Incorporating wind damage in potential flood loss estimation

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Abstract: Despite concentrated global efforts, flood losses worldwide are increasing. This trend is expected to escalate further due to climate change. The fourth IPCC report has explicitly warned against increase of flood disasters and recent studies show increased rainfall intensities and intensification of typhoons will contribute to further increases in flood losses. Estimation of potential flood losses can play an important role in investing for prevention as well as for developing financial instruments to reduce flood risks. However only a few flood loss estimation models consider damages caused by wind effects during flooding. The main objective of this paper is to review and discuss the possibility of incorporating wind induced damage in urban flood loss estimation. First, an overview of the flooding loss and damage models is presented. Then, the applicability of flood loss estimation with inundation using loss function and inundation modeling is introduced as an example in the Ichinomiya River basin, Japan. Finally, an approach to estimate wind damage loss on urban buildings during flooding events is introduced. The flood damage case study is then analyzed to assess wind related damage.

Keywords: Urban flood, wind damage, loss estimation

1. Introduction

Disaster Risk Reduction, Global Review, 2007, prepared by United Nations (UN) analyzed the global trends of disasters and main issues needed to be addressed in reducing disaster risks. The analysis is mainly based on the data available in EM-DAT Emergency Events Database (OFDA/CRED, 1988). Recent disaster trends from 1980 to 2005 reveal that while mortality associated with geologic hazards has increased since 1990's mainly due to 2003 Bam earthquake, 2004 Indian Ocean earthquake and 2005 Kashmir earthquake, mortality associated with climate data has remained unchanged while that associated with droughts have dramatically reduced. This trend in stabilizing mortality is significant when the same data sets show that number of disasters has almost doubled between 1995 and 2005. This may be due to an increased effectiveness of warning and preparedness as well as a rapid increase of reports of small scale climatic hazards that does not cause deaths. The same analysis also shows that if mega disasters with over 10,000 deaths are excluded mortality associated with climatic disasters is increasing at a rate faster than global population increase (Burby, 1998).

In the case of economic risks, there is a clear upward trend of economic losses according to data compiled by Munich Re. (Munich Re., 1997). From the data of great natural disasters from 1950-2006, climatic events (windstorms, floods and extreme temperatures) comprise 71% of all large scale economic disasters and accounts for 69% of total economic losses while causing 49% of mortalities. Thus, the economic impact of climatic events has a much higher share among all disasters compared to mortality. In this distribution, floods comprise 25% of all events, accounting for 24% of total economic losses, while causing 7% of fatalities (Munich Re., 2001).

Disasters result from a combination of natural hazards events and the degree of exposure and vulnerability of the society. The trend in increasing economic risk of extreme events in recent times can be attributed to the increased concentration of population and assets in vulnerable areas. According to Munich-Re there had been 20 ‘great natural catastrophes’ between 1950 and 1959 that

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has caused US$ 38 billion economic losses where as the number of such disasters has increased to 82 between 1990 and 1999 causing US$ 535 billion damage. It is clear that damage from 'catastrophic events', rare events that go beyond the coping capacity of infrastructure, inflict heavy losses and these losses are increasing.

In addition to the increase of exposure, climate change increases risk from natural hazards. The recently released Intergovernmental Panel on Climate Change (IPCC) report 4 has explicitly warned against increase of flood disasters as a consequence of climate change. The working group II that focuses on Climate Change Impacts, Adaptation and Vulnerability, has identified following risks; In Asia, glacier melt in the Himalayas is projected to increase flooding, and rock avalanches from destabilized slopes. Coastal areas, especially heavily populated mega-delta regions in South, East and Southeast Asia, will be at greatest risk due to increased flooding from the sea and, in some mega-deltas, flooding from the rivers. Europe will experience increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storms and sea-level rise). In Australia and New Zealand, on going coastal development and population growth in areas such as Cairns and Southeast Queensland (Australia) and Northland to Bay of Plenty (New Zealand), are projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050.

The current characteristics of flood risk increase, coupled with intensification of flood risks associated with climate change, require increased efforts to reduce future flood losses. The current flood risk reduction emphasis on saving lives has produced positive results as indicated by the trends discussed above. However, this approach should be complemented by protecting livelihoods and economic assets. The concentration of economic assets in areas exposed to climate hazards would continue to grow and will not be protected by improved early warning, preparedness and response although they are effective against reducing mortality. This protection should be provided by safe buildings, developing basic flood protection infrastructure, risk sensitive planning and ensuring adequate investment. Use of financial instruments in reducing basin wide flood risk, need to be utilized more to make flood reduction strategies sustainable. In this regard assessment of potential economic losses is a pre-requisite for allocate necessary investment as well as to establish safety mechanisms to finance rapid recovery and absorb losses.

