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Replacement of Weathered Clay Shale Using Soil Cement for Bridge Approach Embankment in Purwakarta - Indonesia

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ABSTRACT Clay shale is a sensitive soil material that easily experiences weathering if exposed to open air, sunlight, water. Weathered clay shale is commonly located near the surface and has a soft consistency due to surface water infiltration. Referring to this condition, weathered clay shale is prone to experience soil movement if backfill work is conducted on the top side of weathered clay shale material. Therefore, to minimize the potential of soil movement during backfilling, soil replacement using soil cement is recommended to be conducted to gain higher soil shear strength and to prevent excessive water infiltration to the fresh clay shale. To gain further understanding, a comprehensive study about the replacement of weathered clay shale using soil cement for bridge approach embankment in Purwakarta was carried out. This study comprises site observation, field data collection, laboratory test, explanation about implementation and quality control. The stages in implementation of soil cement is carried out in several stages such as : evaluation of soil condition on the project site, checking the suitability of local soil for the soil cement stabilization, conducting field test trial mockup followed by quality control, conducting crumb test and mechanical properties test for soil cement mixture. Based on assessment results, the soil cement mixture shall be directly compacted after the soil cement mixture is homogeneous to prevent segregation and shall be given a curing time of at least 3-7 days without additional water to gain better soil shear strength. Furthermore, according to the crumb test result, soil cement material was identified as quite impermeable which is verified by evidence that there was no significant change in water content and the soil cement sample could still stand firm after soaked for 7 days.

KEYWORDS Soil Stabilization; Weathered Clay Shale; Soil Cement; Bridge Approach Embankment

1 INTRODUCTION

Clay shale is an argillaceous material, an over-consolidated soil - rock that undergoes various types of sedimentation, consolidation, and cementation process. Clay shale is a degradable material, easily fragile, and has a low level of durability (Taylor, 1948). If it is exposed to open air, sunlight, and water, it will be weathered quickly and transform from hard rock to soft clay (Alatas et al., 2015) and change properties from high shear strength to lower shear strength (Adisurya & Makarim, 2022). The illustration of the degradation of clay shale under exposure conditions (Sadisun et al., 2010) is shown in Figure 1.

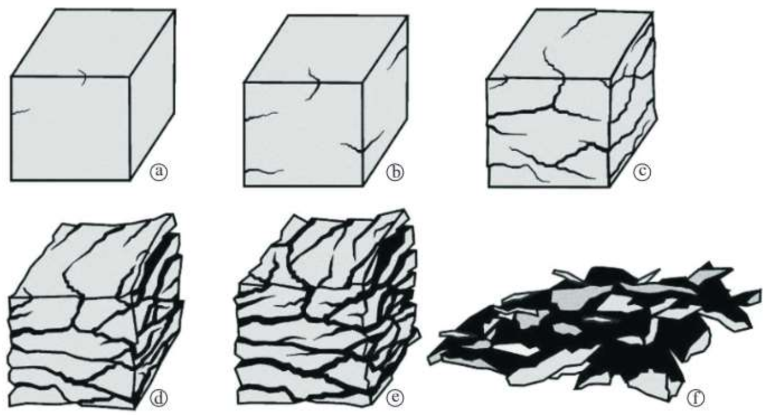

Figure 1. General appearances of the body clay shale under exposure condition (Sadisun et al., 2010)

2 PROJECT DESCRIPTION

Regarding the development of industrial, residential, and commercial areas in Purwakarta - West Java, Cilangkap bridge was designed as one of the main access roads in the development area. Cilangkap bridge is basically designed using concrete as the main structural system (Figure 2). It has a total span of 21 m and uses a diameter 60 cm spun pile with 10 - 12 m length as the foundation system. Furthermore, bridge approach embankment is planned up to 10.5 m in height.

