Optimized Design Aspects of Low-Volume Traffic Roads on Expansive Soil Stabilized with Fly Ash

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Abstract:- A significant portion of villages in India has been built with water-bound macadam (WBM) or bituminous roads. Rural roads typically experience low traffic volume, usually less than 0.50 MSA, primarily consisting of light transport vehicles with infrequent heavy traffic. If a pavement is constructed over a weak subgrade soil, such as expansive soil, and is unable to sustain the prevailing traffic load, it could lead to various issues and pavement failures. Maintenance of these roads is often neglected due to limited budgetary allocations, leading to deterioration of the road assets. There is an urgent need to examine alternative pavement designs to construct sustainable, enduring rural road infrastructure. In this research, a traffic survey was conducted between Undargaon–Wakav-Londhewadi village road block Madha, district Solapur, Maharashtra, India, to assess the traffic count of three days by an automatic traffic count classifier (ATCC). This research explores the strength characteristics of expansive soil near Undargaon–Wakav-Londhewadi village road block in the Madha, district of Solapur, Maharashtra, India. Fly ash utilized in this research was sourced from coal fired facility operated by National Thermal Power Corporation Ltd. (NTPC) in Solapur, Maharashtra, India. This study assessed the impacts of fly ash on the index properties and strength-related parameters of soil, including an unconfined compressive strength (UCS) and california bearing ratio (CBR). Tests were executed using expansive soil blended with varying proportions of fly ash in increments of 10%, ranging from 0% to 50% by weight. The findings indicate that incorporating 20% fly ash markedly enhanced the engineering behaviour of the expansive soil. UCS and CBR values improved by approximately 2.98 and 3.92 times, respectively, compared with untreated soil. Overall, the inclusion of fly ash produced favourable outcomes by strengthening the soil and allowing a reduction in pavement thickness by about 1.46 times relative to the natural soil condition. The study determines that fly ash as an effective additive is suitable for road construction, particularly in rural areas. The development of predictive systems using linear regression and nomographs based on the study results delivers practical tools for field engineers to guide road construction projects.

Keywords*: CBR, UCS, NTPCL, ATCC, ADT, AADT, VDF and ESAL.*

1. Introduction

Expansive soils in India enhance agricultural productivity but pose significant challenges for civil engineering projects. These soils expand during the rainy season, leading to heaving and reduced strength, and contract during dry periods, which can cause structural damage. Expansive soil is widely distributed across the country (Anandet et al. 2021) and is estimated to occupy nearly 10 to 20 percent of the total land area (Shukla et al. 2011). Such soils are commonly found in regions including Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, and Madhya Pradesh (Chitragar et al. 2021). Their pronounced swelling and shrinkage behavior (Srikanth et al 2021) creates serious concerns for road construction, particularly because the bearing capacity of the subgrade becomes extremely low under wet conditions (Amadi and Osu 2018). Soil stabilization improves engineering performance by

increasing strength, minimizing volume changes caused by swelling, enhancing durability. limiting erosion, and reducing overall costs (Patil 2013; Habal et al. 2013). Stabilized soils often out perform untreated soils, and previous studies indicate that stabilization can help decrease pavement thickness while extending service life (Patil 2013). In India, low volume roads include feeder routes connected to national and state highways, village access roads, and roads linking nearby markets. They also extend to cross routes in hilly and desert areas, as well as roads constructed along riverbanks, canal banks, and boundary embankments. Traffic on these roads is generally light, typically below 300 motorized vehicles per day with farm tractors and light commercial vehicles forming the majority and heavy vehicles appearing infrequently low volume roads typically have several distinguishing characteristics.(i) they are often constructed using locally available materials that may be nonstandard and moisture sensitive, (ii) their deterioration is largely governed by environmental conditions, and (iii) the alignment may not always be fully engineered, especially where traffic demand is minimal. resulting in routes that frequently follow existing paths. For roads carrying less than 0.50 MSA, environmental influences tend to contribute more to pavement deterioration than traffic loads, with moisture variations in pavement layers and subgrade playing a critical role. Consequently, there is a need to develop improved specifications and technologies for both new alignment construction and the upgradation of original roads to achieve longer lasting performance at a reasonable cost. Adopting sustainable practices can support the development of solutions that are both economical and environmentally responsible. For low volume roads built on expansive soils, incorporating industrial by-products such as fly ash can be an high-efficiency strategy. This arrangement not only strengthens soil performance but also supports to the beneficial reuse of industrial waste. The present study therefore concentrates on enhancing the strength behavior of expansive soil obtained near the Undargaon-Wakav-Londhewadı village road in block Madha, Solapur district, Maharashtra, India. The soil is proposed for subgrade use and is stabilized with locally available fly ash sourced from a coal fired facility operated by National Thermal Power Corporation Ltd. (NTPC) in Solapur, Maharashtra, India. This method aims to facilitate the construction of more durable low volume roads at reduced cost while maintaining satisfactory serviceability.

