Study of Intersection Coverage Area for Pedestrian Overpasses as Vertical Evacuation from Tsunami in Padang, West Sumatra

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Abstract-Padang City, as one of the highest vulnerable from earthquake and tsunami, has been transforming to become disaster smart city. However, the inadequacy of horizontal evacuation routes is caused by numerous tremors in 2007, 2009, 2010, and 2016 are indicating it is lack of occupancy for evacuee. Then, these condition is decreasing by traditional behavior evacuee are still using the vehicle and unwell planned evacuation as personally or in the community. The small number of vertical evacuation building and lack of awareness of community, and unmanaged the evacuation facilities make emergency response from earthquake and tsunami is uncontrolled in 0 – 20 minute for 30 minutes remaining time evacuate to inland in personally or community. Padang city has people density in the more than 1,317 people/km2 in the coastal area numerous potential for earthquake and tsunami risk. Pedestrian overpasses as primary facilities in many main roads in Padang City should be utilized for people to cross the road but it does not work properly but in fact, type of material, steel construction, was not durable with the climate in Padang that have coastal climate and a high number of behavior for crossing road in uncertain places. Regarding of the vulnerability in earthquake and tsunami risk, unmanaged construction and bad culture in crossing the road, pedestrian overpasses, especially in the intersection, will be redesigned to be a vertical evacuation. It will have a multifunction structure that is not simply for passing the pedestrian but also comprises remarkable facilities as a meeting point, commercial place and public facilities. Pedestrian overpasses for vertical evacuation from the tsunami will solve lack of area for construct vertical evacuation in the community. It can duplicate easily for any coastal cities that require vertical evacuation structures. Apparently, area availability will determine how vulnerable the site for vertical evacuation will suit for evacuee who living surrounding. Road intersection will be a good site for redesigning vertical evacuation Intersection of the road and have large space will be a good candidate for redesigning pedestrian overpasses as vertical evacuation structure.

Road Intersection as vulnerable routes for horizontal evacuation is already happened in several occurrence of earthquake in Padang City. Based on google maps, every road will contribute a number of evacuee and mostly by using vehicle and fewer people who will evacuate by walking. The Study of coverage area intersection pedestrian overpasses as vertical evacuation from tsunami in Padang, West Sumatra will describe about how large the estimated capacity of pedestrian overpasses can be suit for vertical evacuation and how wide the area can be facilitated by this evacuation site. Remaining time of tsunami, walking space, readiness evacuation time, and time to reach upland. Those will be determined into how far the evacuee can reach the site. Based on the population density, it can observed the length of the radius can be serviced the evacuee to evacuation structure. People density will influence how large the coverage area for each site. According to this study, horizontal evacuation from tsunami in Padang city is still vulnerable for the people who living in coastal area. Bottleneck evacuation can be solved by build a vertical evacuation near by the bottleneck zone. Pedestrian overpasses for vertical evacuation is designing to accommodate the evacuee can save their life from the tsunami run up because incapability to reach inland.

Keywords— *Tsunami, vertical evacuation, pedestrian overpasses, intersection, and road.*

I. INTRODUCTION

Earthquake gap along Mentawai Island contribute earthquake and tsunami potential risk directly to Padang city. This segment is one the gap Sunda mega-trench that is located next to Sumatra Island. According to seismology, Sunda mega-trench has probability exceedance of tsunami occurrence in every 30 to 200 years. Based on history tsunami occurrence in Padang city is exposed in table 1,

Pedestrian Overpasses Bridge for Vertical Evacuation from Tsunami (POBET) becomes one of the substitute solutions for the lack of the availability if it compares to people density is concentrated in the coastal area [1]. The motivation POBET as the best alternative solution for vertical evacuation is,

1) To accommodate evacuation blockage triggered while community evacuate horizontally
2) To distribute evacuee to have alternative evacuation site with efficient and discrete evacuation or evacuation shelter.
3) To effortlessness the accessibility of the traffic ways that is passed by peoples, drivers or community nearby.

