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SEISMIC VULNERABILITY ASSESSMENT OF MEDICAL FACILITIES: A GIS BASED APPLICATION FOR CHITTAGONG, BANGLADESH

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Abstract: Medical facilities are one of the most important lifelines that need to remain functional during and after an earthquake. Bangladesh is a multi-hazard prone country located in the southern part of Asia where a significant number of natural disasters are recorded each year. The second largest city and economic hub, Chittagong, is located in the south-eastern part of the country, falls in the seismically moderate zone as per Bangladesh National Building Code (BNBC 2017) with a seismic zoning coefficient of 0.28g based on 2 percent probability of exceedance in 50 years. Most of the buildings were built before implementation of seismic code practiced in Bangladesh. Based on growing need for developing disaster risk plan, seismic performance is evaluated for existing important medical facilities by applying simple visual risk assessment procedure. The structural database is developed through field survey and result of seismic performance is presented in Geographic Information System (GIS).

Keywords: *Chittagong, GIS, performance, seismic vulnerability, medical facilities*

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1.0 Introduction

Bangladesh is a rapidly growing developing country in the southern part of Asia, shares land borders with Myanmar and India (Wikipedia, 2017). The country is affected by various natural disasters that include cyclones, tornados, floods, earthquakes, droughts, landslides, etc. Bangladesh is one of the most affected regions due to global climate change impact over last decades (Kreft *et al*., 2014). Every year thousands of peoples are affected by various natural calamities almost all over the country, and these natural disasters result in a huge socio-economic loss. Besides these natural disasters, a significant number of casualties occurred due to the manmade event (e.g., road accidents, building collapse due to unauthorized and poor construction, overloaded sea-truck sinks in waterways, etc.). One of the big challenges for the local government is to reduce future disaster risk in the densely populated urban areas.

Among the natural hazards, cyclone and flood are the most frequent ones that occur every year in this regime. Although life loss due to the cyclone is reduced remarkably with the improvement in weather prediction and early warning system during last two decades, however, physical and economic losses are still significant. The southern part of the county along the coastline is the most susceptible to cyclone storm surge (Barua *et al*., 2016). Bangladesh experiences more than six months dry period in each year and north-western part of the country is highly drought-prone areas (Habiba *et al*., 2011). Impact of drought is reduced with the improvement in electrical power supply system and water pumping from deep well during the dry season. Flash floods are very common phenomena in the low-lying belt of the country due to heavy rainfall in monsoon time, often leads to huge economic loss. Barua *et al*. (2016) prepared a district wise multi-hazard map where seven largest past flood events are used to prepare probable flood susceptible zones. Heavy rainfall also leads to debris flows and landslides in the hilly regions. In recent years, series of landslide events occurred in the hilly regions and resulted in the highest number of deaths over other disaster events. For example, 133 peoples had died in the Chittagong hilly areas due to a single landslide on June 13, 2017 (Daily Star, 2017). Landslide susceptibility in the hilly areas and their impact in recent years can be further found in the literature (Chisty, 2014; Ahmed, B. 2015).

Bangladesh is located in the region of moderate seismicity in the world seismic map (GSHAP, 1992). Although there is no large earthquake recorded in last 100 years in and around Bangladesh, potential earthquake sources and seismic activities have been identified in this region (CDMP 2009a, Steckler *et al*., 2016). Specialists are expecting huge energy stored underground in this region that may result in a large earthquake. CDMP (2009a) documented that each seismic fault is capable of generating large size earthquake in this area. Moreover, existing vulnerabilities in buildings increased seismic risk especially in unplanned urban areas. A majority of existing buildings in urban areas in Bangladesh are constructed without following seismic code guideline (Ara, 2014). Some recent studies reveal that presence of a high number of seismically vulnerable structures potentially increased seismic risk in this region even under a moderate size earthquake (Ara, 2014; CDMP, 2009b; Sarker *et al*., 2010). Recent earthquakes in the Indian subcontinent (e.g. Bhuj earthquake in 2001, Ziarat earthquake in 2008, Sikkim earthquake in 2011, Nepal earthquake in 2014) made people aware of the future seismic risk. Hence, it is important to evaluate seismic vulnerability of existing building stocks in order to reduce the impact of an earthquake disaster. Since it is neither feasible nor possible to evaluate all buildings individually by the local authorities with the existing manpower and resources, buildings are required to evaluate based on their priority of building use.

