ASEAN Engineering Journal

Full Paper

EVALUATING THE PHYSICAL VULNERABILITY OF PUBLIC SCHOOL BUILDINGS AGAINST FLOODING IN METRO MANILA, PHILIPPINES

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Article history
Received
04 August 2022
Received in revised form
27 October 2022
Accepted
27 October 2022
Published online
31 May 2023

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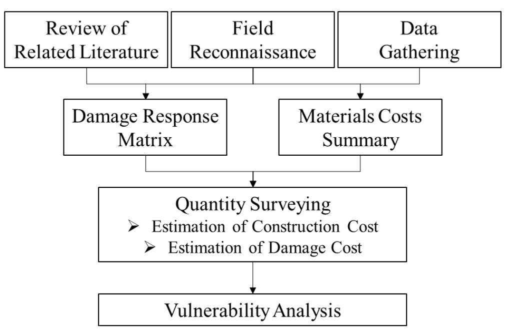
Graphical abstract



Abstract

Vulnerability analysis has always been an integral part of disaster risk assessment. This study aims to assess the physical vulnerability of public school buildings against flooding. It discusses the vulnerable elements or attributes, the extent of damages incurred during flood events, the damage response, and the future steps that must be taken to increase flood resiliency. The study used empirical data collection using semi-structured interviews to characterize the common types of public schools and to collate the damage responses. Quantity surveying was performed to measure the amount of damages related to different flood depths. Structural damages to public school buildings are not expected for flood heights ranging from ground level up to ten (10) m. However, damages are incurred by building finishes and fixtures. Floors, walls, and septic system are cosmetically damaged. Vulnerable components include wooden elements like doors, cabinets, blackboards and ceiling, and electrical fixtures such as wiring, lighting, outlets, switches, and fire alarm system. Comprehensive vulnerability description of public school buildings were represented as curves of flood depth vs. damage index. The damage ratio decreases as the number of floors increase. Maximum damage to one-story building is 23.6% while at 15.02% for four-story school building. This study is an attempt to promote further research of the subject matter in developing countries towards flood resiliency in the built environment.

Keywords: flood risk, flood damage, vulnerability curve, inundation depth, damage cost

1.0 INTRODUCTION

1.1 Background

With naturally abundant rainfall amounts and unplanned developments accompanying unmitigated population growth, vulnerability to flood disasters has become a major concern in the Philippines. According to the Department of Public Works and Highways' (DPWH) 1970-2003 flood damage records as reported by Kamoto [1], around 544 people died each year, and a total of 1,487 people were reported missing or injured. Cases of damaged households and injured people numbered to 500,000 and 2,800,000, respectively. Seventy thousand [70,000] out of 730,000 reports on damaged houses were declared to be destroyed. The total damage cost was approximately 4.6 billion PhP a year (94.6 million USD) and more than 10 billion Php (205.7 million USD) once every six (6) years. Because of these, 2% of the national budget was allocated to flood damages because of the said disaster's impacts to Philippine economy. Budget allocation of DPWH to flood control also doubled yearly.

The country's capital region, Metro Manila, is likewise greatly affected by floods. It experiences eighteen (18) to twenty (20) flood events every year, directly affecting 190,000 households and 70% of its total population [2].

Vulnerability analysis had always been an integral part of disaster risk assessment. Vulnerability pertains to the inherent quality of elements at risk to incur damage upon exposure to a particular hazard. Although the Philippines is frequented by floods, there are little to no recorded information of actual damages brought to public schools.

The aim of this paper is to provide detailed assessment of physical vulnerability of public school buildings against flooding. In particular, the following inquiries were addressed:

- What are the specific elements or attributes of a school building that are vulnerable to floods?
- Up to what extent are the building components damaged during flood events?
- How does the people respond to flood damages?
- Based on the vulnerability and response mechanism, how could flood resiliency be increased in the case of public school buildings?

