FLOOD ANALYSYS IN THE URBAN AREA OF APIA, SAMOA ISLANDS USING 2D NUMERICAL SIMULATION MODEL

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BACKGROUND

During the rainy season, Apia, the capital city of Samoa Islands, is usually damaged by the river flood especially in the urban area. The city has three main rivers, the Vaisigano, the Vailima and the Vaivase. Recently, the most flood damages were occurred in year 2001, 2003 and 2006. These heavy floods were caused by the heavy rain.

Generally, More than one river flow through Apia downtown to the Pacific Ocean, thus we need to quantify the discharge exchanged each river in flood events. And this urban area has been formed along the shore, the tidal effect should be considered with the flood events. Since we don't have enough hydrological information, (e.g. rainfall data, discharge and water level, and the data of the flood history to understand the flood event, it is difficult to perform the effect in flood control.

In this study, we firstly calculate the 2D numerical model of the year 2001's flood based on shallow water equation, using discharge from runoff calculation[1),2)]. This model could reproduce the flood and provide the flood's characteristics and mechanism. Verification of the result depends on field survey, listening survey and reference materials from the Government of Samoa. Next, the proposed model was applied for deciding flood control in the future and also for finding the relations with urban formation.

LOCAL CONDITION

Objective Area

The objective area is rivers and its basins flowing in Apia, the capital of Samoa. Fig.1 shows the location of objective area and Fig.2 is its enlargement to show the objective rivers. In this study, the Vaisigano River, the largest basin in the 3 rivers, the Vailima River 10 times smaller basin than the Vaisigano River, and the Vaivase River are selected as objectives.

Outline of 2001 April Flood

Very heavy rain about 200mm in 4 hours from 15th to 16th April 2001 caused the large flood for the around urban area. Most of infrastructures, such as road and drainage, were heavily damaged. While 5000 people suffered their houses and 28000 people were influenced by cutting off of water supply. The characteristics of the flood were described below;

1. It was composite event of river water and interior runoff flood.
2. High velocity area was observed.
3. Flush flooding was observed.

However, the characteristics are not detail enough about the exact time and location, and are remained question[3)]. Considering about topographical characteristics, the urban area is located the foot of steep mountains. Therefore, we thought that the flood event was expanded as river water flood due to heavy rain and early response.

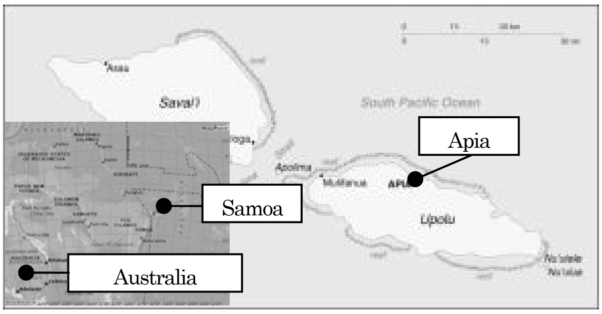

Fig.1. The location of Samoa Island

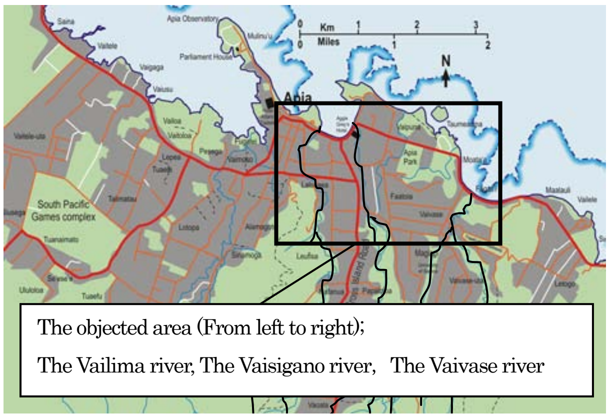

Fig.2. The location of objective area

CALCULATION

Runoff Calculation

Discharge is given each river from storage function method using rainfall data at Apia Observatory. Continuity equation and storage function equation is shown below;

$$\frac{ds}{dt} = fr - q \qquad (1)$$

$$s = Kq^{p}$$

where, S is the storage height ; K and P are coefficient ; q is the height of runoff ; f is the runoff coefficient ; r is the rainfall ; t is time. In our study, K=5.0 and P=0.6 are given as coefficient, and calculation is conducted with the condition $\triangle t$=0.1. In our study, f=1.0 is given as runoff coefficient. Calculated discharge is shown in Fig.3. Samoa government reported[4),5)] that calculated maximum discharge of the Vaisigano River around Apia is 530m^3/sec similar with our calculated result.

