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

Titi Kurniati[1,*], *Adrial* Sy[2], and *Purnawan* Purnawan[1]

[1]Associate Professor, Civil Engineering Department, Andalas University, Indonesia
[2]Graduate, 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 case 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
	Close together	Medium Accessibility	High Accessibility
TransportConnections		Very poor	Very good

* Corresponding author: titi@eng.unand.ac.id

 https://doi.org/10.1051/e3sconf/202015604001

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 2.15m/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/m^2) [7]

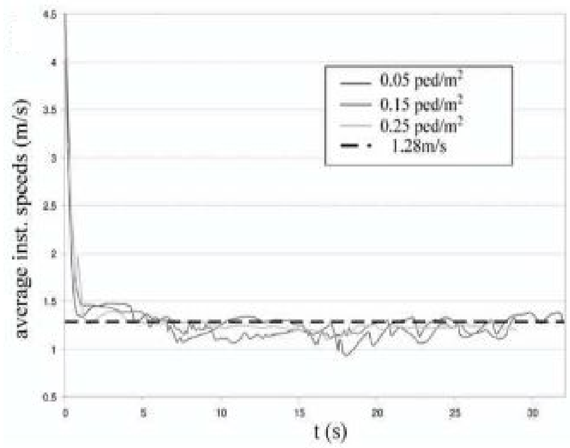

Fig.1. Evacuation speeds trends during evacuation time [7]

In normal conditions of 8-15 pedestrians per square foot, according to the Transportation Research Board (TRB, 2000), walking speed is 2.50-3.75 ft/s, or 0.763-1.144 m/s. [8]

The walking speed to reach an evacuation site will be influenced by the location of the evacuation, the condition of the route and the density of the people on that route. Assuming that the speed of people running in these conditions is between 2.5 km/h and 3.6 km/h (0.7-1 m/s), evacuation locations should be situated within 400 - 600 m of the center of settlement or community activities so they can be reached within 10 minutes based on the Padang city tsunami evacuation time line shown in Fig. 2. [9]

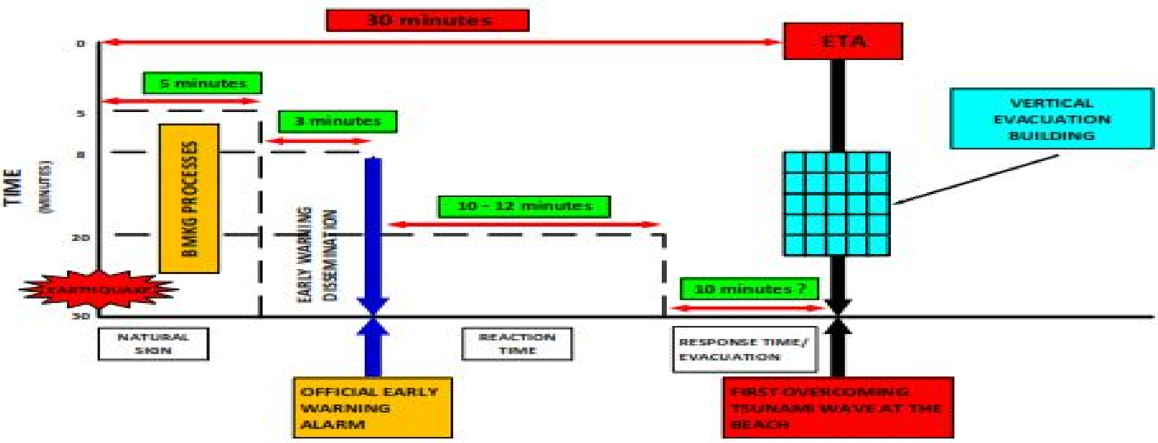

Fig.2. Time line tsunami evacuation diagram [9]

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 the BPBD. Table 2 shows potential shelter data in Padang Barat. [10]

Table 2. Potensial 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 Inpres	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 Muhammadiyah	Jalan M. Yamin

