

Evaluation of Subgrade Bearing Capacity (CBR) And Subsurface Layer On Treated Subgrade Using Grouting Water Cement In The Tuban-Babat-Lamongan-Gresik National Road

Edwin Mehator Situngkir^{1,a)}, Trihanyndio Rendy Satrya²⁾, Ria Asih Aryani Soemitro^{2,b)} & Vidi Ferdian³⁾

¹⁾Masters in Ministry of Public Works and Housing (PUPR), Department of Civil Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.

²⁾Department of Civil Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia.

³⁾Ministry of Public Works and Housing (PUPR), Directorate General of Highways, BBPJJ East Java-Bali, Indonesia

Correspondent : ^{a)}edwin.ms@pu.go.id & ^{b)}ria@ce.its.ac.id

ABSTRACT

One of the causes of the damage that occurred on the Tuban–Babat–Lamongan–Gresik national road is the subgrade condition which has a low CBR value. From the results of the soil investigation, the CBR value is less than 3.0%. To evaluate soil bearing capacity (CBR) and the condition of the subsurface layer after grouting, laboratory and field scale tests were carried out. Laboratory testing by modeling CBR test objects according to field density with injection variations in the quantity of grouting material and water-to-cement ratio (w/c). Variations in the quantity of grouting material injected were 3%, 5%, and 7% of the dry unit weight of the soil samples tested with variations in the ratio of water-to-cement w/c=1, w/c=1.5, and w/c=2. While field testing is carried out by acquiring Ground Penetrating Radar (GPR). The greatest increase in the CBR value occurred in variations in the injection quantity of grouting material at 7% and w/c=1. In the soil sample Sta 37+850 the initial CBR value of 1.41% increased to 2.47%, but the soil bearing capacity of the resulting subgrade was still weak because the CBR value is less than 6%. From the analysis of the GPR data at Sta 37+850, can be seen on the radargram that the grouting material has increased due to back pressure because it cannot penetrate the subgrade layer so the grouting material spreads on the aggregate layer, and exits through the grouting holes at other points on the asphalt surface.

Keywords : Grouting Water Cement, Subgrade, CBR, Ground Penetrating Radar (GPR)

INTRODUCTION

The Tuban–Babat–Lamongan–Gresik road section is located on the Pantura line of Java, Java Island, Indonesia. Pantura line is known as national road from Merak to Banyuwangi along the northern coast of Java Island. This road was first built in 1808 by the Governor General of the Dutch East Indies, Herman Willem Daendels. Since that time, many improvements have been made, starting from subgrade improvement, and overlay to widening. However, from year to year on this route there is often damage to the road structure in the form of cracks, potholes, local settlements, and bumpy asphalt as shown in Figure 1.



Figure 1. Road Damage On The Tuban–Babat–Lamongan–Gresik Road Section
source: BBPJJN East Java-Bali, 2021

From **Figure 1** above can be seen that the damage that occurs on the asphalt pavement surface, some of the possible causes of damage are high daily traffic (LHR), passing vehicles with dimensions and overload (ODOL), problematic and soft soil conditions. In addition, road damage is also caused by subgrade conditions that have low CBR values. From the results of soil investigations using the DCP test, the CBR values are obtained as shown in Table 1.

Table 1. CBR value of subgrade

Location	Position	CBR (%)
35+000	Right	2.00
35+400	Right	1.70
35+600	Middle	1.80
35+800	Left	1.95
36+200	Middle	2.00
36+400	Left	2.50
36+800	Right	2.20
37+000	Middle	2.50
37+200	Left	2.60
37+400	Right	2.80
37+600	Middle	2.10
37+800	Left	2.00
38+000	Right	2.80
38+200	Middle	2.10
38+400	Left	2.90

source: BBPJJN East Java-Bali, 2021

From **Table 1** above can be seen that the initial CBR values were taken at Sta. 35+000 to Sta. 38+400. The test was carried out with a Dynamic Cone Penetrometer (DCP). The resulting subgrade CBR value varies but is very small below <3% so it is necessary to improve the subgrade to increase the bearing capacity of the soil before construction is built on it.

