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Title:
Utilisation of Fly Ash-Bentonite Mixture as an Alternate Liner Material

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CONTENTS

INTRODUCTION:

- A landfill liner prevents the migration of potential pollutants from entering into ground water and surface water.
- Hydraulic conductivity should be : 1×10^{-9} m/sec.(according to Environmental protection agency, EPA(1993))
- Natural clays, bentonite and its mixes used as liners.
- Sand- Bentonite mixture as a liner material.
- Due to increase in non-availability of sand, Fly ash is used as an alternate material for sand in Sand-Bentonite liner.
- Fly ash as an major constituent liner material.

Literature review

AUTHOR	YEAR	SUMMARY
Akgun et al.	2015	They found that the specific gravity, maximum dry density, UCS, Maximum swelling pressure, Young'smodulus, cohesion increased and the optimum moisture content, angle of internal friction and hydraulic conductivity decreased with the increased bentonite content of the bentonite–sand mixture.
Al-Rawas et al.	2006	They found that, sand + 30% clay mixture prepared at 2 % above moisture content satisfied the requirements for waste containment liners.

AUTHOR	YEAR	SUMMARY
Bello	2013	Design parameters such as hydraulic conductivity, volumetric shrinkage and unconfined compressive strength varied as the molding water content and compactive efforts varied for soil samples compacted at -2, 0, 2, and 4% of OMC for different compactive energies namely RP, SP, and MP.
Benson et al	1994	Based on the experimental results, they have evaluated the relationships between hydraulic conductivity, compositional factors, and compaction variables and identified minimum values for soil properties that are likely to yield a geometric mean hydraulic conductivity $\leq 1\times10^{-9}$ m/s.

AUTHOR	YEAR	SUMMARY
Bowders et al.	1994	For a compacted mixture containing 40% fly ash, 30% clay and 30% sand, hydraulic conductivity was found to be 1.5 x 10-9 m/s.
Srikanth and Mishra	2016	Conducted geotechnical investigation on mixture of Sand and Bentonite. It was found that hydraulic conductivity of sand–bentonite mixtures not only depend upon particle size of sand but also on the other things like bentonite content, mixing water content, compaction energy used and quality of bentonite used etc.

OBJECTIVE

Objective of the present study is

- To determine the feasibility of using fly ash-bentonite mixture as an alternate liner material.
  - Hydraulic conductivity characteristics
  - Strength characteristics
  - Plasticity
  - Swelling characteristics
  - Shrinkage

Materials

- Non-plastic cohesion less material:

  Fly ash from Aditya Alumina Ltd. situated in Lapanga town in Sambalpur district, Odisha.

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- High plastic cohesive materials:

  commercial bentonite.

Fig 1. Fly ash

Fig 2. Bentonite

Experimental Procedure:

- Fly ash and bentonite mixtures with dry weight percentages of bentonite of 5, 10 and 15% were prepared
- The liquid limit and plastic limit of above mentioned trial mixes were obtained to find the plasticity index.
- Swelling characteristics for these trial mixes were obtained by conducting differential free swell index test
- OMC and MDD were determined for these samples at four compaction energies of 355, 592, 1296 and 2700 kJ/m^3 respectively.
- The hydraulic conductivity was determined using falling head.
- The strength of fly ash-bentonite mixes were determined by conducting unconfined compressive strength test.

Properties of Fly ash and Bentonite

Table-1 Geotechnical properties of materials used

Property	Fly ash	Bentonite
Specific Gravity, *Gs*	2.08	2.74
Liquid limit, *LL(%)*	33.3	256
Plastic limit, *PL(%)*	Np	50
Linear Shrinkage, *Ls*	-	41
Plasticity Index, *PI(%)*	-	206
Differential free swell index, *DFS(%)*	-34.8	400
Colour	Grey	Yellowish Brown

Results and Discussions:

Effect of bentonite content on pasticity characteristics of FA:B mixes

Table-2 Liquid limit and Plastic limit of trial mixes

FA+B mixture	Liquid Limit (LL) %	Plastic Limit (PL) %	Plasticity Index (PI=LL-PL) %	Differential free swell Index (DFS) %
85:15	62.15	31.68	30.47	157
90:10	56.44	27.37	29.07	60%
95:5	40.84	15.79	25.05	6.7%

From the obtained results it is clear that, all the fly ash- bentonite trail mixes are satisfying the plasticity criteria (Benson et al. 1994) (i.e. $LL \geq 20\%$ and $PI \geq 7\%$) and it was observed that the addition of bentonite to fly ash increases plasticity index of the mixture.