The study is designed with the following objectives:

• To examine the characteristic of expansive soil and determine the most effective mix with fly ash.
• To study the optimum design aspects of low-volume roads on expansive soil stabilized with fly ash.
• To establish the correlation between different parameters, which can be useful for road engineers.
• To develop nomographs for road design parameters, i.e., soil strength properties.

2. Literature Review

Stabilization is a cost-effective technique used to improve expansive soil so that it becomes suitable for road construction. A detailed review of previous research related to this topic is summarized in the table below.

Table No.1: Comprehensive Study

Sr. No.	Waste Categories	Tests	Results	References
1	Class-C fly ashes	SP	A reduction of 75 % in SP was observed after 7 days of curing, which increased to 79 % after curing period of 28days	Cocka (2001)
2	Class-F fly ashes	CBR	The inclusion of 20% fly ash resulted in a 200 percent increase in the CBR value.	Pandian et al. (2001)
3	Fly ash & Lime	SP, OMC, MDD and CBR	SP, MDD reduced and OMC, CBR increased	Zhang Ji-ru et al. (2002)

4	Class-F fly ashes	PI, SP, MDD, K and penetration resistance.	The values of Permeability (K), PI, SP, MDD decreased, while penetration resistance increased.	Phanikumar et al. (2004)
5	Expansive soil	FSR	FSR identifies clay mineralogy and degree of expansivity of fine grained soil.	K. Prakash et al. (2004)
6	Expansive soil	OMC and MDD	Mini compaction apparatus designed to find OMC and MDD of fine grained soil finer than 2.0 mm.	A Sridharan et al. (2005)
7	Fly ash	SP, UCS	SP decreased and UCS increased significantly after 7 days curing	Fusheng zha et al. (2008)
8	Fly ash & Lime	CBR	It's noticed that adding 30% fly ash and 3% lime showed increased in CBR value by 55.80%	Niroj Kumar Mishra (2012)

3. Material and Methodology

3.1 Expansive Soil:

For this research, expansive soil was collected from pilot field site located Undargaon-Wakav-Londhewadi village road, block Madha, district Solapur, State Maharashtra, India. The sample was collected using disturbed-sampling techniques after stripping the upper layer of soil at a depth of about 500 mm. It was then sealed in moisture-proof sacks and transferred to the testing facility i.e. PMGSY District Laboratory Chiplun in Ratnagiri district, Maharashtra, India. Before testing, the soil specimens underwent air-drying and pulverization, followed by screening through a 4.75 mm IS sieve to prepare it for laboratory analysis.

3.2 Fly Ash:

Fly ash is an inorganic, economical and environmentally friendly material commonly used for soil stabilization to strengthens durability and cost efficiency. For this research, fly ash was sourced form a coal fired facility operated by National Thermal Power Corporation Ltd. (NTPC) in Solapur, Maharashtra, India. Both the expansive soil & fly ash samples were cleaned to remove impurities such as vegetation, stones and organic matter and were then thermally dried for approximately 24 hours. Fly ash was integrated into the soil matrix at varying weight-based percentages, and the mixtures were prepared manually before conducting the laboratory tests using established procedures.

Fig 1. Mixing Expansive Soil with Fly Ash

Geotechnical attributes of untreated swelling soil are reported in table-2. The clay and silt content in the soil were observed to be 54.30 percent and 32.20 percent, respectively. The LL of the soil was found 59.50 percent using the Casagrande apparatus, and a plasticity index of 28.91percent suggests that the soil has high plasticity. The

soil's 10.00 percent shrinkage limit confirms that it is of poor quality. The soaked CBR of the expansive soil is 1.36 percent, which is unsuitable for road construction, and this soil requires modification or stabilization.

