Engineering Properties of Soils Recovered from Disaster Waste

2015

Mohammed Nasir Uddin

ABSTRACT

The 2011 earthquake off the Pacific coast of Tohoku created several serious geo-environmental problems including the generation of huge amount of disaster debris and tsunami deposits in Japan**.** As a part of disaster debris management, several treatment processes were applied and at the end, a significant amount of soil fractions were recovered that contained wood fractions. From geotechnical point of view, it was expected that wood fractions were remained in the recovered soil, and it`s associated decomposition behavior, might affect the engineering properties of the recovered soil. Therefore, this study was undertaken to investigate the engineering properties of recovered soil, considering wood fractions inclusion and the decomposition behavior of the wood fractions. The study especially aimed at determining the maximum acceptable ratio of wood fractions in recovered soil for geotechnical utilizations. Besides, the objectives of this study were: (1) to understand the effects of wood fractions on the engineering properties of recovered soil; and (2) to evaluate the effects of simulated decomposition of wood fractions on the strength and compressibility parameters of recovered soil.

In order to provide valuable information on engineering properties of recovered soil for geotechnical utilizations, the effects of wood fractions inclusion on the engineering properties of recovered soil were investigated. A series of Standard compaction tests, Unconfined compression tests, California bearing ratio (CBR) tests and Compressibility tests were conducted with simulated samples. Moreover, a simple linear regression model was developed to explain the variations of output variable CBR value influenced by the input variable void ratio. The standard compaction test results showed that maximum dry density was decreased but optimum moisture contents were increased with increased wood fractions inclusion. The unconfined compressive strength and deformation modulus of samples were decreased with wood fractions inclusion obtained by the unconfined compression test. None of the samples used including control soil (without wood fractions) met the minimum requirements of the unconfined compressive strength for embankment construction according to Japanese geotechnical guidelines. However, the CBR test results indicate that all samples might be acceptable for pavement design as subgrade materials according to JIS standard. While CBR value was decreased with increased wood fractions inclusion. Moreover, a simple linear regression model confirmed that void ratio inversely and significantly affects the CBR value of the recovered soil. The model also indicated that with 1 unit increase in void ratio, the CBR value of the recovered soil would significantly decrease by 20.396 units. In addition, the compressibility test results showed that compressibility parameters, particularly compression index, compression ratio and settlement were increased with increased wood fractions inclusion. The

reduction of volume was possible reason for the compressibility of the recovered soil with increased wood fractions inclusion. However, weaker interlocking between soil particles was the influential factor of reducing strength with wood fractions inclusion.

The effects of simulated decomposition of wood fractions on the unconfined compressive strength and compressibility parameters of recovered soil were also evaluated. Simulated samples were investigated by a series of unconfined compression tests and compressibility tests. Unconfined compression tests indicated that samples containing more wood fractions showed more sensitivity to simulated decomposition issue compared to samples containing less wood fractions. It is also observed that compressibility of the samples was increased with samples containing more wood fractions compared to sample contained less wood fractions. The most important reason for the change in compressibility is related to volume change due to simulated decomposition of wood fractions. Removal of wood fractions, especially for samples containing more wood fractions, with constant soil and total volume resulted in larger volume change compared to those in samples containing less wood fractions. Thus, the change in the volume contributed to a relatively higher change in the compressibility parameters of samples containing more wood fractions compared to samples containing less wood fractions.

Finally, it was an important task to find a maximum acceptable ratio of wood fractions in recovered soil for geotechnical utilizations. It was found that maximum acceptable ratio of wood fractions might be between 6W and 8W samples for geotechnical utilizations, as the 8W sample showed loose stated, verified by the e_{max} of the soil fractions (0.94). The simulated decomposition of 50SD for the 6W basic sample might be applicable because of its 0.79 void ratio, which is lower than the e_{max} of the soil fractions.

ACKNOWLEDGEMENTS

The author expressed his heartiest gratefulness to Almighty Allah (God) for his farthest blessing for the successful completion of his dissertation.

The author never forgets to express his heartfelt indebtedness, sincere appreciation and best regards to his research supervisor Dr. Takeshi Katsumi, Professor of Graduate School of Global Environmental Studies, Kyoto University for his distinguishable scholastic guidance, valuable suggestions, constructive instructions, criticism, motivation and continuous inspiration throughout the research work and in the preparation of this dissertation.

The author conveys is deepest thankfulness to Dr. Toru Inui, Associate Professor of Graduate School of Global Environmental Studies, Kyoto University for his worthy guidance, creative suggestions, keen ideas and kind cooperation for developing in this research.

The author expresses his gratitude to Dr Masaki Takaoka, Professor of Graduate School of Global Environmental Studies, Kyoto University, for his valuable suggestions and comments on the contents to improve this dissertation.

The author finds it a great pleasure in expressing his heartfelt gratitude to Dr. Atsushi Takai, Assistant Professor of Graduate School of Global Environmental Studies, Kyoto University for his suggestions, criticism, constant inspiration and facilitates to set up experimental conduction.

The author is also grateful to Dr. Giancarlo Flores, Associate Professor of Graduate School of Engineering, Kyoto University and Dr Surendra Tamrakar, former teaching staff of Graduate School of Engineering, Kyoto University for their constructive kind academic support, comments, suggestions and cordial cooperation in conducting this research.

The author also would like to express his appreciations to Yasumoto-san, Laboratory Assistant, Environmental Infrastructure Engineering Laboratory at Kyoto University for her continuous cooperation.

Special thanks to Dr Naka-san, Dr Lan-san, Dr Harris-san, Dr Tang-san, Dr Mae-san, Mr Mogami-san, Mr Morita-san, Mrs.Yamane-san, Mr Mo-san, Mr. Nakamura-san, Mrs Wang san, Mr Bobea san, Mr Oashima san, Mr Sano san, Mr Ogawa san, Mr Lincon san, Mr. Kimura san,Mr Tamura san, Mr kihara-san, Mrs, Miyoki-san, Mr Mikata-san, Mr Nakazawa-san, Mr sato-san, Mr Lee san, Mrs Van san for their kind cooperation, inspirations and continuous helping both in academic and Japanese culture throughout my living tenure in Kyoto.

The author wishes to thanks all Bangladeshi people who encouraged him to move forward with this research work. Among them, the author would like to convey his gratitude to Prof. Dr Hoque, Dr Mustafiz, Dr Suman, Dr Ataharul, Mr Arif and Dr Bellal for their kind academic assistance. The author is highly acknowledged to Professor Dr Momen, Professor Dr Sarker and Professor Dr Jahangir for their continuous encouragement.

Notably, Author would like to express his heartiest gratitude to his family more specifically to his wife Mrs. Nahid Anjuman Nijhoom, lovely angels Azmayeen Muhtasim Norit and Nayyara Nasir Nitra, parents and relatives living in Bangladesh who supported and encouraged him through all his study in Japan. The author expresses his immense gratefulness to his parents in law especially mother in law whose support was invaluable to work smoothly at laboratory for improving this dissertation.

Last but not least, financial support from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is also gratefully acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 General Remarks

The consequences of natural disasters for wider spectrum of the society including political, social, economic and environmental aspects tend to increase the vulnerability of a nation (Huppert and Sparks 2006). Of the many kinds of natural disasters that endanger the nature and society, earthquake and tsunami are particularly appear to be one of the most devastating events giving rise to different socio-economic and environmental crises (Bachev 2014). These crises are important for the concurrent research arena particularly in geo-environmental field. Of note, Japan was severely affected by the 2011 earthquake off the Pacific coast of Tohoku at 14:46 on March 11, 2011 with 9.03 (Mw) magnitudes (Fig. 1.1). This earthquake triggered a tsunami that reached up to 40.5 m height and travelled up to 10 km inland. It was the strongest earthquake ever recorded in Japan and one of the five most powerful in the world (Katsumi et al. 2014; Kamiyama and Iijima 2012).

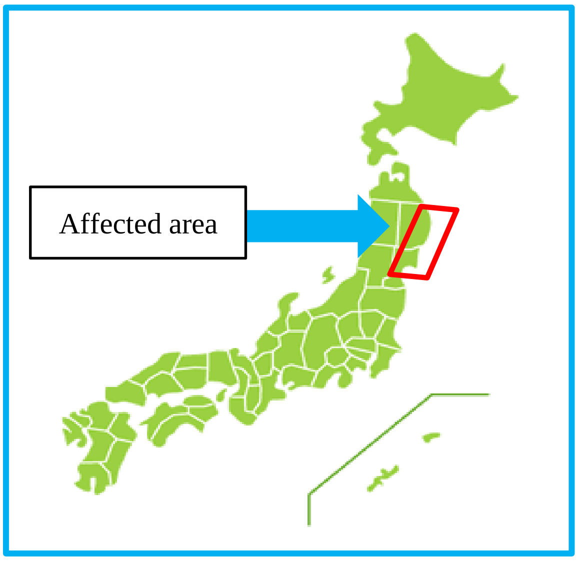


Fig. 1.1 Map showing the affected area

The earthquake caused serious geo-environmental problems including generations of huge amount of mixed debris and tsunami deposits (estimated approximately 20 million tons disaster debris and 10 million tons of tsunami deposits), contamination with salt, land subsidence and geo-environmental contaminations with nuclides explored by Fukushima Daiichi Nuclear Plant (Katsumi et al. 2014; Yamane et al. 2013; Inui et al. 2012; MOE 2011). Photo 1.1 and 1.2 show disaster debris and tsunami deposits in the affected sites at temporary stockyards.

Photo 1.1 Disaster debris

Photo 1.2 Tsunami deposits

Disaster debris encompassed a wide variety of huge materials including wood, paper, textile, and plastic, concrete, metal, tatami, and soil which stood in the way of recovery work in the affected areas because of the limited number of disposal sites, inadequate funds and management activities (Inui et al. 2012). The consequence of natural disaster that led to Japanese government to take initiatives for managing disaster debris generated while traditionally Japan bringing all wastes under treatment process for different utilizations is shown in Table 1.1.

Table 1.1 Comparison of waste treatment practices (%) (ADB 2011)

Country (Year)	% of untreated waste	% of treated waste
Bangladesh (2001)	88	12
China (2006)	48	52
European Union	0	100
Hong Kong	0	100
India (2001)	60	40
Japan (2005)	0	100
Nepal (2001)	70	30
Singapore (2007)	0	100
United States (2007)	0	100

Henceforth, Japanese Ministry of the Environment (MOE) prepared a guideline in 2011 for the "Removal of Damaged Houses and Structures after the Tohoku-Pacific Ocean Earthquake and the Guidelines for the Disposal of Damaged Houses and Other Structures". With this guideline, several treatments processes (Fig.1.2 in brief) were proposed and conducted accordingly (Katsumi et al. 2014; Yamane et al. 2013; Takai at al. 2013; Morita et al. 2012; Inui et al. 2012**)** to reduce the volume of debris and to promote reuse and recovery work.

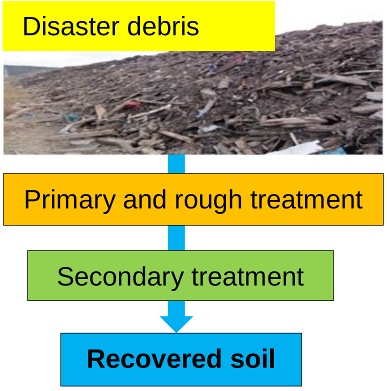


Fig. 1.2 Treatment process in brief

Photo 1.3 Recovered soil

Separation of waste matters from mixed waste were made by crushing (facilitate sieving or reduce size of bulk waste) as well as sieving (reduce the waste size for further treatment processes, either suitable for reuse or disposal). While the basic idea of the separation or treatment is to separate the all fractions from the mixed waste. At the end of the treatment processes, a significant amount of fine fractions hereafter called recovered soil (Photo 1.3) was remained which was expected to be reused as geo-materials (MOE 2011; Inui et al. 2012,; Takai et al. 2013). This recovered soil was mostly mixed with soil and wood fractions while a very low amount of other fractions like plastic, pieces of glass, papers etc. were also remained (Morita et al. 2012). Notably, wood fraction, which is also well known as organic fraction, remained in the recovered soil that could not be separated like other fractions, causing the soil weak (Huat et al. 2009). Moreover, wood fractions would be decomposed under certain conditions (optimum temperature, moisture, presence of micro-organisms etc.) because of its organic behavior (O'Kelly and Pichan 2013). Nevertheless, presence of wood fractions in the recovered soil might affect engineering properties of soil (Katsumi 2012; Huat et al. 2009; Rabbe and Rafizul 2012; Puppala et al. 2007; Haan and Kruse 2006; Song et al. 2003; Thiyyakkandi and Annex 2011).

As wood fractions are remaining in the recovered soil, there are growing concerns about settlement of the recovered soil due to both wood fractions inclusions and decomposition phenomena when this soil is used as material of the soil structure (Fig. 1.3).

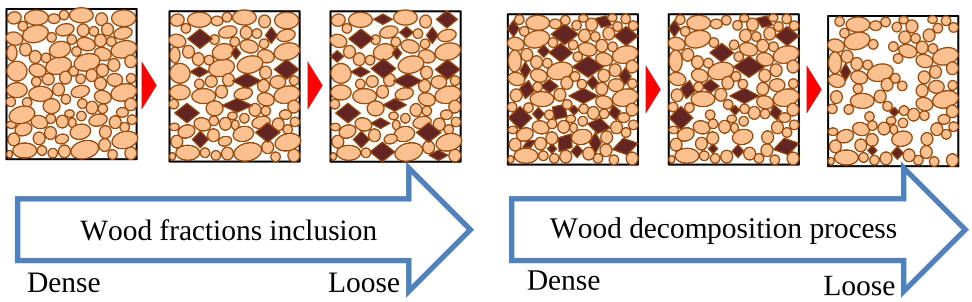


Fig.1.3 Schematic chart of wood fractions inclusion and decomposition process

There is extremely limited research focused on determining the effects of wood fractions on the engineering properties of soil. While Morita et al. (2012) and Yamane et al. (2013) studied the effects of waste contents on the physical properties of recovered soil. They concluded that combustible contents less than 7% in the recovered soil could be properly compacted to be used as ground materials while higher amount of combustible matter led less maximum dry density of the recovered soil. Moreover, there is no quantitative study in the literature about decompositions of wood fractions in constructed structures like embankment. There is a failing concern that majority of the studies were limited to investigating on or above the surface of forest soils, not incorporated into the soil (Rayner and Boddy 1988). Ghozla et al. (1991) conducted a study and found that the rate of disappearance of buried wood is 15%/year while about 60-70% volume of original volume of wood was lost just after 5 years due to consumptions and compressions. The research indicated loss of dry mass of wood was less than 40% and 20% dry mass remained after 10 years and 20 years respectively.

Other studies examined the effects of organic contents on the geotechnical properties of soil (Zhang and O'Kelly 2013; Huat et al. 2009; Kazemian et al. 2011; Edil 1997; Puppala et al. 2007; Inui et al. 2012; Rabbe and Rafizul 2012; Katsumi 2012; Song et al. 2003; Thiyyakkandi and Annex 2011). However, organic and peat soils were treated as problematic soils because of their high compressibility, very low shear strength (Rafizul et al. 2010; Huat et al. 2009).With an increase in organic content, the natural water content, liquid limit, compression index and void ratio are increased and the specific gravity and bulk density are decreased. Besides, inclusions of organic fractions in the soil greatly affect the volume change owing to pressure applied. Other studies concluded that bearing capacity was affected by the high moisture content and the presence of woody debris in the soil (Islam and Hashim 2008a and 2008b). There is a possibility that organic constituents upon further humidification change the engineering properties of peat soil, such as, strength, compressibility, and hydraulic conductivity (Huat 2004). Therefore, the decomposition of organic fractions remains as an important issue for further investigation along with its effect on the properties of soil while decomposition involve: i) loss of organic matter, either in gas or in solution;

ii) disappearance of physical structure; iii) change in chemical state of organic matter (Huat et al. 2009; Kazemian et al. 2011). There is a general consensus in geotechnical literature that the compressibility of peat reduces with increasing degree of decomposition (Hobbs 1986; Price et al. 2005). Therefore, organic soil has a low initial elasticity, large deformation and big changes of physical and engineering properties (Meyer and Kozłowski 2008). However, based on review of literature mentioned above, further research is necessary because of failing to investigate the wood fractions affecting the engineering properties of recovered soil. Thus, this research intends to fill that research gap. The overall goal of this research was to determine the maximum acceptable ratio of wood fractions in recovered soil for geotechnical utilization.

1.2 Objectives and scopes of this study

The previous studies did not investigate about the wood fractions affecting engineering properties of soil before using this soil in geotechnical utilizations (Morita et al. 2012; Yamane et al. 2013). Therefore, this research mainly aimed at determining the maximum acceptable ratio of wood fractions in the recovered soil for geotechnical utilizations. Besides, the specific objectives of this study were; (1) to understand the effects of wood fraction on the engineering properties of the recovered soil; and (2) to evaluate the effects of simulated decomposition of wood fractions on the strength and compressibility parameters of recovered soil.

1.3 Dissertation outline

The dissertation consists of six chapters, which are organized in a logical order in the Figure 1.4. Chapter 1 presents the justification along with objectives and outline of the research. Chapter 2 deals with overview of the great east Japan earthquake and tsunami 2011, literature review on organic matters and other wastes utilizations, properties of decomposed granite soil and wood fractions and previous research studies about the waste mixed soil. Chapter 3 discusses the effects of wood fractions content on the engineering properties of recovered soil while different proportions (0%, 2%, 4%, 6%, 8%, 10% and 12%) of wood fraction inclusions in the soil were considered simulated samples and used for experimental conduction. Chapter 4 describes the effects of simulated decomposition of wood fractions on the strength and compressibility parameters of recovered soil. While this simulated decomposition phenomenon includes only the reduction of wood fractions at different percentages. Chapter 5 summarizes the results obtained from the different experimental works and explained the practical implications of those results for the geotechnical utilizations. Chapter 6 concludes the results of the study and includes suggestions for further research topics in this particular area.

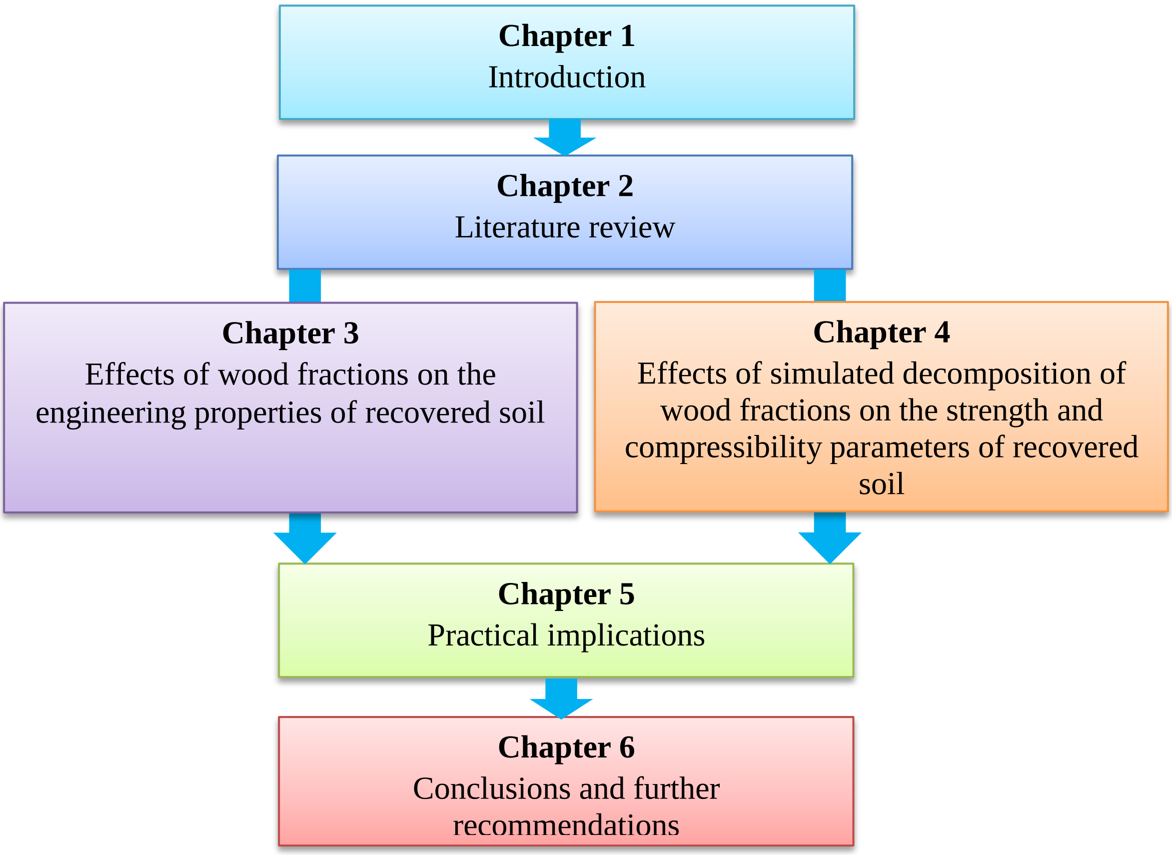


Fig. 1.4 Outline of the dissertation

1.4 Originality of the research

This research addresses an important research question which endeavors to find out the effects of wood fractions inclusion and it`s simulated decomposition on the engineering properties of recovered soil, and has not been addressed in previous studies. The previous studies focused on mixed soil, particularly for physical, mechanical, chemical and geotechnical properties of waste mixed soil. This research aimed at understanding engineering properties of soils recovered from disaster waste. Moreover, it was mainly intended to determine maximum acceptable ratio of wood fractions in the recovered soil for geotechnical utilizations which might be economical and environmental friendly. As of today, most of the researchers focused on geotechnical properties of municipal solid waste mixed soil, plastic chips mixed soil, tire chips mixed soil, jute fiber mixed soil, coir fiber mixed soil (Babu and Choukesly 2011; Singh and Vinot, 2011; Dutta and Sarda, 2007; Subbarao et al. 2011; Singh and Mittal, 2014; Choudhury et al. 2010) but very limited research focused on wood chips mixed soil (Gasparaovic et al. 2010; Ghozla et al. 1991). Therefore, this research highlighted on recovered soil considering two phenomena, such as, wood fractions inclusion and simulated decomposition. This study also explained the mechanism of wood-soil interactions. This study presented several results, especially strength and compressibility parameters of recovered soil based on the various experimental works conducted**.** Until today, there is no available research that deals with the effects of wood decompositions on the engineering properties of recovered soil. Simulated decomposition of wood fraction was also adopted to evaluate the effects of simulated decomposition of wood fraction on the soil properties especially strength and compressibility parameters of the recovered soil. Thus, this research will hopefully be a good contribution to the scientific research as we expect to discover some parameters which might be applicable in the future case.

CHAPTER 2: LITERATURE REVIEW

2.1 General Remarks

The proper utilizations of resources is a vital issue for every country especially for developed countries like Japan that have limited land area along with high populations. At the same time, it is very difficult task to dispose the huge generated waste due to shortage of disposal sites. Therefore, the concept of 3-Rs is given greater emphasise to reduce the volume of waste to be managed effectively (Chau 2013). Economic as well as environmental issue is also need to be prioritized. Thus, the generation of waste is increasing day by day in the world and is urgently necessary to treat those waste by following proper techniques to keep evnironment sound. It is important to remove or treat the waste, generated by disaster, such as, earthquake with an environmentally and socially acceptable manner for their sustainable management (Yoon and Jo 2002). Immediate removal of disaster waste is mainly require to protect the environment from air pollutions, soil and ground water contaminations, keeps the emissions of gas especially greenhouse gases to a minimum, recovery works, even safe the lives etc.

Waste mixed soil is an important material for reconstrcutions work while understanding the effects of wood fractions on the engineering properties of recovered soil is also important for geotechnical utilizations. This research investigated the engineering properties of recovered soil. An attempt has been made in this chapter to make the review of available information related to the overview of the Great East Japan Earthquake and Tsunami 2011 including generations of disaster wastes and resources losses, guidelines for waste management, waste separation and utilizations, generation of recovered soil and it`s properties; overview of organic matter, properties of decomposed granite soil and wood and finally discussed about the previous research studies on engineering properties of waste mixed soil.

2.2 The overview of the Great East Japan Earthquake and Tsunami 2011

This section is composed of summary of overall scenario of the Great East Japan Earthquake and Tsunami 2011. While generation and treatment of the waste were also considered as a central talk and discussed in this chapter.

2.2.1 Generations of disaster waste and resources losses

On 11 March 2011, at 14:46 an earthquake of magnitude 9.03 (Mw) had attacked at the Pacific coast of Tohoku in Japan which is triggered a massive tsunami that reached maximum heights of up to 40.5 m and travelled up to 10 km inland in Miyagi prefecture. (Katsumi et al. 2014; CO 2011). The area inundated by the tsunami was about 561 km^2 where 24 km^2 in Aomori, 58 km^2 in Iwate, 327 km^2 in Miyagi, 112 km^2 Fukushima, 23 km^2 in Ibaraki and 17 km^2 in Chiba (GIA 2011). Huge human lives as well as infrastructures and buildings were damaged which is shown in Table 2.1.

Table 2.1 Damage estimation in terms of human life, buildings and infrastructures (NPA 2012)

Prefectures	Population		Buildings			Infrastructures	
	Dead	Missing	Total-collapsed	Half-collapsed	Burned down	Road collapsed	Bridge collapsed
Aomori	3	1	311	852	0	2	0
Iwate	4755	1237	20185	4562	15	30	4
Miyagi	9512	1688	84749	147165	135	390	29
Fukushima	1605	214	20194	65733	80	187	3
Ibaraki	24	1	2723	24046	31	307	41
Chiba	20	2	798	9861	15	2343	0
Others prefectures	19	0	326	2413	5	659	1
Total	15854	3143	129286	254632	281	3918	78

It is clearly indicated that Iwate, Fukushima and Miyagi prefectures have been seriously damaged of which Miyagi prefecture has indicated severe one by the earthquake and tsunami compared to others. Moreover, a large amount of disaster debris were generated which is composed of woods, papers, textiles, plastics, concretes, metals, tatami, soils etc. It is surprising that the amount of disaster debris generated by East Japan Earthquake and Tsunami was estimated about more than 20 million tons which is also exactly the same amount of the 20 million tons generated by Hyogoken-Nambu Earthquake in 1995 (Hayashi and Katsumi 1996). Disaster debris generation as well treatment which is briefly summarized in the Table 2.2.

Table 2.2 Status of disaster debris generation and treatment (Inui et al. 2012)

Prefectures	Debris generation in × 10^6 kg	Storage in the stockyard in ×10^6 kg (Ratio)	Treatment /Disposal in × 10^6 kg (Ratio)	As of	Sources
Aomori	202	-	-	March 1, 2012	Aomori Prefecture, 2012
Iwate	4755	4161 (88%)	478 (10.1%)	April 2, 2012	MOE, 2012a
Miyagi	15691	11395 (73%)	1184 (7.5%)	April 2, 20	MOE, 2012a
Fukushima	2015	1380 (68%)	146 (7.3%)	April 2, 201212	MOE, 2012a
Ibaraki	755	-	-	December 21, 2011	Ibaraki Shinbun, 2012
Chiba	145	-	-	January 31, 2012	Chiba Nippou, 2012
Total	23,563	-	-	-	-

This huge amount of wastes appeared to be a big challenge for the Government of Japan, due to its huge economic and environmental impacts. Therefore, the Ministry of Environment (MOE 2011) prepared a guideline to overall management of these generated wastes indicating the specific methods as well as treatment process which are briefly explained below:

2.2.2 Guidelines for waste management

Just after the East Japan Earthquake and Tsunami 2011, Japan introduced a guideline on how to manage disaster waste by holistic approach where representatives were involved from all major institutions such as central, prefectural and municipal governments and even concerns industries. This guideline MOE (2011) specifies each actor`s roles which is as briefly summarized below:

The central government should monitor the activities of the prefecture and municipal governments to ensure that their waste management is efficient and appropriate. Moreover, preparation of master plane, provide various assistances such as fiscal measures, appointing experts, providing information on treatment facilities etc. The prefectural government (PG) acts as a conduit of municipal government, to oversee the temporarily established storage sites for waste management. The PG developed a disaster management plan and specifies the treatment methods. On the other hand, municipal government was required to treat the waste as per plans developed by the PG. The necessary treatment methods have also been specified according to the nature of the waste to manage disaster waste and few important methods of them are briefly mentioned in below:

Combustible waste should be used as cement calcinations and waste power generation to the greatest extent possible after being shredded while waste wood will be mainly used for making boards and as fuel for boilers and power generation. Besides, waste wood should be stored without being processed to chips to protect from decomposing as well as firing. Non-combustible waste should separate from waste mixed by screening with a trommel or a vibrating screen, float and sink separation, magnetic separation before being disposed of in landfills. Scrap metal should be recycled but before that ferrous metal should be separated from non-ferrous like copper.

Waste concrete must be utilized as reconstruction materials in the affected sites that lead to reduce the volume of final disposal. In this connection, there should be a good coordination approach between environmental departments and civil engineering departments. Home appliances and automobiles such as televisions, air conditioners, washing machines/clothes dryers and refrigerators should be separated and being used as per Designated Home Appliances Recycling Act based on their extent of damages. Vehicles should be delivered to collection companies for recycling according to Vehicle Recycling Law. Scrap metal should also be recycled after dismantling the ships. Waste plastic and waste wood should be incinerated in a manner that involves effective use, such as waste power generation, to the extent. Hazardous wastes, Polychlorinated Biphenyls (PCB) wastes, asbestos-containing wastes etc. should be separated from other wastes, treated as hazardous materials or specially controlled wastes and disposed of according to their properties.

Tsunami sediments containing toxic substances (e.g., heavy metals), perishable combustible materials and oil-containing materials those should be used as raw materials of cement or be subjected to incineration or landfills at final disposal sites. Sediments should be used as backfill materials in ground subsidence, recycled into civil engineering materials, or put into the ocean and it is only possible after removal of foreign matters.

2.2.3 Waste separation and utilizations

Due to massive earthquake of magnitude 9.03 (Mw), several serious geo-environmental problems occurred mainly in the coastal area of the Tohoku and North-Kanto Regions in Japan. One of the most important problems was the generation of disaster debris and tsunami deposits. The governments estimated that approximately 30 million tons of disaster debris and tsunami deposits were generated (Katsumi et al. 2014) through this disaster mostly in Iwate, Miyagi, and Fukushima prefectures, which needed proper treatment. These numbers were comparable to those generated at the previous catastrophic disasters such as 2010 Haiti earthquake, 2008 Si-chuan earthquake in China, etc (Brown et al. 2011). Since, it was geographically and economically unrealistic to construct new waste disposal facilities having a sufficient capacity to accept these wastes, which corresponds to several times of the annual generation of municipal solid waste in each local municipalities, treatment those disaster debris and utilizations were expected.

The treatment of the disaster debris and tsunami deposits leads to the separation of the fractions for proper reuse, recycle, incineration, landfill or others purposes. Several treatments processes were proposed and subsequently applied to reduce the volume of waste and reuse it, according to the guidelines prepared by the Ministry of the Environment (MOE), 2011. First, the debris was cleared at the affected sites, collected, and transported to the primary storage sites, which counted more than 300 sites at maximum. At the primary storage sites, wastes were stockpiled depending on the separation upon collection, such as waste mixtures dominant with burnable materials, collapsed wooden houses, concrete-dominant stockpiles, tatami mat dominant stockpiles, soil-dominant stockpiles, etc. Only rough separation, such as separation using operation vehicles and manual separation, is conducted. After the rough separation, secondary "mechanical separation treatment" by use of various mechanical equipments has been installed. "Mechanical separation" systems mostly consisted of "crushing" and "separating" processes. The basic idea of the separation system was to separate mixed wastes into fractions based on the substances, such as burnable materials, unburnable materials, metals etc. as shown in the Figure 2.1 illustrating the general flow of disaster waste treatment.

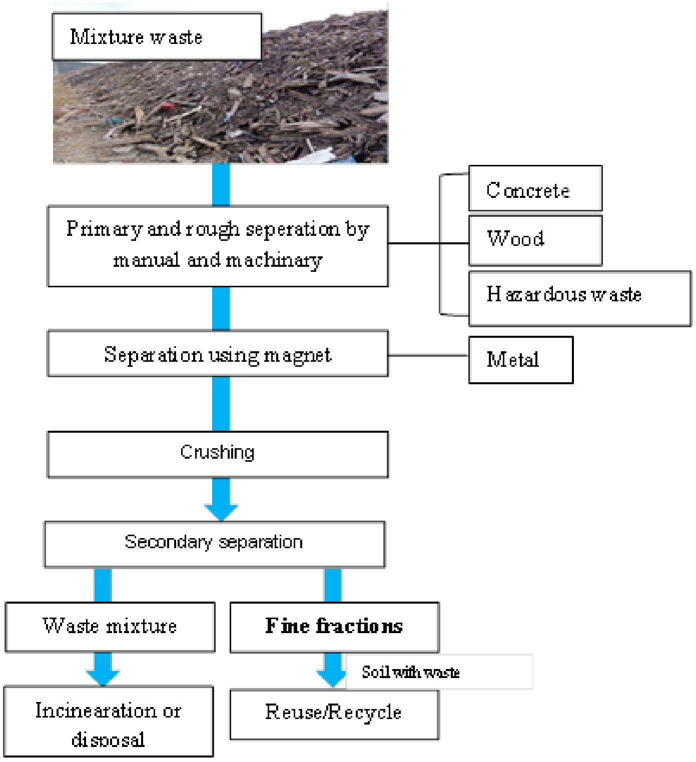


Fig. 2.1 The general flow of disaster waste treatment (Inui et al. 2012)

As a result, significant amount of soils and other fine fractions can be obtained. As for the soil-dominant stockpiles which are mainly the collections of tsunami deposits, only sieving (separation using sieve) was conducted to separate soils from the wastes. At the end of the treatment process, still a large amount of recovered soil was remaining which was expected to be reused as geo-materials (MOE 2011; Inui et al. 2012; Morita et al. 2012; Takai et al. 2013). One of the important considerations on recovered soil was the effect of combustible substances such as wood chips, paper scraps or plastic, on the engineering properties, since these combustibles may be deteriorated, resulting in the emission of gas and leachate and ground settlement, since only a limited studies investigated geotechnical properties of waste-mixed soil (e.g. Puppala et al. 2007).

However, it was a big challenge for the geotechnical utilization of the soil fraction recovered from disaster debris and tsunami deposits. While clearance of disaster wastes and tsunami deposits should be urgently accomplished within a short durations and before utilizations of these recovered soil for embankments and levees construction should consider the temporal and spatial variations in the geotechnical properties of recovered soil. According to two technical guidelines that prepared by the Ministry of Land, Infrastructure, and Transport (MLIT) in Japan, the utilization of recovered materials from disaster debris in recovery works like embankment constructions in which park and afforestation would be constructed using disaster wastes to protect future tsunami (MLIT 2012a) shown in the Figure 2.2. While recovered soil might also use to fill embankments at point where ground subsidence occurred because of earthquake (MLIT 2012b). Afforestation as well as embankment construction might significantly reduce the energy of the future tsunami and protect different materials from flow away. Moreover, tress those are previously planted were shallow rooted resulting insufficient resistance again tsunami, flood, tidal force and so on. Therefore, afforestation along with embankment construction in the affected areas is advantageously required (Katsumi 2015).

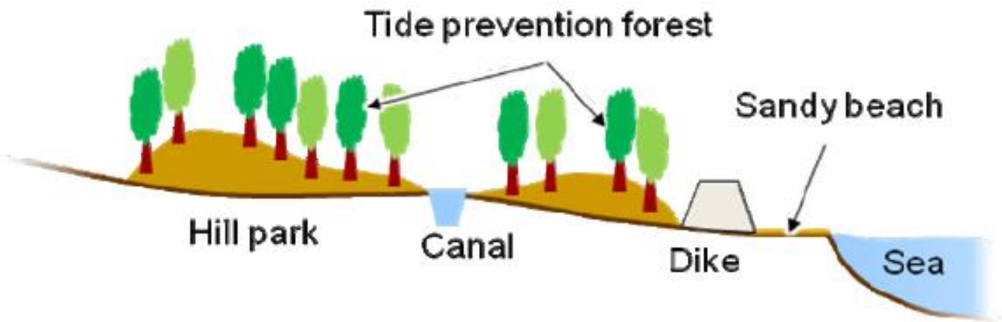


Fig. 2.2 Afforestation for disaster recovery using disaster waste materials
(Adopted from Katsumi et al. 2012)

2.2.4 Generation of recovered soil and its properties

Several treatment process are applied on disaster wastes and tsunami deposits generated by the Great East Japan Earthquake and Tsunami 2011 to recovered soil fractions of which at disaster waste treatment sites in Iwate Prefecture is shown in the Figure 2.3 (Iwate Prefecture 2013). Soil fraction recovered from the disaster wastes and tsunami deposits of which disaster wastes composed of noncombustible-rich wastes and combustible-rich wastes in the first temporary storage site. After- wards, separation is practiced by using trommels or vibrating screens at a secondary storage site as part of advanced separation. While recovered soil is categorized into three categories (Table 2.3) named as recovered soil class A, recovered soil class B and recovered soil Class C (Iwate Prefecture 2013). Recovered soil A was separated from tsunami deposit of which most of the materials are soil-dominant stock-piles, and the fraction passed through the sieving as part of advanced separation. Accordingly, recovered soil B and C were originated from disaster debris of which class B from noncombustible-rich wastes and C from combustible wastes and both fractions passed through same as previous one as the advanced separation.

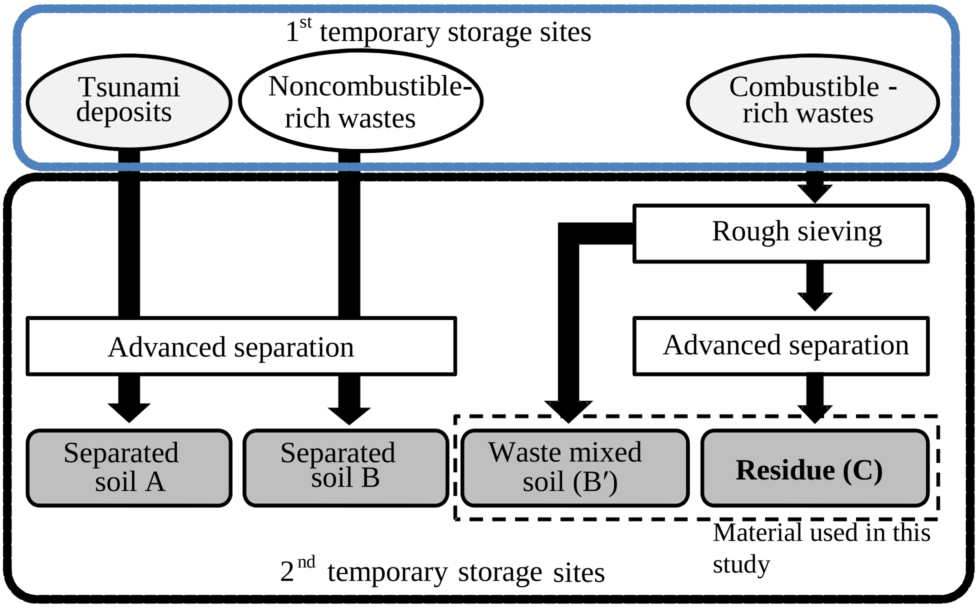


Fig. 2.3 Typical treatment flow of disaster waste (Iwate Prefecture 2013)

In addition to class C, there is another recovered soil Class B′ was originated from the combustible matter of which soil fraction less than 20 mm recognized as soil B′ and residue recognized as soil C. While the soil B′ was separated by passing through the 1st sieving as a pre-treatment of the advanced separation and recovered soil C was the residual of the disaster waste treatment which is separated from the fraction passed through the sieving as the final step of the advanced separation. Important issue was that the separated soil B′ contains less combustible than the separated soil C because fine wood fractions generated through the advanced separation are not admixed. Thus, recovered soil especially C was also recognized as poor and problem soil because of organic fractions, more specifically wood fractions contents. Moreover, recovered soil A and B was already decided that these soils would be utilized for recovery work once all treatment process completed in all affected cities. So, there is still need to be careful about the utilization of the recovered soil C requiring investigations before geotechnical utilizations.

