DEVELOPMENT OF LOSS FUNCTIONS FOR URBAN FLOOD RISK ANALYSIS IN BANGKOK

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ABSTRACT

Assessment of economic losses due to a natural disaster or estimating potential losses due to a possible disaster is very important for disaster risk management. Loss functions are the building block for estimating economic losses caused by any natural disasters. These functions provide relationship between the parameters defining the magnitude of a disaster and damage to different landcover features caused by it. The parameters are different for different types of natural disasters. Velocity, depth and duration are the three main parameters used for loss functions for flood disaster loss estimation. Most of the countries around the world, especially the Asian countries, do not have any standard loss estimation methodology for assessment of losses due to a natural disaster and loss functions are rarely available for different landcover features.

This paper summarizes the outcome of a study conducted for development of loss functions in some selected regions of Bangkok as a part of a project for urban flood risk analysis. The paper presents the loss functions developed for Bangkok for residential and non-residential buildings.

1. INTRODUCTION

Bangkok is a natural floodplain due to its low elevation and geographic location at the lower basin of the Chao Phraya River. Frequent floods have been a big hindrance in its development. Although the Royal Thai Government has been undertaking various measures, it has not yet become possible to mitigate the flood disasters in this capital city and economic hub of Thailand. In the Bangkok Metropolitan and its vicinity, urban and built-up lands have increased by 115% from 1,058 km^2 to 2,280 km^2 in the last 15 years (Vibulsresth, 2003). The rapid urbanization and heavy soil settlement have adversely affected the flooding situation in Bangkok. Climatic change is likely to worsen the situation. Under such circumstances, it is an urgent need to develop a proper urban flood risk management strategy for Bangkok metropolitan, which is the home to more than 10 million people. Hazard and vulnerability analysis is an important step towards risk management (Fig. 1) (Plate, 2002). Loss functions are the building block for disaster vulnerability and risk analyses (Smith, 1994; Berning et al., 2001). These functions provide relationship between the parameters defining the magnitude of a disaster and economic damage to different landcover features caused by it. There have been only a very few attempts for developing loss estimation methodology for Thailand and no loss functions exist for Bangkok for flood risk analysis (Tang et al., 1992). This paper presents the outcome of a study conducted for development of loss functions in some selected regions of Bangkok as a part of the "Flood Risk Mapping" Project of the Regional Network Office for Urban Safety (RNUS).

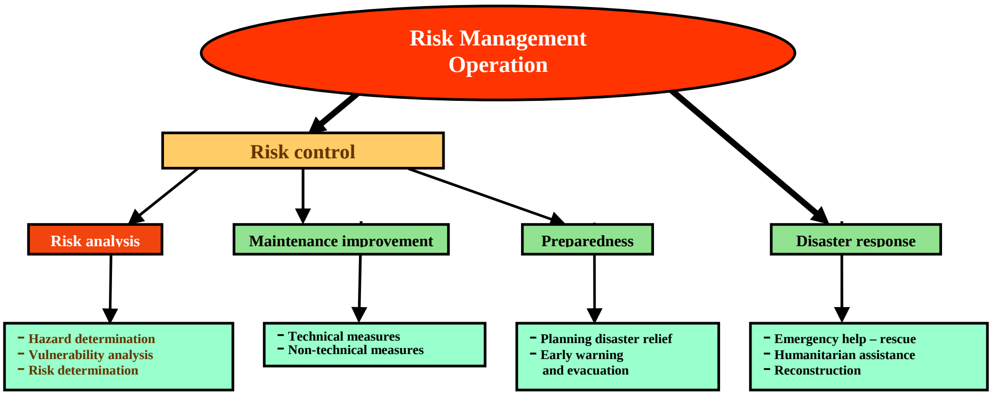

Fig. 1: Steps involved in operational risk management (from Plate, 2002)