Table No.2 Geo-technical properties

Sr. No.	Soil Properties	Symbol	Results (%)	Test Method
1.	Gravel	G	0.80	IS2720 (Part 4) 1985
2.	Sand	S	12.70	
3.	Silt	Silt	32.20	
4.	Clay	clay	54.30	
5.	Liquid Limit	LL	59.50	IS2720 (Part 5) 1985
6.	Plastic Limit	PL	30.59	
7.	Plasticity Index	PI	28.91	
8.	Shrinkage Limit	SL	10.00	IS2720 (Part 6) 1972
9.	IS soil Classification system	-	CH	IS 1498 1970
10.	Specific gravity	G	2.27	IS2720 (Part 3) 1980
11.	Free Swell Index	FSI	100.00	IS 2720 (Part 40) 1977
12.	Free Swell Ratio	FSR	2.00	
13.	Optimum Moisture Content	OMC	24.742	IS 2720 (Part 7) 1980
14.	Maximum Dry Density	MDD	14.610 KPa	
15.	Colour	-	Dark Black	
16.	Principal Clay Mineral	-	Montmorillonite	
17.	PH Value	-	8.29	
18.	CBR Value (Soaked)	-	1.36%	IS 2720 (Part 16) 1987
19.	CBR Value (Un-Soaked)	-	3.07%	
20.	UCS Value	-	0.138 MPa	IS 2720 (Part 10) 1991

Fly ash was incorporated into the expansive soil at dosages spanning 0% to 50% by weight. Both untreated and treated samples were evaluated through preliminary and performance-based laboratory tests. These included consistency limits, free swelling index, free swell ratio, moisture-density relationship (MDR), unconfined compressive strength (UCS), California bearing ratio (CBR).

3.3 Free Swell Ratio (FSR):
Advance techniques such as X-ray diffraction (XRD), differential thermal analysis (DTA), and electron-based microscopy rely on complex and specialize instruments. FSR is an indirect, simple, and user-friendly approach for approximately predicting the clay mineralogy and degree of expansivity of fine-grained soils. It also overcomes the negative free swell indices (A. Sridharan et al. 2004). The procedure adopted to obtain FSR is as follows.

- Following thermal drying, the soil was processed through a 425 μm IS sieve to isolate a 10 g representative sample. Mix it thoroughly with distilled water to prepare a soil water suspension having an initial volume of 100 ml in a graduated jar. Allow the suspension to stand undisturbed for about 24 hours until a state of stability is attained, and then record the settle soil volume, denoted as Vd.
- Repeat the procedure using carbon tetrachloride or kerosene instead of water to form a soil liquid suspension of the same initial volume. After 24 hours of standing, measure the equilibrium sediment volume, referred to as Vk.
- The free swell ratio is obtained by dividing Vd by Vk

$$FSR = \frac{Vd}{Vk}$$

- The soil is identified as kaolinitic when the FSR is less than 1.0 and as montmorillonitic when the FSR is greater than 1.50.
- If FSR located between 1.0 and 1.50, the soil specimen falls under the category of a mixed clay mineral type, indicating a combination of kaolinite and montmorillonite.

3.4 Moisture-Density Relationship Test:
The dynamics between moisture content & maximum dry density (MDD) was studied for both untreated soil & treated soil samples using a mini compaction apparatus. This testing method, developed specifically for fine

grained soils, has been reported by Sridharan and Shivapullaiah (Sridharan et al. 2005). Compared to the standard Proctor test, the mini compaction method requires nearly one tenth of the soil quantity, approximately 200 g, and significantly reduces testing time and effort. The experiment setup consists of a steel mould, base plate, detachable collar, and a steel drop hammer with a guiding frame. The mould has an inner diameter of 38.10 mm, an external diameter of 46.10 mm, and a height of 100 mm. The same mould was also used to prepare soil for the unconfined compressive strength (UCS) tests carried out in this study.
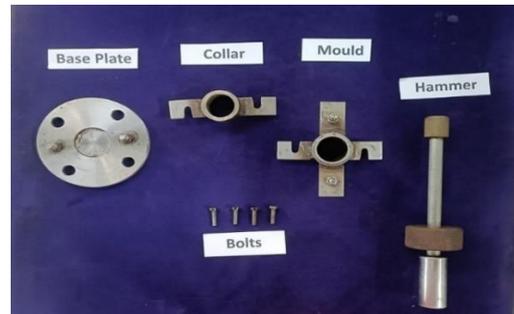
Fig 2. Mini compaction apparatus

