

IMPROVEMENT OF SWELLING SOIL FOR CONSTRUCTIONS BY INDUSTRIAL CHEMICAL WASTES

Submitted By

Marwa Salama Hussein Mohammed

B.Sc. (Chemistry), Faculty of Science, Al-Azhar University, 2008

A thesis submitted in Partial Fulfillment
Of
The Requirement for the Master Degree
In
Environmental Sciences

Department of Environmental Basic Sciences
Institute of Environmental Studies and Research
Ain Shams University

2016

APPROVAL SHEET
**IMPROVEMENT OF SWELLING SOIL FOR
CONSTRUCTIONS BY INDUSTRIAL CHEMICAL
WASTES**

Submitted By

Marwa Salama Hussein Mohammed

B.Sc. (Chemistry), Faculty of Science, Al-Azhar University, 2008

A thesis submitted in Partial Fulfillment
Of

The Requirement for the Master Degree
In

Environmental Sciences

Department of Environmental Basic Sciences

This thesis Towards a Master Degree in Environmental Sciences

Has been Approved by:

Name

Signature

1-Prof. Dr. Salah A. Abo-El-Enein

Prof. of Physical Chemistry and Building Materials

Faculty of Science

Ain Shams University

2-Prof. Dr. Khaled Mohamed El Zahby

President of the National Center for Housing and Building Research

3-Dr. Mohamed Gharib El Malky

Prof. of Geophysics, Department of Environmental Basic Sciences

Institute of Environmental Studies & Research

Ain Shams University

4-Dr. Mohie Eldin Mohamed El Mashad

Associate Prof. and Head of Geotechnical Engineering Department
Construction Research Institute - National Water Research Center

Ministry of Water Resources & Irrigation

2016

IMPROVEMENT OF SWELLING SOIL FOR CONSTRUCTIONS BY INDUSTRIAL CHEMICAL WASTES

Submitted By

Marwa Salama Hussein Mohammed

B.Sc. (Chemistry), Faculty of Science, Al-Azhar University, 2008

A thesis submitted in Partial Fulfillment
Of
The Requirement for the Master Degree
In
Environmental Sciences
Department of Environmental Basic Sciences

Under The Supervision of:

1-Dr. Mohamed Gharib El Malky

Prof. of Geophysics, Department of Environmental Basic Sciences
Institute of Environmental Studies & Research
Ain Shams University

2-Dr. Mohie Eldin Mohamed El Mashad

Associate Prof. of Engineering Construction Research Institute
National Water Research Center
Ministry of Water Resources & Irrigation

2016

Acknowledgment

First I would like to thank God for the mercy and support and giving me the strength to complete this study.

Special thanks are extended to my supervisor **Prof. Dr. Mohamed Gharib Elmalky**, Professor of Geophysics, Environmental Research Institute, Basic Science Department - Ain Shams University for his great help and continuous scientific directing along this study and for his supervision through the M.Sc. research.

I gratefully acknowledge the supervision and support of **Prof. Dr. Mohie Eldin Mohamed El mashad**, Associate Professor at Construction Research Institute. National Water Research Center (NWRC) for his sincere support, He suggested the research point and kindly guided me with his distinctive advice till this work finally came true.

I am also extremely grateful to **Dr. Samy Said Zaher** Researcher at Construction Research Institute (NWRC); for his support and comments throughout this thesis. Deep thanks go to the staff of Laboratory Soil Mechanics and Foundation in the CRI and to everyone who participated in some way or another, in this work; I owe my thanks and gratitude.

Thanks also to my friends and colleagues especially Al shimaa Embaby, Thanks for your good thoughts and encouraging words; she is very meaningful for me. I am also thankful to the lawyer Ayman Elgendy and agriculture engineers Osama Diab, Hussien Mohamed Ali, and also grateful to engineer Mohamed Awad for their kind cooperation and support.

Would like to acknowledge the financial support of Abu Zaabal Phosphatic Fertilizer Plant and Helwan Cement Factory for permission to collect waste slurry and acknowledge Construction Research Institute and National Research Center for the laboratory facilities.

Finally, my most appreciations are to my family my precious parents, my loving sons Mahmoud and Mohammed, my sisters Eman, Zainab and Mona, brothers Hassan and Ahmed and my husband social worker Hassan for their full support, help and patience. I am so grateful to have you in my life... this work is dedicated to you.

ABSTRACT

Many arid and semi-arid regions have a problem of swelling soil which is one of the problematic soils that face many geotechnical engineers in the field (others include collapsible soil, soft clay, etc.). Swelling soil is known to cause severe damage to structures that are founded on it as a result; some houses and roads were destroyed. The presence of montmorillonite clay in these soils imparts them high swell–shrink potentials.

