

FOREWORD

The fields of Earth, Mines, and Environmental sciences (EME) have emerged and evolved alongside with the evolution of human society, and have created a profound impact on all aspects of life and socio-economic development through utilizing natural resources, impacting the environment, and driving global change. The robust development of these areas serves as the foundation for various other fundamental and applied sciences, and concurrently act as a catalyst for technological advancements worldwide, contributing to the common prosperity and safety of humankind as well as the conservation of the blue Earth.

Global change, rapid development of science and technology, and the fourth industrial revolution (Industry 4.0) create many opportunities and challenges for sustainable development. Vietnam, being one of the most vulnerable countries to climate change and natural disasters, is devoting great efforts to achieve sustainable development goals and achieve net zero emissions by 2050 as well as to improve productivity and national competitiveness. In this context, innovation, digital transformation in training, basic and applied research on EME become more urgent than ever for green, circular development and response to global change, sustainable development, prosperity, and safety of the country, the region and the world.

Against such considerations, Viet Nam National University Ho Chi Minh City, in collaboration with Viet Nam Meteorological and Hydrological Administration, the Interdisciplinary Council for Professorship of Earth - Mining Sciences, as well as various research institutes and local and international higher education institutions, jointly co-organizes the International Conference “Earth Science, Mining, Environment for Digital Transformation, Green Development, Circular Growth, and Response to Global Change” (GREEN EME 2023).

The GREEN EME 2023 is a forum for scientists, administrators, and businesses, who are passionate about Earth Science and Environment, Mining (EME) to meet, present and share their research findings, to engage in discussions, and to exchange solutions for a wide range of overall academic issues in these fields. The specific objectives include:

- Publishing outstanding research results and sharing, replicating achievements and experiences in innovation and digital transformation in fundamental and applied research and technology development in Earth Science, Mining, Environment, and related fields in*

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MEASURES FOR EARTH, MINING AND ENVIRONMENTAL SCIENCES
(innovative measures for earth, mining and environment
sciences to meet sustainable development goals)**

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COUPLED EVALUATION OF POLYMER-CEMENT MODIFIED SOIL MIXTURE USED FOR THE IMPROVEMENT OF HAUL ROAD PERFORMANCE AT A COAL MINING SITE

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Abstract: The performance of haul roads is considered one of the crucial factors affecting the efficiency of mining site management. Due to heavy dynamic loads, and the frequency of passes, it is important to provide safe and reliable working conditions for the haul roads on mining sites. Since the technology of road construction in mining areas is well established, it is the construction material that is still a matter of scientific research. The aim of the study is to address the issue of poor haul road performance at a mining site in Quang Ninh province, Vietnam, due to construction material properties used. The present research conducted a laboratory and field test for haul road natural and modified soil mixed with different ratios of polymer-cement additives. The laboratory tests aimed at identifying the most effective material composition for this case study. The major part of laboratory tests comprised compaction behavior, unconfined compressive strength (UCS), and indirect tensile strength (ITS). The laboratory test results proved that the samples prepared on modified soil of 5% polymer and 7% cement gave the highest values of UCS (> 5MPa) and ITS (> 1.2MPa). To confirm the most effective ratios in situ conditions, the study was extended by performing field tests on already constructed roads filled with materials of different compositions. The field test comprised a dynamic cone penetrometer (DCP) and lightweight deflectometer. The results confirmed the conclusions from the laboratory tests. The largest values of the modulus of deformation (> 400MPa), as well as the DCP depth (>30mm), were achieved for soil mixtures as tested in the laboratory. As expected, the lowest values were obtained for untreated material. The research study allowed proposing the most effective solution for the road construction material used for the haul road, so the management and safety of the mining site could be improved.

1. INTRODUCTION

Transportation management in the open pit mines industry in Vietnam continues to develop by improving the technologies of road contraction procedures and materials used. The transportation management expenses encompass a range of costs, including fuel and equipment maintenance that according to available reports [1] contribute to over 65% of total transportation costs. The haul road systems are usually planned and managed based on practical local engineering experience. The increasing demand for development requiring conventional resources of energy requires of larger scale of transportation vehicle employment which leads to burdened road performance, insufficient maintenance planning, and higher overall costs associated with demanding conditions of technological road

