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STUDY ON CHANGE OF SOIL PROPERTIES DURING DRY AND RAINY SEASONS FOR STABILITY ANALYSIS OF BENGAWAN SOLO RIVER EMBANKMENT

TRIHANYNDIO RENDY SATRYA

03111360010012

SUPERVISORS:

ITS:

Dr. Ir. RIA ASIH ARYANI SOEMITRO, M.Eng.

Prof. Dr. Ir. INDARTO, DEA.

KUMAMOTO UNIVERSITY:

Assoc. Prof. TOSHIFUMI MUKUNOKI

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Trihanyndio Rendy Satrya
03111360010012 (ITS) / 131-D9406 (Kumamoto University)

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Approved by:
Institut Teknologi Sepuluh Nopember
Principal Supervisor,

Dr. Ir. Ria Asih Aryani Soemitro, M.Eng
NIP. 19560119 198601 2 001

Kumamoto University
Principal Supervisor,

Toshifumi Mukunoki

Assoc. Prof. Toshifumi Mukunoki

Co-Supervisor,

Prof. Dr. Ir. Indarto, DEA
NIP. 19501011 198203 1 002

Committee,

Prof. Dr. Ir. Herman Wahyudi
NIP. 19550329 198003 1 002

Committee,

Dr. Dwa Desa Warnana, S.Si., M.Sc.
NIP. 19760123 200003 1 001

Dean of Faculty of Civil, Environmental and Geo Engineering

I.D.A.A.Warmadewanthi, ST., MT., Ph.D.
NIP. 19750212 199903 2 001

ABSTRACT

Study on Change of Soil Properties during Dry and Rainy Seasons for Stability Analysis of Bengawan Solo River Embankment

The soil properties generally change due to change of water content. In particular, change of soil properties in river embankment, that always experiences water level fluctuation throughout the year due to the cycles of the dry and rainy seasons. The river embankment, that had been built by dredged material from riverbed, tends to fail along the Bengawan Solo river, Indonesia. The embankment soil was classified as inorganic clayey silt with low plasticity (CL) and grouped as medium expansive soil. High river water level fluctuation and excessive rainfall during the rainy season might become one of the reasons of soil properties changes. This research is aimed to investigate soil properties relationship between in-situ and laboratory investigations and to investigate the influence of soil properties changes due to cyclic drying and wetting processes on slope stability. The physical and mechanical soil properties change due to the cyclic drying and wetting were investigated from the fresh Proctor compacted and remolded in-situ initial conditions. In-situ soil properties were measured at two-week interval time for 4 months.

Soil properties changes of in-situ investigation are strongly related to those of fresh Proctor compacted on 2nd and 3rd cycle of drying and wetting. Both dry density and undrained cohesion highly decreased from 1st to 2nd cycle, then slightly decreased from 2nd to 3rd cycle. The hysteresis of those properties from 1st to 2nd cycle is greater than those from 2nd to 3rd cycle.

Sensitivity analysis result showed that cohesion change was the most influential soil property in unsaturated slope stability equation, therefore cohesion change was introduced in those equation. Safety factor considering cohesion change is decreased from 1st cycle to 2nd cycle, then it is nearly constant from 2nd to 3rd cycle of drying and wetting.

It is thought to be due that in-situ soil properties changes might be simulated using laboratory investigation. River embankment stability is somewhat more accurate if considering the cohesion change.

KEYWORDS: *Bengawan Solo river, river embankment, clayey silt, drying-wetting cycles, soil property change, unsaturated slope stability.*

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CHAPTER I
INTRODUCTION

1.1 Background

Bengawan Solo river become one of the longest rivers in Indonesia that has ± 600 km in length and 150 m in width. Most of path are curvaceous shape and it flows from central of Java end ends in East Java. The problems occurred in section of Kanor Village, Bojonegoro city where plenty of river embankment falures take place during dry and rainy seasons. In addition, sedimentation and erosion which happened in curvaceous area also become considerations on selecting Kanor Village as research observation site.

At the end of 2007 and in the beginning of 2008 and 2009, heavy rainfalls occurred in the Central Java, Indonesia which is the upstream area of the Bengawan Solo river, hence flooding occurred in the downstream area. The floods had overtopped the river embankment and further continued to the residential area. More than one thousand civilians were evacuated to secure the area. Reported by the government, several million dollars had been lost due to damaged property that included more than a thousand houses and farmland. In addition, hundred schools and offices were flooded and river embankments were collapsed. Although the main cause of the floods was the heavy rainfall in the upstream area, other factors, such as sedimentation in the riverbed, improper operation of the reservoir gate, diverted function of the catchment area into the farm land, and the unprotected river embankment, might also has contribution to the flooding. Until recently, failures of river embankment are still likely to be happened in Bengawan Solo river during the seasons, as it could be seen in **Figure 1.1.**

In the beginning, river embankment was constructed by using local fine material sourced from the river, it was dredged from the river bed and placed on the top of embankment. Then, it was freshly compacted until fulfilling the Standard Proctor compaction effort. Throughout the time, river embankment experiences low water level during dry season and high level during rainy season, where the height difference between dry and rainy is around 10 m. The fluctuation of water level develops annually due to seasons. This cyclic fluctuation and the weather might change the physical and mechanical soil properties which starting when it was freshly compacted.

In addition, Soemitro et al, 2007 studied the change of river embankment properties (in-situ) after it was initially compacted in construction stage. The study compares the dry density at construction stage and actual dry density (in-situ) upon 5 years after construction. It shows that after 5 years, in-situ dry density decreases for about 0.15-0.26 times of construction stage. It implies that the physical soil property is changing since it was freshly compacted. In normal situation, the dry density should remain constant throughout the time.

(a)

(b)

(c)

(d)

Figure 1.1. Failure of river embankment in: (a) dry season, 2013; (b) dry season, 2014; (c) rainy season, 2016 and (d) rainy season, 2017.

It is seen that after it was freshly compacted, physical soil properties of in-situ has been changed along the dry and rainy seasons. Based on this research, it is possible to simulate the condition through laboratory investigation which by performing soil compaction and then continuing with cyclic drying and wetting process. Hence, the soil properties change could be investigated. In addition, finding the relationship of soil properties change between the in-situ and laboratory investigations has not been investigated recently.

Besides physical property, soil shear strength as mechanical property might also change due to the seasons. Shear resistance reduction has important role in slope stability during water fluctuation (Schnellmann et al, 2010). Gui, M.W. and Wu, Y.M. (2014) revealed that the water infiltration has a good agreement with the suction and soil shear strength as the soil mechanical properties. Furthermore, the combination between physical and mechanical properties change will influence the slope stability change. Mountassir et al, (2010) pointed out that besides seasonal change, the river embankment instability was also induced by value of soil embankment properties which is vulnerable to the water content change. Consequently, an advanced understanding of mechanical soil properties value under water content change needs to be performed for better understanding the behavior. Fredlund (1993) expressed that when the water content decreases along drying process, the air fills the pore of the soil as clogged air bubbles and continues to increase the air volume phase in the soil and furthermore there will be a difference between pore air pressure and pore water pressure. This kind of soil is different with saturated soil and more suitable to be classified as unsaturated soil. According to the river embankment, the activity of soil compaction process and the fluctuation of river water level trigger the unsaturated soil condition. Therefore, the unsaturated slope stability should be considered in determining the safety factor.

Unsaturated slope stability involves physical and mechanical soil properties, Zhang, L.L. et al (2014) investigated the effectiveness of considering the matric suction effect on unsaturated shear strength (internal angle friction due to suction, ϕ^b) towards the slope stability. Effect of river water level variation and tension crack on slope stability were investigated by Chen, C.H. et al (2017). However, analysis on effect of cohesion to unsaturated slope stability has not been investigated recently.

In fact, river embankment failures tend to be caused by several factors i.e. geometry of the embankment, external loads, river profile and river current. However, this research only concerns on the effect of soil properties change due to water level fluctuation on unsaturated slope stability.

1.2 Research study location

Bengawan Solo river embankment at Kanor village is frequently collapsed due to vulnerability of soil properties that induced by water content change during dry and rainy seasons (Mountassir et al, 2010). Moreover, many researchers have not thoroughly discussed about river embankment properties change induced by water content change as well as the relationship between the in-situ and laboratory investigations. In addition, influence of soil properties change on river embankment stability has been not thoroughly investigated.

The detailed study location, (**Figure 1.2**)**,** is located on the Bengawan Solo river embankment at Semambung district, Kanor village, Bojonegoro city, East Java Province, Indonesia. The research object is located on the outer side of the river meandering section, where landslide annually occurs and even endangers the local houses stability.

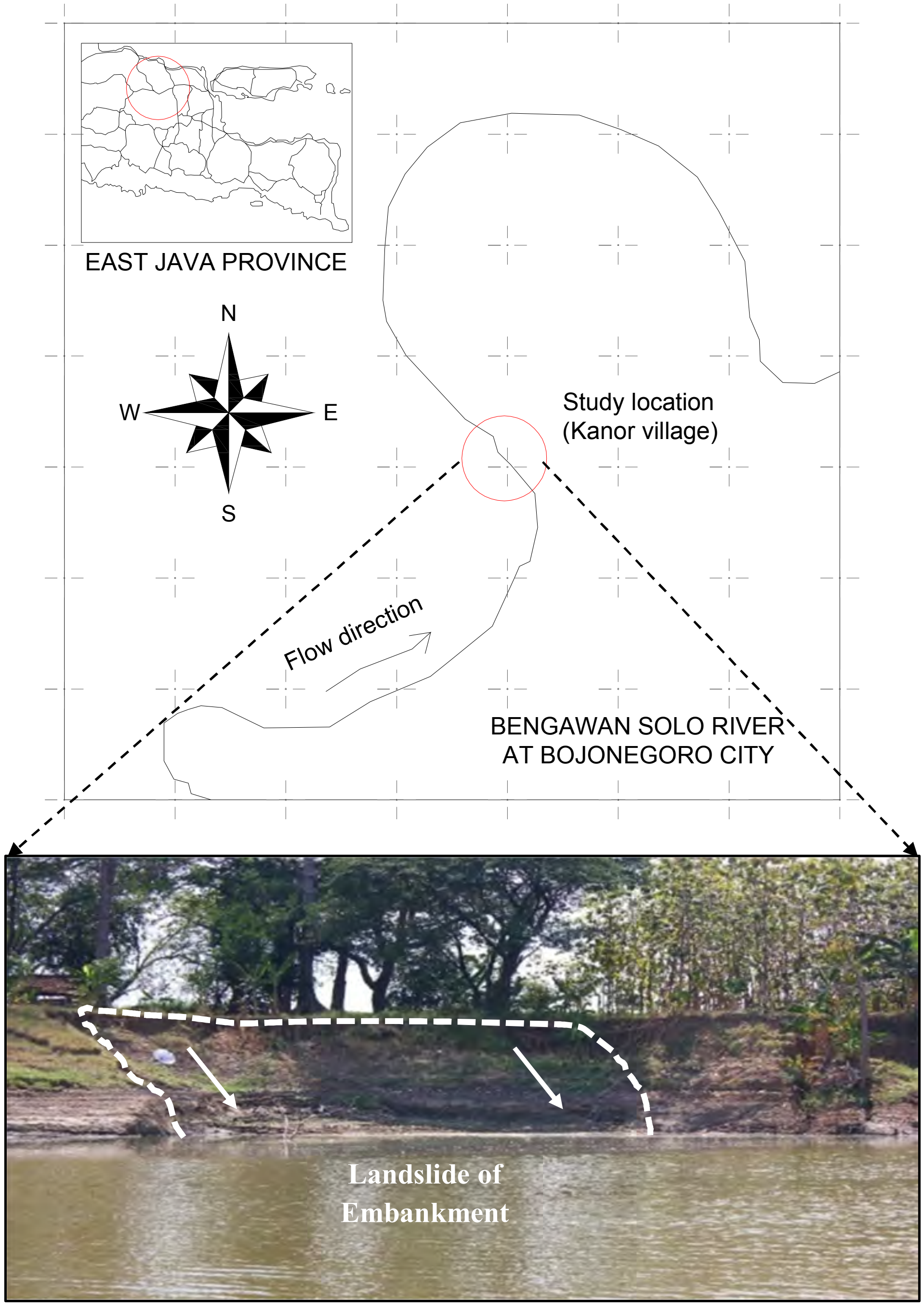

Figure 1.2 Description of study location

This research investigates the surficial soil (-0.50 m from original ground level) properties change due to dry and rainy seasons, that sampled from upper and lower parts of river embankment on Bengawan Solo river at Kanor village.

1.3. Research objective

This research has 2 (two) objectives, first objective is to find the relationship of physical and mechanical soil properties between in-situ and laboratory investigations. Hence, the change of soil properties due to drying and wetting process, since it was freshly compacted, could be investigated. Second objective is to investigate the influence of cohesion change as mechanical soil properties to the unsaturated slope stability.

In-situ and laboratory investigations were performed to characterize the in-situ condition and compaction behavior; to observe the physical and mechanical properties change due to drying-wetting cycles of in-situ sample (existing stage) and fresh compacted sample (construction stage); to compare the in-situ and laboratory conditions for finding the relationship; to propose the influence of cohesion change due to drying-wetting condition to the safety factor of unsaturated slope stability.

This research activities were held in 4 (four) years which consist of in-situ investigation due to dry and rainy seasons (1^{st} year); laboratory investigation of drying-wetting test of in-situ and fresh compacted samples (2^{nd} year) and evaluation of soil properties change, relationship between in-situ and laboratory investigations and slope stability analysis (3^{rd} and 4^{th} year).

1.4. Research originality

The soil properties commonly change due to change of water content especially soil that located in the river embankment which always experiences water level fluctuation. In a same stress condition, soil has different behavior when it experiences drying and wetting processes which triggering hysteresis (Goh, S.G. et al, 2014). An unsaturated soil condition affects the change of suction that can change the shear strength and effect of erosion of the embankment (Mountassir et al, 2010). In an unsaturated soil, the negative pore water pressures influence the shear strength of soil and increase the stability (Ali et al, 2014).

Drying and wetting process, through laboratory test, induce the change of physical soil properties [Li, Z et al (2018), Suhail, A.A.K. et al (2018), Gallage, C. and Uchimura, T. (2016), Goh, S.G. et al (2014), Chiu et al (2014), Gui, M.W. and Wu, Y.M. (2014), Oh, S and Lub, N (2014), Zhou et al (2014), Calabresi, G. et al (2013), Whalley et al (2011), Sheng, D. (2011), Kim, C.K. and Kim, T.H. (2010), Guan, G.S. et al (2010), Mountassir et al (2010), Schnellmann, R. et al (2010), Rahardjo, H. et al (2010), Gallage, C.P.K. and Uchimura, T. (2010), Nuth and Laloui (2008), Salager et al (2007), Fredlund, D.G. (2006), Anderson, C.E. and Stormont, J.C. (2006), Alonso, E.E. (2006), Chen, H. et al (2004)]. In addition, drying and wetting process, through in-situ investigation, induce the change of physical soil properties [Calabresi, G. et al, (2013), Fan and Hsiao (2010), Alonso, E.E. (2006), Thielen et al (2006)].

The relationship between negative pore water pressure and mechanics properties of soil was pointed out by Chen, H. et al (2004). There was weakening process of mechanical surface soil properties due to pore water pressure changes. Han, Z and Vanapalli, S.K. (2017) reveals that soil suction is a variable that influences the soil stiffness and shear strength. Drying and wetting process, through laboratory test, induce the change of mechanical soil properties [Han, Z and Vanapalli, S.K. (2017), Hossain, Md. S. et al (2016), Gallage, C. and Uchimura, T. (2016), Goh, S.G. et al (2014), Chiu, C.F. et al (2014), Gui, M.W. and Wu, Y.M. (2014), Zhang, L.L. et al (2014), Oh, S and Lub, N (2014), Sheng, D. (2011), Biglari, M. et al (2011), Kim, C.K. and Kim, T.H. (2010), Guan, G.S. et al (2010), Mountassir et al (2010), Fredlund, D.G. (2006), Chen, H. et al (2004)]. Soil shear strength in slope is governed by the effective stress and this stress is referred as difference between total stress and pore-water pressure (Schnellmann et al, 2010). Moreover, shear strength changes due to drying-wetting path and cycles were studied by Goh, S.G. et al (2014). Cyclic drying and wetting process, through laboratory test, induce the change of physical and mechanical soil properties [Wong, K.S. et al (2014), Chen and Ng, C.W.W. (2013), Park, S. (2010)]. In addition, cyclic drying and wetting process, through in-situ investigation, induce the change of physical and mechanical soil properties [Bodner et al (2013)]. In conclusion, there has been few researches of both laboratory and in-situ investigations related to the behavior of physical and mechanical soil properties change due to cyclic drying-wetting process.

The different behavior of the soil during drying and wetting induces the instability of slope (Rahardjo, H. et al, 2010). It indicates water content and suction has crucial role on soil behavior. Measurement of suction is very important to maintain unsaturated conditions as well as to evaluate the slope stability (Calabresi et al, 2013). Thielen et al, 2006 investigates change of saturation degree, volumetric water content and suction at in-situ condition throughout summer and winter period. It is aimed to observe the causal of slope instability in North Switzerland. Gallage, C. and Uchimura, T. (2016) reveals that internal friction angles of tested soil do not have relationship with suction and hysteresis of SWCC due to drying-wetting. On the other hand, the results show that the apparent cohesion increases with the suction where soil with suction in wetting path has higher apparent cohesion than soil with suction in drying path, even though at the same suction. Gallage, C.P.K. and Uchimura, T. (2010) also expressed that along the drying-wetting test, fine-grained soil has higher hysteresis than coarse-grained soil. Li, Z et al (2018) investigated that when drying process of soil compacted at Standard Maximum Proctor, the samples experienced drying; water flowing out; shrunk volume and decrease of saturation degree. On the other hand, when wetting process, the samples experienced wetting; water flowing in; enlarged volume and increase of saturation degree. However, from the discussed research above, it had not many discussed about the relationship of soil properties change between laboratory and in-situ investigations.

In this thesis, the study is focused on the change of the soil properties due to drying and wetting. Series of cyclic drying and wetting tests were conducted in the laboratory to evaluate the changes in its physical and mechanical properties. In-situ investigation of soil properties was conducted to evaluate the change of in-situ soil properties due to dry and rainy seasons. Then, relationship of soil properties change, between in-situ and laboratory investigations is investigated. After the relationship is established, it is possible to trace back the initial construction time of the river embankment and it is possible to know when the river embankment starts to lose their best initial condition as they were freshly compacted.

A rising of water table increases the value of pore-water pressures in the soil slope and it is lowering the effective stress as well as the slope stability (Schnellmann et al, 2010). Yao, C. and Yang, X. (2017) reveals that matric suction could highly improve the slope stability. Suhail, A.A.K. et al (2018) expressed that slope stability depends on suction; cohesion and applied loading. Zhang, L.L. et al (2014) reveals the non-linear relationship between matric suction and shear strength of unsaturated soil. Tohari et al (2007) investigated a laboratory model of soil slopes which pointed to be fail by using types of raising water level where it is aimed to clarify the failure process. Oh, S and Lub, N (2014) reveals that pore water pressure change and suction are responsible for the slope instability. Chen, H. et al (2004) expressed that soil suction is influenced by rainfall infiltration, and it will become the triggering factor in slope failure. Zhan, T.L.T. et al (2006) observed the change of soil phreatic line as well as hydraulic properties along the rising of water level at reservoir. Similar with Zhan, T.L.T. et al, 2006, Bodner et al, 2013 observed drying-wetting data at in-situ to better analyzed the scattered of soil properties. Unsaturated condition induces the stability of the slope [Suhail, A.A.K. et al (2018), Yao, C. and Yang, X. (2017), Chen, C.H. et al (2017), Ali et al, (2014), Zhang, L.L. et al (2014), Oh, S and Lub, N (2014), Calabresi, G. et al, 2013, Rahardjo, H. et al (2010), Tohari et al (2007), Tony et al (2006), Zhan, T.L.T. et al, 2006]. However, it had not many discussed about the influence of cohesion change as mechanical soil properties on unsaturated slope stability.

This thesis consists of 10 (ten) chapters as follows.

Chapter 1, This chapter mainly discusses the research background, details of study location, objectives of the research and research originality.

Chapter II, Basic study of the analysis is discussed in this chapter, including the explanation of river embankment, history of embankment failure, history of construction process and issues.

Chapter III, Literature study relating with the in-situ investigation, river embankment and unsaturated soil condition are discussed in this chapter.

Chapter IV, Details of the research methodology throughout 4 years. The applied research orientation with the related literatures are also explained in this chapter.

Chapter V, Method of field and laboratory investigations are explained in this chapter. The detail of field investigation within the tools and its standard are discussed in this chapter. Also, the physical, mechanical properties and drying-wetting process as laboratory investigation types, are discussed respectively.

Chapter VI, Result of in-situ and laboratory investigations are analyzed in this chapter.

Chapter VII, Correlation between soil properties are analyzed in this chapter, related literatures are also cited as basic study.

Chapter VIII, Soil properties relationship between in-situ condition and drying-wetting condition at laboratory are analyzed in this chapter.

Chapter IX, Influence of cohesion change due to drying and wetting on unsaturated slope stability is analyzed in this chapter.

Chapter X, Summary of the research and future works that are possible to be proposed are discussed in this chapter.

Table 1.1 Related topics of published research

Soil type	Laboratory investigation			In-Situ investigation			Relationship between soil properties upon laboratory and in-situ condition	Unsaturated slope stability	Influence of soil properties change on safety factor of unsaturated slope stability
	Drying-wetting		Cyclic drying-wetting	Drying-wetting		Cyclic drying-wetting			
	Physical properties	Mechanical properties	Physical / Mechanical properties	Physical properties	Mechanical properties	Physical / Mechanical properties			
	$-U_w, w_c, e, S_r, K_s, \gamma$	τ, c, ϕ	$-U_w, w_c, e, S_r, K_s, \gamma, \tau, c, \phi$	$-U_w, w_c, e, S_r, K_s, \gamma$	τ, c, ϕ	$-U_w, w_c, e, S_r, K_s, \gamma, \tau, c, \phi$			
Natural Soil	Li, Z et al (2018), Suhail, A.A.K. et al (2018), Gallage, C. and Uchimura, T. (2016), Goh, S.G. et al (2014), Chiu et al (2014), Gui, M.W. and Wu, Y.M. (2014), Oh, S and Lub, N (2014), Zhou et al (2014), Calabresi, G. et al (2013), Whalley et al (2012), Sheng, D. (2011), Kim, C.K. and	Han, Z and Vanapalli, S.K. (2017), Hossain, Md. S. et al (2016), Gallage, C. and Uchimura, T. (2016), Goh, S.G. et al (2014), Chiu, C.F. et al (2014), Gui, M.W. and Wu, Y.M. (2014), Zhang, L.L. et al (2014), Oh, S and Lub, N (2014), Sheng, D. (2011), Biglari, M. et al (2011), Kim, C.K. and Kim,	Wong, K.S. et al (2014), Chen and Ng, C.W.W. (2013), Park, S. (2010).	Calabresi, G. et al, (2013), Fan and Hsiao (2010), Alonso, E.E. (2006), Thielen et al (2006).	*This research*	Bodner et al (2013)	*This research*	Suhail, A.A.K. et al (2018), Yao, C. and Yang, X. (2017), Chen, C.H. et al (2017), Ali et al, (2014), Zhang, L.L. et al (2014), Oh, S and Lub, N (2014), Calabresi, G. et al, 2013, Rahardjo, H. et al (2010), Tohari et al (2007), Tony et al (2006), Zhan, T.L.T. et al, 2006.	*This research*

	Kim, T.H. (2010), Guan, G.S. et al (2010), Mountassir et al (2010), Schnellmann, R. et al (2010), Rahardjo, H. et al (2010), Gallage, C.P.K. and Uchimura, T. (2010) Nuth and Laloui (2008), Salager et al (2007), Fredlund, D.G. (2006), Anderson, C.E. and Stormont, J.C. (2006), Alonso, E.E. (2006), Chen, H. et al (2004).	T.H. (2010), Guan, G.S. et al (2010), Mountassir et al (2010), Fredlund, D.G. (2006), Chen, H. et al (2004).							

Remark: $-U_w$ (suction), w_c,(water content) e (void ratio), S_r (saturation degree), K_s (permeability coefficient), γ (volume unit weight), τ (shear stress), c (cohesion), ϕ (internal angle friction), SI (swelling index), A (activity), PI (plasticity index)

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CHAPTER II
RIVER EMBANKMENT IDENTIFICATION

2.1 Observation Site

The Bengawan Solo is the longest river on Java island, which is located along the Center of Java and East Java provinces. It is approximately 600 km in length and has a 16,000 square kilometers catchment area. It passes through 17 districts and 3 cities in both provinces. In addition to collecting water, the river is also used as drinking water, for farming, sand mining, transportation, and home industry needs. **Figure 2.1** shows the Bengawan Solo river path, including the research observation site that located in the Kanor district of Bojonegoro city, East Java.

Water in the upstream area of the river is sourced from several other rivers and collected by the “Gajah Mungkur” water reservoir. A large amount of sedimentation, that occurred in upstream area, reduced river capacity and subsequently transported the excessive water into Bengawan Solo river. This triggered the flooding of the river and endangered the stability of the river embankment.

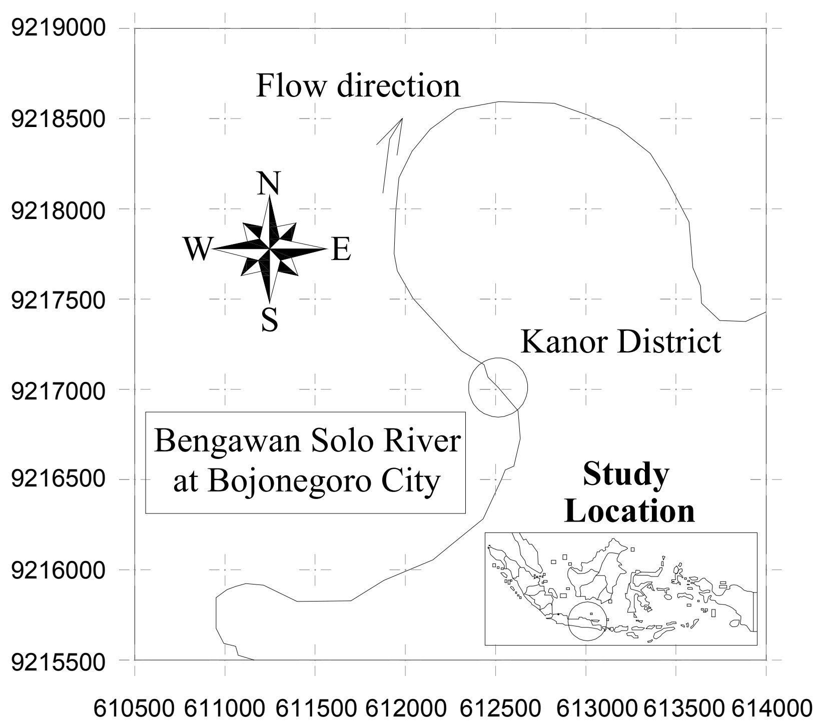


Figure 2.1 Research study location (abscissa and ordinate in unit of meter)

2.2 History of Embankment Failure

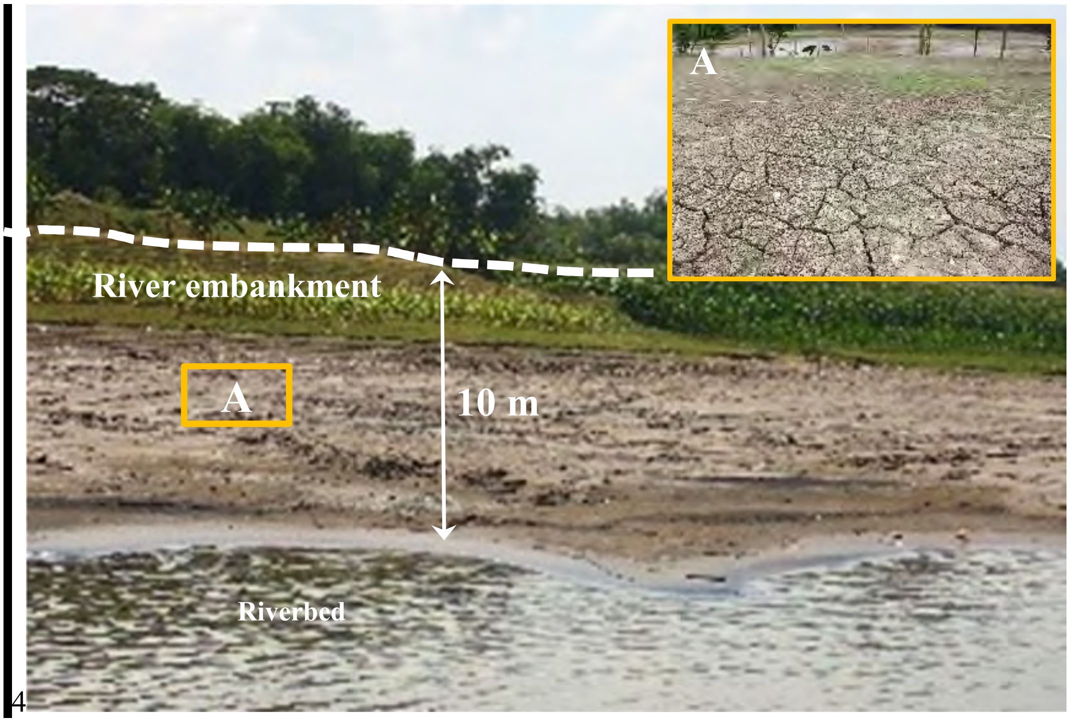
In 2007 until 2009, Bengawan Solo experienced heavy rainfall that inducing overtopped river embankment and inundated residential area due to flooding (Satrya et al, 2017). Flooding and embankment failure occurred in the downstream area, especially in the meandering area at Kanor district (**Figure 2.1.**), that is considered as the observation site of this research. The historical failure occurred since 2007 and it is continuous and progressive recently. The main failure type is shallow slippage failure and it is due to the high of water level upon flooding. The failure details within the time collected from related news are mentioned below (**Table 2.1**).