The subgrade improvement on this road segment is carried out by the grouting water cement method, namely by injecting cement water into the soil through drilled holes, one of which aims to increase the CBR value of the subgrade. The grouting is expected to strengthen the formation of the soil layer and make the subgrade soil layer denser (increase the value of

the soil modulus) and the carrying capacity of the soil. Details of the water-cement grouting work can be seen in Figure 2.

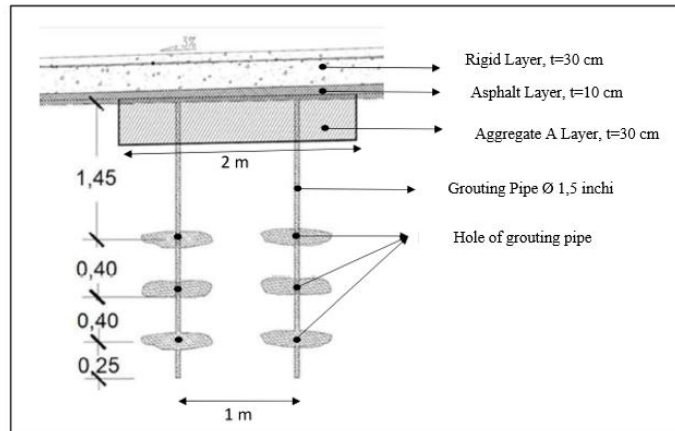


Figure 2. Water Cement Grouting Method Details
source: BBPJJN East Java-Bali, 2021

From Figure 2 above can be seen that the grouting pipe is made of perforated iron pipe with a length of 2.5 meters and a diameter of 1.5 inches which is inserted into the ground. The distance from the top end of the pipe to the first hole is 1.45 meters. The configuration of the distance between these holes aims to ensure that the liquid grouting material enters the subgrade layer, not the aggregate foundation layer of the pavement. The second hole's distance from the first hole is 0.40 meters and so on as shown in Figure 2. The number of horizontal holes in each grouting pipe module is 1 hole. After the grouting points in the field were marked according to the injection pattern, these points were then drilled to penetrate the existing asphalt layer. After being drilled, the grout pipe was inserted into the ground and cement water was injected with a pressure of 5 bar. The injection stops after the grouting fluid comes out from another adjacent point and is injected at the next point

Because one of the goals of grouting on this road is to increase the CBR value of the subgrade, it is necessary to evaluate how grouting affects water-cement on the structural strength of the subgrade bearing capacity. How to test can be done by way of field CBR testing. This test is intended to obtain CBR values directly in place with the help of a truck as a penetration load barrier. However, this test was not applied to this road section with consideration of the high traffic volume and the grouting work area which was not possible. Based on the above considerations to evaluate the effect of grouting water cement on the carrying capacity of the CBR subgrade, a laboratory CBR test was carried out by modeling the CBR test object with field density and variations in the injection quantity of the grouting material, namely 3%, 5% and 7% of the dry unit weight of the test object (γ_{dry}). For each variation of injection, the quantity of grouting material also varies with the water-cement ratio, namely $w/c=1$, $w/c=1.5$, and $w/c=2$.

The condition of the subsurface layer after grouting is difficult to know the distribution of grouting material in the soil, so it is necessary to carry out direct inspections in the field using the Ground Penetrating Radar (GPR) method. This method is non-destructive and has a high degree of accuracy in describing and searching for subsurface anomalies. The geophysical method proved to be a powerful tool in studying the Earth. In the last two decades, ground penetrating radar (GPR) is one of the geophysical methods that is increasingly being used in various scientific and engineering disciplines for various applications. By exploiting the propagation of electromagnetic waves in electromagnetic fields, GPR provides very high-resolution subsurface basin information down to depths typically 0 to 10 m, although depths of up to 40 m (Franke & Yelf, 2003; Jo1, 2003) are

possible in some environments ecological. Recent advances in the use of GPR for sediment investigation can be found in Bristow and B. Venkateswarlu and Vinod C. Tewari Jol (2003). Recently, several studies have proven that GPR plays an important role in analyzing the structure of the Earth near the surface (Gross et al., 1999 and 2000 and Al - Shukri et al., 2006).

