

From: geomate

Sent: 16 March 2021 17:44

To: y.arifin@ulm.ac.id

Subject: j2141: Dr. Yulian Firmana Arifin :International Journal of GEOMATE :4916970961321158433

Dear Dr. Yulian Firmana Arifin,

Thanks. Your Paper ID is j2141 . **Please use this ID for further communication.**

We would get back to you with review results as early as possible.

Best regards.

=====

Prof. Dr. Zakaria Hossain (Ph.D. Kyoto University),

Editor-in-Chief, International Journal of GEOMATE
(Geotechnique, Construction Materials and Environment)
Professor, Mie University, Japan

E-mail: editor@geomatejournal.com

j2141 Dr. Yulian Firmana Arifin International Journal of GEOMATE 4916970961321158433	
Paper ID Number	j2141
Full Name	Dr. Yulian Firmana Arifin
University/Institute or Company Name	University of Lambung Mangkurat
Office Address	Street Address: Jl. A. Yani km 35.5 City: Banjarbaru State / Province: South Kalimantan Postal / Zip Code: 70714 Country: Indonesia
Phone Number	(+62) 81251160862
E-mail	y.arifin@ulm.ac.id
Co-authors E-mail (separated by comma)	y.arifin@ulm.ac.id
Paper Title	The Permeability and Compressive Strength of Compacted Claystone-Bentonite Mixtures
Research Area	Geotechnique
Recommend Reviewer-1 (E-mail, affiliation & address)	Meilana Dharma Putra, mdputra@ulm.ac.id , Faculty of Engineering, University of Lambung Mangkurat

Recommend Reviewer-2 (name E-mail & affiliation)	Ria Asih Aryani Soemitro, ria@ce.its.ac.id , Laboratory of Soil and Rock Mechanics, Sepuluh November Institute of Technology, Surabaya, Indonesia
---	--

Type of Paper	Research Paper
---------------	----------------

Upload Paper (Form 1)	Permeability full journal template proof reading.docx
-----------------------	---

Upload Copyright (Form 2)	Form 2 copyright.pdf
---------------------------	--------------------------------------

Upload Info (Form 3)	Form 3.pdf
----------------------	----------------------------

From: Geomate Editor
Sent: 27 March 2021 9:29
To: y.arifin@ulm.ac.id
Subject: j2141 : Additional Review Results:- Int. J. of GEOMATE

Dear Authors,

Thanks for your kind contribution. We have reviewers' comments on your paper (attached). Please incorporate all the review results (including the previous if any) in one file of response to reviewer by authors. Please send the revised paper by a maximum of 10 days upon receiving this email. Please send responses to reviewers by authors in separate files. An example of "response to reviewers by authors" is attached. Please use the following link:

<https://www.geomatejournal.com/revised>

Any revisions should be clearly highlighted, for example using the "Track Changes" function in Microsoft Word, so that changes are easily visible to the editors and reviewers. Please provide a cover letter to explain point-by-point the details of the revisions in the manuscript and your responses to the reviewers' comments. Please include in your rebuttal if you found it impossible to address certain comments. The revised version will be inspected by the editors and reviewers. Please detail the revisions that have been made, citing the line number and exact change, so that the editor can check the changes expeditiously. Simple statements like 'done' or 'revised as requested' will not be accepted unless the change is simply a typographical error.

Best regards.

Dr. Zakaria Hossain (Ph.D. Kyoto Univ.)
Professor, Mie University, Japan
Editor-in-Chief, Int. J. of GEOMATE
editor@geomate.org


From: geomate
Sent: 26 April 2021 3:35
To: y.arifin@ulm.ac.id
Subject: j2141: Journal Revised paper

Dear Dr. Yulian Firmana Arifin,

Thanks. You have successfully submitted the revised paper. We would take necessary action as early as possible.

Best regards.

Prof. Dr. Zakaria Hossain

 j2141: Journal Revised paper	
Paper ID number	j2141
Revised Title	THE PERMEABILITY AND SHEAR STRENGTH OF COMPACTED CLAYSTONE-BENTONITE MIXTURES
Full Name	Dr. Yulian Firmana Arifin
E-mail	y.arifin@ulm.ac.id
Co-authors E-mails	emarsyad@ulm.ac.id aprianaji1133@gmail.com 1610811210015@mhs.ulm.ac.id
Revised Paper (Word)	Final article based on the reviewers comments.docx
Response to Reviewers	Response Authors to Reviewers 26042021.docx
(Form 2) Copyright	Form 2 copyright 26042021.pdf
(Form 3) Info	Form 3 26042021 complete.pdf

Now create your own JotForm - It's free!

[Create a JotForm](#)

Response Authors to Reviewer's Comments/Remarks

THE PERMEABILITY AND SHEAR STRENGTH OF COMPACTED CLAYSTONE-BENTONITE MIXTURES

Authors: Yulian Firmana Arifin, Muhammad Arsyad, Aprian Aji Pangestu, Dhandy Pratama

Dear Editor and Reviewers,

I hereby submit the revised article based on the reviewers' comments and suggestions. I apologize for the delay in sending the article because I was infected with Covid19 for quite a long time. Besides, we conducted some experiments on claystone samples that were not mixed with bentonite to meet reviewers' suggestions. We also have to wait a few days for professional English editing corrections. We appreciate your feedback and suggestions for improving the quality of this article. Some of the improvements we made in response to the reviewer's comments are listed below.

	Reviewer A's Comments	Authors response
	The paper is interesting but does not convey the technical explanation of test results. See annotated copy for various suggestions:	We do appreciate the reviewer's comprehensiveness. Following are some of the changes we made in response to the Reviewer's comments.
1	The title of the article	We've changed the title from compressive strength to shear strength.
2	The content of the Abstract does not match with the title of the paper	We revised the abstract in light of the findings and conclusions.
3	The word "passed", Table 1 and the numbers in Table 1, zero air void, Table 2, "The numbers and letters in the legend"	We have been rewritten the sentence in lines 111, 171-174, 192, 197, and the title of Figure 1
4	Author need to explain why permeability is decreasing with increase in bentonite content. Also, plot the permeability of the untreated soil in all figures for comparison purposes.	The discussion regarding the effect of bentonite content of the permeability of samples has been added in lines 274-283. For comparison, we plotted the permeability and shear strength data of compacted claystone having the same density and moisture content in Figures 1-6. Previously, the permeability data of the claystone-bentonite mixture were compared to that of the undisturbed claystone sample.
5	Authors have not explained the role of bentonite in the increase undrained shear strength of the composite soil sample.	We have added a discussion regarding the role of bentonite in increasing the undrained shear strength of the sample in lines 325-341, 342-363, 364-375, and 452-468. We appreciate the reviewer's valuable comment, which has improved the manuscript's consistency.
6	Scale in Figure 2(d)	We have already revised the figure as suggested by reviewer.
7	Axis title in Figures 3, 4, and 6	The axis titles in Figures 3, 4, and 7 (previously Figure 6) have been revised

8	What is the mechanism behind the effect of water content on the permeability of the samples	We have already added the discussion in lines 518-535. We do thank the reviewer for the comment that improve the quality of the manuscript.
9	The conclusions should be point-wise and quantitative in nature rather than paragraphs. Avoid general statements in the conclusions.	We've rewritten the conclusions in lines 705-738. We have also added a qualitative result by adding the data in Table 3-8 in the revised article.
	Reviewer B's Comments	Authors response
1	The authors only checked the permeability and compressive strength. They also observed the effect of water content. Is it possible to check the degree of saturation of the mix so that the authors can relate their compressive strength with the shear strength of soils?	We do thank the reviewer for conscientious review. We have presented the degree of saturation of samples versus the shear strength in Figure 7. The discussion is presented in line 603-636.
2	Generally, the compressive strength of soils does not portray the actual shear strength of soils. Without knowing the microstructure, it is difficult to predict the actual behaviour. The research is solely based on simplified experiments, which may not explain why the authors want to figure it out. The authors need to explain why they discard microstructure analysis and how the simplified experiments show the study's significance	As rightfully stated by the reviewer, the microstructure investigation is very important in this study. However, it is difficult for us to perform SEM testing according to the sample conditions. Some laboratories in Indonesia require samples to be dry. This does not correspond to the real situation. We are trying to collaborate with overseas laboratories that make this testing possible. We write this problem as a limitation of this article in lines 637-646. Thus, we conducted a discussion based on the results of a limited claystone-bentonite microstructure study from the literature. We also write some discussions based on the microstructure of bentonite and bentonite-sand mixture.
	the abstract need to be revised and shortened. The objectives and findings are not clear in the abstract.	The Abstract has been rewritten including the objectives and the results.
	The authors need to submit a native English Editing before its final acceptance to improve the writing quality. Overall, this research is worthy of being published in the GEOMATE journal	The English of the revised manuscript has been improved and check by professional English editing (certificate attached). We do thank the reviewer for the valuable comment to improve the quality of the manuscript.
	Reviewer C's Comments	
	The paper aims to study how the compacted clay stone bentonite mixture affect the geotechnical properties. The paper is informative and is well presented ;however, some changes need to be made:	We do thank the reviewer for conscientious review. The following are revisions in response to the comments and suggestions of the reviewer.
	1.Try to create cohesion and clarify relationships through the sophisticated use of	We agree the suggestion of the reviewer. We add cohesion to the graphs in addition to compressive strength. The cohesion value is

	appropriate transition within and between paragraphs.	written in lines 299-305. We also add to the discussion and some literature relating to increased cohesion with enhanced clay/bentonite content in the soil in lines 364-375.
	2.The noun phrases seem to miss a determiner before it.	The English of the revised manuscript has been improved and check by professional English editing (certificate attached).
	3.Consider adding an article or preposition wherever necessary.	
	4.Study limitations should also be identified and thoroughly discussed.	We agree that this article has limitations, in particular in the discussions about the material's microstructure. We've written it in lines 637-646.
	5. Comparison of the results can be made in the form of percentage reduction or a percentage increase in a tabulated manner instead of text.	We agree the suggestion of the reviewer. We have added Tables 3-8 to provide a qualitative analysis of the results and describe them in the revised article in lines 284-293, 376-390, 469-480, 481-489, 536-547, and 590-597.
	6.State insightful conclusions that will expand and reflect the content	We have rewritten the conclusion in lines 705-738. The addition of qualitative data provides additional information to the conclusions we have written. We do thank the reviewer for the valuable comment to improve the quality of the manuscript.



We certify that the following article

**THE PERMEABILITY AND SHEAR STRENGTH OF COMPACTED CLAYSTONE-
BENTONITE MIXTURES**

Yulian Arifin

has undergone English language editing by MDPI. The text has been checked for correct use of grammar and common technical terms, and edited to a level suitable for reporting research in a scholarly journal.

MDPI uses experienced, native English speaking editors. Full details of the editing service can be found at

► <https://www.mdpi.com/authors/english>.



Basel, Switzerland
April 2021



THE PERMEABILITY AND SHEAR STRENGTH OF COMPACTED CLAYSTONE–BENTONITE MIXTURES

*Yulian Firmana Arifin¹, Muhammad Arsyad², Aprian Aji Pangestu², and Dhandy Pratama²

¹Professional Engineer Education Study Program, University of Lambung Mangkurat, Indonesia; ²Civil Engineering Study Program, University of Lambung Mangkurat, Indonesia

*Corresponding Author, Received: 00 Oct. 2018, Revised: 00 Nov. 2018, Accepted: 00 Dec. 2018

ABSTRACT: A compacted claystone–bentonite mixture is proposed for use as a clay barrier. This research, in turn, focuses on the effects of bentonite mix on the permeability and shear strength of compacted claystone–bentonite mixtures. The claystone used was obtained from the Banjarbakula landfill project, approximately 10 km from Banjarbaru, the South Kalimantan Government's Administrative Center, Indonesia. The bentonite used is commercially sold in Indonesia. The claystone was mixed with bentonite at a percentage of 5%, 10%, 15%, and 20% bentonite by dry-weight bases. The mixtures were compacted at a moisture content of 10%, 15%, and 20% to reach the dry unit weight of 16kN/m³–19kN/m³. Permeability and unconfined compressive strength tests were performed in this study. The result showed that the permeability of mixtures decreases with increasing bentonite content. The addition of up to 20% bentonite to the mixture reduced the permeability by 4.5 times, as compared to the sample without bentonite. Moreover, the mixtures' shear strength indicated by compressive strength and cohesion increased by increasing the bentonite content to 15%. The maximum shear strength obtained was three times higher than without bentonite. The mixtures' permeability and shear strength were also significantly affected by the sample's density and moisture content. A percentage of 20% bentonite is recommended, considering the wide range of acceptability based on two criteria (i.e., permeability and shear strength).

Keywords: claystone, bentonite, permeability, shear strength, acceptable zone

1. INTRODUCTION

Permeability is an essential parameter in determining whether a material qualifies as a clay liner, and the limits required to determine the clay liner layer vary in different countries. Austria, Belgium, Hungary, Italy, Portugal, Switzerland, and Turkey, for instance, require a permeability of 1×10^{-9} m/s [1,2], and the same value is observed for other developed countries such as the UK and the USA [1]. Meanwhile, Germany requires a permeability of 1×10^{-10} m/s with a layer thickness of ≥ 0.75 m, and France requires a higher value of 1×10^{-6} m/s, but with a mineral barrier thickness of at least 5 m [1]. Moreover, Asian countries such as Japan also require the permeability of mineral barriers to be 1×10^{-9} m/s for type C municipal solid waste. In Indonesia, the standard landfill base layer can use a geomembrane with a thickness of 1.5–2.0 cm or a clay liner with a permeability of 1×10^{-8} m/s with a total thickness of 60 cm [3]. In this study, we adopted the requirement used in many countries: a minimum permeability of 1×10^{-9} m/s

Several methods are commonly applied to obtain low permeability in which compaction is the most common one [4–6]. This method leads to a reduction in soil pore volume, thereby inhibiting the flow of water in the soil. However, soils compacted at different moisture contents, despite having the

same density, have different permeabilities [4,5]. Moreover, compacted clays with high water contents have smaller pore sizes despite having the same pore volume [7].

It is also possible to reduce permeability by mixing the sample with bentonite [5,8–11]. The addition of bentonite, however, has an estimated efficacy of less than 15% [12], with only negligible changes to permeability being observed. It was also reported in a previous study that 15% clay was required to obtain a permeability that met the minimum requirements of 1×10^{-9} m/s [4]. Arifin and Sambelum [5] also mixed commercial bentonite at 5–20% with local soil containing a lot of sand and silt in a landfill development project in Rikut Jawa, Central Kalimantan. The results showed that the permeability of the sample mixture met the requirements after being mixed with 50% bentonite. It is important to note that a higher density is needed to achieve the required permeability.

In several countries, a mixture of sand and compacted bentonite has also been proposed for use as a clay liner [4,8,9,12], especially at high-level waste repositories [2,6,13–17]. It involves mixing sand and bentonite at different percentages, taking into consideration how the sand's size influences the permeability of the mixture [9,18]. Moreover, different types of bentonite were used in previous studies, such as sodium bentonite [2,6,8,17–20],

86 calcium bentonite [13,14], and others [9,11,12]. The
 87 behavior of each mixture has been found to heavily
 88 influenced by the type of bentonite used [20].
 89 Recently, a mixture of claystone and bentonite
 90 is the most common approach for alternative barrier
 91 layers in high-level waste repositories [6,21–23].
 92 Claystone is found in large quantities during
 93 excavation and tunnel projects. This material is
 94 usually discarded because of its unfavorable
 95 properties when interacting with water [24–28].
 96 Claystone layers are also often believed to be the
 97 source of failures in civil constructions. However,
 98 its combination with bentonite has several
 99 advantages due to the low permeability of both
 100 bentonite and claystone. The use of 80% claystone
 101 and 20% bentonite in a claystone–bentonite mixture
 102 has been reported to reduce permeability by one
 103 order [21], showing that the presence of claystone
 104 reduced the quantity of bentonite used in the
 105 mixture.
 106 Cui [6] reported that crushed Callovo–
 107 Oxfordian (COx) claystone behaved as an inert
 108 material, such as sand, in a swelling pressure test.
 109 Meanwhile, Zhang [22] found that a fracture in the
 110 claystone closed itself due to the development of
 111 clay minerals when filled with water. This means
 112 that the behavior of claystone depends on the clay
 113 minerals it contains due to the fact that it is usually
 114 obtained from nature. Therefore, it is necessary to
 115 investigate the behavior of claystone–bentonite
 116 mixtures to determine their optimum use as barrier
 117 layers.
 118 Shear strength is also considered to be an
 119 important parameter in determining the suitability
 120 of clay liner materials [29,30]. The recommended
 121 minimum remolded undrained shear strength in the
 122 UK is 50 kPa (or higher for specific locations) [31].
 123 Moreover, waste engineering properties such as
 124 shallow slope liner stability and integrity, steep
 125 slope liner stability and integrity, and cover system
 126 integrity are also considered in landfill design [32].
 127 However, everything is directly related to the clay
 128 liner's strength, meaning that it is vital to determine
 129 the shear strength parameter.
 130 Previous studies mostly focus on high-density
 131 samples, which are applied as barriers in the nuclear
 132 waste repositories. However, claystone–bentonite
 133 mixtures are expected to be useful in broader
 134 applications in which lower densities are required,
 135 such as landfills. Therefore, it is necessary to
 136 investigate the behavior of claystone–bentonite
 137 mixtures at different bentonite contents, densities,
 138 and moisture contents.
 139 This research focuses on the permeability and
 140 shear strength of claystone–bentonite mixtures at
 141 different compositions. The results are expected to
 142 determine the best composition and the ranges that
 143 meet the permeability and strength criteria. The
 144 claystone was obtained from the excavation of a

145 landfill development project in Banjarbaru City,
 146 South Kalimantan, where it was discarded. The
 147 density and moisture contents of the samples were
 148 also considered to affect the permeability of the
 149 mixture in addition to the bentonite content.

150
 151 **2. MATERIALS AND METHODS**

152
 153 **2.1 Materials**

154
 155 The claystone used in this study was obtained
 156 from the Banjarbakula landfill development project,
 157 where over 8000m³ was surplus to requirements.
 158 The bentonite used was from common commercial
 159 sources in Indonesia. Table 1 shows the engineering
 160 properties of the claystone and bentonite used. The
 161 bentonite had very high plasticity, with a liquid
 162 limit of 351.71% and a plasticity index of 307.03%,
 163 while the claystone had a liquid limit of 50.76% and
 164 a plasticity index of 29.81%. The dominant
 165 fractions in the claystone were clay and silt, making
 166 up 51.55% and 43.94%, respectively. In contrast,
 167 the bentonite was composed of up to 90.28% clay
 168 fractions. From Table 1, the dominant exchangeable
 169 cation in each sample was Ca²⁺.

170
 171 Table 1. Physical and index properties of the
 172 claystone and bentonite used.

