EFFECT OF FREEZING AND THAWING ON THE BEHAVIOUR OF MUNICIPAL SOLID WASTE (MSW)

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

IN

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Under the supervision of

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By

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To

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CERTIFICATE

This is to certify that the work being presented in this project report titles "EFFECT OF FREEZING AND THAWING ON THE BEHAVIOUR OF MUNICIPAL SOLID WASTE (MSW)" in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in civil engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat. This is an authentic record of work carried out by Namit Sharma (141625) during a period from July 2018 to May 2019 under the supervision of Dr. Saurabh Rawat (Assistant Professor) and Dr. Rishi Rana (Assistant Professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan.

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ABSTRACT

This study has been conducted to study the effect of freezing and thawing cycles on the behavior of municipal solid waste. Municipal Solid Waste soil samples were collected from the municipal solid waste site of Shimla city. Samples from three different locations were collected from the site and the samples from 4 different depths were kept separately. All these samples were first studied for some basic properties like moisture content specific gravity. The physical and chemical characterization of the solid waste was also done. After this the samples were put under freezing and thawing cycles at different temperatures. The changes in permeability and unconfined strength before and after the application of freezing and thawing cycles were recorded and analyzed.

The results are recorded from the results of permeability and unconfined compressive strength before the freezing and thawing cycle were calculated; these results show the effect of MSW on the soil and its properties. The results recorded after the freezing and thawing cycle show the effect of freezing and thawing on the properties of soil contaminated by MSW.

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LIST OF ABBREVIATIONS

MSW	–	Municipal Solid Waste
MC	–	Municipal Corporation
MCS	–	Municipal Corporation Shimla
UCS	–	Unconfined Compressive Strength
k	–	Coefficient of Permeability
SWM	–	Solid Waste Management

CHAPTER 1
INTRODUCTION

1.1 General

This chapter explores the basic concepts and introduction related to the project on effect of freezing and thawing cycle on behavior of Municipal Solid Waste. The introduction tells us what MSW is, and the basic terms related with it. Infiltration, leachate and other terms are explained. The basic components of MSW are also discussed in this chapter. Discussion is done about the study area and its waste management system. Details about the MSW dump site are also mentioned followed by a basic introduction to the freezing and thawing process. A basic outline of the project is also shown in the end.

1.2 Municipal Solid Waste

Municipal Solid Waste (MSW) is generated in a large amount in most cities due to high production of different types of wastes and their dumping in solid waste dump sites of the municipality. Recurrent dumping of toxic solid wastes leads to accumulation on these sites. This accumulation substantially affects various properties of the soil on and around the site in different wastes. The waste management in hilly areas is different as well as difficult as compared to the plain regions. The constraints faced while going for waste management in hilly areas are difficult terrain, land issues, small size of towns and other technical as well as financial issues. Shocking amount of toxic waste is dumped all along the slopes of dump sites. This toxicity can be harmful for the environment in different ways. For example, the dumped waste in the upstream area can have adverse effects on the freshwater ecosystems in the downstream area. In a similar way, the soil also goes through various changes when it undergoes interaction with the MSW in hilly regions.

Infiltration is a term used in hydrology and soil sciences and it refers to the process by which water above the ground surface finds its way into the soil. The water also moves underground and between soils and rocks. The remaining water reaches the ground water level and mixes with the ground water. Now, considering a MSW dump site, in a hilly area which faces enough rainfall, infiltration will occur. But this will be different from the normal infiltration because the water is entering the soil through heaps of solid waste which are toxic. So the water infiltrating into the soil takes with it a lot of toxic waste into the soil. A toxic part of water is bound to reach the ground water and pollute it or make it toxic. Also, there will be changes in the properties of soil when this water passes through.

Leachate is any liquid which during the course of passing through matter, extracts suspended or soluble solids, or any other component of any material through which it passes. It has also been termed as the liquid that drains or ‘leaches’ from the landfill. The water that is undergoing infiltration also behaves as leachate. It extracts the toxicity from the solid wastes and enters the soil with all the toxic material. This toxic material causes properties of the soil which it enters as well as that of water with which it mixes. It is necessary to know the composition of pollutants of any particular leachate, so that treatment systems can be starts for eliminating or at least reducing them. The organic constituents of leachate include microorganisms, their metabolic products and wastes from living organisms which are under the process of decomposition. The inorganic constituents are ammonia, phosphorous, sulphates and other metals. The inorganic wastes can cause hardness of water, have impact on turbidity and other properties of water. The organic part affects the color, odour, taste and other such physical properties.

In areas suffering from cold climate, a lot of problems are faced due to the leachate produced from the MSW. In hilly regions and areas affected by cold climate, the effect of leachate on soil changes significantly. The frequent temperature variations naturally bring changes in the properties of soil. So, when the soil is exposed to toxic leachate in such temperature variations, the behavior of both the soil and leachate changes. This is because the temperature changes cause a natural freezing and thawing cycle to occur. This freeze-thaw cycle can affect the amount of toxicity through leachate and the changes it brings on the properties of soil present around it.

The changes in the properties of soil, in the presence of leachate, undergoing through freezing and thawing required a need to be studied to see the effects on different properties of the soil. The samples taken from a MSW dump site at different locations and depths are put through freezing and thawing cycles. Different tests are then to be performed to study the changes in the properties of soil. The effects of variation of temperature and also the variation of depth of soil will be studied from the results of the tests.

1.3 Components of Municipal Solid Waste

Municipal Solid Waste (MSW) – more commonly known as garbage or trash- contains the various everyday items we bring into use and then throw away. For example, various such items are product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paints, batteries etc. the major components of MSW according to a study on the basis of percentage are: 35.2% paper, 12.1% yard waste, 11.7% food waste, 11.3% plastics, 8% metals, 7.4% rubber/leather, 5%wood, 7-8% other wastes.

The characteristics of fresh MSW are important for planning, designing, operating and upgrading waste management plants. The physical composition, moisture content, compacted unit weight and permeability are the important MSW characteristics that have to be considered for planning a system. Management of these wastes properly and effectively is very important. After knowing the various properties related to MSW a waste management system is constructed. The municipal solid waste system has four main categories which are recycling, composting, disposal and -incineration (waste-to-energy).

Both organic and inorganic components of MSW add to the toxicity of leachate produced in any MSW dump site. The organic wastes include microorganisms, food products and wastes from living organism which are undergoing decay. The inorganic wastes include ammonia, phosphorous and various metals. Both these types of wastes have their own effects on the properties of leachate and also on the properties of any soil or water present around it. The organic components affect the physical properties like odour, taste etc while the inorganic components cause change in other properties like turbidity and hardness of water etc.

1.4 Study Area

Mountains play a critical role in providing water, energy, food and other services to all the population living in the mountains as well as downstream. However many mountainous regions are experiencing a growing solid waste problem. Steepness, remoteness, existing socio-economic conditions, and susceptibility to many natural hazards, makes solid waste management in mountains more challenging than in lower areas. Most mountain communities face major challenges in managing large amount of non organic waste. All remote communities are now facing more of plastics, metals and other non-biodegradable wastes. Despite these challenges some communities have put into action various remedies to deal with waste issues in hilly or mountainous regions.

Shimla has become one of the most popular tourist destinations in India. Shimla became the capital of newly born state of Himachal Pradesh in 1971. The topography of Shimla is marked by steep slopes, deep valleys, and rugged hills and mountains. Located at an altitude of 2130 meters above mean sea level, Shimla experiences cold winters with snowfalls in December and January.

The temperature goes below -5 degree Celsius in nights during winters and varies at a maximum of 30 degree Celsius in summers.

As per the 2011 Census, Shimla is the one Class 1 city in the state of Himachal Pradesh, with the municipal corporation of Shimla having a population of 1,69.758 people. At present, the municpal corporation of Shimla (MCS) is subdivided into 25 wards covering all the major urban area of Shimla. The governing body structure of the MCS is given in Table 1.1.

Table 1.1 Governing Body Structure (MCS)

1.	President	Commissioner
2.	Vice President	Assistant Commissioner
3.	Member Secretary	Corporation Health Officer
4.	Treasurer	Accounts Officer
5.	Executive Members	Legal Advisor-cum-Law Officer, Project Director (XEn), Municipal Engineer, Architect Planner etc.

The Health Department of MC Shimla is working for the development of sound municipal waste management system through proper transportation, collection, treatment and disposal of MSW in the city in a more planned manner. As per MC Shimla’s current estimates, the everyday waste generation in the city of Shimla is 86.01

MT approximately. This shows that the current per capita per day waste generation is 350 gm/capita/day. The population growth in the last few decades has been significant. Table 2 shows the relation between growing population and its effects on waste generation of Shimla city.

Table 1.2 Population Growth and MSW generation from MCS

Years	**2011**	**2021**	**2031**	**2041**
Resident population	169758	2,56,883	3,49,361	4,18,296
Floating population	76,100	1,00,000	1,25,000	1,50,000
Solid Waste Generation (MT)	86.01	124.91	166.03	198.90

Source: City Sanitation Plan for Shimla: figures for 2011 are from Census 2011

1.5 Management System of Municipal Corporation Shimla

The MCS has divided its collection system into various components to provide proper disposal of solid wastes produced within the city of Shimla. Household wastes are collected through door to door campaigns and then collected and accumulated and brought to the MSW dump site after transportation and other processes. The components or parts of the campaign are:

Primary Collection System: According to the MCS, nearly 85% of the total population of the city gets its waste collected from its door under the door to door waste collection system, while the remaining 15 % use community bins for disposing their wastes. The door to door waste collection has been initiated in all the ward Shimla Environment, Health conservation and Beautification (SEHB) society. A large number of workers cover the entire urban area of Shimla to collect wastes from the doors of the residents.

Secondary collection system: The community bin system holds 23 concrete dust bins and 93 small dust bins of 1 m^3 are placed for disposal of wastes by the residents of Shimla. Also, there are 148 dumper containers of 4.5 m^3 capacity and 54 dumper containers of 3.0 m^3 capacities. The clearing of these bins vary from daily, alternate day, twice a week, or once a week depending upon the area.

Transportation of waste: Transportation of wastes from secondary collection points to the treatment plant is the responsibility of MC Shimla. The entire town's wastes are collected and transported through 32 different vehicles with different capacities, procured under the Jawaharlal Nehru Nation Urban Renewal Mission (JNNURM) project of the Government of India. MC Shimla is in process of procurement of 2 compactors and 1 mechanical sweeping machine. Table 4 gives a description of the different types of transportation vehicles currently being used by MCS for solid waste collection and transportation.

Table 1.3 Details of solid waste transportation vehicles

S. No.	Type of Vehicle	Quantity	Capacity
1.	Pickups(hydraulic)	25`	1-1.5
2.	Pickups (non-hydraulic	5	1
3.	Dumper placer	5	Single
4.	Dumper placer	3	Twinned
5.	Auto tipper	3	1
6.	Auto tipper	3	5
7.	Back e-loader	1	

(A) (B)

(C) (D)

Fig 1.1 Transportation vehicles of MCS, A) Dumper Placer, B) Auto Tipper, C) Pickups, D) Back-hoe Loader

Treatment: Established in 1999, the older treatment plant in Shimla is located at Darni Ka Bagicha for conversion of solid waste into compost. The plant was initially run by L&T Company on a turnkey basis. Because of the increase in population, the amount of waste generation was highly increased. Later this plant was known to be inadequate for the large amount of waste produced. In 2012, the plant was successfully shifted to a new location in Bharial. A Mumbai based firm, named M/s Hanjer Biotech Energies Pvt. Ltd. has been awarded the project for setting the processing and treatment facility.MCS is now planning to expand the project in Bharial as the waste generation keeps on increasing. The large range of work under the project at Bharial includes development, design, construction, operation and maintenance of municipal solid waste processing facility and leachate management system. The concession agreement signed between MC Shimla and M/s Hanjer is for a time period of 20 years.

Disposal: Presently, wastes from the processing unit along with other non-biodegradable wastes are being disposed through landfills in a valley near the old compost plant in Darni Ka Bagicha. To address this, MC Shimla has recently prepared the documents for the implementation of a scientifically constructed landfill facility in Bharial. A Gurgaon based consultancy organization M/s Voyants Solution Pvt. Ltd. has prepared the DPR which has been approved by the Ministry of Urban Development for the construction of the landfill facility. After the shifting of the compost plant to Bharial, the reject waste was brought back to Darni Ka Bagicha for disposal until the new sanitary landfill comes into operation. The estimated time for it construction was 2 years.

