ISSN 2541-223X
Volume 4 2022

ANALYSIS OF LIQUEFACTION EFFECT ON SETTLEMENT USING ROCSCIENCE SETTLE AT MALALAYANG BEACH AREA, NORTH SULAWESI

J Prayogo[1*], F Faris[2], H C Hardiyatmo[3]

[1]Master student in Natural Disaster Management Engineering, Department of Civil and Environmental Engineering Universitas Gadjah Mada, Yogyakarta, Indonesia
[2]Directorate General of Human Settlements, The Ministry of Public Works and Housing, South Jakarta, Indonesia
[3]Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

Abstract.
The Malalayang Beach area is a strategic tourist destination close to Manado city. Arrangement of the area is carried out by building several buildings that can support this area as a tourist destination. Liquefaction is a phenomenon when the soil loses its strength of contact between particles. This is due to earthquake shocks that trigger an increase of water pressure in areas with loose sand characteristics (not dense). The settlement of soil due to liquefaction is a vertical deformation of the soil in the soil layer caused by soil compaction due to earthquakes. The study purpose is to determine how much reduction could occur at the research site as an early stage of the early stages of risk management. With the N-SPT data, the Yoshimine method and the computational method Rocscience Settle 3D can be used to analyze the settlement. Yoshimine method indicates settlement with a very low classification in BH-MLY-01 and high in BH-MLY-05. In RS Settle 3D, the location of BH-MLY-01 has a very low classification, and the location of BH-MLY-05 is dominated by low classification. The maximum settlement resulted from the Rocscience Settle 3D at the BH-MLY-05 location by 11,588 cm.

Keywords: Liquefaction; The settlement of soil; Risk Management

1. INTRODUCTION

Malalayang Beach area is a coastal area located in Manado City. Its close to the center of Manado City is an easily accessible location for local residents. In addition to presenting the beauty of the beach above the water level, this location also gives a wonderful underwater nature tour. This location has long been a paradise for divers looking for the beauty of underwater nature. To maximize the natural beauty this beach area, an arrangement of the area is carried out so that it is hoped will be more visitors come to visit the location. An overview of the location of this study can be seen in Figure 1.
Liquefaction is a phenomenon triggered by earthquake events that cause loss of soil strength due to increased pore water. Beaches whose soil layers are dominated by loose sand are considered to have a great potential for liquefaction if a large enough earthquake hits the location.
One of the side effects that the occurrence of liquefaction may cause is settlement of soil. This settlement of soil is caused by compaction due to shocks that cause the shaking

[1*] Corresponding author's email: jodieprayogo@mail.ugm.ac.id
DOI: https://doi.org/10.20885/icsbe.vol4.art38

between the loose sand layers to fill each other. Uncontrolled settlement of the soil so that a considerable settlement occurs can result to damage to its structure.

This study wanted to determine the risk of settlement that can occur at the research site. Identifying the risk is initial stage of the risk management stage. Then we also want to know how much soil settlement occurred at the research site due to liquefaction. The effect of that liquefaction is the potential for a liquefaction event if the location experiences an earthquake with a maximum magnitude. After knowing the value of the settlement, it can also be seen the classification of the settlement danger level. So that in the future appropriate actions can be taken to minimize the settlement.