2. Estimating potential flood losses

There are basically two methods in carrying out flood damage estimations. One is to carry out a thorough questionnaire survey of affected population and properties to estimate the incurred loss after a flood disaster. The other is to use what are known as stage-damage functions which describe the damage extent to different types of property for a given inundation depth and inundation duration. The second approach can also be used to estimate potential flood loss for an anticipated flood if the resulting inundation can be projected with reasonable accuracy. Some of the most important issues in using this method for flood loss estimation are obtaining detailed flood parameters such as flow velocity, depth and duration at any given location; proper classification of damage categories considering nature of damage; and establishment of functions between flood parameters and damage for different damage categories (Dutta et al., 2003). Generally, flood damage functions are determined using a specified relationship between flood characteristics (usually depth) and the extent of economic damage (Jonkmana et al., 2008). Stage damage curves were first proposed in the USA in the 1960s (White, 1964; Kates, 1965). Since then, methods for flood damage estimation have been developed in several other countries (Penning-Rowsell and Chatterton, 1977, Parker et al., 1987, Dutta et al. 2003). Most stage damage functions include water depth as the main determinant of direct damage. Kreibich et al. (2005) and Thieken et al. (2005) also investigated the influence of other factors, such as flood duration, contamination and preparedness for flood damage based on data for the 2002 floods in Germany. However, different countries or agencies define the flood damage in different ways. For example, the U.S.A National Weather Service (NWS) defines flood damage more narrowly than many other agencies. Emergency management agencies generally include both river and coastal flooding whenever water rises to overflow land that is not normally submerged. In contrast, the NWS estimates include only flooding whose primary cause is rainfall, snowmelt, or river flows, excluding flooding caused by wind-driven waves associated with coastal storms or hurricanes. In recent decades, there is an increasing recognition of the importance of considering combined impacts of floods associated with strong winds, but no scientific analysis of the problem has been made so far. One of the reasons is that it is sometimes impossible to separate damage by flood and other storm-related causes (e.g. wind, hail, snow, or ice). Typically, the total losses are labeled as flood damage if heavy rain or river flows are considered to be the primary cause. Thus, the flood damage estimates are sometimes inflated by effect of other causes. Conversely, flood damage may be omitted when the major cause of damage is wind (hurricanes, tornadoes), snow, or ice.

The main objective of this paper is to review and discuss the possibility of incorporating wind induced damage in urban flood loss estimation.

3. Methodology for flood loss assessment

Given the complex interrelated processes that can cause and influence floods, defining and classifying all of them is not simple. For example, flood is defined as “the presence of water where water does not normally appear” (OED, 2003), or “a temporary covering of land by water as a result of surface waters (still or flowing) escaping from their normal confines or as a result of heavy precipitation” (Munich Re, 1997), or “significant rise of water level in a stream, lake, reservoir or a coastal region.” (UNDHA, 1992). Flood type definitions often reflect both the source of the event (coast, river) and the flood characteristics (water depth, rise rate). Three types of floods are distinguished as: coastal, river and flash floods (Berz et al., 2001; French and Holt, 1989). Tsunamis and tidal waves are generally treated as separate hazards, although they also result in flooding. Also dam breaks are often considered as distinct hazards, as they are considered “manmade” events and floods as “natural” disasters.

Accordingly, the consequences of a flood encompass multiple types of damage, i.e. they are multi-dimensional. In **Table 1**, a classification of various types of damages characterizing flood and wind events was summarized (Smith, 1994; Dutta et al., 2003; Kelman and Spence, 2004; etc.). There is a distinction between direct damages inside the flooded area and indirect damages that occur outside the flooded area (Jonkmana et al., 2008). Direct economic losses are caused mainly by material losses and in general it is possible to classify them into the loss of property, losses to the infrastructure and also to the environment. Another distinction is made between tangible damages that can be priced, and intangible damages for which no market prices exist. Direct costs are closely connected to a flood event and the resulting physical damage. In addition to immediate losses and repair costs they include short-term costs stemming directly from the flood event, such as flood fighting, temporary housing, and administrative assistance. By contrast, indirect costs are incurred in an extended time period following a flood. They include loss of business and personal income (including permanent loss of employment), reduction in property values, increased insurance costs, loss of tax revenue, psychological trauma, and disturbance to ecosystems. They tend to be more difficult to account for than direct costs (Pielke et al., 2002).