1.6 Municipal Solid Waste Dump Site

The MSW dump Site for the Shimla region at Bharial on the Totu-Tara Devi road is to be put under study in this project. The samples that are to be put under the freezing and thawing cycle were collected from this site at different locations and depths. All the daily waste generated in urban Shimla is brought to this site for dumping purposes. Over around 86 MT of waste is produced daily in Shimla city. All this waste is brought to this dump site for disposal. The waste generation in Shimla in terms of per capita per day is estimated to be about 350 g/capita/day. The waste collected from the door to door campaign alone totals to around 70-75 MT out of the total of 86.01 MT.

The leachate entering through this waste into the soil can highly change the properties of soil below this site as well as around it. Also some of the leachate is going to enter the ground water and pollute it. Changes coming in the properties of this leachate affected soil due to processes of freezing and thawing which also occurs naturally in this region of Shimla.

Fig 1.2 MSW dump site Shimla

1.7 Application of Freezing and Thawing cycles

Shimla is situated at an altitude of 2130 meters above the mean sea level. It faces severe cold in winters with snowfall and not very hot summers. The temperature stays in the 20s during the summers. During winters though, the freezing can be experienced naturally for the soil. The temperature stays around a maximum of 10-12^{o} Celsius during the day, but at night goes down the negative scale till -8 to -10^{o} Celsius. So during the winters a natural freezing cycle occurs at night and a natural thawing cycle during the day. So we will use some specific equipment to put the soil samples from this site under the freezing and thawing cycles and then perform certain tests to note down the changes in the properties of the samples.

Freezing: The equipment used for the freezing process is very basic. A simple refrigerator with temperature control can be used. Also use of a thermometer is advised so that the temperature can be measured ourselves. Now each sample from a location and depth is to be put through 12 hour cycles at 3 different temperatures in the freezing category. The temperatures are 0, -6, -12^{o} Celsius. Each sample will be put for 12 hours in freezing environment at the different temperatures.

Thawing: The samples are to be put through the thawing cycles with the help of a water bath in which the samples will be placed. The basic idea was to use an emulsion rod, with a thermostat attached to it which cuts of the supply at any desired temperature. This process could be completed using an aquarium temperature regulator. It is used to maintain the temperature of the water environment of fish inside an aquarium. Certain fish survive at limited temperature ranges, so this regulator is used to maintain the temperature of an aquarium. The various cycles will be held at temperatures of 0, 6, 12^{o} Celsius. Each sample will be put for 12 hours in thawing environment at different temperatures.

Each sample before being put through the cycles is going to be tests for various properties like moisture content, specific gravity, permeability and unconfined compressive strength. Then after each cycle, the soil is again to be tested for all the above properties. A comparison is to be made showing the effects of freezing and thawing cycle on MSW and the soil.

1.8 Organization of Thesis

The first chapter of this thesis gives a brief insight about Municipal Solid Waste, Waste Management practices in the study area and other details related to the study area and its waste generation. Also a basic idea of the freezing and thawing process is also discussed in the first chapter. The basic aim discussed in this chapter is to study the effect of freezing and thawing cycles on the behavior of MSW.

The second chapter is a summarization of the various studies and research done related to the topic. This chapter summarizes various other publications related to the concepts of municipal solid waste, waste general, physical and chemical characterization of waste etc. Also the studies about the area Shimla and other information related to its waste management system are also studied.

The third chapter talks about the methodology used for characterization of waste, freezing and thawing process, and the various soil tests conducted. It also discusses about the equipment used for freezing and thawing processes. The various tests like moisture content, specific gravity etc are also discussed in this chapter and the main two tests for permeability and unconfined compressive strength are also highlighted. This part of the chapter involves the procedure and instrumentation required to record the various readings.

The fourth chapter deals with all the results and readings obtained. The results obtained from laboratory tests, before and after freezing and thawing cycles have all been recorded and tabulated and corresponding graphs have been plotted. The chapter shows a comparison between permeability and UCS values.

The sixth chapter is the conclusion of the entire study conducted in this thesis and an insight for the scope of the future work related to the topic is also given.

A list of all the research work, studies, publications, books and website which have been referred for this study are also shown in the end for referencing.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Studies have been made on the changes of properties of soil which have been subjected to freezing and thawing cycles, upon application of MSW compost. An effect on various properties showing changes on MSWC application is studied. Effects on properties such as aggregate stability, permeability, soil texture, compressive strength, initial soil properties have been studied over the past few years. The changes or variations in these properties of a soil that has been exposed to MSW and gone through freezing and thawing cycles are studied by performing various tests. It is seen in hilly areas that the leachate from MSW dump sites flows into the soils in a large area tends to change the properties of the soil. This soil is also undergoing a natural freeze thaw cycle. So, the soil samples from a municipal solid waste dump site are put under cycles of freezing and thawing. Certain tests are conducted before and after the cycles on various samples and the changes after the freezing and thawing process are observed. This will help to study the effect of freezing and thawing on MSW.

2.2 Research Work

Even though there has not been much research on the effect of municipal solid waste compost on soils of various regions, we still manage to find sufficient research on different topics which can be brought together to get a fair amount of information on this topic. We can start by studying about the research area, its topography, populations, waste generation and waste management processes. A nice study on the urban solid waste management plan of Municipal Corporation Shimla was searched and studied. We begin by knowing about the area we are studying.

Brar, Z [1] (2018) This paper was released in January 2018 which covered in detail the management of urban solid waste in the Municipal Corporation Shimla. The management of municipal solid waste still is a major infrastructure requirement that needs to be improved and this has been a major issue in all fast growing urban areas of the country. Prediction on the amount and characteristics of municipal solid waste and its forecasting over the planning period is important for a good and sustainable solid waste management plan. The rapid increase in urbanization and population has reflected towards the need for sustainable development, and other existing problems including effective and proper management of urban solid waste.

In this paper, a case study on the city Shimla in the state of Himachal Pradesh is carried out to get information about its existing solid waste management plan and system. The study tells us that the amount of solid waste generated by Shimla accounts to approximately 86.01 MT every day. This accounts to the fact that waste generation per capita per day is 350 g/capita/day in the urban area which had a population of 1, 69, 758 according to the 2011 Census. The waste is disposed of unethically in open dumps along with open incineration, which causes problems related to public health and environment. This study tells about the parameters of waste management starting from the sources, to collection, transportation, treatment and final disposal.

The urban solid waste management plan and system takes into account five main phases as parts of the system. These phases include a system for primary collection through a door to door campaign. After covering most of the area through door to door, the remaining waste is collected from public bins and large dust bins. Then the waste is collected and transported to the MSW dump site by using various vehicles procured by the MC Shimla. After collection at the dump site, the waste undergoes a treatment facility. Following treatment the last phase is the disposal of remaining non usable waste.

According to the MC Shimla, 85% of the population of Shimla gets its waste collected from their door. This is due to the door to door campaign done by the SEHB society to collect household wastes. So, nearly 70-75MT of waste is collected from this primary collection system only. The remaining 15% of the population can dispose its waste from community bins which are located in every area. A large number of workers work across the city to collect the wastes from household directly from their door. The community bin system holds 23 concrete bins and 93 small dust bins of 1 cubic meter capacity. Also there are 148 dumper container of 4.5 cubic meter capacity and dumper cleaners are 54 of 3 cubic meter capacity. The cleaning of these bins varied from daily, alternate day, twice or once a week depending upon the area. This is the secondary collection system of MC Shimla. Through these two phases all the waste is collected by the municipal corporation.

The wastes have to be transported from secondary collection points and brought to a treatment facility. The MC Shimla has procured 32 different vehicles from the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) which it uses to collect all the waste from across the city and bring it to the treatment facility. The older treatment facility for the city of Shimla was located at Darni Ka Bagicha. But with time this plant was termed to be inadequate for the large amount of waste being produced by the city. So this treatment facility was shifted to Bharial successfully in the year 2012, now the treatment process takes place in Bharial area. But problem is that a sanitary landfill was not created in Bharial. So till the sanitary landfill would be created in the Bharial area, the reject waste will have to be taken from Bharial, back to Darni ka Bagicha for disposal. The sanitary landfill facility will soon be ready in the Bharial region and the disposal of the reject can be done there only.

The topography of Shimla consists of steep slopes and high mountains. It has a varying kind of climate all through the year, starting with severely cold winters to moderately warm summers. The temperature variation during summers is from 10 to 30^{o}C while in winters temperature ranges from -10 at night to +10 or 12^{o}C during the day. The variation of temperature during the winters follows a natural freezing and thawing cycle which we will follow in our experiments in this project.

Bharti, O et al. [2] (2014) Shimla is located at an altitude of 2130 meters above the mean sea level. The topography of Shimla region is characterized by rugged mountains, steep slopes and deep valleys. Shimla experiences cold winters between the months of December and February with temperatures ranging between 0-13 degrees Celsius during the day and as low as -8 to -10 degrees Celsius during the nights. Summers are moderately warm with temperature ranging between 20-20 degrees. The monsoon period records a moderate amount of rainfall with an average annual rainfall of 1437mm over the past 25 years. The population of Shimla according to the 2011 Census was 1,69,758 people. The Municipal Corporation of Shimla is divided into 25 wards covering the entire urban area of the city.

The problems related with solid waste and its management in hilly terrain is numerous. Solid Waste Management is an important and necessary function of the Municipal Corporation of Shimla. The Municipal Solid Waste (management and handling) Rules, 2000 made Shimla’s Urban Legislative Body (ULB) to establish a proper system for waste management. The overall monitoring and supervision of waste management is brought into act by the MC Shimla and Himachal Pradesh State Environment and Pollution Control Board (HPSPCB) in a regulatory role. Shimla city has successfully imposed a ban on the usage of plastic in the form of carry bags with thickness less than 75 microns according to the attest Notification on Plastic Waste (management and handling) Rules, 2011.

The approximate waste generation per day in the city of Shimla is 93.0 MT. the per capita per day waste generation is 350g. The waste collected from the door to door campaign is around 70-75 MT. According to population forecast and other calculations, the waste generated in 2021 will be around 125 MT. Shimla city has faced a large scale expansion in the past decade. Population growth is also leading to more and more waste generation which is also affecting the soil and water in the areas neighboring the dump sites. The city has gradually improved its SWM infrastructure and facility through various programs.

Rana, R et al. [3](2017) One of the non ignorable facts of human existence is waste generation and production, to satisfy the needs of the growing population, drainage of various natural resources has resulted in production of large amounts of waste. Much importance is given to the liquid and atmospheric waste that the solid waste management is substantially ignored. The term ‘solid waste’ is nowadays referring to the non-liquid material waste generated from domestic, commercial and industrial activities. Unscientific management of these wastes and their disposal leads to serious environmental hazards. The term ‘Municipal Solid Waste (MSW)’ refers to the rejected or unwanted material generated by the daily practices of residential, institutional, commercial and other areas excluding the bio medical hazardous wastes. Generally, MSW is classified into 3 main categories: (1) organic material including kitchen waste, agricultural waste etc. (2) inert materials, namely sand, dust, gravel and (3) recyclable wastes like glass, metals, paper, plastics etc.

A survey which was conducted in more than 17 states of the country reported that solid waste disposal is the second most serious problem faced in the upcoming cities. Waste Management is a big challenge faced in developing countries, per Capita MSW production in India ranges between 350-600g/capita/day. Waste generation is related to the income of people. A survey showed that low income population have waste generation ranging between 0.6-1.0kg/capita per day, while that of high income population is ranging between 1.0-4.5kg/capita/day. Studies have shown that 50% of the waste produced in low income countries remains unattended due to the lack of collection and management facilities. Over the past few decades, India has faces enormous population growth specifically in urban areas. This is mainly because of the migration of people from rural areas, which not only leads to production of high amount of solid waste but also puts a lot of unwanted pressure on our natural resources. Table 2.1 shows the state wise MSW generation in urban Indian cities.