Properties	Claystone	Bentonite
Specific gravity	2.60	2.71
Water content (%)	2.75	14.17
Soil compositions:		
Gravel (%)	0.0	0.0
Coarse sand (%)	0.1	0.0
Medium sand (%)	0.1	0.0
Fine sand (%)	4.3	1.4
Silt (%)	43.9	8.3
Clay (%)	51.6	90.3
Plasticity:		
Liquid limit (%)	50.76	351.71
Plastic limit (%)	20.95	44.68
Shrinkage limit (%)	9.74	41.89
Plasticity Index (%)	29.81	307.03
Exchangeable Cation:		
Na ⁺ (meq/g)	0.30	0.34
Ca ²⁺ (meq/g)	4.30	18.70
Mg ²⁺ (meq/g)	0.10	0.20
K ⁺ (meq/g)	0.30	0.58

173
 174
 175 **2.2 Techniques and Procedures**

176
 177 **2.2.1 Samples preparation**

178 The standard Proctor compaction [33] test was
 179 conducted to obtain the optimum moisture content
 180 and maximum dry density, which were 15% and
 181 16kN/m³, respectively. The claystone was crushed
 182 and sieved with a mesh No. 40, and mixed with 5,

183 10, 15, and 20% of bentonite on a dry weight basis.
 184 The water content was used at the optimum
 185 condition of 15%, dry of optimum at 10%, and wet
 186 of optimum at 20%. Moreover, the dry volume
 187 weight of the samples was prepared at variations of
 188 16, 17, and 18kN/m³ to determine the dry density
 189 effect. However, high moisture content (i.e., 15 and
 190 20%) was not applied at high densities due to the
 191 difficulty of compaction when working very close
 192 to zero air void line. The sample conditions are
 193 summarized in Table 2.

194
 195 Table 2. Compositions, densities, water content,
 196 and code of samples.

Clayst. (%)	Bent. (%)	Dry unit weight (kN/m ³)	w (%)	Sample code
100	0	16, 17, 18, 19	10	100CS-w10
100	0	16, 17, 18, 19	15	100CS-w15
100	0	16, 17, 18, 19	20	100CS-w20
95	5	16, 17, 18, 19	10	95CS5B-w10
95	5	16, 17, 18	15	95CS5B-w15
95	5	16	20	95CS5B-w20
90	10	16, 17, 18, 19	10	90CS10B-w10
90	10	16, 17, 18	15	90CS10B-w15
90	10	16	20	90CS10B-w20
85	15	16, 17, 18, 19	10	85CS15B-w10
85	15	16, 17, 18	15	85CS15B w15
85	15	16	20	85CS15B-w20
80	20	16, 17, 18, 19	10	80CS20B-w10
80	20	16, 17, 18	15	80CS20B-w15
80	20	16	20	80CS20B-w20

198
 199 2.2.2 Permeability and Unconfined Compressive
 200 Strength Tests

201 A certain amount of bentonite was mixed with
 202 claystone, and the dry weight percentage was
 203 measured. Water was added to the mixture, and the
 204 water content was evaluated. The sample was cured
 205 for 1 day and later compacted statically in a 6 cm
 206 diameter ring using a hydraulic jack to attain the
 207 density, as shown in Table 1. Meanwhile, a thin
 208 sample of 1cm was made to reach quick equilibrium
 209 as indicated by a relatively similar decrease in water
 210 level.

211 A thin layer of grease was applied to the tube
 212 surface to avoid leakage between the tool wall and
 213 the sample before it was inserted into the test
 214 instrument. A falling head test method was
 215 performed to obtain the permeability [34]. This
 216 method is reliable, repeatable, and quite accurate for
 217 soil permeability measurements [35]. Moreover, the
 218 water level in the burette was observed every 24
 219 hours up to the period when there was no change in
 220 water level for each observation.

221 Using the same sample conditions as shown in
 222 Table 2, the claystone-bentonite mixture samples
 223 with a diameter of 47.5mm and a height of 92.4mm

224 were also prepared by static compaction to measure
 225 the shear strength using the UCS test according to
 226 ASTM D2166 [36].

227 228 3. RESULTS AND DISCUSSION

229 230 3.1 Effect of Bentonite Content

231
 232 Figures 1(a)–1(d) show the effect of bentonite
 233 content on the mixture's permeability. We
 234 considered 1×10^{-9} m/s, which is marked with gray
 235 shading, to be acceptable as it is the minimum
 236 requirement in several countries. The numbers and
 237 letters in the legend show the density and moisture
 238 contents of the sample. The highest permeability of
 239 6.6×10^{-9} m/s was recorded in a sample with a 5%
 240 bentonite content and a density of 16kN/m³.

241 Figure 1 (a) shows the reduction in permeability
 242 as the bentonite content increases. The samples with
 243 a density of 16 kN/m³ and moisture contents of 15%
 244 and 20% were observed to meet the required
 245 permeability at 20% bentonite content. Figure 1(b)
 246 presents that permeability also decreased as
 247 bentonite content increased at a density of 17kN/m³.
 248 Three samples met the requirement at this density,
 249 including a sample with a 15% bentonite content. A
 250 similar condition was also observed with the
 251 18kN/m³ sample. Meanwhile, all samples with 5-
 252 20% bentonite contents were observed to meet the
 253 requirements at the highest density of 19 kN/m³.

254 These results showed that the bentonite content
 255 affected the permeability of the claystone-bentonite
 256 mixture such that at a higher percentage, there was
 257 a lower permeability. Furthermore, the permeability
 258 was not constant up to the 20% bentonite level,
 259 which is different from the findings of previous
 260 studies that showed the permeability to be constant
 261 at values more than 15% [12]. This, however, was
 262 in agreement with the results of Arifin and
 263 Sambelum [5], which showed that other parameters
 264 such as density and water contents significantly
 265 influence the mixtures' permeability. Moreover,
 266 Figure 1(d) shows that an elevated density of
 267 19kN/m³ is required at 10% bentonite to ensure the
 268 requirements of the mixture are met. Arifin and
 269 Sambelum [5] also predicted the need for 50%
 270 bentonite to meet the permeability requirements
 271 using standard Proctor density. Therefore, a density
 272 higher than that of the standard Proctor is required
 273 to reduce the percentage of bentonite used.

274 Zang [21] compacted claystone mixed with
 275 bentonite in a different composition. The findings
 276 demonstrated that the macropores in the claystone
 277 aggregate could be more densely filled with
 278 bentonite powder, leading to a low porosity.
 279 Furthermore, as water passes through the sample,
 280 the bentonite, as well as the clay fraction in the

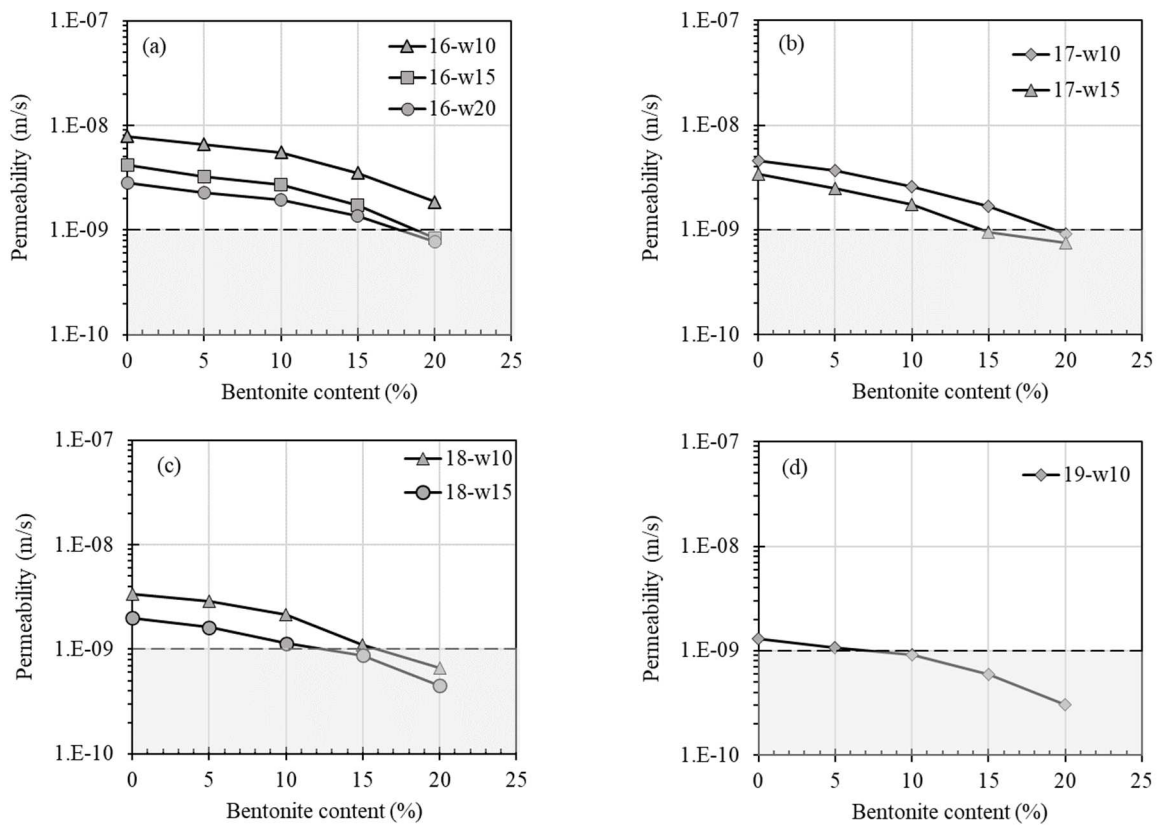


Figure 1. Effect of bentonite content on the permeability of compacted claystone–bentonite mixtures. Note: the numbers and the letters in the legend show the dry unit weight and moisture content of samples.

281 claystone, expands. The larger the proportion of the
282 bentonite, the greater the extension and closing of
283 the pores. Permeability is decreased as a result.

284 The change in permeability of the claystone–
285 bentonite mixture as compared to the permeability
286 without bentonite is summarized in Table 3. It can
287 be seen that the permeability of claystone mixed
288 with 5% bentonite causes a 1.2–1.4-fold decrease
289 (with an average of a 1.2-fold decrease). This
290 reduction continued to occur with an increasing
291 percent of bentonite in the mixture, i.e., at an
292 average of 1.6-, 2.6-, and 4.5-fold for the addition
293 of 10%, 15%, and 20% bentonite, respectively.

294 Figure 2 shows the effect of the bentonite
295 content on the shear strength obtained from the
296 UCS test using a minimum compressive strength of
297 50kPa, as recommended by the Environment
298 Agency [31]. This value corresponds to the medium
299 soil consistency of 48–96kPa [34]. In the figure, the
300 undrained cohesion is plotted as a secondary axis,
301 which is determined as half of the compressive
302 strength. According to Figure 2, the increase in
303 compressive strength is accompanied by an increase
304 in undrained cohesion caused by the addition of
305 bentonite to the mixture.

306 Figure 2 also indicates that all the compressive

307 strength samples met the required criteria, but the
308 sample with 20% bentonite tended to have a
309 constant or decreasing value in almost all densities,
310 as shown in (a)–(d).

311

312 Table 3. Permeability reduction due to the addition
313 of bentonite.

314

Bentonite content (%)			5	10	15	20
γ_d (kN/m ³)	w (%)	Sample code	Permeability reduction			
16	10	16-w10	1.2	1.4	2.3	4.2
16	15	16-w15	1.3	1.6	2.4	5.0
16	20	16-w20	1.2	1.4	2.0	3.6
17	10	17-w10	1.2	1.8	2.7	5.0
17	15	17-w15	1.4	1.9	3.6	4.5
18	10	18-w10	1.2	1.6	3.1	5.1
18	15	18-w15	1.2	1.8	2.3	4.5
19	10	19-w10	1.2	1.4	2.2	4.2
Average			1.2	1.6	2.6	4.5

315

316 Furthermore, the maximum compressive
317 strength was achieved at 15% bentonite, as is
318 apparent from the following results: 299, 456, 502,

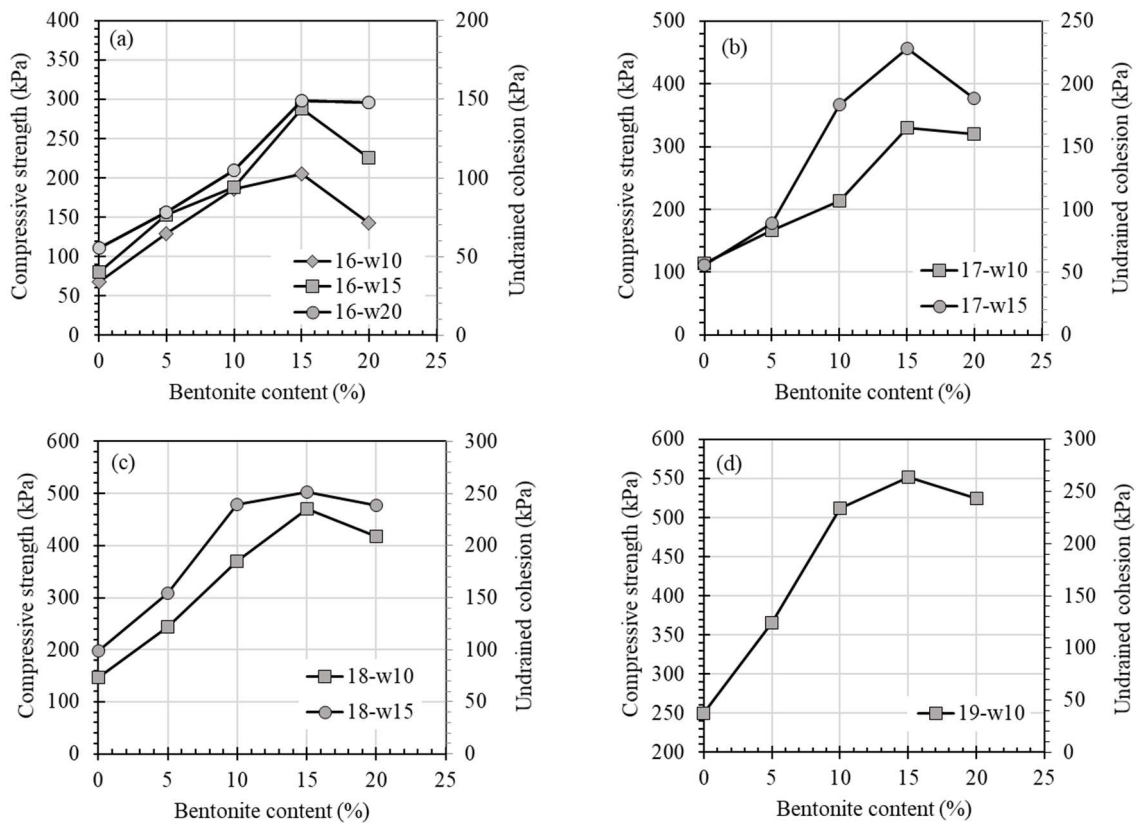


Figure 2. Effect of bentonite content on the compressive shear strength of compacted claystone–bentonite mixtures.

319 and 551kPa recorded at densities of 16, 17, 18, and
 320 19kN/m^3 , respectively. This means that a higher
 321 compressive strength was obtained at a greater
 322 density, which further indicated the important
 323 influence of density on the strength of the
 324 claystone–bentonite mixtures.

325 Zhang [22] compacted a claystone–bentonite
 326 mixture of different compositions (i.e., 60/40 and
 327 80/20). It was found that at the same axial stress, the
 328 80/20 mixture resulted in a higher dry density than
 329 the 60/40 sample. This shows that the percentage of
 330 bentonite in the mixture affects the behavior of the
 331 claystone–bentonite mixture. The composition
 332 influences the density of bentonite that fills the
 333 claystone macropores. In this study, the maximum
 334 density of bentonite in claystone macropores was
 335 produced at 15% bentonite, which resulted in the
 336 maximum compressive strength and undrained
 337 cohesion of the sample. In addition to the shear
 338 strength, the final dry density of bentonite in the
 339 claystone–bentonite mixture was also found to
 340 affect the swelling pressure of the sample, as was
 341 reported by Wang et al. [23].

342 The addition of up to 15% bentonite content in
 343 the mixture was observed to increase the cohesion
 344 of the mixture, and the bentonite was observed to be
 345 dominant at 20%. The sample produced larger

346 macropores at low water contents [7], which
 347 reduced the strength of the claystone–bentonite
 348 mixture. Moreover, the need for the water to reach
 349 the maximum sample density increased at higher
 350 bentonite levels, and the water added was usually
 351 absorbed more by the bentonite, causing the sample
 352 to expand. Pusch et al [37] reported that the mineral
 353 montmorillonite requires 2-3 layers of water
 354 molecules to meet the hydration force. Thickness
 355 and complete hydration layers depend on the
 356 exchangeable cation of the bentonite. Further,
 357 Sayori et al [38] observed that when water is applied
 358 to the bentonite surface, four water molecules
 359 would first be absorbed. Mitchell [39] indicated that
 360 for the complete expansion, bentonites of the
 361 sodium type with a specific surface area of $800\text{m}^2/\text{g}$
 362 exceed the water content of 400% to meet the
 363 exchangeable cation hydration.

364 The effect that the percentage of clay in soil has
 365 on its shear strength has been widely studied.
 366 Increasing the amount of clay in soil results in an
 367 increase in cohesion followed by a reduction in the
 368 friction angle [40–43]. The increase in cohesion is
 369 influenced by the minerals contained in the clay,
 370 i.e., montmorillonite minerals result in a higher
 371 cohesion increase as compared to kaolinite minerals
 372 [40]. In this study, the bentonite used contained

373 montmorillonite so that an increase in the
 374 percentage of bentonite enhanced the amount of this
 375 mineral, resulting in a greater increase in cohesion.
 376 Table 4 presents the improvement in the
 377 compressive strength of the claystone–bentonite
 378 mixture (in percent) as compared to those without
 379 bentonite. As can be seen in the table, the increase
 380 in bentonite (added to claystone) resulted in an
 381 increase in the compressive strength for all samples
 382 up to the addition of 15% bentonite. At 5%
 383 bentonite, the average increase in shear strength
 384 was 1.6-fold, and an average of 2.4- and 3.0-fold at
 385 10% and 15% bentonite contents, respectively. As
 386 shown in Figure 2, supplementing 20% bentonite to
 387 claystone resulted in a reduction in the compressive
 388 strength of the samples. As shown in the table, a mix
 389 with up to 20% bentonite reduced the compressive
 390 strength of all samples by an average of 2.6 times.
 391

392 Table 4. Shear strength changes due to addition of
 393 bentonite.

394

Bentonite content (%)		5	10	15	20	
γ_d (kN/m ³)	w (%)	Sample code	Shear strength change			
16	10	16-w10	1.9	2.7	3.0	2.1
16	15	16-w15	1.9	2.3	3.6	2.8
16	20	16-w20	1.4	1.9	2.7	2.7
17	10	17-w10	1.5	1.9	2.9	2.8
17	15	17-w15	1.6	3.3	4.1	3.4
18	10	18-w10	1.7	2.5	3.2	2.9
18	15	18-w15	1.6	2.4	2.5	2.4
19	10	19-w10	1.5	2.1	2.2	2.1
Average			1.6	2.4	3.0	2.6

395

396 3.2 Effect of Mixture Density

397

398 Figure 3 shows the effect of density on the

399 compacted claystone–bentonite mixtures'
 400 permeability, as indicated in samples with 5–20%
 401 bentonite with a 10% moisture content in Figure
 402 3(a) and a 15% moisture content in Figure 3(b). The
 403 sample legend is written as the claystone percentage
 404 (CS) and bentonite percentage (B), while w is used
 405 as the symbol for the moisture content. Figure 3(a)
 406 shows that a higher density produced a lower
 407 permeability, as was observed in all mixture
 408 variations from 5 to 20% bentonite. However, not
 409 all mixtures met the requirements necessary for a
 410 clay liner, as indicated by the gray area. These
 411 mainly comprised 5% bentonite with a 10%
 412 moisture content. Moreover, 20% bentonite content
 413 samples were the samples that most commonly met
 414 the requirements at a density of ≥ 17 kN/m³, because
 415 they were compacted with more energy than the
 416 Proctor standard.

