UTILISATION OF COAL ASH FOR ROAD CONSTRUCTIONS IN SRI LANKA

B.H.T.Ariyarathne

Abstract: Coal Ash (Bottom Ash & Fly Ash) is very effectively used for various infrastructure project in many countries. Norochcholai coal power plant in Sri Lanka generate about 291,000 tons of ash annually and is being dumped over 30 acres of land near the power plant over the years. It has now become an environmental and social concern and it requires an appropriate measures to recycle this waste as a secondary product.

The utilisation of coal ash in road industry will not only benefit the material scarcity for road construction but also reduce the environmental impact caused by problems associated with ash disposal.

Research and Development Division of RDA has been successfully carried out laboratory trials for the use of coal ash in future road construction projects. First stage of this studies was to assess strength characteristics of marginal soil mix with different proportions of coal ash for road sub base, shoulders and embankment construction. Slope stability analyses were carried out for road embankment constructed using bottom ash.

It is concluded that coal ash can be successfully used as a mechanical stabiliser for marginal soil by addition of 20% to 30% of coal ash and also as an alternative material for embankment filling.

Keywords: Coal Ash, marginal soil, soil stabilisation, embankment fill.

---

1. Introduction

Norochcholai coal power plant in Sri Lanka generate 43% of the total energy production of the Island. Over 291,000 tons of coal ash (Fly ash & Bottom Ash) has been generated annually as a waste-product [1].Only a small percentage of the total production of coal ash (about 30%) is recycled for cement production and rest are dumped near the coal power plant.

The existence of large quantity coal ash stock pile near the power station has now become a major environmental and social problems to the community of that area. Agreements have been signed to purchase up to 90% of the future production of coal ash by various industry partners of cement, asbestos sheet, concrete and brick etc., with effect from March 2018.

It is essential to find out an appropriate solution to utilize this ash dumped for road industry in Sri Lanka. There are more than 3000km of roads to be rehabilitate or construct under iRoad development program, Central and Ruwanpura expressway projects. Present material shortage for road construction industry in Sri Lanka causing significant delays and high project costing.

Therefore, an alternative solution to present material shortage can be address by utilisation of coal ash for soil stabilization.

Coal ash stabilise soil exhibits significant shear strength increase, control shrink-swell properties and improve load bearing capacity. Further benefits include high friction resistance, reduction of plasticity and lowering permeability.

Coal ash can be used for Embankment filling. Low unit weight of coal ash is an advantage of reducing settlement of embankment constructed on low bearing capacity soil.

When compared with natural soil, construction of road embankment using coal ash is less difficult and save both construction time and cost.

Utilization of Coal ash for road construction in Sri Lanka is negligible when compared to most of European countries where these material is successfully utilised for various engineering purposes.

*Eng. **B H T Ariyarathne**, B.Sc. Eng. (Moratuwa), AMIE (SL), Civil Engineer, Research & Development Division, Road Development Authority.*

And only limited studies have been done on coal ash recycling in Sri Lanka. Therefore, laboratory trials has been carried out at the Research & Development Division of RDA for the use of coal ash in road industry.

2. Objectives

Main objectives of this study are to investigate the possibility of utilisation of dumped coal ash for road construction in Sri Lanka. This will enable to provide an alternative solution to material scarcity for road industry in Sri Lanka and also reduce the environmental impact caused by present stock pile.

3. Review of other countries recycling process and previous studies

Global Scenario

Coal plays a vital role in electricity generation in globally, 41% of global electricity is currently fueled by coal-fired plants [4].Coal Combustion Products (CCPs) are waste from thermal power plants such as fly ash, bottom ash, boiler slag, fluidized bed combustion ash; proper management of these waste plays important role for countries environment & social impacts. A summary of the most recent data available on CCP production and utilisation is given in Table 1.