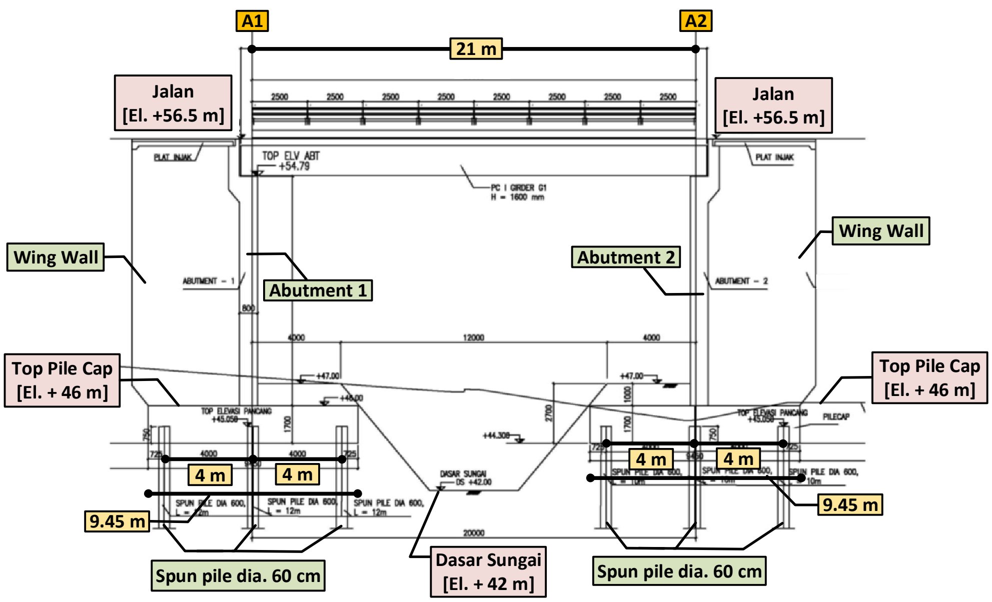

Figure 2. Cross section of Cilangkap Bridge

To gain a better understanding of the soil condition, soil investigation such as deep boring tests and cone penetration tests were conducted to determine the condition of the soil layer in the Cilangkap Bridge development area. Based on site observation, the soil condition in the development area is dominated by weathered clay shale material as shown in Figure 6 and the layout of the soil investigation location is shown in Figure 3.

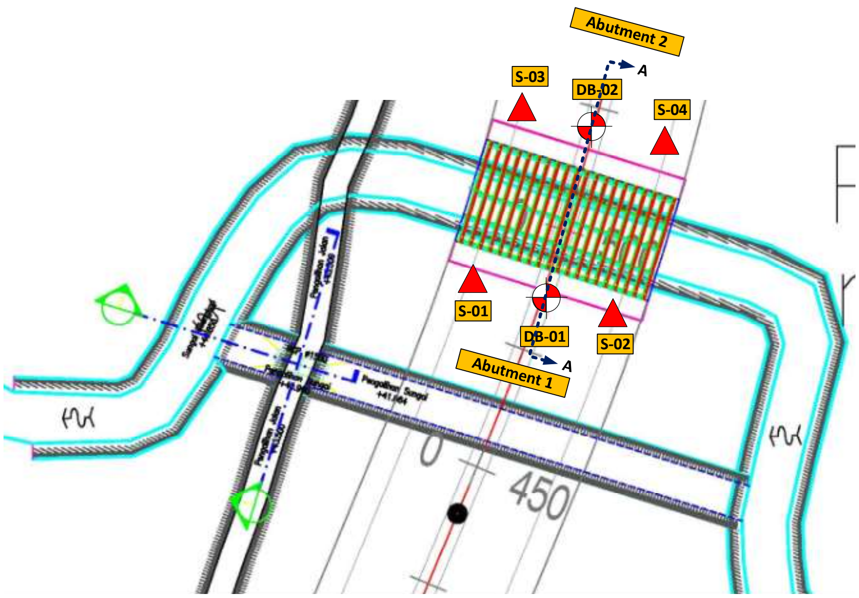

Figure 3. Layout of soil investigation location

Based on soil investigation results (Figure 4 and Figure 5), the soil condition in the development area is dominated by weathered clay shale and followed by fresh clay shale. Unfortunately, it was identified there is a difference between the consistency of weathered clay shale for deep boring tests and cone penetration tests. However, based on visual observation (Figure 6), surface soil is identified with a soft consistency, therefore, cone penetration data is used as reference soil data for the assessment.