Flood Calculation

2D calculation has been well recognized by many researchers. The Continuity equation is given below;

$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \qquad (2)$$

The Momentum equation in x-direction is given as;

$$\frac{\partial (uh)}{\partial t} + \frac{\partial (u^2 h)}{\partial x} + \frac{\partial (uvh)}{\partial y} = -gh\frac{\partial H}{\partial x} - \frac{\tau_x}{\rho} + \frac{\partial}{\partial x}\left[v_t \frac{\partial (uh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[v_t \frac{\partial (uh)}{\partial y}\right] \qquad (3)$$

Also in y-direction;

$$\frac{\partial (vh)}{\partial t} + \frac{\partial (uvh)}{\partial x} + \frac{\partial (v^2 h)}{\partial y} = -gh\frac{\partial H}{\partial x} - \frac{\tau_y}{\rho} + \frac{\partial}{\partial x}\left[v_t \frac{\partial (vh)}{\partial x}\right] + \frac{\partial}{\partial y}\left[v_t \frac{\partial (vh)}{\partial y}\right] \qquad (4)$$

where x and y are Grid mesh ; u and v are Water depth mean velocity of x and y direction ; t is time ; ρ is Density of water ; h is Water depth ; H: Water level.

Eddy coefficient of kinematic viscosity is shown below;

$$\upsilon_t = \frac{1}{6}\kappa u_* h \qquad (5)$$

where, κ is Karman's universal constant; u_* is friction velocity.

τ_x and τ_y are shear stress of river bed shown below;

$$\tau_x = \frac{\rho g n_m^2 u \sqrt{u^2 + v^2}}{h^{\frac{1}{3}}}, \tau_y = \frac{\rho g n_m^2 v \sqrt{u^2 + v^2}}{h^{\frac{1}{3}}} \qquad (6)$$

0.005, and 0.05 are given as $\triangle t$, and Manning's roughness coefficient; n_m. 50m mesh which is made from 10m grid data is applied to the calculation and the observed tide level is used for downstream end.

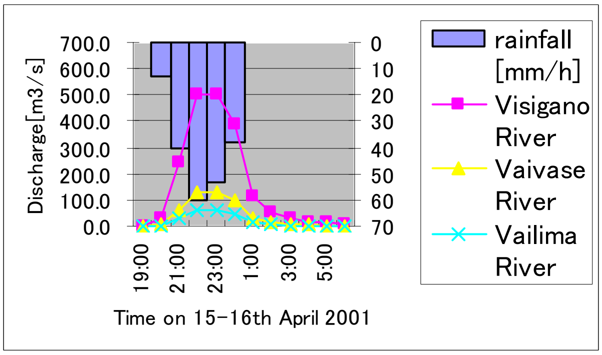

Fig.3. Discharge for Upstream

RESULT

The simulation model is calculated for 7 hours between 9:00 pm to 4:00 am. No water depth is given at 9:00 pm. Fig.4 to 6 shows calculation result of water depth upper than 0.1m in each time for 9:30 pm, 0:30 am and 3:00 am, respectively.

From the result, the flood already expands at 9:30 pm along each rivers and lower area. As for the Visigano River, flood expands to moors from right bank which where drainage channel are going to be constructed. It shows that accurate diversion and cut off will be done if diversion channel is constructed here.

Flood expansion becomes maximum at 0:30 am and downtown area is covered with flood. Discharge exchange between the Vaisigano River and the Vailima River was not observed during the flood. Therefore, we believe that each flood area of the Vaisigano and the Vailima River is independent in such flood event. Moreover, the flood around moors where the diversion channel is going to be constructed is almost caused by the flood of the Vaisigano River.