Table 2.3 Classification of recovered soils designated by Iwate prefecture (2013)

Classes	**Contents**
Recovered soil Class A	Soils separated from soil-dominant stockpiles
Recovered soil Class B	Soils separated from waste mixed dominant stockpiles and satisfying the criteria for utilizations
Separated fine fractions (Recovered soil Class C)	Fine fractions obtained through the treatment process of disaster waste

2.3 Overview of organic matter

2.3.1 Organic matter and its characteristics

Among the four major components of soil (Fig. 2.4), organic matter is one of the important components and accumulated through the formation of biomass and organic detritus during development of soils. Besides, soil organic matter is determined through the process of biomass production, stabilization of detritus and mineralization (respiration) of organic materials (Tiessen et al. 1984). Generally, organic matter has three important functions namely physical, chemical and biological function in the soil. Structure formations, influences the hydrological properties of soil including the water holding capacity, infiltration properties and hydraulic conductivities of subsoil layers, improves the friability and tilth of the soil, lower soil strength, improves aeration, alter thermal properties are included as physical functions. While chemical functions encompasses C sequestration, detoxification of anthropogenic chemicals, the cation exchange capacity of the soil, enhances the ability of the soil to buffer against changes in pH, complexes cations and anions which can reduce the availability of toxic agents such as Al^{3+} in the soil solution, promote the binding of organic matter to soil minerals etc. Besides, provides a source of energy and food for microorganisms, serves as large reservoir of nutrients (especially nitrogen but also phosphorus and sulphur, and the micronutrients) which are available to the plant by decomposition processes (Murphy 2014; Craswell et al. 2001).

Instead of considerable attention, Soil Organic Matter (SOM) remains a mysterious soil composition (Olk and Gregorich 2006). There is close relationship between soil aggregation and SOM dynamics while well-aggregated soils has the higher permeability, larger pore space, and better gaseous exchange between soil and atmosphere compared to poorly aggregated soils and accelerate the microbial activity (Aref and Wander 1997).

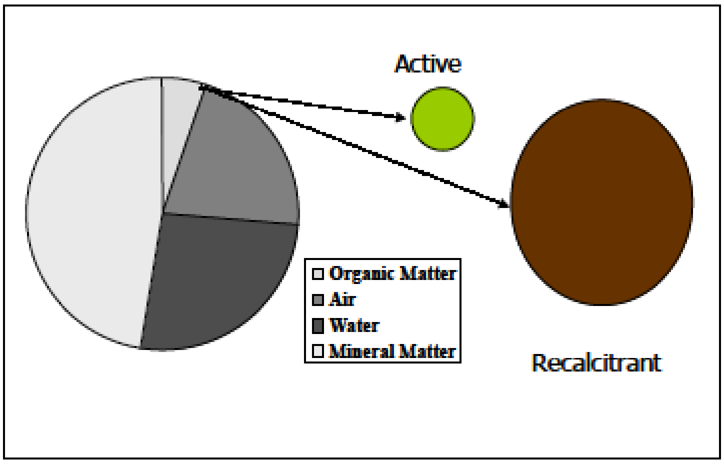


Fig. 2.4 Four components of soil (Cooperbrand 2002)

In the light of environmental issue, study of SOM is one of the vital factors as it might have great influence on global warming and climate change by the potential of sequestration of atmospheric CO_2. The increased ranged of CO_2 from 270 ppm (mid19th century) to 398 ppm at present and between 15% and 17% of this CO_2 is evolved as a result of SOM decompositions process (Houghton and Hackler, 1994). Therefore, the retention of organic carbon (OC) in soils is thus becoming more crucial since the rise in atmospheric CO_2 and global warming is recent not only local but also global concerns. Carbon is accumulated in the soil, mainly in an organic form. This Soil Organic Matter (SOM) undergoes a series of biotransformation, including decomposition and finally mineralization by the activity of microorganisms, with the release of CO_2. The loss of carbon from the soil to atmosphere which contributes to the greenhouse effect and global warming is the result of accelerating of the SOM. While soil organic carbon dominates the terrestrial carbon cycle of which sequestration of soil organic carbon is relatively low (only 0.7%) (Schlesinger 1990).

The presence of OM in soil is attributed by a complex mixture of organic compounds which includes two major categories of which living and non-living organic matter. While living organic matter, the minor fraction of the organic matter, includes soil biota such as bacteria, fungi, and algae, and fresh and un-decomposed animal or plant debris. Non-living organic matter which is results of decomposition and transformation of the plant and animals debris is the major fraction of the total organic composition in soils. Moreover, non-living organic matter is usually categorized into humic and non-humic substances (Hayes and Swift 1978). Thus, humic substances are always denoted as soil organic matter. However, the Figure 2.5 summarized the classification of soil organic matter.

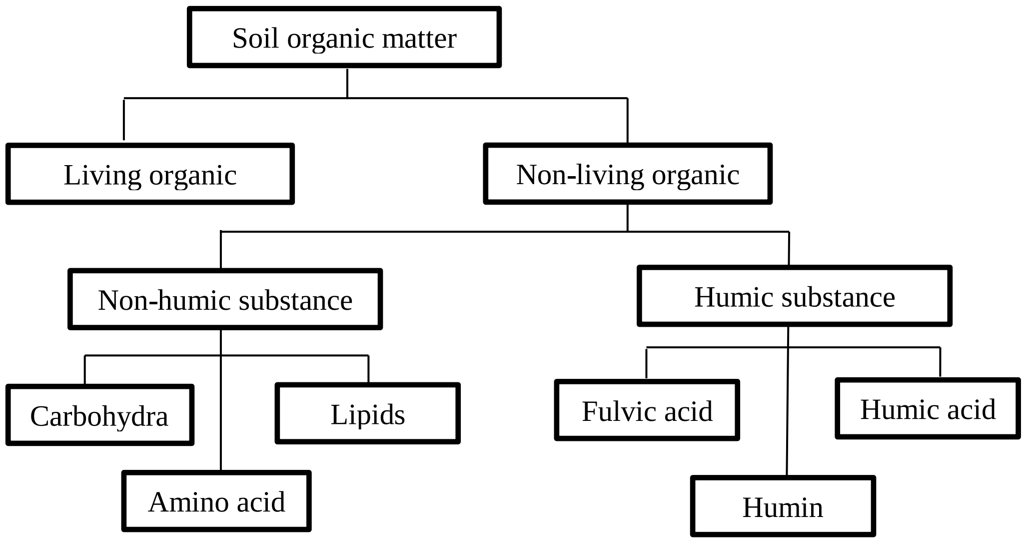
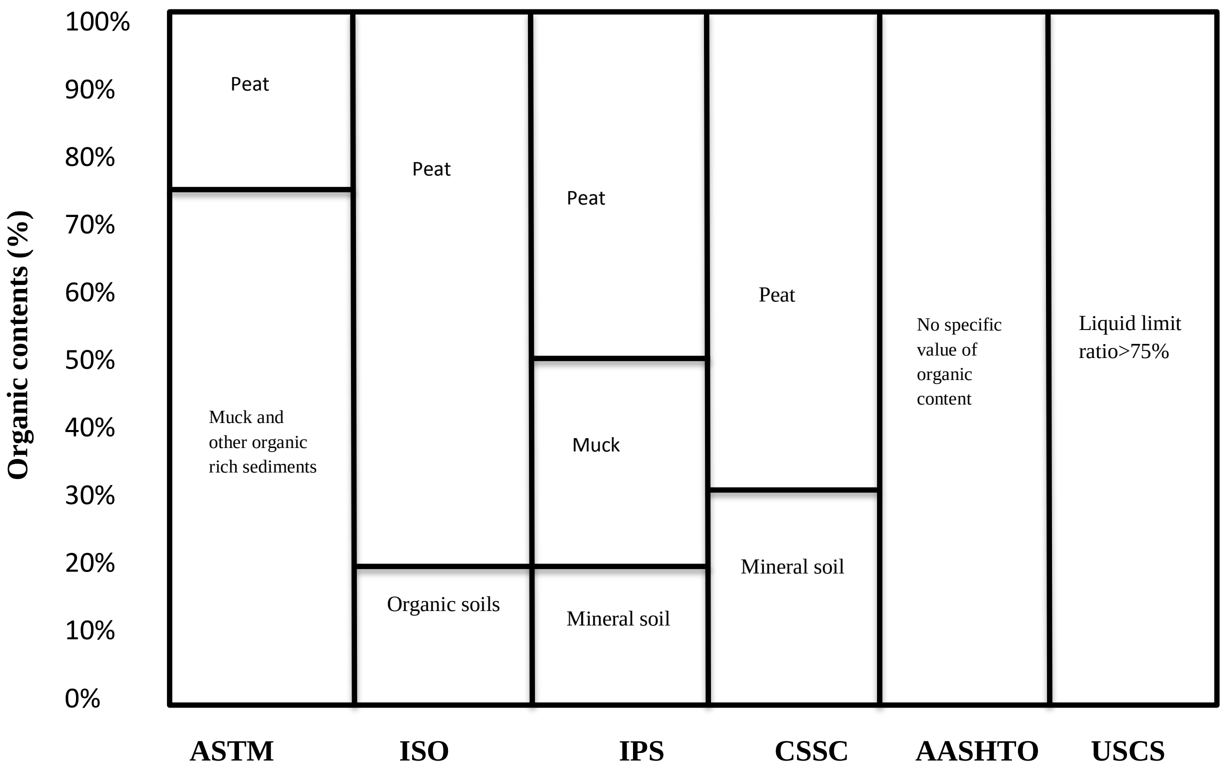


Fig. 2.5 Classification of soil organic matter (Huang et al. 2009)

Therefore, the amount of soil organic matter greatly affects index, physico-chemical and engineering properties of soils including specific gravity, water content, liquid limit, plastic limit, density and cation exchange capacity, hydraulic conductivity, compressibility and strength (Huang et al. 2009). As there is no universally accepted classification for organic soils, therefore, numerous classification systems were developed in different fields including agronomy, botany and engineering of which there is a number of engineering classification systems (Fig. 2.6) available and used around the world.



ASTM: American Standard for Testing Materials
ISO: International Organization of Standardization
IPS: International Peat Society
CSSC: Canada Soil Survey Committee
AASHTO: American Association of State Highway and Transportation Officials
USCS: Unified Soil Classification System

Fig. 2.6 Summarizes some currently used engineering classification systems (Huang et al. 2009)

However, USCS system (documented in ASTM D2487) and AASHTO system are the most widely used of which both are utilized for particle size analysis and/or Atterberg limits for distinguishing for classifying coarse and fine grained soils. A particular group (A-8) is used to identify highly organic soils by visual inspection in the AASHTO system. Moreover, organic soils are attributed by liquid limit decreased by more than 25% after oven drying in the USCS while peats are identified through visual inspection. On the other hand, peats are introduced with ignitions loss (LOI) more than 75% as addressed by a standard (ASTM D4427). It is the limitation of ASTM and AASHTO systems to address classification of soils with low organic matter. While ISO system categorize the soil as low organic soil, medium organic soil, and high organic soil containing 2-6%, 6-20% and >20% organic matter respectively.

2.3.2 Decomposition behavior of organic fractions

The amount of the soil organic matter stored in the soils represents one of the greatest reservoirs of organic carbon (C) and it was the mission and vision of global carbon stabilization taken by the Kyoto Protocol on climate change in 1992 (Schlesinger 1995). Moreover, this carbon stored is basically controlled by two fundamental factor of which decompositions of the organic fractions is one of the key factors (Lutzow et al. 2006). Organic matter decompositions in the soils accelerated by the different factors of which microbial mediated is one of them while abiotic oxidation accounts for less than 5% of OM decomposition (Lavelle et al. 1993). Decompositions of organic fractions taking long time with several phases whereas losses of about a quarter to two-thirds of the initial C within a turnover time of about 1–2 years at the end of first phase (Jenkinson and Ladd 1981). The following phase characterized by a slow decomposition rates with about 90% OM loss and taking long time about 10–100 years. While about 100 to >1000 years requires for a complete decompositions process which termed as very slow decomposition process. In connection to this slow decompositions process, long term stabilization of C in soils is identified for responsible factor (Falloon and Smith 2000) and this factor also attributed by the origin and compositions of the organic matter but stabilization mechanisms still unknown (Lutzow et al. 2006). But, the rate of decomposition and transformation of organic fractions from various sources available in nature is linked to the effects of both climate and chemical, physical and biological soil factors (Ussiri and Johnson, 2004; Chapin et al. 2003). In addition, presence of humic acid and fulvic acid leads to the soil organic matter mineralization (Zhang et al. 2008).

Heal et al. (1997) reported three stages of decompositions while transformation of complex organic compounds to smaller and simpler molecules by catabolism and biochemical process which describes as energy yielding enzymatic reactions. Then, reducing the particle size of organic material by the feeding activity of soil fauna as part of physical process. Finally, this affects the access of substrates to microbial decomposition or even removes them from the system. Besides, based on the decompositions rate, organic compounds are classified in terms of ease of composition which is as follows (Agri Info 2011; Brady and Weil 2002):

(a) Sugars, starches and proteins: Rapidly decomposed

(b) Hemicelluloses and cellulose: Slowly decomposed
(c) Fats, waxes, resins and lignin: Very slowly decomposed

2.3.3 Factors affecting organic matter decomposition in soil

Although, there are lots of things to happen during decomposition of the organic fraction in soil especially huge chemical reactions, however, what specific factors are responsible to encourage the decompositions process is needed be crucial to understand. Therefore, the following section is summarized the factors affecting organic matter levels in soils and soil organic matter decomposition. As we mentioned earlier that the rate of decomposition varied greatly by the composition of organic materials. However, the most important factors are briefly explained below:

(a) **Aeration:** It was found that under aerobic conditions 65 percent of the total organic matter decomposes during six months, while only 47 percent under anaerobic conditions because, fungi and actinomycetes are almost suppressed under anaerobic conditions while only a few bacteria (*Clostridium*) take part in anaerobic decomposition (Agri Info 2011).

(b) **Temperature*:*** Decomposition rate is more rapid in the temperature range from 35° to 40°C (Hobbs 1986) but decomposition is markedly retarded at temperatures below or above of this range. Remarkable organic matter decomposition occurs at 25°C and further fluctuation in the soil temperature has little effect on decomposition. Soil microbes (bacteria, fungi, and actinomycetes) are most active and thrive under moist warm conditions (Vigil and Spark 2004). Therefore, residue decomposition proceeds rapidly during moist warm condition but slowly during wet periods.

(c) **Moisture:** Adequate soil moisture content range from 60 to 80 percent of the water-holding capacity of the soil lead to the proper decomposition of organic matter. But decomposition is slow at soil water contents that are less than 40% water filled pore space and stops in soils with air dry (Vigil and Spark 2004). Microbes need moisture to break down straw. Moreover, in saturated soil, air is excluded and decomposition occurs by the slower, anaerobic decay pathway (Brandon et al. 1999).

(d) **Soil pH/soil reaction**: Soil acidity slows down the rate of decomposition (Ayanaba and Jenkinson 1990; Greenland et al. 1992) by its negative effects on soil organisms. The rate of decomposition is more in neutral soils than that of acidic soils. Therefore, treatment of acid soils with lime can accelerate the rate of organic matter decomposition.

(e) **Microbial activity:** Verhoef and Brussaard (1990) reported that soil fauna can enhance the decomposition of soil organic matter and nutrient release, and hence amend soil physical properties. Franzluebbers (2004) stated that larger soil organisms, therefore, stimulate soil microbial activity and also distribute smaller organisms within soil as a result of their generally greater range of mobility. In addition, larger soil organisms such as earthworms, ants, and beetles physically move organic substrates from the soil surface to within the soil, which can enhance decomposition by placement in a more favorable zone for microbial attack because of less extreme moisture and temperature variations (Franzluebbers 2004).

(f) **Carbon:Nitrogen ratio (C:N ratio):** C: N ratio of organic matter has great influence on the rate of decomposition. Organic matter from diverse plant-tissues varied widely in their C:N ratio (app. 8-10 %). The optimum C:N ratio in the range of 20-25 is ideal for maximum decomposition, since a favorable soil environment is created to bring about equilibrium between mineralization and immobilization processes. Low nitrogen content or wide C:N ratio results lead to the slow decomposition (Silver and Miya 2001; Vivanco et al. 2006; Hobbie et al. 2010). Protein rich, young and succulent plant tissues are decomposed more rapidly than die protein-poor, mature and hard plant tissues.

2.4 Properties of decomposed granite soil and wood

2.4.1 Properties of decomposed granite soil

In south-western part of Japan, the decomposed granite soil is widely distributed (Matsuo 1975). This soil was originated through weathering of granite, schistose granite and granite gneiss on the spot. The characteristics of this decomposed granite soil was different from rock, therefore, after weathering, the engineering properties of decomposed granite soil are affected by the contents of primary minerals, such as quartz, mica and feldspar and bed rock structures as well as natural conditions, such as climates and drain conditions (Kwon and Oh 2011). Natural water contents and void ratios decrease with an increase in depths and unit weights while soil particles become coarser and angular particles increase with increased depth of the soil. Generally, decomposed granite soils are characterized with non-plastic or with a very low plasticity index and it is confirmed by the soil particle size distribution curves and atterberg limits tests. Mainly, soils are classified into sand with silty fines SM or sand with clayey fines SC and recognized as sandy soil following Unified Soil Classification System (USCS). However, completely weathered soils occurred at the ground surface, may change into moisture content (MC) or mixed lining (ML) then thus soil behave like a clayey soil (Lan et al. 2003).

"Masa-do" in Japanese that is easy particle crushing is one of the important characteristic of this soil and this particle crushing refer to the change in the conditions of particles by external forces such as compactions, shear, compression compared to soils in natural conditions. Thus, this particle crushing is considered as influential factor of engineering properties especially compaction, strength, permeability. Moreover, decomposed granite soil`s attributed with compaction energy when it`s increased, its maximum dry density increased while its optimum moisture content (OMC) decreased (Wang et al. 2010). Due to particle crushing, micro cracks and intra-voids developed moreover, mica or feldspar become fine graded rather than quartz (Karimpour and Lade 2010). However, particle crushing of decomposed granite soil make denser and thus, other engineering properties such as compactions, strength permeability might greatly be affected.

Therefore, high stress can lead to particle crushing even strongest soil minerals while weak-grained soils for example decomposed granites, carbonate sands, and volcanic ashes, are also crushable and compressible under normal working loads. The possible reason of particles crushing is higher stress applied on the soil, mostly affecting the particles is more angular and larger. Then contact faces will increase so that contact stress is intensified and thus, larger particle crushing appears. The result found by Ham et al. (2010) that strength reduced as well as strength variability increased due to initial particle crushing and weakening effects induced by the presence of water. Moreover, one-dimensional compression behavior of decomposed granite soil was related to the initial crushing strength. At the end, degree of weathering of the decomposed granite greatly affects the initial crushing strength. Whereas this degree of weathering can be attributed by the specific surface area, ignition loss, and absorption rate of granite soil (Matsuo et al. 1979; Murata et al. 1987; Yasufuku and Kwag 1999). Moreover, it was confirmed that the degree of particles crushing increased with soaking of particles under water. (Miura and Yamanouchi 1975; Miura et al. 1983). This decomposed granite soil is very commonly used in Japan and Korea for construction in many engineering projects (Ham et al. 2010). Thus, it is important to understand the behavior of this soil. The particle size distribution is shown in the Figure 2.7.

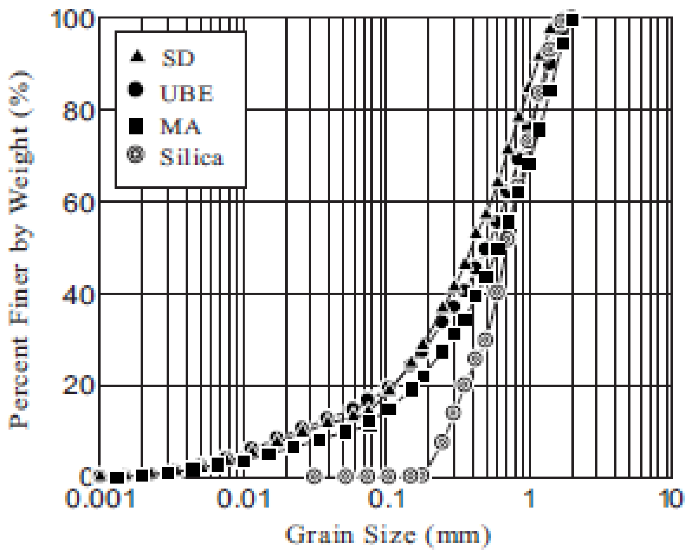


Fig. 2.7 Particle size distributions of decomposed granite soils (Ham et al. 2010)

Moreover, depending on the degree of crushing of coarse-grained soils (sandy soil), the engineering properties of coarse-grained soils may become different. The crushing nature of coarse-grained soils has a significant influence on compaction, and the crushing of particles at the time of compaction has the same effect as over-compaction and, thus, the strength of material will be rather reduced (Kim and Ha 2014).

2.4.2 Properties of wood

Wood is one of the first natural materials people learned to use and never lost its popularity (Woodford, 2014). These days, it's particularly prized for being a natural and environmentally friendly product. However, it has several functions and properties of which mechanical and chemical are important. Basically, wood is bulky, organic which might have degradations effects. Wood is essentially composed of cellulose, hemicelluloses, lignin, and extractives. Table 2.4 presents major chemical compositions of some wood species each of these components contributes to fiber properties, which ultimately impact product properties. However, chemical composition varied with tree part (root, stem, or branch), type of wood (i.e. normal, tension, or compression) geographic location, climate, and soil conditions.

Table 2.4 Chemical compositions of some wood species (Sjostrom 1993)

Constituents (%)	**Scots pine *(Pinus sylvestris)***	**Spruce *(Picea glauca)***	**Eucalyptus *(Eucalyptus camaldulensis)***	**Silver Brich *(Betula verrcosa)***
Cellulose	40	39.5	45.0	41.0
Hemicellulose	28.5	30.6	19.2	32.4
Lignin	27.7	27.5	31.3	22.0
Total extractives	3.5	2.1	2.8	3.0

Decomposition of wood is an important part of the carbon cycle of nature and mostly depends on its compositions. Decomposition is caused by fungi, insects, and marine borers that use the wood as food or shelter, or both. Lignin in wood provides a physical barrier to enzymatic decomposition of cellulose and hemicelluloses. This barrier is breached mechanically by insects and marine borers, biochemically by white- and soft-rot fungi, and possibly by small non-enzyme catalyst. However, Table 2.5 summarized the type of biological deterioration of wood and organisms responsible.

Table 2.5 Type of biological deterioration of wood and organisms responsible (Krik and Cowling 2009)

Type of Deterioration	**Organism (s)**
Deterioration without decomposition	-
Loss of stored food reserves	Living wood cells in sapwood
Mechanical boring, perching, cutting	Insects, birds, mammals
Stain	Fungi
Surface discoloration	Fungi, algae
Pit membrane destruction	Bacteria, fungi
Decompositions of structural polymers , mechano-biochemical and biochemical	Insects, marine borers and fungi

In connection to thermal decompositions of the wood, when wood slab was heated, thermal decomposition of the solid fuel could be divided into four steps: (1) Water vaporized as the temperature reached 100^0C; (2) solid fuel pyrolyzed slowly at the temperature between 180 and 280^0C; (3) pyrolysis of solid was rapid as the temperature of most part of solid was from 280 to 450^0C; (4) the solid fuel decayed after the temperature above 500^0C. Wood begins to lose its water of constitution until the temperature exceeds 100^0C. Weight loss is slow up to 200^0C and the evolved gases are difficult to ignite. Lignin and hemicellulose of wood undergo glassy transition in this range. The pyrolysis is thought to be endothermic and results in evolution from 200^0C to 280^0C. Mixtures of carbon dioxide, water vapor and acetic acid would be evolved. The wood specimen would pyrolyze rapidly from 280^0C to 500^0C (Shen et al. 2007). Gases are evolved at temperatures between 200^0C and 400^0C to 450^0C., with a maximum at about 350^0C to 400^0C. The rate of production of pyroligneous material passes through a maximum between 250^0C and 300^0C and virtually ceases at about 350^0C. Tar forms between about 300^0C and 400 ^{0}C to 450^0C. Some gases, primarily hydrogen, continue to be evolved above 400^0C. Charcoal, which contains practically all the original ash, is not completely carbonized even at 1500^0C (Amy 1961).

2.5 Previous research studies about the waste mixed soil

This important section summarizes a literature review about the engineering properties of the waste mixed soil. It is important to mention here that mostly wastes such as plastic fiber, coir, tire, rice husk, rubber chips, organic matter are considered in the composite of waste mixed soil. Previous studies have discussed the engineering properties of waste mixed soil and pointed out the engineering properties of the waste mixed soil significantly varied with different ratio of waste present in the soil and their decompositions behavior (Rabbee and Rafizul 2012; Hossain et al. 2003; O`kelly and Pichan 2013; Franklin et al. 1973).

2.5.1 Strength of waste mixed soil

In order to proper waste management, Babu and Choukesly (2011) conducted a series of unconfined compression test (UC), consolidated undrained (CU) and one dimensional compression test with plastic waste mixed soil and observed that the strength of soil is improved and compressibility is reduced significantly with addition of a small percentage of plastic waste to the soil. The improvement in strength and compressibility response due to inclusion of plastic waste can be advantageously used in bearing capacity improvement and settlement reduction in the design of shallow foundations. The similar results found by Laskar and Pal 2013; Ahmed 2012 with plastic waste mixed soil where maximum strength found at 1% plastic fiber inclusion in the waste mixed soil. The change of the strength properties with plastic fiber inclusions can be illustrated by the data found in another research and shown in the Figures 2.8 and 2.9.

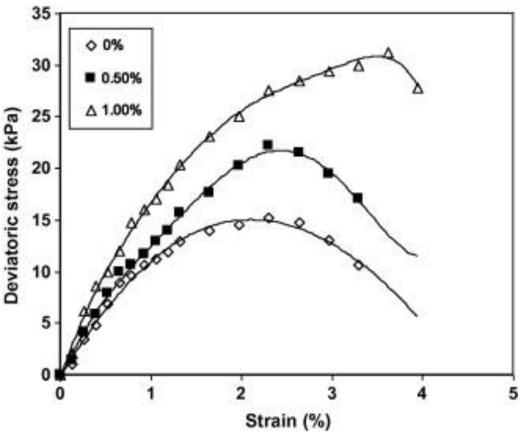


Fig. 2.8 Unconfined compression tests result at different percentages of plastic waste for sand (Babu and Choukesly 2011)

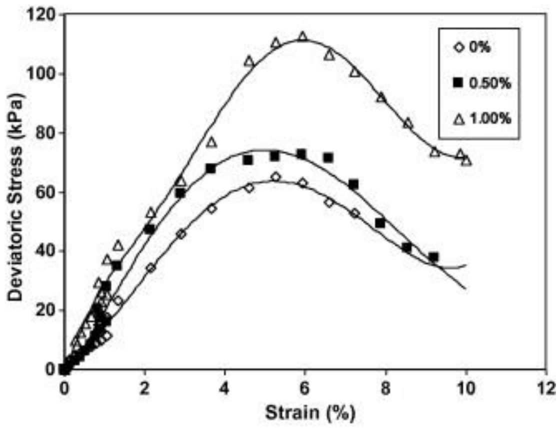


Fig. 2.9 Unconfined compression tests result at different percentages of plastic waste for red soil (Babu and Choukesly 2011)

Puppala et al. (2007) found that decreasing trend of liquid limit as well as plasticity index properties found in manure compost. Free swell strain increased with increased organic content in both amended soils while shrinkage strain value decreased in manure compost but in case of bio-solids compost, initially decreased and then increased because of more organic holding the more moisture content. The value of unconfined compressive strength (UCS) of the compost amended soils varied from 46 to 347 kPa while the same of the boi-solids compost amended soils varied from 76 to 425 kPa at optimum water content condition. The UCS initially enhanced in most of the amended soils while compost materials increased from 20 to 40%, further increased (beyond 40%) resulted drastically decreased the UCS of the amended soils (Puppala et al. 2007). However, optimum organic amendment ratio which is showed maximum enhancements to the present soils is confirmed by using the following formula:

$$\mathrm{R_{ave}} = \left[\frac{w_{FS}\times R_{FS}+w_{LS}\times R_{LS}+w_{UCS}\times R_{UCS}}{3}\right] \quad (2.1)$$

Where,

R_{ave} : average rank,

R_{FS}: rank based on the free-swell property,

R_{LS}: rank based on the linear shrinkage,

R_{UCS}: rank based on the unconfined compression strength and

W_{FS}, W_{LS}, W_{UCS}= Weightage factors for the soil properties=0.33

In addition, Consoli et al. (2002), studied with engineering behavior of sand reinforced with plastic waste by conducting unconfined compression tests and the splitting tensile tests were carried out in accordance with ASTM D 1633 (1990a) and ASTM C 496 (1990b) Standards respectively. They developed a multiple regression model (Eq. 2.2) and explained both q_u and q_{ut}, model indicated that the fiber length is an irrelevant factor, whereas the cement content and the fiber content were found to be significant factors that affected both compressive and tensile strength. Moreover, a nonlinear relationship found between the unconfined compressive strength (q_u) and the cement content. However, a nonlinear response was not detected for tensile strength (q_{ut}). But, inclusion of plastic fiber increased the strength at smaller rate.

$$\begin{aligned}\gamma = a_0 + a_1.x_1 + a_2.x_2 + a_{11}.x_1^2 + a_{12}.x_1.x_2 + \cdots + a_n.x_n \\ + \cdots + a_{nn}.x_n^2 + \cdots + a_{n1n2}.x_{n1}.x_{n2}\end{aligned} \quad (2.2)$$

Where, γ is the response variable; x_n= n^{th} input variable; $a_{n=}$ coefficient of the n^{th} input variable; and a_0 = constant

Another study was conducted by Ahmed (2012) to interpret the three main input variable fiber size, content and aspect ratio by developing multiple linear regressions model (Eq. 2.3) which might affecting the UCS of plastic waste mixed soil .

$$\gamma = K_0 + K_1X_1 + K_2X_2 + \cdots + K_pX_p \quad (2.3)$$

Where, γ is the output variable (UCS), K_0 is the model intercept, K_1-K_p are the coefficients of regression analysis and $X_1 - X_p$ are the ρ input variables.

Moreover, predicted UCS was obtained from the regression model and thus the results were compared with results were found from the experiment conducted. Thus, this value and behavior of predicted strength obtained from regression models are in agreement with the observed strength obtained from experimental (Fig. 2.10). Similar multiple regression model was used by the Singh and Vinot 2012 to explain the strength of the tier mixed soil.

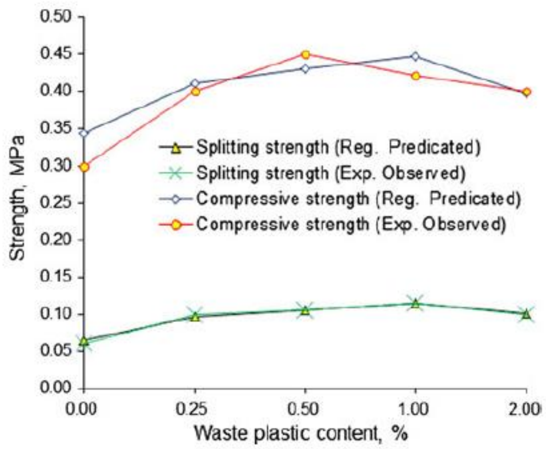


Fig. 2.10 Effects of plastic chips on the predicted and observed strength (Ahmed 2012)

A series of unconfined compression tests were conducted on artificially cemented samples with layered fiber reinforcement. The unconfined compressive strength (UCS) of the samples was evaluated to quantify the uncertainties associated with fiber distribution or concentration in the strength of fiber reinforced soils. The UCS of fiber-reinforced cemented specimens gradually increased as the number of fiber inclusion layers increased. The specimen where fibers were evenly distributed at five layers was twice as strong as the non-fiber-reinforced specimen. When the same amount of fibers was reinforced in the entire specimen, the specimen with five fiber inclusion layers was 1.5 times stronger than the specimen with one layer at the middle. Using fiber-reinforced soils does not necessarily guarantee an anticipated strength increase or a safe design unless the uncertainties associated with the fiber distribution or concentrations are adequately considered (Park 2009).

Singh and Vinot (2011) studied with CBR tests and results which indicates that CBR result for a constant penetration in the specimens, the inclusion of tire chips tends to increase the piston stress. On the other hand, the addition of tire chips to sand increased the shear resistance at higher displacement although the magnitude and nature of this increase were affected by normal stress, chips content and aspect ratio, which were statistically significant at 95% confidence level. Bearing capacity of the peats was very low due to higher moisture content and presence of wood debris in the soil. (Kazemian et al. 2011). Higher fibrous containing peat shows the higher strength because of fibrous acting as reinforcement agent in the soil (Huat et al. 2009). Other than plastic and tier chips; coir fiber, rubber chips, rich husk, peat, compost, palm oil Fly ash mixed soil found significantly affect the strength properties of the soil while most of the case strength properties increased up to 1 to 5% fiber content in the mixer (Rabbee and Rafizul 2010; Subbarao et al. 2011; Singh and Mittal 2014; Puppala et al 2007).

On the other hand, Organic content 6-20% of the soils behavior seems to be mineral soils but organic content 21-74% treated as organic silt/clays. This organic content has the impact of geotechnical properties such as strength, volume change, plasticity index, specific gravity etc (Edil 1997). The effect of organic matter was more significant than that of binder quantity of cement because the organic matter increased resulting degradation of the mechanical behavior. Unconfined compressive strength (q_u) and deformation modulus (E_{u50}) are reduced because of OM content less than 10% destruct the cementation of the solid skeleton of the stabilized soil. However, improvement of engineering properties was observed once binder quantity increased along with organic matter content decreased at remarkably (Paulo et al. 2014).

2.5.2 Compressibility of waste mixed soil

The content of the organic fractions affects the void as well as the compressibility of the soil resulting high organic content clay experienced with a large decrease in void ratio with a small increase in pressure at initial stage. Compression index (C_c) was increased with increase organic content of the clay sample. However, the increasing trend of compression index with organic content tend to be smaller at higher organic content level (beyond 10%). On the other hand, coefficient of primary consolidation was decreased with increased organic content and represented by an equation of $C_v \text{ x } 10^{-8}(m^2/sec) = 4.639e^{-0.037oc.}$. The variation of the rate of secondary consolidation was found with organic content. The secondary compression started before the completion of primary consolidation due to organic soil. The variation of the secondary compression predicted by using the equation of $C_\alpha = 0.0057+0.0006$ OC with a correlation coefficient of 0.989 (Thiyyakkandi and Annex 2011).

The dominant factors that affect the compressibility of peat are fiber content, void ratio, water content, initial permeability, arrangement of soil particles, and inter-particles chemical bonding. Compression of fiber peat continues at gradually decreasing rate under constant effective stress called secondary compression (Kazemian et al. 2011). Compression index increased with increased organic content but beyond 10.5% organic content, smaller variation found. While void ratio increased with increased organic content but void ratio significantly decreased with highly organic content experienced sample even at lower stress (Adejumo 2012).

The organic soil settlement is very crucial for a structure constructed up on this soil. There are many factors affecting settlement of which organic content is one of the crucial issues. Besides, initial density, stress history, water content, compositions and decompositions behaviors are also important. Peat takes a long time to be settled down when loaded by embankment while this soil is very unsuitable for construction due to unable to provide support to the foundation. (Kazemian et al. 2011). However, the settlement is determined by following the one-dimensional consolidation theory while there are three methods from which settlement can be calculated (JIS, 2000).

Compression line method, $$S_f = H\frac{e_i - e_f}{1+e_i} \quad (2.4)$$

C_c method, $$S_f = H\frac{C_c}{1+e_i}\log\frac{p_f}{p_i} \quad (2.5)$$

M_v method, $$S_f = H\, m_v\, \Delta p \quad (2.6)$$

Where, S_f is the final settlement, e_i is the initial void and e_f is the final void ratio, H is the height of the specimen after completion of the consolidation, C_c is the compressibility of the specimen, e_i and e_f are the initial and final void ratio respectively, p_f and pi are the final and initial pressure respectively, m_v is the volume change and Δp is the pressure change.

2.5.3 Decomposition behavior of organic on the engineering properties of waste mixed soil

The effects of organic matter and stiffness of soils depends largely on whether organic matter was decomposed or consists of fibers which can act as reinforcement (Kazemian et al. 2011).The decomposition process produces amorphous peat material, comprised of smaller and approximately equi-dimensional organic grains. Organic matter converted into humus, gases and water at the end of the decomposition process which also causes reduction of organic content. Settlement of the peat may significantly increase due to loss of solid mass associated with microbial activities resulting structural disintegrate of organic solids (Wardwell et al. 1983). The Figure 2.11 indicating the reduction of volume of the organic soil which is basically an account of increased stress and shrinkages along with rapid biological decompositions of the organic matters (Drajad et al. 2003).

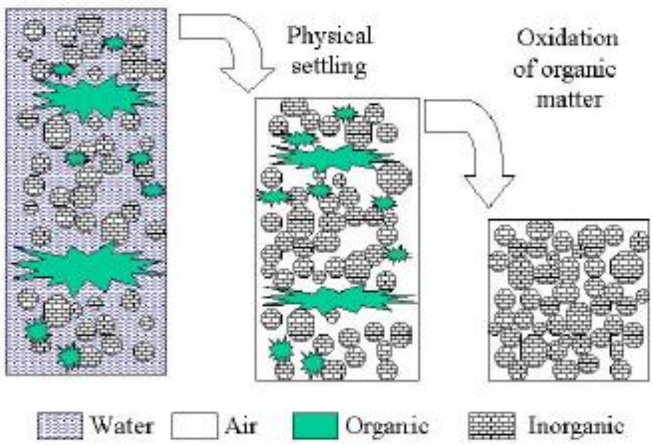


Fig. 2.11 Settlement of the organic soil by physical and decompositions process (Matthiesen 2004).

Fabric destruction, organic reduction due to transform into gas and liquid during decomposition which might have significant influence on the compression behavior of peat. The structural arrangement of the fibers is highly dependent on the source generated from, the circumstances in which the peat was formed and its degree of decomposition. The fibrous peat was high water content, very low specific gravity resulting very low density. On the other hand, a high specific value indicates the higher mineral content and higher state of decompositions. Moreover, bulk density as well as void ratio may also influence by the gas generated during decomposition process. Hossain et al. (2003) reported about waste compressibility during waste decomposition and found the coefficient of primary compression (C_c) increased from 0.16 to 0.37 as (C+H)/L decreased. In comparison, the coefficient of primary compression (C_c) for the control samples was estimated to be 0.16 in refuse with little decomposition and increased to 0.25 in more decomposed refuse. Compressibility increased with increasing gas production as solid-to-gas conversion took place while (C+H)/L was used to quantify the state of waste decomposition.

A significant volume changes (30-70% of the original) found while pressure range between 29-192 kPa. The compression was largely irreversible only except while few proportions of wood decayed. The result also mentioned that presence of decaying wood could easily manifest in significant weaknesses, and is a probable cause of many surface deformities in roads, runways, and other surface covered with flexible pavement. The result from different studies about buried wood of forest in Florida Puerto Rico, Western Washington, Southern Japan and South Carolina indicates less 40% dry mass of wood would remain after 10 yrs. while only 20% reaming the same after 20 years. The engineering and ecological consequences of the potentially rapid decay rates and high compressibility of this more juvenile buried wood, with a half-life well within the design life of most embankments or a single plantation cycle, have not been well studied (Ghozla et al. 1991).