The spectrum of damages that a flood brings about includes economic, political, social, psychological, ecological and environmental damages, all of which are often intertangled in a complex network of modern societies. Each of them alone cannot represent an intricate disaster phenomenon, rather all of them together contribute to the compound picture of disaster consequences. In fact, each of the mentioned damage dimensions needs a model of its own

(Jonkmana et al., 2008). The methods for the estimation of direct economic damage to physical objects (such as structures, houses) are well established, i.e., the conventional way of flood damage estimation in different countries around the world is the stage-damage functions defining the relationship between flood parameters and possible damage, which are derived based on historical flood damage information, questionnaire survey, laboratory experiences, etc. (Krzysztofowicz and Smith, 1994; Kok et al.,2005). However, the methods for the estimation of indirect and intangible damage are less well developed so far (Stuyt et al., 2003, Ahern et al., 2005). In addition, the height of losses is also influenced by the flooding hazard quantified by flood characteristics such as water depth and flow velocity, the duration of flooding and rate of water level increase, the temperature of the water and its quality, sediment transport and some other factors (Kelman and Spence, 2004). Climatic factors such as wind velocity, air temperature and humidity, ice development, etc. are also of importance. Especially, wind and waves often suddenly change water velocity and depth. During a storm surge flood, a sudden shift in wind direction may permit the sea to swiftly drain away in a phenomenon known as an ebb surge (Heneka and Ruck, 2004). The physical forces and pressures created by the sudden retreat of water can exceed those imparted by the ingress of water into a community. As well, powerful gusts of wind, spikes far above the 3-s mean, may destabilize a building under pressure from the flood's lateral pressures. In risk analysis, only a few of the above-mentioned factors are usually taken into account, namely water depth and velocity, and the type and foundation of the structure (Kreibich et al., 2005; NAP, 1999).

Table 1 Different dimensions of flood and wind damages

	Tangible and priced	**Intangible and unpriced**
Direct	Residential building	Injury
	Industrial area	Fatalities
	Recreational and sports facilities,	Inconvenience and moral damage
	Shopping area, Gas station	Animal
	Water work, water and gas supply	Environmental loss
	Sewerage, road	Cultural loss
	Roads, utility & communication infrastructure	Utilities and communication
	Capital asset & inventory	Inconvenience and moral damage
	Agricultural land & cattle	
	Vehicle	
	Business interruption (inside the flooded area)	
	Clean up cost, etc	
Indirect	Temporary line, bypasses, housing	Menace of infections and epidemics
	Standby transport facilities	Psychological traumas
	Consumption outside the flooded area	Undermined trust in public authorities
	Additional travel expense and time delay	Societal disruption
		Hygiene problem

4. Assessing the applicability of flood loss estimation with inundation forecast

A number of studies are reported in literature that describes stage-damage functions derived from post flood damage analysis (Parker et. al., 1987; Smith, 1994; etc.). In Japan and United Kingdom, the procedures are standardized to estimate flood damage for any part of the country using normalized stage-damage functions. The main purpose of these procedures is appraisal of flood control projects through standardized economic loss assessment. The approach can be used to estimate the effectiveness of a particular flood control project in terms of benefit compared with no-flood control mechanism scenario.

The methodology of flood loss estimation is outlined through the **Figures** 1, 2 and 3. The **Figures** 1 and 2 show samples of depth damage functions for Japan established through field sampling of flood events carried out continuously since 1950's for content and structural damage of residential buildings. In order to estimate the potential flood loss, firstly, the flood inundation map is prepared as shown in the top layer of **Figure** 3, either from numerical simulation corresponding to a future scenario or from past inundation data, in a GIS environment with high spatial resolution. Next, an asset map categorized according to available depth-damage functions is prepared and the properties distributed at same grid resolution as in the inundation map. Using the depth-damage functions and these two layers, the distribution of flood loss can be estimated as shown in the last layer of the map in **Figure 3**.

