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Numerical Analysis Finite Element Method of Settlement on Soft Soil, Case Study: National Road of Bts. Kota Sidoarjo – Gempol KM 31+150, Porong, East Java

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ABSTRACT

National Road of Section Bts. Kota Sidoarjo – Gempol is an important access for road users in East Java. A volcanic mud eruption, Lumpur Sidoarjo (Lusi) in 2006 impacted economic and social factors, especially the infrastructure around Lusi. Differential settlement occurs from the research site at the lowest elevation road surface (KM 31+350) near the P10.D levee. This problem affects the level of road safety. it is necessary to analyze settlement to determine the causes of land subsidence in that location. Identification of soft soil condition based on SPT data of BH-2 (west side) and BH03 (east side). Finite Element Method (FEM) numerical analysis is carried out by modeling from the levee to the main road. FEM results showed that vertical deformation (Uy) on the main road is -9,904 cm. FEM results showed that vertical deformation on the levee at 122 days consolidation is 18,27 cm. 19,30 cm vertical deformation from April 2020 – August 2020 (122 days) based on elevation measurements P10D levee's elevation. Based on laboratory test data, BH-2 location depth >-4,45 m are soft clay conditions expect at a depth of 10,45 m which are silty sand soils. BH-3 location depth > -6,45 m are soft clay conditions. FEM results show that the embankment of the levee affects road deformation. Based on a comparison of FEM analysis with embankment deformation data, it can be used as a reference for land subsidence analysis on the road.

Keywords : finite element method, settlement, soft soil, Lusi, road asset management

INTRODUCTION

Bts. Kota Sidoarjo-Gempol Road is one of the important road access connected from Surabaya to Pandaan. There is a mud volcano levee named Lumpur Sidoarjo (Lusi) levee. A mud volcano happened on Mei 29th 2006 at Porong, Sidoarjo, East Java (Davies et al, 2007). This road is located on alluvial conditions formed from gravel, sand, clay, and fossil shell (Santos et al, 1992). Besides that, The road is located on clay soil with soft consistency from clay deposits, silt deposit, and some sand located (Pramudyo et al, 2019). When a saturated soil layer is subjected to a stress increase, the pore water pressure is increased suddenly. Pore water drainage is accompanied by a reduction in the volume of the soil mass, which results in settlement (Das, 2012). Based on a site survey in 2022 at KM 31+150 – KM 31+95-, visually differential settlement and the lowest settlement is in KM 31+350. Vertical displacements in and around the Lusi mud volcano are mainly driven by: mud loading, the collapse of the overburden due to the removal of mud from the subsurface, and land settlement caused by surface works (e.g. constructions of dykes (Abidin et al, 2008). Differential settlement on the road impact the road level of safety with a slope -of 0,483% (P2JN Jatim, 2019). Settlement continues to happen, and there is no research due to soil settlement on the road of Bts Kota Sidoarjo – Gempol to identify the impact of settlement. In addition, it is also necessary to identify the condition of the subsurface against soft soil conditions. The method used in the analysis of land subsidence is needed to determine the condition of subsidence at the study site. Therefore it is important to conduct research related to the impact of land subsidence, especially in locations with the lowest elevation at KM 31+350.

Research Methods

The method used in this study is soil settlement calculations were carried out using numerical analysis of the finite element method. The following are the stages of the research completion method:

Preliminary Observation Survey

Field observations to survey the road conditions in terms of road damage assessments. In addition, a survey was carried out on the road elevation by observing the road surface and the existing condition of the road. The locations under review were KM 31+150 to KM 31+950.

Problem Identification

Problem identification is obtained from secondary data by observed at global and regional geological aspects. Studied the history of the Sidoarjo mudflow and its short-term and long-term impacts. interviews were conducted with field mentors, road section managers, and the Sidoarjo Mud Control Center (PPLS) authorities. The data obtained is secondary data from related parties at the research location, namely on the road, on the embankment, and regional data. Geotechnical data was carried out by PPLS with an SPT drill with a depth of 16.5 m from the road surface on BH-2 and BH-3. Geotechnical laboratory tests were performed based on undisturbed sampling at points BH-2 and BH-3.

