

IMPROVEMENT OF POND ASH WITH GEOSYNTHETICS

by

GOUTAM KUMAR POTHAL

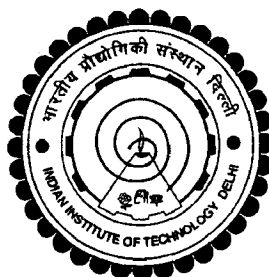
Department of Civil Engineering

Submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

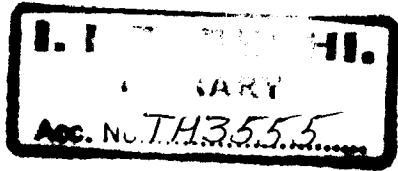
to the



INDIAN INSTITUTE OF TECHNOLOGY, DELHI

JULY 2007

kt - combustion residues
Payments



THI
66 2.613-11:625-87
POT-I

DEDICATED

TO

MY FAMILY

CERTIFICATE

This is to certify that the thesis entitled “**IMPROVEMENT OF POND ASH WITH GEOSYNTHETICS**” submitted by **Mr. Goutam Kumar Pothal** to Indian Institute of Technology Delhi, for the award of degree of Doctor of Philosophy is a record of the bonafide research work carried out by him. **Mr. Goutam Kumar Pothal** has worked under my supervision for the submission of this thesis, which to my knowledge has reached the requisite standard.

This thesis, or any part thereof has not been submitted to any university or any institution for the award of any degree or diploma.



Dr. G. Venkatappa Rao

Professor

Department of Civil Engineering
Indian Institute of Technology Delhi

New Delhi – 110016

INDIA

ACKNOWLEDGEMENT

I wish to express my sincere thanks and deep sense of gratitude to my supervisor Professor G. Venkatappa Rao for his valuable guidance, constant encouragement and inspiration during all the stay of this research work. I am grateful for his co-operation and kind help he rendered from time to time.

Special thanks are due to Dr. K. K. Gupta, Dr. G. V. Ramana and Dr. J. T. Shahu for their kind cooperation for providing me necessary laboratory facilities for my experimental works in different laboratories of the department.

I am also thankful to Dr. Rakesh Kumar Dutta for his valuable suggestions and discussions.

I would like to thank the authorities of KIIT, Bhubaneswar for their support and encouragement for deputing me to carry out this research.

Thanks are due to General Manager, CPP, National Aluminium Company Limited (NALCO), Angul, Orissa for his help during the collection of the pond ash samples from the ash ponds of NALCO. Thanks are also due to the Coir Board and the Kerala State Coir Corporation Ltd. Alappuzha, Kerala for providing the coir geotextile samples.

I have great pleasure in expressing my sincere thanks to my fellow research scholars and friends particularly Mr. Altaf Usmani, Mr. Nitin Chaphalkar, Mr. Amitav Srivastav, Mr. Ramakanta Panigrahi and Mr. P. V. S. R. Prasad for their assistance and help throughout this work.

The assistance rendered by the staff of Soil Engineering, Rock Mechanics and Transportation Engineering Laboratory and Civil Engineering Workshop is gratefully

acknowledged. Special thanks are due to be made of Late Mr. Radhakishan Sah, Mr. D. S. Gosain, Mr. Manoj Neelam, Mr. Siya Ram, Mr. K. Pahari, Mr. K. K. Bali and Mr. Ram Kumar for their support in experimental work. Special mention is due to Mr. Munni Lal, Mr. Charanjeet Singh, Mr. Vipin Gond and Mr. Amit Bisht for their assistance in the laboratory.

I would like to acknowledge the support and patience, contributed by my wife, which provided me the necessary impetus to work on the thesis.

I would like to record my deep sense of gratitude to my parents, parents-in-law and my brother-in-law, without whose blessings and encouragements, the thesis would not have been seen the daylight.

The author would like to thank all those who have rendered help directly or indirectly during the entire research work.


(GOUTAM KUMAR POTHAL)

ABSTRACT

Pond ash, produced in huge quantities by thermal power plants, require large land area for disposal and causes environmental hazards. The application potential of pond ash as a structural fill material for developing low lying areas to construct infrastructure development projects on it is the prime objective of this thesis. The major disadvantage of its low bearing capacity can be improved by applications of geosynthetics reinforcements. The possible improvement of compacted pond ash with different types of geosynthetics and other geotechnical behaviour of reinforced pond ash are examined in this thesis through a comprehensive laboratory study. India, being the largest producer of coir fibre, a special emphasis is given to the use of coir geotextiles, as a reinforcement to improve the pond ash fills.