417 The same trend was found for samples with a
 418 higher moisture content of 15%, as presented in
 419 Figure 3(b), with an increase in density observed to
 420 cause a smaller pore number and permeability. This
 421 is in line with findings of a previous study that
 422 showed that an increase in the density reduced the
 423 macropore size and volume, while the micropores
 424 did not change much [6,7,14]. These macropores
 425 play an important role in the changes experienced
 426 in soil permeability, especially for clay soil, such
 427 that smaller and fewer macropores usually lead to a
 428 lower permeability.

429 This means that all the samples with a 20%
 430 bentonite content, such as 80CS20B-15, qualified
 431 as clay liners, while 85CS15B-15 was partially
 432 compliant, and neither 95CS5B-15 or 90CS10B-15
 433 was satisfactory. These results showed that the
 434 samples compacted with Proctor Standard energy
 435 with a dry density of 16 kN/m³ satisfied the
 436 requirements at higher moisture contents. This,
 437 therefore, shows the importance of water content in
 438 compacted claystone–bentonite mixtures.

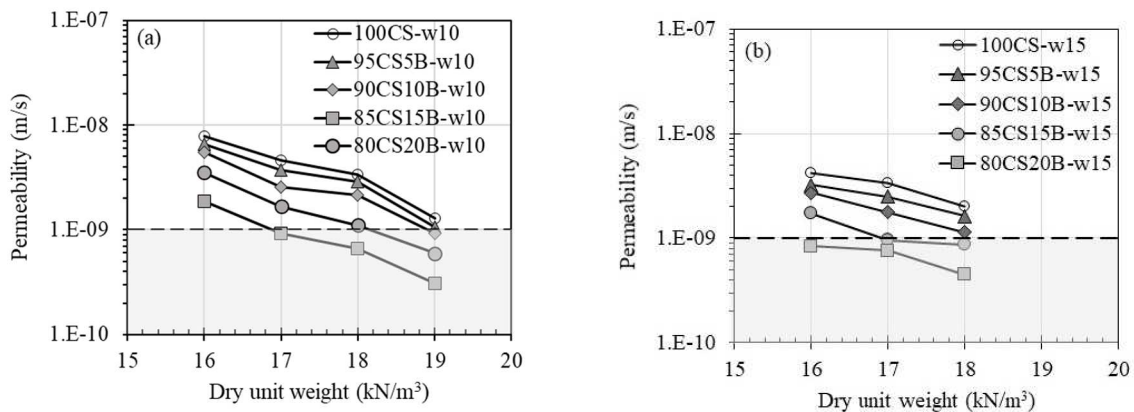


Figure 3. Effect of density on the permeability of compacted claystone-bentonite mixtures.

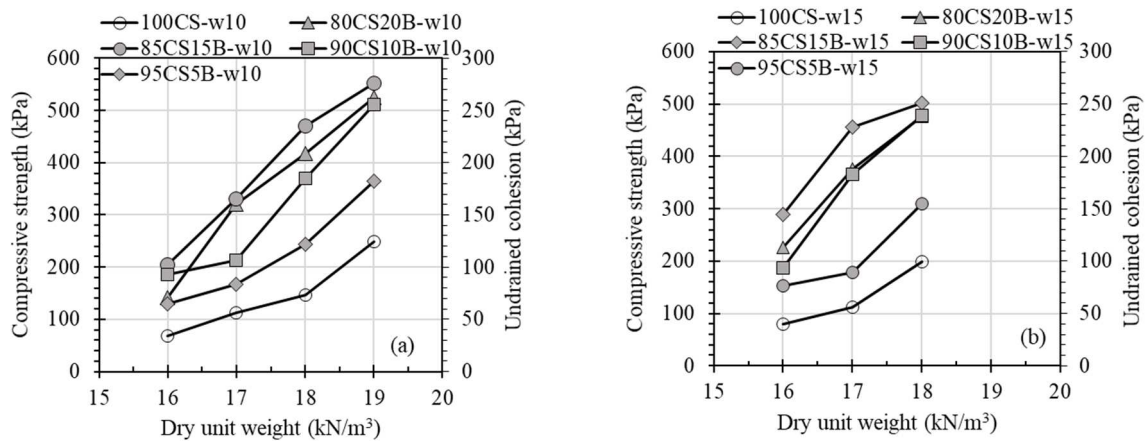


Figure 4. Effect of density on the compressive strength of claystone-bentonite mixtures.

439 Figure 4 shows the compressive strength and
 440 undrained cohesion of compacted claystone–
 441 bentonite as a function of the dry density. This is
 442 demonstrated in samples with a 10% moisture
 443 content in Figure 4(a) and a 15% moisture content
 444 in Figure 4(b), which shows almost all of the
 445 densities used in this study. The sample's
 446 compressive strength and undrained cohesion were
 447 observed to increase as the density of all bentonite
 448 contents increased. The density increment caused a
 449 reduction in the size and number of macropores and
 450 increased the percentage of micropores [7], playing
 451 a role in the shear strength of clay soils.
 452 Zhang [22] reported that the mechanical
 453 stiffness of the compacted claystone–bentonite
 454 mixtures exponentially increases with increasing
 455 dry density. Moreover, at a given dry density, the
 456 stiffness of the claystone–bentonite mixtures was
 457 higher than that of the bentonite–sand mixture. The
 458 low stiffness of the bentonite–sand mixture is due
 459 to the lower density of the bentonite matrix, which
 460 embeds the sand particles, resulting in a lower inner
 461 friction resistance [22]. On the other hand, the high
 462 stiffness of the claystone–bentonite mixture is
 463 caused by the high density of the bentonite matrix
 464 in the claystone. Claystone, unlike generally inert
 465 sand, contains clay minerals, and contact between
 466 claystone and bentonite can occur, influencing the
 467 hydro-mechanical behavior of the compacted
 468 mixture [23].
 469 The changes in the permeability and shear
 470 strength of the claystone–bentonite mixture are
 471 summarized in Tables 5 and 6, respectively. For
 472 samples with a moisture content of 10%, as shown
 473 in Table 5, the decrease in permeability was, on
 474 average, 2.0-, 2.6-, and 6.0-fold due to an increase
 475 in density from 16kN/m³ to 17kN/m³, 18kN/m³, and
 476 19kN/m³, respectively. When the density was
 477 increased from 16kN/m³ to 17kN/m³ and 18kN/m³,

478 the permeability decreased by an average of 1.8 and
 479 2.0 times, respectively, for samples with a moisture
 480 content of 15%.
 481 For the sample shear strength with a moisture
 482 content of 10%, as shown in Table 6, an increase in
 483 density from 16kN/m³ resulted in an average 1.6-,
 484 2.2-, and 3.1-fold increase after the dry unit weight
 485 increased to 17kN/m³, 18kN/m³, and 19kN/m³. At a
 486 15% moisture content, the shear strength increased
 487 by an average of 1.6 and 2.2 times, respectively,
 488 after the dry unit weight was increased from
 489 16kN/m³ to 17kN/m³ and 18kN/m³.

490
 491 Table 5. Permeability change due to the increase in
 492 density.

Dry unit weight (kN/m ³)			17	18	19
Bent. content	w (%)	Sample code	Permeability change		
0	10	100CS-w10	1.7	2.3	6.1
5	10	95CS5B-w10	1.8	2.3	6.2
10	10	90CS10B-w10	2.2	2.6	6.0
15	10	85CS15B-w10	2.1	3.2	5.9
20	10	80CS20B-w10	2.0	2.8	6.1
Average			2.0	2.6	6.0
0	15	100CS-w15	1.2	2.1	
5	15	95CS5B-w15	1.3	2.0	
10	15	90CS10B-w15	1.5	2.4	
15	15	85CS15B-w15	1.8	2.0	
20	15	80CS20B-w15	1.1	1.9	
Average			1.4	2.1	

494
 495 **3.3 Effect of Water Content**

496
 497 Figures 5(a) and 5(b) show the effect of water

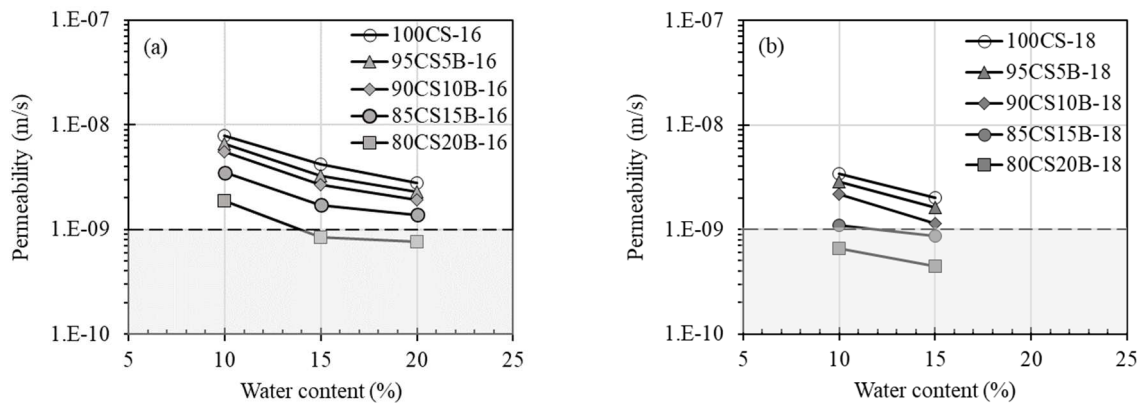


Figure 5. Effect of water content on the permeability of compacted claystone-bentonite mixtures (a) samples with dry density of 16kN/m^3 and (b) samples with dry density of 18kN/m^3 .

498 content on the permeability of the claystone–
 499 bentonite mixture sample, with the legend
 500 indicating the percentages of claystone (CS) and
 501 bentonite (B) and the density of the samples. Figure
 502 5(a) shows the result of the sample with a density of
 503 16 kN/m^3 using three moisture content conditions,
 504 while Figure 5(b) shows a higher density of 18
 505 kN/m^3 . The permeability of the compacted sample
 506 at the optimum water content (i.e., 15%) was
 507 observed to be lower than for the dry condition (i.e.,
 508 10%), while the value in the wet condition (i.e.,
 509 20%) was almost the same as for the optimum.
 510 Similar results were also recorded for samples with
 511 higher densities. Several researchers have
 512 previously discussed this effect [4,5].

513

514 Table 6. Shear strength change due to the increase
 515 in density.

516

Dry unit weight (kN/m^3)		17	18	19	
Bent. content	w (%)	Sample code	Shear strength change		
0	10	100CS-w10	1.7	2.1	3.7
5	10	95CS5B-w10	1.3	1.9	2.8
10	10	90CS10B-w10	1.1	2.0	2.8
15	10	85CS15B-w10	1.6	2.3	2.7
20	10	80CS20B-w10	2.3	2.9	3.7
Average			1.6	2.2	3.1
0	15	100CS-w15	1.4	2.5	
5	15	95CS5B-w15	1.2	2.0	
10	15	90CS10B-w15	2.0	2.5	
15	15	85CS15B-w15	1.6	1.7	
20	15	80CS20B-w15	1.7	2.1	
Average			1.6	2.2	

517

518 Benson et al. [4] showed that low permeability

519 at higher water contents was due to microstructural
 520 changes in the soil. It is important to note that a
 521 bimodal pore size distribution, including macro-
 522 and micropores, exists in dry conditions, while a
 523 unimodal pore distribution, including micropores,
 524 exists at higher moisture contents. It was also
 525 reported by Arifin and Schanz [7] that pores in dry
 526 conditions are large, while micropores are dominant
 527 at wet conditions when the samples are at the same
 528 density or void ratio. In this claystone–bentonite
 529 mixture, the claystone macropores were filled with
 530 bentonite [21]. When interacting with water, the
 531 bentonite expanded and closed these macropores.
 532 At a higher water content, in addition to the
 533 macropores filling with expanding bentonite, the
 534 dominant micropores resulted in a lower
 535 permeability.

536 The effects of water content on changes in
 537 permeability of the claystone–bentonite mixture are
 538 summarized in Tables 7. The data are represented
 539 by samples with densities of 16kN/m^3 and 18kN/m^3 ,
 540 as shown in Figures 5. For samples with densities
 541 of 16kN/m^3 in Table 7, the permeability decreased
 542 by an average of 2.0 and 2.7 times when the water
 543 content increased from 10% to 15% and 20%,
 544 respectively. For samples with a density of
 545 18kN/m^3 , an increase in the initial water content of
 546 the sample from 10% to 15% resulted in a 1.6-fold
 547 lower average.

548 Figure 6 shows the effect of moisture content on
 549 the compressive strength and undrained cohesion of
 550 compacted claystone–bentonite mixtures using a
 551 similar trend as for permeability, with densities of
 552 16 and 18kN/m^3 , as shown in Figures 6(a) and 6(b),
 553 respectively. The compressive strength and
 554 undrained cohesion seemed to be relatively constant
 555 at a density of 16 kN/m^3 with a 5 and 10% bentonite
 556 content, while it was observed to increase with a
 557 moisture content of 15 and 20%. It was discovered
 558 that claystone absorbed more water at lower

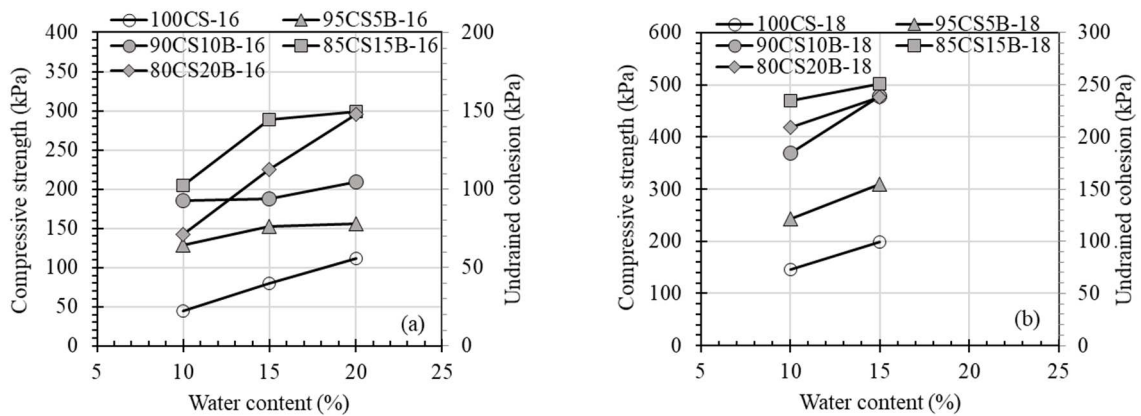


Figure 6. Effect of water content on the compressive strength of compacted claystone-bentonite mixtures (a) samples with dry density of 16kN/m³ and (b) samples with dry density of 18kN/m³

559 bentonite levels (5–10%), and this higher water
 560 content caused a reduction in the claystone–
 561 bentonite mixture strength. This is associated with
 562 the strength usually lost by claystone when
 563 interacting with a lot of water [24–26]. Moreover,
 564 the bentonite absorbed more water at a higher
 565 content of 20%, making the sample more difficult
 566 to compact and decreasing the sample strength.
 567 Furthermore, compressive strength and undrained
 568 cohesion appeared to increase as the moisture
 569 content increased at high densities of 18kN/m³, as
 570 shown in Figure 6(a). This was due to the
 571 compressed bentonite, which supported better
 572 bonding in the claystone–bentonite mixture.

573

574 Table 7. Effect of sample moisture content on the
 575 permeability of the claystone–bentonite mixtures.
 576

Moisture content (%)		15	20
Bentonite content	γ_d (kN/m ³)	Permeability change	
	Sample code		
0	16	100CS-16	1.9 2.8
5	16	95CS5B-16	2.0 2.9
10	16	90CS10B-16	2.0 2.9
15	16	85CS15B-16	2.0 2.6
20	16	80CS20B-16	2.2 2.4
Average			2.0 2.7
0	18	100CS-18	1.7
5	18	95CS5B-18	1.8
10	18	90CS10B-18	1.9
15	18	85CS15B-18	1.3
20	18	80CS20B-18	1.5
Average			1.6

577

578 In general, samples compacted in dry and wet
 579 conditions produce lower shear strength than those
 580 compacted at the optimum moisture content

581 [41,42,44]. Samples that were compacted at dry or
 582 wet moisture contents produced a dry unit weight
 583 that was smaller than those compacted at the
 584 optimum water content, following the compaction
 585 curve. In this study, the dry unit weight of the
 586 samples was prepared equally at different moisture
 587 contents. The compressive strength and cohesion
 588 obtained increased with the increasing water
 589 content, as shown in Figure 6.

590 Table 8 shows the shear strength change due to
 591 the alteration of the initial moisture content of the
 592 samples. As shown in the table, an increase in
 593 moisture content from 10% to 15% resulted in a 1.2–
 594 1.3-fold increase in the compressive strength and
 595 cohesion. The shear strength increased 1.5-fold as a
 596 result of increasing the water content from 10% to
 597 20%.

598

599 Table 8. Effect of sample moisture content on the
 600 shear strength of the compacted claystone–
 601 bentonite mixtures.

