VOL 4 (2020) NO 1

e-ISSN : 2549-9904
ISSN : 2549-9610

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

Liquefaction Potential Map based on Coordinates in Padang City with Google Maps Integration

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***Abstract*— Padang City is prone to liquefaction phenomena due to earthquakes. These phenomena can cause various damages to structures, infrastructures, and even can also cause deaths. Therefore, as one of the urban populated cities, the information about liquefaction potential is needed. One of them is by providing a liquefaction potential map, which is useful for mitigation and seismic disaster risks strategies. This article aims to provide a digital map of liquefaction potential in Padang City that integrates with Google Maps. The map is based on 40 coordinates in 7 subdistricts in the city with 3 colored markers that represent the levels of potential liquefaction i.e. no liquefaction level, moderate liquefaction level, and severe liquefaction level. The levels are classified based on the analysis of the secondary Cone Penetration Test data by using the calculation of the Factor of Safety and Liquefaction Potential Index with an earthquake assumption of 8 SR. The result shows that the map has ben able to display information about liquefaction potential, where 32.05% coordinates are classified as no liquefaction level with the highest percentage are in Kuranji, 22.5% are classified as moderate liquefaction level with the highest percentage are in Padang Utara, and 45.0% are classified as severe liquefaction level with the highest percentage are in Koto Tangah.**

***Keywords*— Liquefaction Potential Map, Padang, Factor of Safety, Liquefaction Potential Index, Google Maps.**

I. INTRODUCTION

Padang City is a capital city in Indonesia which is located on the West-Coast of Sumatra Island, with a population of more than 850,000 people[1]. Geologically, Padang City is located in the Sumatra subduction zone which leads this area prone to the danger of large earthquakes[2], one of which is an earthquake with a magnitude of 7.6 SR that occurred in 2009. In addition to causing damages to various public facilities and infrastructures, causing death, this earthquake also caused the phenomenon of liquefaction[3][4].

Liquefaction occurs when the soil loses its strength so that it is like a liquid due to strong ground movements from an earthquake[5]. This phenomenon is one of the secondary disasters that accompany earthquakes, which can cause structural [6] and infrastructure damage, as well as injuries and loss of life [3]. The liquefaction phenomenon in Padang city occurred in several areas during the 2009 earthquake, which caused the foundation settlement of houses and high building, cracks in the road and river embankments as well as a lateral displacement, and also cause landslides.[5].

Based on liquefaction studies, it can be concluded that the Padang City is prone to liquefaction[6]. Therefore, there is a need for information about liquefaction potential for city development, such as liquefaction potential map. Liquefaction potential maps are very important for mitigation and seismic disaster risks strategies, especially in urban populated areas[7].

Various studies have been carried out in mapping the potential liquefaction in various regions. These studies have utilized digital mapping technology due to its advantages. Win Pyae(2017) proposed a map of liquefaction potential in Yangon City, Myanmar by using GIS with information display in the form of regional color differences according to 2 liquefaction potential classification[8]. Shuvankar (2017) proposed a map of liquefaction potential in the City of Agartala, NorthEast India by using GIS with 5 levels of liquefaction potential which is displayed on the map in the form of color differences according to the levels[9]. Cabalar (2019) proposed a liquefaction potential map for the city of Kahramanmaras, Turkey, by using GIS with 5 classification of liquefaction potential in the form of color differences between levels of liquefaction potential [10].

This article proposed liquefaction potential maps in Padang City by which is integrated with Google Maps. The map displays information about potential liquefaction of several coordinates in the form of colored markers according to the 3 levels of potential liquefaction. The levels are classified based on the Factor of Safety and Liquefaction Potential Index values. With the use of Google Maps, this map can be accessed by anyone and anywhere from a website with a user-friendly interface.

II. METHODS

The levels of potential liquefaction displayed on the map are based on the analysis of the Cone Penetratrion Test (CPT) data of several coordinates in Padang. The analysis is done based on the Factor of Safety and Liquefaction Potential Index calculation. The results of this analysis are then become information on Google Maps in the form of colored markers that represent the levels of liquefaction potential. The flowchart of the design is shown in Fig. 1.