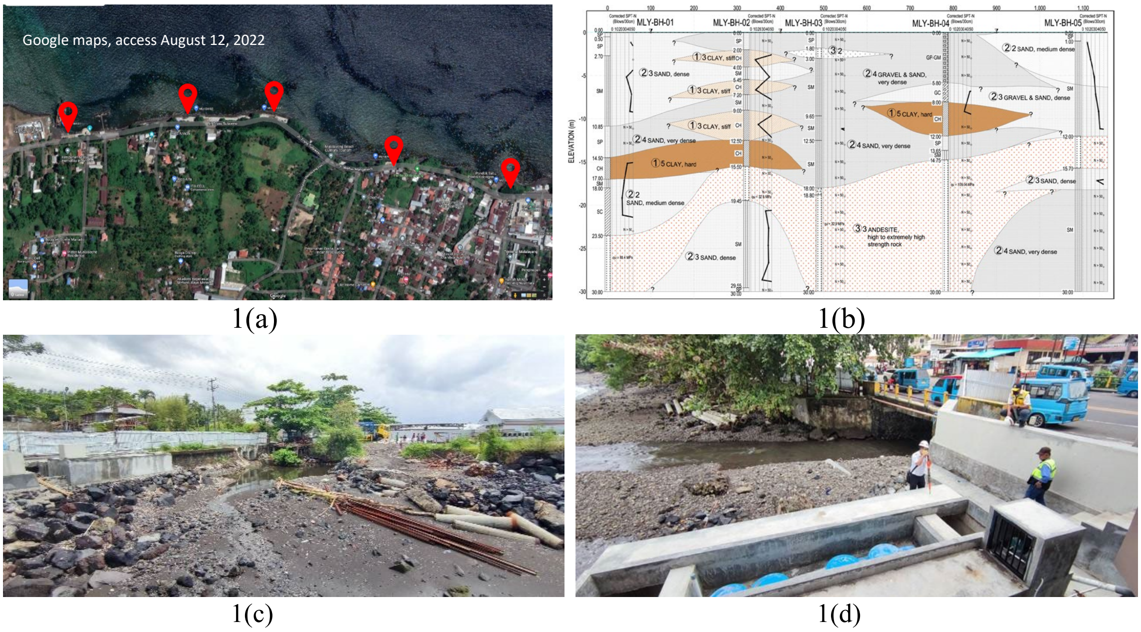

Figure 1. (a) Research Location (b) Illustration of Soil Type of Each Layer [1] (c) Description of Conditions Around the point BH-MLY-01 (d) Description of Conditions Around the point BH-MLY-05

2. THEORETICAL STUDIES

2.1 Liquefaction

Liquefaction is a phenomenon that occurs in soils that have the characteristics of loose (non-solid) sand and water saturated. Earthquake shocks result in a slow increase in water pressure, which results in an effective voltage from the ground (σ') decreasing further [2]. When an earthquake occurs, the volume of loose sand tends to decrease. This decrease in the volume of loose sand results in an increase of pore water pressure. The soil will have more liquid character than solid character because the strength of contact between particles is reduced, causing liquefaction. Soil deposits that have the potential to be displaced at the time of an earthquake are fine sand, silty sand, and normal sand.

The occurrence of liquefaction can have several impacts such as loss of soil bearing capacity, loss of lateral bearing capacity, lateral spreading and lateral flow and than increase of soil lateral pressure which can cause failures in the soil lateral pressure holding structure.

2.2 Settlement

Settlement of soil is the descent of the soil surface elevation from its initial state. The settlement indicates the subsidence of a building due to compression and deformation of

the soil layer under the building [3]. The process of land subsidence can occur instantly or for a long time. The duration of this settlement is affected by several external and internal factors of soil.
The settlement can be caused by several factors, such as natural subsidence caused by geological processes such as geological cycles and sedimentation of basin areas [4]. Land subsidence can also result from the exploitation of groundwater. Land subsidence can also be caused by loads above ground levels such as building construction and other loads. Soil settlement due to liquefaction is a vertical deformation of the soil in the soil layer caused by the densification and compaction of granular soils that are initially loose but eventually compact due to earthquakes [5]. During the reconsolidation of the sandy land, land subsidence due to liquefaction can be observed through the volumetric strains [6].

2.3 Rocscience Settle3

Settle3 is a 3-dimensional program for the analysis of settlement, vertical consolidation, settlement under the foundation, and cut and fill of surface. Settle3 combines the simplicity of one-dimensional analysis with the power and visualization capabilities of a more advanced three-dimensional program. There are some important assumptions and limitations to be aware of when using Settle3. Settle3 calculates the three-dimensional stress due to surface load. However, pore strain and pressure are calculated in one dimension, assuming only vertical displacement can occur. It corresponds to general geotechnical engineering practices and material parameters are determined to reflect the properties of one-dimensional analysis. 3D view allows easy visualization of results in three dimensions. Soil materials can be established with different material properties to visualize differences in the results of the descent analysis corresponding to the nature of the soil material under load along the depth/elevation of the soil model [7].
The total settlement in the calculation of settlement in Settle3 is the sum of 3 components: direct settlement or initial settlement, settlement due to consolidation and secondary reduction. The immediate settlement occurs instantly at the moment when the load begins to be exerted and is considered linear elastic. The settlement resulting from consolidation occurs gradually along with the loss of pore water pressure and increased effective stress. Meanwhile, the settlement in secondary occurs only in some types of soils that experience a constant effective voltage.
In addition to analyzing the results of the settlement, Settle3 can also provide a liquefaction factor that can be calculated based on Standard Penetration Test (SPT), Cone Penetration Test (CPT), or Shear Wave Velocity (VST) data. Analysis of liquefaction in Settle3 using the Seed method (1983), NCEER (1997), Idriss & Boulanger (2004), Cetin (2004), and Japanese Bridge Code. Analysis of land subsidence in Settle3 used several methods, including Ishihara & Yoshimine (1992), Tokimatsu & Seed (1984), Shamato (1998), Wu (2003), Cetin (2009), and Pradel (2009).

3. METHOD

3.1 Calculation of The Potential of Liquefaction

The primary data collection comes from the results of boring tests to obtain N-SPT to get an overview of soil characteristics. Soil samples that were successfully taken from the boring test were taken to the laboratory to obtain soil properties. Groundwater level elevation should also be noted during field testing. As well as the collection of earthquake-related data in the form of recordings of earthquake events around the research site.
The flow of site classification to find out seismic design criteria in the form of amplification factors in buildings. In formulating the seismic design criteria of a building at ground level or determining the amplification of the magnitude of the peak earthquake acceleration from bedrock to the ground surface for a site, the site must be classified first. The soil profile is classified on a site by looking at the soil profile in the top 30 m of the layer [8].

