International Journal of GEOMATE, June, 2022, Vol.22, Issue 94, pp.113-120
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.94.j2391
Geotechnique, Construction Materials and Environment

READINESS ANALYSIS OF PUBLIC BUILDINGS IN PADANG CITY FOR TSUNAMI TEMPORARY EVACUATION SHELTER

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*Corresponding Author, Received: 20 July 2021, Revised: 07 Jan. 2022, Accepted: 02 April 2022

ABSTRACT: The potential mega-earthquake at Mentawai Megathrust could trigger a deadly tsunami. The tsunami can reach Padang City within 20-30 minutes. Thus, people in Padang City need to be evacuated immediately either to the higher ground or to the high-rise buildings located in Padang City. Reaching higher ground is not easy as it takes time and is hampered by traffic. Therefore, vertical evacuation to high-rise buildings is very important to be studied. This paper aims to identify, analyze and measure the readiness of the potential buildings to be used as temporary evacuation shelters for tsunami disaster evacuation. The research was conducted using observation of twenty-three potential buildings and interviews. The readiness of the buildings is assessed using 23 criteria, which were divided into 6 main criteria and 17 supporting criteria. It was found that none of the buildings was ready as a tsunami evacuation shelter. To be ready as a tsunami evacuation shelter, seven buildings that meet all six main criteria need to improve their supporting facilities and infrastructure, while the other 16 buildings have to be improved to meet all the main and supporting criteria.

Keywords: Public Building, Tsunami Evacuation Shelter, Padang City, Disaster Preparedness

1. INTRODUCTION

The geographical condition of Padang City which is close to the Megathrust Fault near the Mentawai Islands can trigger earthquakes and tsunamis. After the earthquake and tsunami in Aceh on December 26, 2004, public awareness of the earthquake and tsunami on the west coast of Padang City has increased. This concern is considered reasonable because Padang City is directly facing the Indonesian Ocean. From the digitization results, the coastline of Padang City reaches 68.126 kilometers, which means that urban residents who live and work on the coastline are vulnerable to tsunamis. If a tsunami occurs, at least six sub-districts or 30 urban villages will be directly exposed to the tsunami [1].

In dealing with the possibility of an earthquake and tsunami disaster, the Padang City Government and disaster-related stakeholders in Padang City have prepared a contingency plan in 2017. In this document, the worst scenario is if the earthquake and tsunami did occur. The scenario is on Monday at rush hour (10.00 WIB), an earthquake with a magnitude of 8.9 on the Richter scale at a depth of 30 km occurs, followed by a tsunami disaster. Based on Fig. 1, the estimated source of the earthquake is 150 km southwest of Padang City. The first tsunami wave or inundation reached the coast of Padang City in 20 minutes, with a height between 8-12 meters above means sea level. The tsunami penetrates 2-3 km inland. The population exposed to the tsunami is 273,755 people out of a total of 914,968 residents of Padang City [1]. Using stochastic earthquakes scenarios, Muhammad et al [2] predicted that tsunami inundation height and depth could reach 15 and 10 m respectively.

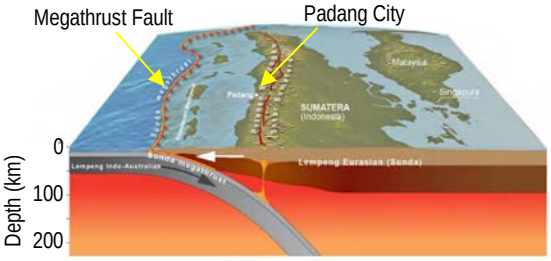

Fig. 1. The Sunda Megathrust fault caused an earthquake and tsunami in Padang City, West Sumatra (Source: Natawidjaja, et al., 2012)

To minimize the number of casualties due to the potential tsunami disaster, a comprehensive disaster management strategy, especially at the preparedness stage, is highly needed. One effort is by providing a Temporary Evacuation Shelter (TES). TES can be existing buildings, new buildings specially made as temporary evacuation sites, or hills, both natural hills and artificial hills [3]. McCaughey et al [4] stressed that tsunami vertical evacuation buildings can save many lives. Fraser et al [5] also highlight the importance of tsunami vertical evacuation. As the time for evacuation is very limited, Rahayu and Anita [6] added that the self-evacuation effort by the community to TES is very important in densely populated coastal areas with dense buildings and limited availability of road infrastructure. Fujita and

Yashiro [7] also reminded us that street blockades caused by destroyed buildings might also happen.

