier. The 1/50 max. run-up height is calculated as 11.4m. Considering the reduction of number of run-up waves, the figure of nine is estimated as the number of the waves which overtopped the storm barrier for one hour during the storm. Only one wave appears as 1/50 max. run-up height and its run-up reached 11.4m. The value of 11.4m corresponds to the visual evidence of witnesses.

The wave overtopping rate for the run-up height of 11.4m and the barrier height of 7.4m was also estimated by using the empirical formula. The rate was calculated as $0.047m^3/s/m$. The value of the rate indicates the possibility of the damage of the storm barriers according to the manual of CIRIA/CUR.

(4) Sliding failure of breakwaters in Susami (Kim et al. 2005)

The high waves generated by Typhoon 0423 induced damages of harbor facilities for a quarter of fishery ports in Wakayama prefectures. West breakwater of Susami fishery port was much damaged by sliding failures as shown in **Photo.2**. The predicted wave height in deep sea is shown in **Fig.15**. The max. wave height reaches 12 to 13m and is used to estimate the sliding distance.

The wave height supposed to act actually on the damaged caisson is estimated by the energy balance

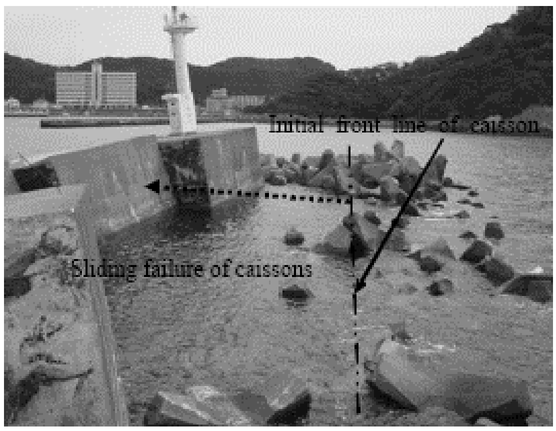


Photo.2 Sliding failure of caissons of Susami West Breakwater

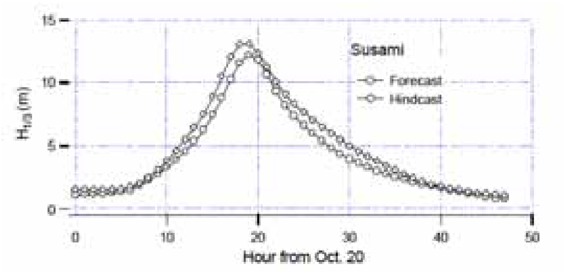


Fig.15 Forcasted and hindcasted wave height in deep sea off Susami

equation method considering the bathymetry and topography around the breakwater. The wave height of 6 to 6.3m was obtained.

A caisson on rubble mound makes motions of sliding and tilting. Kim and Takayama (2004) proposed a computation procedure for the estimation of sliding distance. In the procedure the increase of resistant force due to tilting motion is taken into account. The wave height of 6 to 6.3m predicted the caisson sliding distance of 8 to 12m as shown in Fig.16. The predicted sliding distance well agreed with the actual one of 6 to 10m. Thus it is confirmed that the sliding damage of the caisson can be reproduced well by the caisson sliding computation model.

6. Concluding Remarks

The results obtained in the COE research project were described briefly. The main conclusions drawn from the paper are as follows:

1) The collaborative flood control by a group of dams is quite effective on the enlargement of allowable discharge.
2) The experimental results of the inundation in Oike underground space show that unless people in the underground space go out on the ground promptly within 20 min. after the start of the flood, they may have much danger of being drowned and losing their lives.
3) The mathematical model based on the storage pond model is applicable to real complicated underground space without much difficulty of data set preparation.
4) A numerical computation method for vertical distribution of source points of suspended load was presented ant its validity is confirmed by experiments.
5) Taking into account the small storm surge but large waves in Busan, the high storm waves are mainly related to the disasters in Busan. In Masan the highest storm surge occurred at about 22:00 on Sept. 12 and reached more than 2.5m. We can conclude that the disasters in Masan were mainly caused by the storm surge.
6) The highest run-up height of 11.4m during the storm is estimated at the storm barriers in Murotsu and corresponds to the visual evidence of witnesses.
7) The sliding distance of the caissons of the breakwater in Susami could be reproduced by the existing formula.

