SETTLEMENT OF GEOSYNTHETIC ENCASED STONE COLUMNS LIQUEFACTION CONDITION IN BOX CULVERT

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Abstract. When the box culvert system is placed on a sandy soil layer with a relatively low bearing capacity and is disposed to potential liquefaction, the soil layer must be repaired to avoid damages to the box culvert structure. The proposed method is Geosynthetic Encased Stone Columns (GESC) to increase the bearing capacity and anticipated the liquefaction potential. however, to meet the criteria for a stable and safe GESC soil improvement in liquefaction conditions, the value of the settlement must meet the requirements for the settlement permit limit. This research was conducted to determine the potential for liquefaction at the study location, to calculate the value of single and group settlements in liquefaction conditions and to analyze the stability of single and group settlements including safe or unsafe in liquefaction conditions. Analysis of liquefaction potential was analyzed based on SPT data using the Valera and Donovan method, and settlement analysis applied the Almeida and Alexiew method. The analysis shows that potential liquefaction due to an earthquake with a magnitude of 9.0 SR will be at a depth of 4 to 8 m. Single and group settlements (144 sets) with an installation distance of 1.2 m with a diameter of 0.4 m and at a depth of 10 m are 246.23 and 214.92 mm, respectively. The entire GESC system is considered to be in an unstable and unsafe condition against potential liquefaction and box culvert loading.

1. INTRODUCTION

Box culvert structure is a water drainage that is placed on land with loose or sandy soil layers that have low soil bearing capacity and are susceptible to liquefaction potential [1], [2]. This can be dangerous the box culvert structure. Thus, it is necessary to improve the soil layer. The method proposed in soil improvement, namely Geosynthetic Encased Stone Column (GESC), functions to increase soil bearing capacity, reduce liquefaction that occurs as gravel drainage in air-saturated sand soils, reduce pore water pressure [3]–[6]. Geosynthetic Encased Stone Column can also be used to strengthen road embankment stability and peat soil layer strengthening [7], [8].

However, to meet the criteria for stable and safe soil improvement, the value of the settlement in the Geosynthetic Encased Stone Column (GESC) as a subgrade improvement in the box culvert structure must meet the requirements for a settlement permit limit of 25.4 mm. settlement beyond the permit limit can result in damage to the box culvert structure [9], [10].

Geosynthetic Encased Stone Columns settlement in sandy or loose soil layers was calculated using the Almeida and Alexiew method with using the principles of the Raithel and Kempfert models. where this model assumes a constant column volume subject to uniform lateral deformation over the entire column, and lateral stress from the surrounding soil assuming the ground pressure at rest [7], [11]–[13]. settlement of the geosynthetic encased stone column in sandy soil or loose sand is calculated using the Almeida and Alexiew method shown in Eq. (1) with parameters and E * or modified modulus in Eq. (2) and (3) [14].

$$\left\{ \frac{\Delta\sigma_{v,s}}{E_{oed,s}} - \frac{2}{E^*} \cdot \frac{vs}{1-vs} \left[K_{a,c} \cdot \left(\frac{\Delta\sigma_v}{a_E} - \frac{1-a_E}{a_E} \cdot \Delta\sigma_{v,s} + \Delta\sigma_{v,o,c} \right) - K_{0,S}^* \cdot \Delta\sigma_{v,s} - K_{0,s} \cdot \Delta\sigma_{v,o,s} + \frac{J(r_{geo}-r_c)}{r_{geo}^2} - \frac{J.\Delta r_c}{r_{geo}^2} \right] \right\} \quad (1)$$

$$\Delta r_c = \frac{\Delta\sigma_{h,diff}}{E^*} \cdot \left(\frac{1}{a_E} - 1 \right) \cdot r_c \qquad (2)$$

$$E^* = \left(\frac{1}{1-vs} + \frac{1}{1+vs} \cdot \frac{1}{a_E} \right) \cdot \frac{(1+v_s)-(1-2v_s)}{(1-vs)} \cdot E_{oed,s} \qquad (3)$$

Then in reviewing the dangers and analysis of the potential for liquefaction, the method used by Valera and Donovan aims to find the critical value of SPT or Ncrit as a determination of liquefaction or non-liquefaction conditions with the following Eq. (4) [15]–[17].

$$N_{crit} = \eta[1 + 0,125(ds - 3) - 0,05(dw - 2) \qquad (4)$$

Where N_{crit} is the critical value of N-SPT, d_s is the depth of the sand layer being reviewed, then d_w is the depth of the groundwater level from the ground surface then the value η is a function of the vibration intensity due to tectonic earthquakes. The MMI scale is determined based on the damage to buildings and things felt by humans due to the earthquake.

When liquefaction, the frictional strength of the clay layer only receives 30 percent of the total overburden stress, meaning that the frictional resistance is corrected up to 30 percent [18], [19]. In this study, it is determined that the resistance of friction is corrected by 30-50% of phenomena due to liquefaction that can affect the value settlement of Geosynthetic Encased Stone Columns in single or group settlement.