602

Moisture content (%)		15	20
Bent. content	γ_d (kN/m ³)	Shear strength change	
	Sample code		
0	16	100CS-16	1.2 1.6
5	16	95CS5B-16	1.2 1.2
10	16	90CS10B-16	1.0 1.1
15	16	85CS15B-16	1.4 1.5
20	16	80CS20B-16	1.6 2.1
Average			1.3 1.5
0	17	100CS-17	1.4
5	17	95CS5B-17	1.3
10	17	90CS10B-17	1.3
15	17	85CS15B-17	1.1
20	17	80CS20B-17	1.1
Average			1.2

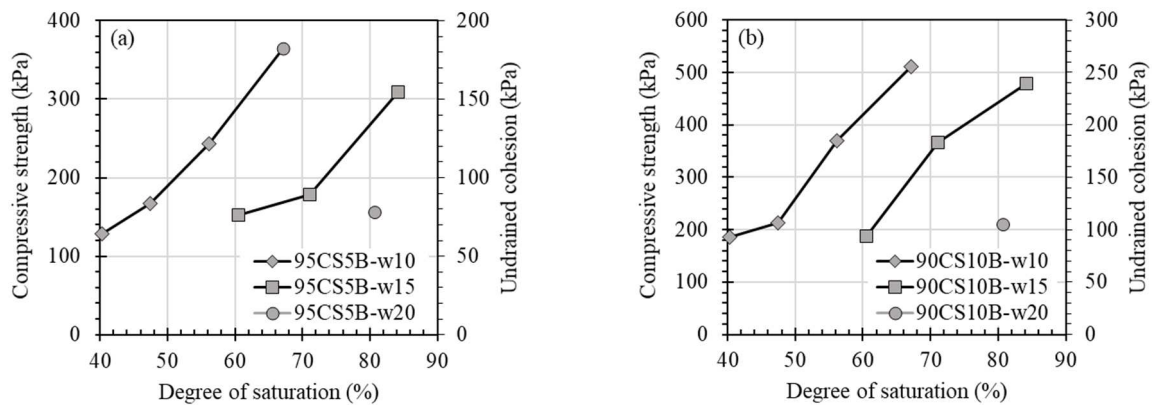


Figure 7. Effect of degree of saturation on the compressive strength and undrained cohesion of compacted claystone-bentonite mixtures (a) 5% bentonite content, and (b) 10% bentonite content

603 The shear strength of sandstone and claystone
 604 fluctuates due to changes in the surrounding
 605 environment such as moisture content or relative
 606 humidity. Shakoor and Berefield [45] reported that
 607 the unconfined compressive strength of the
 608 sandstone decreases with an increasing degree of
 609 saturation. Samples were tested by allowing them to
 610 absorb water so that the degrees of saturation
 611 increase. In other words, the increase in the degree
 612 of saturation was caused by the increase in the
 613 sample moisture content. Meanwhile, Pineda et al.
 614 [46] reported the effect of the relative humidity
 615 cycle on the reduction of cohesion and friction of
 616 claystone. This decrease is due to the accumulation
 617 of strain damage that occurs during the RH cycle.
 618 Figure 7 shows the relationship between the degree
 619 of saturation and the shear strength of compacted
 620 claystone-bentonite mixtures represented by two
 621 bentonite contents, namely 5% and 10%, shown in
 622 Figures 7(a) and 7(b), respectively. Both figures
 623 show the same trend whereby compressive strength
 624 and cohesion samples increase with the increasing
 625 degree of saturation. This effect is different from the
 626 results of other studies. An increase in the degree of
 627 saturation in the study is caused by the increase in
 628 the dry density sample or a reduction in the initial
 629 sample void ratio. Moreover, the increase in water
 630 content, as seen in Figure 6, resulted in a slight
 631 increase in the shear strength of the samples. In this
 632 study, changes were made to the water content
 633 around the optimum water content of claystone (i.e.,
 634 15%) so that the shear strength at that water content
 635 is the shear strength of the maximum density of
 636 claystone.

637 The analysis of its microstructures using both
 638 electron scanning (SEM) and porosimetry intrusion
 639 of mercury (MIP) methods provides a more
 640 comprehensive description of the effects of
 641 supplementing bentonite to the claystone. This is
 642 directly related to the state of the mixtures, which

643 were compacted at various moisture content levels,
 644 as well as the increase in sample density. Further
 645 investigation concerning the microstructure of
 646 compacted claystone-bentonite mixture is required.

647 648 3.4 Acceptable Zone of Clay Liner

649 Daniel and Benson [30] suggested a method for
 650 determining acceptable zones in clay liner designs.
 651 This method combines a zone that meets the
 652 permeability requirements and other criteria, and
 653 relates the parameters to dry unit weight and water
 654 content. Zones overlapping one another become a
 655 single acceptable zone. This method was applied to
 656 the claystone-bentonite mixture data obtained in
 657 this study, as shown in Figure 8. Two criteria were
 658 used in the figure (i.e., permeability and shear
 659 strength). The circles on the curves refer to the
 660 moisture content and density of the samples. The
 661 black symbols show the samples that meet both
 662 requirements.

663 Figure 8(a) shows the criteria for a sample with
 664 5% bentonite. As seen in the figure, there is only an
 665 acceptable zone for shear strength. No permeability
 666 zone was obtained due to the absence of samples
 667 that meet the permeability criteria for 95CS5B
 668 samples, as shown in Figure 1. Moreover, Figure
 669 8(b) shows an acceptable zone for claystone
 670 samples mixed with 10% bentonite. On the basis of
 671 the data summarized from Figures 1 and 2, only one
 672 sample met the two criteria, i.e., 90CS5B at a
 673 density of 19kN/m³ and a water content of 10%. The
 674 overlapping zone is too small and difficult to reach
 675 in the field, especially at very high densities.
 676 Benson et al. [29] reported that only 74% of clay
 677 liners in the field met the permeability criteria of
 678 1x10⁻⁹m/s in North America. The lack of
 679 homogeneity of the mixture may fail to achieve the
 680 permeability requirements as no example met the
 681 sample's criteria with 5% bentonite.

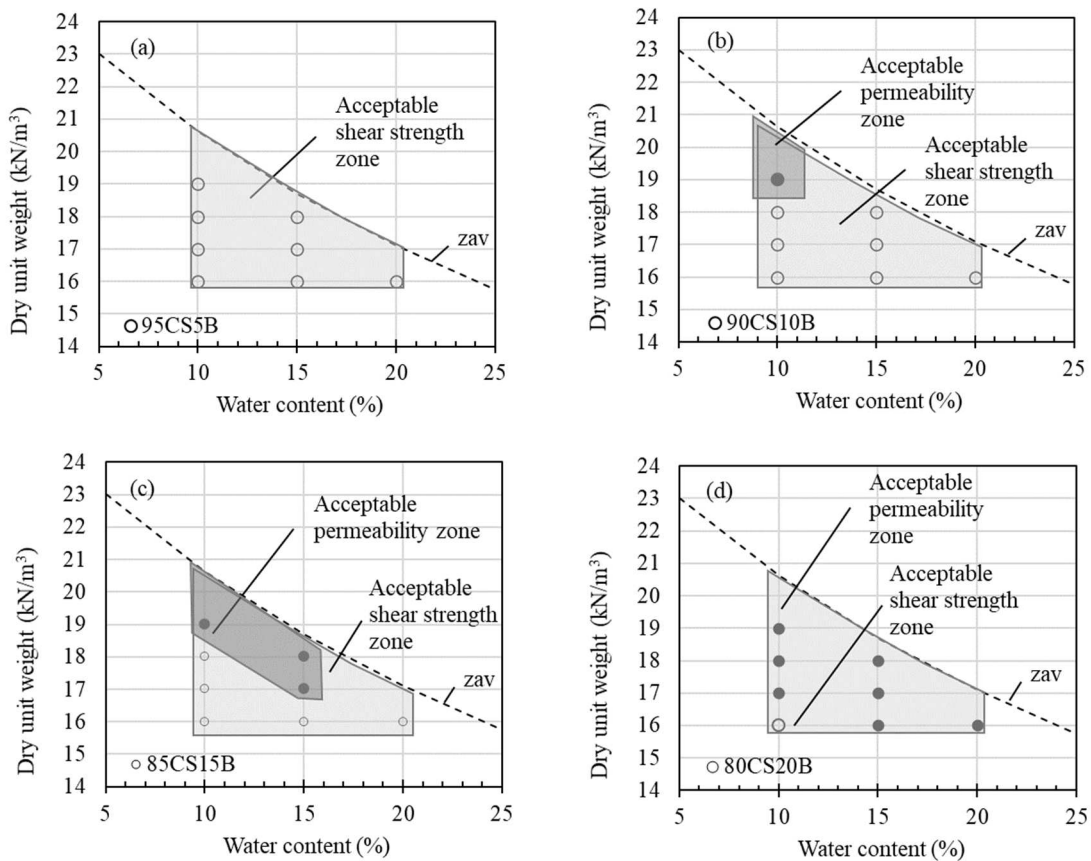


Figure 8. Acceptable zones for the shear strength and permeability of the claystone-bentonite mixtures (a) 95CS5B, (b) 90CS10B, (c) 95CS15B, and (d) 90CS20B

683 For samples with a bentonite content of 15%
 684 (85CS15B), the acceptable zone is depicted in
 685 Figure 8(c). Three samples met both criteria. The
 686 overlapping zone obtained was larger than that of
 687 the 90CS10B sample, as seen in Figure 8(b). These
 688 results are consistent with previous studies that
 689 reported that an increase in the percentage of
 690 bentonite resulted in lower permeability [5,8–11].
 691 Furthermore, seven samples with a bentonite
 692 content of 20% met the two requirements, as shown
 693 in Figure 8(d). As a result, the accepted zone
 694 became larger than those shown in previous curves.
 695 Since the size of the zone was large, the possibility
 696 of this being achieved in the field was high. The
 697 large zone also minimized the inhomogeneous
 698 effect of mixing claystone and bentonite samples.
 699 Benson et al. [29] suggested the use of a wide
 700 variety of clayey soil to achieve the permeability
 701 requirements in the field.

702 703 4. CONCLUSIONS 704

705 The effect of claystone mixed with bentonite on
 706 permeability is herein described and analyzed based
 707 on experiments. The results show that the

708 permeability of mixtures decreases with increasing
 709 bentonite content. Mixtures of 5%, 10%, 15%, and
 710 20% reduced the permeability of the mixture by an
 711 average of 1.2, 1.6, 2.6, and 4.5 times, respectively,
 712 compared to those without bentonite. However, not
 713 all mixtures met the clay liner permeability criteria.
 714 Bentonite in the mixture also affects the shear
 715 strength of the sample. The compressive strength
 716 and cohesion of the mixture were increased after
 717 bentonite was added up to 15%. At 20% bentonite,
 718 the shear strength was constant or decreased. With
 719 the addition of 5%, 10%, and 15% bentonite, the
 720 shear strength of the soil was increased by an
 721 average of 1.6, 2.4, and 3.0 times, respectively,
 722 compared to those without bentonite.

723 The initial density and moisture content of
 724 samples also affect the permeability and shear
 725 strength of the claystone–bentonite mixtures.
 726 Increasing the density from 16kN / m³ to 19 kN /
 727 m³ reduced the sample permeability up to 6.0-fold
 728 and increased the shear strength up to 3.1-fold.
 729 Changes in the initial water content of the sample
 730 from 10% to 20% also resulted in a 2.7-fold
 731 reduction in permeability and a 1.5-fold increase in
 732 soil shear strength.

733 The acceptable zone based on two criteria (i.e.,
734 shear strength and permeability) increased by
735 increasing bentonite content in the mixtures. A
736 percentage of 20% bentonite is recommended,
737 considering the wide range of acceptable sample
738 conditions.

739

740 5. ACKNOWLEDGMENT

741

742 The authors are grateful for the financial support
743 provided by University of Lambung Mangkurat
744 through the "Dosen Wajib Meneliti" program.

745

746 6. REFERENCES

747

748 [1] Chai, J., Miura, N. Comparing the
749 Performance of Landfill Liner Systems. *J*
750 *mater cycles waste Manag*, Vol.4, 2002,
751 pp.135–142.

752 [2] Akgün, H., Ada, M., Koçkar, M.K.
753 Performance Assessment of a Bentonite–Sand
754 Mixture for Nuclear Waste Isolation at the
755 Potential Akkuyu Nuclear Waste Disposal
756 Site, Southern Turkey. *Environ. Earth Sci.*,
757 Vol.73, 2015, pp.6101–6116,
758 doi:10.1007/s12665-014-3837-x.

759 [3] Permen PU Peraturan Menteri Pekerjaan
760 Umum No. 3 tentang Penyelenggaraan
761 Prasarana dan Sarana Persampahan dalam
762 Penanganan Sampah Rumah Tangga dan
763 Sampah Sejenis Sampah Rumah Tangga. In;
764 2013 ISBN 9781626239777.

765 [4] Benson, C.H., Zhai, H., Wang, X. Estimating
766 Hydraulic Conductivity of Compacted Clay
767 Liners. *J. Geotech. Eng.*, Vol.120, 1994,
768 pp.366–387, doi:10.1061/(asce)0733-
769 9410(1995)121:9(675).

770 [5] Arifin, Y.F., Sambelum Bentonite Enhanced
771 Soil as an Alternative Landfill Liner in Rikut
772 Jawa, South Barito. *IOP Conf. Ser. Earth*
773 *Environ. Sci.*, Vol.239, 2019,
774 doi:10.1088/1755-1315/239/1/012003.

775 [6] Cui, Y.J. On the Hydro-Mechanical
776 Behaviour of MX80 Bentonite-Based
777 Materials. *J. Rock Mech. Geotech. Eng.*,
778 Vol.9, 2017, pp.565–574,
779 doi:10.1016/j.jrmge.2016.09.003.

780 [7] Arifin, Y.F., Schanz, T. Microstructure of
781 Compacted Calcium Bentonite-Sand Mixture.
782 In *Proceedings of the the 12th International*
783 *Conference of Quality in Research*; 2011; pp.
784 2156–2161.

785 [8] Mollins, L.H., Stewart, D.I., Cousens, T.W.
786 Predicting the Properties of Bentonite-Sand
787 Mixtures. *Clay Miner.*, Vol.31, 1996, pp.243–
788 252, doi:10.1180/claymin.1996.031.2.10.

789 [9] Sivapullaiah, P. V., Sridharan, A., Stalin, V.K.
790 Hydraulic Conductivity of Bentonite-Sand

791 Mixtures. *Can. Geotech. J.*, Vol.37, 2000,
792 pp.406–413, doi:10.1139/t99-120.

793 [10] Ameta, N.K., Wyal, A.S. Effect of Bentonite
794 on Permeability of Dune Sand. *Electron. J.*
795 *Geotech. Eng.*, Vol.13 A, 2008.

796 [11] Proia, R., Croce, P., Modoni, G. Experimental
797 Investigation of Compacted Sand-Bentonite
798 Mixtures. *Procedia Eng.*, Vol.158, 2016,
799 pp.51–56, doi:10.1016/j.proeng.2016.08.404.

800 [12] Tripathi, K.K., Viswanadham, B.V.S.
801 Evaluation of the Permeability Behaviour of
802 Sand-Bentonite Mixtures Through Laboratory
803 Tests. *Indian Geotech. J.*, Vol.42, 2012,
804 pp.267–277, doi:10.1007/s40098-012-0020-
805 8.

806 [13] Arifin, Y.F. Thermo-Hydro-Mechanical
807 Behavior of Compacted Bentonite Sand
808 Mixtures: An Experimental Study, Bauhaus
809 Universitaet Weimar, Germany, 2008.

810 [14] Agus, S.S. An Experimental Study on Hydro-
811 Mechanical Characteristics of Compacted
812 Bentonite-Sand Mixtures, Bauhaus
813 Universitaet Weimar, Germany, 2005.

814 [15] Ballarini, E., Graupner, B., Bauer, S.
815 Thermal–Hydraulic–Mechanical Behavior of
816 Bentonite and Sand-Bentonite Materials as
817 Seal for a Nuclear Waste Repository:
818 Numerical Simulation of Column
819 Experiments. *Appl. Clay Sci.*, Vol.135, 2017,
820 pp.289–299, doi:10.1016/j.clay.2016.10.007.

821 [16] Sharma, L.K., Singh, R., Ahmad, M., Umrao,
822 R.K., Singh, T.N. Experimental Evaluation of
823 Geomechanical Behaviour of Bentonite-Sand
824 Mixture for Nuclear Waste Disposal. *Procedia*
825 *Eng.*, Vol.191, 2017, pp.386–393,
826 doi:10.1016/j.proeng.2017.05.195.

827 [17] Al-Badran, Y., Baille, W., Tripathy,
828 S., Schanz, T. Swelling Behavior of Bentonite-
829 Based Backfilling Materials in Nuclear Waste
830 Repository Conditions. *J. Hazardous, Toxic,*
831 *Radioact. Waste*, Vol.21, 2017, pp.1–5,
832 doi:10.1061/(asce)hz.2153-5515.0000308.

833 [18] Ghazi, A.F. Engineering Characteristics of
834 Compacted Sand-Bentonite Mixtures, Edith
835 Cowan University, 2015.

836 [19] Wu, Y. Permeability and Volume Change
837 Characteristics of Bentonite-Sand Mixes in a
838 Contaminant Environment Copyright
839 Warning & Restrictions. Vol.c, 1989.

840 [20] Kohno, M., Nara, Y., Kato, M., Nishimura, T.
841 Effects of Clay-Mineral Type and Content on
842 the Hydraulic Conductivity of Bentonite –
843 Sand Mixtures Made of Kunigel Bentonite
844 from Japan. *Clay Miner.*, Vol.53, 2019,
845 pp.721–732.