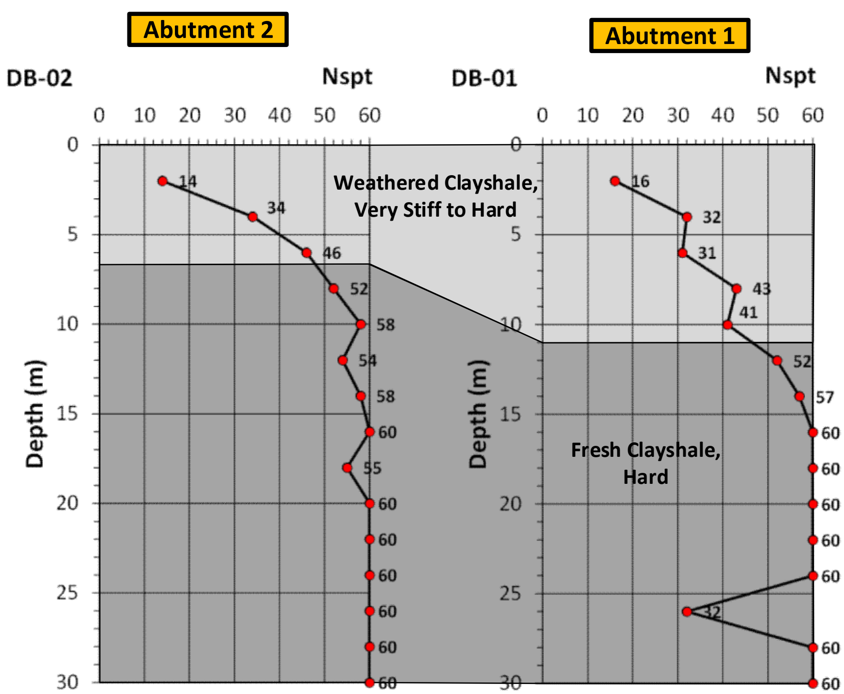

Figure 4. Interpretation of deep boring tests results

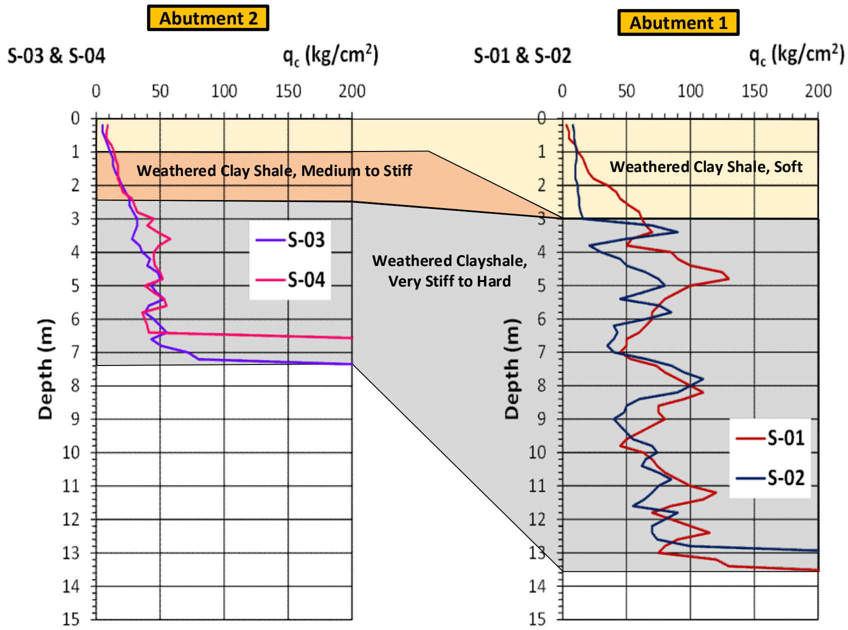

Figure 5. Interpretation of cone penetration tests results

Figure 6. Soil condition on the development area

3 GEOTECHNICAL ASSESSMENT

Based on-site observation, prior to pile driving, some backfilling has been done to reduce the potential for excessive lateral movement on the piles (Figure 7). Since the soil condition is dominated by weathered clay shale with soft consistency on the surface area, backfilling behind the abutment can cause excessive lateral movement (Rahardjo et al., 2015) and additional force to the foundation (Johan et al., 2022). Considering backfilling will later be carried out behind the abutment, some inclinometers have been installed inside the spun pile to monitor the lateral movement (Figure 8).

Figure 7. Documentation of pile driving process

Figure 8. Inclinometer installation inside the spun pile

After the construction of the lower structure had been fully completed (Figure 9), excavation was carried out between abutments as deep as ± 4 m for the river channel. Excavation work caused the foundation to be exposed and deformed as shown in Figure 10 and Figure 11. Due to excavation, the pile foundation was identified as deform ± 6 mm and the sliding plane was identified as located at a depth of 4 m, which is similar to the depth of excavation and located at weathered clay shale with a soft consistency area.

Figure 9. Aerial view of the bridge development area after the lower structure has been fully completed

Figure 10. Documentation of exposed foundation after excavation was conducted between abutments

According to the central difference approximation (Figure 12), deformation that occurred on the pile foundation resulted in the use of the moment capacity of the pile by 100 kN.m out of 170 kN.m (Figure 13). Therefore, to reinforce the foundation, it is proposed to conduct beam reinforcement supported with some mini piles inside the excavated area (Figure 14) and then to prevent any further displacement during backfill, weathered clay shale with soft consistency is proposed to be replaced with soil cement.