2. FLOOD RISK MAPPING PROJECT

The International Center for Urban Safety Engineering (ICUS) of the Institute of Industrial Science, University of Tokyo, set up a Regional Network Office for Urban Safety (RNUS) at the School of Civil Engineering of the Asian Institute of Technology (AIT) in October 2002 to promote collaborative research activities in the region for urban safety. The main areas of research at RNUS include urban disaster mitigation, infrastructure maintenance and management and application of GIS and Remote Sensing for urban safety. As the start-up activity, two pilot projects were initiated by RNUS in 2002 in collaboration with the researchers, scientists and engineers of Thailand. One of these pilot projects is on "Urban Flood Risk Mapping in Bangkok using GIS, RS and Mathematical Model". The organizations involved in this pilot project are RNUS, ICUS, AIT, Chulalongkorn University, and GISTDA (Geo-Informatics and Space Technology Development Agency). A major component of this project was to develop flood loss functions for Bangkok for flood risk mapping. The scope of the project was limited to development of loss function for urban buildings in some selected regions of the Bangkok Metropolitan area.

3. STUDY AREA

Two of the most frequently flood affected districts of the Bangkok Metropolitan area are selected for this pilot project. The selected districts are Bangkapi (Area: 28.5 km^2, population: 0.143 million) and Bungkum (Area: 24.3 km^2; population: 0.137 million), both are adjacent districts located in the eastern side of the Bangkok City (Fig. 2). Mostly residential areas are located in these two districts with a few industries and non-residential buildings. Due to their low elevations, with elevations at places below mean sea level, floods are frequent and prolonged in these two districts.