Research Location, SPT Drilling Data, and Geophysics Data Acquisition

Figure 1. Location of Geotechnic and Geophysic Data

(a) (b)

Figure 2. (a) Existing Condition on West Side KM 31+450 (b) Existing Condition on East Side KM 31+450

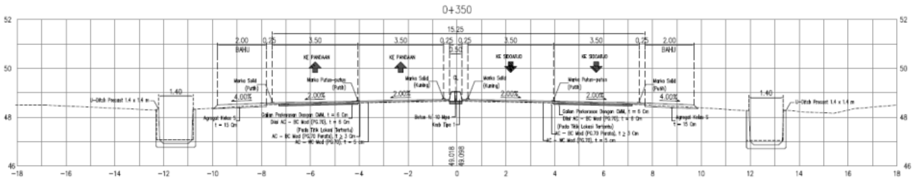


Figure 3. Cross Section of Bts Kota Sidoarjo – Gempol Road KM 31+350 (P2JN Jawa Timur, 2019)

Table 1. Stratigraphy and SPT Value Data of Borehole 2

BORE LOG

Bore No.	: BH - 2	GPS (UTM)	X = 688069.000
Project	: Peningkatan Embung Pamotan		Y = 9168080.000
Client	: -	Diameter of Bore	: 73 mm
Location	: Kab. Sidoarjo	Diameter of Casing	: 89 mm
STA	: -	Date Start	: 13 - 07 - 2022
GWL	: -	Finish	: 13 - 07 - 2022

DEPTH (m)	BORE LOG	Standard Penetration Test (SPT) N / 30 cm	VISUAL DESCRIPTION	COLOUR	UDS Depth / SPT Depth	N1 (0-15)	N2 (15-30)	N3 (30-45)	N-SPT (N2+N3)
0–2		32	Timbunan Sirtu	Coklat	1.50 - 2.00 m UDS 2.00 - 2.45 m SPT	9 /15	14 /15	18 /15	32
3–4		29	Lempung berpasir kasar	Coklat	3.50 - 4.00 m UDS 4.00 - 4.45 m SPT	7 /15	12 /15	17 /15	29
5–6		4	Lanau kelempungan	Coklat	5.50 - 6.00 m UDS 6.00 - 6.45 m SPT	1 /15	2 /15	2 /15	4
7–8		3			7.50 - 8.00 m UDS 8.00 - 8.45 m SPT	1 /15	1 /15	2 /15	3
9–10		5	Lanau kepasiran	Hitam Coklat	9.50 - 10.00 m UDS 10.00 - 10.45 m SPT	2 /15	2 /15	3 /15	5
11–12		4	Lanau kepasiran sedikit kulit kerang	Coklat	11.50 - 12.00 m UDS 12.00 - 12.45 m SPT	1 /15	2 /15	2 /15	4
13–14		5			13.50 - 14.00 m UDS 14.00 - 14.45 m SPT	1 /15	2 /15	3 /15	5
15–16		6	Lanau kelempungan	Coklat	15.50 - 16.00 m UDS 16.00 - 16.45 m SPT	1 /15	3 /15	3 /15	6
17–18									

(PPLS, 2022)