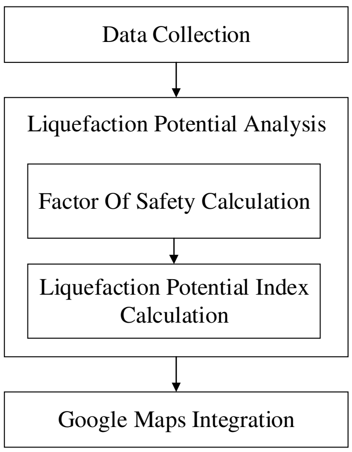


Fig. 1. Methods.

A. Data Collection

The liquefaction potential map is based on secondary Cone Penetration Test (CPT) data at 40 coordinates that are located in 7 subdistricts in Padang with a percentage of the number of the coordinates used in each subdistrict shown in Fig. 2. These data are the results of city development projects obtained from the Padang City Public Works Department (*Dinas Pekerjaan Umum Kota Padang*) and also from several universities in Padang.

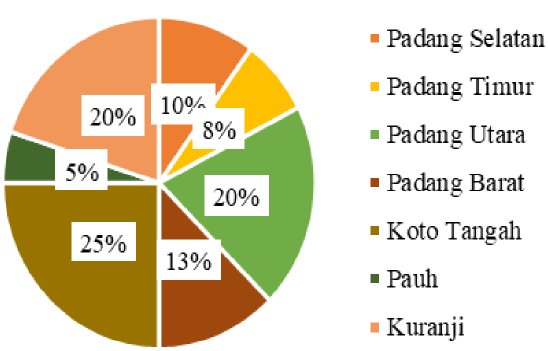


Fig. 2. Percentage of the number of data for each subdistrict.

B. Liquefaction Potential Analysis

Liquefaction potential analysis is carried out based on the Factor of Safety (FS) and Liquefaction Potential Index (LPI) values with the assumption an earthquake occurs on a scale of 8 SR.

1) Factor of Safety Calculation

Liquefaction potential can be identified based on the Factor of Safety (FS) values obtained from the comparison of two seisimics variables, i.e Cyclic Shear Ratio (CSR) and Cyclic Resistance Ratio (CRR) [11]. FS value can estimate the indication of potential liquefaction at a research location. The higher the Factor of Safety value, the higher the soil's resistance to liquefaction [11].

In this article, the results of the FS calculation are classified based on Seed and Idriss (1971) i.e in the form of values > 1, which indicates it is no potential for liquefaction and < 1 indicates it is the potential for liquefaction. FS calculation is done by using Equation 1.

$$FS = \frac{CRR}{CSR} \quad (1)$$

2) Liquefaction Potential Index Calculation

Liquefaction Potential Index (LPI) also used in this article as one of the parameters to assess the level of liquefaction potential in an area[9]. The calculation of LPI values is carried out by using Equation 2. The LPI values are then classified into 3 leves as shown in Table 1.

$$LPI = \int_0^{20} F(z)W(z)dz \quad (2)$$

$$F(z) = 1 - FS \quad for\ FS < 1.0$$

$$F(z) = 0 \quad for\ FS \geq 1.0$$

In equation 2, z denotes the depth; dz denotes the depth-increment; and F (z) denotes the liquefaction severity, which is a function of the FS and b. Then, W (z) is the weighting function.

TABEL I
LIQUEFACTION POTENTIAL LEVELS CLASSIFICATION BASED ON LIQUEFACTION POTENTIAL INDEX

Liquefaction Potential Index	**Level**
< 5	No liquefaction
5 ≤ LPI ≤ 15	Moderate liquefaction
> 15	Severe liquefaction

From the liquefaction potential analysis process, it obtains the information of liquefaction potential at each coordinate, as shown in Table 2.