The research programme included

- 1) A study of the improvement in bearing capacity of compacted pond ash reinforced with both polymeric geogrids and natural fibre coir geotextiles by carrying out model tests with a strip footing.
- 2) A study of the improvement in the strength of double layered system WMM layer and the sand layer underlain by compacted pond ash with application of coir geotextile and polymeric geogrids at their interface and to compare the results for their potential use in pavements.
- 3) A study of the triaxial behaviour of compacted pond ash reinforced with natural fibre coir geotextile in layers and compares the results with that of polymeric counterparts.

- 4) A study of the improvement of settlement behaviour pond ash with loading under natural condition by inclusion of prefabricated vertical drains by large scale model tank tests.
- 5) Analyze and develop a mathematical model to predict the ultimate bearing capacity improvement factor of the reinforced pond ash.

Chapter 1 of the thesis gives the introduction to the present work along with a brief description to the environmental problems with the rising ash production in the country and natural fibre coir geotextiles. In Chapter 2, the available relevant literature has been reviewed. The test equipments and setups used are described along with the detailed procedures and test programme in Chapter 3.

The behaviour of pond ash reinforced with different types of geosynthetics including two polymeric geogrids and three coir woven geotextiles is presented in Chapter 4. The behaviour of unpaved road system with reinforcement at the interface is presented in Chapter 5. Studies on triaxial behaviour of reinforced pond ash with layers of geosynthetic reinforcement are included in Chapter 6. The improvements in the consolidation settlement behaviour of the pond ash with and without prefabricated vertical drains have been presented in Chapter 7. Mathematical model developed by multiple regression analysis based on the model test data for prediction of ultimate bearing capacity ratio is presented in Chapter 8. An overall summary of the work carried out and the salient conclusions drawn are highlighted in Chapter 9.

Tests were conducted in model tank of 750 mm × 300 mm × 400 mm size with a 75 mm wide strip footing, with two types of compacted pond ash reinforced five geosynthetics as reinforcements. From the test results presented in Chapter 4, it is concluded that the ultimate bearing capacity of the reinforced models increased significantly with inclusion of any type of geosynthetics. The ultimate bearing capacity ratio is found to depend upon the parameters like the length of the reinforcement layer (b), the depth of the reinforcement layer below the base of the footing (u) and the number of reinforcement layer (N) for all types of reinforcements. The performance of the coir woven geotextiles is found to depend on the physical properties like mass per unit area and aperture size and mechanical properties like tensile strength and initial slope of the tensile stress-strain curves.

Load tests were also conducted on the model tank with two types of pond ash as subgrade (250 mm thick) and wet mix macadam or sand as base course (100 mm and 60 mm thick) under unreinforced condition. Tests were also carried out under reinforced condition with the geosynthetics at the interface of the compacted pond ash subgrade and wet mix macadam or sand as base course layer. Based on these results presented in Chapter 5, it was found that the ultimate bearing capacity of the reinforced double layer model increased significantly with inclusion of both polymeric geogrids and coir woven geotextiles at the interface of both the WMM and sand base courses and pond ash subgrade. The ultimate bearing ratios of coarser pond ash type NC are better than the finer pond ash type NF. As expected, the performance of the coir woven geotextiles is quite different from that with polymeric geogrids. The improvement with the rigid polymeric geogrid type GGR is better than that with the flexible polymeric geogrid type GGF for both the types of

pond ash subgrades. This can be attributed to the higher stiffness and better friction at the interface of the former. The performance of with the coir woven geotextiles with both the types of pond ash subgrades, clearly depended on their respective physical and mechanical properties. The coir woven geotextile type CWC exhibited the best improvement followed by that with type CWB and CWA.

Drained Triaxial compression tests have been conducted on two types of pond ash under unreinforced and reinforced condition with different layers of geosynthetics reinforcements. From the results presented in chapter 6, it was generally concluded that the strength of the unreinforced specimens of both the types of pond ash increased significantly with inclusion of both polymeric geogrids and coir woven geotextiles. There is an increase in the value of ϕ' by as much as 6° to 8° for both the types of pond ash with all the types of reinforcements. For both the pond ash types, the value of c' increased with an increase in the number of reinforcement layers. The stress-strain relationships follow the hyperbolic variation as per Kondner's procedure.