3.5 California Bearing Ratio (CBR):

The CBR value of subgrade soil specimen is considered as a major performance-indicative characteristics. The CBR test on different fly ash mixtures was executed as per IS: 2720 (Part 16) -1987. After compaction, the stabilized samples were cured at 95-100% for 7 days at room temperature. Subsequently, the soil sample was soaked in water for 96 hours. Additionally, the CBR test was performed using uniformed penetration rate of 1.25 mm/min.

3.6 Unconfined Compressive Strength (UCS):

Unconfined compressive strength (UCS) test is commonly applied to quickly evaluate compressive strength of cohesive soil specimen. The procedure was carried out following IS 2720 (Part 10):1991 guidelines. UCS represents the stress level at which a cylindrical soil sample fails under axial loading without lateral confinement. This method is widely adopted for estimating the strength of stabilized soils. A constant deformation rate of 1% per minute was maintained for all strain-controlled tests in this study.

4. Pavement Design

4.1 Design Process :

When developing an effective and cost efficient pavement design for LVR, priority must be given to estimating traffic level intensity, assessing subgrade strength in the form of CBR value and planning the design accordingly.

- **Estimation of traffic:** When a road is not yet in place, traffic over the design period can not be determined directly through traffic counts. In such situations, it is practical to collect traffic data from an existing road nearby that has comparable conditions. Using observations from a route that serves a known population and supports measurable agricultural or industrial activity, the anticipated traffic for the proposed road can be estimated.
- **Assessment of subgrade strength:** A proper evaluation of subgrade strength requires a systematic soil investigation, including the collection of representative samples and their testing for standard IS classification, compaction characteristics and CBR values. Similar to conventional pavements, the subgrade of rural roads is assessed using CBR as per MoRD guidelines. The subgrade generally consists of a compacted layer of locally available natural soil, typically about 300 mm thick for LVR, placed directly below the road crust and formed from in-situ material.
- **Traffic Parameters:** Rural road design traffic is quantified by the total volume of standard axle passes anticipated throughout the service life of the pavement. Prescribed relationship for the total number of standard axle load applications are as below.

$N = T_0 * 365 * [((1+0.01r)^n -1) / (0.01\ r)]*L$

Where, r = Traffic growth rate at 6%, for rural roads
T_0 = ESAL per day = (Number of CVPD * VDF)

L = Lane distribution factor (1 for single lane)

n = Design life (10 years, for rural roads)

Table No. 3 Group of traffic as specified in IRC:SP:72-2015.

Traffic Categories	Cumulative ESAL Applications in MSA
T_1	0.01-0.03
T_2	0.03-0.06
T_3	0.06-0.10
T_4	0.10-0.20
T_5	0.20-0.30
T_6	0.30-0.60
T_7	0.60-1.00
T_8	1.00-1.50
T_9	1.50-2.00

In this research, a traffic survey was conducted for Undargaon-Wakav-Londhewadi village road block, Madha, district Solapur, Maharashtra, India, to obtain a realistic estimate of traffic count with an automatic traffic count classifier(ATCC) located at Wakav village.

Fig 3. ATCC Camera location at Wakav village

Determination of Pavement Thickness: A detailed field investigation and laboratory testing program should be carried out on representative material samples to ensure effective use of locally available resources for sub-base, base and surface layers through appropriate blending. Based on the selected design traffic values and evaluated subgrade strength, in the form of CBR value required road layer thicknesses and material composition can be established in accordance with road design guidelines for gravel, sub-base and base layers as per guidelines of IRC:SP:72-2015.

