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NUMERICAL MODEL ANALYSIS OF SUBGRADE SETTLEMENT WITH FOAM MORTAR REINFORCEMENT BASED ON THICKNESS VARIATION

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Soft soils have low bearing capacity characteristics and can cause high settlement. Sub grade which becomes the lowest layer in road construction is expected to have a strong bearing capacity so that it can carry the construction load on it. To overcome this problem, it is necessary to reinforce it. Problems will arise if the thickness of the soft soil in the subgrade varies. So, it needs to know and identify the scale of declining that occurs if the soft soil variation is reinforced on it. Foam mortar is an alternative reinforcement that is expected to improve the properties of the soft soil. The purpose of this research is to analyze the soft soil embankment model using foam mortar reinforcement against variations in soft soil height. The method of analysis was carried out by numerical method of Plaxis 2D version 2023. The geometric model in this study with foam mortar thickness of 30 cm was varied against subgrade layer height of 60 cm, 120 cm and 180 cm. The modeled load is a centralized load with variations of 0, 10, 20, 40, 60, 80, 100 and 120 kN. Numerical results obtained the highest settlement occurred at 180 cm soft soil layer of 0.01421 mm. The largest deformation occurred in the soft soil layer of 1,461 x 10-3 mm. In conclusion, the thicker the soft soil layer, the higher the settlement and the greater the deformation.

Keywords: foam mortar, reinforcement, plaxis 2D, subgrade

1 INTRODUCTION

Soft soil problems are part of geotechnical problems in many countries, as well as in Indonesia. [1, 2] Soft soil contains a lot of water causing low bearing capacity, high shrinkage, settlement and compressibility resulting in damage to the construction built on it. [3, 4] Road construction is one of the land transport infrastructure developments that can cause problems if built on soft soil. [5, 6]

Sub grade is the lowest layer of road construction is expected to be a solid part in supporting the construction load and traffic on it. [7] The depth of soft soil in the subgrade varies in each region and area, requiring further study on how to most effectively and safely treat the subgrade as a construction support. [8, 9] Thus, the improvement of soft soil properties in the subgrade is carried out by various methods that are considered to increase the bearing capacity of the subgrade so that there is no damage to the structure above it and the decline that occurs can be overcome from the beginning of road construction work. [9, 10, 11]

One method of soft soil improvement is the using of foam mortar material as backfill over the soft soil. [12] Foam mortar has been widely used in various construction works such as embankments, bridge abutments and tunnels. [13, 14, 15], This is because foam mortar is a lightweight material consisting of cement, sand, water and foam agent.[16, 17] To reduce the lateral load, the content weight and compressive strength of the foam mortar mixture can be planned according to the construction needs resulting in reduced embankment weight. [18, 19] In the subgrade, a self-adhering foam mortar and an indication of ease in the field as it has a flow value of 180±20 mm. [20]

Plaxis 2D is a two-dimensional finite element programme developed for deformation, stability and groundwater flow analysis in geotechnical engineering. The programme is equipped with features to handle various aspects of geotechnical structures and construction processes using computational procedures.[21] The purpose of this research is to analyze the numerical model of safety factor and displacement that occurs in soft soil sub grade layer reinforced with foam mortar embankment with thickness of 30 cm. The variety of testing embankment model is with subgrade thickness of 60 cm, 120 cm and 180 cm. The load given in the form of a centralized load is assumed to receive a load of 0 kN, 10 kN, 20 kN, 40 kN, 60 kN, 80 kN, 100 kN and 120 kN.

The novelty of this research is the variation of subgrade thickness due to embankment with 30 cm thick foam mortar. The analysis conducted is to see the behaviour of soil settlement and deformation that occurs.

2 METHODOLOGY

2.1 Loads

Based on SNI 1725-2016 the loading for roads and bridges used in the modeling is the most critical loading model with a centralized load of 112.5 kN with a wheel width of 200 mm, the load is the largest axle load. [22] Therefore, the loading model starts from 0 kN, 10 kN, 20 kN, 40 kN, 60 kN, 80 kN, 100 kN, up to 120 kN as a loading variation.

