Evacuation Simulation for Earthquake (Case Study in Sayangan Hamlet, Kotagede Complex, Yogyakarta, Indonesia)

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Abstract. Sayangan Hamlet, which is situated in Kotagede Complex Area, Yogyakarta Special Region, is exposed to the physical, socio-economic, and environmental vulnerability. A safe evacuation route to reduce the risks of earthquake impacts, however, has not supported the vulnerable condition. Therefore, the methods in this study designed an evacuation route for the hamlet by employing a staged route of evacuation model, i.e. by mobilizing victims to a temporary evacuation site first and then continued to a final evacuation site. This evacuation route model was applied in Sayangan Hamlet since the existing roads the hamlet were mostly narrow (less than 3 meters) with high and fragile walls/buildings running along the right and left sides. The result in this study: the evacuation route was organized by considering road safety, road width, and road length and accessibility to reach the evacuation site. Evacuation route map for earthquake in Kotagede expected to support disaster risk reduction.

1. Introduction
Yogyakarta Special Region is one of the provincial-level regions in Indonesia, which experienced a high scale earthquake (VIII MMI Scale) with a magnitude of 8.1 on July 23, 1943 at the epicenter of 8.6S and 109.9E. It caused about 213 casualties, more than 3,500 injuries, and around 12,600 houses collapsed [1]. Moreover, this region also suffered from a devastating earthquake in May 27, 2006. The earthquake with the magnitude of 5.9 or VII - VIII MMI Scale took place at the epicenter of 7.96S and 110.458E with a shallow depth of 10 km and a subsurface of ± 25 km on the southeast part of the region [2]. This earthquake caused more than 4,659 people killed, more than 19,304 persons injured and about 703,545 houses destroyed [3].

Some areas in Bantul Regency including Pundong, Imogiri, Jetis, Pleret, Banguntapan and Piyungan had the most severe damage, whereas these are as were located not too close from the earthquake epicentre [4]. The relatively high magnitude (M 5-7) with a shallow depth (h = 0-60 km) and the geological structure in the form of graben, existing fault, as well as uncompact rock bedding structure or loose materials caused the earthquake vibration in the area to expand quickly. This active seismic condition also resulted in catastrophic damage and losses [3].

Kotagede was one of the are as with considerably severe damage due to the 2006 earthquake. This area has a high population density with a population of 11,941 people per km²[5], adjacent houses (1-2 meters), and very narrow, winding roads (0.5 m - 2 m) with walls running along the left and right sides. Because of the earthquake on May 27, 2006, this area suffered from a lot of damage, including150 traditional houses (Joglo house) and 88 houses collapsed [6]. There were some factors contributed to
the extent of the high losses and casualties in Kotagede complex, including the high vulnerability of physical, socio-economic and environmental conditions and the unavailability of an evacuation route.

In addition to the vulnerable environmental condition and buildings, the study results indicated that, in term of social/demographic condition in Sayangan Hamlet, 52% of households belong to a vulnerable group (elderly, infants, pregnant women, the disabled). In this case, the physical, social, environment vulnerable conditions can serve as a basic consideration in disaster management in the hamlet. Therefore, this study attempted to design an evacuation route model to be applied in Sayangan Hamlet, Kotagede Area Complex, Yogyakarta Special Region in the hope that the risks of a disaster (earthquake) which might be faced by the residents can be minimized.

2. The Method of Evacuation Route and Evacuation Site

Evacuation route is a route that can be passed to remove disaster victims from a dangerous area to a safer one. The evacuation process needs communication between residents in regard to their perception whether the disaster is dangerous or not and the design of effective transport network to reach safer areas [7]. Reuben Goldblatt [8] reviewed some concepts related to evacuation plan, as follows 1). Evacuation Time Estimate (ETE) is one of the criteria to develop a protective action recommendation (PAR); 2). Mobilization time is the time needed by victims who will be evacuated to perform all the necessary preparations before evacuation; 3). Both evacuation time and mobilization time refer to the statement/report for evacuation; 4). The mobilization and evacuation process occurs over time and place, both are not an action taken at only certain times.