TABLE I
EARTHQUAKE AND TSUNAMI OCCURRENCES IN PADANG, WEST SUMATRA (BMKG, 2016)

Tsunami			
No.	**Date**	**Location**	**Inundation High** *(meter)*
1.	10 Februari 1797	Padang	5
2.	24 November 1833	Padang – Bengkulu	3 – 4
Tsunami Potential Earthquake			
No	**Date**	**Location**	**SR**
1.	1 October 1822	Padang	No data
2.	26 Augutus1835	Padang	No data
3.	13 November 1981	Padang	5,4 SR
4.	6 March 2007	Padang	6,4 SR
5.	30 September 2009	Padang, Padang Pariaman	7,9 SR
6.	2 June 2016	Mentawai	6.5 SR

Based on necessity due to Padang earthquake and tsunami vulnerability makes the scope of the research on

1) To designate the indicator of tsunami and evacuation in Padang city
2) To indexes sites candidate for POBET based on the indicators
3) To scrutinize intersection capacity based on field investigation
4) To analyze density of pedestrian

the research POBET vulnerability study of site candidate is based on Tsunami Mitigation Guidelines for Evacuation Building – Disaster Management, Cabinet Office Japan, 2005 [6]. Site candidate is also refers to Padang Inundation Map 2005 to search the most vulnerable from tsunami hazard and compatible intersection for POBET.

POBET plan at intersection with the reasons below,

1) Intersection has proper area to build a pedestrian overpasses bridge and have a large space for vertical evacuation as a superstructure.
2) Intersection has a good access for pedestrian vehicle in many directions.
3) Intersection would become assembly point in some sub district and centre of evacuation blockage in emergency response.

Regarding to altitude of sub district in Padang City, it is publicized 34% from total area are inundated from tsunami, it shown on table II

TABLE II
SUBS DISTRICT ALTITUDE OF PADANG CITY, WEST SUMATRA (BPS, 2017)

Subs district	Elevation (m)
Koto Tangah	0 – 1600
Padang Utara	0 – 25
Padang Barat	0 – 8
Padang Selatan	0 – 322
Bungus Teluk Kabung	0 – 850
Lubuk Begalung	8 – 400
Pauh	10 – 1600
Lubuk Kilangan	25 – 1853
Nanggalo	3 – 8

Based on estimated magnitude of earthquake and tsunami [17] West Sumatra claimed is inundated by 15 meter high and Padang city inundated in average by 9 meter high from tsunami with distance of prone area from 0.5 – 1,5 kilometers from the shore line. The most vulnerable zone is in Padang Barat with lowest altitude from the level of sea and also the most protected vicinity to evacuate horizontally.

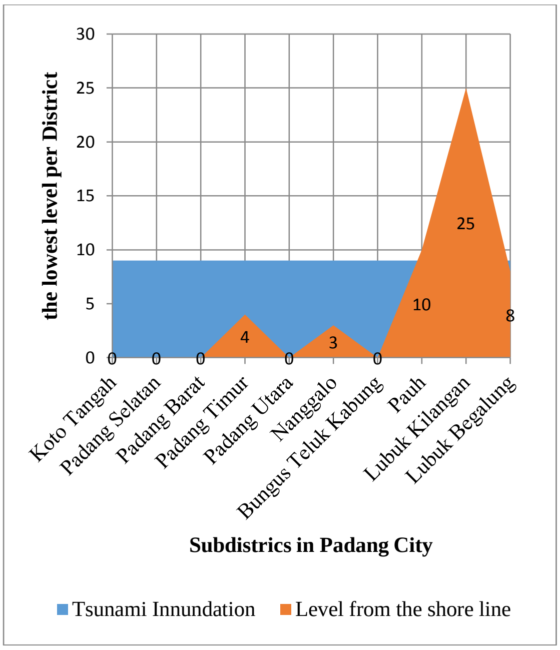
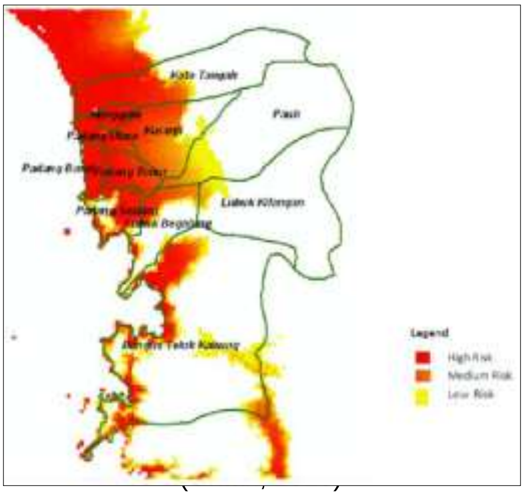


Fig.1 Tsunami Inundation due to the Elevation per Subs district in Padang City, West Sumatra.

