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AN EVALUATION OF LIQUEFACTION POTENTIAL IN THE REGION OF PADANG CITY

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ABSTRACT

Padang City is a city located on the Coastline of West Sumatra Coast that is vulnerable to earthquakes and tsunamis. This vulnerability allows the liquefaction phenomenon when an earthquake occurs. Factors affecting liquefaction are soil type, grain grading, ground water level, relative density and vibration. This study aims to analyze the liquefaction potential based on the value of safety factors obtained by using the Seed et al (1985) method and the Liquefaction Potential Index (LPI) method which aims to map the liquefaction based on the level of liquefaction potential at the location being reviewed. Earthquake data is using the Indonesia meterological, climatology, and geophysics agency (BMKG) (2009-2019) and maximum ground surface acceleration (PGA) using the attenuation equation from Young et al. The liquefaction calculation parameters are judged by a safety factor (FS), if FS> 1 it means there is no potential for liquefaction and if FS <1 means there is potentially liquefaction possibility. Based on calculations from these methods, the results obtained from the ten location points reviewed were almost all sites potentially liquefaction based on variations in earthquake magnitude with sand and silt soil types and other types of soil with an average groundwater level below 1.5m.

Key Word :liquefaction, SPT, CPT, LPI, safety factor (SF).

1. INTRODUCTION

Padang City is one of the coastal cities which potentially vulnerable to the danger of a large earthquake originating from the subduction zone and the Sumatran fault. An earthquake that occurred in 2009 caused damage to road and building infrastructure in the Padang City. In addition to strong vibrations, liquefaction phenomena also occur in some coastal areas and riverbanks.

The danger of liquefaction that occurs due to earthquakes and certain types of soil, resulting in increased pore water pressure on the soil, which results the soil loses its strength. The phenomenon of liquefaction also occurs in some coastal areas and riverbanks. The liquefaction hazard that occurs is caused by vibration and type of water-saturated sand soil. This liquefaction events occurred after the earthquake in Japan, America, New Zealandand Palu, Indonesia in 2018. These phenomena shows how terrible the danger of liquefaction in which thousands of homes sank and the land in the form of mud is moving as it happened in Palu.

Generally, the areas above silt and sand deposits from the coast or rivers that are not consolidated and are saturated with water, have potential for liquefaction (Badrul Mustafa, The expert of earthquake in Unand). Liquidity in soil layers are influenced by soil engineering properties, geological conditions, and vibration characteristics and must take into account

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several factors such as grain size, ground water level and maximum ground vibration acceleration (Seed and Idriss, 1971).

Considering that the potential generated by the liquefaction is very large, especially in Padang City. Some researchers have carried out liquefaction research in several points in Padang City. Referring to researchers who have conducted previous research, the writer wants to make a final project regarding the analysis of potential liquefaction in Padang City using Standard Data Penetration Test (SPT), Cone Penetration Test (CPT), and Laboratory Data. The method used in this study is Seed et al method, NCEER for SPT data along with laboratories and Youd&Idriss for CPT data. The main parameters in liquefaction calculations are effective stress, pore pressure, total stress, earthquake magnitude and maximum ground acceleration (amaks) using the attenuation equation as an indicator in determining the liquefaction potential with the aim of finding a safety factor (FS).

2. RESEARCH PURPOSES

1) Analyzing and detecting liquefaction hazards at several points in Padang City using secondary data from SPT and Laboratory data, finding out the parameters that caused liquefaction and Analyze Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) calculations.
2) Finding out safety factors for potential liquefaction.

3. LIMITATION OF THE PROBLEM

1) Analysis is carried out based on secondary data from SPT, CPT and laboratory data.
2) The method used are:
   a) Seed et al method (1985) (SPT and laboratory data)
   b) Method of Potential Index (LPI)
3) Using the earthquake magnitude limitation (Mw) of 4.6 5.3 6.2 and 7.6.

4. LITERATUREREVIEW

4.1 Soil Parameters

In calculating liquefaction, soil parameters are very influential, such as NSPT values in the field and laboratory data. For laboratory data, the volume weight is used to determine the total stress and the ground water level determines the pore pressure, so that an effective soil stress is obtained. The NSPT value determines the parameters in calculating ground resistance to liquefaction.

