

Seismic vulnerability assessment for buildings typology using DEMATEL approach

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Abstract. During the last two decades, the severity of high magnitude earthquakes rising to a vast extent. A large amount of damage due to such devastating events reflects poor construction planning. Before the 2004 event in Indonesia, we assume poor construction planning with indigent seismic resistance in the Northern Sumatra. However, this event affected the modern buildings in Aceh province. Therefore, authors have categorized all the building types into a catalogue. The typologies are considered hierarchical, construction material, structural irregularities, structural system, building height, and maintenance quality. We applied the Decision Making Trial and Evaluation Laboratory (DEMATEL) method to prepare the vulnerability map using the typology of the building. In addition, the results show that the prepared approach is effective and useful for seismic vulnerability assessment.

Keywords: Earthquake, building typology, vulnerability, mapping, GIS

1. Introduction

Indonesia is one of the seismic prone areas located in Java and the Sumatra subduction zone is associated with the Pacific Ring of Fire. Geologically it is active and lies on several tectonic plates. Earthquakes experienced daily on an average basis in the South-western border of Indonesia [1, 6]. Weekly, an average magnitude of five in Richter scale can be experienced in this country. The epicenters of observed earthquakes in Indonesia during the period of 1992 – 2000, destroyed a lot of property. After the 2004 event, the planning in buildings' structural development has been modified. Recently experienced events such as the 2004 Aceh earthquake, 2005 Nias, 2006 Yogyakarta, Java, and Sumatra earthquake along with the 2007 Bengkulu event is associated with large tsunamis [4]. These events destroyed the lives of people of around hundreds of thousands and on average damaged half a million infrastructures [2, 3]. The major effects due to these events on social and economic properties were massive [7]. The Indonesian government and local community were tried to cope with their coping capacity, by considering the effects of a future hazard. The buildings were damaged because of poor building materials, planning, developmental structure as well as ignorance of seismic resistance [8]. Therefore, afterward, various reconstruction and rehabilitation techniques were taken place to repair and rebuild the schools, universities, housings, and other government and private infrastructures. In the Aceh province, the Indonesian government formed the Reconstruction agencies for Rehabilitation such as (BRR, Badan Rekonstruksi dan Rehabilitasi NAD-Nias) to execute a proper plan and manage the recovery in very devastated regions. Therefore, building structures management and infrastructure replanting can be a strategy for many disaster mitigation activities, projecting the target of raising awareness about the earthquake risk in the community. Combining efforts from the

government, local people along with several local and international agencies were designed to make a safe province of Aceh for earthquake hazards [1, 9].

Recently, the authors have carried out a methodological approach for “Seismic Vulnerability Assessment of Building types in Aceh” with project grants supported by Centre for Advanced Modelling and Geospatial Information System (CAMGIS). The main aim of the project was to analyze and assess the seismic vulnerability for Indonesian construction in an aseismic prone area. Therefore, in this paper, we present the building typology catalogue for the vulnerability assessment in a particular area. It is a combination of various parameters that are considered useful for building classification. It also describes the proposed building typology catalogue based on these parameters. The DEMATEL methodology has been adopted for considering the standard building catalogue and producing a vulnerability map using GIS. The details of seismic vulnerability functions for different building types are also grouped and presented in this paper.

2. Materials and methods

2.1. Study area

Banda Aceh is the capital of Aceh province situated in the north of Sumatra and considered as the largest city in the Aceh region. The city location is presented in Figure 1. The city topography is characterized by quaternary sediments with a flat structure without hilly surfaces. Hilly region can be found at a distance of around 7 km from the city border. Several lagoons are situated is associated with the city in the Northern region. Banda Aceh was heavily damaged because of the 2004 earthquake and tsunami, which cause deaths of around 90 000 people [4]. The rehabilitation and reconstruction operation led by Aceh-Nias Rehabilitation and Reconstruction Agency (BRR Aceh-Nias), the city experienced severe challenges in replacing its affected people to safe places. These challenges mostly faced in several houses, which were being built in the northern coastal part of the city. There is a green belt in the coastal region at a distance of about 500 m to any settlement, associated with an aim of using this part vegetation growth, which is a specific part of the tsunami mitigation. The Master Plan proposed by the agencies for Rehabilitation and Reconstruction characterized by the mentioned green belt for development (BAPPENAS, 2005). The process of planning from the last 14-year for rehabilitation and reconstruction until now has already failed because of poor city planning.