exploitation. The planning of mine haul roads involves considering structural, functional, and maintenance aspects [2, 3]. While there is a significant connection between the structural and functional performance of roads and the safe, cost-effective operation of mining transport, it's essential to recognize that the maintenance component of haul road design cannot be treated as distinct from the structural and functional aspects because they are interrelated [4, 5]. The expenses associated with designing and constructing most haul roads make up only a small part of the total costs for operation and maintenance. An ideal functional design will incorporate a specific level of maintenance, including activities like grading, conducted at intervals that align with the required road performance standards and the aim of minimizing both vehicle operating costs and road maintenance costs. In engineering practice, the design and construction of haul roads is only a minor part of the expenses and deserves more attention [2, 6]. Following the common rule, "it is better to prevent than to cure" more consideration needs to be paid when it comes to planning the construction, focusing more on the material used in road works. The factors influencing the open mine management systems are fuel consumption, vehicle operating costs, and maintenance, which are directly related to transport infrastructure conditions [7]. Thus the quality of the road pavement plays a crucial role when the economy is considered. Currently, Vietnamese open-pit mines follow the standards outlined in Article 11 of TCVN 5326: 2008, which focuses on open-pit mining techniques. The transportation standards closely resemble those found in TCVN 4054: 2005, intended for road design and limited to roads accommodating a maximum load of 10 tons. Such standards differ from the reality of Vietnamese open pit mines, where transportation equipment with considerably larger capacities, ranging from 55 to 130 tons, is employed. The mining sites of Vietnam are usually located in mountainous regions with uneven sections and steep slopes, making the site's safety and economy of transport even more challenging. The most efficient means of providing safe and low-maintenance pavements is to establish a permanent road structure using materials like asphalt or concrete, similar to regular highways. However, applying this concept to mining haul roads can be challenging due to their temporary nature and the frequent alterations required to accommodate mining operations [8, 9]. Due to economic factors, haul road construction at the mining sites is usually performed using the natural soil material available and from the excavation works [10].

The present research aims to analyse and propose the optimum soil and additive mixtures used in haul road construction that would allow for improving transport performance and decrease the expenses associated with the maintenance of transportation equipment. For that purpose, soil samples of natural soil available at the site mixed with polymer and cement in different ratios were laboratory tested to verify the mechanical and physical parameters of the proposed mixtures. Based on the results observed in the laboratory, the sections of the haul road were constructed using the mixtures. Then the efficiency of the proposed building material was monitored and tested in situ. Such an approach allowed the adoption of recommendations for the transportation network at the mining site also contributing to the reduction of dust emissions due to the bonding characteristics of polymers and their moisture content containment properties.

2. PRESENTATION OF CASE STUDY

The haul road in the present case study is located in an open pit mine site of Cao Son Coal Join Stock company, Cam Pha city, Quang Ninh province. There are two critical

sections that were studied, namely Section No. 1 and Section No.2. The total lengths of the sections are 2,2km and 0,5km, respectively. The plan view of both sections is presented in figures 1 and 2. Prior to the haul road improvement works, the site condition was investigated using both visual monitoring and in-situ testing methods. The in-situ tests consisted of Light Weight Deflectometer (LWD) Test and Dynamic Cone Penetrometer (DCP) tests. The investigation results indicated that due to improperly adopted design solutions a series of issues, like uneven surface deformations causing potholes, extensive dusting, and surface erosion were identified. The haul road conditions and associated issues are presented in figure 3.

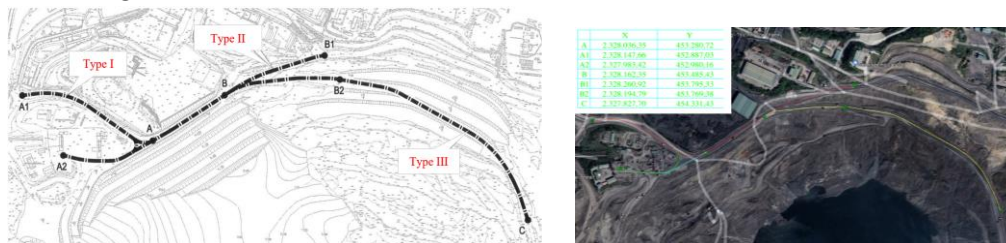


Figure 1. Plan view of Section No. 1 including subsections ($A_1 \div A$), ($A_2 \div A$), ($A \div B$), ($B \div C$), ($B \div B_1$).



Figure 2. Plan view of Section No. 2.