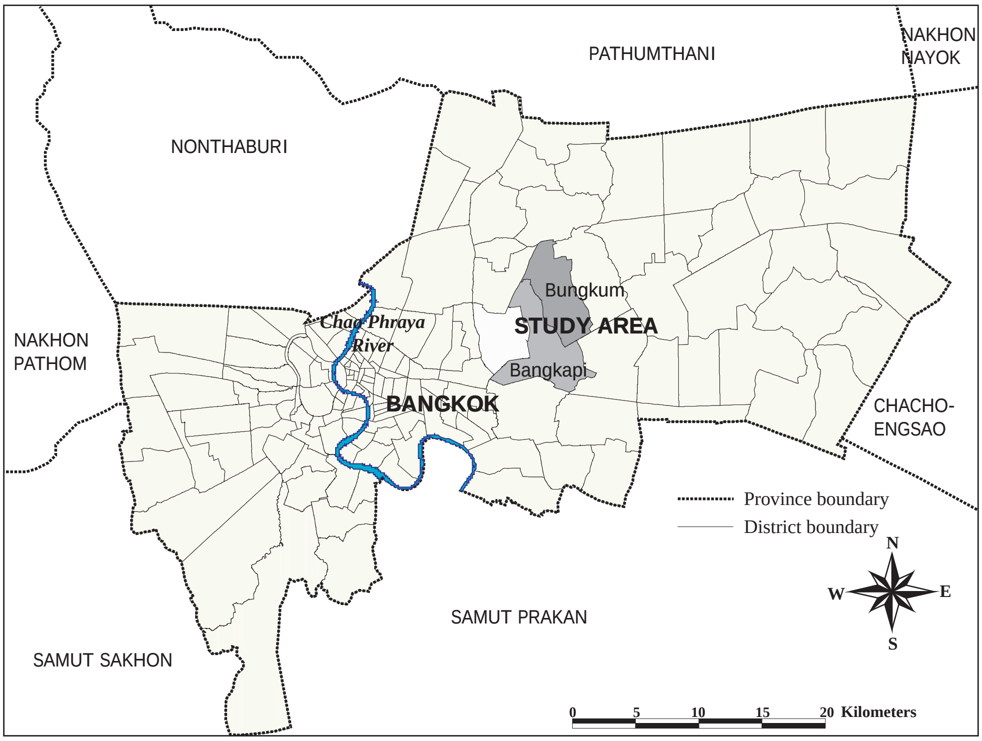

Fig. 2: Location map of the study area

4. METHODOLOGIES

Questionnaire surveys were carried out in the selected two districts for gathering data and information for development of loss functions. The survey was targeted for residential and non-residential buildings. Based on building types, distribution and past history of floods, a total of 350 samples were selected for the survey. The details of the selected building categories are shown in Table 1. The selected residential buildings were mainly concrete buildings. The main categories of non-residential buildings were service, production, retail sale and government buildings. As the floods in the past years affected only a limited number of non-residential buildings in the selected two districts, the sample size of the non-residential buildings were much smaller compared to the residential buildings. Figure 3 shows the locations of the samples surveyed in the two districts. The survey was conducted by six undergraduate students of Irrigation Development Institute (IDI) of the Royal Irrigation Department (RID), Thailand. The students were given initial guidelines and training for carrying out the survey. Efforts were put on collecting damage statistics for different categories of items including building structures, contents, outside properties caused by the floods of September 2002 and other floods during 1995-2001. The recent events were selected to make it easier for the respondents to answer the questions. A set of hypothetical questions were included in the questionnaire survey to get the response of people about possible damage to their buildings due to hypothetical floods of different heights and durations. Although the survey was carried out separately for the two districts, the surveyed datasets were merged together for analysis due to the limited sample sizes from each district to treat them independently.

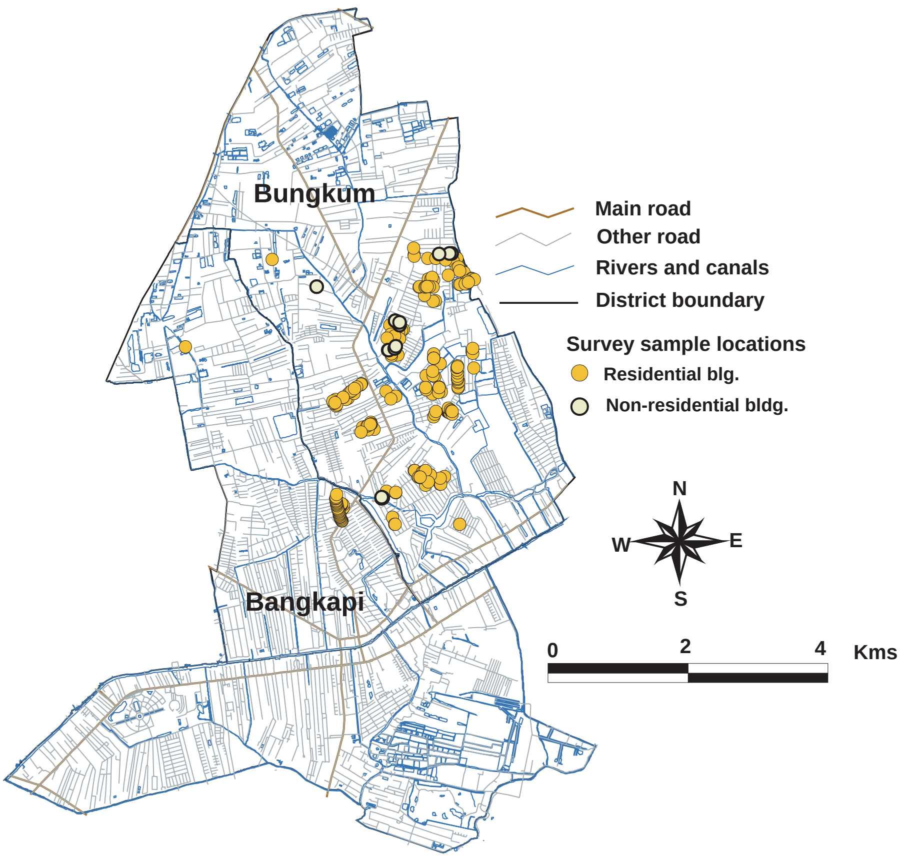

Fig. 3: Locations of the Surveyed samples in the study area

Table 1: Details of samples selected for questionnaire survey

Building Category	Building construction material	Number of samples	
		Bangkapi district	**Bungkum district**
Residential	Wooden	0	7
	Concrete	65	186
	Mixed	0	42
	Total	65	235
Non-residential		15	35

5. DEVELOPMENT OF LOSS FUNCTIONS

The summary of the surveyed statistics of the residential buildings is shown in Table 2. As can be seen from the table, the average age of the surveyed residential buildings was 21 years. The most of the buildings were of RCC type and average number of stories was 1.8. The averaged maximum duration of floods in the last 8 years (the period covered by the survey) was 2.5 days. As the maximum observed flood height in the last 8 years was only 87cm, damage to the building structure was less than 1%. The maximum content damage was 25% and the maximum damage to outside property was as high as 100%. No surveyed building had any basement floor.