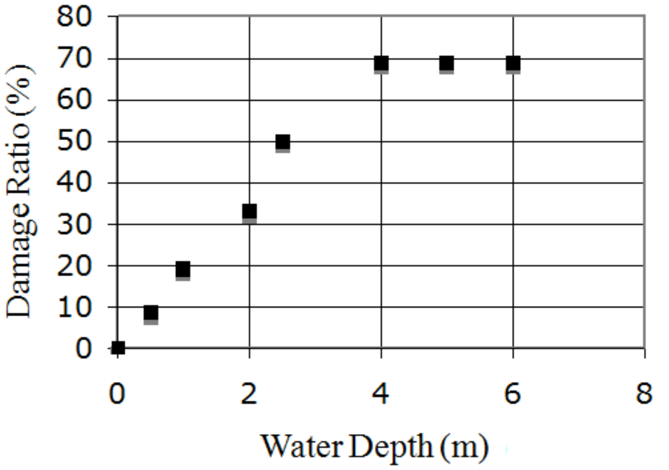

Figure 1 Depth damage function for residential content

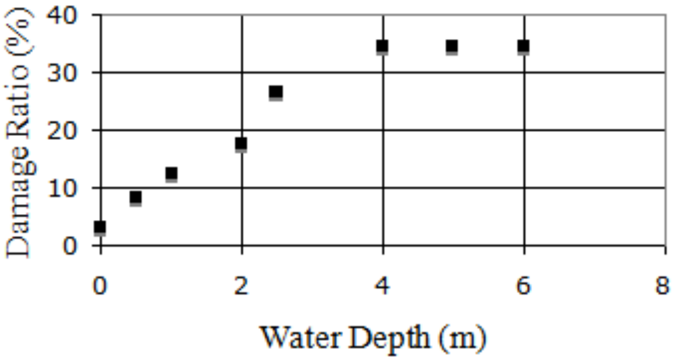

Figure 2 Depth damage function for residential structure

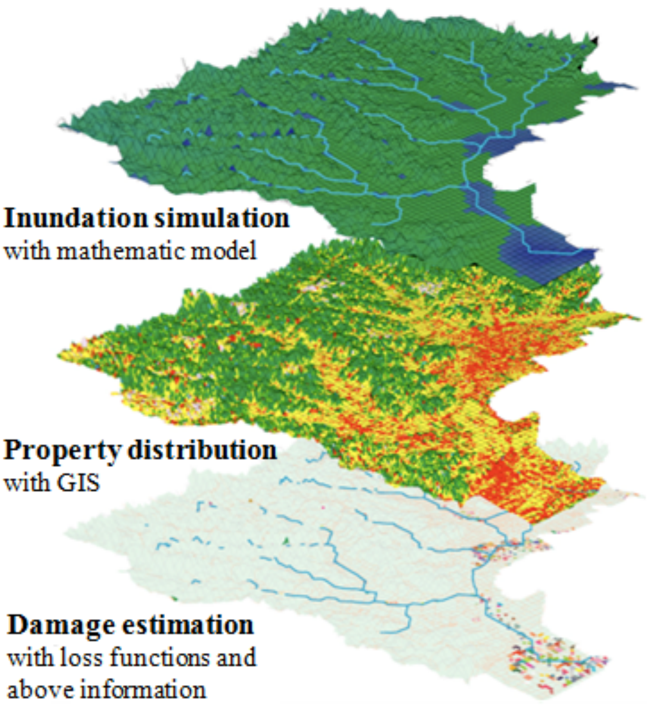

Figure 3 Procedure for flood loss estimation

The above methodology was applied in a case study to assess the effectiveness of different river improvement works in reducing flood losses. The study area is a moderate size basin, named Ichinomiya river basin, with an area of 220 km^2, located in the Chiba prefecture, Japan between latitude 35° 18´ N to 35° 30´ N and longitude 140° 10´ E to 140° 25´ E. The mean annual rainfall is approximately 1,700 mm and total population within the basin is about 144,000 mainly concentrated in the urban areas in lower flat part of the basin. The basin has suffered a large scale flood in 1996 and a detailed field survey has been carried out to assess the total flood damage. The main categories of depth-damage functions used in Japan are shown in **Table 2**. In this study the following procedures were carried out.

Established a detailed GIS using remote sensing and administrative data at 50m grid scale.
Estimated the flood loss using actual flood heights observed in the ground and compared with the flood damage assessment carried out using the GIS.
Carried out numerical simulation to establish inundation map to estimate potential flood loss and assessed the accuracy of predictions compared to the field survey as well as estimations done with actual flood height observations.

Details of these studies are given in Herath et. al. (1999) and Dutta et. al. (2006). The main results of the studies were:

1. The flood loss estimation from the established GIS using the measured water heights match very well with the flood loss estimated from field survey. This means that asset distribution is adequately represented in the GIS.
2. Damage estimates from actual water levels and those from the simulated water levels tend to have some discrepancy in the structural damage assessment, where as the content damage is estimated correctly. This error could be due to discrepancies associated with inundation modeling as well as use of grid averaged elevation for deriving damage coefficients. The comparisons of different estimates are shown in **Figure 4**.

3. The methodology adopted can provide information on flood loss distribution, enabling to understand investment that can produce the maximum benefits. The **Figure 5** shows the spatial distribution of flood damages to residential content.

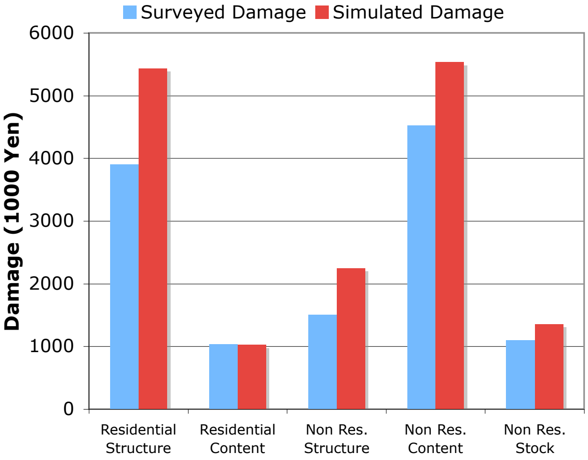

Figure 4 Comparison of flood loss estimations from different damage coefficients and inundation estimates (Unit of Y-axis: 1000 Yen)