Table 2. Stratigraphy and SPT Value Data of Borehole 3

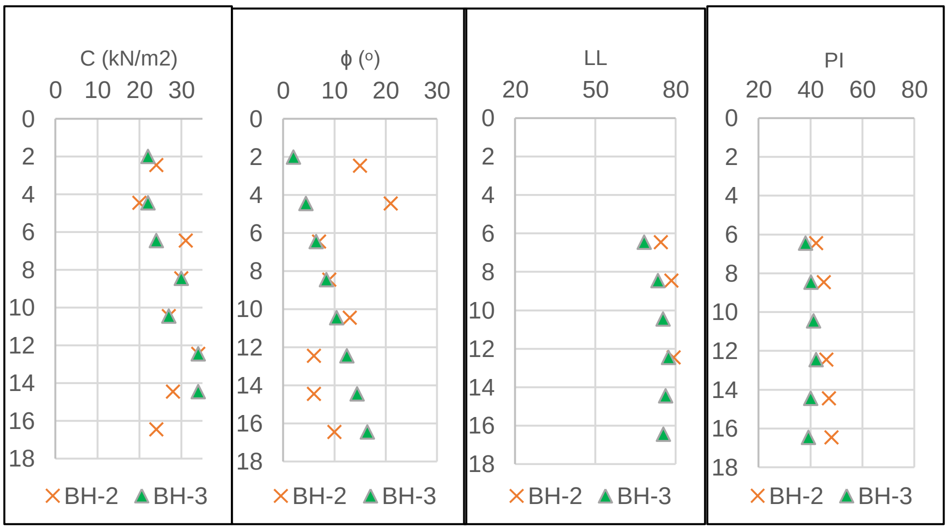
BORE LOG

Bore No.	: BH - 3	GPS (UTM)	X = 688095.000
Project	: Peningkatan Embung Pamotan		Y = 9168072.000
Client	: -	Diameter of Bore	: 73 mm
Location	: Kab. Sidoarjo	Diameter of Casing	: 89 mm
STA	: -	Date Start	: 14 - 07 - 2022
GWL	: -	Finish	: 14 - 07 - 2022

DEPTH (m)	VISUAL DESCRIPTION	COLOUR	UDS Depth / SPT Depth	N1 (0-15)	N2 (15-30)	N3 (30-45)	N-SPT (N2+N3)
0 – 3	Timbunan Sirtu	Coklat	1.50 - 2.00 m UDS 2.00 - 2.45 m SPT	9 /15	15 /15	22 /15	37
3 – 4.5	Lempung berpasir kasar	Coklat	3.50 - 4.00 m UDS 4.00 - 4.45 m SPT	7 /15	14 /15	19 /15	33
4.5 – 8.5	Lanau kelempungan	Coklat	5.50 - 6.00 m UDS 6.00 - 6.45 m SPT	8 /15	16 /15	23 /15	39
			7.50 - 8.00 m UDS 8.00 - 8.45 m SPT	1 /15	1 /15	2 /15	3
8.5 – 10.5	Lanau kepasiran	Hitam Coklat	9.50 - 10.00 m UDS 10.00 - 10.45 m SPT	1 /15	2 /15	2 /15	4
10.5 – 15	Lanau kepasiran sedikit kulit kerang	Coklat	11.50 - 12.00 m UDS 12.00 - 12.45 m SPT	1 /15	2 /15	3 /15	5
			13.50 - 14.00 m UDS 14.00 - 14.45 m SPT	1 /15	2 /15	3 /15	5
15 – 16.5	Lanau kelempungan	Coklat	15.50 - 16.00 m UDS 16.00 - 16.45 m SPT	1 /15	2 /15	2 /15	4

(PPLS, 2022)

Geotechnical Parameter Data



(PPLS, 2022)

Figure 4. Shear Strength and Atterberg Limis of BH-2 and BH-3

Table 3. Soil Parameter for Finite Element Method Analysis

No	Parameter	Units	Material or Layer						
			0-6,45	**6,45-10,45**	**10,45-14,45**	**14,45-30**	**Dykes**	**Dykes**	**Mud**
	Data		UDS-1	UDS-3	UDS-5	UDS-7	Layer 1	Layer 2	
1	N-SPT		37	39	4	5			
2	Soil Descriptions		Sandy Silt	Clayey Silt	Clayey Silt	Clayey Silt	Sandy Silt	Silty Sand	Mud
	Material Set								
3	Model Material		M-C	M-C	Soft Clay	Soft Clay	M-C	M-C	M-C
4	Drainage Type		Drained	Drained	Undrained A	Undrained A	Drained	Drained	Undrained A
	Unit Weight								
5	γ_{sat}	(kN/m^3)	21,71	20,62	15,09	14,67	16	18	15
6	γ_d	(kN/m^3)	19,06	17,44	8,40	6,38	15	17	14
7	Angka Pori		0,427	0,57	2,231	2,519			
	Stiffness								
8	E'	(kN/m^2)	10000	7000	6000	5000	6000	9000	1000
9	V'		0,3	0,45	0,45	0,45	0,2	0,2	0,3
10	λ*				0,079	0,081			
11	K*				0,025	0,023			
	Shear Strength Soil								
12	C	(kN/m^2)	22,00	24,00	27,00	34,00	5,00	1,00	1,00
13	ϕ	(°)	16,00	16,00	16,00	8,00	27,00	34,00	38,00
	Sieve Analysis								
14	Gravel	(%)	11,14	13,16	0	6,05			
15	Sand	(%)	34,12	26,96	27,98	13,62			
16	Silt	(%)	54,75	32,81	42,96	51,27			
17	Clay	(%)	0	27,06	29,05	29,06			
18	K	m/day	4,32000	0,86400	0,00864	0,00864	0,00864	0,00864	0.000864