TABLE III
THE PERCENTAGE INUNDATED AREA DUE TO SUBS DISTRICT ELEVATION OF PADANG CITY, WEST SUMATRA (BPS, 2017)

Subdistrict	Level from the shore line	The Highest Level	Estimated Tsunami Innundation	%
Koto Tangah	0	1600	9	1%
Padang Selatan	0	322	9	3%
Padang Barat	0	8	9	100 %
Padang Timur	4	10	9	100 %
Padang Utara	0	25	9	36%
Nanggalo	3	8	9	100 %
Bungus Teluk Kabung	0	850	9	1%
Pauh	10	1600	9	1%
Lubuk Kilangan	25	1853	9	0%
Lubuk Begalung	8	400	9	2%
% Innundation in Padang City				34%



II. METHODOLOGY

This research is based on a road map of vertical evacuation study from tsunami study on figure 4 is shows about preliminary study for vertical evacuation is observed about the condition of prone area related to the vulnerability come up on the community and the environment that is measured the level of awareness community who's living in the prone area. [1] Type of evacuation, horizontal and vertical evacuation, will be indicated from the behavior and evacuation culture of community to reach inland/high building, this factor will estimate travelable time due to remaining time for tsunami inundation. Location for evacuation would be nearest site for community to reach, good access, adequate to facilitated people to get inside. Then, the adequacy of evacuation (horizontal and vertical) should be compromising the population density, capacity of routes and capacity of shelters.

The existing evacuation feasibility study contributed the impact for searching for candidacy the site for horizontal and vertical evacuation. It will be measured by the ratio from the evacuation (horizontal and vertical) infrastructure can be occupied by the community. Then, it also figure out by supporting facilities such as hospital, schools, government building, army facilities and any public building that should be withstand during the emergency response. These parameters will be determined into table IV about vulnerable index for evacuation.

POBET vulnerability parameters for tsunami is considering about location, buildings, social, infrastructure, shelters, and accessibility. Location vulnerability will indicate about buildings plan and coordinates for candidates of POBET by using Google earth application to estimate location and affected area would be accommodated by POBET [1]. Evacuations vulnerability, Routes or Buildings, will consider about distance from shoreline and riverside. Minimum distance from is approximate 1 km far from coastline. Parameters is used to identify the buildings candidate for POBET will be indexed to measure the vulnerability based on,

1. Location
   a. Buildings planning
   b. Buildings coordinates
2. Buildings
   a. Inundation
   b. Distance from shoreline and riverside
3. Social
   a. People density in region/village
   b. People density by gender
   c. People density by age
4. Infrastructure
   a. School in every village
   b. Medical Facilities
   c. Religion Facilities
   d. Public Facilities
5. Shelter availability
6. Accessibility
   a. Number of Road
   b. Public facility
   c. Public transport

Primary data resources are taken from field study about geometrics of roads and traffic capacity. Demographic study will refer to Badan Pusat Statistik (Statistic Central Data Boards) of Padang City to observe people density, building data, and length of roads. Vulnerable desk study will considered about vulnerable map (BPBD Padang, 2010) and Tsunami and Earthquake Zone in Padang City (BMKG, 2010) to observe designated horizontal evacuation routes from Tsunami in Padang City. These data is determined by using regulation of transportation in Indonesia [8] and developed based on data satellite on Google map [2]. All the parametric study is referred to Table IV about vulnerability index for evacuation [3]. The result demonstrates about the adequacy of intersection for pedestrian overpasses for vertical evacuation from tsunami in Padang, West Sumatra – Indonesia.