The purpose of this study was to see the potential for liquefaction in the sewer box review area using the Valera and Donovan method based on standard penetration test (SPT) data. then to calculate the settlement of single and group Geosynthetic Encased Stone Columns in liquefaction conditions based on the results of potential analysis liquefaction method of Valera and Donovan. and for analysis stability the settlement of Geosynthetic Encased Stone Columns in single and group against box culvert loading.

2. METHODS

In this study, the box culvert planning located at STA 127 + 100 Trans Sumatra Toll Road Kisaran-Tebing Tinggi section Indrapura-Kisaran with a sandy soil layer that has a relatively low bearing capacity and is in an area with a high potential for earthquakes and the potential for liquefaction shown in Figure 1. In this case, the Geosynthetic Encased Stone Columns was provided as soil improvement at the STA 127 + 100 box culvert location.

Figure 1. Trans Sumatra Toll Road Kisaran - Tebing Tinggi section Indrapura - Kisaran

2.1 Design Data

The data used in this study are secondary data from the results of field investigations standard penetration test (SPT) point BH-01 STA 127 +100 and laboratory testing by PT. Cipta Indah Citra and PT. PP also USU soil mechanics laboratory are shown in Table 1 and Figure 2. and other data in the form of box culvert dimensions, road cross-sections shown in figure 3.

Table 1. Resume of Laboratory Testing Results

FORM SUMMARY OF TESTS

Project : Rencana Akhir (DED) Jalan Tol Indrapura - Kisaran
Location : Indrapura - Kisaran

| Location	Sample no.	Sample Type	Depth	Depth	Water Content	Unit Weight	Dry Density	Specific Gravity	Saturability	Void Ratio
			(m)	(m)	W_n (%)	γ_n (gr/cm³)	γ_n (gr/cm³)	G_s (gr/cm³)	S_r (%)	e -
Sta. 122+525	BH-19	UDS	3.50-4.00	4	32,75	1,682	1,267	2,59	81	1,049
Sta. 122+525	BH-19	UDS	5.50-6.00	6	35,79	1,854	1,365	2,69	98,95	0,976
Sta. 122+525	BH-19	DS	13.50-14.00	14	30,62	1,923	1,472	2,71	98,49	0,844
Sta. 122+525	BH-19	DS	19.50-20.00	20	26,83	1,947	1,535	2,69	95,52	0,758
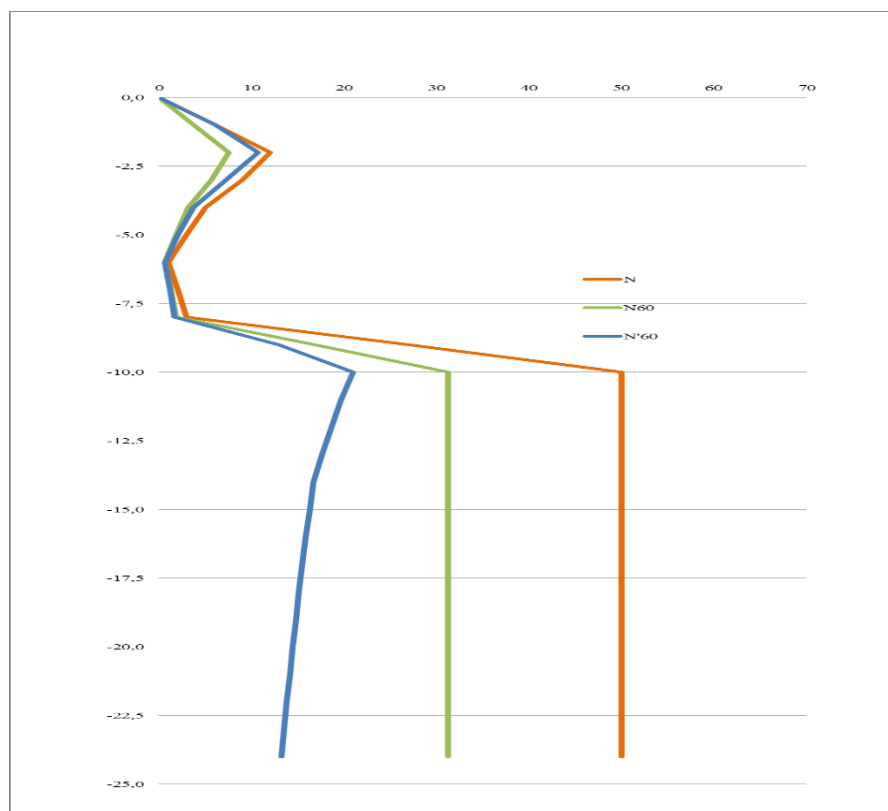
Figure 2. N-SPT BH-01