In this study, an effort has been made to evaluate seismic vulnerability of medical facility buildings located in Chittagong City Corporation (CCC) area. The main objective of this study was to prepare a structural inventory and seismic vulnerability database of medical facility buildings. A GIS base map containing buildings footprint was prepared, and relevant necessary information was collected from local authorities (e.g. City Corporation) in the first level. Then map was updated by incorporating field survey information. In the second level, simple seismic vulnerability assessment technique was applied to identify seismic vulnerability in existing medical buildings and their results were incorporated in GIS environment. The outcomes of the study can be used for future seismic risk mitigation plan of CCC area.

2.0 Seismicity of Bangladesh

Bangladesh is located close to the junction of the Eurasian plate and the Indo-Australian plate and seismic activities surroundings Bangladesh can be explained based on the collision between north moving the Indo-Australian plate and south moving the Eurasian plate (Bolt, 1987). Although the country is located in the seismically susceptible region, nature of seismic activities has not been well understood yet (CDMP, 2009a). There are four major faults identified by Bolt (1987). Recently time predictable fault model study is performed by Comprehensive Disaster Management Program (CDMP) using available seismic data, existing literature and trench investigation. This study proposed five major faults and corresponding earthquake scenarios where each scenario represents a maximum possible moment magnitude earthquake (M_W) occurring within a fault zone (CDMP, 2009a). Detail explanation of five faults identification and corresponding earthquake scenarios can be further found in CDMP (2009a) report. Table 1 summarizes earthquake scenarios proposed in CDMP (2009a) study and Figure 1 shows the location of five faults.

Table 1: Identified seismic faults by CDMP (2009a)

Case	Fault Name	Coordinate of Epicenter		M_w	depth (km)	Dip Angle	Fault type
		Latitude	Longitude				
1	Madhupur Fault	24.3	90.1	7.5	10.0	45°	Reverse
2	Plate Boundary Fault -1	21.1	92.1	8.5	17.5	30°	Reverse
3	Plate Boundary Fault -2	23.8	91.1	8.0	3.0	20°	Reverse
4	Plate Boundary Fault -3	25.7	93.7	8.3	3.0	30°	Reverse
5	Dauki Fault	25.1	91.0	8.0	3.0	60°	Reverse

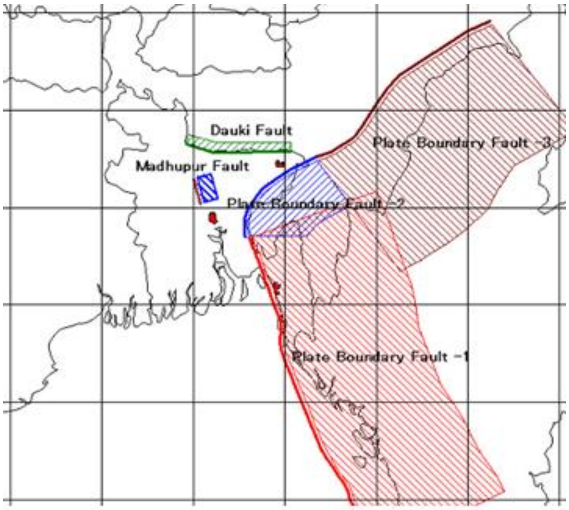

Figure 1: Seismic faults identified by CDMP (2009a)

There is no evidence of large earthquake occurred in and around Bangladesh in last 100 years. The latest large size earthquake stroke in this region on July 18, 1918, with an estimated surface magnitude M_S 7.6. The epicenter was at Srimangal, Maulvi Bazar which is about 180 km away from the Capital Dhaka and 71 km from Sylhet (Sarker *et al*., 2010). About 100 people were injured near to epicenter region and only a minor structural damage was observed in Dhaka and Sylhet (Ansary and Sadek, 2003). The largest earthquake occurred in this region was on June 12, 1897, with an estimated moment magnitude M_W 8.1. The earthquake was generated from Dauki fault and epicenter location was inside Assam which is about 300 km northeast from Dhaka and about 60 km away from Sylhet (Sarker *et al*., 2010). This earthquake is also known as the Great Indian Earthquake. Strong ground shaking was observed all over the Bengal region, and 545 peoples were died in Sylhet due to the collapse of masonry buildings (Ansary and Sadek, 2003). An earthquake with moment magnitude M_W 5.1 hit the south-eastern region on July 27, 2003. This was a very shallow earthquake (focal depth is 10 km), and epicenter location was at Barkal, Rangamati. This earthquake created visible ground rupture and damaged many masonry and adobe buildings in Rangamati and Chittagong. At least two peoples died, and 100 peoples were injured during this earthquake (Alam, 2010). Figure 2 shows observed damages in buildings and ground displacement after Barkal, Rangamati earthquake. In last decade, there are a number of 4.0 to 5.0 magnitude earthquakes occurred in a regular interval in this area. Bangladesh also experienced strong ground shaking during 2015 Nepal earthquakes, 2011 Sikkim earthquake and other moderate size earthquakes occurred in Myanmar-India bordering region. Since there is no earthquake occurred over last 100 years from the identified faults, specialists are expecting huge energy stored underground that may result in a large earthquake near future. Steckler *et al*. (2016) identified Megathrust activity beneath the Bangladesh which is linked to the active subduction belt. Their study identified the presence of plate movement under a large part of Bangladesh along with Myanmar and northeast of India.