Table 1 Production & Utilizations of CCPs in other countries

Country	CCPs Production (Mt)	Utilization	Year[Ref]
USA	106	56%	2015[3]
China	350	67%	2010[5]
India	258	N.A	
	131*	56%	2011[6]
Eu15	56	54%	2008[7]
Australia	12	43%	2016[8]

*Fly ash

Utilisation of coal combustion products in America

During 2016, 56% of the coal ash was recycled [3] including 60% of fly ash & 37% bottom ash. Among that, 9.4% of ash utilized for embankments, structural fills & road bases, 2.9% for soil stabilization [3].

Utilisation of coal combustion products in Australia

According to 2016 Annual Membership Survey Results of the Ash Development Association of Australia; 43% coal ash was utilized. Among that 68% have been utilized for cementitious binders, concrete manufactures or mineral fillers, 18% for flowable fills, structural fills, road bases, 14% for other applications [8].

Also there were large number of studies undertaken for power station ash utilization; mixed with soil & hydraulic binders to use in road soil and structural/embankments fills based on that various recommendations were provided. Not only that so many guidelines had been developed for use of this ashes directly for constructions. Ex; A Guide to Benefits and Impacts, America Coal Ash Association[9], ASTM E2277–14 Standard Guide for Design and Construction of Coal Ash Structural Fills [10], Technical Advisory T 5080.9 “Use of coal ash in Embankment and Bases” U.S Department of Transportation [11]

Physically, Coal Ash has a semi spherical to spherical particle shape and a complex morphology with a rough surface texture [12]. The rough surface and angular shape of the coal ash generally increase particle interlocking and restrict movement from one particle to another, therefore it will be effected to providing mechanical stabilization for soil. Rifa’i et al.[13] Recommended the use of coal ash as a mechanical stabilizer for soft soil based on laboratory results showed a rise in California Bearing Ratio(CBR) upon addition of coal ash to a soft soil[14]. Also a decreased in swelling potential ranging from 14% to 0% was observed when using a coal ash content of 45% by weight of a soft soil [15]. However, addition of ash beyond that percentage was reduced the strength of the coal ash mixture.

Coal combustion products (CCPs) such as FA and BA are widely used as structural fills worldwide. CCPs are lightweight, easy to compact and have a consistent particle size distribution making for predictable performance in use as structural fills. High angle of shearing resistance, greater stability of slopes could be achieved as compared to natural soils.

4. Approaching Methodology

When looking at other countries recycling methods and their findings were vital important to consider utilisation of coal ash for road construction in Sri Lanka. Based on these information and methodology, a serious of laboratory trial were carried out for the use of coal ash for road construction industry in Sri Lanka.

The coal ash from dumping site near Norochcholai power plant was used for this study. The physical and chemical properties of the coal ashes (Fly Ash & Bottom Ash) in this study were initially characterized and evaluated to check the ability of use as a soil stabiliser and as an embankment filling material.

Chemical composition of the Norochcholai coal ashes are shown in Table 2 and consistence of Silica and Aluminium indicates the pozzolanic properties. In other words, they react with water and free lime (calcium oxide) to produce a cementitious compound which improves the mechanical properties of soil and other unbound pavement materials [3]. Moreover, it contains 6% to 7.5% calcium that needs additional lime to obtain self-hardening properties [3].

Table 2: Chemical composition of Ashes

Chemical	Fly Ash	Bottom Ash
Silica (SiO2)	48.09%	47.98%
Phosphorus (P_2O_5)	2.29%	2.03%
Sulphur (SO3)	0.31%	0.08%
Iron Oxide (Fe3+)	3.61%	4.86%
Aluminium (AL)	16.48%	15.59%
Titanium (Ti)	0.98%	0.98%
Calcium (Ca)	6.68%	7.22%
Potassium (K)	0.45%	0.40%
Magnesium (Mg)	0.94%	1.01%
Manganese (Mn)	0.04%	0.04%
Sodium (Na)	0.02%	0.20%
Nickel (Ni)	<0.010%	<0.010%
Arsenic (As)	77.67 ppm	70.90 ppm
Cadmium (Cd)	ND	ND
Lead (Pb)	5.31 ppm	ND
Antimony (Sb)	ND	ND

That is soil mixed with coal ash with lime increases CBR Ratio[16] also Scanning Electron microscope(SEM) image analysis was shown that many unreacted ash particles in 24% ash treated samples[17]. Therefore, adding lime could be an advantage to react this particles and cement is considered as the most adaptable binder for immobilisation of heavy metals [20]. Addition of cement would be an advantage to reduce leaching of heavy metals and result from leachate test results was provided by CEB.