As an preliminary design planning for the box culvert design, dimensions of 1.5 x 1.5 are used with a length of 86 m according to the cross section of the road STA 127+100 shown in figure 3. Then in the initial design Geosynthetic Encased Stone Columns using a diameter of 0.4 m and 3D distance or 1.2 m with a length of 10 m using Ringtrac 6500 PM geosynthetic tubular protective material with a diameter of 0.4 m shown in figure 4.and then stone material with specifications γs is 2.2 t/m², φ is 34˚, C or cohesion is 0 t / m² [7], [20].
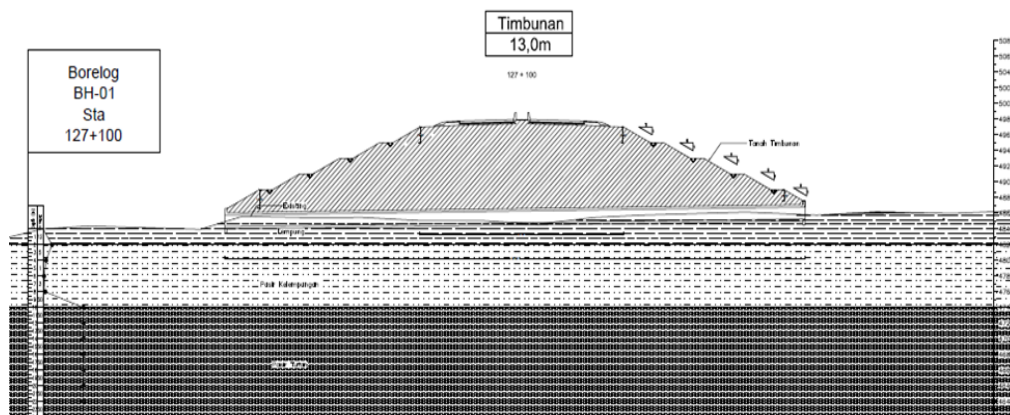
Figure 3. Cross Section STA 127+100 Trans Sumatra Toll Road Kisaran - Tebing Tinggi Section
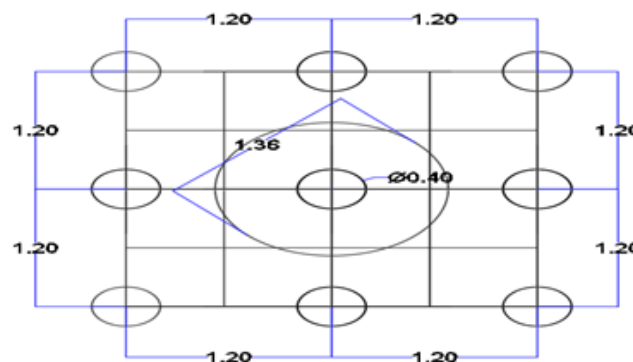Indrapura – Kisaran

Figure 4. Visualization of The Unit Cell Concept

Research in this study includes several stages, including preliminary design, calculation of loading, soil cohesion analysis and correction of N on N-SPT, etc. there are several stages in this research that must be carried out in data analysis.

1. Calculating the load on the box culvert using references to SNI 1725: 2016 and SNI 1726: 2019 [21], [22]. Calculated based on the dimension data of the box culvert and the cross section of the road.
2. Perform axial, transverse and moment force analysis on the calculation results of the box culvert loading using SAP 2000 software.
3. Calculate soil cohesion along the soil layer depth and make corrections to the N value using standard penetration test (SPT) data
4. Performing critical Ncrit or N calculations along the depth of the soil layer based on standard penetration test data and determining the soil condition for potential liquefaction or non-liquefaction based on the Valera and Donovan liquefaction potential analysis method.
5. Calculating and determining the geosynthetic encased stone column design parameters in liquefied soil conditions, namely the corrected soil cohesion in the soil layer that occurs liquefaction based on the results of the analysis of the potential liquefaction of the Valera and Donovan method and several other parameters such as void ratio, soil weight, active soil pressure coefficient and passive, lateral rest pressure coefficient based on Broker and Ireland also Jaky, Poisson ratio, modulus of soil elasticity based on Webb [23].
6. Planning a geometric pattern of the distance and diameter of the geosynthetic encased stone column based

on the Raithel and Kempfert models.

7. Calculating column and soil stress, vertical stress on the column and, also calculate horizontal stress on the column and the surrounding soil based on the Raithel and Kempfert method.

8. Calculating the geotextile requirement using the Ringtrac 6500 PM to produce the horizontal geotextile stress and the total horizontal soil stress based on the Raithel and Kempfert methods

9. Perform geosynthetic settlement calculations for single and group encased stone columns using the Almeida and Alexiew method [14].

10. Analyze settlement stability of single and group Geosynthetic Encased Stone Columns.

11. Conducting final conclusions on single and group settlement of Geosynthetic Encased Stone Columns under liquefaction conditions based on the analysis of liquefaction potential using the Valera and Donovan method .