The results of this study can be used by several entities. Firstly, the comprehensive evaluation presented in this paper is a first attempt to quantify physical damages brought about by floods in public infrastructures in the Philippines. International and local researchers, as well as risk managers can refer to the developed vulnerability curves as a supplementary tool in full-blown flood risk studies. Similarly, the curves can be used to develop insurance mechanisms for public schools. In a way, this research can give valuable information for the government to decide the specific disaster risk management strategy that must be adopted by public schools.

1.2 Theory and Research

Assessment of physical vulnerability to flooding is an integral part of flood risk management. There are several approaches in flood vulnerability studies, depending on the available damage data and required level of details. Indicator-based approaches with varying degrees of complexities are available as shown in the works of Nazeer & Bork [3] and Ciurean et. al. [4], and reviews of Rehman et. al. [5] and Marvi [6]. Meanwhile, flood vulnerability analysis attributed to flash floods can be done by combining GIS techniques to hydrologic-hydraulic models [7, 8]. There are also simpler methods such as vulnerability curve and disaster loss methods [9], as discussed further below.

Some countries have well-documented damage data through insurance agencies and public offices, which can be used as a major tool in vulnerability analysis. In the United States, flood damage data of the Federal Insurance Administration (FIA), the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers (USACE) are used to generate nationally applicable flood vulnerability curves incorporated in their multi-hazard risk assessment platform, HAZUS-MH [10]. In Australia, defining the vulnerability of buildings involves extensive data gathering that includes post-disaster survey and detailed damage costing [11].

In some areas where flood damages are not recorded on a regular basis, interviewing the locals is proven to be of fundamental value. Zein [12] and Sagala [13] used the concept of flood damage states in describing the physical vulnerability of buildings in Surakarta City, Indonesia and Naga City, Philippines, respectively. The method involves assigning numerical values to qualitative descriptions of interviewees, from zero (0) for "nothing is happening" to one (1.0) for "total building collapse".

In general, it is expected that the major structural components of a building will survive a flood, but that the structural finishes may be severely damaged due to inundation [10]. Generally, wooden structures are more vulnerable as compared to concrete and steel buildings. Building classifications are usually based on combinations of different floor, wall and roof materials. In HAZUS-MH, since much information are based on insurance claims data, building types are largely categorized according to occupancy class, e.g. residential, commercial, and industrial, etc.

Vulnerability of structures to floods is also influenced by human behavior. Maqsood [11] pointed out the difference in structural vulnerability between insured and uninsured buildings, mainly due to post-flood response. Coping mechanisms during flooding event are also developed in flood-prone areas, reducing the potential damages to some extent. Vulnerability assessment must also capture these factors to arrive at a more comprehensive flood risk management scheme.

Description of physical vulnerability to floods is commonly described via historical mean damage ratio [14] or stage-damage functions [15], the latter being widely accepted as better and more flexible. Inundation depth is the most common parameter linked to building damages because it is easier to identify as compared to velocity, duration, and sediment concentration associated to a flood event. One of the front-runners in published stage-damage functions can be found in the works of Dutta et. al. [15]. Stage-damage curves were derived from historical data in the repository of Japanese Ministry of Construction. Since then, several research [16, 17] used these curves in their respective flood damage assessment studies. Alternatively, some studies attempt to create own stage-damage curves as applicable to pilot sites [18]. It has also been reported that Malaysia has official flood damage functions [19]. Unfortunately, this information is not readily accessible to ASEAN research community at the moment.

Up to date, building damage assessments are mainly focused on residential units [20, 21, 22], while few literatures can be found for buildings meant for other uses, especially for public owned infrastructures like schools, hospitals and offices.

Figure 1 Standard types of public school buildings in Metro Manila as used in the study *(source: DPWH, n.d.)*

2.0 METHODOLOGY

Physical vulnerability assessment involves describing the elements at risk and evaluating their damages upon exposure to the hazard. The methodological approach was primarily divided into two (2) activities. The first was empirical data collection using semi-structured interviews to characterize the common types of public school buildings within Metro Manila and also to collate the damage responses. The second activity was quantity surveying to measure the amount of damages related to different flood depths.