Besides, organic content in the clay soil tremendously affected the geotechnical properties of soil where plasticity and compressibility of soil have increased due to increase of organic content and shear strength of the soil has greatly decreased for the same (Thiyyakkandi and Annex 2011). Schmidt (1965) found that plastic limit of the soil was linearly related to organic carbon while liquid limit did not vary linearly and plasticity index was independent of organic content. The liquid and plastic limit of the artificially prepared organic soil has increased with organic content (Krizek et al. 1975). Another study conducted by Song et al. (2003) and explained that compaction curve of the solid waste soil which was used as sub-base materials of road construction was tended to be located below and to the right of the curves. The specific gravity of the soil has been decreased according to increase of organic content (Puppala et al. 2007) while unconfined compressive strength of the soil was also decreased for the same issue (Franklin et al. 1973)**.** On the other hand, organic contents below about 4% appear to influence certain geotechnical properties to some degrees this effect was relatively insignificant in comparison to the influence of high (>4%) concentrations of organic carbon (Mcdonald 1982). It is also found by another studied that increased soil strength and decreased compressibility of soil was found due to increase of organic content in the soil (Mitchell and Soga 2005). Reducing the wood chips and other impurities into the soil collected from several temporary and secondary storing sites of East Japan Tsunami affected area would enhance the high compaction performance where it was also demanded that organic matter in the soil might be responsible for long-term subsidence because of it`s decomposition behavior (Katsumi 2012).

However, based on the above discussions, no available literatures which addressed the effects of wood fractions on the engineering properties of the soil. Moreover, wood fractions remaining in the soil recovered from disaster debris were varied from one site to another sites and was unknown the maximum acceptable ratio of wood fractions in recovered soil for utilizations as engineering materials. Decomposition of the wood fractions in the soil that affects the engineering properties was also absent in the previous literatures. In this regards, there is a research gap and therefore, this study dealt with engineering properties of recovered soil which is discussed in the following chapters.

CHAPTER 3: EFFECTS OF WOOD FRACTIONS ON THE ENGINEERING PROPERTIES OF RECOVERED SOIL

3.1 General Remarks

Generally soil has four major components *viz*. mineral matter, organic matter, water and air (Cooperbrand 2002). The soil (recovered soil) used in this research has a wood fraction as an additional component. Wood fractions in the recovered soil are one of the important considerations for the geotechnical utilizations of this soil. It was assumed that presence of wood fraction in the soil might affect the engineering properties of soil especially, strength and deformation properties. Therefore, it is important to understand the strength and deformation properties of the recovered soil. The effects of organic content on the engineering properties of soils is well studied (Zhang and O'Kelly 2013; Huat et al. 2009; Kazemian et al. 2011; Edil 1997; Puppala et al. 2007; Rabbe and Rafizul 2012; Rafizul et al. 2010; Huat 2004; Song et al. 2003; Thiyyakkandi and Annex 2011). Moreover several researches have focused on geotechnical properties of waste mixed soil, composed of municipal waste, plastic waste, tier chips, jute fiber, coir fiber, rice husk ash etc. (Babu and Choukesly 2011; Singh and Vinot, 2011; Dutta and Sarda 2007; Subbarao et al. 2011; Singh and Mitra 2014; Choudhury et al. 2010). But, the effects of wood fractions on the engineering properties of soil is yet to be studied. Therefore, there is a clear research gap in the effects of wood fractions on the engineering properties of soil and, thus, it is necessary to fill this gap by conducting research.

Wood fractions mixed with soil at different ratio might be crucial for the engineering properties of soil. There is no available information about the effects of the wood content on the engineering properties of recovered soil. Moreover, there is no maximum acceptable limit of wood fractions in the soil for its geotechnical utilization. But, several findings are available on the effects of waste fractions or chips/fibers and organic content on the aforementioned properties of soil. Peat soil, which has high organic matter content, generally has poor strength, large deformation, high compressibility, high magnitude and rates of creep. It is also subjected to instability as well as long term settlement problem. The bearing capacity of the peat soil is very low due to presence of wood debris in it (Kazemian et al. 2011). On the other hand, Rabbee and Rafizul (2012) described that the initial void ratio (e_o) has a linear relationship with organic matter content; e_o was significantly increased from 1.26 to 1.47 and 1.47 to 1.94 along with the increase of organic matter content from 5 to 17% and 17 to 35%, respectively. Moreover, the compressibility index (Cc) was significantly increased with the increase of organic matter content. Because organic matter occupied more space resulting void enlargement and is filled by air and/or water. Ranjan et al. 1994 investigated that the strength of reinforced sand increased with an increase in plastic fiber content. The authors pointed out that the rate of increase was higher at lower fiber content (*i.e.* $w_f < 2\%$). But, at higher fiber content (*i.e.* $w_f > 2\%$), the relative gain in strength was small. The fact may be that fibers, of specific gravity ~0.92, occupy a relatively large volume in the composite (a fibre content of 2% by weight is approx. equal to 4% by volume of the composite). Thus, with higher fiber content, the quantity of soil matrix available for holding the fibers was insufficient to develop an effective bond between fiber and sand. Also, for fiber content beyond 2% (by weight), the mixing of fibers and soil is impracticable as bailing up of fibers takes place and a uniform distribution cannot be obtained. Another study indicated that an organic content of between 6 to 20% may affect soil properties, behaving like mineral soil (Edil 1997).

Wood fractions in recovered soil seem to be problem; however, it could be reused as geo-materials either for recovery work or other re-construction works at up to certain ratio which is still unknown. This field has received little focus, therefore; this study investigates the effect of wood fractions on the engineering properties of recovered soil. In this research, simulated samples (wood fractions mixed with decomposed granite soils) were used to conduct the experimental works. A series of Standard Compaction tests, Unconfined Compression tests, CBR tests and Compressibility tests were conducted with the simulated samples. Based on the experimental results and observations, the interaction of wood fractions with soil is discussed in this chapter.

3.2 Materials and methods

3.2.1 Materials

A series of experiments were conducted with simulated recovered soil was prepared by mixing decomposed granite soil with wood fractions extracted from actual recovered soil sample. Firstly, actual recovered soils were collected from different earthquake and tsunami affected areas of the coastal region of Japan. Afterwards, wood fractions were separated from actual recovered soils by float separation using tape water (Fig. 3.1) and then dried in oven at 110 ^{0}C for 24 hrs. Moreover, commercially available sandy soil (decomposed granite soil) with its particle size distribution similar to those of actual recovered soils was prepared. Particle size distribution of decomposed granite soil (Fig. 3.2) was determined by sieve analysis and it was compared with the particle size distribution of the recovered soil samples from the affected sites (S-1 to S-7 in Fig.3.2) while results showing a similar trend of particle size distribution (Fig.3.2). Before mixing wood fractions with decomposed granite soil for sample preparation, the size of wood fractions from 2 mm to 4.75 mm while soil particle size up to 4.75 mm were taken into consideration.

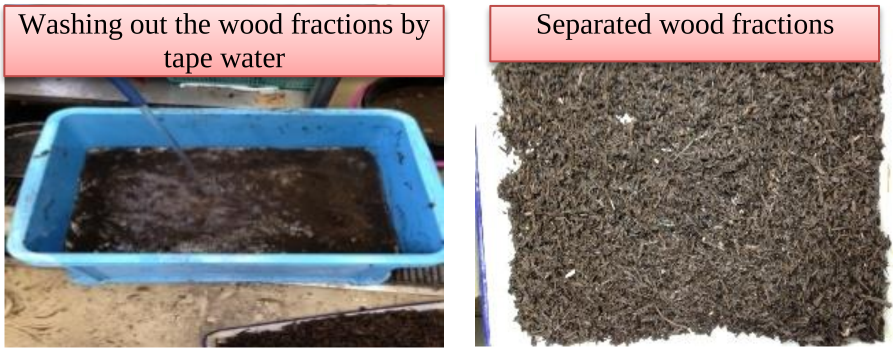


Fig. 3.1 Wood fraction separation from actual recovered soil

Sizes of the wood fractions as well as soil particles were done by hand sieving according to JIS A 1204 standard. Extracted wood fraction was mixed with decomposed granite soil at a designated content (0%, 2%, 4%, 6%, 8%, 10% and 12%) of wood fractions by dry weight of the simulated sample (Photo 3.1). These simulated samples, shown in Table 3.1.

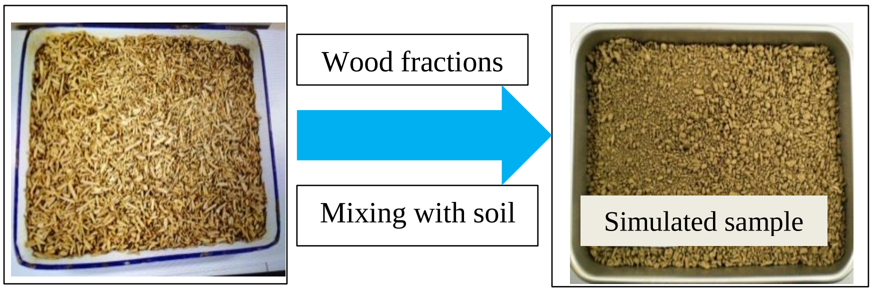


Photo 3.1. Image showing the simulated sample

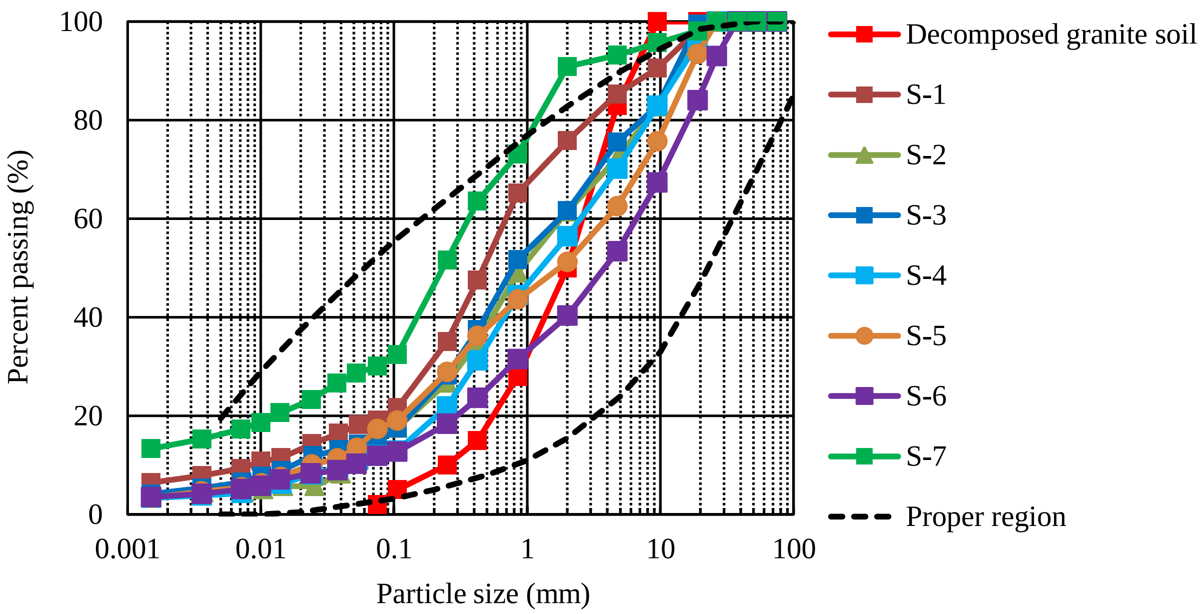


Fig. 3.2 Particle size distribution of affected sites soil along with decomposed granite soil

Table 3.1 Simulated soil sample sorting

Wood mixing ratio (%)	Components ratio in total mass (%)		Symbol showing on the graph
	Wood fraction	Decomposed granite soil	
0	0	100	0W
2	2	98	2W
4	4	96	4W
6	6	94	6W
8	8	92	8W
10	10	90	10W
12	12	88	12W

The particle density of soil particles (2.7 g/cm^3) and wood fractions (1.33 g/cm^3) were determined following JIS A 1202 standard. The method is recommended for soil particle density but here we used the same method for determining particle density of wood fraction. However, repeated measurements (five times) were done for before and after compaction of the wood fraction (1.25, 1.17, 1.34, 1.33, 1.41 g/cm^3 and 1.38, 1.41, 1.14, 1.38, 1.59 g/cm^3 for before compaction and after compaction, respectively. Maximum and minimum values were omitted and the average value of the rest three values were taken for particle density for both before and after compaction of wood fractions. Basic density and ignition loss value of the wood fractions used in this study were also conducted following the standard of SCAN-CM43:89 and JIS 1226:2009 respectively. The heating temperature used in this study was 330 ^{0}C instead of 750 ^{0}C for ignition loss test of wood fractions. Wood fractions were soaked in water for 20 hrs at room temperature. The principles and calculation procedure of basic density following standard of SCAN-CM43:89 is summarized below.

The apparent mass of the immersed wood fractions was taken. The wood fractions were oven-dried and their mass was determined. The basic density is calculated by using following formula:

$$\mathrm{X} = \frac{cp}{(b-a)} \tag{3.1}$$

Where

X is the basic density, a is the mass of the empty basket, b is the mass of busket full with wood fractions, c is the mass of dried wood fractions and p is the density of water. The mean of the three replications was considered.

The physical properties of decomposed granite soil and wood fractions have been presented in Table 3.2.

Table 3.2 Physical properties of decomposed granite soil and wood fractions

Physical properties of decomposed granite soil	
Parameters	**Value**
Maximum dry density (g/cm^3)	2.01
Optimum water content (%)	10.50
Particle density (g/cm^3)	2.70
Ignition loss at 330^0C (%)	0.35
e_{max}	0.94
e_{min}	0.73
Physical properties of wood fractions	
Particle density (g/cm^3) (before compaction)	1.31
Particle density (g/cm^3) (after compaction)	1.39
Basic density (g/cm^3)	0.36
Ignition loss at 330^0C (%)	56.1

The amount of wood fraction in the recovered soil was calculated from the difference between the weights of oven dried samples at 110 ^{0}C and then heated at 330 ^{0}C for 11 hours in a muffle furnace. In the JIS method soil is burned at 750±50 ^{0}C temperature for I hr which is used to determine organic matter while we burned wood fraction at 330±10 ^{0}C for 11 hrs. Besides, ignition loss test was also conducted at 350 ^{0}C burning for 11 hrs to find the differences between two heating temperatures of 330 ^{0}C and 350 ^{0}C. A T-test was done to test the significance of the differences. A descriptive statistics was alone done to explain the results obtained from the ignition loss test. Moreover, two different wood sizes (<2 mm addressed small size and 2-4.75 mm addressed large size) and three heating durations (11hrs, 24hrs, and 48 hrs) were used at constant heating temperature of 330 ^{0}C to find the differences of the ignition loss. Three replications were done for each combination of wood size and heating duration. Specimen inside the muffle furnace is shown in in Photo 3.2.

Photo 3.2 Specimen inside the muffle furnace

The results of the ignition loss test have been summarized in Table 3.3. The Fig. 3.3 indicates ignition loss value and wood fractions have positive relationships. However, the trend of the trend of the ignition loss is relatively linear at higher heating temperature of 350 ^{0}C as compared to 330 ^{0}C. Moreover, ignition loss value of wood fraction at 330 ^{0}C and 350 ^{0}C temperatures showed significantly differences except 2W and 6W samples and the relationship is confirmed by T-test (Table 3.3). Similar result was found by Morita (2014) in case of relatively smaller wood fraction while most of the literature found that ignition loss of wood temperature range 300^{0}C and 365^{0}C (Babrauskas 2001). It was also observed that there was no significant difference among the three replications for each sample (Figs. 3.4 and 3.5) and descriptive statistics indicates in the Table 3.3. None of the samples show higher value of coefficient of variance for three replications of each sample indicating no variations among the three replications for each sample.

Table 3.3 Results of ignition loss test

Sample	**Ignition loss (Mean)**		**Std. dev**		**CV (%)**		**T-test**
	at 330 ^{0}C	at 350 ^{0}C	at 330 ^{0}C	at 350 ^{0}C	at 330^{0}C	at 350 ^{0}C	
0W	0.36	0.41	0.02	0.012	5.60	2.93	2.78 (0.02*)
2W	1.78	1.85	0.08	0.05	4.50	2.70	1.15 (0.33)
4W	2.84	3.05	0.08	0.08	2.82	2.62	2.17 (0.03*)
6W	4.94	5.05	0.10	0.07	2.02	1.40	1.56 (0.19)
8W	5.43	7.04	0.07	0.09	1.30	1.30	-23.92 (1.8E-05**)
10W	6.74	9.31	0.05	0.02	0.74	0.21	-84.46 (3.7E-06**)

"( )" indicates level of probability

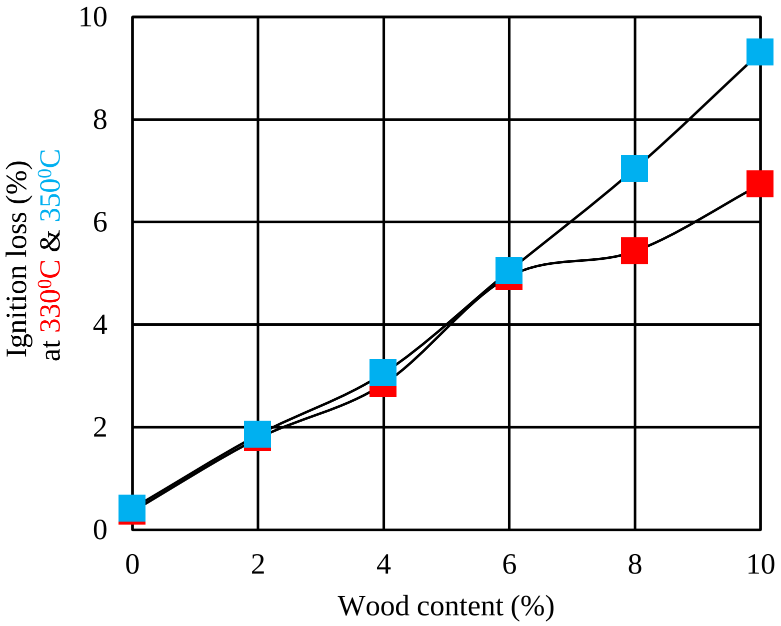


Fig 3.3 Ignition loss and wood contents

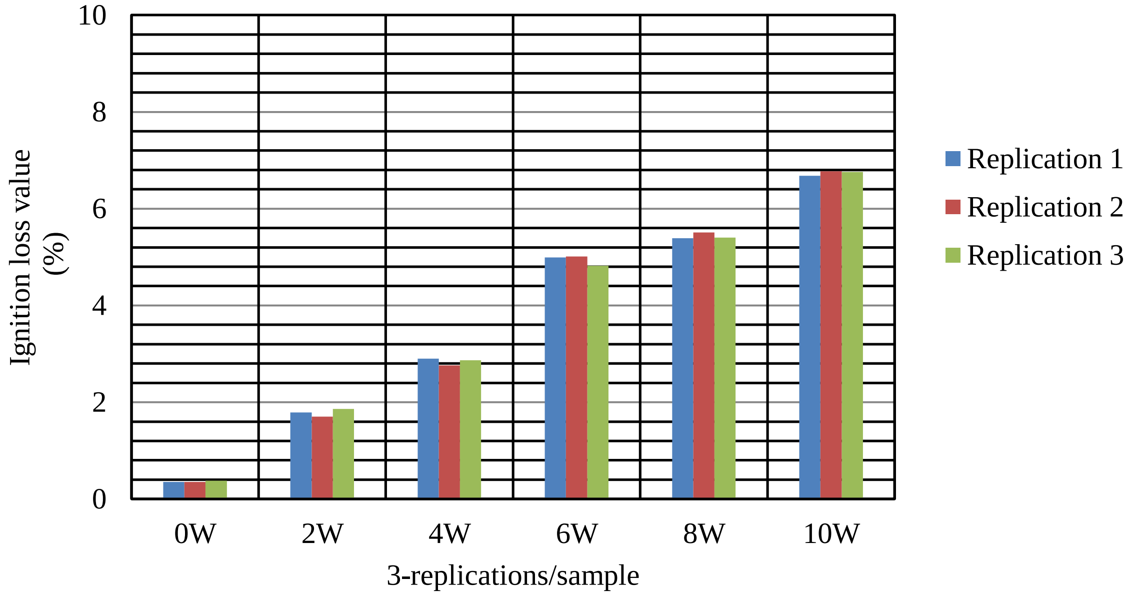


Fig 3.4 Graph showing the three replications for each sample at 330^{0}C temperature

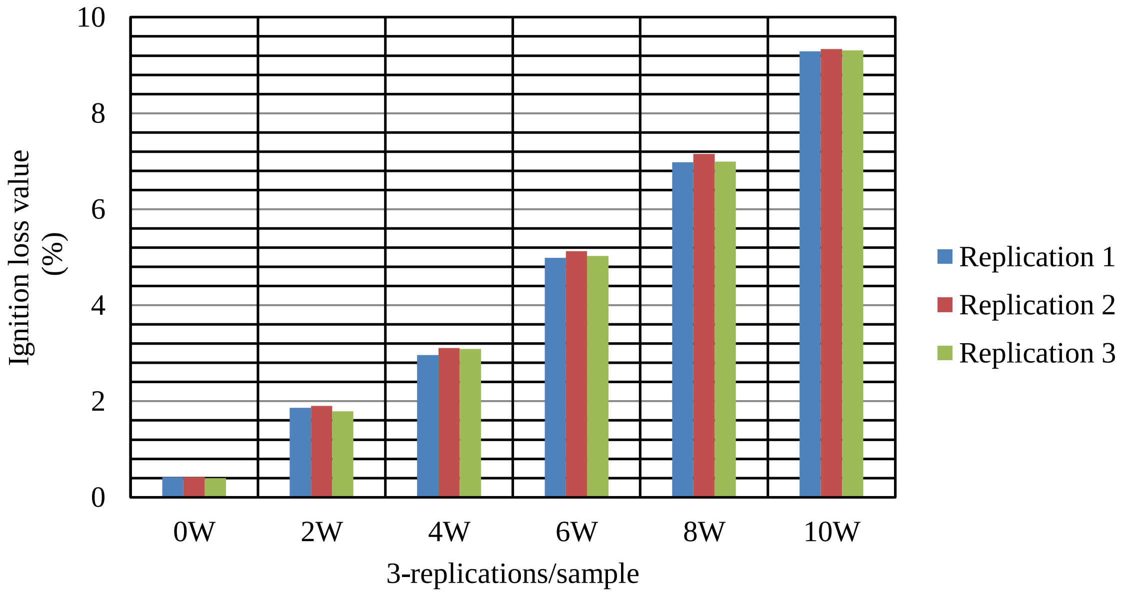


Fig 3.5 Graph showing the three replications for each sample at 350 ^{0}C temperature

The results of the ignition loss of the wood fractions at three different heating duration (11 hrs, 24 hrs and 48 hrs) at 330^{0}C are summarized in Table 3.4. The ignition loss value for all each samples were increased with increased duration of the heating while larger increased found in samples containing more wood fractions. It was also found that a relatively linear relationship showed between wood fractions contents (larger size) and ignition loss value heated at 48 hrs duration which was indicates in the Figure 3.6. The results found at higher heating duration for large size were the almost similar and close to smaller wood fractions size that was heated at 11 hrs

(Fig. 3.7). Our another study conducted (Uddin et al. 2014) at same heating temperature at 330^{0}C and duration (11 hrs) (Fig.3.8). The results indicate that smaller wood fraction size showed relatively more linear relationships with ignition loss as compared to larger size. This is why, this study was investigates the larger wood fraction sizes with higher heating durations to observe whether ignition loss value is increased or not. While increased results were found and proved the assumption. Besides, small changes in the value of ignition loss between the two wood sizes found at each sample. Based on the experimental results it was concluded that heating duration as well as size of the wood fractions influences the variations of the ignition loss value of wood fractions. However, it can be concluded that no specific temperature and durations for wood ignition loss determination rather we can say, temperature and durations may depends on size of the woods, mass of the woods, types of wood fractions etc.

Table 3.4 Ignition loss value at different heating duration

Sample	11 hrs	24 hrs	48 hrs
0W	0.36	0.43	0.44
2W	1.78	1.83	1.90
4W	2.84	2.99	3.44
6W	4.94	4.98	5.06
8W	5.43	6.21	7.02
10W	6.74	7.50	8.51

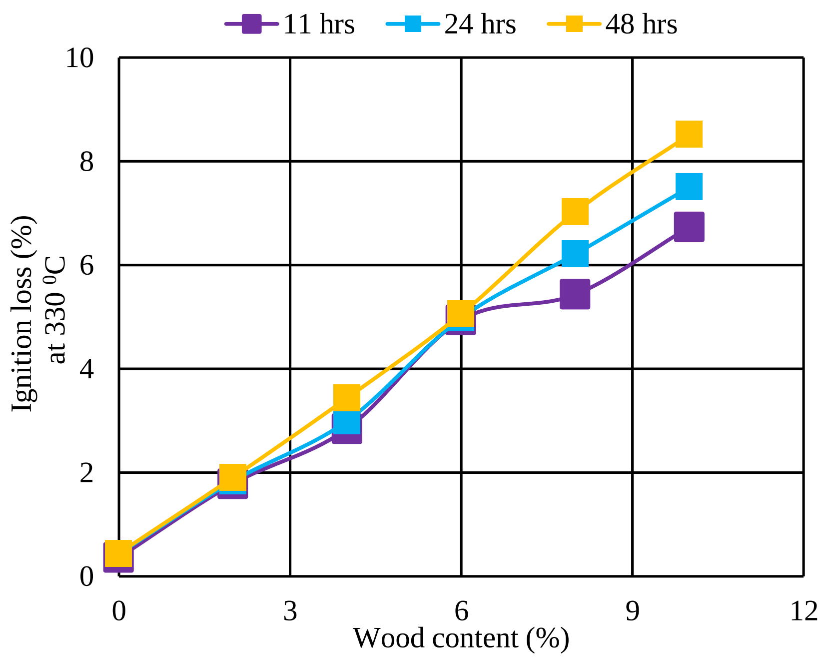


Fig. 3.6 Ignition loss and wood contents at three different heating durations with larger wood size

Fig. 3.7 Ignition loss and wood contents at different heating durations for both size

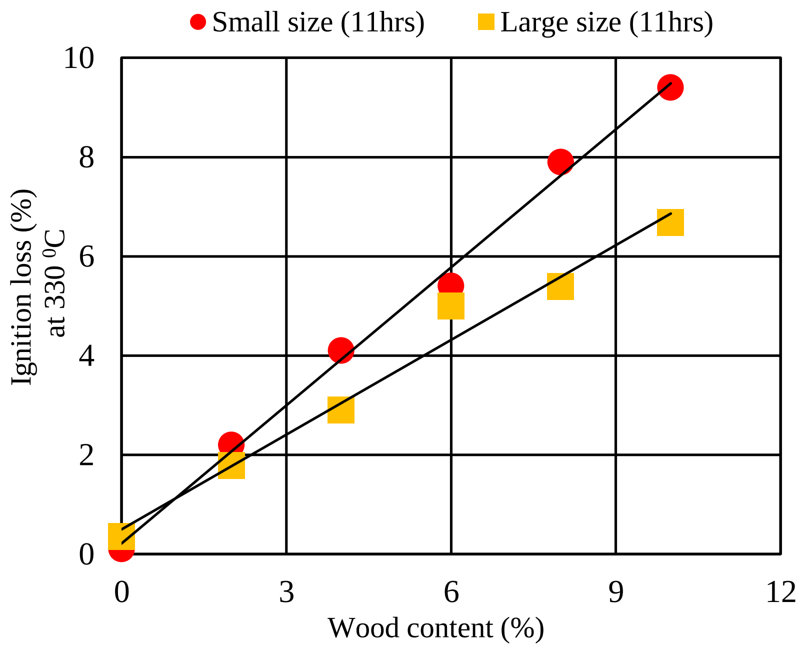


Fig. 3.8 Ignition loss and wood contents at same heating duration and temperature (11 hrs at 330^{0}C)

In this research, in order to understand the effect of wood fractions on the engineering properties of recovered soil, simulated samples were tested by using four different experimental methods. Of which standard compaction test, unconfined compression test, CBR test and compressibility tests were conducted for samples with various ratios of wood fractions to achieve the objectives of the research. All tests were conducted following Japanese Industrial Standard (JIS).

3.2.2 Standard compaction test

Standard compaction test was done to determine the maximum dry density and optimum moisture content according to the procedures stipulated in 2009: JIS A 1210 following A-a method in the test method. In other words, in the compaction conditions 2.5 kg rammer mass, rammer falling high 30 cm, mold inner diameter 10 cm, and 1000 cm^3 volume, put the soil was divided into three equal layers applying 25 times blows each layer. The Figure 3.9 shows the apparatus used for compaction of the soil.

Fig. 3.9 Compaction apparatus

Then determined the optimum moisture content (OMC) and maximum dry density (MDD) from the compaction curve drawn by using the data from the compaction test. The dry density was calculated by using the following formula:

$$\rho_d = \frac{\rho}{1+\frac{W}{100}} \tag{3.2}$$

Where,

ρ_d: dry density

ρ: wet density

w: water content

3.2.3 Unconfined compression test

This test was conducted to understand the strength properties of the recovered soil according to the procedures stipulated in JIS A 1216:2009. During specimen preparation, about 90% or more of the maximum dry density and optimum moisture contents obtained in the compaction tests (Table 3.5) carried out in advance was used. The soils were divided into five layers during specimen preparations for unconfined compression test in split mold (50 mm inner diameter and 100 mm height) as shown in the photo 3.3 along with a prepared specimen while specimens were prepared by tapping.

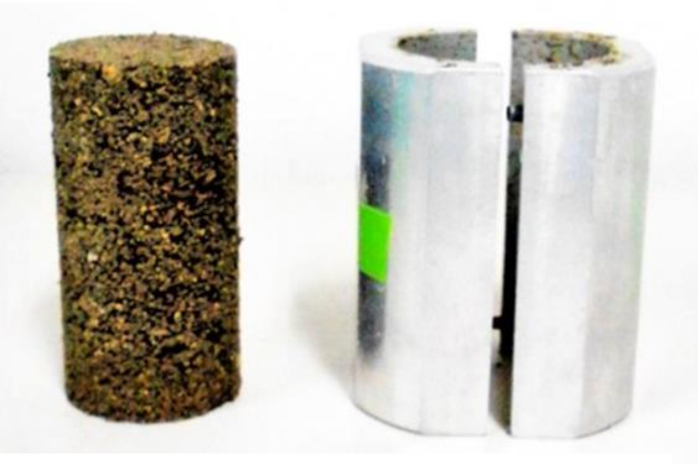


Photo 3.3 Mold used for specimen preparation

Table 3.5 Dry density and compaction degree of the UCS test specimens

Samples	Dry density (g/cm^3)	Replications No.	Dry density (g/cm^3)	Compaction degree (%)
0W	2.01	1	1.93	96.0
		2	1.91	94.9
		3	1.90	94.5
2W	1.87	1	1.84	98.4
		2	1.83	97.9
		3	1.84	98.4
4W	1.78	1	1.75	98.3
		2	1.76	98.9
		3	1.74	97.8
6W	1.66	1	1.62	97.6
		2	1.61	96.9
		3	1.60	96.4
8W	1.58	1	1.54	97.5
		2	1.55	98.1
		3	1.51	95.6
10W	1.51	1	1.46	96.7
		2	1.47	97.4
		3	1.49	98.7
12W	1.43	1	1.39	97.2
		2	1.41	98.6
		3	1.42	99.0

However, three replications per sample were done to obtain the test result; the arithmetic mean of those three was considered for each unconfined compressive strength and deformation modulus. Moreover, the measurement of the water content and wet density of the specimen, calculate the compaction degree and dry density of the specimen, compaction of the specimens were those greater than 90% was confirmed. The Figure 3.10 shows the specimen at unconfined compression test while taking reading.

Fig. 3.10 Specimen while taking reading at unconfined compression test

3.2.4 California bearing ratio (CBR) test

CBR test was conducted to understand the strength (at confined condition) of the recovered soil following JIS A 1211. Before preparing the CBR specimen, a Modified Compaction Test was done following JIS A 1210 method to determine the maximum dry density and optimum water content. Modified Compaction Test was conducted using a rammer of 4.5 kg and a mold of 15 cm in a diameter (E-a method). In this method, the sample was usually compacted into the mold of 15 cm in a diameter along with 12.5 cm height to three equal layers while each receiving 92 blows from a 4.5 kg weighted rammer at 45 cm height (Fig 3.11). This process was then repeated for various moisture contents and the dry densities were determined for each. The reason behind using this heavy compaction energy was to more densify the samples that lead to enhance the strength of the soil. It was important to note it down here that two compaction energy used in this study; one was applied during standard compaction test of which results was used during specimens' preparation for unconfined compressive strength determination. But, none of samples met the minimum embankment construction requirements. Therefore, we applied another one that was heavy load during CBR specimen preparation and assumed that this heavy load might accelerate the density which leads to the higher strength and thus, we also observed.

The relationship of the dry density to moisture content was then plotted to establish the compaction curve (Fig. 3.12). The maximum dry density (MDD) was finally obtained from the peak point of the compaction curve and its corresponding moisture content known as the optimal moisture content (OMC). Therefore, 90% or more maximum dry density and optimum moisture contents obtained from compaction test was used for CBR test specimen preparation.

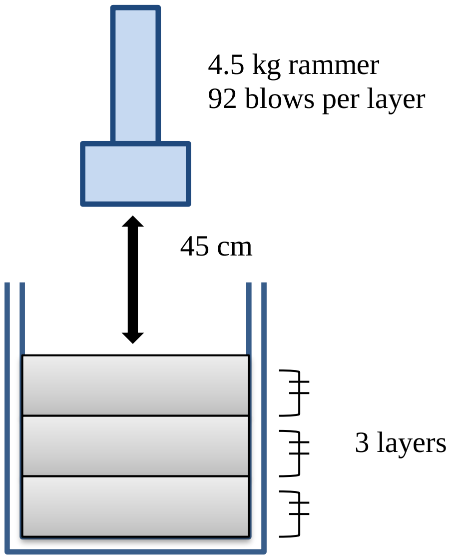


Fig 3.11 Schematic structure of the apparatus of compaction test along with specimen preparation

After getting maximum dry density along with maximum moisture content, specimen was prepared for CBR test while each sample had three specimen and compacted with each 17, 42, 92 blows per layer (Fig. 3.13). The prepared specimen in the mold was soaked in water for 4 days (or until soaking stop) and water absorption readings were noted at different time intervals (1h, 2h, 4h, 8h, 24h, 48h, 72h, 96h) (Photo 3.4). The surcharge weight of 5 kg was placed on the top of the specimen in the mold and the assembly was placed under the plunger of the loading frame. Load was applied on the specimen by a standard plunger with diameter of 50 mm at the rate of 1mm/min. Readings on pressure gage was recorded when load was penetrated at 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, 12.5 mm. The Figure 3.14 shows the CBR apparatus with specimen while taking reading.

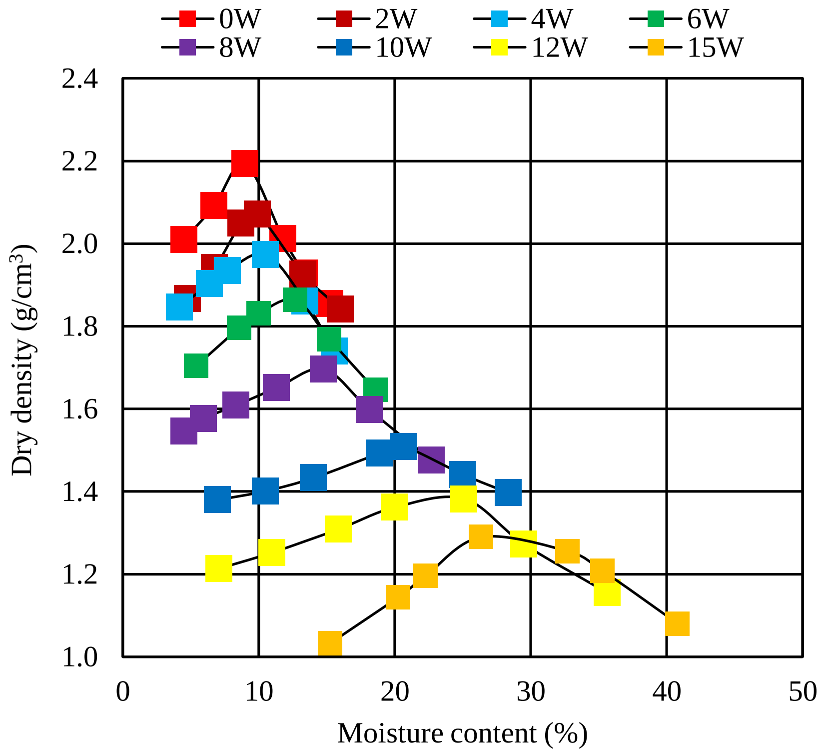


Fig. 3.12 Compaction curves of the samples with modified compaction test

Photo 3.4 Specimens soaking by water

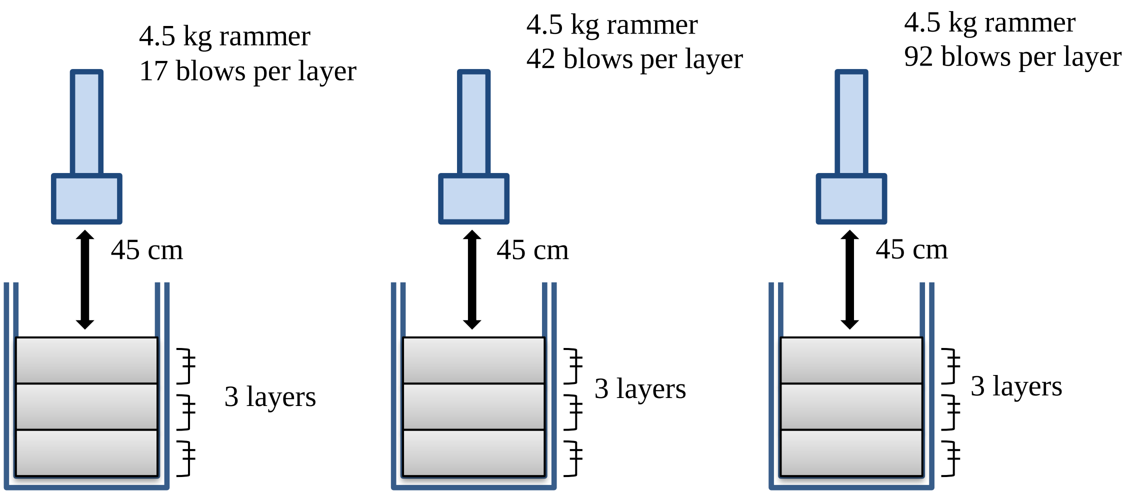


Fig. 3.13 Different compaction energy applied during specimens preparation

Fig. 3.14 CBR specimen with apparatus while taking reading

3.2.5 Compressibility test

Basically, this test was studied in an oedometer to determine the compressibility parameters of recovered soil. This test was carried out in a standard consolidation apparatus following JIS A 1217:2009 standard. Similar to unconfined compression test, the specimen prepared to fill the sample into consolidation ring with the goal of 90% or more compaction degree which is shown in Table 3.6. It is note it down here that this test was conducted samples containing wood fractions up to 10% based on the results observed from the unconfined compression test and CBR test. It was assumed that samples with higher wood fractions for example 8 or 10% might be significantly affecting the strength of the recovered soil which was also observed at 8W sample in the UCS and CBR test. Thus, up to 10% wood fractions samples were considered for this compressibility test. The inner diameter of consolidation ring is used as of 60 mm and 70 mm height. The consolidation ring of 70 mm height was used in this study instead of consolidation ring of 20 mm height because of samples compacted with granular materials which is shown in photo 3.5 (left, 20 mm) and (right, 70 mm).