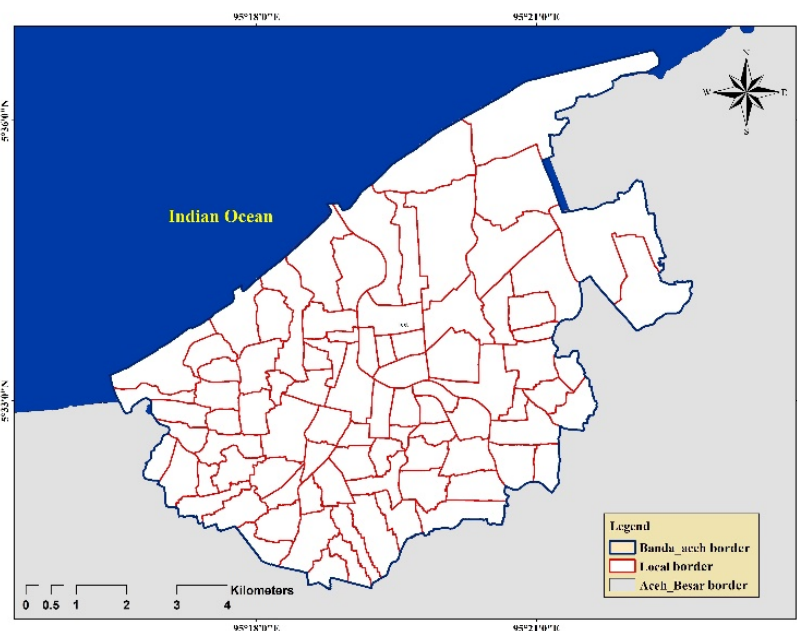


Figure 1. Location of study area.

2.2 Data specifications

Earthquake catalog was collected from USGS earthquake events from 2000-2019. Building data was collected from statistics Indonesia (<https://www.bps.go.id/>). The buildings' typology information such as hierarchical, construction material, structural irregularities, structural system, building height, and maintenance quality collected and maps were prepared using GIS. The resolution of the map was characterized by 5m. We considered the three specific magnitudes of the earthquake in the analysis, that is, magnitude 7, 8 and 9 Mw. The seismic vulnerability was assessed for the city using the building topology based on the above-mentioned magnitudes. The details of the data were presented in the table below.

Table 1. Data used for the vulnerability assessment.

Criteria	Type	Map resolution
Material Type	Masonry and Mortar, Structural Concrete, Steel, Timber, Bamboo	
Height of the Building	Horizontal Irregularities Vertical Irregularities	5m
Quality of Construction	Code Complied or Not Complied, Status of maintenance or visual appearance: Good/Poor	
Ground Slope	Level Ground (Slope $\leq 20^\circ$) Sloping Ground (Slope $> 20^\circ$)	

2.3 Methodology.

DEMATEL is the method through which an impact relationship map can be created. It is a visual presentation of own decisions by which the respondent takes action. The process is internally coherent and reaches a specific goal. The details of the steps were described below [5].

Step 1 Find the average matrix.

a_{ij} can be computed using the $n \times n$ average matrix A which should be averaging by the h experts' score matrices. The element (i, j) of matrix A can be presented as a_{ij} , where

$$a_{ij} = 1/h \sum_{k=1}^h x_{ij}^k \quad \text{Eq (1)}$$

Step 2 Calculate the normalized initial direct-relation matrix

Then creation of a matrix D need to be prepared by applying a normal matrix operation process on A. For example, we created matrix D, where $D = s \cdot A$ then,

$$S = \text{Min} \left[\frac{1}{\text{Max}_{1 \leq i \leq n} \sum_{j=1}^n |a_{ij}|}, \frac{1}{\text{Max}_{1 \leq j \leq n} \sum_{i=1}^n |a_{ij}|} \right] \quad \text{Eq (2)}$$

Matrix **D** can be described as the normalized initial direct-relation matrix and then $W_i(d)$ and $V_j(d)$ can be analyzed through the formula presented below.

$$W_i(d) = \frac{d_i}{\sum_{i=1}^n d_i} \quad \text{Eq (3)}$$

$$V_j(d) = \frac{d_j}{\sum_{j=1}^n d_j} \quad \text{Eq (4)}$$

d_i, d_j can be considered as the sum of influence

Step 3 Compute the total relation matrix.