Effect of betonite content on swelling characeristics of FA:B mixes

Table-3 Differential free swell index of trial mixes

Mix proportion	Differential free swell Index (DFS)
Fly ash : Bentonite (85:15)	157%
Fly ash : Bentonite (90:10)	60%
Fly ash : Bentonite (95:5)	6.7%
Bentonite	400%

Results show that addition of fly ash to bentonite has decreased the swelling behaviour of bentonite. The decrease in swelling is due to the replacement of plastic fines of bentonite by non-plastic fines of fly ash (Phanikumar et al, 2007).this is due to the addition of fly ash to bentonite which causes flocculation and cementation to take place

Compaction and hydraulic conductivity characteristics

Four different compaction energies such as standard Proctor (SP, 592 kJ/m^3), reduced standard Proctor (RSP, 355 kJ/m^3), modified Proctor (MP, 2700 kJ/m^3) and reduced modified Proctor (RMP, 1296 kJ/m^3) tests were carried out for three fly ash- bentonite mixtures (95:5; 90:10; 85:15). The results were analysed to determine the effect of different compaction methods on hydraulic conductivity of above mentioned fly ash-bentonite mixtures.

- Trail mix of FA+B(85:15)

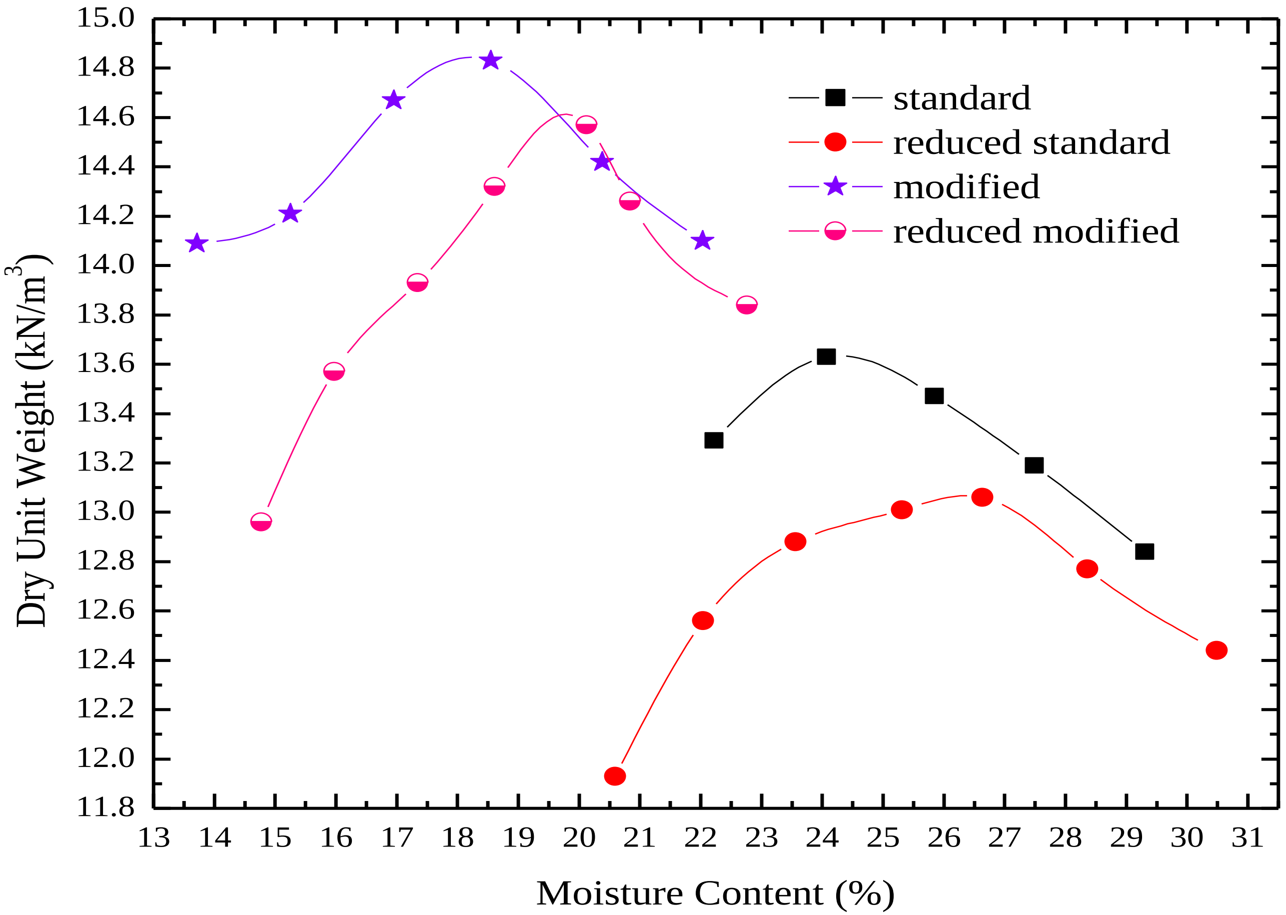

Fig 3. Compaction curves of FA+B (85:15) mix for different compaction methods

Variation of OMC and MDD for FA+B (85:15) with compaction energy

Table-4 Compaction characteristics of FA+B (85:15) mix for different compaction methods

Type of compaction	OMC (%)	MDD (kN/m^3)
Reduced standard proctor	26.21	13.08
Standard proctor	24.11	13.53
Reduced modified proctor	19.78	14.61
Modified proctor	18.21	14.83

Variation of permeability for FA+B (85:15) with compaction energy

Table-5 Permeability characteristics of FA+B (85:15) mix for different compaction methods

Type of compaction	Permeability, k (m/sec)	Avg. Permeability, k (m/sec)
Reduced standard proctor	2.90×10^{-9}	3.20×10^{-9}
	3.68×10^{-9}	
	3.03×10^{-9}	
Standard proctor	3.88×10^{-10}	4.16×10^{-10}
	3.56×10^{-10}	
	5.04×10^{-10}	
Reduced modified proctor	4.28×10^{-10}	4.02×10^{-10}
	3.37×10^{-10}	
	4.00×10^{-10}	
Modified proctor	1.75×10^{-10}	1.55×10^{-10}
	1.56×10^{-10}	

Compaction and hydraulic conductivity characteristics

- Trail mix of FA+B(90:10)