Figure 2: Building damages and ground displacement in Rangamati Earthquake in 2003 *(image courtesy: www.cuet.ac.bd/ieer)*

3.0 Building Vulnerability

A recent study on earthquake vulnerability assessment for existing buildings of Dhaka, Chittagong, and Sylhet is performed by CDMP (2009b), and the outcome of the study indicates a large number of buildings are seismically vulnerable in these cities. However, CDMP (2009b) detail structural evaluation was based on a relatively small number of representative samples for each building class. The vulnerability scenario for a whole city area was predicted based on the performance of representative building for each structural typology. However, there are uncertainties remain inherently in case of selecting building samples, and the overall results could be either conservative or overestimated. Ansary and Meguro (2003) performed probable loss estimation of Dhaka city in case of a large earthquake. Their study indicates a high likelihood of severe casualties and building damages due to a reoccurrence of 1897 Great Indian Earthquake. Sarker *et al*. (2010) performed seismic loss estimation for Sylhet city corporation area in case of reoccurrence of 1918 Srimangal Earthquake. This study also indicates the possibility of severe damage to buildings and infrastructures. Mazumder *et al*. (2011) performed seismic vulnerability assessment by applying multi-levels assessment technique developed by Ozcebe *et al*. (2006) for reinforced concrete (RC) buildings located in the word number nine of Sylhet City Corporation. Mazumder and Hossain (2011) evaluated the structural integrity of Unreinforced Masonry buildings in older part of Dhaka city by applying FEMA 310 and IITK-GSDMA standards. These old unreinforced lime mortar masonry buildings contain high structural vulnerability as most of the buildings have been modified over the years and constructed prior the establishment of the local building code guideline. Mazumder *et al.* (2014) applied

FEMA 154, FEMA 310 and Ozcebe *et al*. (2006) assessment procedures to evaluate the vulnerability of buildings located at Chittagong University of Engineering and Technology (CUET) campus. Their results reveal that most of existing buildings at CUET campus are in the good performance class.

Outcomes of past studies indicate the presence of a high seismic vulnerability in existing buildings and further detailed structural assessment is needed for important and low-performance category building class. A large number of buildings became vulnerable since those buildings are constructed without incorporating earthquake resistance features in it or without following building code guidance. Hence, it is necessary to identify seismically vulnerable structures and strengthen them based on the priority of building use. This study was performed to identify the seismic vulnerability of medical facility buildings located in CCC area by applying simple risk assessment method.

4.0 Study Area

Chittagong is the second largest and business hub of Bangladesh. The densely populated urban CCC area consists of 41 administrative wards. The area of CCC is about 185 square kilometers, and approximately 15000 peoples live in per square kilometer (CDMP, 2009b, CCC, 2015). The CCC area falls into the moderate seismic zone in BNBC (1993) seismic zoning map with a coefficient of 0.15g where the map was prepared based on 200 years return period earthquake (BNBC 1993, Al-Hussaini *et al*., 2012). The BNBC (1993) map was prepared with limited existing earthquake database inside the country. In recent years, seismic zonation map is revised in BNBC (2017draft) based on a maximum credible earthquake and earthquake hazard scenario 2 percent probability of exceedance in 50 years. In the updated seismic map, CCC is located in zone 3 with a seismic coefficient of 0.28g (BNBC, 2017draft). Figure 3 shows the seismic zoning maps of Bangladesh of BNBC (1993) and BNBC (2017 draft). The CCC area is located close to the plate boundary faults (as shown in figure 1) and contains a high seismic vulnerability in existing structures (CDMP, 2009a; 2009b). About 1150 school buildings, 1000 religious mosque and temples, 6 fire service stations, 11 emergency responses office, and 630 km of road network are located inside CCC area (CCC, 2015). A total 172 medical facilities have been identified during this study, and structural inventory was prepared for these buildings. Figure 3 shows buildings footprint map of CCC area.