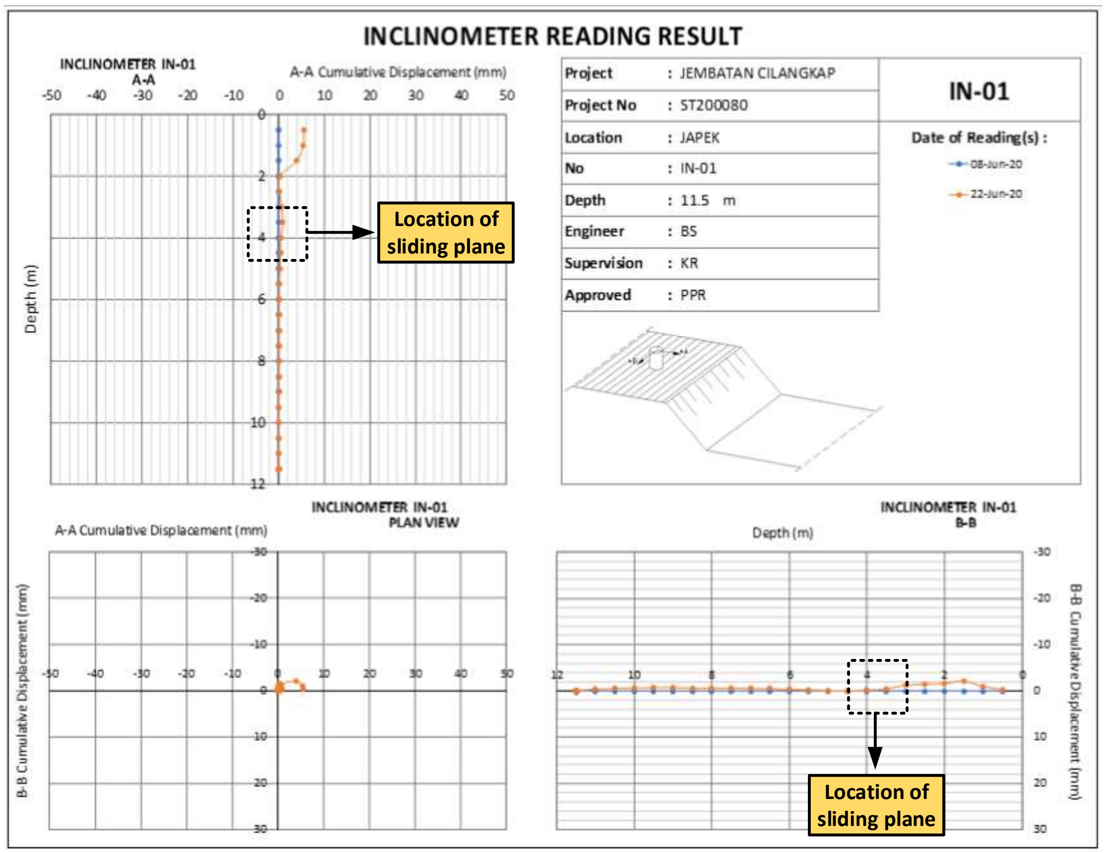

Figure 11. Inclinometer reading results after excavation was conducted

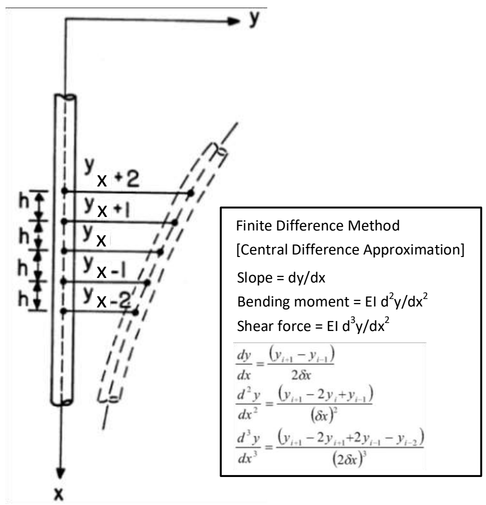

Figure 12. Central difference approximation using finite difference method

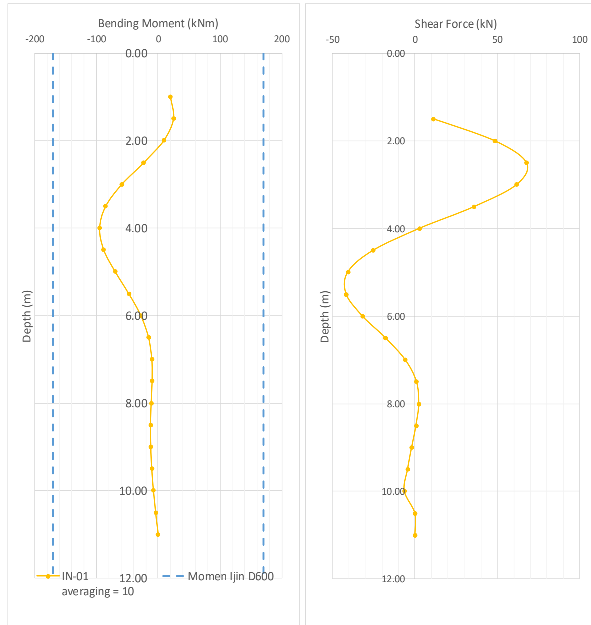

Figure 13. Estimated bending moment dan shear force that occurred on the pile foundation