3. RESULTS AND DISCUSSION
3.1 Calculation of box culvert loading

Calculation of box culvert loading using SNI 1725: 2016 and 1726: 2019 and loading analysis using SAP 2000 [21], [22]. The following are the results shown in Table 2.

Table 2. Result of Calculation and Analysis of Box Culvert Loading

Data	Nilai	Satuan
Pv	4330,66	ton
Mx	0	ton-cm
My	27979,77	ton-cm
Mx(Gempa)	20597,17	ton-cm
My(Gempa)	39250,31	ton-cm
Mx total	20597,17	ton-cm
My total	67230,08	ton-cm
H	30	cm
Berat Isi	2.4	t/m3
Wpile-cap Grup 144	123,84	ton
Σ(tiang) (n)	144	buah
Ptotal/n	30,93	ton
My . x	4033805	ton-cm . cm
Σx2	518400	cm2
My . x/Σx2	7,781	ton
Mx . y	1235830	ton-cm . cm
Σy2	518400	cm2
Mx . y/Σy2	2,384	ton
Pmaks	41,1	ton

3.2 Soil Cohesion Analysis

Secondary data obtained were processed by data processing in the form of soil cohesion analysis and N correction on the N-SPT data. The results are shown in Table 3.

Table 3. Result of Calculation and Analysis of Soil Cohesion

STANDARD PENETRATION TEST

Project	: Pondasi Box Culvert		Date	
Test No.	: BH-01 (STA 127+100)		Tested by	:
Site name	: Jalan Tol Indrapura - Kisaran		Weather	: Fine
Location	: Kabupaten Batubara, Sumatera Utar		GWL	: -14,0 m

PERHITUNGAN DATA SPT

Depth	N	Parameter-parameter koreksi peralatan dan lokasi					Cu	Cu	γ_m	σ_v'	σ_r	Perbandingan	Koreksi	N'$_{60}$	Lapisan tanah
		E_m	C_B	C_S	C_R	N$_{60}$	(t/m2)	(kPa)	(t/m³)	(t/m²)	(t/m²)	(σ_v'/σ_r)	(C$_N$)		
(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)
0,00	0	0,5	1,0	1,0	0,75	0,00	0,00	0	1,58	0,00	10	0,00	1,83	0,00	
-1,00	6	0,5	1,0	1,0	0,75	3,75	3,60	35	1,64	1,64	10	0,16	1,61	6,05	Lempung
-2,00	12	0,5	1,0	1,0	0,75	7,50	7,20	71	1,70	3,40	10	0,34	1,43	10,71	
-3,00	9	0,5	1,0	1,0	0,75	5,63	5,40	53	1,670	5,01	10	0,50	1,29	7,28	
-4,00	5	0,5	1,0	1,0	0,75	3,13	3,00	29	1,630	6,52	10	0,65	1,19	3,71	
-5,00	3	0,5	1,0	1,0	0,75	1,88	1,80	18	1,610	8,05	10	0,81	1,10	2,06	
-6,00	1	0,5	1,0	1,0	0,75	0,63	0,60	6	1,590	9,54	10	0,95	1,02	0,64	Pasir Kelempungan
-7,00	2	0,5	1,0	1,0	0,75	1,25	1,20	12	1,600	11,20	10	1,02	0,95	1,19	
-8,00	3	0,5	1,0	1,0	0,75	1,88	1,80	18	1,610	12,88	10	1,07	0,88	1,66	
-9,00	27	0,5	1,0	1,0	0,75	16,88	16,20	159	1,850	16,65	10	1,28	0,77	12,96	
-10,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	20,80	10	1,49	0,67	20,96	
-11,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	22,88	10	1,53	0,63	19,71	
-12,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	24,96	10	1,56	0,60	18,60	
-13,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	27,04	10	1,59	0,56	17,61	
-14,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	29,12	10	1,62	0,54	16,72	
-15,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	30,20	10	2,01	0,52	16,29	
-16,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	31,28	10	1,96	0,51	15,88	
-17,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	32,36	10	1,90	0,50	15,50	
-18,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	33,44	10	1,86	0,48	15,13	Pasir Tufan
-19,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	34,52	10	1,82	0,47	14,78	
-20,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	35,60	10	1,78	0,46	14,44	
-21,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	36,68	10	1,75	0,45	14,12	
-22,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	37,76	10	1,72	0,44	13,82	
-23,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	38,84	10	1,69	0,43	13,52	
-24,00	50	0,5	1,0	1,0	0,75	31,25	30,00	294	2,080	39,92	10	1,66	0,42	13,24	

3.3 Analysis of the Liquefaction Potential of the Valera and Donovan method

In the analysis of the liquefaction potential of the Valera and Donovan method, the largest earthquake data in the last 100 years was used, namely the Aceh earthquake in 2004, the magnitude of the earthquake was 9.0 SR including the maximum intensity on the MMI level IX scale [24]. The value of η with MMI level IX was obtained values of 16 blows/feet [15]–[17].

then based on SPT data that the depth of the groundwater level is 14 m, then the N_{crit} calculation can be done according to the depth of the soil. From several N_{crit} calculations, it can be compared between N and N_{crit} at a depth of 0-24 m at the test point BH-01 STA 127 +100.