There are several criteria required to create a feasible shelter for evacuated victims: (1) security, (2) stability and continuity, (3) accommodation capacity, (4) comfortability, (5) accessibility to shelter, and (6) connectivity to external resources and information [9].

The determination of evacuation site and evacuate time is affected by the type, the magnitude and the perception of disaster [8]. Earthquake with a high magnitude will be perceived safer if the evacuation site is located in an open area such as soccer field or wide school yard. In addition to considering the security level, an ideal evacuation site should also pay attention to supporting facilities such as the availability of toilets or clean water, the ratio between evacuation site area and population, and the evacuation site should be easily accessed using adequate transport lines [10].

Narrow roads with walls/buildings on the right and left sides, which are vulnerable in the event of an earthquake, are obstacles and barriers during evacuation process [11]. Based on these conditions, the method developed in designing an evacuation route is the staged route, i.e. evacuating victims to a temporary evacuation site first and then to a final evacuation site. Some variables and parameters in designing this evacuation route model included: first, paying attention to road safety factors associated with road barriers by analyzing all road network; second, road capacity in relation to the road width; third, road network accessibility to the evacuation site; fourth, considering the community vulnerability and the density/number of residents in relation to the road capacity [12].

2.1. The planning of evacuation route

The earthquake evacuation route applied in Sayangan Hamlet included two routes: the route toward a temporary shelter and the route from temporary shelter to final shelter. The first stage was to assess the existing road class in the hamlet. The assessment was done by employing several variables (road safety level, road width and road accessibility). The assessment on road class was conducted through a survey of all the roads (collector roads, local roads, and footpaths) in the hamlet. The identification of evacuation site included temporary evacuation site and final evacuation site. Both were based on the classification by adjusting it to the conditions and characteristics of the study area [9]. The design of a temporary evacuation site was made by considering the safety and accessibility to reach the location. As for the design of final evacuation site, it was made by considering the security and road width related to the capacity for victims, basic facilities (clean water and sanitation), as well as road accessibility and good connectivity. The final evacuation site is a location used by victims for a long time. Thus, a feasible final evacuation site requires a wide, easily accessible area with adequate basic facilities.
The steps in designing an evacuation route in this study were based on the research conducted by Campos [8] and adapted it to the existing conditions in Sayangan hamlet. The steps of the analysis were as follows: 1. Identify the road network; 2. Map the house’s position as a dangerous area and include the road class assessment; 3. Determine a safe temporary evacuation site within the closest distance from each house, identify the characteristics and temporary evacuation site class in the network; 4. Assess the level of security as well as obstacles in the road network, road width and road accessibility as an evacuation route to reach the temporary evacuation site (there are no high walls/vulnerable and dangerous buildings, and the road networks are flat, not steep and less twists, and not a dead end); 5. Determine a safe final evacuation site and assess its class based on the security level, space, accessibility and existing facilities; 6. Identify and select the evacuation route from the temporary evacuation site to the final evacuation site by considering the following criteria: safe road, road width related to the road capacity, and road accessibility.

In this study, earthquake disaster threats were the basis for the analysis of evacuation route preparation. Earthquake is a natural disaster which usually causes damage to buildings (houses, fences, electricity poles, towers, and public facilities), trigger off landslides and cause subsidence. A shallow earthquake with a large magnitude (> 6 Richter scale) which occurs on vulnerable soil structure and materials for a fairly long time can cause buildings to collapse. The most dangerous threat is the ruins of building materials which can strike down people, causing injuries or even casualties.

In regard to the building/physical distribution in Sayangan Hamlet, as many as 2,99 buildings are in a vulnerable condition, while only 67 buildings are in a good condition. This problem is exacerbated by the narrow road network (66% of homes have an access to road with a width of less than 3 m), the adjacent buildings (79% of buildings have a distance of less than 3m), and the absence of open space as an evacuation site (39% of homes). These factors would make it difficult for people to evacuate.