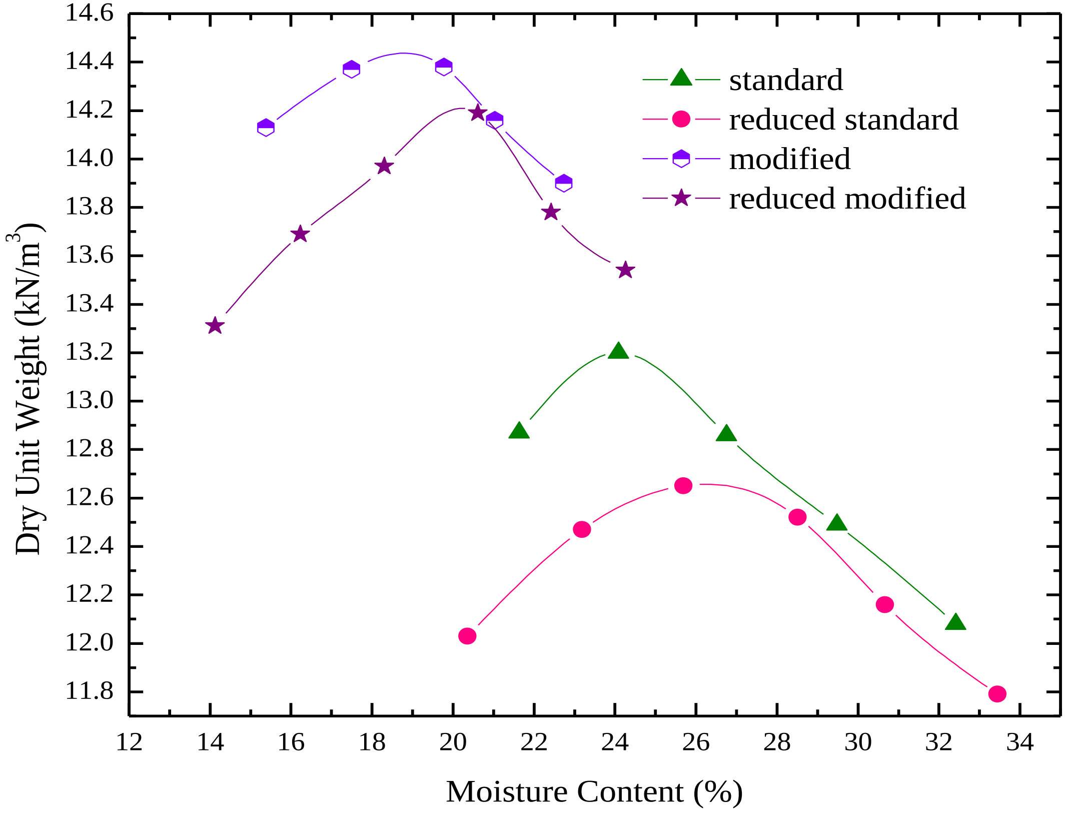

Fig 4. Compaction curves of FA+B (90:10) mix for different compaction methods

Variation of OMC and MDD for FA+B (90:10) with compaction energy

Table-6 Compaction characteristics of FA+B (90:10) mix for different compaction methods

Type of compaction	OMC (%)	MDD (kN/m^3)
Reduced standard proctor	26.34	12.66
Standard proctor	24.29	13.2
Reduced modified proctor	20.44	14.2
Modified proctor	18.79	14.44

Variation of permeability for FA+B (90:10) with compaction energy

Table-7 Permeability characteristics of FA+B (90:10) mix for different compaction methods

Type of compaction	Permeability, k (m/sec)	Avg. Permeability, k (m/sec)
Reduced standard proctor	3.14×10^{-9}	3.44×10^{-9}
	4.04×10^{-9}	
	3.13×10^{-9}	
Standard proctor	1.88×10^{-9}	2.57×10^{-9}
	3.01×10^{-9}	
	2.81×10^{-9}	
Reduced modified proctor	2.23×10^{-9}	2.10×10^{-9}
	2.14×10^{-9}	
	1.94×10^{-9}	
Modified proctor	1.17×10^{-9}	1.20×10^{-9}
	1.04×10^{-9}	

Compaction and hydraulic conductivity characteristics

- Trail mix of FA+B(95:5)