(a) Potholes formed on the haul road



(b) Post mining rock material used for road construction



(c) Dusting issues during transport

Figure 3. Haul road conditions and issues caused by improperly adopted design solutions.

3. MATERIALS AND IMPROVEMENT CONCEPTS

3.1. Materials

Since the purpose of the study was to determine the most efficient soil mixture to improve the driving performance of the haul road the first step was to prepare several samples of different material composition and content ratios. The laboratory testing was performed using the following materials natural soil available at the site (originally used for haul road in section No. 2), blasted residual rock material (used for both surface and base layers in section No. 1), polymer additive (GeoStabTM), and Portland Cement PCB40. The soil and rock samples (exploitation residual material) were collected from an open pit mine of Cao Son Coal company in Cam Pha, Quang Ninh province in Vietnam. The samples were transported to the construction laboratory LAS-XD 1679, weighed, and oven dried in 40°C for 4-5 days. The geotechnical and chemical characteristics of samples of different content and compositions were determined using laboratory equipment following current testing standards i.e. AASHTO T88 (Standard Test Method for Particle-Size Analysis of Soils), AASHTO T90 (Standard Method of Test for Determining the Plastic Limit and Plasticity Index of Soils), AASHTO T 267 (Standard Method of Test for Determination of Organic Content in Soils by Loss on Ignition), AASHTO T85 (Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate), AASHTO T180-19 (Method of Test for Moisture-density Relations of Soils), AASHTO T193-13 (Standard Method of Test for California Bearing Ratio), ASTM D1633-17 (Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders), TCVN 8862:2011 (Standard test method for indirect tensile strength of aggregate material bonded by adhesive binders). The soil samples for laboratory testing were prepared according the characteristics provided in Table 1. The grain size distribution curves for natural soil and the aggregates used for laboratory testing are presented in Figure 4.

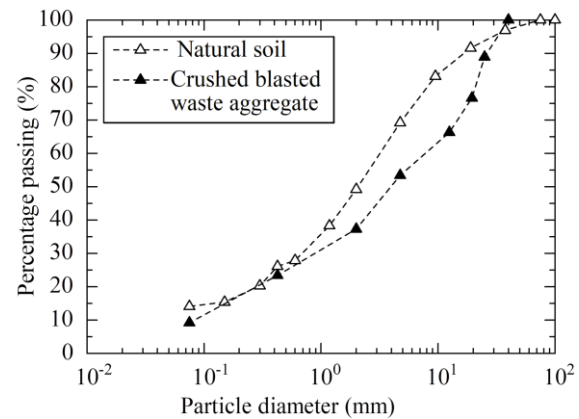


Figure 4. Grain size distribution of soil and rock materials used in the study.

Table 1. Profile of soil specimens for the compaction tests.

| Soil samples | Descriptions |
|--------------|-------------------------------------------------------------------------------------------------------------------------|
| SP1 | Natural soil (including particle size greater than 19 mm in diameter: occupied 8,4% in mass) |
| SP2 | Natural modified soil where a smaller particle size (4,75-19mm in diameter) was used to replace the larger size of 19mm |
| SP3 | SP2+ 5% Geostab + 5% Cement |
| SP4 | SP2 + 5% Geostab + 7% Cement |

3.2. Haul road improvement concepts

The major part of the research was to suggest the most effective material mixture to improve the transport conditions of the haul road. Although equally important was to propose the road construction design so the optimised soil mixtures could meet performance properties obtained in the laboratory. To do so, the authors proposed three different road design approaches, distinguished by the thickness of layered and engineered material, their composition and the location of application to make the results more representative.

The method used to improve the transport condition and the quality of the existing mine haul road for each segment in sections No.1, No.2 was chosen mainly based on the observation and monitoring of the damages caused by heavy vehicles and the erosion effect of the haul road, as well as their functional design in the study mining site. Detail of 3 different concepts of road conditions improvement and the approach used for the two study sections is shown in Figure 5. The mixtures (1, 2, 3) used for different sections and different concepts (1, 2, 3) presenting their particle size composition is given in Table 2.