Table 2.1 State wise MSW Generation in India

S. no.	**Name of state/UT**	**MSW generation MT/day**	**S. no.**	**Name of State/UT**	**MSW generation MT/day**	**S. no.**	**Name of State/UT**	**MSW generation MT/day**
1.	Andaman and Nicobar	50	12.	Haryana	536.85	23.	Nagaland	187.6
2.	Madhya Pradesh	4500	13.	Himachal Pradesh	304.3	24.	Daman Diu and Dadra	41
3.	Uttranchal	752	14.	Jammu and Kashmir	1792	25.	Chandigarh	380
.4.	Assam	1146.28	15.	Jharkhand	1710	26.	Puducherry	380
5.	Bihar	1670	16.	Karnataka	6500	27.	Punjab	2793.5
6.	Orissa	2239.2	17.	Kerala	8388	28.	Rajasthan	5037.3
7.	Chhattisgarh	1167	18.	Lakshadweep	21	29.	Sikkim	40
8.	Delhi	7384	19.	Maharashtra	19204	30.	Tamil Nadu	12560
9.	Goa	193	20.	Manipur	112.9	31.	Uttar Pradesh	11585
10.	Mizoram	4742	21.	Meghalaya	283.6	32.	Arunachal Pradesh	93.802
11.	Gujarat	7378.75	22.	Andhra Pradesh	11500	33.	West Bengal	12557

With the expected rise in Indian economy to be around 38% by 2026, this will surely increase the volume of MSW generated by a few times. Correct management of MSW is a complex process which has been affected by improper management and budget issues. An effective and proper waste management system uses the data like quality, quantity, and characterization of waste to get an effective system. The study of characterization of wastes helps determining the deficiency present in the MSW system and also helps finding the solution towards the same.

Determining the physical composition of MSW is very important as it provides us the required information for attaining the suitable technology for implementing an effective waste management system. The samples collected are analyzed on wet weight basis(without prior drying of samples) and segregation into their components is done. The components of segregation are mostly paper, polythene/plastic, textiles/clothes, agricultural waste, leather/rubber, some metals and inert wastes. Inert wastes are chemically non reactive in nature and are also non biodegradable. The main inert components of the wastes in the tricity region were main sand, dust and gravel. The main source of these inert components into solid waste is the high amount of construction in the area. Every component of the waste has to be weighed separately and the percentage contribution is to be worked out. Moisture content of the waste was analyzed in the laboratory right in the beginning because delaying can alter the characterization properties.

The final proximate analysis of the MSW was also performed to determine the ash content and fraction of crustal elements of the MSW because the physical composition provides only main component fraction present in MSW. The analyzed properties include moisture content, ash content, fixed carbon and elemental analysis.

Oztas, T et al. [4] (2013) MSW application on soils leads to the leachate entering the soil and changing its properties. The changed properties of the soil are due to the toxicity present in the leachate. Leachate enters the soil through infiltration and also reaches the ground water thus polluting it. This contamination of water is not bearable as it makes water unfit for drinking. But the changes in the properties of the affected soil are to be studied. In hilly areas with cold climate, nature puts the soil through a natural freeze thaw cycle. So, the objective of the study is to study the effect of MSW application on certain properties of a soil subject to freezing and thawing.

First the soil samples have to be collected from a municipal solid waste dump site. The samples when brought to the laboratory have to be tested for some basic properties like moisture content. Also the physical and chemical characterization of the samples was done. After this the soil samples were made ready in cylindrical shapes, ready to undergo freeze thaw cycles. Different samples are collected from different location at the sump site. The soil from the first location is collected by digging at different depths. Similar process was followed for collection of sample from second location as well.

The soils which had been affected by MSW were put in cycles of freezing and thawing multiple times. Different samples for different time periods and at different temperatures were put for freezing or thawing using the freezing and thawing equipment. After each sample has gone through its allotted cycle the sample was kept aside for certain test. For the waste site of the city of Shimla, in this project we will be putting samples through freezing cycles of 6 hours at -6 and -12^{o} Celsius while thawing at +6 and +12^{o} Celsius.

After completing the subjection to freezing and thawing the samples are laboratory tested for various properties and the results are compared with when the soil was not subjected to freezing and thawing. This will show the effect of freezing and thawing on the soil subjected to MSW which will be the main objective of our project.

Some points noted from this experimental study were the effects of MSW compost application on certain properties of soils. It says that the aggregate stability of soils is improved when soil undergoes freeze thaw cycle and the permeability of the soil is also improved. The soils initial properties and soil texture is also changed. MSW application reduces the effects of freeze thaw cycle on a soil.

2.3 Summary of Literature Review

The literature review summarizes some facts about the MC Shimla, its waste collection treatment and disposal process. The topography and general climate of Shimla was also studies. The total waste generation and per capita per day waste generation were also found out. Then the process of freezing and thawing was also studies in detail and the general outline of the freeze-thaw process and the equipment to be used was decided. Sample collection points and methods were studied. Then the properties that were affected on MSW application to soils subjected to freeze thaw were studied and the major changes were noted. A general outline of the entire project was made through this literature study:

Shimla MC collects on average a total of over 86 MT of waste in total every day. The per capita per head production of waste was found to be 350g/capita/day. The MSW dump site near Totu was finalized as the study area. The samples of soils will be taken from the dump site.

For the freezing equipment, a normal refrigerator can be used with temperature control. A separate thermometer will be used for measuring the temperature. Freezing will be done at 0,-6,-12 degrees. Each cycle will be of 12 hours.

For the thawing equipment, a water bath with an aquarium temperature regulator will be used. The regulator will set the temperature of the bath and thawing will be done. The cycles of 12 hours will be done for temperatures at 0,6,12 degrees.

From the study of MSW application we studied the effects of MSW application on soils subjected to freeze thaw cycles and saw the effects on some of the properties of the soil. The aggregate stability of the soils is increased when soils are subjected to freeze thaw cycles after MSW application.

MSW application also improves the permeability of a soil subjected to freezing and thawing. Effectiveness of MSW compost changes the soil’s texture and initial properties. MSW application reduces the negative effects caused on soils going through natural freeze thaw cycles.

2.4 Objectives

Based on the Literature review, following objectives are determined:

1) To study the effect of freezing and thawing on permeability of Municipal Solid Waste (MSW) so as to assess the leachate infiltration behavior.

2) To determine the variation in MSW permeability with number of freeze thaw cycles.

3) To evaluate the strength (UCS) of MSW under different freeze thaw cycles.

CHAPTER 3
METHODOLOGY

3.1 General

In the beginning of the project, the MSW dump site to be taken under consideration was decided and studied. The other information about the waste generation in the city, the waste management practices it follows studied. Then physical and chemical characterization of the MSW was done. This characterization is useful to know about the type of treatment system required for disposal of waste. Different types of equipment for putting the samples through freezing and thawing cycles are used in this project. Also the various tests to be performed on the samples before and after the cycles are also studied in this project. The whole methodology used in this project is studied in this chapter.

3.2 Site Identification and Details of Study Area

In the areas of hilly terrain and cold climate, the soil exposed to the MSW present in the waste site undergoes a natural freeze-thaw cycle. The effects caused by infiltration of leachate into the soil are changed a bit to the soils exposed to freezing and thawing. The natural temperature change implements a natural freeze thaw process. So, the site area we chose to study was the city of Shimla, capital of the state of Himachal Pradesh. Shimla is an area characterized by rugged mountains, steep slopes, and deep valleys. The area is at an altitude of 2130 meters above mean sea level. Shimla faces a very cold winter with snowfall and temperatures as low as -10^{o}C. The summers are moderately warm.

The population of Shimla city was 1,69,758 according to the Census of 2011.a study tells us that the solid waste generated by Shimla is around 86.01MT per day. This is the total waste produced by the city. This depicts that the wastes generated per capita per day is 350 g/capita/day. A large part of the total waste is collected by a door to door campaign. It is stated to be around 70-75 MT. Waste is collected from the doors of houses and then brought to the dump site. It is transported from the main city to the dump site through different kind of vehicles procured by the MC Shimla.

The Municipal Solid Waste dump site is present at Bharial near Totu in Shimla. All the waste from all across the city is collected and transported to this dump site. This was the site from where the samples of soil will be collected. The climate and temperature variation of the Shimla was suitable for testing the freezing and thawing as these processes also occurs naturally in this region during winters.

Fig 3.1 Waste Dump Site and Sample Collection Points

Samples were collected from the site by digging three pits at different locations in the site. The digging was done with the help of a JCB machine. 3 meter deep pits were made and 4 samples were collected at different depths. The same was done with the other pits. A total of 12 samples, 5kg each was collected from the dump site and brought to the laboratory. Now first testing of these samples was to be done to know their index properties and permeability and unconfined compressive strength. Then samples will be created and put through freezing and thawing cycles using the equipment. Then again the samples will be tested for the above properties and the changes in the properties will be noticed.

3.3 Physical and Chemical Characterization of MSW

3.3.1 Physical Characterization Procedure

Waste characterization methods have been developed for various different applications. This method shows a phased approach for the characterization of MSW especially which is used for geotechnical purposes. The use of physical properties and characterization has a significant effect on the mechanical properties of MSW. The given waste characterization procedure is designed to accurately collect information on some factors and also other important information on their physical properties.

Determining the physical composition of MSW is very important as it provides us the required information for attaining the suitable technology for implementing an effective waste management system. The samples collected are analyzed on wet weight basis (without prior drying of samples) and segregation into their components is done. The components of segregation are mostly paper, polythene/plastic, textiles/clothes, agricultural waste, leather/rubber, some metals and inert wastes. Inert wastes are chemically non reactive in nature and are also non biodegradable. The main inert components of the wastes in the tricity region were main sand, dust and gravel. The main source of these inert components into solid waste is the high amount of construction in the area. Every component of the waste has to be weighed separately and the percentage contribution is to be worked out. Moisture content of the waste was analyzed in the laboratory right in the beginning because delaying can alter the characterization properties.

3.3.2 Chemical Characterization Procedure

The final proximate analysis of the MSW was also performed to determine the ash content and fraction of crustal elements of the MSW because the physical composition provides only main component fraction present in MSW. The analyzed properties include moisture content, ash content, fixed carbon and elemental analysis.

The moisture content of the sample is determined by heating the sample (weighed) of the waste sample in a 105^{o}C oven till some constant weight is reached, value of moisture content can be found from the formula as in given equations.

Moisture Content (%) = (Initial weight – Final weight) /Initial Weight x 100 (1)

Ash Content (%) = Weight of Ash x 100/ Initial weight (2)

Volatile Matter (%) = ((initial weight – final weight)x100)/Initial weight (3)

Calorific Value (Kcal/kg) = (rise in sample temp. x water equivalent)/weight of the sample) (4)

Fixed carbon (%) = 100(%) – moisture (%) – ash (%) – volatile matter (%) (5)

Elemental analysis has the sample oven dried at 75^{o}C and broken down to small particles, sieved through 2mm and 1mm sieves. Elements C, H, N, S and O were determined using Organic Elemental Analyzer (Model-Flash 2000).

3.4 Equipment Used

Shimla is situated at an altitude of 2130 meters above the mean sea level. It faces severe cold in winters with snowfall and not very hot summers. The temperature stays in the 20s during the summers. During winters though, the freezing can be experienced naturally for the soil. The temperature stays around a maximum of 10-12^{o} Celsius during the day, but at night goes down the negative scale till -8 to -10^{o} Celsius. So during the winters a natural freezing cycle occurs at night and a natural thawing cycle during the day. So we will use some specific equipment to put the soil samples from this site under the freezing and thawing cycles and then perform certain tests to note down the changes in the properties of the samples.

3.4.1 Freezing

The equipment used for the freezing process is very basic. A simple refrigerator with temperature control can be used. Also use of a thermometer is advised so that the temperature can be measured ourselves. Now each sample from a location and depth is to be put through 12 hour cycles at 3 different temperatures in the freezing category. The temperatures are 0, -6, -12^{o} Celsius. Each sample will be put for 12 hours in freezing environment at the different temperatures.

3.4.2 Thawing

The samples are to be put into the thawing cycles with the help of a water bath in which the samples will be placed. The basic idea was to use an emulsion rod, with a thermostat attached to it which cuts of the supply at any desired temperature. This process could be completed using an aquarium temperature regulator. It is used to maintain the temperature of the water environment of fish inside an aquarium. Certain fish survive at limited temperature ranges, so this regulator is used to maintain the temperature of an aquarium. The various cycles will be held at temperatures of 0, 6, 12^o Celsius. Each sample will be put for 12 hours in thawing environment at different temperatures.

Each sample before being put through the cycles is going to be tests for various properties like moisture content, specific gravity, permeability and unconfined compressive strength. Then after each cycle, the soil is again to be tested for all the above properties. A comparison is to be made showing the effects of freezing and thawing cycle on MSW and the soil.

3.5 Soil Tests

3.5.1 Determination of Moisture Content

The aim of the experiment is to determine the moisture content of any soil sample. The analysis of moisture content is used to determine the amount and percentage of moisture present in any soil sample. Water content is the ratio of the mass of water to the mass of soil in which it is present. The water content of soils is also responsible for behavior of soils in different properties.