This research is very important because very little previous research has been done regarding the injection of cement water in road subgrades and variations in the quantity of grouting material to increase the carrying capacity of the CBR subgrade. Several studies studying the effect of water-cement grouting injection on road subgrades, namely Teck Shang Goh and Osamu Takashi (2014) with the research title Laboratory Study On Grout Injection for Improving Airport Pavement Subgrades. In this study, it was proven that injection of cement water could increase the CBR value of subgrade soil but did not mention the type of soil studied, or how much grout was injected. Jagad (2023) in the study of The Effect of Water Fly Ash Cement Grouting on Clay Soil Characteristics of the Tuban-Babat-Lamongan-Gresik National Road Section also concluded that the fly ash-cement mixture injected into the soil layer can increase the CBR value. Therefore, this research is expected to be able to find out how much influence water-cement grouting has on increasing the strength of the subgrade soil bearing capacity (CBR) with variations in the quantity of grout injection and water-cement ratio (w/c) and to be able to find out the description of the subsurface layer after it has been carried out. grouting on subgrade by direct field testing using the Ground Penetrating Radar (GPR) method.

RESEARCH METHOD

The research method used in this study is to model the CBR specimen sample according to the field density (γ_{dry}) with several variations of the grouting material quantity injection and the ratio of water and cement mixture (w/c) and acquisition of Ground Penetrating Radar (GPR) data to determine the sub-surface layer on the subgrade that has been grouted by water-cement. The research method used in this study can be seen in Figure 3.