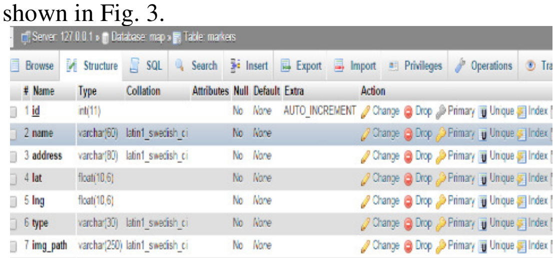
TABEL II
LIQUEFACTION POTENTIAL INFORMATION

Factor of Safety	:	
Depth	:	
Settlement	:	
Liquefaction Potential Index	:	
LIQUEFACTION POTENTIAL LEVEL		

C. *Google Maps Integration*

The liquefaction potential map is integrated with Google Maps that can be accessed in a website, where the data that has been obtained are stored in a database. With this database, it will give the ability to provide functions for the process of searching, selection or filtering as well as the ability to manipulate data[12]. These data are then presented to the user to provide information which can be in the form of images, tables or other data formats[13].

Data obtained from the liquefaction potential analysis are then stored in a database, i.e. name, city, location coordinates in the form of latitude and longitude, as well as information on liquefaction potential as shown in Table 2.2 in the form of image. The database structure of this system is shown in Fig. 3.



Server: 127.0.0.1 » Database: map » Table: markers

Browse | Structure | SQL | Search | Insert | Export | Import | Privileges | Operations

#	Name	Type	Collation	Attributes	Null	Default	Extra	Action
1	id	int(11)			No	None	AUTO_INCREMENT	Change Drop Primary Unique Index
2	name	varchar(60)	latin1_swedish_ci		No	None		Change Drop Primary Unique Index
3	address	varchar(80)	latin1_swedish_ci		No	None		Change Drop Primary Unique Index
4	lat	float(10,6)			No	None		Change Drop Primary Unique Index
5	lng	float(10,6)			No	None		Change Drop Primary Unique Index
6	type	varchar(30)	latin1_swedish_ci		No	None		Change Drop Primary Unique Index
7	img_path	varchar(250)	latin1_swedish_ci		No	None		Change Drop Primary Unique Index

Fig. 3. Database structure of liquefaction potential map

Data stored in this database are then displayed in a menu that appears on coordinate on the Google Maps view. When the user accesses a coordinate, then the coordinate, subdistrict name, and the **Liquefaction Potential Level** menu are displayed, as shown in Fig. 4. The **Liquefaction Potential Level** menu displays 5 potential liquefaction information as in Table 2.2, as shown in Fig. 5.

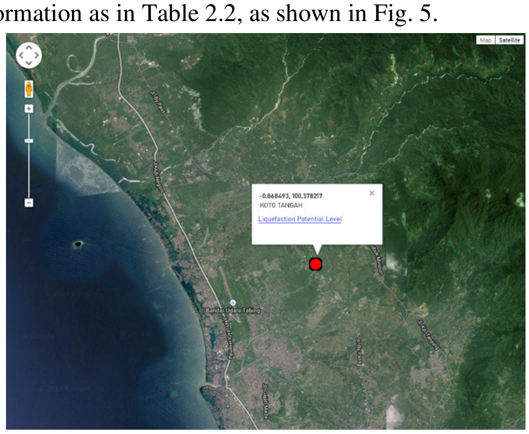


Fig. 4. The design of main menu at a coordinate.

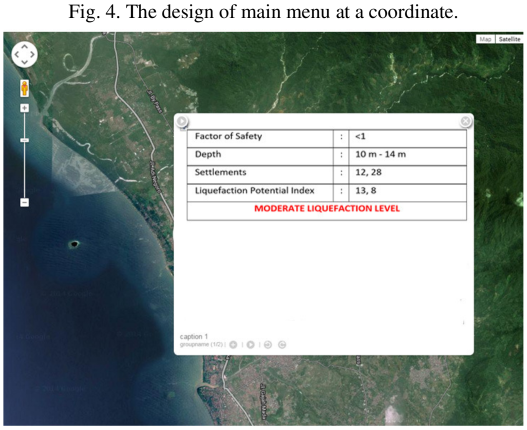


Fig. 5. The design of liquefaction potential information at a coordinate.