Large scale tests were carried out in a model tank in order to qualitatively assess the in-situ performance of the prefabricated vertical drains (PVDs) in ash ponds. From the test results presented in Chapter 7, it is observed that there are significant improvements by the pond ashes in terms of total settlements and moisture content by the use of PVDs.

A mathematical model was developed to predict the ultimate bearing capacity of reinforced pond ash by multiple regression analysis. The experimental data obtained

from 90 model tests on the two types of pond ash and the five types of geosynthetics with varying parameters like b , u , d and N were used to develop a mathematical model by multiple regression analysis.

The application of the above results in typical field situations is mentioned below.

1. The bearing capacity of compacted pond ash can be improved by providing different layers of geosynthetics reinforcements including both polymeric and coir geotextiles and can be used advantageously as a fill material in construction of many infrastructure projects and to save valuable soil.
2. The inclusion of coir woven geotextiles in compacted pond ash improves the strength behaviour and consequently the bearing capacity of a double layered system. With the use of a reinforcement layer the required depth of base course can be reduced upto 40 %, which not only reduces the cost of construction but also the application of natural fibre coir geotextile in rural roads as reinforcement will be an eco-friendly approach.
3. PVDs can be suitably used for rehabilitation of pond ash deposits.

The thesis ends with suggestions for further work.

CONTENTS

	Page No.
CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iv
CONTENTS	ix
LIST OF FIGURES	xv
LIST OF TABLES	xxxii
NOTATIONS	xxxvii
 CHAPTER 1 INTRODUCTION	
1.0 GENERAL	1
1.1 SCOPE OF WORK	1
1.2 OBJECTIVES OF THE STUDY	3
1.3 CHAPTER OUTLINE	5
 CHAPTER 2 LITERATURE REVIEW	
2.0 GENERAL	9
2.1 POND ASH	9
2.1.1 Geotechnical Characteristics of Pond Ash	11
2.1.2 Chemical Composition	11
2.1.3 Properties of Pond Ash	13
2.1.3.1 Grain size distribution	13
2.3.1.2 Consolidation characteristics	15
2.3.1.3 Permeability	15
2.1.3.4 Pond ash as fill material	16
2.2 GEOSYNTHETICS AS REINFORCEMENT	16
2.3 COIR	17

2.3.1	Physical and Chemical Characterization	18
2.3.1.1	Physical properties	18
2.3.1.2	Chemical composition	18
2.4	COIR GEOTEXTILES	19
2.4.1	Studies on Characterization of Tensile Strength and Durability	19
2.4.2	Applications of Coir Geotextiles in Ground Improvement	22
2.5	REINFORCED SOIL BEDS	23
2.5.1	Experimental Studies on Reinforced Sand	28
2.5.2	Experimental Studies on Reinforced Clay	45
2.5.3	Experimental Studies on Reinforced Fly Ash	48
2.5.4	Experimental Studies on Reinforced Pond Ash	48
2.6	DOUBLE LAYER SOIL SYSTEM	53
2.6.1	Studies on Reinforced Sand Underlain by Weak Clay	53
2.7	STUDIES ON UNPAVED ROAD MODELS	56
2.7.1	Behaviour of Unpaved Roads	56
2.8	TRIAXIAL BEHAVIOUR OF REINFORCED SOIL	60
2.8.1	Experimental Studies with Randomly Distributed Fibres	63
2.8.2	Experimental Studies with oriented reinforcements	66
2.8.3	Studies with Natural Fibres	68
2.9	PREFABRICATED VERTICAL DRAINS (PVD)	70
2.9.1	Consolidation of Soft Soils	70
2.9.2	Materials Used for PVD	70
2.9.3	Model Tank Studies	72
2.9.4	Field Studies	75

2.10	SUMMARY AND CONCLUSIONS	75
CHAPTER 3	EXPERIMENTAL WORK	
3.0	GENERAL	77
3.1	MATERIALS	77
3.1.1	Pond Ash	77
3.1.2	Sand	81
3.1.3	Wet Mix Macadam (WMM)	81
3.1.4	Geosynthetic Reinforcements	83
3.1.4.1	Polymeric geogrids	83
3.1.4.1.1	Rigid biaxial geogrids	84
3.1.4.1.2	Flexible biaxial geogrids	84
3.1.4.2	Coir geotextiles	84
3.1.4.3	Tensile strength	88
3.2	MODEL TESTS	92
3.2.1	Experimental Programme	92
3.3	MODEL STUDIES ON REINFORCED POND ASH (TEST GROUP 1)	94
3.3.1	Model Tank	94
3.3.2	Model Studies on Reinforced Pond Ash (Test Series 1)	94
3.3.3	Procedure	97
3.3.4	Model Footing Tests on Pond Ash Overlain by WMM Layer with Geosynthetic Reinforcements at the Interface (Test Series 2)	98
3.3.5	Model Footing Tests on Pond Ash Overlain by Sand Layer with Geosynthetic Reinforcements at the Interface (Test Series 3)	99
3.3.6	Assembly	101
3.3.7	Test Procedure	101