(PPLS, 2021)

Numerical Analysis Finite Element Method of Road Existing Deformation

The finite element modeling was carried out based on the cross-section at the location of the P10D embankment and the KM 31+450 road based on **Figure 5**. The modeling conditions were carried out with the input geometry and soil parameters. Soil parameters are used in **Table 1**. In this modeling, a loading analysis is carried out on embankments, railroad tracks, and national railroads. In embankment conditions, the biggest load is the condition of the PC200 long-arm excavator operating with a load of 20 kPa (PPLS, 2021) as line load, The load of the railroad track is based on class IV railways with a maximum axle load of 18 tonnes as a point load (Kemenhub, 2012) and a sub-ballasted load with a total load of 13.67 kN/m2 as a line load. The traffic load is 22.7 kPa consisting of class 1 traffic load Arterial and road pavement loads.

In the flow condition process, the groundwater level is at the surface elevation in the mud and embankment area and then at an elevation of -1.00 m at the existing road surface. The conditions on the east side of the mud boundary are made inflow boundaries with the assumption that the water flows to the road direction. On the downside, modeling is made of outflow behavior with the assumption that the condition of the water flows continuously. On the west side of the modeling is modeled inflow behavior with the assumption that the condition of the Pamotan pond is not modeled, there is an influence of water flow. The flow conditions model can be seen in **Figure 6.**

Next is the staged construction process. At this stage, modeling is carried out by determining the type of calculation based on each phase. Phase 1 is the initial condition where the initial stress condition on the soil is influenced by the weight of the soil, the water condition, and the history of the soil formation (Bentley, 2020). In this phase 1 condition, a calculation type is determined, namely gravity loading with consideration that the modeling conditions have a slope of the embankment slope. In phase 2, it is a plastic condition, namely an analysis of the calculation of elastic-plastic deformation without considering changes in pore pressure (Bentley, 2020). In plastic conditions, the embankment load, train load, and traffic load are determined. Modeling conditions can be seen in **Figure 5.**

In the output stage, the total displacement |u| can be displayed to determine the deformation in the two-way condition. Based on **Figure 7**, it can be seen that the embankment slope is the largest total deformation. At the location of a load of heavy equipment on the embankment it influences the deformation which is directed towards the west side. At the location of the road body, the total deformation visually leads to the west side due to the deformation of the embankment.

Analysis of P10D Deformation Elevation

The P10D embankment point is one of the embankments with the largest settlement rate (PPLS, 2021). Based on the period February 2018 to February 2022. The embankment was backfilled by raising the elevation in April 2018. The first backfilling work was completed in October 2018. In May 2019 the embankment condition required backfilling and finished in April 2020. In August 2020 the 3rd backfill was carried out until completed in January 2021. In the period from February 2018 to February 2022, there has been a total subsidence of 1,317 m. Monitoring data for the P10D elevation in the period February 2018 to February 2022. The graph of monitoring data for the P10D mud embankment for the period February 2018 to February 2022 can be seen in **(Modification** of PPLS, 2021)

Figure 10.