The earthquake source used is the earthquake's source from the Northern Sulawesi Thrust by assuming the earthquake source point with the closest distance from the study site. The largest earthquake magnitude value that may occur around the study site is 8.5.
Ground Motion Prediction Equation (GMPE) or soil acceleration attenuation equation is a physical formulation used to estimate the PGA value based on earthquake source parameters. GMPE generally considers factors such as hypocenter distance, epicenter, depth, magnitude, type of earthquake, and soil site condition. GMPE is usually created empirically through regression from various existing soil acceleration measurement data. Earthquake parameters are used as inputs to calculate PGA values using existing attenuation equations (GMPE). In this study, the Kanno, 2006 [9] attenuation equation was used, which was considered the most suitable for geological and tectonic conditions at the study site with a PGA value of 0.447 g.
To calculate the potential for liquefaction, many studies have tried to analyze the potential through various calculation methods. The basis for analyzing potential liquefaction by calculating the soil safety factor (*Factor of Safety / FS*) is comparing CRR and CSR. It was on this basis that the Idriss-Boulanger Method was born [10]. The Idriss-Boulanger method bases their calculation theory on calculating PGA data (a_{max}), Earthquake Magnitude (M_w), N-SPT Value (N), σ_v (effective voltage), and soil grain size percentage (%). This calculation can obtain the soil layer at any depth with the potential for liquefaction.

3.2 Soil Settlement Prediction of Yoshimine Method (2006)

Yoshimine formulated the descent in the soil after the liquefaction by considering the shear deformations that may occur. Post-lyric reconsolidation strains were calculated using relationships derived mostly from laboratory studies. One approach commonly used today is the result of development by Ishihara and Yoshimine [6]. They observed that the volumetric strain that occurred during the reconsolidation of post-twist sand samples actions was directly related to the maximum shear strain that enlarged during undrained cyclic loading and with the initial relative density of sand.
The equations that Yoshimine [11] used to obtain the value of the land subsidence used the equations (1)-(8) below:

$$\gamma_{\lim} = 1,859\left(1,1-\sqrt{\frac{(N_1)_{60cs}}{46}}\right)^3 \geq 0 \quad (1)$$

$$F_\alpha = 0,032 + 0,69\sqrt{(N_1)_{60cs}} - 0,13(N_1)_{60cs} \quad (2)$$

$$\gamma_{\max} = 0 \qquad \text{if } FS_{liq} \geq 2 \quad (3)$$

$$\gamma_{\max} = \min\left(\gamma_{\lim}, 0,035(2-FS_{liq})\left(\frac{1-F_\alpha}{FS_{liq}-F_\alpha}\right)\right) \qquad \text{if } 2 > FS_{liq} \geq F_\alpha \quad (4)$$

$$\gamma_{\max} = \gamma_{\lim} \qquad \text{if } FS_{liq} \leq F_\alpha \quad (5)$$

$$LDI = \int_0^{z_{\max}} \gamma_{\max} \cdot dz \quad (6)$$

$$\varepsilon_v = 1,5 \cdot \exp\left(-0,369\sqrt{(N_1)_{60cs}}\right) \cdot \min(0,08; \gamma_{\max}) \quad (7)$$

ISSN 2541-223X
Volume 4 2022

$$S_{v-1D} = \int_{0}^{z_{max}} \varepsilon_v \cdot dz \quad (8)$$

Where $(N_1)_{60cs}$ is the net sand equivalent value $(N_1)_{60}$ to calculate the CRR value. $\gamma_{\lim}$ is the minimum shear strain limit. F_α is the additional parameters for the safety factor. $\gamma_{\max}$ is the maximum shear strain. z is the thickness of the layer (m). LDI is the value that represents the magnitude of the potential lateral displacement of the soil when liquefaction occurs. FS_{liq} is the soil safety factor against liquefaction. ε_v is the vertical volumetric strain against the soil (%). S_{v-1D} is a settlement of post-liquefaction soil (one-dimensional post-liquefaction reconsolidation settlement). And to classify the extent of damage due to liquefaction, use Table 1 below:

Table 1. Classification of Damage Levels Due to Liquefaction [12]

Settlement (cm)	Degree of damage Liquefaction aftermath
0-5	Very Low
5-10	Low
10-30	High
30-70	Very High

3.3 Soil Settlement Prediction Using Rocsience Settle3

Prediction of soil settlement using the Rocscience Settle3 program requires data input in the form of field test results on the soil. In this study using N-SPT data inputted with each description of soil material. The information of soil parameter data entered in the Rocscience Settle3 application can be seen in Figure 2 and Figure 3 below:

Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Material Type	Cc	Cr	OCR	e0	Fines Content (%)	D50 (mm)	Liquefaction Prone	Su A (kN/m2)	Su S	Su m
Poorly Graded Sand 1		16.2	19	Non-Linear	0.3	0.1	1	1.1	16	2	Yes	0	0.2	0.8
Silty Sand With Gravel 2		20	21.5	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Silty Sand With Gravel 3		16.3	18.6	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Silty Sand With Gravel 4		16	19.8	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Silty Sand With Gravel 5		16.4	20.2	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Poorly Graded Sand With Gravel 6		20	22	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Poorly Graded Sand With Gravel 7		20	22	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Sandy Fat Clay 8		20	20.2	-	-	-	-	-	50	2	Yes	0	0.2	0.8
Silty Sand 9		20	20.2	-	-	-	-	-	16	2	Yes	0	0.2	0.8
Clayey Sand 10		18	19.8	-	-	-	-	-	24	2	Yes	0	0.2	0.8

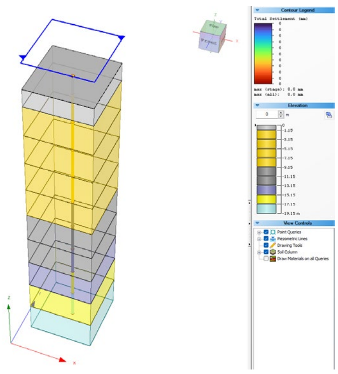

Figure 2. Soil Parameter Input in BH-MLY-01 (RS Settle3)

Material Name	Color	Unit Weight (kN/m3)	Sat. Unit Weight (kN/m3)	Fines Content (%)	D50 (mm)	Liquefaction Prone	Su A (kN/m2)	Su S	Su m
Poorly Graded Sand 1		15.2	16.6	32	2	Yes	0	0.2	0.8
Silty Sand 2		14.4	17.3	32	2	Yes	0	0.2	0.8
Silty Sand 3		15.5	18.1	32	2	Yes	0	0.2	0.8
Silty Sand 4		15.5	18.1	32	2	Yes	0	0.2	0.8
Silty Sand 5		17.4	19.4	32	2	Yes	0	0.2	0.8
Silty Sand 6		16.2	20.1	32	2	Yes	0	0.2	0.8
ANDESITE 7		20	22	0	2	Yes	0	0.2	0.8
ANDESITE 8		20	22	0	2	Yes	0	0.2	0.8
Silty Sand 9		17.3	20.8	32	2	Yes	0	0.2	0.8
Silty Sand 10		20	22	32	2	Yes	0	0.2	0.8

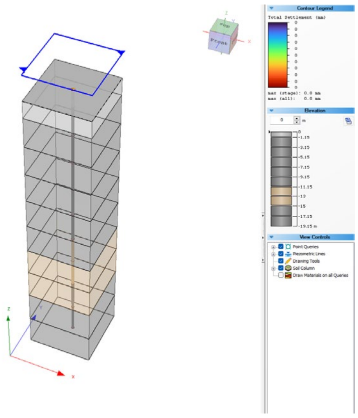

Figure 3. Soil Parameter Input in BH-MLY-05 (RS Settle3)

After inputting the soil parameters, continued with the conditioning of the liquefaction on the Liquefaction Option: Standard Penetration Test (SPT) menu. In this menu are input Peak Ground Acceleration (PGA), earthquake magnitude, and data correction methods, as well as the desired liquefaction analysis methods used in the analysis of the RS Settle3 program. The input and selection of the method used can be seen in Figure 4 below:

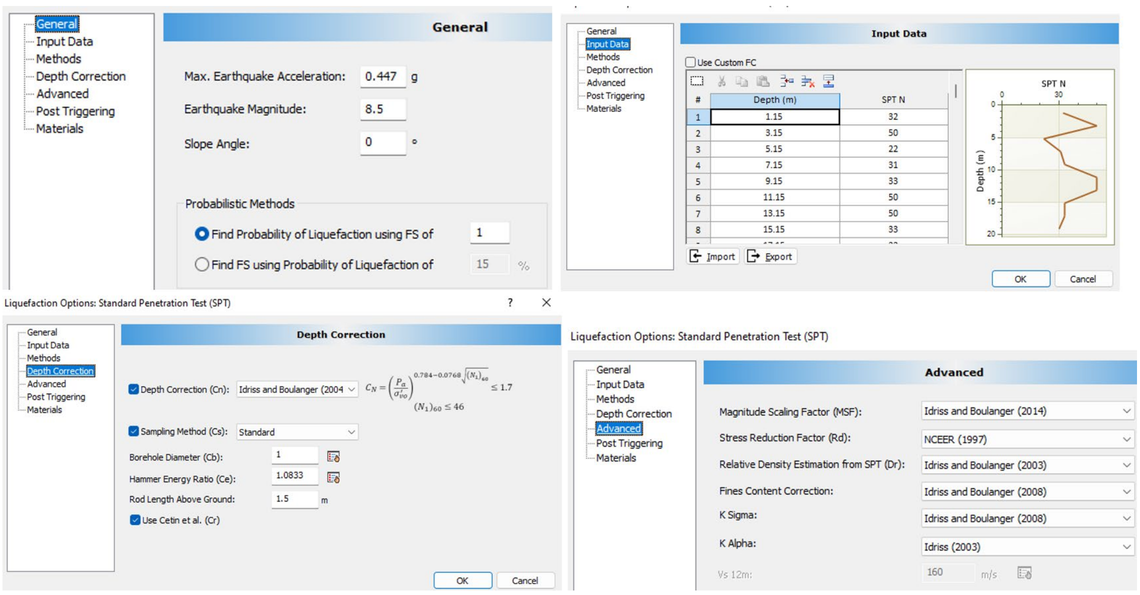

Figure 4. Input and Selection Method for Liquefaction Conditioning

4. RESULT

4.1 Result Analysis Liquefaction

The method applied to analyze the liquefaction basis in this study used the method of Idriss-Boulanger (2008). Using borehole data at points BH-MLY-01 and BH-MLY-05. Because the research location is on a coastal area, the condition of the soil studied is below sea level. The results of the analysis of the study can be seen in Table 2 below:

ISSN 2541-223X
Volume 4 2022

Table 2. Results of the Liquefaction Potential Analysis

Borehole 01

No.	USCS	SPT (m)	Blow	N_{60}	$(N_1)_{60cs}$	CSR	CRR	FS	Liquefiable
1	SP	1,15	32	26,000	47,776	0,690	1,685	2,444	Non-Liq
2	SM	3,15	50	46,042	63,605	0,611	1,685	2,760	Non-Liq
3	SM	5,15	22	22,642	33,327	0,698	0,677	0,971	Liquefiable
4	SM	7,15	31	31,904	39,070	0,650	1,685	2,595	Non-Liq
5	SM	9,15	33	35,750	39,943	0,629	1,558	2,479	Non-Liq
6	SP	11,15	50	54,167	53,672	0,578	1,398	2,420	Non-Liq
7	SP	13,15	50	54,167	51,544	0,570	1,323	2,321	Non-Liq
8	CH	15,15	33	35,750	n.a.	0,604	n.a.	#VALUE!	Non-Liq
9	SM	17,15	33	35,750	32,968	0,594	0,501	0,843	Liquefiable
10	SC	19,15	30	32,500	n.a.	0,595	n.a.	#VALUE!	Non-Liq

Borehole 05

Name	USCS	SPT (m)	Blow	N_{60}	$(N_1)_{60cs}$	CSR	CRR	FS	Liquefiable
1	SP	1,15	8	6,500	16,483	0,816	0,143	0,175	Liquefiable
2	SM	3,15	13	11,971	25,783	0,768	0,261	0,340	Liquefiable
3	SM	5,15	18	18,525	30,665	0,720	0,446	0,620	Liquefiable
4	SM	7,15	18	18,525	28,083	0,714	0,326	0,456	Liquefiable
5	SM	9,15	27	29,250	36,015	0,654	1,100	1,681	Non-Liq
6	SM	11,2	32	34,667	38,775	0,625	1,475	2,358	Non-Liq
7	ANDESITE	13	50	54,167	48,113	0,571	1,329	2,328	Non-Liq
8	ANDESITE	15	50	54,167	46,335	0,562	1,264	2,248	Non-Liq
9	SM	17,2	37	40,083	38,615	0,580	1,251	2,158	Non-Liq
10	SM	19,2	50	54,167	48,936	0,542	1,153	2,127	Non-Liq

From the results of the analysis, it can be seen that the locations of Borehole 01 and 05 have the liquefaction potential. The potential for liquefaction in each borehole is in a different layer. For Borehole 01, visible glycation can occur in layers of 3.15-5.15 m and in layers of 15.15-17.15 m. As for Borehole 05, the incidence of liquefaction allows it to appear at a layer of 0-7.15 m.

4.2 Settlement Analysis Result Using Yoshimine Method (2006)

BH-MLY-01

Table 3. Settlement Analysis Results in BH-MLY-01 by Yoshimine Method (2006)