Table 2.1. Historical occurrence of embankment failure at Bengawan Solo river.

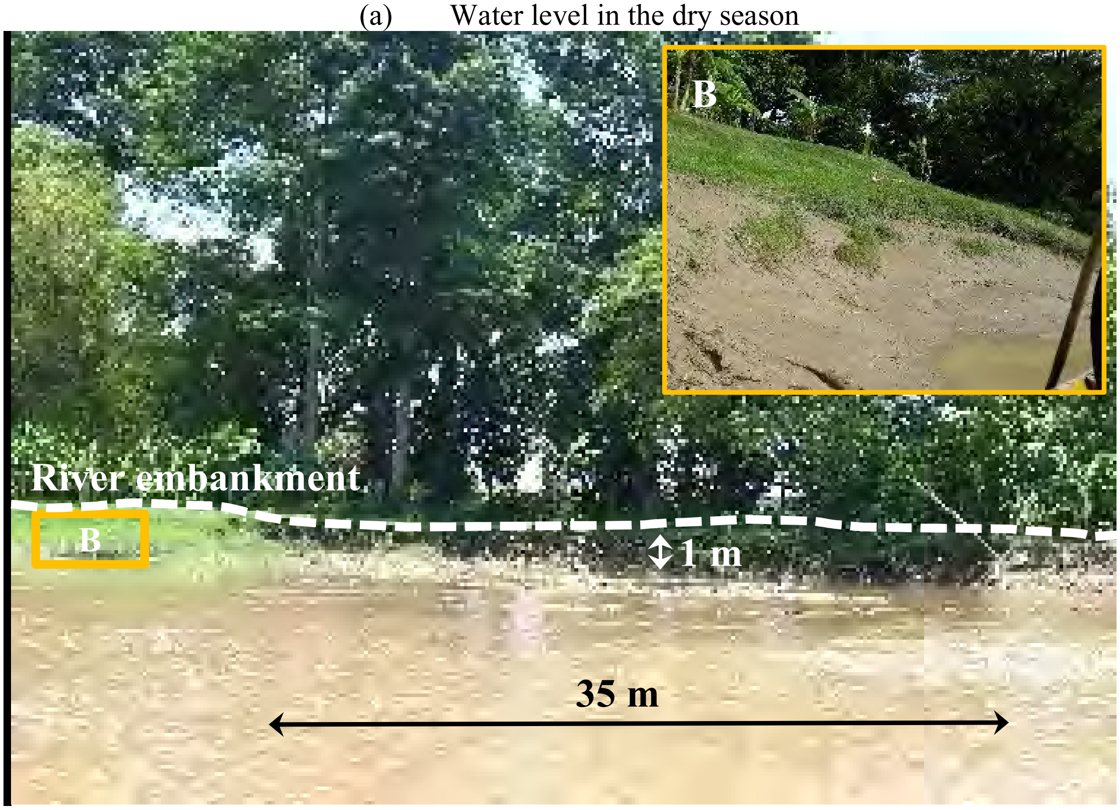
No.	Year	Occurrence	Remark
1.	2007	a. Embankment failure at upstream area induces flooding in landward. b. Main road was flooded in 50 cm – 100 cm in height c. As much as 20,000 houses, 114 villages; 7,352 acres of farming were flooded. d. Railway was disconnected due to flooding	There was civilian evacuation towards safely area as disaster mitigation procedure.
2.	2008	Continuously heavy rain inundates embankments along the river and destruct 7 (seven) embankments point.	The embankments were temporary improved.
3.	2009	a. Embankment along 200 m was collapsed at Semambung, Kanor village area b. The landward was inundated about 1.50 m	There were over 500 civilians evacuated into the highly area

(source: from several collected news)

Mountassir et al. (2010) expressed that the Bengawan Solo river water level at Kedungharjo village, Tuban city fluctuated by as much as 10 m between dry and rainy seasons. **Figure 2.2.a.** shows the river water level during the dry season. The water level was lowering down until the riverbed could be seen directly in the field. Soil cracks were discovered due to the evaporated water during this period. **Figure 2.2.b**. shows the river water level during the rainy season. During this season, the water level was high enough to almost reach the top of the river embankment. In addition, the soil was soft and weak owing to the abundance of water. **Figure 2.2.c.** shows the recent shallow-slip slope failure at Semambung village, Kanor district, Bojonegoro city on March 11, 2014. Until 2014, shallow slip failure still occurred annually during the peak rainy season.



(a) Water level in the dry season



(b) Water level in the rainy season

(c) Shallow slip failure on March 11, 2014

Figure 2.2. River embankment at Kanor district

2.3 History of Construction Process

In the past, the government decided to build a river embankment owing to the large population of civilians who chose to live near the river. Indeed, there is a minimum requirement of selected embankment material for purpose of embankment construction. In 2004, the Ministry of Public Works and Housing of Indonesia issued a technical specification which mainly acquires non-cohesive soil with certain properties for embankment material.

However, in fact lots of material, which is generally dominated by fine grained soil, has been deposited in the riverbed due to sedimentation and river embankment failure. Therefore, due to the abundant riverbed material and certainly for efficiency reason, the government preferred to utilize this existing riverbed material for constructing the river embankment. This material was taken from riverbed and layered on the embankment during the dry season. The Standard Proctor compaction is applied as the specification of the embankment compaction. The dry season was preferable for this activity because it was favorable for construction due to workability reasons.

2.4 Actual Issues of River Embankment

An excavating, remolding and recompacting processes result an unsaturated soil condition (Fredlund, D.G. and Rahardjo, H., 1993). It implies that embankment compaction induces an unsaturated soil condition. Certainly, surface soil layer in the slope is in unsaturated condition which its mechanic properties govern the occurrence of shallow slip failure (Fan, Ch and Hsiao, Ch., 2010).

Soemitro et al, 2007 studied the change of river embankment properties (in-situ) after it was freshly compacted in the construction stage. The study compares the dry density at construction stage and actual dry density (in-situ) upon 5 years after construction. Compaction test at laboratory was performed to determine the dry density specification upon construction stage, while in-situ investigation was performed to obtain the actual dry density after 5 years of construction stage. The graph of in-situ investigation result is shown in **Figure 2.3.** The maximum dry density (γ_d max) is 14.3 KN/m^3 and by using relative density (R = 95 %), the dry density specification is 13.6 KN/m^3. It is clearly seen that after 5 years, in-situ dry density decreases for about 0.15-0.26 times of the specification. In normal situation, the dry density should remain constant throughout the time. Hence, in-situ investigation shows that the dry density decreases throughout the time.

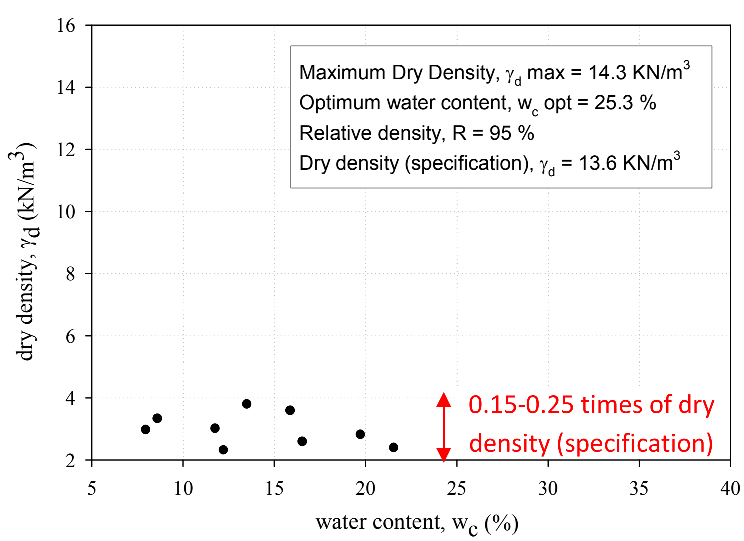


Figure 2.3. In-situ Investigation of Dry Density after 5 years construction, (Soemitro et al, 2007).

Therefore, the important issue with the river embankment is that the soil properties might change and become more likely to lose their fresh compacted condition owing to changeable and repetitive seasons over several years.

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CHAPTER III
LITERATURE STUDY

3. Introduction

This literature study discusses about river embankment especially about its in-situ soil investigation, river embankment and natural soil.

3.1. In-situ soil investigation

Soil suction mainly depends on the season which consists of dry and rainy season like it is in Indonesia. The suction value change has several impacts on soil properties, therefore in-situ soil monitoring is required for investigating the actual situation in the field.

3.1.1. Change of soil physical properties due to suction

A site in Switzerland was investigated in any observation depth (15 cm; 45 cm; 90 cm and 150 cm) by using measuring devices to obtain the effect of water penetration through rainfall infiltration on saturation ratio and suction as physical soil properties and its influence on slope stability (Thielen, A. and Springman, S.M., 2006). The result showed that during summer period, normal rainfall intensity does not trigger saturation and suction value changes in deep soil layers (**Figure 3.1.**), therefore shear resistance of the soil will not be affected. In winter, both of deep and surficial soil layers are influenced by rainfall and soil suction, even suction lowering to zero. In addition, clear hysteresis between summer and winter happened as it could be seen in the depth 90 cm and 150 cm. From result above, it shows that the monitoring of saturation and desaturation processes during changeable seasons is a critical issue to assess the soil properties changing.

Early warning system is an effective way to minimize failure risk, as well as any other rainfall intensity-influenced hydrological and geological risks, flood and flow of debris (Greco R. et al, 2010). This system actually monitors the in-situ soil properties, hence the critical location as well as the hazard could be observed respectively. As an example, the observed experimental result on an instrumented flume equipped with rainfall simulation system (**Figure 3.2.**) reveals a collapsed volumetric water content (θ) which triggers the infiltration process, then it increases penetration of water from the top towards the bottom of the slope, hence it accelerates the soil saturation process as physical soil properties.

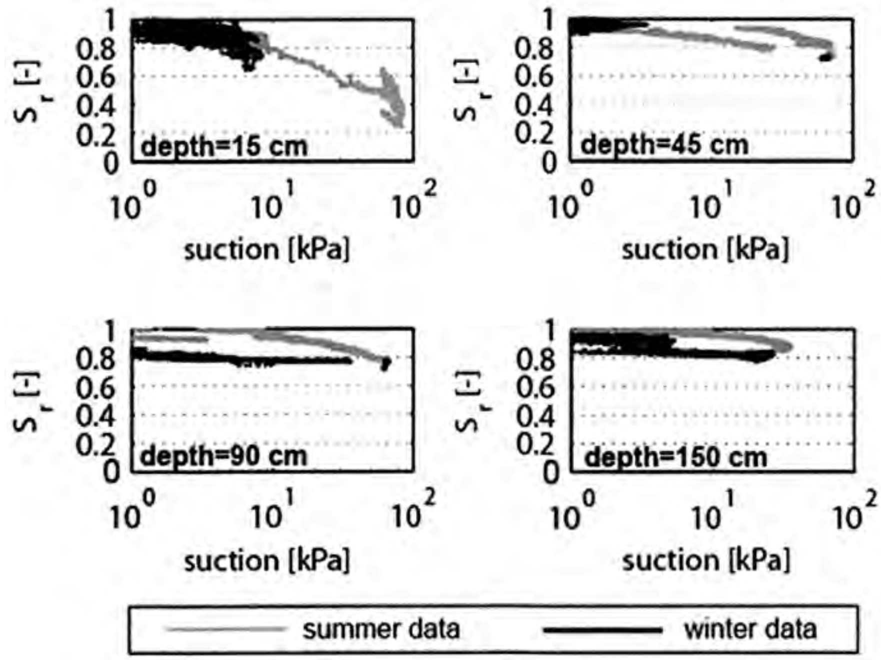
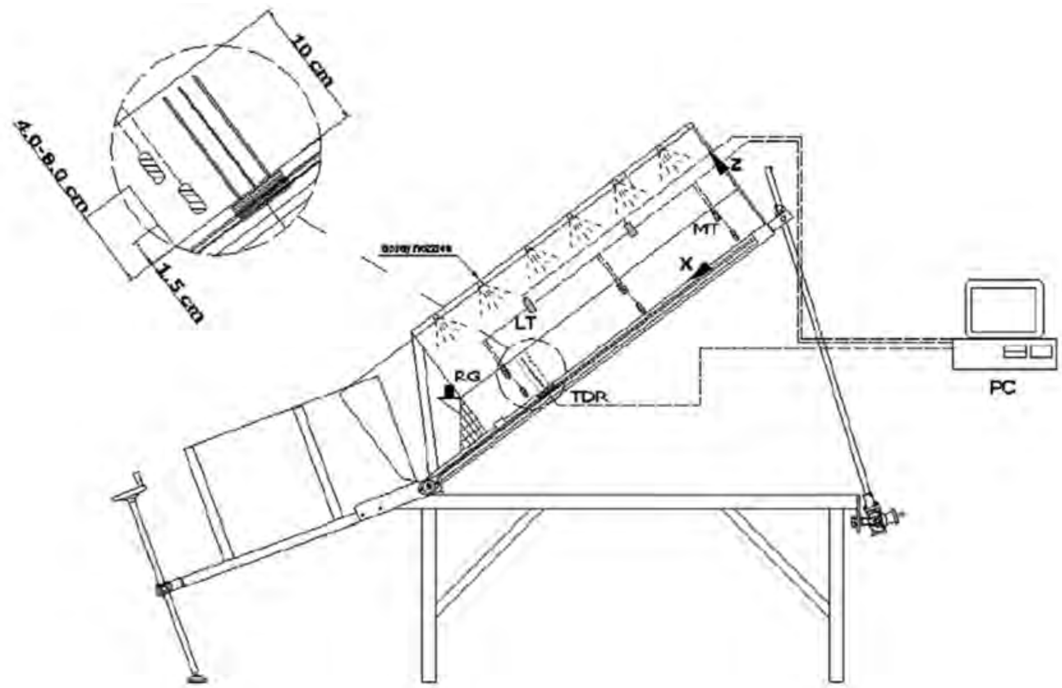


Figure 3.1. In-situ water retention curves in lower left test field
(Thielen, A. and Springman, S.M., 2006)

From result above, variables which triggering the slope failure are rainfall, temporal variability, mechanical and hydraulic soil properties, geometry of the slope, vegetation, initial soil suction and moisture content.

3.1.2. Change of soil mechanical properties due to suction

The soil shear strength characteristics by using direct shear test equipment for unsaturated silty sand under the influence of different net normal stress and matric suctions were investigated by Zhou et al, 2016. SWCC (Soil Water Characteristic Curve) were also determined under different normal stress to observe the correlation of shear strength. It is investigated to correlate the unsaturated soil shear strength with shear strength obtained from unconfined compressive test. **Figure 3.3.** shows the shear strength of unsaturated soil obtained from direct shear test.



(a)

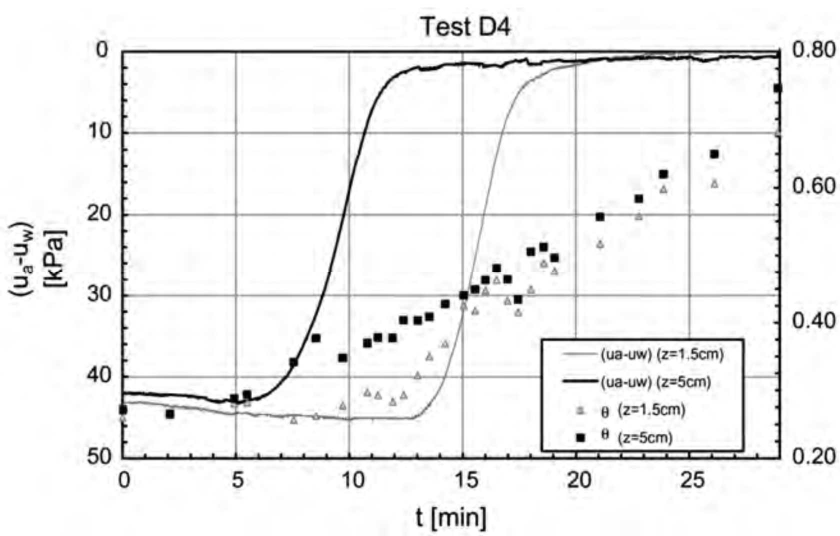


Figure 3.2. (a) instrumented flume; (b) matric suction (continuous and dashed lines) and volumetric water content (dots) time histories during infiltration experiments (Greco R. et al, 2010)

From **Figure 3.3.,** it is found that the unsaturated shear strength significantly increases with increase in matric suction as well as the net normal stress. It could be concluded that matric suction and net normal stress change mainly influence the unsaturated soil shear strength.

3.2. River embankment

River embankment always corresponds with soil material that supported the stability under several conditions including external load and seasons effects.

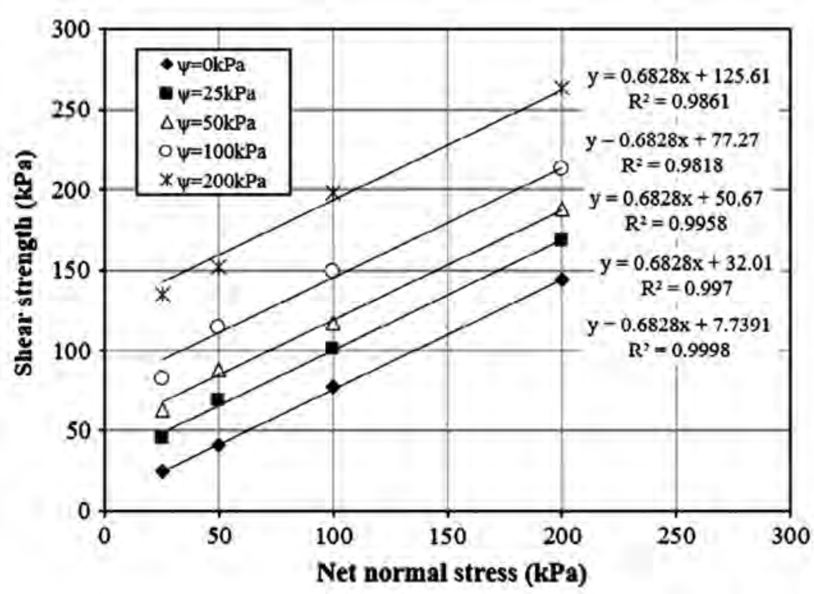


Figure 3.3. Failure envelopes due to different matric suctions of direct shear test (Zhou et al, 2016)

3.2.1. Natural soil

ORIGIN

River bed soil, as the origin of usual on-site soil, is generally in the form of fine-grained soil which is usually discovered on subsoil of river embankment and it does not have the physical soil properties which is not good enough as general embankment material (Money et al, 2006). Xiao et al (2014) investigated the silt soil exposed from river bed as embankment material which is unstable due to the water.

In several cases, the type of failure mechanism observed is a direct result of the fill material used during construction. In New Orleans in 2005, failures occurred in sections of embankment constructed of lightweight shell-sand fill, due to its low resistance to erosion (Seed et al., 2008). Furthermore Seed et al. (2008) pointed a second material which is responsible in the catastrophic failures of sections of embankments in New Orleans: dredged material from shipping channels. However, the interesting point to note here is that the problem not only from the characteristics of the material but also the fact that it was created at high moisture contents with little effort or without compaction, therefore inducing erodible material (Seed et al., 2008),

In Indonesia, it is generally known that to upgrade the river embankment due to river flooding, the sediment soil which is in the form of silty soil, is removed from the river bed and placed on the top of embankment. Furthermore, soil type along the Bengawan Solo river at Kanor section is dominated by the alluvium sediment soil which is in the form of silty soil.

CHEMICAL CONTENT

The soil particles are composed from soil minerals due to chemical process, this composition depends on the origin of the rock (Ninov and Donchev, 2007). The soil behavior depends on the composite effects of several related factors, where are compositional and environmental factors (Al-Shayea, N., 2001). Compositional factors consist the soil mineralogy, the shape and size distribution of soil particles, adsorbed of cations, and composition of pore water. Clay minerals produce very important soil types which are referred to have high plasticity, cohesion and swelling potential, but low in hydraulic conductivity and low in friction angle.

3.2.1.1. Mechanical stabilization

Mechanical stabilization usually correlated with physical action which performed on the soil or widely known as soil compaction to improve soil strength. The conceptual of soil compaction is to enhance the solid grain composition by removing the composition of air volume and there is no significant change in the water volume in the soil. In geotechnical engineering, compaction is defined as the densification of soils by the application of mechanical energy. Compaction process improves engineering properties of soils such as increasing shear strength and reducing hydraulic conductivity. As an example, compacted clayey soils are used in various building structures including earth dams and river embankments.

Determination of optimum water content and maximum dry density of the soil is important to their volumetric change behavior. The lowest volumetric shrinkage strains generally happened in soil sample compacted near optimum water content. Volumetric shrinkage strains as much as 30% were investigated at water contents > 5% wet of optimum. In same manner, the volumetric shrinkage strain increased as the compaction water content shifted into dry of optimum, with volumetric shrinkage strains above 15% (Chen et al, 2004).

From the research that investigated by Xiao et al (2014), high compaction effort induces high compression stress and high stiffness. The stiffness is strongly related between behavior of strain-softening and hardening with the relative compaction. For relative compaction 90 % and 95 %, there was a peak strength and the stress-strain curve pattern shows high value of stiffness. Whilst, for relative compaction 80 %, there was no peak in the strength and the stress-strain curve pattern shows low value of stiffness.

For all various relative compaction, the soil shear strength decreases with the change of water content (Xiao et al, 2014). Increase of degree of saturation induces the change of cohesion and internal friction angle of the soil. Soil with different relative compaction and the increase in degree of saturation, the cohesion decreases due to the decrease in the matric suction value in soil samples, similar condition occurred in internal friction angle of the soil.

The initial water content and density determination, which is derived from mechanical stabilization, affects the water retention capacity and volumetric change behavior (Chen et al, 2004). The value of soil relative compaction induces the stress-strain behavior as it has different stiffness value and peak compression strength. Change of degree of saturation also has main influence on the cohesion and internal angle friction value change (Xiao et al, 2014).

STANDARD PROCTOR COMPACTION

In the Proctor test, the soil is compacted in a compacting mold that has a volume of 944 cm^3 (1/30 ft^3). The diameter of the mold is 101.6 mm (4 in.). During the laboratory test, the mold is added to a baseplate at the bottom and to an extension at the top. The soil is mixed with various water content and then compacted in three equal layers by a hammer that has 25 blows to each layer. The hammer has a mass of 2.5 kg (6.5 lb) and has a drop of 30.5 mm (12 in.). For each test, the moist unit weight of compaction, γ, can be calculated as,

$$\gamma = \frac{W}{V_{(m)}} \quad \text{(3.1.)}$$

(Das, M. Braja, 2010)

where W = weight of the compacted soil in the compacting mold

$V_{(m)}$ = volume of the compacting mold [944 cm^3 (1/30 ft^3)]

For each test, the moisture content of the compacted soil is determined in the laboratory.

With the known moisture content, the dry unit weight can be calculated as

$$\gamma_d = \frac{\gamma}{1 + \frac{w_c(\%)}{100}} \quad \text{(3.2.)}$$

(Das, M. Braja, 2010)

where w_c (%) = moisture content.

The values of γ_d determined from Eq. (3.2) can be plotted against the corresponding moisture contents to obtain the maximum dry unit weight and the optimum moisture content for the soil. **Figure 3.4.** shows such a plot for a silty-clay soil. The procedure for the standard Proctor test is elaborated in ASTM Test Designation D-698 (ASTM, 2007) and AASHTO Test Designation T-99 (AASHTO, 1982). For a given *moisture content* w_c and *degree of saturation* S_r, the dry unit weight of compaction can be calculated as follows.

$$\gamma_d = \frac{G_S \cdot \gamma_w}{1 + e} \quad \text{(3.3.)}$$

(Das, M. Braja, 2010)

where: G_s = specific gravity of soil solids

γ_w = unit weight of water

e = void ratio

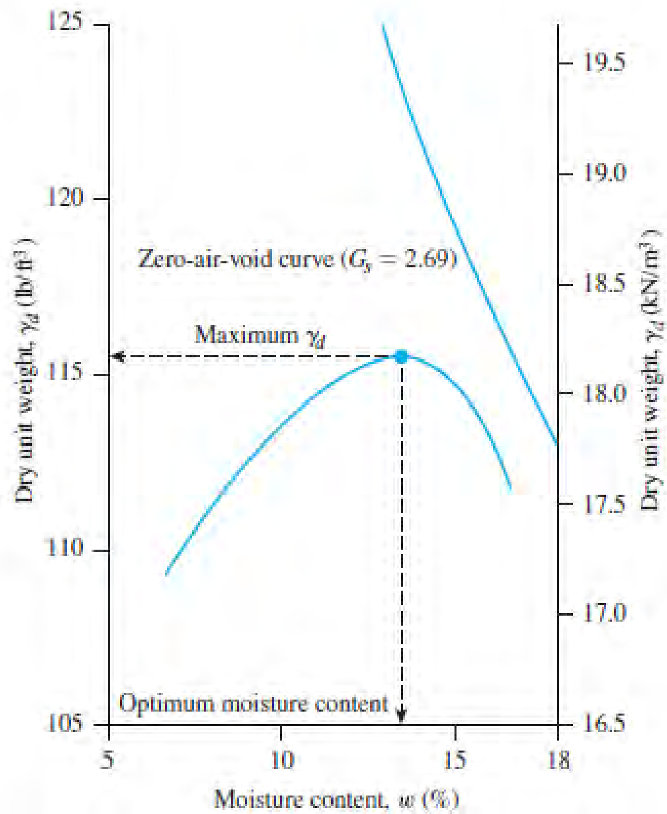


Figure 3.4. Standard Proctor compaction test results for a silty clay

(source: Das M. Braja, 2010)

3.3. Unsaturated soil condition

The zone between the ground surface and the water table is generally referred to zone of unsaturated condition (**Figure 3.5.**) where the soil condition is influenced by the negative pore water pressure change. The zone becomes between the water in the atmosphere and the groundwater, for example the saturated zone.

The negative pore–water pressures in that zone can vary from zero at the water table to a high maximum pressure pore water under dry soil conditions. Insitu soil starts a saturation condition at the water table and tends to become under negative pore water pressure toward the ground surface. Soils near to the ground surface are often classified as "problematic" soils since it is due to the changes in the negative pore–water pressures that can result in changes in soil properties.