3.2 Data Processing

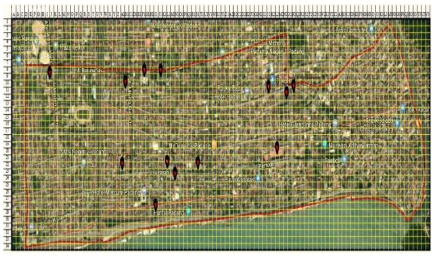

Fig.3. Padang Barat Subdistrict Map

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

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

https://doi.org/10.1051/e3sconf/202015604001

Fig.4. The flow of movement map

Table 5. Accessibility Level in Padang Barat Subdistrict based on travel time

No.	Potensial Shelter Location	Number of grid/cell	Level Accessibility			% low accessibiliyy grid
			High	Medium	Low	
1	Bappeda Prov. Sumbar	242	31	107	104	42,975%
2	SD Percobaan	305	31	116	158	51,803%
3	Polda Sumbar	257	34	96	127	49,416%
4	Kantor Gubernur Sumbar	251	15	63	173	68,924%
5	SD 23 & 24 Ujung Gurun	443	37	143	263	59,368%
6	Rusunawa	285	39	111	135	47,368%
7	Mesjid Al Wustha	413	34	174	205	49,637%
8	SD 03, 04 &21 Purus	385	40	161	184	47,792%
9	STBA Prayoga	394	24	122	248	62,944%
10	Pasar Inpres	338	38	148	152	44,970%
11	SPR Plaza	339	32	135	172	50,737%
12	Mesjid Taqwa Muhammadiyah	303	22	135	146	48,185%
13	Plaza Andalas	403	40	158	205	50,868%
Total grid		**4358**	**417**	**1669**	**2272**	**52,134%**
%			**9,569%**	**38,297%**	**52,134%**	

Accessibility levels based on travel time and road width are shown in Table 6 and the map in Fig. 6.

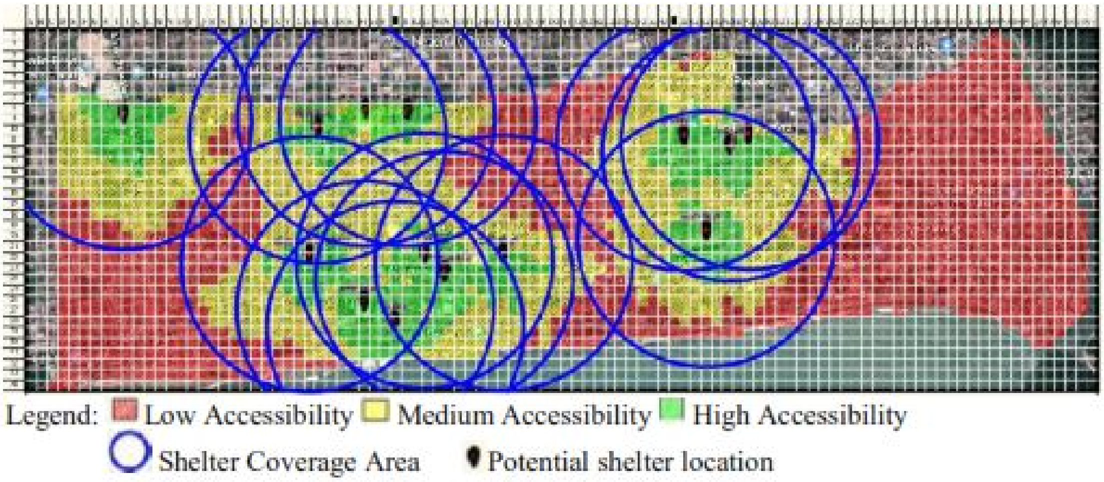

Fig.5. Accessibility map without road width parameter in Padang Barat

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

No.	Potensial Shelter Location	Number of grid/cell	Level Accessibility			% low accessibiliyy 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%**	