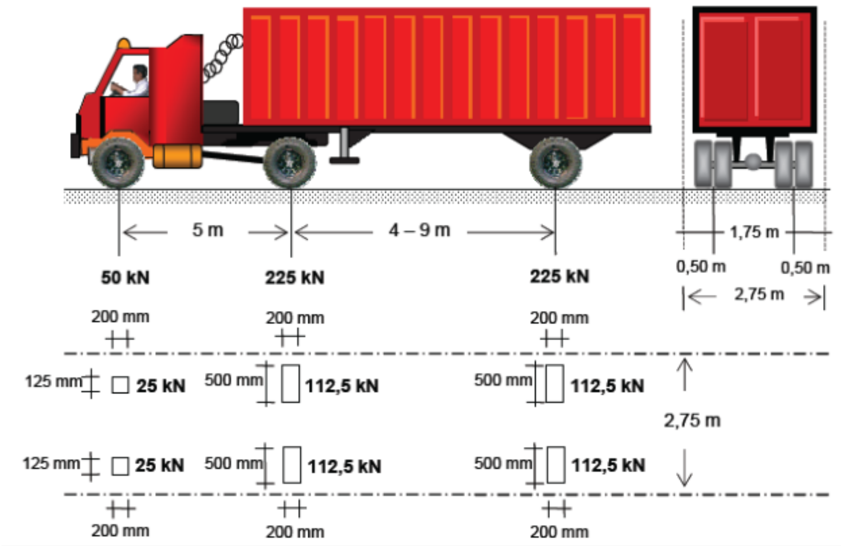

Fig. 1. Truck loading T

The loading is carried out in stages starting from a load of 0 kN up to a load of 120 kN. The loading model created in the construction stage is carried out in stages, starting from a load of 0 kN to a load of 120 kN.

2.2 Material Properties

1. Subgrade

Sampling of subgrade soil in a predetermined location is with the help of hand-bore tools. The subgrade taken as a sample is undisturbed subgrade. After the soil samples were obtained, laboratory testing was carried out to obtain the original soil properties value. Laboratory testing includes:

a) Sieve analysis test (SNI 3423-2008) to determine the gradation of soil grains and percent passing No.200.
b) Bulk unit weight test (ASTM D 4253-91) to obtain wet volume weight of native soil (γb) and pore number (e).
c) Unconsolidated Undrained (UU) triaxial testing (ASTM D-2850-95) is to obtain shear angle (φ) and soil cohesion (c).
d) Atterberg Limit Testing (SNI 1967-2008) to determine the value of Liquid Limit (LL), Plastic Limit (PL) and Platicity Limit (PI).

2. Non-Woven Geotextile

The geotextile material in this test was used as a separator between the subgrade and the foam mortar. The type of geotextile is non-woven polyester (PET), with specifications in Table 1 below:

Table 1. Specifications of geotextile

No	Item	Test Method	150 gr	unit
1	Thickness	ASTM D5100-12	1.1	mm
2	Tensile Strength	ASTM D4595-11	7.1	kN/m
3	Elongation	ASTM D4594-11	≥50	%
4	CBR Brust Strength	ASTM D6241-14	1017.3	N
6	Tearing Strength	ASTM D4533-15	280	N

3. Foam Mortar

Foam mortar testing stages include:

a) Fine aggregate testing
   1) Sieve Analysis : ASTM C109 and 3423-2008
   2) Sand specific gravity testing: SNI 1964-2008
   3) Sand silt content testing : SNI 03-6819-2002
b) Mix design formula
   1) Calculation of mix design
   2) Jobmix design foam mortar
   3) Foam making
c) Mixing foam with materials (sand, water and cement)

4. Loading Plate

The loading plate on the modeling made of K-250 concrete is used as the basis for placing a Linear Variable Differential Transformer (LVDT) with a thickness of 10 cm which is used to calculate the displacement that occurs in the modeling circuit.

2.3 Numerical Model Variations

This geometric modeling variation with foam mortar reinforcement uses Plaxis 2D software version 2023. The geometric modeling consists of 3 variations of soft soil geometric modeling with soft soil thicknesses of 60 cm, 120 cm and 180 cm, reinforced with 30 cm thick foam mortar with a central load of 0 kN. 10 kN. 20 kN. 40 kN, 60 kN, 80 kN, 100 kN and 120 kN.

The numerical model for the subgrade is hardening soil because it will study consolidation settlement. The foam mortar model is linear elastic because mortar is a solid material. The concrete slab model also uses the same linear elastic as the foam mortar.