Calculation Of Total Vertical Stress

(σvo) for initial depth

$$\sigma vo = H.\boldsymbol{\gamma} \quad (1)$$

To Calculate Effective Vertical Pressure σ'_{vo} and pore pressure (u)

$$\sigma' vo = \sigma vo - u$$

$$= (H.\boldsymbol{\gamma}) - (H_w .) \quad (2)$$

Information:

σvo = total voltage or stress due to working load (KN/m^2)

$\sigma' vo$ = ground effective vertical stress (KN/m^2)

H = water level measured from ground level (m)

γ = Correlation volume weight (KN/m^3)

U = Pore pressure (KN/m^2)

Hw = thickness of subsoil (m)
γw = weight volume of water (0,000981 kg/cm^3/9.81KN/m^3)

4.2 Earthquake Parameters

Earthquake data needed in the calculation of liquefaction is earthquake magnitude (Mw) and the maximum of ground acceleration (PGA). The parameters of the earthquake include:

1) Epicenter
2) Depth (Hypocenter)
3) Magnitude

For earthquake magnitude the authors used BMKG earthquake catalog (2009-2019) and earthquake acceleration using the attenuation equation from Young et al (1997):

$$\text{Ln (PGA)} = 0{,}6687 + 1{,}438\ Mw - 2{,}329 \ln[R + 1{,}097\ e^{0{,}617Mw}] + 0{,}00648\ H + 0{,}3643Zt \quad (3)$$

Information :
R = epicenter distance (km)
H = depth (km)
Zt = earthquake source type (0 for interface, and 1 for intraslab)
Mw = The Magnitude of Earthquake moment

4.3 The Method of Potential Liquidation Evaluation

The reduction factor (rd) is a value that can affect stresses in the soil. The farther the depth of the soil the smaller reduction factor will be.

Reduction factor using the equation proposed by Liao and Whitemann (1986) is:
rd = 1-0.00765xz for z < 9.15 m
rd = 1.174-0.0267xz for 9.15 m < z < 23m
rd=0.744-0.008xz for 23 m < z <30 m (4)

4.4 Cyclic Stress Ratio (CSR)

Cyclic Stress Ratio is the cyclic stress caused by an earthquake divided by the effective stress. Seed and Idriss (1971) formulate equations for CSR, namely:

$$C = 0{,}65 * \left(\frac{\propto m \quad * \sigma}{g * \sigma' v}\right) * r_d \quad (5)$$

Note:
G = acceleration of gravity (m/s^2)
σv = stress total or stress due to working load (KN/m^2)
σ'vo = teganganvertikalefektiftanah(KN/m^2)
rd = reduction coefficient

The factor 0.65 is the assumption that the uniform shear stress is equivalent to 65% of the absolute maximum shear stress produced by the earthquake.

4.5 Cyclic Resistance Ratio (CRR)

Cyclic Resistance Ratio value is soil resistance to liquefaction obtained through field testing.Such as the Standard Penetration Test (SPT) and Cone Penetration Test (CPT).

4.6 Standard Penetration Test (SPT)

Seed et al method is based on soil parameters the corrected penetration resistance and the SPT tool correction factor.

SPT test correction factor (SNI 4153: 2008): for the first layer with a value of N = 6.

$$C_N = \frac{2{,}2}{(1{,}2(\frac{\sigma}{\rho}))} \quad (6)$$

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Cn value must be <1.7

To calculate CRR, the N-SPT value is corrected for the field testing procedure using formula:

$$N_{60} = 1.67\ N\ CbEmCr \qquad (7)$$

(For the values of Cb, Em, and Cr are tool factors, the writer assumes that their value are in accordance with the standard equipment in the field.

$$(N1)\ 60 = CN \times N60 \qquad (8)$$

$$C = \frac{1}{3 - (N1)6} + \frac{(N1)6}{1} + \frac{5}{[1\ .1(N1)6\ +4\ ]^2} - \frac{1}{2} \qquad (9)$$

Table 1. Corrections used in the SPT test (SNI 4153: 2008)