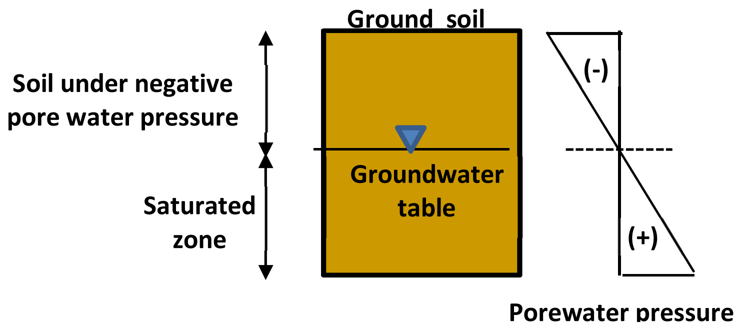


Figure 3.5. Soil profile under hydraulic condition (Fredlund, 2006)

3.3.1. Drying wetting process

A wetting–drying cycle test was completed with the saturation of samples and their drying in an air-dry condition (Kalkan, 2011). Drying-wetting cycle process always induces the negative pore water pressure (suction) value, thus the soil properties could be influenced respectively.

Drying-wetting process involves laboratory works to dry and wet the soil samples in cycles generation, and it would be continued with soil properties tests (Muntaha, 2013). To determine the drying and wetting model step in each cycle, there is a upper and lower limit of water content range. The upper limit is the saturated soil water content, whilst lower limit is the water content when the sample is in the air-dry condition. Then from the range, step is created by dividing the range into certain value (**Figure 3.6.**).

The soil sample starts in initial condition (1^{st} cycle), then dried until the lower limit (W dry) and wetted back until the initial condition, this drying-wetting path is regarded as 1st cycle. Then the next action is wetting the soil sample from initial until upper limit condition (W sat) and continue to dry until its initial condition, this path is regarded as 2^{nd} cycle. The similar process followed until 3^{rd}, 4^{th}, 5^{th} and 6^{th} cycle (Muntaha, 2013). The soil properties tests would be conducted on each of step (signs with blue, red and black circle marks).

From the past research, drying-wetting process results is eventually performed in a curve which defines the relationship between the number of water in the soil and soil suction. The amount of water can be a gravimetric water content, *w*, a volumetric water content, Ɵ, or degree of saturation, *S*. This curve is referred as soil-water characteristic curve, SWCC (Vanapalli et al, 1996).

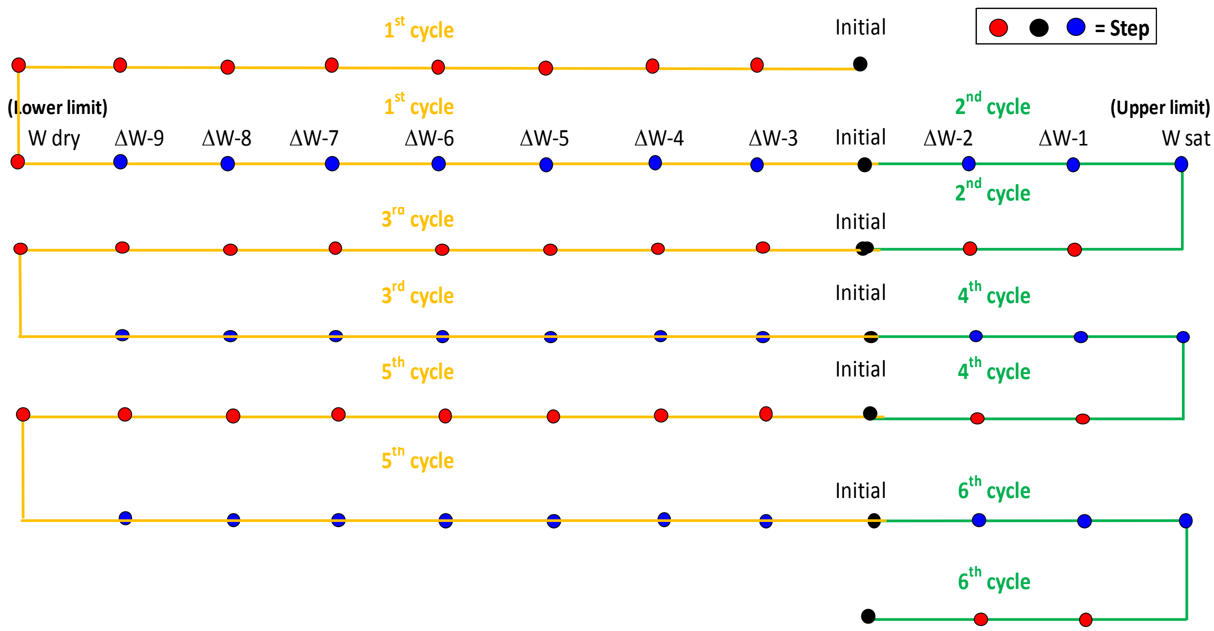


Figure 3.6. Drying-wetting process (Muntaha, 2013)

From **Figure 3.7.**, it could be seen that there are 2 (two) main curves in each cycle, which are drying and wetting curves. There is also certain value which separates the condition between low and high suction that defined as air entry value (AEV) point, that means in the drying process from the saturated condition, the air starts to enter the soil particles for shifting into the dry condition. (Vanapalli et al, 1996)

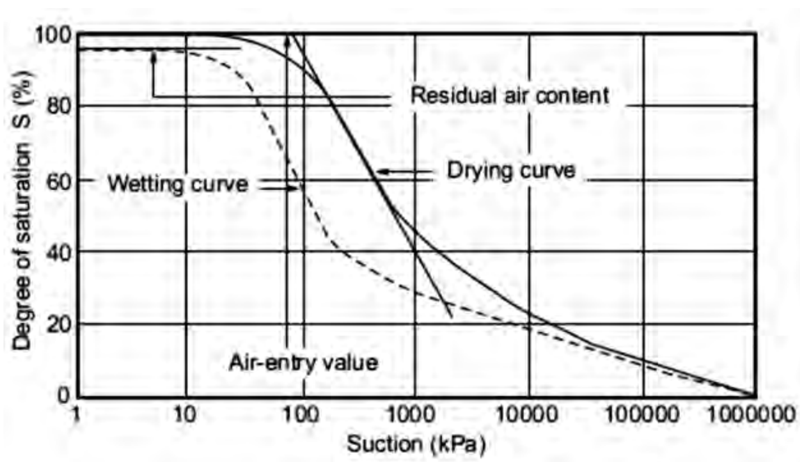


Figure 3.7. Typical soil-water characteristic curve features for the drying and wetting of a soil (Vanapalli et al, 1996).

3.3.2. Soil water retention curve

Negative pore water pressure or suction in soil consists of two components, which are matric suction and osmotic suction. The total of these components is called total suction (Fredlund, 2006). Matric suction is referred as the difference between the pore-air pressure, u_a and the pore-water pressure, u_w (matric suction $=u_a - u_w$). The soil suction in the literature of soil modelling (Sheng et al, 2011) usually refers to the matric suction.

The soil suction is mainly correlated with the physical and mechanical properties change, where the rate of desaturation process would influence the increase in saturation degree and the soil shear strength. The saturation degree would increase during saturation process and decrease during desaturation process (Vanapalli et al, 2006). The soil shear strength increase in linear path from low suction value (saturated condition) until air entry value point during drying. Then, soil shear strength continues to increase in non-linear path until residual air content condition during drying. The following soil shear strength path after the residual air content condition depends on the soil types, where the shear strength of grained soil (sand and silt) would decrease since the water is easy to come out from soil particles during drying process or desaturation process (Vanapalli et al, 2006). On the other hand, the shear strength of fine-grained soil (clay) would increase as the water is still available on the soil particle during desaturation process.

The soil suction has the general role in soil condition under negative pore water prressure, the physical and mechanical soil properties would be easily correlated when using suction value change instead of moisture content change.

Many methods have been applied for measuring soil suction, however the filter paper method seems to be a simple way for estimating the suction in certain value range. Although further analysis is required for this method, however the results can be used as an indication of the negative pore-water pressures in the soil.

Generally, the chosen measurement of matric suction is the filter paper method that particularly as a laboratory investigation. There is an ASTM standard (D5298-94) for filter paper measurements, but there are main concerns regarding the factors affecting the calibration of the filter paper and the measurement of total as well as the matric suction depends on the soil condition (Leong et al. 2002).

The method is based on the assumption that a filter paper can come to equilibrium state (balance) in a soil having a specific suction. The balance can be reached by water exchange between the soil and the filter paper in a liquid. When a dry filter paper is placed in contact with a soil specimen, moisture flow adsorbed from the soil to the filter paper until equilibrium is reached. When a dry filter paper is suspended above a soil specimen, the water should flow from the soil to the paper until equilibrium is obtained. After being in equilibrium conditions, the water content in the filter paper can be measured (Fredlund and Rahardjo, 1988). The filter paper water content is related to a matric suction value by using calibration curve of filter paper.

PHYSICAL PROPERTIES

An experimental study of the water retention curve relating with void ratio observation on a drying path was presented by Salager, S. et al, 2007. Tests were aimed to determine the variations of water content, w and void ratio, e induced by variations of the suction, s. The relationship between suction and soil water content is generally shown through the Soil Water Characteristic Curve (SWCC), it is a fundamental relation used to describe the relationship of hydraulic properties of unsaturated soils. Most of authors present the SWCC using the saturation degree or the water content, but despite void ratio measurements in some cases are using volume changes (T.M.H., Le et al. 2012).

This study shows that the SWCC in term of void ratio become independent when ranging exceed a suction of 100 kPa **(Figure 3.8.)**; when void ratio changes between the saturated and dry condition, it induces volumetric strain ranging from 4.9 to 12.5% regarding to the initial void ratio; change of void ratio is proportionally to the initial void ratio by a coefficient relating on suction (**Figure 3.9**.).

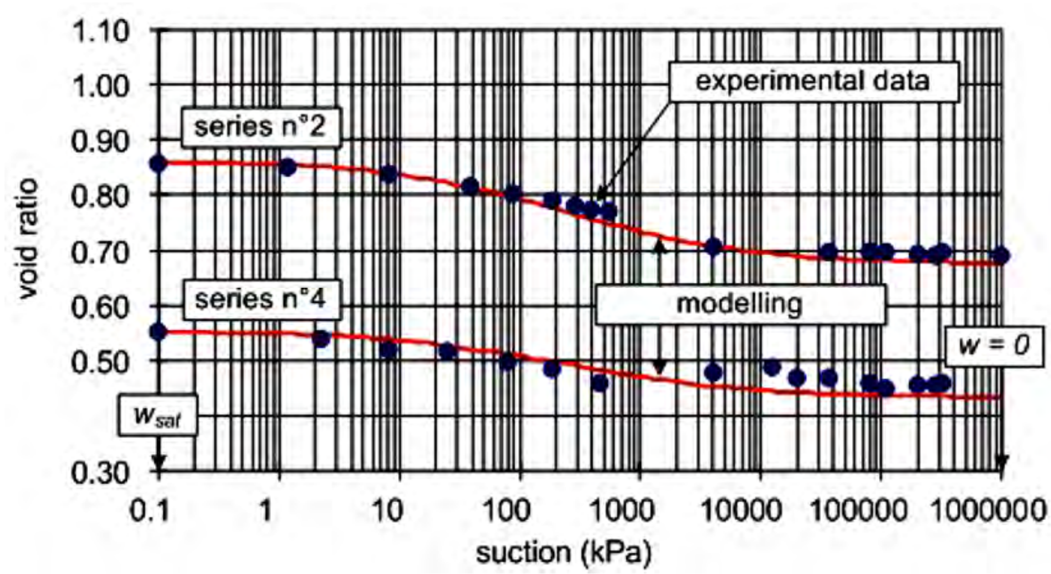


Figure 3.8. Void ratio versus suction from experimental data and modelling (Salager, S. et al, 2007)

MECHANICAL PROPERTIES

Soil shear strength is mainly needed in stability assessment of embankment. The Mohr–Coulomb theory, is commonly used for identifying the saturated soil shear strength. However, in a certain situation, soils become unsaturated rather than of fully saturated and in order to study the behavior of an unsaturated soil, an analysis has considered with the consideration of change of shear strength due to matric suction.

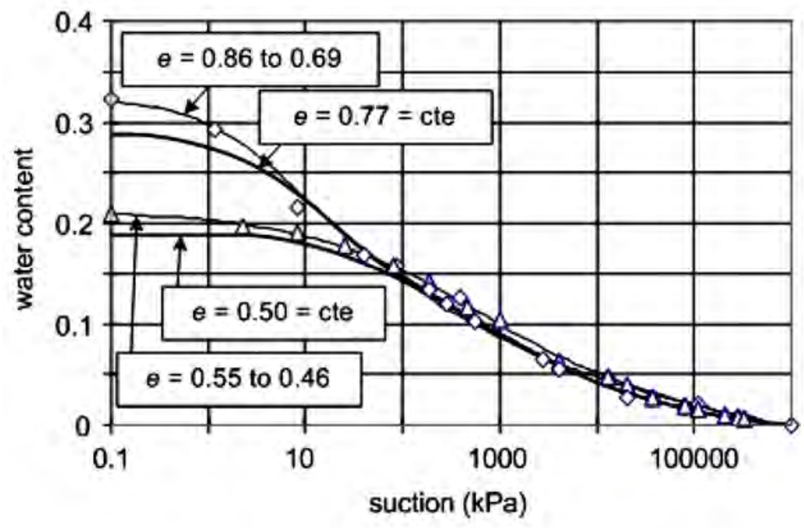


Figure 3.9. Comparison between different SWCC (Salager, S. et al, 2007)

SUCTION PROPERTIES

Considering the negative water pressures occurs in an unsaturated soil, if soils are placed in contact with free water under atmospheric pressure, it would have a same condition for this water and it is commonly referred to as soil suction.

Matric suction

Matric suction is generally defined as the excess of pore air pressure, U_a over pore water pressure, U_w (Fredlund and Rahardjo, 1993).

$S = U_a - U_w$ ....(3.4)

Total suction

Aitchison (1965) defined the soil-water (total) potential (Ψ), which corresponds to the free energy state of the soil per unit mass (J/kg) as being the sum of four components:

$\Psi = \Psi g + \Psi p + \Psi m + \Psi o$ ....(3.5)

Where g is the gravitational potential, ρ is the gas pressure potential, m is the matric potential and o is the osmotic potential.

RELATIONSHIP BETWEEN SOIL PROPERTIES AND SUCTION

The embankment soil properties may be affected significantly by changes in moisture content and suction (Mountassir, 2010). Drying and wetting cycles can also change the structure of a soil, especially in pore pressure value which reflects the degree of saturation.

The relationship between water content of the soil and matric suction, which is commonly referred to as the soil – water characteristic curve, can be used together with the shear strength of the soil at different matric suctions to give valuable information on the soil strength improvement.

Soil volumetric change might be either increase or decrease during wetting process. Thus, the drying and wetting process have an important role in the changes of physical and mechanical properties of the soil (Fredlund, 1999).

Figure 3.10. shows the water retention behavior for three soil samples of compacted Boom clay resulting drying paths each at a different initial void ratio (Nuth et al 2008). In **Figure 3.10.**, when the initial void ratio decrease, the main drying curve is shifted into the right side which means that higher suctions are needed to drain water from the soil pores in order to achieve a given degree of saturation.

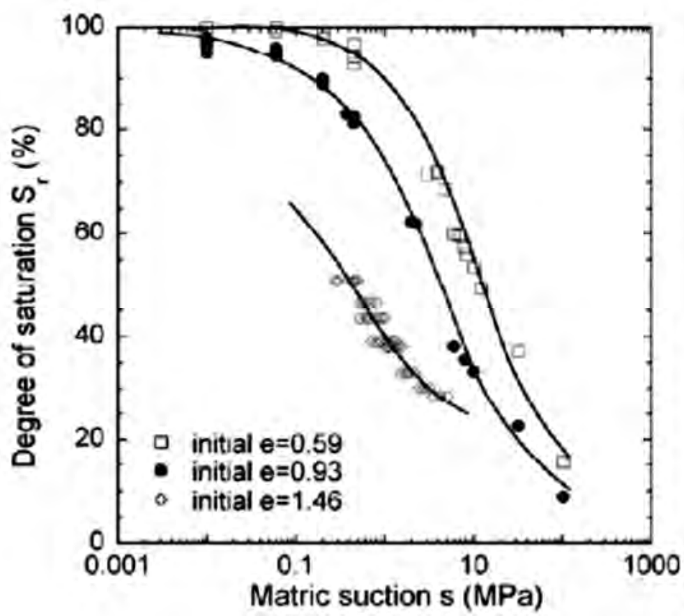


Figure 3.10. Influence of void ratio and structure on water retention behaviour of Boom clay (Nuth et al, 2008)

From **Figure 3.11**., it has commonly been experimentally observed that the shear strength of soils increases as suction increases (e.g. Fredlund et al., 1978; Escario and Sáez, 1986). The influence of suction on soil behavior could be determined by corresponding the influence of meniscus water at inter particle contacts.

The physical and mechanical properties of soil are always influenced by the various suction value as well as water content value (Schnellmann et al, 2010 and El Mountassir, 2010). The void ratio is well correlated with the suction value (Nuth et al, 2008), which low void ratio increases the degree of saturation at certain suction value. The suction value also has relationship with the shear strength, where the high suction value increases the shear strength value (Escario and Sáez, 1986).

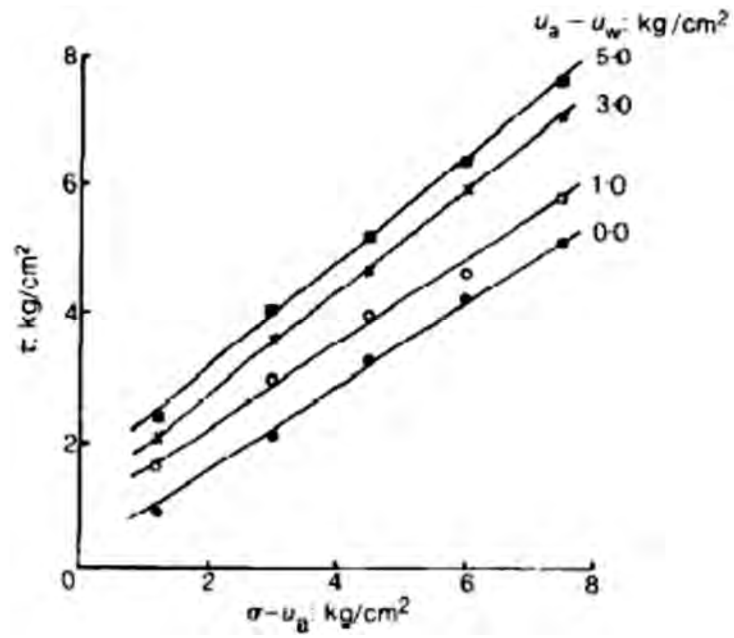


Figure 3.11. Shear strength data obtained for tests on Guadalix de la Sierra red clay in suction controlled direct shear tests (Escario and Sáez, 1986).

3.3.3. Genuchten equation

From insipration of van Genuchten's equation (van Genuchten, 1980), Peng and Horn (2005) developed a simple model with five parameters for the SSC:

$$e(\vartheta) = e_r + \frac{e_s - e_r}{\left[1+(\chi\vartheta)^{-p}\right]^q} \quad \text{..........(3.6.)}$$

where *e*r and *e*s are the residual and saturated void ratio, respectively, which can be determined directly in the laboratory. X, *p*, and *q* are fitting parameters.

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CHAPTER IV
RESEARCH METHODOLOGY

4. General

These research activity works were held in 4 (four) years respectively. First year research was aimed to investigate the in-situ condition. Second year research was to investigate the soil properties through laboratory test. Third year research was to evaluate the change of soil properties during drying and wetting between in-situ and laboratory investigations; and to investigate the influence of cohesion change as mechanical soil properties change on unsaturated slope stability.

4.1. Research Framework

In the first year, it was the field investigation that consists of river geometry measurement and in-situ soil properties tests. Geometry measurement consists of water level fluctuation measurement. Meanwhile, in-situ soil properties tests were performed to identify in-situ soil properties and to collect soil sampling (undisturbed and disturbed samples). The expected result in the first-year activities are to investigate the river condition, in-situ soil properties and soil samples needed for the second-year research activities. The second-year research activities were the laboratory investigation to investigate the physics and mechanics of in-situ and fresh compacted soil properties under drying-wetting condition. The appropriate physical and mechanical soil properties of laboratory for further analysis was regarded as output of second phase of research activities.

The research outcome in first year were the result of insitu investigation (physical and mechanical soil properties) and river condition (water fluctuation) on the dry and wet seasons. Research outcome on the second year was the in-situ and fresh compacted soil properties behavior affected by drying-wetting condition. Meanwhile the evaluation of in-situ and laboratory investigations; and also the influence of soil properties on unsaturated slope stability are regarded as the research outcome in the third and fourth year. The general research work is described in the research flow chart in **Figure 4.1.**

Table 4.1. Research outcomes in each year

Year	Research outcome
1st year	The insitu soil properties and river condition on the dry and rainy seasons.
2nd year	In-situ and fresh compacted soil properties behavior affected by drying-wetting condition.
3rd and 4th year	- Relationship between in-situ and fresh compacted soil properties - Soil properties evaluation and analysis of unsaturated slope stability

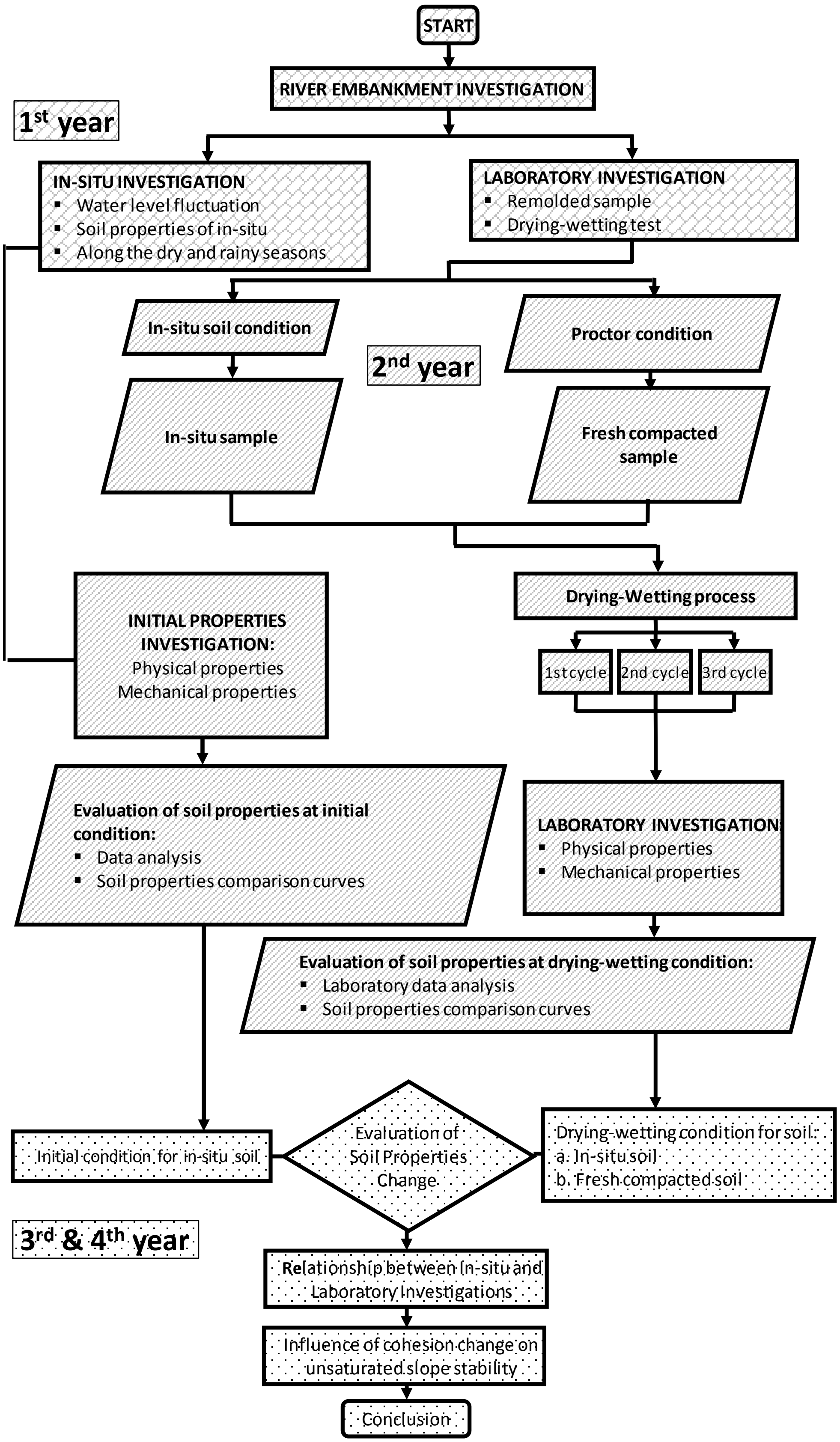

Figure 4.1. Research flow chart

4.2. Research Methodology

In the first year which mainly observes the field investigation, the following field investigations are:

a. In-situ dry density test.
b. In-situ negative pore water pressure test
c. In-situ soil shear strength test

Meanwhile, the following laboratory investigations are:

a. Drying-wetting of in-situ soil
b. Drying-wetting of fresh compacted soil

4.3. Research orientation

The research investigations are based on related studies which are shown in the research orientation as shown in **Table 4.2** below.

Table 4.2. Research orientation

Investigation	Method	Literature study
In-situ negative pore water pressure test	Field suction test (in-situ)	Gardner, 1937; Marinho and Oliveira, 2006; Bulut and Leong, 2008
Drying-wetting of in-situ soil	Drying-wetting test (laboratory)	Kalkan, 2011 and Al-Homoud et al., 1995
Cyclic drying-wetting of in-situ soil	Drying-wetting test (laboratory)	Fan and Hsiao (2010), Thielen et al, 2006, Zhan, T.L.T. et al (2006) and Bodner et al, 2013

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CHAPTER V
METHOD OF FIELD AND LABORATORY INVESTIGATIONS

5.1. In-situ Investigation

The in-situ investigation was conducted in the river embankment at Kanor village (**Figure 5.1.**) which was performed every 2 weeks for 4 months, starting in January 2014 and ending in April 2014. January 2014 was in the middle of the rainy season, February 2014 was in the peak rainy season, March 2014 was at the end of the rainy season and April 2014 was at the dry season. Four months investigation is selected since the critical condition of both dry and rainy seasons occurred in this investigation. The physical and mechanical soil properties were investigated by undisturbed soil sampling and soil matric suction by performing field tests. Surface soil layer of the river embankment had been selected as it always experienced drying and wetting conditions during changes in the seasons.

The field investigation is held every 2 weeks for obtaining the continuous data upon the water level fluctuation between dry and rainy season. There are 2 (two) types of field test that conducted which are suction test (soil matric suction) and undisturbed soil sampling.

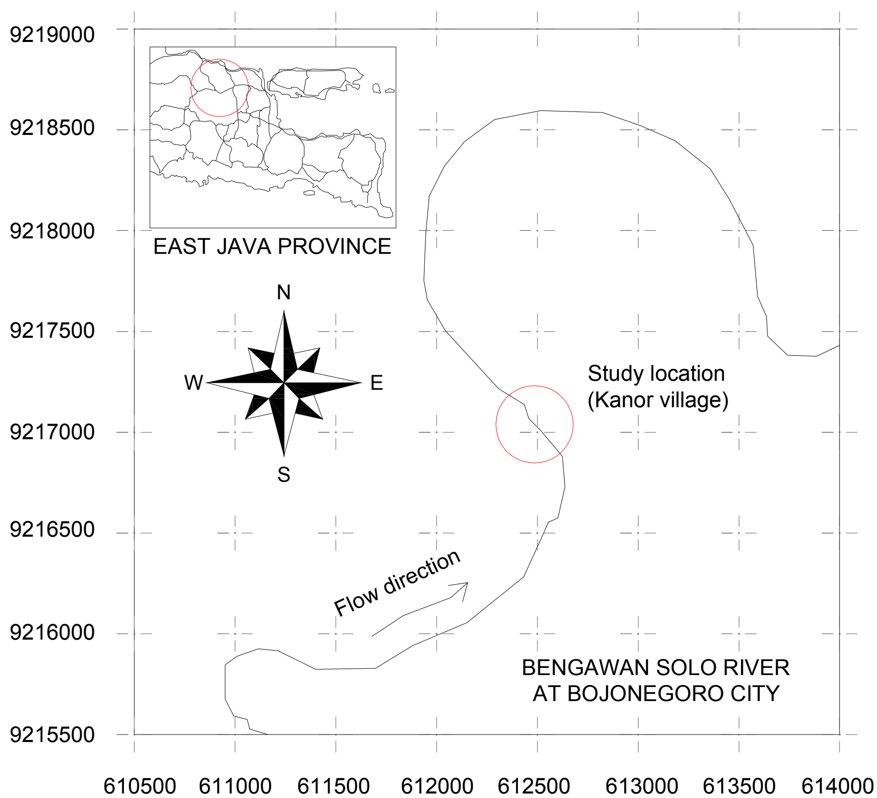

Figure 5.1. Layout of geotechnical investigation

Due to the high river embankment, the observation is investigated at section A (upper part) and section B (lower part) of river embankment (Satrya et al, 2016). Selection of these parts is based on the unsaturated condition existed above water level and saturated condition that existed below the water level. The distance between upper and lower part is approximately about 3 m (**Figure 5.2**).