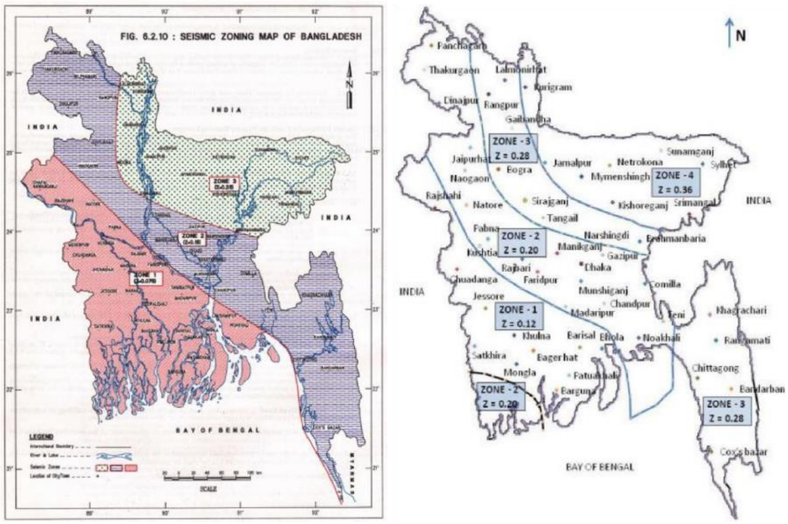

Figure 3: Seismic zoning map of BNBC (1993) (left) and BNBC (2017 Draft) where zoning coefficient represents Peak Ground Acceleration in unit of gravitational acceleration (g)

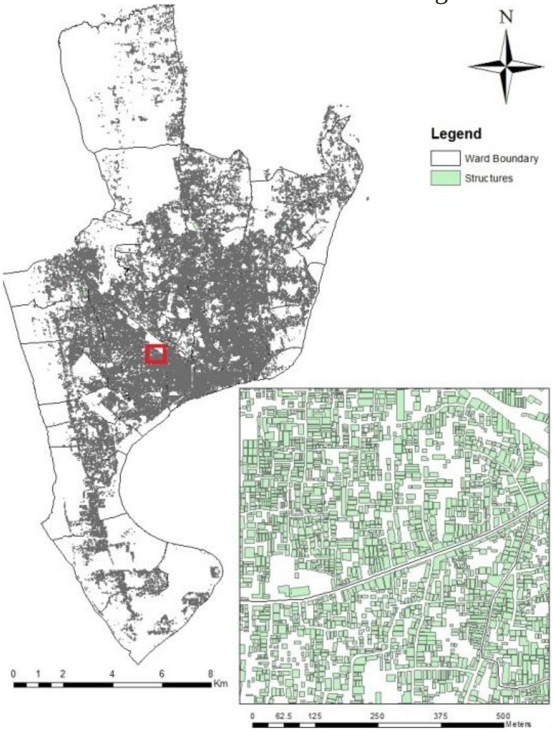

Figure 4: Building footprint map of CCC area and building density (inset)

4.0 Methodology

The study was divided into two levels. In the first level, up-to-date structural footprint base map was prepared. To prepare an up-to-date structural footprint base map, available maps and information were collected from local authorities and relevant organizations (e.g. Chittagong Development Authority, Chittagong City Corporation, NGOs, etc.). Then map was updated in GIS by incorporating available information, google earth image and field survey data. Building occupancy class, location, structural typology, number of story information are verified and further updated during the field survey. Then, the second level study includes walkdown rapid visual screening to identify structural vulnerability parameters. Seismic performance score proposed by Ozcebe *et al*. (2006) was calculated for each building using available filed survey information. The overall study was performed to identify existing vulnerabilities, prepare a structural inventory and rank the most vulnerable medical building against earthquake loading. Field survey information and analysis results are compiled into GIS framework. Figure 5 shows the outline of this study.