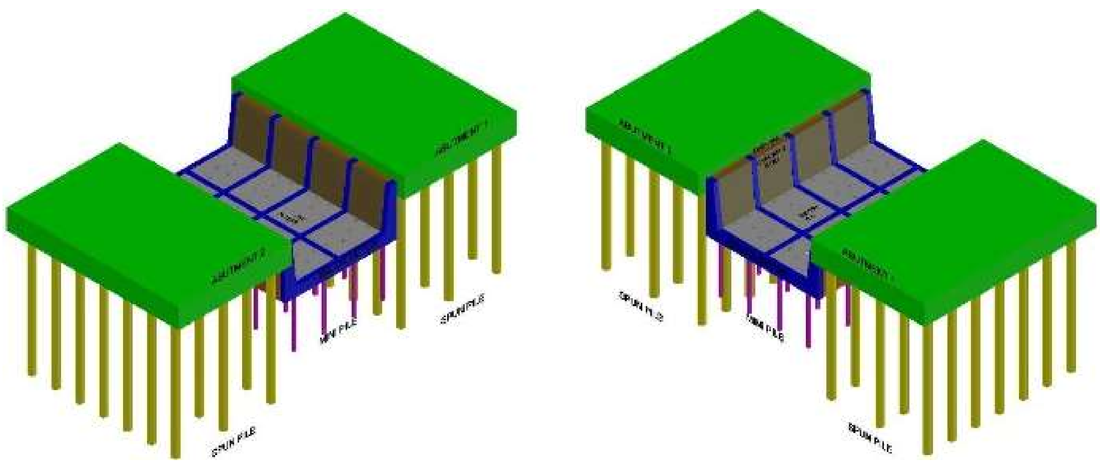

Figure 14. Illustration of beam reinforcement supported with mini piles inside the excavated area

4 SOIL CEMENT

Soil cement is an engineered material that can be used for various material characteristics. Soil cement is often used as a construction material for pipe bedding, slope protection, and road construction as a subbase layer (Dheeraj et al., 2018). Soil cement has a good compressive strength, however, in most cases, it is prone to cracks. There are several factors that affect the properties of soil cement material such as : the nature of the soil and the proportion of the mixing (soil, cement, water), compaction, curing, and any added admixtures.

When cement is mixed with cohesive soil, the calcium ions released during the initial cement hydration reaction area are marked to reduce the soil plasticity. Besides that, it also increases the shear strength and reduces the water-holding capacity of clayey soils. Therefore, it prevents soil from swelling and softening from absorption of the moisture (Limprasert, 1995).

The following describes several stages in the implementation of soil cement stabilization.

a. Evaluation of soil condition on the project site

Since there is soft soil located near the surface layer that is prone to induce lateral movement during backfilling, to verify the thickness of the soft soil layers that need to be replaced with soil cement, additional cone penetration tests were conducted. The location of the additional cone penetration tests are shown in Figure 15. Due to additional soil investigation results (Figure 16 - Figure 19), the weathered clay shale with soft consistency which is proposed to be replaced with the soil cement is 1-2 m as shown in Figure 20.