Photo 3.5 Consolidation ring with 20 mm (left) and 70 mm (right) height

Table 3.6 Dry density and compaction degree of the compressibility test specimen

Samples	Dry density of the compaction test (g/cm^3)	Dry density of the specimen (g/cm^3)	Compaction degree (%)
0W	2.01	1.91	95.2
2W	1.87	1.80	96.3
4W	1.78	1.73	97.2
6W	1.66	1.63	98.2
8W	1.58	1.51	95.6
10W	1.51	1.45	96.0

The compressibility parameters especially, $\mathrm{e} - \log p$ curve, deformation, void ratio, compression index etc. were calculated using the data obtained after this test. Moreover, measurement of the water content and wet density of the specimen, calculate the compaction degree and dry density of the specimen, considering the compaction of the specimens were those greater than 90% was confirmed. The Figure 3.15 showing the specimen on the Oedometer apparatus while taking reading.

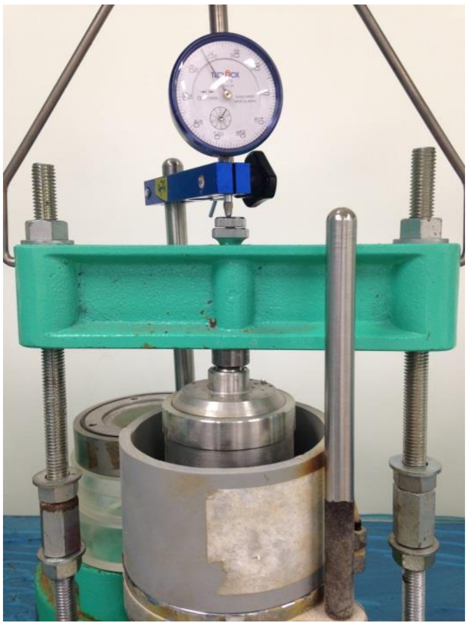


Fig. 3.15 Specimen at Oedometer apparatus while taking reading

3.3 Results and discussions

3.3.1 Compaction characteristics

The standard compaction test results are summarized in Table 3.7. The data plotted in the Figure 3.16 shows compaction characteristics of each sample and indicates that dry density of the samples tend to be decreased with increasing wood fraction contents. While increasing trend was found for optimum moisture content (OMC) but decreasing trend for maximum dry density (MDD) along with increased wood fractions inclusion (Fig. 3.17). The maximum dry density was varied from 2.01 to 1.43 (g/cm^3) along with wood fractions content varied from 0 to 12% while the variation of the optimum water contents from 10.48 to 21.81% with the same wood factions inclusion (0 to 12%). The decreasing trend of dry density was found along with increasing optimum moisture contents because, may be samples which contained more wood fractions absorbed more water in micro-pores, and can not be compacted properly.

Table 3.7 Summarized results of the compaction tests

Samples	MDD (g/cm^3)	OMC (%)
0W	2.01	10.48
2W	1.87	13.71
4W	1.78	14.95
6W	1.66	17.10
8W	1.58	19.57
10W	1.51	21.11
12W	1.43	21.81

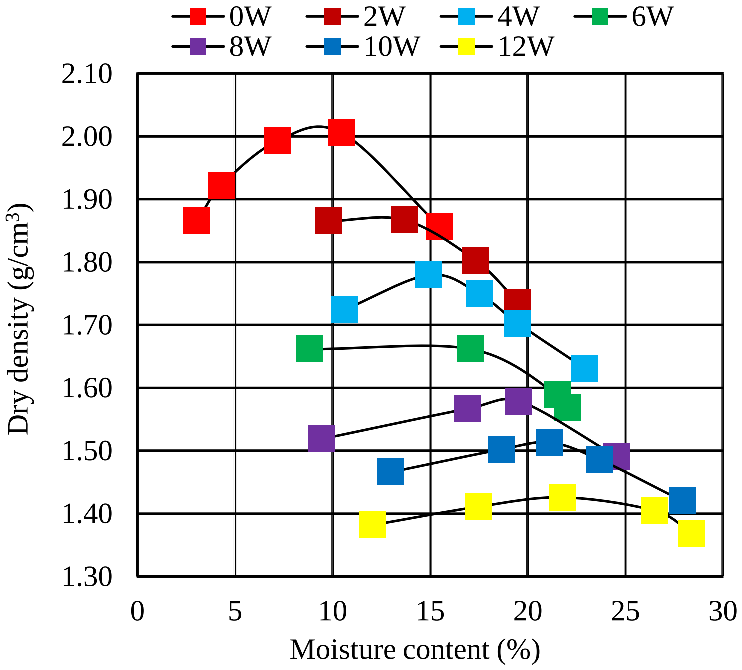


Fig. 3.16 Compaction curves

Wood fractions remaining in the recovered soil occupied more space (Rabbee and Rafizul 2012) and lay between the soils particles causing weaker inter-locking between particles. It behaves act as a separator of the particles interlocked together. Similar results have found by the previous studies while organic matter causes the lower density of the soil (Li et al. 2014; Thiyyakkandi and Annex 2011). But results found by the Laskar and pal (2013) was almost constant maximum dry density and optimum moisture content with addition of different percentages of plastic fiber content in plastic mixed soil.

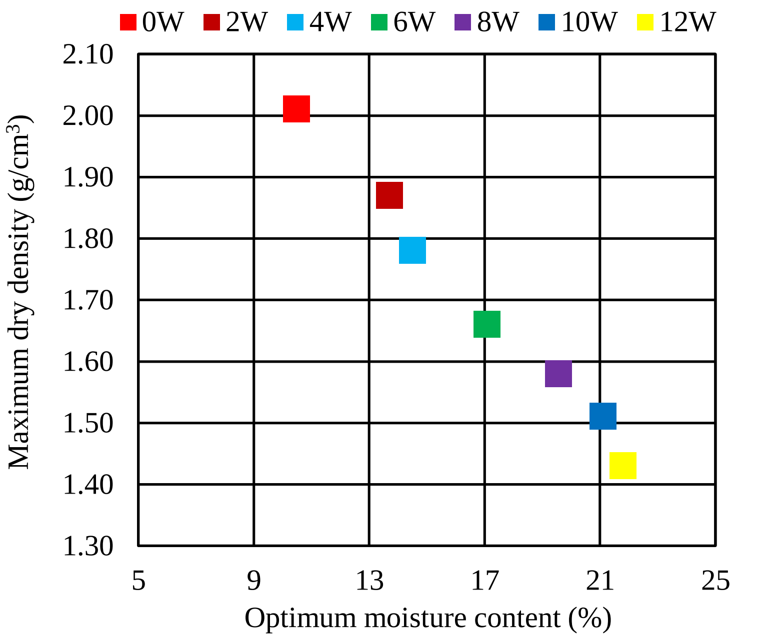


Fig. 3.17 Maximum dry density and optimum moisture content

3.3.2 Unconfined compression

3.3.2.1 Stress-strain behavior of recovered soil

The unconfined compression test results are summarized in Table 3.8. The Figure 3.18 shows the stress-strain behavior for samples prepared with wood fractions at different percentages (0, 2, 4, 6, 8, 10 and 12). Unconfined compressive stress was calculated by using the following equations (3.1)

$$\sigma = \frac{P}{A_0}\left(1 - \frac{\varepsilon}{100}\right) \tag{3.1}$$

$$A_0 = \frac{\pi D^2{}_0}{4} \tag{3.2}$$

$$\varepsilon = \frac{\Delta H}{H_0} \tag{3.3}$$

Where, σ : compressive stress (kN/m^2)

P : Compressive force applied to specimen (kN)

A_0 : Area of specimen (cm^2)

D_0 : initial diameter of specimen (cm)

ε : axial strain

ΔH : Change of specimen height (cm)

H_0 : Initial height of specimen (cm)

Table 3.8 Results of unconfined compression test

Percent of wood fractions in the samples	**Sample ID**	**Unconfined compressive strength, q_u (kPa)**	**Deformations modulus, E_{50} (MPa)**	**Axial strain (%)**
0	0W	38.93	1.42	3.22
2	2W	36.62	1.08	3.68
4	4W	35.44	1.18	3.25
6	6W	34.20	0.93	4.19
8	8W	32.15	0.78	4.45
10	10W	29.84	0.69	4.79
12	12W	29.84	0.69	4.62

Generally, unconfined compression stress increased rapidly from 0% to 3% of the axial strain and reach peak at different axial strain varied from 3% to 5%. Stress reduces after reaching the peak point. Samples which had no wood fractions, the peak of the unconfined compression stress was about 38.93 kPa while the peak of the samples which had wood fractions at different percentages (2 to 12%) was reduced to 36-29 kPa which is not noticeable. It was observed that samples having more wood fractions showed a lower unconfined compression stress compared to samples containing less wood fractions.

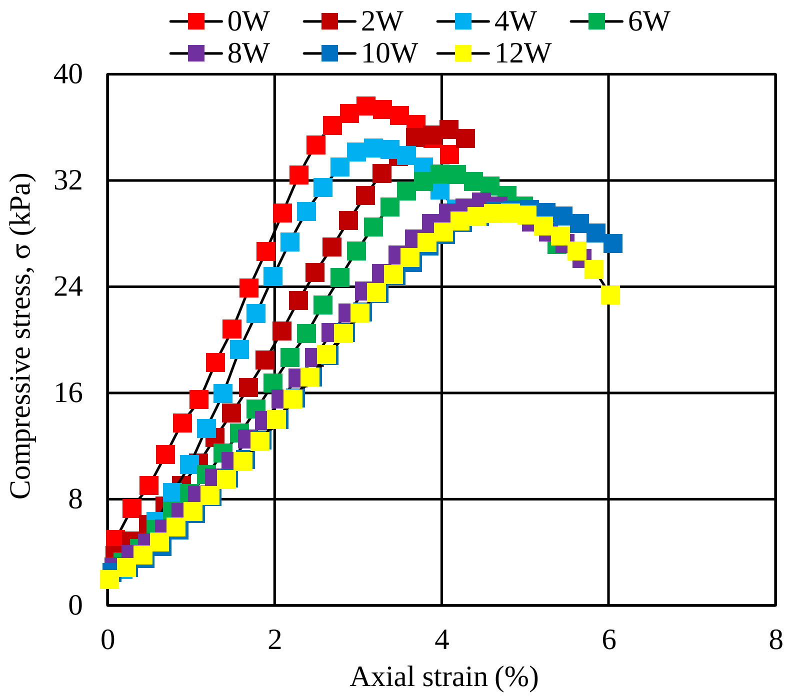


Fig. 3.18 Stress-strain relationship of the recovered soil

3.3.2.2 Unconfined compressive strength

The Figure 3.19 indicates that mean value of the three replications of unconfined compressive strength shows a decreasing trend with increasing wood content in the sample. The variation of the unconfined compressive strength from 29.84 to 38.93 kPa with the variations of the wood fractions content in the recovered soil from 12 to 0%. With the addition of wood fractions, the behavior of soil characters may have changed for example dry density decreases and moisture contents increases resulted in strength reduction. But, main reason may be the weak binding strength between soil particles resulting soil structure affected. This result is consistent with the similar results and interpretations given by the Ranjan et al. (1994), Franklin et al. (1973), Huat et al. (2009).

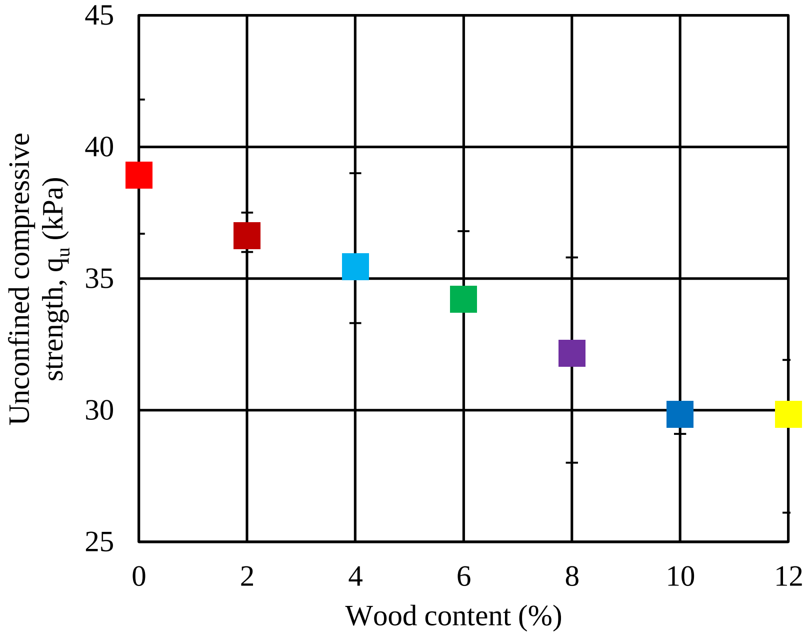


Fig. 3.19 Unconfined compressive strength and wood content

3.3.2.3 Deformation modulus (E_{50})

The deformation modulus was obtained from the stress- strain curve which was a non-linear curve (Fig. 3.18). In this research, the deformation modulus for the recovered soil with different percentages of wood fractions was calculated by using the following equation 3.4:

$$E_{50} = \frac{q_u}{20\varepsilon_{50}} \qquad (3.4)$$

Where, E_{50} : Deformation modulus

q_u : Unconfined compressive strength (kPa)

ε_{50} : Compressive strain (%) at the compressive stress $\sigma = q_u/2$

For all samples, the mean of the three replications of deformation modulus was varied from 1.42 to 0.69 MPa along with wood fractions varied in the samples from 0 to 12% (Table 3.8). This deformation modulus depends on the wood fractions remained in the recovered soil. Due to wood fractions inclusion in the samples, deformation modulus showed decreasing trend while it is observed that deformations modulus at 10W and 12W samples showed the exactly same value (0.69 MPa) which was also less than half compared to 0W sample. Moreover, Fig. 3.20 showed that the deformation modulus tends to decrease with increasing wood mixing ratio while after sample 10W it seems to be constant. Thus, the results indicate, wood fraction contents after 10% in the recovered soil may be apparently no influence on the deformation modulus characteristic.

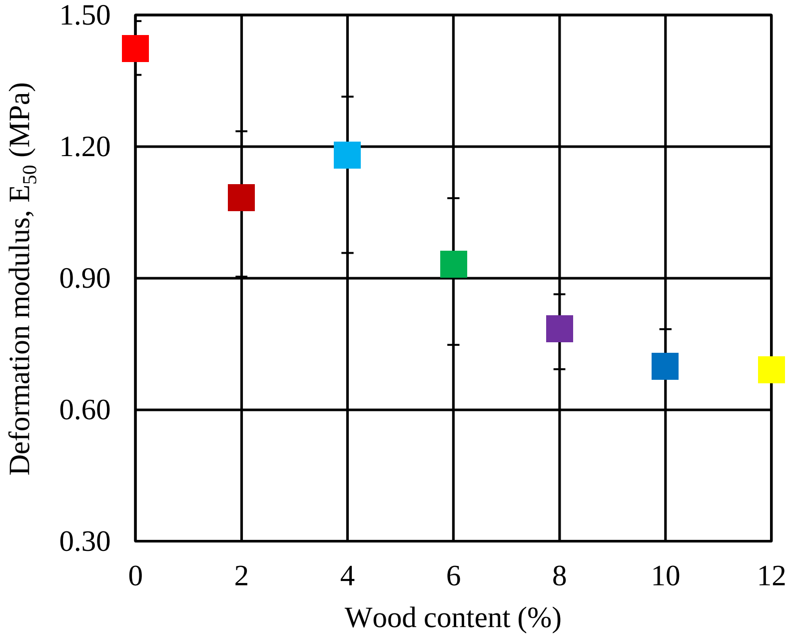


Fig. 3.20 Deformation modulus and wood content

3.3.3 California bearing ratio (CBR)

The California Bearing Ratio (CBR) test was conducted on recovered soil with simulated samples and shown load-penetration behavior in the Figure 3.21 (a, b, c). Generally, from the results it can be seen that for any constant penetration depth the load decreased with wood fractions inclusion whereas load consistently increased for any given two consecutive point for a particular sample. It is also seen that initially, load increased very slowly and then gradually it goes up for every cases.

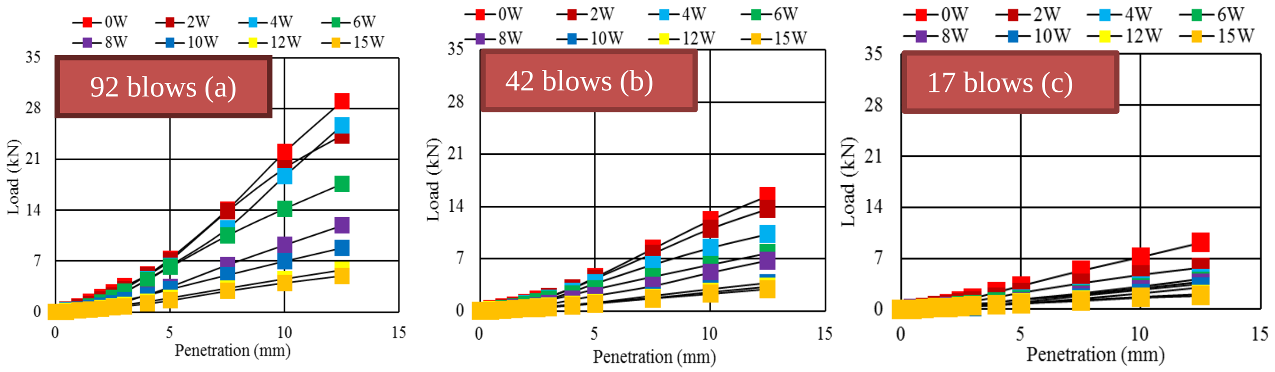


Fig. 3.21 load penetration curve at different blows

It can be observed that samples containing more wood fractions showed less load bearing capacity compared to samples containing less wood fractions. The Figure 3.22 presents change of the expansion ratio with time. The water absorption did not stop even after four days passed. However, the expansion ratio of each sample was satisfactorily over the expansion ratio of 3%, which is a requirement for the reconstruction materials (MLIT 2012a). In this Figure 3.22, based on the expansion ratio, up to 4W samples, soil particles seems to be compacted and at 6W may be transition while afterwards all samples may be loose state because of higher water absorption capacity of wood fraction.

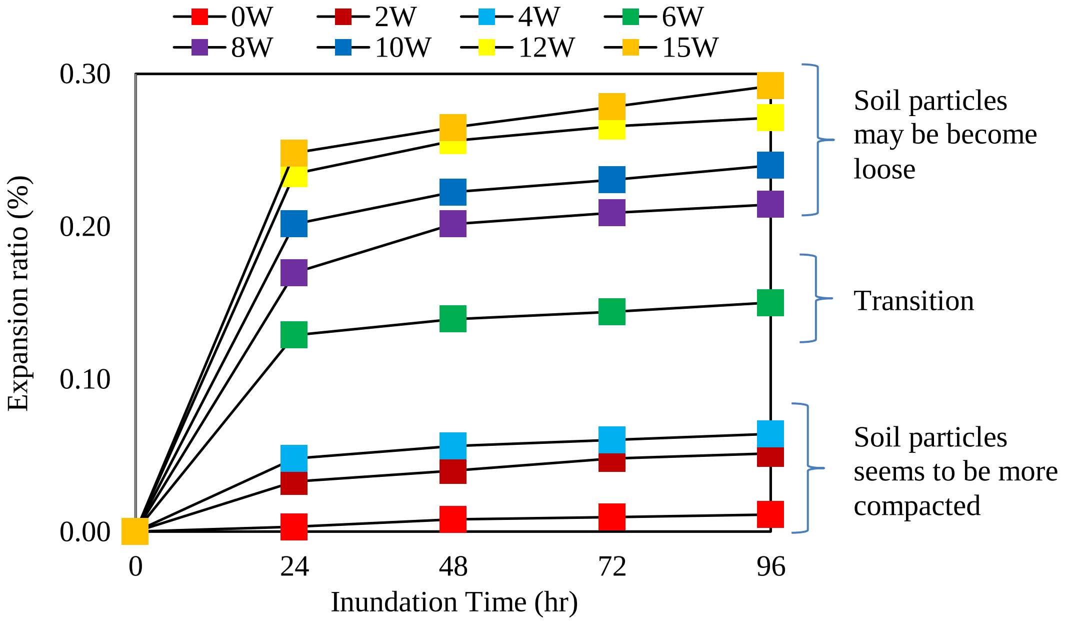


Fig. 3.22 Change of expansion ratio with time

The CBR value along with % loss of CBR value for each sample compared to control sample (without wood fractions) were determined in the laboratory for soil mixed with varying percentage of wood fractions content and results are shown in Table 3.9. While the Figure 3.23 indicates that CBR value decreases with wood fractions inclusion. Similar results found by Singh and Mittal (2014), Khalid et al. (2014), Singh (2013). However, the loss of CBR value was calculated by using the following formula:

$$CBR_r = \frac{CBR_r - CBR_c}{CBR_c} \tag{3.5}$$

Where, CBR_r = CBR for recovered soil

CBR_c = CBR value for control soil

Table 3.9 CBR value of different samples of recovered soil

Sample	CBR value (%)	Loss of CBR = $(CBR_r\text{-}CBR_c)/CBR_c$	% loss of CBR of recovered soil
0W	28.0	0	0
2W	26.0	0.07	7
4W	24.0	0.14	14
6W	23.0	0.18	18
8W	13.75	0.51	51
10W	11.4	0.59	59
12W	7.75	0.72	72
15W	6.0	0.79	79

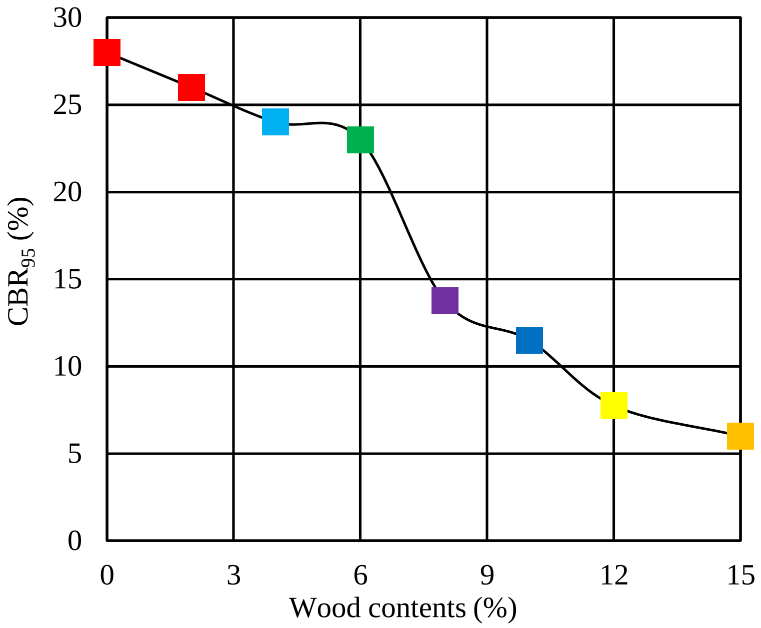


Fig 3.23 CBR value and wood contents

Based on the results, it is appeared that maximum loss of CBR value (compared to previous value) found at 8W sample. It is also seen that, CBR value decreased slowly with samples containing less wood fractions and it's up to 6W sample while similar trend observed from at 8W to 15W samples case. The rate of decrease was smaller and consistence both at lower (WF ≤ 6%) and higher (WF>8%) wood fraction contents. But, somewhere in between 6w and 8W samples, there was a dramatic reduced of CBR value obtained. This was may be because of the fact that wood fractions, of lower basic density (0.36), occupy a relatively large volume in the composite. Thus, with higher wood fraction contents, the quantity of soil matrix available for holding the wood fractions was insufficient to develop an effective bond between wood and sand. Besides, it can be explained that beyond 6% wood fractions by dry weight, the mixing of the wood fractions and soil was impracticable as balling up of wood fractions takes place and a uniform distribution cannot be obtained. A conceptual diagram is shown in the Figure 3.24 focusing on soil-wood interactions at different samples of CBR test. Based on this result, this Figure 3.24 can be interpreted that up to 6W sample, soil particles may be interacts with strong interlocking each other, afterwards this interlocking becoming weaker between soil particles because of more wood fractions inclusion along with soil reductions at constant volume.

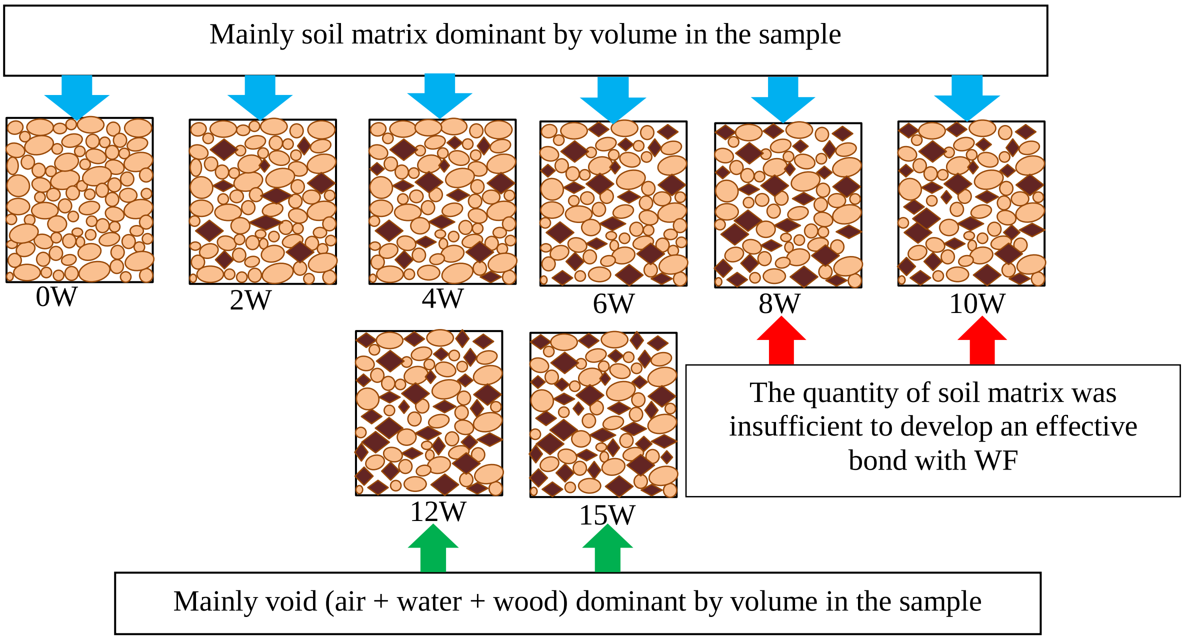


Fig.3.24 Conceptual diagram of wood-soil interactions at different samples

3.3.4 Compressibility

The compressibility behavior of soil specimens was studied in an Oedometers to determine the compressibility characteristics of recovered soil. The purpose of the compressibility test was to obtain the data that may be used in explaining the void ratios versus normal stress ($e - \log p$ curve), deformation characteristic in terms of settlement, compression index (C_c) and compression ratio (CR) at varying wood fractions contents of 0 to 10% in the recovered soils. The summary of the results (after compression) for each sample shown in Table 3.10 and hence discussed in the followings section.

Table 3.10 Summarized results of compressibility test

Sample	Void ratio (e)	Compression index (C_c)	Compression ratio (CR)	Settlement (S_f) (h= 7 cm)
0W	0.38	0.023	0.017	0.13
2W	0.48	0.054	0.036	0.22
4W	0.55	0.104	0.064	0.30
6W	0.66	0.144	0.082	0.40
8W	0.81	0.165	0.085	0.48
10W	0.91	0.196	0.095	0.52

3.3.4.1 Void ratio (e)

The result of the variations of the void ratio (it is important to mention here that volume of wood also considered as part of volume of void) with wood fractions inclusion is shown in Table 3.10. Equilibrium void ratio of the recovered soil at the end of the each pressure increment was calculated using the height of soil solids method and observed in the Figure 3.25. The initial void ratio was lower for control soil and increased with wood fractions inclusions in the soil. The void ratio increased with increase wood fractions contents while up to 4 % sample the void ratio did not decreased noticeably with higher pressure but afterward (6-10% samples) decreased significantly. Moreover, reduction of void ratio tend to be higher for samples containing more wood fraction while slope of the $e - \log p$ curve increase due to wood fraction inclusion at higher pressure. These slopes of the $e - \log p$ curve showed significantly higher at higher pressure for samples containing more wood fractions as compared to samples containing less wood fractions. More particularly 0W and 2W sample almost no slope of the $e - \log p$ curve rather there was distinct slope of the $e - \log p$ curve found in case of 4W to 10W sample at higher pressure especially at 8W and 10W samples.

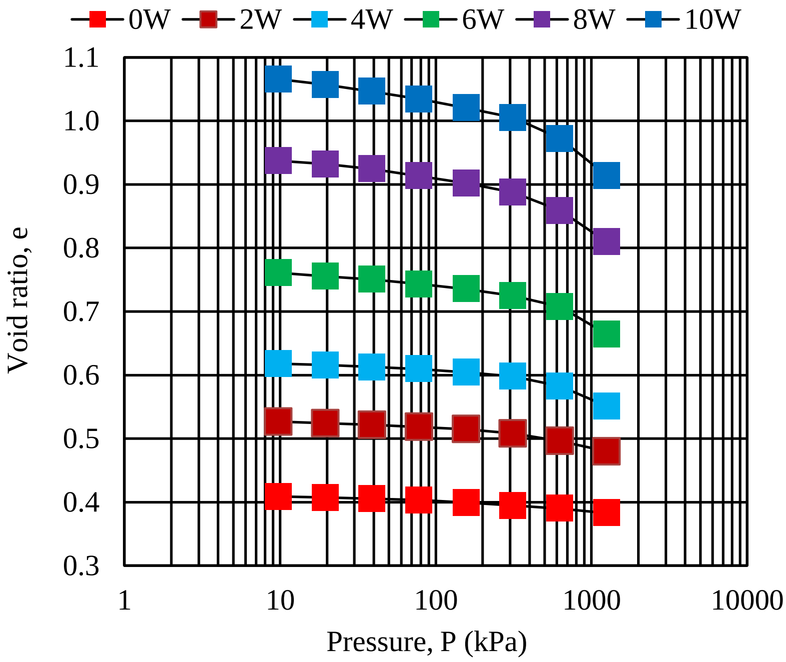


Fig. 3.25 Void ratio and pressure

On the other hand, the variation of the initial void ratio (e_o) with the increase of wood fractions is shown in the Figure 3.26. This Figure showed that there was definite increasing trend of e_o as a linear variation with increase of wood fractions contents. Here, e_o had significantly increased from 0.41 to 1.07 with the increase of wood fraction contents from 0W to 8W but at after 8W, the initial void ratio increased a bit slower. The finding was similar to organic soil while in organic soil void space was more and filled it up by air or/and water (Rabbee and Rafizul 2012). Moreover, several studies described that physical properties were changed significantly with organic fractions remain in the soil (Oades 1989; Huat et al. 2009).

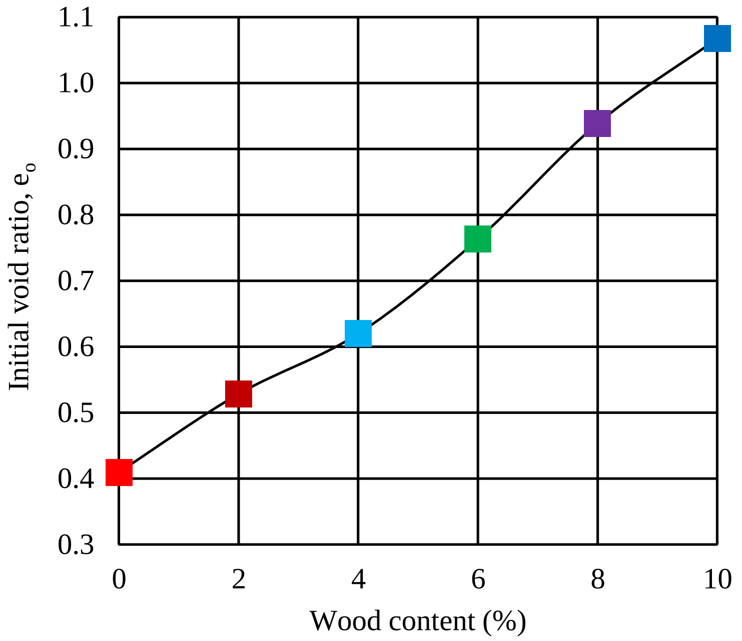


Fig. 3.26 Variation of initial void ratio with increase of wood fraction pressure

3.3.4.2 Compression index (C_c)

Compression indices (C_c) of soil with various wood fractions contents were determined from the void ratio-pressure relationship ($e - \log p$ curve) while slope of the $e - \log p$ p curve increased as increased the wood fractions. It indicates that the compressibility of the recovered soil increased as wood contents increased and result varied from 0.023 to 0.20. The Figure 3.27 indicates the compression index and shows increasing trend with wood fractions inclusion and it was noticeable at higher wood content case. It is appeared that compression index value had increased significantly (from 0.023 to 0.15) up to 6W sample while afterwards, the value of C_c increased relatively a bit slower (at 8W) and then again shows higher trend at 10W. So, the rate of C_c value increased relatively higher but a bit slower at 8W while at 10W it showed again higher tendency. This phenomenon was occurred may be due to wood–soil particles interactions. However, the C_c value of this research was consistent with results found by the other researchers Landva et al. (2000), Chen et al. (2009) and Vilar and Carvalho (2004). Moreover, Edil (1997) explained that organic content in the soil lies in between 6 to 20%, it behaves of organic silts and clay. The results found in this research supported well with the statement given by Edil (1997). To predict the amount of settlement, knowledge on C_c of soil must be understood to solve the soil engineering problems. However, the composition of the soil mass along with its pore spaces affects the amount of settlement (Rabbee and Rafizul 2012). Therefore, the settlement of the recovered soil was explained later in the following sub-section.

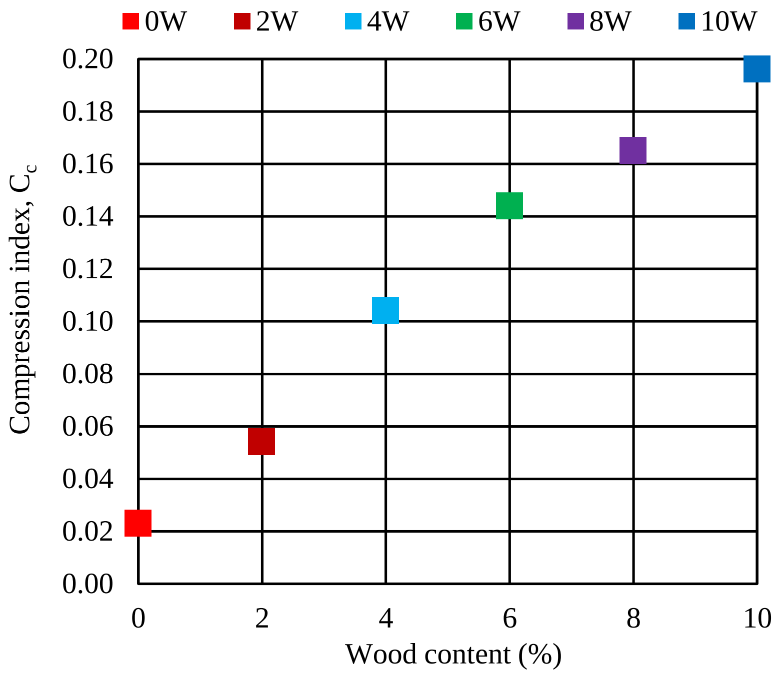


Fig. 3.27 Compression index and wood content

3.3.4.3 Compression ratio (CR)

The compressibility parameter $C_c/1+e_0$ was more reliable than parameter C_c alone and comparisons of compressibility would be better on the basis $C_c/1+e_0$ rather than C_c (Wesley 1988). The similar trend of compression index was found in case of compression ratio (CR). Moreover, Saxena et al. (1978) adopted this approach and defined $C_c/1+e_0$ as compression ratio (CR). The Figure 3.28 indicates the variations of compression ratio from 0.02 to 0.10 with wood fraction inclusions and the trend of compression ratio, CR was similar as compression index C_c while CR value increased almost linear up to 6W. But, in between 6W and 8W samples showing almost same CR value which was indicating equilibrium state. Interestingly, after 8W sample the CR value showing increased trend which is also shown in case of C_c. The CR value of the recovered soil seems to be very slightly compressible (0-0.05) to slightly compressible (0.05-0.10) soil according to classification made by O'Loughlin and Lehane (2003).

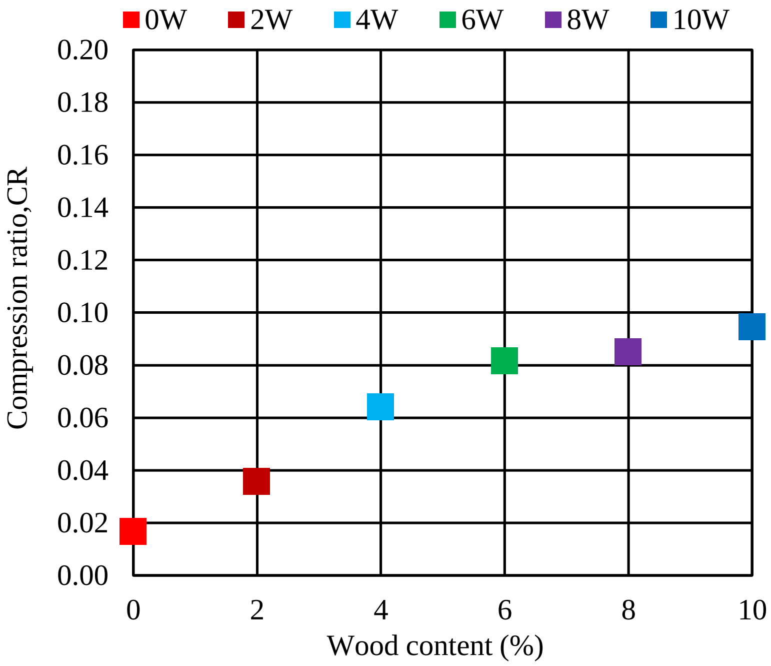


Fig. 3.28 Compression ratio and wood content

3.3.4.4 Settlement

The results shown in the Figure 3.29, the settlement of the specimen was increased with increased wood fractions inclusion along with increment of pressure while significant increased found at samples containing more wood fractions (8W and 10W) along with higher pressure as compared to control soil. Moreover, settlements which were achieved when the specimens reached at total compression during the compressibility test indicated that specimens with higher percentage of wood fractions experienced higher subsidence. The settlement of samples varies from 0.13 cm to 0.52 cm with various wood contents in samples ranging from 0 to 10% at higher pressure (Fig.3.29). The Figure 3.30 showed the variations of compressive strain of the samples from 1.90% to 7.44% with increased wood fractions inclusion from 0% to 10% at higher pressure which may not be noticeable.