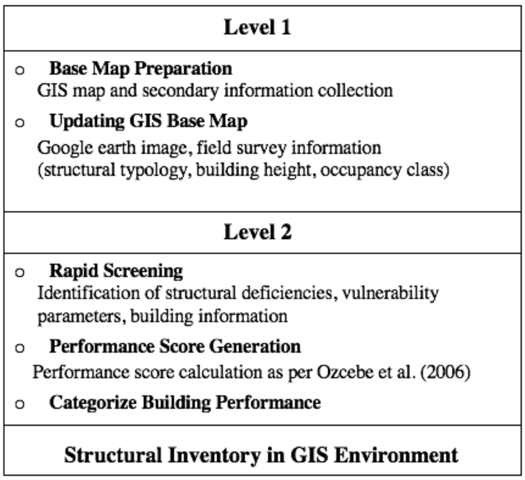

Figure 5: Overall study procedure

In the level 1 assessment, it has been found that most of the medical facility buildings are RC moment resisting frame with masonry infill walls. In the second level, seismic performance score for an individual structure is calculated based on guideline provided by Ozcebe *et al*. (2006). The seismic performance score is a good indicator of the expected performance of a building during an earthquake. Along with this performance calculation, collected other vulnerability information (physical condition of structures, plan shape, shape in elevation, etc.) can be further taken into account for decision making in risk mitigation plan. Table 2 shows the building basic score and vulnerability parameter matrix for performance score calculation.

Ozcebe et. al. (2006) defined structural vulnerability parameters that are required for performance calculation. A soft story exists in a multi-story building if one particular story has significantly lesser stiffness and strength compared to another story of the building. Heavy overhang presence in a building if it there exists heavy balconies and overhanging floors which increases lateral seismic force and overturning moment. Partial infill in the frame structure creates short columns which result in heavy damage due to high shear force impact during lateral loading. If spaces between two adjacent buildings are not large enough, buildings may collide during an earthquake due to different fundamental frequency and impact become significant if floor levels differ from one another. Buildings located on a steeper slope may not be able to distribute ground distortion evenly among structural elements due to the steep foundation. A close relationship between building performance and visible apparent quality has been found in the past earthquakes. Building with good physical appearance is expected to perform well than a building having a poor physical appearance. The local soil parameter is very important for selecting the basic score of the building. According to BNBC (2017 draft), CCC area falls into a zone with peak ground acceleration 0.28g. The estimated peak ground acceleration value can be increased to more than 0.35 g during strong shaking if site amplification effect is considered for loose soil condition. Hence, the corresponding PGV for the study area is taken as 60 cm/s to 70 cm/s class which refers to Zone I in table 2 for base score calculation (Mazumder *et al*., 2014). The Performance Score of a building is calculated using equation 1.

$$\text{Performance Score, PS} = \text{BS} - \sum \text{VS} \times \text{VSM} \qquad (1)$$

Table 2: Base scores and vulnerability scores of RC building (Ozcebe *et al*., 2006)

No. of Story	Base Scores (BS)			Vulnerability Scores (VS)					
	Zone I (PGV: 60-80 cm/s)	Zone II (PGV: 40-60 cm/s)	Zone III (PGV: 20-40 cm/s)	Soft Story	Heavy Overhang	Apparent Quality	Short Column	Pounding	Topo. Effect
1	100	130	150	0	-5	-5	-5	0	0
2	100	130	150	0	-5	-5	-5	0	0
3	90	120	140	-15	-10	-10	-5	-2	0
4	75	100	120	-20	-10	-10	-5	-3	-2
5	65	85	100	-25	-15	-15	-5	-3	-2
6	60	80	90	-30	-15	-15	-5	-3	-2
7	60	80	90	-30	-15	-15	-5	-3	-2

Table 3: Vulnerability Score Modifier (VSM) (Ozcebe *et al.*, 2006)

Soft story	No (0); Yes (1)
Heavy overhangs	No (0); Yes (1)
Apparent quality	Good (0); Moderate (1); Poor (2)
Short columns	No (0); Yes (1)
Pounding effect	No (0); Yes (1)
Topography effect	No (0); Yes (1)

5.0 Results

Building density in the CCC area is very high. More than 15000 people live in a square kilometer of CCC area (CDMP, 2009b). Figure 4 (inset) shows how buildings are closely located in a commercial area of CCC. A total 172 medical facility buildings were identified during the study. Figure 6 shows existing hospital buildings by the number of story and pie chart shows that most of the buildings (about 92 percent) are low to mid-rise structures (less than 7 story building). Figure 7 shows medical facilities exist in CCC area before and after the year 2009. About 20 percent of existing medical facilities are constructed after 2009.