TABLE IV
VULNERABILITY INDEX FOR EVACUATION

No.	**Parameter**	**Index**				
		5	***4***	***3***	***2***	***1***
Location*(km)*						
A	Inundation Distance	0 – 0.5	0.5 - 1	1 – 1.5	1.5 – 2	>2
B	Shorline Distance	0 – 0.5	0.5 - 1	1 – 1.5	1.5 – 2	>2
C	Riverside Distance	0 – 0.5	0.5 - 1	1 – 1.5	1.5 – 2	>2
D	Inundation	>2	1.5 – 2	1 – 1.5	0.5 – 1	0 – 0.5
People Density *(people)*						
E	District	>100000	7500 - 10000	5000 - 7500	2500 - 5000	0 - 2500
F	Male	0 – 300	300 – 600	600 – 900	900 – 1200	>1200
G	Female	>1200	900 – 1200	600 – 900	300 – 600	0 – 300
H	Age Composition					
	a. Infant	0 – 100	100 - 200	200 - 300	300 - 400	>400
	b. Adult	>400	300 - 400	200 - 300	100 - 200	0 – 100
	c. Old	0 – 100	100 - 200	200 - 300	300 - 400	>400
	d. Reside	0 – 100	100 -	200 -	300 -	>400

No.	Parameter	Index 5	4	3	2	1
	nt		200	300	400	
Facilities *(unit)*						
I	Education	>10	9 – 10	6 – 8	3 – 5	0 – 4
J	Religion	>24	18 – 24	13 – 18	12 - 7	0 - 6
K	Health	>20	15 – 20	15 – 10	10 – 5	0 – 5
L	Others	>1000	1000 - 750	750 - 500	500 – 250	0 - 250
Shelter availability *(km)*						
M	Vertical Evacuation	>2	1,5 – 2	1 – 1,5	0,5 – 1	0 – 0,5
N	Horizontal Evacuation	>2	1,5 – 2	1 – 1,5	0,5 – 1	0 – 0,5
O	Eavcuation Travel time *(minute)*					
	a. Vehicle	32 - 40	24 - 32	16 - 24	8 – 16	0 – 8
	b. Walking.	120 - 150	90 - 120	60 - 90	30 - 60	0 - 30
P	Evacuation Routes Capacity					
	a. Number of route	0 – 2	3 – 4	5 – 6	7 – 8	>8
	b. Distance of route	>0,8	0,8 – 0,6	0,6 – 0,4	0,4 – 0,2	0,2 - 0
	c. Number of public transport	>8	6 - 7	5 - 6	3 - 4	0 -2

III. Result and Analysis

This Study is focus on how to determine and select potential site candidate for POBET.

A. Evacuation Routes Vulnerability Study

Regarding to evacuation map on figure 3 from BPBD Padang City, Padang City is divided into 6 (six) zone evacuation area [13]. It is shown on evacuation map that is produced by BNPB in 2010. The Evacuation zone is derived into,

1) Sector I, all the region between Anai river and Kalumpang river. This sector have 4 evacuation route: Jl. Adinegoro – Basarnas, Jl. Adinegoro – Jl. Bunga Tanjung, Jl. Adinegoro – Anak Air, Jl.Adinegoro – Simpang Kalumpang
2) Sector II, the area between Kalumpang river to Muaro Panjalinan. this sector have evacution route: Jl. Pasir Sebelah – Muaro Panjalinan – Koto Pulai, Jl. Adinegoro – Raya Kalumpang – Kampung Jambak – By Pass.
3) Sector III, the region between Muaro Panjalinan to Kuranji river, the routes is Jl. M. Hatta – Simpang Tabing, Jl. Cendrawasih – Simpang Tunggul Hitam – By Pass
4) Sector IV, the region between Kuranji river to Bandar Bakali river, the routes is Jl. Raden Saleh – Jl. KH. Ahmad Dahlan, Jl. Jakarta – Khatib Sulaiman – Jhoni Anwar – Gadjah Mada.
5) Sector V, all the region betwen Bandar Bakali river to Anai river, the route is Jl. Nipah – Pulau Air – Ps Gadang – Ps Mudik Selatan – St. Syahrir, Jl. HOS Cokroaminoto – Tepi Pasang – Imam Bonjol – Ganting – Parak Pisang – Air Cama, Jl. Hang Tuah – M.Yamin, Proklamasi – Dr. Wahidin – Sisingamangaraja, Jl.Agus Salim – Sawahan – Simpang Haru – Andalas, Jl. Purus, Ujung Gurun-Mangunsarkoro – Perintis Kemerdekaan – Sawahan.
6) Sector VI, Jl. By Pass, Jl. Pantai Air Manis