Apparatus Used:

1) 5 containers namely A, B, C, D, E.
2) Weight balance or weighing machine
3) Electric oven
4) Desiccators

Procedure:

The first step is to select a soil sample for measuring its moisture content. The five containers are labeled properly with names A, B, C, D, E and kept in sequence. Weight of can ‘A’ was recorded as W_1 (g). Fill the soil sample in the container. Then weigh the container with the soil in it. The weight is recorded as W_2 (g). Put the container in the electric oven at around 105^{o}C for about 24 hours. Remove the cans from the oven after

24 hours and weigh them. This sample now contains the dry sample without moisture. Record this weight as W_3 (g). Find out the mass of water by subtracting W_3 from W_2 (W_2-W_3). Find the mass of dry soil by subtracting W_1 from W_3 (W_3-W_1). Calculate the water content w (%) for each of the samples using different containers. ‘w’ can be calculated by the formula w% = ((W_2-W_3)/(W_3-W_1))x100 as given in various lab manuals. Determine the average moisture content by taking average of various samples. The formulas as cited in the equations

Mass of Soil, $M_s = W_3 – W_1$ (1)

Mass of Pore Water, $M_w = W_2 – W_3$ (2)

Water Content (%) ‘w’ =(M_w/M_s)x100 (3)

The purpose of this experiment is to work out the moisture content of a soil sample. This purpose can be achieved by following the experimental procedure and calculations given above. Some deviations may occur while calculating the water content due some reasons. Firstly, organic type of soils may get some part of them decomposed in the oven at around 105^oC. This may change the resultant water content. If desiccators are not used for cooling the sample after removing from the oven, some water or moisture from the atmosphere may lead to a small percentage error in the results.

3.5.2 Specific Gravity Test using Density Bottle

This test is performed to determine the Specific Gravity of a soil sample by density bottle method. Specific gravity is the ratio of weight in air of a given volume of any material at a fixed temperature to the weight in air of an equal volume of distilled water at the same stated temperature. Specific gravity may be used to find the degree of saturation and the unit weight of moist soil. Specific Gravity is determined in the laboratory using the cited equation:

$G = (m_2 – m_1)/((m_4 – m_1) – (m_3 – m_2))$ (1)

Where,

m_1 = mass of density bottle in gram;

m_2 = mass of bottle with dry soil in it;

m_3 = mass of bottle, soil and water in gram;

m_4 = mass of bottle full with water only in gram.

Apparatus Used:

i) Density bottle with stopper.
ii) Oven (105^{o}C)
iii) A weight balance
iv) Spatula
v) Thermometer

Procedure: The density bottle is washed with distilled water and dried properly. Drying can be done in oven followed by cooling in desiccators. Weigh the density bottle with the stopper to two decimal places (m_1). Take an oven dried soil sample and place around 5 gram of it in the density bottle. Weigh the bottle with the soil in it (m_2). Add water to the bottle containing soil to fill it completely and then allow it to settle. Stir the soil in the bottle properly with spatula. Allow the soil to properly mix with water. The room temperature should be constant through the process. If the water and soil mixture do not completely fill the bottle, add more water. Then close the bottle with a stopper. The bottle has to be cleaned dry and then weighed to the nearest two decimal places. This weight is soil, water and bottle (m_3). Clean the bottle properly till the neck. Add water to the bottle up to the neck and close the bottle with stopper. Weight the bottle and water up to two decimal places (m_4).

The specific gravity of the soil was measured at a temperature of 27^{o}C. Organic clay has a specific gravity ranged between 2.58-2.65.the less the size of particles, more is the value of specific gravity and vice versa. Specific gravity is the ratio of weight in air of a given volume of a material at standard temperature to the weight in air of an equal volume of distilled water at the same temperature. A sample observation table is shown below in the given table.

Table 3.1 Observation table for moisture content

S. no.	Description	Sample 1	Sample 2	Sample 3
1	Temperature in ^{o}C			
2	Weight of bottle (w_1)			
3	Weight of bottle + dry soil (w_2)			
4	Weight of bottle + soil + water(w_3)			
5	Weight of bottle + water (w_4)			

3.5.3 Unconfined Compression Test

The main objective of this test is to find the unconfined compressive strength of a cohesive soil sample. We will measure the strength through unconfined compression test, which is an unconsolidated undrained (UU or Q type) test. In this the lateral pressure is equal to zero, i.e. the atmospheric pressure. The unconfined compression test is one of the most popular and commonly practiced tests because it is the quickest and the least costly method to calculate the shear strength. The unconfined compression test is not appropriate for dry sands and crumbly clays. It is mainly used for saturated, cohesive soils.

To perform the unconfined compression test, a cylindrical sample of soil is carved out such that the ends are reasonably smooth and the ratio of length and diameter is of the order of 2.the soil sample is placed inside a loading frame on a metal plate,. Then by turning the machine on, the bottom plate raises its level. The upper part of the sample is restrained by the top plate, which is attached to a calibrated proving ring. When the bottom plate starts to raise an axial load is applied on the sample. The switch has to be turned in such a way that there is a constant strain rate applied on the sample. The load is increased slowly to shear the sample, and the reading of force applied to the sample and the resulting deformation are taken. The loading is continued till the sample does not attain a specific shear plane or either the deformation increase a lot. The observed data can be used to find the strength of the soil specimen and stress strain data. Finally the sample is oven dried and its moisture content is measured. The maximum load per unit area is equal to the unconfined compressive strength, q_u.

In this test we assume that during the process or during the setup there is no loss of pore water. Therefore a saturated same will remain saturated throughout the testing and afterwards with same volume, voids ratio or water content. Pore pressures are not measured in this test so the effective stress is unknown to us. The undrained shear strength measured is expressed in terms of the total stress.

Apparatus Used:

The loading frame has its two metal plates. Top upper or top plate is not movable and has been joined to a load measuring device. The bottom plate is raised and lowered using a switch or crank on the front of the loading frame. After placing the soil sample in between the plates, the lower plate is slowly raised, and the resistance or reaction provided by the top plate forces an axial load onto the soil sample. The loading frames are of two types, one which are worked manually or are hand operated, and electric, motor driven and hydraulic frames are also common. The deformations are measured using a dial gauge which has been attached to the top plate. It measures the movement of the top and bottom plate relatively. The strain is applied at a constant rate in this test.

Procedure: The first part is to examine the loading frame. Turn the switch or crank and learn how to take load readings and the deformation dial gauge. Find the units of the dial gauge and calibration constant of proving ring. The strain rate for our experiment will be at a strain rate of 1% per minute. From the length of the sample we determine the deformation at 1% strain. Learn how o apply the strain at a fixed and constant rate. It is important that the soil sample is not sheared at a faster rate than the specified rate. Measure the initial height and the diameter of the cylindrical samples. Take proper measurements using calipers multiple times to ensure it is done correctly. Measure the weight of the soil sample and find the total (moist) unit weight. Keep the soil sample in the loading frame, and zero the dials. In this experiment we have to record the load applied at different strain values. It is recommended that the reading have to be taken at the various strain values of 0,0.1,0.2,0.5,2,3,4,5,6,8,10,1,14,16,18 and 20 percent. The vertical deformation dial reading have to be taken beforehand at these values of strain, using the height of sample (H_o), the percentage strain and the initial dial reading(S_o), the dial readings can be calculated using the cited equation.

$$S = S_o + (E/100)\ H_o \tag{1}$$

Readings for the force (F) are taken from the proving ring dial gauge and the stress applied to the ends of the sample. Is computed as follows:

$$\sigma = F/A \tag{2}$$

Where, A is the cross-sectional area of the sample.

$$A = A_o / (1-\sigma) \tag{3}$$

After applying strain the sample fails in one of two ways. A distinct failure plane is formed in stiff clays. Failure can be identified by measurement of the peak followed by decrease in load. The undrained shear strength is typically taken as the maximum shear stress.

$$S_u = q_u/2 \tag{4}$$

When the lab experiment has been completed, dismantle the loading frame and measure the water content of the soil sample. It is recommended that you reduce the data for this test during the lab experiment.

3.5.4 Constant Head Permeability Test

The objective of this experiment is to measure the permeability of a soil sample using the constant head method. This property of permeability is very important for solving problems related to seepage through earthen dams, stability of earthen dams etc. The experiment is carried out in two different parts,(1) preparation of soil sample for the test and (2) find the discharge through the sample specimen under some particular head of water.

Coefficient of Permeability is referred as the rate of flow under laminar conditions through a unit cross sectional area of porous medium under unit hydraulic gradient.

Apparatus used: Compacting Equipment, Drainage bade: a bade with a porous disc, 12mmthick which has permeability 10 times the expected permeability of soil, Drainage cap: a porous 12mm thick disc, Constant head tank: a suitable water reservoir, Permeameter mould of non corrodible material, Graduated glass cylinder to receive discharge, Stopwatch. A meter scale to measure the head differences.

Preparation of Samples: 1) Undisturbed soil sample: Note the sample number, pit number and the depth at which the sample was taken. Remove the protective cover from the sampling tube. Use the sampling tube to make a cylindrical sample of around 36mm diameter. The specimen shall be placed at the centre of the porous disc. Drainage cap to be fixed over the top of the mould. 2) Disturbed Soil Sample:The sample should be taken from a mixed air dried or oven dried material. Initial moisture content of the sample is to be determined and the required quantity of water is added to the soil to get desired moisture content. Mix the soil thoroughly. Weigh the empty permeameter mould. Clamp it between the compaction base plate and extension collar. Place the assembly on solid waste and fill it with the sample. Compact the sample if necessary. After compaction, the collar and excess soil is removed. Find weight of mould with the sample.

Procedure: For constant head arrangement, the specimen has to be connected through the top inlet to the constant head reservoir. Open the bottom outlet. Establish a steady flow of water. The quantity of flow for a fixed time interval may be collected. Repeat the process thrice for the same interval. Coefficient of permeability for a constant head test is given by:

$$K = qL / Ah, \quad (1)$$

Where k = coefficient of permeability in cm/sec

q= discharge in cm^3/sec

L = length of specimen in cm

A = cross sectional area of sample in cm^2

h = constant head causing flow in cm.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 General

In this chapter the results of various studies and tests are given. The chapter starts with physical characterization and chemical characterization of MSW. It is followed by some basic soil properties like specific gravity and moisture content were calculated. This was followed by calculation permeability and unconfined compressive strength of the samples. Then the samples were put through multiple cycles of freezing and thawing and the effect of these cycles on the permeability and UCS of the samples were calculated and analyzed.

4.2 Characterization of MSW

4.2.1 Physical Characterization

Physical characterization plays an important role in the identification of the waste stream, whose results tell us about the fraction of organic materials, inert and recyclables present in the MSW. This characterization also helps in determining the treatment procedure for the solid waste. The results for physical characterization of MSW from Shimla are given in the following table:

Table 4.1 Physical characterization of MSW in Shimla City

Component of waste	**Waste Sample 1**	**Waste Sample 2**	**Waste Sample 3**	**Average**
Compostable (%)	40.80	37.52	41.57	38.70
Paper/clipboard (%)	6.24	7.47	6.75	6.82
Plastics/polythene (%)	7.01	7.33	8.12	7.48
Glass (%)	0.95	1.21	1.11	1.09
Rubber/leather (%)	1.45	1.52	1.26	1.41
Metals (%)	0.71	0.68	0.84	0.74
Inert (%)	26.53	27.10	25.22	26.28
Miscellaneous (%)	16.31	18.69	15.13	16.71
Total	100	100	100	100
Density of waste (kg/m^3)	420.42	427.33	419.45	422.4

The miscellaneous waste generally comprises of materials like thermocol, straw/hay, foam and also dry leaves etc. The density of solid waste plays an important role in deciding the waste handling and treatment procedures beginning with collection, storage as well as transportation of the waste. It was observed that the compostable and inert fractions in the wastes were generally high. The average density of the waste was reported to be 422.4 kg/m^3. It was noted that a major component of the waste produced in Shimla was organic, 30-60% of the total MSW produced in the city. The composition of inert waste also ranged between 20-30%.

A lot of other studies also show that a large part of MSW generated in developing countries consist a large organic fraction. Organic waste is the major fraction of wastes produced. A study showed that developing countries have large organic content in their waste with high moisture content making it unsuitable for incineration. A large fraction of inert material waste in the MSW is basically due to combining of the normal household and commercial wastes with construction and demolition wastes. Large inert content increases density and decreases the calorific value of the waste material. Similar studies in the city of Jalandhar, Punjab showed that MSW was 20-30% inert. Pune had 26% inert waste while metropolitan cities like Delhi and Bangalore show high inert component between 30-55%.