If $N > N_{crit}$, which means that there is no liquefaction in the existing depth with a 9.0 SR earthquake, then if the results are $N < N_{crit}$, which means the soil is in the existing depth of liquefaction with a 9.0 SR earthquake, the results of the analysis and calculation of the potential liquefaction of the Valera and Donovan method can be seen in Table 4.

Table 4. N_{crit} Calculation and Evaluation Results at STA 127 + 100 Valera and Donovan Method

No	STA	MAT	Depth (m)	N (blow/ft)	Ncrit(blow/ft)	Evaluation
			0	0	0	No Liquefaction
			1	6	2,4	No Liquefaction
			2	12	4,4	No Liquefaction
			3	9	6,4	No Liquefaction
			4	5	8,4	Liquefaction
			5	3	10,4	Liquefaction
			6	1	12,4	Liquefaction
			7	2	14,4	Liquefaction
			8	3	16,4	Liquefaction
			9	27	18,4	No Liquefaction
			10	50	20,4	No Liquefaction
			11	50	22,4	No Liquefaction
1	127+100	14	12	50	24,4	No Liquefaction
			13	50	26,4	No Liquefaction
			14	50	28,4	No Liquefaction
			15	50	30,4	No Liquefaction
			16	50	32,4	No Liquefaction
			17	50	34,4	No Liquefaction
			18	50	36,4	No Liquefaction
			19	50	38,4	No Liquefaction
			20	50	40,4	No Liquefaction
			21	50	42,4	No Liquefaction
			22	50	44,4	No Liquefaction
			23	50	46,4	No Liquefaction
			24	50	48,4	No Liquefaction

Table 4 shows the results at a depth of 4-8 m, there will be liquefaction, so that the area is safe at a depth of more than 8 m.

3.4 Settlement Geosynthetic Encased Stone Column
Design Parameters

The GESC design parameters are determined in liquefaction conditions at a depth of 4-8 m based on the analysis of the liquefaction potential of the Valera and Donovan method, namely the value of FS or in this case the corrected cohesion of 30% at a depth of 0 to 8 m. and corrected 50% at a depth of 9 to 24 m is shown in Table 5.

Table 5. Design Parameters Geosynthetic Encased Stone Columns

Depth (m)	e0	Cu (t/m2)	φ (°)	γt (t/m3)	γsat (t/m3)	vs	kos	E (t/m²)	Eoed,s t/m2	kac	kpc
0-2	1.05	1.62	25	1.682		0.4	0.69	2039	432	0.2827	3.537
2-10	0.98	3.40	25	1.854		0.3	0.58	1245	1417	0.2827	3.537
10-14	0.76	15	40	1.947		0.3	0.36	3175	6037	0.2827	3.537
14-24	0.76	15	40		1.966	0.3	0.36	3175	6037	0.2827	3.537

Geometric Plan Geosynthetic Encased Stone Columns

Diameter GESC is 0.4 m with a distance of 1.2 m with a rectangular pattern. then calculate several parameters including calculated area of the column (Ac) see in Eq. (5).

$$Ac = \frac{\pi}{4}.D^2 = 0.13 \tag{5}$$

Diameter unit cell area refer to Eq. (6) and Unit Cell Area (Ae) refer to Eq. (7)

$$De = 1.13.S = 1.13 \times 1.2 = 1.36 \, m \tag{6}$$
$$Ae = \frac{\pi}{4}.D^2 \quad = 0.13 \tag{7}$$

Area replacement ratio stone column refer to Eq. (8)
$$\alpha c = \frac{A_c}{A_e} = 0.09 \tag{8}$$
Area replacement ratio of the surrounding soil refer to Eq. (9)
$$\alpha s = 1 - \alpha c = 0.91 \tag{9}$$

Stress Ratio on column refer to Eq. (10).
$$qc = \frac{n}{1+(n-1)\propto c} = \frac{5}{1+(5-1)0.09} = 3.71 \tag{10}$$

Stress Ratio on Soil refer to Eq. (11).
$$qc = \frac{n}{1+(n-1)\propto c} = \frac{1}{1+(5-1)0.91} = 0.21 \tag{11}$$

Calculation of vertical and horizontal stress Column and Soil
Vertical Stress
Calculation of the stress received by the stone column and surrounding soil is calculated by multiplying the stress due to the box culvert load by the stress ratio. For vertical stress on column refer to Eq. (12).

$$\sigma_{vc} = q_o.q_c = 41.1 \times 3.71 = 152.44 \, ^t/_{m^2} \tag{12}$$

And vertical stress on soil refer to Eq. (13).

$$\sigma_{vs} = q_o.q_s = 41.1 \times 0.21 = 8.84 \, ^t/_{m^2} \tag{13}$$

After that, the calculation of the vertical stress on the soil and stone column per soil layer is shown in Table 6. due to loading on the box culvert structure produces horizontal pressure. And The summary of the horizontal stresses from the column (σhc) and the horizontal stresses from the surrounding soil (σhs) is shown in Table 7 and 8.