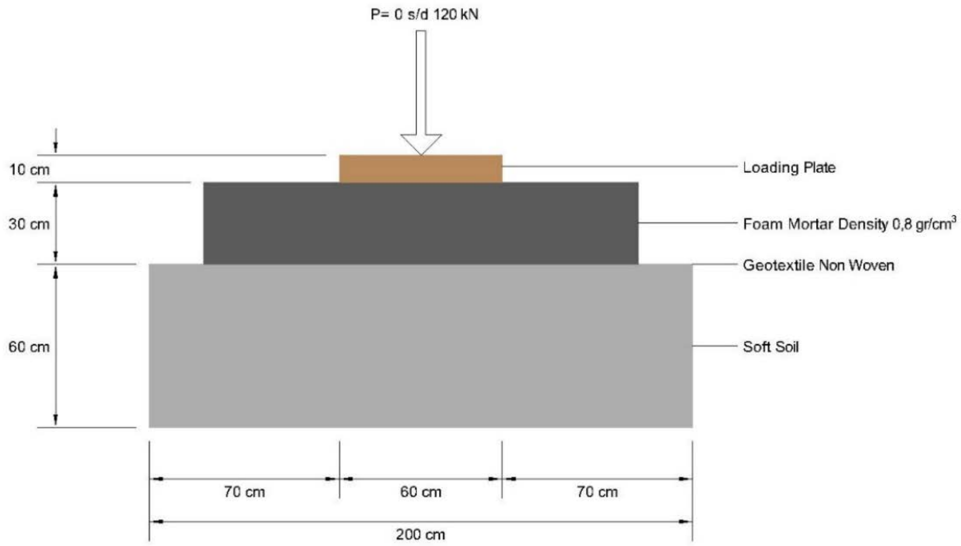

Fig. 2. 60 cm subgrade geometric model

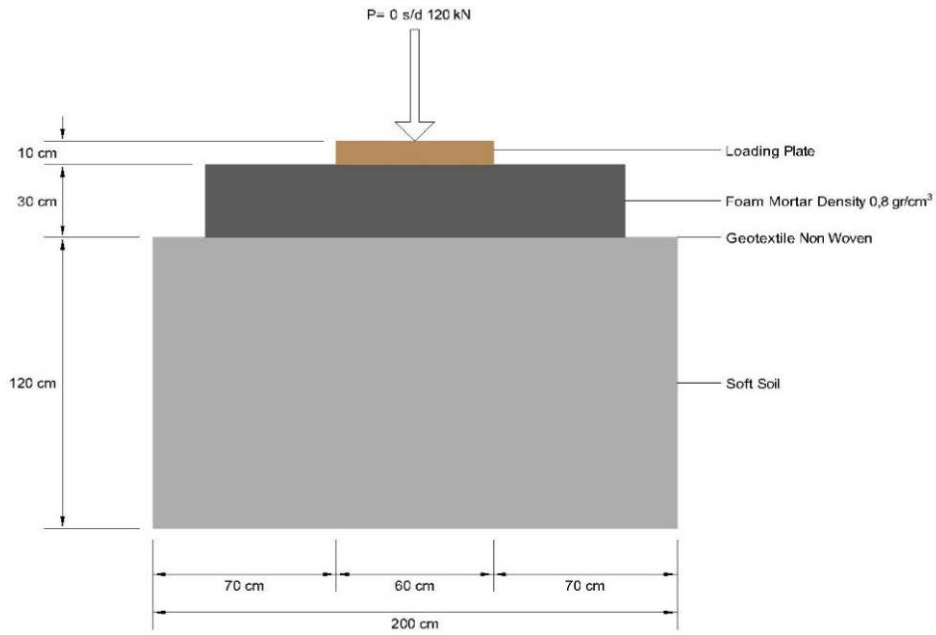

Fig. 3. 120 cm subgrade geometric model

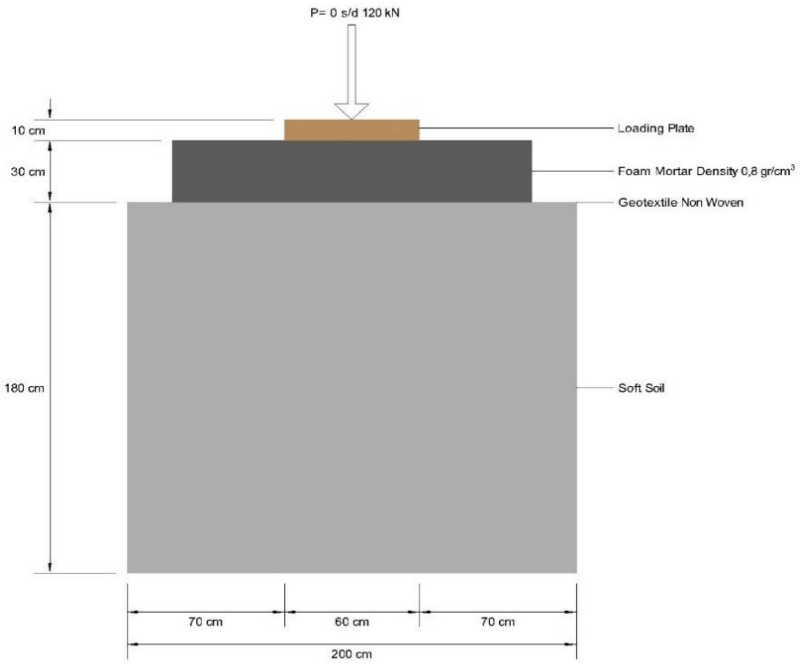

Fig. 4. 180 cm subgrade geometric model

This research uses the 2D Finite Element Method to analyze the data to be obtained. The field-testing equipment uses a test tub with dimensions of 200 cm x 100 cm x 50 cm made of angle steel and iron plate. In modeling for Plaxis 2D geometry, it used the same dimensions as in the field. The boundary conditions in the 2D Plaxis car are the same as in the field experiment.

2.4 Construction phase model requirements

A series of numerical analyses with Plaxis 2D version 2023 with 3 variations of geometric models based on subgrade thicknesses of 60 cm, 120 cm and 180 cm reinforced with 30 cm thick foam mortar. The stages of the construction phase model were taken with the consolidation time calculated for 100 years (365 days x 100). The stages can be seen in table 2 below:

Table 2. Construction phase model of variation in subgrade height

No	Stuged construction	Time interval (day)
1	Initial phase	0
2	Subgrade	1
3	Geo textile non-woven	1
4	Foam Mortar	1
5	K250 concrete slab	1
6	0 kN loading	36500
7	10 kN loading	36500
8	20 kN loading	36500
9	40 kN loading	36500
10	60 kN loading	36500
11	80 kN loading	36500
12	100 kN loading	36500
13	120 kN loading	36500

3 RESULT AND DISCUSSION