846 [21] Zhang, C.-L. Characterization of Excavated
847 Claystone and Claystone-Bentonite Mixtures
848 as Backfill/Seal Material. *Geol. Soc. Spec.*
849 *Publ.*, Vol.400, 2014, pp.327–337,

- 850 doi:10.1144/SP400.28.
- 851 [22] Zhang, C.-L. Sealing Performance of
852 Fractured Claystone and Clay-Based
853 Materials. Gesellschaft für Anlagen- und
854 Reaktor- sicherheit (GRS) gGmbH, 2017.
855 ISBN 978-3-946607-38-0.
- 856 [23] Wang, Q., Tang, A.M., Cui, Y.J., Delage, P.,
857 Gatmiri, B. Experimental Study on the
858 Swelling Behaviour of Bentonite/Claystone
859 Mixture. Eng. Geol., Vol.124, 2012, pp.59–
860 66, doi:10.1016/j.enggeo.2011.10.003.
- 861 [24] Sadisun, I.A., Shimada, H., Ichinose, M.,
862 Matsui, K. Study on the Physical
863 Disintegration Characteristics of Subang
864 Claystone Subjected to a Modified Slaking
865 Index Test. Geotech. Geol. Eng., Vol.23,
866 2005, pp.199–218, doi:10.1007/s10706-003-
867 6112-6.
- 868 [25] Espitia, J.M., Caicedo, B., Vallejo, L.
869 Comparison of the Uniaxial Compressive
870 Strength of the Belencito Claystone Under
871 Stress Control and Suction Control Paths.
872 Rock Mech. Rock Eng., Vol.52, 2019, pp.19–
873 34, doi:10.1007/s00603-018-1588-9.
- 874 [26] Liu, Z., Shao, J. Moisture Effects on Damage
875 and Failure of Bure Claystone under
876 Compression. Geotech. Lett., Vol.6, 2016,
877 pp.182–186, doi:10.1680/jgele.16.00054.
- 878 [27] Wan, M., Delage, P., Tang, A.M., Talandier,
879 J. The Water Retention Properties of the
880 Callovo-Oxfordian Claystone. Unsaturated
881 Soils Res. Appl. - Proc. 6th Int. Conf.
882 Unsaturated Soils, UNSAT 2014, Vol.2, 2014,
883 pp.1011–1016,
884 doi:10.1016/j.ijrmmms.2013.08.020.
- 885 [28] Özbek, A., Gül, M. The Geotechnical
886 Evaluation of Sandstone–Claystone
887 Alternations Based on Geological Strength
888 Index. Arab. J. Geosci., Vol.8, 2015, pp.5257–
889 5268, doi:10.1007/s12517-014-1541-5.
- 890 [29] Benson, C.H., Daniel, D.E., Boutwell, G.P.
891 Field Performance of Compacted Clay Liners.
892 J. Geotech. Geoenvironmental Eng., Vol.125,
893 1999, pp.390–403, doi:10.1061/(asce)1090-
894 0241(1999)125:5(390).
- 895 [30] Daniel, D.E., Benson, C.H. Water Content-
896 Density Criteria for Compacted Soil Liners. J.
897 Geotech. Eng., Vol.116, 1990, pp.1811–1830,
898 doi:10.1061/(ASCE)0733-
899 9410(1992)118:6(967.2).
- 900 [31] Environment-Agency Earthworks in Landfill
901 Engineering: Design, Construction and
902 Quality Assurance of Earthworks in Landfill
903 Engineering. Environment Agency: Bristol,
904 2014.
- 905 [32] Dixon, N., Jones, D.R. V. Engineering
906 Properties of Municipal Solid Waste. Geotext.
907 Geomembranes, Vol.23, 2005, pp.205–233,
908 doi:10.1016/j.geotextmem.2004.11.002.
- 909 [33] ASTM-D698-07 Standard Test Methods for
910 Laboratory Compaction Characteristics of
911 Soil Using Standard Effort. Am. Soc. Test.
912 Mater., 2007, pp.13.
- 913 [34] Das, B.M. Soil Mechanics Laboratory
914 Manual. Sixth. Oxford University Press: New
915 York, 2002.
- 916 [35] Pedescoll, A., Samsó, R., Romero, E., Puigagut,
917 J., García, J. Reliability, Repeatability and
918 Accuracy of the Falling Head Method for
919 Hydraulic Conductivity Measurements under
920 Laboratory Conditions. Ecol. Eng., Vol.37,
921 2011, pp.754–757,
922 doi:10.1016/j.ecoleng.2010.06.032.
- 923 [36] ASTM D2166-00 Standard Test Method for
924 Unconfined Compressive Strength of
925 Cohesive Soil. ASTM Int. West
926 Conshohocken, PA, 2000, www.astm.org,
927 Vol.04, 2000.
- 928 [37] Pusch, R., Karnland, O., Hökmark, H. GMM
929 – A General Microstructural Model for
930 Qualitative and Quantitative Studies of
931 Smectite Clays. SKB Tech. Rep., Vol. TR-90-
932 43, 1990, pp.105.
- 933 [38] Saiyouri, N., Tessier, D., Hicher, P.Y.
934 Experimental Study of Swelling in
935 Unsaturated Compacted Clays. Clay Miner.,
936 Vol.39, 2004, pp.469–479,
937 doi:10.1180/0009855043940148.
- 938 [39] Mitchell, J.K., Soga, K. Fundamentals of Soil
939 Behavior. Third Edit. John Wiley & Sons, Inc:
940 Hoboken, New Jersey, 2005. ISBN
941 0471463027.
- 942 [40] Charkley, F.N., Zhang, K., Mei, G. Shear
943 Strength of Compacted Clays as Affected by
944 Mineral Content and Wet-Dry Cycles. Adv.
945 Civ. Eng., Vol.2019, 2019,
946 doi:10.1155/2019/8217029.
- 947 [41] Cokca, E., Erol, O., Armangil, F. Effects of
948 Compaction Moisture Content on the Shear
949 Strength of an Unsaturated Clay. Geotech.
950 Geol. Eng., Vol.22, 2004, pp.285–297,
951 doi:10.1023/B:GEGE.0000018349.40866.3e.
- 952 [42] Dafalla, M.A. Effects of Clay and Moisture
953 Content on Direct Shear Tests for Clay-Sand
954 Mixtures. Adv. Mater. Sci. Eng., Vol.2013,
955 2013, doi:10.1155/2013/562726.
- 956 [43] Kim, D., Nam, B.H., Youn, H. Effect of Clay
957 Content on the Shear Strength of Clay–Sand
958 Mixture. Int. J. Geo-Engineering, Vol.9, 2018,
959 doi:10.1186/s40703-018-0087-x.
- 960 [44] Ghosh, R. Effect of Soil Moisture in the
961 Analysis of Undrained Shear Strength of
962 Compacted Clayey Soil. J. Civ. Eng. Constr.
963 Technol., Vol.4, 2013, pp.23–31,
964 doi:10.5897/JCECT12.070.
- 965 [45] Shakoor, A., Barefield, E.H. Relationship
966 between Unconfined Compressive Strength
967 and Degree of Saturation for Selected

- 968 Sandstones. Environ. Eng. Geosci., Vol.15, 975 doi:10.1680/geot.13.T.025.
969 2009, pp.29–40, 976
970 doi:10.2113/gseegeosci.15.1.29. 977
-
- 971 [46] Pineda, J.A., Romero, E., De Gracia, M.,
972 Sheng, D. Shear Strength Degradation in
973 Claystones Due to Environmental Effects.
974 Geotechnique, Vol.64, 2014, pp.493–501,

978

Copyright © Int. J. of GEOMATE All rights reserved,
including making copies unless permission is obtained
from the copyright proprietors.

Last page, both columns must be same height from top or bottom. Please do not change journal and authors information.

Please do not change format of this template

THE PERMEABILITY AND SHEAR STRENGTH OF COMPACTED CLAYSTONE-BENTONITE MIXTURES

*Yulian Firmana Arifin¹, Muhammad Arsyad², Aprian Aji Pangestu², and Dhandy Pratama²

¹Professional Engineer Education Study Program, University of Lambung Mangkurat, Indonesia; ²Civil Engineering Study Program, University of Lambung Mangkurat, Indonesia

*Corresponding Author, Received: 00 Oct. 2018, Revised: 00 Nov. 2018, Accepted: 00 Dec. 2018

ABSTRACT: A compacted claystone-bentonite mixture is proposed for use as a clay barrier. This research, in turn, focuses on the effects of bentonite mix on the permeability and shear strength of compacted claystone-bentonite mixtures. The claystone used was obtained from the Banjarbakula landfill project, approximately 10 km from Banjarbaru, the South Kalimantan Government's Administrative Center, Indonesia. The bentonite used is commercially sold in Indonesia. The claystone was mixed with bentonite at a percentage of 5%, 10%, 15%, and 20% bentonite by dry-weight bases. The mixtures were compacted at a moisture content of 10%, 15%, and 20% to reach the dry unit weight of 16kN/m³–19kN/m³. Permeability and unconfined compressive strength tests were performed in this study. The result showed that the permeability of mixtures decreases with increasing bentonite content. The addition of up to 20% bentonite to the mixture reduced the permeability by 4.5 times, as compared to the sample without bentonite. Moreover, the mixtures' shear strength indicated by compressive strength and cohesion increased by increasing the bentonite content to 15%. The maximum shear strength obtained was three times higher than without bentonite. The mixtures' permeability and shear strength were also significantly affected by the sample's density and moisture content. A percentage of 20% bentonite is recommended, considering the wide range of acceptability based on two criteria (i.e., permeability and shear strength).

Keywords: claystone, bentonite, permeability, shear strength, acceptable zone

1. INTRODUCTION

Permeability is an essential parameter in determining whether a material qualifies as a clay liner, and the limits required to determine the clay liner layer vary in different countries. Austria, Belgium, Hungary, Italy, Portugal, Switzerland, and Turkey, for instance, require a permeability of 1×10^{-9} m/s [1,2], and the same value is observed for other developed countries such as the UK and the USA [1]. Meanwhile, Germany requires a permeability of 1×10^{-10} m/s with a layer thickness of ≥ 0.75 m, and France requires a higher value of 1×10^{-6} m/s, but with a mineral barrier thickness of at least 5 m [1]. Moreover, Asian countries such as Japan also require the permeability of mineral barriers to be 1×10^{-9} m/s for type C municipal solid waste. In Indonesia, the standard landfill base layer can use a geomembrane with a thickness of 1.5–2.0 cm or a clay liner with a permeability of 1×10^{-8} m/s with a total thickness of 60 cm [3]. In this study, we adopted the requirement used in many countries: a minimum permeability of 1×10^{-9} m/s

Several methods are commonly applied to obtain low permeability in which compaction is the most common one [4–6]. This method leads to a reduction in soil pore volume, thereby inhibiting the flow of water in the soil. However, soils compacted at different moisture contents, despite having the

same density, have different permeabilities [4,5]. Moreover, compacted clays with high water contents have smaller pore sizes despite having the same pore volume [7].

It is also possible to reduce permeability by mixing the sample with bentonite [5,8–11]. The addition of bentonite, however, has an estimated efficacy of less than 15% [12], with only negligible changes to permeability being observed. It was also reported in a previous study that 15% clay was required to obtain a permeability that met the minimum requirements of 1×10^{-9} m/s [4]. Arifin and Sambelun [5] also mixed commercial bentonite at 5–20% with local soil containing a lot of sand and silt in a landfill development project in Rikut Jawu, Central Kalimantan. The results showed that the permeability of the sample mixture met the requirements after being mixed with 50% bentonite. It is important to note that a higher density is needed to achieve the required permeability.

In several countries, a mixture of sand and compacted bentonite has also been proposed for use as a clay liner [4,8,9,12], especially at high-level waste repositories [2,6,13–17]. It involves mixing sand and bentonite at different percentages, taking into consideration how the sand's size influences the permeability of the mixture [9,18]. Moreover, different types of bentonite were used in previous studies, such as sodium bentonite [2,6,8,17–20],

Deleted: -

Commented [MOU1]: Please ensure the meaning has been retained.

Deleted: ...AA... compacted claystone... bentonite mixture is currently suggested... proposed to be used [1]

Deleted: dan ...nd 20% to reach the dry unit weight of 16kN/m³–19kN/m³. The ... permeability and unconfined compressive strength tests were performed in this study. The result showed that the permeability of mixtures decreases by with increasing bentonite content. The addition of up to 20% bentonite to the mixture reduced the permeability by 4.5 times, as compared to the sample without bentonite. Meanwhile... moreover, the mixtures' shear strength indicated by compressive strength and cohesion increased by increasing the to 15% ... bentonite content to 15%. The maximum shear strength obtained was three times higher than that ... without bentonite. The mixtures' ... permeability and shear strength were also significantly affected by the sample's density and moisture content. A percentage of 20% bentonite is recommended, considering the wide range of acceptable zone... [2]

Deleted: is the same... have different permeabilities [4,5]. Moreover, compacted clays at [6]

Deleted: ied... for ...n different countries. Austria, Belgium, Hungary, Italy, Portugal, Switzerland, and Turkey in E... [3]

Deleted: ... has been ...n estimated to be... efficacy of less than 15% effective ... ADDIN CSL_CITATION {"citationItems": [{"id": "ITEM-1", "itemData": {"DOI": "10.1007/s40098-012-0020-8", "ISSN": "22773347", "abstract": "In recent years, when suitable impervious soils are not available for containing the waste, barriers constructed using sand-bentonite mixtures are being frequently adopted to contain the waste. This paper presents the laboratory evaluation of permeability of sand-bentonite mixtures through falling head tests performed with rigid wall permeameter and oedometer on different categories of sand-bentonite mixtures. Five different categories of sand-bentonite mixtures were formulated by varying bentonite content in increments of 5 % from 5 to 25 % by dry weight. Atterberg limits and compaction characteristics of sand-bentonite mixtures were evaluated. With an increase in bentonite content, the unconfined compressive strength of the sand-bentonite mixture was found to increase linearly and a sharp decrease in permeability was registered up to a bentonite content of 15 % and beyond this the decrease in the permeability was marginal. Permeability tests were car... [7]

Commented [MOU2]: Please ensure the meaning has been retained.

Deleted:

Deleted: the ... with a mineral barrier's... thickness is ... f at least 5 m [1]. Moreover, Asian countries such as Japan also require the permeability of mineral barriers of ... be 1×10^{-9} m/s for type C municipal solid waste. In Indonesia, the... [4]

Deleted: suggested ... proposed to be used ... or use as a clay liner [4,8,9,12], especially at high-level waste repositories [2,6,13–17]. It involves mixing sand and bentonite at different percentages, in consideration to that ... aking i... [8]

Deleted: s'... volume, thereby... inhibiting the flow of water in the soil. Meanwhile... however, soils compacted at different moisture contents, even though... despite having [5]

calcium bentonite [13,14], and others [9,11,12]. The behavior of each mixture has been found to heavily influenced by the type of bentonite used [20].

Recently, a mixture of claystone and bentonite is the most common approach for alternative barrier layers in high-level waste repositories [6,21–23]. Claystone is found in large quantities during excavation and tunnel projects. This material is usually discarded because of its unfavorable properties when interacting with water [24–28]. Claystone layers are also often believed to be the source of failures in civil constructions. However, its combination with bentonite has several advantages due to the low permeability of both bentonite and claystone. The use of 80% claystone and 20% bentonite in a claystone–bentonite mixture has been reported to reduce permeability by one order [21], showing that the presence of claystone reduced the quantity of bentonite used in the mixture.

Cui [6] reported that crushed Callovo–Oxfordian (COx) claystone behaved as an inert material, such as sand, in a swelling pressure test. Meanwhile, Zhang [22] found that a fracture in the claystone closed itself due to the development of clay minerals when filled with water. This means that the behavior of claystone depends on the clay minerals it contains due to the fact that it is usually obtained from nature. Therefore, it is necessary to investigate the behavior of claystone–bentonite mixtures to determine their optimum use as barrier layers.

Shear strength is also considered to be an important parameter in determining the suitability of clay liner materials [29,30]. The recommended minimum remolded undrained shear strength in the UK is 50 kPa (or higher for specific locations) [31]. Moreover, waste engineering properties such as shallow slope liner stability and integrity, steep slope liner stability and integrity, and cover system integrity are also considered in landfill design [32]. However, everything is directly related to the clay liner's strength, meaning that it is vital to determine the shear strength parameter.

Previous studies mostly focus on high-density samples, which are applied as barriers in the nuclear waste repositories. However, claystone–bentonite mixtures are expected to be useful in broader applications in which lower densities are required, such as landfills. Therefore, it is necessary to investigate the behavior of claystone–bentonite mixtures at different bentonite contents, densities, and moisture contents.

This research focuses on the permeability and shear strength of claystone–bentonite mixtures at different compositions. The results are expected to determine the best composition and the ranges that meet the permeability and strength criteria. The claystone was obtained from the excavation of a

landfill development project in Banjarbaru City, South Kalimantan, where it was discarded. The density and moisture contents of the samples were also considered to affect the permeability of the mixture in addition to the bentonite content.

2. MATERIALS AND METHODS

2.1 Materials

The claystone used in this study was obtained from the Banjarbakula landfill development project, where over 8000m³ was surplus to requirements. The bentonite used was from common commercial sources in Indonesia. Table 1 shows the engineering properties of the claystone and bentonite used. The bentonite had very high plasticity, with a liquid limit of 351.71% and a plasticity index of 307.03%, while the claystone had a liquid limit of 50.76% and a plasticity index of 29.81%. The dominant fractions in the claystone were clay and silt, making up 51.55% and 43.94%, respectively. In contrast, the bentonite was composed of up to 90.28% clay fractions. From Table 1, the dominant exchangeable cation in each sample was Ca²⁺.

Table 1. Physical and index properties of the claystone and bentonite used.

Properties	Claystone	Bentonite
Specific gravity	2.60	2.71
Water content (%)	2.75	14.17
Soil compositions:		
Gravel (%)	0.0	0.0
Coarse sand (%)	0.1	0.0
Medium sand (%)	0.1	0.0
Fine sand (%)	4.3	1.4
Silt (%)	43.9	8.3
Clay (%)	51.6	90.3
Plasticity:		
Liquid limit (%)	50.76	351.71
Plastic limit (%)	20.95	44.68
Shrinkage limit (%)	9.74	41.89
Plasticity Index (%)	29.81	307.03
Exchangeable Cation:		
Na ⁺ (meq/g)	0.30	0.34
Ca ²⁺ (meq/g)	4.30	18.70
Mg ²⁺ (meq/g)	0.10	0.20
K ⁺ (meq/g)	0.30	0.58

2.2 Techniques and Procedures

2.2.1 Samples preparation

The standard Proctor compaction [33] test was conducted to obtain the optimum moisture content and maximum dry density, which were 15% and 16kN/m³, respectively. The claystone was crushed and sieved with a mesh No. 40, and mixed with 5,

Deleted: used in previous studies ...ADDIN CSL_CITATION {"citationItems":[{"id":"ITEM-1","itemData":{"DOI":"10.1139/t99-120","ISSN":"00083674","abstract":"The use of bentonite alone or amended with natural soils for construction of liners for water-retention and waste-containment facilities is very common. The importance of bentonite content in reducing the hydraulic conductivity of liners is well recognised. The study illustrates the role of the size of the coarse fraction in controlling the hydraulic conductivity of the clay liner. It has been shown that at low bentonite contents the hydraulic conductivity of the liner varies depending on the size of the coarser fraction apart from clay content. At a given clay content, the hydraulic conductivity increases with an increase in the size of the coarser fraction. But when the clay content is more than that which can be accommodated within the voids of the coarser fractions, the hydraulic conductivity is controlled primarily by clay content alone. Four different methods of predicting hydraulic conductivity of the liners are presented. Using two constants, related to the liquid limit, the hydraulic conductivity can be predicted at any void ratio."},"author":{"dropping- ... [9]

Deleted: be ...ffecting ... [18]

Deleted: has been suggested most to be used...s the most common approach for as an ...lternative barrier layers in the high-level waste repository ... [10]

Commented [MOU3]: Please ensure the meaning has been retained.

Deleted: The...aystone can be...s found in large quantities during excavation and tunnel projects. This material is usually discarded because of its unfavorabl... [11]

Deleted: found and not used...urplus to requirements. Meanwhile...T...e bentonite used was from common commercial sources commonly used ...n Indonesia. T... [19]

Commented [MOU4]: Please ensure the meaning has been retained.

Deleted: the ... claystone–bentonite...laystone–bentonite mixture has been reported to reduce permeability to ... [12]

Commented [MOU5]: Please ensure the meaning has been retained.

Deleted: and this...showings ... [13]

Commented [MOU6]: Please ensure the meaning has been retained.