That evacuation route needs an assessment for travelable time to reach intersection to see the vulnerable routes like evacuation bottleneck, evacuation traffic jam and exceeding from the tsunami remaining time. By using Google map application, Table V shows all the evacuation routes from the shoreline have travelable time up to 10 minute evacuation time until 30 minute evacuation time to reach intersection. This case indicate, it is tranquil vulnerable for evacuee in shoreline area to reach inland because based on data on Table 6, they necessitate evacuation time in average 20 minute to inland. This condition is in idea l condition for walking only without worst scenario such us accidental condition, traffic jam and numerous vehicles during evacuation

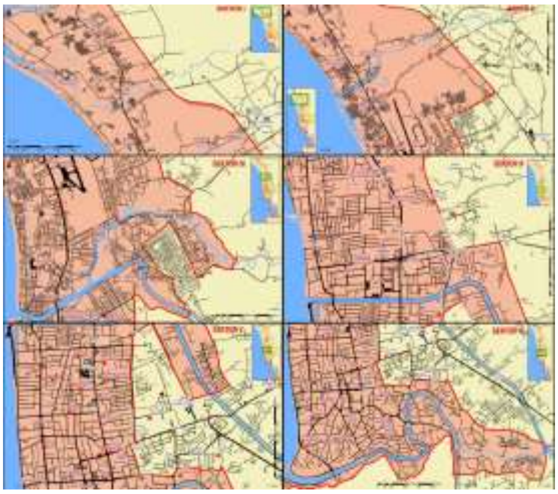


Fig.3 Tsunami Evacuation Map of Padang City, West Sumatra, (BPBD, 2010)

EVACUATION FROM THE SHORELINE TRAVELABLE TIME TO INTERSECTION

Sector	District	Prone Area		
		shoreline to assembly point	Driving	Walking
I	Koto Tangah	2500	7	30
		1700	7	23
		2300	6	24
		1900	5	23
II	Koto Tangah	900	3	11
		950	5	12
III	Padang Utara	900	4	12
		1600	5	19
IV	Padang Barat	2000	3	13
V	Padang Barat	1000	4	13
VI	Padang Selatan	1800	5	22

All this evacuation routes in these sector is eliminated for POBET site candidate by the evacuation routes have junction and 500 meters as minimum distance from the shoreline. The candidate intersection evacuation routes for POBET are selected into 11 intersections from all evacuation routes that have been claimed by BPBD of Padang City. The candidates are,

1) POBET I, Jl. Adinegoro – Basarnas,
2) POBET II, Jl. Adinegoro – Jl. Bunga Tanjung,
3) POBET III, Jl. Adinegoro – Anak Air,
4) POBET IV, Jl.Adinegoro – Simpang Kalumpang
5) POBET V, Jl. Pasir Sebelah – Muaro Panjalinan – Koto Pulai,
6) POBET VI, Jl. Adinegoro – Raya Kalumpang – Kampung Jambak – By Pass.
7) POBET VII, Jl. Cendrawasih – Simpang Tunggul Hitam – By Pass
8) POBET VIII, Jl. Raden Saleh
9) POBET IX, Jl. Jakarta – Khatib Sulaiman – Jhoni Anwar – Gadjah Mada.
10) POBET X, Jl. Purus, Ujung Gurun-Mangunsarkoro – Perintis Kemerdekaan – Sawahan.
11) POBET XI, Jl.Agus Salim – Sawahan – Simpang Haru – Andalas,

By using Google map as the real time application, all the intersections are measured the estimation to inland and travelable time by walking and driving. Based on table 5, it is shown the candidate POBET V, VI, and VIII have vulnerable routes to inland with more than 30 minute travelable time regarding to tsunami remaining time first waves to the shoreline of Padang city.