In terms of physical features, the Philippines has diverse building types as described in a study of the University of the Philippines – Diliman, Institute of Civil Engineering [23]. For public schools in particular, the selection varies from lightweight makeshift buildings to steel-framed structures. However, with the overhaul in primary and secondary education system In 2013, design and construction of school buildings ever since have been standardized by the Department of Public Works and Highways (DPWH) [24]. This study focused on these standard buildings to evaluate flood vulnerability. Figure 1 shows the architectural layout of typical school buildings within the study area.

Multiple public schools were visited all throughout the study area, locations of which are shown in Figure 2. Semi-structured interviews were conducted regarding flood damages and damage responses. Inquiries about flood experiences were made, soliciting key information such as historical flood characteristics (depth, water quality and flood velocity), building properties that were damaged, and personnel activities before, during and after a flood incident. All in all, fifty (50) respondents had participated coming from sixteen (16) public schools visited. These data were collated and were used as baseline information for damage accounting and calculations.

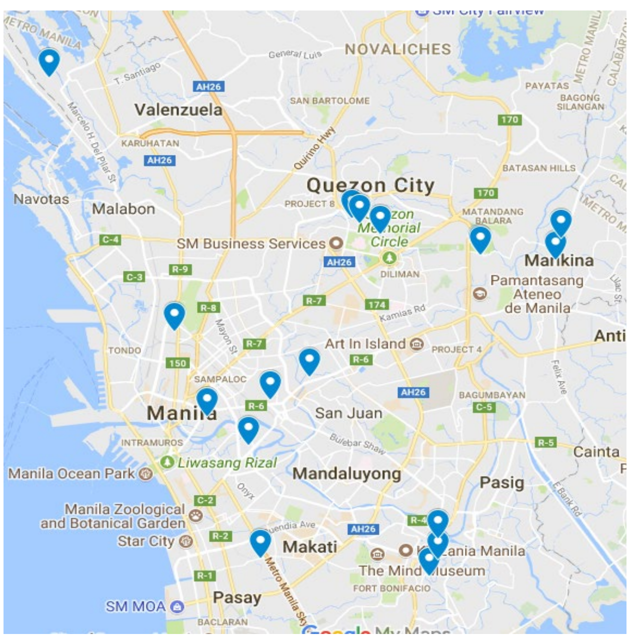


Figure 2 Relative locations of public schools within the study area where primary information came from

Physical vulnerability can be represented by vulnerability curves. For flood risk, the vulnerability curve is a plot of a flood attribute versus damage index. Based on empirical data collection, flood depth is the most critical variable as compared to water quality or velocity in the study area. Damage index is a ratio describing damage extent, ranging from 0 (no damage) to 1.0 (complete damage). For this study, the damage index was interpreted as the ratio between damage cost and construction cost, same as FEMA's definition [10]. The construction cost was obtained through quantity surveying of standard building types. In some studies, damage costs are derived from insurance claims. However, most public schools are uninsured, especially those located in high flood-risk areas. As an alternative, the damage cost was derived from itemized cost accounting. Damage costs are based on the solicited damage responses from the interviews.

3.0 RESULTS AND DISCUSSION

3.1 Characterization of Public School Buildings

Standard public school buildings in Metro Manila ranges from 1-story to 4-story structures. They are made of reinforced concrete frame compliant with the National Structural Code of the Philippines (NSCP). The walls are made of concrete hollow block masonry while the roof is made of corrugated galvanized iron sheets attached to light metal trusses. Floor-to-ceiling height of all building types across all floor levels are uniform at 3.0 m. As the region is prone to multiple hazards such as floods, typhoon and earthquake, most public schools are used as evacuation centers during emergencies. Hence, the buildings are constructed as sturdy as possible.

Table 1 shows the building costs for the four (4) types of buildings considered in this study. The cost of a bare structure is about 60-70% of the total cost while the rest is spent on the finishes composed of fabricated materials and hardware, ceiling, painting, and electrical and plumbing works.