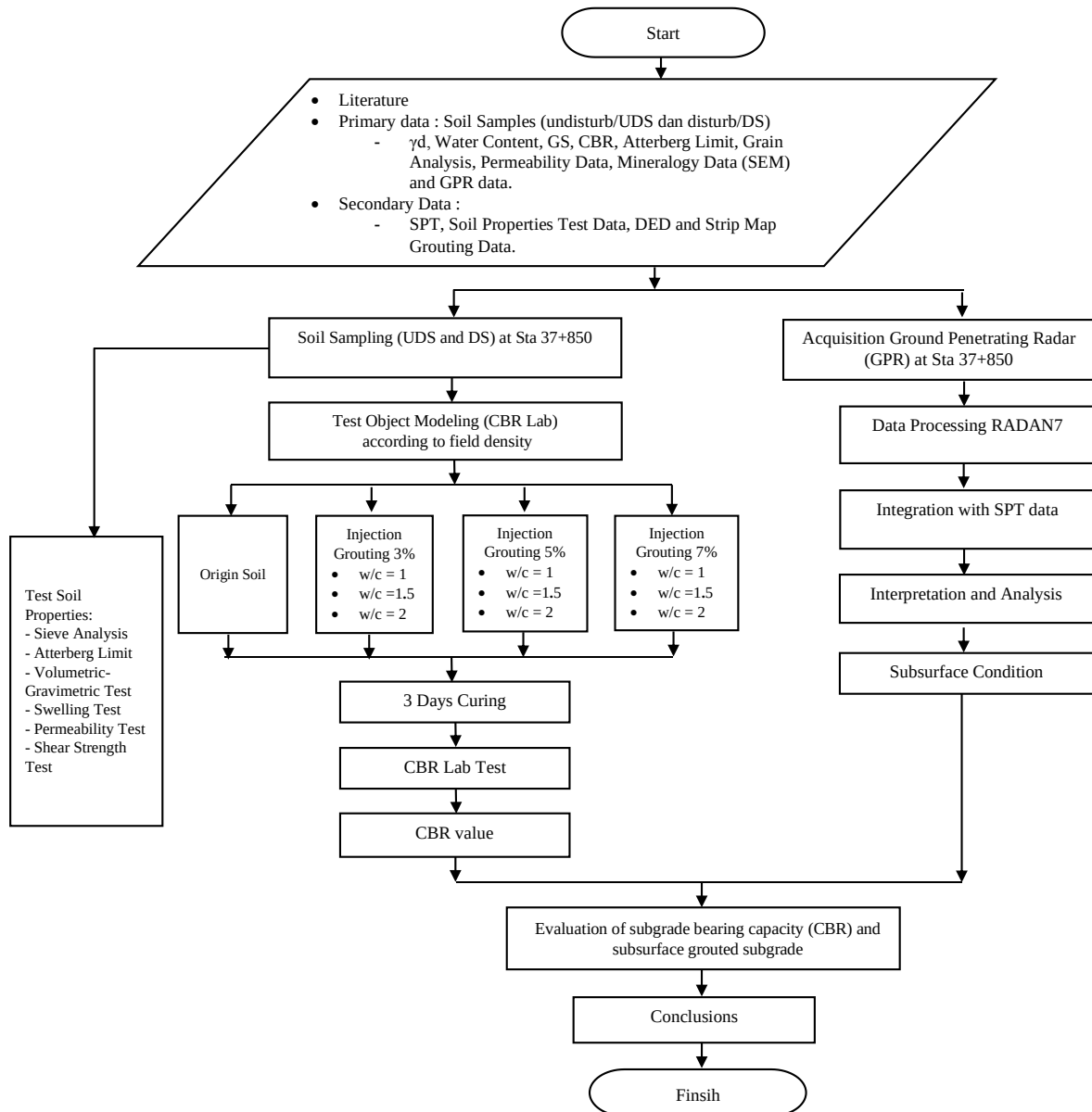


Figure 3. The Flowchart Of Research Method
source: Author's Data, 2022

DATA COLLECTION

The first primary data used in this study was obtained by taking disturbed and undisturbed soil samples. Soil samples were taken from the road shoulder Sta 37+850, then the physical and mechanical properties of the soil were tested and modeling of the CBR specimen was made according to the density of the field with variations in several mixtures of grouting material quantities and variations in the ratio of the mixture of water and cement (w/c). The second primary data is the acquisition of Ground Penetrating Radar (GPR) data at Sta 37+850.

The secondary data used in this study were obtained from BBPJJN East Java-Bali. Secondary data include N-SPT data, DED, and Strip Map of Grouting.

RESEARCH ANALYSIS

Field Density Data

To obtain field density, a volumetric-gravimetric test was carried out and the soil dry unit weight (γ_{dry}) and water content (w_c) were obtained as shown in **Table 2**.

Table 2. Field density

Location	Density γ_{dry} (gr/cm ³)	Water Content w_c (%)	Remark
37+850	1.32	35.24	<i>Subgrade layer</i>

source: Author's Data, 2022

Soil density is usually expressed in its dry unit weight (γ_{dry}). If the soil is compacted with constant compaction at varying moisture content, then at a certain water content value the maximum density (γ_{dmax}) will be reached. Soil samples at Sta 37+850 were taken from the subgrade layer at a depth of 1.0 meters. From Table 2 above can be seen that the density of the soil is 1.32 gr/cm³ and the water content is 35.24%, this shows that there are many pores in the soil.

Evaluation of CBR Subgrade

CBR values after injection of grouting material of 3%, 5%, and 7% with variations in the water-cement ratio $w/c = 1$, $w/c = 1.5$, $w/c = 2$ in the soil sample Sta 37+850 can be seen in **Table 3**.

Table 3. CBR value of injected subgrade 3%, 5%, and 7% grouting material of several variations w/c on sample Sta 37+850

No.	Grouting Material Injection	Variation of Water-to-Cement (w/c)	Curing (Day)	CBR %
1.	-	Origin Soil	-	1.41
2.	3%	1	3 days	2.00
3.	3%	1.5	3 days	1.93
4.	3%	2	3 days	1.56
5.	5%	1	3 days	2.15
6.	5%	1.5	3 days	2.00
7.	5%	2	3 days	1,78
8.	7%	1	3 days	2.47
9.	7%	1.5	3 days	2.21
10.	7%	2	3 days	1,85

source: Author's Data, 2022

There are nine variations of the grouting material injection model in soil sample Sta 37+850. From **Table 3** above can be concluded that the CBR value increased after grout injection with a curing period of 3 days. CBR analysis after grouting is described in Figure 4.