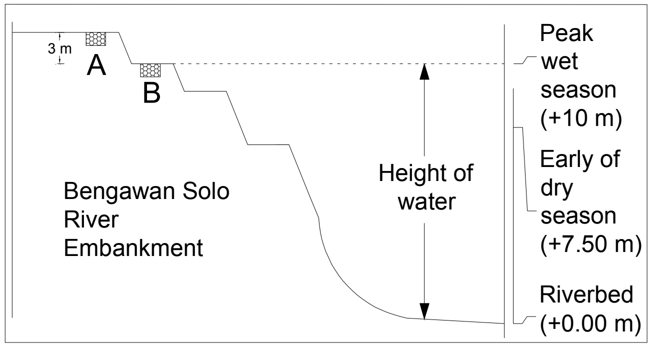

Figure 5.2. Detail of test location on river embankment

Field test and undisturbed sampling were performed in upper and lower part during dry and rainy season (starting from January, 2014 until April, 2014). To observe the soil density distribution, the sand cone test is conducted along upper and lower part of river embankment. The principal of sand cone test is observing the soil weight and volume of dig soil by using Ottawa sand. Ottawa sand is used since this material has uniform grain distribution. The moisture unit weight could be obtained from soil weight and volume and the dry unit weight could be obtained by using moisture unit weight and water content measured in the laboratory.

To observe the actual soil shear strength, vane shear test is conducted to obtain the undrained shear strength. The principal of vane shear test is rotating the vane into the soil until collapsed, then the collapsed shear strength would be regarded as the undrained soil shear strength. The suction test is conducted along upper and lower part of river embankment. The principle of suction test is measuring the soil matric suction by using Whatman filter paper no.42. All of these investigation procedures are based on the ASTM code as it could be seen in below.

a. The in-situ soil dry density and soil water content are measured by the sand cone test (ASTM D1556-00)
b. In-situ negative pore water pressure test

   The in-situ negative pore water pressure is measured using Whatman paper no. 42 method (ASTM D5298-03).
c. In-situ soil shear strength test

   The in-situ soil shear strength test is measured using the vane shear test (ASTM D2573-01)

In addition to these field tests, the undisturbed and disturbed soil are also sampled (ASTM D6282-98) at field to get the soil properties through set of laboratory tests. In the beginning, the grass and root were taken out from the surface layer since the original natural soil is approximately located 100 mm below the top soil. The undisturbed natural soil was taken by using Shelby tube having 75 mm in diameter and 600 mm in length. The tube was inserted into the soil by either pushing or hitting the tube. After completing the sampling into desired depth, the tube was taken out and continuing to a process for maintaining the original water content. This process (waxing) is performed by protecting the both sides of the tube with the liquid wax. The boiled or liquid wax is poured into the both tube sides until reaching 30 mm in thickness. After the wax is cold, the plastic tape is used to assure the safe condition for the wax. In the laboratory, the undisturbed soil sample is ejected by using sample extruder and cut in specific dimension according to the required test.

5.1.1. Undisturbed soil sampling

The tube used for undisturbed soil sampling was 7.62 cm in diameter and 60 cm in length. Firstly, brush was removed from the top soil in a 50 cm × 50 cm area. Then, the tube was manually inserted on the ground. The starting penetration depth was 0.50 m below the top soil, and the tube was removed after achieving the designated depth. To maintain the undisturbed condition, both sides of the tube were sealed with liquid wax and plastic sealer. Filled-soil tubes were then brought to the laboratory for investigating the physical and mechanical properties. The undisturbed soil samples then were taken to the laboratory.

5.1.2. Field suction test

The field suction test was regularly monitored to obtain soil matric suction by using the filter paper method. Many researchers have used filter paper to estimate the soil suction (Gardner, 1937; Marinho and Oliveira, 2006; Bulut and Leong, 2008). The contact filter paper, which used in this research, is one of the method that defines the water content of filter paper as the soil matric suction (Fredlund and Rahardjo, 1993). Whatman filter paper no.42 was used in this method. In addition, the calibration curve of filter paper was also used to correlate between the water content of filter paper and the related matric suction value.

Prior to use, the Whatman filter paper was protected with ordinary filter paper on both sides so that it comprised three stacks of filter paper in total. During the in-situ investigation, first a 50 cm × 50 cm area of the surface soil layer of the river embankment was cleared of brush. The soil was dug to 50 cm depth, and then Whatman filter paper was placed inside. Furthermore, the removed soil was placed back into the hole for maintaining the original condition. Filter paper had been allowed to be left in for 6 hours before it was taken out.

In addition to the regular field suction test, an additional field suction test was required to be conducted to determine the reason why the surface soil layer was selected as the object of investigation. Therefore, matric suction measurements using the Whatman filter paper method were performed vertically at several points, starting from the lower part and gradually moving toward the upper part of surface soil layer of the river embankment. It was measured at the following elevation depths: ± 0.0 m, -0.6 m, -1.2 m, -1.5 m, -1.8 m, -2.1 m, -2.4 m, and -2.7 m (measured from original ground level).

All of the field suction tests were using filter paper method that measured in the laboratory. Sets of the suction test, which started from placing the filter paper in the field until weighing at laboratory, were conducted under the similar humidity and temperature. The humidity ranged between 50–55 % and temperature ranged between 30-32 degree of celsius. These similar range values occur throughout the year in Indonesia.

5.1.3. Soil properties of In-situ condition

The investigated physical soil properties at in-situ condition were as follows: dry unit weight, water content, void ratio, and saturation degree. The investigated mechanical soil properties were as follows: undrained cohesion derived from an unconfined compression strength test and soil suction derived from a field suction test. The physical soil properties and undrained cohesion were tested by using extracted soil collected by the sample tube during the in-situ investigation.

5.2. Laboratory test of disturbed soil

5.2.1. Materials and method of disturbed soil

5.2.1.1. Material used

The disturbed soil sample, which derived from field investigation, is applied for in-situ and fresh compacted soil samples. Several tests were also conducted for the disturbed soil such as gravity characteristic test (specific gravity, G_s); Atterbeg limit test (liquid limit, LL; plastic limit, PL and plasticity index, PI) and sieve analysis test.

5.2.1.2.Compaction Test for Determination of Initial Fresh Compacted Condition

Standard Proctor compaction test was performed to determine the maximum dry unit weight and optimum water content values as the initial compacted soil condition. Disturbed soil from the surface soil layer was taken to conduct this test. Prior to soil compaction, eight soil samples with various water contents were homogeneously mixed and cured for 4 days. Furthermore, these samples were compacted according to the standard Proctor compaction test.

5.2.2. Cyclic drying wetting test

5.2.2.1.Soil sample preparation (in-situ and fresh compacted condition)

In order to simulate the cycles of dry and rainy seasons on the river embankment, the cyclic drying–wetting tests for in-situ and fresh compacted soil samples were performed at the laboratory. In-situ sample means that the sample condition is according to the density of in-situ soil, meanwhile fresh compacted soil means that the sample condition is according to the maximum density of Standard Proctor compaction test. As preparation, by using compression machine, the soil samples were statically compacted according to the in-situ and fresh compacted condition. The static compaction method in laboratory was selected where the soil was remolded using a PVC mold as shown in **Figure 5.3**. The remolded soil has dimension in accordance to the soil sample test requirement. A volumetric-gravimetric test required the sample to be of 3 cm height and 3.5 cm diameter, and the unconfined compression test required the sample to be of 8 cm height and 3.5 cm diameter.

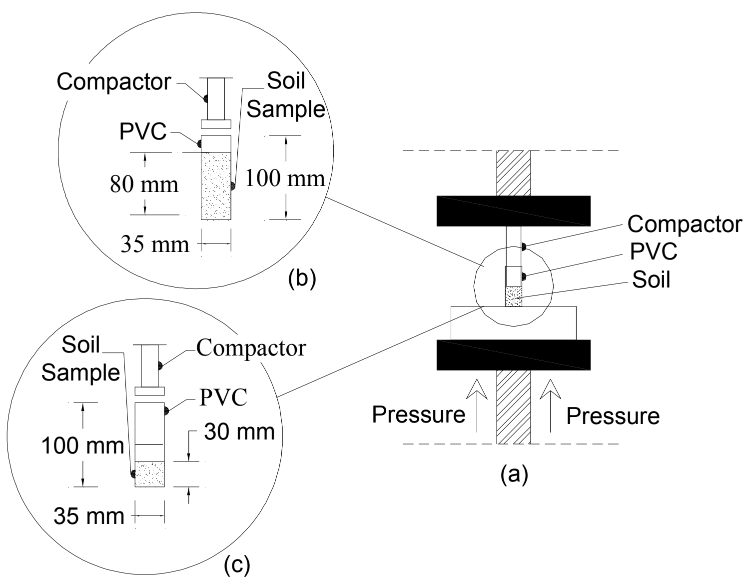

Figure 5.3. Remolding soil sample (a) compression machine; (b) soil sample dimension of unconfined compression test; (c) soil sample dimension of volumetric-gravimetric test

5.2.2.2.Drying-wetting procedure (in-situ and fresh compacted condition)

The cyclic drying and wetting test was performed in the laboratory by adjusting the water content of the soil sample. Similarly, as it had been investigated previously by Kalkan, 2011 and Al-Homoud et al., 1995, the drying and wetting test was completed by inundating soil sample with the water in the consolidation cell as wetting test and then continued to air-dry the soil sample as drying test.

The difference between these previous researches and this research is the wetting process. In this process, the water was gradually added until saturation condition was reached. This process was necessary because of the river water level also gradually fluctuates throughout the dry and rainy seasons.

To equalize the dry and rainy seasons that occur annually on the river embankment condition, the maximum limit of water content during the rainy season (saturated water content) and the minimum limit of water content during the dry season (air-dry water content) were required.

The extent to which the soil sample could be dried to its driest condition in air-dry environment was identified as the air-dry water content, and the extent to which it could be wetted to its wettest condition was identified as saturated water content. In the drying–wetting process, the soil sample was first dried until it achieved air-dry water content as to equalize the dry season, then the soil sample was wetted until saturated water content as to equalize the rainy season.

There were two steps for obtaining air-dry water content. The first step was oven heating, and the second step was aerating in an open-air environment. In the first step, the oven was used to heat the soil to 30 °C until it achieved equilibrium. This means that the water content does not change with successive measurements. This equilibrium condition took seven days to reach. The second step was soil sample aeration in the open dry air environment until the equilibrium condition was reached. This process also took seven days. At the end of the second step, the soil was sampled to observe the value of the water content.

This observed water content w_c was then defined as the air-dry water content. For obtaining the saturated water content, the soil sample was wetted until it achieved the saturated sample condition (S_r = 100 %). As a result, the air-dry water content was 7.09 % and the saturated water content was 37.83 %. These water contents were measured under similar humidity and temperature, where humidity ranged between 50–55 % and temperature ranged between 30-32 degree of celsius. In fact, these similar range values occur throughout the year in Indonesia.

After obtaining the saturated water content and air-dry water content, the drying–wetting process could be applied to the initial compacted soil samples. In the drying-wetting process, the fresh compacted soil condition was defined as the initial condition. To perform the gradual change of drying and wetting, there were a series of steps that determined from air-dry water content and saturated water content values. As many as ten series of steps were created in the range between air-dry water content and saturated water content values. These series steps controlled the drying and wetting process of the soil sample, where each step in the series was using water content as the criterion value to be achieved. The water content value for each series step was derived from the calculation of water content difference (ΔW) that divided by 10 as the number of steps. The water content difference (ΔW) was defined as the difference value between saturated water content and air-dry water content. The water content value for each steps is indicated with an index number as shown in **Table 5.1**. As a term, each of the drying series steps were indexed with the letter "D", while wetting series steps were indexed with the letter "W". This letter was followed by the index number.

Table 5.1. Water Content for Each Drying– Wetting Step Series

Drying–Wetting Process	
Step Index Number	Water Content, w_c (%)
1	7.09
2	10.17
3	13.24
4	16.31
5	19.39
6	22.46
7	25.54
Initial	27.19
8	28.61
9	31.68
10	34.76
11	37.83

All of the soil samples start from the initial condition. Then, the soil sample were first gradually dried in the step series **(Table 5.1)** until the air-dry water content condition was achieved. This drying method was performed by exposing the soil samples to the open-air environment and under the sun heat.

Furthermore, the soil samples were gradually wetted in the step series **(Table 5.1)** until it achieved the saturated water content condition. This wetting method was performed by adding water. Water were dropped into the soil samples until equally uniformed. Also, samples were turned upside down and vice versa to maintain the samples homogeneity. The process for the sample to achieve the air-dry water content condition and then continues to achieve the saturated water content condition, was defined as one cycle of drying and wetting. Three cycles were chosen, which refers to three cycles of dry and rainy seasons in the in-situ condition. The elapsed time for one cycle of drying and wetting at the laboratory was approximately ±4 days.

5.2.2.3. Soil Property Test after Drying and Wetting Test

In each series step at all cycles, the dried–wetted soil samples underwent sets of laboratory test to determine their physical and mechanical soil properties. The physical properties of the dried and wetted soil were as follows: dry unit weight, water content, void ratio, and saturation degree. The mechanical properties of dried and wetted soil were as follows: undrained cohesion derived from unconfined compression strength test and soil suction.

All of these investigation procedures are based on the ASTM code as it could be seen in below.

- Volumetric-gravimetry (ASTM D 2216-71; ASTM D 854-72)
- Soil consistency index (ASTM D 423-66; ASTM D 424-74; ASTM D427-74)
- Grain size analysis and hydrometer (ASTM D 422-63; ASTM D 1140-54)
- Negative pore water pressure by using Whatman paper no. 42 (ASTM D5298-03)
- Unconfined compression strength (ASTM D 3080-72)

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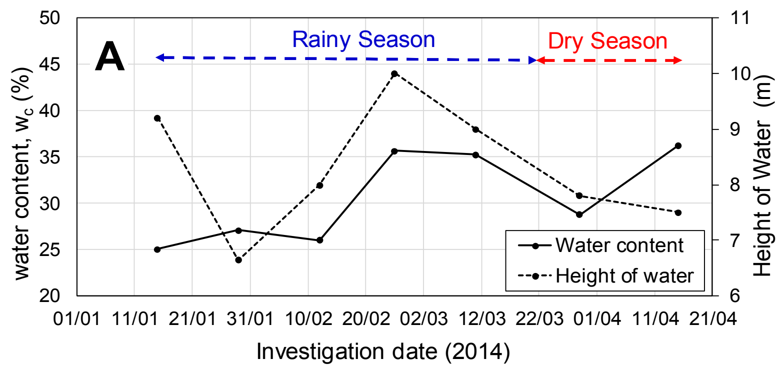
CHAPTER VI
DATA ANALYSIS

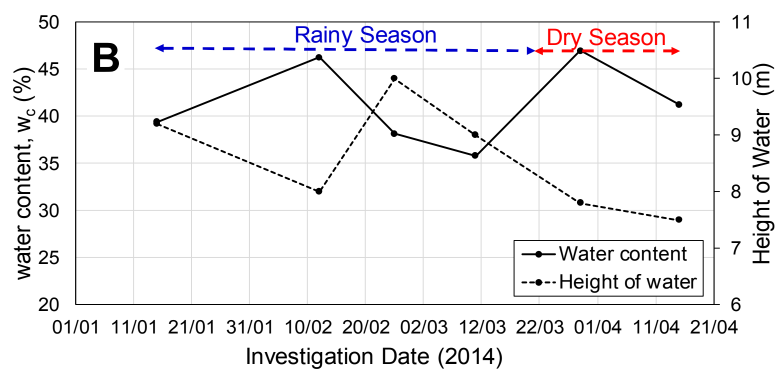
6.1.In-situ data sampling

The in-situ investigation was conducted to obtain the actual condition of physical and mechanical properties at surface layer of river embankment soil. Surface soil layer is frequently influenced by the water content change during changeable seasons, therefore the actual soil properties in this layer should be thoroughly investigated.

In detail, the water level fluctuation in section A (upper part) and section B (lower part) are shown in **Figure 6.1**. below.



(a)



(b)

Figure 6.1. Water level fluctuation at (a) section A (upper part);(b) section B (lower part)

Height of water is measured from riverbed where it increases from 6.5 until 10 m during peak rainy season and decreases from 10 until 7.5 m during dry season. January is the middle of the rainy season; February until early of the March is the peak rainy season; end of March is the end of rainy season; while April is the early of dry season.

Investigation at upper part and lower part was maintained to be conducted in the same location and the same elevation. However, water content of section B is nearly constant than section A since it is almost always in wet condition. Hence at section B, wet density, undrained cohesion and matric suction are nearly constant along the change of water content.

The field tests consist of sand cone test and suction test as physical soil properties; and vane shear test as mechanical soil properties. Sand cone test is aimed to measure the actual field dry density; suction test by using Whatman filter paper is conducted for observing the matric suction value and vane shear test which aimed to measure the undrained soil shear strength.

Soil sampling consist of 2 (two) types which are undisturbed and disturbed soil sampling, undisturbed soil sample is used for determining the physical and mechanical soil properties. The physical soil properties are density, void ratio and saturation degree, while the mechanical soil properties are undrained soil shear strength that derived from unconfined compression strength test. The disturbed soil sampling is objected to observe the soil grain size distribution, specific gravity and compaction behavior.

6.2. In-situ condition

6.2.1. Physical properties of in-situ soil

Field dry density is observed by using sand cone equipment where it was located on the upper and lower part of river embankment. The top soil of surface layer was removed beforehand to obtain the in-situ condition. **Figure 6.2** until **Figure 6.4.** below presents change of dry density due to change of water content along the change of height of water at section A (upper part) and B (lower part).

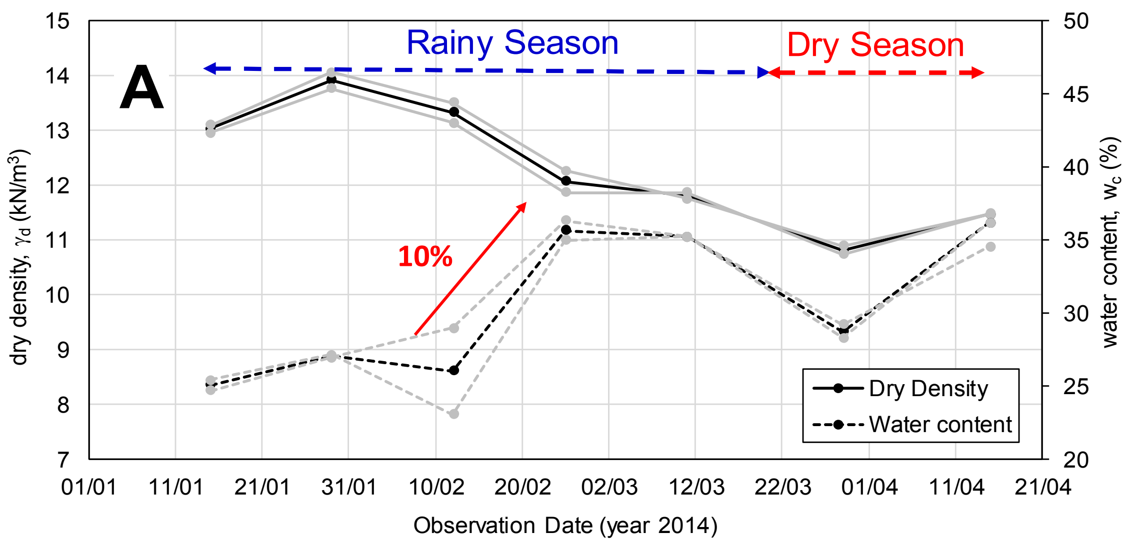


Figure 6.2. Relationship between dry density and water content during in-situ observation at section A

Section A (at upper part): the change of dry density is unaligned with the change of water content. Upon maximum change of water content ($\Delta w_c = 10\%$), the dry density decreases ($\Delta \gamma_d = 1.5$ kN/m^3).

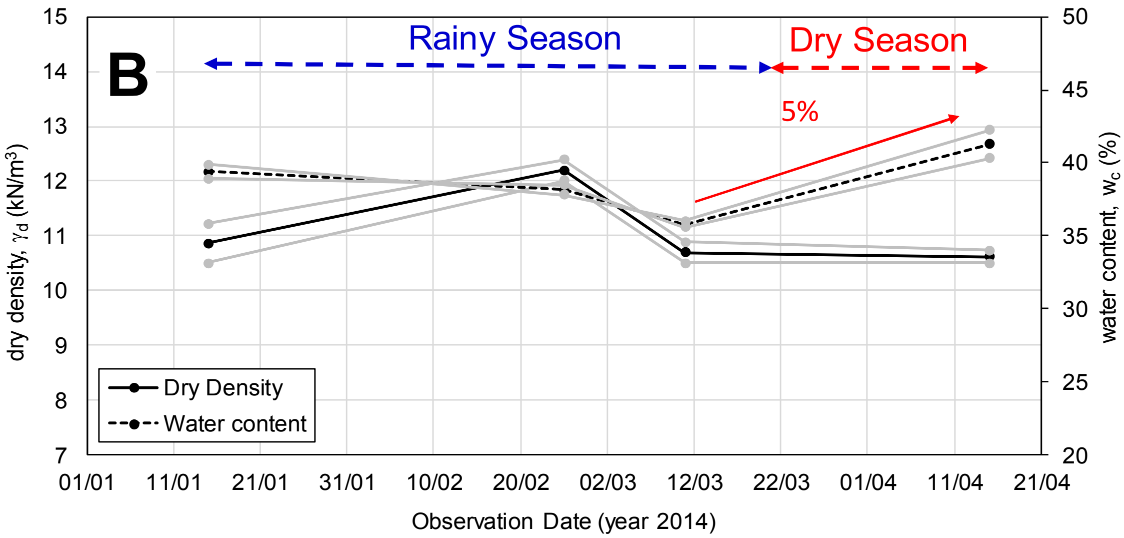
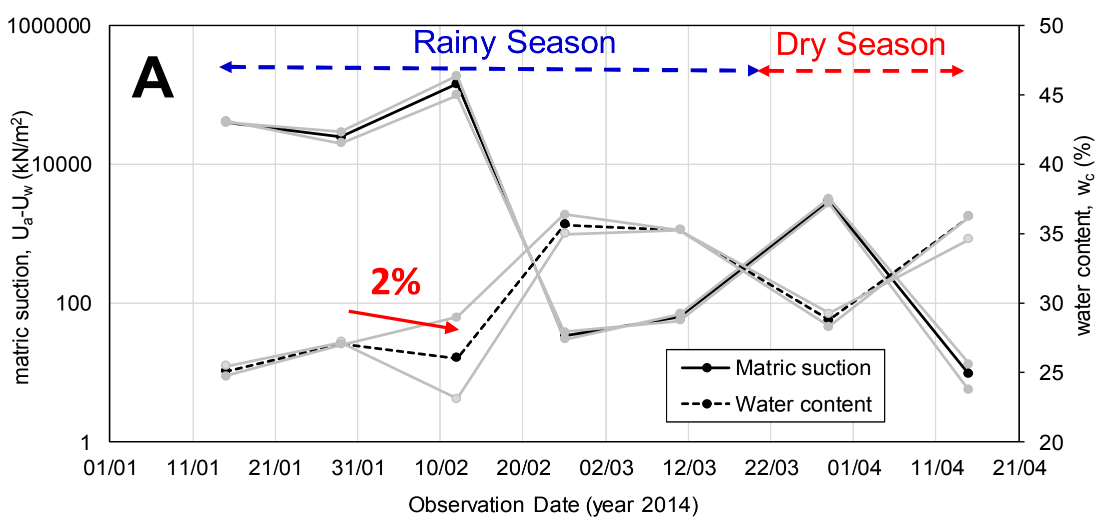


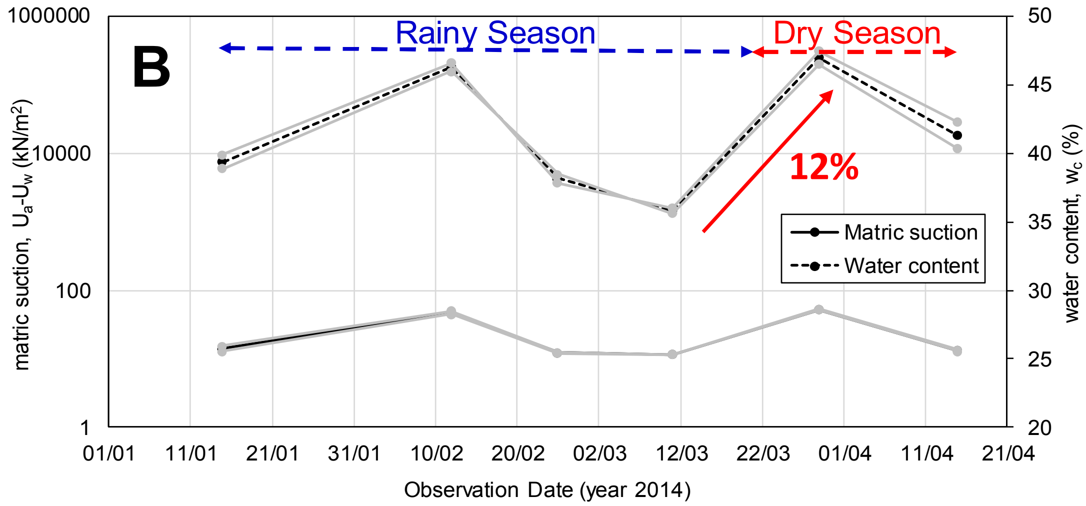
Figure 6.3. Relationship between dry density and water content during in-situ observation at section B

Section B (at lower part): dry density, undrained cohesion and matric suction are nearly constant along the change of water content. Upon maximum change of water content ($\Delta w_c = 5\%$), the dry density decreases ($\Delta \gamma_d = 0.2$ kN/m^3). Water content data is observed by using samples taken from undisturbed soil sampling, it was investigated at both upper and lower parts of river embankment.

Suction is observed by using filter paper testing equipment which conducted at both upper and lower part of river embankment. The measured suction is matric suction value.



(a)



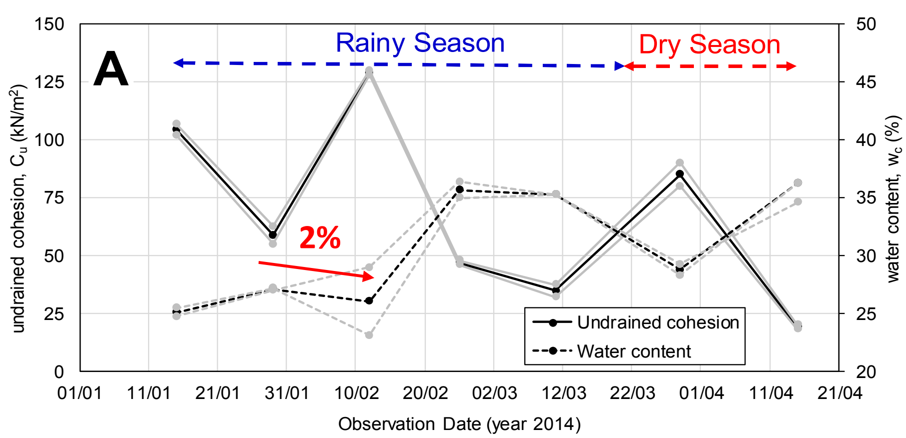
(b)

Figure 6.4. Relationship between suction and water content at (a) section A and (b) section B

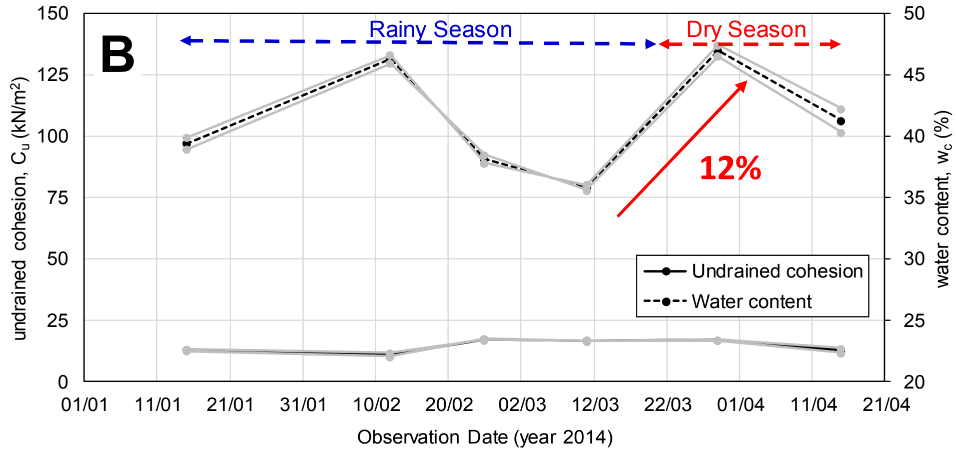
Change of matric suction in section A are unaligned with the change of water content. When water content decreases ($\Delta w_c = 2\%$), the matric suction increases (ΔU_a-U_w)= 300,000 kN/m^2). In section B, when water content increases ($\Delta w_c = 12\%$), the matric suction change only (ΔU_a-U_w)= 10 kN/m^2). Constant change of properties is due to lower part which is almost always influenced by the river water level.