III. Result and Discussion

Based on the Factor of Safety, 13 coordinates are classified as no potential liquefaction with FS values is > 1. These coordinates are in 4 subdistricts, i.e Kuranji, Pauh, Koto Tangah and Padang Timur, with the highest percentage is 53.85% located in Kuranji. While as many as 27 coordinates are classified as potentially liquefaction with FS values is < 1, which are located in 6 subdistricts, i.e Padang Utara, Koto Tangah, Padang Barat, Padang Selatan, Padang Timur dan Kuranji. The highest percentage is Padang Utara and Koto Tangah with a percentage of 29.63%. Overall, based on the FS values, a percentage of 32.50% are classified as no potential liquefaction and 67.5% are classified as potentially liquefaction, as shown in Fig. 6.

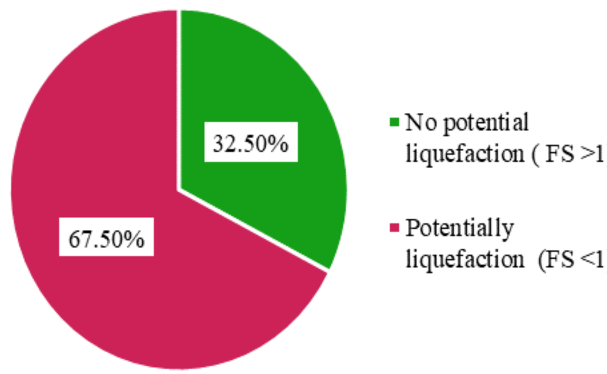


Fig. 6. Liquefaction potential classification based on the Factor of Safety.

Based on LPI, 13 coordinates are classified as no liquefaction level, which are shown in Table 3. These coordinates are in 4 subdistricts with a percentage of 53.85% of the them are in Kuranji, and 15.38% are in the Pauh, Koto Tangah, and Padang Timur. From these 13 coordinates, 53.85% have LPI of 0 and 46.15% have LPI in the range > 0 and < 5. The highest LPI value is 4.22 which is in the Koto Tangah at coordinates -0.833567 100.315243 with the settlement of 24 cm.

There are 9 points classified as moderate liquefaction level with a percentage of 55.56% are in the Padang Utara, 22.22% in the Padang Selatan, 11.11% in the Padang Barat and 11.11% in the Kuranji. The highest LPI value is 13.8 in the Koto Tangah at coordinates -0.868493 100.378217 with a settlement of 12.28 cm. While the lowest LPI with a value of 8.11 in the Padang Barat at coordinates -0.951665 100.360735 with a settlement of 14.8 cm. These coordinates are shown in Table 4.

There are 18 coordinates classified as severe liquefaction level, which are shown in Table 5. They are spread in 6 subdistricts with a percentage of 38.89% are located in Koto Tangah, 22.22% are in Padang Barat, 16.67% are in Padang Utara, 11.11% are in Padang Selatan, 5.56% are in Padang Timur, and 5.56% are in Kuranji. The highest LPI value is 69, 21 which is in the Padang Selatan at coordinates -0.957600 100.363074, with a settlement of 72.66 cm. Meanwhile, the lowest LPI with a value of 17.71 is in the Koto Tangah at coordinates -0.879313 100.346390 with a settlement of 10.43 cm.

TABLE III
THE COORDINATES THAT CLASSIFIED AS NO LIQUEFACTION LEVEL.

No	Subdistrict	Coordinate	Factor of Safety	Depth (m)	Settlement (cm)	Liquefaction Potential Index
1	Koto Tangah	-0.845238 100.365082	>1	3 to 3.41	1.45	0.5
2	Koto Tangah	-0,833567 100,315243	>1	18	24	4.22
3	Kuranji	-0.937345 100.399629	>1	1.95 to 2	0	3.03
4	Kuranji	-0,899494 100.393388	>1	-	-	0
5	Kuranji	-0.930349 100.385547	>1	1	2	2.68
6	Kuranji	-0.930388 100.384857	>1	16	20	0.12
7	Kuranji	-0.930388 100.384857	>1	1	2	0.8
8	Kuranji	-0,933697 100.399071	>1	-	-	0
9	Kuranji	-0.893092 100.404285	>1	-	-	0
10	Padang Timur	-0.943081 100.377829	>1	-	-	0
11	Padang Timur	-0.919194 100.457179	>1	-	-	0
12	Pauh	-0.913639 100.467030	>1	-	-	0
13	Pauh	-0.941397 100.465379	>1	-	-	0

TABEL IV
THE COORDINATES THAT CLASSIFIED AS MODERATE LIQUEFACTION LEVEL.