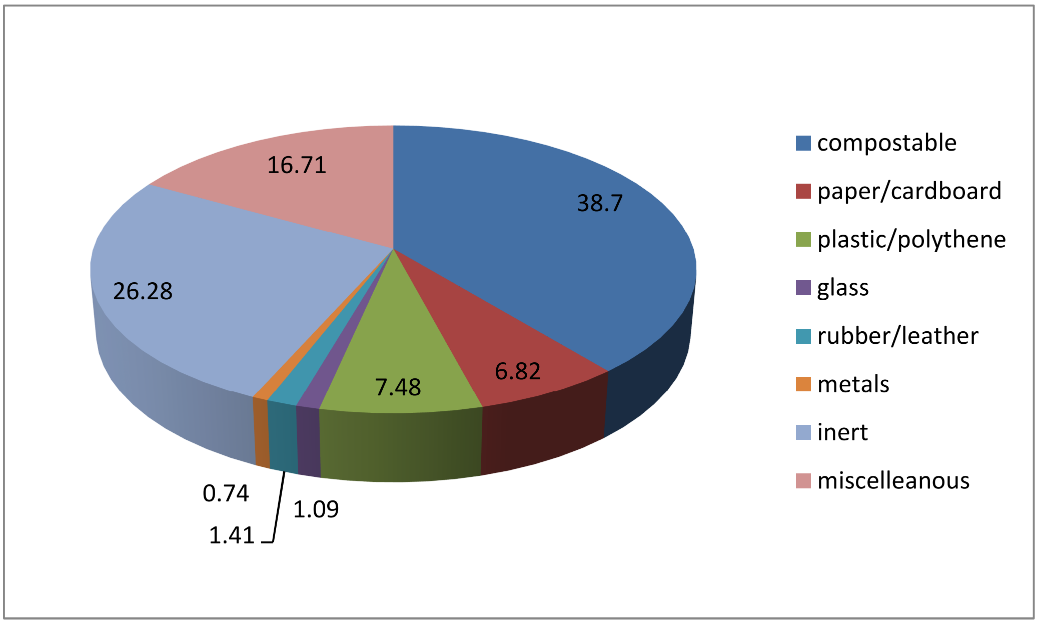

Fig 4.1 Physical Composition of MSW

The inorganic fraction in Shimla mainly consists of paper, plastic, cardboard, polythene, rubber, leather, metals and glass. The characterization results show that the inorganic fraction of Municipal Solid Waste in Shimla was found to be 17.54%. Main inorganic content was paper and plastic. The quantity of metals, rubber and leather were found to be very less in the waste.

4.2.2 Chemical Characterization

The physical characterization of wastes provided information about the composition of the waste stream generated. But the physical characterization of MSW alone is not enough. Chemical characterization helps us know the course of waste treatment processes as it gives the composition of the crustal elements present in the MSW. So it is very important to chemically characterize the solid waste present. For chemical characterization, both proximate and ultimate analyses are to be done on the waste. The analyses were performed on three different samples collected from different areas of the waste dump site. The results of chemical characterization through proximate and ultimate analyses are discussed below in the Table 4.2.

Table 4.2 Proximate and ultimate analysis of MSW

Proximate Analysis				
	Waste Sample 1	**Waste Sample 2**	**Waste Sample 3**	**Average**
Moisture Content (%)	41.64	43.34	42.26	42.41
Volatile Matter (%)	24.44	23.25	23.13	23.60
Ash Content (%)	26.80	27.15	28.25	27.40
Fixed Carbon (%)	7.12	6.26	6.36	6.58
Gross Calorific Value (Kcal/Kg)	1246	1272	1350	1289
Ultimate Analysis				
Carbon (%)	30.51	31.23	29.90	30.54
Hydrogen (%)	4.56	4.44	4.25	4.41
Sulfur (%)	0.2	0.16	.009	.121
Nitrogen (%)	1.15	1.45	1.44	1.34
Oxygen (%)	10.68	11.36	11.75	11.26
Mineral Content (%)	52.9	51.36	52.65	52.33
C/N ratio	26.53	21.5	20.76	22.93

Moisture Content: Wet moisture content of the MSW found in Shimla was determined to b around 40-45%. It was studied earlier that the moisture content of MSW in Asian countries varies between 17% and 65%. The moisture content found in wastes of Shimla was observed to be within these limits. The presence of high moisture content predicts a high fraction of organic materials in the waste samples.

Ash Content: Ash refers to the residue that is left over after combustion. Due to the presence of inert materials, the ash content of the MSW was found to be high. The combined average ash content of the waste samples collected from Shimla was found to be 27.4 %.

Volatile Matter: The volatile matter is the left over material after subjecting the waste to a temperature of 950^{o}C for seven minutes. Studies showed that the volatile material in the waste from the city of Kolkata were 38.51%. In Shimla, the average volatile matter present in the MSW waste samples was 23.6%.

Calorific Value: the calorific value is important for us to design the energy recovery system from MSW.MSW characteristics studied in Delhi and Mumbai showed the calorific values of their waste to be 4498Kcal/Kg and 7477Kcal/Kg respectively. In a much smaller city the calorific values of the waste generated were expected to be much lower. Such was the case when the calorific value of MSW samples of Shimla was found to be 1289Kcal/Kg.

Fixed Carbon: Fixed Carbon tells us about the portion of combustible matter that has to be burned in the solid state and not as gas or vapor. The average fixed carbon in the samples of Shimla city was found to be 6.58%.

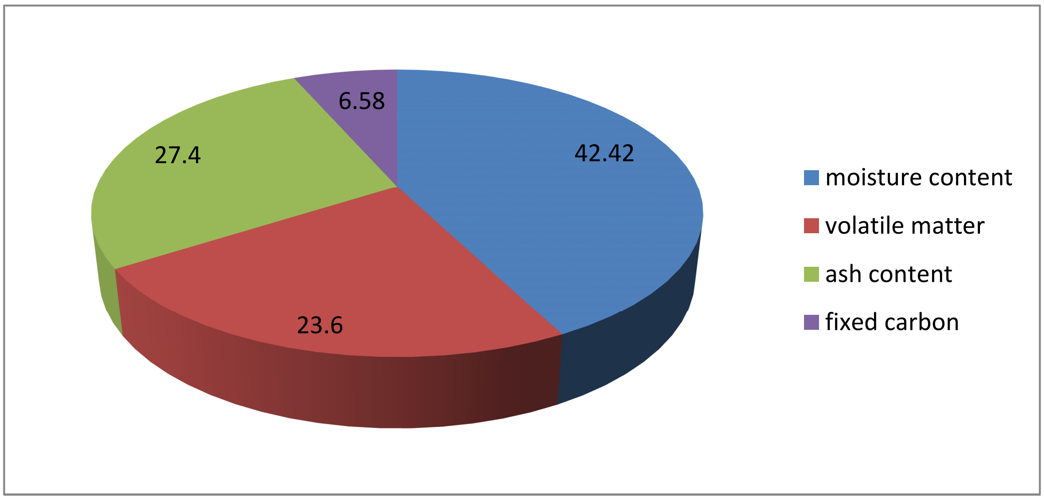

Fig 4.2 Proximate Analysis of MSW

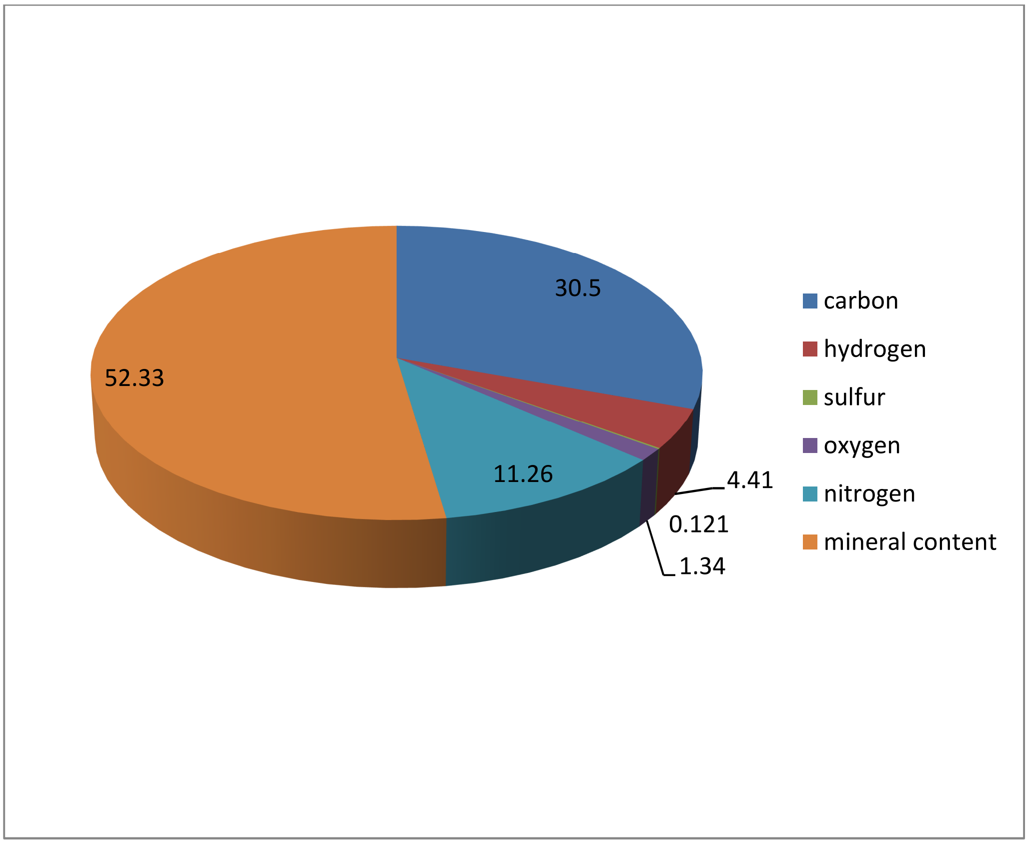

Fig 4.3 Ultimate Analysis of MSW

Elemental Analysis: The elemental analysis of the waste samples showed that the maximum content was taken up by carbon at 30.54%, followed by oxygen at 11.25%. Hydrogen content was found to be 4.41%, while oxygen took up 1.34% and sulfur only 0.121%. The C/N ratio of the samples was 22.93. According to a study the C/N ratio in Asian countries in expected to be within 17 and 54%. Fig 4.2 shows the result of average proximate analysis while Fig 4.3 shows the average ultimate analysis.

4.3 Basic Properties of Soil before Freezing and Thawing

4.3.1 Specific Gravity

The results of the specific gravity test are presented in Fig 4.4. These results show that the soils that are less contaminated showed generally lower specific gravity than the soil which is more contaminated due to more direct exposure. The variation of specific gravity with depth is shown for all the three samples.

Table 4.3 Specific Gravity Values

Soil Sample	Depth (m)	Specific Gravity
Sample 1	0	2.49
	1	2.31
	2	2.37
	3	2.44
Sample 2	0	2.53
	1	2.36
	2	2.46
	3	2.49
Sample 3	0	2.50
	1	2.35
	2	2.38
	3	2.46

The specific gravity of the sample was found to be the highest for the soil at the top layer. For the depth of 1m, the specific gravity decreased steeply and then started increasing for the remaining depths. This is because direct contact with MSW saw specific gravity of the soil at the top to increase a lot. The soil at 1m depth had less contact with MSW and was less contaminated so it had a low specific gravity value. The subsequent values showed little increase with depth.

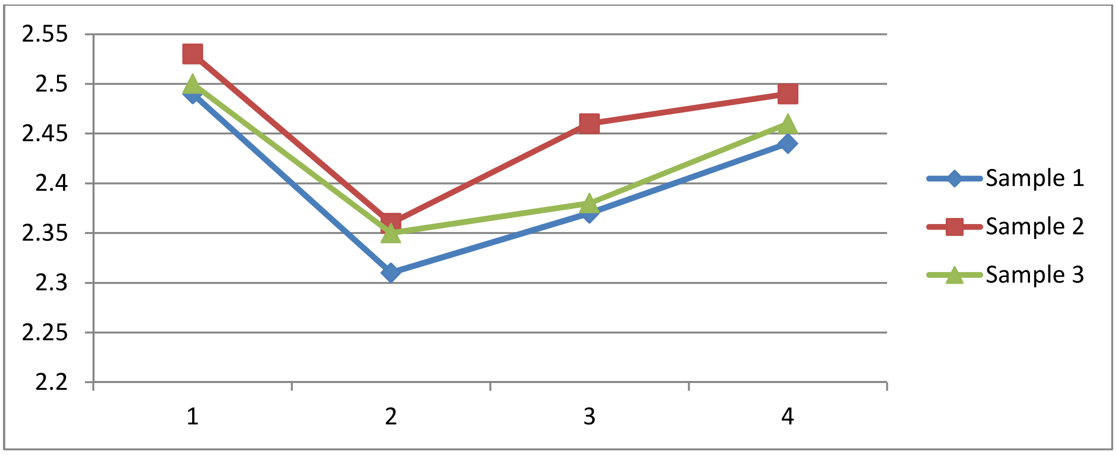

Fig 4.4 Variation of Specific Gravity of the soil with depth

The above graph shows that the specific gravity of the three showed a similar pattern. The top sample at zero depth showed a high value, followed by a steep increase and then slow increase.