The high number of vulnerable groups (elderly, infants, pregnant women and the disabled) in Sayangan Hamlet is also an obstacle during evacuation process. The disaster management which can be performed on an area with these characteristics is related to how to make risks caused by earthquake able to be suppressed/reduced. Certain efforts to evacuate people to a safe place in a quick response to avoid dangerous objects are essential to do. Thus, the staged route of evacuation is a solution offered for disaster management in Hamlet Sayangan, especially in the event of earthquake.

There are several stages in developing a method of evacuation route in Sayangan Hamlet including: assessment of road class; determination and assessment of temporary evacuation site; preparation of temporary evacuation route; determination and assessment of final evacuation site; preparation of the final evacuation route.

Road Class Analysis: Roads are an important means for people in Sayangan hamlet to do an evacuation. The assessment on road class in this study used several variables:

2.1.1. Road safety level. Safety level is a major requirement for the road to be passed as an evacuation route. The field survey showed that most of roads in Sayangan Hamlet are in unsafe condition and less secure. Based on level of security, roads can be categorized into the following classes:

(a) Safe road: no road barriers (not dead end), the left and right sides of the road are open space instead of old buildings high walls, and not steep slopes.

(b) Less safe road: the left and right sides of the road are high walls/buildings with strong structure, or building fences with a height of less than 1 m and in the event of earthquake, they are not expected to collapse.

(c) Unsafe road: the left and right sides of the road are walls/building which are very old, tall (3 m), and very fragile so that in case of an earthquake they are expected to collapse, or the dead, or road with slope/abyss/trench in the surrounding area.

2.1.2. Road width. A wide road can facilitate and provide flexibility for people to seek refuge. The wider the road, the better the capacity and the more flexible the people using means of transportation (motorcycle/car/bicycle) during an evacuation process. The minimum width of road, which is ideal for
the evacuation, is more than 4 m. This width allows vehicles to pass through and provides more flexibility for road users. The road width also gives influence on the speed for the community evacuation.

2.1.3. Road accessibility. A road that has good accessibility and is connected with other roads/highways is recommended as the main evacuation route. The more the number of roads with good quality, the easier the evacuation process. The number of adequate road network can reduce or break down a victim crowd in one particular way during evacuation. Therefore, road accessibility and network are essential for the evacuation process. Based on the survey results, the roads in this study are categorized into 5 classes as shown in Table 1.

Table 1. Classification road in Sayangan Hamlet.

| No | Road class | Description |
|----|------------|-------------|
| 1  | Class 1    | Wide more than 4 meters (m), save, better accessibility |
| 2  | Class 2    | Wide 3 – 4 m, wall 1 m, better accessibility |
| 3  | Class 3    | Wide 2-3 m, strong wall, good accessibility |
| 4  | Class 4    | Wide 1 – 2 m, less save/high wall 3 m), less accessibility |
| 5  | Class 5    | Wide > 1 m, unsafe (high wall, fragile walls), bad accessibility |

Source: Data Analysis (2014)

The road assessment was done using a survey of all existing roads in Sayangan hamlet. Every road with the same category and characteristics (security level, width, accessibility) was assessed in on category with particular road class. The assessment was made by using a list of road assessment checklist. Security factors were the most influencing variables in the class assessment. On the contrary, the road accessibility was the most minor influence in the class assessment. Although a road has a width of 3 m and good accessibility, when its condition is not safe, the class will be reduced (class 4 or 5) and, conversely, a road with poor accessibility(with a width of ± 2 m) but has a good level of security, then it will be categorized into a good class (class 2).

3. Results and discussion

3.1. The analysis of Temporary Evacuation Site (TES) class
An earthquake occurs so fast without any previous signs and, so far, humans cannot predict when it will happen. An earthquake with a large force takes place quickly and cause damage to the buildings so an evacuation to the safest and closest location is required to save victims from disaster impacts. In this study, the first thing to do was to analyze the location that could serve as a temporary evacuation site.