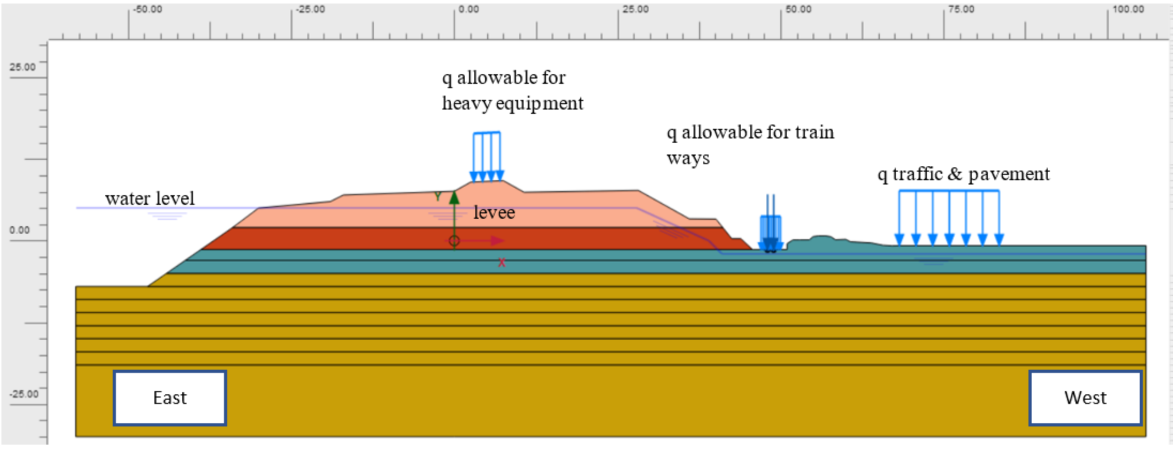


Figure 5. Cross Section of P10D and Road Existing Modelling

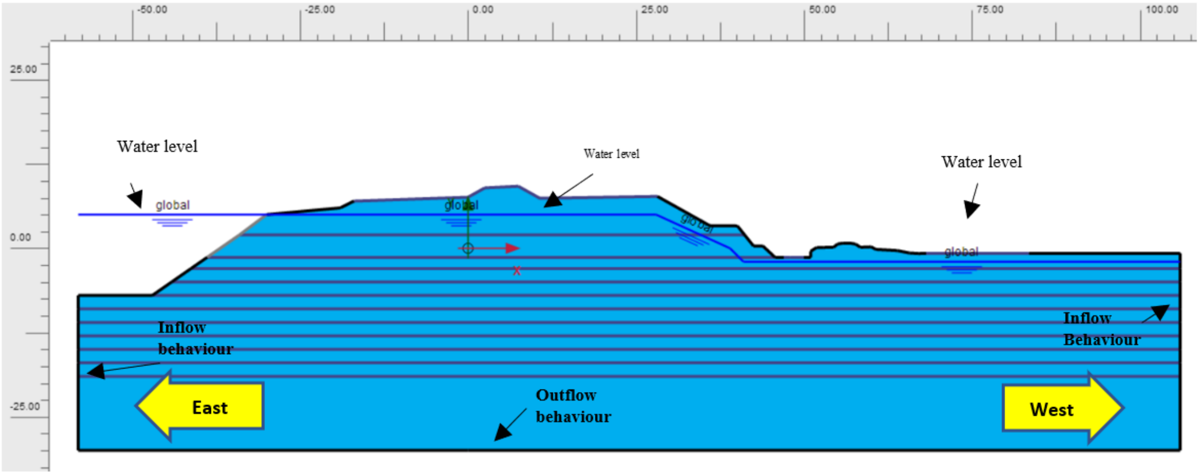


Figure 6. Flow Conditions Model

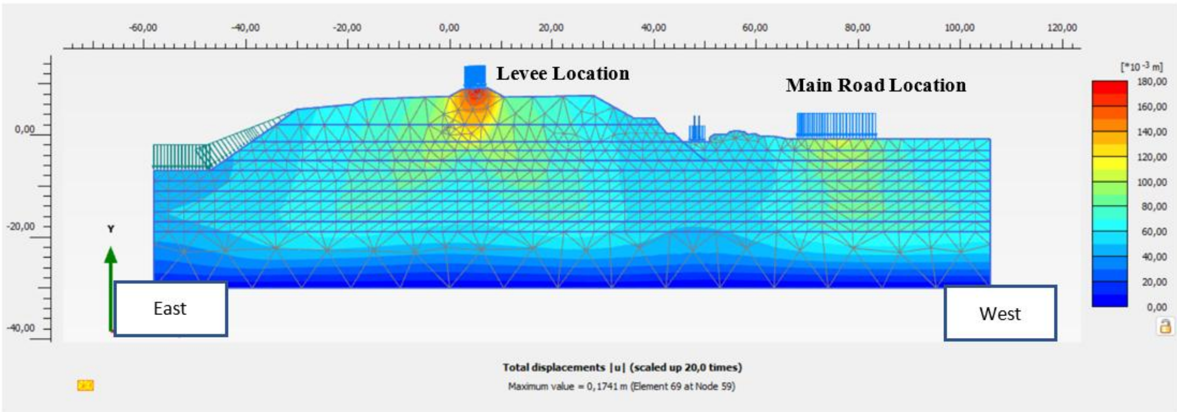