Table 2: Summary of the surveyed statistics of residential buildings

Questions	**Response**	
	Average	**Range**
Building age (years)	21	4-35
Building plinth area (m^2)	138	25-500
Construction material	Wooden: 7; Concrete: 233; Mixed: 42	
Number of stories	1.8	Single: 66; Double: 206; Higher: 10
Height of 1st floor (m)	3.5	2-5
Availability of flood insurance for building (structure and content/stock)	No	No
Availability of basement floor	0	0
Present replacement value of building structures (million Baht) (*1US$ = 40 Baht*)	2.3	0.24-10.2
Present replacement value of building contents (thousand Baht)	96.5	5-3,000
Present replacement value of outside properties of building (thousand Baht)	8	0-150
Maximum flood heights in last 8 years (m)	0.32	0.0-0.87
Maximum flood duration in last 8 years (days)	2.5	0-25
Maximum damage to building structures in last 8 years floods (Baht)	318	0-5,000 (0 – 0.5% of total)
Maximum damage to building contents in last 8 years floods (Baht)	1,264	0-25,000 (0 – 25%)
Maximum damage to bldg outside property in last 8 years floods (Baht)	229	0-20,000 (0 – 100%)
Maximum cleaning costs in last 8 years floods (Baht)	160	50-600
Available flood warning (hrs)	0	0
Warning time needed to remove all transportable contents (hrs)	42	6-72
Potential damage could be prevented by warning (%)	61	30-100
Water supply interruption (hrs)	0	0
Electric supply interruption (hrs)	4.2	1-6

Table 3 shows the summary of the surveyed statistics of the non-residential buildings. The number of surveyednon-residential buildings was limited with wide variation in type. The average age of the buildings was 16 years with 1.37 stories on average. Construction materials of the 50% of the surveyed buildings were RCC and other 50% were of mixed structures of wood and concrete.

Table 3: Summary of surveyed statistics of non-residential buildings

Questions	Response	
	Average	Range
Building age (years)	16	8-30
Building plinth area (m^2)	84	22-240
Construction material	Wooden: 0; Concrete: 50%; Mixed: 50%	
Number of stories	1.37	Single: 24; Double: 0; Higher: 4
Height of 1st floor (m)	3.83	3-8
Availability of flood insurance for building (structure and content)	No	No
Basement Floor availability	0	0
Present replacement value of building structures (million Baht)	2.71	0.62-12.0
Present replacement value of building contents (million Baht)	17.57	0.03-200.0
Maximum flood heights in last 8 years (m)	0.2	0.10-0.5
Available flood warning (hrs)	0	0
Warning time needed to remove all transportable contents (hrs)	64	24-94
Potential damage could be prevented by warning (%)	47	15-90

Based on the data of the questionnaire survey, it was targeted to develop four categories of loss functions for residential and non-residential buildings, which are same as the categories used in the standard loss estimation methodologies (Parker et al., 1972; Smith et al., 1983; NTIS, 1996; Dutta et al., 2003). These four categories are as follows;

- Category 1: Damage to building structures,
- Category 2: Damage to building contents/stocks,
- Category 3: Damage to outside properties, and
- Category 4: Emergency and cleaning costs due to floods.

Initially, residential buildings were divided into two groups based on their construction materials: wooden and non-wooden (concrete), for establishment of loss-functions. However in the final analysis, these two datasets were merged as no significant difference was observed in damage to building structures due to construction materials. It happened due to the small amount of damage to building structures observed in the surveyed samples. It was observed that damage to different categories was significantly varied with the duration of floods and due to that flood duration was considered as one variable in loss function development.

Figures 3-6 show the best-fitted loss-functions of the four categories for residential buildings. Amount of data were not enough to consider more than two-day duration of floods for any categories except for the category 1. The depth-damage functions of category 1 shows a logarithmic relationship for different flood durations. Other depth-damage functions mainly show the linear relationship. From these figures, it can be observed that the statistical significance of the best-fitted functions are low except for the linear depth-damage function of building contents for 1-day duration, which has R-square value of 0.82. The depth-damage functions of category 1 for different durations show the lowest significance, which can be attributed to the negligible amount of structural damage to the surveyed buildings due to low floodwater depth.