6.2.2. Mechanical properties of in-situ soil

The actual shear strength (undrained cohesion) was observed by using vane shear testing equipment which conducted at both upper and lower part of river embankment. **Figure 6.5**. below presents change of undrained cohesion due to change of water content at section A (upper part) and section B (lower part).



(a)



(b)

Figure 6.5. Change of undrained cohesion due to change of water content at (a) section A and (b) section B

Change of undrained cohesion in section A are unaligned with the change of water content. When water content decreases (Δw_c = 2%), the undrained cohesion increases (Δc_u = 60 kN/m²). In section B, when water content increases (Δw_c = 12%), the undrained cohesion only change (Δc_u = 0.50 kN/m²). Constant change of properties is due to lower part which is almost always influenced by the river water level. Therefore for the next, section A is used as in-situ data.

6.3. Disturbed soil condition

6.3.1. Initial data analysis

6.3.1.1. Initial soil properties

Satrya et al, 2016 reveals that the clayey-silty soil as the type of natural soil of river embankment at Bengawan Solo river. **Table 6.1** presents the physical properties of natural soil that was taken from January until April 2014. Soil grain distribution analysis and plasticity test results are analyzed respectively based on the previous study.

Based on the common minerals in the soil (Das, 2010), specific gravity, G_s value of this natural soil is classified as quartz soil where silicon element mostly found. In addition, the Unified Soil Classification System, USCS, classify the soil type as lean clay soil with low plasticity (CL).

Regarding the range of liquid limit, plastic limit and activity values as soil plasticity behavior, it shows that the clay mineral is classified as kaolinite material. This material having silica and alumina elements with ratio 1:1, and also there is potassium ion existed between particles, therefore the soil structure is not able to be penetrated by the water. Hence, it is not classified as high expansive soil. Similarly, by using the soil plasticity value, Chen (1988) classify this kind of soil as medium expansive soil.

Table 6.1. Physical properties of natural soil

Soil Characteristics		Natural soil
Specific gravity, G_s	-	2.55-2.70
Gravel	(%)	0
Sand	(%)	3 – 25
Silt	(%)	36 – 39
Clay	(%)	34 – 60
USCS classification	-	CL
Liquid limit, LL	(%)	36 – 50
Plastic limit, PL	(%)	22 – 28
Plasticity index, PI	(%)	14 – 26
Gradation	-	Poor Graded
Expansive soil characterization (Chen, 1988)	-	Medium

6.3.1.2.Chemical soil properties

To better analyze the chemical compound contained on natural soil of section II, XRD (X-Ray diffractometer) test was conducted in the laboratory. The chemical composition is dominated by Sodium Calcium Alumina (37%); Silicon Oxide (34%) and Calcium Carbonate (29%) which illustrated in **Figure 6.6.**

Soil type	Compound	Perc.
Natural	Sodium Calcium Alumina	37 %
	Silicon Oxide	34 %
	Calcium Carbonate	29 %

The Calcium Carbonate compound indicates that the part of the soil derived from limestone material. Even though more quartz and alumina elements commonly contained in the clayey soil, this natural soil particularly contains less quartz (SiO_2) and less alumina element. The embankment material might be composed of clay fraction mixed with the limestone material. The clay materials might be taken from the sedimented river bed and further mixed with the limestone material.

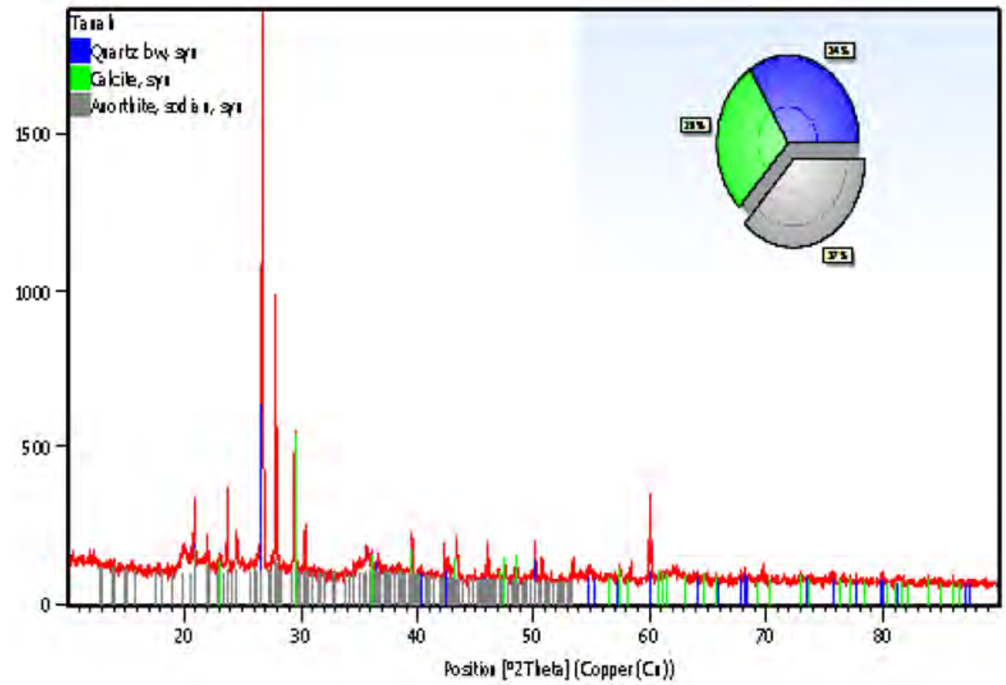


Figure 6.6. Graphic of laboratory XRD test result

6.3.1.3. Compaction behavior

From the compaction test result, the relationship between the water content (w_c) and the dry unit weight (γ_d) of soil is presented in **Figure 6.7**. It could be seen from the standard Proctor compaction result (with compaction energy 594 kJ/m^3) that the initial compacted soil exhibited a double peak compaction curve. The first peak of natural soil is 13.70 kN/m^3 at 5 % of water content, and the second peak is 13.96 kN/m^3 with 28 % of water content value. **In Figure 6.7**, irregular double-peak compaction curves also existed on the soil that was compacted with a low compaction effort where two peaks occurred upon identical dry unit weight value. This generally means that when low compaction effort is applied, the dry unit weight might result in a different value owing to a slight change of water content.

However, this double peak can be altered into a single peak content if the soil is compacted with a high compaction effort. Higher given compaction energy influences solid grain is easier to move closely each other and finally form the higher density.

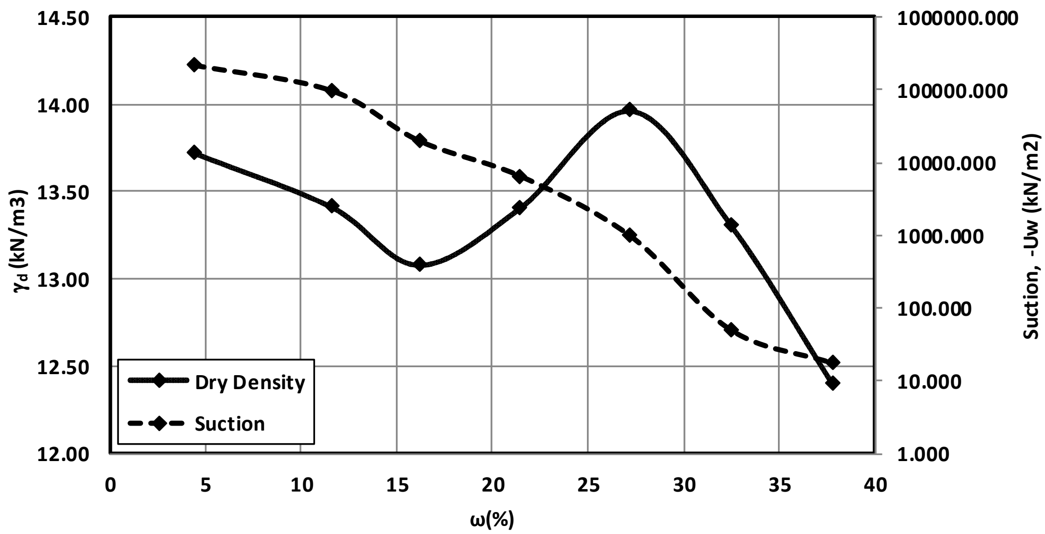


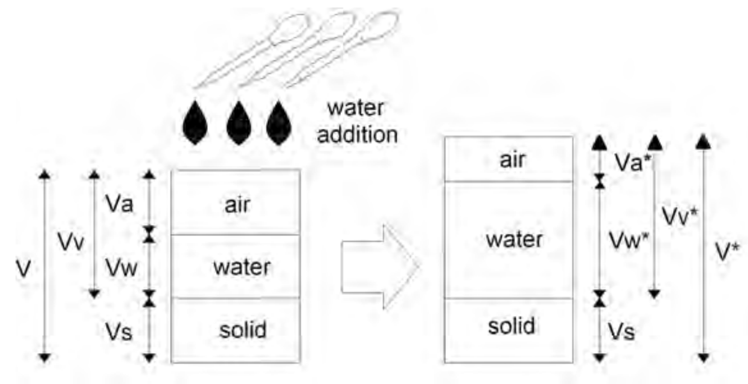
Figure 6.7. Laboratory compaction test results in three different compaction energies

Regarding the suction value, suction does not depend on the soil dry density, it shown from the decreasing of suction value due to water addition. Generally, the suction value is related with the pore distribution as the soil packing structure where dense soil will have high suction value. From Young-Laplace capillary rise equation, the smaller capillary radius, the higher capillary height. Therefore, during compaction test, the suction should be increased due to dense condition of soil structure. However, the suction value is decreasing along the increasing of soil density. It is due to the water that continuously added in compaction test, therefore the pore distribution is no longer dominant in influencing the suction value, rather than adding the water. In addition, the sample condition is not in saturated condition, hence the suction value will be decreased as it could be seen in **Figure 6.7.**

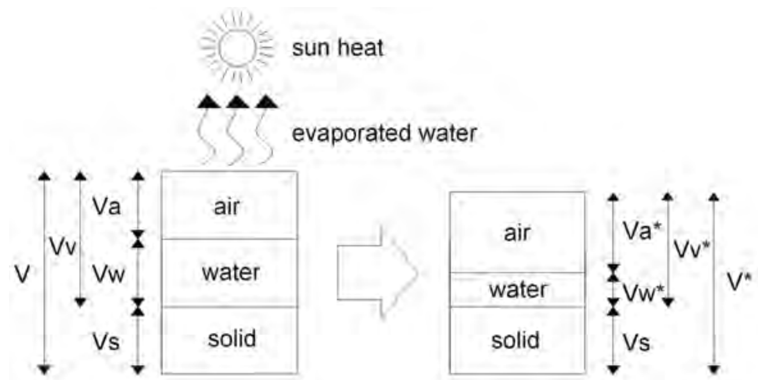
6.3.2. Drying-wetting data analysis of in-situ soil

6.3.2.1 Behavior of River Embankment Soil due to Drying and Wetting

Figure 6.8 illustrates the volume phase of clay soil after the drying and wetting process. It was mentioned in **Table 6.1.** that the river embankment soil is classified as inorganic clay and silt, with medium expansive characterization behavior. Furthermore, this behavior means that not only do soil particles have the ability to volumetrically increase or swell when adsorbing the water, but they also have the ability to volumetrically decrease or shrink when desorbing the water (Basma et al., 1996, Estabragh et al., 2015, Lin and Cerato, 2015).



a. Wetting process



b. Drying process

Figure 6.8 Soil volume phase illustration of clay soil due to drying and wetting

(* = altered volume phase)

During the wetting process of clay soil, as shown in **Figure 6.8 (a)**, the water volume phase (Vw), volume of void (Vv), as well as the total volume of soil (V) increased to Vw*; Vv* and V*, respectively. Volume of air (Va) decreases into Va*. However, the solid volume (Vs) was unchanged. Therefore, the void ratio increased and the dry unit weight decreased owing to these changes. This occurred due to the physicochemical factor of clay mineralogy (Seed et al., 1962). The surface structure of clay has negative ions that strongly attract water molecules; hydrogen bonding is then formed from an anion of clay and a cation from the water. In addition, clay also has a negative electrical charge that always attracts cations to the surface to achieve electrical neutrality in soil. Hence, owing to the hydrated water and attracted cations, there will be an imbalance in electrical charge The electrical charge imbalance mostly occupies the space in the soil and then soil particles start to be apart.

Meanwhile, during the drying process of clay soil, as shown **Figure 6.8 (b)**, the water volume phase (Vw), volume of void (Vv), as well as the total volume of soil (V) decreased to Vw*; Vv* and V*, respectively. Volume of air (Va) increases into Va*. However, the solid volume phase was unchanged throughout the experiment. Therefore, the void ratio decreased and the dry unit weight increased owing to these changes. The drying process could be analogized with the higher capillarity or high negative pore water pressure, which reduces the hydrostatic pressure. Therefore, the effective stress and soil shear strength increases. However, if the negative pore water pressure is more than the soil cohesion value, the soil cracks.

The drying and wetting of clay as fine-grained soil results in different behavior than the drying–wetting of coarse grained soil (sand or gravel), especially different total volume of soil. In coarse-grained soil, soil particles do not swell when they adsorb water or shrink when the water is desorbed. Therefore, the total volume of soil is unchanged. In sandy granular soil, the void ratio hardly changes during drying and a bit increase during moistening activity (Eid et al., 2015).

6.3.2.2. Behavior of physical in-situ soil and compacted soil properties due to drying-wetting

Water content as initial condition of natural and compacted soil is different, where in-situ condition is greater than fresh compacted condition. Low water content at fresh compacted condition is due to the maximum dry density condition, meanwhile water content at in-situ is high. **Figure 6.9** until **Figure 6.12.** below showing the set of in-situ and fresh compacted soil properties curve during cyclic drying-wetting test.

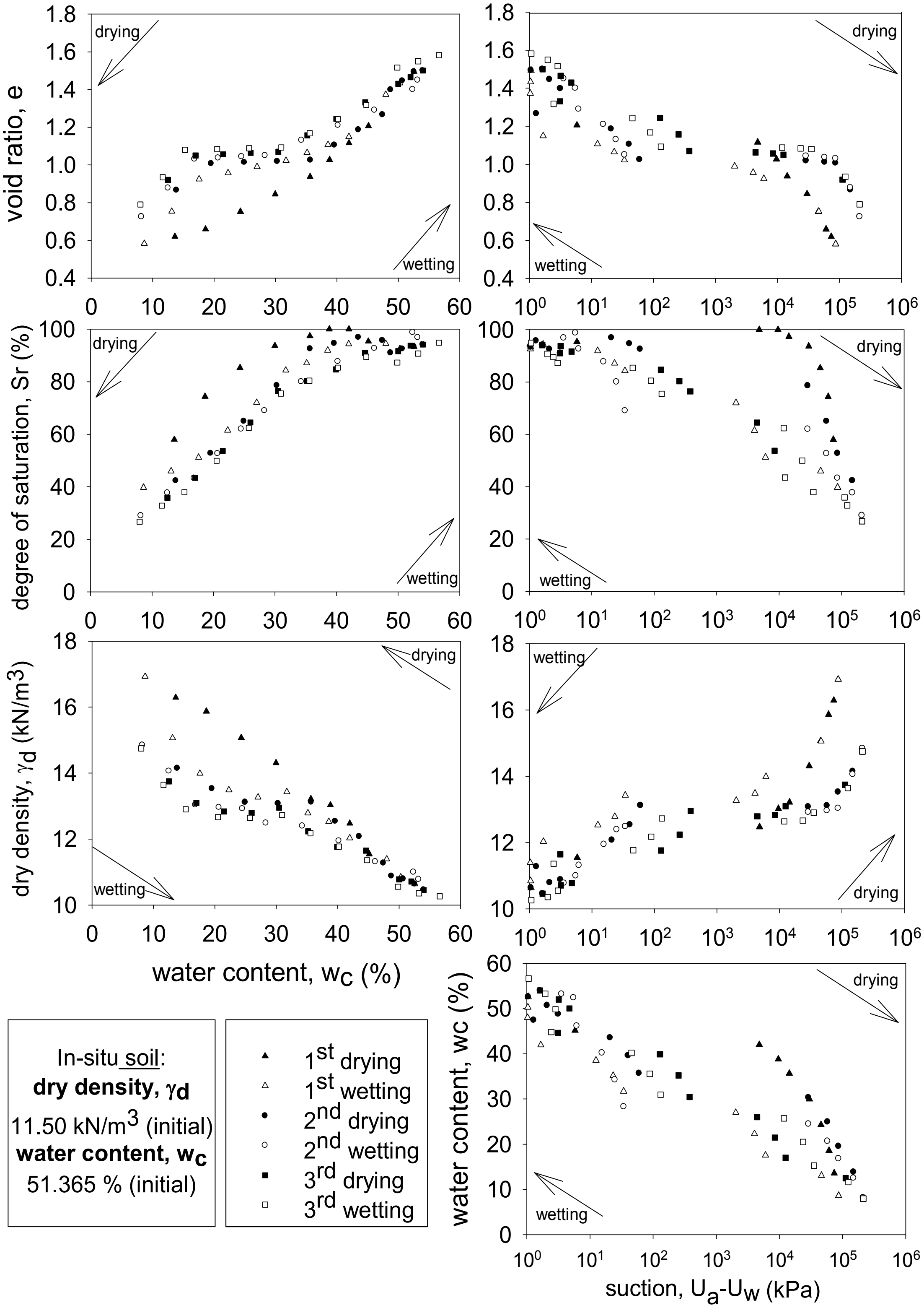


Figure 6.9. Physical soil properties change of in-situ soil due to cyclic drying-wetting test

At the end of drying process of in-situ soil, the dry density is decreasing during successive cycles where dry density is 16.9 kN/m^3 at 1st cycle; 14.84 kNm^3 at 2nd cycle and 14.75 kN/m^3 at 3rd cycle. Below is the difference of dry density (compared with the dry density at initial condition) along the drying-wetting cycles.

Item	Initial condition	1st drying	1st wetting	2nd drying	2nd wetting	3rd drying	3rd wetting
Dry density, γ_d (kN/m^3)	11.50	16.92	10.64	14.84	10.46	14.75	10.26
Difference (times)	-	1.47	-0.92	1.29	-0.91	1.28	-0.89

There is drop decrease between 1st and 2nd cycle, however, there is slight decrease between 2nd and 3rd cycle. It generally means that after 2nd cycle, the properties start to be in constant value.

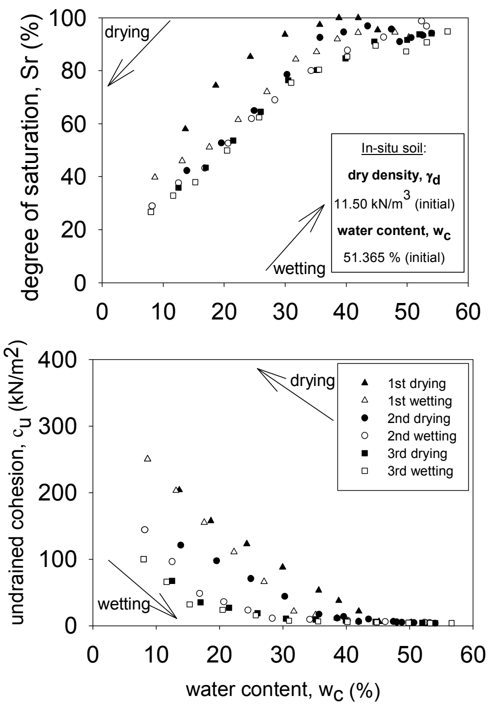


Figure 6.10. Mechanical soil properties change of in-situ soil due to cyclic drying-wetting test

At the end of drying process of in-situ soil, the undrained cohesion is decreasing during successive cycles where undrained cohesion is 250.36 kN/m^2 at 1st cycle; 143.99 kNm^2 at 2nd cycle and 100 kN/m^2 at 3rd cycle. Below is the difference of undrained cohesion (compared with the undrained cohesion at initial condition) along the drying-wetting cycles.

Item	Initial condition	1st drying	1st wetting	2nd drying	2nd wetting	3rd drying	3rd wetting
Undrained cohesion, c_u (kN/m^2)	6	250.36	3.89	143.99	3.78	100	3.67
Difference (times)	-	41.7	-0.65	24	-0.63	16.7	-0.61

There is drop decrease between 1st and 2nd cycle, however, there is slight decrease between 2nd and 3rd cycle. It generally means that after 2nd cycle, the properties start to be in constant value.

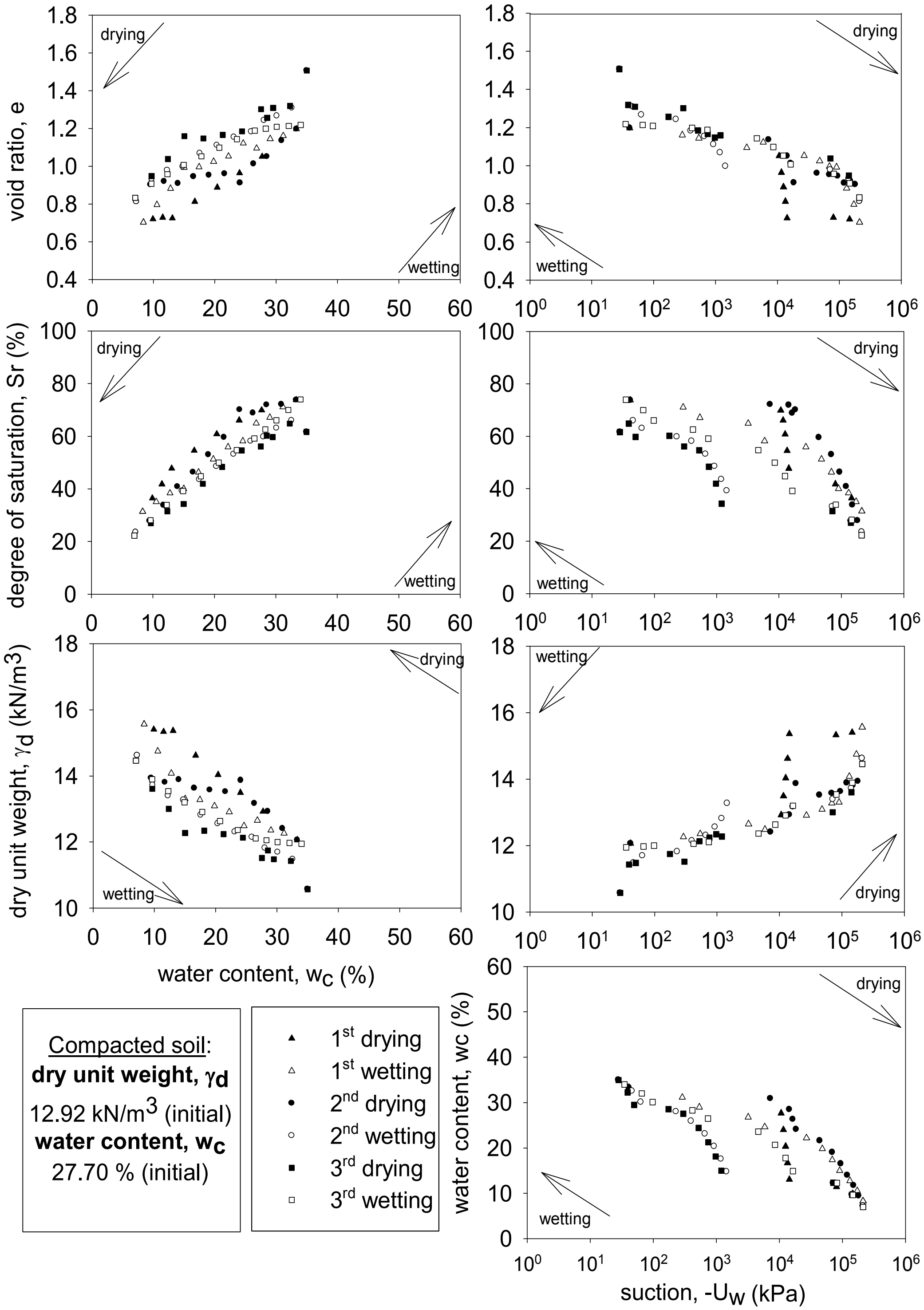


Figure 6.11. Physical soil properties change of fresh compacted soil due to cyclic drying-wetting test

At the end of drying process of fresh compacted soil, the dry density is decreasing during successive cycles where dry density is 15.56 kN/m^3 at 1st cycle; 14.62 kNm^3 at 2nd cycle and 14.46 kN/m^3 at 3rd cycle. Below is the difference of dry density (compared with the dry density at initial condition) along the drying-wetting cycles.

Item	Initial condition	1st drying	1st wetting	2nd drying	2nd wetting	3rd drying	3rd wetting
Dry density, γ_d (kN/m^3)	12.92	15.56	12.06	14.62	10.57	14.46	11.95
Difference (times)	-	1.20	-0.93	1.13	-0.82	1.12	-0.93

There is drop decrease between 1st and 2nd cycle, however, there is slight decrease between 2nd and 3rd cycle. It generally means that after 2nd cycle, the properties start to be in constant value.

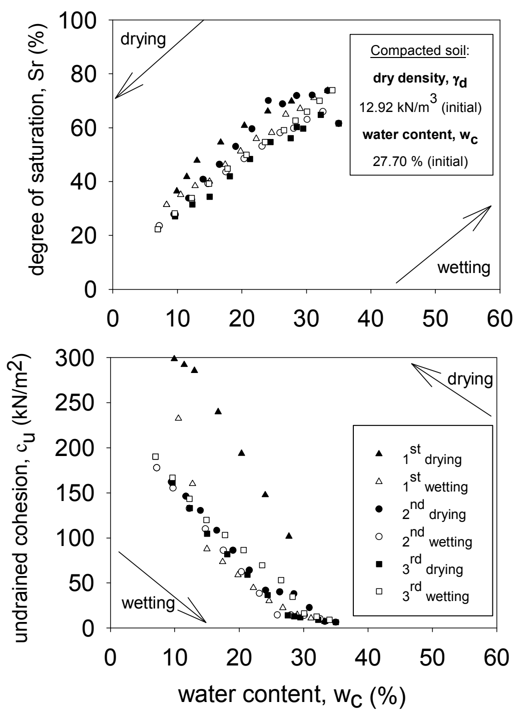


Figure 6.12. Mechanical soil properties change of fresh compacted soil due to cyclic drying-wetting test

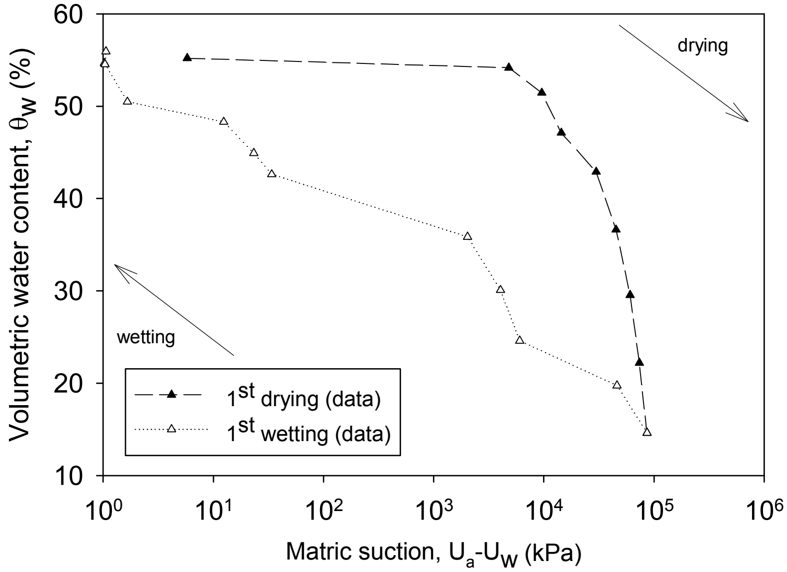
At the end of drying process of fresh compacted soil, the undrained cohesion is decreasing during successive cycles where undrained cohesion is 304.73 kN/m^2 at 1st cycle; 177.8 kNm^2 at 2nd cycle and 190 kN/m^2 at 3rd cycle. Below is the difference of undrained cohesion (compared with the undrained cohesion at initial condition) along the drying-wetting cycles.