The most important consideration in determining a temporary evacuation site (TES) is that the location is in the form of a safe space with no buildings nearby as well as fragile tall trees/poles/towers. In addition to security assessment, TES should also cover a wide range of area and be easily accessed. More importantly, the road to reach the location should be safe. The class of temporary evacuation site in this study is determined by several factors, which refer to the criteria [9] and are adapted to the conditions and characteristics of Sayangan Hamlet. The variables to determine the temporary evacuation sites are as follows:

a. TES Security Level: A safe TES is in the form of space that is not surrounded by fragile walls/buildings, flat and stable.

b. TES Width: This refers to the capacity of a TES to accommodate victims. The more extensive the location, the more increased the capacity.

c. TES Accessibility: In designing a temporary evacuation site, accessibility to the site should be taken into account. Although an evacuation site is very extensive, but the access to the location is very difficult and unsafe, then it cannot be used as a TES.

d. TES Facilities and Infrastructure: In designing a temporary evacuation site, infrastructure is not the main factor, so it has low score in TES preparation. Those included in the infrastructure and facilities are: clean water and toilets.

The temporary evacuation sites are categorized into 3 classes as shown in Table 2.
Table 2. The classification of temporary evacuation sites.

| No. | TES Class | Description |
|-----|-----------|-------------|
| 1   | Class 1   | Very safe, no dangerous buildings/trees/towers, wide space (more than 150 m\(^2\)) and flat, easy to access/reach and adequate facilities (clean water, toilets) |
| 2   | Class 2   | Safe, wide range of 100-150 m\(^2\), quite easy to access/reach, no facilities (clean water, toilets) |
| 3   | Class 3   | Quite safe, wide range of less than 100 m\(^2\), quite easy to reach, no facilities (clean water, toilets) |

Source: Data Analysis (2014)

Based on the analysis results, there are 101 locations, which can serve as a temporary evacuation site in Sayangan Hamlet. Some locations are spacious but not worth as a temporary evacuation. This is because high and fragile walls surround the spaces, and the community found it difficult to reach the location due to narrow roads (to reach the location) and road barriers. In this study, the percentage of temporary evacuation site: 2% class 3, 61 % class 2 and 37 % class 1.

The class distribution of temporary evacuation site in Sayangan Hamlet is mostly at class 2 due to a very limited space with a very safe condition. Some of the spaces in the hamlet are surrounded by old walls that are feared to collapse in the event of an earthquake, in addition to the lack of a security factor where most of spaces in the hamlet cover less than 50 m\(^2\). The class 3 temporary evacuation sites located in the hamlet are still used because there is no longer safer areas to be served as TES.

3.2. The analysis of evacuation route to the temporary evacuation site

The temporary evacuation routes are paths existing in every household to reach the temporary evacuation sites. These temporary evacuation routes should be arranged since earthquake occurs suddenly, forcing residents to immediately seek refuge in a safe and accessible place. In the tectonic earthquake, the first shock is the most powerful one compared with the aftershocks. On the 2006 earthquake, several people were injured/killed because they did not have time to leave their houses quickly. They were trapped in the houses, which instantly collapsed since they were unable to withstand the earthquake shocks. There was a large number of casualties in the 2006 earthquake since the victims were stricken down by falling debris from collapsed buildings. Some people were also injured in the evacuation process since they did not pay attention to the environmental condition. For instance, the collapsed walls crushed some residents as they walked to the evacuation site.

An evacuation route design should consider the security factor. In this way, although some areas have a detour (farther distance), the road security is better. The main consideration in planning a temporary evacuation route is that all residents are expected to survive by going to the nearest evacuation site through a secure way.

The survey showed that there is an area (i.e. the neighborhood of RT 4) in Sayangan Hamlet in which most of households are in isolated condition because the area is exposed total buildings with high vulnerability and narrow roads (<1 m) with fragile walls and buildings running along the right-left sides. Several options of solution to address this problem are first, create a route with the risk of less safe road; second, wreck the old and empty buildings nearby to be used as a temporary evacuation site; or third, strengthen the structure and quality of the existing buildings so that in the event of earthquake some residents can shelter under a strong table in the house.