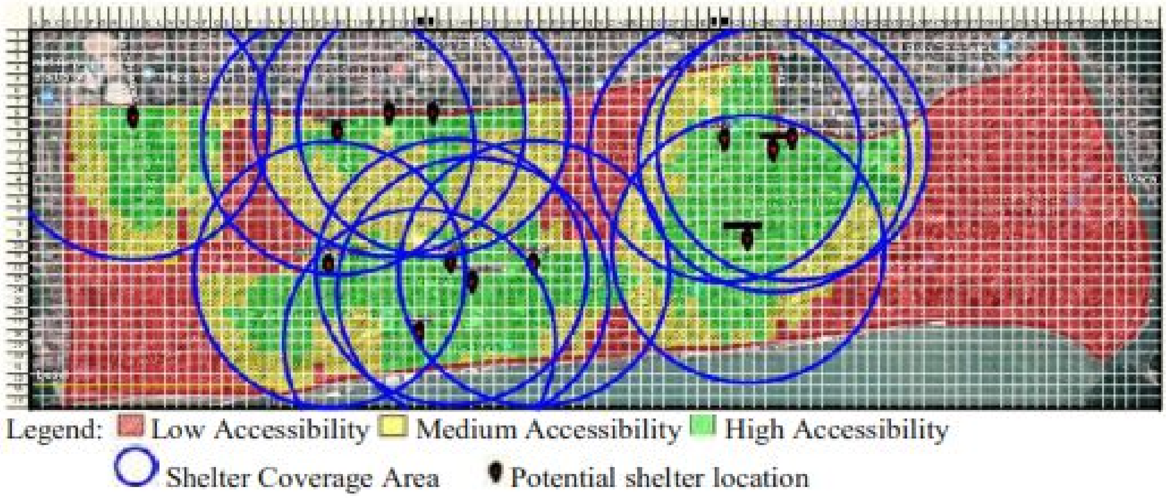

Fig.6. Accessibility map with road width in Padang Barat

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.

The authors would like to thank Engineering Faculty for the financial support provided through Hibah Publikasi Fakultas Teknik Tahun Anggaran 2019 under contract no.013/UN.16.09.D/PL/2019.
Data collection shown in this paper is part of the author's 2 undergraduate thesis under the writer supervision

References

1. D.H. Natawidjaja, K. Sieh, J. McCaughey, A. Lubis, *Tsunami Event Scenarios Caused by the 8.8 SR Earthquake in West Sumatra*, Report for Meetings with Stakeholders, Sumatra Barat Province (2012) in bahasa
2. O.Z. Tamin, *Transportation Planning and Modeling* (ITB, Bandung, 2000) in bahasa
3. F. Ashar, D. Amaratunga, R.Haigh,. *Procedia Economics and Finance* 18 916-923 (2014)
4. N. Ramadhani, N., A.Suprayogi., L.M. Sabri, J.Geodesi Undip. **2** Num.1 (2013)
5. A.Budiarjo, *Evacuation Shelter Building Planning forTsunami-prone Area; a Case Study of Meulaboh City, Indonesia*, Thesis, Enschede, The Netherlands (2006)
6. M. D'Orazio, L. Spalazzi, E. Quagliarini, G. Bernardini, Safety Sci. **62** 450–465 (2014)
7. G. Bernardini, M. D'Orazio, L. Spalazzi, E. Quagliarini, *Transportation Research Procedia* 2 255 – 263 (2014)
8. C.J. Khisty and B.K. Lall, *Fundamentals of Transportation Engineering* 2 (Erlangga, Jakarta, 2006)
9. Yunarto, H.Z. Anwar, S. Wibowo, M. Ruslan, A. Wahyudin, Proc. of. Research Results of the Geotechnology Research Center-LIPI (2009)
10. BPBD Padang City, *Tsunami Evacuation Map and Padang City Potential Shelter* (2016)
11. T. Kurniati, N. Pratama, J. Teknika **20** (1) (2013)