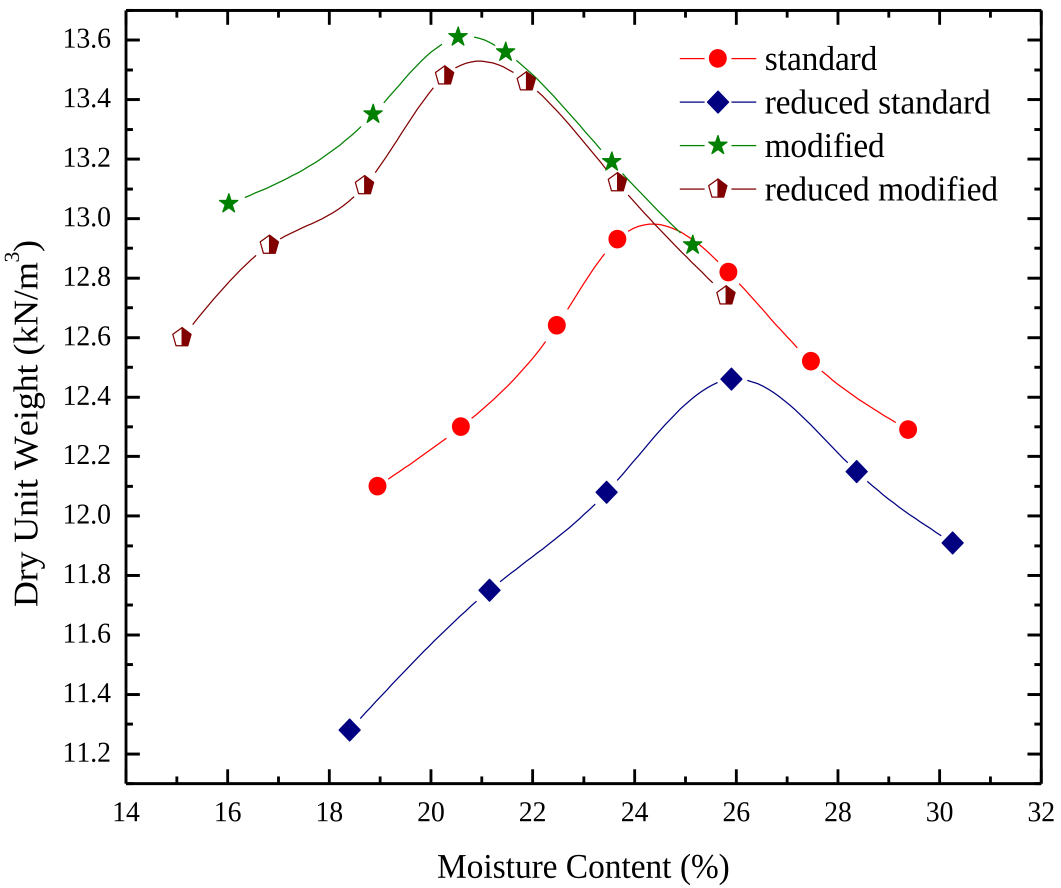

Fig 5. Compaction curves of FA+B (95:5) mix for different compaction methods

Variation of OMC and MDD for FA+B (95:5) with compaction energy

Table-8 Compaction characteristics of FA+B (95:5) mix for different compaction methods

Type of compaction	OMC (%)	MDD (kN/m^3)
Reduced standard proctor	26.97	12.46
Standard proctor	24.33	12.98
Reduced modified proctor	20.96	13.53
Modified proctor	20.68	13.61

Variation of permeability for FA+B (95:5) with compaction energy

Table-9 Permeability characteristics of FA+B (95:5) mix for different compaction methods

Type of compaction	Permeability, k (m/sec)	Avg. Permeability, k (m/sec)
Reduced standard proctor	5.41×10^{-8}	4.24×10^{-8}
	3.17×10^{-8}	
	4.15×10^{-8}	
Standard proctor	2.90×10^{-8}	3.11×10^{-8}
	3.88×10^{-8}	
	2.54×10^{-8}	
Reduced modified proctor	1.87×10^{-8}	2.60×10^{-8}
	2.25×10^{-8}	
	3.69×10^{-8}	
Modified proctor	9.08×10^{-9}	8.67×10^{-9}
	8.35×10^{-9}	
	8.58×10^{-9}	

