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Geotechnical evaluation of pond ash and bentonite mixes for highway engineering applications

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Abstract
Background: Pond ash a byproduct of coal base thermal power plants, poses significant disposal and environmental challenges. Geotechnical properties however suggest potential reuse in infrastructure; particularly in highway embankments. This study investigates the compaction characteristics and California Bearing Ratio (CBR) values of pond ash sourced from Rajghat, Badarpur and Dadri thermal power plant and evaluate the effect of bentonite and lime admixtures on its suitability for highway applications.
Methods: Pond ash samples were collected from 3 sites and tested for compaction characteristics using Standard and Modified Proctor tests to determine maximum dry density (MDD) and optimum moisture content (OMC) to optimize performance. Pond ash was mixed with bentonite in proportions of 2-10% by weight and separate mixes were prepared with lime: 2-10%. California Bearing Ratio (CBR) tests were conducted on all mixes to assess subgrade strength.
Results: MDD of pure pond ash ranged from 1.15-1.22 g/cc (Standard Proctor) and 1.22-1.29 g/cc (Modified Proctor) across sites. Addition of bentonite decreased MDD and CBR values with CBR dropping from 12.05% (2% bentonite) to ~9-10% (10% bentonite). Conversely, lime improved strength significantly. CBR increased from 20.08% (2% lime) to 31.4% (10% lime). Site-wise variations were observed with Badarpur sample showing marginally higher strength than Rajghat and Dadri.
Conclusion: Pond ash alone exhibits limited strength for direct highway use. When stabilized with lime. However, it demonstrates substantial improvement in load-bearing capacity making it suitable for embankments and pavement subgrades. In contrast, bentonite reduced performance due to its water retention properties. Utilization of pond-ash with lime not only enhances geotechnical properties but also provides an environmentally sustainable method of waste reuse in highway engineering.

Keywords: Pond ash, bentonite, lime stabilization, compaction, California Bearing Ratio (CBR), highway embankments, waste utilization

Introduction
Coal-based thermal power plants generate large volume of ash as a by-product of combustion, where coal remains the dominant energy source, disposal of this ash has become an increasing environmental and economic challenge in India. Pond ash consisting of a mixture of fly ash and bottom ash transported as slurry to ash ponds, represents the bulk of this kind of waste. With limited land availability and rising environmental concerns, effective strategies for pond ash utilization are essential. Highway construction shows a promising avenue for large scale pond ash reuse. Embankments subgrades, and pavement layers often require bulk materials with adequate compaction and strength characteristics, which industrial byproducts such as pond ash may provide. However, in its natural state, pond ash often exhibits lower bearing capacity and higher variability compared to conventional soils. This necessitates modification with stabilizing agents to meet engineering requirements.
Several admixtures have been studied to enhance the geotechnical behaviour of pond ash. Bentonite, a clay mineral with high swelling and water retention capacity, can influence compaction characteristics but may reduce bearing strength due to its fine particle size and moisture affinity. Conversely, lime has long been recognized as a cost-effective stabilizer, imparting pozzolanic properties that improve strength and durability.

1. The present study evaluates the geotechnical performance of pond ash samples collected from three thermal power plants — Rajghat, Badarpur and Dadri.
2. The compaction behaviour of pond ash using Standard and Modified Proctor tests.
3. The effect of bentonite (2-10%) and lime (2-10%) additions on maximum dry density (MDD), optimum moisture content (OMC) and California Bearing Ratio (CBR).

The suitability of stabilized pond ash for use in highway embankments and pavement subgrades.

By integrating laboratory characterization with comparative site-wise analysis, this study aims to demonstrate an environmentally sustainable pathway for the beneficial reuse of pond ash in highway engineering.

The application of coal combustion residues in highway engineering has been widely studied over the past few decades with pond ash receiving particular attention due to the challenges associated with its disposal and its potential as a bulk construction material. Sridharan *et al*. (1996) [1] highlighted that pond ash generally exhibits low unit weight and higher optimum moisture content compared with natural soils, making it suitable for lightweight fill applications but limiting its strength. Ranjan and Rao (1996) [2] similarly reported that while the bearing capacity of untreated pond ash is relatively low its reduced density can be advantageous for embankment construction on weak clay foundations.