4.3.2 Moisture Content

The results of the moisture content test on the soils are shown in Table 4.4. It is a graph showing the variation of moisture content with changing depth of three different samples. The moisture content was noted to be more than the normal uncontaminated soil. With the increase in depth, it was noted that the moisture content of the soil starts to decrease

Table 4.4 Moisture Content Values

Soil Sample	Depth (m)	Moisture Content (%)
Sample 1	0	16.18
	1	15.90
	2	14.05
	3	13.60
Sample 2	0	17.1
	1	16.42
	2	14.85
	3	13.90
Sample 3	0	16.55
	1	15.85
	2	13.95
	3	13.35

The moisture content of soils contaminated by MSW is more than those of normal soils. This is mainly because of the reasons that the soil contaminated by the MSW is not directly exposed to sunlight as it has been covered by the wastes, so there are no chances of evaporation of moisture from the soil.

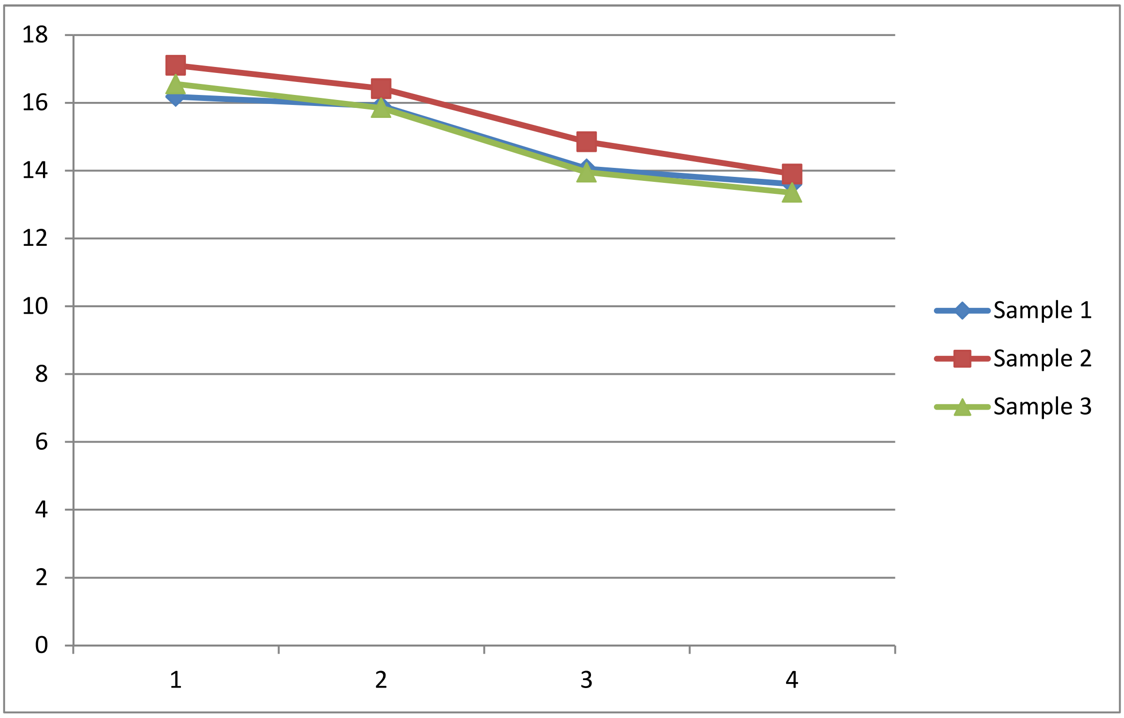

Fig 4.5 Variation of moisture content with depth

Fig 4.5 shows the depth versus moisture content graph for the three samples. The three samples show that the moisture content is decreased with depth for all the three samples. This is because more water is carried by the uppermost layer because it faces all kinds of moisture from the waste as well as from rainfall etc.

4.4 Permeability and Unconfined Compressive Strength

4.4.1 Coefficient of permeability before freezing and thawing

The coefficient of permeability of a normal soil will show a normal variation, the value of the coefficient decreasing slowly with depth. For example, a normal soil would have values of like 0.074 at 0.5m depth, 0.035 at 1m depth and 0.018 at 2m depth. But the soils been contaminated of affected by MSW will have higher value of coefficient of permeability which decrease in a lot steeper manner. The results of the coefficient of permeability test are shown in the table below. Results were taken for all the three samples for three different locations at all four depths.

Table 4.5 Coefficient of permeability of the soil samples

Soil Sample	**Depth(m)**	**Coefficient of permeability, K Cm/sec**
Sample 1	0	0.21
	1	0.14
	2	0.094
	3	0.085
Sample 2	0	0.18
	1	0.135
	2	0.086
	3	0.044
Sample 3	0	0.16
	1	0.115
	2	0.085
	3	0.056

The table shows the values of k, the coefficient of permeability for all the three samples and at the 4 depths. It was seen that the values are decreasing with depth but the general value of k is much more than that of normal soil.

4.4.2 Unconfined Compressive Strength before Freezing and Thawing

The unconfined compressive strength of the different soil samples collected from various depths was found out. The results are given below in the tables. The results are compared to the unconfined compressive strength of uncontaminated soil. Uncontaminated soil had much higher UCS as compared to the contaminated soils. Also, the contaminated soils showed increase in unconfined compressive strength with increase in the depth

Table 4.6 UCS of MSW sample 1

Test	Uncontaminated soil	Contaminated MSW soil samples with depth			
		0m	**1m**	**2m**	**3m**
UCS (Kn/m^2)	44.0	17.00	22.5	31.55	42.25

Table 4.7 UCS of MSW sample 2

Test	Uncontaminated soil	Contaminated MSW soil samples with depth			
		0m	**1m**	**2m**	**3m**
UCS (Kn/m^2)	39.50	16.50	20.25	29.75	40.36

Table 4.8 UCS of MSW sample 3

Test	Uncontaminated soil	Contaminated MSW soil samples with depth			
		0m	**1m**	**2m**	**3m**
UCS (Kn/m^2)	26.50	13.80	21.98	25.45	28.5

The UCS decreased by a massive 60-70% at 0m as compared to the uncontaminated soil. The values then increased quickly and almost reached the same level as the uncontaminated soil at 3m depth. The figure below shows the variation of unconfined compressive strength of the three samples with the increase in depth. It is a plot between depth and UCS.

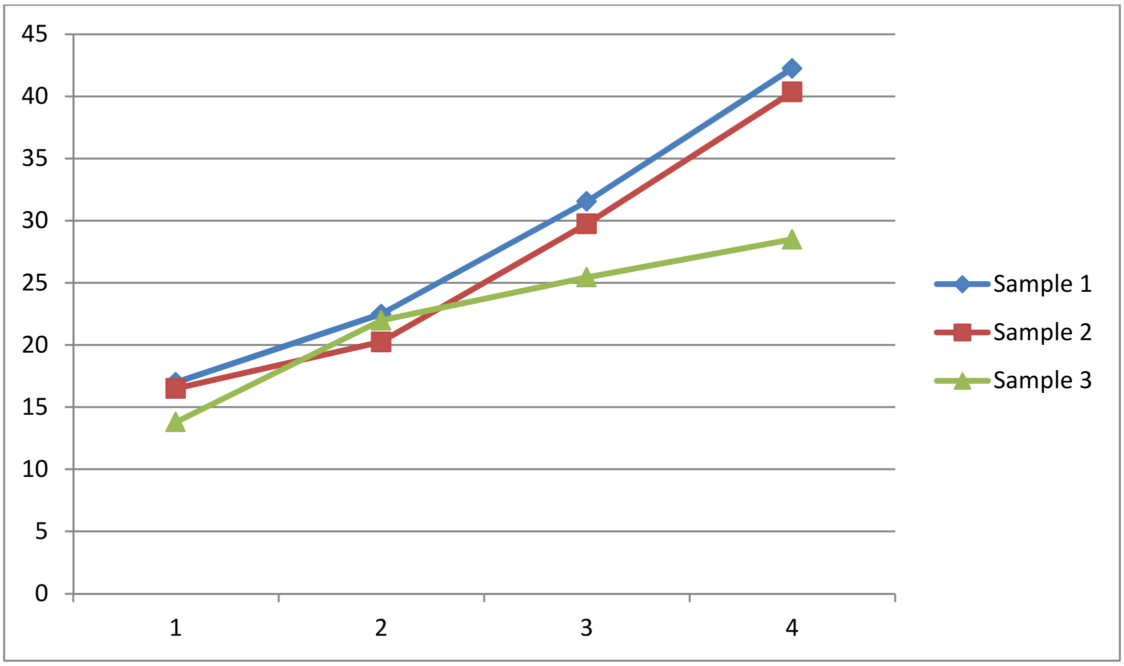

Fig 4.6 UCS of the three samples

The above plot shows the changing UCS with depth for the three samples. Sample 1 and 2 show a similar behavior as the values increased at a normal rate. Sample 3 had low strength at zero depth as compared to the other 2 samples. So, after 1m depth it showed a sudden increase in the UCS values.

4.5 Soil Properties after Freeze/Thaw Cycles

The different soil samples were collected from three different locations of the MSW dump site, and were named as sample 1, sample 2 and sample 3. At each of these locations, 4 different samples were collected at different depths. The first sample was collected after removing the top 30cm, followed by three more sample collected from depths of 1, 2 and 3m. before putting the samples through freezing and thawing cycles, some of the properties of soil were measured. The same properties were measured after the cycles to see their effect on the soil. Freezing and thawing were done at 0^{o}C, 6 and -6^{o}C, 12 and -12^{o}C for 12 hours each.

4.5.1 Coefficient of Permeability

Values of K, the coefficient of permeability after freezing and thawing cycles are given in the tables below:

Freezing and Thawing cycle at 0^{o}C: One freezing and thawing cycle includes 12hours of freezing at 0^{o}C followed by 12 hours of thawing at the same temperature. 3 such cycles were done and the values of coefficient of permeability were calculated.

Table 4.9 Sample 1, k values for cycles of 0^{o}C

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.21	0.201	0.194	0.187
1	0.14	0.135	0.122	0.118
2	0.094	0.086	0.079	0.073
3	0.085	0.080	0.075	0.072

Table 4.10 Sample 2, k values for cycles of 0^{o}C

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.18	0.165	0.152	0.141
1	0.135	0.120	0.114	0.100
2	0.086	0.081	0.076	0.052
3	0.044	0.040	0.035	0.029

Table 4.11 Sample 3, k values for cycles of 0^{o}C

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.16	0.152	0.145	0.136
1	0.115	0.107	0.091	0.085
2	0.085	0.073	0.065	0.058
3	0.056	0.051	0.045	0.037

It was seen that for freezing and thawing at 0^0C, the value of coefficient of permeability were decreasing for all the three samples. With the depth increase, the values of k were decreased and the amount of decrease in these values also decreased.

Freezing and thawing at -6^0 and 6^0C: One cycle of freezing and thawing included 12 hours of freezing at -6^oC followed by 12 hours of thawing at 6^0C. Three such cycles were carried out for all the three samples and the values of coefficient of permeability were calculated. The change in the values of the coefficient were noted and analyzed.

Table 4.12 Sample 1, k values for cycles of 6^oC and -6^oC

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.21	0.190	0.178	0.167
1	0.14	0.134	0.125	0.110
2	0.094	0.087	0.075	0.070
3	0.085	0.076	0.072	0.055

Table 4.13 Sample 2, k values for cycles of 6^oC and -6^oC

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.18	0.164	0.158	0.151
1	0.135	0.128	0.115	0.102
2	0.086	0.072	0.056	0.047
3	0.044	0.038	0.035	0.030

Table 4.14 Sample 3, k values for cycles of 6°C and -6°C

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.16	0.158	0.150	0.141
1	0.115	0.103	0.095	0.088
2	0.085	0.075	0.068	0.055
3	0.056	0.046	0.039	0.035

For the cycles of 6°C and -6°C, and also of 12°C and -12° C, the values were not decreasing that steeply but the behavior and variation of the values with the depth were same. So, we find that the soil which has been contaminated by MSW shows an improvement in its coefficient of permeability values.