The parameters obtained from the subgrade properties testing, the mix design of foam mortar, K-250 concrete slab, as well as the material properties of non-woven geotextile will be input into Plaxis 2D version 2023.

Table 3. Subgrade properties parameter

No	Test Type	Results	Unit
1	Bulk unit weight (γb**)**	17.84	kN/m³
2	Pore number (e)	0.96	-
3	Cohesion (c)	21.0	kN/cm²
4	Shear angle (φ)	5.237	º
5	Compression coefficient (Cc)	0.0345	-
6	Swelling coefficient (Cs)	0,0023	-

Cu value of 21.0 kN/cm², the clay is classified as soft consistency based on Bowles, the soft consistency type is in the range of 20-50 kN/cm².

The following table shows the job mix results of foam mortar:

Table 4. Job mix design of foam mortar

Cement (kg)	Water (kg)	Sand (kg)	Foam (kg)	Total (kg)
270	135	406.599	46.749	0.858

The recapitulation of material properties inputted in the Plaxis 2D version 2023 application can be seen in the following table:

Table 5. Recapitulation of Plaxis 2D parameter data version 2023

No	Type Material	Material Model	Type Drainage	γb (kN/m³)	e	Eu (kN/m²)	vu	c (kN/m2)	Cc	Cs
1	Subgrade	Hardening soil	Undrained B	17.84	0.96	2000	0.2	21.0	0.0345	0,0023
2	K-250 concrete slab	Linear Elastic	Non-Porous	24	-	21289390	0.2	-	-	-
3	Foam mortar	Linear Elastic	Non-Porous	24	-	2000	0.2	-	-	-
4	Geotextiles	Geogrid	Tensile strength / elongation = 7.1 kN/m/50% = 14.2							

Variations in subgrade height of 60 cm, 120 cm and 180 cm modeled using Plaxis 2D numerical analysis version 2023 with foam mortar reinforcement thickness of 30 cm and subjected to stepwise loading of 0 kN, 10 kN, 20 kN, 40 kN, 60 kN, 80 kN, 100 kN and 120 kN.