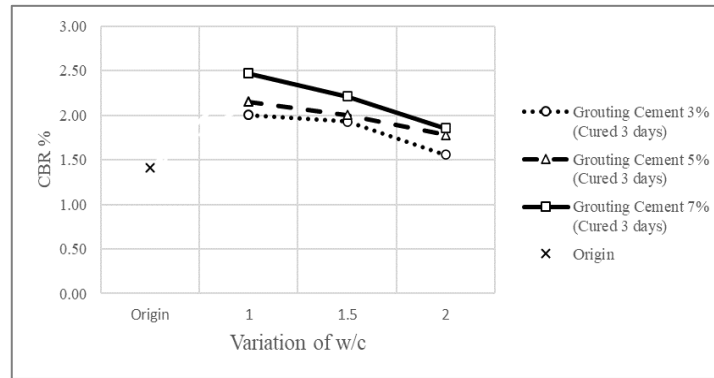


Figure 4. CBR value of injected 3%, 5%, and 7% grouting material of several variations w/c on sample Sta 37+850
source: Author's Data, 2022

From Figure 4 above can be seen that in sample Sta 37+850 the CBR test object was injected with 3%, 5%, and 7% grouting material with variations $w/c = 1$, $w/c = 1.5$, $w/c = 2$ and was then cured for three days and the CBR test was carried out, there was an increase in the CBR value. The greatest increase in CBR value occurred in the injection of 7% grouting material and $w/c=1$. At Sta 37+850 the initial CBR value of 1.41% increased to 2.47% resulting from the injection of a 7% quantity of grouting material with a water-to-cement ratio (w/c) = 1 and is the maximum increase in the CBR value.

A comparison of the results of this study with previous studies shows that this study concluded that the greater the amount of grouting material, the CBR value increases, while the higher the water-to-cement (w/c) value, the lower the CBR value. The behavior of the value of water to cement (w/c) in this study is also in line with the research of Teck Shang Goh and Osamu Takashi, 2014 with the research title Laboratory Studies of Grout Injection for the Improvement of Airfield Pavement Subgrade which shows that the greater the ratio of water-to -cement, the higher the viscosity. low so that the strength is reduced which results in a decrease in the CBR value. In their research, Teck Shang Goh and Osamu Takashi, 2014 also concluded that water cement grouting can increase the subgrade CBR value. Jagad, 2023 in the Study of the Effect of Water Flyash Cement Grouting on Clay Characteristics of the Tuban-Babat-Lamongan-Gresik National Road Section also concluded that the greater the quantity of cement mixture injected into the soil layer of the test object, the higher the CBR value produced. A mixture of water and cement will produce a very thick cement paste that is unable to flow through the soil sample as shown in Figure 5.



Figure 5. A layer of cement paste on the surface of the soil sample at Sta.37+850
source: Author's Data, 2022

From **Figure 5** above it can be seen that the cement water injected into the soil sample of the test object does not enter and spreads into the soil layer so as to form a paste layer on

the top surface of the test object. So that the increase in the CBR value that occurs during CBR testing is due to the paste layer on the surface of the test object becoming hard, not due to increased soil density. The strength of the CBR value is also influenced by the location of the grouting point on the CBR sample where the grouting point on the sample is right in the middle and the piston penetration of the CBR laboratory test equipment also hits the middle of the sample surface so that it greatly influences the increase in the resulting CBR value. In addition, the resulting CBR value also depends on the density of the soil on the specimen. The higher the soil density, the higher the CBR value will be. This is due to the nature of cement which absorbs water and the smooth texture of cement so that it can fill the pores of clay soil thereby increasing the unit weight of the soil which automatically increases soil strength.

