

**FEASIBILITY OF USING COAL BOTTOM ASH, POND  
ASH OR FLY ASH AS STRUCTURAL FIL MATERIAL  
IN MECHANICALLY STABILIZED EARTH WALLS**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI  
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IN MECHANICALLY STABILIZED EARTH WALLS**

*by*

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*Submitted*

**in fulfilment of the requirements of the degree of Doctor of Philosophy**

*to the*



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**MAY 2020**

# *Dedicated*

To Mukesh My Friend

And

My Dear Husband

## **CERTIFICATE**

This is to certify that the thesis entitled — **“FEASIBILITY OF USING COAL BOTTOM ASH, POND ASH OR FLY ASH AS STRUCTURAL FILL MATERIAL IN MECHANICALLY STABILIZED EARTH WALLS”**, being submitted by **Ms. Aali Pant** to the Indian Institute of Technology Delhi is a record of bonafide research work carried out by her under our supervision and guidance. The thesis work, in our opinion, has reached the standard fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and results presented in this thesis have not been submitted, in part or full, to any University or Institute for the award of any degree or diploma.

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Aali Pant

## ABSTRACT

Granular materials with low organic content are generally considered the preferred structural fill in the construction of mechanically stabilized earth (MSE) walls such as flyovers, bridge abutments etc. Due to scarcity of naturally available granular materials because of environmental regulations, efforts are in progress worldwide to explore possible reuse of a wide range of waste materials as substitutes. Coal ash is one such waste material. In the present study, an experimental investigation has been undertaken to experimentally assess the feasibility of using different types of coal ashes namely, bottom ash, pond ash and fly ash separately as structural fill in MSE walls as an alternative for natural soil.

Detailed geotechnical and electrochemical characterization of coal ashes have been carried out and results have been compared with locally available Yamuna Sand (reference material). Pullout test apparatus meeting the requirements of ASTM-D6706 has been designed and fabricated for the present study. Thereafter, pullout tests have been conducted to evaluate the pullout behavior of geogrids embedded in different coal ashes and reference material. The results have been compared with conventional fill materials (CFMs) reported in the literature. The influence of normal stress, percentage of fines in ash, under-compaction, geogrid from different manufacturing methods as well as of transverse members of geogrid on pullout behavior have also been studied. Efforts have been made to assess the suitability of predicting pullout behavior of geogrids embedded in coal ash using numerical simulations in PLAXIS 3D. Subsequently, the design and costs implications of using coal ashes as structural fill in the construction of MSE walls have been studied.

Bottom ash meets the gradation requirements for a structural fill of both national and international guidelines while pond ash and fly ash used in the present study satisfy only the requirements of national guidelines for structural fill. Both bottom ash and pond ash with less than 50 % of fines content meet the angle of shearing resistance and electrochemical

requirements of fill materials as per international guidelines when used with polymeric reinforcement. Fly ash meets the requirements of national guidelines only.

The pullout behavior of geogrids embedded in bottom ash and pond ash with less than 50 % of fines are comparable with those of CFMs. The pullout behavior observed in fly ash as well as mixture of bottom ash and fly ash with more than 60 % fines are on the other hand 30 to 40 % lower than bottom ash, reference soil and CFMs. Pullout resistance decreases by 30 to 70 % on under-compaction of coal ashes with larger reduction observed in fly ash.

The results obtained through numerical simulation match well with the laboratory tests and lie within  $\pm 10$  to 20 % from experimental results.

MSE walls constructed with bottom ash as structural fill requires least amount of reinforcement due to its low unit weight and high shear strength. Pond ash with less than 50 % of fines require equivalent number of reinforcement layers as those by natural reference soil. Fly ash requires more reinforcement layers than natural reference soil due to its low angle of shearing resistance.

The results of present study encourage the construction industry for bulk utilization of bottom ash as an economical alternative to natural soil. Pond ash with less than 50 % of fines offers an alternative to natural soil. However, to ensure free drainage, it is recommended that few additional horizontal drainage layers of bottom ash/sand be introduced in the design to allow free flow of infiltrated water. Fly ash and mixture of bottom ash and fly ash with more than 60 % of fines is not suitable (by itself) for utilisation as structural fill without adequate design safeguards i.e. addressing the critical factors of providing intermittent drainage layers, decrease in pullout capacity due to under-compaction, and studying pullout behavior of geogrids embedded in saturated fly ash.