TABLE VI
EVACUATION TRAVELABLE TIME FROM INTERSECTION TO INLAND

Sector	sub district	POBET	Assembly point to inland *(m)*	Walking	Driving
				time *(minute)*	Time *(minute)*
I	Koto Tangah	I	950	11	2
		II	850	10	2
		III	950	12	4
		IV	1500	19	4

II	Koto Tangah	V	3300	41	7
		VI	3300	41	5
III	Padang Utara	VII	2400	29	6
		VIII	2600	32	8
IV	Padang Barat	IX	1300	16	3
V	Padang Barat	X	2200	27	6
VI	Padang Selatan	XI	1000	13	3

B. *Preliminary Study for POBET Site Candidate*

According to type of tsunami in Padang, Samuel, 2012, is mentioned tsunami in Padang has 30 minute maximum for the remaining time. It has 200 km far epicenter and estimated have big tremor and devastated any buildings surrounded. It follows with big magnitude and tides.

Coverage area for evacuation based on tsunami mitigation guidelines for evacuation building specified on the travelable distance for evacuation, (L_1), from the relationship between the length of time which tsunami takes to reach ,(T), the walking space, (P_1), time take to start evacuation after the occurrence of an earthquake, (t_1), and time taken to reach uplands, upper floors, etc, (t_2). This correlation factors is designated into formula [7],

$$L_1 = P_1 \times T - t_1 - t_2 \tag{1}$$

Time taken to reach uplands, upper floors, etc ,(t_2), is estimated from the maximum run up of tsunami in certain place to speed for ascent/descent of stairs (minimum condition for elderly person), *(P_2).* This condition can derived into,

$$t_2 = \frac{H_{\max}}{P_2} \tag{2}$$

Specification of walking space indicates the worst circumstances for a person to evacuate to inland or upper floors. It figure out into two condition, walking under normal conditions (P_1) and ascending/descending (P_2) based on table VII

TABLE VII
WALKING SPACE FOR EVACUATION (CABINET OFFICE JAPAN, 2006)

Condition	**Walking Space**	**Velocity (m/sec)**
Normal (P_1)	Elderly person walking unassisted	1,3
	Crowd Walking	0.88 to 1.29
	Handicapped persons (using wheel chair)	0.91
Ascending/Descending (P_2)	Elderly person	0.21

Regarding to the candidate intersection site for POBET, they need to measure the coverage area can accommodate people to evacuate to POBET as alternative vertical evacuation from tsunami. It derived from how large the estimation area intersection, elevation from the shore line, estimation of people density that will accommodate for POBET capacity with 1 people will accommodate for 1 meter square. These data is shown on table VIII,

TABLE VII
PARAMETRIC DATA FOR POBET CAPACITY

Sector	**District**	**Geo and Demography**				
		POBET	**Area (m^2)**	**Elevation (m)**	**POBET Area (m^2)**	**people density (people/m^2)**
I	Koto Tangah	I	498	4	498	0.0015
		II	636	3	636	0.0031
		III	498	4	498	0.0031
		IV	486	2	486	0.0030
II	Koto	V	403	4	403	0.002

	Tangah					4
		VI	1021	4	1021	0.0009
III	Padang Utara	VII	675	7	675	0.0143
		VIII	1600	3	1600	0.0060
IV	Padang Barat	IX	2063	9	2063	0.0249
V	Padang Barat	X	1750	10	1750	0.0119
VI	Padang Selatan	XI	1700	8	1700	0.0124

Identified candidate for tsunami evacuation structures is extracting facilities located in a tsunami inundation area which convince the structural requirements. In addition, determination of area are covered by each candidate building based on the relationship between the reachable evacuation range and achievable accommodation range. Then, these study select candidates for tsunami evacuation structure in a manner that ensure all difficult to evacuate areas are covered by those candidates [9]. For this purposes perform

1. Selection of candidates for tsunami evacuation structures
2. Estimation of the variety within which evacuation to each candidate for tsunami evacuation structure would be achievable
3. Estimation of the range commensurate with the capacity of each candidate for tsunami evacuation buildings
4. Specification of a coverage area

