The accessibility of tsunami prone areas society towards potential shelters: a case study in Padang Barat sub-district

Titi Kurniati1,*, Adrial Sy2, and Purnawan Purnawan1

1Associate Professor, Civil Engineering Department, Andalas University, Indonesia
2Graduate, Civil Engineering Department, Andalas University, Indonesia

Abstract. Padang city, which is located on the western coast of Sumatra, has the potential to experience a powerful earthquake and thus generate tsunami. After the earthquake, with or without a tsunami warning, the society is required to evacuate. Because of the short time, vertical evacuation is the best alternative for the safety of society. Evacuation on foot to the temporary rescue building (Temporary Evacuation Shelter, TES) is more advisable than evacuation using motorized vehicles that tends to cause congestion. Temporary evacuation maps and potential shelters in Padang have been established by BPBD (Disaster Management Agency). In the Padang Barat sub-district, there are 13 potential shelters. This study aims to determine the level of accessibility to potential shelters based on travel time and road width parameters. In determining accessibility, the study area is divided into 50x50m size grids. The travel time is determined based on the distance from the center of the grid to the nearest TES through the road network. The limitation of evacuation time is 10 minutes. The results of data analyzing showed that among the 4358 grids which were occupied by society, there were 2272 grids (52.1%) which have low accessibility (based on travel time) and 30% has a low level of accessibility based on travel time and width road parameter.

1 Introduction

Padang is a large city on the West Coast of Sumatra and has experienced many earthquakes both large and small. According to research there is a high likelihood of an 8.8 SR earthquake along the "Sunda megathrust" fault-line which will cause a large tsunami in some indefinite time in the future, in Sumatra Barat province. [1]

The city of Padang requires a preparedness program to mitigate the effects of predicted earthquakes and tsunamis. Tsunamis, which could be 5 to 11 meters or more, are likely to hit the west coast of Sumatra Barat, which includes Padang, in within 20 to 30 minutes of an earthquake [1]. In the case of a large earthquake the population of Padang who are in coastal areas need to flee immediately to higher areas. Rapid horizontal evacuation, moving inland, is difficult to achieve. In the September 30, 2009 earthquake, the people of Padang who evacuated horizontally using four-wheeled vehicles and motorbikes were hampered by traffic jams where the traffic flow did not move at all so could not reach a tsunami safe area.

Another alternative is vertical evacuation to shelter buildings. As a tsunami disaster mitigation effort, the city government of Padang has purpose built tsunami shelters and designated existing buildings as tsunami shelters. These are located around populated areas, so can be easily reached quickly. It has been recommended that people walk to these shelters to avoid the congestion of a motorized vehicle evacuation.

Padang Barat District is fairly densely populated and is in a high risk tsunami zone because it is 0-700 m from the coast and only 0-5 m above sea level. This means provision for vertical evacuation by walking to a shelter would be the recommended action in case of an earthquake. This research provides this information in the form of accessibility maps for this area. Levels of accessibility is determined without considering the shelter capacity and population density in the coverage area.

2 Literature Review

2.1 Accessibility Concept

Accessibility, ease of movement between two places, is a function of distance, travel time, and travel costs. The travel time factor is largely determined by the availability of reliable transportation infrastructure and facilities [2]. High levels of accessibility result from a high quality road network connecting origin and destination along with reliable means of transport fleets that are available at all hours as in Table 1(a).

Table 1(a). Classification of Accessibility Levels [2]

| Land use activities | Far apart | Low Accessibility | Medium Accessibility | High Accessibility |
|---------------------|----------|-------------------|----------------------|--------------------|
| Close together      | Medium   | High              |
| TransportConnections| Very poor| Very good         |

* Corresponding author: titi@eng.unand.ac.id
2.2 Vertical Evacuation

Vertical evacuation is an effort to save yourself by moving to a higher place, which can be a hill (natural shelter) or a building with more than one floor preferably by foot. [3-5]. Evacuation routes are along the road network in the city center, and several main roads in residential areas. The speed of evacuation is a key factor so people can reach the shelters before the tsunami strikes. The Japan Institute for Fire Safety and Disaster Preparedness 1987 in [5] gives an overview of average walking speed in disaster evacuation as shown in Table 1(b).