Table No. 4 Design catalogues

Pavement Composition:

Subgrade – Earth soil.
Sub-base – Modified soil or Murum.
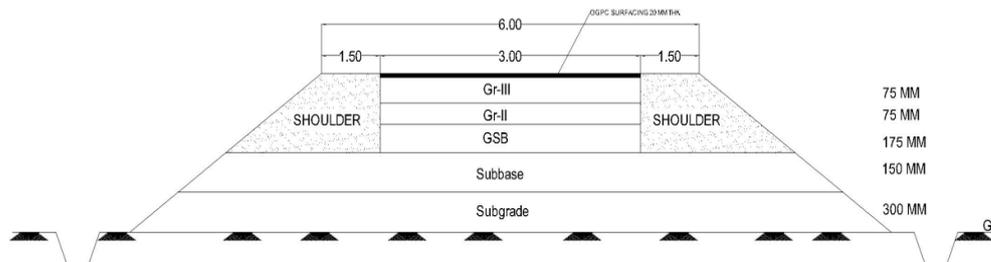Base course – GSB, Gr-II, Gr-III.
Surfacing – OGPC and Seal Coat.

Fig 4. General C/S of a Rural Road

4.2 Pavement Design:

Assumptions

- The low volume road is designed in accordance with IRC: SP:72-2015 guidelines.
- Subgrade strength is determined using the four days soaked CBR value.
- Design life of pavement is considered to be 10 years.
- A uniform annual traffic growth rate of 6 percent is assumed throughout the design period.
- Traffic count conducted for a period of 3 days with ATCC in both directions.
- Correction factor = 1.0 for iron rimmed carts.
- AADT considers two non-harvesting seasons of 2.5 months, t = 75 days.
- Time periods between the last count and the year of road opening to the traffic are two years, i.e., n = 2.
- ADT for peak harvesting season is double that of ADT for lean season (Non-harvesting season) n = 1.

Table No. 5: Summary of 3-days traffic count

| Name of Work: -Traffic Count Study for pilot field experimentation between Undargaon-Wakav-Londhewadi village road. (Location – Wakav)																Total
Day	Vehicle Class															
	Cars, Jeeps, Vans, Three wheelers	Motorised two-wheelers	Commercial vehicles										Cycles	Cycle Rick shaws	Animal-drawn Vehicles	
			LCV	Trucks			Agricultural Tractors/Trailers			Buses					SWC	Num tyres
				L	U	OL	L	U	OL	L	U	OL				
Day1	10	397	14	0	0	0	5	5	0	0	0	0	19	0	0	0	450
Day2	6	346	9	0	0	0	8	8	0	0	0	0	10	0	0	0	387
Day3	6	388	9	0	0	0	5	5	0	0	0	0	10	0	0	0	423
Average Daily Traffic (ADT)	7	377	11	0	0	0	3	6	3	0	0	0	13	0	0	0	420
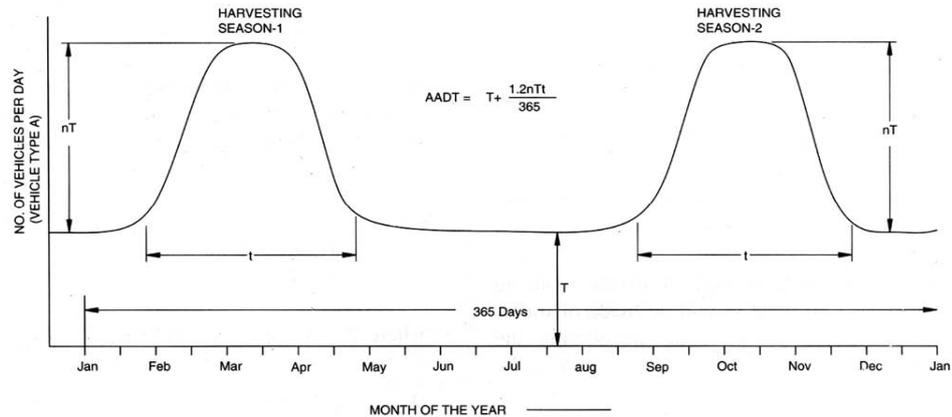
Fig 5. Rural Traffic Seasonal Variation

Estimation of ADT (average daily traffic) :
For Non-Harvesting season = 420/2 = 210

Correction Factor = 1.00
ADT = Total ADT* Corr. Factor
ADT = 210

Estimation of AADT (average annual daily traffic) **:**

AADT during the non-harvesting season
AADT = T + 1.2nTt/365
AADT = T_0 = 262
T_0 = Traffic in the zero year

AADT before commencement of traffic flow
AADT = Tn = T0 $(1+ r)^n$
Tn = Traffic in the nth year
AADT = 294