Deleted: the ...hat crua...hed Callovo...xfordian (COx) claystone to have ...ehaved as an inert material, such as sand, in the ... swelling pressure test. Meanwhile, Zhang [22... [14]

Deleted: with ...aking up 51.55% and 43.94%, respectively. In contrast, the bentonite contained ...as composed of clay fractions ...p to 90.28%...clay fractions. From Table ... [20]

Deleted: apart from permeability ...n determining the suitability of material as a ...lay liner materials [29,30]. The recommended minimum remolded undrained shear str... [15]

Deleted: were ...ostly focused...on high-density samples, which were ...re applied as a...barriers in the nuclear waste repositories... Meanwhile...however, the ...laystone... [16]

Deleted: zones ...anges that meets ... [17]

Deleted: and the values

10, 15, and 20% of bentonite on a dry weight basis. The water content was used at the optimum condition of 15%, dry of optimum at 10%, and wet of optimum at 20%. Moreover, the dry volume weight of the samples was prepared at variations of 16, 17, and 18kN/m³ to determine the dry density effect. However, high moisture content (i.e., 15 and 20%) was not applied at high densities due to the difficulty of compaction when working with an air void line that is very close to zero. The sample conditions are summarized in Table 2.

Table 2. Compositions, densities, water content, and code of samples.

Clayst. (%)	Bent. (%)	Dry unit weight (kN/m ³)	w (%)	Sample code
100	0	16, 17, 18, 19	10	100CS-w10
100	0	16, 17, 18, 19	15	100CS-w15
100	0	16, 17, 18, 19	20	100CS-w20
95	5	16, 17, 18, 19	10	95CS5B-w10
95	5	16, 17, 18	15	95CS5B-w15
95	5	16	20	95CS5B-w20
90	10	16, 17, 18, 19	10	90CS10B-w10
90	10	16, 17, 18	15	90CS10B-w15
90	10	16	20	90CS10B-w20
85	15	16, 17, 18, 19	10	85CS15B-w10
85	15	16, 17, 18	15	85CS15B-w15
85	15	16	20	85CS15B-w20
80	20	16, 17, 18, 19	10	80CS20B-w10
80	20	16, 17, 18	15	80CS20B-w15
80	20	16	20	80CS20B-w20

2.2.2 Permeability and Unconfined Compressive Strength Tests

A certain amount of bentonite was mixed with claystone, and the dry weight percentage was measured. Water was added to the mixture, and the water content was evaluated. The sample was cured for 1 day and later compacted statically in a 6 cm diameter ring using a hydraulic jack to attain the density, as shown in Table 1. Meanwhile, a thin sample of 1cm was made to reach quick equilibrium as indicated by a relatively similar decrease in water level.

A thin layer of grease was applied to the tube surface to avoid leakage between the tool wall and the sample before it was inserted into the test instrument. A falling head test method was performed to obtain the permeability [34]. This method is reliable, repeatable, and quite accurate for soil permeability measurements [35]. Moreover, the water level in the burette was observed every 24 hours up to the period when there was no change in water level for each observation.

Using the same sample conditions as shown in Table 2, the claystone-bentonite mixture samples with a diameter of 47.5mm and a height of 92.4mm

were also prepared by static compaction to measure the shear strength using the UCS test according to ASTM D2166 [36].

3. RESULTS AND DISCUSSION

3.1 Effect of Bentonite Content

Figures 1(a)–1(d) show the effect of bentonite content on the mixture's permeability. We considered 1×10^{-9} m/s, which is marked with gray shading, to be acceptable as it is the minimum requirement in several countries. The numbers and letters in the legend show the density and moisture contents of the sample. The highest permeability of 6.6×10^{-9} m/s was recorded in a sample with a 5% bentonite content and a density of 16kN/m³.

Figure 1 (a) shows the reduction in permeability as the bentonite content increases. The samples with a density of 16 kN/m³ and moisture contents of 15% and 20% were observed to meet the required permeability at 20% bentonite content. Figure 1(b) presents that permeability also decreased as bentonite content increased at a density of 17kN/m³. Three samples met the requirement at this density, including a sample with a 15% bentonite content. A similar condition was also observed with the 18kN/m³ sample. Meanwhile, all samples with 5-20% bentonite contents were observed to meet the requirements at the highest density of 19 kN/m³.

These results showed that the bentonite content affected the permeability of the claystone-bentonite mixture such that at a higher percentage, there was a lower permeability. Furthermore, the permeability was not constant up to the 20% bentonite level, which is different from the findings of previous studies that showed the permeability to be constant at values more than 15% [12]. This, however, was in agreement with the results of Arifin and Sambelum [5], which showed that other parameters such as density and water contents significantly influence the mixtures' permeability. Moreover, Figure 1(d) shows that an elevated density of 19kN/m³ is required at 10% bentonite to ensure the requirements of the mixture are met. Arifin and Sambelum [5] also predicted the need for 50% bentonite to meet the permeability requirements using standard Proctor density. Therefore, a density higher than that of the standard Proctor is required to reduce the percentage of bentonite used.

Commented [MOU7]: Please ensure the meaning has been retained.

Deleted: ally

Deleted: ed

Deleted: different

Deleted: in

Deleted: very close to zero

Deleted: used

Deleted: with the

Deleted: considered

Deleted: required

Deleted: marked with gray shading

Deleted: , respectively, and

Deleted: t

Deleted: having

Deleted: density

Deleted: density

Deleted: Meanwhile

Deleted: and

Deleted: this was

Deleted: ,

Deleted: ing

Deleted: It

Deleted: agreed

Deleted: one

Deleted: -

Deleted: exhibits

Deleted: fulfilment

Deleted: meets

Deleted: the as a clay liner

Deleted: a

Deleted: percentage of

Deleted: the

Deleted: Meanwhile

Deleted: At

Deleted: claystone-bentonite

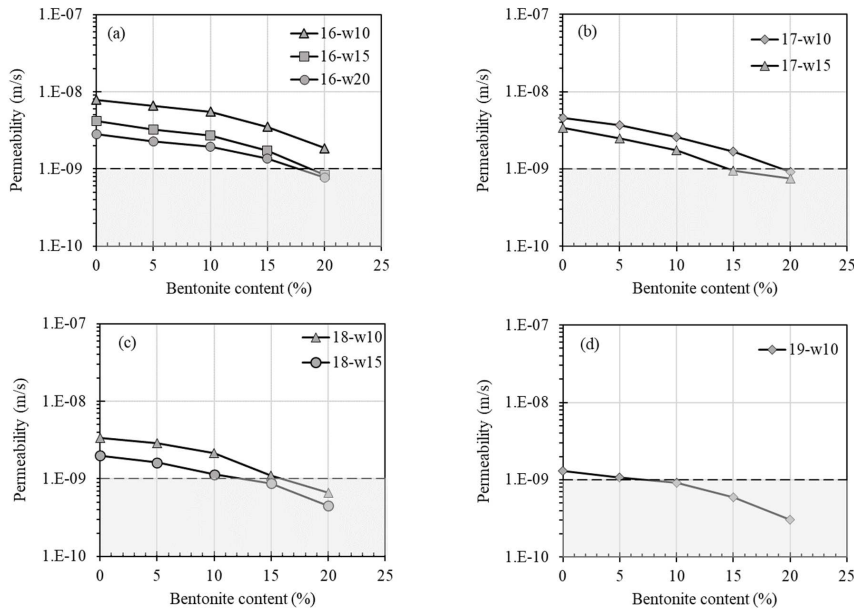


Figure 1. Effect of bentonite content on the permeability of compacted claystone-bentonite mixtures. Note: the numbers and the letters in the legend show the dry unit weight and moisture content of samples

Zang [21] compacted claystone mixed with bentonite in a different composition. The findings demonstrated that the macropores in the claystone aggregate could be more densely filled with bentonite powder, leading to a low porosity. Furthermore, as water passes through the sample, the bentonite, as well as the clay fraction in the claystone, expands, resulting in a smaller water path. Permeability is decreased as a result.

The change in permeability of the claystone-bentonite mixture as compared to the permeability without bentonite is summarized in Table 3. It can be seen that the permeability of claystone mixed with 5% bentonite causes a 1.2-1.4-fold decrease (with an average of a 1.2-fold decrease). This reduction continued to occur with an increasing percent of bentonite in the mixture, i.e., at an average of 1.6-, 2.6-, and 4.5-fold for the addition of 10%, 15%, and 20% bentonite, respectively.

Figure 2 shows the effect of the bentonite content on the compressive shear strength obtained from the UCS test using a minimum limit of 50kPa, as recommended by the Environment Agency [31]. This value corresponds to the medium soil consistency of 48-96kPa [34].

Table 3. Permeability reduction due to the addition of bentonite.

γ _a (kN/m ³)	w (%)	Sample code	Bentonite content (%)			
			5	10	15	20
16	10	16-w10	1.2	1.4	2.3	4.2
16	15	16-w15	1.3	1.6	2.4	5.0
16	20	16-w20	1.2	1.4	2.0	3.6
17	10	17-w10	1.2	1.8	2.7	5.0
17	15	17-w15	1.4	1.9	3.6	4.5
18	10	18-w10	1.2	1.6	3.1	5.1
18	15	18-w15	1.2	1.8	2.3	4.5
19	10	19-w10	1.2	1.4	2.2	4.2
Average			1.2	1.6	2.6	4.5

Figure 2 displays the undrained cohesion as a secondary axis, which is determined as half of the compressive strength. According to Figure 2, the increase in compressive strength is accompanied by an increase in undrained cohesion caused by the addition of bentonite to the mixture.

Figure 2 also indicates that all the compressive strength samples met the required criteria, but the

Commented [MOU8]: Please ensure that an en dash is added to the figure legend below between claystone and bentonite. And please add a full stop.

Deleted: of this

Deleted: in the table

Deleted: decreases between

Deleted: times

Deleted:

Deleted: also

Deleted: a

Commented [MOU9]: Please ensure the meaning has been retained.

Deleted: , as a secondary axis

Deleted: -

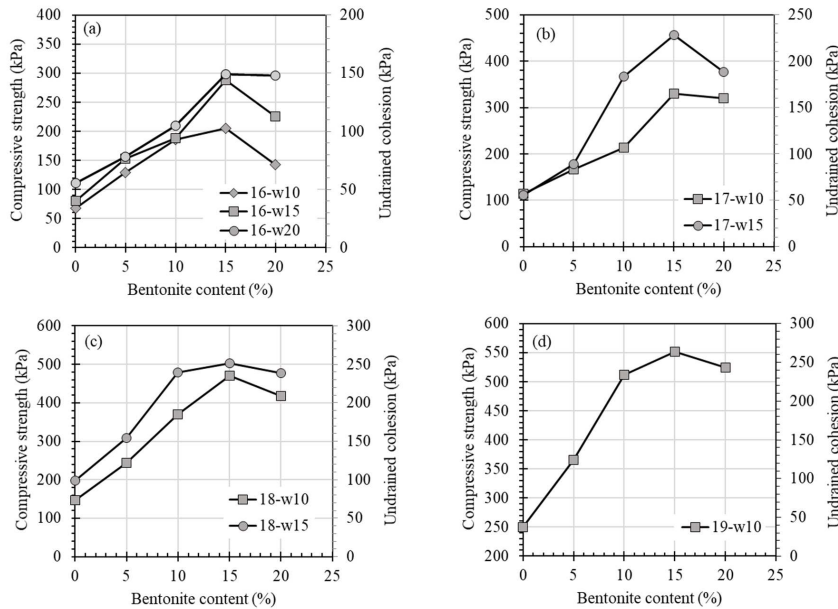


Figure 2. Effect of bentonite content on the compressive shear strength of compacted claystone-bentonite mixtures

sample with 20% bentonite tended to have a constant or decreasing value in almost all densities, as shown in (a)–(d).

Furthermore, the maximum compressive strength was achieved at 15% bentonite, as is apparent from the following results: 299, 456, 502, and 551 kPa recorded at densities of 16, 17, 18, and 19 kN/m³, respectively. This means that a higher compressive strength was obtained at a greater density, which further indicated the important influence of density on the strength of the claystone-bentonite mixtures.

Zhang [22] compacted a claystone-bentonite mixture of different compositions (i.e., 60/40 and 80/20). It was found that at the same axial stress, the 80/20 mixture resulted in a higher dry density than the 60/40 sample. This shows that the percentage of bentonite in the mixture affects the behavior of the claystone-bentonite mixture. The composition influences the density of bentonite that fills the claystone macropores. In this study, the maximum density of bentonite in claystone macropores was produced at 15% bentonite, which resulted in the maximum compressive strength and undrained cohesion of the sample. In addition to the shear strength, the final dry density of bentonite in the claystone-bentonite mixture was also found to

affect the swelling pressure of the sample, as was reported by Wang et al. [23].

The addition of up to 15% bentonite content in the mixture was observed to increase the cohesion of the mixture, and the bentonite was observed to be dominant at 20%. The sample produced larger macropores at low water contents [7], which reduced the strength of the claystone-bentonite mixture. Moreover, the need for the water to reach the maximum sample density increased at higher bentonite levels, and the water added was usually received more by the bentonite, causing the sample to expand.

The effect that the percentage of clay in soil has on its shear strength has been widely studied. Increasing the amount of clay in soil results in an increase in cohesion followed by a reduction in the friction angle [37–40]. The increase in cohesion is influenced by the minerals contained in the clay, i.e., montmorillonite minerals result in a higher cohesion increase as compared to kaolinite minerals [37]. In this study, the bentonite used contained montmorillonite so that an increase in the percentage of bentonite enhanced the amount of this mineral, resulting in a greater increase in cohesion.

Table 4 presents the improvement in the compressive strength of the claystone-bentonite

Commented [MOU11]: See previous comment for figures.

Deleted: indicated

Deleted: Meanwhile,

Deleted: Meanwhile,

Deleted: t

Deleted: densities

Deleted: and this made little

Commented [MOU12]: Please ensure the meaning has been retained.

Deleted: and this

Deleted: was higher

Deleted: thereby

Deleted: /

Deleted: of

Deleted: the

Deleted: with a composition of 80/20

Deleted: the

Deleted: that of

Deleted: addition of

Deleted: claystone-bentonite

Deleted: where

Deleted: the

Deleted: s

Deleted: s

Deleted: a rise

Deleted: s

Deleted: Apart from

Deleted: high

Commented [MOU10]: Please ensure the meaning has been retained.

Deleted: claystone-bentonite

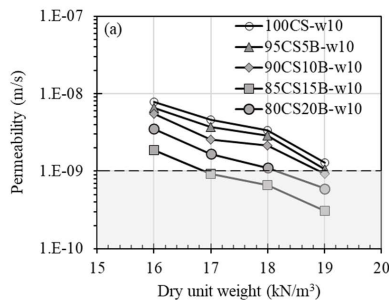
mixture (in percent) as compared to those without bentonite. As can be seen in the table, the increase in bentonite (added to claystone) resulted in an increase in the compressive strength for all samples up to the addition of 15% bentonite. At 5% bentonite, the average increase in shear strength was 1.6-fold, and an average of 2.4- and 3.0-fold at 10% and 15% bentonite contents, respectively. As shown in Figure 2, supplementing 20% bentonite to claystone resulted in a reduction in the compressive strength of the samples. As shown in the table, a mix with up to 20% bentonite reduced the compressive strength of all samples by an average of 2.6 times.

Table 4. Shear strength changes due to addition of bentonite.

Bentonite content (%)		5	10	15	20
γ_d (kN/m ³)	w (%)	Sample code	Shear strength change		
16	10	16-w10	1.9	2.7	3.0
16	15	16-w15	1.9	2.3	3.6
16	20	16-w20	1.4	1.9	2.7
17	10	17-w10	1.5	1.9	2.9
17	15	17-w15	1.6	3.3	4.1
18	10	18-w10	1.7	2.5	3.2
18	15	18-w15	1.6	2.4	2.5
19	10	19-w10	1.5	2.1	2.2
Average			1.6	2.4	3.0

3.2 Effect of Mixture Density

Figure 3 shows the effect of density on the compacted claystone-bentonite mixtures' permeability, as indicated in samples with 5–20% bentonite with a 10% moisture content in Figure 3(a) and a 15% moisture content in Figure 3(b). The sample legend is written as the claystone percentage



(CS) and bentonite percentage (B), while w is used as the symbol for the moisture content. Figure 3(a) shows that a higher density produced a lower permeability, as was observed in all mixture variations from 5 to 20% bentonite. However, not all mixtures met the requirements necessary for a clay liner, as indicated by the gray area. These mainly comprised 5% bentonite with a 10% moisture content. Moreover, 20% bentonite content samples were the samples that most commonly met the requirements at a density of ≥ 17 kN/m³, because they were compacted with more energy than the Proctor standard.

The same trend was found for samples with a higher moisture content of 15%, as presented in Figure 3(b), with an increase in density observed to cause a smaller pore number and permeability. This is in line with findings of a previous study that showed that an increase in the density reduced the macropore size and volume, while the micropores did not change much [6,7,14]. These macropores play an important role in the changes experienced in soil permeability, especially for clay soil, such that smaller and fewer macropores usually lead to a lower permeability.

This means that all the samples with a 20% bentonite content, such as 80CS20B-15, qualified as clay liners, while 85CS15B-15 was partially compliant, and neither 95CS5B-15 or 90CS10B-15 was satisfactory. These results showed that the samples compacted with Proctor Standard energy with a dry density of 16 kN/m³ satisfied the requirements at higher moisture contents. This, therefore, shows the importance of water content in compacted claystone-bentonite mixtures.

Figure 4 shows the compressive strength and undrained cohesion of compacted claystone-bentonite as a function of the dry density. This is demonstrated in samples with a 10% moisture content in Figure 4(a) and a 15% moisture content

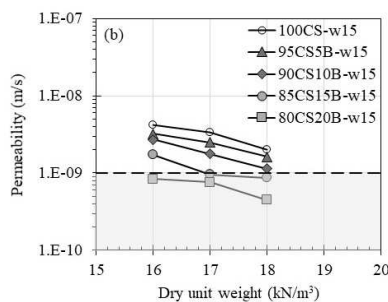


Figure 3. Effect of density on the permeability of compacted claystone-bentonite mixtures

- Deleted: Based on
- Commented [MOU13]: Please ensure the meaning has been retained.
- Deleted: of
- Deleted: rise
- Deleted: the
- Deleted: a
- Deleted: times
- Deleted: times
- Deleted: 's requirements
- Deleted: ,
- Deleted: ing
- Deleted: Meanwhile
- Deleted: that
- Deleted: also di
- Deleted: the
- Deleted:
- Deleted: density
- Deleted: bentonite mix of
- Deleted: %
- Deleted: by
- Deleted: times on average
- Deleted: the
- Deleted: ing
- Deleted: smaller
- Deleted: none of
- Deleted: and
- Deleted: having
- Deleted: could
- Deleted: y
- Deleted: s'
- Deleted: claystone-bentonite
- Deleted: claystone-bentonite
- Deleted: as indicated

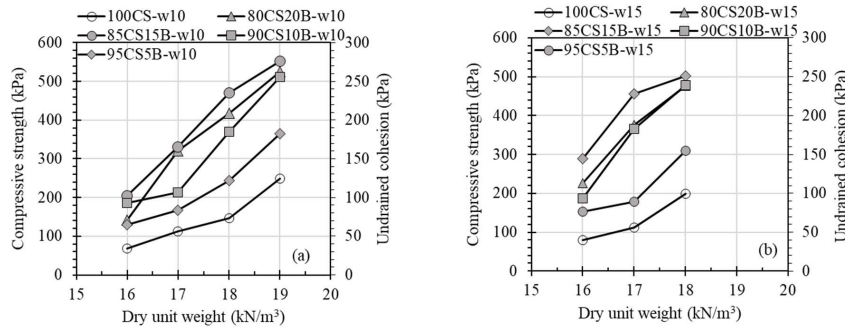


Figure 4. Effect of density on the compressive strength of claystone-bentonite mixtures

in Figure 4(b), which shows almost all of the densities used in this study. The sample's compressive strength and undrained cohesion were observed to increase as the density of all bentonite contents increased. The density increment caused a reduction in the size and number of macropores and increased the percentage of micropores [7], playing a role in the shear strength of clay soils.