Table 6. Safety factor results of Plaxis 2D numerical model version 2023 variations of 60 cm, 120 cm and 180 cm subgrade height.

Load (kN)	30 cm Foam Mortar 60 cm Subgrade	30 cm Foam Mortar 120 cm Subgrade	30 cm Foam Mortar 180 cm Subgrade
0	53.630	53.490	53.880
10	20.790	20.730	20.820
20	12.880	12.840	12.900
40	7.322	7.294	7.329
60	5.115	5.089	5.120
80	3.930	3.909	3.933
100	3.191	3,173	3.193
120	2.686	2.671	2.687

From the table above, it can be seen that the safety factor value generated by reinforcing 30 cm foam mortar with a variation in subgrade height of 60 cm, 120 cm and 180 cm with a loading variation from 0 kN to a maximum loading of 120, respectively at a value of 2.686, 2.671, 2.687 obtained > 1.4. This means that based on Geotechnical Guideline 4 for the Indonesian region, the load carried is safe for subgrade variations in road construction. [23]

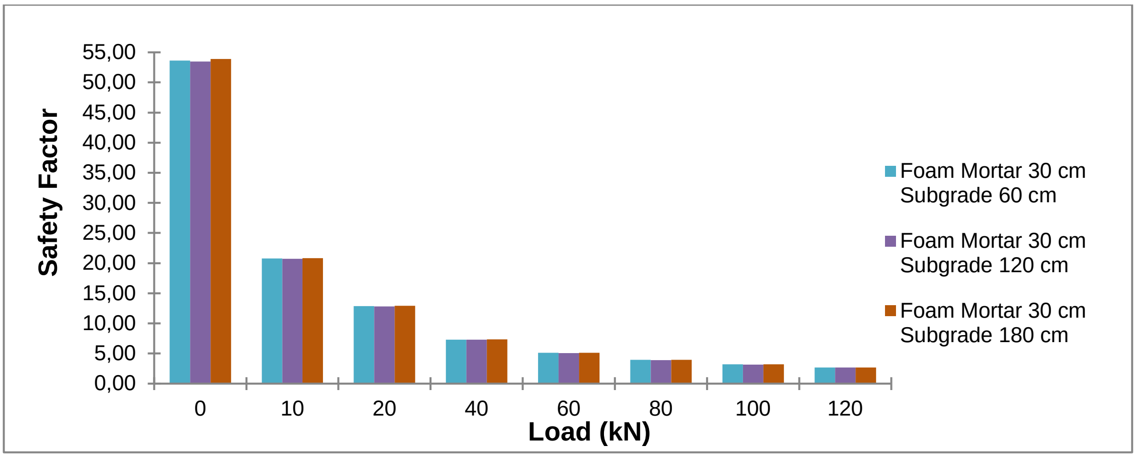

Fig. 5. Safety factor for variation of subgrade height with 30 cm foam mortar reinforcement

From the figure above, it can be seen that the reinforcement of 30 cm thick foam mortar on the subgrade with a height variation of 60 cm, 120 cm and 180 cm produces a small safe factor value at a maximum load of 120 kN. The figure also shows that the thicker the subgrade the smaller the factor value due to the maximum load.

Table 7. Displacement results of Plaxis 2D numerical model version 2023 variations of 60 cm, 120 cm and 180 cm subgrade height

Load (kN)	30 cm Foam Mortar 60 cm Subgrade	30 cm Foam Mortar 120 cm Subgrade	30 cm Foam Mortar 180 cm Subgrade
0	0	0	0
10	-0.00009	-0.00082	-0.00109
20	-0.00018	-0.00167	-0.00222
40	-0.00036	-0.00341	-0.00452
60	-0.00053	-0.00521	-0.00688
80	-0.00070	-0.00704	-0.00928
100	-0.00086	-0.00891	-0.01172
120	-0.00101	-0.01082	-0.01421