Padang City has several high-rise buildings. Yet, the Government of Padang City does not have a fixed list of buildings that can be used as TES. It seems that not all high-ribuildingsing can be used as TES as certain criteria have to be met. Hence, this research aims to identify buildings that can be used as temporary TES and also to analyze and measure their readiness.

2. RESEARCH SIGNIFICANCE

The findings of this study will contribute significantly to decreasing the physical vulnerability of Padang City in facing tsunami disasters. In case of tsunami happened, the community will know to which building they are heading. In addition, the government will know what has to be done in potential TES buildings to be ready to function as TES. All the efforts will contribute to the disaster risk reduction program of Padang City.

3. LITERATURE REVIEW

A vertical tsunami evacuation site is a building or mound of earth that is of sufficient height to lift IDPs above the tsunami inundation level and is designed and constructed with the strength and resilience required to withstand the effects of a tsunami wave [8]. Considering the limited number of designated vertical evacuation sites (shelters), the existing building such as a public building that has a multi-story structure is another alternative place for saving and evacuating people. This alternative building is called a potential temporary evacuation site. In some locations, the high ground may not be present, or the resulting tsunami may not provide sufficient warning time to evacuate to higher ground. Therefore, the option of carrying out a vertical evacuation is very urgent for the majority of the population compared to walking along with a horizontal evacuation to an elevation area [9].

A potential solution is to carry out vertical evacuation above the rising water to buildings and other structures that have the adequate strength and resilience to withstand the effects of tsunami waves. The vertical evacuation building is a building intended as a shelter in the event of a tsunami. These shelters are designed for short-term protection (12-24 hours), are of sufficient height to accommodate refugees above tsunami inundation levels, and have been designed and constructed to withstand earthquakes and withstand the effects of tsunami loads. When referring to the 2011 Japanese tsunami, vertical evacuation buildings have saved many lives).

Rahayu and Anita [6], Federal Emergency Management Agency [8], Minister of Public Works Regulation Number 06/PRT/M/2009 concerning Guidelines for General Planning for Infrastructure Development in Tsunami Prone Areas [10], Minister of Public Works Decree of the Republic of Indonesia Number: 468/ KPTS/1998 concerning Technical Requirements for Accessibility in Public Buildings and the Environment [11] suggested some requirements that need to be checked for existing buildings to be used as TES. They are as below:

1. Identification and review of buildings.
    a. Space requirements and utilities.
    b. Location and accessibility.
    c. Building height.
    d. Vertical circulation.
    e. Building mass composition.
    f. Building structure.
2. Recommendation for the building, whether it can be used directly, needs to be retrofitted or tested for the feasibility of the structure.
3. Legality.
    a. Statements may or may not be accessible to the public.
    b. Building sign as an evacuation site.
4. Building partnerships, such as cooperation between the government, business entities, stakeholders, and the community.

Based on the requirements above, a guideline related to the assessment of the potential readiness of public buildings as a temporary evacuation site during the tsunami disaster in Padang City was prepared and 23 criteria were established.

4. METHODOLOGY

The location of the research was Padang City, the capital of West Sumatra Province, Indonesia. Padang City is one of the highest tsunami risks in the world due to its close location to hazards, the number of people exposed, and its vulnerability.

The flowchart of the research can be seen in Fig 2. Buildings to be examined are the buildings located in the estimated tsunami inundation area based on the Map of Temporary Evacuation Sites and Potential Shelter Locations [12] which was resulted from an agreement between the Padang City Government and disaster-related stakeholders such as academia, NGOs, and professional. In addition, the height of the tsunami inundation refers to the Last Mile Evacuation Modelling Map which was developed in 2010. These maps can be seen in Fig. 3.

The proposed perspective building for potential temporary evacuation sites to be investigated is based on survey data from the BPBD (Local Disaster Management Agency) of Padang City in 2017, which has also been included in the Map of

Temporary Evacuation Sites and Potential Shelter Locations [12].