Table 3: Leachability test results for metal elements

Chemical	Fly Ash	Bottom Ash
Copper (Cu)	<0.05	<0.05
Nickel (Ni)	0.17	<0.05
Manganese (Mn)	1.73	0.52
Antimony and Compounds	<0.05	<0.05
Beryllium & Compounds	<0.05	<0.05
Molybdenum (Mo)	0.09	<0.05
Thallium & Compounds	<0.05	<0.05
Vanadium Compounds	0.65	<0.05
Aluminum (Al)	0.95	4.96
Calcium (Ca)	1055	167.6
Magnesium (Mg)	78.85	16.14
Arsenic (As)	0.27	<0.05
Chromium (Cr)	<0.05	<0.05
Cadmium (Cd)	<0.05	<0.05
Cobalt (Co)	0.06	<0.05
Lead (Pb)	<0.05	<0.05
Barium (Ba)	0.16	0.75
Mercury (Hg)	<0.01	<0.01
Selenium (Se)	0.06	<0.05
Silver (Ag)	<0.05	<0.05
Zinc (Zn)	0.07	0.05

Leaching of some heavy metal in considerable amount causes on some environmental issues especially contaminate with ground water. But several leachate studies carried out for coal as embankment over the past two decades has shown no impact on ground water and surface water quality but , some precautionary measures are necessary to implement minimize the risk of leachate[3].

Since environmental risk is a function of toxicity and contaminate with ground water can be avoided [18]. Therefore, for the embankment fillings it is proposed to construct outer-zone layer (cladding) using type I or II embankment material and a geomembrane at the bottom layer according to Sri Lankan guide line [21].

Investigations for the stabilisation four different types of soil were used particularly from two different types of soil (Soil C & Soil D) from two rejected borrow pits located at Galle & Hambanthota. Material from these two borrow pits were rejected due to non-conformity for road construction works (as a sub base material) [3]. The properties of above two soil samples were determined initially for comparison of strength characteristics.

Table 4: Soil properties

Soil ID	LL	PI	Type	OMC	MDD	CBR 98% MDD
A	52	24	SC	15.2	1.78	17
B	22	8	SC	12.3	1.92	11
C	59	24	SM	15.3	1.87	29
D	40	20	SC	16.8	1.81	26

5. Laboratory Investigation & Discussion

5.1 utilize as a stabiliser

Strength characteristics were evaluated by adding 20%, 30% & 40% of coal ash to soil. Liquid Limit & Plastic Index were also evaluated according to BS Standard [19]. The variation of CBR (98% Maximum dry density, optimum Moisture Content and soaked for 4 days), Liquid Limit & Plasticity Index were tested and are shown below in figure 1 & figure 2.

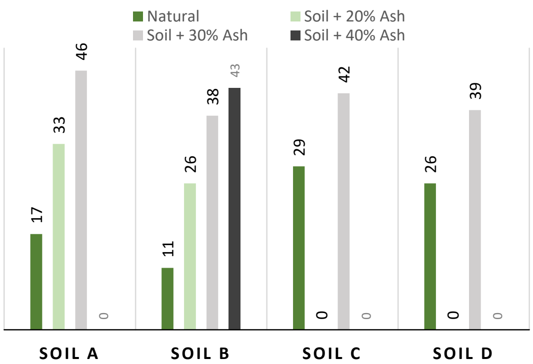

Figure 1: Variation of CBR for different kind of soil with 20%, 30% & 40% of Coal Ash.