Stabilization efforts have examined both clay minerals and chemical additives to enhance performance and Kaniraj and Havangi (1999) [2] studied fly ash-soil mixtures and demonstrated that the inclusion of bentonite increased plasticity but simultaneously reduced compaction efficiency and strength. This negative effect has since been reaffirmed in later compaction and strength studies, which showed declining maximum dry density (MDD) and California Bearing Ratio (CBR) values with rising bentonite content.

In contrast, lime has consistently been shown to improve the geotechnical properties of ash and Sherwood and Ryley (1966) [4] were among the earliest to demonstrate the benefits of lime-treated pulverized fuel ash in flexible pavement construction in the United Kingdom, providing evidence of improved long-term performance. More recently, Chand and Subbarao (2007) [5] investigated lime-stabilized pond ash and reported significant gains in strength and durability, supporting the use of lime as a cost-effective stabilizer in road and embankment construction. Bera *et al*. (2007) [6] further confirmed that lime treatment enhances compaction characteristics and long-term stability, making pond ash more suitable for civil engineering applications.

Collectively, these studies suggest that pond ash, though limited in its untreated state, can be effectively utilized in highway construction when properly stabilized. Bentonite, despite its impermeability benefits, reduces strength due to its high water retention, while lime induces pozzolanic reactions that markedly improve load-bearing capacity. Nevertheless, most prior work has been site-specific, and comprehensive comparative evaluations across different ash sources remain scarce. This gap underscores the need for systematic studies, such as the present work, which investigates pond ash from Rajghat, Badarpur and Dadri thermal power plants in combination with bentonite and lime to assess its suitability for highway engineering applications.

Materials and Methods

Materials

The study use Pond ash collected from three different thermal power stations, Rajghat (Delhi), Badarpur (U.P) and Dadri (Delhi NCR). The ash was taken from slurry disposal ponds where both fly ash and bottom ash are dumped together. Samples were air dried and sieved through 4.75 mm IS sieve before carrying out the tests.

For stabilization, two materials were used. First one is Bentonite clay, which is known for its swelling capacity and was mixed with ash in 2%, 5%, 8% and 10% by weight. Second material was Hydrated Lime, also mixed in same proportions by weight.

The equipment required for study were Proctor test apparatus, CBR test machine, cylindrical moulds, rammer, oven, weighing balance etc.

Methods

The experimental programme mainly focus on compaction test and CBR test of Pond ash and its mix with bentonite and lime.

Compaction test

Standard Proctor and Modified Proctor tests (IS codes 2720 Part VII and VIII) were performed. Around 4.5 to 5.5 kg of dried ash was taken for each test. The samples were compacted in mould in 3 layers for Standard and 5 layers for Modified test, giving required number of blows by rammer. The test was repeated for different moisture contents, and from compaction curve the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were found for each mix.

California Bearing Ratio (CBR) test

The CBR test was carried out for soaked as well as unsoaked condition. The specimens were prepared at their OMC and MDD values. The plunger of 50 mm diameter was penetrated in sample at rate of 1.25 mm/min. Load was recorded at penetration of 2.5 mm and 5 mm and then compared with standard values to calculate CBR. Tests were done for pure pond ash, bentonite mixes (2-10%) and lime mixes (2-10%) for all three sites.

Data analysis

The results of compaction and CBR were compiled and compared for different mixes and also between three sites Rajghat, Badarpur and Dadri. Graphs and plots were prepared to understand the trend in properties when bentonite or lime was added.

Results

The data presented in the following tables were collected from laboratory experiments conducted on pond ash samples of three sites: 1) Rajghat, 2) Badarpur and 3) Dadri. Each sample was air dried, sieved and then tested. Compaction characteristics (MDD and OMC) were obtained using Standard and Modified Proctor tests. For strength evaluation, California Bearing Ratio (CBR) tests were done on specimens prepared at their MDD and OMC the effect of bentonite and lime was studied by mixing them in different proportions (2%, 5%, 8% and 10% by weight).