Variation of MDD with bentonite content

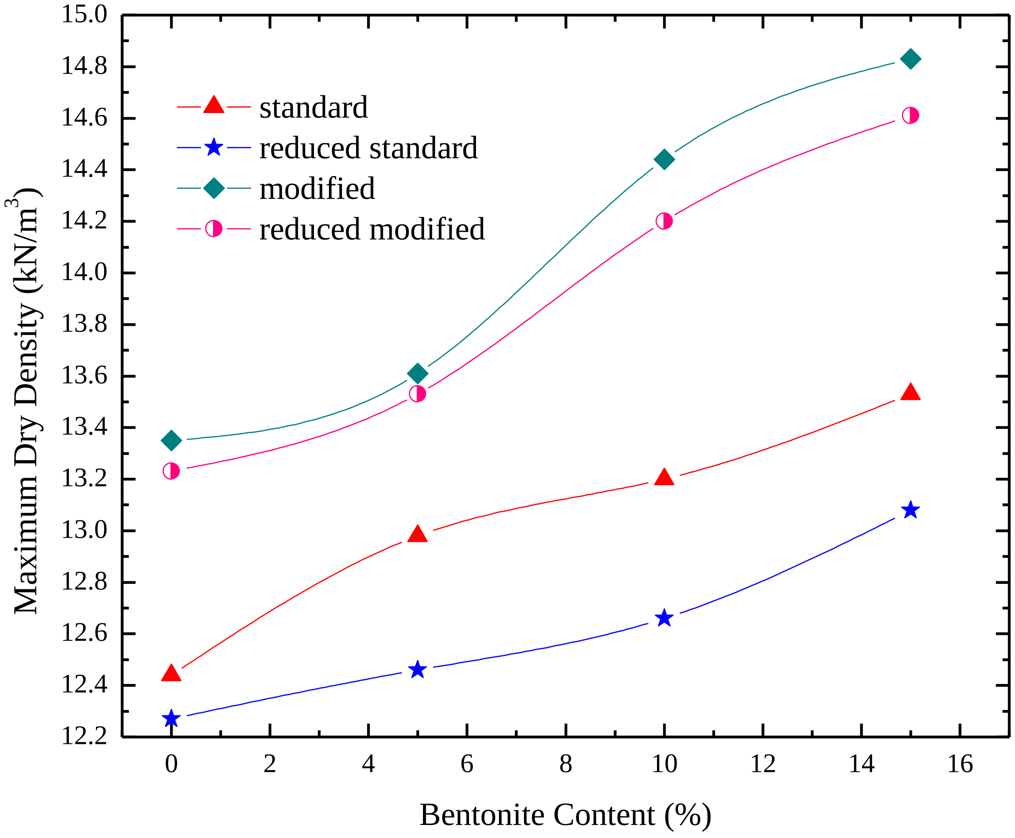

Fig 6. Variation of MDD with bentonite content

Fig above shows that the increase of bentonite content in fly ash-bentonite mixtures increases the maximum dry density (MDD) for all compaction efforts.

Variation of OMC with bentonite content

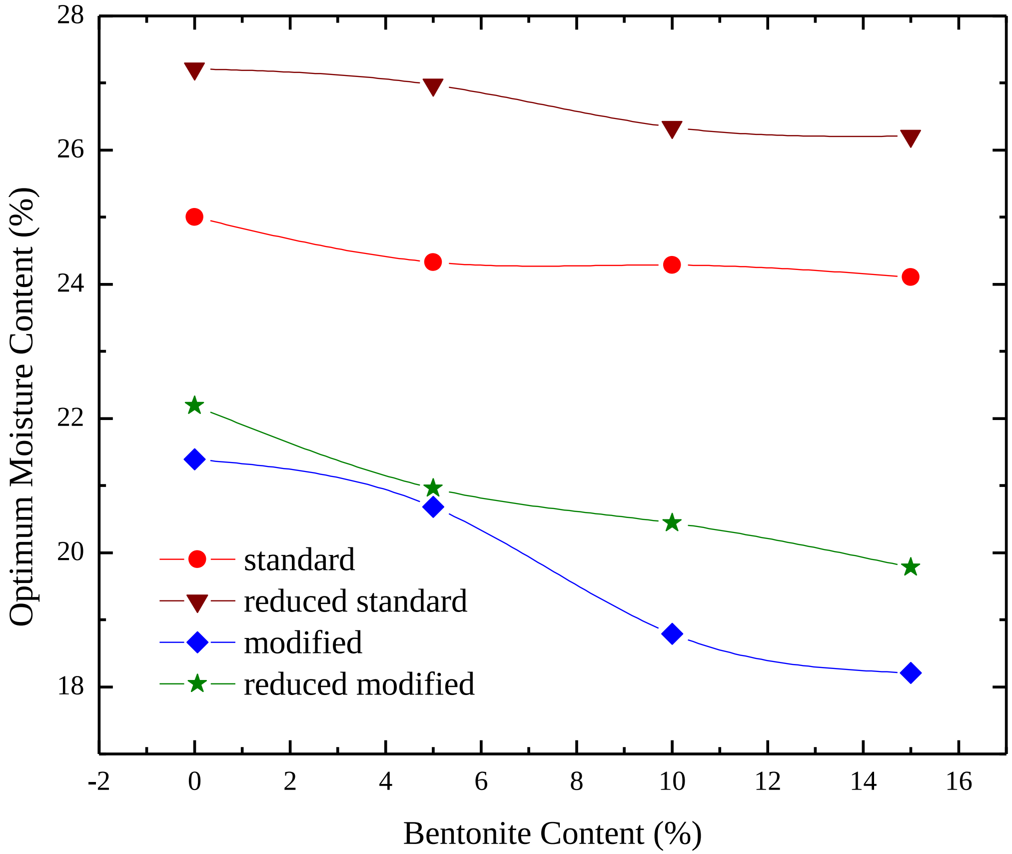

Fig 6. Variation of OMC with bentonite content

Fig above shows that the optimum moisture content of fly ash-bentonite mixtures decreased with an increase in bentonite content for all compaction efforts.