Factors	Types of tool	Parameters	Correction
Effective vertical stress	-	C_N	2.2/(1.2+($^{\sigma'}$vo/ pa
Effective vertical stress	-	C_N	$C_N \leq 1.7$
Energy ratio	Donut hammer	C_E	0.5 – 1.0
Energy ratio	Safety hummer	C_E	0.7 – 1.2
Energy ratio	Autimatic-trip Donut-type hammer	C_E	0.8 – 1.3
Drill diameter	65-115 mm	C_B	1.0
Drill diameter	150 mm	C_B	1.05
Drill diameter	20 mm	C_B	1.15
Stem lenght	<3 mm	C_R	0.75
Stem lenght	3 -4 m	C_R	0.8
Stem lenght	4-6 m	C_R	0.85
Stem lenght	6 – 10 m	C_R	0.95
Stem lenght	10 – 30 m	C_R	1.0
Sampling	Standard Tube	C_S	1.0
Sampling	Coating tube (liner)	C_S	1.1 – 1.3

Information:

$(N_1)_{60}$ = corrected SPT value of 60% energy
C = Correction Factor (where CN ≤ 1.7)
$^{\sigma'}$vo = Effective vertical stress (KN / m^2)
N_{60} = corrected SPT value
Pa = pressure in I atm = 100 kn / m^2
Em = hammer efficiency
Cb = borlog diameter
Cr = rod length

4.7 Magnitude Scaling Factors (MSF)

An earthquake with an M = 7.5 is said as a reference earthquake Youd and Idriss, 2001; Olson et al., 2005) so it is necessary to make corrections for earthquakes with smaller magnitudes orwith magnitudes greater than 7.5. In Seed et al method the formula is:

$$M = 10^{2.24} / M \quad 2{,}5 \qquad (13)$$

For an earthquake with magnitudes greater than 7.5, use the MSF formula as follows:

$$M = \frac{(M\ \ )-2{,}5}{7{,}5} \qquad (14)$$

Information:

Mw = Earthquake Magnitude (SR)

To calculate CRR with earthquake magnitude other than 7.5, a correction factor called Magnitude Scale Factor (MSF) is needed. Seed (1983) provides an equation, namely:

$$CRRMW = CRR_{7.5} x MSF \qquad (15)$$

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4.8 Safety Factor (FS)

The safety factor is a comparison of the value of Cyclic Stress Ratio (CSR) and Cyclic Raseistance Ration (CRR) as shown in the following equation:

$$F = \frac{C}{C} \qquad (17)$$

RESEARCH METHODOLOGY

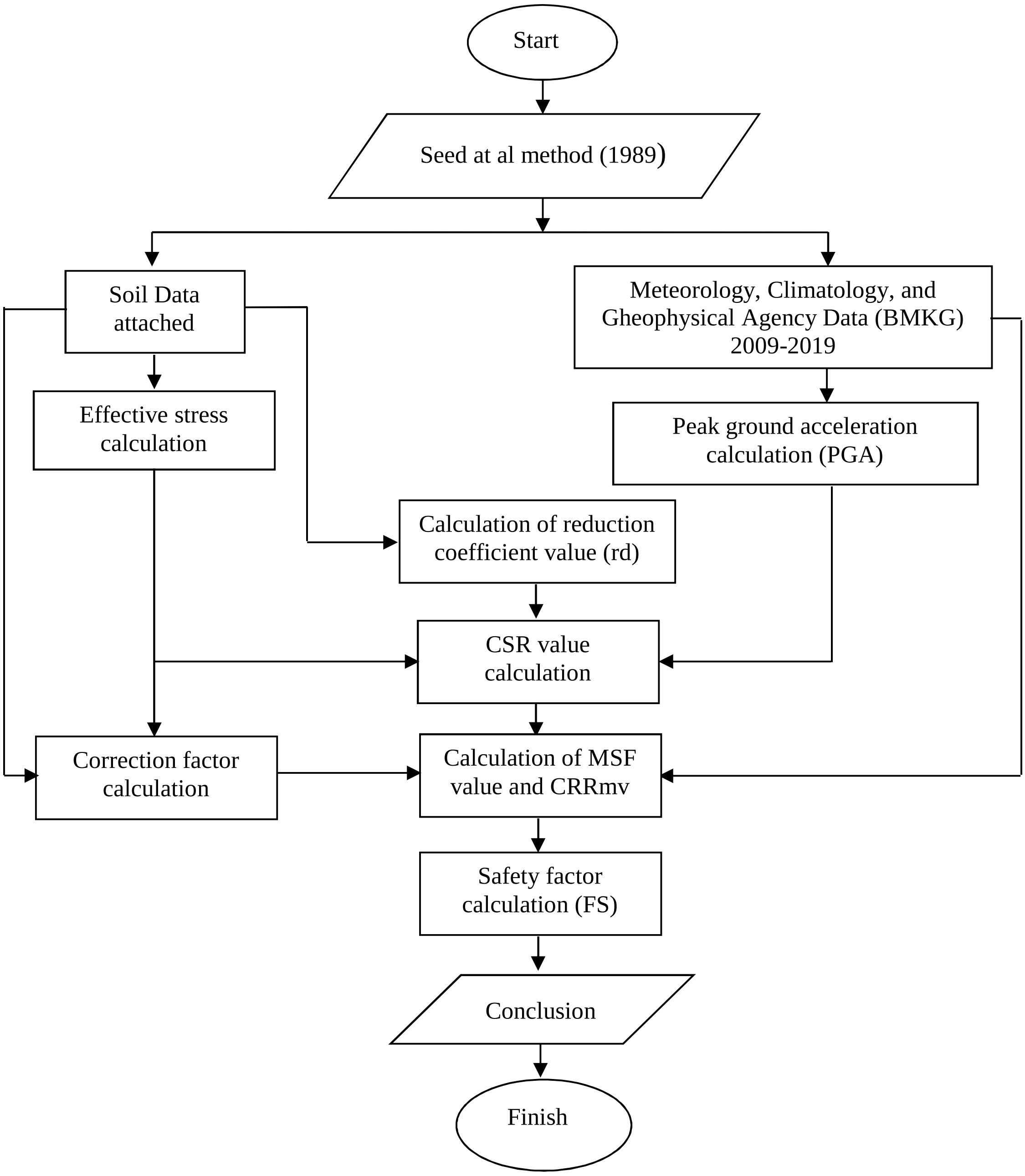

Figure 1. Methodology of liquefaction calculation based on the method of Seed et al

5. DISCUSSION

In this study, the researcher randomly picked the location points in Padang City based on the soil data obtained, namely: Inna Muara Hotel, a Building in Hangtuah Street No. 150, Housing in GunungPangilun, Kali Kecil Street No. 2, West Sumatera Plantation, and a Hotel at BagindoAzizchan Street.

5.1 Based on Seed et al Method

In liquefaction calculation based on liquefaction potential formula, for the varian of earthquake magnitude, it is obtained one sample of soil data in a Building in Hangtuah Street No. 150, Calculating the value of Cyclic Stress Ratio (CSR).

Based on Young et al formula it is Obtained PGA = 0.28 g = 2,7468 m/s^2

Table 2. BMKG earthquake data (2009-2019)

Earthquake Magnitude (Mw)	Depth (Km)	Erthquake Distance
4,6	97	10
5,3	23	105
6,2	10	80
7,6	71	57

Table 3. Calculation of CSR values

DATA	SPT							
Depth(m)	N	AT ISI(KN/	otal (KN/	rpori(KN/	ektif(KN/	rd	amaks	CSR
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.5	6	16.1	24.15	4.905	19.245	0.988	2.746	0.225
3.5	38	19.5	63.15	24.525	38.625	0.973	2.746	0.289
5.5	33	18.3	99.75	44.145	55.605	0.957	2.746	0.312
7.5	8	17.9	135.55	63.765	71.785	0.942	2.746	0.323
9.5	8	17.9	171.35	83.385	87.965	0.920	2.746	0.326
11.5	5	15.5	202.35	103.005	99.345	0.866	2.746	0.321
13.5	7	17.1	236.55	122.625	113.925	0.813	2.746	0.307
15.5	6	17.1	270.75	142.245	128.505	0.760	2.746	0.291
16	8	17.8	279.65	147.15	132.5	0.746	2.746	0.286
17.5	5	15.5	302.9	161.865	141.035	0.706	2.746	0.276
19.5	10	18.1	339.1	181.485	157.615	0.653	2.746	0.255
21.5	18	18.4	375.9	201.105	174.795	0.599	2.746	0.234
23.5	29	18.9	413.7	220.725	192.975	0.556	2.746	0.216
25.5	60	22.5	458.7	240.345	218.355	0.540	2.746	0.206
27.5	60	22.5	503.7	259.965	243.735	0.524	2.746	0.197
29.5	60	22.5	548.7	279.585	269.115	0.508	2.746	0.188
31.5	51	22	592.7	299.205	293.495	0.492	2.746	0.180