Figure 15. Layout of additional cone penetration tests location

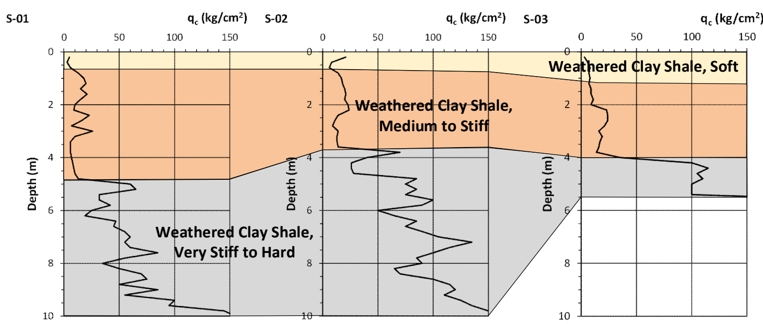

Figure 16. Soil stratification in section A-A

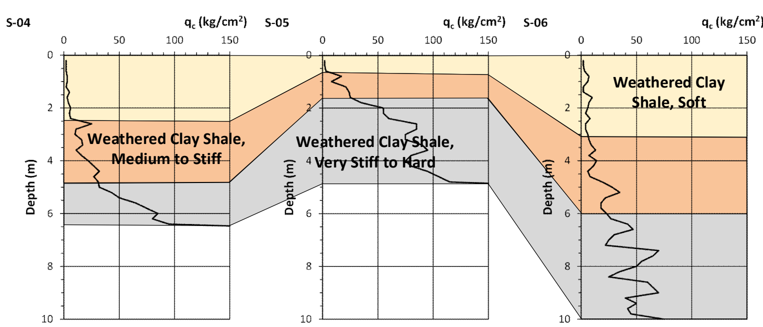

Figure 17. Soil stratification in section B-B

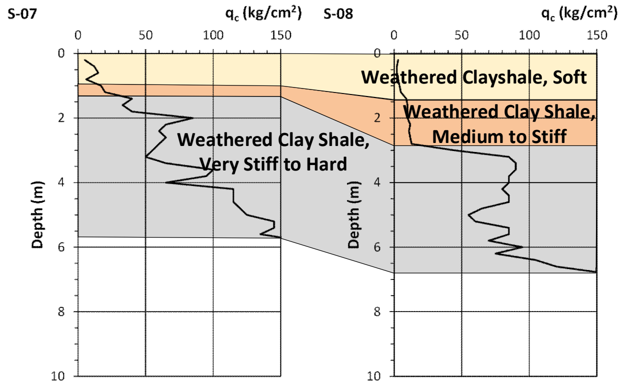

Figure 18. Soil stratification in section C-C

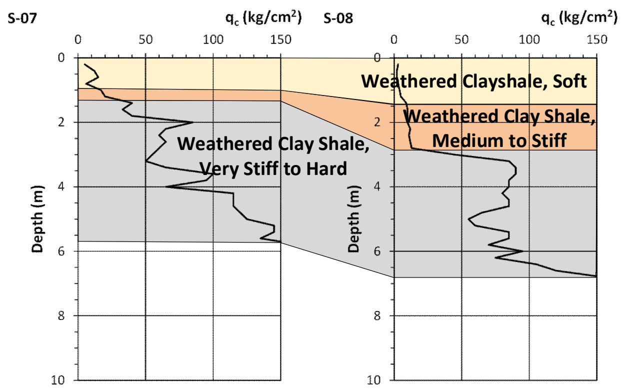

Figure 19. Soil stratification in section D-D

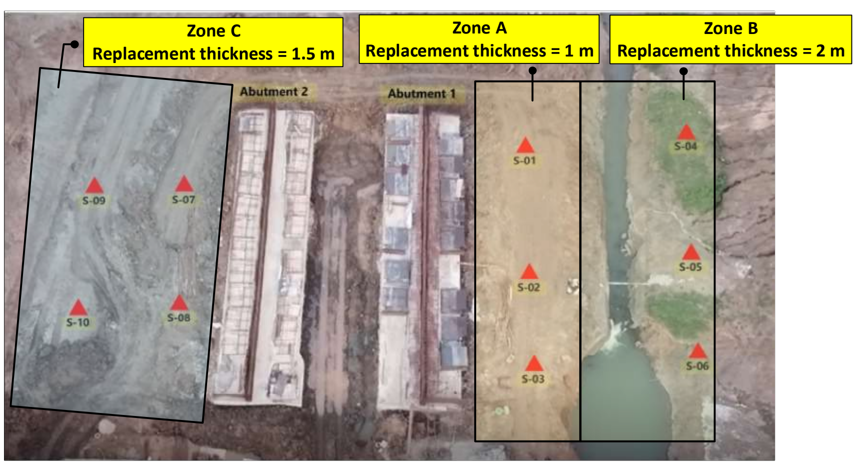

Figure 20. The proposed zone for soil cement replacement thickness

b. Checking the suitability of local soil for the soil cement stabilization

Due to unfavorable existing soil conditions, local lateritic soil material was decided to be used as mixture of soil cement. Lateritic soil is commonly weathered, decomposed residual soil, which occur as surface deposits. Lateritic soil is distinguished by aluminium and iron oxides and has high clay content, thus, with water retention capacity (Ademila, 2022). Lateritic soil consists of a variety red - brown to yellow, fine-grained soils with a light texture (Lambe and Whitman, 1979).

To check the soil suitability, laboratory tests such as CBR tests have been conducted in unsoaked and soaked conditions to know the level of soil sensitivity to water (Figure 21). The target criteria for the unsoaked and soaked condition are CBR ≥ 10% and CBR ≥ 6%.