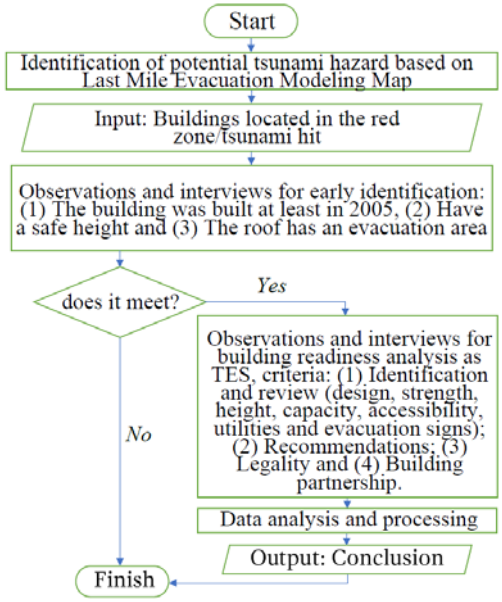

Fig. 2. Research flowchart

BPBD is a government agency that carries out disaster management tasks in the region, both in the Regency, City, and Province. Fig. 4 shows one of three buildings in Padang City that has been specially designed for TES. The buildings are government office buildings, private offices, hospitals, markets, school buildings, campuses, hotels, and places of worship. 60 buildings have the potential to be used for evacuation in the event of a tsunami.

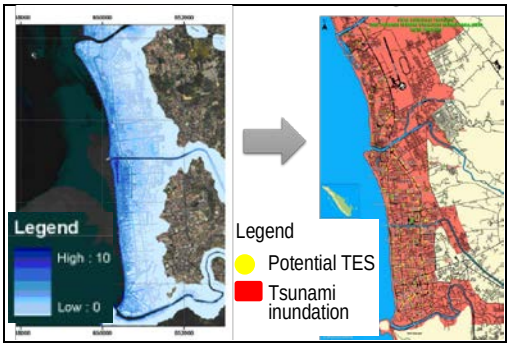

Fig. 3. Last Mile Evacuation Map and Tsunami Evacuation Map (left) and Potential Temporary Evacuation Shelter for Padang City (right) (source: BPBD of Padang City)

After obtaining a list of prospective temporary evacuation sites, the initial identification of the building is carried out. The purpose is to ensure that these buildings meet the basic criteria for assessing the readiness of potential temporary evacuation sites. The criteria that must be met in the initial identification of potential temporary evacuation sites are as follows [6]:

Fig 4. Specially designed TES in Padang City (source: BPBD of Padang City)

1. Earthquake-resistant buildings have to meet the requirements of the Indonesian Standard for Earthquake Resistant Building Design SNI-03-1726-2002 or subsequent regulations and were built after 2005. The year 2005 was chosen with the assumption that the socialization of SNI-03-1726-2002 required socialization time and was fully implemented in approximately 3 years. Data were obtained through interviews with building owners or their representatives.
2. Have a safe height from tsunami inundation. This data was obtained through observation by directly measuring the height of existing buildings, using digital measuring instruments. The altitude data will be processed so that a safe altitude value is obtained based on FEMA P646 (2012):
   $T = Ti + (3 + 30\%Ti)$ ..... (Eq 1)
   where:
   T = Building height from ground level (meter)
   Ti= Tsunami height (meter)
3. Meet the sustainability aspects. Under normal conditions (no tsunami disaster), the building can function as a public building, thus fulfilling the sustainability aspect. But the basic thing from this sustainability aspect is that the designation of the building can be accessed by everyone, not only people who are active in the building. The roof of the building must have an evacuation area and be accessible to everyone. Data for this criteria is obtained through interviews with building owners or their representatives.

Buildings that meet all criteria in the initial identification will proceed into a further investigation which includes observations, interviews, and a comprehensive study of documents related to the criteria.

To elaborate on the standard for each criterion, a focus group discussion was held at the BPBD of Padang City in October 2020. The meeting was attended by the Head of Prevention and Preparedness of BPBD, Head of Reconstruction

Section, and Rehabilitation and Reconstruction Staff. From the results of the discussion, it was agreed that public buildings that can be used as TES must meet the main criteria and supporting criteria, and classify the assessed TES into 3 categories. The main criteria are the criteria that must or must be met by a TES potential building. While the supporting criteria are criteria in the form of supporting facilities for evacuation activities and this criterion may not be met by a TES potential building. The next step in determining these criteria is to validate the findings with the building experts through interviews. The experts are two academia from the Disaster Study Centre of Universitas Andalas who have extensive experience in Disaster Management.

The final results of these discussions are criteria for the readiness of potential buildings for temporary evacuation sites which consist of 6 main criteria, 17 supporting criteria as shown in Table 1 and Table 2, then building assessment categories are shown in Table 3.