Estimation of CVPD:
Total avg. Heavy commercial vehicle per day HCV = No. of trucks + No. of Buses
HCV (loaded) = 0.00   HCV (Unloaded) = 0.00   HCV (Overloaded) = 0.00
Total avg. medium commercial vehicle per day MCV = No of MCV + Agr. Tractors/Trailers
MCV (loaded) = 18   MCV (loaded) = 3   MCV (Overloaded) = 3
MCV (Unloaded) = 6

Table No. 6 – Effective estimation of HCV and MCV

HCV (loaded) = 0		HCV (Unloaded) = 0	HCV (Overloaded) = 0	
MCV (loaded) = $\frac{294 \times 18}{420}$ = 12.60 say 13			MCV (loaded) = $\frac{294 \times 3}{420}$ = 2.10 say 2	
MCV (overloaded) = $\frac{294 \times 3}{420}$ = 2.10 say 2			MCV (unloaded) = $\frac{294 \times 6}{420}$ = 4.20 say 4	
MCV (loaded) = 13	MCV (loaded) = 2		MCV (Overloaded) = 2	MCV (unloaded) = 4

CVPD = $\frac{13+2+2+4}{2}$ = 10.50 say 11

Estimation of VDF:

VDF = 2.58 * Laden HCV + 0.31 * Unladen HCV + 2.86 * Overladen HCV + 0.31 * Laden MCV + 0.019 * Unladen MCV + 0.344 * Overladen MCV

VDF = 2.58 * 0.0 + 0.31* 0.0 + 2.86 * 0.0 + 0.31 * 13 + 0.019 * 2 + 0.344 * 2
VDF = 4.75

Cumulative ESAL application:
Considering the growth rate as r = 6%
And design the life of the road as 10 years, n = 10
This is a single lane road of 3.0 m carriage way, L = 1
$N = T_0 * 365* [((1+0.01r)^n -1) / (0.01 r)] * L$
T_0 = ESAL per day (Number of CVPD * VDF)
$N = 11 * 4.75 * 365* [((1+0.01 * 6)^{10} - 1) / (0.01 * 6)] * 1$
N = 11 * 4.75 * 365 * 13.18
N = 251359
ESAL = 251359 (0.251 MSA)
Group of traffic for the above ESAL, as per guidelines of IRC: SP:72-2015, is T5

Pavement composition for group of traffic T5 and soil subgrade strength,
Expansive soil CBR = 1.36% says 2.00%

Table No.7 - Design Summary

Sr. No.	Description	CBR value (%)	Group of traffic	Pavement Composition
1	ES	2.00	T 5	Sub-base course = 150 mm, Base course: GSB = 175mm, G-II = 75mm, G-III = 75mm
2	ES + 20% FA	5.33	T 5	Base course: GSB = 175mm, G-II = 75mm, G-III = 75mm

5. Results and Discussion

5.1 Effects on OMC and MDD: The relationship between dry density and moisture content at varying percentages of fly ash is shown in Table 8.

Table No. 8 Expansive soil parameters for different percentages of fly ash.

Sample	L.L. %	P.L. %	P.I. %	S.L. %	Sp. Gr. %	F.S.I. %	F.S.R. %	OMC %	MDD (KPa)	CBR %			UCS	
										Soaked	% Increase	UCS (MPa)	% Increase	
ES	59.50	30.59	28.91	10.00	2.27	100.00	2.00	24.742	14.610	1.36	---	0.138	---	
ES+10% FA	53.36	37.87	15.49	47.28	1.97	54.55	1.54	25.000	13.818	4.91	261.02	0.380	175.36	
ES+20% FA	52.24	34.69	17.55	47.81	1.99	50.00	1.50	22.368	14.820	5.33	291.91	0.412	198.55	
ES+30% FA	39.00	27.46	11.54	43.32	2.02	60.00	1.60	26.410	13.994	4.72	247.05	0.353	155.80	
ES+40% FA	36.40	27.65	8.75	36.95	1.96	68.42	1.68	28.333	13.533	3.70	172.05	0.322	133.33	
ES+50% FA	33.00	27.17	5.83	33.73	1.98	70.00	1.70	29.353	13.465	3.16	132.35	0.264	91.30	

OMC increases with an rise in dosage of fly ash. Although the MDD decreases with the addition of fly ashes, because fly ashes are a low-density material in loose condition, adding them to the expansive soil will minimizes the overall density of the soil, which makes it highly desirable for subgrade constructions of roads.