Table 1 Construction cost of public school buildings

Building Type	Description	Total Construction Cost		Cost per Unit Area	
		thousand PhP	thousand USD*	PhP/m^2	USD/m^2*
Type I	1-storey, 4 classrooms	5,550.55	112.12	16.01	0.32
Type II	2-storey, 12 classrooms	22,608.89	456.70	18.89	0.38
Type III	3-storey, 15 classrooms	29,776.12	601.48	19.35	0.39
Type IV	4-storey, 20 classrooms	34,816.45	703.29	22.62	0.46

**based from 2021 exchange rate (1 PhP = 0.0202 USD)*

3.2 Elements of Flood Related to Damages

Different characteristics of floods affect the extent of damages to built environments. Different flood depths cause different levels of exposure. Similarly, floods of long duration have higher impact than short-term flood events. Flash floods or high-velocity floods are more dangerous than tranquil flow of water. Water quality can also play a role in causing damages.

In the study area, field survey indicated that flood damages are most sensitive to flood depths. Anecdotal accounts from the visited public schools suggested that the duration, water quality and velocity of floods resulting from multiple past events have insignificant differences in terms of the damages. An exception to this is a flood event in Mines Elementary School in Brgy. Vasra, Quezon City in 2012, when the school suffered an unusually high-velocity flood that destroyed a retaining wall and entrance gate of the school. Other than the cited instance, all flood damage accounts are related to flood levels. The subsequent vulnerability assessments were tied up to flood depths because of this important finding. The datum for all depths and heights in the succeeding discussions are reckoned from a building's lowest level's inside floor elevation.

3.3 Building Elements Vulnerable to Flood Inundation

For the study area, the load-bearing components of a building are not vulnerable to floods. There are multiple records of 1-story school buildings being completely submerged to flood water and having no structural damage at all. In the past ten (10) years, there are no identified case in Metro Manila that a concrete building had been structurally damaged by flood inundation. However, the non-structural components were found out to be vulnerable to floods. That is, different degrees of damages are expected to be incurred once they are exposed to flood. These include the following building elements:

- Floor finish
- Interior and exterior wall finishes
- Doors and Windows
- Wooden fixtures such as cabinets and blackboards
- Ceiling
- Non-movable electrical equipment including circuit breaker, wiring, outlets, lighting fixtures and switches, and fire alarm system
- Septic Tank

3.4 Damage Description and Response

In general, building finishes, electrical components, and wooden fixtures are the most affected by floods. For serviceability, cosmetic damages, or those items that must be cleaned and/or repainted, must be attended to. Floors and walls must be cleaned right after any flood event. When flood level had become high, i.e., more than 0.5 m, the walls would have to be repainted afterwards. For this scenario, the associated damage cost will sharply increase as it is more costly to repaint than clean. Also, the whole wall must be repainted, not only the flooded portions.

The electrical parts of 104ccur104l buildings are the most seriously affected by floods. Once exposed to the hazard, school administration always opts to replace the affected electrical components for safety. It must be noted that this response is different from residential houses, which majority according to GMMA RAP study [23] chose to simply let the electrical fixtures dry up and were ready to be used without repairing anything after several days.

Among the wooden components of a building, the door is the most resilient as based on conducted surveys, there are minimal damages for low-height floods. If flood is only ankle high, there can be no damages, and cleaning is enough. For knee-high floods, minor repair is enough, but for higher floods, it is normally replaced. Meanwhile, other wooden fixtures such as blackboards, ceiling and cabinets need to be replaced once inundated.

Septic tanks and fire alarm system malfunction after being flooded because of water intrusion, and therefore maintenance and/or repair are also required. Table 2 summarizes the consolidated and generalized flood damage response related to public school buildings.