Item	Initial condition	1st drying	1st wetting	2nd drying	2nd wetting	3rd drying	3rd wetting
Undrained cohesion, c_u (kN/m^2)	101.61	304.73	7.21	177.8	6.5	190	9.19
Difference (times)	-	3	-0.071	1.75	-0.064	1.87	-0.090

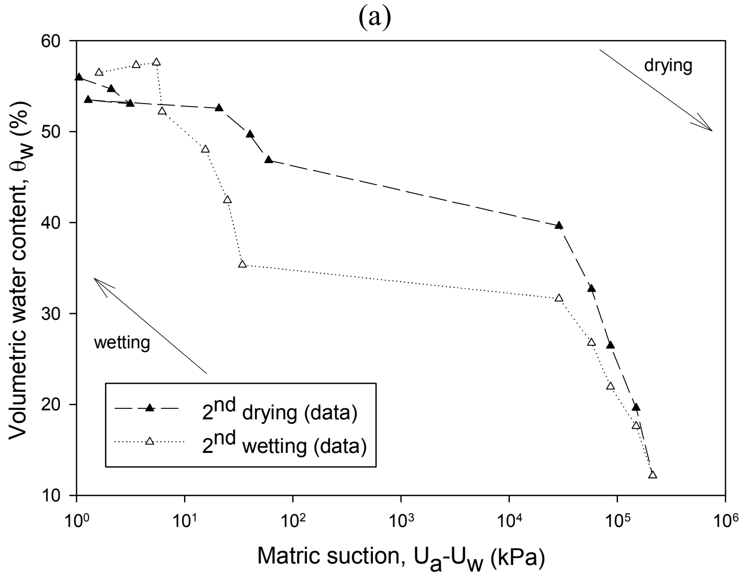
There is drop decrease between 1st and 2nd cycle, however, there is slight decrease between 2nd and 3rd cycle. It generally means that after 2nd cycle, the properties start to be in constant value.

6.3.2.3.Behavior of in-situ soil water characteristics curve due to drying-wetting

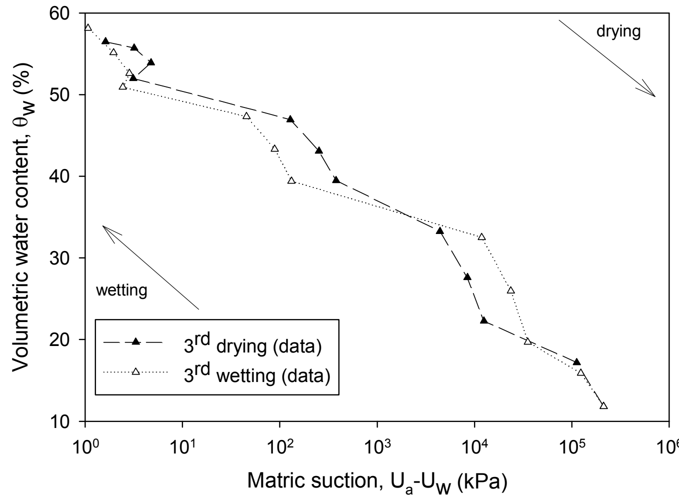
For better understanding the phenomenon of drop and slight change of in-situ soil properties during cyclic drying-wetting process, the soil water characteristic curves, are presented below.



(a)



(b)



(c)

Figure 6.13. Soil water characteristic curve (SWCC) of in-situ soil; (a) 1st cycle; (b) 2nd cycle and (c) 3rd cycle

From the SWCC curve of in-situ soil, it shows that the hysteresis is decreasing within the cycle and it will be low in the 3rd cycle of drying and wetting process. Therefore, the hysteresis phenomenon could be the cause of drop and slight change of in-situ soil properties during cyclic drying-wetting process.

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CHAPTER VII
SOILPARAMETER CORRELATION ANALYSIS

7.1.In-situ properties correlation

7.1.1. Correlation of suction change behavior

Schnellmann et al (2010) investigated delayed on pore water pressure distribution during rising of 4 (four) types of Ground Water Table (GWT) elevations which are -0.7 m; -0.6 m; -0.45 m and -0.275 m, as it shown in **Figure 7.1.** It reveals that distribution of pore water pressure is influenced by the distance of flowing penetration and low permeability in the unsaturated zone above the phreatic level.

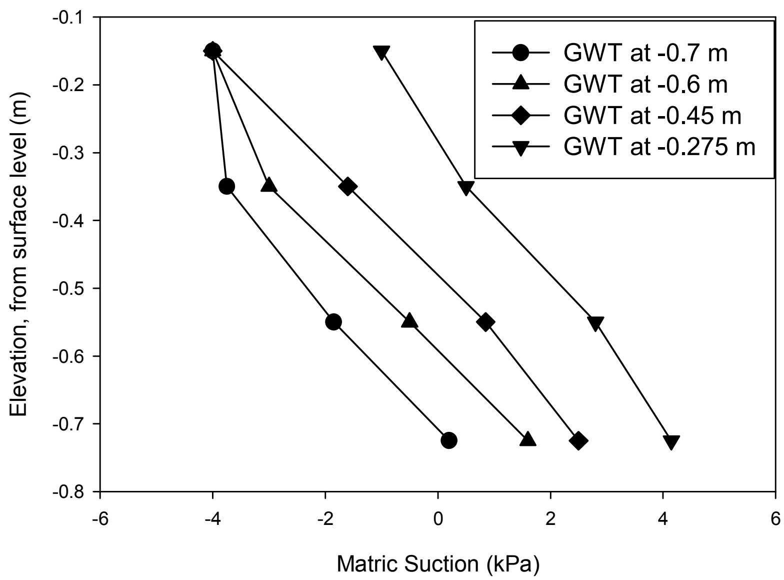


Figure 7.1. Pore-water pressure distribution during rising water table (Schnellman et al, 2010)

As comparison with this research, **Figure 7.2** showing the profile of pore water pressure at any elevation at 3 (three) sections of river embankment during rising Ground Water Table (GWT). The GWT as well as the profile of pore water pressure were observed on May 06, 2014 and May 20, 2014. All of the sections experienced rising water table, where section I and II undergoes high rising water table, while section III undergoes low of rising water table. Section I experienced rising of ground water table from elevation -4.8 m to -3.1 m (Δ = 1.7 m), section II experienced rising of ground water table from elevation -3.9 m to -3.3 m (Δ = 0.6 m) and section III experienced rising of ground water table from elevation -3.95 m to -3.9 m (Δ = 0.05 m). Section III shows similar value of pore water pressure since it is coincided with the elevation of GWT. Section I and II exhibits high difference of suction value during rising water table. It means that it shows delays of matric suction at surface layer during risen water table where it needs certain time for water to penetrate up into the surface soil layer of river embankment. In addition, change of suction during fluctuation might trigger the value of soil shear strength, hence it needs to observe the effect of matric suction on the shear strength.

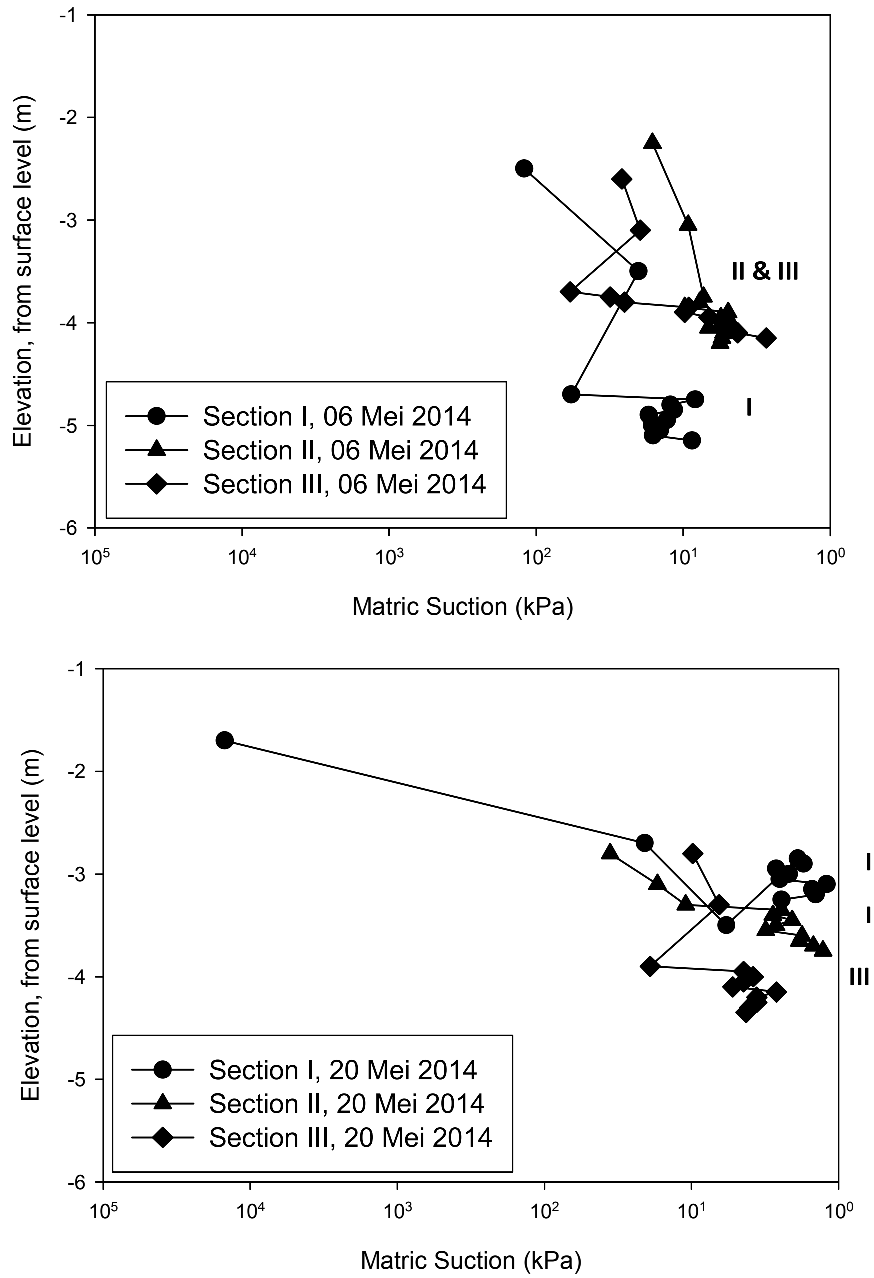


Figure 7.2. Suction in any observation depth at section I, II and III

7.1.2. Shear strength and suction correlation

The matric suction and shear strength have relationship where shear strength increases with the matric suction as shown in **Figure 7.3.** Madrid clayey sand was investigated by Chae et al, 2010 where at the higher normal stress, shear strength increases until residual failure strength. Meanwhile, the section I, II and III as the result of in-situ investigation are plotted far below the previous study, it might be due to the low density at those sections. The initial value of density and suction of embankment seem to induce the value of shear strength. In addition to in-situ investigation, the drying-wetting result of compacted soil is also investigated for identifying the reason. For instance, shear strength of compacted soil undergoes higher shear strength than section I, II and III which could be seen in **Figure 7.2.** The shear strength difference between compacted soil and in-situ soil might be caused by the drying wetting cycle during water level fluctuation along the seasons.

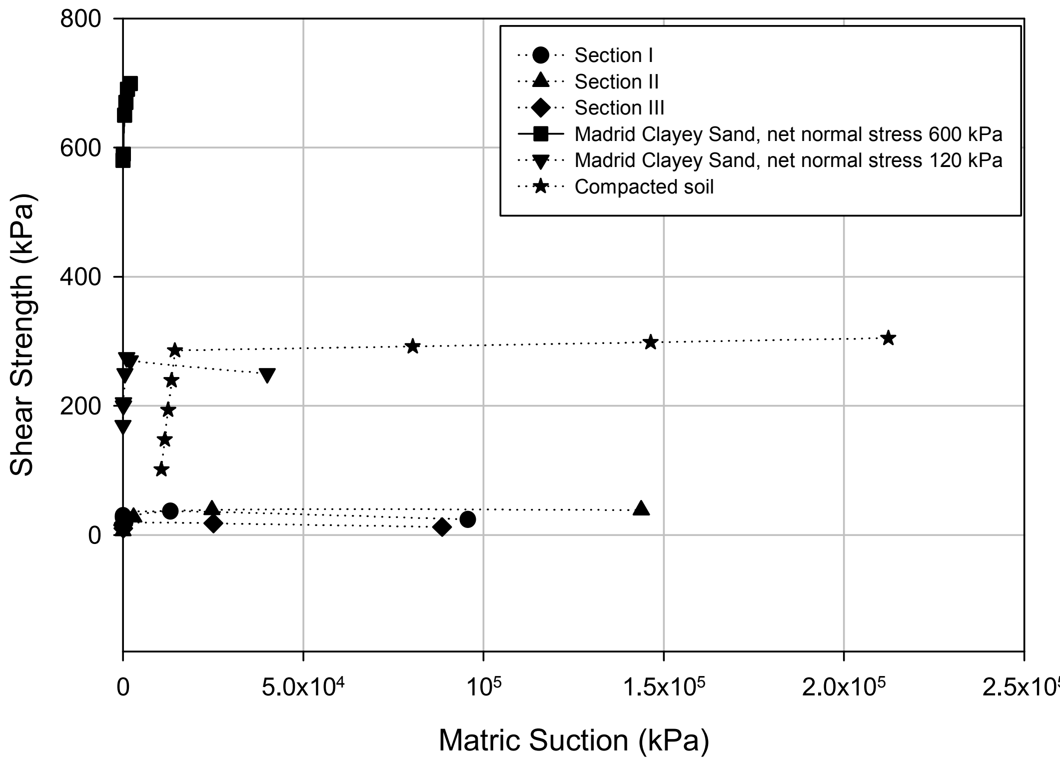


Figure 7.3. Relationship between matric suction and shear strength upon relevant studies

7.1.3. Suction profile observation

Geometry of the unsaturated slope has influence on the matric distribution which subjected to rainfall (Fan et al, 2010). **Figure 7.4.** showing the suction profile monitoring at any elevation level of section I, II, III as the result of this research and various slope geometry which investigated by Fan et al, 2010. Shape of various slope geometry investigated by Fan et al, 2010 could be seen in **Figure 7.5.** The measurement was observed on the above of water table when prior and after rainfall. Due to the slope geometry, behavior of suction change of this research is similar to the gullied slope. The suction value of gullied slope is lower than ridge and planar slope since it retains lot of water in this geometry.

In addition, from **Figure 7.5**, it shows that even though the slope composed by similar silty clay with minor sand, the suction profile implies different behavior. All of the sections (I, II and III) exhibits slow response of pore water pressure rather than slope observed by Fan et al, 2010. It means that there is delayed response of pore water pressure during rainfall activity which is similar with rising water table activity that investigated by Schnellmann et al (2010).

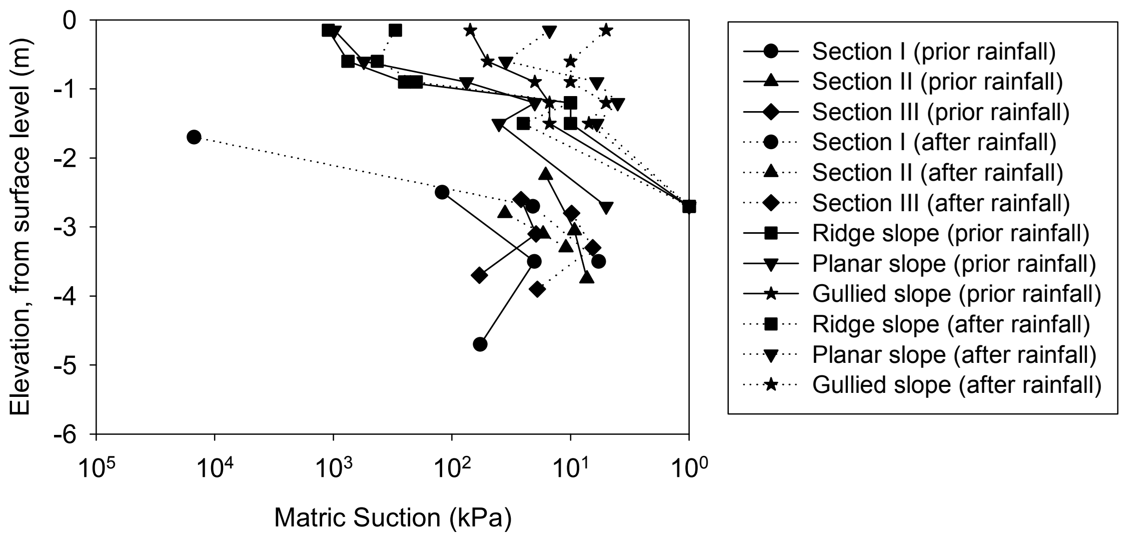
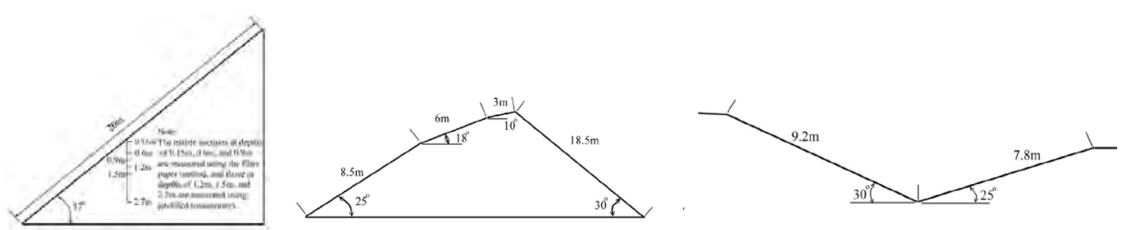


Figure 7.4. Suction profile at any elevation from monitoring result

(All sections as the result of this study and geometry of slope investigated by Fan et al, 2010)

There are 3 (three) observed slopes (Fan et al, 2010) which are ridge slope; planar slope and gullied slope as shown in **Figure 7.5**. below.



(a) (b) (c)

Figure 7.5. Geometry of the slope (Fan et al, 2010)

Regarding the suction profile at below of water table, **Figure 7.6.** showing the comparison between suction monitoring result of all sections (I, II, III) observed on May 6 and 20, 2014 and soil water characteristics curve (SWCC) investigated by Cui et al, 2006 and Estabragh et al, 2015.

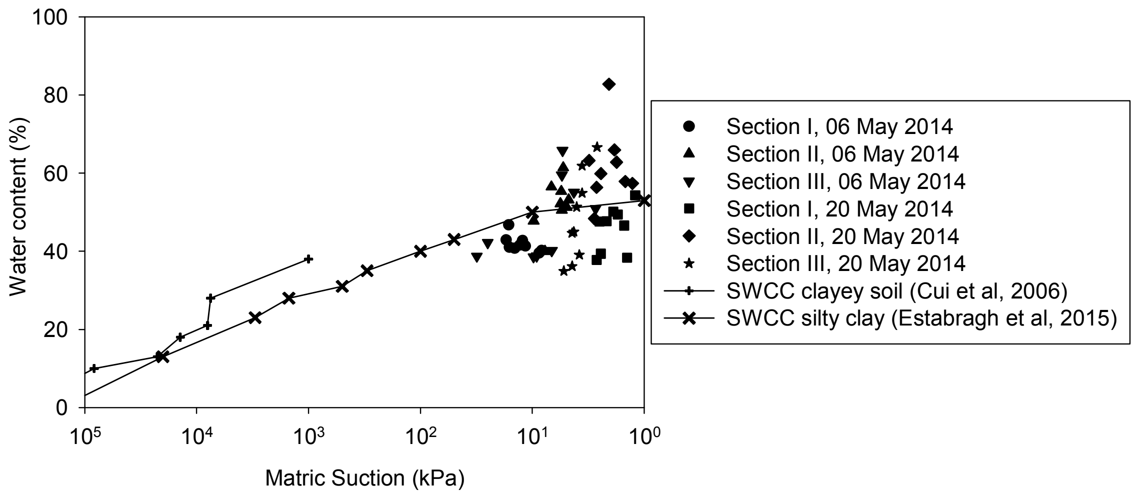


Figure 7.6. Comparison of soil water characteristics curve and suction monitoring result

From **Figure 7.6**, it shows that the wetting condition of present study is scattered on the range of low suction value that has high soil water content. It generally means that the in-situ condition at all sections are inside the range of wetting phase of SWCC.

7.2. Laboratory properties correlation

7.2.1. Compaction behavior

Table 6.1 provides soil characteristics sampled on June, 2014. Based on the Unified Soil Classification System (USCS), the soil type is CL, inorganic clay and silt (fine-grained soil) with low plasticity. Furthermore, in terms of expansive soil characterization (Chen, 1988), the soil is classified as medium expansive characterization.

From the compaction test result, the relationship between the water content (w_c) and the dry unit weight (γ_d) of soil is presented in **Figure 7.7**. It could be seen from the standard Proctor compaction result (with compaction energy 594 kJ/m^3) that the initial compacted soil exhibited a double peak compaction curve. In fact, similar compaction behavior was also encountered on river embankment soil that was investigated by Mountassir et al. (2014). In **Figure 7.7**, irregular double-peak compaction curves also existed on the soil that was compacted with a low compaction effort (British Standard Light, BSL with compaction energy 596 kJ/m^3), where two peaks occurred upon identical dry unit weight value.

This generally means that when low compaction effort is applied, the dry unit weight might result in a different value owing to a slight change of water content. However, this double peak can be altered into a single peak if the soil is compacted with a high compaction effort (British Standard Heavy, BSH with compaction energy 2682 kJ/m^3), as shown in **Figure 7.7**. In this research, the second peak of the compaction curve was selected as the initial compacted soil condition for the cyclic drying–wetting test.

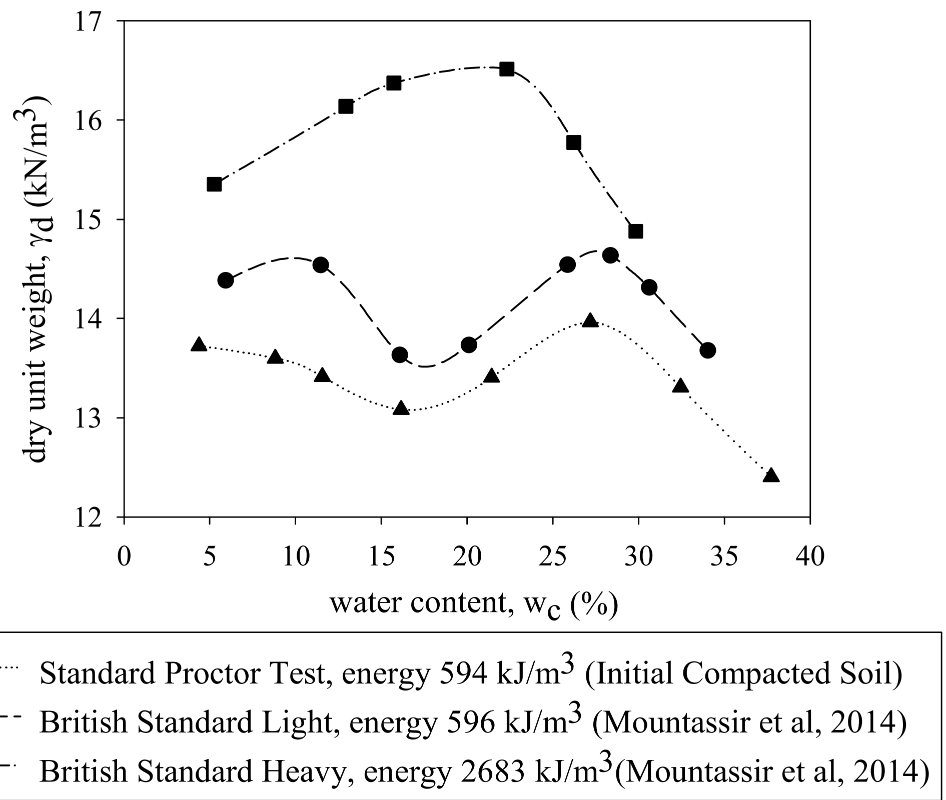


Figure 7.7 Compaction test results in three different compaction energies

This selection was made owing to a greater dry unit weight value and was also based on the actual soil condition when it was initially used as river embankment material. The soil material was derived from a riverbed that possessed high water content and was composed of fine-grained soil. Practically, greater compacted condition was achieved by using this material. The application of wet and large soft aggregate material in low compaction efforts will create more homogeneous fabric (Mountassir et al., 2014). Based on the compaction test results, the maximum dry unit weight and optimum water content was 13.96 kN/m^3 (γ_d max) and 26 % (w_c opt).