No	Subdistict	Coordinate	Factor of Safety	Depth (m)	Settlement (cm)	Liquefaction Potential Index
1	Koto Tangah	-0.868493 100.378217	<1	10 to 14	12.28	13.8
2	Padang Selatan	-0.994496 100.373028	<1	1.59 to 2.02; 7 to 8	5.79	8.47
4	Padang Selatan	-0.994841 100.375727	<1	2 to 3; 17	8.41	10.35
3	Padang Utara	-0.918685 100.365733	<1	1.9 to 4	4.18	10.09
5	Padang Utara	-0.897794 100.351313	<1	16 to 40	78.57	11.72
6	Padang Utara	-0.898532 100.350406	<1	14 to 40	92.04	13.33
7	Padang Utara	-0.895472 100.350375	<1	16 to 40	87.70	9.47
8	Padang Utara	-0.898551 100.349796	<1	14 to 40	90.54	13.11
9	Padang Barat	-0.951665 100.360735	<1	14 to 18	14.80	8.11

TABLE V
THE COORDINATES THAT CLASSIFIED AS SEVERE LIQUEFACTION LEVEL.

No	Subdistrict	Coordinate	Factor of Safety	Depth (m)	Settlement (cm)	Liquefaction Potential Index
1	Koto Tangah	-0.876453 100.386698	<1	1 to 8	58.66	61.83
2	Koto Tangah	-0.876453 100.386698	<1	1 to18	61.05	64.11
3	Koto Tangah	-0.876453 100.386698	<1	1 to16	51.43	62.68
4	Koto Tangah	-0.869253 100.380246	<1	1 to 6; 9 to 10; 13 to 24	51.97	41.85
5	Koto Tangah	-0.829898 100.322453	<1	14 to 30; 34 to 36	70.5	25.78
6	Koto Tangah	-0.867397 100.380211	<1	1 to 10; 15 to 16	42.75	56.38
7	Koto Tangah	-0.879313 100.346390	<1	10 to18; 22 to 32	63.20	17.71
8	Kuranji	-0.913720 100.403244	<1	16.9 -19.1	37.04	36.56
9	Padang Barat	-0.936068 100.360748	<1	1 to 6; 11 to 30	58.88	32.94
10	Padang Barat	-0.96112 100.354235	<1	2 to 25	33.24	36.27

11	Padang Barat	-0.945452 100.359322	<1	1 to 6; 9 to 28	52.64	20.12
12	Padang Barat	-0.936068 100.360748	<1	1 to 6; 11 to 24; 27 to 30	52.41	32.15
13	Padang Selatan	-0.9506337 100.3680775	<1	1.58 to 9	10.43	17.98
14	Padang Selatan	-0.957600 100.363074	<1	1 to 20	72.66	69.21
15	Padang Timur	-0.944749 100.375605	<1	2 to 10	38.92	55.52
16	Padang Utara	-0.914795 100.358089	<1	16 to 30	62.12	30.51
17	Padang Utara	-0.908357 100.354177	<1	12 to 26	54.73	36.67
18	Padang Utara	-0.921187 100.366778	<1	0 to 6; 12 to 18	42.67	46.17

Overall, we obtained 32.05% coordinates are classified into No Liquefaction potential, 22.5% are into Potentially Liquefaction and 45.0% are into Very Potential Liquefactionas shown in Fig. 7.

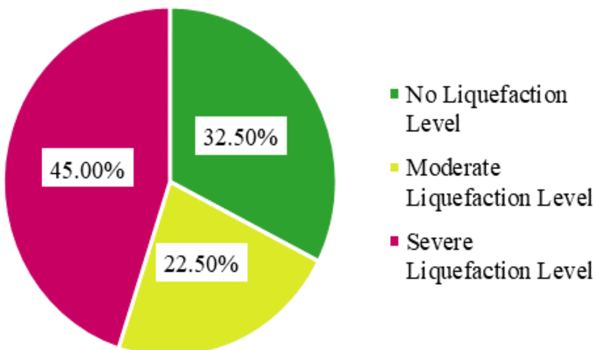


Fig. 7. Liquefaction potential level classification based on the Liquefaction Potential Index.