To overcome this problem there are two solutions one is replace the swelling soil by good quality granular material. The second is stabilizing the subgrade clayey soil by using various industrial wastes. The volume of by-product materials generated from industries such as Phosphogypsum, cement dust, and other mining and heavy industries are increasing, the cost of removal of wastes is continuing to rise day-by-day in our society.

Phosphogypsum (PG) is a solid waste generated from natural phosphate rock in phosphoric acid fertilizer production (H_3PO_4), composed of calcium sulfate contaminated by other impurities; it is produced in large quantities worldwide. These wastes pollute the environment. Most phosphogypsum is stockpiled while lesser quantities are recycled or dumped into water. On the other hand cement kiln dust (CKD) is fine dust results from cement plants, the disposal of this fine dust becomes an environmental danger; These waste pollutes the soil, air and water. Now-a-days easily available industrial by-products are used for the enrichment of soil properties and become economically sound and environmentally friendly.

In this research i have targeted to use Phosphogypsum (PG), cement kiln dust (CKD) and NaCl for swelling soil improvement by mixing them mixing them with bentonite in three groups (A, B, C).

This study carried out to check the improvement of the properties of swelling soil with phosphogypsum in various percentages i have tried to use the small ratio of PG (i.e., 0.6, 1.2, 1.8, 2.4 and 3%) with in various small ratio of CKD (i.e., 0.6, 1.2, 1.8, 2.4 and 3%) and chemical additives like NaCl.

After treatment of soil the properties of the mixture samples were investigated, the natural soil properties were used as control points for comparison purposes. Since the swelling soil has the same property of bentonite, I used bentonite as a substitute of the swelling soil.

In this regard important chemical analysis determined for all samples, and engineering tests like free swell test determined for all samples, Atterberg's limit test were conducted on some samples. Analytical technique x-ray diffraction (XRD) used to identify composition of bentonite and the reaction Products of the clay fraction of some test bentonite mixed with various amount of PG, CKD and NaCl. This pure clay test soil was used to ease identification of the reaction products.

Some good results were obtained to use PG, CKD and NaCl for improvements of the properties of swelling soil by mixing them with bentonite, and I obtained good results as follows:

For all additives used in the tests, the free swelling of bentonite generally decreased when the additive percentages increased and change its chemical and mechanical properties as pH increase due to cations exchange reactions occurred between the soil and additives, But all the mixtures cannot have the same type of influence over the swelling soil, The swelling rate of bentonite decreases strongly with increasing the percentages of NaCl and It is also observed that group B (PG + NaCl + B) has more_effective additive than the others.

All the examined samples consisted mainly of SiO_2 , Al_2O_3 and Fe_2O_3 (R_2O_3) and CaO in a descending order of abundance. A minor to trace amounts of MgO were also detected of the treated samples indicated the presence of kaolinite clay. Low loss on ignition (LOI) as in appendix and alkalinity (high pH) improve the swelling properties and reduce the plasticity index (PI).

Liquid limit, plasticity index of bentonite for some mixtures is also decreased with the increase of percentages of the chemical wastes and NaCl , while the plastic limit for these mixtures is decrease but slightly increased for few samples when the concentration of the chemical wastes and NaCl percentages increased.

The results from XRD analyses of the bentonite and some mixtures showed that large amounts of montmorillonite were approximately transformed to other phases during the reaction that are (a non-swelling clay mineral commonly Kaolinite and Microcline).

The aim of this study is to treatment of swelling soil using wastes and to determine the rate of change in swelling behavior of swelling soil when exposed to chemical wastes .This achieves the double objective of reducing the problems of this type of soil by improvement its characteristics, and also of providing a use for the additives (wastes), thus eliminating the economic and environmental cost involved in managing them.

Key Words: Swelling soil; waste Phosphogypsum; waste cement kiln dust; NaCl ; soil improvement; free swell; liquid limit; plastic limit; plasticity index; x- ray diffraction.