Zhang [22] reported that the mechanical stiffness of the compacted claystone-bentonite mixtures exponentially increases with increasing dry density. Moreover, at a given dry density, the stiffness of the claystone-bentonite mixtures was higher than that of the bentonite-sand mixture. The low stiffness of the bentonite-sand mixture is due to the lower density of the bentonite matrix, which embeds the sand particles, resulting in a lower inner friction resistance [22]. On the other hand, the high stiffness of the claystone-bentonite mixture is caused by the high density of the bentonite matrix in the claystone. Claystone, unlike generally inert sand, contains clay minerals, and contact between claystone and bentonite can occur, influencing the hydro-mechanical behavior of the compacted mixture [23].

The changes in the permeability and shear strength of the claystone-bentonite mixture are summarized in Tables 5 and 6, respectively. For samples with a moisture content of 10%, as shown in Table 5, the decrease in permeability was, on average, 2.0-, 2.6-, and 6.0-fold due to an increase in density from 16kN/m³ to 17kN/m³, 18kN/m³, and 19kN/m³, respectively. When the density was increased from 16kN/m³ to 17kN/m³ and 18kN/m³, the permeability decreased by an average of 1.8 and 2.0 times, respectively, for samples with a moisture content of 15%.

For the sample shear strength with a moisture content of 10%, as shown in Table 6, an increase in

density from 16kN/m³ resulted in an average 1.6-, 2.2-, and 3.1-fold increase after the dry unit weight increased to 17kN/m³, 18kN/m³, and 19kN/m³. At a 15% moisture content, the shear strength increased by an average of 1.6 and 2.2 times, respectively, after the dry unit weight was increased from 16kN/m³ to 17kN/m³ and 18kN/m³.

Table 5. Permeability change due to the increase in density.

Bent. content	w (%)	Sample code	Dry unit weight (kN/m³)		
			17	18	19
0	10	100CS-w10	1.7	2.3	6.1
5	10	95CS5B-w10	1.8	2.3	6.2
10	10	90CS10B-w10	2.2	2.6	6.0
15	10	85CS15B-w10	2.1	3.2	5.9
20	10	80CS20B-w10	2.0	2.8	6.1
Average			2.0	2.6	6.0
0	15	100CS-w15	1.2	2.1	
5	15	95CS5B-w15	1.3	2.0	
10	15	90CS10B-w15	1.5	2.4	
15	15	85CS15B-w15	1.8	2.0	
20	15	80CS20B-w15	1.1	1.9	
Average			1.4	2.1	

3.3 Effect of Water Content

Figures 5(a) and 5(b) show the effect of water content on the permeability of the claystone-bentonite mixture sample, with the legend indicating the percentages of claystone (CS) and bentonite (B) and the density of the samples. Figure 5(a) shows the result of the sample with a density of 16 kN/m³ using three moisture content conditions,

- Deleted: had
- Deleted: change of
- Commented [MOU14]: Please ensure the meaning has been retained.
- Deleted: times greater
- Commented [MOU17]: Please ensure the meaning has been retained.
- Deleted:
- Deleted: for
- Deleted: is
- Deleted: -
- Deleted: -
- Deleted: that
- Deleted: claystone-bentonite
- Deleted: -
- Deleted: claystone-bentonite
- Deleted: is
- Commented [MOU15]: Should a unit be added here (or times/fold)
- Commented [MOU16]: Please ensure the meaning has been retained.
- Deleted: be
- Deleted: claystone-bentonite
- Deleted: as well as
- Deleted: number for
- Deleted: Meanwhile
- Deleted: f

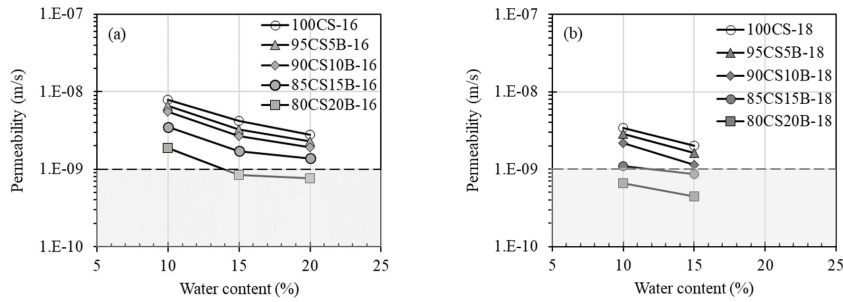


Figure 5. Effect of water content on the permeability of compacted claystone-bentonite mixtures (a) samples with dry density of 16kN/m^3 and (b) samples with dry density of 18kN/m^3

while Figure 5(b) shows a higher density of 18kN/m^3 . The permeability of the compacted sample at the optimum water content (i.e., 15%) was observed to be lower than for the dry condition (i.e., 10%), while the value in the wet condition (i.e., 20%) was almost the same as for the optimum. Similar results were also recorded for samples with higher densities. Several researchers have previously discussed this effect [4,5].

Table 6. Shear strength change due to the increase in density.

Dry unit weight (kN/m^3)		17	18	19
Bent. content	w (%)	Sample code	Shear strength change	
0	10	100CS-w10	1.7	2.1
5	10	95CS5B-w10	1.3	1.9
10	10	90CS10B-w10	1.1	2.0
15	10	85CS15B-w10	1.6	2.3
20	10	80CS20B-w10	2.3	2.9
Average			1.6	2.2
0	15	100CS-w15	1.4	2.5
5	15	95CS5B-w15	1.2	2.0
10	15	90CS10B-w15	2.0	2.5
15	15	85CS15B-w15	1.6	1.7
20	15	80CS20B-w15	1.7	2.1
Average			1.6	2.2

Benson et al. [4] showed that low permeability at higher water contents was due to microstructural changes in the soil. It is important to note that a bimodal pore size distribution, including macro- and micropores, exists in dry conditions, while a unimodal pore distribution, including micropores, exists at higher moisture contents. It was also

reported by Arifin and Schanz [7] that pores in dry conditions are large, while micropores are dominant at wet conditions when the samples are at the same density or void ratio. In this claystone-bentonite mixture, the claystone macropores were filled with bentonite [21]. When interacting with water, the bentonite expanded and closed these macropores. At a higher water content, in addition to the macropores filling with expanding bentonite, the dominant micropores resulted in a lower permeability.

The effects of water content on changes in permeability of the claystone-bentonite mixture are summarized in Tables 7. The data are represented by samples with densities of 16kN/m^3 and 18kN/m^3 , as shown in Figures 5. For samples with densities of 16kN/m^3 in Table 7, the permeability decreased by an average of 2.0 and 2.7 times when the water content increased from 10% to 15% and 20%, respectively. For samples with a density of 18kN/m^3 , an increase in the initial water content of the sample from 10% to 15% resulted in a 1.6-fold lower average.

Figure 6 shows the effect of moisture content on the compressive strength and undrained cohesion of compacted claystone-bentonite mixtures using a similar trend as for permeability, with densities of 16 and 18kN/m^3 , as shown in Figures 6(a) and 6(b), respectively. The compressive strength and undrained cohesion seemed to be relatively constant at a density of 16kN/m^3 with a 5 and 10% bentonite content, while it was observed to increase with a moisture content of 15 and 20%. It was discovered that claystone absorbed more water at lower bentonite levels (5–10%), and this higher water content caused a reduction in the claystone-bentonite mixture strength. This is associated with the strength usually lost by claystone when interacting with a lot of water [24–26]. Moreover, the bentonite absorbed more water at a higher

- Deleted: is
- Deleted: for
- Deleted: the
- Deleted: at
- Deleted: at
- Deleted: is
- Deleted: s
- Deleted: s
- Deleted: ed
- Deleted: is
- Deleted:
- Deleted: Whereas
- Deleted: f
- Deleted: an average of
- Deleted: times
- Commented [MOU19]: Please ensure the meaning has been retained.
- Deleted: the
- Deleted: the
- Deleted:
- Deleted: represented by
- Deleted: density
- Deleted: at
- Deleted: the soil
- Deleted: e
- Deleted: claystone-bentonite
- Deleted: at
- Deleted: Meanwhile
- Commented [MOU18]: Please ensure the meaning has been retained.

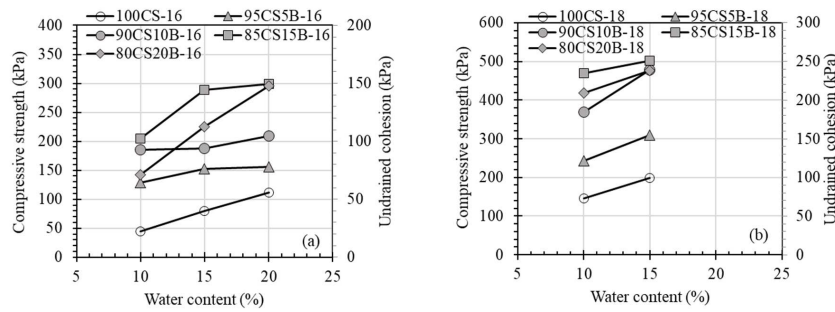


Figure 6. Effect of water content on the compressive strength of compacted claystone-bentonite mixtures (a) samples with dry density of 16kN/m³ and (b) samples with dry density of 18kN/m³

content of 20%, making the sample more difficult to compact and decreasing the sample strength. Furthermore, compressive strength and undrained cohesion appeared to increase as the moisture content increased at high densities of 18kN/m³, as shown in Figure 6(a). This was due to the compressed bentonite, which supported better bonding in the claystone-bentonite mixture.

Table 7. Effect of sample moisture content on the permeability of the claystone-bentonite mixtures.

Moisture content (%)		15	20
Bentonite content	γ_d (kN/m ³)	Sample code	Permeability change
0	16	100CS-16	1.9 2.8
5	16	95CS5B-16	2.0 2.9
10	16	90CS10B-16	2.0 2.9
15	16	85CS15B-16	2.0 2.6
20	16	80CS20B-16	2.2 2.4
Average			2.0 2.7
0	18	100CS-18	1.7
5	18	95CS5B-18	1.8
10	18	90CS10B-18	1.9
15	18	85CS15B-18	1.3
20	18	80CS20B-18	1.5
Average			1.6

In general, samples compacted in dry and wet conditions produce lower shear strength than those compacted at the optimum moisture content [38,39,41]. Samples that were compacted at dry or wet moisture contents produced a dry unit weight that was smaller than those compacted at the optimum water content, following the compaction curve. In this study, the dry unit weight of the

samples was prepared equally at different moisture contents. The compressive strength and cohesion obtained increased with the increasing water content, as shown in Figure 6.

Table 8 shows the shear strength change due to the alteration of the initial moisture content of the samples. As shown in the table, an increase in moisture content from 10% to 15% resulted in a 1.2-1.3-fold increase in the compressive strength and cohesion. The shear strength increased 1.5-fold as a result of increasing the water content from 10% to 20%.

Table 8. Effect of sample moisture content on the shear strength of the compacted claystone-bentonite mixtures.

Moisture content (%)		15	20
Bent. content	γ_d (kN/m ³)	Sample code	Shear strength change
0	16	100CS-16	1.2 1.6
5	16	95CS5B-16	1.2 1.2
10	16	90CS10B-16	1.0 1.1
15	16	85CS15B-16	1.4 1.5
20	16	80CS20B-16	1.6 2.1
Average			1.3 1.5
0	17	100CS-17	1.4
5	17	95CS5B-17	1.3
10	17	90CS10B-17	1.3
15	17	85CS15B-17	1.1
20	17	80CS20B-17	1.1
Average			1.2

The shear strength of sandstone and claystone fluctuates due to changes in the surrounding environment such as moisture content or relative

Deleted: thereby

Deleted: Moreover

Deleted: by

Deleted:

Deleted: s

Deleted: rise

Deleted: s'

Deleted: of 1.2-1.3 times

Deleted: extends

Deleted: to

Deleted: times by

Deleted: s'

Deleted: of

Deleted: at

Deleted: of optimum moisture content

Deleted: those

Deleted: at

Deleted: alters

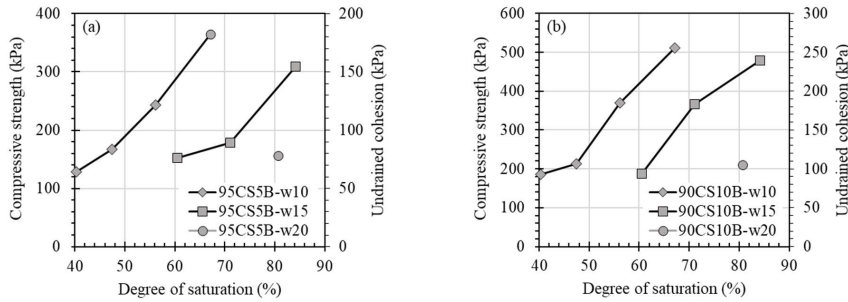


Figure 7. Effect of degree of saturation on the compressive strength and undrained cohesion of compacted claystone-bentonite mixtures (a) 5% bentonite content, and (b) 10% bentonite content

humidity. Shakoore and Berefield [42] reported that the unconfined compressive strength of the sandstone decreases with an increasing degree of saturation. Samples were tested by allowing them to absorb water so that the degrees of saturation increase. In other words, the increase in the degree of saturation was caused by the increase in the sample moisture content. Meanwhile, Pineda et al. [43] reported the effect of the relative humidity cycle on the reduction of cohesion and friction of claystone. This decrease is due to the accumulation of strain damage that occurs during the RH cycle. Figure 7 shows the relationship between the degree of saturation and the shear strength of compacted claystone-bentonite mixtures represented by two bentonite contents, namely 5% and 10%, shown in Figures 7(a) and 7(b), respectively. Both figures show the same trend whereby compressive strength and cohesion samples increase with the increasing degree of saturation. This effect is different from the results of other studies. An increase in the degree of saturation in the study is caused by the increase in the dry density sample or a reduction in the initial sample void ratio. Moreover, the increase in water content, as seen in Figure 6, resulted in a slight increase in the shear strength of the samples. In this study, changes were made to the water content around the optimum water content of claystone (i.e., 15%) so that the shear strength at that water content is the shear strength of the maximum density of claystone.

The analysis of its microstructures using both electron scanning (SEM) and porosimetry intrusion of mercury (MIP) methods provides a more comprehensive description of the effects of supplementing bentonite to the claystone. This is directly related to the state of the mixtures, which were compacted at various moisture content levels, as well as the increase in sample density. Further investigation concerning the microstructure of

compact claystone-bentonite mixture is required.

3.4 Acceptable Zone of Clay Liner

Daniel and Benson [30] suggested a method for determining acceptable zones in clay liner designs. This method combines a zone that meets the permeability requirements and other criteria, and relates the parameters to dry unit weight and water content. Zones overlapping one another become a single acceptable zone. This method was applied to the claystone-bentonite mixture data obtained in this study, as shown in Figure 8. Two criteria were used in the figure (i.e., permeability and shear strength). The circles on the curves refer to the moisture content and density of the samples. The black symbols show the samples that meet both requirements.

Figure 8(a) shows the criteria for a sample with 5% bentonite. As seen in the figure, there is only an acceptable zone for shear strength. No permeability zone was obtained due to the absence of samples that meet the permeability criteria for 95CS5B samples, as shown in Figure 1. Moreover, Figure 8(b) shows an acceptable zone for claystone samples mixed with 10% bentonite. On the basis of the data summarized from Figures 1 and 2, only one sample met the two criteria, i.e., 90CS5B at a density of 19kN/m³ and a water content of 10%. The overlapping zone is too small and difficult to reach in the field, especially at very high densities. Benson et al. [29] reported that only 74% of clay liners in the field met the permeability criteria of 1x10⁻⁹m/s in North America. The lack of homogeneity of the mixture may fail to achieve the permeability requirements as no example met the sample's criteria with 5% bentonite.

For samples with a bentonite content of 15% (85CS15B), the acceptable zone is depicted in Figure 8(c). Three samples met both criteria. The

- Deleted: claystone-bentonite
- Deleted: are
- Deleted: zones
- Deleted: raise
- Deleted: zone
- Deleted: addition
- Deleted: of
- Deleted: with
- Deleted: claystone-bentonite
- Deleted: claystone-bentonite
- Deleted: , meanwhile,
- Deleted: s
- Deleted: where
- Deleted: rise
- Deleted: the
- Deleted: rise
- Deleted: is
- Deleted: of
- Deleted: Meanwhile
- Deleted: Based on
- Deleted: on
- Deleted: the
- Deleted: the
- Deleted: rules
- Deleted: because
- Deleted: one
- Deleted: ets
- Deleted: are
- Deleted: rise
- Deleted: on

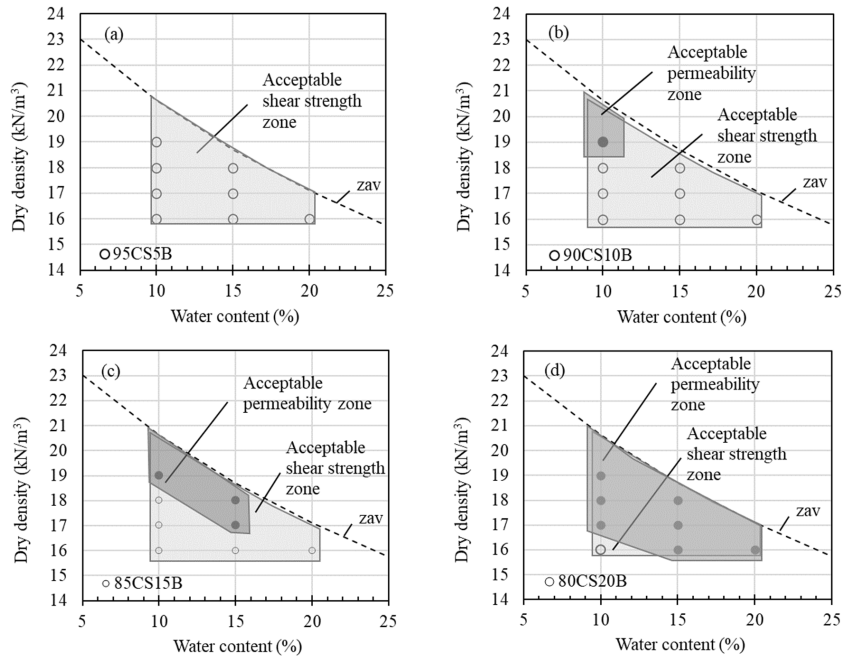


Figure 8. Acceptable zones for shear strength and permeability of claystone-bentonite mixtures (a) 95CS5B, (b) 90CS10B, (c) 95CS15B, and (d) 90CS20B

overlapping zone obtained was larger than that of the 90CS10B sample, as seen in Figure 8(b). These results are consistent with previous studies that reported that an increase in the percentage of bentonite resulted in lower permeability [5,8–11]. Furthermore, seven samples with a bentonite content of 20% met the two requirements, as shown in Figure 8(d). As a result, the accepted zone became larger than those shown in previous curves. Since the size of the zone was large, the possibility of this being achieved in the field was high. The large zone also minimized the inhomogeneous effect of mixing claystone and bentonite samples. Benson et al. [29] suggested the use of a wide variety of clayey soil to achieve the permeability requirements in the field.