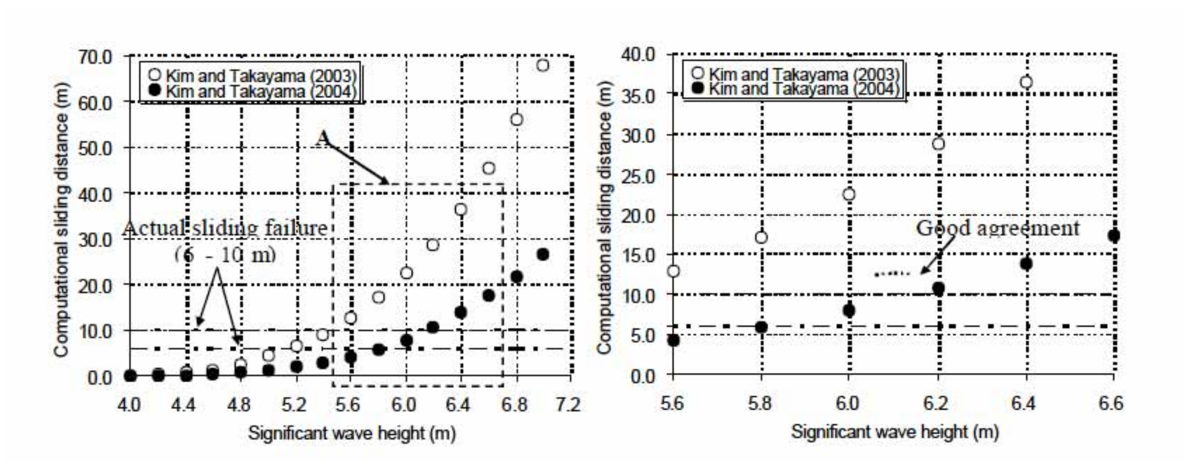


Fig.16 Comparison between the computed and surveyed sliding distances for the Susami West Breakwater (Left Fig.: total results; Right Fig. detail in A of the left Fig.)

Since the COE research project continues for two more years, new and fruitful research results are expected to find more by the end of the projects.

A lot of researchers other than the authors joins this project and have contributed the results described in the paper. The authors much appreciate their contributions.

References

Fujita, M., and T. Mizuyama (2005) : A difufsusion equation of suspended load with a source term and its application, Journal of Japan Society of Erosion Control Engineering, Vol.57, No.6, pp.3-12 (in Japanese).

Kim, T-M. and T. Takayama (2004) : Effect of caisson tilting on the sliding distance of a caisson , Annual Journal of Civil Engineering in the Ocean, JSCE, JSCE, pp.89-94.

Kim, T-M. T. Yasuda, H.Mase and T. Takayama (2005) : Computational analysis of caisson sliding distance due to Typhoon Tokage, Proc. of Asian and Pacific Coasts 2005, Jeju, Korea.

Mase, H., T. Yasuda, T-M. Kim, T. Takayama, T. Hiraishi and K. Hirayama (2005) : Coastal disasters at Murotsu and Susami due to Typhoon 0423 (Tokage) , Annuals of Disas. Prev. res. Inst., Kyoto Univ., No.48, (in Japanese).

Rouse, H. (1937): Modern conception of fluid turbulence, Trans. ASCE, Vol.102, pp.463-543.

Sayama, T., Y. Tachikawa and K. Takara (2004) : Development of a distributed rainfall-runoff prediction system considering dam's flow regime control, Annuals of Disas. Prev. res. Inst., Kyoto Univ., No.47, pp.1-16 (in Japanese).

Takayama, T., H. Amamori, T-M. Kim, H. Mase, Y-K. Kang and H. Kawai (2004) : Characteristics of storm surge and wave disasters caused by Typhoon 0314 (Maemi) in Korea, Annuals of Disas. Prev. res. Inst., Kyoto Univ., No.47A, pp.99-111 (in Japanese).

Takedomari, K. et al. (2001): An experimental study on the danger to wakers caused by inundation flow over stairs into underground space, Proc. Of the 56th annual conference of JSCE, (CD-ROM) (in Japanese).

Toda, K., K. Inoue, R. Oyagi and K. Kuriyama (2003) : Inundation analysis of complicated underground space with subway, International Symposium on Disaster Mitigation and Bsin-Wide Water Management, ISDB2003, Niigata Convention Center TOKI MESSE, Niigata,Japan.

Toda, K., K. Inoue, T. Nakai and R. Oyagi (2004) : Hydraulic model test of inundation water intrusion in underground space, Proc. of the 4th International Symposium on Environmental Hydraulics and the 14th Congress of Asia and Pacific Division, International Association of Hydraulic Engineering and Research, , Hong Kong, pp.1403-1409.

都市水害の危険度評価技術とその社会的応用に関する研究開発

高山知司・井上和也・寶　馨・戸田圭一・間瀬　肇・立川康人・藤田正治

要　旨

通年においてわが国へ上陸する台風ははは 2～3 個であるのに対して，昨年（2004 年）は 10 個にも達し，観測史上最大の個数であった. 台風 0416 と 0418 号では瀬戸内海に大きな高潮が発生し, 多くの犠牲者が出るとともに，多大な被害を被った．また，高知沿岸を走った台風 0423 号では防潮堤のパラペットが破壊され，越波による浸水で数名の死者が出た．さらに，台風による集中豪雨によって河川が氾濫して，福井県や新潟県で多くの住民が避難生活を余儀なくされた．そこでは河川堤防の決壊が氾濫水域を拡大し，大量の土砂を堤内地に運び込み，被害を拡大させた．このような氾濫災害の発生は，わが国が水害に対して十分に対応できていないことを如実に示していると言える．本報告は，このような氾濫災害を軽減するために 21 世紀 COE プロジェクトの一環として行ってきた研究のうち，現在までに得られた成果の一部を概述したものである．

キーワード：河川氾濫，洪水共同制御，地下空間の氾濫，浮遊土砂，波の遡上，越波，滑動破壊