Table 2 Summary of flood damage response resulting from the conducted semi-structure interviews

Building Component	Damage Response
Floor	Clean
Interior Wall	Clean (d=0.1m) / Repaint (d≥0.5m)
Exterior Wall	Clean (d=0.1m) / Repaint (d≥0.5m)
Door	Clean (d=0.1m) / Repair (d=0.5m) / Replace (d≥1m)
Window	Clean and Repair
Blackboard	Replace
Ceiling	Replace (Wood) / Repaint (Concrete)
Electrical Outlets	Replace
Electrical Switch	Replace
Other Electrical Fixtures	Replace
Lighting Fixtures	Replace
Fire Alarm System	Repair
Septic Tank	Maintenance
Roof	Clean

Direct damage costs were calculated based on typical expenses incurred in performing the damage response. Cleaning cost is derived from janitorial service cost per unit area. The same approach but at different unit cost was used for wall repainting. Repairs of windows, doors, septic tank and fire alarm system were based from actual price quotations from competitive service providers. It must be noted that replacement of electrical fixtures and reconstruction of ceiling is around 30% more expensive than the case for new building constructions. The increase is related to removal of flooded components prior to installing the new parts. Table 3 summarizes the direct damage costs per flood-levels in different building types.

Table 3 Physical damage costs of public school buildings for different flood depths

Flood Height (m)	Damage Cost per School Building Type, in thousand PhP*			
	Type I	Type II	Type III	Type IV
0	0	0	0	0
0.1	12	24	22	22
0.5	230	530	520	520
1	380	1,450	1,160	1,160
2	430	1,530	1,210	1,220
3	1,280	1,920	1,570	1,570
4	1,300	3,330	2,920	2,920
6	1,300	4,880	3,330	3,330
8.9	1,300	5,230	4,983	5,143
10	1,300	5,230	5,610	5,830

**based from 2021 exchange rate (1 PhP = 0.0202 USD)*

3.5 Flood Vulnerability Curves

Another reliable presentation of flood stage-damage relationship is by using damage indices instead of damage costs. This way, the time-value of money is removed and hence damage description is normalized. Figure 3 shows the vulnerability curves for the analyzed building types. Maximum flood depth of 10 m was used in the evaluation as this is the maximum reported flood height within the study area. In the figure, the points represent the calculated damage indices. To generate the curves, linear connection was made between adjacent points. The results are fundamentally different from the ones derived from fragility curves of past studies [12, 13] wherein the vulnerability curves are presented as smooth plots. The researcher believes that linear connections with variable slopes (as shown in Figure 3) is more apt because:

i. The change in slope indicates that new vulnerable elements were reached at a certain height. The change in slope after reaching 0.5 m signifies that electrical outlets were flooded, and therefore this element starts contributing to the damages. Likewise, the sudden increase in damage at 3.0 m is because of the damages in first floor's ceiling.

ii. Another damage response being considered is the cleaning activity of exposed elements, which is linearly related to inundation depth.

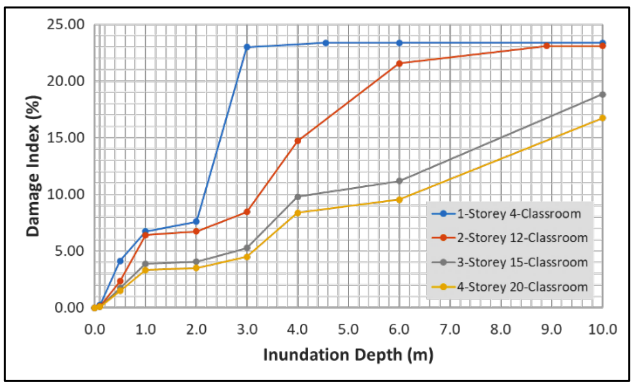


Figure 3 Flood vulnerability curves of public school buildings in Metro Manila

It can be seen from Figure 3 that as the number of floors increase, the damage ratio decreases. This is to be expected since the damages are being referred to from the value of the building, that is, the denominator of the ratio increases as the number of floors increase. A one-story school building can take up to 23.6% damage upon complete submergence, afterwards no further damage will occur since it was previously established that no structural damage historically occurred for up to 10 m of flood depth. The 2-story school building will also be completely submerged at maximum flood height, indicating that all building elements will also be exposed to flooding. On the other hand, the 3-story and 4-story school buildings will not experience complete submergence. These two (2) building types have the same level of exposure to floods at all flood heights and therefore, their vulnerability curves have similar trends, but different damage ratios.