3.3. The analysis of final evacuation site class

The final evacuation site is an area that allows people to seek refuge in or to stay within a few days/weeks/months until the rehabilitation and reconstruction process is done and the condition is declared safe. Final evacuation site is a safe location with a wide-open area. It has various facilities such as toilet and clean water. Moreover, the strategic connectivity accessibility of the [7] are adapted to the conditions and characteristics in Sayangan Hamlet. The good accessibility can facilitate the aids distribution process and the victims’ movement when they need for health care. The analysis and classification of the final evacuation site applies certain criteria as presented in Table 3.
Table 3. The classification of final evacuation sites.

| No. | TEA Class | Description |
|-----|-----------|-------------|
| 1   | Class 1   | Very safe, wide range of more than 200 m², adequate facilities including clean water, toilets and other supporting facilities, good accessibility (cars can freely reach the location) |
| 2   | Class 2   | Safe, wide range of 100-200 m², adequate basic facilities such as water supply and sanitation, but poor accessibility (cars cannot reach the location) |

Based on the assessment of the final evacuation site class, Sayangan Hamlet has 8 class-1 evacuation sites and 9 class-2 evacuation sites. Some evacuation sites are classified into class since the sites are in the middle of settlement and not accessible by four-wheel vehicles. The evacuation site with the excellent quality lies in the Mataram mosque complex’s space. This evacuation site is supported by a wide space and strategic location (adjacent to highway). It also enables vehicles to reach the location and has complete facilities (clean water, sanitary facilities, place of worship, hydrants, and health clinics).

3.4. The evacuation route to the final evacuation site

This route is an evacuation route arranged from a temporary evacuation site to the final evacuation site. The selection of road and evacuation site was based on the analysis of the final evacuation site capacity and the existing road network in Sayangan Hamlet. With the preparation of this evacuation route, it is expected that the distribution of refugees be in line with the capacity of evacuation site, so that evacuation process can run smoothly and safely.

Some roads in Sayangan hamlet, which have several obstacles (narrow, unsafe), make some evacuation routes to reach the final evacuation site not in a feasible condition. The evacuation routes are classified into four classes based on road safety, road width and road accessibility. The criteria used for classifying the evacuation routes into 4 classes are shown in Table 4.

Table 4. The classification of evacuation route to the final evacuation site.

| No. | Evacuation Route Class | Description |
|-----|------------------------|-------------|
| 1   | Level 1                | Passing through a very safe road with a width of > 3 m, no barriers, or passing through a secure open area |
| 2   | Level 2                | Passing through a safe road with a width of 2 - 3 m |
| 3   | Level 3                | Passing through a road with fairly strong buildings on the left and right sides, and a width of 1.5 - 2 m |
| 4   | Level 4                | Passing through a road with a width of < 1.5 m, some parts of the road are insecure |

About results of the assessment of final evacuation route, the number of final evacuation route classification are: 40 % class 1; 4 % class 2; 33% class 3 and 5 % class 4. Some evacuation routes to reach the final evacuation site are categorized into class 4, meaning some roads are still less safe. This evacuation route remains prepared because there is no other route option for households to reach the final evacuation site. This can be taken into consideration on how to create a solution to address this problem. A solution proposed in this area is by approaching to the owners of the old and fragile fences/buildings to replace them with the stronger ones, or replacing the fences into the hedge, which is safer in the event of an earthquake.

4. Conclusions

The staged route of evacuation, which is done by mobilizing people to a temporary evacuation site first and then to a final evacuation site is an appropriate model of evacuation route for earthquake disaster. The design of an evacuation route by taking into account certain factors including road safety, road width, and road accessibility, and by making it in detail can be applied to areas with specific characteristics such as Sayangan Hamlet with its high building density, narrow road network, limited availability of space, population density and high number of vulnerable groups. The earthquake disaster management can be done by pressing the level of physical vulnerability through restoration/reinforcement of building structure, socialization and control from government in relation to the earthquake resistant building standard. Social and economic vulnerability can be reduced by
improving the quality of human resources through improved education, skills and knowledge. Making good use of the available space in association with disaster risk management and allocating it for an evacuation site can increase the environment carrying capacity. Meanwhile, the community capacity can be enhanced through the development of public awareness and the disaster-related education and training.

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