Freezing and thawing at -12^0 and 12^{0}C: One cycle of freezing and thawing included 12 hours of freezing at -12°C followed by 12 hours of thawing at 12^{0}C. Three such cycles were carried out for all the three samples and the values of coefficient of permeability were calculated. The change in the values of the coefficient were noted and analyzed.

Table 4.15 Sample 1, k values for cycles of 12°C and -12°C

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.21	0.193	0.151	0.137
1	0.14	0.125	0.116	0.105
2	0.094	0.087	0.074	0.068
3	0.085	0.072	0.067	0.061

Table 4.16 Sample 2, k values for cycles of 12^oC and -12^oC

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.18	0.168	0.157	0.139
1	0.135	0.126	0.114	0.097
2	0.086	0.075	0.065	0.055
3	0.044	0.040	0.034	0.029

Table 4.17 Sample 3, k values for cycles of 12^oC and -12^oC

Depth (m)	**Value of k(cm/s) before cycles**	**New value of k(cm/s)after freeze/thaw**		
		1 cycle	**2 cycles**	**3 cycles**
0	0.16	0.151	0.145	0.134
1	0.115	0.104	0.096	0.09
2	0.085	0.081	0.075	0.067
3	0.056	0.045	0.041	0.039

From the results above relating permeability we can study the effects of freezing and thawing on MSW soil and its effect on the permeability of the soil. The three samples were put through different freezing and thawing cycles and the values of K, the coefficient of permeability were recorded after each cycle for three cycles for all the samples. The values of K were calculated prior to the freeze/thaw cycles also. A trend in the change of this value was noted in the above results. It was seen that for freezing and thawing at 0^{0}C, the value of coefficient of permeability were decreasing for all the three samples. With the depth increase, the values of k were decreased and the amount of decrease in these values also decreased. For the cycles of 6^{o}C and -6^{o}C, and also of 12^{o}C and -12^o C, the values were not decreasing that steeply but the behavior and variation of the values with the depth were same. So, we find that the soil which has been contaminated by MSW shows an improvement in its coefficient of permeability values. This shows that the application of MSW reduces the effects of freezing and thawing on the permeability of the soil samples.

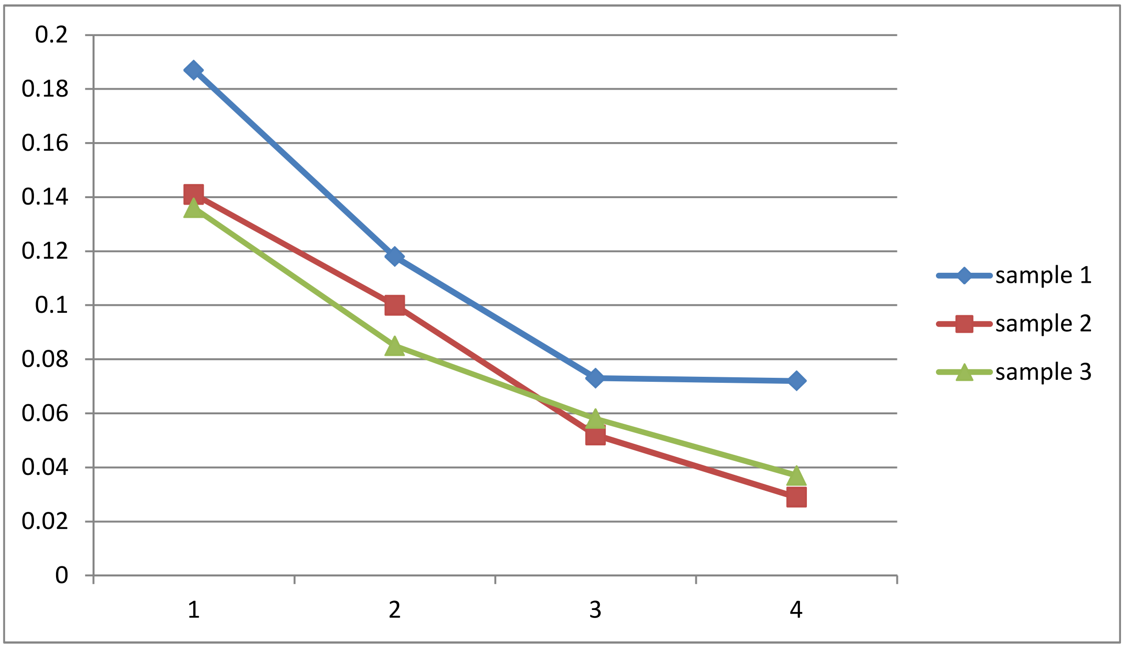

Fig 4.7 Variation of permeability coefficient with depth after three freeze/thaw cycles (0^oC)

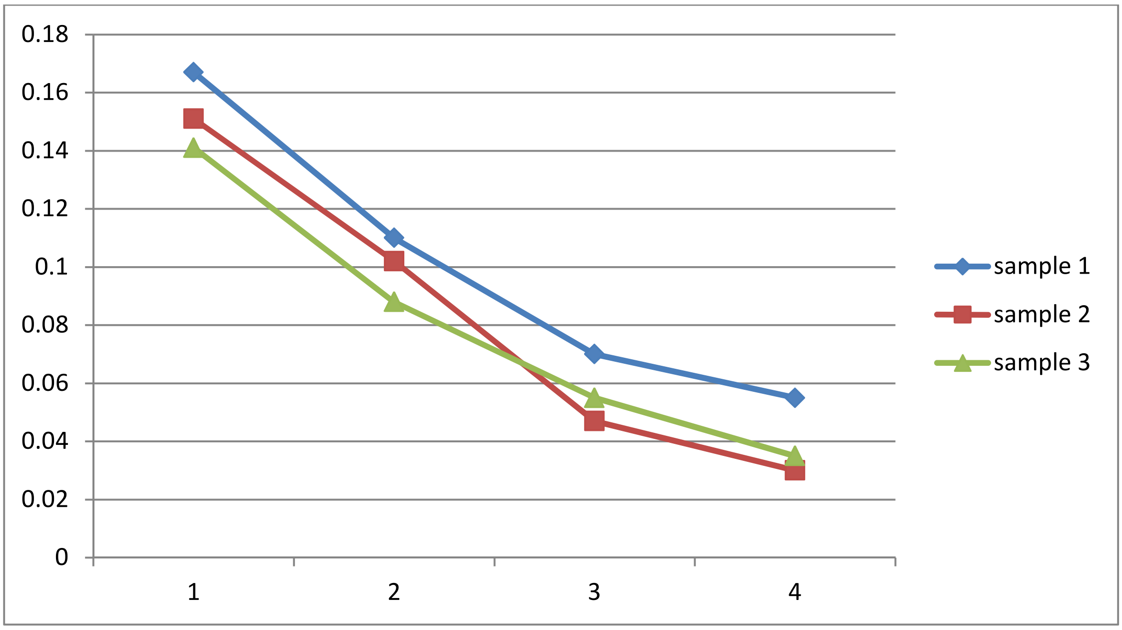

Fig 4.8 Variation of permeability coefficient with depth after 3 freeze/thaw cycles (6 and -6^oC)

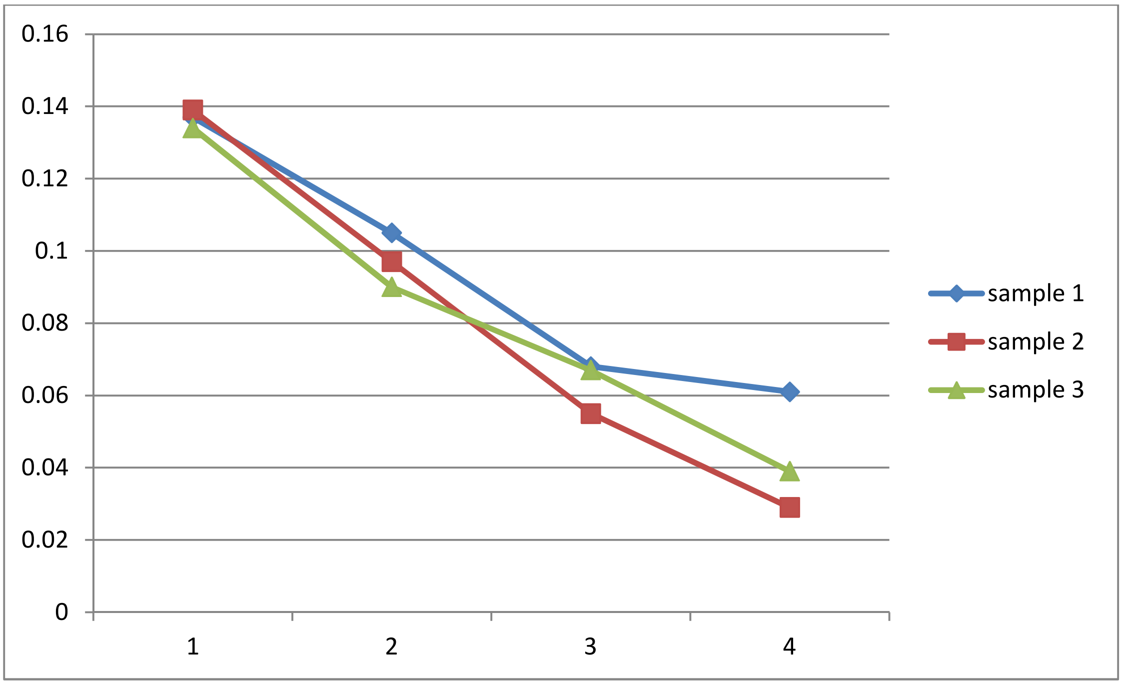

Fig 4.9 Variation of permeability coefficient with depth after 3 freeze/thaw cycles (12 and -12^{o}C)

The general trend saw a decrease of 20-30% of the value of coefficient of permeability after three freeze thaw cycles at 0^{o}C. In the other cycles, in decrease was around 20% for 6 and -6^{o}C, while around 15-20% for 12 and -12^{o}C cycles. After these tests, the unconfined strength and shear strength parameter were also to be compared. Given below, the graphs show the effect on permeability of the three samples after three cycle's at different temperatures.

4.5.2 Unconfined Compressive Strength (UCS)

Values of Unconfined Compressive Strength were calculation for the three samples at the 4 different depths. After these tests, the samples were put under different freezing and thawing cycles and the values of unconfined compressive strength were calculated.

Freezing and Thawing cycle at 0^{o}C: One freezing and thawing cycle includes 12hours of freezing at 0^{o}C followed by 12 hours of thawing at the same temperature. 3 such cycles were done and the values of coefficient of permeability were calculated. The tables below show the results:

Table 4.18 Sample 1, UCS values for cycles of 0^{o}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	17	16.45	15.10	14.25
1	22.5	20.25	18.95	17.5
2	31.55	28.75	26.50	23.35
3	42.25	39.25	35.50	33.25

Table 4.19 Sample 2, UCS values for cycles of 0^{o}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	16.5	15.75	15.10	14.50
1	20.25	18.75	17.55	16.75
2	29.75	27.50	25.75	23.00
3	40.35	38.70	35.25	32.50

Table 4.20 Sample 3, UCS values for cycles of 0^{o}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	13.8	13.25	13.10	12.75
1	21.98	20.15	19.50	17.25
2	25.45	24.25	22.75	21.35
3	28.5	26.95	25.25	23.60

The values of UCS for all the three samples before freeze/thaw cycles are given. The value of UCS was seen to increase with depth. This means that the application of MSW decreases with depth. Then the value was again measured after one cycle of freezing and thawing at 0^{o}C. It was seen that the values of UCS were seen to decrease after every freeze/thaw cycle. Also, with depth the decrease was steeper.

Freezing and thawing at -6^{0} and 6^{0}C: One cycle of freezing and thawing included 12 hours of freezing at -6^{o}C followed by 12 hours of thawing at 6^{0}C. Three such cycles were carried out for all the three samples and the values of coefficient of permeability were calculated. The change in the values of the coefficient were noted and analyzed.