No.	Depth (m)	z (m)	FS	$(N_1)_{60cs}$	γ_{lim}	Fa	γ_{max}	LDI_i (m)	ε_v (%)	S (cm)	Σ	S from Above (cm)
1	1,15	1,15	2,44	47,78	0,001	-1,410	0,000	0,000	0,000	0,000	0,000	2,112
2	3,15	2,00	2,76	63,60	0,000	-2,734	0,000	0,000	0,000	0,000	0,000	2,112
3	5,15	2,00	0,97	33,33	0,029	-0,317	0,029	0,057	0,005	1,021	1,021	2,112
4	7,15	2,00	2,59	39,07	0,011	-0,734	0,000	0,000	0,000	0,000	1,021	1,091
5	9,15	2,00	2,48	39,94	0,009	-0,800	0,000	0,000	0,000	0,000	1,021	1,091
6	11,15	2,00	2,42	53,67	0,000	-1,890	0,000	0,000	0,000	0,000	1,021	1,091
7	13,15	2,00	2,32	51,54	0,000	-1,715	0,000	0,000	0,000	0,000	1,021	1,091
8	15,15	2,00	#VALUE!	n.a.	#VALUE!	0,948	0,000	0,000	0,000	0,000	1,021	1,091
9	17,15	2,00	0,84	32,97	0,030	-0,292	0,030	0,061	0,005	1,091	2,112	1,091
10	19,15	2,00	#VALUE!	n.a.	#VALUE!	0,948	0,000	0,000	0,000	0,000	2,112	0,000

BH-MLY-05

Table 4. Settlement Analysis Results in BH-MLY-05 by Yoshimine Method (2006)

No.	Depth (m)	z (m)	FS	$(N_1)_{60cs}$	γ_{lim}	Fa	γ_{max}	LDI_i (m)	ε_v (%)	S (cm)	Σ	S from Above (cm)
1	1,15	1,15	0,17	16,48	0,234	0,691	0,234	0,269	0,027	3,085	3,085	11,222
2	3,15	2,00	0,34	25,78	0,081	0,184	0,081	0,161	0,018	3,685	6,770	8,137
3	5,15	2,00	0,62	30,67	0,042	-0,134	0,042	0,085	0,008	1,647	8,418	4,452
4	7,15	2,00	0,46	28,08	0,060	0,038	0,060	0,120	0,013	2,553	10,971	2,805
5	9,15	2,00	1,68	36,01	0,019	-0,509	0,008	0,015	0,001	0,252	11,222	0,252
6	11,15	2,00	2,36	38,78	0,011	-0,712	0,000	0,000	0,000	0,000	11,222	0,000
7	13,00	1,85	2,33	48,11	0,001	-1,437	0,000	0,000	0,000	0,000	11,222	0,000
8	15,00	2,00	2,25	46,33	0,002	-1,295	0,000	0,000	0,000	0,000	11,222	0,000
9	17,15	2,15	2,16	38,61	0,012	-0,700	0,000	0,000	0,000	0,000	11,222	0,000
10	19,15	2,00	2,13	48,94	0,001	-1,503	0,000	0,000	0,000	0,000	11,222	0,000

ISSN 2541-223X
Volume 4 2022

Table 3 and Table 4 show that the liquefaction causes the occurrence of soil settlement, and that settlement will be calculated from each layer there is a settlement. Table 4 shows that the settlement occurring in BH-MLY-01 can cause a **Very Low** damage level, while Table 5 shows that the settlement that happened in BH-MLY-05 can cause a **High** damage level.

4.3 Settlement Analysis Result Using Rocscience Settle3

From the results of the running effect of the liquefaction in the Rocscience Settle3 program, the calculation results have been obtained, which have been recapitulated in Table 6 and Table 7 below:

Table 5. Recap of Settlement Analysis Results Using RS Settle3 at BH-MLY-01

BH-MLY-01						
Elevation (m)	Settlement (cm)					
	Ishihara & Yoshimine (1992)	Tokimatsu & Seed (1984)	Shamato (1998)	Wu (2003)	Cetin (2009)	Pradel (2009)
-1,15	0,795	0	2	0	1,293	0
-3,15	0,795	0	2	0	1,293	0
-5,15	0	0	0	0	0	0
-7,15	0	0	0	0	0	0
-9,15	0	0	0	0	0	0
-11,15	0	0	0	0	0	0
-13,15	0	0	0	0	0	0
-15,15	0	0	0	0	0	0
-17,15	0	0	0	0	0	0
-19,15	0	0	0	0	0	0