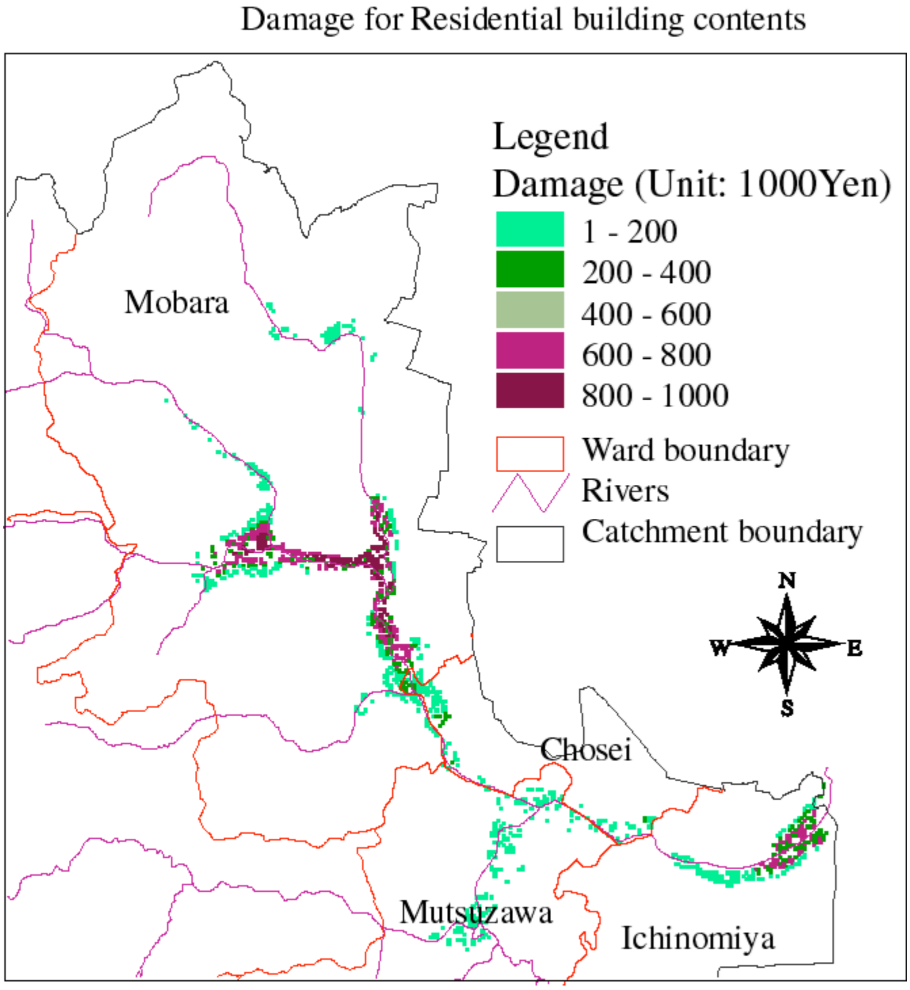

Figure 5 Distribution of residential flood content damage

Table 2 Main categories of depth-damage functions used in Japan.

Damage Category	Details considered		Normalizing parameters	Influencing flood parameters
Urban Residential Damage	Structure	Wooden	Floor area, region	Flood depth
	Contents	Non-wooden All types	Household unit	
Urban Industrial Damage	Structure	Ten types of industry classes	Number of employees, region	Flood depth
	Content	Ten types of industry classes		
Crop Damage	Nine types of major crop classes		Crop area, production per crop, unit price per crop	Flood depth, duration, season

5. Estimating wind damage on urban buildings

Despite the enormous impacts of floods on global scale a limited number of models are available for the estimation of loss of damage caused by floods. All of the models include some kinds of damage function which relates damage to flood related characteristics. Few of the models consider damage to urban buildings in the flooded area caused by wind effects during flooding. **Table 3** shows the general descriptions of urban building's damage due to wind (Smith, 1994; Kelman and Spence, 2004; Heneka and Ruck, 2008; etc). Basically, it can be categorized as direct and indirect damage. The direct building damage occurs most frequently to roofs, walls, claddings and openings. Indirect building damage due to wind borne debris is dominated by broken trees. Wind damage estimation can be done either at large spatial units or at individual building unit scales. The methodology described above for flood damage estimation can be carried out for individual building units and it can be combined with wind damage estimated either at mesoscale or at individual building scale.

Mesoscale assessments of storm damage aim at loss determination on the spatial unit of postal-code zones or municipalities with a country-wide extent (Kelman and Spence, 2004; Heneka and Ruck, 2004). For mesoscale damage assessment, some models have been developed which can be summarized as qualitative and quantitative models. The latter are subdivided into empirical, theoretical and stochastic models (Heneka and Ruck, 2008). Qualitative models describe the consequences of extreme wind speeds by means of their visual effects of natural phenomena on structures. They calculate building damage in relation to available meteorological and structural information such as wind speeds, storm duration, and building type.