Table 1. Main Criteria for Assessment of Building Readiness for Temporary Evacuation for Tsunami Disasters

No	Criteria	Standard
1	Access to the building yard must be more than one.	If the building has fences and gates, there must be more than one entrance (gate) to the building's yard; or if the building does not have fences and gates, access to the building's courtyard is sufficient.
2	Meets the safe high requirements.	Fulfil the formula: T = Ti + (3 m + 30%Ti)}.
3	The topmost space for the evacuation area is an open space.	The evacuation area is an empty room, without any partitions or walls and no furniture to make it easier to gather and carry out activities together.
4	Have stairs and/or ramps that can be reached from the yard.	Have stairs and/or ramps that can be reached from the yard (without entering the building).
5	Earthquake resistant.	Minimum compliance with SNI-03-1726-2002 or regulations thereafter and built after 2005;nc, or have a structural test document that states the building is safe against earthquake loads.
6	Resistant to tsunamis.	Have a structural test document that states the building is safe against tsunami loads.

Table 2. Supporting Criteria for Assessment of Building Readiness for Temporary Evacuation for Tsunami Disasters

No	Criteria	Standard
1	Toilets and showers are available.	There is a minimum of 1 room for women and 1 room for men. The area of each bathroom is at least 2 meters x 1.2 meters with 1 closet and has a water reservoir.
2	A water reservoir is available.	Capacity can meet the needs of the community who evacuated. The minimum standard for clean water assistance is 7 liters per person in the first three days.
3	There is a pantry, kitchenette, or logistics warehouse.	There is a room that can function as a pantry, small kitchen, or emergency equipment warehouse to store first aid equipment, instant food, cleaning equipment, generators, and others.
4	Equipped with fire protection.	Available hydrants, sprinkler systems, or at least 3 units of light fire extinguishers in the building.
5	Equipped with an electrical system or have a generator as backup power.	Have at least 1 portable generator unit to turn on the water pump and turn on the room lights when the electricity goes out.
6	Safe from sources of danger (sources of debris, hazardous and toxic materials, breaking waves, and building structures that are prone to collapse).	- The location must be far from sources of hazardous and toxic materials and radioactive materials. - The location must be far from potential sources of large, dangerous debris. - The location must be away from building structures that are thought to be vulnerable or unsafe.

Table 2 Continue

No	Criteria	Standard
7	The road leading to the entrance of the building yard has a minimum width of 7 m.	The road leading to the entrance to the building yard has a minimum width of 7 meters (equivalent to a collector road).
8	The surface of the entrance to the yard must be flat, not slippery, and not perforated.	The surface of the entrance to the yard must be flat, not slippery, and not perforated
9	Evacuation signs are available.	There are signs indicating tsunami evacuation directions that are placed outside the building, at certain points along the evacuation route, until they reach the evacuation site on the top floor of the building.
10	Meet the requirements for the width and slope of the stairs and/or ramp and have a handrail.	The minimum width of the stairs is 1.2 m with a slope not exceeding 40^o and has a handrail. And/or a ramp width of at least 1.2 meters with a small slope of 7^o and have a handrail.
11	The part of the building facing the direction of the waves must be aerodynamic.	The building has an angle facing the direction of the wave so that it can break the waves when it hits the building.
12	The lower part of the building should be open.	The lower floor only consists of supporting columns of the building, and vertical circulation (stairs and ramps). The open space at the bottom of the building allows tsunami wave water to flow and prevents the building from being hit by waves.
13	Can be used directly, and needs to be retrofitted or tested for structural feasibility.	Have a document that states the building can be used as a temporary evacuation site or needs to be retrofitted. If there is none, then the building must be tested for structural feasibility.
14	The statement may or may not be accessed by the public.	Have an emergency procedure document that allows the public to access the building when a tsunami disaster occurs.
15	Building code.	Have a symbol or logo depicting the building as a temporary evacuation site.
16	Involvement of surrounding community in building management.	Have a document that states community involvement in building management, such as maintenance of evacuation areas and signs, periodic simulation activities, fulfillment of supporting facilities, the person in charge of access to and from the building, and others.
17	Socialization with the public or community	There has been socialization to the public that the building can and may be used as an evacuation site through seminars, bulletins, leaflets, electronic media, evacuation maps, and/or evacuation simulation.