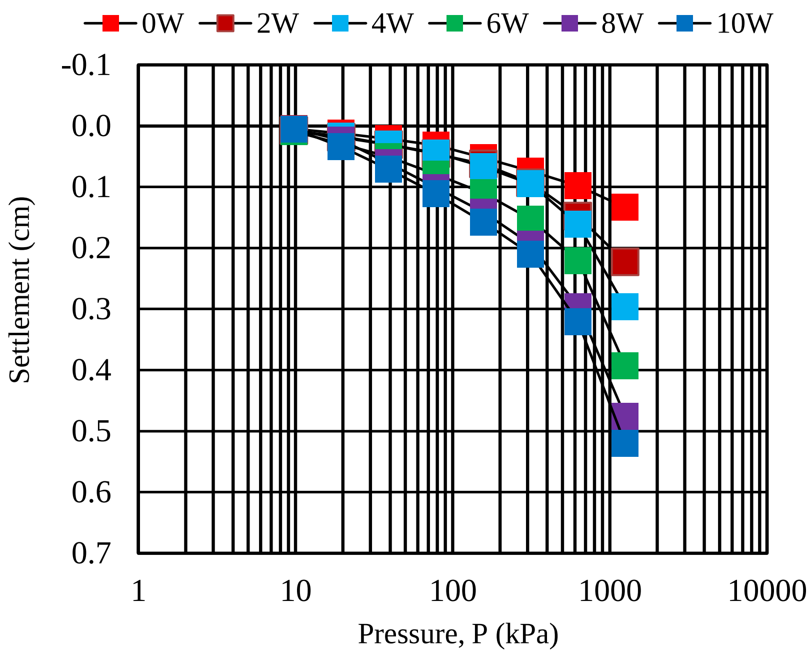


Fig.3.29 Settlement and pressure

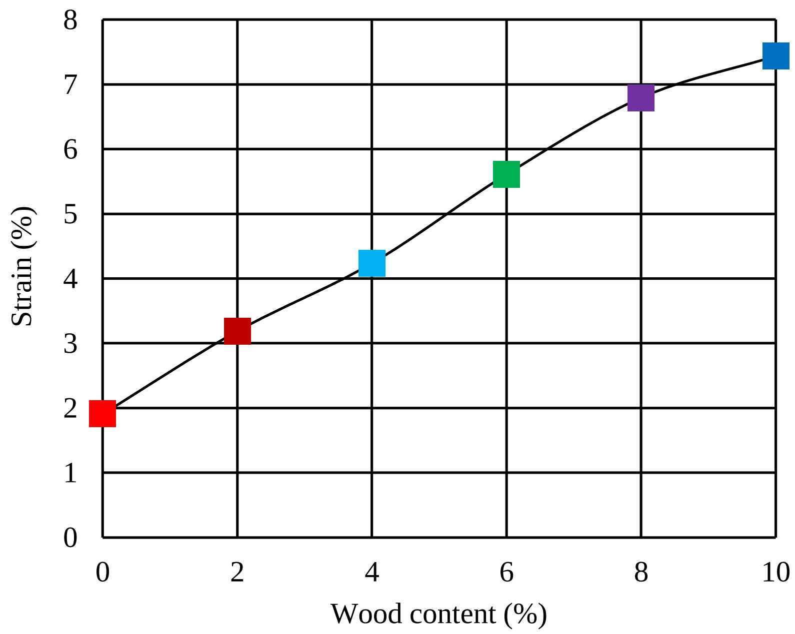


Fig. 3.30 Strain and wood content

3.3.5 Effects of wood fractions inclusion on the engineering properties of recovered soil

The relationship between wood fraction contents and void ratio (V_v/V_s) at different percentages of wood fractions is calculated from CBR test results and is illustrated in the Figure 3.31. The variations of the void ratio varied at different compaction energies and compaction degrees which were found in compaction, compression, CBR and compressibility test. The void ratio, found from different tests with different compaction energies, followed a similar trend while it is increased with increased wood fractions inclusion in the sample.

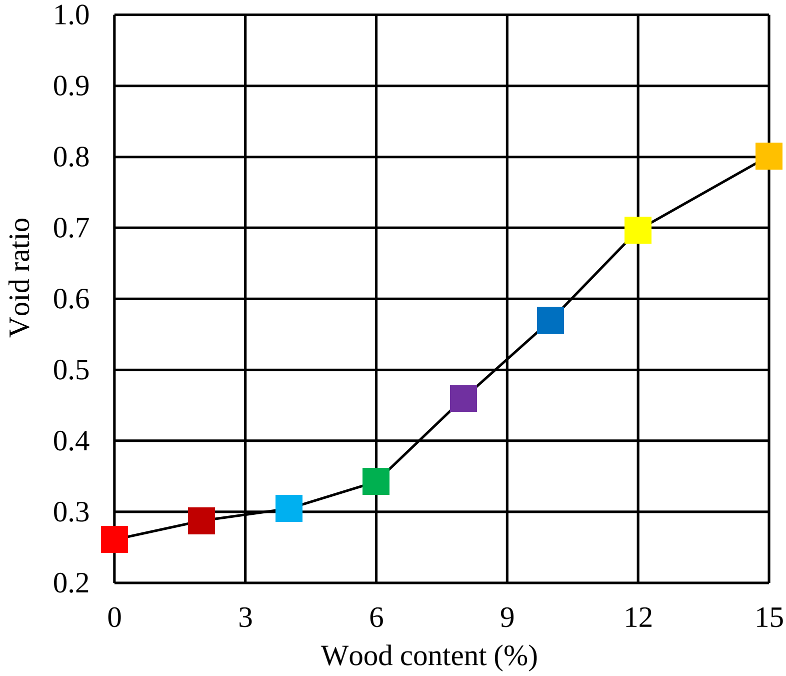


Fig. 3.31 Void ratio versus wood content

In the Figure 3.31 shows that the void ratio for recovered soil without wood fractions is extremely low (0.26) as normally sandy soil has relatively higher void ratio (Babu and Choukesly 2011). The reason behind of this low void ratio was compaction energy, while samples were compacted by using modified compaction test which is indicating more energy applied. Therefore, larger particles were crushed into smaller particles which occupied the void space between larger particles. This research proved this phenomenon by conducting particle size distribution test before and after compaction of the recovered soil (Fig. 3.32). Thus, void ratio of the recovered soil without wood fractions showed extremely low. This is the nature of the decomposed granite soil while particles crushing are the common issue for this soil due to higher load (Kwon and Oh 2011). But, it was observed that up to 6% wood fractions in samples, void ratio increased consistently while after that void ratio seems to be increased significantly. May be this significant increased void ratio at sample 8W, is one of the reasons of dramatic reduction of CBR value.

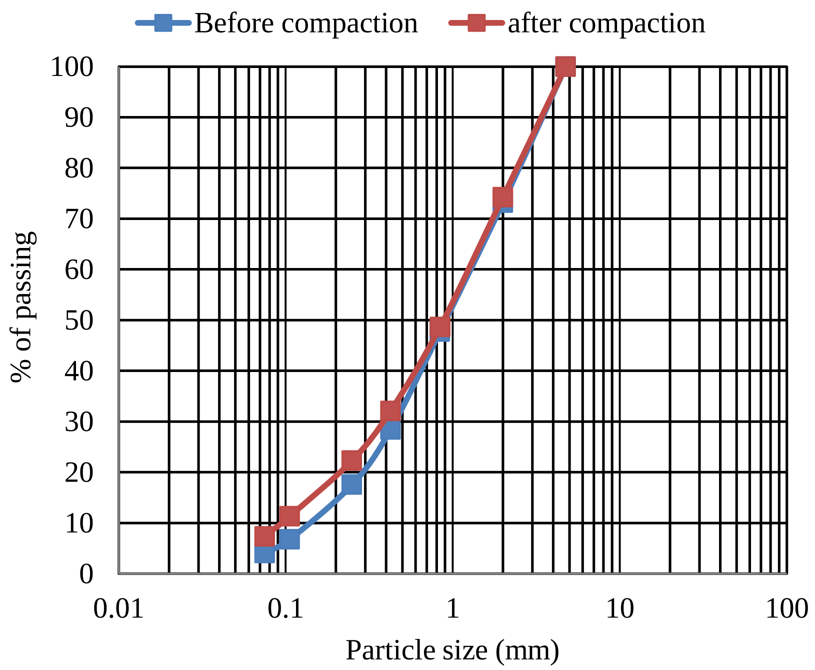


Fig. 3.32 Particle size distribution of recovered soil at after and before compaction

Moreover, wood fractions inclusion affects the soil structure resulting significant void increased, especially at samples containing more fractions. The conceptual diagrams of recovered soil showed soil particles and wood fractions interactions in the Figure. 3.33 that could be used to explain the behavior of the recovered soil as well. This phenomenon was tried to explain based on the principle illustrated by Thevanayagam (2007) and proposed different scenario of intergranular matrix of two different size particles (Fig. 3.34). With wood fraction inclusions, soil particles were reduced by both the volume and by dry mass while it is assumed that structure of the specimen significantly affected, especially at samples containing more fractions for example 8% sample. Wood fractions occupied space between soil particles even in void created by the larger particles while presence of wood fractions, soil particles interactions may be weaker. Therefore, wood seems to be acting as separator of particles as the phenomena explained by the Thevanayagam (2007) while small particles were acting the same phenomena in the intergranular soil mix (case ii and iii). Moreover, wood absorbed more water and was swelled for which void structure was affected. Instead of increased void, there was another possibility that was inter-locking system between soil particles becoming loose with wood fractions inclusions. Therefore, strength of the recovered soil (both UCS and CBR) was decreased with increased wood fraction that is obtained in the experimental results.

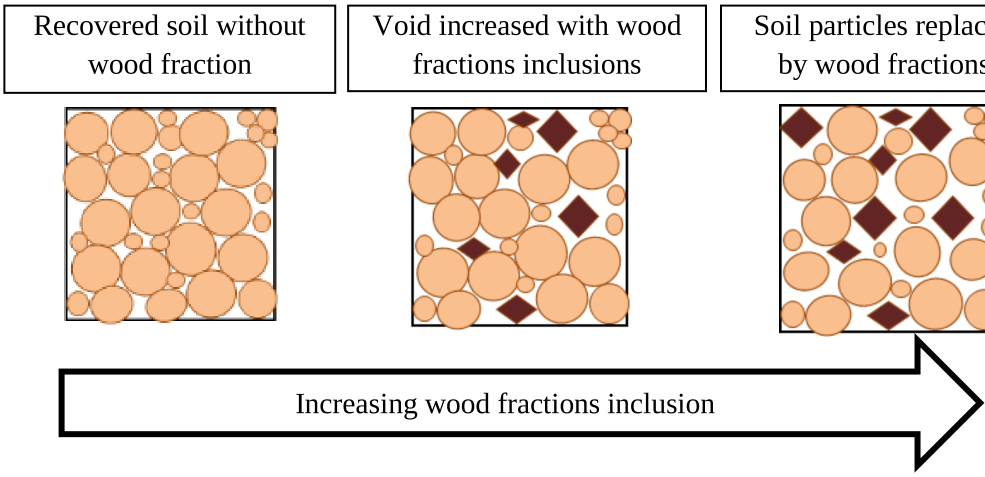


Fig. 3.33 Conceptual diagrams of soil particles and wood fractions interaction

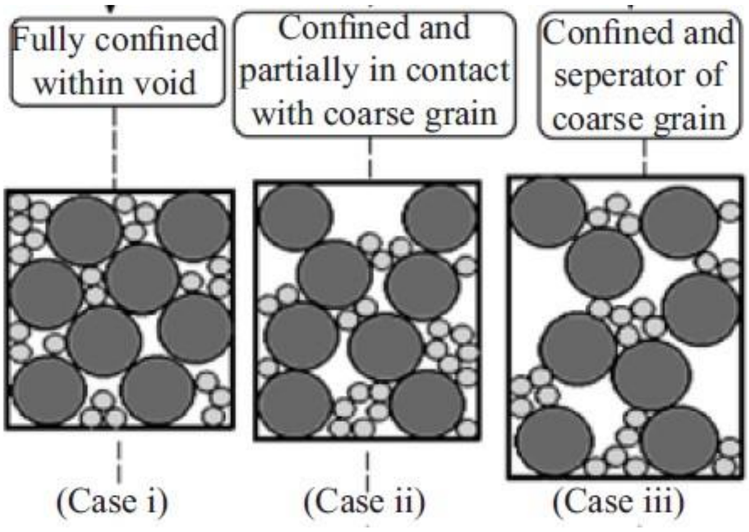


Fig. 3.34 Intergranular soil mix classification (Thevanayagam 2007)

On the other hand, this research also calculated the $(V_v+V_W)/V_s$ while it was assumed that wood was a part of void and made a relationship between $(V_v+V_W)/V_s$ or V_v'/V_s as void ratio versus CBR value (Fig. 3.35). The Figure 3.35 showed the relationship between CBR value and void ratio while void ratio value V_v'/V_s varied from 0.26 to 1.41 along with wood fraction contents from 0 to 15%. The Figure 3.36 indicates the similar trend that was found in case of relation between V_v'/V_s versus UCS value while it $(V_v'/V_{s)}$ value varied from 0.36 to 1.15 with wood fractions inclusion varied from 0 to 12% .

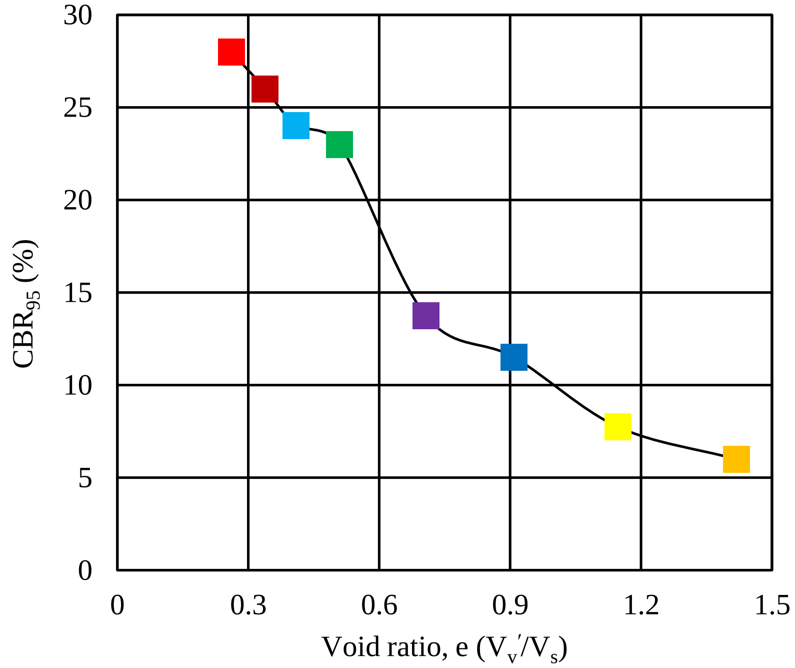


Fig. 3.35 CBR value versus void ratio (V_v'/V_s)

However, the Figure 3.35 may appear that void ratio increased significantly from 6W sample to 8W sample and resulted in CBR value reduced dramatically. That means, sample 8W seems to be loose. But, may be there was another reason behind the strength reduced rather than void ratio. In this connection, the quantity of soil matrix may be insufficient at 8W sample to make effective bond with wood fractions resulting weaker inter-locking system exits. The similar explanation was made about plastic fiber-sand inter-locking system at higher fiber contents (>2%) by the Ranjan et al. (1994). Therefore, this weaker bonding may lead to significant reduction of strength.

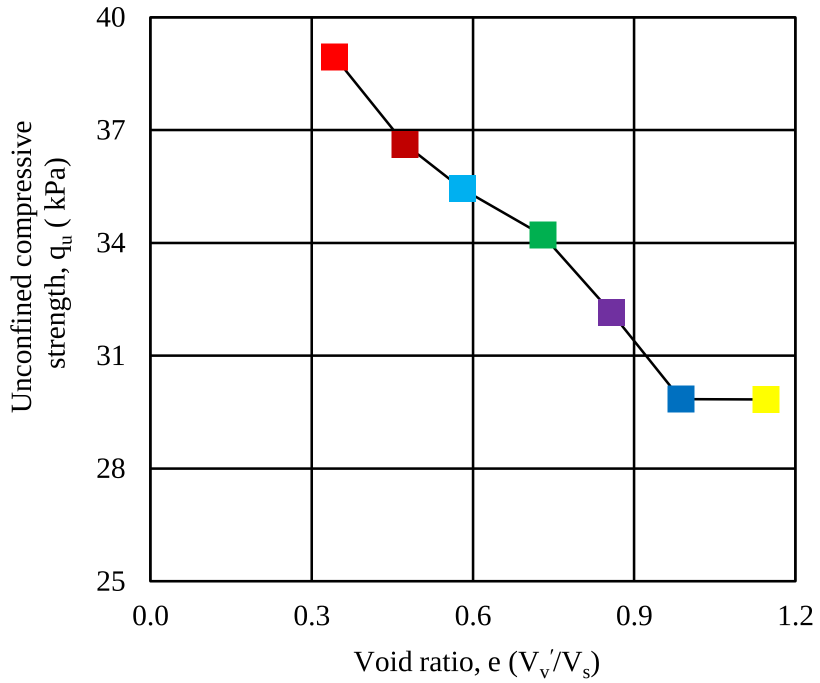


Fig. 3.36 UCS value versus void ratio (V_v'/V_s)

The similar predictions were also observed in the compressibility test results that was explained earlier in the above sections and found that compressibility was increased with increased wood fractions inclusion. While at 8W sample seems to be the similar behavior of CBR and UCS results. In addition, about the compressibility of the samples, the possible relationship between coefficient of volume changes and pressure along with wood fraction inclusions are plotted in the Figure. 3.37. In this Figure, volume was reduced with increased pressure along with wood fractions inclusion while 8W sample or more seems more volume reduced as compared to others. This volume change was one of the possible reasons of the compressibility of the recovered soil with increased wood fractions inclusion.

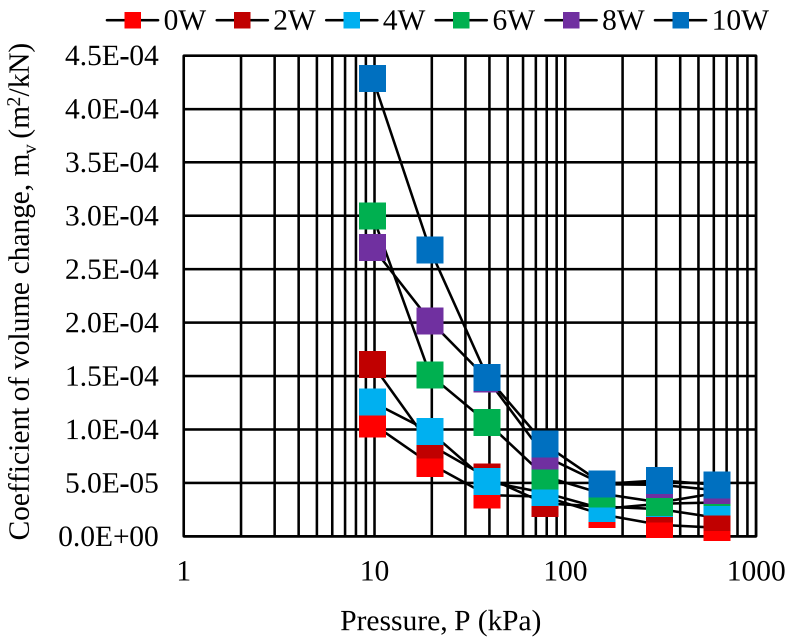


Fig. 3.37 Variation of volume changes versus pressure

The differences in compressibility and strength for samples containing less and more wood fractions might be influenced by the volume change, particles crushing and interlocking between particles. This particle crushing tendency may be more, for samples containing more wood factions because of higher ignition loss value; void ratio and moisture contents of the recovered soil (Matsou et al.1979; Murata et al. 1987; Yasufuku and Kwag 1999; Ham et al. 2010) and these were obtained in this study. Thus, the results showed that larger volume was reduced for samples containing more wood fractions compared to samples containing less wood fractions due to reduction of soils and crushability of the soil particles. This larger volume reducing leads to the compressibility of the samples. The similar behavior was observed in the previous research conducted by Kokusho et al. (2004) and Chau (2013). On the other hand, the strong interlocking between soil particles lead to the increases strength while particle crushing decreases the strength. In this study, samples containing more wood fractions seems to be larger breakage of particles while presence of wood fractions between soil particles may lead to weaker interlocking between particles. Thus, the strength of the samples containing more wood fractions was reduced compared to results from samples containing less wood fractions. These results are consistence with similar results presented by Chau (2013), Fragaszy (1990), Kokusho et al. (2004).

However, based on the results found from CBR test, a simple linear regression model was developed to interpret the effect of input variable (e) to output variable (cbr).

3.3.6 Regression model

The engineering properties of the recovered soil was examined by focusing on wood fractions inclusions at various ratio while a series of CBR tests were conducted to understand the strength properties of the recovered soil. The experimental results quantitatively analyzed by simple linear regression model was used to establish relationships between output variable CBR (Y_{cbr}) with input variable void ratio (X_e). The output of the linear regression model is presented in Eq. 3.6.

$$Y_{cbr} = \beta_0 + \beta_1 X_e + \boldsymbol{\varepsilon} \qquad (3.6)$$

Where, Y_{cbr} is the output variable (CBR) and β_0 and β_1 are the parameters to be estimated as a part of the regression analysis, X_e is the input variable and $\boldsymbol{\varepsilon}$ is the error.

In this study, only one input variable void ratio was considered, thus, we developed simple linear regression model rather than multiple regressions. It was importantly noted down here that we tried to run multiple regression model with three different input variables namely volume of soil, volume of wood and volume of void that greatly affect CBR value of the recovered soil. But, there was problems found because of multicollinearity exits among the three variables and poorly explained the model. Therefore, we considered the void ratio as input variable which was calculated by using these three variables and developed a good regression model while results of this model are presented in the Table 3.11. The following regression model is developed (Eq.3.7) using the input variable void ratio (X_e) which explains the variations of the output variable CBR (Y_{cbr}).

$$Y_{cbr} = 32.029 - 20.396 X_e \qquad (3.7)$$

Table 3.11 Results of regression model for CBR of recovered soil

Variables	Coefficient	SE	t-stat.	P-value
Intercept	32.029***	1.723	18.59	0.000
X_e	-20.396***	2.125	-9.60	0.000
F-value	92.160***			
R^2	0.939			

Note: *** indicates 1.0 % level of significant

The regression model stated above confirmed that void ratio and CBR value was inversely and significantly correlated each other. Thus, wet can be interpreted that with 1 unit increase in void ratio the CBR value of the recovered soil significantly decrease by 20.396 units. In addition to this model, the best fit trend line for all samples as shown in the Figure 3.38.

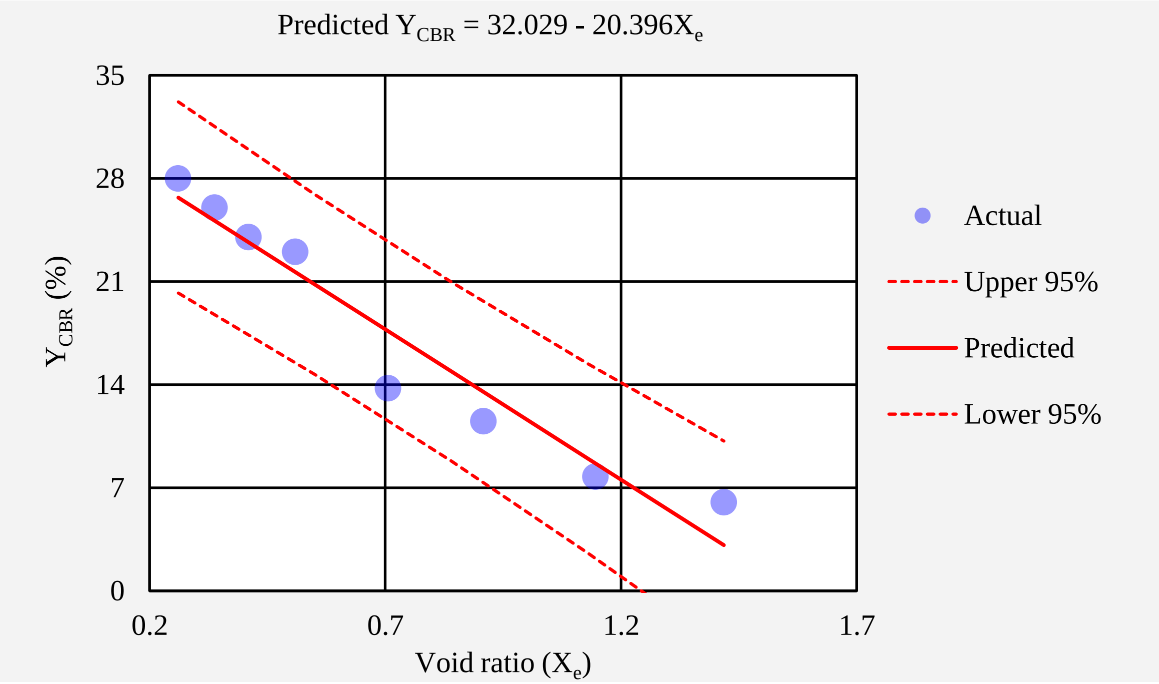


Fig. 3.38 Effects of void ratio on the predicted and observed CBR of recovered soil

All observed values are located very close to predicted line and thus, value and behavior of predicted CBR obtained from the regression model was in agreement with the observed CBR obtained from the experimental results. Therefore, results indicated that the developed regression model has been influential to predict the CBR value of recovered soil. The similar model was used and was explained by other researchers (Singh and Vinot 2012; Ahmed 2012; Consoli et al. 2002).

3.3.7 Acceptable ratio of wood fractions for geotechnical utilizations with mechanism

Based on the above-mentioned experimental results of strength and compressibility, it is assumed that there is a transitional point at sample 8W in which soil particles may be weaker interlocking each other. This weaker condition of the sample is verified by the e_{max} of the soil fractions. In this case, ratio of soil fractions volume is calculated by using e_{max} of the soil that is 0.515 (eq. 3.8) which means that soil particles are loose state or no interlocking each other (Fig.3.39). It is important to mention here that volume of wood fractions was assumed as a part of volume of void (V_v ') while V_v' is consist of volume of air and water (V_{a+w}) and volume of wood fractions (V_{wood}). (Fig. 3.40). The Figure 3.41 shows the ratio of soil fractions volume over the total volume of the composite (Vs/V), in relation to the wood content. From this Figure, soil volume ratio is exactly 0.515 when wood fractions content is 8%. This means that soil particles at 8W sample are no more interlocked each other and/or loose state.

$$\frac{V_s}{V} = \frac{V_s}{V_s + V_v'} = \frac{1}{\frac{V_v'}{V_s} + 1} = \frac{1}{1 + e_{max}} = 0.515 \qquad (3.8)$$

Where, e_{max} of the soil is 0.94

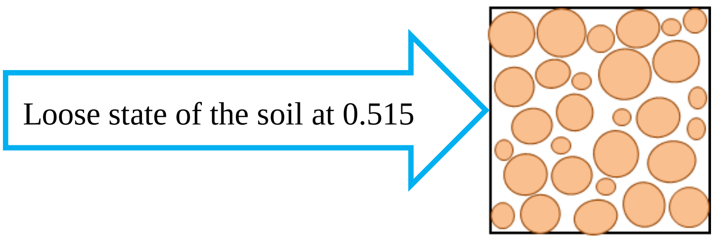


Fig. 3.39 Conceptual diagram of soil particles at loose state

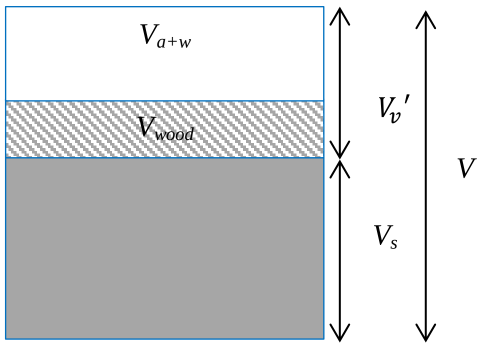


Fig. 3.40 Different elements of recovered soil

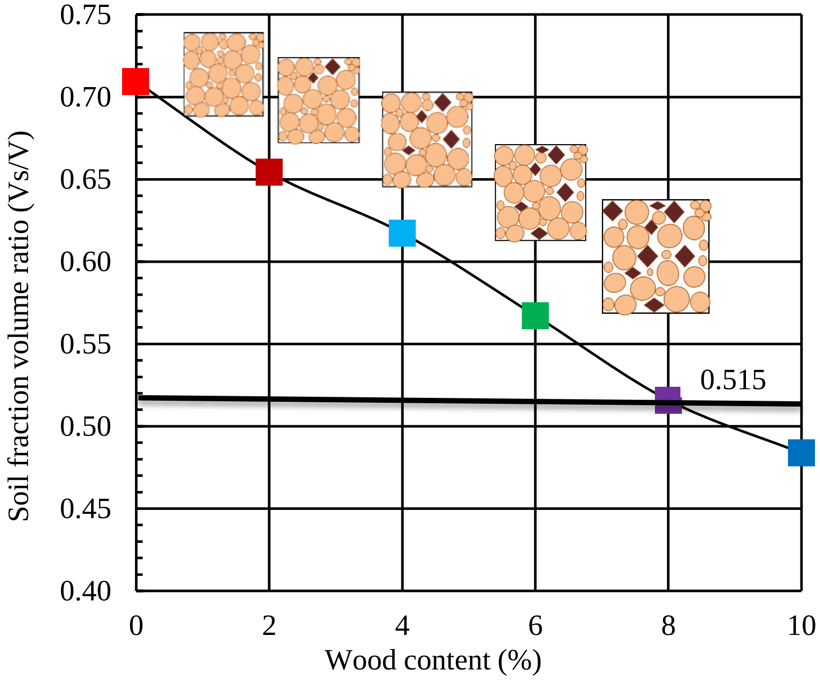


Fig. 3.41 Volume occupied with soil fraction relative to total volume of composite

Thus, at 8w sample shows dramatic reduction of strength as compared to sample containing relatively less wood fractions such as 6W. Therefore, we can make a conclusion based on this discussion that maximum acceptable ratio of wood fractions might be somewhere between 6W and 8W samples for geotechnical utilizations.

From the different experimental results and interpretations, the loose state mechanism of recovered soil can be summarized in the Figure 3.42. In this Figure, wood fractions inclusion at different percentages was the phenomenon while soil particles and wood fractions mixed together, wood fractions-soil particles interactions in addition to soil particles-soil particles was found. The amount of soil was reduced with increased wood fractions at constant total volume resulting pore structure of the samples was increased. Because, wood fractions occupied more space into the soil even lay between soil particles resulting soil particles separate with each other. Moreover, water absorbed in the micro pores of the wood fractions increased with increased wood fractions and samples becoming loose at 8W sample which is verified by the e_{max} of the soil fraction. Presence of wood fractions in between soil particles act as separator of soil particles which leads to weaker inter-locking system of the soil particles. Therefore, samples containing more wood fraction such as 8W and more become looser and showed increased pore structure and decreased dry density. Thus, the strength of the recovered soil, such as, UCS and CBR value were reduced. In the case of compressibility test, the loose state of the recovered soil and the increased pore structure lead to increase the compressibility of the recovered soil. Moreover, a higher volume change obtained with higher wood fractions contents samples resulted in increased compressibility of the recovered soil.

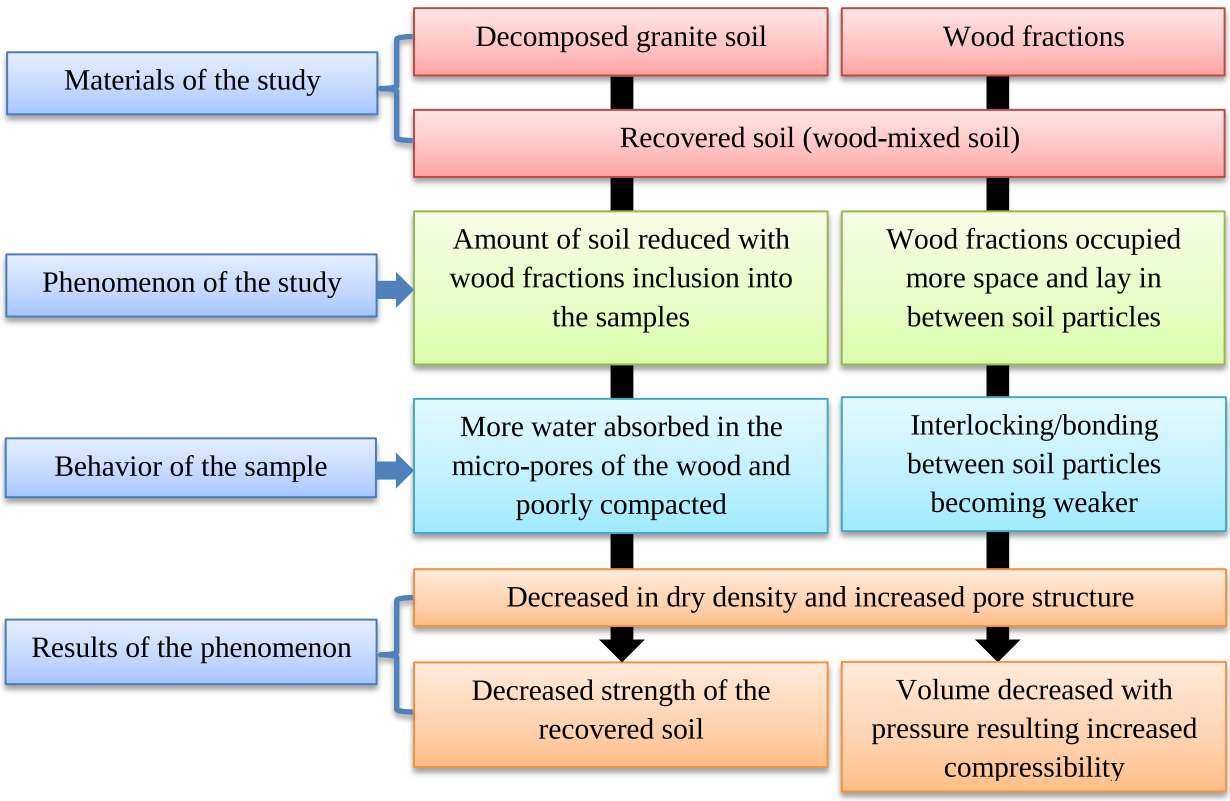


Fig. 3.42 Mechanism of soil-wood fractions interactions due to wood fractions inclusion

3.4 Conclusions for this chapter

This study investigated the effects of wood fractions on the engineering properties of recovered soil in order to utilize as geo-materials. The experimental results are summarized below:

Simulated samples prepared by mixing decomposed granite soils and different percentage of wood fractions (0%, 2%, 4%, 6%, 8%, 10%, 12% and 15%) were subjected to investigate for engineering properties. The standard compaction test results showed that maximum dry density was decreased with increased wood fractions inclusion while optimum moisture contents were increased for the same. Unconfined compressive strength of the recovered soil samples show decreasing trend with wood fractions inclusion. Moreover, samples showed a decrease trend in the deformation modulus (E_{50}) with wood fractions inclusion and become soften for samples containing more wood fractions. This trend is consistent with the decrease of unconfined compressive strength of recovered soil samples. Therefore, recovered soil of this study could be used after careful investigation of the engineering parameters.

California bearing ratio (CBR) was decreased with increased wood factions inclusion while CBR value was decreased significantly at sample contained more wood fractions (8% sample) because of loose state conditions occurred at this sample. Besides, void ratio of the recovered soil without wood fractions (0W) showed extremely low (0.26) (CBR test case) because of larger particles were crushed into smaller particles and thus, resulting void space between larger particles become filled up by smaller particles. This was observed by conducting particle size distribution test before and after compaction of the recovered soil .Thus, void ratio of the recovered soil without wood fractions showed extremely low.

The result of the compressibility test, obtained compressibility parameters, particularly compression index (C_c), compression ratio (CR), settlement (S_f) were increased with increased wood fractions inclusion. The coefficient of volume changes, obtained along with wood fraction contents increased. This volumes change was one of the possible reasons to the increased compressibility of the recovered soil with increased wood fractions inclusions.

A simple linear regression model was developed and confirmed that void ratio and CBR were inversely and significantly correlated with each other. It can be interpreted that with 1 unit increase in void ratio the CBR value of the recovered soil significantly decrease by 20.396 units. Finally, it can be concluded that maximum acceptable ratio of wood fractions in the recovered soil might be somewhere between 6W and 8W samples for geotechnical utilizations as 8W samples showed loose stated, verified by the e_{max} of the soil fractions.

CHAPTER 4: EFFECTS OF SIMULATED DECOMPOSITION OF WOOD FRACTIONS ON THE STRENGTH AND COMPRESSIBILTY PARAMETERS OF RECOVERED SOIL

4.1 General Remarks

Organic matter in the soil is an important element for agricultural production but it is problematic for geotechnical utilizations (Huat et al. 2009). The result is attributable to decomposition behavior of the organic fractions that remain in the soil. As recovered soil has wood fractions at different percentages, moreover wood recognized as organic matter, therefore, decomposition of the wood fractions might affect the soil properties, especially compressibility, including physico-chemical and biological changes in wood fraction in the recovered soil. It is predicted that with the acceleration of decomposition of organic fraction in the soil, strength and compressibility properties and subsequently settlement of the soil might be changed (Hossain et al. 2003). There is rare information available on settlement related to biological decomposition of waste (like wood fractions in the soil) (Edgars and Noble 1992). Moreover, decomposition of organic fractions affects the structure of the soil particles which may increase the void spaces resulting increased settlement rate and compressibility of soil (Hossain et al. 2003). The degradation of organic matter changes the composition of solids matrix of the wastes; with the drastic changes in solids composition and increased moisture content, the mechanical behavior of wastes is predicted to be quite different than undegraded conditions (Reddy at al. 2011). Therefore, in reference to the above statements, it was expected that wood fractions remaining in recovered soil at various percentages might show similar behavior to organic matter and/or MSW according to their decompositions rate.

A good number of studies have been reported on geotechnical properties of Municipal Solid Waste (MSW) (Chau 2013; Kavazanjian 2001; Zekkos 2005; Jones et al. 1997; Vilar and Carvalho 2004; Reddy et al. 2009a) while very few studies focused on determining the effect of decomposition of organic matters/waste on their properties changes by using laboratory scale-reactor or bioreactor at laboratory (Wall and Zeiss 1995; Gabr and Valero 1995; Reddy et al. 2011). But none of research was found on effects of decomposition of wood fractions look solely at the engineering properties of recovered soil. Therefore, it is necessary to determine the effects of wood decomposition on the engineering properties of recovered soil. It is noteworthy that simulated decomposition were considered rather than natural decomposition while a certain portion of wood fractions removal was considered keeping soil particles constant in this simulated decomposition case. This phenomenon is considered based on the principle of natural decompositions of organic matter while organic matter reduces and/or transforms into gas and liquid due to decomposition

(Hobbs 1986; Huat et al. 2009; Kazemian et al. 2011). A series of unconfined compression tests and compressibility tests were carried out on these simulated decomposition samples to evaluate the decomposition effects of the wood fractions on the strength and compressibility behavior of recovered soil.

4.2 Materials and methods

4.2.1 Materials and sample simulation

The materials (soil and wood fractions) were used and explained in the previous chapter were also considered for simulated decomposition specimens preparation and ignition loss test. While decomposed granite soil which was brought from company and wood fractions were separated from disaster debris and used for sample simulations of this research as described earlier in chapter 3. Several samples composed of different ratios of wood fractions were used to understand the effects of wood fractions on the engineering properties of recovered soil but few of them specifically 3%, 4%, 6%, and 8% samples were taken into considerations to understand the effects of simulated decomposition on engineering properties of recovered soil. The reason for taking these samples was that sample 8W was already verified as loose stated and sample between 6W and 8W might be acceptable for geotechnical utilizations which was explained in chapter 3. As there was no available method of determining the effects of simulated decomposition of wood or organic fractions on the engineering properties of soil, therefore, certain percentages (20%, 30%, 40% etc.) of wood fractions was removed. Moreover, constant soil particles and total volume was considered for specimen preparations while soils and wood fractions assumed as solid of the samples (Fig 4.1). This phenomenon is derived from the theory of decomposition of organic matter while organic matter is transformed into gas and liquid due to its decomposition behavior. For example 4W sample assumed that without decomposition it has 100% wood fractions in the soil and then certain percentages of wood removed as part of simulated decomposition which is placed in the Table 4.1 for all samples taken for simulated decomposition issue. It is important to mention here that during specimen preparation samples 6W and 8W, after certain simulated decomposition case (for example 60% or more), specimen could not prepared**.** It is also important to mention here that unconfined compression test is conducted with 4W, 6W and 8W samples while 3W, 4W and 6W samples were taken for compressibility test.