From the results of evaluating the bearing capacity of the soil, the initial subgrade CBR value = 1.41% obtained from the results of laboratory scale modeling is included in the soft soil category based on the Bina Marga Specifications 2018 because it has a CBR value of <2.5%. The same CBR value is also shown from the results of CBR testing in the field using the DCP tool, the CBR value is <3% so it can be included in the soft soil category. The subgrade CBR value from the CBR test specimen modeling after injection of the grouting material and the water-cement ratio in sample Sta 37+850 is less effective because the injection of the grouting material is not able to increase the CBR value to above 6%, and the injected grouting material does not enter the layer of the test object thus creating a layer of cement paste on the surface of the test object. The CBR value produced after injection of grouting material = 2.47% is still less than 6% where the CBR value of 6% is the minimum CBR requirement for the road pavement foundation layer issued by Directorate of Highways of the Ministry of PUPR. The low CBR value is because the liquid cement is not mixed homogeneously with the soil, so there is no cementation reaction which can form new, harder grains so that the soil is not strong enough to withstand the given load.

Ground Penetrating Radar (GPR) Data Acquisition

GPR data acquisition was taken in the Gresik direction on the left side of the road. Measurements were made on the road body above the rigid pavement (grouted) and on the shoulders (not grouted). GPR data acquisition locations at Sta 37+850 (E: 663092 S: 9211765).

Interpretation and Analysis

In **Figure 6** can be seen at a depth of 0-2.0 meters that the reflector is in the form of several thick and continuous layers. This layer looks like an elongated layer array and there are more layers than Sta 34+700. The difference in sharpness of contrast is very clear between the layers indicating the different types of materials. If you look at the topography of this area where the left and right sides of this location are ponds, road elevations may have been carried out with embankments against the existing road. This layer can be interpreted as a structural layer in the form of a rigid concrete pavement structure layer on the top surface, the existing asphalt layer, the aggregate foundation layer and the existing embankment. The layer shown by this radargram corresponds to the pavement construction layer in the field.

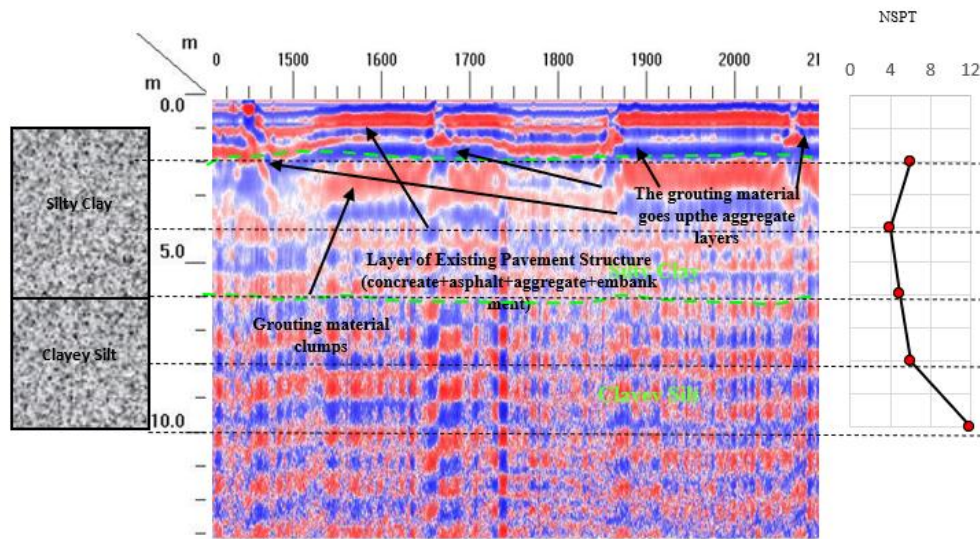


Figure 6. Radargram Sta 37+850 on trace 1500-2075
source: Author's Data, 2022

From **Figure 6** above can be seen that at a depth of 2-3 meters below the structure layer, there is a thicker and continuous layer like a lump with a slightly different reflector model from the layer below where the reflector below is like a sharp horizon, it is possible that this thick layer is grouting material that comes out of the pipe hole grouting but cannot penetrate the layer below it because of the high density of the soil so that the grouting material clumps and forms a layer. In traces 1650, 1850 and 2075 reflectors are resembling a solid and vertical line that breaks the continuous thick layer on the surface of the radagram layer. The possibility of this trace is the weak point of the foundation layer and can be interpreted as the grouting material rising when injected because it cannot penetrate the underlying clay layer so it spreads through the aggregate foundation layer and then exits to the asphalt surface through grouting holes at other adjacent points as happened during the implementation of grouting injections in the field.