Variation of hydraulic conductivity (k) with bentonite content

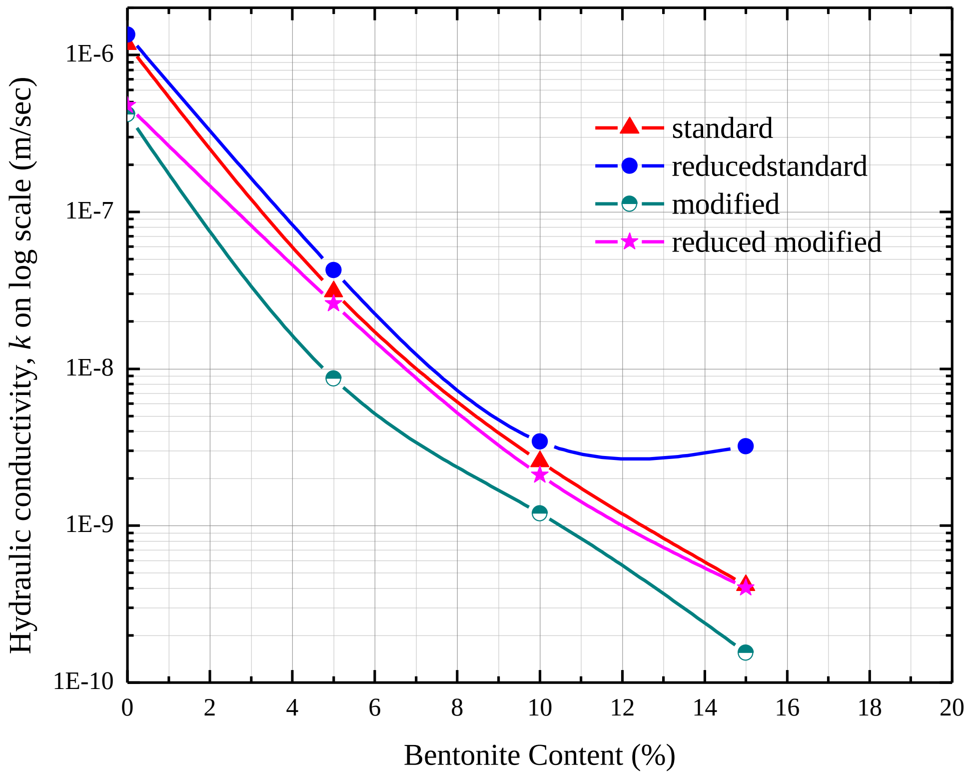

Fig 7. Variation of coefficient of permeability (k) with bentonite content

Fig shows that increase of bentonite content in compacted fly ash-bentonite mixes decreased their hydraulic conductivity. Bentonite being an extremely low hydraulic conducting soil (with permeability, k ranging from 1×10^{-12} to 1×10^{-14} m/sec) when comes in contact with water, swells and fills the interconnected voids thus, reducing hydraulic conductivity of fly ash-bentonite mixtures.

Strength characteristics of fly ash-bentonite mixtures

To determine the effect of bentonite content and compaction effort on the unconfined compressive strength of fly ash-bentonite mixes, cylindrical samples are prepared at 5%, 10% and 15% bentonite content compacted at OMC and MDD obtained through different compaction efforts such as reduced standard Proctor (355 kJ/m^3), standard Proctor (592 kJ/m^3), reduced modified Proctor (1296 kJ/m^3) and modified Proctor (2700 kJ/m^3). The unconfined compressive strength tests were carried out as per IS 2720: (1991-Part 10) just after the samples are prepared.

Table-10 Summarized results of UCS values corresponding to different compaction efforts for fly ash and bentonite mixtures

Mix proportion	Compaction effort	UCS (MPa)
FA+B (85:15)	Reduced standard proctor	0.159
	Standard proctor	0.202
	Reduced modified proctor	0.255
	Modified proctor	0.273
FA+B (90:10)	Reduced standard proctor	0.081
	Standard proctor	0.125
	Reduced modified proctor	0.134
	Modified proctor	0.195
FA+B (95:5)	Reduced standard proctor	0.072
	Standard proctor	0.080
	Reduced modified proctor	0.090
	Modified proctor	0.134