Figure 7. Total Deformation |u| of Levee and Road

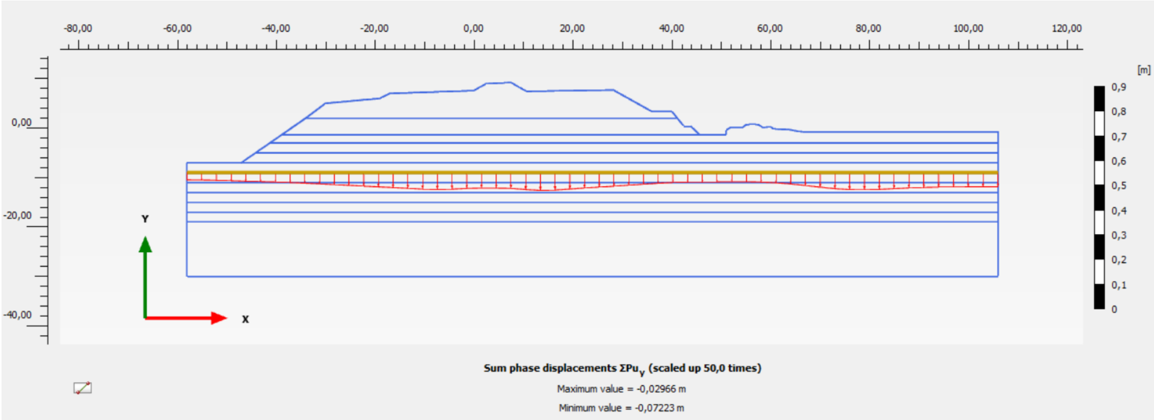


Figure 8. Vertical Displacement (Uy) output of Cross-Section -8,00 m

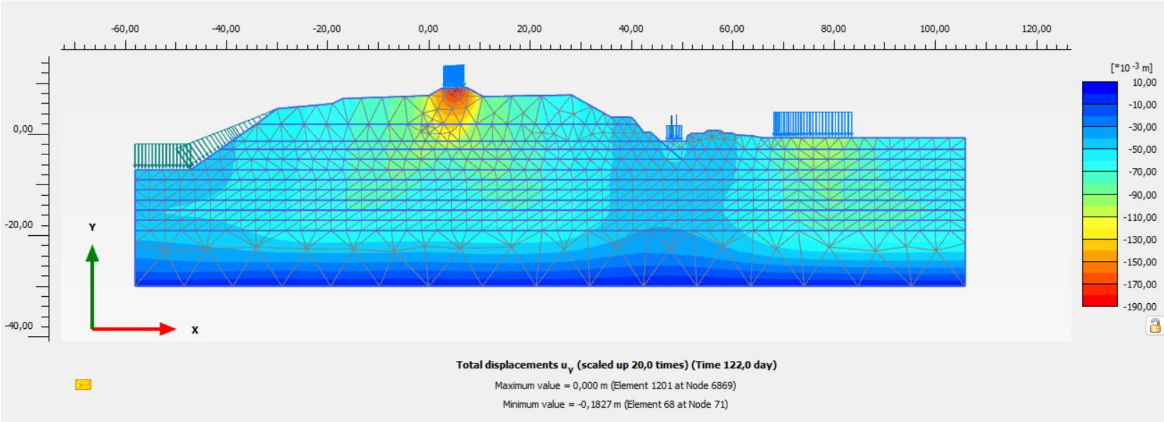
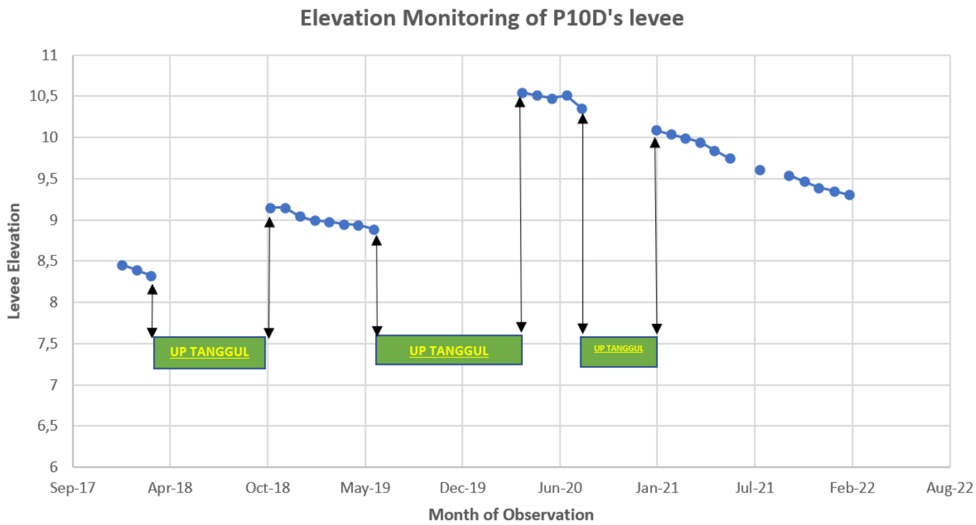