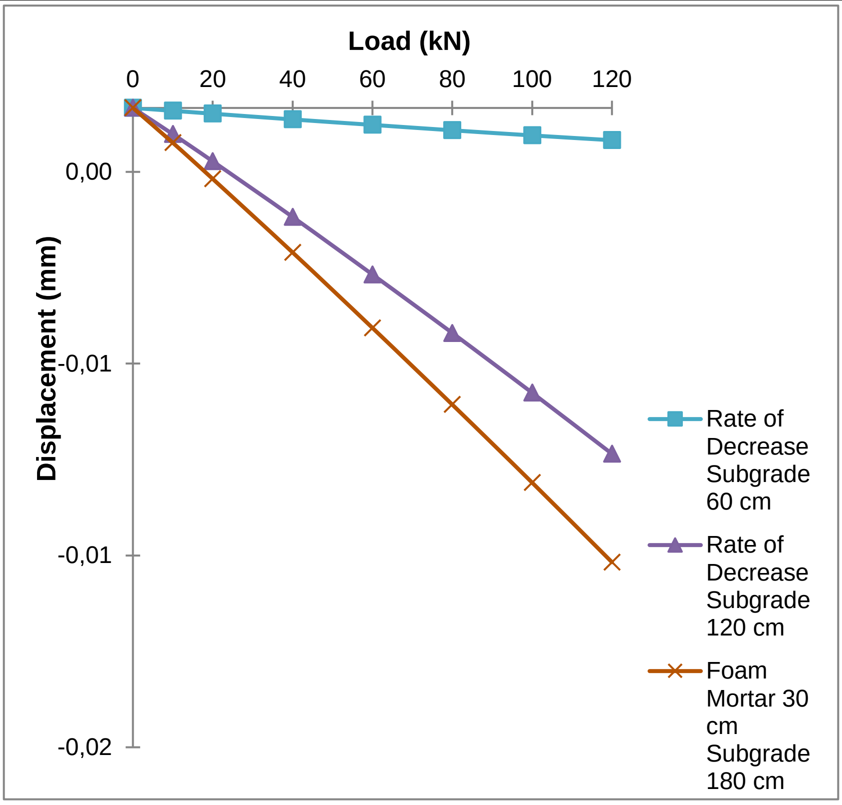

Fig. 6. Settlement with foam mortar 30 cm variation in subgrade height

The consitutive equation due to the variation of the applied load is linear type, because the greater the applied load, the higher the settlement. The resulting numerical solution method is the relationship between load and settlement.

From the table and figure above, it can be seen that the decrease that occurred with the reinforcement of foam mortar 30 cm variation of subgrade height, the highest decrease was 0.01421 mm in the variation of subgrade height of 180 cm. Based on the analysis of the South Carolina Department of Transportation (SCDOT) (2008) decline criteria, the maximum value is 2.54 mm for road class 1 with a plan life of 100 years. This means that the settlement that occurs is still safe against the required value.