5.2 Effect on California Bearing Ratio (CBR): It is desirable to provide better support to different structural layers of pavement over subgrade. However, with the inclusion of fly ash, significant improvements in CBR value were achieved. The unstabilized expansive soil had a CBR value of 1.36%, & the CBR value of the expansive soil after treatment elevated by 3.92 times that of virgin soil with the addition of 20% fly ash. Overall, it may be concluded that fly ash addition may significantly improve the CBR value of low-plasticity soil, thereby enhancing the shear strength of subgrade soil.

5.3 Effect on Unconfined compressive strength (UCS): The inclusion 20% of fly ash content leads to an increase in the UCS value by 0.412 MPa, and 2.98 times more than that of untreated expansive soil. This improvement highlights the suitability of fly ash for enhancing expansive soil properties. The failure pattern observed after testing is presented in Fig.7, where cracks were seen progressing from the base toward the top of the specimen during loading.

Fig 6. UCS testing in progress.

Fig 7. UCS specimens after failure (i) 0% FA (ii) 10% FA (iii) 20% FA (iv) 30% FA (v) 40% FA (vi) 50% FA

5.4 Comparative Analysis of Unstabilized and Stabilized Expansive Soil:
Table 9 compares the geotechnical attributes of expansive soil and expansive soil stabilized with 20% fly ash.

Table No. 9. Comparative analysis of the soil properties

Sr. No.	Property	Symbol	Unstabilized Expansive Soil	Stabilized Expansive Soil with 20 % Fly Ash
1.	Liquid Limit	LL	59.50 %	52.24 %
2.	Plastic Limit	PL	30.59 %	34.69 %
3.	Plasticity Limit	PI	28.91 %	17.55 %
4.	Shrinkage Limit	SL	10.00 %	47.81 %
5.	Specific Gravity	G	2.27	1.99
6.	Free Swell Index	FSI	100.00 %	50.00 %
6.	Free Swell Ratio	FSR	2.00	1.50
7.	Optimum Moisture Content	OMC	24.742 %	22.368%
8.	Maximum Dry Density	MDD	14.610 KPa	14.820 KPa
9.	Soaked CBR	CBR	1.36 %	5.33 %

10.	Unconfined Compressive Strength	UCS	0.138 MPa	0.412 MPa
11.	Group of traffic as per IRC:SP:72 2015	T5	0.251 msa	0.251 msa
12.	Road crust thickness as per IRC:SP:72 2015	Curst thickness	475 mm	325 mm

The LL of the expansive soil decreased from 59.50 percent to 52.24 percent after adding of 20 percent fly ash, representing a decrease of about 12.20 percent.

- The plastic limit increased by 13.40 percent after incorporation of 20 percent fly ash suggesting a shift in the soil mixture towards a semi-solid condition.
- The plasticity index also declined to 39.29 percent following fly ash treatment, indicating that the soil exhibits medium plasticity.
- The OMC of unstabilized expansive soil was found to 24.742 percent, but this decreased to 22.368 percent when 20 percent fly ash was added. The reduction in optimum moisture content is caused by finer fly ash particles filling voids more efficiently, reducing the water needed for compaction.
- The MDD was found to be 14.820 KPa and increased by 1.44 percent after inclusion of 20 percent fly ash.
- The free swell ratio lowered by 25 percent when 20 percent fly ash was added. This decrease in FSR indicates a low degree of soil expansivity.
- The soaked CBR and UCS values increased by 291.91 percent and 198.55 percent, respectively, when 20 percent fly ash was added, compared with the virgin expansive soil.
- Overall, the inclusion of fly ash was found to have an encouraging effect on improving strength and reducing the pavement thickness by 31.57 percent compared to virgin expansive soil.

5.5 Determination of Optimum Content of Fly Ash: This study suggests that the shrinkage limit (SL) can serve as an indicative parameter for determining the optimal fly ash percentage. In this study, the SL of expansive soil was 10 percent; however, it increased to 47.81percent when 20 percent of fly ash was added. Fly ash percentage yielding the maximum SL value can be considered the optimum percentage for an expansive soil mix.