Table 3 Descriptions of urban building's damage due to wind.

Damage type	Damage description
Direct damage	Light damage to roof tile
	Shingle removed, leaving decking exposed
	Roof partly uncovered, light damage to structure
	Half loss of roof sheeting, some structural damage
	Change in roof-surface elevation
	Severe damage to roof, loss of roof sheeting
	Loss of roof structure, some damage to wall
	Severe damage to structure, some collapse
	Original roof edge are not intact
	Loss of all wall
	Collapse of some building
	Total collapse of all building, etc.
Indirect damage	Rain falling into house from opened roof and window
	Function of the utilities inside house is damaged, etc.

5.1 Building damage due to wind

For the development of wind damage functions, where the storm damage can be assigned to a certain wind speed, the investigation of the vulnerability of structures during winds is necessary. An overall scheme of the damage process during a wind event was summarized in Unanwa et al. (2000). From it, each building component may suffer damage either through the direct impact of the wind or as a result of damage of other components (i.e., damage propagation). Each building component (except the structural system and interior) in the damage model is connected with three lines. The first line indicates its contribution to the propagational damage of other components, while the second and third lines show the component's direct (basic) damage and propagational damage, respectively (Unanwa et al., 2000).

5.2 Relationships between wind speed and losses of urban buildings

The loss due to wind on buildings is assessed through two stages. In the first stage, the damage ratio is established as a function location which describes the exposure and the wind speed. The former is estimated from past data and its spatial variation should be known for a given census track or a postal code zone. The relation between damage ratio for a given location and the wind speed, normally the gust speed, is used to obtain the damage ratio. The second stage is the establishment of loss rate which defined as the ratio of the insured loss to a replacement value in the building. Again the loss rate is expressed as a function of surface wind speeds, termed loss rate curve, and is established from past insured loss data. However, the uncertainty in determining the loss rate and wind speed is very large. The factors responsible for this uncertainty are the differences in the building strengths, exterior material used, quality of the building construction, etc (Watabe et al., 2005). In the Hazus-MH model (Vickery et. al., 2006) a physical damage modeling approach is used where a given storm is modeled and used to assess the damage on exterior component using a load resistance methodology.

Table 4 Damage States for Residential Construction Classes (Vickery et. al., 2006).

Damage state	Qualitative damage description	Roof cover failure	Window door failures	Roof deck	Missile impacts on walls	Roof structure failure	Wall structure failure
0	**No damage or very minor damage** Little or no visible damage from the outside. No broken windows, or failed roof deck. Minimal loss of roof over, with no or very limited water penetration.	≤2%	No	No	No	No	No
1	**Minor damage** Maximum of one broken window, door, or garage door. Moderate roof cover loss that can be covered to prevent additional water entering the building. Marks or dents on walls requiring painting or patching for repair.	>2% and ≤15%	One window, door, or garage door failure	No	<5 impacts	No	No
2	**Moderate damage** Major roof cover damage, moderate window breakage. Minor roof sheathing failure. Some resulting damage to interior of building from water.	>15% and ≤50%	> one and ≤ the larger of 20% and 3	1to3 panels	Typically 5to10 impacts	No	No
3	**Severe damage** Major window damage or roof sheathing loss. Major roof cover loss. Extensive damage to interior from water.	>50%	> the larger of 20% and 3 and ≤50%	>3 and ≤25%	Typically 10 to 20 impacts	No	No
4	**Destruction** Complete roof failure and/or failure of wall frame. Loss of more than 50% of roof sheathing.	Typically >50%	>50%	>25%	Typically >20 impacts	Yes	Yes

Table 4 shows an example of the damage state definitions used in Hazus-MH model for single-family residential buildings. Such definitions are used for all types of buildings defined in the model (Vickery et. al., 2006; Ishihara et al., 1995). As shown in **Table 4** the damage is categorized by 5 stages, varying from 0 (no damage) o stage 4 which signify total collapse. The mean number of particular building type expected to experience a given damage state for a study region are extracted from the model database, which are defined for each census track. An example probability stage damage ratio vs. peak gust wind is shown in **Figure** 6. **Figure** 7 and 8 show a number of damage ratio functions used by different organizations based on field data. This does not distinguish among different damage levels. Once the damage probability is known, the economic loss associated with the damage to the building is estimated using the economic loss rate functions. Loss rate defines the total loss ratio with respect to the building cost. Some of the loss ratio functions used in industry is shown in **Figure 7** (Haneka and Ruck, 2008). This approach is compatible with the flood damage estimation method, where the percentage loss compared to the cost of the building is estimated by the flood loss estimation models.