At 3:00 am, the flood is receded along the Vaisigano and the Vaivase River, however there are still flooding around moors and downstream area of the Vailima River. Yeo's report[7)] described that "The flood rose at about 9:30 pm and was reported to have receded from most affected properties by 3 am" about the Vaisigano River and it is similar with our calculated result. On the other hand, flood does not recede around moors and downstream area of the Vailima River after 7hours. The ground height around moors and downstream area of the Vailima River is lower than other area so once flood comes into here, it is hard to drain and also it is expected that there are big damages for long time. Especially downstream of the Vailima, downtown is formed around left bank side so more flood damages to the infrastructure will be expected. From the beginning, it is said drainage difficulty is caused by banks which is constructed along the shore in the downtown. In addition,

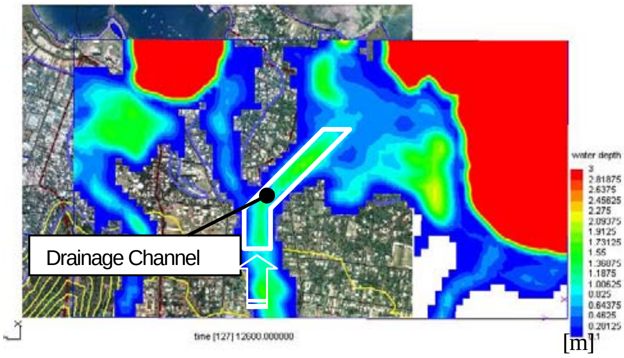

Fig.8. Water Depth at the Maximum Discharge with Drainage Channel (Compared with Fig.5.)

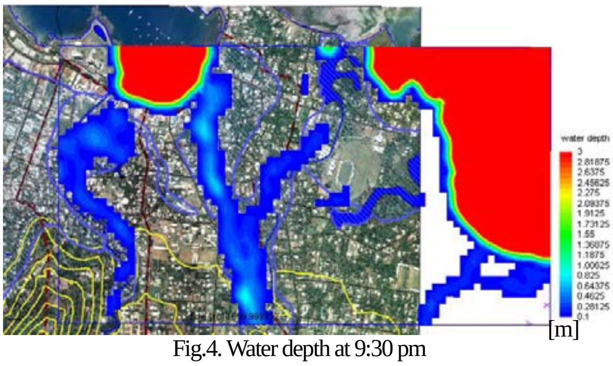

Fig.4. Water depth at 9:30 pm

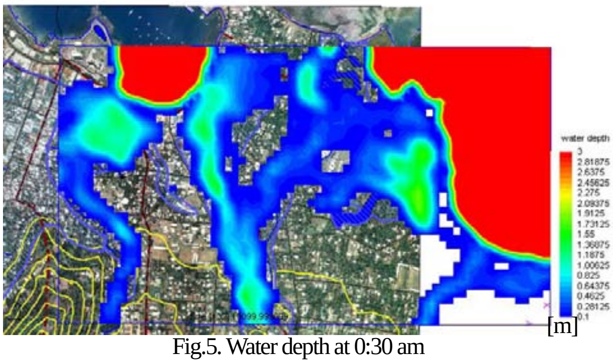

Fig.5. Water depth at 0:30 am

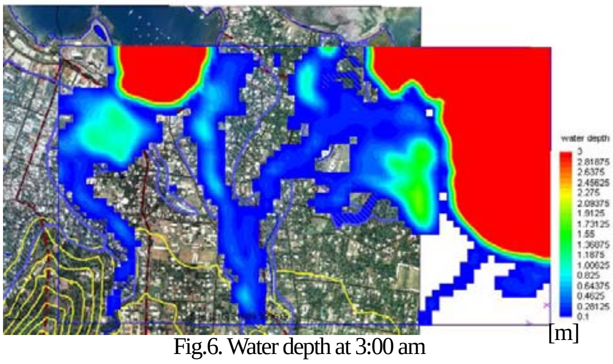

Fig.6. Water depth at 3:00 am

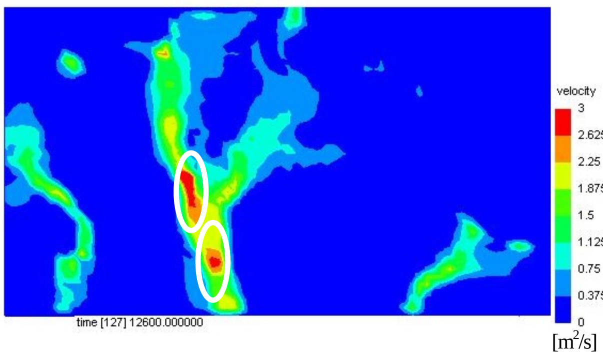

Fig.7. Velocity Contour at Maximum Discharge

calculated result shows original topological characteristics also causes drainage difficulty.

About flood characteristics which described in chapter 'Local Condition', some considerations are following. Concerning 'It was composite event of river water and interior runoff flood', it is not enough to have detail discussion yet. It should be well considered in future. Concerning 'High velocity area was observed' and 'Flush flooding was observed', Velocity contour at maximum discharge time shows in Fig.7 that Velocity becomes faster in white circle area than other area. Moreover, there are less buildings and houses than other area. It suggested that it is difficult to form city area around here due to high velocity during the flood events.