Table 1: Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of Pond Ash (Standard & Modified Proctor)

Site	Test Type	MDD (g/cc)	OMC (%)
Rajghat	Standard Proctor	1.20	19-22
Rajghat	Modified Proctor	1.27	16-19
Badarpur	Standard Proctor	1.22	18-21
Badarpur	Modified Proctor	1.29	16-18
Dadri	Standard Proctor	1.15	20-24
Dadri	Modified Proctor	1.22	18-21

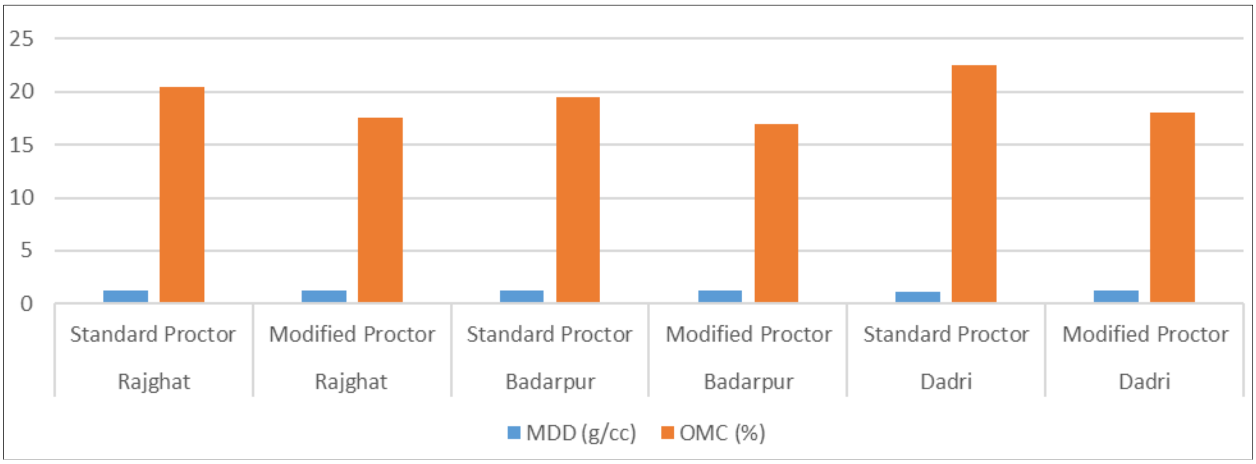

Fig 1: MDD and OMC under Standard and Modified Proctor Tests

Data collected by compacting 4.5-5.5 kg of sample in cylindrical moulds, with specified number of blows. The dry density was calculated at different moisture contents and curves were plotted to determine MDD and OMC.

Table 2: Effect of Bentonite on CBR of Pond Ash (Rajghat, Badarpur and Dadri)

Site	Bentonite %	CBR (%)
Rajghat	2%	11.5%
Rajghat	5%	11.2%
Rajghat	10%	9.4%
Badarpur	2%	12.0%
Badarpur	5%	11.9%
Badarpur	10%	10.3%
Dadri	2%	12.3%
Dadri	5%	11.6%
Dadri	10%	10.1%