## सार

कम कार्बनिक सामग्री वाली मिट्टी को आमतौर पर यांत्रिक रूप से स्थिर करी गयी पृथ्वी (एमएसई) की दीवारों जैसे कि फ्लाइंगोवर, पुल के अपघटनों आदि के निर्माण में पसंदीदा संरचनात्मक भरण माना जाता है। पर्यावरणीय नियमों के कारण प्राकृतिक रूप से उपलब्ध मिट्टी की कमी के कारण, दुनिया भर में विकल्प के रूप में अपशिष्ट पदार्थों की एक विस्तृत श्रृंखला के संभावित पुनः उपयोग का पता लगाने के लिए प्रयास जारी हैं। कोयला राख एक ऐसा अपशिष्ट पदार्थ है। वर्तमान अध्ययन में, प्राकृतिक मिट्टी के विकल्प के रूप में एमएसई की दीवारों में संरचनात्मक भराव के रूप में अलग-अलग प्रकार के कोयले की राख निम्नतः, बॉटम ऐश, तलाबीय राख और फ्लाइंग ऐश का उपयोग करने की व्यवहार्यता का आकलन करने के लिए एक प्रयोगात्मक जांच की गई है।

कोयला राख का विस्तृत भू-तकनीकी और विद्युत रासायनिक लक्षण वर्णन किया गया है और परिणामों की तुलना स्थानीय रूप से उपलब्ध यमुना रेत (संदर्भ सामग्री) से की गई है। वर्तमान अध्ययन के लिए पुलआउट टेस्ट तंत्र को डिजाइन किया गया है। इसके बाद, विभिन्न कोयले की राख और संदर्भ सामग्री में जीओग्रेड्स के पुलआउट व्यवहार का मूल्यांकन करने के लिए पुलआउट परीक्षण किए गए हैं। परिणामों की तुलना पारंपरिक भरण सामग्री (सीएफएम) के साथ की गई है जो साहित्य में रिपोर्ट की गई है। सामान्य तनाव के प्रभाव, राख की बारीकी का प्रतिशत, कम-संघनन, विभिन्न विनिर्माण विधियों से निर्मित जियोग्रेड और साथ ही पुलआउट व्यवहार पर जियोग्रेड के अनुप्रस्थ सदस्यों का भी अध्ययन किया गया है। PLAXIS 3D में संख्यात्मक सिमुलेशन का उपयोग करके कोयले की राख में दबी जियोग्रेड के पुलआउट व्यवहार की भविष्यवाणी करने की उपयुक्तता का आकलन करने का प्रयास किया गया है। इसके बाद, एमएसई की दीवारों के निर्माण में संरचनात्मक भराव के रूप में कोयला राख का उपयोग करने के डिजाइन और लागत का अध्ययन किया गया है।

बॉटम ऐश राष्ट्रीय और अंतर्राष्ट्रीय दोनों दिशा-निर्देशों के संरचनात्मक भरण के लिए ग्रेडेशन आवश्यकताओं को पूरा करता है, जबकि वर्तमान अध्ययन में इस्तेमाल करी गयी तालाबीय राख और

फ्लाई ऐश संरचनात्मक भरण के लिए राष्ट्रीय दिशानिर्देशों की आवश्यकताओं को पूरा करता है। 50% से कम बारीकी वाली तालाबीय राख और बॉटम ऐश, पॉलिमर सुदृढीकरण के साथ उपयोग किए जाने पर अंतरराष्ट्रीय दिशानिर्देशों के अनुसार भराव सामग्री के कतरनी प्रतिरोध और विद्युत रासायनिक आवश्यकताओं को पूरा करती है। फ्लाई ऐश केवल राष्ट्रीय दिशानिर्देशों की आवश्यकताओं को पूरा करता है।

50% से कम बारीकी वाली तालाबीय राख और फ्लाई ऐश में दबी जियोग्रिड का व्यवहार सीएफएम के साथ तुलनीय है। दूसरी ओर फ्लाई ऐश के साथ-साथ बॉटम ऐश और फ्लाई ऐश के मिश्रण जिनमें 60% से अधिक बारीक राख है, 30-40% कम मूल्य देते हैं। कोयले की राख के कम-संघनन पर पुलआउट प्रतिरोध 30 से 70% तक कम हो जाता है, जिसका ज्यादा असर फ्लाई ऐश में विस्तृत होता है। संख्यात्मक सिमुलेशन के माध्यम से प्राप्त परिणाम प्रयोगशाला परीक्षणों के परिणामों से  $\pm 10-20\%$  का अंतर दिखाते हैं। बॉटम ऐश के साथ संरचनात्मक भराव के साथ निर्मित दीवारों को कम से कम सुदृढीकरण की आवश्यकता होती है। 50% से कम बारीकी वाली तालाबीय राख को प्राकृतिक संदर्भ मिट्टी के समान सुदृढीकरण परतों की समान संख्या की आवश्यकता होती है तथा फ्लाई ऐश में अधिक सुदृढीकरण परतों की आवश्यकता होती है।