7.3. Drying-wetting properties correlation

7.3.1. Initial Compaction

Figure 7.8. below describes the comparison of drying-wetting results between natural soil as the result of this research with the other researches. From the figures below, it shows that during desorption due to drying process, the loose soil sample exhibits larger value of void ratio and suction change rather than dense soil sample. For example, the in-situ soil investigated by Azam, 2013 which has the loose condition experienced void ratio change (Δe) as much as 0.45 which is much more than the dense soil (5-10 sample) investigated by Jotisankasa, 2005 that has Δe = 0.015. The change of void ratio and suction value during drying process could be seen in **Table 7.1.**

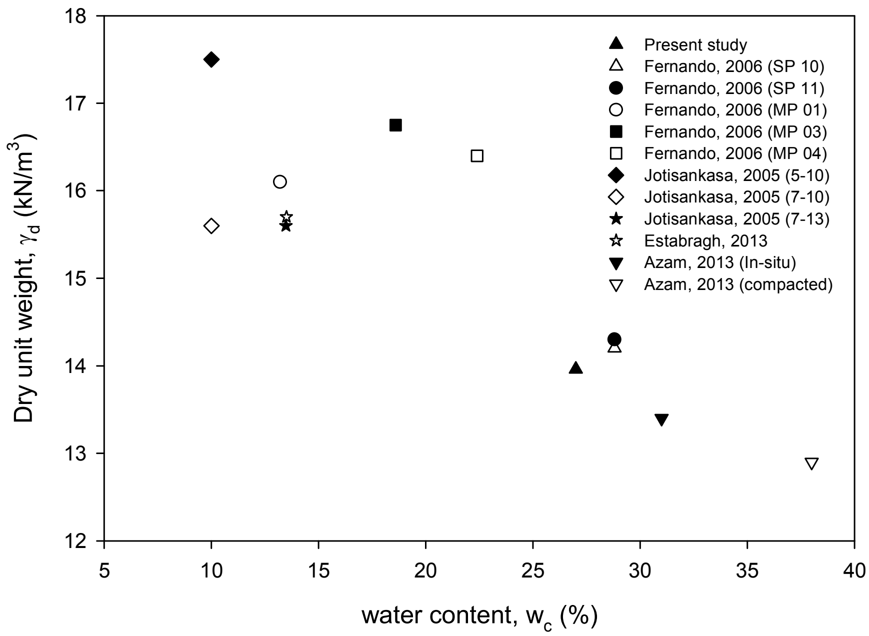
Table 7.1. Recapitulation of change in void ratio and suction value of all investigated soil

Research history	Volume change (Δe)	Suction change (Δuw, kPa)
Fernando, 2006 (MP 04 sample)	0.015	920
Jotisankasa, 2005 (5-10 sample)	0.015	13500
Jotisankasa, 2005 (7-13 sample)	0.015	17780
Jotisankasa, 2005 (7-10 sample)	0.017	28750
Fernando, 2006 (MP 01 sample)	0.02	47500
Fernando, 2006 (MP 03 sample)	0.03	10100
Fernando, 2006 (SP 11 sample)	0.16	49970
Fernando, 2006 (SP 10 sample)	0.19	44980
Present study	0.348	201642.1
Azam, 2013 (Compacted)	0.45	999
Estabragh, 2013	0.46	24200
Azam, 2013 (In-situ)	0.54	79999

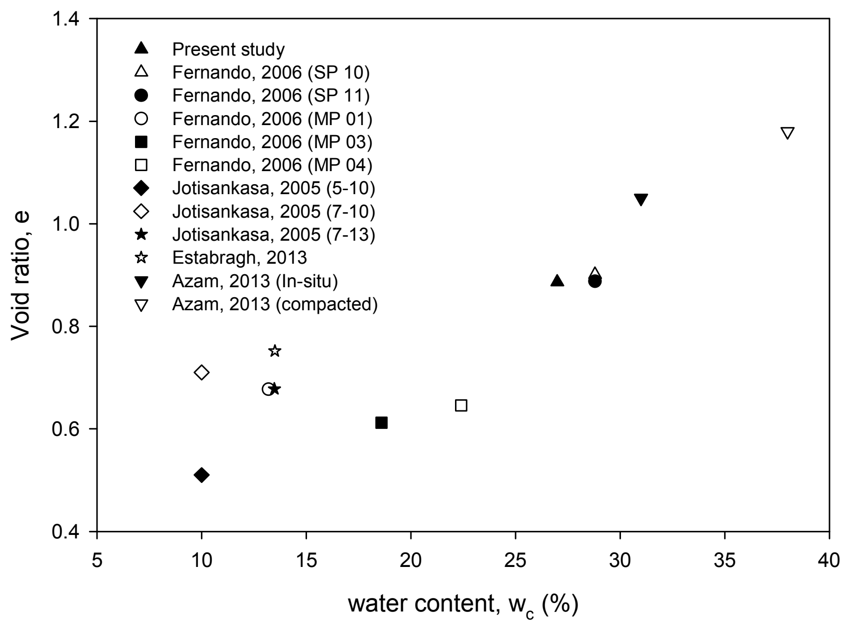
Also, in-situ soil investigated by Azam, 2013 experienced suction change (Δ-U_w) during drying process as much as 79,999 kPa which is much more than 5-10 sample (Δ-U_w 13,500 kPa) investigated by Jotisankasa, 2005. The phenomenon might be caused by:

1. Loose soil sample has high void ratio in the soil, hence during drying process all of the volume of void will be shrunk into the denser condition. It is the reason why the soil experiences high void ratio change during drying process.
2. Loose soil sample will also have high range of matric suction value where it will be started from low value since it is sufficient enough to drain out the water. Meanwhile, higher matric suction necessified to drain out the water at residual phase.

For the constant value of dry unit weight (sample 7-10 and sample 7-13 investigated by Jotisankasa, 2005), the dry soil sample (Jotisankasa, 2005 sample 7-10) exhibits low void ratio range during drying process rather than wet soil sample. Another evidence such as MP-03 and MP-04 sample investigated by Fernando, 2005, it also shows that the dry soil sample (MP-03) has low void ratio range during drying process than wet soil sample (MP-04). Similar condition for insitu and compacted soil investigated by Azam, 2013 where dry soil sample (in-situ) experiences low void ratio range during drying process than wet sample (compacted).



(a)



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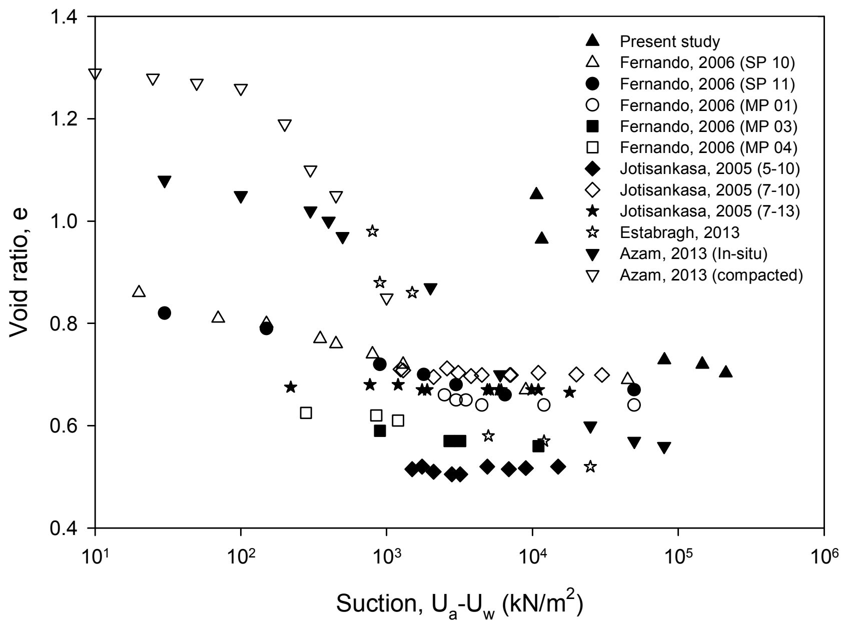

(c)

Figure 7.8. The comparison of drying-wetting test between the result of this research with other researches, (a) water content, w_c vs dry density, γ_d; (b) water content, w_c vs void ratio, e and (c) suction, U_a - U_w vs void ratio, e

In addition to void ratio change, the suction value of dry sample during drying process implies higher value than wet sample. This phenomenon might be caused by:

1. If soil is compacted below optimum water content, total volume of the soil is reduced by the decreasing of water volume. In this condition, residual shrinkage occurs during drying process where it means that total soil volume slightly decreases as the water volume lost.
2. If soil is compacted more than optimum water content, total volume of the soil is enhanced by the increasing of water volume. In this condition, normal shrinkage occurs during drying process where it means that total soil volume lost as exactly water volume lost.
3. Also, if the soil is compacted more than optimum water content, matric suction value range during drying process will also be higher. Reduction of total volume of soil induces high suction range needed to drain the water out from the soil sample. On the other hand, if the soil is compacted below than optimum water content, matric suction value range during drying process will be lower. Enhancement of total volume of soil induces only low suction range needed to drain the water out from the soil sample

7.3.2. Water content

For the constant value of water content (sample 5-10 and sample 7-10 investigated by Jotisankasa, 2005), the high dry unit weight sample implies lower void volume change during drying process than low dry unit weight. It is also shown between MP-01 investigated by Fernando, 2005 and 7-13 sample investigated by Jotisankasa, 2005. Another evidence proven between MP-10 and MP-11 investigated by Fernando, 2005. This phenomenon might be caused by the initial void ratio of high soil density that is less than low soil density upon matric suction up to air entry value (AEV). After AEV point, all curves in different compaction energy have similar trend. It is due to the pore size distribution at saturated pores is equal. Therefore, compaction energy affects the soil water retention curve.

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CHAPTER VIII
SOIL PROPERTIES RELATIONSHIP BETWEEN IN-SITU AND DRYING-WETTING CONDITION AT LABORATORY

8.1. In-situ investigation result

Satrya et al, 2017 correlated soil parameter between in-situ and drying-wetting condition at laboratory. **Table 8.1** shows the result of the in-situ investigation during the season that was from January 2014 to April 2014. In this area, various levels of rain intensity occurred, which started from the middle of the rainy season in January 2014 (151–200 mm) until the peak of the rainy season at the end of February and in the beginning of March 2014 (201–300 mm). Then, the dry season started from the mid-month of March 2014 until the end of the investigation in April 2014. The flow area of the river (m^2) is presented in Table 3 to better describe the river water level due to various rain intensities. A high value of flow area implies an increasing water level, and vice versa.

From **Table 8.1**, it can be concluded that if water level rises, the following soil properties will increase: water content (w_c), saturation degree (S_r), and void ratio (e). Meanwhile, the following soil properties will decrease: dry unit weight (γ_d), undrained cohesion (C_u) and matric suction (U_a-U_w). On the other hand, in terms of water content change during the investigation period, several data showed irregular behavior where it was not consistent with the flow area change. For example, data on January 29, 2014 and February 12, 2014 showed a low water content value, even though the flow area started to increase. This might be due to a technical problem where the soil sampling location had to be moved to another location owing to a shallow landslide occurrence. This particular circumstance might cause irregular behavior in water content change. In addition, in terms of suction value change during the investigation period, several data also showed irregular behavior. Even though the rainy season started in January 2014 and ended in April 2014, data on January 29, 2014 and February 12, 2014 showed high suction value, while a low value was evident in the remaining data until April 2014. This might be induced by the suction value on surface soil that was susceptible to change due to evaporation upon low rainfall intensity; therefore, a high suction value occurred even in the rainy season. In addition, a low suction value during the dry season (middle of March until April 2014) occurred owing to the fine-grained behavior of silty clay soil. It has low permeability value which are 3.71 x 10-6 m/s (upper part) and 1.08 x 10-6 m/s (lower part). Therefore, it still retains water after the peak rainy season (high rainfall intensity) and even though the dry season had already started, the soil still contained lots of water and thus low suction was evident. The moisture retention capacity of the surface soil layer is high and the permeability is low to prevent the high flow into the deeper layer depth (Thielen, A. and Springman, S.M., 2006). Furthermore, during summer the surface soil layer is generally less saturated but water content varied due to rainfall and evaporation (Thielen, A. and Springman, S.M., 2006), therefore suction varied correspondingly.

Table 8.1 Soil Property Results of the In-Situ Investigation during the Season

Soil Property		**In-Situ Investigation**						
Item	Unit	15/01/2014	29/01/2014	12/02/2014	25/02/2014	11/03/2014	29/03/2014	15/4/2014
Rain intensity*	mm	151-200	151-200	151-200	151-200	201-300	201-300	201-300
Dry unit weight, γ_d	kN/m^3	13	14	13	12	12	11	11
Water content, w_c	%	25	27	26	36	35	29	36
Saturation degree, S_r	%	67	82	73	82	78	54	76
Void ratio, e	-	0.99	0.87	0.95	1.15	1.20	1.40	1.26
Undrained cohesion, c_u	kN/m^2	104	59	129	47	35	85	19
Suction, (U_a-U_w)	kN/m^2	40888	24672	143765	34	62	2966	9
Flow area, A	m^2	489	548.24	566.87	702.5	597	355.5	580

*data sourced from http://karangploso.jatim.bmkg.go.id (Indonesian Agency for Meteorological, Climatological and Geophysics)

8.2. Drying–Wetting Behavior in the Laboratory

8.2.1. Drying–Wetting Behavior of Dried–Wetted Soil in Each Cycle

The changes in soil properties during drying-wetting cycles are important and should be analyzed. Based on the previous discussion, the soil is classified as medium expansive characterization, which means that the volume change is susceptible to change due to the presence of water. **Figure 8.1** shows the change of soil dry unit weight due to cyclic drying-wetting. In all cycles, the soil dry unit weight gradually increases during drying process (upward arrow) and gradually decreases during the wetting process (downward arrow). It generally means that the volume of soil increased during wetting process and it decreased during drying process. Based on research conducted by Osipov et al. (1987), if the dry clay is moistened, it induces an entrapped air that increases the internal pressure and total swelling of the soil. Hence, the soil dry unit weight is reduced during wetting process.

Owing to wetting in the 1st cycle, the soil dry unit weight decreased by approximately 22.49 %, from 15.56 kN/m^3 to 12.06 kN/m^3. Similarly, the soil dry unit weight decreased gradually by 21.48 %, from 14.62 kN/m^3 to 11.48 kN/m^3 in the wetting process of the 2nd cycle. However, it was slightly lower in rate of reduction than in 1st cycle. In the 3rd cycle, soil dry unit weight decreased gradually by approximately 17.36 %, from 14.46 kN/m^3 to 11.95 kN/m^3. This means that the rate of reduction was lower than in the 2nd cycle.

However, at the end of wetting process, the soil dry unit weight value decreased from 1st cycle to 2nd cycle, and then it increased in the 3rd cycle. These changes exhibit that the expansive characterization was proven from the 1st cycle to the 2nd cycle, but it was reduced in the 3rd cycle.

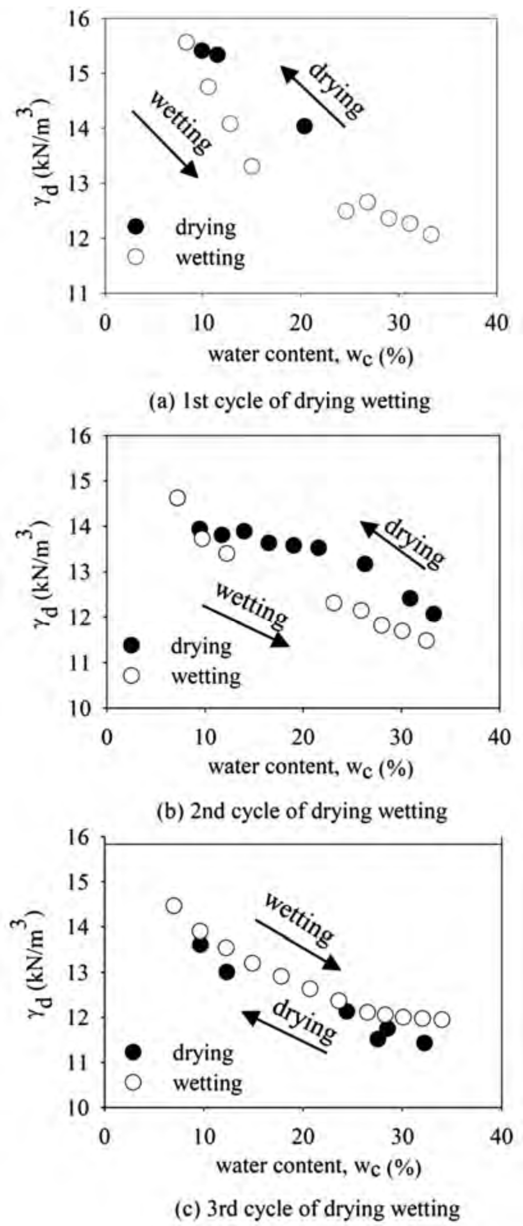


Figure 8.1. Comparison of water content (w_c) and dry unit weight (γ_d) due to cyclic drying-wetting

In terms of cyclic drying-wetting, Al-Homoud et al. (1995) revealed that if the soil is dried until it reaches its initial water content, there will be reduction of swelling intensity due to the cycles. However, if the soil is dried until it reaches its shrinkage limit value, the soil will experience incremental swelling due to the cycles. In this thesis, before conducting the wetting process, the soil had been dried until it reached 7.09 % (air-dry water content) which is far below even the shrinkage limit value, SL 11.73 %. Therefore, as the soil experienced a swelling increment due to the drying–wetting cycle, the soil dry unit weight was gradually reduced.

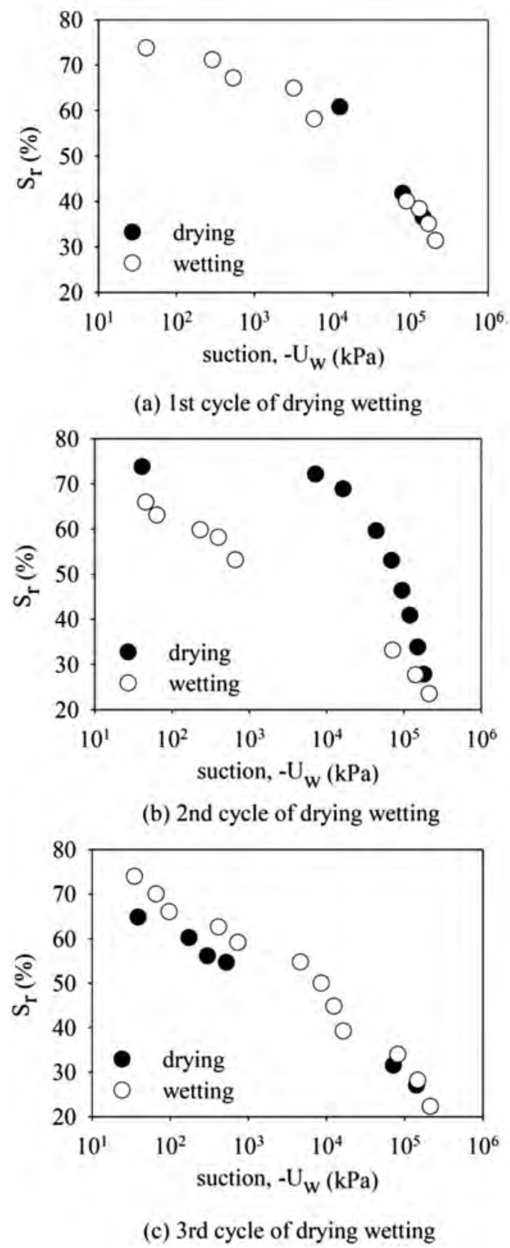


Figure 8.2. Comparison of suction ($-U_w$) and saturation degree (S_r) due to cyclic drying-wetting

From **Figure 8.2**, it can be concluded that hysteresis occurred as a result of the drying and wetting process. Moreover, the hysteresis was slightly to be started in the 1st cycle, it then reached the highest value in the 2nd cycle, and continuously decreased in the 3rd cycle. In term of saturation degree, hysteresis could also be seen from the suction value gaps at certain value of saturation degree particularly at 2^{nd} cycle as shown in **Figure 8.2.b**. Hysteresis theoretically occurred because the soil could not attain the same suction value during the drying and wetting process. Hysteresis of drying–wetting cycles is caused by several factors such as the ink bottle effect (Radcliffe and Simunek, 2010). The ink bottle effect can be seen when the soil does not possess uniform pore size. Therefore, after draining the water through small pores in the drying process, the water could not repeatedly drain into the same pore size at certain suction values during the wetting process. This is due to the difficulty of the water when attempting to reach large pores during the wetting process.

In fact, the peak hysteresis increment in the 2nd cycle was consistent with the change of soil dry unit weight; it also reached the lowest value in 2nd cycle. In addition, the hysteresis reduction in the 3rd cycle induced the change of soil dry unit weight where it started to be increased in the 3rd cycle. From these occurrences, it seems that the expansive characterization has its influence on the soil dry unit weight change as well as on the hysteresis intensity.

8.2.2. Corresponding Soil Properties Between In-Situ Condition and Dried-Wetted Soil

In order to clarify the soil property changes, the results from the in-situ investigation and laboratory tests were compared. The corresponding soil properties among this comparison would be used to determine the number of required drying and wetting cycles for dried-wetted soil to exhibit behavior similar to that of the in-situ condition.

From this comparison, as much as four datasets correspond between in-situ soil and dried-wetted soil properties as it shown in **Table 8.2**. Three in-situ data, which were investigated on January 15, February 25, and March 11, 2014, consecutively correspond with the wetting process at W4, W7 and W8 in 2nd cycle of dried–wetted soil. Meanwhile, one piece of in-situ data, which was investigated on April 15, 2014, corresponds with the drying process at D9 in 3rd cycle of the dried–wetted soil. Dry unit weight (γ_d), void ratio (e), and undrained cohesion (c_u) are the in-situ soil properties that have values identical to the dried-wetted soil. However, there are some soil properties that have different values, such as the water content (w_c), saturation degree (S_r) and matric suction ($-U_w$). This might be due to the difference of absorbability and desorption ability between in-situ and dried-wetted soil. Generally, the in-situ condition has greater absorbability and desorption ability than dried-wetted soil that is modeled in the laboratory. Therefore, these in-situ soil properties were almost always higher than those of the dried-wetted soil.

The results show that the dried–wetted soil requires 2 to 3 cycles to behave like in-situ soil. Or in another meaning, the in-situ soil had already experienced 2 to 3 cycles of drying–wetting since it was initially constructed.

8.2.2.1. Time Ratio

To clarify the rate of soil property changes after being subjected to the drying and wetting process from its initial compacted condition, matter of time is necessary to compare between laboratory and in-situ investigation test. To solve this matter, a time ratio is proposed to synchronize the elapsed time period which the soil was dried and wetted in the laboratory and elapsed time period which the in-situ soil was dried and wetted in the field. This information is then used to trace back the real construction time of river embankment. For this purpose, the corresponding soil properties between in-situ and dried-wetted soil are used to determine the time ratio. In addition, the time difference of in-situ soil at each investigations and time difference of laboratory dried-wetted soil at each step are required. Furthermore, the proposed time ratio (t_r), as shown in Eq. (8.1), is ratio between elapsed time in field (t_{field}) and elapsed time in the laboratory ($t_{laboratory}$), as shown below:

$$t_r = \frac{t_{field}}{t_{laboratory}} \tag{8.1}$$

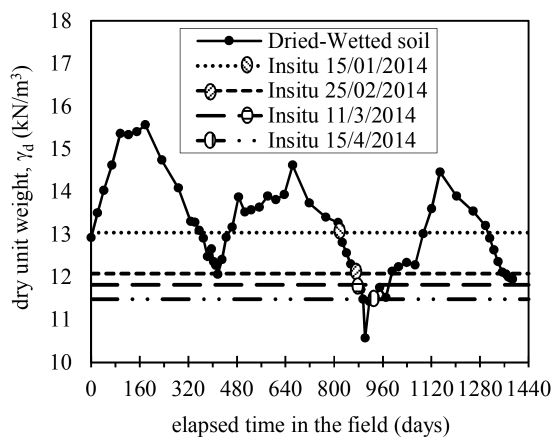
For example, two in-situ soil properties investigated on January 15 and February 25, 2014 which correspond with two laboratory dried-wetted soil properties at W4-2nd cycle and W7-2nd cycle. The in-situ time difference between them (t_{field}) is 41 days, and the laboratory dried-wetted time difference ($t_{laboratory}$) is 9 hours. Hence, the time ratio (t_r) is 109.33. This time ratio value means that if one day is needed as elapsed time in the laboratory, it will be equal to 109.33 days needed as elapsed time in the field (in-situ).

8.2.2.2. Comparison curve

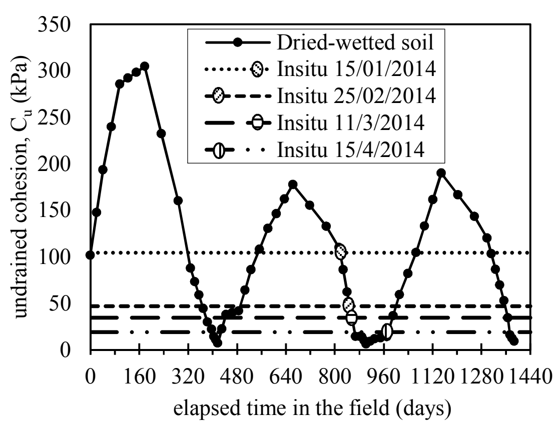
Prior to comparison, within successive cycles, it could be summarized that the dry unit weight (γ_d) and undrained cohesion (c_u) are likely to be constant after experiencing the 3rd cycle of drying wetting process. Based on the soil investigated by Maekawa and Miyakita (1991), the physical and mechanical soil properties value starts to be constant after experiencing 3 cycle of drying wetting process.

Table 8.2. Corresponding Soil Properties between In-Situ and Dried-Wetted Soil Condition

Date of observation		January 15, 2014		February 25, 2014		March 11, 2014		April 15, 2014	
Soil Condition		In-Situ	Dried-wetted	In-Situ	Dried-wetted	In-Situ	Dried-wetted	In-Situ	Dried-wetted
Series Step		-	W4 – 2nd cycle	-	W7 – 2nd cycle	-	W8 – 2nd cycle	-	D9 – 3rd cycle
Soil properties	Unit								
Dry unit weight, γ_d	kN/m^3	13	13	12	12	12	12	11	11
Void ratio, e	-	0.99	0.96	1.15	1.11	1.20	1.20	1.26	1.26
Undrained cohesion, c_u	kN/m^2	104	110	47	38	35	14	19	12
Water content, w_c	%	25	15	36	23	35	28	36	29
Sat. degree, S_r	%	67	41	82	55	78	62	76	62
Matric suction, (U_a-U_w)	kPa	40888	1456	34	663	62	231	9.4	50
Flow area, A	m^2	489	-	702.5	-	597	-	580	-



(a) Dry unit weight comparison



(b) Undrained cohesion comparison

Figure 8.3. Comparison of soil property between dried-wetted soil and in-situ soil conditions

Moreover, in laboratory investigation of this research, the peak properties change occurs in the alteration from 1st cycle into 2nd cycle of drying wetting process. Meanwhile, during field investigation, peak change of soil properties occurs coincidentally with the failure of the embankment.

Among these evidences, it could be assumed that upon drying and wetting process, there are strong relations between laboratory and field data.

To present the time consideration of the soil property changes for both in-situ and laboratory conditions, the time ratio is used. Based on this ratio, the comparison curve is plotted as a function of time (days), which describes elapsed time in the field (in-situ condition). **Figure 8.3** shows the comparison between physical (dry unit weight, γ_d) and mechanical soil property (undrained cohesion, c_u) changes of dried-wetted soil due to the cycles, as well as the in-situ soil properties investigation result. From **Figure 8.3**, it can be seen that four in-situ investigation results were in good agreement with laboratory dried-wetted soil, as discussed in previous chapter. Corresponding data, marked with circles, were the in-situ investigations that were performed on January 15, 2014; February 25, 2014; March 11, 2014; and April 15, 2014. Meanwhile, the in-situ soil property investigations that existed in between those corresponding data points (January 29, 2014; February 12, 2014; and March 29, 2014), did not correspond with the dried-wetted soil properties. This might be caused by a river water fluctuation that was not always in sequence where the water level during investigations even decreased in the rainy season or even increased in the dry season. According to the research investigated by Duong et al. (2014), river water level was monitored during the flooding seasons. However, even still in the same flooding period, the river water level experienced several cycles of rises and falls.

Eventually, the four datasets were selected as corresponding data between dried–wetted soil and in-situ soil. In order to better understand the importance of the time ratio, the relationship between drying–wetting behavior at the laboratory (dried-wetted soil) and at the field (in-situ soil) needs to be analyzed.

8.2.2.3. Relation between Drying–Wetting Behavior at Laboratory Dried-Wetted Soil and In-Situ Soil

Regarding the discussion in previous section, in the 2nd cycle of the wetting process, the lowest value of soil dry unit weight was reached. This condition is in accordance with the in-situ investigation data on March 11, 2014 where there was shallow slip failure occurred in the field, as shown in Figure 2.c. The failure might be caused by the reduction of soil dry unit weight during the 2nd cycle of the wetting process.

In addition, to clarify the rate of soil property change, time ratio is used to trace back the construction time of river embankment. The calculation is based on the total elapsed time of three drying–wetting cycles in the laboratory which needs 12.7 days. Using this total elapsed time in laboratory, the total elapsed time in the field is calculated by using previous calculated time ratio (tr = 109.33). Thus, the calculated total elapsed time duration in the field is ±1388 days.

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CHAPTER IX
RIVER EMBANKMENT STABILITY

9.1. Introduction

Based on previous discussion, soil properties changes under drying-wetting process are related between in-situ and laboratory, it implies that the soil properties start to change since initial condition when the embankment was initially compacted. Furthermore, slope stability could then be determined due to the soil properties change.

Commonly, in the equation of saturated slope stability, various positive pore water pressure, that located below ground water table, decreases the safety factor. However, the negative pore water pressure or matric suction that located above ground water table in fact has beneficial effect to increase the safety factor. This effect is considered in the equation of unsaturated slope stability. However, instead of matric suction, the physical and mechanical soil property change due to change of matric suction has not been discussed by the other researchers, even though this matter might cause the river embankment instability. Therefore, modification of equation of unsaturated slope stability is proposed. A comparison between saturated slope stability; unsaturated slope stability and modified-unsaturated slope stability are herein presented. To determine the safety factor, water table inside the slope upon various river water level should be defined beforehand.

9.2. Water table definition

To draw the free water surface inside the embankment, it is assumed that is through an isotropic earth embankment (Marino, M.A. and Luthin, J.M. 1982), as it could be seen from Figure 9.1. The seepage analysis throughout the time is not discussed here since it is assumed as steady state flow which time difference is constant.