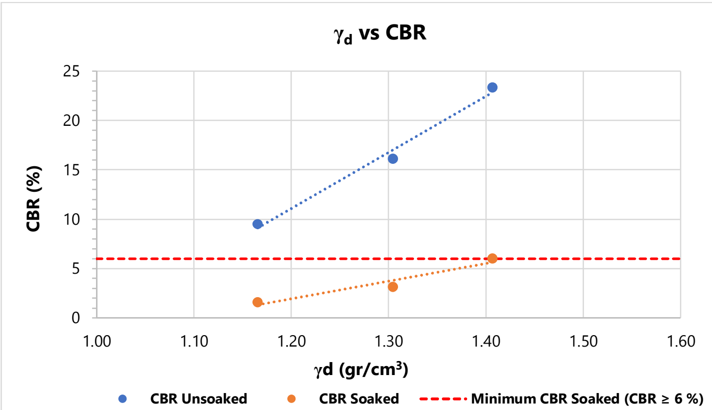

Figure 21. CBR unsoaked and soaked result

c. Conducting field test trial mockup

Field test trial mockup was conducted in several steps such as :

- Trial mockup area preparation

Soil cement trial mockup area is determined with 4 m x 4 m x 0.5 m in dimension (volume = 8 m^3) as shown in Figure 22.

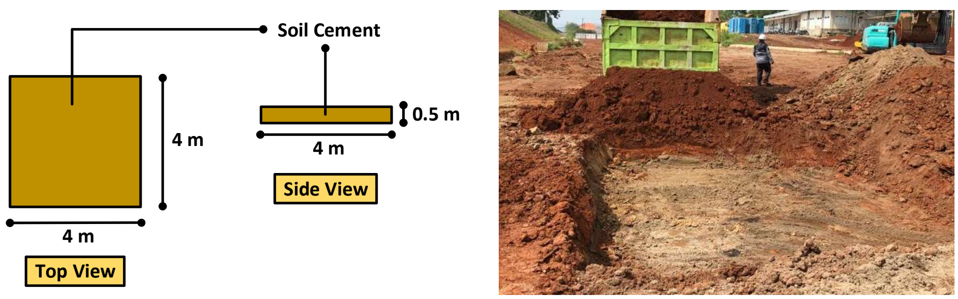

Figure 22. Soil cement trial mockup area

- Soil cement mixing

After the trial mockup area is fully prepared, the selected lateritic soil is placed inside the trial mockup area as shown in Figure 23. Furthermore, 8 % of cement is placed for every 25 cm of soil thickness with a certain grid to facilitate the mixing process (Figure 24). Afterward, the cement was mixed with the soil using a backhoe until the soil was homogeneous as shown in Figure 25.

Figure 23. Selected lateritic soil is placed inside the trial mockup area

Figure 24. Cement is placed for every 25 cm of soil thickness inside the trial mockup area

Figure 25. Soil cement was mixed using a backhoe

- **Soil cement compaction**

After the soil cement mixture is homogeneous, it shall be directly compacted using vibro roller with a certain number of passes to prevent soil segregation as shown in Figure 26

Figure 26. Soil cement compaction using vibro roller

- **Curing Process**

After the soil cement was well compacted, the curing process was conducted for 7 days. The curing process does not allow for additional water since the water content refers to the optimum water content. The curing process can be done by covering the trial mockup area with a tarpaulin as shown in Figure 27.

Figure 27. Curing process by covering the trial mockup area with a tarpaulin

- **Quality Control**

To carry out quality control of the soil cement mixture, CBR test using dynamic cone penetrometer (DCP) was carried out after 3 days and 11 days of curing time. The layout and result of the DCP tests after 3 days and 11 days of curing time are shown in Figure 28 and Table 1.

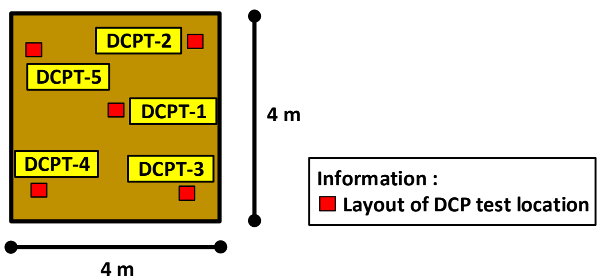

Figure 28. Dynamic cone penetrometer test location layout

Table 1. Recapitulation of dynamic cone penetrometer tests result

Test Point	CBR (%) after 3 days of curing	CBR (%) after 11 days of curing
DCPT-1	12.06	13.56
DCPT-2	11.67	14.25
DCPT-3	13.10	12.80
DCPT-4	19.17	19.18
DCPT-5	12.78	23.56

Based on DCP tests result, 11 days of curing did not experience a significant increase in CBR value compared to the results of the 3 days of curing.

d. Conducting crumb test and mechanical properties test for soil cement mixture

Crumb test and mechanical properties test were conducted on the undisturbed soil cement sample that was taken by coring the soil-cement mixture in the field.

Crumb test for the soil cement sample was conducted for 7 days. From the moisture content and observation result, it was found that the soil-cement sample was quite impermeable (Table 2) and could still stand firm after being soaked for 7 days. Documentation of the crumb test is shown in Figure 29 and Figure 30.