Table 4.21 Sample 1, UCS values for cycles of 6^{o}C and -6^{0}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	17	15.85	14.35	13.65
1	22.5	19.85	18.25	16.95
2	31.55	27.95	26.10	22.75
3	42.25	38.85	34.55	32.5

Table 4.22 Sample 2, UCS values for cycles of 6^{o}C and -6^{o}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	16.5	15.15	14.0	12.95
1	20.25	17.95	16.75	15.85
2	29.75	26.75	25.15	22.50
3	40.35	37.80	34.35	31.75

Table 4.23 Sample 3, UCS values for cycles of 6^{o}C and -6^{o}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	13.8	13.05	12.75	12.15
1	21.98	19.95	18.75	16.85
2	25.45	23.75	22.35	20.55
3	28.5	26.25	24.35	22.85

The samples were also put through freeze/thaw cycles at -6^o and 6^{o}C for 12 hours. Values were taken for the UCS after each of the three cycles. The values of UCS decreased a little after each of the 3 cycles. The decrease in values is shown in the above tables.

Freezing and thawing at -12^0 and 12^{0}C: One cycle of freezing and thawing included 12 hours of freezing at -12^{o}C followed by 12 hours of thawing at 12^{0}C. Three such cycles were carried out for all the three samples and the values of coefficient of permeability were calculated. The change in the values of the coefficient were noted and analyzed.

Table 4.24 Sample 1, UCS values for cycles of 12^{o}C and -12^{0}C

Depth (m)	Value of UCS(Kn/m^2) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	17	15.25	14.05	13.15
1	22.5	19.20	17.85	16.35
2	31.55	26.5	25.15	22.30
3	42.25	36.85	35.15	31.35

Table 4.25 Sample 2, UCS values for cycles of 12°C and -12°C

Depth (m)	Value of UCS(Kn/m²) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	16.5	14.55	13.75	12.75
1	20.25	17.25	15.85	14.95
2	29.75	26.1	24.75	22.25
3	40.35	36.50	33.45	31.25

Table 4.26 Sample 3, UCS values for cycles of 12°C and -12°C

Depth (m)	Value of UCS(Kn/m²) before cycles	New value of UCS after freeze/thaw		
		1 cycle	2 cycles	3 cycles
0	13.8	12.65	12	11.50
1	21.98	18.55	17.45	16.10
2	25.45	22.95	21.55	20.2
3	28.5	25.5	24.05	22.15

The graphs below show the trend of UCS values for the three different temperature cycles followed.

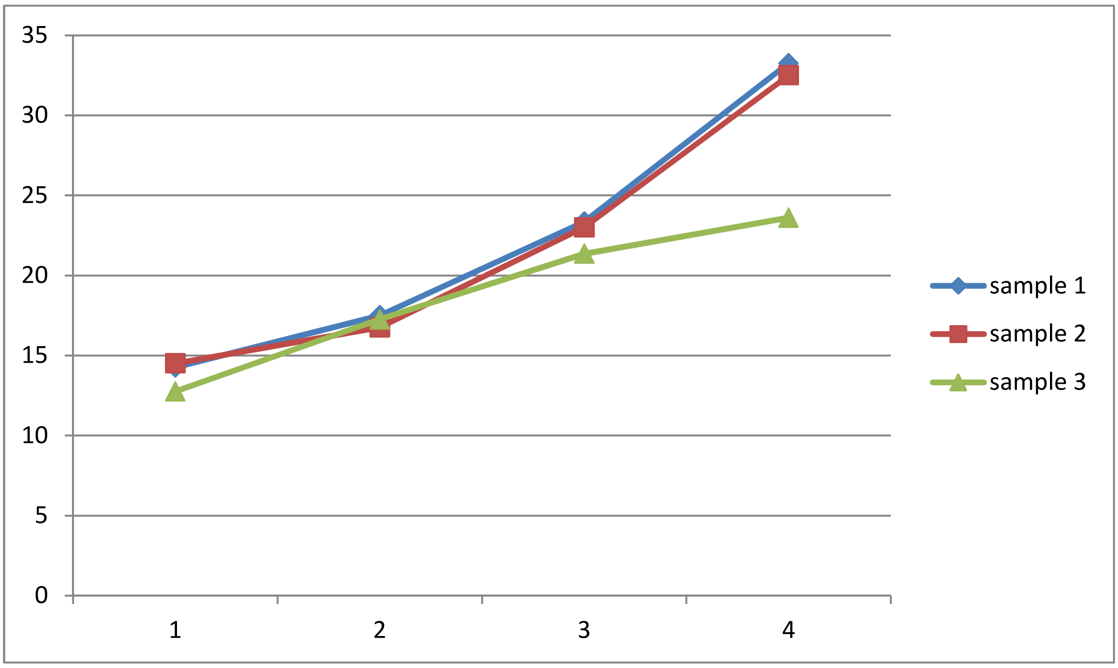

Fig 4.10 Variation of UCS with depth for freeze/thaw cycles (0°C)

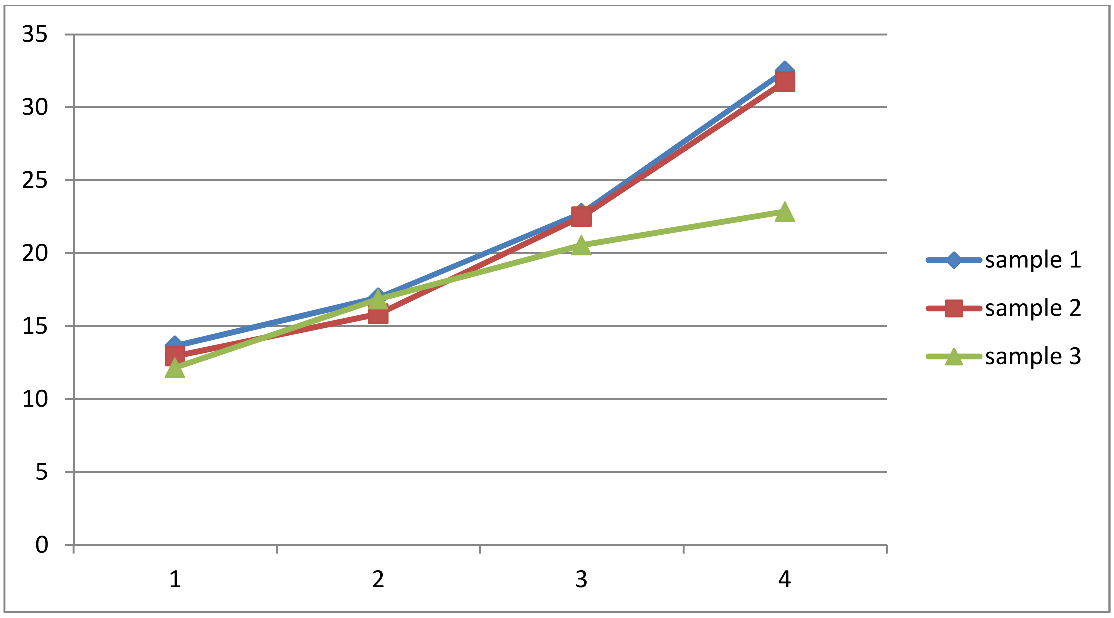

Fig 4.11 Variation of UCS with depth for freeze/thaw cycles (6^{o}C and -6^{o}C)

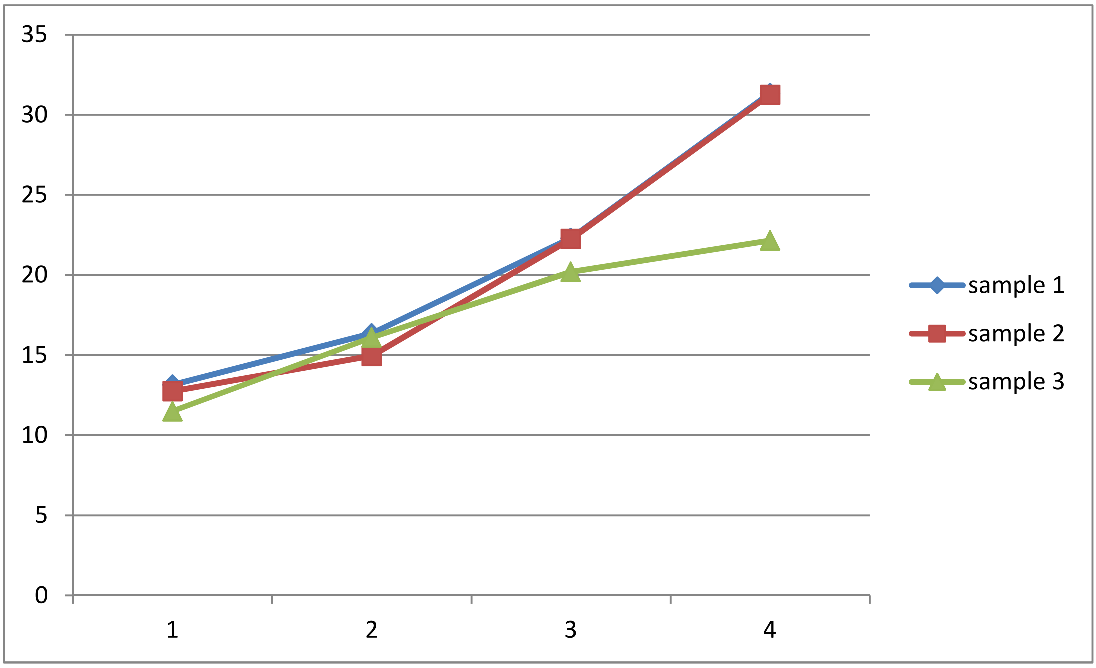

Fig 4.12 Variation of UCS with depth for freeze/thaw cycles (12^{o}C and -12^{o}C)

The unconfined compressive strength of the soil samples was calculated before the freezing and thawing process. The values were seen to increase with the increase in depth. The values for the three samples were calculated. Now after the different freezing and thawing cycles, the values of UCS were calculated again. For all the samples, 3 cycles at the three different temperatures were carried out and the results were noted. It was seen that the unconfined compressive strength of MSW contaminated soil is low and further decreases after the first freezing and thawing cycle. This showed that MSW had a negative effect on the unconfined compressive strength of soil. The effect of freezing and thawing showed furthermore decreased values of UCS. It might be noted that if an uncontaminated soil was exposed to freeze/thaw cycles, it would see much more steep decrease in the values of UCS.

CHAPTER 5
CONCLUSION

5.1 General

The aim of this project was to study the effect of freezing and thawing on the behavior of MSW. Samples were collected from the municipal waste dump site of Shimla city. The samples were tested for characterization and certain properties. Then, the samples were put under freezing and thawing cycles at different temperatures and the same properties were measured again after each cycle. The change in certain soil properties after freeze/thaw cycles were recorded in this thesis.

5.2 Conclusions

From the study undertaken, the following conclusions were made regarding the effect of freezing and thawing on the behavior of MSW and the characterization of MSW.

1) The municipal solid waste generation in Shimla was studied and the site was selected for sample collection was the MSW dump site of Shimla. The waste management system was discussed and the types of waste were studied.

2) The waste was studied for physical and chemical characterization by proximate and ultimate analysis. In proximate analysis, the moisture content, ash content, calorific value, fixed carbon and volatile matter were calculated. The physical composition of waste was also done.

3) Then the equipment required for implementing the freezing and thawing cycles was also explained and discusses. Each sample was put under multiple cycles and various properties were studied.

4) Results were show for various properties of the soil before freezing and thawing cycles. The moisture content, specific gravity, permeability, unconfined compressive strength were studied before the freeze/thaw cycles. These results were compared with those of uncontaminated soil.

5) After freezing and thawing cycles, the changes in values of permeability and unconfined compressive strength were studied. The effect of freezing and thawing on these properties were studied.

6) The UCS values of the samples were seen to decrease after each freeze/thaw cycle. The value of UCS was first lowered by application of MSW and it further decreases after freezing and thawing.

7) Due to the presence of MSW in the soil, the negative effects of freezing and thawing on permeability were reduced. The values of k were seen to decrease a little only after each freeze/thaw cycle.

5.3 Scope of Future Work

The effect of freezing and thawing on the behavior of MSW was studied in this project. Soil infected by municipal solid waste leachate was first studied for moisture content and specific gravity. The waste was also characterized chemically and physically, and the soils permeability and unconfined compressive strength were calculated for all samples. After this, the soil was put under cycles of freezing and thawing. Then the effect of freezing and thawing on these properties were studied after the cycles.

The scope for future work in this project lies in studying the effect of these cycles on properties other than permeability and UCS. Some other properties can be the shear strength parameters, cohesion and angle of friction, compressibility, bearing capacity etc. also in this project the samples could only be put through a limited number of cycles. So there is further scope of study on the affects of freezing and thawing on the soil properties after furthermore cycles.

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