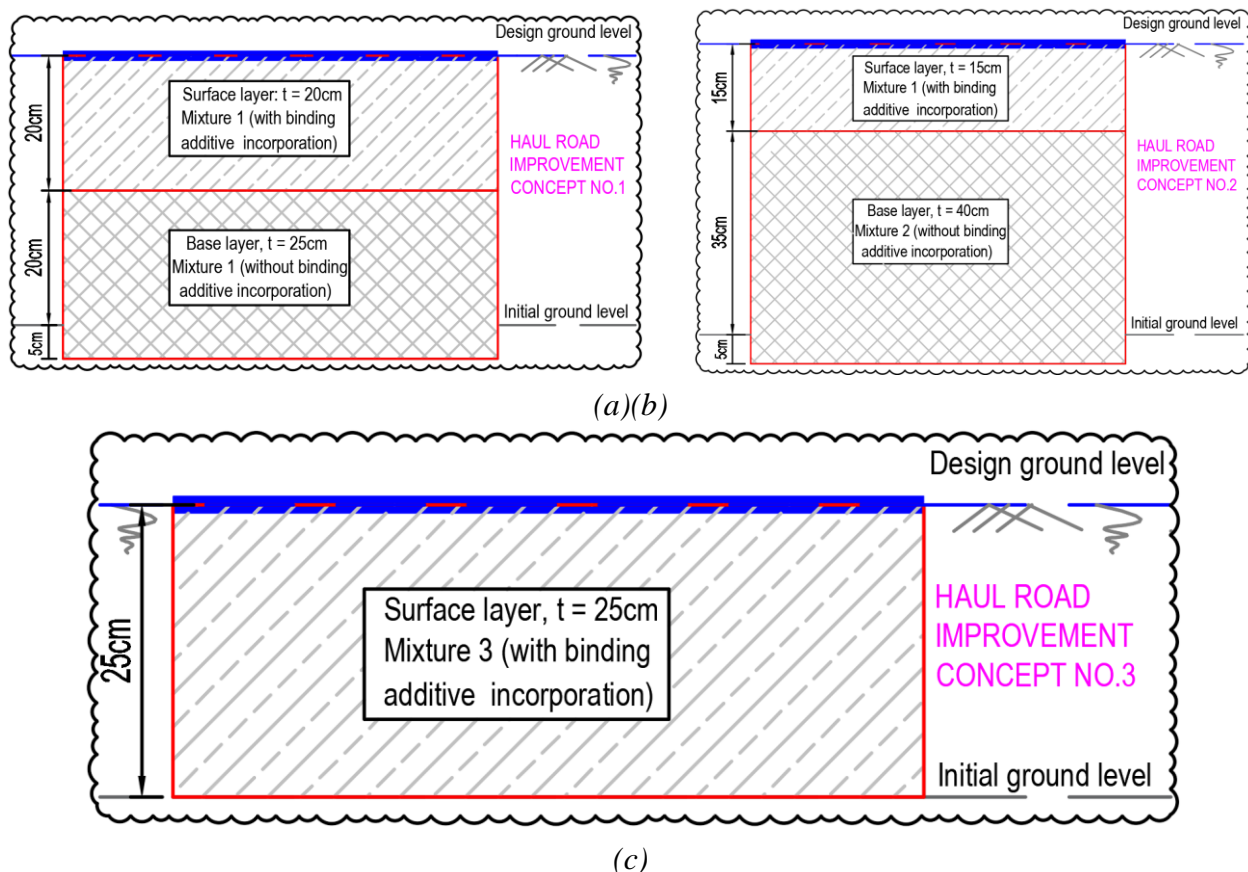


Figure 5. Design concepts for improving the quality of haul roads in each section:

(a) Concept 1 for segments ($A_2 \div A$) for section No. 1; (b) Concept 2 for segments ($A_1 \div A$), ($A \div B$), ($B \div C$), ($B \div B_1$) for section No. 1; Concept 3 used for entire section No. 2.

Table 2. Material's characteristics used in mixtures.

| Descriptions | Maximum size of grain, mm | Group coefficient | Passing 2mm sieve (%) |
|--------------|------------------------------------------------|-------------------|-----------------------|
| Mixture 1 | 40 | 20-35 | n/a |
| Mixture 2 | 150 | n/a | < 20 |
| Mixture 3 | Modified natural soils (grain size from fig 4) | | |