Table 6. Summary of The Calculation of Vertical Stress In The Surrounding Soil and Stone Column

				Surrounding soil					Stone Column	
Depth Column (m)	h (m)	γt (t/m3)	γsat (t/m3)	Vertical Stress (σ'v,o,s) - t/m² Layer 1	Layer 2	Σσ'v,o,s (t/m²) Per Layer	Depth Column (m)	h (m)	γc (t/m3)	Vertical Stress
0-2	2	1.682		1.68		1.68	0-2	2	2.2	4.4
2-10	8	1.854		13.46	7.42	20.87	2-10	8	2.2	17.6

Table 7. Summary of The Calculation of Horizontal Stress In The Surrounding Soil

			Surrounding Soil					
Depth Column (m)	h (m)	Kos	Vertical Stress (σ'v,o,s) - t/m² Layer 1	Layer 2	Σσ'v,o,s (t/m²) Per Layer	σro'=Σσ'v,o,s x Kos (t/m2)	σvs x Kos (t/m2)	σhs (t/m2)
0-2	2	0.69	1.68		1.68	1.16	6.11	7.27
2-10	8	0.58	13.46	7.42	20.87	12.04	5.10	17.14

Table 8. Summary of the calculation of horizontal stress in stone column

			Stone Column			
Depth Column (m)	h (m)	Kac	Vertical Stress (σ'v,o,c) t/m²	(σ'v,o,c) x Kac (t/m²)	(σvc) x Kac (t/m²)	σh,c (t/m²)
0-2	2	0.2827	4.40	1.244	43.09	44.34
2-10	8	0.2827	17.60	4.976		48.07

Horizontal stress calculation after encased is installed

From Table 7 and 8, it can be seen that the soil is not able to withstand the horizontal stress from the column because $(\sigma h_c > \sigma h_s)$ it requires a geotextile. calculation of σh_{geo} with the Ringtrac 6500 PM high modular low creep geotextile encased material refer to Eq. (14)-(15).

$$\Delta Fr = J \times \frac{\Delta r}{r_{geo}} = 650 \times \frac{0,009}{0,4} = 28.29 \; {}^t/_{m^2} \tag{14}$$

$$\sigma h_{geo} = \frac{r}{r_{geo}} = \frac{28,29}{0,2} = 141.40 \; {}^t/_{m^2} \tag{15}$$

After obtaining the horizontal stress that the geotextile is able to withstand, it can be added with the horizontal stress of the soil in an effort to withstand the horizontal stress of the column. A summary of these conditions can be seen in Table 8.

Table 8. Horizontal Stress Comparison After Encased Installed

σh,c column (t/m²)	σh,s soil (t/m²)	Information	σh diff (t/m²)	σh geo (t/m²)	σhs total (t/m²)	condition (t/m²)
44.339	7.275	need encased	37.064	141.40	148.676	safe
48.071	17.141	need encased	30.930	141.40	158.542	safe

Single Settlement of Geosynthetic Encased Stone Columns
In the results of the design parameters, the calculation of vertical and horizontal stresses can be calculated settlement consisting of Layer 1 with a length of 2 m at a depth of 0–2 m and Layer 2 with a length of 8 m at a depth of 3–10 m. with the modulus of constrain, it is determined by an average value of 8D above and 4 D down of 3757.9 t / m². The following is the calculation of a single settlement Geosynthetic Encased Stone Columns using the Almeida and Alexiew method at the length of the Geosynthetic Encased Stone Columns 0-2 m depth refer to Eq. (16)-(21).

$$E^* = \left(\frac{1}{1-vs} + \frac{1}{1+vs}.\frac{1}{a_E}\right).\left(\frac{(1+vs)-(1-2vs)}{(1-vs)}.E_{oed,s} = 3790.2\ ^t/_{m^2}\right) \tag{16}$$

$$\frac{\sigma v,s}{E_{oed,s}} - \frac{2}{E^*}.\frac{vs}{(1-vs)} = 0.0020 \tag{17}$$

$$K_{ac}.\left(\frac{\Delta\sigma_v}{a_E} - \frac{1-a_E}{a_E}.\Delta\sigma_{v,s} + \Delta\sigma_{v,o,s}\right) = 10.06 \tag{18}$$

$$\frac{J.\Delta rc}{r_{geo}^2} = \frac{J.\frac{\Delta\sigma h_{diff}}{E^*}.\left(\frac{1}{a_E}-1\right).rc}{r_{geo}^2} = -9.77 \tag{19}$$

$$K_{0,s}^*.\Delta\sigma_{v,s} - K_{0,s}.\Delta\sigma_{v,o,s} + \frac{J.(r_{geo}-r_c)}{r^2} - \frac{J.\Delta rc}{r^2} = 14.7 \tag{20}$$

$$Sc = (12.\ (\ 13-15)).h = -1.87\ mm \tag{21}$$

From the calculation results, the results can be formulated in Table 9.