The above results indicate the increase of CBR value when coal ash mix with soil. Decrease of plasticity index (PI) also noticed with addition of coal ash. Coal ash-soil mix became non-plastic when soil mix with 40% of coal ash. Therefore, preferred percentage of coal ash for better performance is estimated as 30% by weight.

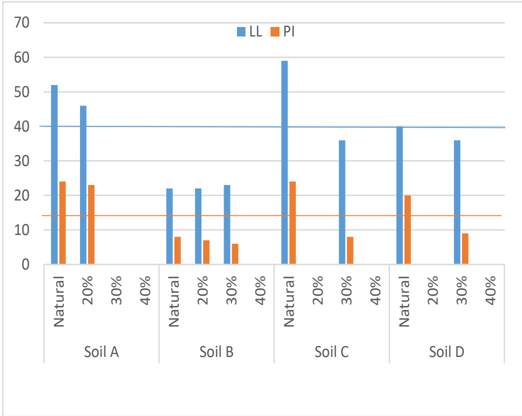

Figure 2: Variation of LL & PI with addition of 20%, 30% & 40% of Coal Ash.

Further, 1% cement was added to coal ash – soil mix to study the improvement and also to bind the heavy metals together [20]. Soil mix with 1 % cement and 30% coal ash was tested to compare results (figure 3). The results indicated CBR(98% Maximum dry density, Optimum moisture content and 24 days Air curing and soaked for 4 days) value increased by adding of 1% cement.

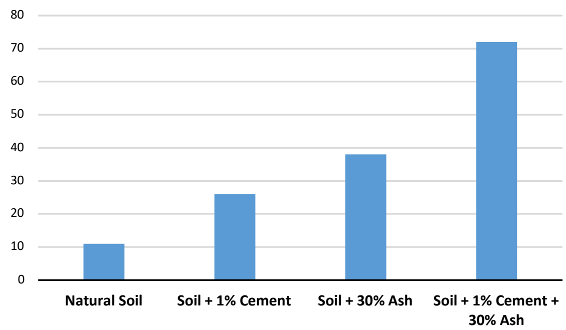

Figure 3: Variation of CBR value with addition of Cement & Coal Ash.

But similar results could be achieved by adding only 30% of coal Ash. Further, addition of both cement & coal ash together would result high CBR value and it will be an advantage to reduce the leachate issue, if any.

Further, by adding 3% of lime (using lime demand test was done to calculate required lime for natural soil and coal ash – soil mix) a significant improvement to CBR(98% Maximum dry density, Optimum moisture content and 24 days Air curing and soaked for 4 days) value was noticed and shown in figure 4.The results of CBR valve over 110 indicate that the stabilised soil mix can be used for sub base construction.

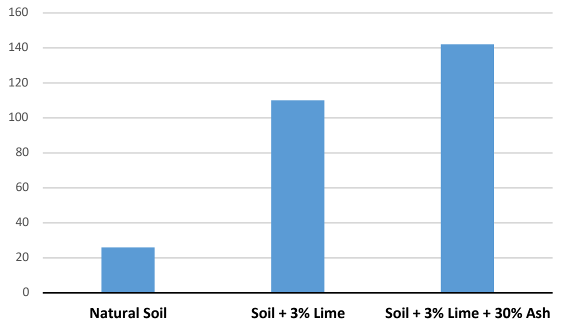

Figure 4: Improvement of CBR with lime & Coal Ash

Finally soil mixed with cement, lime and coal ash were tested for improvement. This indicate (Figure 5) the high CBR(98% Maximum dry density, Optimum moisture content and 24 days Air curing and soaked for 4 days) value over 200, compared with 20% and 30% ash mix. This change could be explained by analysing lime demand curve (figure 6).