4. RESULTS AND DISCUSSIONS

4.1. Laboratory tests

4.1.1 Compaction characteristics

A series of laboratory compaction tests were performed to evaluate the compaction characteristics of both soil and rock materials, such as maximum dry density and optimum moisture content. For the crushed blasted waste aggregate, the optimum moisture content was about 8%. The soil material's compaction characteristics of all test samples are shown in Figure 6 a and b. The composition of the tested samples is presented in Table 1. Figure 6 a presents the lowest value of the organic matter content (OM) observed for SP1, with the lowest maximum dry density (MDD) which is for the sample consisting of natural soil (including particle size greater than 19 mm in diameter: occupied 8,4% in mass) and the highest MDD for SP2 consisting of modified natural soil where a smaller particle size (4,75-19mm in diameter). The compaction test was performed applying national standards using California Bearing Ration (CBR) and is represented by giving the maximum CBR values. The highest value is obtained for SP4 samples which consist of modified natural soil where a smaller particle size (4,75-19mm in diameter) was used to replace the larger size of 19mm, with 5% addition of Geostab and 7% content of cement, while the lowest is obtained for SP1 sample.

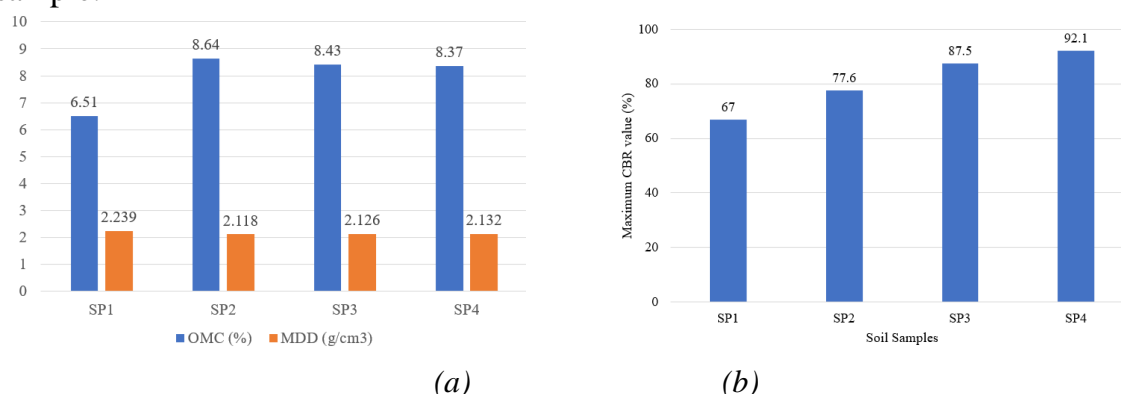


Figure 6. Compaction characteristics of soil samples
a) organic matter content and maximum dry density b) CBR values.

4.1.2. Unconfined Compressive Strength

The unconfined compression test is a common method to determine the strength of the bonded mixtures used for road construction subbase. The unconfined compressive strength (UCS) in the present study was adopted as a parameter reflecting best mixture design for stabilising the natural modified soil that was considered for further application in reinforcing the haul road sub base.

The test was performed for two sample types, SP3 (consisting of SP2 soil+ 5% Geostab + 5% Cement) and SP4 (consisting of SP2 + 5% Geostab + 7% Cement), the UCS was determined at 4 different curing times (3, 7, 14 and 28 days.). The maximum unconfined compressive strength was achieved for the SP4 sample (5% of Geostab and 7% of cement), while the UCS maximum value for the same testing conditions for sample SP3 (5% of Geostab and 5% of cement) was found to be below the required standard. The compressive strength results of tested samples at different curing time are presented in Figure 7.

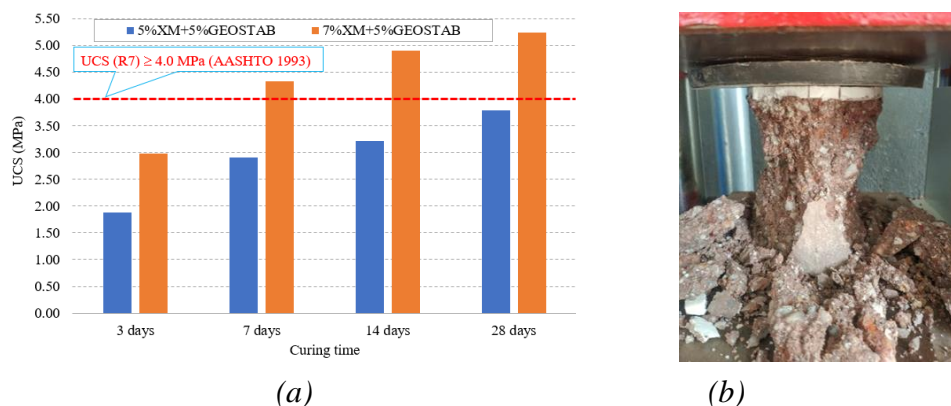


Figure 7. Unconfined compressive strength test a) results, b) tested sample.