वर्तमान अध्ययन के परिणाम प्राकृतिक मिट्टी के किफायती विकल्प के रूप में बॉटम ऐश के थोक उपयोग के लिए निर्माण उद्योग को प्रोत्साहित करते हैं। 50% से कम बारीकी वाली तालाबीय राख प्राकृतिक मिट्टी के लिए एक विकल्प प्रदान करती है। हालांकि, पर्याप्त जल निकासी सुनिश्चित करने के लिए, यह अनुशंसा की जाती है कि बॉटम ऐश/ रेत की कुछ अतिरिक्त क्षैतिज जल निकासी परतों को डिज़ाइन में पेश किया जाए। फ्लाई ऐश तथा 60% से अधिक बारीकी वाली बॉटम ऐश और फ्लाई ऐश के मिश्रण पर्याप्त डिज़ाइन सुरक्षा उपायों के बिना अपने आप में संरचनात्मक भरण के रूप में उपयुक्त नहीं है, अर्थात् आंतरायिक जल निकासी परतों को प्रदान करने, कम-संघनन के कारण खींचने की क्षमता में कमी, और संतृप्त फ्लाई ऐश में दबी जियोग्रिड के पुलआउट व्यवहार का अध्ययन महत्वपूर्ण है।

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## LIST OF NOTATIONS AND ABBRIVATIONS

TPP = Thermal Power Plant

RSS = Reinforced Soil Structures

MSE= Mechanically Stabilized Earth

CFM = Conventional Fill Material

PET = Polyester

ESP = Electrostatic Precipitator

CBR = California Bearing Ratio

MSW = Municipal Solid Waste

USEPA = United States Environmental Protection Agency

HDPE = High Density Polyethylene

PP = Polypropylene

J\_BA = Jhajjar Bottom Ash

D\_BA = Dadri Bottom Ash

E\_PA = Ennore Pond Ash

J\_FA = Jhajjar Fly Ash

D\_FA = Dadri Fly Ash

B\_FA = Badarpur Fly Ash

YS = Yamuna Sand

DS = Delhi Silt

PVC = Polyvinyl Chloride

W-C = Well Compacted

U-C = Under-Compacted

R.D = Relative Density

ICPMS = Inductively Coupled Plasma-Mass Spectrometry

$W_l$  = width of longitudinal ribs

$W_t$  = width of transverse ribs

$B_l$  = thickness of longitudinal ribs

$B_t$  = thickness of transverse ribs

MD= Machine Direction

CMD= Cross Machine Direction

$T_{ult}$  = Ultimate Tensile Strength

$J_{2\%}$  = secant tensile modulus at 2 % elongation

$J_{5\%}$  = secant tensile modulus at 5 % elongation

$C_U$  = Coefficient of Uniformity

$C_C$  = Coefficient of Curvature

$\gamma_{d,max}$  = Maximum Dry Unit Weight

$\gamma_{d,min}$  = Minimum Dry Unit Weight

OMC = Optimum Moisture Content

$C_c$  = Compression Index

$\phi$  = Angle of shearing resistance

LL = Liquid Limit

PI = Plasticity Index

$\mu_{s/GSY}$  = soil-geosynthetic interface apparent coefficient of friction

$P_R$  =Peak pullout resistance per unit of width

L = Embedment length of the reinforcement

$\sigma_n$  = Normal Stress

$D_{50}$  = Average particle size

$P_B$  = bearing resistance against transverse members

$P_{Rexp}$  = Experimental pullout resistance of geogrid with transverse members

$P_{\text{Exp\_OT}}$  = Experimental pullout resistance of geogrid without transverse members

$G$  = shear modulus;

$E$  = Elastic Modulus

$R_i$  = Interaction parameter

$\psi$  = dilation angle

$\nu$  = Poisson's ratio

$r_{\text{CA}}$  = Rate of Coal Ash

$r_{\text{soil}}$  = Rate/royalty of natural soil

$r_m$  = Rate of mining natural soil

$r_{t1}$  = Transportation rate for initial 5 km

$r_{t2}$  = Transportation rate per km beyond 5 to 10 km

$r_{t3}$  = Transportation rate per km beyond 10 to 20 km

$r_{t4}$  = Transportation rate per km beyond 20 km

$r_{\text{GG}}$  = Rate of Geogrid

$d_1$  = Distance of transportation of natural soil

$d_2$  = Distance of transportation of coal ash

$n_s$  = Number of reinforced layers required by soil

$n_{\text{CA}}$  = Number of reinforced layers required by coal ash

$d_{t\_CA}$  = Threshold distance of coal ash transportation from construction site