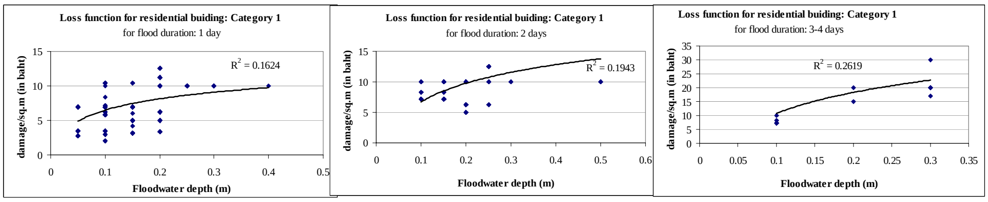

Fig. 3: Established depth-damage functions for residential buildings (Category 1: building structure) for different duration of flood inundation based on survey

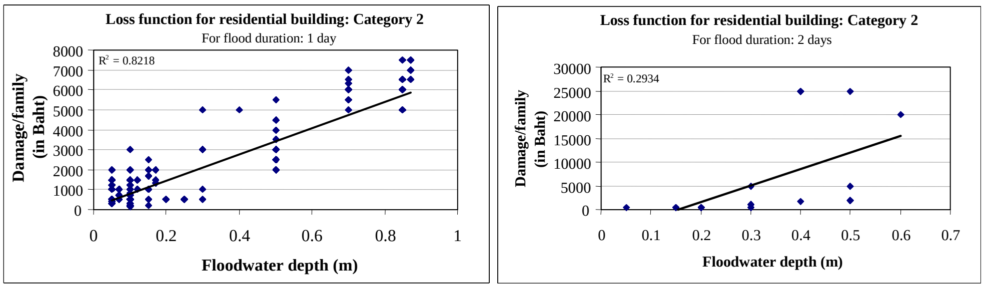

Fig. 4: Established depth-damage functions for residential buildings (Category 2: building contents) for different duration of flood inundation based on survey

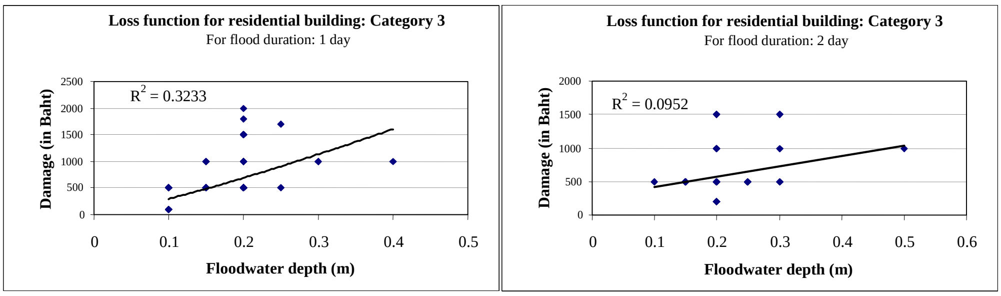

Fig. 5: Established depth-damage functions for Residential buildings (Category 3: outside properties) for different duration of flood inundation based on survey

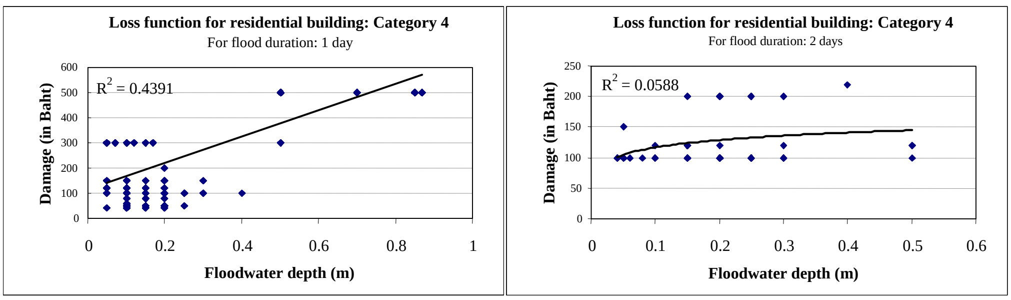

Fig. 6: Established depth-damage functions for Residential buildings (Category 4: emergency costs) for different duration of flood inundation based on survey

The flood damage statistics of the sampled non-residential buildings were not significant enough to fit any depth-damage function. As the averaged maximum floodwater height in the sampled buildings was only 20cm during the past 8 years, there was no damage observed to building structures and content or stocks in most of the surveyed non-residential buildings.