Table 2. Recapitulation of moisture content of the soil cement sample after soaked for 7 days

Soil Sample	Moisture Content (%)
Soil cement sample before soaked	39.85
Soil cement sample after soaked for 7 days	42.83

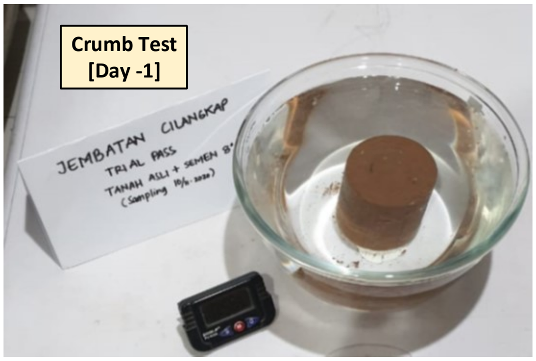

Figure 29. Documentation of the initial condition of the soil cement sample after being soaked

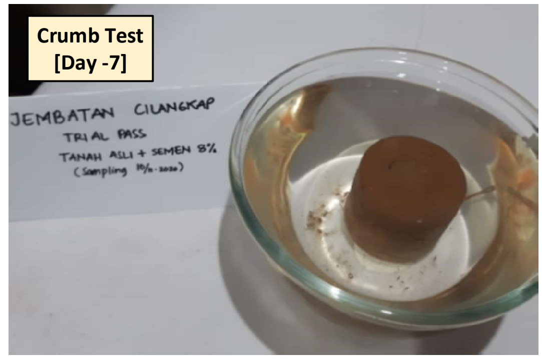

Figure 30. Documentation of soil cement sample after soaked for 7 days

Furthermore, the unconfined compression test that was carried out for the soil cement sample after soaked for 7 days is shown in Figure 31 and Figure 32.

Figure 31. Unconfined compression test to the soil cement sample after soaked for 7 days

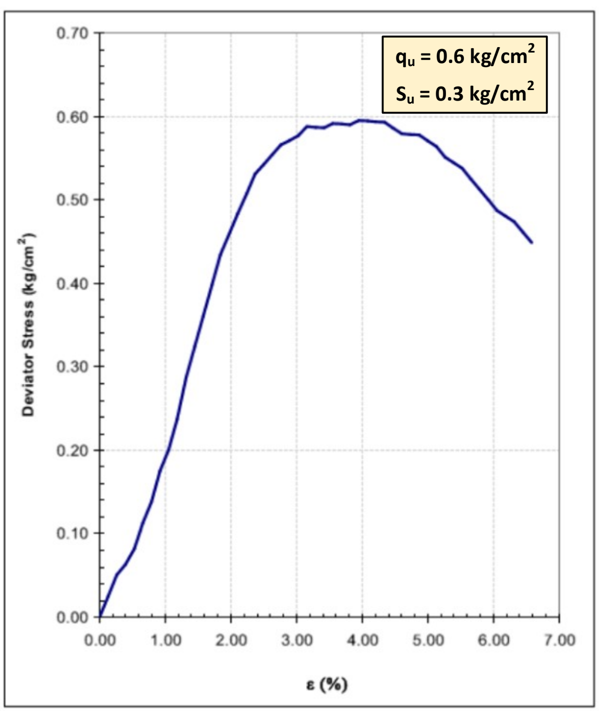

Figure 32. Unconfined compression test result for the soil cement sample after soaked for 7 days

5 CONCLUSION

Based on the geotechnical assessment, the following are several conclusions that can be conveyed.

- Clay shale is a degradable material, easily fragile, and has a low level of durability. If it is exposed to the open air, sunlight, and water, it will be weathered quickly and transform from hard rock to soft clay.
- Regarding the development of industrial, residential, and commercial areas in Purwakarta - West Java, Cilangkap bridge was designed as one of the main access roads in the development area. Based on site observation and soil investigation data, soil condition at project location is dominated by weathered clay shale with soft consistency and followed with fresh clay shale.
- During construction process, excavation work between abutments caused the foundation to be exposed and deformed. Therefore, to prevent excessive lateral movement and additional force to the foundation during backfilling behind the abutments, foundation is proposed to be reinforced using structural reinforcement and weathered clay shale with soft consistency is proposed to be replaced with soil cement.
- The implementation of soil cement stabilization is conducted in several stages such as evaluation of soil condition on the project site, checking the suitability of local soil for the soil cement stabilization, conducting field test trial mockup followed by quality control, conducting crumb test and mechanical properties test for soil cement mixture.
- The soil cement mixture shall be directly compacted after the soil cement mixture is homogeneous to prevent segregation and shall be given a curing time of at least 3-7 days to gain better soil shear strength.
- According to the crumb test result, soil cement material was identified as quite impermeable which is verified by evidence that there was no significant change in water content and the soil cement sample could still stand firm after soaked for 7 days.

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