Variation of UCS with bentonite content and compaction energy

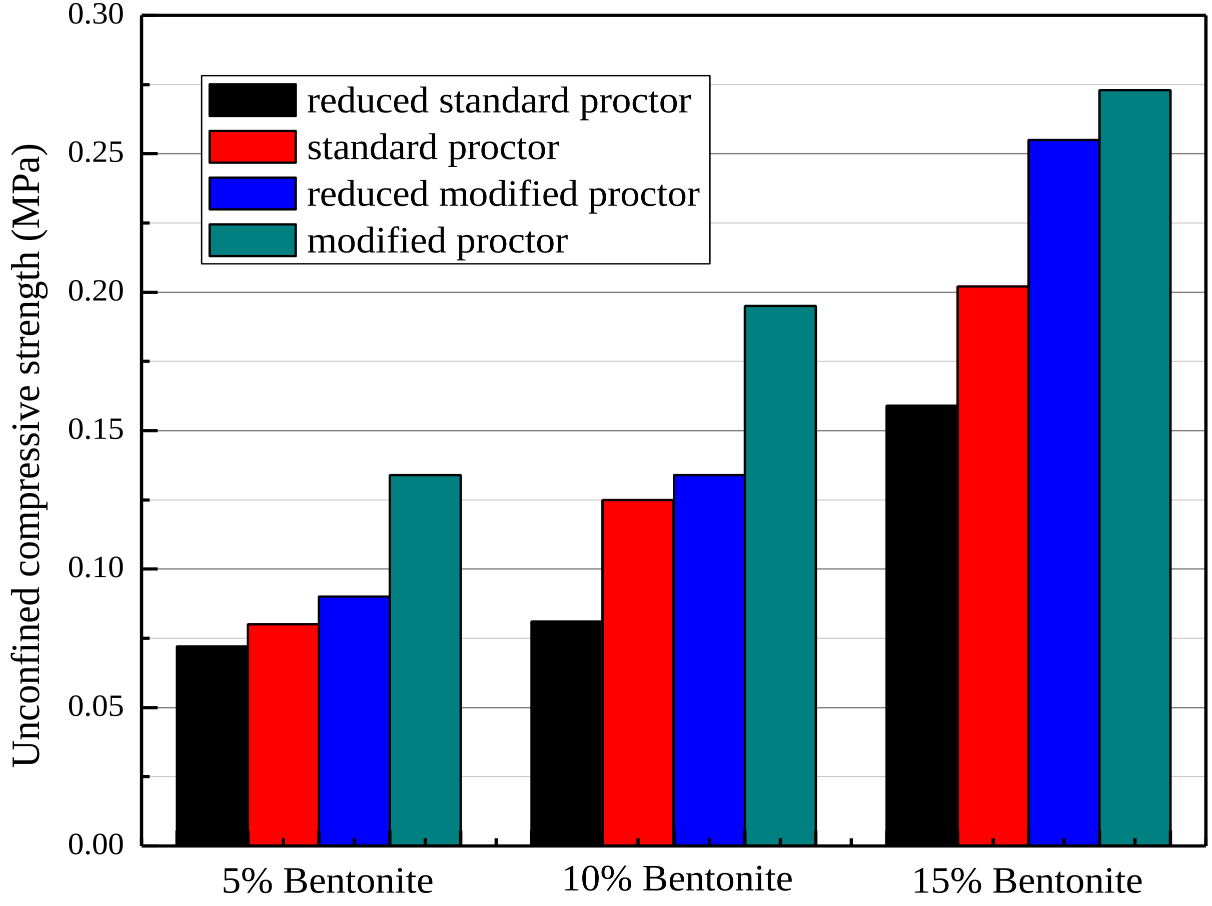

Fig 8. Variation of UCS with bentonite content and compaction energy

Conclusions

Feasibility of fly ash-bentonite mixture as an alternate liner material was investigated in this research work.

On the basis of experimental results based on hydraulic conductivity ($k \leq 10^{-9}$ m/sec), unconfined compressive strength ($\sigma >$ 0.2 MPa), plasticity characteristics (LL $\geq$ 20% and PI $\geq$ 7%), shrinkage characteristics and swelling characteristics, the following fly ash-bentonite mixtures were suggested for hydraulic barrier in waste containment system. They are:

- FA+B (85+15) mixture compacted under modified Proctor compaction
- FA+B (85+15) mixture compacted under reduced modified Proctor compaction
- FA+B (85+15) mixture compacted under standard Proctor compaction..

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Thank you...