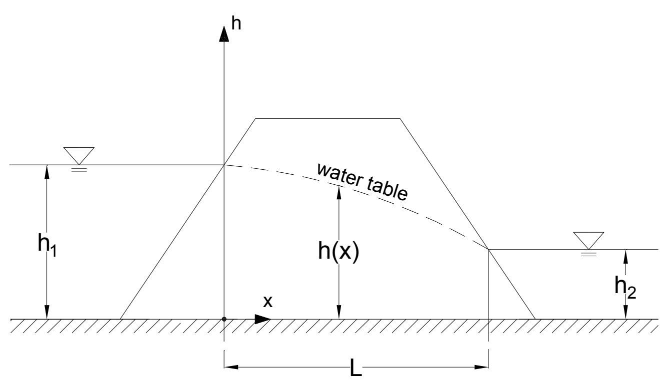


Figure 9.1. Water table through an isotropic earth embankment (Marino, M.A. and Luthin, J.M. 1982)

An equation (9.1) for the one dimensional of free water surface in steady state problem was derived by P. Forchheimer.

$$\frac{\partial^2(h^2)}{\partial x^2} = 0 \quad (9.1)$$

Due to integration:

$$h^2 = a\,x + b \quad (9.2)$$

Where a and b are the constant numbers of the integration, the conditions used to obtain these constant numbers are:

$x = 0,\ h = h_1$

$x = L,\ h = h_2$

$$h_2^2 = a\,L \quad (9.3)$$

$$b = h_1^2 \quad (9.4)$$

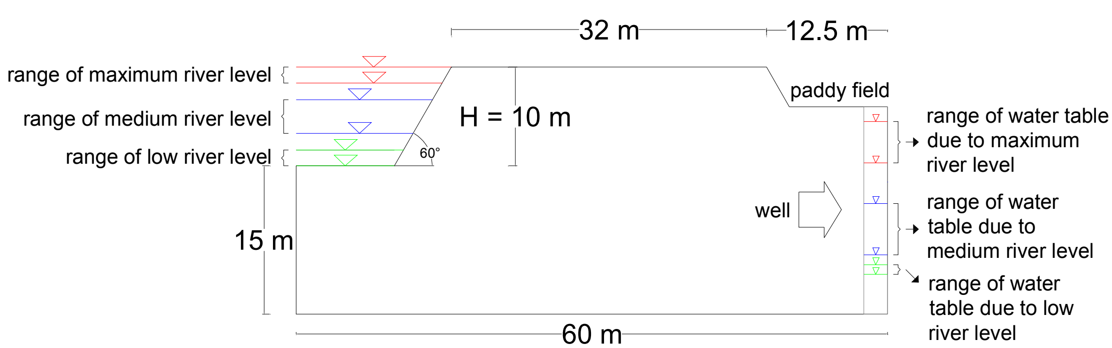
$$a = (1/L)\,(h_2^2 - h_1^2) \quad (9.5)$$

Hence, the equation for free water surface is:

$$h^2(x) = h_1^2 + \left(h_2^2 - h_1^2\right)\left(\frac{x}{L}\right) \quad (9.6)$$

The equation for free water surface is called Dupuit's parabola.

Based on the in-situ observation, the geometry of river embankment, is 10 m in height that having angle of the slope as much as 60°, as it could be seen in **Figure 9.2**. Both of water levels inside the river section and water table inside the well of paddy field are monitored during in-situ investigation. The water level is directly measured, while the water table inside the well is measured by monitoring the height of the water inside the well of paddy field. Range of maximum; medium and low water levels are observed at both of river section and well of paddy field as shown in **Figure 9.2.**



Range of Water Level	Height
Low water level	0 – 0.16 H
Medium water level	0.33 H – 0.67 H
Maximum water level	0.84 H – 1.00 H

Figure 9.2. Geometry and water level of the river embankment

Water table definition of all of the range river water levels are analyzed respectively. According to the equation 9.6, result of seepage analysis in the riverbank could be seen in Figure 9.3.

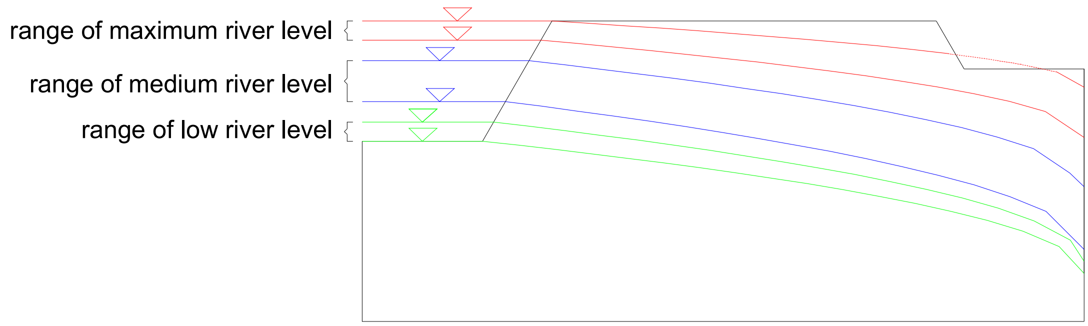


Figure 9.3. Water table definition result

9.3. Slope stability

A comparison between saturated slope stability; unsaturated slope stability and modified-unsaturated slope stability are analyzed to observe the behavior. The common equation of saturated slope stability could be seen below.

$$FS = \frac{FR}{FD} = \frac{c'.\,L\; + [W cos\,\beta + ((P cos\,(\theta - \beta) - U_w).\,L)]\; tan\emptyset'}{W\; sin\,\beta - ((P\,\sin(\theta - \beta)).\,L)}$$

where:

FS = safety factor

FR = Resistance factor

FD = Driving factor

c' = effective cohesion

ϕ' = effective internal angle friction

W = mass of failure plane

U = U_w = uplift force due to pore water pressure

P = hydrostatic-confining force due to water level

θ = angle of the river embankment

β = angle of failure plane

To analyze the finite slope stability, there are assumptions according to the river embankment condition. Planar failure is assumed in this river embankment, Osman and Thorne (1988) indicated that planar riverbank failure pattern often occurs when the bank slopes are steep. According to the riverbank classification (Taylor, 1948; Lohnes and Handy, 1968), steep slope is defined as one with an angle greater than 60 degrees.

Other assumption is the respect of importance of matric suction, Casagli et al (1999) and Rinaldi and Casagli (1999) reveals the importance of matric suction value during change of pore-water pressure value inside riverbank in improving stability. Nardi et a (2012) observed that rises of water level could reduce matric suction inside river embankment. Figure 9.4. shows the forces which act in the river embankment, where S is matric suction (U_a-U_w).

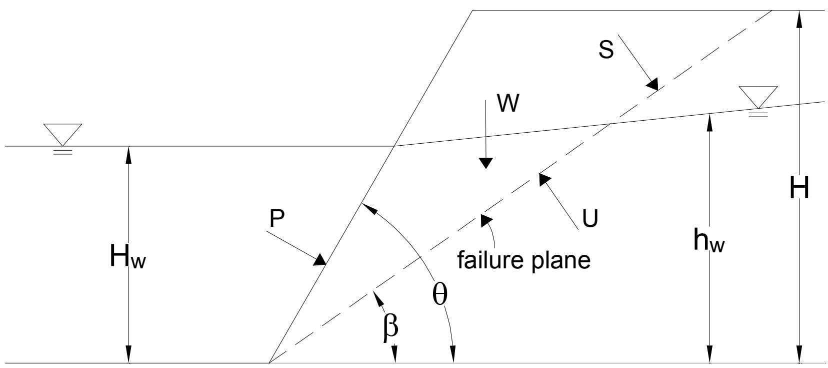


Figure 9.4. Forces on unsaturated slope stability (Chen, C.H. et al, 2017)

Therefore, an equation of safety factor of unsaturated slope stability (Casagli et al., 1999; Rinaldi and Casagli, 1999; Simon et al., 2000; Simon and Thomas, 2002; Chiang et al., 2011) is shown below.

$$FS = \frac{FR}{FD} = \frac{c'.L + S\ .tan\emptyset^{b'} + [W cos\ \beta + ((P cos\ (\theta - \beta) - U))]\ tan\emptyset'}{W\ sin\ \beta - ((P\ \sin(\theta - \beta)).L)} \quad \text{.............................. (9.7)}$$

where:

$\phi^{b'}$ = angle for determining the rate of increase in shear strength due to increasing matric suction

ϕ' = effective friction angle

Uplift and matric suction value is related to the height of free water surface or ground water table which is inside the embankment (h_w). According to the assumption of saturated condition, pore water pressure (U_w) varies hydrostatically with distance above or below groundwater level. Pore-water pressure is negative and decreases linearly above the groundwater table, and conversely below the groundwater table pore-water pressure is positive and increases linearly (Simon et al, 2000). On the other hand, the hydrostatic force is related to the height of the river water level (H_w).

However, due to the vary of pore water pressure value in each section of failure plane, the planar failure surface could not be assumed. Therefore, it is assumed to analyze the finite slope with circular failure surface by method of slices (Das, B.M., 2010). Advantage of this method is the variation of both pore water pressure and normal stress in each slice could be taken into consideration. In addition, shape of failure plane is derived from the theory of Fellenius (1927) and Taylor (1937) in Das, B.M. (2010), they investigated a slope angle (θ) greater than 53°and expressed that the critical circle is always a toe circle. Failure circle is named as a toe circle if it passes through the toe of the slope. Furthermore, the location of the center of the critical toe circle is determined with the aid of Figure 9.5.

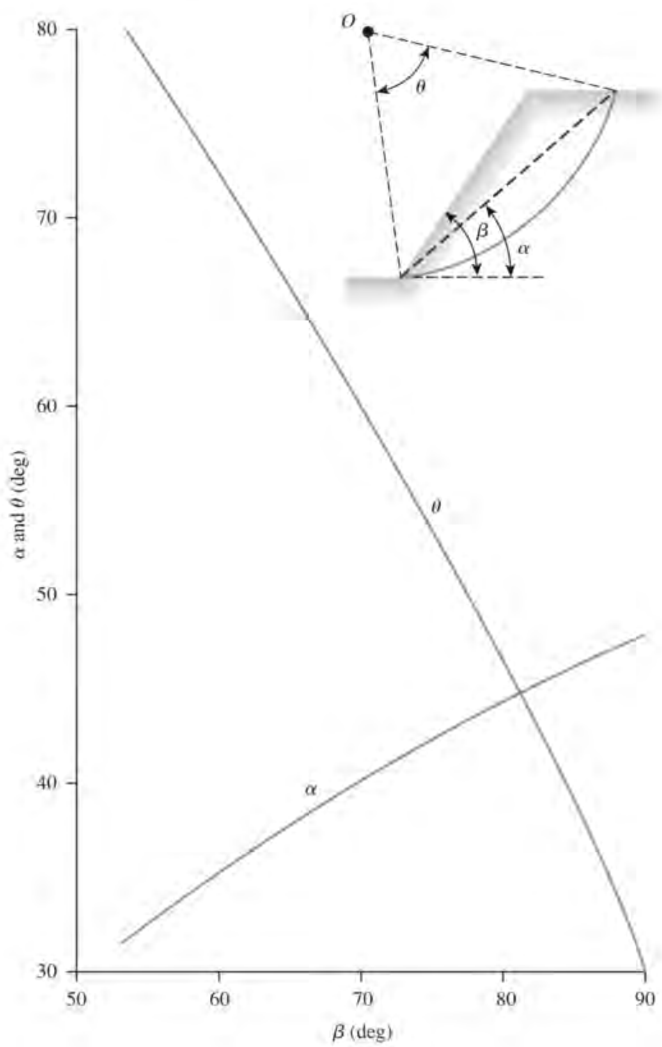


Figure 9.5. Location of the center of critical circles for θ > 53° (Das, B.M., 2010)

In method of slices, soil on failure surface is divided into several vertical slices. Hence, safety factor is based on the stability calculation of all slices, as it could be seen below.

$$FS = \frac{FR}{FD} = \frac{\sum_{i=1}^{n} c'_i . L_i + \left[W_i cos\ \beta_i + \left(\left(P_i cos\ (\theta_i - \beta_i) - U_{w_i}\right) . L_i\right)\right] tan\emptyset'_i}{\sum_{i=1}^{n} W_i\ sin\ \beta_i - ((P_i \sin(\theta_i - \beta_i)) . L_i)} \dots\dots\dots\dots (9.8)$$

$$FS = \frac{FR}{FD} = \frac{\sum_{i=1}^{n} c'_i . L_i + (U_{a_i} - U_{w_i})\ . tan\emptyset^{b\prime}_i + \left[W_i cos\ \beta_i + \left(\left(P_i cos\ (\theta_i - \beta_i) - U_{a_i}\right) . L_i\right)\right] tan\emptyset'_i}{\sum_{i=1}^{n} W_i\ sin\ \beta_i - ((P_i \sin(\theta_i - \beta_i)) . L_i)} (9.9)$$

where:

FS = safety factor

FR = factor of resistance

FD = factor of driving

c' = drained cohesion

L = length of failure plane

Equation 9.8., which shows the saturated slope stability, is based on Mohr-Coulomb (Terzaghi, 1942). In addition, equation 9.9 which shows the unsaturated slope stability, is based on the combined theory of Mohr-Coulomb and extended Mohr-Coulomb failure principle (Fredlund and Rahardjo, 1993).

A sensitivity analysis is performed to observe the most influential properties among physical and mechanical soil properties on safety factor of slope stability.

9.2. Sensitivity analysis

By using statistical consideration, the sensitivity analysis is performed for cohesion, density and suction as soil properties that aimed to find out the property which has the most influence on safety factor of unsaturated slope stability. Steps for this analysis are identifying the data distribution of each parameter; creating the random variable and obtaining the influential parameter. The result of this analysis is presented on **Figure 9.6.**

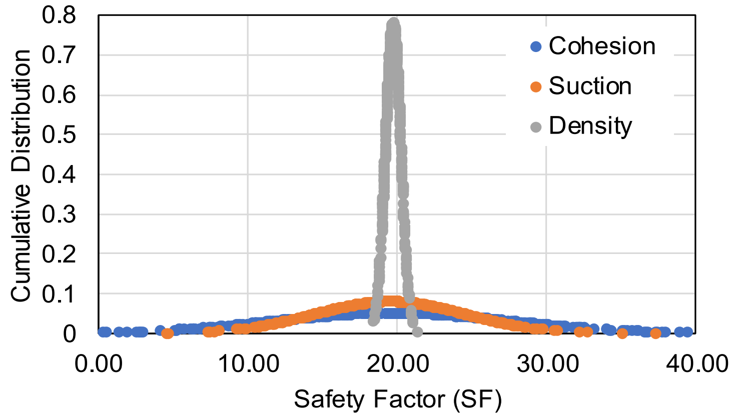


Figure 9.6. Result of sensitivity analysis

From **Figure 9.6.**, it shows that the less influential parameter on safety factor is density, on the other hand the most influential parameter is cohesion.

Therefore, it is proposed to consider the cohesion as soil property value that varies due to matric suction change. In slicing plane, cohesion in each slice is changed due to various matric suction which is according to the height of ground water table (h_w).

Below is the result of cohesion value change, derived from laboratory test, along the drying-wetting test on the 1st, 2nd and 3rd cycle.

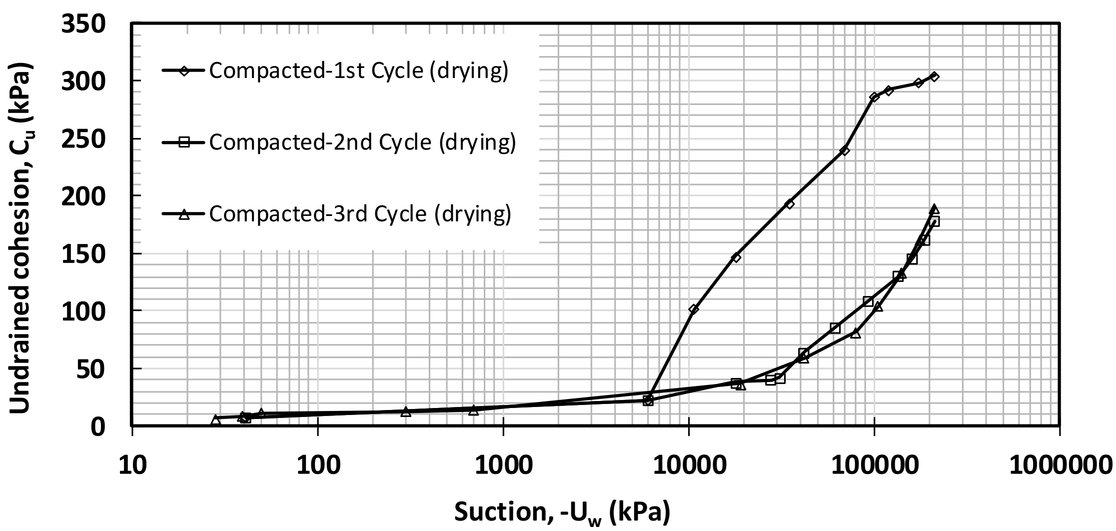


Figure 9.7. Relationship between suction (U_a -U_w) and undrained cohesion (c_u) along the drying test at 1st, 2nd and 3rd cycle

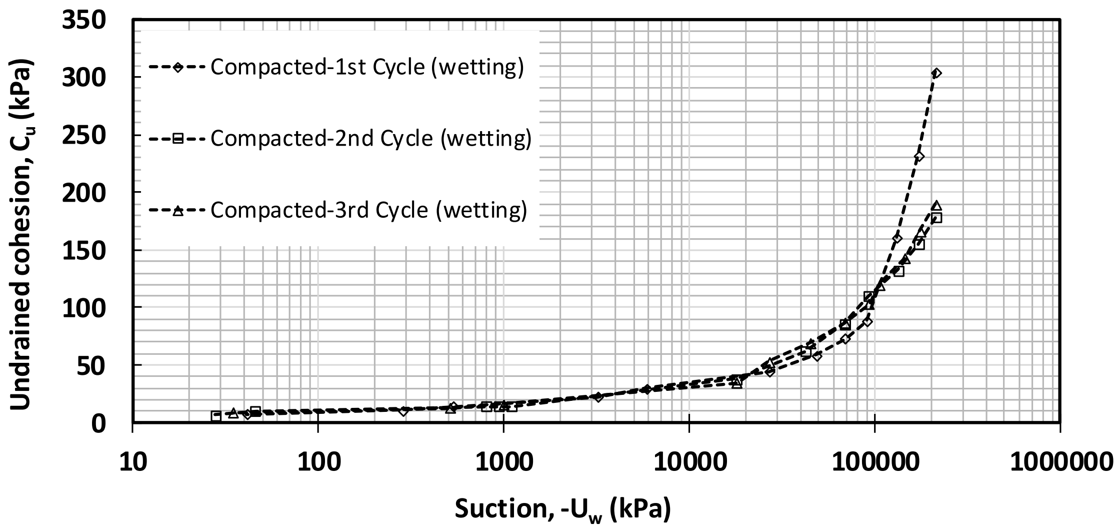


Figure 9.8. Relationship between suction (U_a -U_w) and undrained cohesion (c_u) along the wetting test at 1^{st} cycle, 2^{nd} and 3^{rd} cycle

The undrained cohesion, c'_i in each slice during 1^{st}, 2^{nd} and 3^{rd} cycle could be observed according to these relationships. Hence the cohesion change due to cycles is considered in the equation of unsaturated slope stability (equation 9.9).

Example of method of slices could be seen in **Figure 9.9** according to the seepage result during the medium river water level, the failure plane is divided into 15 slices. Each of slice has specific pore water pressure and normal stress values.

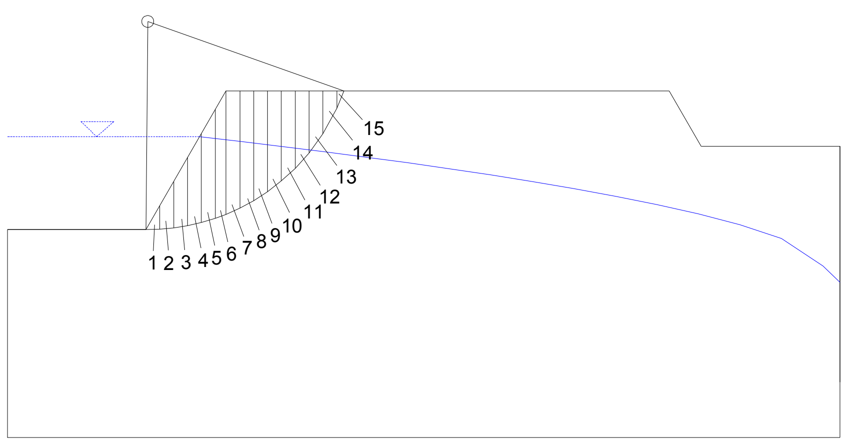


Figure 9.9. Method of slice during medium water level

The safety factor of all range of river water level in all cycles could be seen in **Table 9.1**. below. Safety factors are calculated for cyclic fluctuation of maximum, medium and low water levels by using equation of saturated slope stability and equation of unsaturated slope stability (with and without cohesion change).

Table 9.1. Safety factor analysis regarding saturated and unsaturated slope stability (with and without cohesion change) due to cyclic fluctuation of water levels.

Water level - Condition	1st drying	1st wetting	2nd drying	2nd wetting	3rd drying	3rd wetting
Maximum water level-saturated	0.22	0.22	0.22	0.22	0.22	0.22
Maximum water level-unsaturated (without cohesion change)	0.22	0.22	0.22	0.22	0.22	0.22
Maximum water level-modified unsaturated (with cohesion change)	0.50	0.48	0.46	0.42	0.44	0.44
Medium water level-saturated	0.18	0.18	0.18	0.18	0.18	0.18
Medium water level-unsaturated (without cohesion change)	0.18	0.18	0.18	0.18	0.18	0.18
Medium water level-modified unsaturated (with cohesion change)	0.42	0.40	0.39	0.35	0.36	0.37
Low water level-saturated	0.17	0.17	0.17	0.17	0.17	0.17
Low water level-unsaturated (without cohesion change)	0.18	0.18	0.18	0.18	0.18	0.18
Low water level-modified unsaturated (with cohesion change)	0.39	0.38	0.37	0.34	0.35	0.36

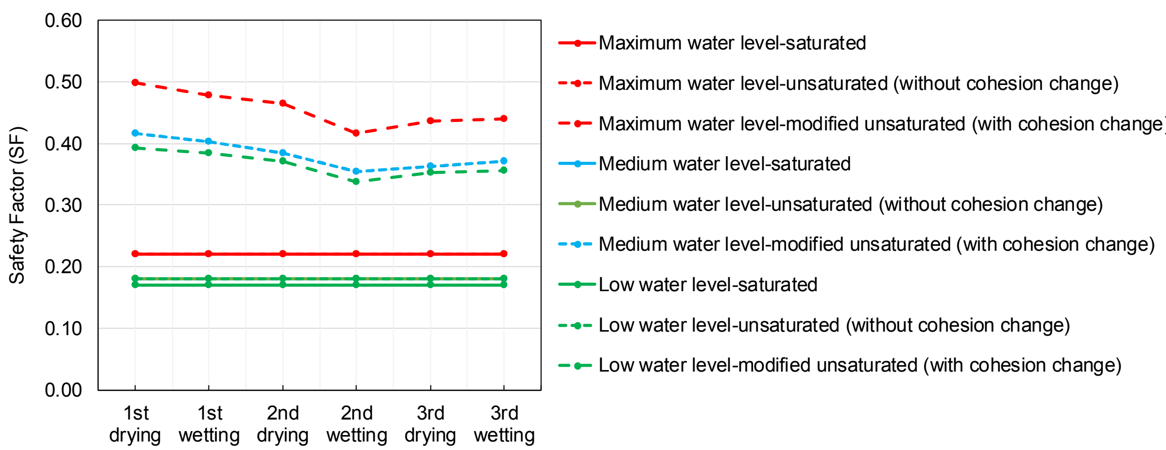


Figure 9.10. Curve of safety factor regarding saturated, unsaturated and modified-unsaturated slope stability

According to the **Table 9.1**., safety factor varies due to water level where it increases when the water rising up, while it decreases when the water lowering down. It shows that the hydrostatic force increases the stability.

Due to consideration of negative pore water pressure above groundwater level, safety factor of unsaturated slope stability is greater than saturated slope stability. However, safety factor of the unsaturated slope stability (without cohesion change) at 1st, 2nd and 3rd cycle is higher than unsaturated slope stability (with cohesion change) since cohesion change due to suction is incorporated. In addition, the result shows that safety factor decreases to nearly constant after 2nd cycle of drying and wetting, it is due to the cohesion change along the cycles which is also nearly constant.

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CHAPTER X
SUMMARY

10.1. Introduction

This research is aimed to investigate the relationship of soil properties changes between in-situ and laboratory investigations due to drying-wetting cycles and to investigate the influence of soil properties changes due to cyclic drying and wetting processes on slope stability.

10.2. Data analysis

10.2.1. Relevance to site condition

Both dry density and undrained cohesion of in-situ investigation were changed due to drying and wetting process. Those soil properties also changed for fresh Proctor compacted and in-situ initial conditions during drying and wetting tests. In term of cyclic conditions, those soil properties highly decreased from 1^{st} to 2^{nd} cycle, then slightly decreased from 2^{nd} to 3^{rd} cycle. The hysteresis of those soil properties from 1^{st} to 2^{nd} cycle is greater than those from 2^{nd} to 3^{rd} cycle.

10.2.2. Contribution to existing knowledge

Cyclic drying and wetting for both fresh Proctor-compacted and in-situ initial conditions showed the high soil properties change from 1^{st} to 2^{nd} cycle and less soil properties change from 2^{nd} to 3^{rd} cycle. In in-situ initial condition, the change of dry density highly decreased from 16.9 kN/m^3 (1^{st} cycle) to 14.8 kN/m^3, but it slightly decreased to 14.7 kN/m^3 at 3^{rd} cycle. Undrained cohesion also highly decreased from 250 kN/m^2 (1^{st} cycle) to 144 kN/m^2, but it slightly decreased to 100 kN/m^2 at 3^{rd} cycle.

The hysteresis derived from Soil Water Retention Curve (SWRC) showed that the hysteresis of those soil properties from 1^{st} to 2^{nd} cycle is greater than those from 2^{nd} to 3^{rd} cycle.

10.2.3. Limitations and recommendations for future work

A limitation of this work is that the soil shear strength was obtained from unconfined compression test that has no lateral pressure when shearing the sample. It is recommended for carrying out the triaxial compression test to get the cohesion as well as the internal angle friction with and without applying suction pressure.

10.3. Soil parameter correlation analysis

10.3.1. Relevance to site condition

Compared to those obtained from previous studies; during drying and wetting process, change of matric suction induced by change of water content; influences the soil shear strength. Soil with low density seems to have higher change of matric suction and shear strength during drying and wetting.

The river embankment soil had been built from riverbed material having low density, hence the physical and mechanical soil properties is greatly changing due to drying and wetting. Data analysis showed that in-situ initial condition had higher change of soil properties than fresh Proctor compacted condition having the higher density.

10.3.2. Contribution to existing knowledge

Loose soil experiences higher change of soil properties than dense soil, as soil density is one of the reasons that might cause the change of physical and mechanical soil properties during drying and wetting.

10.4. Soil Properties Relationship between In-Situ and Drying-Wetting Condition at Laboratory

10.4.1. Relevance to site condition

Soil properties changes of in-situ investigation are strongly related to those of fresh Proctor compacted on 2nd and 3rd cycle of drying and wetting.

10.4.2. Contribution to existing knowledge

Regarding the result of in-situ and laboratory investigations, it showed that soil properties changes of in-situ investigation are strongly related to those of fresh Proctor compacted on 2nd and 3rd cycle of drying and wetting. It is thought to be due that in-situ soil properties changes can be simulated using laboratory investigations.

10.5. River embankment stability

10.5.1. Relevance to site condition

Safety factor of unsaturated slope stability with cohesion change consideration is decreased from 1st cycle to 2nd cycle, then it is nearly constant from 2nd to 3rd cycle of drying and wetting. This analysis is somewhat more accurate rather than using common saturated slope stability.

10.5.2. Contribution to existing knowledge

Considering the negative pore water pressure above groundwater level and cohesion change due to drying and wetting process are important to determine the safety factor of unsaturated slope stability. River embankment stability is somewhat more accurate if considering the cohesion change.

10.6. Future Works

Soil properties change during drying-wetting cycles can be used to predict the soil properties and the more accurate slope stability in the future.

It is better to investigate the in-situ soil properties on a long period of time observation and shorter time interval for better continuous data. It is recommended to carry out the unsaturated triaxial compression test to get the soil shear strength at a certain matric suction.

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