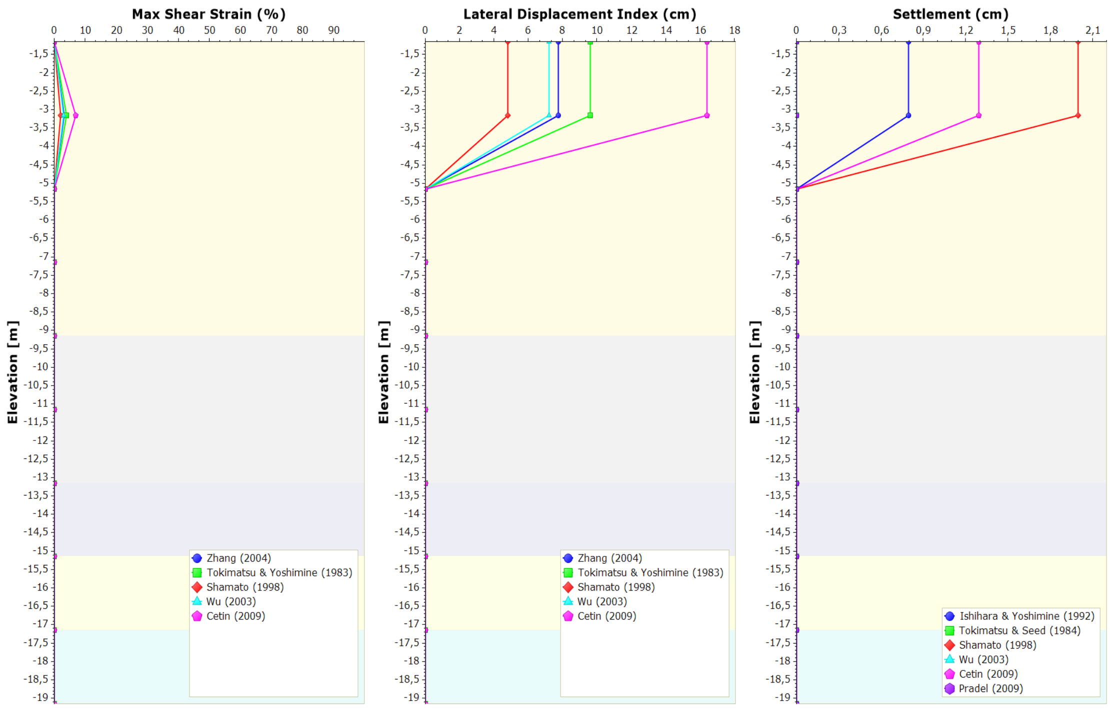

Figure 5. The Comparison of BH-MLY-01 Soil Settlement of Each Method

With the RS Settle3 program, a settlement was seen at the borehole point BH-MLY-01 occurring in layers 0 to -3.15 meters. The settlement occurred by 0.795 cm with the Ishihara & Yoshimine Method (1992), a settlement of 1.293 cm in the Cetin Method (2009), and a settlement of 2 cm with the Shamato Method (1998). The Tokimatsu & Seed Method (1984), Wu method (2003), and Pradel method (2009) showed the settlement didn't happen at the site. Based on Table 2, settlement of soil with this value belong to the classification of **Low** damage levels.

Table 6. Recap of Settlement Analysis Results Using RS Settle3 at BH-MLY-05

BH-MLY-05						
	Settlement (cm)					
	Ishihara & Yoshimine (1992)	Tokimatsu & Seed (1984)	Shamato (1998)	Wu (2003)	Cetin (2009)	Pradel (2009)
-1,15	9,454	6,398	11,588	9,787	7,772	0
-3,15	3,548	2,404	3,059	3,513	2,751	0
-5,15	0	0	0	0	0	0
-7,15	0	0	0	0	0	0
-9,15	0	0	0	0	0	0
-11,15	0	0	0	0	0	0
-13	0	0	0	0	0	0
-15	0	0	0	0	0	0
-17,15	0	0	0	0	0	0
-19,15	0	0	0	0	0	0