At a depth of 3.0-13 meters, uniform and regular reflectors are also seen, there is a slight difference in sharpness, but if observed, the reflector looks like a sharp horizon almost along the trace to the lowest depth it is possible in this trajectory the clay content is relatively thick and saturated so that it affects the radar response. Sharp horizons can also be interpreted as layers of sand and silt. From the drill data (SPT) the type of soil at this location is dominated by clay, silt, and little sand.

Evaluation of Subsurface Layer

From the results of the interpretation and analysis of GPR data at Sta 37+850, it can be seen that the grouting material injected with a pressure of 5 bar (5 kg/cm^2) through the grouting pipe into the soil cannot enter and spread to the subgrade layer. The grouting material rises when injected so that it spreads to the aggregate foundation layer and exits the existing asphalt surface as in the implementation of injection in the field, it can be seen from the reflector resembling a vertical and solid line that breaks the continuous thick layer on the surface of the radagram layer. The grouting material comes out of the bottom hole of the grouting pipe but cannot penetrate the layer below it so the grouting material partially clots and forms this layer which can be seen from the continuous thick reflector under the foundation layer like a different lump from the subgrade layer below which is like a reflector small horizon sharp and uniform. In the subgrade layer, the grouting material doesn't spread because there is no visible change in the soil layer, this can be seen from the layer in the form

of a uniform and continuous reflector along the trace to the lowest layer which forms a small sharp and regular horizon. Based on field observation, the grouting material cannot enter the subgrade layer when injected with a pressure of 5 bar (5 kg/cm^2) so the grouting material spreads on the aggregate layer and then exits onto the asphalt surface through grouting holes at other adjacent points, the same as happened during construction grouting injection in the field. The grouting material rises through the grouting pipe or the gap between the pipe and the soil because there is a cavity during drilling to insert the grouting pipe into the soil.

CONCLUSION

Based on the results of evaluating CBR by modeling injection variations in the quantity of grouting material and water-cement ratio (w/c) and processing of Ground Penetrating Radar (GPR) data on Jalan Tuban–Babat–Lamongan–Gresik, the following conclusions were obtained:

1. From the results of laboratory scale modeling, it was found that the soil bearing capacity (CBR subgrade) before grouting water cement was very low at Sta 37+850 CBR value = 1.41% with $\gamma_{\text{dry}} = 1.32 \text{ gr/cm}^3$; water content $w_c = 35.24\%$.
2. The effect of grouting water cement can increase the soil-bearing capacity of the subgrade soil (CBR). The biggest increase occurred in variations in the injection quantity of 7% grouting material with w/c=1. At Sta. 37+850 the initial CBR value of 1.41% increases to 2.47%, but the soil bearing capacity is still small because the resulting CBR value is less than 6% (CBR requirements for highways subgrade from Directorate of Highways of the Ministry of PUPR).
3. The condition of the subsurface layer after water cement grouting at Sta 37+850:
 - In the subgrade layer there is no spreading of grouting material because, at a depth of 3-13 meters, there is no visible change in the soil layer, this can be seen from the layer in the form of a uniform and continuous reflector along the trace to the bottom layer which forms a small sharp and regular horizon.
 - The grouting material rises when it is injected so that it spreads over the aggregate base layer and out of the existing asphalt surface as can be seen from the reflector that resembles a vertical and solid line that breaks a continuous thick layer on the surface of the radargram layer.
 - The grouting material comes out of the bottom hole of the grouting pipe but cannot penetrate the underlying layer so the grouting material partially agglomerates and forms a layer. This can be seen from the continuous thick reflector under the foundation layer, which is like a lump, which is different from the subgrade layer below, which is like a small, sharp, and uniform reflector horizon.
 - The spread of grouting material does not match the pattern of grouting pipe holes embedded in the soil.

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