Table 1(b). Evacuee walking condition and average walking condition. [5]

| Walking condition               | Average walking speed (m/s) |
|--------------------------------|----------------------------|
| A person pushing a perambulator| 1.07                       |
| A person with a child          | 1.02                       |
| An independent walking elderly person | 0.948                     |
| A group of walking elderly people | 0.751                     |

According to experimental data and previous works [6], pedestrians initially move faster, in order to distance themselves from buildings and from other individuals. The average speed for this part of the evacuation (from exiting to 8m far from building) is equal to 2.15 m/s. After these first evacuation moments, speeds decrease and become close to group average desired speed.

Fig. 1. shows trends of average instantaneous speeds in evacuation groups for different pedestrians’ densities (ped/m²) [7]

Fig. 2. Time line tsunami evacuation diagram [9]
3 Methodology

3.1 Data Collection

The data needed to determine accessibility when evacuating to the shelter is a road network map and road width. Road network maps were taken from Google Maps and the width of the road was measured directly in the field. Secondary data in the form of the number, location and capacity of the shelter buildings was obtained from BPBD. Table 2 shows potential shelter data in Padang Barat. [10]

Table 2. Potential Shelter Location [10]

| No. | Shelter Name               | Address                      |
|-----|----------------------------|------------------------------|
| 1   | Bappeda Propinsi SumBar    | Jalan Khatib Sulaiman      |
| 2   | Escape Building Kantor Gubernur | Jalan Sudirman No.51  |
| 3   | Polda Sumbar               | Jalan Sudirman             |
| 4   | Pasar Impres               | Jalan Sandang Pangan (Pasar Raya) |
| 5   | SD 03 41 Purus             | Jalan Veteran              |
| 6   | SD Percobaan               | Jalan Ujung Gurun          |
| 7   | SD 23 dan 24 Ujung Gurun  | Jalan Ujung Gurun          |
| 8   | STBA Prayoga               | Jalan Veteran              |
| 9   | SPR Plaza                  | Jalan M.Yamin              |
| 10  | Plaza Andalas              | Jalan Pemuda               |
| 11  | Rusunawa                   | Jalan Purus IV             |
| 12  | Masjid Al Wustha           | Jalan Veteran              |
| 13  | Masjid Taqwa Muhammediyah  | Jalan M. Yamin             |

3.2 Data Processing

The steps for processing data in this study were:

1. A 50x50 meter grid was imposed on the map of the area. (Fig. 3.)
2. The closest distance from the center of the grid to the shelter through the road network was calculated using AutoCAD where the map used had been scaled according to its actual size. [11]
3. The time to walk to the shelter assuming an evacuation speed of 1 m/s was determined.
4. Accessibility levels were determined based on travel time in table 3 and based on both travel time and road width in table 4 with limitations 10 minutes is available for evacuation.
5. The results formed the basis of an accessibility map to the shelter.

Table 3. Accessibility Levels based on travel time

| Travel time (minutes) | Accessibility Level |
|-----------------------|---------------------|
| < 5                   | High                |
| 5 – 10                | Medium              |
| >10                   | Low                 |

Table 4. Accessibility Levels based on travel time and road width

| Road Width (metre) | Travel time (minutes) |
|--------------------|-----------------------|
| < 5                | 5- 10                 |
| >14                | High                  |
| 7 - 14             | High                  |
| <7                 | Medium                |
|                      | Low                   |

4 Results

A flow map to existing and potential shelters was drawn up. The flow of movement was always away from the coast. The flow map can be seen in Fig. 4. The level of accessibility to shelters is shown in Table 5. Level of accessibility maps based on travel time are shown in Fig. 5.

Results show, if the evacuation is only carried out to the shelter and potential shelter provided by the government, 52% of the 50x50 m cells are in areas with a low accessibility level indicating people will not be able to access shelters within 10 minutes during a tsunami evacuation. However, there are a number of privately owned multi-storey buildings which, if they withstand the earthquake, could also be used as shelters.
Table 5. Accessibility Level in Padang Barat Subdistrict based on travel time