The total relation matrix T can be calculated as $n \times n$ matrix and should be described as follows.

$$\sum_{m=1}^{\infty} D^i = D + D^2 + D^3 \dots + D^m$$

$$= D(I - D)^{-1} \quad \text{Eq (5)}$$

Where I =identity matrix

T= total relation matrix

D, D^2, D^3 = can be considered as powers of the matrix

Step 4 Set a threshold value and obtain the impact-relations map.

In this particular stage, the threshold value should be chosen by any decision-making approach or through proper discussion with experts. An acceptable threshold value needs to be calculated which is necessary to generate a suitable impact-relations map as well as appropriate data for further examination and decision-making.

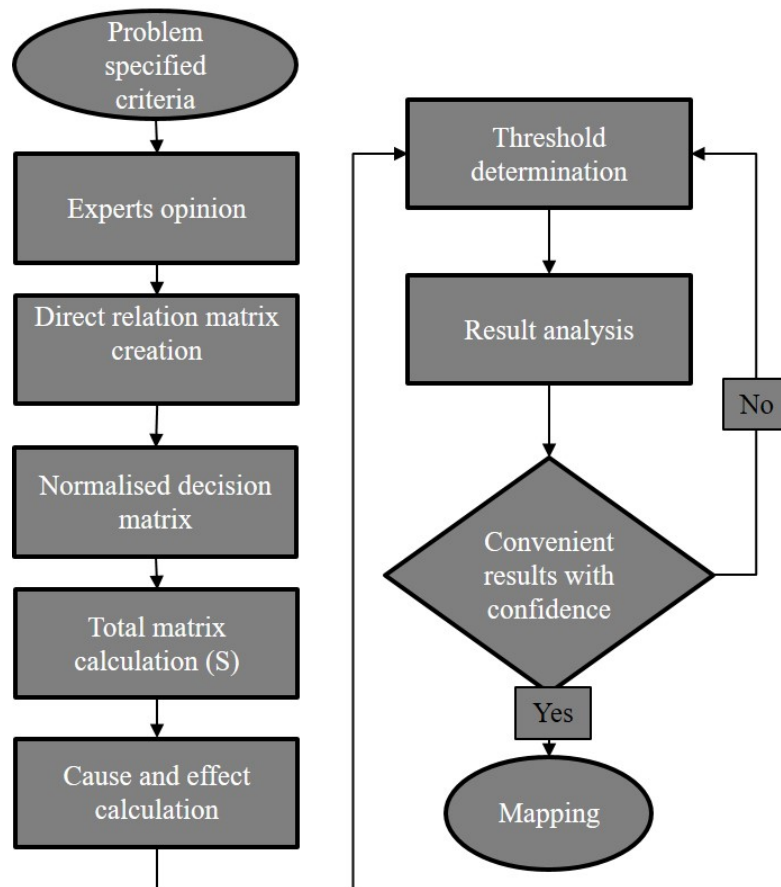


Figure 2. Represents the methodological flow chart of DEMATEL

3. Results and Discussion

By applying the GIS technique we analyzed, the earthquake data with different magnitudes in a model for different scenarios and the vulnerability assessment was presented in building polygon map as buildings typology vulnerability as shown in figure 4. In figure 3 the structural vulnerability assessment was performed. Structural vulnerability shows that the central region of the city is highly vulnerable to the surrounding areas. However, the structural vulnerability was calculated by considering the building density as well as the size of buildings in the area. Building's previous damage was not considered into account. In the next mapping process, we used the details of buildings' characteristics for the building's typology vulnerability. The results of the vulnerability distribution show that central region buildings are highly vulnerable than northwestern buildings in the city for an earthquake scenario with Mw more than 7. Nevertheless, an earthquake with Mw 7 near the Banda Aceh city may damage 30% - 40% of total buildings. The earthquakes with Mw < 7 because of the active Seulimeum fault movement could cause 10%- 20% of the buildings in the city. The Banda Aceh city consists of 9 zones where each zone characterized by different areas and populations. Therefore, the total number of population injuries, death, building damage, and intensity depends specifically on the typology of buildings as well as the magnitude of earthquakes. For this purpose, we should focus on the inventory earthquake intensity map, population death tolls during the last experienced 2004 earthquake, which had precisely measured. The structural vulnerability was projected in figure 3.