Figure 9. Consolidation of 122 Days



(Modification of PPLS, 2021)

Figure 10. Elevation Data of P10D Levee

Finite Element Method Numerical Analysis

Modeling using the finite element method is carried out on cross-sectional conditions from the location of the embankment to the location of the main road. The condition of the soil on the first layer of the embankment is silt sand with a medium consistency and the soil on the second layer of the embankment is silty sand with loose consistency. In modeling, the original soil layer uses BH-3 drill data with the consistency of silt sand at a depth of 2 meters and silty sand at a depth of 4.45 meters. At a depth of > 4.45 meters is clay silt-type soil with high plasticity. The load modeled on the cross-section is the load on the embankment which is the load of the long-arm excavator heavy equipment. The load on the railroad is modeled based on axle loads and ballast and sub-ballast loads. On the road body, the traffic load is modeled for Class I Primary Artery and pavement loads. The condition of the groundwater level on the embankment is modeled at the maximum condition of the embankment guard height. The groundwater level on the condition of the road body is at a depth of 1.00 meters. Modeling is done with static conditions without calculating the earthquake analysis (pseudo-static).

From the modeling results, the total displacement in |u| is 0.1741 m based on **Figure 7**. The biggest decrease is at the location of the embankment when viewed from the color tends to be red. The P10.D embankment wall contributes to the additional load on the retaining structure in terms of the total deformation value |u| and the value of vertical deformation (Uy) (Agustawijaya et al, 2012), the total deformation on main road value |u| which is 6 centimeters.

The vertical direction decrease (Uy) is identified on the cross section of the road at a depth of 4,00 m (A-A) and the depth section. Based on the results of displacement modeling in the Uy direction, the largest value that occurs on the road section is -9.904 cm. the output image of a decrease in the vertical direction (Uy) can be seen in **Figure 8**.

Based on monitoring data on land subsidence on embankment P10D by PPLS (2022), subsidence from February 2018 to February 2022 decreased by 1.317 m. At location P10D, embankments were piled up to maintain the embankment elevation against water and mud. PPLS stated that the P10D deformation was one of the embankment observation points that experienced the highest settlement. Based on Abidin et.al 2008, one of the vertical deformation at the Lusi location was caused by the construction of an embankment. In the condition that the existing embankment was built with a poor design because it was built from continuous emergency construction conditions (Rahardjo et al. 2017). Deformation in elevation monitoring data in April 2020 – August 2020 (122 days) the decreased was 19.30 cm **(** **(Modification** of PPLS, 2021)

***Figure 10*)**, while the deformation of Uy in the consolidation condition of 122 days on the finite element method analysis yielded 18.27 cm **(Figure 9)**. There is a margin of error between the data from Terzaghi 1-D analysis and numerical analysis about 5.63%.

CONCLUSION

Based on land subsidence analysis on Bts. City of Sidoarjo-Gempol KM 31+450, the conclusion can be summarized as follows:

1. The subsurface soil conditions to a depth of -16.50 m have compressible soil conditions at the BH-2 point > -6.45 meters which are categorized as soft soil (which is soil with clay silt except at a layer of -10.5 meters (which is a silty sandy soil). At the BH-3 point, compressible soil is at a depth of -6.45 meters which is included in the soft soil category with clayey silt soil. In clayey silt soil conditions, it is soil with a high plasticity value (PI). The condition of soft soil at the study site is also proven based on the atlas of soft sheet distribution of East Java Province by the Geological Agency, ESDM, 2019.
2. Based on numerical analysis of the finite element method on the Bts Kota Sidoarjo – Gempol KM 31+350, mud and levee have an effect on the deformation of the road with

the largest deformation caused by the embankment load whose deformation direction is towards the west side.

3. Land subsidence in the vertical direction at the location of the road body is -7.9 cm at the road surface location.

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