Based on the estimated damage to residential and non-residential buildings due to hypothetical floods of different durations, hypothetical loss-functions were established for the four categories. Figures 7 and 8 show the best-fitted hypothetical loss-functions of the four categories for residential and non-residential buildings.

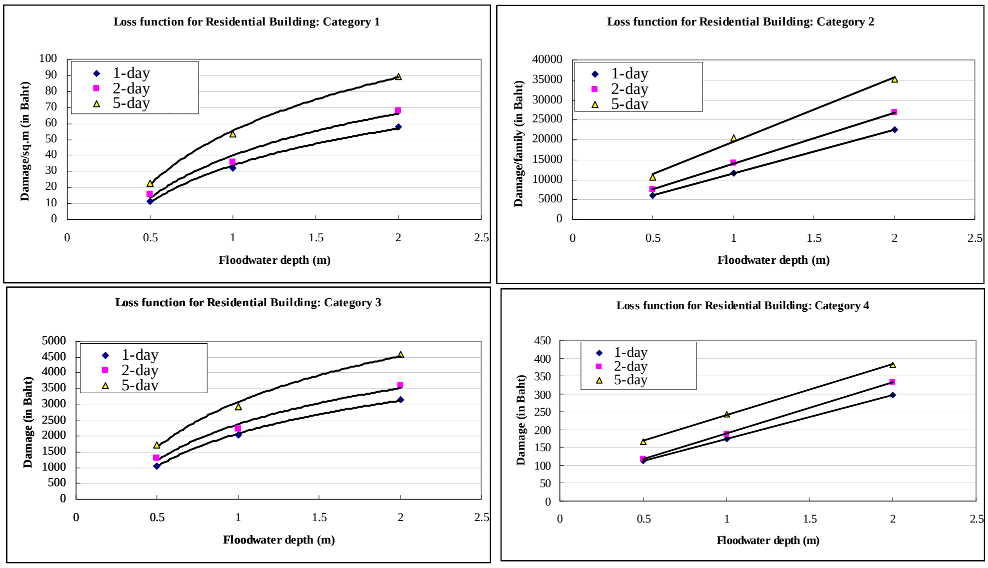

Fig. 7: Hypothetical depth-damage functions for residential buildings for different flood durations

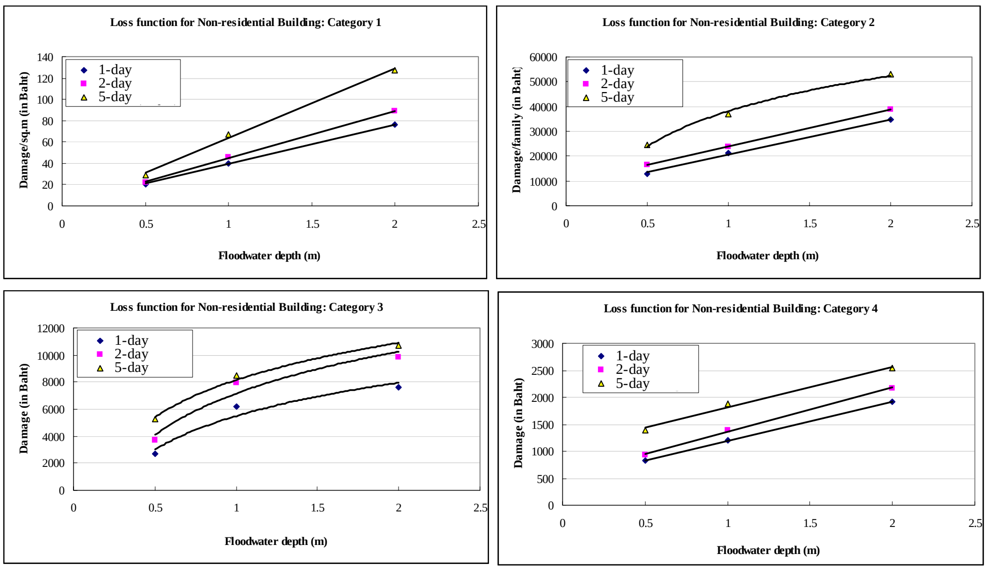

Fig. 8: Hypothetical depth-damage functions for non- residential buildings for different durations