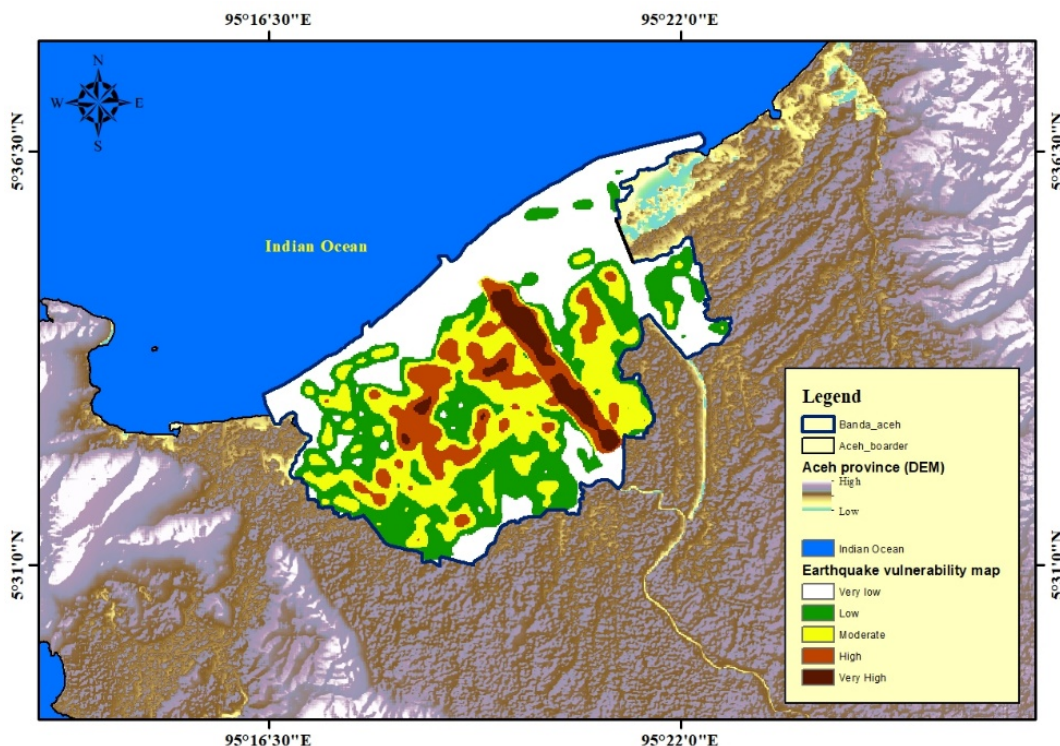


Figure 3. Structural vulnerability based on building density and building size and age.

Buildings and engineering infrastructure construction approaches and practices are the main reason for the increment of vulnerability in the city. Generally, construction workers learn bit by bit from previous generations about the planning, building procedure and a lot from workshops and training held to upgrade their skills. Previously, it was a practice of building the structures in a simple way they think and project the easiest path for building construction. Because of the little concern about the

building quality without properly equipped machinery and knowledge of perfect construction procedures along with lack of basic concepts of buildings quality. Therefore, this problem is apparent in non-engineered buildings while the process is more autonomous in engineered structures. Many man-made works were low in quality than proper engineered and planned machine-based buildings. However, many non-engineered structures in Banda Aceh were built by applying the conventional building technology using reinforced concrete frames. Therefore, it is clear that the central parts of Banda Aceh are characterized by very high building density along with some low-quality buildings with large population density. Therefore, the results show that the central part is very highly vulnerable while the eastern-southern part is highly vulnerable and other parts are coming under medium to a very low vulnerable zone. The problems which are discussed above on building typology vulnerability was assessed using a proper technique. Here we understood that these buildings are usually lacking in structural integrity because they do not have sufficient connections and anchorage among the major components such as beam-column connection. The building's typology vulnerability was presented in figure 4.