LIST OF ABBREVIATIONS

Al	Aluminum
Al₂O₃	Aluminium Oxids
B	Bentonite
BC	Black Cotton Soil
Ca	Calcium
C	Cohesion
°C	degree Celsius
CaCl₂	Calcium Chloride
CaCo₃	Calcium Carbonate
Ca (OH)₂	calcium Hydroxide
CaSO₄	Calcium Sulphate
CBR	California Bearing Ratio
CKD	Cement kiln dust
CEC	Cation exchange capacity
CL	Chlorine
DFS	differential free swell
DTA	Differential Thermal Analysis
E	Axial Strain
EC	Electrical Conductivity
ESP	Egg Shell Powder
ESP	Exchangeable Sodium Percentage
FA	Fly Ash
Fe₂O₃	Ferric Oxide
FSI	Free Swell Index
FS	Free Swell
GGBS	Ground Granulated Blast Furnace Slag
G	Specific Gravity

HC	Hydraulic Conductivity
HCl	Hydrochloric acid
HCO₃	Alkalinity
IP	Index Plasticity
KCl	Potassium Chloride
k_e	Correlation Factor
LL	Liquid Limit
LOI	Loss On Ignition
LS	Linear Shrinkage
MDD	Maximum Dry Density
Na⁺	Sodium Ions (Cations)
NaCl	Sodium Chloride Salt
O.M	Organic Material
O.M.C	Optimum Moisture Content
PG	Phosphogypsum
pH	Log ₁₀ (Hydrogen Ion Concentration)
PI	Plasticity Index
PL	Plastic Limit
PPM	Parts per million
P_s	swelling pressure
RHA	Rice Husk Ash
SEM	Scanning Electron Microscopy
SI	Free Swell Index
SiO₂	Silicate Content
SL	Shrinkage Limit
SO₃	Sulfate As Sulfur Trioxide
SP	Shear Strength Parameters
SR	100% : Saturation Line
TDF	Tire Derived Fuel
UCS	Unconfined Compressive Strength
WC	Water Content
XRD	X-Ray Diffraction
Φ	Friction Angle

TABLE OF CONTENTS	
ACKNOWLEDGEMENTS.....	II
ABSTRACT.....	IV
LIST OF ABBREVIATIONS.....	VII
TABLE OF CONTENTS.....	IX
LIST OF TABLES.....	XV
LIST OF FIGURES.....	XVI
CHAPTER	Page
1 INTRODUCTION	1
1.1 General.....	1
1.2 Soil Improvement.....	3
1.3 The Objectives of the Current Research.....	4
1.4 Organization of the Present Work.....	4
2 LITERATURE REVIEW	6
2.1 General.....	6
2.2 The Composition of Soils and Clay Mineralogy.....	7
2.2.1 Soil Composition and Morphology.....	7
2.2.2 Clay Mineralogy.....	7
2.2.2.1 Montmorillonite.....	8
2.3 Mechanism of Swelling.....	9
2.4 Soil Stabilization.....	11
2.4.1 Advantages of Soil Stabilization.....	12
2.4.2 Stabilization of Expansive Soil Using Industrial Solid Wastes.....	13
2.4.2.1 Cement kiln dust.....	13
2.4.2.2 Silica Fume.....	14
2.4.2.3 Copper Slag.....	14

2.4.2.4 Red Mud.....	14
2.4.2.5 Granulated Blast Furnace Slag.....	14
2.4.2.6 Ceramic Dust.....	15
2.4.2.7 Brick Dust.....	16
2.4.2.8 Phosphogypsum.....	17
2.4.3 Stabilization of Expansive Soil Using Agricultural Solid Wastes.....	17
2.4.3.1 Rice Husk Ash.....	17
2.4.3.2 Bagasse Ash.....	19
2.4.3.3 Olive Cake Residue.....	20
2.4.3.4 Wheat Husk.....	20
2.4.3.5 Groundnut Shell Ash.....	20
2.4.4 Stabilization of Expansive Soil Using Domestic Solid Wastes.....	21
2.4.4.1 Incinerator Ash.....	21
2.4.4.2 Waste Tire.....	21
2.4.4.3 Egg Shell Powder.....	22
2.4.4.4 Grain Storage Dust.....	22
2.4.4.5 Glass Cullet.....	22
2.4.5 Stabilization of Expansive Soil Using Mineral Solid Wastes.....	23
2.4.5.1 Quarry Dust.....	23
2.4.5.2 Marble Dust.....	24
2.4.5.3 Baryte Powder.....	25
2.4.5.4 Pyroclastic Dust.....	25
2.4.5.5 Lime Stone Dust.....	25
2.4.5.6 Granite Dust.....	25
2.4.5.7 Mine Tailings.....	26
2.4.6 Stabilization of Expansive Soil Using Low Cost Methods...	26
2.4.6.1 Stabilization with Portland cement.....	26
2.4.6.2 Stabilization with lime.....	27