4.1.3. Indirect tensile strength

The test involves loading a cylindrical specimen with compressive loads distributed along two opposite generators. The advantage of the test is that the failure is not seriously affected by the surface condition and is initiated in a region of relatively uniform tensile stress. The test allows capturing the peak compressive load applied transversely to a cylindrical specimen prior to or on the onset of cracking. The test was performed according AASHTO. Since the used standard does not recommend any particular value for Indirect Tensile Strength (ITS) of cement-treated aggregate base for road pavement, the Vietnam national standard (TCVN 8858:2023), was used as the reference, where the minimum value of ITS at the curing time of 14 days is 0,45 MPa. Figure 8 shows the results for ITS test indicating that all soil samples met the standard value. As expected the highest values (1.20MPa) were obtained for SP4 sample (consisting of modified natural soil with 5% additive of Geostab and 7% of cement), and only half that strength (0.65 MPa) was achieved for SP3 at 14 day curing time.

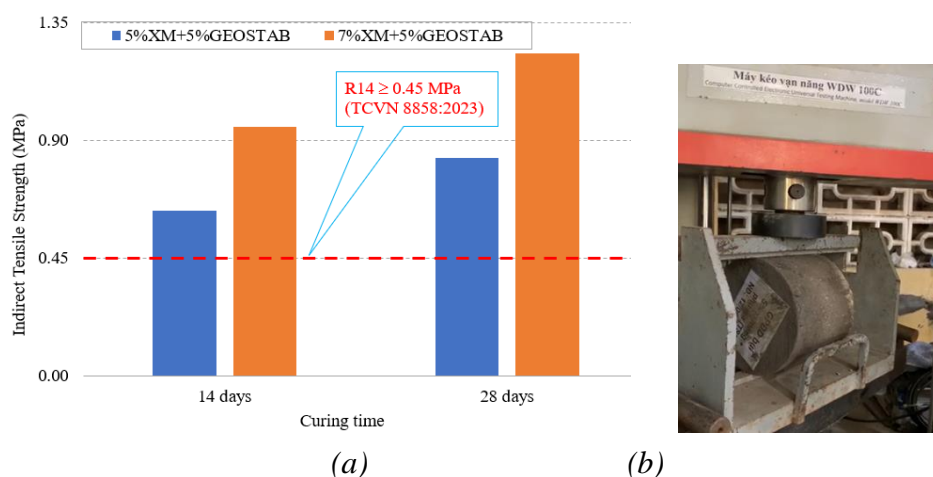


Figure 8. Indirect tensile strength of treated soils SP3 and SP4 a) results b) test in progress

4.2. In situ Assessment

4.2.1. Light Weight Deflectometer (LWD) Test

The present research study aimed also at verifying the laboratory test by performing in-situ investigation before the haul road improvement works and after the new construction approach was implemented. One of the most common on-site test to determine the stiffness of unbound materials (subgrade/subsoils and base layers, granular layers & backfilling

materials) is Light Weight Deflectometer (LWD). The LWD is a lightweight portable tool used for measuring the bearing capacity (deflection) of subgrade/subsoils and unbound base layers. The zone of influence for the test typically extends to between 1 and 1.5 times the plate diameter. It is designed to provide a quick and non-destructive method for determining the load-bearing capacity of soil and assessing its stiffness.

The primary interest in the present study was the determination of Modulus of Deformation. For that purpose, LWD was performed meeting ASTM E2583-27(2015) standard requirements. The part of results of deformation modulus values from point 9 to point 21 representing segments A-A2 and A-B, is shown in figure 9a, b.