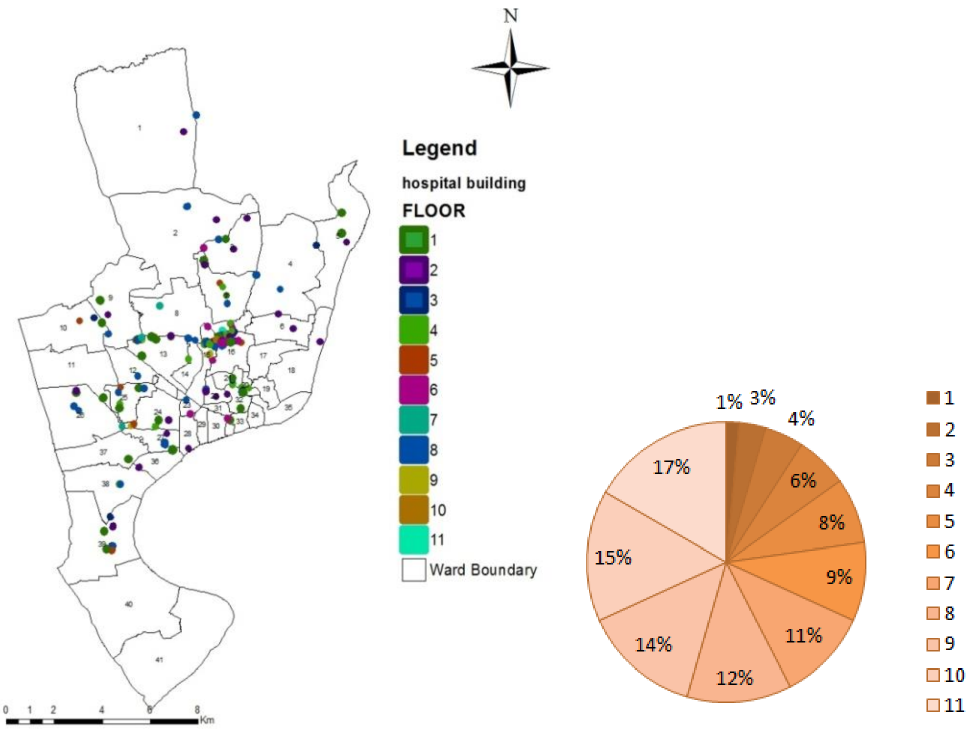

Figure 6: Distribution of medical facility buildings as per number of story

Most of the medical building facilities are RC moment resisting frame with masonry infill walls. About 92 percent of medical facilities are identified as structural type “Pucca” which represents either concrete or masonry structure with rigid floor, 6 percent of medical facilities are identified as “Semi Pucca” which represents a non-engineered structure with flexible roof and rest of the buildings are identified as “Tin Shade” which represents a structure constructed using Tin alloy and non-engineered column. Figure 8 (left) shows the medical facilities by structural types. About 75 percent buildings structural floor plan is rectangular. Figure 8 (right) shows the plan shape of medical buildings. About 16 percent buildings contain setback in elevation and rest of the buildings are regular in elevation. Figure 9 shows the building elevation shape and presence of the soft story in the buildings. First soft story presence in about 20 percent medical facility buildings. About 80 percent Pucca buildings have short column effect. As many buildings are situated closely with each other. It was found that about one-fourth of buildings have pounding possibilities during an earthquake. This pounding vulnerability is significant for the existing medical facilities. Only 35 percent of buildings are in good visible physical condition, 60 percent of buildings are in average physical conditions and remain 5 percent of buildings are in poor condition. Figure 10 shows visible physical conditions of the buildings. Figure 11 shows a perspective view of two medical facilities.