Estimation the range allowing the accommodation, which has a population equivalent to the number of people who will be accommodated, as calculated the distance allowing accommodation (L2) (semicircle)

$$L2 = \sqrt{\frac{Capcity(person)/Population\_Density}{3.14}} \times 4 \qquad (3)$$

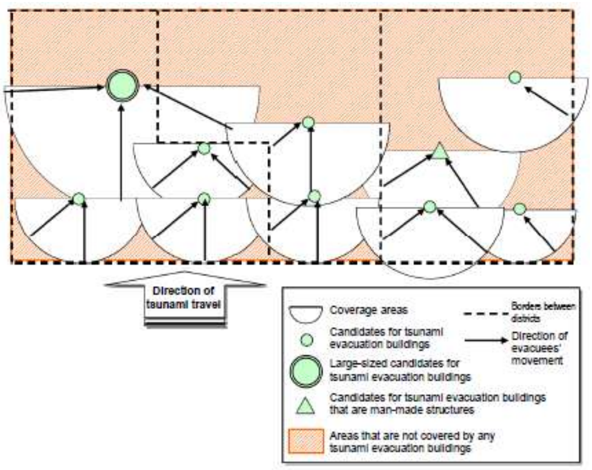


Fig. 5 Image of the selection of candidates for tsunami evacuation buildings (Cabinet Office Japan, 2005)

According to equation (1) the travelable distance for evacuation is derived from the walking space for evacuation that condition is imagined crowed situation, coefficient of walking space, *(P1)* 1,29, the remaining time from tsunami *(T)* is taken for the minimum time in 20 minutes (1200 seconds), time take to start evacuation after the occurrence of an earthquake *(t_1)* is about 30 second and time taken to reach uplands, upper floors, etc, *(t_2)* is about 3,15 second. As the result, estimated coverage in every site POBET has 1505 meter or 1,5 km. Based on the field data, estimated POBET area and density of population will influence the accommodation coverage of POBET based on equation (3) in table

TABLE VIII
ACCOMMODATION COVERAGE AREA FOR POBET

Sector	**District**	**Site**		**Coverage**	
		POBET	**POBET Area**	**L1**	**L2**
I	Koto Tangah	I	498	1505	1320
		II	636	1505	1030
		III	498	1505	912
		IV	486	1505	912
II	Koto Tangah	V	403	1505	929

		VI	1021	15 05	23 68
III	Padang Utara	VII	675	15 05	49 0
		VIII	1600	15 05	11 67
IV	Padang Barat	IX	2063	15 05	65 0
V	Padang Barat	X	1750	15 05	86 7
VI	Padang Selatan	XI	1700	15 05	83 5

IV. CONCLUSIONS

This study shows horizontal evacuations routes is still need substitute infrastructure to accommodate evacuee to safe from the tsunami. Most of the routes are insufficient to deal out people to reach inland safely. Hereby, some wrapping up that commence POBET as a better solution for evacuation,

1) Elevation Padang city is about 34% is inundated by tsunami that have 9 meter high of run up
2) In the remaining time from tsunami in 20 – 30 minute is not suitable for peoples in Padang reach inland safely by horizontal evacuation by walking.
3) Travelable time from shore line to the intersection in evacuation routes are still in excess of remaining time from tsunami. It is about 50% intersection is still reach more than 20 minutes.
4) Accumulation of travelable time (shoreline to intersection – intersection to inland) to inland is still over 30 minute.
5) Regarding to the behavior peoples in Padang City are still using vehicle than for evacuation will triggered evacuation bottleneck in every intersection.
6) As solution the evacuation bottleneck, POBET will accommodate people who get in trap during the evacuation to evacuate vertically.
7) Based on the remaining time tsunami, inundation high, the average coverage area of POBET have radius 1,5 km far from the POBET site.
8) The Accommodation Radius of POBET, it has 0,5 – 2,5 km far based on the people density are living surrounding the POBET.
9) The large of radius of coverage area of POBET is influenced the people density, walking space, travelable time, inundation height and remaining time from the tsunami.

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