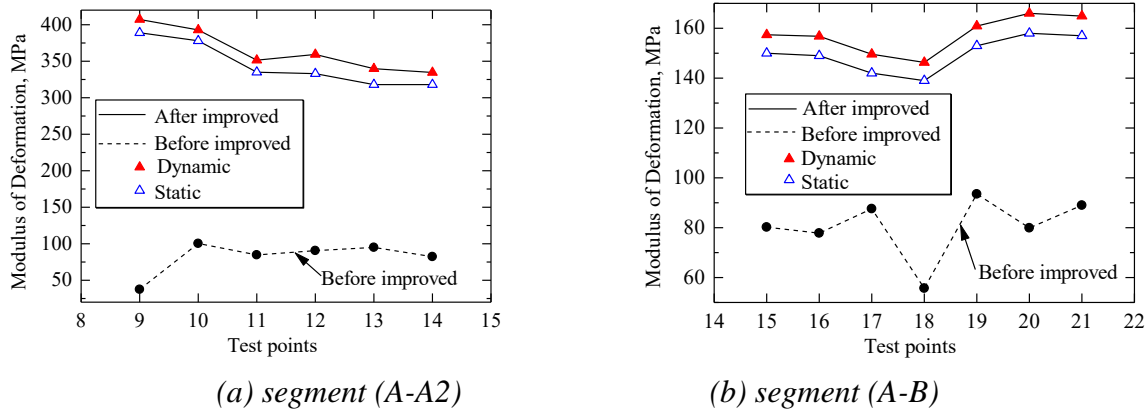


Figure 9. Improvement of modulus of deformation after improvement (stabilised with 7% cement- Concept 1).

The testing procedure was started by selecting 32 test to determine the deformation modulus of the mining road before and after the improvement works (using laboratory-tested mixtures) were executed. There were, 8 testing points in segment (A-A1), 6 points in A-B0, 7 points in A-A2 and 11 points (B-C). In these locations Concept 1 of improvement was used, layering in particular thicknesses soil mixture containing modified natural soil with 5% Geostab and 7% cement. It is clear that the increase in the modulus of deformation is significant for stabilizer-improved soil mixture conditions.

4.2.2. Dynamic Cone Penetrometer (DCP) Test

Another type of test used for coupled verification of results and to confirm best performing results of soil mixture used for haul road improvement was Dynamic Cone Penetrometer (DCP) Test.

The method is used to determine underlying soil strength by measuring the penetration of the device into the soil after each hammer blow. test is conducted by lifting and dropping the hammer onto the anvil, and measuring the penetration of the DCP cone into the pavement layers. Data are typically collected by measuring the penetration after every 5 blows, up to a total depth of 800 mm. The interpretation of DCP test is usually expressed in penetration depth in (mm). However, for comparison with laboratory test purposes, the DCP values could correlated and expressed using CBR approach. The values obtained from DCP test and presented both in CBR values (%) and depth (mm) are given in figure 10 a and b.

Figure 11a shows the CBR values of the haul road in section A-A1 obtained from DCP test, and Figure 11b shows the total DCP penetration. It is noted that the highest values of CBR were obtained for testing point 2 in section A-A1 and the deepest penetration depth

(30mm) was reached for the location of point 6 at the same section. The CBR values presenting the conditions before improvement works are significantly lower, by as much as 50% and more for test point no 2.

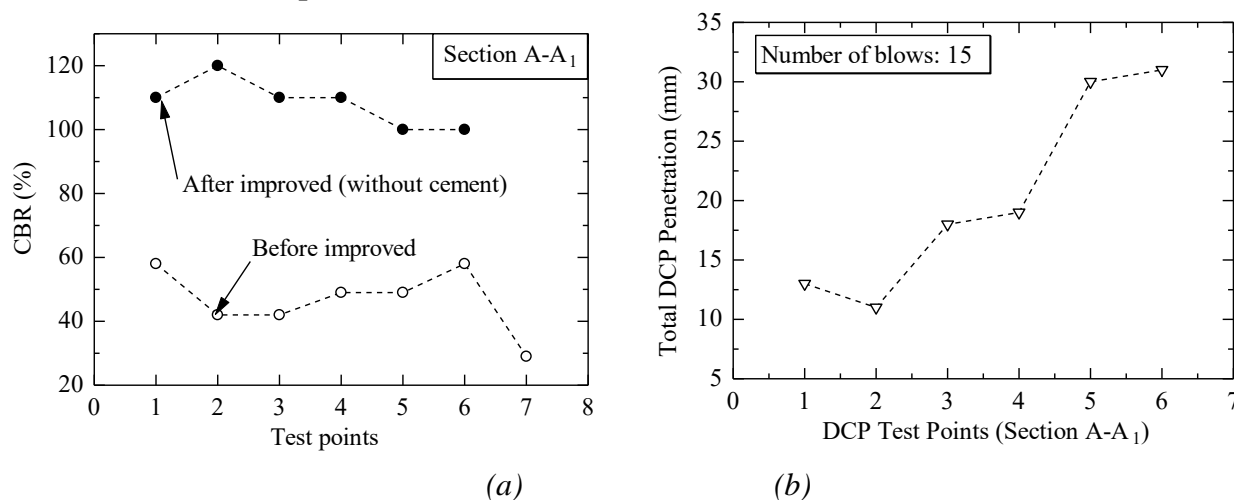


Figure 10. DCP test results a) CBR correlated values before and after improvement
b) penetration depth.