2.4.6.3 Stabilization with fly ash.....	29
2.4.6.4 Scrap Tire.....	30
2.4.7 Stabilization of Expansive Soil Using Different Chemical Additives.....	31
2.4.7.1 KCL and Ca(OH) ₂	31
2.4.7.2 Mineral Salts (KCl and MgCl ₂).....	32
2.4.7.3 Aluminum (Al).....	32
2.4.8 Stabilization of Expansive Soil Using Different Stabilizers.....	34
2.4.8.1 Cement, Steel Fibers, Gasoline Fuel and Injection by Cement Grout.....	34
2.4.8.2 Sugar Cane Molasses.....	34
3 MATERIALS AND METHODS.....	37
3.1 General.....	37
3.2 Properties of the Used Materials.....	37
3.2.1 Bentonite.....	37
3.2.1.1 Properties of Bentonite.....	37
3.2.1.2 Mineralogy of the Used Bentonite.....	38
3.2.1.3 Applications of Bentonite in Construction and Civil Engineering.....	39
3.2.2 Phosphogypsum (PG)	39
3.2.2.1 Properties of Phosphogypsum and its different Applications.....	40
3.2.2.2 Environmental Impact of Phosphogypsum.....	41
3.2.3 Cement kiln dust (CKD).....	42
3.2.3.1 Environmental Impact of Cement kiln dust.....	42
3.2.3.2 Uses of Cement kiln dust.....	43
3.2.4 Chemical Additives - Sodium Chloride Salt (NaCl).....	44
3.2.5 Mixing Water.....	45
3.3 Experimental Work.....	46
3.3.1 Samples Preparation for Chemical Analysis.....	46

3.3.2 Chemical Analysis.....	47
3.3.2.1. Determination of pH.....	47
3.3.2.2 Determination of Electrical Conductivity and Total Dissolved Solids.....	49
3.3.2.3 Determination of Chloride.....	51
3.3.2.4 Determination of Sulfate Ions.....	53
3.3.2.5 Determination of Loss On Ignition.....	54
3.3.2.6 Determination of Oxides.....	55
3.3.2.6.1 Determination of Silicon Di Oxide (SiO ₂ %).	55
3.3.2.6.2 Determination of Ferric Oxide and Aluminum Oxide (R ₂ O ₃ %).....	56
3.3.2.6.2 Determination of Calcium Oxide (Cao %).....	57
3.3.2.6.3 Determination of Magnisium oxide (Mgo %).....	58
3.3.3 Samples Preparation for Engineering Properties.....	59
3.3.4 Geotechnical Engineering Tests.....	59
3.3.4.1 Free Swell.....	59
3.3.4.2 Atterberg's Limits.....	61
3.3.5 Mineralogical Composition.....	66
3.3.5.1 Analytical Techniques (X- Ray Diffraction).....	66
3.3.5.2 Advantages and Disadvantages of Using X – Ray Diffraction.....	67
3.3.5.3 Bragg's law.....	68
3.3.5.4 Samples Preparation for XRD (Powder Preparation).....	69
3.3.5.5 X-Ray Diffraction Instrument (Bragg's Instruments).....	70
4 RESULTS AND DISCUSSION	72
4.1 Chemical Tests.....	72
4.1.1 Variation of Total Dissolved Salts TDS.....	73
4.1.1.1 Group (A).....	73
4.1.1.2 Group (B).....	76
4.1.1.3 Group (C).....	79

4.1.2 Variation of Chloride.....	80
4.1.2.1 Group (A).....	80
4.1.2.2 Group (B).....	80
4.1.2.3 Group (C).....	80
4.1.3 Variation of pH.....	81
4.1.3.1 Variation of pH by Addition of PG and CKD on Bentonite in Group (A).....	82
4.1.3.2 Variation of pH by Addition of PG and NaCl on Bentonite in Group (B).....	90
4.1.3.3 Variation of pH by Addition of PG, CKD and NaCl on Bentonite in Group (C).....	96
4.1.4 Variation of Oxides (SiO ₂ , R ₂ O ₃ , Cao, Mgo and LOI).....	97
4.2 Geotechnical Engineering Tests.....	110
4.2.1 Free Swell Test Results.....	111
4.2.1.1 Effects of PG and CKD on Swelling Behavior of Bentonite.....	111
4.2.1.2 Effects of PG and NaCl on Swelling Behavior of Bentonite.....	121
4.2.1.3 Effects of PG, NaCl and CKD on Swelling Behavior of Bentonite.....	131
4.2.2 Atterberg's Limits Results.....	131
4.2.2.1 Effects of PG and CKD on Atterberg's Limits of Bentonite.....	132
4.2.2.2 Effects of PG and NaCl on Atterberg's Limits of Bentonite.....	132
4.2.2.3 Effects of PG, CKD and NaCl on Atterberg's Limits of Bentonite.....	133
4.3 X-Ray Diffraction (XRD) Results.....	134
4.3.1 Bentonite X-Ray Diffraction.....	135