The resulting vulnerability curves can also be compared to study results from other countries. Similar with the evaluated cases in Metro Manila, Dutta et. al.'s study in Japan [15] also concluded that total damage is not expected when structure is totally submerged in flood. This is contrary to Festa et. al. [18] in Italy and Genevese [22] in Czech Republic wherein the damage ratios reached 0.9 and 1.0 respectively at flood depths above 3 m, which indicates near or total damages to 1-story structures. In terms of expected damages however, Dutta et. al. has higher damage ratios as compared to the present study. For instance, at a flood height of 1m, they estimate that there will be 20% damage to structures, while the current study has a computed damage of only 7%. The difference in damages is attributed to different building finishes caused by (i) geographical and cultural difference between the two countries; and (ii) difference in occupancy type, i.e., residential vs. school. It must also be noted that the result of this study is comparable to Ranger et. al.'s [14] empirical mean damage ratio in a historical event in India.

3.6 Proposed Strategies to Increase Flood Resilience

Flood hazard is ever present in Metro Manila and public school buildings are always expected to incur certain amount of damage once subjected to flooding. Below are some strategies developed to cope with the flooding, minimize the damages, and increase resiliency.

- Retrofit school buildings in high-risk zones. Slight modifications can significantly reduce damages. For instance, electrical outlets can be placed higher than the standard placement of 0.5 m from floor elevation. Also, use of flood-damage resistant materials for blackboards and ceiling are recommended. Although flood proofing recommendations may sound intuitive, these measures are not necessarily implemented based on the conducted field survey. This fact leads to the next recommendations.
- Institutionalize a disaster risk management committee in the ground level, or if there is any, strengthen its capacity. One major finding through interviews is that it usually takes a prolonged period before things are restored after a flood incident. This causes further deterioration of some damaged elements, and at the same time, classes are delayed. Both direct costs and opportunity costs pile up in the case of delayed flood restoration efforts. The delay stems from the fact that a flood response/restoration team is formed in an ad-hoc basis, and oftentimes, it is hard to find volunteers because people's priority is in their respective homes or at some other places. Therefore, it will be more effective if there is a committee composed of appointed personnel that will take charge in the event of disasters, not only for floods, but including other hazards.
- Invest in flood insurance as a way to effectively address damages. Another difficulty in flood restoration efforts is the lack of emergency funds, especially for the public sector. Even if there is government appropriation for disaster response, it takes a long time to reach the ground level. Also, the amount per public school is largely indeterminate and oftentimes not enough. One alternative is to apply for insurance coverage, to the Government Service Insurance System (GSIS) in particular. If every school

can develop a scheme to pay for insurance premiums, post-disaster efforts would be smoother.

4.0 CONCLUSION AND RECOMMENDATION

For public school buildings in Metro Manila, flood damage is limited to building finishes and fixtures only. No structural building damages have been reported. Vulnerable components include wooden elements like doors, cabinets, blackboards and ceiling, and electrical fixtures such as wiring, lighting, outlets, switches and fire alarm system. Damage response is a function of inundation depth and varies from simple cleaning up to total replacement of building components. Comprehensive vulnerability description of different types of public school buildings are represented as curves (Figure 3) of flood depth vs. damage index.

Flood proofing is not yet implemented even for high flood-risk schools. It is recommended to have an operational disaster risk management committee in the local level, and to explore insurance opportunities.

Acknowledgement

The author would like to acknowledge the support of Japan International Cooperation Agency (JICA) in the conduct of this study. Special thanks is also given to retired professor Peter Paul Castro of the Institute of Civil Engineering University of the Philippines - Diliman for providing guidance and academic review related to the outputs of this study.

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