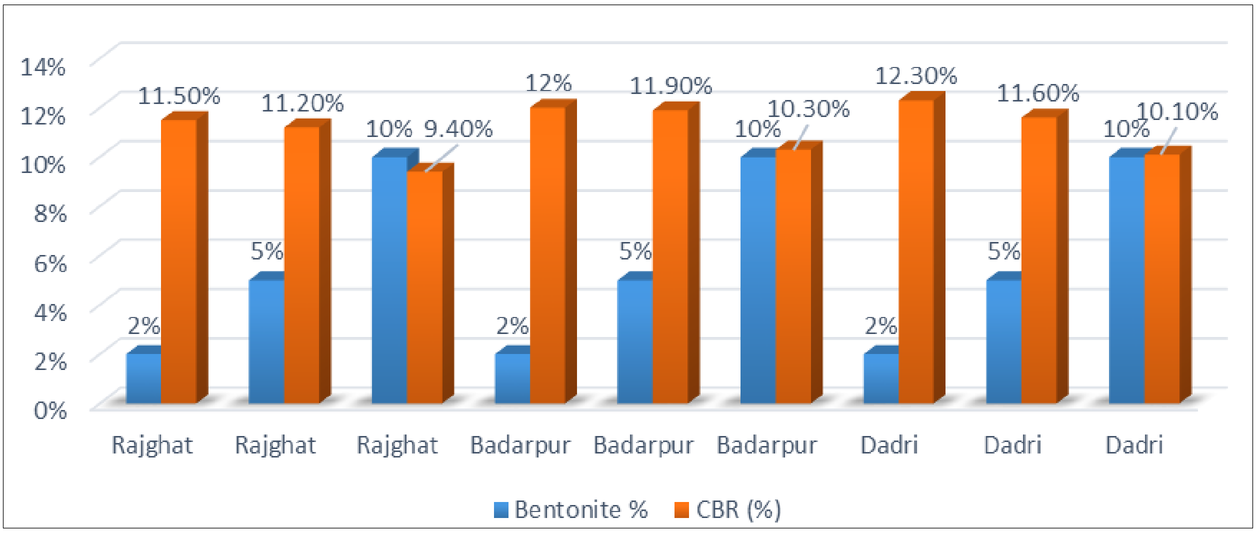

Fig 2: CBR variation with Bentonite content at different sites

Data obtained from CBR tests by preparing samples at MDD and OMC soaking for 4 days; (for soaked condition) and then penetrating 50 mm plunger at 1.25 mm/min. Load values were taken at 2.5 mm and 5 mm penetration and compared with standard values.

Table 3: Effect of Lime on CBR of Pond Ash (Rajghat, Badarpur and Dadri)

Site	Lime %	CBR (%)
Rajghat	2%	20.1%
Rajghat	5%	23.4%
Rajghat	10%	26.8%
Badarpur	2%	20.1%
Badarpur	5%	23.4%
Badarpur	10%	31.4%
Dadri	2%	20.1%
Dadri	5%	23.4%
Dadri	10%	29.6%

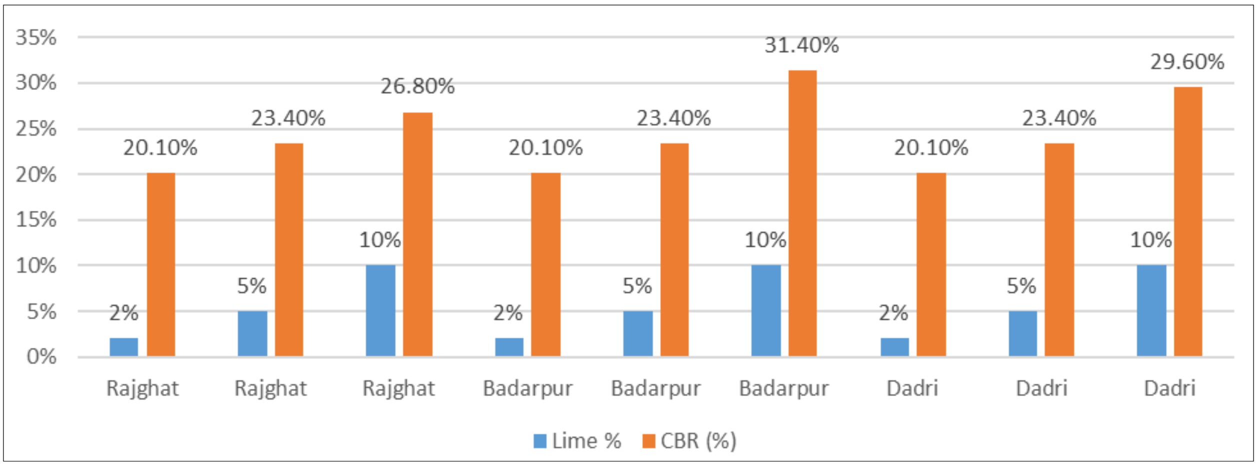

Fig 3: Variation of CBR with Lime content in Pond Ash

Values recorded from CBR, penetration tests. Lime was mixed with ash in different percentage by weight, samples compacted to MDD & OMC and penetrated with plunger. CBR calculated at 2.5 mm and 5 mm penetration.

Discussion

The laboratory results clearly show that pond ash in the natural form has low compaction density and moderate bearing capacity, which limit its, direct application in highway construction. The MDD values from Standard and Modified Proctor test ranged between 1.15 to 1.29 g/cc, which was lower compared to conventional soils. This observation is also supported by Sridharan *et al.* (1996) [1] who reported similar low density and high OMC of Indian pond ash. Our results therefore confirm that untreated pond ash is not sufficient as a strong subgrade material.

When bentonite was mixed with pond ash, the CBR values decreased gradually. For example, at Rajghat site, CBR dropped from about 11.5% at 2% bentonite to 9.4% at 10% bentonite. This is due to the swelling and water retention property of bentonite which increases moisture but reduces load bearing strength. Similar effect was mentioned by Kaniraj and Havangi (1999) [2] who also found bentonite increases plasticity but lowers strength of fly ash-soil mixes. Thus, even though bentonite may improve impermeability, its role in strength improvement is very limited.