Table 9. Result Single Settlement of The Geosynthetic Encased Stone Columns

Data	Value	Unit
Sc1	-0.0187	M
Sc2	0.2648	M
Sc Total	0.2462	M
	246.23	mm

Group Settlement of Geosynthetic Encased Stone Columns
In calculating settlement in Geosynthetic Encased Stone Columns Group with the formation of 144 Geosynthetic Encased Stone Columns, namely 2 rows of 72 columns, it begins with calculating q group GESC refer to Eq. (22-24).

$$q_{groupGESC} = \frac{Q_g}{(B_g \times L_g)} = \frac{Pmaks \times n}{(B_g \times L_g)} = \frac{41.1 \times 144}{2 \times 86} = 34.41\ ^t/_{m^2} \tag{22}$$

$$\sigma_{v,c} = q_{groupGESC} \times q_c = 34.41 \times 3,71 = 127.62\ ^t/_{m^2} \tag{23}$$

$$\sigma_{v,s} = q_{groupGESC} \times q_s = 34.41 \times 0,21 = 7.40\ ^t/_{m^2} \tag{24}$$

Calculation of the Settlement of the 144 Geosynthetic Encased Stone Columns group using the Almeida and Alexiew method. The calculation results are then recapitulated in Table 10.

Table 10. Result Group Single Settlement of The Geosynthetic Encased Stone Columns

Data	Value	Unit
Sc1	-0.0114	m
Sc2	0.226	m
Sc Total	0.2149	m
	214.92	mm

Stability Analysis on Single Settlement of Geosynthetic Encased Stone Columns
From the calculation results shown in Table 9 for a single settlement Geosynthetic encased stone columns, it was found that 246.23 mm exceeded the permit requirements of 25.4 mm. thus the single settlement of the

geosynthetic encased stone column is considered unstable and unsafe. excessive settlement can also cause damage to the box culvert structure.

Stability Analysis on Group Settlement of Geosynthetic Encased Stone Columns
From the calculation results shown in Table 10, for the settlement of 144 geosynthetic encased stone column formation, it was found that 214.92 mm exceeded the settlement permit requirement of 25.4 mm. Soil repair with the encased stone column Geosynthetic method was not appropriate for the box culvert structure with an earthquake load of magnitude 9.0 SR

4. CONCLUSION
From the analysis and discussion of the settlement in geosyntetics encased stone column liquefaction condition in box culvert, the following conclusions can be drawn:
1. Based on the results of the analysis of the potential for liquefaction with the Valera and Donovan method, it is found that at a depth of 4 to 8 m, there is a liquefaction with an earthquake of magnitude 9.0 SR.
2. Based on the results of calculations and analysis of the settlement of the Almeida and Alexiew method on a single settlement in the Geosynthetic Encased Stone Columns, it is obtained 246.23 mm. Then on settlement of the 144 Geosynthetic Encased Stone Columns formation group obtained 214.92 mm.
3. In the stability analysis on single and group settlement 144 Geosynthetic Encased Stone Columns exceeds the settlement requirement of 25.4 mm, the single and group settlement does not meet the requirements and is declared unstable and unsafe under liquefaction conditions against box culvert loading.