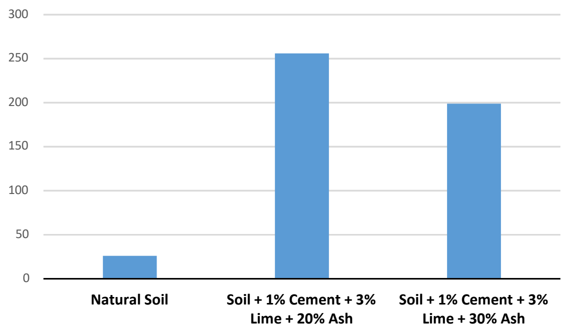

Figure 5: Improvement of CBR with together with cement & lime

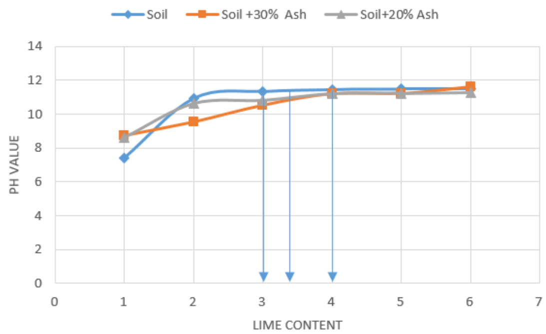

Figure 6: Lime demand curve for natural soil & coal ash mixed soil

According to the test results, it shows the requirement of lime for fully saturated soil is higher when adding coal ash.

Therefore, it is required more than 4% of lime to achieve fully saturated condition when 30% of ash is used and this is not a cost effective solution.

5.2 Use as an embankment fill

Numerical analyses of the embankments were carried out using finite element computer program Slope/w 2018. The analyses of the models were carried out based on Mohr Coulomb yield criteria to evaluate the safety factor of the embankment slope and its variation with ground water table. Considering previous studies and trial analysis, two typical sections was proposed .one is for embankment filling height less than 4m (figure 6) and other one for height higher than 4m (figure 7).For embankment height higher than 4m,embankments with layered system was considered for this analysis.

Following material properties (Table 4) were adopted in the analysis. Properties of coal ash indicate in bellow table was taken from direct shear laboratory test results carried out for Norochchaolai coal ash stock pile. Properties for Outer zone & foundation materials were taken as commonly available material properties from literatures.

Table 5: Material properties for embankment analysis

Material	Density (kN/m3)	Cohesion (kPa)	Angle of Friction (Deg)
Coal Ash	12	0	29
Outer Zone	18	5	34
Foundation	20	18	36

<u>Low embankment less than 4m</u>

Typical cross section of proposed low embankment using coal ash is shown in Figure 7.Outer layer of minimum one meter thickness of either type I or II embankment material was included to a confine heavy metals leaching from coal ash.

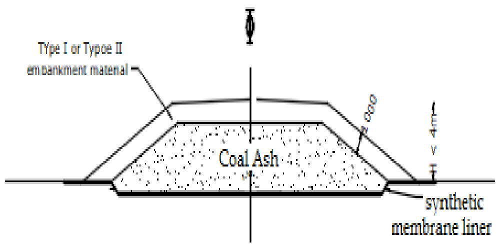

Figure 7: Typical cross section of embankment filling-High less than 4m

Two cases were examined for the design of 4m high embankment.

Case 1: Embankment to final height with traffic load of 20kPa- Low water level

Direct shear test was done to obtain a real value of cohesion and friction angle values of coal taken from dumping site. Unsaturated values from test result of c′=0 & ϕ=29 were adopted in this analysis and results are as sown as follows.

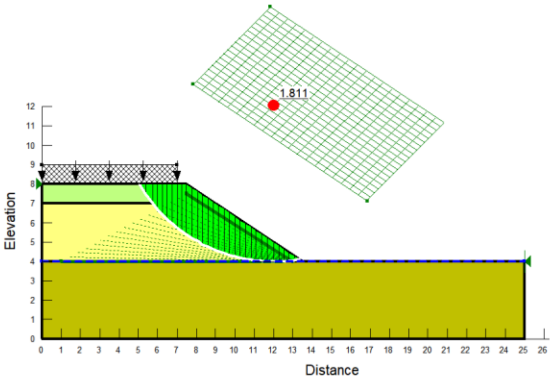

Figure 8: Analysis result for 4m embankment with low water table

Case 2: Embankment to final height with traffic load of 20kPa-water level 1m above