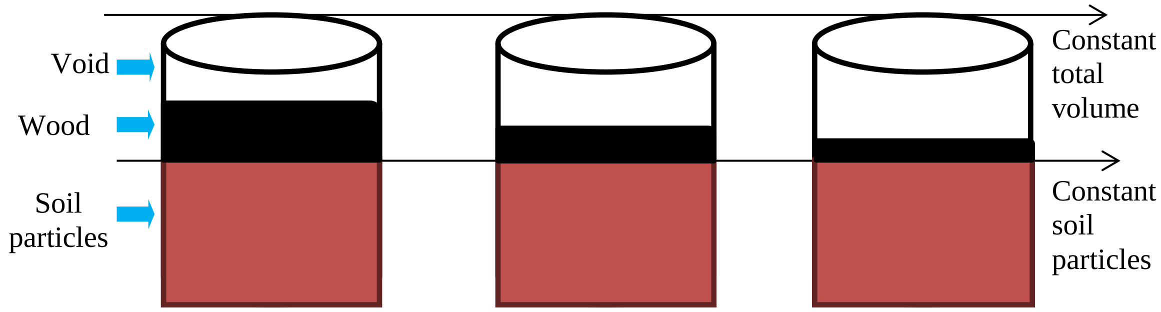


Fig 4.1 Flow chart of simulated decomposition process

Table 4.1 Samples sorting for simulated decomposition case

Name of the methods	Basic samples	Percentage (%) of simulated wood decomposition	Symbol showing on the graph (SD= simulated decomposition)
Unconfined compression test	4W	0, 20, 50, 80	0SD, 20SD, 50SD, 80SD
	6W	0, 20,30,50	0SD, 20SD, 30SD, 50SD
	8W	0, 20, 30,50	0SD, 20SD, 30SD, 50SD
Compressibility test	3W	0, 20, 50, 80, 100	0SD, 20SD, 50SD, 80SD, 100SD
	4W	0, 20, 50, 80	0SD, 20SD, 50SD, 80SD
	6W	0, 20, 40, 50	0SD, 20SD, 40SD 50SD

In this chapter, in order to understand the effect of simulated decomposition of wood fraction on the strength and compressibility parameters of recovered soil, simulated decomposition samples were tested by using two different experimental methods. A series of unconfined compression test and compressibility tests were conducted for samples with various ratios of simulated decomposition of wood fractions to achieve the objectives of the research. All tests were conducted following Japanese Industrial Standard (JIS).

4.2.2 Unconfined compression test

A series of unconfined compression tests were conducted following JIS A 1216:2009 while samples were compacted into the mold (50 mm inner diameter and 100 mm in height). About 90% or more of the maximum dry density (MDD) and optimum moisture content (OMC) according to the value obtained from the standard compaction test (Table 3.7) was used. All samples were prepared by tapping 5 layers of recovered soil into mold. For each basic samples have several specimens based on the simulated decompositions while MDD and OMC of the basic sample was considered for their respective specimens of simulated decompositions. However, three replications per specimen were done to obtain the test result; the arithmetic mean of those three was considered for each unconfined compressive strength, deformation modulus E_{50} .

4.2.3 Compressibility test

Basically, this test was conducted in an oedometer to determine the compressibility parameters of recovered soil. All experiments were carried out in a standard consolidation apparatus following JIS A 1217:2009 standard. All specimens were compacted into the consolidation ring (60 mm inner diameter and 70 mm height) while about 90% or more of the maximum dry density (MDD) and optimum moisture content (OMC) according to the value obtained from the standard proctor compaction test (Table 3.7) was used. For each basic samples have several specimens based on the simulated decompositions while MDD and OMC of the basic sample was used for their respective specimens of simulated decompositions. However, the similar procedure of this test explained in the chapter 3 is also applied in case of simulated decomposition specimens.

4.3 Results and discussions

4.3.1 Unconfined compression

The UCS test results are summarized in Table 4.2. Figures 4.2, 4.3 and 4.4 shows the stress-strain behavior of specimens prepared considering simulated decompositions issue from 0SD to 80SD for each basic sample (4W, 6W and 8W).

Table 4.2 Results of unconfined compression test for SD specimen

Basic Samples	Percent of wood removal (SD) (%)	Unconfined compressive strength, q_u (kPa)	Deformations modulus, E_{50} (MPa)
4W	0	35.44	1.18
	20	29.30	1.11
	50	22.81	0.97
	80	8.05	0.40
6W	0	34.20	0.93
	20	30.19	0.87
	30	27.83	0.98
	50	12.98	0.59
8W	0	32.15	0.78
	20	28.42	0.82
	30	17.32	0.70
	50	9.82	0.48

Generally, unconfined compression stress increased rapidly from 0% to 5% of the axial strain and reach peak at different axial strain varied from 3% to 5% along with various percentages of simulated decompositions**.** Samples containing less wood fractions for example 4W sample, unconfined compression stress increased rapidly from 0% to 3% of the axial strain and reach peak at different axial strain varied from 2 % to 3% along with various percentages of simulated decomposition (Fig.4.2). While peak reach at various axial strain range from 3% to 4% but unconfined compression stress increased rapidly from 0% to 4% of the axial strain for sample of 6W with various percentages of simulated decompositions (Fig.4.3). The Figure 4.4 showed the results of various percentages of simulated decompositions specimens of 8W sample where unconfined compression stress increased rapidly from 0 % to 5% of the axial strains and peak reaches at different axial strain range from 3% to 5%. The peak of the unconfined compression stress was relatively higher for all simulated decomposition specimens of 4W samples compared to other two samples of 6W and 8W. It was clearly indicates that up to 20SD or less SD case for all samples, the unconfined compression stress showed higher compared to higher percentages of simulated decompositions specimens. For example, the unconfined compression stress of 40SD or more for 6W and 8W samples showed significantly reduced compared to 20SD or less simulated decompositions case while similar trend was found in case of 4W sample for the same phenomenon. It can be observed that samples containing more wood fractions showed more sensitive to simulated decompositions issue compared to samples containing less wood fractions.

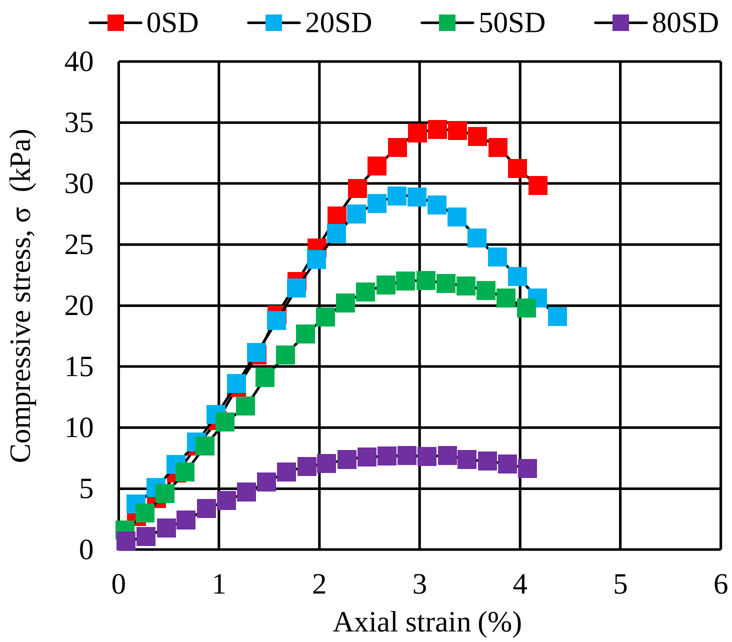


Fig. 4.2 Stress-strain relationship for various percentages of simulated decomposition for basic sample 4W

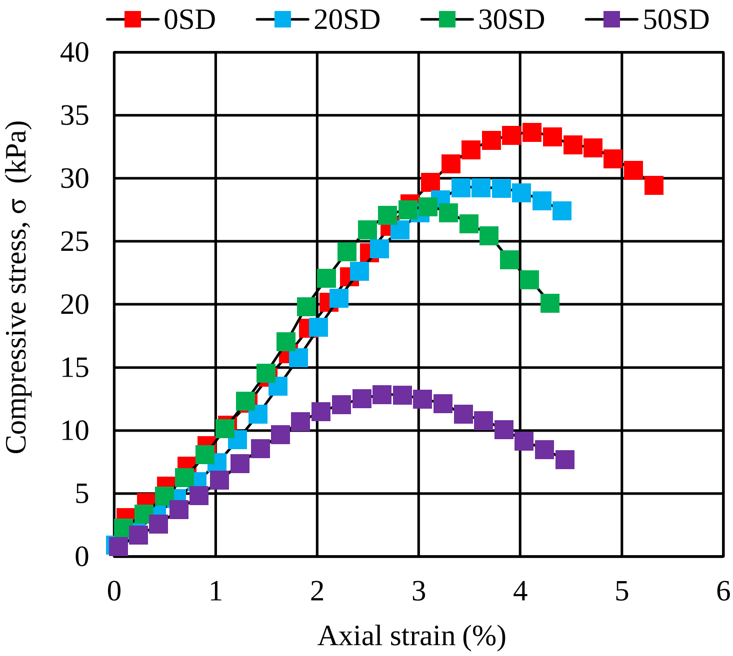


Fig. 4.3 Stress-strain relationship for various percentages of simulated decomposition for basic sample 6W

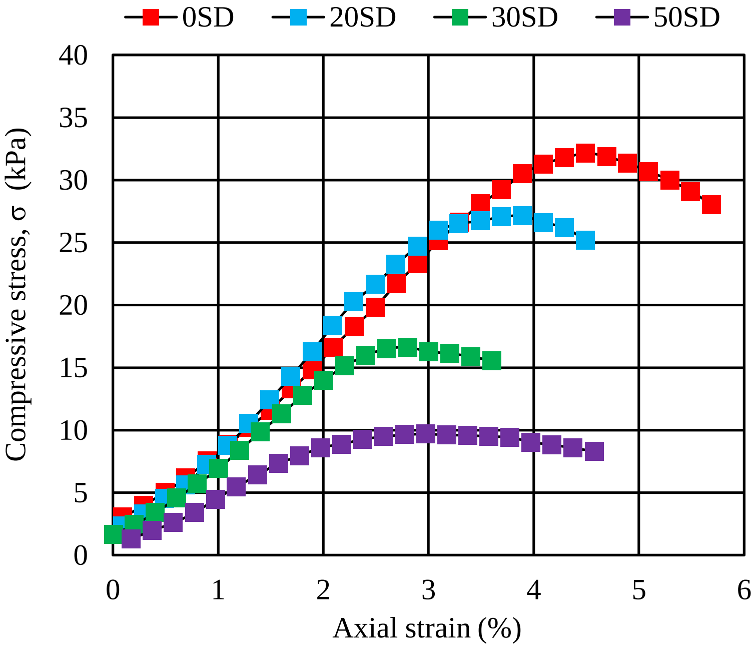


Fig. 4.4 Stress-strain relationship for various percentages of simulated decomposition for basic sample 8W

On the other hand, Figures 4.5 to 4.7 showed the results of unconfined compressive strength versus simulated decompositions. The inverse relationships was found between unconfined compressive strength and simulated decompositions for all samples. The decreasing trend of unconfined compression strength tend to be higher at samples containing more wood fractions even though low simulated decompositions is considered. Moreover, samples containing more wood fractions (6W and 8W), could not prepared specimens at 60SD or more simulated decomposition (Figs. 4.6 and 4.7). The sample containing less wood fractions (4W), can prepared specimen with more simulated decomposition like 80SD but could not with 100SD (Fig. 4.5).

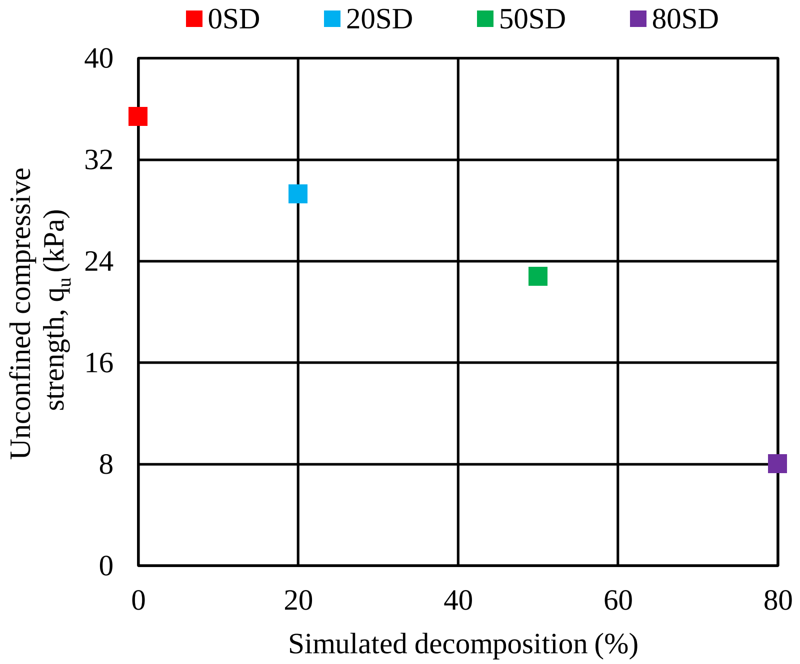


Fig. 4.5 Unconfined compression strength versus simulated decomposition for basic sample 4W

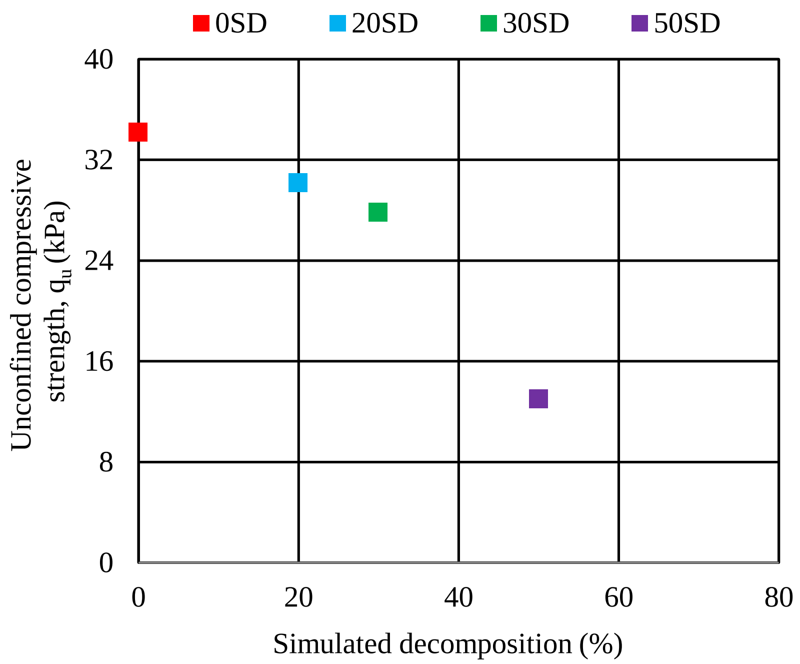


Fig. 4.6 Unconfined compression strength versus simulated decomposition for basic sample 6W

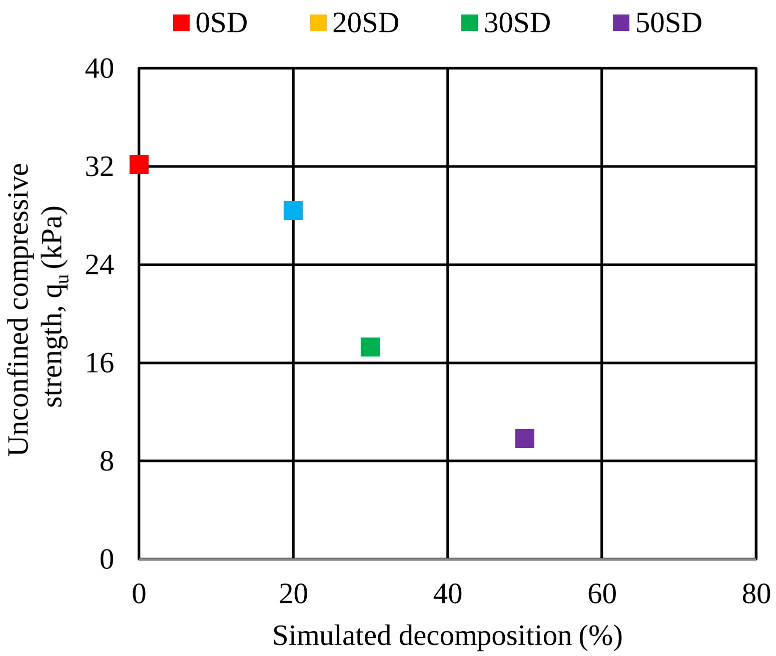


Fig. 4.7 Unconfined compression strength versus simulated decomposition for basic sample 8W

Moreover, the Figure 4.8 showed the results of unconfined compression strength versus simulated decomposition for all basic samples together where as it was clearly indicates the variations of the mentioned strength versus simulated decomposition among three different basic samples. Results also showed that no significant variation of unconfined compressive strength at 20SD among three basic samples but afterwards showed noticeable strength. Besides, unconfined compressive strength at 50SD for 6W and 8W basic samples showed the value which were equivalent to 70SD value for 4W basic sample. The deformation modulus (E_{50}) was obtained from the stress-strain curve which was also explained in the earlier and the similar manner was followed in this section. The Figure 4.9 showed the results of the deformation modulus of all three basic samples along with various percentages of simulated decomposition and indicates the similar trend as we found in case of unconfined compressive strength with same samples and but different phenomenon. Besides, decreasing trend of the deformation modulus with wood fraction inclusions indicates the softening behavior of the samples. Thus, sample contained more wood fractions (8W) showed lower deformations modulus value (0.78-0.48 MPa).

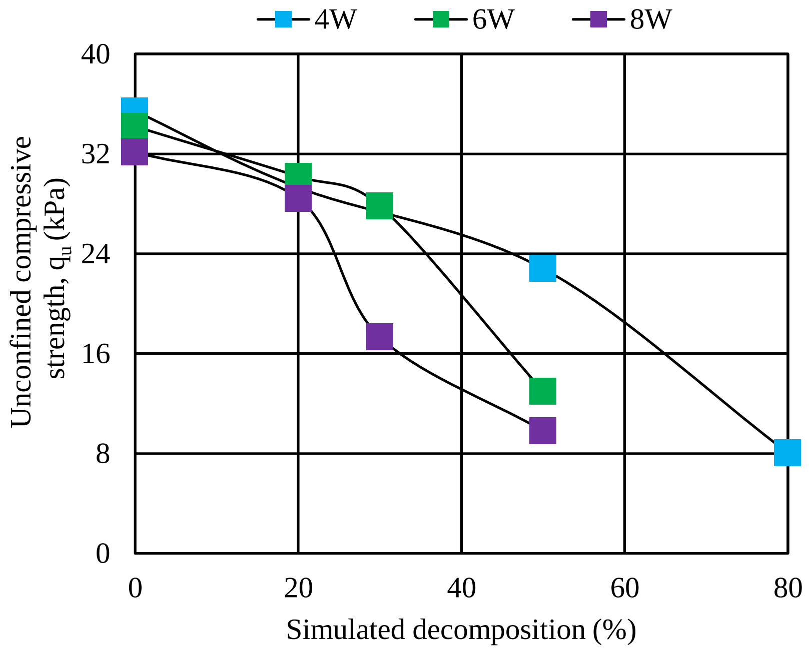


Fig. 4.8 Unconfined compression strength versus simulated decomposition for all basic samples

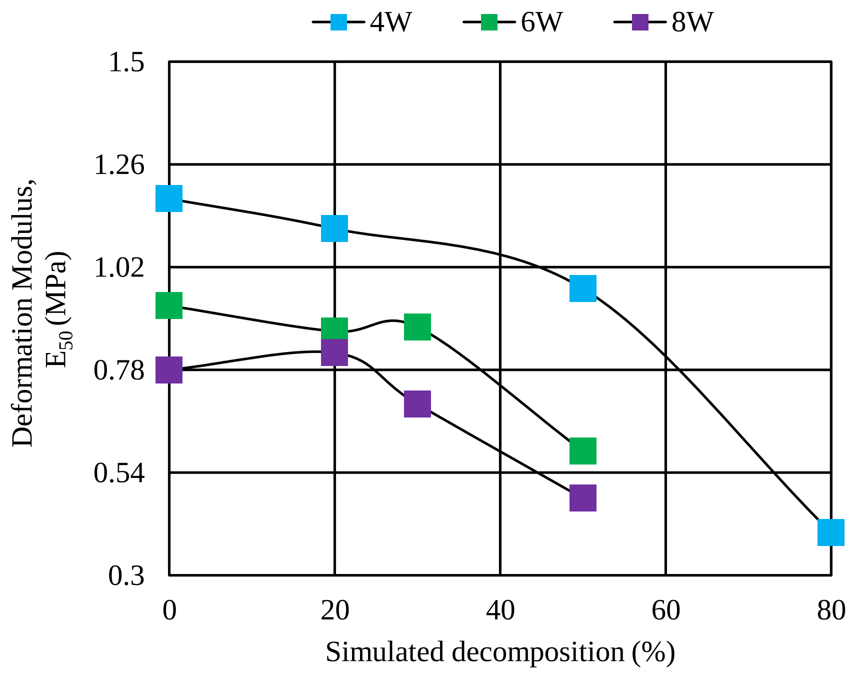


Fig. 4.9 Deformation modulus versus simulated decomposition for all basic samples

From the experimental results, it was observed that simulated decompositions of the wood fractions affect the strength as well as deformation of the recovered soil. Moreover, it was clearly mentioned that samples containing more wood fractions (8W) was highly affected by simulated decompositions issue even though less simulated decompositions (30SD) of the wood fractions was considered (Fig. 4.8) compared to sample contained less wood fractions (4W). The possible reason may be structure of the soil was affected due to removal of certain portions of wood fractions (so-called SD) from the specimens with constant volume. Thus, samples containing more wood fractions along with simulated decompositions show less dense structure resulting decreased strength and increased deformation.

4.3.2 Compressibility

The compressibility test results were presented in Table 4.3. The compressibility behavior of soil specimens was studied in an Oedometer to determine the compressibility parameters of recovered soil based on the simulated decompositions issue. This sub-section explaining the void ratios versus normal stress (e log P curve), deformation characteristic in terms of settlement, compression index (C_c) and compression ratio (CR) at various simulated decompositions for all basic samples for example 3W, 4W and 6W and eventually explained below.

Table 4.3 Summarized results of compressibility test for SD specimen

Basic Samples	Percent of wood removal (SD)	Initial void ratio (e_0)	Compression index (C_c)	Compression ratio (CR)	Settlement (S_f) (h=7 cm)
3W	0	0.48	0.08	0.05	0.27
	20	0.49	0.09	0.06	0.30
	50	0.51	0.10	0.07	0.35
	80	0.53	0.14	0.08	0.43
	100	0.54	0.15	0.09	0.51
4W	0	0.53	0.09	0.06	0.30
	20	0.54	0.10	0.07	0.35
	50	0.56	0.13	0.08	0.37
	80	0.59	0.16	0.10	0.51
6W	0	0.61	0.13	0.08	0.40
	20	0.65	0.15	0.09	0.45
	40	0.67	0.17	0.10	0.53
	50	0.69	0.19	0.11	0.62

4.3.2.1 Void ratio (e)

The variations of the void ratio (it is important to mention here that simulated decomposed wood fractions assumed as part of void) with simulated decomposition for all three basic samples are shown in Table 4.3. The initial void ratio was lower for with 0SD issue and increased with simulated decompositions increased which are shown in Figures 4.10 to 4.12. The tendency of void ratio increased was relatively higher at higher simulated decompositions case for samples containing more wood fractions (6W) compared to samples containing less wood fractions. A significant void ratio increase was found for 6W sample even though only 20SD is considered (Fig. 4.12) while it was absent in sample contained less wood fractions (3W). Moreover, reduction of void ratio tend to be higher with higher simulated decompositions while slope of the $\mathrm{e} - \log p$ curve increased for the same issue at higher pressure. But, these slopes of the $\mathrm{e} - \log p$ curve showed significantly higher at higher pressure for sample contained more wood fractions (6W) as compared to less wood content sample (3W). The specimens with higher simulated decomposition of 6W sample shows more distinct slope of the $\mathrm{e} - \log p$ curve compared to others at higher pressure.

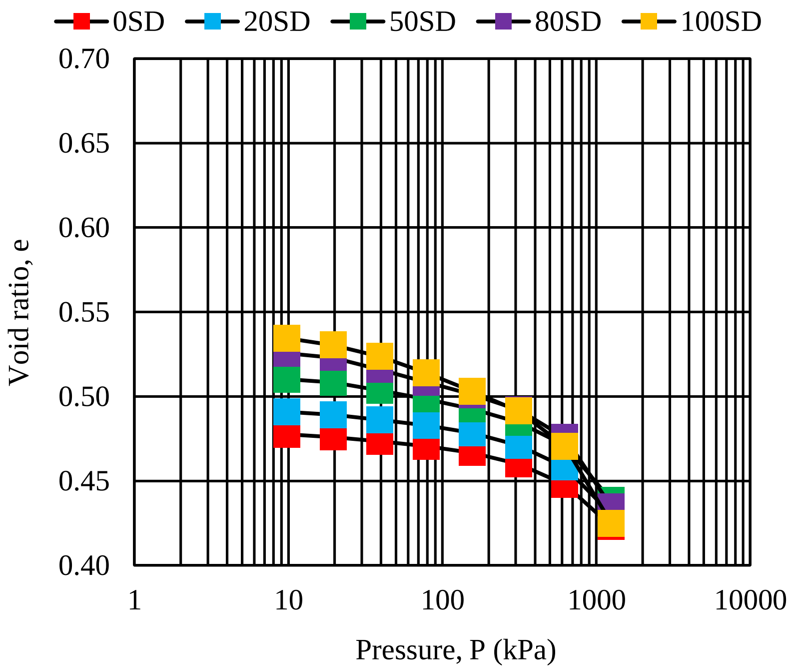


Fig. 4.10 void ratio versus pressure for basic sample 3W

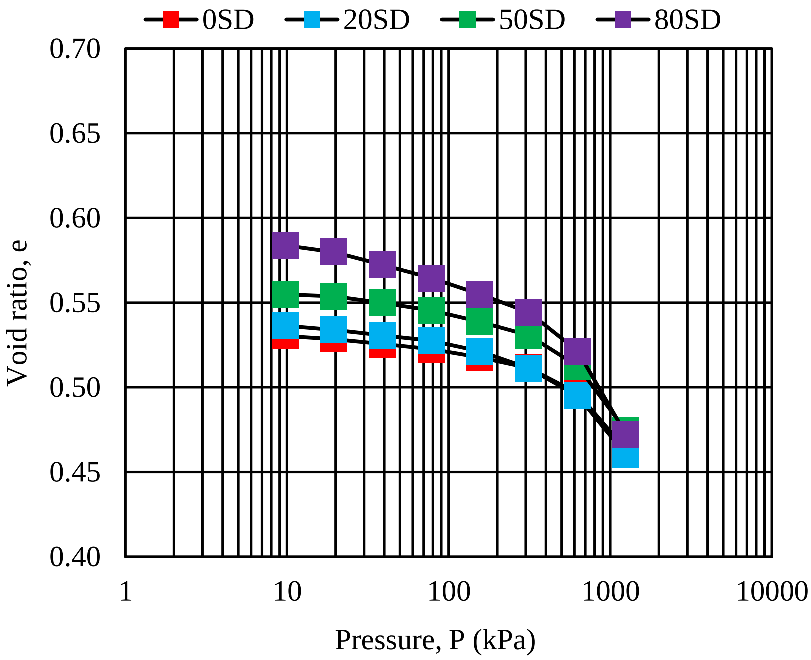


Fig 4.11 void ratio versus pressure for basic sample 4W

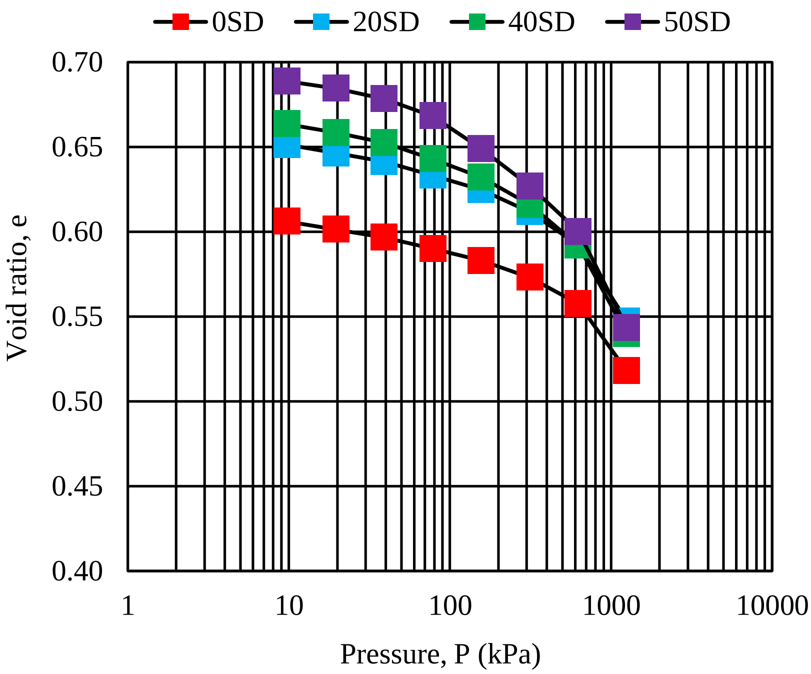


Fig. 4.12 void ratio versus pressure for basic sample 6W

4.3.2.2 Compression index (C_c)

The results of the void ratio-pressure relationship ($e - \log p$ curve) was used to estimate the compression indices (C_c) of samples with various simulated decompositions. Compression index increased with increased simulated decompositions for all samples (Figs. 4.13 to 4.15) but increasing trend was higher for sample contained more wood fractions (6W) and ranging from 0.13 to 0.19 along with various simulated decompositions from 0SD to 50SD (Fig. 4.15) compared to samples containing less wood fractions (3W and 4W). Moreover, compression index varied from 0.08 to 0.15 and 0.10 to 0.16 for basic samples of 3W and 4W (Figs. 4.13 and 4.14) respectively along with the same phenomenon. On the other hand, the rate of Cc value increased relatively lower with lower simulated decompositions (20SD and 50SD) for basic sample of 3W and 4W but relatively higher for sample of 6W with the same simulated decompositions of 20SD. The Figure 4.16 presents compression index (C_c) value for all samples together while it is clearly indicates that sample contained more wood fractions (6W) was relatively more susceptible to simulated decompositions compared to others (3W and 4W). Therefore, this increased value of compression index (C_c) should carefully take into considerations as crucial task before utilizations of this soil.

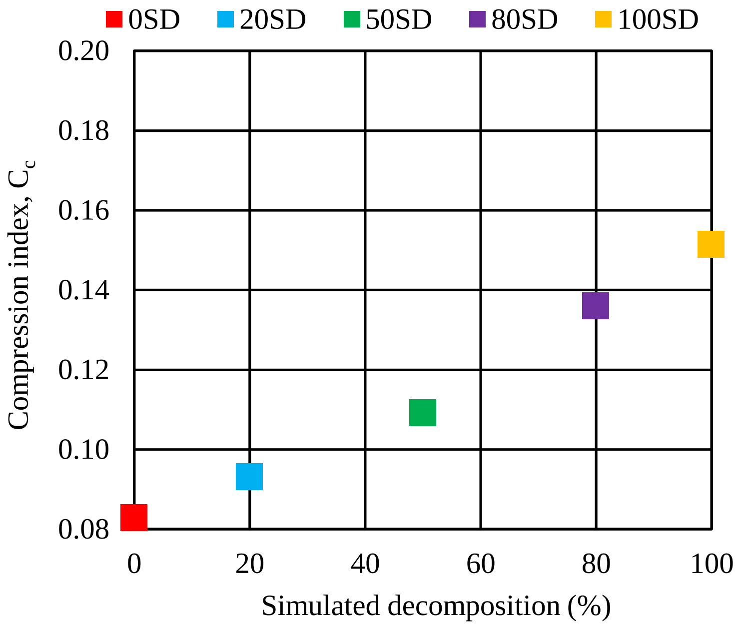


Fig. 4.13 Compression index versus simulated decomposition for basic sample 3W

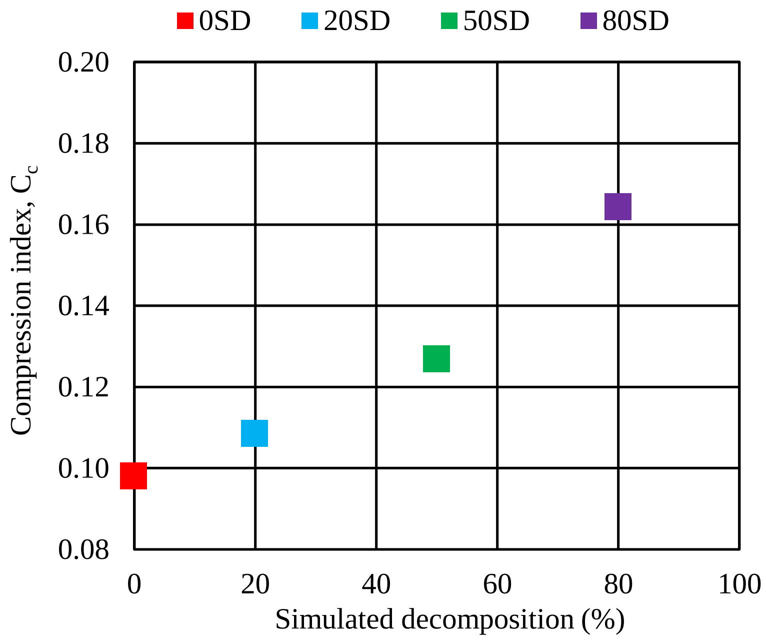


Fig. 4.14 Compression index versus simulated decomposition for basic sample 4W

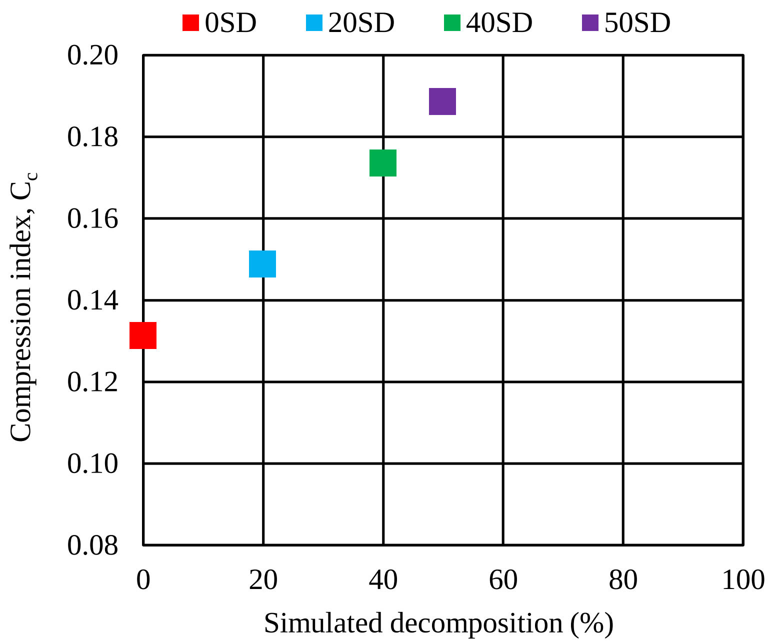


Fig. 4.15 Compression index versus simulated decomposition for basic sample 6W

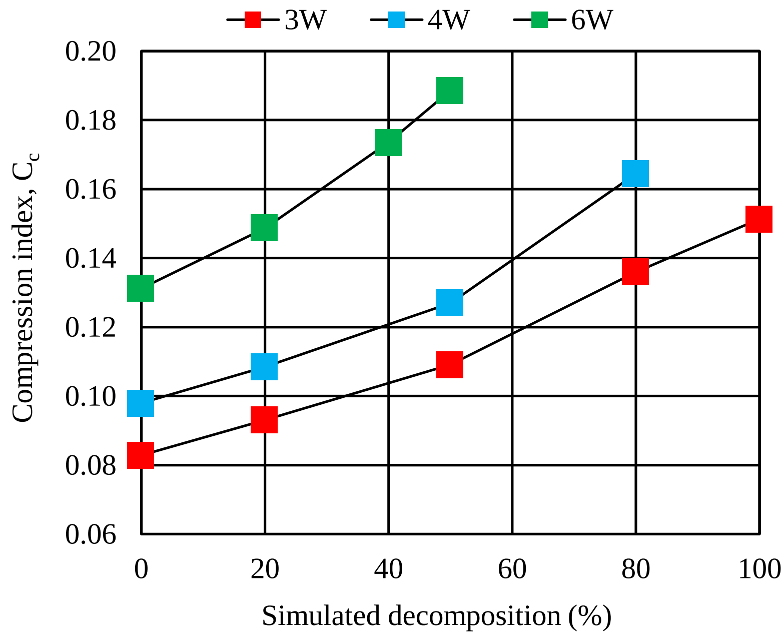


Fig. 4.16 Compression index versus simulated decomposition for all basic samples

4.3.2.3 Compression ratio

The Figure 4.17 to 4.19 indicates compression ratio (CR) was almost similar trend as compression index (C_c) found for all samples while trend of CR value increased with increased simulated decompositions. The variations of compression ratio were higher for sample contained more wood fractions (6W) with simulated decompositions and ranging from 0.08 to 0.11 (Fig 4.19). Besides, the compression ratio showed relatively lower and varied from 0.05 to 0.09 and 0.06 to 0.10 for basic samples of 3W and 4W respectively (Figs 4.17 and 4.18). Interestingly, the compression ratio was relatively slowly increased with up to 50SD afterwards the rate of CR increased relatively higher for samples of 3W and 4W. The rate of CR value increased relatively higher even though SD at lower for example 20SD for sample 6W. The Figure 4.20 presents compression ratio value for all samples together and made comparisons among them regarding the effects of simulated decompositions issue. Based on the results, all samples even with higher simulated decompositions seems to be slightly compressible (0.05-0.10) soil according to classification made by O'Loughlin, and Lehane (2003).