| No. | Potensial Shelter Location       | Number of grid/cell | Level Accessibility | % low accessibility grid |
|-----|----------------------------------|---------------------|---------------------|--------------------------|
| 1   | Bappeda Prov. Sumbar             | 242                 | 31                  | 107                      | 42.975%                  |
| 2   | SD Percobaan                     | 305                 | 31                  | 116                      | 51.803%                  |
| 3   | Polda Sumbar                     | 257                 | 34                  | 96                       | 49.416%                  |
| 4   | Kantor Gubernur Sumbar           | 251                 | 15                  | 63                       | 68.924%                  |
| 5   | SD 23 & 24 Ujung Gurun           | 443                 | 37                  | 143                      | 59.368%                  |
| 6   | Rusunawa                         | 285                 | 39                  | 111                      | 47.368%                  |
| 7   | Mesjid Al Wustha                 | 413                 | 34                  | 174                      | 49.637%                  |
| 8   | SD 03, 04 & 21 Purus             | 385                 | 40                  | 161                      | 47.792%                  |
| 9   | STBA Prayoga                     | 394                 | 24                  | 122                      | 62.944%                  |
| 10  | Pasar Inpres                     | 338                 | 38                  | 148                      | 44.970%                  |
| 11  | SPR Plaza                        | 339                 | 32                  | 135                      | 50.737%                  |
| 12  | Mesjid Taqwa Muhammadiyah        | 303                 | 22                  | 135                      | 48.185%                  |
| 13  | Plaza Andalas                    | 403                 | 40                  | 158                      | 50.868%                  |
|     | Total grid                       | 4358                | 417                 | 1669                     | 52.134%                  |

Accessibility levels based on travel time and road width are shown in Table 6 and the map in Fig. 6.
Fig. 5. Accessibility map without road width parameter in Padang Barat

Table 6. Accessibility Levels in Padang Barat based on travel time and road width

| No. | Potential Shelter Location          | Number of grid/cell | Level Accessibility | % low accessibility grid |
|-----|------------------------------------|---------------------|---------------------|--------------------------|
|     |                                    |                     | High  | Medium | Low   |                      |
| 1   | Bappeda Prov. Sumbar               | 242                 | 83    | 97     | 62    | 25.620%              |
| 2   | SD Percobaan                       | 305                 | 41    | 131    | 133   | 43.607%              |
| 3   | Polda Sumbar                       | 257                 | 62    | 126    | 69    | 26.848%              |
| 4   | Kantor Gubernur Sumbar             | 251                 | 39    | 79     | 133   | 52.988%              |
| 5   | SD 23 & 24 Ujung Gurun             | 443                 | 102   | 170    | 171   | 38.600%              |
| 6   | Rusunawa                           | 285                 | 90    | 162    | 33    | 11.579%              |
| 7   | Mesjid Al Wustha                    | 413                 | 111   | 162    | 140   | 33.898%              |
| 8   | SD 03, 04 & 21 Purus                | 385                 | 98    | 137    | 150   | 38.961%              |
| 9   | STBA Prayoga                       | 394                 | 122   | 168    | 104   | 26.396%              |
| 10  | Pasar Inpres                        | 338                 | 33    | 122    | 183   | 54.142%              |
| 11  | SPR Plaza                          | 339                 | 164   | 157    | 18    | 5.310%               |
| 12  | Mesjid Taqwa Muhammadiyah           | 303                 | 105   | 126    | 72    | 23.762%              |
| 13  | Plaza Andalas                      | 403                 | 166   | 194    | 43    | 10.670%              |
|     | Total grid                         | 4358                | 1216  | 1831   | 1311  | 30.083%              |
|     | %                                  |                     |       |        |       | 27.903% 42.015% 30.083% |
If road width is taken into account the number of cells with low accessibility drops to 30% because a wide road can improve evacuation flow. Also the number of cells with a high level of accessibility increases for each potential shelter location. A summary of the comparison of accessibility levels with and without the width of the road being taken into account are displayed in Table 7.

Table 7. Comparison of Accessibility Level in Padang Barat

| Level Accessibility | Without road width | With road width | difference  |
|----------------------|--------------------|-----------------|-------------|
| High                 | 9.569%             | 27.03%          | 18.334% Up  |
| Medium               | 38.297%            | 42.015%         | 3.717% Up   |
| Low                  | 52.134%            | 30.083%         | -22.051% Down|

5 Conclusion

The results of the accessibility analysis to potential shelters in West Padang sub-district showed that 30% of the populated area has a low level of accessibility. People will not be able to reach the shelter within 10 minutes of the signal to evacuate. To mitigation this independent shelters in the form of privately owned buildings need to be made available as shelters.

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