The assessment model from this analysis has two categories (binary), namely if a criterion is met it will be worth 1 (one) and if a criterion is not met it will be worth 0 (zero). From the assessment, buildings that have the potential as temporary evacuation sites will be grouped into 3 categories related to whether or not the building is ready to be used as an evacuation site against a tsunami disaster. They are:

1. Category 1; ready to be used as a temporary evacuation site. The category is if the assessed building meets all the main criteria and supporting criteria. This category is obtained from buildings that are designed as temporary evacuation sites for tsunami disasters.
2. Category 2; is ready to be used as a temporary evacuation site, but it is necessary to improve the facilities and supporting infrastructure. The category is if the building meets all of the main criteria and all of the supporting criteria have not been met. This category is obtained from office buildings, mosques, or other buildings whose initial concept was not for a temporary evacuation place for the tsunami disaster.
3. Category 3; Not ready to be used as a temporary evacuation site or ready to be used as a temporary evacuation site if it immediately meets the main criteria required. The category is if the building does not meet all the main criteria, even though all the supporting criteria are met. Buildings in this category must immediately meet the main criteria so that they can be used as temporary evacuation sites in the future.

If presented in its rating score, the category of potential buildings for temporary evacuation sites for tsunami disasters based on the assessment can be seen in Table 3. The only building that can fulfill all the 6 main criteria and all the 17 supporting criteria can be considered Category 1.

Table 3. Category of Building Potential Temporary Evacuation Site for Tsunami Disaster based on Assessment

No	Category	Rating Score
1	Category 1	Main Criteria = 6 Supporting Criteria =17
2	Category 2	Main Criteria = 6 Supporting Criteria <17
3	Category 3	Main Criteria < 6 Supporting Criteria ≥ 1

5. RESULTS AND DISCUSSION

After conducting an assessment and analysis of each building, we found 23 buildings are the potential to be used as TES (Table 4). Currently, Padang City has 3 buildings that are purposely built for TES. These buildings do not have other functions except for TES. They are Darussalam Shelter (Bungo Pasang Village), Nurul Haq Shelter (Parupuk Tabing Village) and Wisma Indah Shelter (Ulak Karang Village). If it is added to the buildings in this study, it can be described that the distribution of temporary evacuation sites and buildings that have the potential as temporary evacuation sites in the city of Padang as shown in Figure 4.

Table 4. The results of the buildings readiness assessment as TES in Padang City

No	Building Name	Rating Score	
		Main Crite-ria	Suppor-ting Criteria
1	Dinas Pekerjaan Umum dan Permukiman Provinsi Sumbar	6	12
2	*Escape Building* Kantor Gubernur Sumbar	6	11
3	Pasar Raya Blok III	6	11
4	STBA Prayoga	6	10
5	SD Agnes	6	10
6	SMP Negeri 7 Padang	6	9
7	SMP Negeri 2 Padang	6	8
8	Hotel Grand Zuri	5	12
9	Hotel Truntum	5	12
10	SMP-SMA Pembangunan Universitas Negeri Padang	5	10
11	Rektorat Universitas Negeri Padang	5	9
12	Fakultas Ilmu Kependidikan Universitas Negeri Padang	5	9
13	Pasar Raya Blok I	5	9
14	Pasar Raya Blok II	5	9
15	Pasar Raya Blok IV	5	9
16	Pasca Sarjana Universitas Negeri Padang	5	8
17	Menara Masjid Muhajirin	5	6
18	TK-SD Pembangunan Universitas Negeri Padang	5	6
19	SMA Negeri 1 Padang	4	10
20	SMK Negeri 5 Padang	4	9
21	SD Negeri 23 dan 24 Ujung Gurun	4	9
22	SMP Negeri 25 Padang	4	8
23	Kelas Terpadu Universitas Negeri Padang	4	6

By comparing the categorization in Table 3 and the results of the readiness in Table 4 it can be analyzed that:

a. None of the buildings with Category 1; are ready to be used as a temporary evacuation site as it is.
b. There are 7 buildings with Category 2; ready to be used as a temporary evacuation place, but it is necessary to improve supporting facilities and infrastructure:
   1) Dinas Pekerjaan Umum dan Permukiman Provinsi Sumbar
   2) Escape Building Kantor Gubernur Sumbar
   3) Pasar Raya Blok III
   4) STBA Prayoga
   5) SD Agnes
   6) SMP Negeri 7 Padang
   7) SMP Negeri 2 Padang
c. There are 16 buildings with Category 3; not ready to be used as a TES or ready to be used as a temporary evacuation site if it immediately meets the main criteria:
   1) Hotel Grand Zuri
   2) Hotel Truntum
   3) Rektorat Universitas Negeri Padang
   4) Pasca Sarjana Universitas Negeri Padang
   5) Fakultas Ilmu Kependidikan Universitas Negeri Padang
   6) Kelas Terpadu Universitas Negeri Padang
   7) Pasar Raya Blok I