5. ACKNOWLEDGEMENT

6. REFERENCES
[1]   P. A. M. Agung and M. B. A. Ahmad, "Potential Liquefaction Of Loose Sand Lenses (Case Study In Surabaya East Coastal Plain , Indonesia)," vol. 6, no. 2, pp. 1–10, 2014.
[2]   T. W. Kuningsih, A. Rifa'i, and K. B. Suryolelono, "Analisis Ketahanan Tanah Dasar Fondasi Candi Prambanan Terhadap Ancaman Likuifaksi Berdasar Simplified Procedure," *Politeknologi*, vol. 16, no. 1, pp. 7–14, 2017.
[3]   L. Zhang and M. Zhao, "Deformation analysis of geotextile-encased stone columns," *Int. J. Geomech.*, vol. 15, no. 3, pp. 1–10, 2015, doi: 10.1061/(ASCE)GM.1943-5622.0000389.
[4]   C. Yoo, "Performance of geosynthetic-encased stone columns in embankment construction: Numerical investigation," *J. Geotech. Geoenvironmental Eng.*, vol. 136, no. 8, pp. 1148–1160, 2010, doi: 10.1061/(ASCE)GT.1943-5606.0000316.
[5]   E. Guler, D. Alexiew, A. Abbaspour, and M. Koc, "Seismic performance of geosynthetic-encased stone columns," *Transp. Res. Rec.*, vol. 2462, pp. 77–88, 2014, doi: 10.3141/2462-10.
[6]   Y. Zhou, G. Kong, Q. Yang, and H. Li, "Deformation analysis of geosynthetic-encased stone column using cavity expansion models with emphasis on boundary condition," *Geotext. Geomembranes*, vol. 47, no. 6, pp. 831–842, 2019, doi: 10.1016/j.geotexmem.2019.103498.
[7]   I. D. G. W. WIDIARTHA, "Installation of Strengthening Peat Soil Layer in," *Sipil, Jur. Tek.*, 2015.
[8]   A. D. Wicaksono, N. E. Mochtar, and P. T. Kumalasari, "Perencanaan Perbaikan Tanah Dasar dan Perkuatan Stabilitas Timbunan Jalan Tol Pasuruan-Grati STA 30+100 s.d STA 31+500," *J. Tek. ITS*, vol. 6, no. 2, pp. 72–76, 2017, doi: 10.12962/j23373539.v6i2.26381.
[9]   S. Rahmatika, "ANALISIS DAYA DUKUNG DAN PENURUNAN PONDASI OIL STORAGE TANK PADA PROYEK PEMBANGUNAN TERMINAL TRANSIT BAUBAU DI SULAWESI," *J. IPB*, 2016.
[10]   R. Yuliawan, Eko; Tanjung, "ANALISIS DAYA DUKUNG DAN PENURUNAN PONDASI TIANG BERDASARKAN PENGUJIAN SPT DAN CYCLIC LOAD TEST," *J. Konstr.*, vol. 9, 2018.
[11]   C. Yoo and S. Bin Kim, "Performance of a two-tier geosynthetic reinforced segmental retaining wall under a surcharge load: Full-scale load test and 3D finite element analysis," *Geotext. Geomembranes*, vol. 26, no. 6, pp. 460–472, 2008, doi: 10.1016/j.geotexmem.2008.05.008.
[12]   B. Kempfert, Hans-Georg ; Raithel, Marc ; Indraratna, *Soil Improvement and Foundation Systems with Encased Columns and Reinforced Bearing Layers*. Oxford: Butterworth-Heinemann, 2015.
[13]   M. Raithel and H. G. Kempfert, "Calculation models for dam foundations with geotextile coated sand columns," *ISRM Int. Symp. 2000, IS 2000*, 2018.
[14]   D. Marcio de Souza Soares de; Filho, Mario Viccente Riccio; Babaei, Iman Hosseinpour; Alexiew, "Geosynthetic Encased Columns for Soft Soil Improvement," in *Geosynthetic Encased Columns for Soft Soil Improvement*, London: Taylor & Francis Group, 2019, p. 14.

[15] H. Hasmar, *Dinamika Tanah dan Rekayasa Kegempaan*. Yogyakarta: UII Press, 2013.

[16] Srikit, "Analisis potensi likuifaksi berdasarkan distribusi ukuran butir dan data n-spt," *UIII J.*, 2019.

[17] F. Selviana, "Analisis dan Tinjauan Potensi Likuifaksi pada Lapisan Pasir di Bawah Jembatan Weri-Saharei Kabupaten Fakfak , Papua Barat(Menggunakan Metode Kishida, Whitman, dan Valera and Donovan)," *J. Civ. Eng. Student*, vol. 1, no. 1, pp. 25–31, 2019.

[18] I. M. Idriss and R. W. Boulanger, "Center for Geotechnical Modeling Cpt and Spt Based Liquefaction Triggering Procedures Cpt and Spt Based Liquefaction Triggering Procedures," *Cent. Geotech. Model.*, no. April, p. 134, 2014.

[19] R. W. Boulanger, I. M. Idriss, and R. W. Boulanger, "CPT and SPT Based Liquefaction Triggering Procedures," *Cent. Geotech. Model.*, no. 10–02, p. 134, 2010, [Online]. Available: https://faculty.engineering.ucdavis.edu/boulanger/wp-content/uploads/sites/71/2014/09/Boulanger_Idriss_CPT_and_SPT_Liq_triggering_CGM-14-01_20141.pdf%0Ahttp://nees.ucdavis.edu/publications/Boulanger_Idriss_CPT_and_SPT_Liq_triggering_CGM-14-01_2014.pdf.

[20] HUESKER Synthetic GmbH, *Reliable Ground Improvement Particularly for Soils with very low Bearing Capacity*. Gescher: HUESKER Synthetic GmbH, 2020.

[21] SNI 1726-2019, "Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung," *Bandung Badan Stand. Indones.*, no. 8, p. 254, 2019.

[22] SNI 1725-2016, "Standar pembebanan untuk jembatan," *Badan Stand. Indones.*, 2016.

[23] J. Ameratunga, N. Sivakugan, and B. M. Das, *Correlations of Soil and Rock Properties in Geotechnical Engineering*. 2016.

[24] Badan Meteorologi Klimatologi dan Geofisika, *Katalog Gempa Bumi Signifikan dan Merusak Tahun 1821 - 2018*. Jakarta: Badan Meteorologi Klimatologi dan Geofisika, 2019.