4. CONCLUSIONS

The effect of claystone mixed with bentonite on permeability is herein described and analyzed based on experiments. The results show that the permeability of mixtures decreases with increasing bentonite content. Mixtures of 5%, 10%, 15%, and 20% reduced the permeability of the mixture by an

average of 1.2, 1.6, 2.6, and 4.5 times, respectively, compared to those without bentonite. However, not all mixtures met the clay liner permeability criteria.

Bentonite in the mixture also affects the shear strength of the sample. The compressive strength and cohesion of the mixture were increased after bentonite was added up to 15%. At 20% bentonite, the shear strength was constant or decreased. With the addition of 5%, 10%, and 15% bentonite, the shear strength of the soil was increased by an average of 1.6, 2.4, and 3.0 times, respectively, compared to those without bentonite.

The initial density and moisture content of samples also affect the permeability and shear strength of the claystone-bentonite mixtures. Increasing the density from 16kN / m³ to 19 kN / m³ reduced the sample permeability up to 6.0-fold and increased the shear strength up to 3.1-fold. Changes in the initial water content of the sample from 10% to 20% also resulted in a 2.7-fold reduction in permeability and a 1.5-fold increase in soil shear strength.

The acceptable zone based on two criteria (i.e., shear strength and permeability) increased by increasing bentonite content in the mixtures. A

- Deleted: on average
- Deleted: e
- Deleted: ting
- Deleted: has
- Deleted: received
- Deleted: on average
- Deleted: to
- Deleted: claystone-bentonite
- Deleted: s
- Deleted: times
- Deleted: s
- Deleted: times
- Deleted: by 2.7 times
- Deleted: raise
- Deleted: has been
- Deleted: by 1.5 times
- Deleted: ed
- Deleted: by
- Deleted: enlarges
- Deleted: The
- Deleted: m

percentage of 20% bentonite is recommended, considering the wide range of acceptable sample conditions.

5. ACKNOWLEDGMENT

The authors are grateful for the financial support provided by University of Lambung Mangkurat through the "Dosen Wajib Meneliti" program.

6. REFERENCES

- [1] Chai, J., Miura, N. Comparing the Performance of Landfill Liner Systems. *J mater cycles waste Manag.* Vol.4, 2002, pp.135-142.
- [2] Akgün, H., Ada, M., Koçkar, M.K. Performance Assessment of a Bentonite-Sand Mixture for Nuclear Waste Isolation at the Potential Akkuyu Nuclear Waste Disposal Site, Southern Turkey. *Environ. Earth Sci.*, Vol.73, 2015, pp.6101-6116, doi:10.1007/s12665-014-3837-x.
- [3] Permen PU Peraturan Menteri Pekerjaan Umum No. 3 tentang Penyelenggaraan Prasarana dan Sarana Persampahan dalam Penanganan Sampah Rumah Tangga dan Sampah Sejenis Sampah Rumah Tangga. In: 2013 ISBN 9781626239777.
- [4] Benson, C.H., Zhai, H., Wang, X. Estimating Hydraulic Conductivity of Compacted Clay Liners. *J. Geotech. Eng.*, Vol.120, 1994, pp.366-387, doi:10.1061/(asce)0733-9410(1995)121:9(675).
- [5] Arifin, Y.F., Sambelum. Bentonite Enhanced Soil as an Alternative Landfill Liner in Rikut Jawa, South Barito. *IOP Conf. Ser. Earth Environ. Sci.*, Vol.239, 2019, doi:10.1088/1755-1315/239/1/012003.
- [6] Cui, Y.J. On the Hydro-Mechanical Behaviour of MX80 Bentonite-Based Materials. *J. Rock Mech. Geotech. Eng.*, Vol.9, 2017, pp.565-574, doi:10.1016/j.jrmge.2016.09.003.
- [7] Arifin, Y.F., Schanz, T. Microstructure of Compacted Calcium Bentonite-Sand Mixture. In *Proceedings of the 12th International Conference of Quality in Research*; 2011; pp. 2156-2161.
- [8] Mollins, L.H., Stewart, D.I., Cousens, T.W. Predicting the Properties of Bentonite-Sand Mixtures. *Clay Miner.*, Vol.31, 1996, pp.243-252, doi:10.1180/claymin.1996.031.2.10.
- [9] Sivapullaiah, P. V., Sridharan, A., Stalin, V.K. Hydraulic Conductivity of Bentonite-Sand Mixtures. *Can. Geotech. J.*, Vol.37, 2000, pp.406-413, doi:10.1139/t99-120.
- [10] Ameta, N.K., Wayal, A.S. Effect of Bentonite on Permeability of Dune Sand. *Electron. J. Geotech. Eng.*, Vol.13 A, 2008.
- [11] Proia, R., Croce, P., Modoni, G. Experimental Investigation of Compacted Sand-Bentonite Mixtures. *Procedia Eng.*, Vol.158, 2016, pp.51-56, doi:10.1016/j.proeng.2016.08.404.
- [12] Tripathi, K.K., Viswanadham, B.V.S. Evaluation of the Permeability Behaviour of Sand-Bentonite Mixtures Through Laboratory Tests. *Indian Geotech. J.*, Vol.42, 2012, pp.267-277, doi:10.1007/s40098-012-0020-8.
- [13] Arifin, Y.F. Thermo-Hydro-Mechanical Behavior of Compacted Bentonite Sand Mixtures: An Experimental Study, *Bauhaus Universitaet Weimar, Germany*, 2008.
- [14] Agus, S.S. An Experimental Study on Hydro-Mechanical Characteristics of Compacted Bentonite-Sand Mixtures, *Bauhaus Universitaet Weimar, Germany*, 2005.
- [15] Ballarini, E., Graupner, B., Bauer, S. Thermal-Hydraulic-Mechanical Behavior of Bentonite and Sand-Bentonite Materials as Seal for a Nuclear Waste Repository: Numerical Simulation of Column Experiments. *Appl. Clay Sci.*, Vol.135, 2017, pp.289-299, doi:10.1016/j.clay.2016.10.007.
- [16] Sharma, L.K., Singh, R., Ahmad, M., Umrao, R.K., Singh, T.N. Experimental Evaluation of Geomechanical Behaviour of Bentonite-Sand Mixture for Nuclear Waste Disposal. *Procedia Eng.*, Vol.191, 2017, pp.386-393, doi:10.1016/j.proeng.2017.05.195.
- [17] Al-Badran, Y., Baille, W., Tripathy, S., Schanz, T. Swelling Behavior of Bentonite-Based Backfilling Materials in Nuclear Waste Repository Conditions. *J. Hazardous, Toxic, Radioact. Waste*, Vol.21, 2017, pp.1-5, doi:10.1061/(asce)hz.2153-5515.0000308.
- [18] Ghazi, A.F. *Engineering Characteristics of Compacted Sand-Bentonite Mixtures*, Edith Cowan University, 2015.
- [19] Wu, Y. *Permeability and Volume Change Characteristics of Bentonite-Sand Mixes in a Contaminant Environment* Copyright Warning & Restrictions. Vol.c, 1989.
- [20] Kohno, M., Nara, Y., Kato, M., Nishimura, T. Effects of Clay-Mineral Type and Content on the Hydraulic Conductivity of Bentonite - Sand Mixtures Made of Kunigel Bentonite from Japan. *Clay Miner.*, Vol.53, 2019, pp.721-732.
- [21] Zhang, C.-L. Characterization of Excavated Claystone and Claystone-Bentonite Mixtures as Backfill/Seal Material. *Geol. Soc. Spec. Publ.*, Vol.400, 2014, pp.327-337, doi:10.1144/SP400.28.
- [22] Zhang, C.-L. Sealing Performance of Fractured Claystone and Clay-Based Materials. *Gesellschaft für Anlagen- und Reaktor- sicherheit (GRS) gGmbH*, 2017.

- ISBN 978-3-946607-38-0.
- [23] Wang, Q., Tang, A.M., Cui, Y.J., Delage, P., Gatmiri, B. Experimental Study on the Swelling Behaviour of Bentonite/Claystone Mixture. *Eng. Geol.*, Vol.124, 2012, pp.59–66, doi:10.1016/j.enggeo.2011.10.003.
- [24] Sadisun, I.A., Shimada, H., Ichinose, M., Matsui, K. Study on the Physical Disintegration Characteristics of Subang Claystone Subjected to a Modified Slaking Index Test. *Geotech. Geol. Eng.*, Vol.23, 2005, pp.199–218, doi:10.1007/s10706-003-6112-6.
- [25] Espitia, J.M., Caicedo, B., Vallejo, L. Comparison of the Uniaxial Compressive Strength of the Belencito Claystone Under Stress Control and Suction Control Paths. *Rock Mech. Rock Eng.*, Vol.52, 2019, pp.19–34, doi:10.1007/s00603-018-1588-9.
- [26] Liu, Z., Shao, J. Moisture Effects on Damage and Failure of Bure Claystone under Compression. *Geotech. Lett.*, Vol.6, 2016, pp.182–186, doi:10.1680/jgele.16.00054.
- [27] Wan, M., Delage, P., Tang, A.M., Talandier, J. The Water Retention Properties of the Callovo-Oxfordian Claystone. *Unsaturated Soils Res. Appl. - Proc. 6th Int. Conf. Unsaturated Soils, UNSAT 2014*, Vol.2, 2014, pp.1011–1016, doi:10.1016/j.ijmms.2013.08.020.
- [28] Özbek, A., Gül, M. The Geotechnical Evaluation of Sandstone–Claystone Alternations Based on Geological Strength Index. *Arab. J. Geosci.*, Vol.8, 2015, pp.5257–5268, doi:10.1007/s12517-014-1541-5.
- [29] Benson, C.H., Daniel, D.E., Boutwell, G.P. Field Performance of Compacted Clay Liners. *J. Geotech. Geoenvironmental Eng.*, Vol.125, 1999, pp.390–403, doi:10.1061/(asce)1090-0241(1999)125:5(390).
- [30] Daniel, D.E., Benson, C.H. Water Content-Density Criteria for Compacted Soil Liners. *J. Geotech. Eng.*, Vol.116, 1990, pp.1811–1830, doi:10.1061/(ASCE)0733-9410(1992)118:6(967.2).
- [31] Environment-Agency Earthworks in Landfill Engineering: Design, Construction and Quality Assurance of Earthworks in Landfill Engineering. Environment Agency: Bristol, 2014.
- [32] Dixon, N., Jones, D.R. V. Engineering Properties of Municipal Solid Waste. *Geotext. Geomembranes*, Vol.23, 2005, pp.205–233, doi:10.1016/j.geotextmem.2004.11.002.
- [33] ASTM-D698-07 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. *Am. Soc. Test. Mater.*, 2007, pp.13.
- [34] Das, B.M. *Soil Mechanics Laboratory Manual*. Sixth. Oxford University Press: New York, 2002.
- [35] Pedescoll, A., Samsó, R., Romero, E., Puigagut, J., García, J. Reliability, Repeatability and Accuracy of the Falling Head Method for Hydraulic Conductivity Measurements under Laboratory Conditions. *Ecol. Eng.*, Vol.37, 2011, pp.754–757, doi:10.1016/j.ecoleng.2010.06.032.
- [36] ASTM D2166-00 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. *ASTM Int.* West Conshohocken, PA, 2000, www.astm.org, Vol.04, 2000.
- [37] Charkley, F.N., Zhang, K., Mei, G. Shear Strength of Compacted Clays as Affected by Mineral Content and Wet-Dry Cycles. *Adv. Civ. Eng.*, Vol.2019, 2019, doi:10.1155/2019/8217029.
- [38] Cokca, E., Erol, O., Armangil, F. Effects of Compaction Moisture Content on the Shear Strength of an Unsaturated Clay. *Geotech. Geol. Eng.*, Vol.22, 2004, pp.285–297, doi:10.1023/B:GEGE.0000018349.40866.3e.
- [39] Dafalla, M.A. Effects of Clay and Moisture Content on Direct Shear Tests for Clay-Sand Mixtures. *Adv. Mater. Sci. Eng.*, Vol.2013, 2013, doi:10.1155/2013/562726.
- [40] Kim, D., Nam, B.H., Youn, H. Effect of Clay Content on the Shear Strength of Clay-Sand Mixture. *Int. J. Geo-Engineering*, Vol.9, 2018, doi:10.1186/s40703-018-0087-x.
- [41] Ghosh, R. Effect of Soil Moisture in the Analysis of Undrained Shear Strength of Compacted Clayey Soil. *J. Civ. Eng. Constr. Technol.*, Vol.4, 2013, pp.23–31, doi:10.5897/JCECT12.070.
- [42] Shakoor, A., Barefield, E.H. Relationship between Unconfined Compressive Strength and Degree of Saturation for Selected Sandstones. *Environ. Eng. Geosci.*, Vol.15, 2009, pp.29–40, doi:10.2113/gsegeosci.15.1.29.
- [43] Pineda, J.A., Romero, E., De Gracia, M., Sheng, D. Shear Strength Degradation in Claystones Due to Environmental Effects. *Geotechnique*, Vol.64, 2014, pp.493–501, doi:10.1680/geot.13.T.025.

From: Geomate Editor

Sent: 29 April 2021 14:48

To: y.arifin@ulm.ac.id; emarsyad@ulm.ac.id; aprianaji1133@gmail.com;
1610811210015@mhs.ulm.ac.id

Subject: Pay Notice : j2141 : Dr. Yulian Firmana Arifin : Journal Revised paper

Dear Authors,

Thanks. Our decision is as follows:

Your paper has been examined by our external referees and then re-evaluated in-house. Your revised paper has been accepted provisionally. Congratulations.

For necessary action, please pay publication fees of total 1400USD included 600 USD for Extra 6 pages, using the following link.


<https://www.geomatejournal.com/pay>

After your payment confirmation, we would take the necessary action.

Best regards.

Editor-in-Chief
International Journal of GEOMATE

On Mon, Apr 26, 2021 at 4:35 AM Dr. Yulian Firmana Arifin <noreply@jotform.com> wrote:

 j2141 : Dr. Yulian Firmana Arifin : Journal Revised paper	
Paper ID number	j2141
Revised Title	THE PERMEABILITY AND SHEAR STRENGTH OF COMPACTED CLAYSTONE–BENTONITE MIXTURES
Full Name	Dr. Yulian Firmana Arifin
E-mail	y.arifin@ulm.ac.id
Co-authors E-mails	emarsyad@ulm.ac.id aprianaji1133@gmail.com 1610811210015@mhs.ulm.ac.id
Revised Paper (Word)	Final article based on the reviewers comments.docx
Response to Reviewers	Response Authors to Reviewers 26042021.docx
(Form 2) Copyright	Form 2 copyright 26042021.pdf

(Form 3) Info

[Form 3 26042021 complete.pdf](#)

You can [edit this submission](#) and [view all your submissions](#) easily.

From: geomate

Sent: 30 April 2021 8:14

To: y.arifin@ulm.ac.id

Subject: Journal Paper Publication Fee: j2141: : Mr. Yulian Firmana Arifin: GEOMATE All Payments: Receipt

Official Receipt

Journal Paper Publication Fee: j2141: : Mr. Yulian Firmana Arifin: GEOMATE All Payments: Receipt

Amount and Quantity • 100 USD (Amount: 100.00 USD, Quantity: 14)

Total: \$1,400.00

==Payer Info==

First Name Yulian F
Last Name Arifin
E-Mail y.arifin@ulm.ac.id
Transaction ID 71S65148SF372101B

==Address==

Name Yulian F Arifin
Street Jl. A. Yani km 35.5
City Banjarbaru
State KALIMANTAN SELATAN
Zip 70714
Country Indonesia

Full Name Mr. Yulian Firmana Arifin

E-mail y.arifin@ulm.ac.id

Address Street Address: Jl. A. Yani km 35.5
City: Banjarbaru
State / Province: South Kalimantan
Postal / Zip Code: 70714
Country: Indonesia

University/Company Universitas Lambung Mangkurat

Item Journal Paper Publication Fee

ID or Your Name j2141

From: Geomate Editor

Sent: 13 June 2021 16:03

To: y.arifin@ulm.ac.id; emarsyad@ulm.ac.id; aprianaji1133@gmail.com;
1610811210015@mhs.ulm.ac.id

Subject: Final Page Proof-----

Dear Authors,

Attached herewith, please see the page proof paper for final checking. Please note that this is the final correction and after this checking, you will not be able to change anything later on.

Please do not change the format if there is any correction. Please send PDF and WORD versions (**Publishable Format including all journal information such as page numbers, vol, issue number, date of received, revised and accepted, etc.**) of your page proof paper by 4 days from the date of this email using the following link.
<https://www.geomatejournal.com/page>


If we do not receive the response within the deadline, then the attached paper will be the final one.

Best regards.

Prof. Dr. Zakaria Hossain
Editor-in-Chief
International Journal of GEOMATE

From: geomate
Sent: 16 June 2021 13:20
To: y.arifin@ulm.ac.id
Subject: Page Proof- Dr. Yulian Firmana Arifin

Thanks. The final paper must contain the page number, Vol., Issue, year and all other information in publishable format.

 Page Proof	
Paper ID	j2141
Full Name	Dr. Yulian Firmana Arifin
Corrections	Yes (Upload the corrected paper)
Upload PDF	48-61-j2141-Arifin-Aug-2021-84[4870] rev.pdf
	48-61-j2141-Arifin-Aug-2021-84[4870] rev.docx
E-mail	y.arifin@ulm.ac.id

[Now create your own JotForm - It's free!](#)

[Create a JotForm](#)