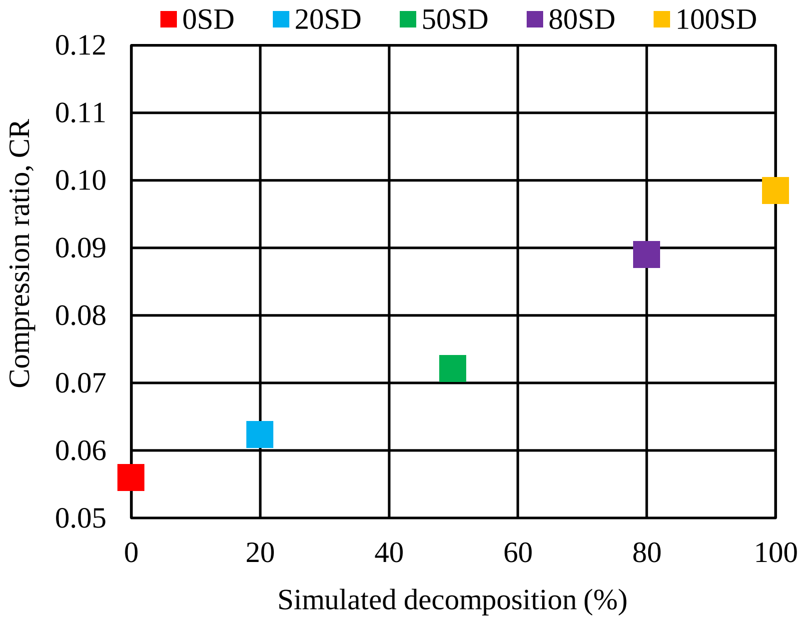


Fig. 4.17 Compression ratio versus simulated decomposition for basic sample 3W

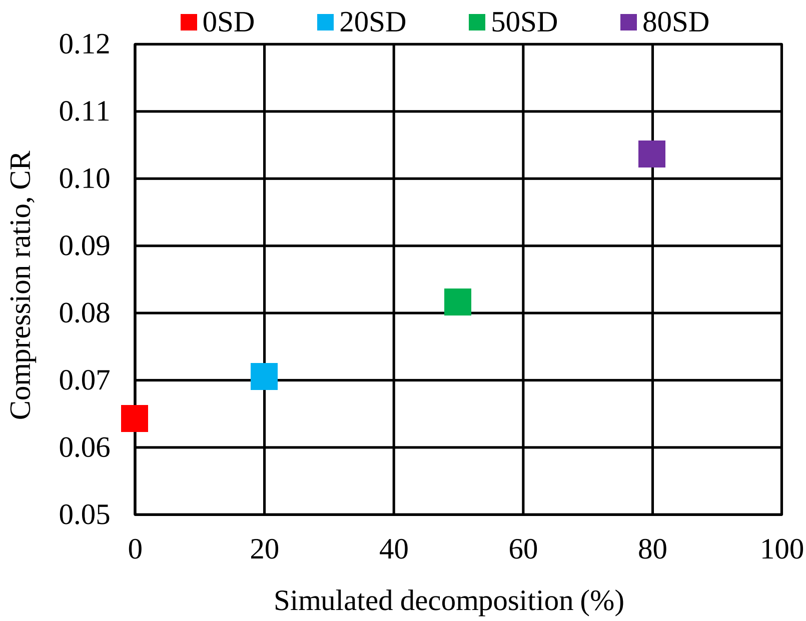


Fig. 4.18 Compression ratio versus simulated decomposition for basic sample 4W

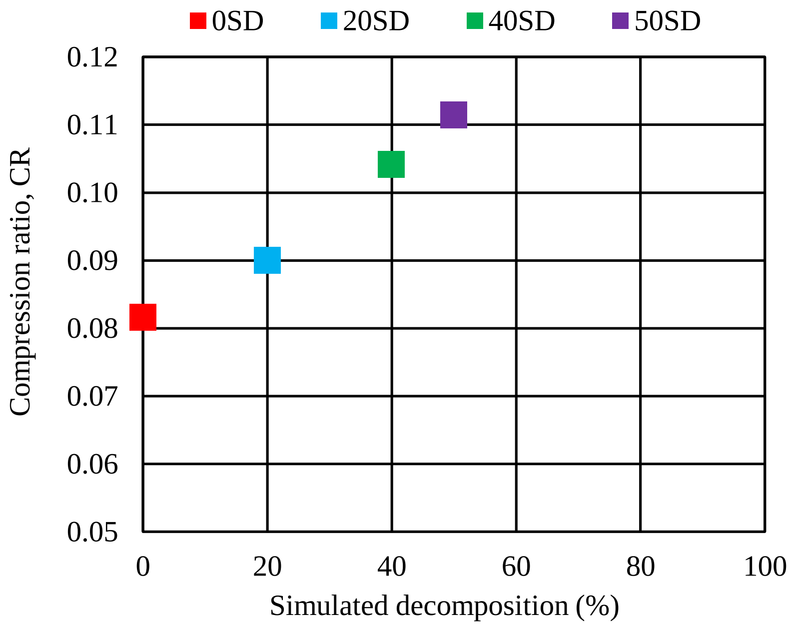


Fig. 4.19 Compression ratio versus simulated decomposition for basic sample 6W

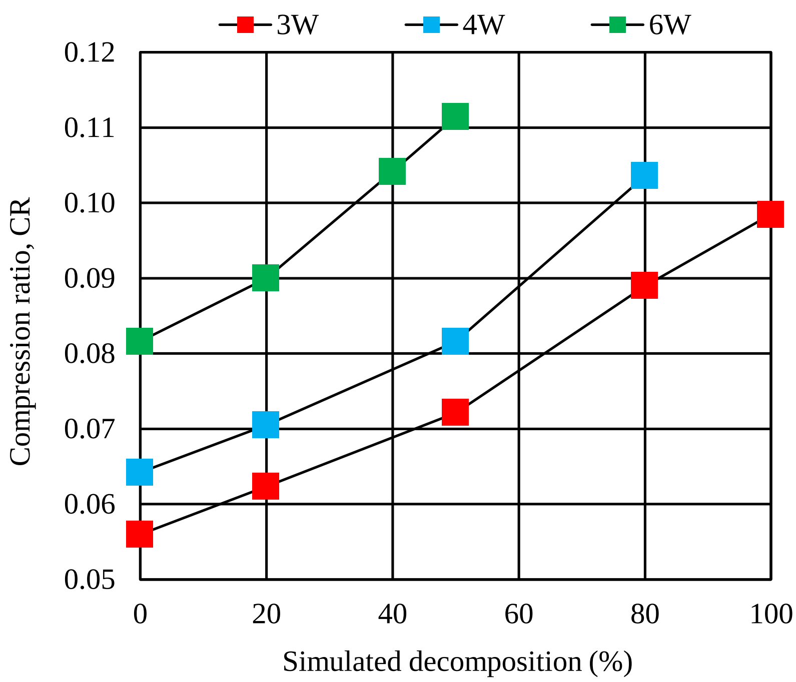


Fig. 4.20 Compression ratio versus simulated decomposition for all basic samples

4.3.2.4 Settlement

The results shown in Figures 4.21 to 4.23**,** the settlement of the specimen was increased with increased simulated decompositions along with increment of pressure while significant increased found at sample contained more wood fractions (6W) as compared to others two sample. Moreover, settlements which were achieved when the specimens reached at total compression during the compressibility test indicate that specimens contained more wood fractions along with higher simulated decompositions experienced higher subsidence (Fig 4.23). The Figure 4.23 showed the variations of settlement of the sample with more wood fractions (6W) from 0.40 to 0.62 cm with various simulated decompositions ranging from 0SD to 50SD at higher pressure. Besides, The variations of the settlement from 0.27 to 0.51 cm and 0.30 to 0.51 cm shows for sample 3W and 4W with various simulated decompositions ranging from 0SD to 100SD at higher pressure (Figs. 4.21 and 4.22).

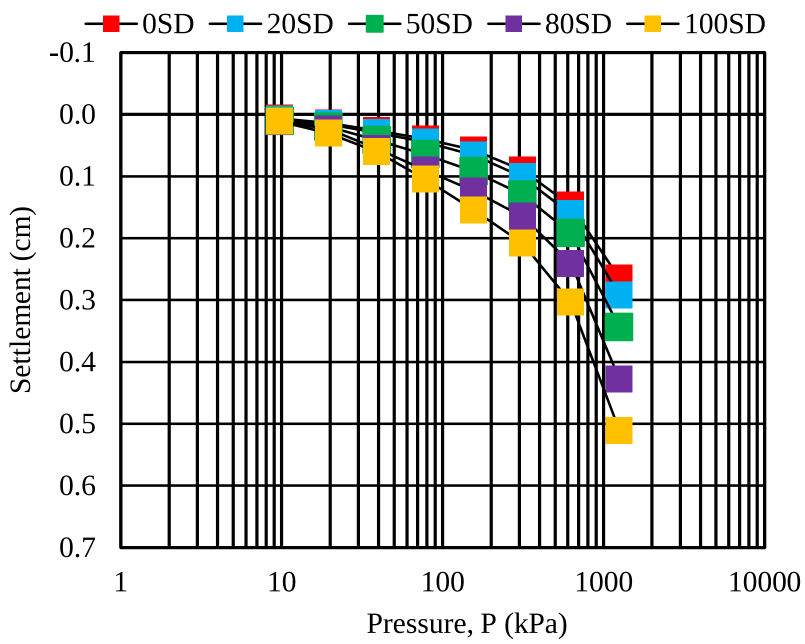


Fig. 4.21 Settlement versus pressure for basic sample 3W

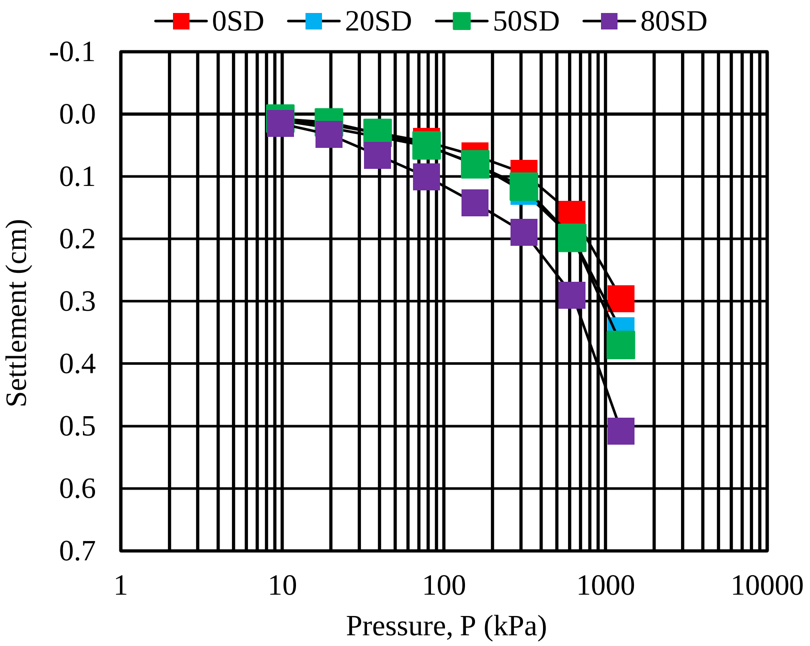


Fig.4.22 Settlement versus pressure for basic sample 4W

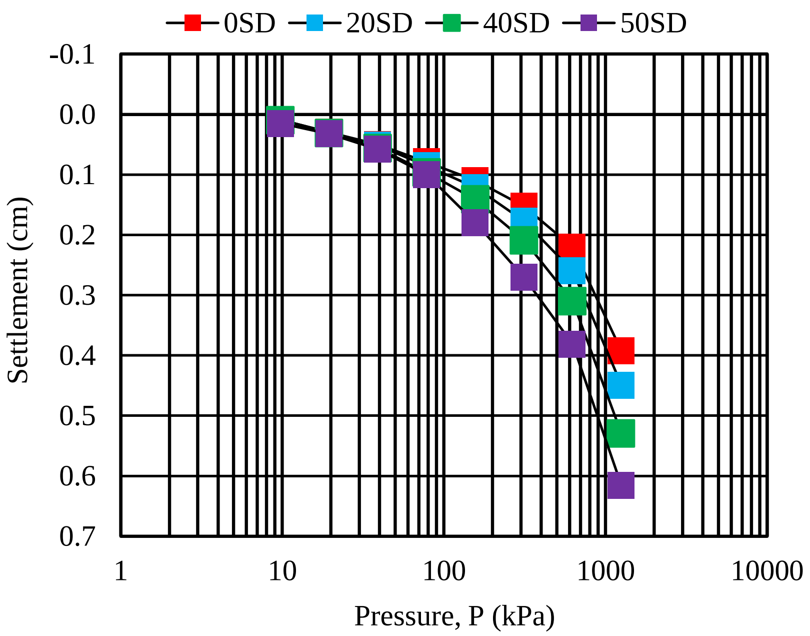


Fig. 4.23 Settlement versus pressure for basic sample 6W

From the deformations characteristics obtained in compressibility tests results, it was observed that compressibility of the samples increased for samples containing more wood fractions may be due to volume change. Thus, samples containing more wood fractions along with simulated decomposition may affect the structure of the soil and showed more compressible due to volume decreased.

4.3.3 Effects of simulated decomposition of wood fractions on the strength and compressibility parameters of recovered soil

The possible relationship between simulated decomposition and void ratio, e (V_v/V_s) is illustrated in the Figure 4.24. The void structure showed increasing trend with increased simulated decomposition of the wood fractions but samples containing more wood fractions showed relatively higher void ratio compared to samples containing less wood fractions with simulated decomposition. This increasing trend of void ratio may be responsible for reducing the trend of unconfined compressive strength for all basic samples (Figs. 4.25, 4.26 and 4.27). Moreover, samples containing more wood fractions for example 8W even with moderate simulated decomposition (50SD) showed higher void ratio (0.94) which was exactly same to loose state (e_{max} 0.94) of the soil fractions, resulting significant strength reduction. Thus, samples containing relatively more wood fractions was highly susceptible to strength properties of the recovered soil. Moreover, it was observed during the preparation of specimen, samples containing 6 to 8 % wood fractions with 60SD and more, specimen did not prepare. While similar behavior was found with more than 80SD for 4W sample. This indicates that higher simulated decomposition affect the structure of the soil even though samples with less wood factions while it seems more susceptible for samples containing more wood fractions with moderate simulated decomposition.

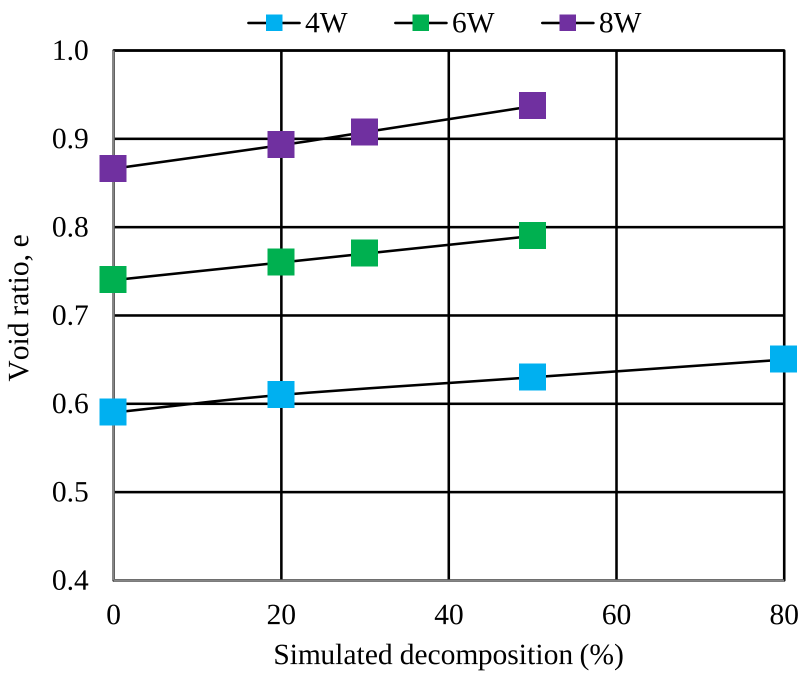


Fig. 4.24 Void ratio versus simulated decomposition for all basic samples

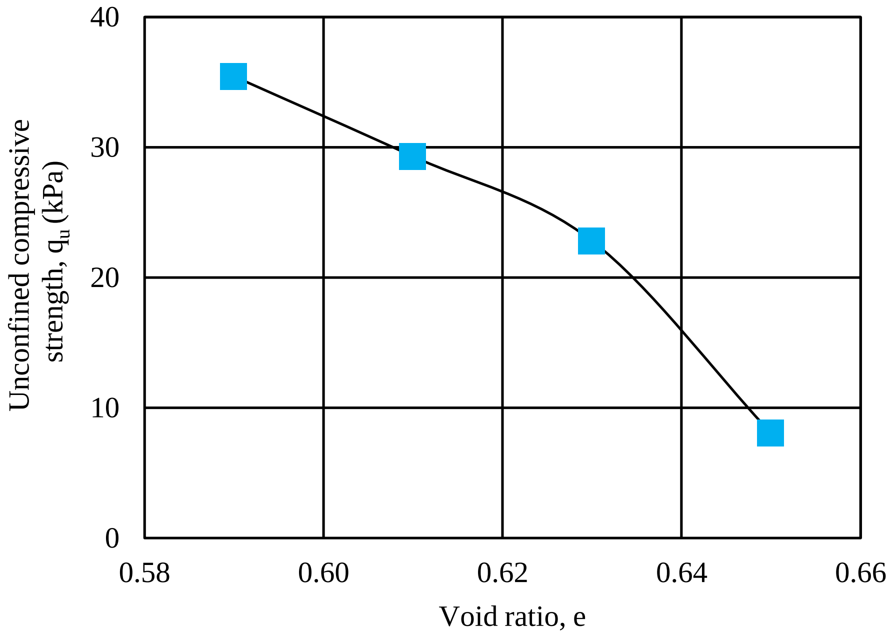


Fig. 4.25 Void ratio versus unconfined compressive strength for basic sample 4W

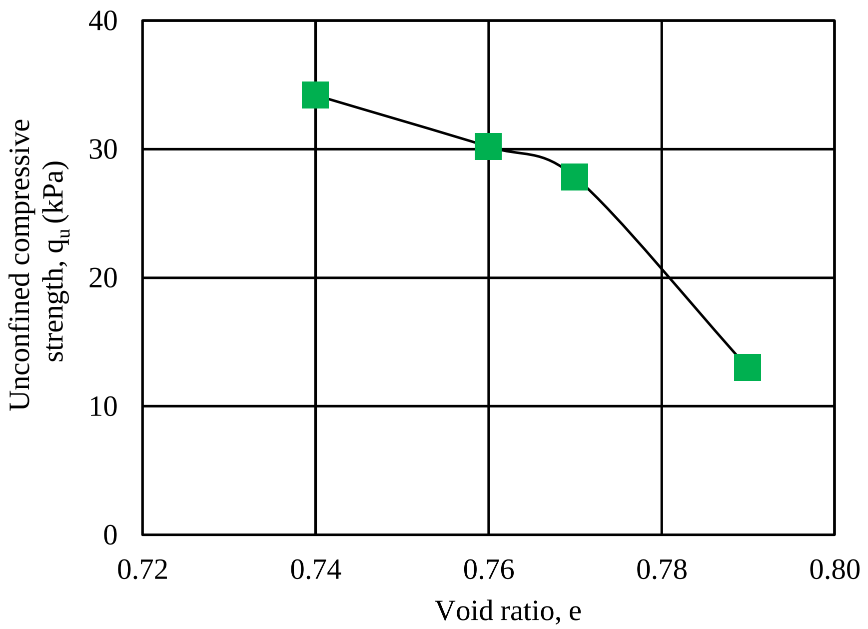


Fig. 4.26 Void ratio versus unconfined compressive strength for basic sample 6W

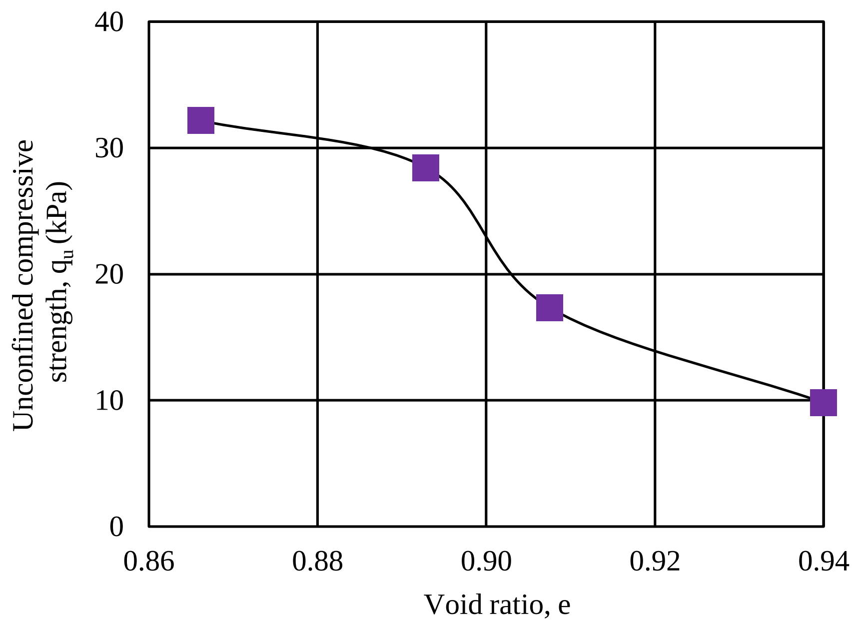


Fig. 4.27 Void ratio versus unconfined compressive strength for basic sample 8W

It is noted here (though explained earlier) that during specimen preparation considering simulated decomposition phenomenon, the constant total volume and soil is considered. The conceptual diagram of simulated decompositions process shown in the Figure 4.28 could be used to describe this phenomenon.

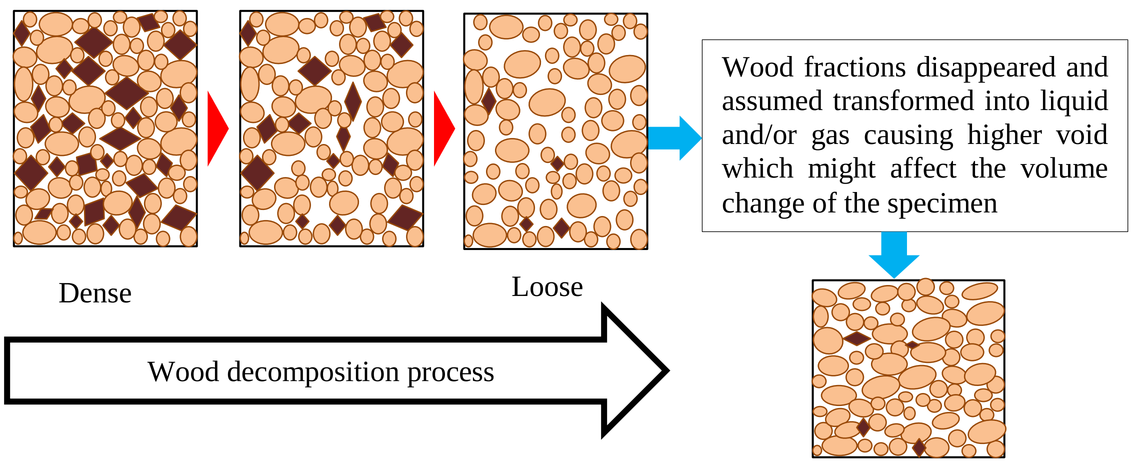


Fig. 4.28 Conceptual diagram of decomposition process

According to simulated decomposition, specimens becoming loose because of removal of wood fractions with constant volume and thus, increased void space (Fig. 3.28) which was observed in unconfined compression tests and thus decreasing trend of strength reductions found. The similar void structure was also observed in compressibility tests for all samples along with various simulated decompositions. Thus, compressibility parameters for examples C_c, CR and S_f were increased accordingly. The most important reason for the change in compressibility parameters (C_c, CR and S_f) was related to volume change occurred due to simulated decompositions of wood fractions (Fig.4.29). Sample with more wood fractions, removal of larger wood fractions with constant soil resulting volume changed was higher compared to those samples with less wood fractions. Thus, the change in volume contributed to relatively higher change in compressibility parameters of samples containing more wood fractions compared to sample with less wood fractions.

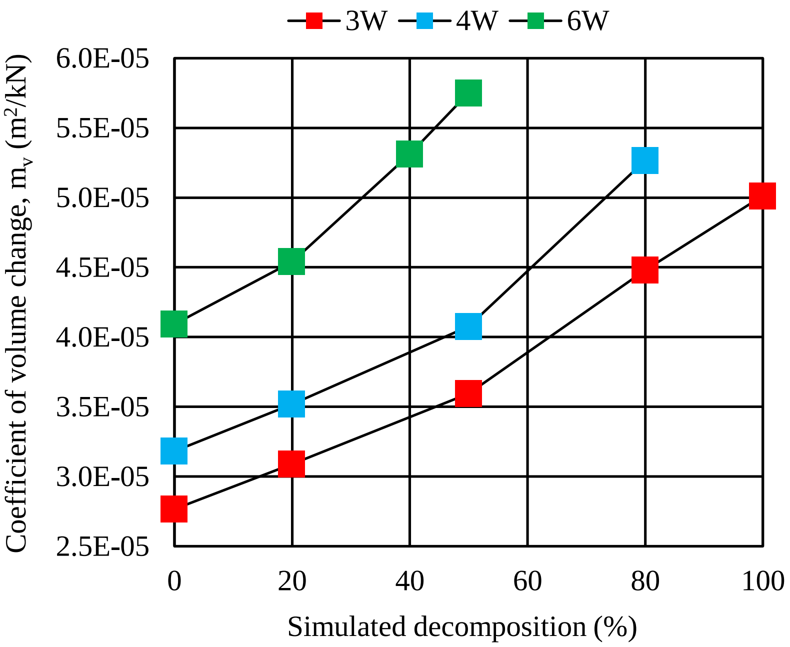


Fig. 4.29 Variation of volume changes with simulated decomposition for all basic samples

Another factor that may be governed the strength as well as compressibility of the recovered soil was interlocking between soil particles. The interlocking between particles may be increased the strength of the samples. But, in this study, higher simulated decomposition had larger removal of wood fractions while keeping total volume and soil constant that seems to be loose stated of the sample. Thus, the results of this study showed that strength was decreased while compressibility was increased due to simulated decomposition. These results are consistent with similar study investigated by O`Kelly and Pichan, (2013), Huat (2004), Hossain et al. (2003) and Hobbs (1986).

From the above discussions, the mechanism of the recovered soil with simulated decompositions phenomenon was illustrated in the Figure. 4.30. In this Figure, with increase simulated decompositions, volume of the soil was decreased and voids structure was increased while keeping constant total volume and soil. Moreover, wood fractions occupied between soil particles even in the void created by the larger soil particles, was disappeared due to simulated decomposition resulting larger void structure created which was also shown in the conceptual diagram in the Figure. 4.28. Therefore, volume of the samples was reduced with load and shown in the Figure 4.29. Thus, this volume reduction affect the strength as well as compressibility of recovered soil with simulated decomposition especially for samples containing more wood fractions.

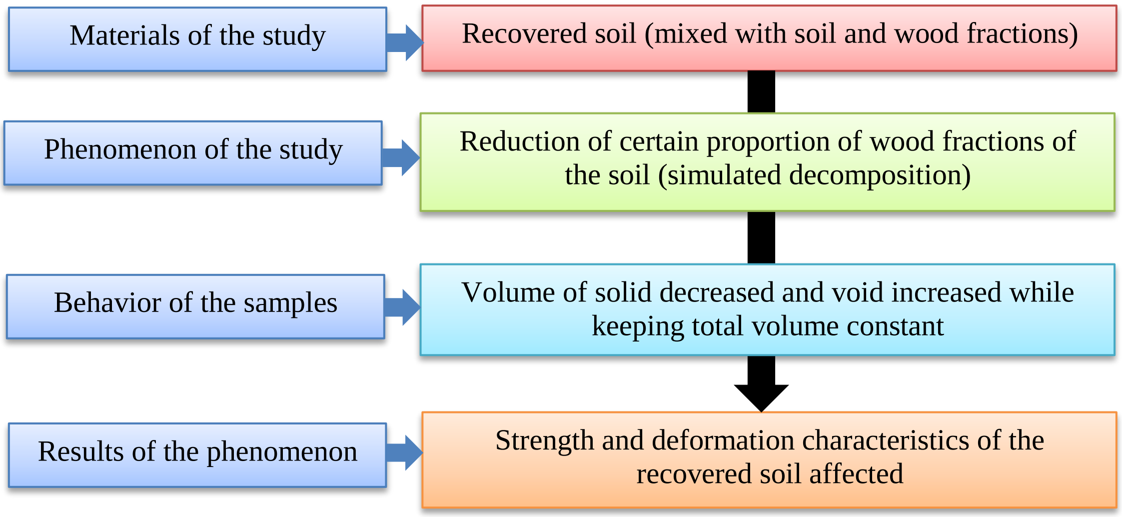


Fig. 4.30 Mechanism of soil-wood fractions interactions due to simulated decomposition

4.4 Conclusions for this chapter

This chapter broadly discussed about the effects of simulated decomposition of wood fractions on the engineering properties particularly strength and compressibility parameters of recovered soil in order to utilize these in geotechnical field. Based on the experiment, the findings about the effects of simulated decomposition of wood fractions on the strength and compressibility parameters of recovered soil are summarized below:

Special attention should be given about the strength compressibility parameters of the structure that is built on the soil containing organic matter. In connections to this issue, this research determined the unconfined compressive strength and compressibility parameters especially C_c, CR and S_f considering the simulated decomposition issue.

Four basic samples of 3W, 4W, 6W and 8W were taken for specimens preparations with different simulated decompositions for examples 0SD, 20SD 50SD etc. and subjected to conduct a series of unconfined compression tests and compressibility tests to understand unconfined compressive strength and compressibility behaviors.

Experimental results indicate that simulated decomposition of the wood fractions affect the deformation as well as strength of the recovered soil. While samples containing more wood fractions for example 8W was highly affected by simulated decomposition issue even though less simulated decomposition (30SD) of the wood fractions was considered compared to sample contained less wood fractions (4W). The reasons behind of these results were specimens becoming looser and increased void space due to removal of certain wood fractions based on simulated decomposition.

From the compressibility test, it is observed that compressibility of the samples was increased relatively more for samples containing more wood fractions due to higher volume change. The most important reason for the change in compressibility parameters (C_c, CR and S_f) was related to volume change occurred due to simulated decomposition of wood fractions. Sample contained more wood fractions, removal of larger wood fractions with constant soil, resulting larger volume changed compared to those in sample contained with less wood fractions. Thus, the volume change contributed to relatively higher change in compressibility parameters of samples containing more wood fractions compared to sample contained less wood fractions.

It is also an important task to make a conclusion about an acceptable simulated decomposition for geotechnical utilizations. But, it can be observed that samples containing relatively more wood fractions even with moderate simulated decomposition, might affect the strength and compressibility parameters. However, simulated decomposition of 50SD for basic sample 6W might be applicable because of this condition sample showed void ratio 0.79 which lower than e_{max} of the soil fractions.

CHAPTER 5: PRACTICAL IMPLICATIONS

5.1 Overall summary of all experimental results

This study was carried out to understand the effects of wood fractions on the engineering properties of recovered soil. Moreover, effects of simulated decomposition of wood fractions on the strength and compressibility of the recovered soil were also evaluated by conducting unconfined compression tests and compressibility tests. However, maximum acceptable ratio of wood fractions in recovered soil was also evaluated for geotechnical utilizations. The mechanism, involved with wood fractions inclusions and simulated decompositions in recovered soil were also explained. The main results and conclusions are summarized as follows:

Chapter 1: The first chapter articulates the background, objectives, and contents of this research. This chapter explains the generation and importance of recovered soil for geotechnical utilizations. It focuses on wood fractions that remained in the recovered soil that might affect the engineering properties of the recovered soil. Moreover, it also identifies the research gap and encompasses with originality of the research.

Chapter 2: In the second chapter, the overview of the Great East Japan Earthquake and Tsunami 2011 was explained with facts and figures. Here, we introduced the disaster wastes generated by the Great East Japan Earthquake and Tsunami 2011 along with their compositions, separations and treatment techniques. Furthermore, we also described the recovered soil along with its generation and importance in geotechnical utilization. Recovered soil, containing wood fractions which may affect the engineering properties of the soil, were discussed as well. This chapter gave a brief overview of the organic matters and their decomposition behavior in brief. The materials used for a sample simulation of an example decomposed granite soil with wood fractions were discussed along with their properties. Moreover, we explained how engineering properties, especially strength, CBR and compressibility parameters of the waste mixed soil were affected by inclusions of different waste at various proportions and their decomposition issues based on the previous literature.

Chapter 3: In this chapter, we conducted a series of standard compactions tests, unconfined compression tests, California bearing capacity (CBR) tests and compressibility tests to investigate the effects of wood fractions on the engineering properties of recovered soil. From the experimental results, we concluded that, maximum dry density showed an almost linear and inverse relationship with wood fraction inclusion in the recovered soil. The unconfined compressive strength of the recovered soil samples show a decreasing trend with wood fractions inclusion and a similar decreasing trend was found in the case of deformation modulus with the same phenomenon. The

CBR test results indicate a decreasing trend of CBR value for all samples, while the CBR value was significantly decreased at 8W sample because of the loose state conditions that existed. Besides, the void ratio of the recovered soil without wood fractions (0W) shows an extremely low result (0.26) (CBR test case) because larger particles were crushed into smaller particles and thus, the resulting void space between larger particles became filled with fine particles. This was observed by conducting a particle size distribution test before and after compaction of the recovered soil. Thus, the void ratio of the recovered soil without wood fractions was extremely low. The compressibility parameters particularly compression index (C_c), compression ratio (CR) and settlement were increased with increased wood fractions inclusion. One of the possible reasons for increasing compressibility parameters was the volume change found due to wood fractions inclusions. A simple linear regression model was developed and confirmed that void ratio and CBR were inversely and significantly correlated each other. Finally, it can be concluded that acceptable ratio of wood fractions in recovered soil might be somewhere between 6W and 8W samples for geotechnical utilizations.

Chapter 4: This chapter explained the effects of simulated decomposition of wood fractions on the strength and compressibility parameters of the recovered soil. Removal of certain portions of wood fractions, for example 0%, 20% 50% 80% from the basic sample while keeping constant total volume and soil was considered as simulated decomposition. However, natural decomposition is a time consuming process, therefore, could not be conducted within the time of this research. Besides, this simulated decomposition was derived from the concept of natural decomposition wherein a certain percentage of organic matter is transformed into gas or/and liquid. To understand the effects of simulated decompositions of wood fractions on the strength and compressibility parameters of the recovered soil, a series of unconfined compression tests and compressibility tests were conducted.

Results indicate that simulated decomposition of the wood fractions affect the deformation as well as strength of the recovered soil. Samples containing more wood fractions were highly affected by simulated decompositions even though less simulated decomposition of the wood fractions was considered compared to the samples containing less wood fractions. The possible reason may be increased void space due to removal of certain wood fractions resulting in reduced strength.

From the compressibility test, it was observed that compressibility increased for samples containing more wood fractions due to higher volume change. The most important reason for the change in compressibility parameters was volume reduction. Where samples containing more wood fractions, removal of larger wood fractions with constant soil and total volume resulted in greater volume reduced compared to those in samples containing less wood fractions. Thus, the change in volume contributed to a relatively high change in compressibility parameters for samples containing more wood fractions compared to those with less. However, it can be concluded that simulated decomposition of 50SD for basic sample 6W might be applicable because of this condition specimen showed a void ratio 0.79, which is lower than the e_{max} of the soil.

5.2 Practical implications

Developed countries like Japan have experience in treating all wastes generated from different sources (ADB 2011). However, soils recovered from disaster waste generated from the Great East Japan Earthquake and Tsunami 2011 are very challenging to manage especially, when considering them for utilization. In connection to this issue, this research tried to establish the parameters of this recovered soil for geotechnical utilizations. However, these parameters might be applicable for a future case (either in Japan or in other arena in the world) as almost all recovery works in the affected sites are completed as planned. It was mentioned earlier that recovered soils were treated as problematic and weak soils, so that it is important to conduct careful investigation of their properties before utilization. Thus, it was suggested to use these soils in the shallow foundation structure such as construction of embankment and park construction, and afforestation belt in the coastal area, or as subgrade materials in pavement design rather than heavy structures. However, based on the experimental results, obtained in this study, the following practical implications of these results are summarized:

The results found in unconfined compression test were very low even though the control soil showed a very low value (38.93kPa). None of the samples used met the minimum standard for unconfined compressive strength (50kPa) for embankment construction according to the Japanese Geotechnical Guidelines (JGG) (Fig. 5.1). But, all samples met the value of unconfined compressive strength proposed by Das (1994) for soft subgrade of pavements (25-50kPa). However, this strength was measured within unconfined conditions using granular soil resulting low unconfined compressive strength value obtained. Therefore, it was proposed here and subsequently, determined strength property within confined conditions (CBR test) which is indicated in the following paragraph.

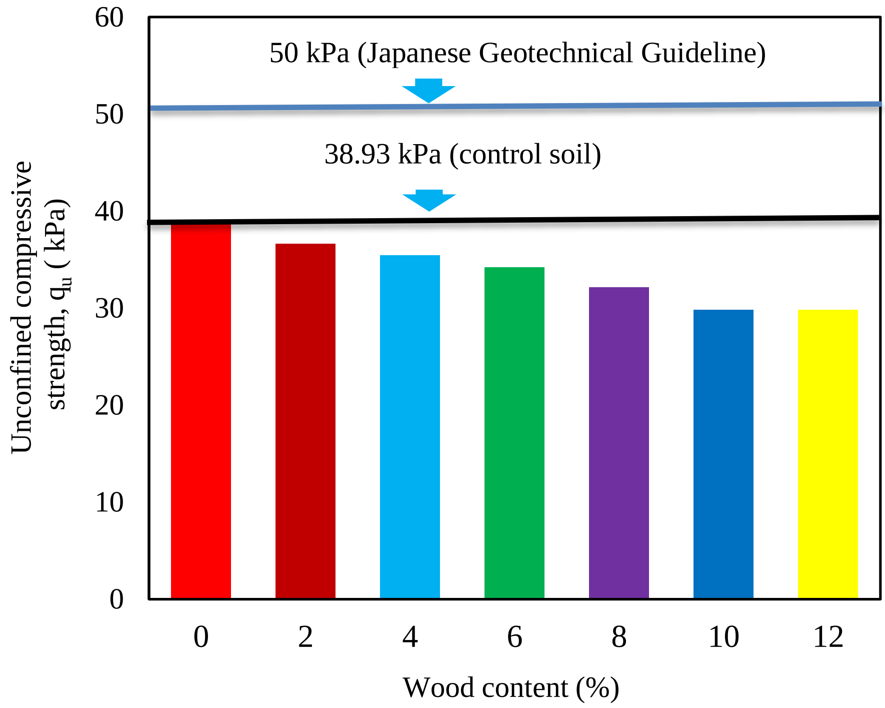


Fig. 5.1 Comparison of unconfined compressive strength of recovered soil with strength standard by JGG

From CBR test results, it was revealed that all samples might be acceptable for pavement design though, none of them were acceptable as sub-base materials according to JIS standard. While CBR value of 5% and 10% are the minimum standards for subgrade materials for lower and upper part of the highway pavement respectively. Moreover, a CBR value of 30% is standard for sub-base material for the lower part highway pavement design while all samples show CBR value below 30% (Fig. 5.2). Thus, these samples were expected to be suitable as subgrade materials for pavement design. However, further discussion is needed for other parameters rather than CBR value before it`s applications. Moreover, decomposition of wood fractions issue is also an important phenomenon which might affect the engineering properties of recovered soil. Keeping in mind these concerns, we conducted compressibility tests and explained in the following section while decomposition issues were discussed in details with results in chapter 4.