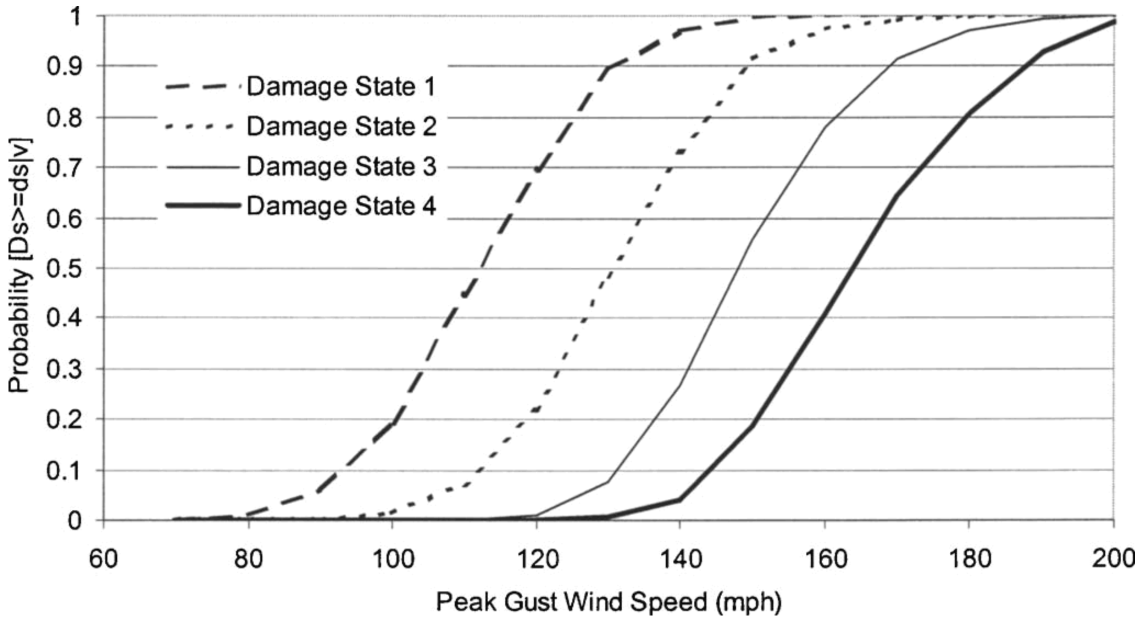

Figure 6 Example building damage state versus peak gust wind speed function (from Vickery et. al., 2006).

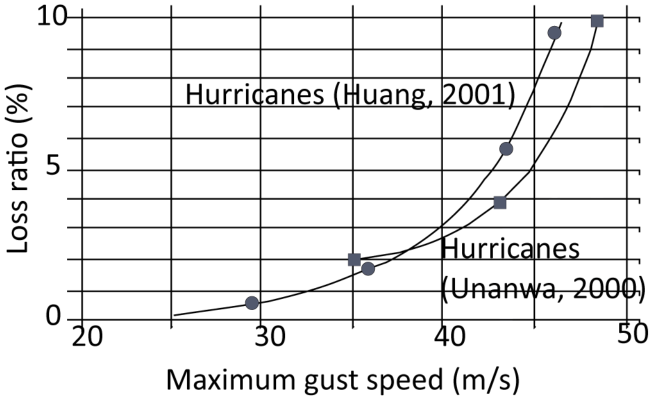

Figure 7 Wind damage used by different organizations (from Heneka and Ruck, 2008).

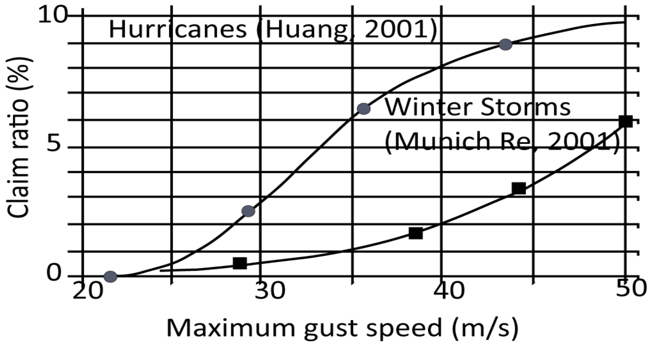

Figure 8 Loss ratio functions of Huang (2001), Munich Re (2001)