Calculating the value of Cyclic Resistance Ratio (CRR)

Table 4. CRR 7,5 Value

Depth (m)	N_{60}	CN	$(N_1)_{60}$	CRR_{75}
1,5	4,509	1,580	7,124	0,088
3,5	28,557	1,387	39,606	0,110
5,5	24,800	1,253	31,069	0,567
7,5	6,012	1,147	6,896	0,087
9,5	6,012	1,057	6,360	0,083
11,5	3,758	1,003	3,769	0,063
13,5	5,260	0,940	4,947	0,071
15,5	4,509	0,885	3,992	0,065
16	6,012	0,871	5,238	0,074
17,5	3,757	0,843	3,167	0,059
19,5	7,515	0,792	5,955	0,079
21,5	13,527	0,746	10,095	0114
23.5	21,793	0,703	15,319	0,163
25.5	45,090	0,650	29,317	0,426
27.5	45,090	0,605	27,272	0,346
29.5	45,090	0,565	25,493	0,301
31.5	38,326	0,532	20,392	0,220

CRRmw with Magnitude Scaling Factor (MSF) Correction Factor

Table 5. MSF Value

MSF			
4,6	5.,3	6,2	7,6
0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967
3,494	2,431	1,627	0,967

From the calculation results shown in the above table, it can be seen in every depth of the soil with variations in earthquake magnitude, that the MSF value will get smaller along with the magnitude of the earthquake magnitude scale that occurs.

After obtaining the MSF value for each earthquake magnitude, the Cyclic Resistance Ratio (CRR) value is based on the earthquake plan that shows the CRRMw calculation results with the magnitude of the existing MSF.

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Table 6. CRRmw Value

Depth (m)	4,6	5,3	6,2	7,2
1,5	0,310	0,215	0,144	0,085
3,5	0,385	0,268	0,179	0,106
5,5	1,980	1,377	0,922	0,547
7,5	0,303	0,211	0,141	0,083
9,5	0,288	0,200	0,134	0,080
11,5	0,221	0,154	0,103	0,061
13,5	0,250	0,174	0,116	0,069
15,5	0,227	0,157	0,105	0,062
16	0,258	0,180	0,120	0,071
17,5	0,207	0,144	0,096	0,057
19,5	0,277	0,193	0,129	0,077
21,5	0,398	0,277	0,185	0,110
23.5	0,570	0,396	0,265	0,157
25.5	1,489	1,036	0,693	0,411
27.5	1,209	0,841	0,563	0,334
29.5	1,055	0,734	0,491	0,291
31.5	0,770	0,535	0,358	0,212

The calculation of Safety Factor (FS) value

Table 7. Safety factor value

Metode Seed et al

POTENSI LIKUIFAKSI BERDASARKAN FAKTOR KEAMANAN (FS) DATA SPT

Depth (m)	FS Mw 4,6		FS Mw 5,3		FS Mw 6,2		FS Mw 7,6	
	FS	KET	FS	KET	FS	KET	FS	KET
1,5	1,372	TL	0,955	L	0,695	L	0,379	L
3,5	1,330	TL	0,925	L	0,673	L	0,368	L
5,5	6,331	TL	4,405	TL	3,205	TL	1,751	TL
7,5	0,936	L	0,651	L	0,474	L	0,259	L
9,5	0,883	L	0,615	L	0,447	L	0,244	L
11,5	0,688	L	0,478	L	0,348	L	0,190	L
13,5	0,815	L	0,566	L	0,412	L	0,225	L
15,5	0,777	L	0,540	L	0,393	L	0,214	L
16	0,899	L	0,625	L	0,455	L	0,248	L
17,5	0,751	L	0,522	L	0,380	L	0,207	L
19,5	1,083	KRITIS	0,753	L	0,548	L	0,299	L
21,5	1,695	TL	1,179	TL	0,858	L	0,469	L
23.5	2,630	TL	1,829	TL	1,331	TL	0,727	L
25.5	7,212	TL	5,018	TL	3,651	TL	1,995	TL
27.5	6,136	TL	4,269	TL	3,106	TL	1,697	TL
29.5	5,596	TL	3,893	TL	2,833	TL	1,548	TL
31.5	4,257	TL	2,962	TL	2,155	TL	1,177	TL

Note:
TL = No Liquifaction> 1
L = Liquidity <1
Critical = 1 Approaching Liquidation

In conclusion the comparison between the safety factors of the four magnitudes of the earthquake can be obtained.