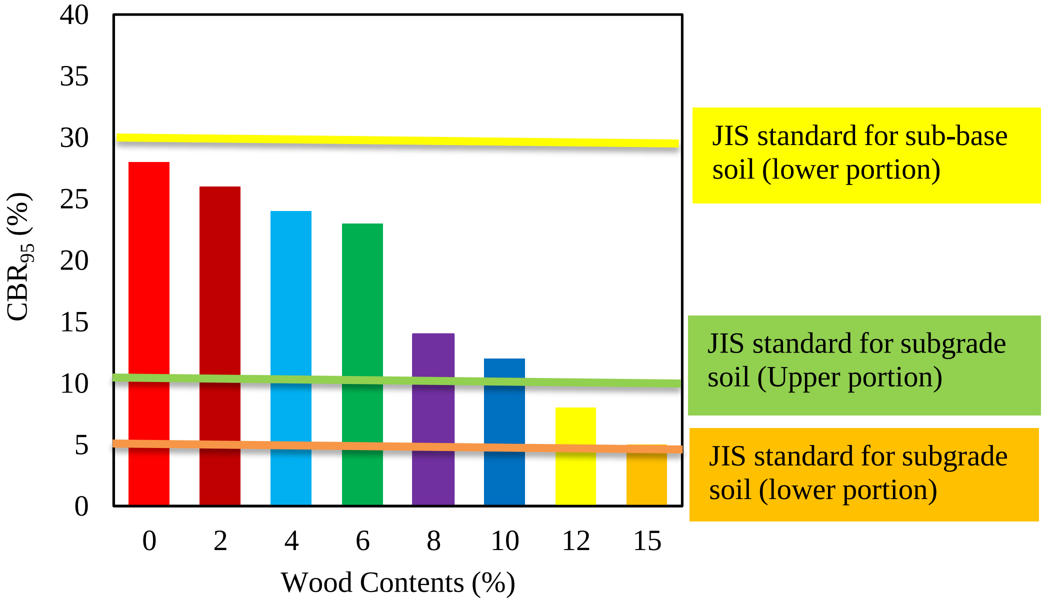


Fig. 5.2 CBR value along with it`s applications

Compressibility parameters are important for estimating settlement of the recovered soil. In this research, the effects of wood fraction on the compressibility of the recovered soil was studied and explained in Chapter 3. The results showed that compressibility parameters especially compression index (C_c), compression ratio (CR) and settlement of the samples were increased with wood fractions inclusion and ranged from 0.023 to 0.20; 0.02 to 0.10 and 0.13 cm to 0.52 cm for C_c, CR and S_f respectively and seems to be slightly compressible (O'Loughlin and Lehane 2003). The most important reason for the change in compressibility parameters is related to void structure and volume change that were occurred due to inclusion of wood fractions. Therefore, void and volume change in the recovered soil should be carefully investigated for geotechnical utilizations.

As explained earlier, organic matter is decomposable with time and is affected by other factors. In general, decomposition of organic fractions leads to the change of physico-chemical and mechanical properties of the soil (Biester et al. 2014). Therefore, simulated decomposition of the wood fractions of the samples was also considered and was tested to observe the change of the engineering properties of the recovered soil. In case of simulated decomposition of wood fractions, the similar trend of strength and compressibility behavior of the recovered soil was obtained as we found in case of wood fractions inclusion. However, none of the samples with simulated decomposition met the minimum requirements of unconfined compressive strength for embankment construction according to JIS. But, only meeting, up to 20SD for all basic samples as soft subgrade for pavement according to category made based on the UCS value by the Das (1994). With simulated decomposition, the compressibility parameters were measured by compressibility test, which showed that the compression index (C_c), compression ratio (CR) and settlement (S_f) of the samples varied from 0.08 to 0.19, 0.05 to 0.11 and 0.27 cm to 0.62 cm respectively for all basic samples which is categorized as slightly compressible (O'Loughlin and Lehane 2003). But, a very important issue is that simulated decomposition greatly affects engineering properties, especially samples containing more wood fractions even with moderate simulated decomposition. Moreover, samples containing more wood fractions even with moderate simulated decompositions; specimen could not be prepared as observed during specimen preparations. Thus, simulated decomposition of the wood fractions should carefully be investigated before geotechnical utilizations.

Finally, it is an important task to make a conclusion about a maximum acceptable ratio of wood fractions for all geotechnical utilizations. A maximum acceptable ratio of wood fractions in recovered soil might be somewhere between 6W and 8W samples for geotechnical utilizations, because the 8W sample is verified as loose stated by the e_{max} of the soil. Nevertheless, simulated decomposition of 50SD for basic sample 6W might be applicable because of this condition specimen showed a void ratio of 0.79, which is lower than e_{max} of the soil. Samples containing more wood fractions with higher simulated decomposition for example 60 to 100 SD might be susceptible, but real decomposition would depends on external factors such as air, water, temperature, organisms etc. (Vigil and Spark 2004; Brandon et al. 1999; Franzluebbers 2004). Moreover, it is expected that decomposition may not be greatly affected if the samples are compacted properly. This means that the availability of air and water and even optimum temperature are controlled properly, resulting no microbial activities and no decomposition occurring.

CHAPTER 6: CONCLUSIONS AND FURTHER RECOMMENDATIONS

6.1 Conclusions

This study discussed the engineering properties of soils recovered from disaster waste, generated by the Great East Japan Earthquake and Tsunami 2011. It is expected that presence of wood fractions in recovered soil is problematic for its geotechnical utilizations. Accordingly, recovered soil was recognized as poor soil and need to be investigated before applications in geotechnical field. Besides, it was particularly important from an economic and environmental point of view to understand the behavior of this soil properties before disposal or utilizations in a particular structure. Consequently, this research conducted several laboratory tests and obtained the results which are summarized below:

Engineering properties for simulated samples, prepared with different percentages of wood fractions and soils were investigated. The results showed that maximum dry density was decreased with increased wood fractions inclusion while optimum moisture contents were increased. Besides, unconfined compressive strength of the recovered soil samples showed a decreasing trend with wood fractions inclusion, while none of the specimen met the minimum requirements for embankment construction according to Japanese Geotechnical Guidelines. But, all samples met the value of unconfined compressive strength proposed by Das (1994) as soft subgrade of pavements (25-50 kPa). The recovered soil samples showed a decreasing trend in deformation modulus (E_{50}) with wood fractions inclusion and seems to be soft for samples containing more wood fractions. This trend was consistent with the results of unconfined compressive strength of recovered soil samples. California bearing ratio (CBR) value was decreased with increased wood factions; while results indicate that all samples may be acceptable for pavement design. But, none of them were acceptable as sub-base materials according to JIS standard. In addition, the CBR value was decreased significantly at the higher wood fractions samples such as 8W, because of loose state conditions where soil particles showed no interlocking with each other. Besides, the void ratio of the recovered soil without wood fractions (0W) was extremely low (0.26) (CBR test case) because larger particles being crushed into smaller particles which occupied void space created between larger particles. This was observed by conducting a particle size distribution test before and after compaction of the recovered soil. Thus, the void ratio of the recovered soil without wood fractions was extremely low. A simple linear regression model was developed and confirmed that void ratio and CBR were inversely and significantly correlated each other. Moreover, the model can be indicated that with 1 unit increase in void ratio, the CBR value of the recovered soil would significantly decrease by 20.396 units. However, it can be concluded that a maximum acceptable ratio of wood fractions in recovered soil might be somewhere between 6W and 8W samples for geotechnical utilizations because sample 8W is verified as being in a loose stated by the e_{max} of the soil. The results of the compressibility test showed compressibility parameters particularly compression index (C_c), compression ratio (CR) and settlement (S_f) were increased with increased wood fractions inclusion. The increased coefficient of volume changes was obtained along with wood fractions inclusion. This volume change was the possible reason of the compressibility of the recovered soil with increase wood fractions inclusion.

When building structures on the soil containing organic matter, strength and compressibility parameters, especially with regard to settlement, need to be carefully considered. In connection to this issue, this research determined the strength and compressibility parameters: compression index, compression ratio and settlement considering the simulated decomposition issue. Four basic samples, namely 3W, 4W, 6W and 8W were taken for specimens preparations with different simulated decompositions, for example 0SD, 20SD 50SD etc. A series of unconfined compression tests and compressibility tests were conducted to understand unconfined compressive strength and compressibility parameters of these samples.

Results of the unconfined compression test indicate that simulated decomposition of the wood fractions affect the deformation as well as strength of the recovered soil. While samples containing more wood fractions (8W), are highly affected by simulated decomposition even though less simulated decompositions (30SD) were considered compared to sample containing less wood fractions (4W). The possible reason for these results may be increased void space due to removal of certain wood fractions based on simulated decompositions. From the compressibility test, it was observed that the compressibility of samples was increased with samples containing more wood fractions due to higher changing volume. The most important reason for the change in compressibility parameters (C_c, CR and S_f) was the volume change that occurred due to simulated decomposition of wood fractions. Removal of larger wood fractions resulting relatively higher volume change which was found for samples containing more wood fractions compared to those in sample containing less wood fractions. Thus, the change in the volume contributed to a relatively higher change in the compressibility of samples containing more wood fractions compared to sample containing less wood fractions. Nevertheless, it can be concluded that simulated decomposition of 50SD for basic sample 6W might be applicable for geotechnical utilizations. Because, specimen showed void ratio 0.79 which is lower than e_{max} of the soil fractions. While samples containing more wood fractions with higher simulated decompositions (60 to 100SD) may be susceptible, because at this condition specimen could not be prepared.

6.2 Further recommendations

This study focused on the engineering properties of the recovered soil considering two phenomena: (1) wood fractions inclusion; and (2) simulated decomposition. This study contributed to the understanding of the behavior of necessary parameters, such as compaction characteristics, unconfined compressive strength, California bearing ratio and compressibility of the recovered soil. Moreover, it is determined maximum acceptable ratio of wood fractions in the recovered soil for geotechnical utilizations. However, further research is necessary for the following issues:

We could not accelerate natural decomposition of the wood fractions in the recovered soil. Therefore, interested researchers are encouraged to investigate the long time decompositions of the wood fractions and it's effect on engineering properties of recovered soil. Moreover, environmental safety will also be considered in this regards and long term changes in engineering properties by corrosion should also be taken into considerations.

We developed a simple linear regression model due to limited input variables and limited samples. Therefore, a multiple regression model could be developed using the different inputs variables such as wood contents, size, aspect ratio and other variables which might have great influence to engineering properties of recovered soil.

Recovered soil was recognized as soft and weak soil. In this study we observed the decreased strength and increased compressibility with increased wood fractions inclusion in the soil which in turn significantly changed the engineering properties of the recovered soil. Therefore, a stabilization method should be established by mixing recovered soil with stabilizing agents to improve the engineering properties which results in improved bearing capacity and reduced settlement under imposed loads.

Though this study estimated the strength parameters by unconfined compression and CBR tests, it is an important to understand the shear strength behavior of the recovered soil. Therefore, strength parameters like friction angle (ϕ) and cohesion (c) should be evaluated by conducting a triaxial test.

The samples used this study should be investigated to consider with curing time, as it is expected that curing time may affect the density of the samples.

Apart from civil engineering structure, the possibility of the utilization of this recovered soil should be investigated in building recreational parks, creating forests on the coastal belt, and applying in agricultural land.

REFERENCES

ADB. (2011)."Towards sustainable municipal organic waste management in South Asia: A guidebook for policy makers and practioners." *Mandaluyong city, Philippines: Asiab Development Bank.* Cited in Chau, N. L. (2013)."Aging Effects on the Engineering properties of Waste landfills." *PhD Thesis*, Graduate School of Global Environmental Studies, Kyoto University, Japan.

Adejumo, T. E. (2012). "Effects of organic content on compaction and consolidation characteristics of lagos organic clay." *The Electronic Joural of Geoenvironmental Engineering*, 17, 2201-2211.

AgriInfo-My Agriculture Information Bank (2011). "Introduction to soil science." Retrieved on http://agriinfo.in/default.aspx?page=topiclist&superid=5&catid=20

Ahmed, A. (2012). "Simplified regression model to predict the strength reinforced sand with waste polystyrene plastic type." *Journal of Geotechnical and Geological Engineering*, 30, 963-973.

Amy, L. (1961). "Physico-chemical basis of the combustion of cellulose and igneous materials." Cah. du. Center Tech. du Bios No. 45, 33.

Aref, S. and Wander, M., M. (1997). "Long-term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments." *Advanced Agronomy* ,62, 153-197.

Ayanaba, A. and Jenkinson, D. S. (1990). "Decomposition of ^{14}C labeled ryegrass and maize under tropical conditions." *Soil Science Society of America Journal*, 54, 112-115.

Babrauskas, V. (2001). "Ignition of Wood: A Review of the State of the Art.", pp. 71-88 in Interflam 2001, Interscience Communications Ltd., London. Retireved on 20.05.2014 from http://www.marioloureiro.net/ciencia/ignicao_vegt/wood_ign.pdf

Babu, S. G. L and Choukesly, S. K. (2011). "Stress-strain response of plastic waste mixed soil." *Waste Mamagement*, 31, 481-488.

Bachev, H. (2014). "Socio-economic and environmental impacts of Match 2011 earthquake, tsunami and Fukushima nuclear accident in Japan." Retrieved on 17.09.2015 and available at https://mpra.ub.uni-muenchen.de/60661/

Biester, H., Knorr, K. H., Schellekens, J., Basler, A. and Hermanns, Y. M. (2014). "Comparison of different methods to determine the degree of peat decomposition in peat bogs." *Biogeosciences* 11, 2691-2707.

Brady, N. C. and Weil, R. R. (2002). "The nature and properties of soils." 13^{th} Edn. Pearson Education (Singapore) pvt. Ltd., India Branch, Delhi, 110092, India.

Brandon, D. M., Brouder, S., Chaney, D., Hill, J. E., Payne, J. M., Scardci, S. C., Williams, J. F. and Wrysinski, J. E. (1999). "Soil Incorporation: Rice Straw Management Today and Tomorrow." Cited in Arthur, A. (2009). "Effect of decomposing crop residues on soil properties and crop productivity in the semi−deciduous forest zone of Ghana." *PhD thesis*, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Brown, C., Mike, M. and Seville, E. (2011). "Disaster waste management: A review article", *Waste Management*, 31, 1085-1098

Chapin, F. S., Matson, P. A. and Mooney, H. A. (2003). "Terrestrial decomposition: principles of terrestrial ecosystem ecology." Chapter 7, Springer, USA.

Chau, N. L. (2013). "Aging Effects on the Engineering properties of Waste landfills." *PhD Thesis*, Graduate School of Global Environmental Studies, Kyoto University, Japan.

Chen, Y. M., Zhan, L. T., Wei, H. Y. and Ke, H. (2009). "Aging and compressibility of municipal solid wastes." *Waste Management*, 29(1), 86–95.

Choudhary, A., Jha, J. and Gill, K. (2010). "Utilization of plastic wastes for improving the sub-grades in flexible pavements." *Paving Materials and Pavement Analysis*: pp.320-326.doi: 10.1061/41104(377)39.

CO (Cabinet Office). (2011). Disaster management. Government of Japan.

Consoli, N. C., Montardo, J. P., Prietto, P. D. M. and Pasa, G. S. (2002). "Engineering Behavior of Sand Reinforced with Plastic Waste." *Journal of Geotechnical and Geoenvironmental. Engineering*, 128, 462-472

Cooperbrand, L. (2002)."Building soil organic matter with organic amendments". Report was published by the Center for Integrated Agricultural Systems (CIAS), College of Agricultural and Life Sciences, University of Wisconsin-Madison. Retrieved on 22th May and available at http://www.cias.wisc.edu/wp-content/uploads/2008/07/soilorgmtr.pdf

Craswell, E. T. and. Lefroy, R. D. B (2001). "The role and function of organic matter in tropical soils." *Nutrient Cycling in Agroecosystems*, 61, 7-18.

Das, B. M. (1994). "Principles of Geotechnical Engineering". *PWS-Kent Publishing Company*, Boston.

Drajad, M., Soekodramodjo, S., Hidayat, M. S. and Nitisapto, M. (2003). "Subsidence of peat soils in the tidal swamplands of Barambai, South Kalimantan." *Journal Ilmu Tanah dan Lingkungan,* 4(1), 32-40.

Dutta, R. K. and Sarda, V. K. (2007). "CBR behavior of waste plastic strip-reinforced stone dust/fly ash overlying saturated clay," *Turkish Journal of. Engineering. Environmental. Science*, 31, 171-182.

Edgars, L. and Noble, J. J. (1992). "A biological model for long term settlement in landfills." *Environmental geotechnology,* M. Usmen and Y. Acars, eds., A. A. Balkema, Rotterdam, The Netherlands, 177–184.

Edil, T. B. (1997). "Construction over peats and organic soil." Conference on recent advances in soft soil engineering, Kuching.

Falloon, P. D. and Smith, P. (2000). "Modeling refractory soil organic matter." *Biol Fertil Soils*, 30, 388-398.

Fragaszy, R., Su, W. and Siddiqi, F. (1990). "Effects of oversize particles on the density of clean granular soils." *Geotechnical Testing Journal*, 13(2), 106-114

Franklin, A. G., Orozco, L. F. and Semrau, R. (1973). "Compaction and strength of slightly organic soils." *Journal of Soil Mechanics and Foundations Division,* American Society of Civil Engineers, 99(7), 541-557.

Franzluebbers, A. J. (2004). "Eolss-Soil Biology." USDA. Agricultural Research Service. Watkinsville, GA, USA.

Gabr, M. A. and Valero, S. N. (1995). "Geotechnical properties of municipal solid waste." *Geotechnical. Testing Journal.*, ASTM, 18(2), 241–251.

Gasparovic, L., Korenova, Z. and Jelemensky, L. (2010). "Kinetic study of wood chips decomposition by TGA." *Chemical Papers*, 64(2), 174-181.

Ghozla, H. L., Krazynski, L. M. and Volk, B. G. (1991). "Disappearance and compressibility of buried pine wood in a warm temperate soil environment." *Ecological Applications*, 1(1), 85-88.

GIA (Geospatial Information Authority of Japan), (2011). "About the total tsunami inundated area." retrived from 20.12.2012 and Available at http://www.gsi.go.jp/common/000059939.pdf, 2011).

Greenland, D. J, Wild, A. and Phillips, D. (1992). "Organic matter in soils of the tropics: from myths to complex reality." P.17-34. In: Lal. R and Sanchez, P.A. (eds). Myths and Sciences of Soils in the tropics, Am. Soc. Agron., Madison, Wisconsin.

Haan, E, J. D. and Kruse, G. A. M (2006). "Characterization and engineering properties of dutch peats. characterization and engineering properties of natural soils." *Proceedings of 2nd International Workshop*, Singapore, Taylor & Francis, London, 3, 2101-2133.

Ham T. G., Nakata Y., Orense, R. and Hyodo, M. (2010). "Influence of water on the compression behavior of decomposed granite soil." *Journal of Geotechnical and Geoenvironmental Engineering*, 136(5), 679-705.

Hayashi, H. and Katsumi, T. (1996). "Generation and management of disaster waste." *Soils and Foundations*, Special Issues on Geotechnical Aspects of the January 17, 1995 Hyogoken–Nambu Earthquake, pp. 349–358.

Hayes, M. H. B. and Swift, R. S. (1978). "The chemistry of soil organic colloid." In D.J. Greenland and M.H.B. Hayes (Ed.), the Chemistry of Soil Constitutes, Wiley-Intersci, New York.

Heal, O., Anderson, J. and Swift, M. (1997). "Plant litter quality and decomposition: an historical review." cited in G Cadisch, KE Giller (eds.) Driven by nature: plant litter quality and decomposition. Wallingford, UK: CAB International, 3–32.

Hobbie, S. E., Oleksyn, J., Eissenstat, D. M. and Reich, P. B. (2010). "Fine root decomposition rates do not mirror those of leaf litter among temperate tree species." *Oecologia*, 162, 505–513.

Hobbs, N. B. (1986). "Mire morphology and the properties and behavior of some british and foregin peats." *Quarterly Journal of Engineering* , 19(1), 7-80.

Hossain, M. S., Gabr, M. A. and Bazlar, M. A. (2003). "Relationship of compressibility parameters to municipal solid waste decomposition." *Journal of Geotechnical and Geoenvironmental Engineering*, 129(12), 1151-1158.

Houghton, R., A. and Hackler, J. L. (1994). "The net flux of carbon from deforstation and degradation in South and Southest Asia." In: Dale, V. (Ed.), Effects of Land-Use Change on Atmospheric CO, Concentrations: South and Southeast Asia as a Case Study. Springer Verlag, New York, pp. 301-327.

Huang, P. T., Patel, M., Santagata, M. C. and Bobet, A. (2009). "Classification of organic soils." Final report Conducted in Cooperation with the Indiana Department of Transportation and the U.S. Department of Transportation Federal Highway Administration, School of Civil Engineering Purdue University.

Huat, B. B. K. (2004). "Organic and peat soils engineering". University Putra Malaysia Press Serdang, Malaysia.

Huat, B. B. K; Asadi, A and Kazemian, S. (2009). "Experimental Investigation on Geo-engineering properties of Tropical Organic Soil and Peat." *American Journal of Engineering and Applied Science*, 2(1), 184-188.

Huppert, H. E. and Sparks, R. S. J. (2006). "Extreme natural hazards: population growth, globalization and environmental change." *Philosophical Transactions of the Royal Society A* 364, 1875-1888.

Inui, T., Yasutaka, T., Endo, K. and Katsumi, T. (2012). "Geo-environmental issues induced by the 2011 off the Pacific Coast of Tohoku Earthquake and tsunami." *Soils and Foundations*, 52(5), 856–871.

Islam, M. S and Hashim, R. (2008a). "Use of machintosh probe test for field investigation in peat soil." *Proceeding of the International Conference*, May 26-27, Best Western Premeier Seri Pacific Kuala Lumpur, Malaysia, pp. 27.

Islam, M. S, and Hashim, R. (2008b). "Engineering properties of peat soils." cited in Mesri G, Stark TD, Ajlouni MA, Chen CS (1997). Secondary Compression of Peat With or Without Surcharging. *Journal of Geotechnical and Geoevironmental. Engineering*, 123(5), 411-421.

Iwate Prefecture (2013). "Guideline for Utilization of Treated Wastes for the Recovery Works" (Revised version), http://ftp.www.pref.iwate.jp/download.rbz?cmd=50&cd=43951&tg=3(in Japanese, accessed on 25th Feb., 2013)

Jenkinson, D. S. and Ladd, J. N. (1981). "Microbial biomass in soil: measurement and turnover." Cited in Soil Biochemistry (eds E. A. Paul & J. N. Ladd), pp. 415–471. Marcel Dekker, New York.

Jones, D. R. V., Taylor, D. P. and Dixon, N. (1997). "Shear strength of waste and its use in landfill stability." *Proc. of the Geoenvironmental Engineering Conference*, Thomas Telford, 343–350.

Kamiyama, A. and Iijima, A. (2012). "Current Trends in Eco-Friendly Reconstruction after the Great East Japan Earthquake." *World Academy of Science Engineering and Technology* 72.

Karimpour, H. and Lade, P. (2010). "Time Effects Relate to Crushing in Sand." *Journal of Geotechnical and Geoenvironmental Engineering*, 136(9), 1209–1219**.**

Katsumi, T. (2015). "Soil excavation and reclamation in civil engineering: environmental aspects." *Soil science and plant nutrition*, pp, 1-8.

Katsumi, T., Endo, K., Imanishi, H., Inui, T., Kazama, M., Nakashima, M., Okawara, M., Otsuka, Y., Sakamoto, H., Sakanakura, H., Suzuki, H., Takai, A. and Yasutaka, T. (2014). “Environmental Geotechnics for the recovery from 2011 East Japan earthquake and tsunami." *Proceedings of the seventh International Congress on Environmental Geotechnics*, A. Bouazza, S.T.S. Yuen, and B. Brown (eds.), Engineers Australia, pp. 170-189.

Katsumi, T. (2012). "Treatment of debris and tsunami deposits, and their effective utilization for restoration and reconstruction. Steel construction: today & tomorrow." The Japan Iron and Steel Federation & Japanese Society of Steel Construction. [Online Access on 20.4.2013 and available at http://www.jisf.or.jp/en/activity/sctt/documents/SCTT36.pdf].

Katsumi, T., Katake, N. and Viwanadham, B. V. S. (2012). "Geosynthetics for environmental protection-Compatability and integrity." *Geosynthetics Asia 2012-5th Asian Regional Conference on Geosysthetics*, D. T. Bergado (ed.), pp.47-68.

Kavazanjian, E. (2001). "Engineering properties of municipal solid waste." *Eighth International Waste Management and Landfill Symposium*, Cagliari, Italy, 3, 415–424.

Kazemian, S., Huat, B. B. K., Prasad, A. and Barghchi, M. (2011). "A state of art review of peat: geotechnical engineering perspective." *International Journal of Physical Science*, 6(8), 1974-1981.

Khalid, N., Arshad, M. F., Mukri, M., Kamarudin, F. and Ghani, A. H. A. (2014). "The california bearing ratio (cbr) value for banting soft soil subgrade stabilized using lime-pofa mixtures, *Electrical Journal of Geotechnical Engineering*, 19, 155-163.

Kim, D. and Ha, S. (2014). "Effects of Particle Size on the Shear Behavior of Coarse Grained Soils Reinforced with Geogrid." *Materials,* 7, 963-679.

Kirk, T. K. and Cowling, E. B. (2009). "The Chemistry of Solid Wood." American Chemical Society, 12, 455–487.

Kokusho, T., Hara, T. and Hiraoka, R. (2004). "Undrained shear strength of granular soils with different gradations." *Journal of Geotechnical and Geoenvironmental Engineering*, 130(6), 621-629.

Krizek, R. J., Max, W. G. and Paul. L. H. (1975). "Organic content and engineering behavior of typical maintenance dredging." *4th South East Asian Conference on Soil Engineering,* Kuala Lumpur, Malaysia, 6-15.

Kwon, Y. and Oh, S. (2011). "Physical and engineering properties of decomposed granite soils sampled in cheongju korea." *International Journal of Physical Science.* 6(24), 5777-5794.

Lan, H. X., Hu, R. L., Yue, Z. Q., Lee, C. F. and Wang, S. J. (2003). "Engineering and geological characteristics of granite weathering profiles in south Chin." *Journal of Asia Earth Science.* 21(4), 353-364

Landva, A. O., Valsangkar, A. J. and Pelkey, S. G. (2000). "Lateral earth pressure at rest and compressibility of municipal solid waste" *Canadian Geotechnical Journal*, 37(6), 1157–1165.

Laskar, A. and Pal, S. K. (2013). "Effects of waste plastic fibers on compaction and consolidation behavior of reinforced soil." *The Electronic Journal of Geotechnical Engineering*, 18, 1547-1558.

Lavelle, P., Blanchart, E., Martin, A., Martin, S., Spain, A., Toutain, F., Barois, I. and Schaefer, R. (1993). "A hierarchical model for decomposition in terrestrial ecosystems: application to soils of the humid tropics". *Biotropica*, 25, 130–150.

Li, J., Tang, C., Wang, D., Pei, X. and Shi, B. (2014). "Effect of discrete fibre reinforcement on soil tensile strength." *Journal of Rock Mechanics and Geotechnical Engineering,* 6, 133-137.

Lutzow M. V., Knabner, I. K, Ekschmitt, K., Matzner, E., Guggenberger, G., Garschner, B. and Flessa, H. (2006). "Stabilization of organicmatter in temperate soils: mechanisms and their relevance under different soil conditions a review." *European Journal of Soil Science,* 57, 426–445.

Matsuo, S. (1975). "Studies of the crushability of decomposed granite soil grains." *Bulletin of the International Association of Geology*, 11(1), 71-76.

Matsuo, S., Nishida, K. and Sasaki, S. (1979). "Physical properties of weathered granite soil particles and their effect on permeability." *Soil Found* 19(1), 13-22.

Matthiesen, H. (2004). "State of preservation and possible settling of cultural layers below Bredsgarden and Bugaden tenements." Rreport. no. 10832-0004-3. Bryggen, Bergen: Department of Conservation, National Meseum of Denmark.

Mcdonald, W. P. (1982). "Influence of organic matter on the geotechnical properties and consolidation characteristics of northern oregon continental slope sediments." *MS thesis*. Oregon State University, USA.

Meyer, Z. and Kozlowski, T. (2008). "Organic soil with elasto-plastic properties settlement under periodic load." *11th Baltic Sea geotechnical conference: Geotechnics in Maritime engineering*. Gdansk, Poland.

Ministry of Land, Infrastructure, and Transport – MLIT 2012a: "Technical guideline on the development of parks and green spaces in the reconstruction from the off the pacific coast of tohoku earth`quake disaster." http://www. mlit.go.jp/common/ 000205823.pdf (March 30, 2012, in Japanese).

Ministry of Land, Infrastructure, and Transport – MLIT 2012b: "Basic concepts on the utilization of recycled materials in constructing fill embankment to accelerate the revitalization from the earthquake disaster." http:// www.mlit.go.jp/common/ 000205731.pdf (March 30, 2012, in Japanese).

Mitchell, J. and Soga, K. (2005). "Fundamentals of soil behavior," 3rd Ed., Wiley, New York.

Miura, N. and Yamanouchi, T. (1975). "Effect of particle crushing on the shear characteristics of sand." *Journal of Japan Society of Civil Engineering*, 260, 109– 108.

Miura, N., Murata, H. and Harada, A. (1983). "Changes in shear characteristics of collapsible soils due to variations in water content." *Journal of Japan Society of Civil Engineering*, 336, 105–112 .

MOE (Ministry of Environment), (2011). "Guidelines (Master Plan) for Disaster Waste Management after the Great East Japan Earthquake." [Online Access on 11.05.2013. and Available at http://www.env.go.jp/jishin/attach/haiki_masterplan-en.pdf]

Morita, K. (2014). "Study on characteristics of soil separated from disaster waste of earthquake and tsunami." *MS thesis*, Graduate School of Engineering, Kyoto University, Japan.

Morita, K., Katsumi, T., Takai, A. and Inui, T. (2012). "Characterization of waste mixed tsunami sediments generated by the 2011 East Japan earthquake and tsunami." *Geo-Environmental Engineering 2012 – Proceedings of the 11th Japan-Korea-France-Canada* Joint Seminar on Geoenvironmental Engineering, pp. 33-42.

Murata, H., Hyodo, M. and Yasufuku, N. (1987). "Compressive and shear characteristics of undisturbed decomposed granite soils paying attention to the degrees of weathering." *Journal of Japan Society of Civil Engineering*, 382, 131–140.

Murphy, B. W. (2014). "Soil organic matter and soil function – review of the literature and underlying data." Department of the Environment, Canberra, Australia.

NPA. (2012). "National police academy." Government of Japan.

O`Kelly, B. C. and Pichan, S. P. (2013). "Effects of decomposition on the compressibility of fibrous peat—A review." *Geomechanics and Geoengineering: An International Journal*, 9(4), 286-296.

O'Loughlin, C. D. and Lehane, B. M. (2003) "A study of the link between composition and compressibility of peat and organic soils." In *Proceeding of 2nd International Conferenc on Advances in Soft Soil Engineering and Technology*, Putrajaya, Malaysia, ed. Huat et al. 135-152.

Oades, J. M. (1989). Cited in J. B. Dixon and S. B. Weed (EDS.) An Introduction to Organic Matter in Mineral Soils (Chap. 3., Minerals in Soil Environment, 2nd edition, Madison, WI,198).

Olk, D. C and Gregorich, E. G. (2006). "Overview of the symposium proceedings, meaningful pools in determining soil carbon and nitrogen dynamics." *Soil Science Societ of American Journal*, 70, 967-974.

Park, S. (2009). "Effect of fiber reinforcement and distribution on unconfined compressive strength of fiber-reinforced cemented sand." *Geotechnical and Geomembrane*, 27,162-166.

Paulo J. V. O., Antonia, A. S. C and Tiago, J. S. L. (2014). "Effects of organic matter content and binder quantity on the uniaxial creep behavior of an artificially stabilized soil." *Journal of Geotechnical and Geoenvironmental Engineering*, Online version available at http://dx.doi.org/10.1061/(ASCE)GT.1943-5606.0001158.

Price, J. S., Cagampan, J. and Kellner, E. (2005). "Assessment of peat compressibility: is there an easy way?" *Hydrological Process*, 19(17), 3469-3475.

Puppala, A. J, Pokola, S. P, Intharasombat, N., and Williammee, R. (2007). "Effects of organic matter on physical, strength, and volume change properties of compost amended expansive clay," *Journal of Geotechnical and Geoenvironmental Engineering*, 133(11), 1449-1461.

Rabbee, T. and Rafizul, I., M. (2012). "Strength and compressibility characteristics of reconstituted organic soil at khulna region of Bangladesh." *International Journal of Engineering and Technology*, 2(10), 1672-1681.

Rafizul, I. M., Asaduzzaman, M. and Alamgir, M. (2010). "The effect of chemical admixtures on the geotechnical parameters of organic soil: a new statistical model." *International Journal of Applied Sciences and Engineering Research*, 1(4), 623-634.

Ranjan, G., Vasan, R. M. and Charan, H. D. (1994). "Behavior of plastic-fiber-reinforced sand." *Geotextile and Geomembrane*, 13,555-565.

Rayner, A. D. M. and Boddy, L. (1988). "Fungal decomposition of wood: its biology and ecology." Chichester, New York.

Reddy, K. R., Hettiarachchi, H., Gangathulasi, J. and Bogner, J. E. (2011). "Geotechnical properties of municipal solid waste at different phases of biodegradation." *Waste Management* 31, 2275-2286.

Reddy, K. R., Gangathulasi, J., Parakalla, N. S., Hettiarachchi, H., Bogner, J. and Lagier, T. (2009a). "Compressibility and shear strength of municipal solid waste under short-term leachate recirculation operations." *Waste Management Reserach*, 27(6), 578–587.

Saxena, S., Hedberg, J. and Ladd, C. C. (1978). "Geotechnical properties of hackensack valley varved clays of New. Jersey." *ASTM Geotechnical Testing Journal*, 1(3), 148−161.

Schlesinger, W.H. (1995). "An overview of the C cycle." Cited in Soils and Global Change (eds R. Lal, J. Kimble, J. Levin & B. A. Stewart), pp. 9–26. Lewis Publishers, Boca Raton, FL.

Schmidt, N. O. (1965). "A study of the isolation of organic matter as a variable affecting properties of a soil," *PhD Thesis*, University of Illinois.

Schlesinger W. H. (1990). "Evidence from chronosequence studies for a low carbon potential of soils." *Nature*, 348, 232-234.

Shen, D. K., Fang, M. X., Luo, M., Cen, K. F. and Chow, W. K. (2007). "Thermal degradation and ignition of wood by thermal radiation." *AOFST* 7. Retrieved on 20.06.2014 and available at http://www.iafss.org/publications/aofst/7/90

Silver, W. L. and Miya, R. K. (2001). "Global patterns in root decomposition: comparisons of climate and litter quality effects." *Oecologia* 129, 407–419.

Singh, B. and Vinot, V. (2011). "Influence of waste tier chips on the strength characteristics of soil." *Journal of Civil Engineering and Architecture*, 5(9), 819-827.

Singh, R. R. and Mittal, S. (2014). "Improvement of local subgrade soil for road construction by the use of coconut coir fiber. *International Journal of Research in Engineering and Technology,* 3(5), 707-711.

Singh, H. P. (2013). "Effects of coir fiber on CBR value of itnagar soil." *International Journal of Current Engineering and Technology*. 3(4), 1283-1286.

Sjostrom, E. (1993). "Wood Chemistry. Fundamentals and Applications." Second edition ed. 1993, San Diego: Academic press. 292.

Song, Y. S., Yun, J. M., Hong, W. P. and Kim, T. H. (2003). "Investigation of solid waste soil as road construction material." *Environmental Geology,* 44, 203-209.

Subbarao, G. V. R., Siddartha, D., Muralikrishna, T., Sailaja, K. S. and Sowmya, T. (2011). "Industrial wastes in soil improvement." ISRN civil engineering 2011, 1-5.

Takai, A., Endo, K., Yasutaka, T., Inui, T. and Katsumi, T. (2013)."Characterization of tsunami deposits toward utilization followed by the 2011 East Japan Earthquake and tsunami." *Proceedings of Congrès GESeD (Gestion Environnementale des Sédiments de Dragage).*

Thevanayagam, S. (2007). "Interaction contact density indices for granular mixes-I: Framework. " *Earthquake Engineering and Engineering Vibration* 6(2), 135-146.

Thiyyakkandi, S. and Annex, S. (2011). "Effect of organic content on geotechnical properties of kuttanad clay." *The Electronic Journal of Geotechnical Engineering*, 6, 1653-1663.

Tiessen, H., Stewart, J. W. B. and Hunt, H. W. (1984). "Concepts of soil organic matter transformations in relation to organo-mineral particle size fractions." *Plant and Soil* 76, 287-295.

Uddin, M. N., Takai, A. Morita, K., Yamane, K., Inui, T., Kaysumi, T. and Flores, G. (2014). "Geotechnical properties of soil fraction recovered from disaster wastes generated by the Great East Japan Earthquake." *Geo-Environmental Engineering 2014 – 13th Global Joint Seminar on Geo-Environmental Engineering*, Hokkaido University, Sapparo, Japan pp. 129–135.

Ussiri, D. A. N. and Johnson, C. E. (2004). "Sorption of organic carbon fractions by spodosol mineral horizons." *Soil Science Society of America Journal*, 68, 253-262.

Verhoef, H. A. and Brussaard, L. (1990). "Decomposition in natural and agro-ecosystems: The contribution of soil animals." *Biochemistry,* 11, 175 − 211.

Vigil, M. F.and Spark, D. (2004). "Factors affecting the rate of crop residue decomposition under field conditions." Conservation tillage Fact Sheet 33-95. USDA-ARS and USDA- NRCS, Akron, Colorado.188

Vilar, O. M. and Carvalho, M. F. (2004). "Engineering properties of municipal solid waste." *Journal of Testing Evaluation*, 32(6), 438–449.

Vivanco, I. and Austin, A. T. (2006). "Intrinsic effects of species on leaf litter and root decomposition: a comparison of temperate grasses from North and South America." *Oecologia* 150, 97–107.

Wall, D. K. and Zeiss, C. (1995). "Municipal landfill biodegradation and settlement." *Journal of Environmental Engineering* 121 (3), 214–224.

Wang, S. Y., Chan, D. H. and Lam, K. C. (2010). "Numerical and experimental studies of pressure-controlled cavity expansion in completely decomposed granite soils of Hong Kong." *Computer Geotechnique*, 37(7-8), 977-990.

Wardwell, R. E., Charlie, W. A. and Doxtader, K. A. (1983). "Test method for determining the potential for decomposition in organic soils." In: P.M. Jerrett ed. *Testing of Peats and Organic Soils*, ASTM STP 820. West Conshohocken, PA: American Society of Testing and Materials, 218-229.

Wesley, L. D. (1988). "Compression index: misleading parameter?" *Journal of Geotechnical Engineering* 114 (6), 718-723.

Woodford, C. (2014). "Wood."Retrieved on 2.2.2015 at http//www.explainthatstuff.com/wood.html

Yamane, K., Morita, K., Takai, A., Inui, T., Katsumi, T. and Otsuka Y (2013). "Physical properties of the soils separated from disaster wastes." *Geo-Environmental Engineering 2014 – 13th Global Joint Seminar on Geo-Environmental Engineering*, Seoul National University, South Korea, pp. 130–136.

Yasufuku, N. and Kwag, J. M. (1999). "Significance of soil particle fragmentation strength related to soil crushability." *Proceedings of 11th Asian Regional Conf. on Soil Mechanics and Geotechnical Engineering*, Balkema, Rotterdam, 149–152.

Yoon, E. and Jo, S. (2002). "Municipal Solid Waste Management in Tokyo and Seoul." *Proceedings of Workshop of IGES/APN Mega-City Project* 23-25, January 2002 (Rihga Royal Hotel Kokura, Kitakyushu Japan).

Zekkos, D. P. (2005)."Evaluation of static and dynamic properties of municipal solid waste." *PhD thesis*, Department of Civil and Environmental Engineering, University of California, Berkeley, Calif.

Zhang, D., Hui, D., Luo, Y. and Zhou, G. (2008). "Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factors." *Journal of Plant Ecology,* 1, 85–93.

Zhang, L. and O`kelly, B. C. (2013)." The principle of effective stress and triaxial compression testing of peat." *ASTM Geotechnical Testing Journal*, 167(1), 40-5012.