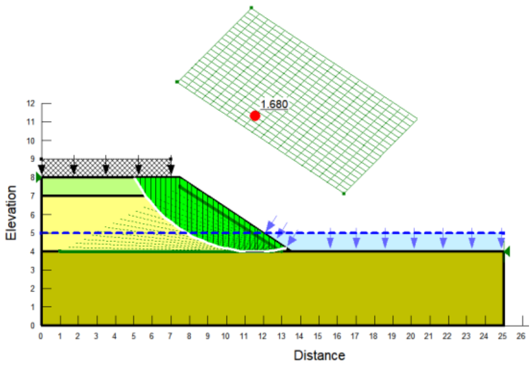

Figure 9: Analysis result for 4m embankment with low water table

Analysis indicated FOS of 1.811 with low water level & 1.680 with high water levels. The results appear embankment in good stable condition even in worst case scenario.

<u>High embankment over 4m</u>

Few trail analyses were carried for embankment over 4m high with multiple layers of coal ash and 500mm thick type I or II material as shown in figure 10. A minimum of one meter thick outer layer of soil was used as the previous analysis.

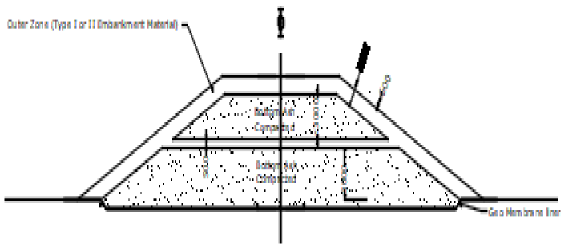

Figure 10: Typical cross section of embankment fill-over 4m

As per previous case the analysis were done for two scenario; low water level & High water level.

Case 1: Embankment to final height with traffic load of 20kPa- Low water level

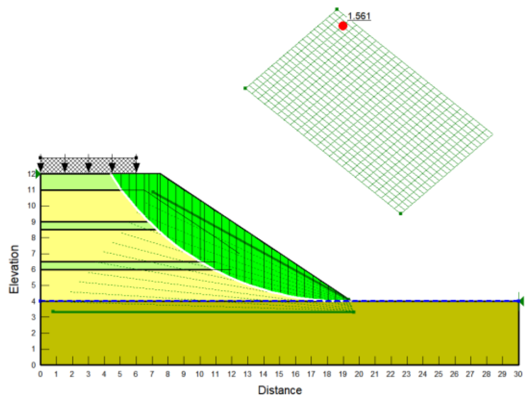

Figure 11: Analysis result for 4m embankment with low water table

It is observed that the F.O.S,1.561 against stability is well enough to withstand the embankment without any strengthening.

Case 2: Embankment to final height with traffic load of 20kPa-water level 1m above

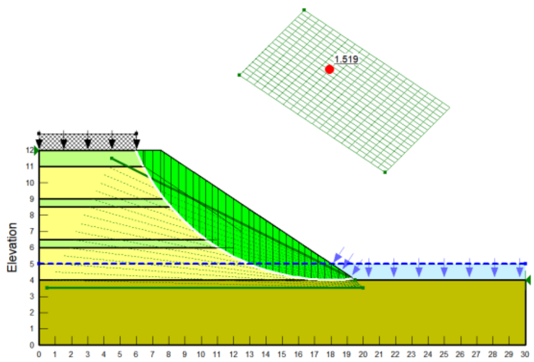

Figure 12: Analysis result for 4m embankment with water level 1m above

Above results (F.O.S 1.519) indicate that even in high water level this embankment appears stable.