The wind speed of Ichinomiya during an example flooding averaged over 10 min is shown in **Figure 9**. Ideally, the gust factor can be used to calculate the gust wind speed. However, the gust factor is influenced by many factors, e.g., height, ground roughness condition, wind speed, etc., which makes the calculation of gust factor complicated. In addition, the reliability of the calculated gust factor is based on the quantity and quality of wind observation samples. In this study, due to lack of available data for the event simulated, we assumed the relationship between the maximum gust wind speed and the maximum average wind speed (10 minute averaged) is linear. The peak gust wind speed in the study area had been estimated as 50m/s based on a numerical model simulation (Watabe et al., 2005). AMeDAS (Automated Meteorological Data Acquisition System) data were used to set the maximum average wind speed for the area for the simulation period (1th October, 2002). The coefficient between the maximum gust wind speed and the maximum average wind speed can be thus estimated as 50m/s÷16m/s=3.1m/s. Then the maximum gust wind speed in the flooding event is estimated as 11m/s*3.1=34.1m/s, where 11m/s is the average wind speed from AMeDAS records for the event. This value may be considered to be on the higher side, but we used this value in the present study due to two reasons. Firstly the factor we used as gust factor would be more of a transfer coefficient from AMEDAS data to simulated values in the absence of observed data. Secondly, according to Okda et. al. (2002) new wind load provisions in revised building code in Japan, gust factors range from 2 (zone I) to 3.1 (zone IV). As per the recommendations of Architectural Institute of Japan (AIJ), zone I corresponds to open space where as zone IV corresponds to city (rough) space in close proximity to sea. The study site, Ichinomiya City, is located by the sea and is close to zone IV in this categorization. Although the winds are not extensive to cause wide spread damage, based on the **Figure 7**, a loss rate of 0.5% is assumed. Here, the definition of the loss rate is a ratio of the insured loss to a replacement value in the building (Watabe et al., 2005). The number of houses flooded in the 1996 floods was 237 with average cost per structures at 170 million yen. If we assume all flooded houses were subjected to roof damage, the total loss amounts to 202 million yen. Compared with surveyed values in **Figure 4**, this is 5% of structural building damage, or 4% of total damage that include both structural and content damage. Compared with simulated structural and total damage, the roof damage amounts to 4% and 3% respectively.

The total number of detached houses in Ichinomiya basin was estimated as 30265. The number of flooded houses, 237, constitutes 1% of the total houses. While all flooded houses may not contain wind induced damage the houses that are not subjected to floods could be affected by wind damage. Using the average of claim ratios (as equivalent to damage ratio) from **Figure 7**, we would expect 1.5% of detached houses or 454 to be damaged. With the same loss ratio as above, this would amount to a damage of 387 million yen or about 8% of the estimated flood only losses to residential buildings (6% of simulated flood damage).

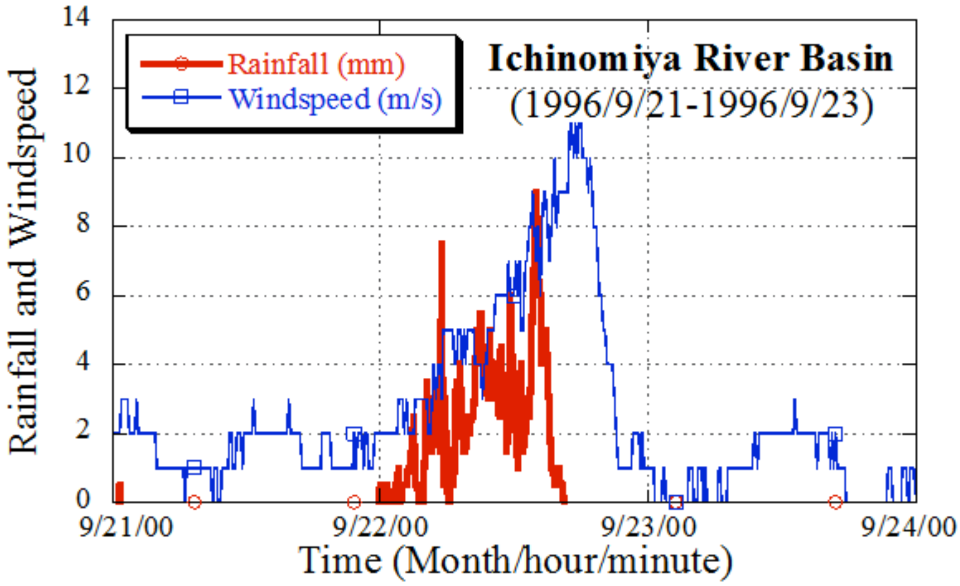

Figure 9 Wind speed and rainfall averaged over 10 minutes during the flooding event.

6. Conclusions

This paper explored combining existing wind loss estimation methods with the flood loss estimation approach for urban losses associated with both floods and winds. As flood losses are generally estimated from loss functions associated with flood levels, it is possible that associated wind damage is not included in rapid loss estimation, or when estimating potential climate related losses. In the case study considered it is seen that wind related damage could be around 4% of the flood damage for flood-affected buildings, or about 8% of the flood losses if basin wide wind damage is considered. However, further detailed case studies with wind field information and ground survey are required to arrive at range of additional losses that can be expected from combined extreme flood and intense wind events.

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