3.4	TRIAXIAL TESTS OF REINFORCED POND ASH	104
3.4.1	Apparatus	104
3.4.2	Experimental Procedure	105
3.4.3	Parameters Varied in Triaxial Testing	106
3.4.3.1	Reinforcements	106
3.4.3.2	Number of reinforcement layers	108
3.4.3.3	Confining pressure	108
3.5	MODEL CONSOLIDATION TEST ON POND ASH WITH PVD	109
3.5.1	Model Tank	109
3.5.2	Testing Procedure	109
3.6	CONCLUDING REMARKS	113
CHAPTER 4	BEHAVIOUR OF REINFORCED POND ASH	
4.0	GENERAL	115
4.1	BEARING CAPACITY OF REINFORCED POND ASH	115
4.2	BEARING CAPACITY RATIO	125
4.2.1	Ultimate Bearing Capacity Ratio	125
4.2.1.1	Comparison	134
4.2.1.2	Discussion	134
4.2.2	Bearing Capacity Ratio at Any Settlement	135
4.2.2.1	Comparison	159
4.3	CONCLUSIONS	161
CHAPTER 5	BEHAVIOUR OF DOUBLE LAYERED SYSTEM	
5.0	GENERAL	163
5.1	MODEL TEST ON POND ASH OVERLAIN BY WMM	163
5.1.1	Comparison with Geosynthetic Reinforced Models	172

5.2	MODEL TEST ON POND ASH OVERLAIN BY SAND	173
5.2.1	Comparision	180
5.2.2	Comparision between WMM and Sand Models	180
5.4	CONCLUSIONS	182
CHAPTER 6	TRIAXIAL BEHAVIOUR OF REINFORCED POND ASH	
6.0	GENERAL	185
6.1	TRIAXIAL TEST RESULTS OF UNREINFORCED POND ASH	185
6.1.1	Comparision	188
6.2	TRIAXIAL BEHAVIOUR OF REINFORCED POND ASH	188
6.2.1	Polymeric Geogrid Reinforced Pond Ash	188
6.2.2	Woven Coir Geotextile Reinforced Pond Ash	188
6.2.3	Comparision	201
6.2.4	Strength Ratio	209
6.3	STRENGTH CHARACTERISTICS	221
6.3.1	Comparision	229
6.4	CONSTITUTIVE RELATIONSHIPS	229
6.4.1	Hyperbolic Stress – Strain Relationship	229
6.4.2	Initial Tangent Modulus	244
6.5	CONCLUSIONS	251
CHAPTER 7	CONSOLIDATION BEHAVIOUR OF POND ASH WITH PREFABRICATED VERTICAL DRAINS	
7.0	GENERAL	253
7.1	SETTLEMENT BEHAVIOUR OF POND ASH WITH PVD	253
7.2	MOISTURE CONTENT VARIATION WITH PVD	259

7.3	CONCLUSIONS	261
CHAPTER 8	DEVELOPMENT OF A MATHEMATICAL MODEL	
8.0	GENERAL	263
8.1	REGRESSION ANALYSIS	263
8.2	PARAMETERS CONSIDERED	264
8.3	THE MODEL	267
8.4	VALIDATION OF MODEL	269
8.4	CONCLUSIONS	277
CHAPTER 9	SUMMARY AND CONCLUSIONS	
9.0	INTRODUCTION	279
9.1	STUDIES ON REINFORCED POND ASH	280
9.2	STUDIES ON DOUBLE LAYER SYSTEM	281
9.3	SUDIES ON TRIAXIAL BEHAVIOUR OF REINFORCED POND ASH	283
9.4	STUDIES WITH PREFABRICATED VERTICAL DRAINS	284
9.5	DEVELOPMENT OF MATHEMATICAL MODEL	285
9.6	CONCLUDING REMARKS	285
9.7	FUTURE SCOPE OF WORK	288
REFERENCES		289
APPENDIX A		297
APPENDIX B		307
BIODATA		319