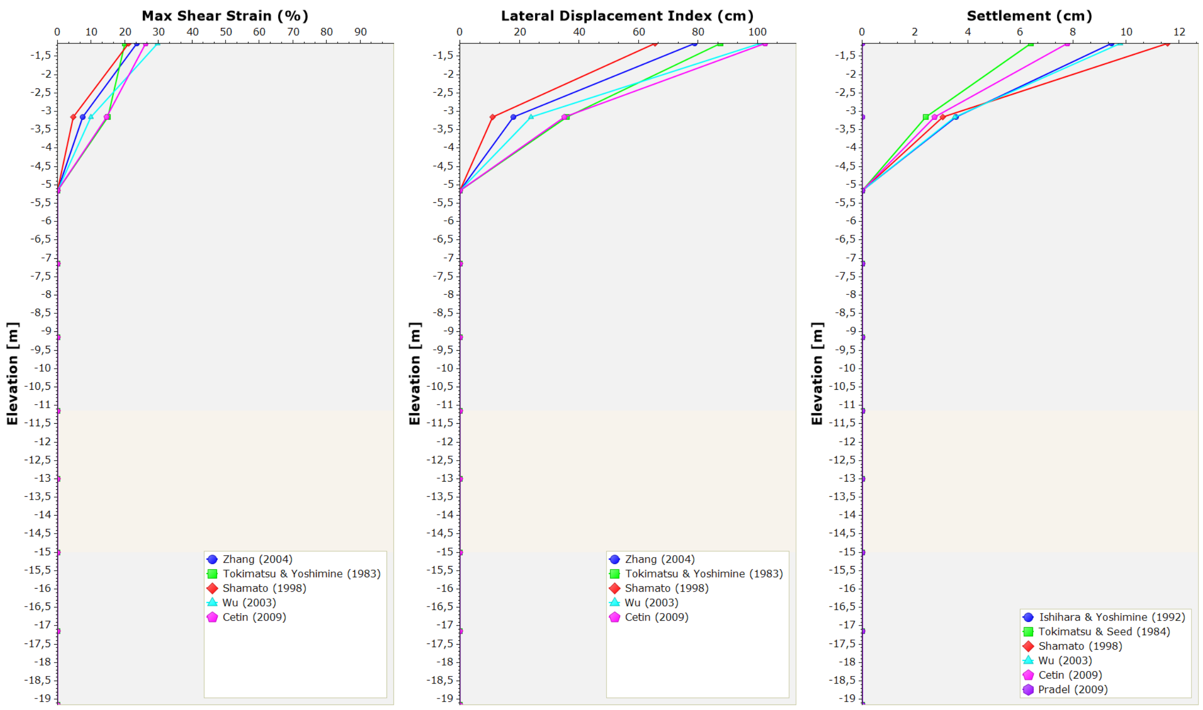

Figure 6. The Comparison of BH-MLY-05 Soil Settlement of Each Method

With the RS Settle3 program, a settlement was seen at the borehole point of BH-MLY-05 occurring in layers 0 to -3.15 meters. The implicated settlement can occur using almost all of the methods used, only the Pradel Method (2009) which does not indicate any settlement. The most significant settlement can be seen from the analysis using the

Shamato Method (1998) of 11,588 cm and the smallest settlement can be seen from the analysis using the Tokimatsu & Seed Method (1984) of 6,398 cm. Based on this analysis, it can be seen that the average settlement at this location belong to the classification of damage among **Low** to **High** level.

5. COCLUSION

The settlement of soil can result from liquefaction. Soil settlement due to liquefaction is a vertical deformation of soil in the soil layer caused by soil compaction, which is initially loose but eventually solidifies due to the effect of the earthquake. Soil settlement occurs in the upper layers of the soil surface. Based on the two methods used, the BH-MLY-01 point has a very low damage level classification as seen from a settlement of 2,112 cm with the Yoshimine Method (2008) and a settlement in the largest worth 1,293 cm of the RS Settle3 Method. While point BH-MLY-05, it produces a classification of high damage levels seen from a settlement of 11,222 cm with the Yoshimine Method (2008) and the largest settlement of 11,588 cm from RS Settle3 Method. The high settlement in BH-MLY-05 needs to handle because it is belong to high damage level. Further analysis is needed to know what actions or efforts can reduce the level of soil settlement so that damage can be avoided.

6. REFERENCES

PT. SOILENS 2021 Laporan Penyelidikan Tanah untuk Proyek Kawasan Pantai Malalayang dan Penataan Ecotourism Village Bunaken Sulawesi Utara Indonesia, PT. SOILENS

Towhata I 2008 Geotechnical Earthquake Engineering. (1st Edition), *Springer Science & Business Media*, Berlin

Hermansyah D 2018 SETTLEMENT (PENURUNAN) (Rangkaian dan pembahasan serta penjelasan tentang settlement). Yogyakarta

Whittaker D N and Reddish D J 1989 Subsidence Occurence, Prediction and Control, *DME Univ of Notthingham*, Elsiver, New York, p 359-376

Zhang G, Robertson P K and Brachman R W I 2002 Estimation Liquefaction Induced Ground Settlement from CPT for Level Ground. *Canadian Geotechnical Journal*, **39**, pp.1168-11680.

Ishihara K and Yoshimine M 1992 Evaluation of settlements in sand deposits following liquefaction during earthquakes, *Soils Found*, 32(1), 173-188

Rocscience Inc Team 2022 Settle3 User Guide: Settlement and consolidation analysis Theory Manual, 2007-2022 Rocscience Inc

SNI 1726:2019 2019 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Nongedung. Jakarta: Badan Standardisasi Indonesia.

Kanno T, Narita A, Morikawa N, Fujiwara H, and Fukushima Y 2006 A new attenuation relation for strong ground motion in Japan based on recorded data. *Bulletin of the Seismological Society of America*, 96(3), 879-897.

Idriss I M and Boulanger R W 2008 Soil Liquefaction during Earthquake. *EERI Publication, Monograph MNO-12*, Earthquake Engineering Research Institute, Oakland

Yoshimine M, Nishizaki H, Amano K, and Hosono Y 2006 Flow deformation of liquefied sand under constant shear load and its application to analysis of flow slide in infinite slope, *Soil Dynamics and Earthquake Eng.* **26**, 253–264

Barlett S F, Gerber A P, and Hinckley D 2007 Probabilistic Liquefaction Potential and Liquefaction Induced Ground Failure Map for The Urban Wasatch Front. *Collaborative Research*. USA: Universitas of Utah and Bringham Young University