CALCULATION OF DRAINAGE CHANNEL

Drainage channel should be constructed to reduce the damage at downstream area of the Vaisigano River and not to flood to the lower area in downstream area of the Vailima River. Therefore, the drainage channel is assumed to put on the upper side than the point where overflow to the Vailima River can be expected. In this study, 200m^3/s is cut off at the maximum discharge. Fig.8 shows the comparison of the water depth with the calculation result with drainage channel. Water depth is decreased in downstream area of the Vaisigano River comparing with the result of no drainage channel. Water level reduces more than 0.7m in downstream compared with 0.3m increasing around moors.

VARIFICATION OF CALCULATION RESULT IN LOW WATER CHANNEL

To validate the calculatied result, it is important to know the size of the influences topographical configuration has. As said in Chapter 6, flood of the Vaisigano River is not influenced by other river's flood. Therefore, the calculated result which is based on satellite survey data is compared with the one based on cross sectional survey data of river channel in the same area to discuss differences between two results. Fig.9 and 10 shows calculation result of water depth based on cross sectional survey data at 9:30 pm and 3:00 am. Please note that each figure should be compared with Fig.4 and 6.

From our study, the result of water depth using cross section

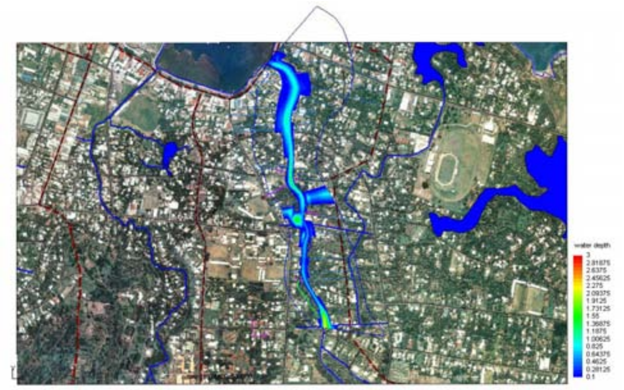

Fig.9. Water Depth Contour at 9:30 pm

Fig.10. Water Depth Contour at 3:00 am

data at low water channel becomes deeper than the one using satellite survey data because ground height data of satellite data is consisted of water surface data at low water channel.

Next, flooded area by time is considered. The flood is start expanding at downstream area on 9:30 pm and it similar the discussed result in the previous section. However, flooded area around whole along the river is smaller than the one using satellite survey data, especially upstream side. And flood is receded around downstream area at 3:00 am. Similarly, the flood is receded earlier comparing with the result using satellite survey data.

Therefore, calculated result (at least under small discharge) has some differences between 2 topological data. It indicates that topological configuration of low water channel influences calculation result under the small discharge. On the other hand, it is not important under the big discharge although we need to consider the roughness of calculation grid under the consideration for each water channel scale, such case as the Vailima River and the Vaisigano River.

We concluded that the satellite survey data is appropriate for consideration about flood area of such as whole city area but cross sectional survey data is also needed considered in the calculation to know detail information such as disaster prevention and evacuation along the river.

CONCLUSION

Our study showed the characteristics and mechanism of the flood of 3 rivers in urban area at Apia. From the result, the following conclusions have been drawn:

1. Calculation result showed that drainage channel are constructed at flooding channel to the moors, it can make stable cutting off and drainage.
2. No discharge exchanges are observed in 2001 flood between the Visigano River and the Vailima River.
3. Topological characteristics cause drainage difficulty around city area along the Vailima River.
4. Topological configuration of low water channel influences calculation result under small discharge.

The relationships between flood characteristics and urban formations have not been discussed yet. One example can be given why downtown area has grown around the Vailima River nevertheless drainage characteristic is not good here compared with the Visigano River. This is just supposition that the Vailima river basin is more suitable than the Visigano River to prevent big damages by frequent floods because velocity of the Visigano River is faster than that of the Vailima River shown in Fig.7. Moreover, city area has not developed where the flood velocity is higher compared with other area. Therefore it can be expected to find the relations between city formation and flood characteristic. We found that the numerical calculation is one of the effective tools to obtain the relations among flood, city formation and disaster prevention.

REFFERENCES

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[7]Previous 3)