In contrast, lime stabilization gave very positive results. All three sites showed continuous increase of CBR value with higher lime content. At Badarpur site, CBR reached 31.4% with 10% lime which is almost three times higher than untreated pond ash. Lime reacts with silica and alumina in ash and forms cementitious products which bind particles and increase strength. Similar observations were reported by Sherwood and Ryley (1966) [4] in UK and later by Chand and Subbarao (2007) [5] in India. The study therefore supports the previous findings that lime is an effective and economical stabilizer for ash materials.

Among the three sites, Badarpur ash showed better performance compared to Rajghat and Dadri. This may be due to difference in source coal quality and combustion conditions which affect ash properties. This highlights that site-to-site variation is important and pond ash cannot be considered uniform everywhere.

Some limitations of the present study should be acknowledged. The focus was only on compaction and CBR tests, while other important tests like shear strength, permeability and durability were not covered. Special performance such as behaviour under cyclic loading or long-term weathering was also not evaluated. Fatty and silty nature, in few samples sometimes caused variability in test results. In addition, though lime showed good short-term results, long-term field performance still needs monitoring.

Even with these limitations, the study highlights that lime stabilized pond ash is suitable for embankments and pavement subgrade, while bentonite mixes are not recommended where strength is the main criteria. From environmental point of view also, using pond ash with lime will solve disposal problem and contribute to sustainable highway construction.

Conclusion

From the present investigation it can be concluded that pond ash alone is not suitable for directed use in highway subgrade due to its low density and moderate strength values. The compaction results showed low MDD (1.15 - 1.29 g/cc) and high OMC, which confirm that untreated ash cannot provide adequate load bearing capacity.

When bentonite was mixed with pond ash, the bearing strength reduced further. With increasing percentage of bentonite the CBR, values kept on decreasing for all three sites Rajghat, Badarpur and Dadri; Because is bentonite absorbs more water, increase plasticity but reduces strength. So, bentonite mix pond ash cannot be recommended for highway embankments where strength is important.

On the other hand, lime stabilization improved the properties significantly. At 10% lime content the CBR values reached up to 31.4% in Badarpur ash, which is much higher than natural pond ash. Lime reacts pozzolanically and binds the ash particles into a cemented structure giving more load bearing capacity and durability. The results are in agreement with earlier researchers and prove that lime treated pond ash can be used as a reliable construction material.

Among the three sites, Badarpur ash gave slightly better results than Rajghat and Dadri, which shows that ash properties vary from plants to plants and need to be tested before application.

Overall, it can be said that lime stabilized pond ash is a sustainable and economical alternative for highway embankment and pavement construction, which not only solve the problem of ash disposal but also reduce the use of natural soil. Further long term field trials and performance monitoring are suggested to validate the laboratory findings.

References

1. Sridharan A, Pandian NS, Rajasekhar C. Geotechnical characterization of pond ash. In: Raju VS, editor. Ash Ponds and Ash Disposal Systems. New Delhi: Narosa Publishing House; 1996. p. 97-110.
2. Ranjan G, Rao ASR. Basic and Applied Soil Mechanics. New Delhi: Wiley Eastern; 1996.
3. Kaniraj SR, Havanagi VJ. Geotechnical characteristics of fly ash-soil mixtures. Geotech Eng J. 1999;30(2):129-147.
4. Sherwood PT, Ryley MD. Use of stabilized pulverized fuel ash in road construction. Road Research Laboratory Report, UK Ministry of Transport. 1966;(49):1-44.
5. Chand SK, Subbarao C. Strength and slake durability of lime stabilized pond ash. J Mater Civ Eng. 2007;19(7):601-608.
6. Bera AK, Ghosh A, Ghosh A. Compaction characteristics of pond ash. J Mater Civ Eng. 2007;19(9):754-760.
7. Mathur VK. Fly ash as a source material for construction industry. J Inst Eng (India). 2004;85:31-35.
8. Stewart JP. Soil compaction properties. J Geotech Eng. 1998;124(3):231-238.
9. Terzaghi K, Peck RB, Mesri G. Soil Mechanics in Engineering Practice. 3rd ed. New York: John Wiley & Sons; 1996.
10. Appolonia DJD. Soil-bentonite slurry trench cut-offs. J Geotech Eng Div, ASCE. 1980;106(GT4):399-417.