Figure 7: Medical facilities exist before 2009 (left) and after 2009

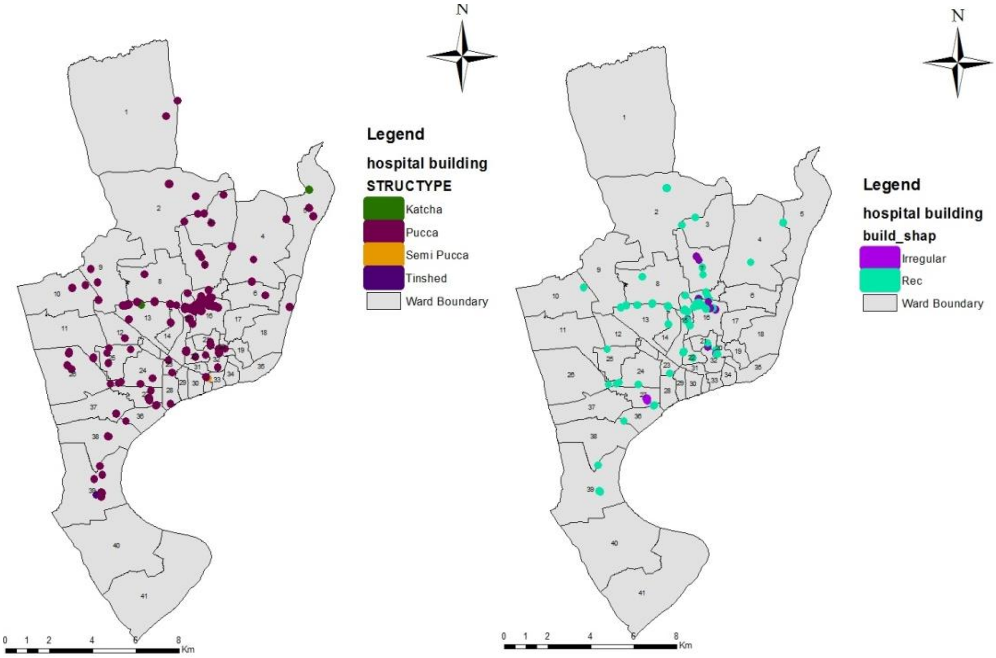

Figure 8: Structural types (left) and plan shape of the buildings

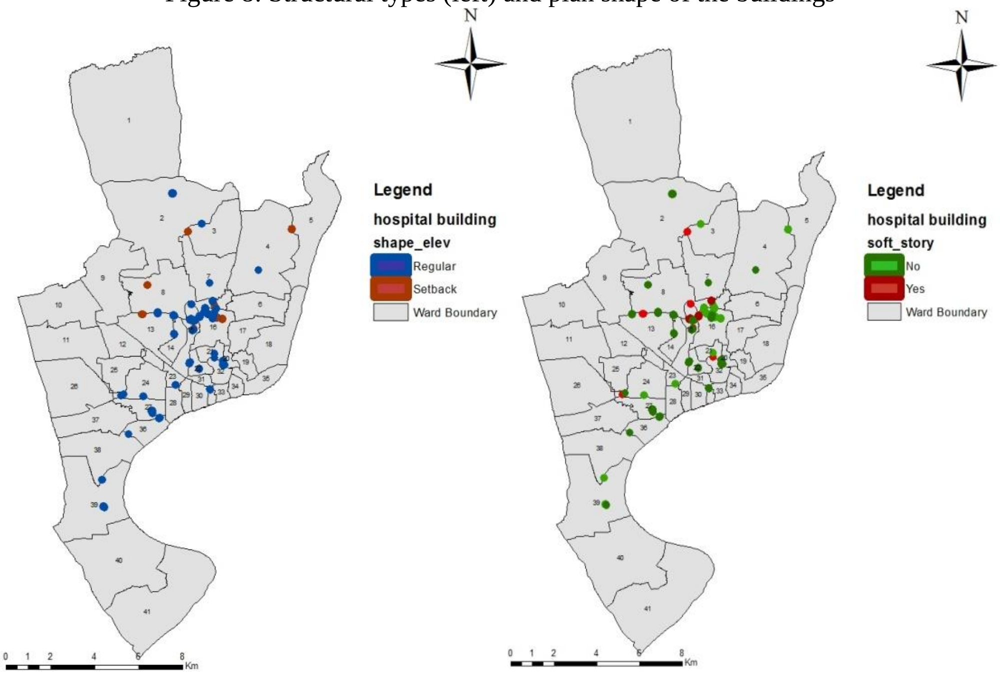

Figure 9: Building shape in elevation (left) and presence of soft story

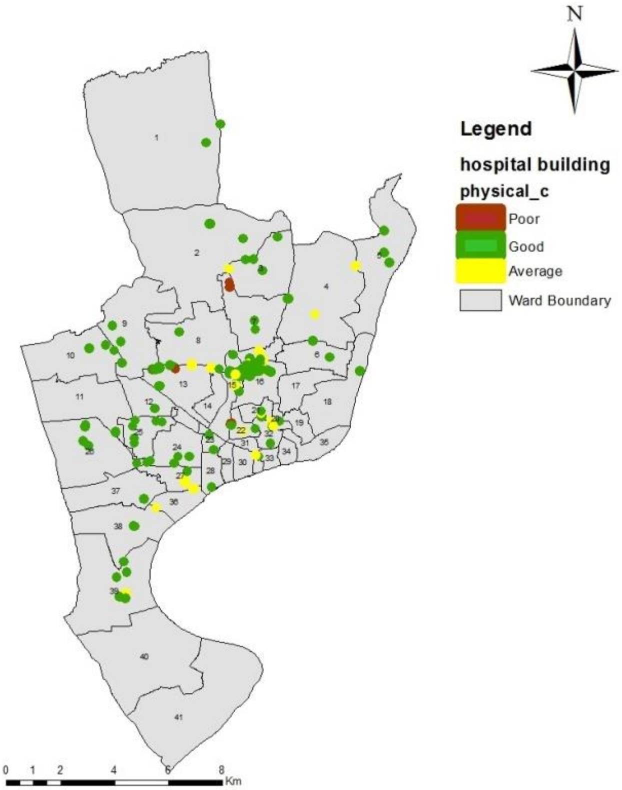

Figure 10: Visible physical condition of the buildings

Figure 11: Prospective view of medical buildings in CCC area

Among identified 172 medical facility buildings, 63 Pucca buildings were selected for second level assessment based on engineering judgment, analyzing first level data and building accessibility. The building performance divided into three categories (low, moderate and good) depending on performance score value. There is no specific guideline exist to categorize building based on performance score. Engineering judgment and local expert opinion typically used for categorizing building performance class. In this case, a score less than 40 was categorized as low performance and building with a performance score more than 70 was considered as good performance. Performance score from 40 to 70 was defined as moderate performance. Figure 12 shows building performance in GIS