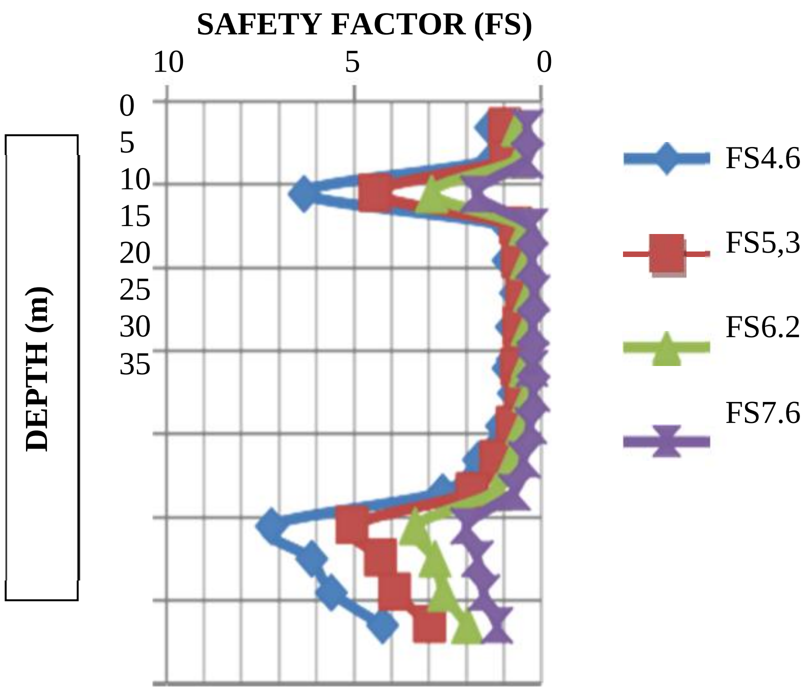

Figure 2. The safety factor of the seed et al

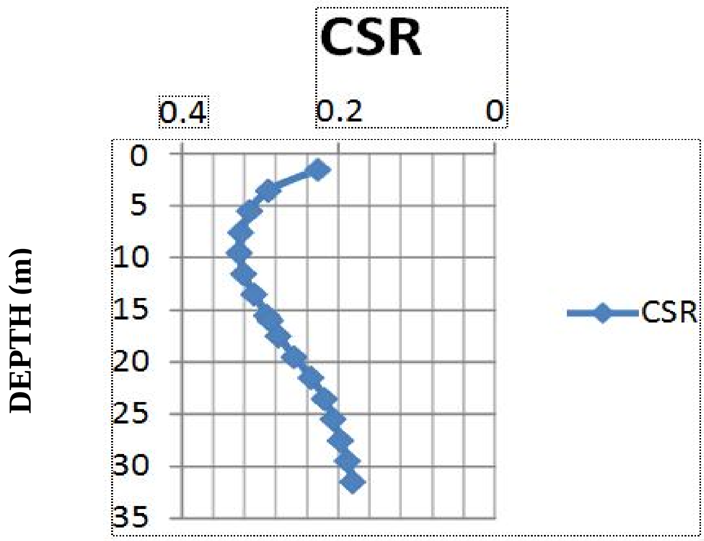

Figure 3. The value of CSR using Seed et al Method

The calculations for the 7 locations reviewed have the same calculations, therefore to map the location of the liquefaction points the author uses the Liquefaction Potential Index (LPI) method, which is to determine the level of potential liquefaction based on the results of the safety factor of each method previously calculated using the formula:

$$L = \int_0^2 {}^m F \quad (Z)d \tag{18}$$

1 - SF for SF <1 and SF value > 1 then the value of F = 0, W(z) = 10-0.5(z).
The overall value of the LPI will be totaled to get the limit:
LPI < 5 Low liquefaction
5 < LPI < 15 Moderate liquefaction
LPI > 15 High liquefaction
LPI = 0 Very low liquefaction