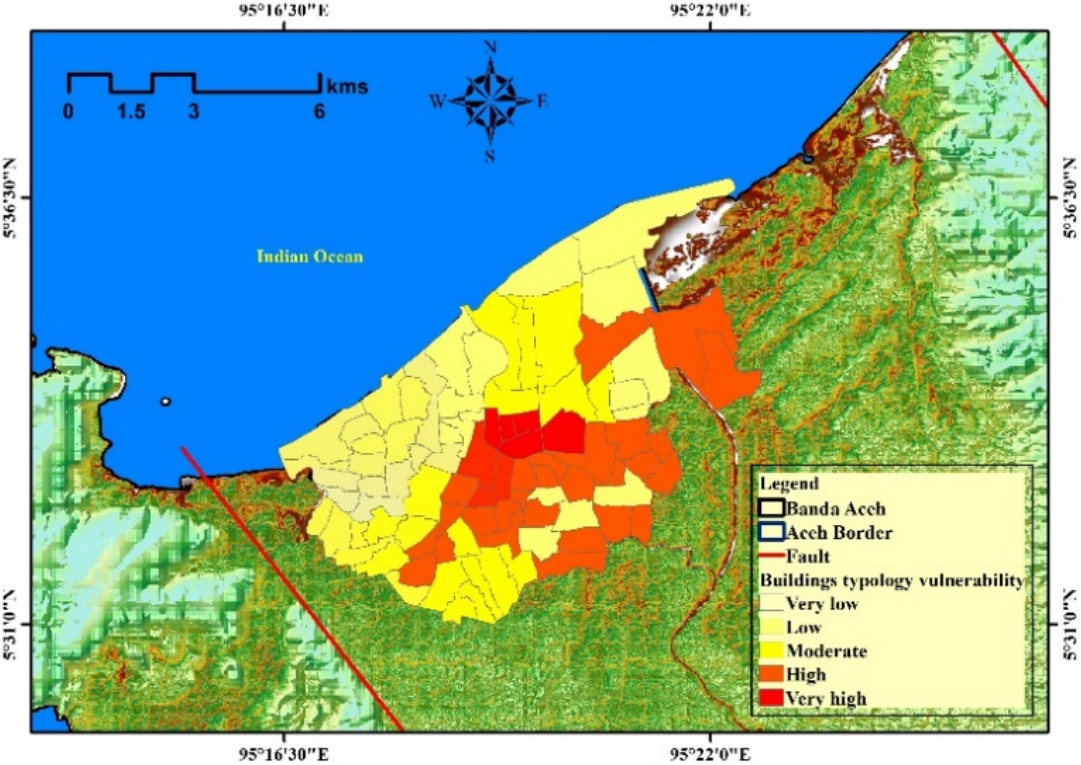


Figure 4. Mapping of buildings typology vulnerability in villages in the city.

4. Conclusion

Recent earthquakes near Banda Aceh city show that damages and economic losses, as well as casualties, can be avoided if the typology of the building is considered while constructing buildings in a proper way to resist earthquakes. Building damages exposed the problems stemmed from minimum compliance in association with the codes and regulations policy. The aspects of design and planning along with conformity to codes and building standards are necessary to ensure the important step in preparing less vulnerable buildings or infrastructures towards earthquakes. Therefore, with clear drawings and design plans, the work should be implemented with proper specifications and an easier

strategy of construction. In the stage of construction, the quality of the materials should be controlled. The workers should be well equipped along with some basic skills and good knowledge of affordable construction approaches. Inspections on quality controls should be the major purpose during the development stage to execute a guaranteed plan for the built of structures according to the design. Finally, proper maintenance of engineered structures needs to perform satisfactorily for the whole life span. Building codes dissemination and regulations are necessary for modifying the knowledge about earthquake-resistant constructions. All parties involved in the construction works should focus on capacity building on a national level with a significant impact on better infrastructure development. The perception of earthquake risk should be improved so that mitigation planning can be organized on national as well as local levels in the country. Efforts and coordination of Indonesian government and national research agencies, infrastructure developers, personnel such as contractors, masons, technicians, crafts and the community are required in upgrading building performance for future events.

Acknowledgments

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