map. Building mean performance score was 65 whereas the mode value was 90. It was found that 30 buildings are in good, 24 buildings are in moderate and 9 buildings are in the low-performance state.

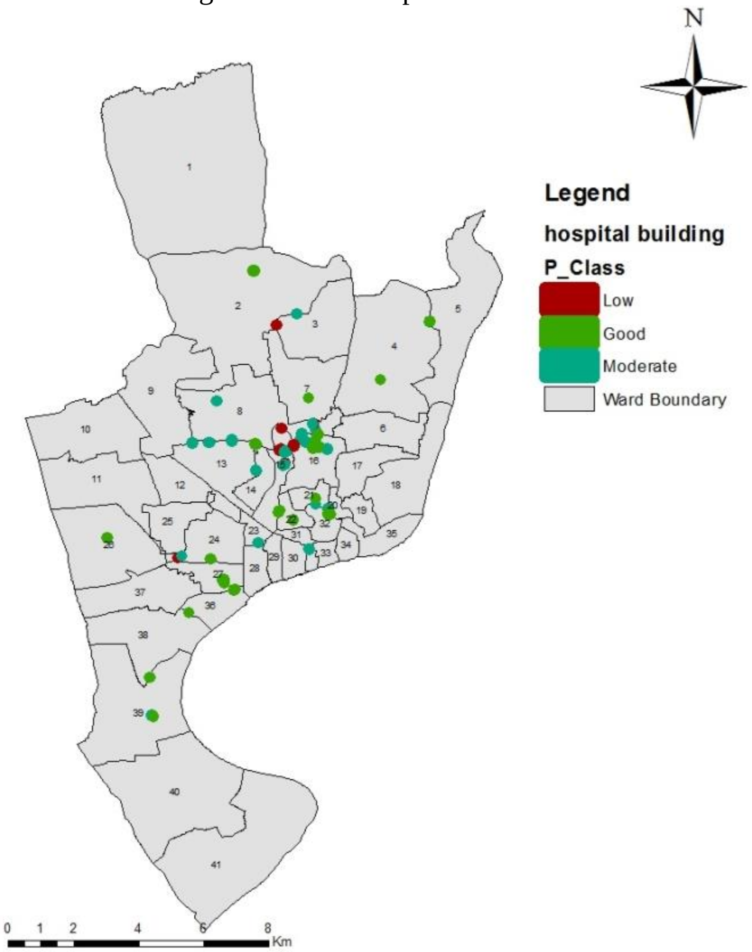

Figure 12: Seismic performance of medical buildings

7.0 Conclusions

The primary objective of this study was to develop a structural inventory of medical facility building. This structural inventory can be useful for future seismic risk mitigation planning of CCC area. The building vulnerability assessment of existing medical facility buildings was performed based on simple risk assessment procedures. Obtained performance scores reveal that high vulnerability presence in the existing medical facility buildings (about 14 percent low-performance class and about 38 percent moderate performance class). These results indicate the requirement of future detailed structural assessment for the medical facility buildings especially those were categorized into low to moderate performance class. Similar information can be acquired for other important structures for future seismic risk mitigation strategies of CCC area.

8.0 Acknowledgement

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