Table 12. Results of LPI values

LPI Mw 4.6					
Depth (m)	**FS**	**F**	**W(Z)**	**LPI**	**POTENCY**
1,5	1,372	0	9,25	0	AVERAGE
3,5	1,330	0	8,25	0	
5,5	6,331	0	7,25	0	
7,5	0,936	0,063	6,25	0,793	
9,5	0,883	0,116	5,25	1,220	
11,5	0,688	0,311	4,25	2,649	
13,5	0,815	0,185	3,25	1,205	
15,5	0,777	0,222	2,25	1,003	
16	0,899	0,100	2	0,100	
17,5	0,751	0,248	1,25	0,466	
19,5	1,083	0	0,25	0	
TOTAL LPI				**5,425**	

Then the LPI results for all locations can be obtained:

Table 13. LPI results for all locations

Liquefaction Potential Based on Liquefaction potential Index					
Location	**FS Seed et al**				
	Borhole	Mw 4.6	Mw 5.3	Mw 6.2	Mw 7.6
Hang Tuah Street No. 150	BH 01	Average	Average	High	High
	BH 02	Average	Average	High	High
Muara Inna Hotel	BH 01	Average	Average	High	High
	BH 02	Average	Average	High	High
	BH 03	Average	Average	High	High
	BH 04	Average	Average	Average	High
A Hotel in Bagindo	BH 01	Low	Average	High	High
Azischan Street	BH 02	Low	Average	High	High
Prasjal Tarkim	BH 01	Average	High	High	High
	BH 02	Average	Average	High	High
West Sumatera Plantation	BH 01	Average	Average	High	High
West Sumatera Plantation	BH 01	Low	Average	High	High
Aliga Padang Hotel	BH 01	Vey Low	Low	Average	Average

6. CONCLUSION

1) Based on the calculation of the analysis of the potential for liquefaction at 7 points in the Padang city using SPT and laboratory data, it can be detected in almost all the case study sites, the seven places are classified as moderate liquefaction levels for earthquake magnitudes above 4.0 and high levels of liquefaction with earthquake magnitudes above 6.0. The parameters used for this calculation are the CSR values using earthquake or vibration data, and the CRR value is obtained from the soil data from the SPT test results.

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2) Based on the value of the Safety Factor (FS) using the Seed et al method, it was found that the average soil which had a liquefaction impact was at a depth of 1.5 to 20 m. All of these are based on FS> 1, so there is no liquefaction, while for FS <1, there is liquefaction.

7. BIBLIOGRAPHY

Das, Braja M. 1988**.** *mekanika tanah II.*Surabaya : Erlangga, 1988.

Hasmar,H.A.Halim.2013,*Dinamika Tanah dan Rekayasa Kegempaan*.UII PressYogyakarta.

Hwang, Jin hung. 2019. *Soil Liquefaction evaluation and countermeasures. National Central* University, Taiwan

Idriss, IM and Boulonger, R.W. 2008, *Soil Liquefaction during Earthquakes.* 2008

Ikhsan, Rifa. 2011**,** *Analisis Potensi Likuifaksi berdasarkan data CPT dan SPT Studi kasus PLTU Ende Nusa Tenggara Timur.* Depok : Universitas Indonesia, 2011.

Karmer, Steven L. *Geotechnical Earthquake Engineering*. Prentice Hall, New Jersey, USA.

Katalog Gempa Bumi 2018, BMKG

Lindung Zalbuin Mase. *Analisis Pendahuluan Potensi Likuifaksi di Kali Opak Imogiri Daerah Istimewa Yogyakarta, Seminar Nasional Geoteknik 2014 Yogyakarta, 10-11 Juni 2014, ugm.*

Liquefaction Resistance of Soils: *Summary Report from the 1996 NCEER and 1998 NCEER/NSFWorkshops on Evaluation of Liquefaction Resistance of Soils, Article in Journal ofGeotechnical and Geoenvironmental Engineering* October 2001 DOI: 10.1061/(ASCE)1090-0241(2001)127:10(817)

Mulyani, Rini .2013, Extended Framework For Earthquake and Tsunami Risk *Assesment Padang City a case Study.* The University of Sheffield.

PUPR. 2019, *Kumpulan Korelasi parameter Geoteknik dan Fondasi.*jakarta

Putra,Hendri Gusti, Hakam, Abdul, *Analisa Likuifaksi Berdasarkan Data Pengujian Sondir(Studi Kas Haji Agus salim)* .

SNI 8460:2017, *Persyaratan Peran perancangan Geoteknik*