8) Pasar Raya Blok II
9) Pasar Raya Blok IV
10) TK-SD Pembangunan Universitas Negeri Padang
11) SMA Negeri 1 Padang
12) SMK Negeri 5 Padang
13) SMP Negeri 25 Padang
14) SMP-SMA Pembangunan Universitas Negeri Padang
15) SD Negeri 23 dan 24 Ujung Gurun
16) Menara Masjid Muhajirin

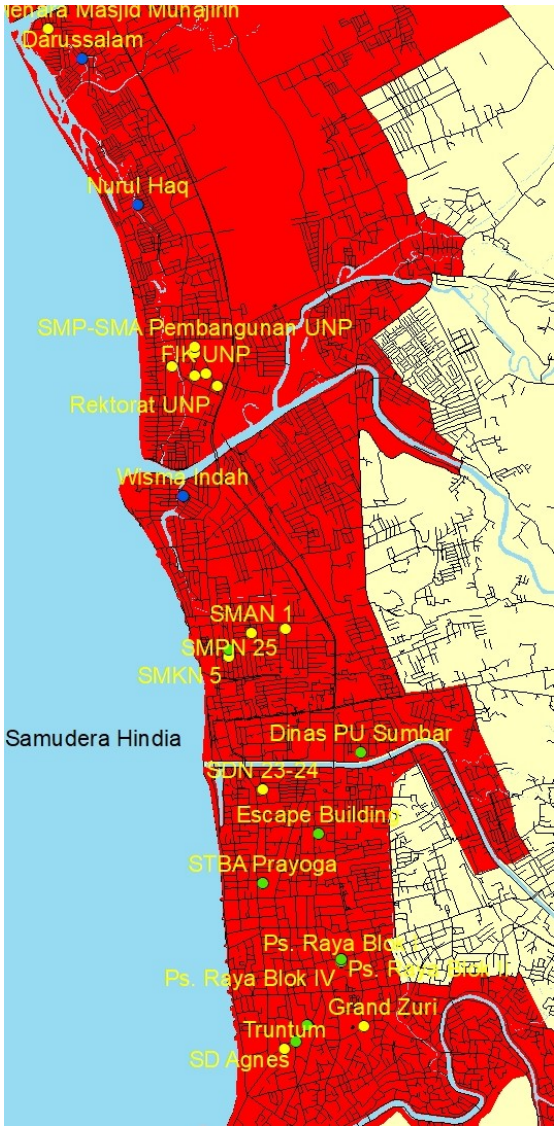

Fig. 5. Map of Potential Temporary Evacuation Sites for Tsunami in Padang City

As the number of buildings that can be used as TES is very limited, sitting is recommended that The Padang City Government through the BPBD accelerate the assessment of the strength of buildings that may be used as TES, follow up on the recommendations given by the Universitas Andalas Disaster Study Center and The Padang State University Disaster Study Center related to structural strengthening in several public buildings, and held meetings with possible building owners as TES to ensure the availability of buildings that could be used and accessed during the tsunami disaster. This can be done by making a memorandum of understanding or cooperation agreement. If it has been obtained, then further improvement of facilities and infrastructure can be done such as the installation of easily visible labels/symbols/logos that illustrate that the building can be used and accessed as a TES, installation of signs for disaster emergency preparation, and preparation.

Further, the map of potential TES in Padang City according to Fig. 5 is expected to be a guide in planning the evacuation of the people of Padang City if an earthquake and tsunami disaster occurs. From the results of the mapping carried out, it can be seen that buildings that have the potential as temporary evacuation sites are only scattered in the center area of Padang City. In the northern and southern parts of the tsunami red zone, there is almost no building that has the potential for a temporary evacuation site. Therefore, in the future, further research should be carried out regarding the distribution and needs of temporary evacuation shelter buildings in Padang City. Considering that Padang City is also has a liquefaction hazard, further analysis on liquefaction also needs to be conducted, such as the one conducted by Yuliet et al [13].

6. CONCLUSIONS

This research has found that 23 public buildings have the potential to be used as temporary evacuation shelters in Padang City. However, none of them can meet all the criteria required to be used as TES. Only seven buildings can meet the main criteria, but they need to improve their supporting facilities. Shelters' location is not distributed evenly but most of them are located at the center of Padang city.

7. ACKNOWLEDGMENTS

We want to express our sincere gratitude to the University of Andalas for the 2021 Research Grant No.T/17/UN16.17/PT01.03/IS-PTU-KRPGB Unand/2021.

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