6. Conclusion and Recommendation

This study evaluate the suitability of coal ash as a substitutes for material in road construction industry in Sri Lanka. Base on the results of detailed laboratory trial and the literature survey, the following conclusion are drawn:

- Effectively use as a stabiliser for marginal soil improvement
- Excellent stabiliser for base course material if suitably stabilised.
- Mixing of marginal soil with 30% coal ash (by weight) significantly improve the engineering properties of soil for sub base.
- 3% lime and with 30% coal ash exhibit high CBR values and prove to be effective stabilise for construction of road base.
- Addition of cement 1% could minimize leachate potential of heavy metals. However, field trials are recommended for detail assessment of leachate potential with and without cement.
- Bulk utilization of dumped ash is found to be highly feasible for highway embankments construction.
- Provision of one meter thickness of type I or II outer layer and a single layer of synthetic membrane (HDPE 1.5mm or more) is required to minimize the leachate issues.
- Further studies are required to justify generalise acceptance of coal ash for highway construction.

Acknowledgement

This experimental study has been conducted at the R &D Division of RDA as a request made by Chairman, RDA. Therefore, I would like to give my gratitude to Eng. Nihal Sooriyarachchi (Chairman, RDA), Dr (Mrs). H.L.D.M.A. Judith (Director, R&D) and Mr.Lalith Welikala (Geotechnical Consultant, iRoad Project) and all the staff of R&D Division, RDA.

References

[1] Ceylon Electricity Board, www.ceb.lk, visited 18th February 2018

[2] Institute for Construction Training and Development (ICTDA) "Standard specification for construction and maintenance of roads bridges", 2009.

[3] American Coal Ash Association, Using Coal Ash in Highway Construction: A Guide to Benefits and Impacts

[4] World Coal Association, Coal facts 2017, www.worldcoal.org/resources, Visited, 22nd February 2018.

[5] Asian Coal Ash Association, www.asiacoal.org, visited 28th February 2018

[6] Haque, M.E. (2013). Indian fly-ash: production and consumption scenario. International Journal of Waste Resources (IJWR)

[7] Hans-Joachim Feuerborn, Coal Combustion Products in Europe - an update on Production and Utilization, Standardization and Regulation, World of Coal Ash (WOCA) Conference - May 9-12, 2011, in Denver, CO, USA

[8] Ash Development Association of Australia Annual Membership Survey Results, January - December 2016

[9] Using Coal Ash in Highway Construction:A Guide to Benefits and Impacts, America Coal Ash Association

[10]ASTM E2277 – 14 Standard Guide for Design and Construction of Coal Ash Structural Fills ASTM Standard.

[11]Technical Advisory T 5080.9 "Use of coal ash in Embankment and Bases" U.S Department of Transportation.

[12]R. K. Seals, L. K. Moulton, and B. E. Ruth, "Bottom ash: an engineering material," Journal of the Soil Mechanics and Foundations Division, vol. 98, no. 4, pp. 311–325, 1972.

[13]A. Rifa'i, N. Yasufuku, K. Omine, and K. Tsuji, "Experimental study of coal ash utilisation for road application on soft soil," Fukuoka, Japan, September 2009

[14]Hamza Güllü, Factorial experimental approach for effective dosage rate of stabilizer: Application for fine-grained soil treated with bottom ash

[15]C.Rajakumar, T.Meenambal, Experimental Study on Utilization of Bottom Ash to Stabilize Expansive Soil Subgrades

[16]Sharda Dhadse, Pramila Kumari and L J Bhagia Fly ash characterization,utilization and government initiatives in India-A review.

[17]T. B. C. H. Dissanayake ,S. M. C. U. Senanayake,M. C. M. Nasvi Comparison of the stabilization behavior of fly ash and bottom ash treated expansive soil

[18]Madawala Liyanage Duminda Jayaranjan Eric D. van HullebuschAjit P. Annachhatre, Reuse options for coal fired power plant bottom ash and fly ash.

[19]BS 1377-2:1990, Methods of test for soils for civil engineering purposes. Classification tests

[20]Giergiczny Z1, KrólA.Immobilization of heavy metals (Pb, Cu, Cr, Zn, Cd, Mn) in the mineral additions containing concrete composites

.

[21]Central Environmental Authority (CEA), Technical Guidelines on solid waste management in Sri Lanka, pp22