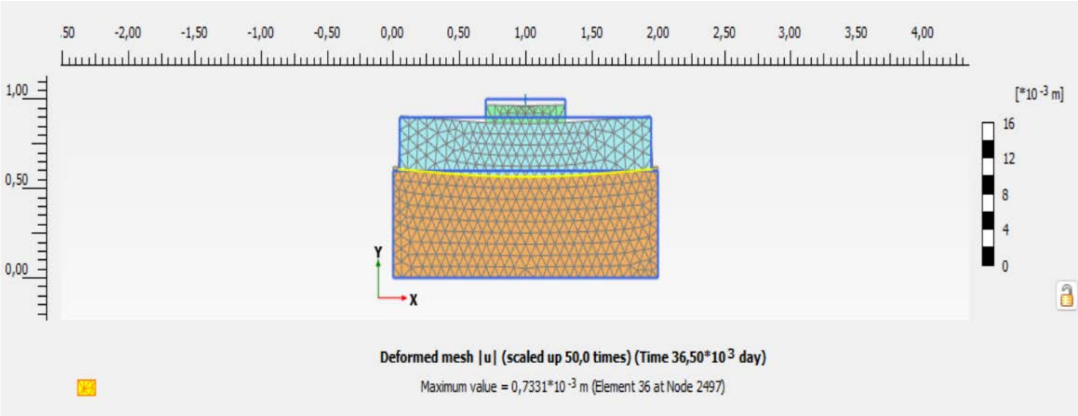

Fig. 7. Deformation of 60 cm thick subgrade

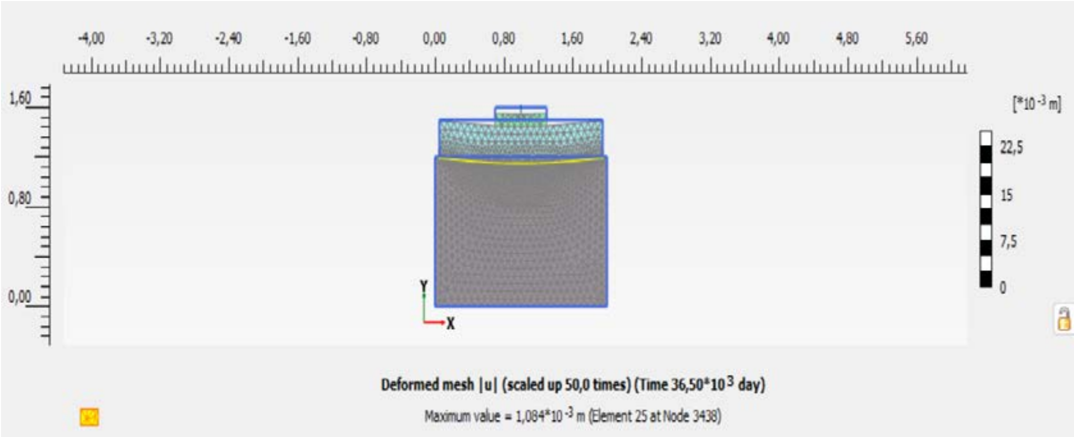

Fig. 8. Deformation of 120 cm thick subgrade

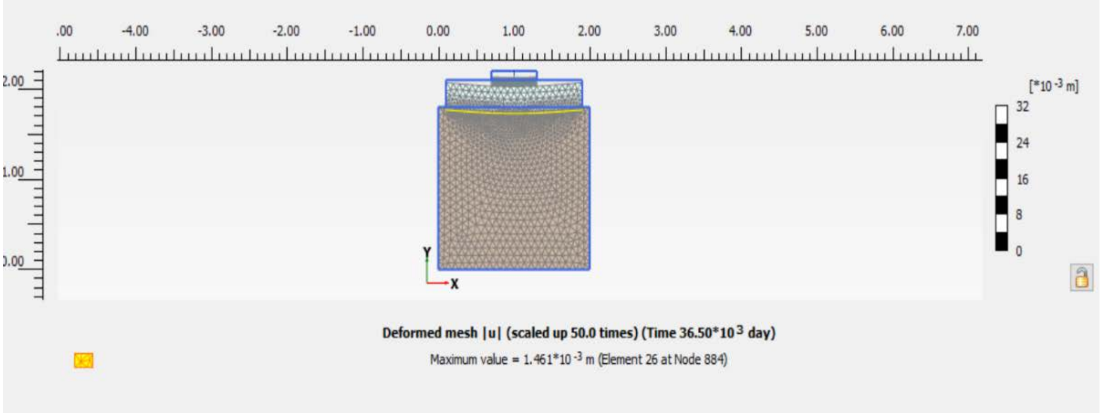

Fig. 9. Deformation of 180 cm thick subgrade

The deformation that occurs is the thicker the subgrade layer, the greater the deformation that occurs where the maximum value of deformation is 1,461 x 10-3 on 180 cm thick subgrade.

Numerical analysis of the variance of subgrade thickness in 30 cm foam mortar embankment is that due to the maximum load of 120 KN the largest settlement occurs at 180 cm subgrade thickness with a value of -0.01421 mm. The value obtained is less than 20 mm as required by the Ministry of Public Works and Housing 2017.

The deformation that occurs is that the thicker the subgrade in the 30 cm foam mortar backfill, the greater the deformation that occurs.

4 CONCLUSIONS

The conclusion is that foam mortar can minimise the occurrence of soil settlement. The thicker the subgrade used in the 30 cm thick foam mortar embankment, the higher the settlement value. The deformation that occurs is the thicker the subgrade layers the greater the deformation that occurs.

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