These data are then displayed on Google Maps in the form of different color markers according to the liquefaction potential level at certain coordinate, as shown in Table 6.

TABLE IV
MARKERS CLASSIFICATION

Marker	Level
	No Liquefaction Level
	Moderate Liquefaction Level
	Severe Liquefaction Level

The results the liquefaction potential mapping at 40 coordinates in the Padang City can be seen in Fig. 3.3. The map can be accessed on a website and has been able to display the difference in marker colors according to the level of liquefaction potential at these coordinates. Besides, the map also displays information on liquefaction potential at a coordinate shown in Fig. 8.

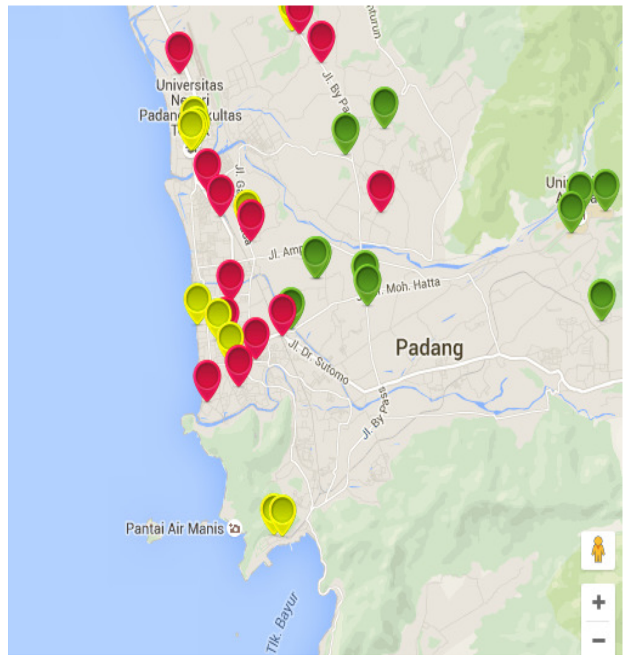


Fig. 8. Main display of Potential liquefaction map.

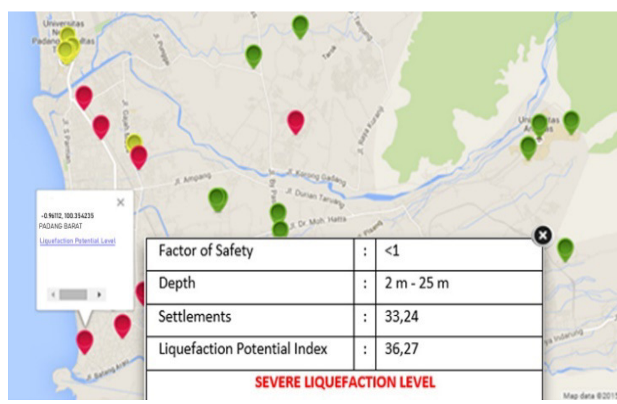


Fig. 9. Liquefaction Potential Information at a coordinate in the map.

IV. CONCLUSSION

Based on the results of the FS calculations, it can be concluded that 32.50% coordinates are classified as no potential liquefacion and 67.5% are as potentially liquefaction. Based on the LPI value, 32.50% coordinates are classified as no liquefaction level with the highest percentage are in Kuranji. While, 25% are as moderate liquefaction level with the highest percentage are in Padang Utara. Then, 43.18% coordinates are as severe liquefaction level with the highest percentage are in KotoTangah. These coordinates can be displayed on Google Maps in the form of colored markers; green for no liquefaction level, yellow for moderate liquefaction level and red for severe liquefaction level.

In this article, there is a difference in the number of coordinates in each subdistrict. To find out the distribution of the liquefaction potential levels based on these subdistricts, it is better to increase the number of coordinates with the same number of coordinates in each district.

ACKNOWLEDGMENT

This research is funded by Kementrian Riset, Teknologi dan Pendidikan Tinggi Republik Indonesia.

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