5. CONCLUSIONS

The current study involved both laboratory and field experiments to assess the performance of haul road surfaces made from a combination of natural and treated soils, with varying ratios of polymer-cement additives. In the laboratory experiments, the primary goal was to determine the most efficient material composition specifically designed to meet the requirements for improving the road conditions presented in the present case study. The primary focus of the laboratory tests involved examining the compaction characteristics, unconfined compressive strength (UCS), and indirect tensile strength (ITS) of the materials under investigation. The laboratory test outcomes demonstrated that the specimens prepared using modified soil with a composition of 5% polymer and 7% cement exhibited the most substantial values for unconfined compressive strength (UCS) exceeding 5MPa, indirect tensile strength (ITS) exceeding 1.2MPa. To validate the optimal ratios under in situ conditions, the study was extended to include field tests on existing roads constructed using materials with various compositions. The field testing involved the use of a dynamic cone penetrometer (DCP) and a lightweight deflectometer. The outcomes validated the findings derived from the laboratory experiments. The highest values for modulus of deformation (> 400MPa) and DCP depth (> 30mm) were attained in the soil mixtures tested in the laboratory. As anticipated, the untreated material yielded the lowest values. The research study facilitated the formulation of the most efficient solution for the construction material employed in haul road design, thereby enhancing both the management and safety of the mining site.

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SHORELINE CHANGES FROM QUANG NINH TO THAI BINH IN THE PERIOD 1987 TO 2021 USING GIS TECHNOLOGY AND REMOTE SENSING DATA

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Abstract: The article analyses the process of shoreline changes in the region from Quang Ninh to Thai Binh using different Normalized Difference Water Indices (NDWIs) to separate the boundary between the coastal area and the water bodies on satellite images from 1987 to 2021. The calculation of the shoreline change rate for accretion/erosion processes was performed using the DSAS tool and was validated by Linear Regression Rate (LRR), End Point Rate (EPR) and Net Shoreline Movement (NSM) methods on cross sections along the region. The shoreline in study area was divided into two sub-regions: South Do Son (112 sections) and North Do Son (97 sections). The results from 209 cross-sectional lines show that modern shoreline displacement in the period 1987-2021 in the South Do Son area was alternating processes, both erosion and accretion. Sections at the outer bank of Van Uc estuary showed erosion process with a speed of 14.2m/year. However, the sedimentation process tends to take place strongly at the outer bank of Van Uc river to Thai Binh river with a speed of up to 72.66m/year. The shoreline of the North Do Son sections showed clearer trend in accretion process with an accumulated area of 3,889.67 ha (1987-2003) and 4,179.93 ha (2003-2021). This trend follows the long-term shoreline displacement during the Middle-Late Holocene to present day.

Keywords: *Shoreline changes, GIS, remote sensing, Quang Ninh - Thai Binh*

1. INTRODUCTION

The changes in the topography of the coastline have a great impact on the communities and shoreline ecosystems. The results of the study of topographic changes both on land as well as at the coast are recognized as one of the important sources of documents to develop planning for development and environmental management of the shore zone. Many studies attempted to use remote sensing and geographic information systems as useful tools for monitoring coastline changes in terms of erosion and accretion. A study of shoreline change for over 9000 islands in South East Asia showed that approximately 12% of the total islands had undergone changes in coastlines, resulting in about 251km² decrease in area (Zhang et al., 2021). However, another study by Cui et al. (2022) indicated the length of shorelines around the South East Asia maintained growth, especially in the 1990s, which increased by 734.8 km, from 28,243.8 km (1990) to 28,978.6 km (2000). The increase of artificial shorelines was mostly driven by the expansion of constructed and aquaculture dikes but the proportion of natural shorelines decreased from 92.4% to 73.3% during the past 40 years. Recent study in Phuket, Thailand (Nidhinarangkoon, 2023), also indicated that eight of the study site's locations were under mild erosion from 2013 to 2021. The average shoreline change varied between -4.10 and 5.47m/year.