The depth-damage functions of categories 1 and 3 for both the residential and non-residential buildings show logarithmic relationships. Other categories show linear relationship for different duration of floods.

There were some other important information obtained from the questionnaire survey. It showed that there was no flood warning system available for the people. Although the response to requirement of flood warning time varied widely (for residential buildings: 6-72 hours; for non-residential buildings: 24-94 hours), the importance of flood warning can be understood from the responses. On average more than 60% of damage to movable contents can be reduced for both residential buildings and non-residential buildings if flood warning is provided.

6. CONCLUSIONS

This paper presents the summary and analysis of a questionnaire survey conducted for development of loss functions for urban flood risk analysis in Bangkok. Based on the outcomes of the survey, four categories of loss functions were established for residential buildings. The depth-damage functions for residential-building contents show the highest statistical significance, whereas the other functions show low or negligible statistical significance. It may be due to the limited number of samples and the low damage caused by the flood events covered in the questionnaire survey. Nevertheless, the survey helped establishing hypothetical flood loss functions for both residential and non-residential buildings. Most of the participants in the surveyed area have experienced floods many times in the last eight years. Due to these recent experiences, their interpretation of damage to the hypothetical flood inundation heights should be reasonably well. Therefore, the established loss functions can be considered as the representative loss functions for risk analysis. The survey also showed the importance of the flood warning system for reduction of flood damage.

This study was the first attempt of its kind to establish detailed flood loss functions in Bangkok. Most of the people participated in the questionnaire survey had no past experience of such questionnaire survey. In such situation, the responses of the participants to the questionnaire survey varied significantly. The flood events considered in the questionnaire survey did not cause much damage to the selected buildings as the floodwater depth was less than 50cm on average. Due to this, the established loss functions can be applied flood loss estimation due to higher magnitude floods.

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REFERENCE

Berning, C., L.D. Plessis and M.F. Viljoen (2001). Loss functions for structural flood mitigation measures, Water SA Vol. 27, No. 1, pp. 35-38.

Dutta, D., S. Herath and K. Musiake (2003). A Mathematical Model for Flood Loss Estimation, Journal of Hydrology, Elsevier Science, Volume 277, Issue 1-2 June, pp. 24-49.

Plate, E.J. (2002). Flood Risk and Flood Management, Journal of Hydrology, Elsevier Science, Vol. 267, Issue 1-2, pp. 2-11.

NTIS (1996). 'Analysis of Non-residential Content Value and Depth-Damage Data for Flood Damage Reduction Studies', National Technical Information Service, U.S. Department of Commerce, USA.

Parker, D.J. and E.C. Penning-Rowsell (1972). 'Problems and Methods of Flood Damage Assessment', Report 3, Middlesex Polytechnic Flood Hazard Research Center, Enfield, UK.

Smith, D.I., T.L. Lustig and J.W. Handmer (1983). Tangible Urban Flood Damage: An Outline Manual, Proceedings of the 2nd National Conference on Local Government Engineering, Institute of Engineers, Canberra, Australia, pp. 376-381.

Smith, D.I. (1994). Flood Damage Estimation – A Review of Urban Stage-Damage Curves and Loss Functions, Water SA, Vol. 20, pp. 231-238.

Vibulsresth, S. (2003). Urban Landuse Study with High-Resolution Satellite Imagery, Proceedings of the 2nd International Symposium on New Technologies for Urban Safety in Mega Cities of Asia, ICUS, The University of Tokyo, Japan, Oct.

Tang, J., S. Vongvisessomjai and K. Sahasakmontri (1992). 'Estimation of Flood Damage Cost for Bangkok', Water Resources Management, 6, pp. 47-56.