6. Correlation between Performance Parameters

The correlation coefficient indicates how strongly two variables are linearly related. The correlation between different performance parameters, namely FA (%), LL, SL OMC, MDD, FSR, UCS, and CBR, was studied. These relationships can be useful for quickly estimating parameters in the design and evaluation of pavement sections. The correlations were developed for an expansive soil-fly ash mixture. The correlations between performance parameters for stabilized soils are shown in Tables 10 and 11. Overall, a good relationship was established among the performance parameters.

Table No. 10. correlation between FA (%), LL, OMC, and MDD

Parameters		Relationship	R^2
X	Y		
FA(%)	LL(%)	LL (%) = 59.628 – 0.562 * FA(%)	0.94
LL(%)	OMC(%)	OMC = 35.058 – 0.198 * LL(%)	0.71
OMC(%)	MDD(KPa)	MDD = 19.163 – 0.197 * OMC(%)	0.81

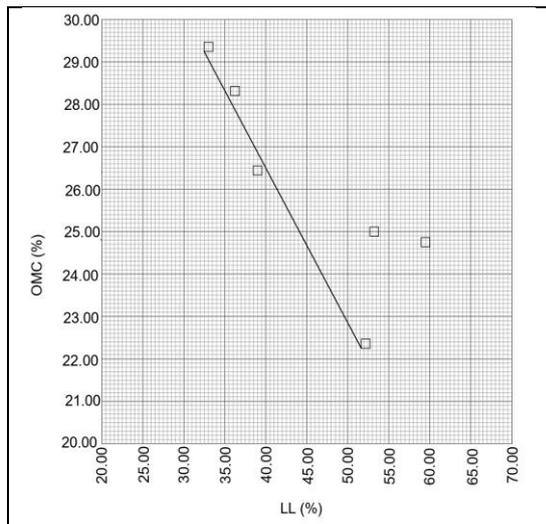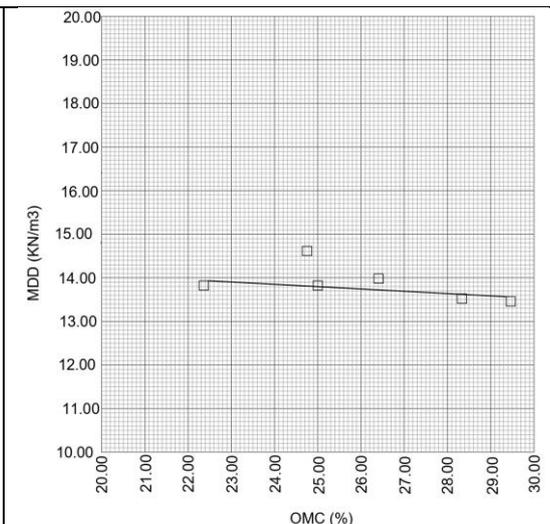| $y = 35.058 – 0.198\ x \quad r^2 = 0.71$	$y = 19.163 – 0.197\ x \quad r^2 = 0.81$

Fig 8. Correlation between LL and OMC

Fig 9. Correlation between OMC and MDD

Table No. 11. Correlation between FSR, SL, UCS, and CBR

Parameters		Relationship	R^2
X	Y		
FSR	SL(%)	SL (%) = 167.797 – 78.612 * FSR	0.99
FSR	UCS (MPa)	UCS = 1.221 – 0.545 * FSR	0.98
UCS	CBR (%)	CBR = 14.66 * UCS – 0.702	0.98

$y = 1.221 – 0.545\ x \quad r^2 = 0.98$
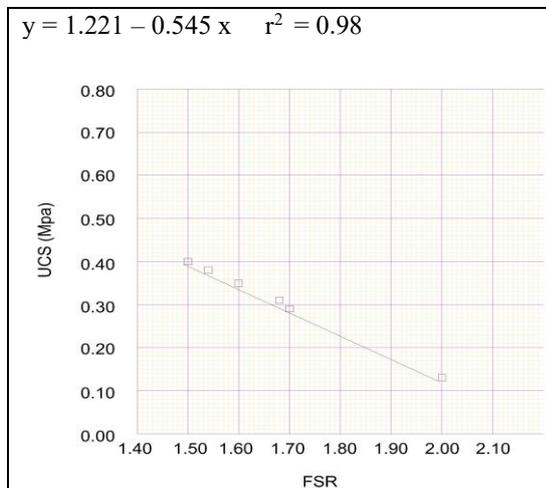
Fig 10. Correlation between FSR and UCS

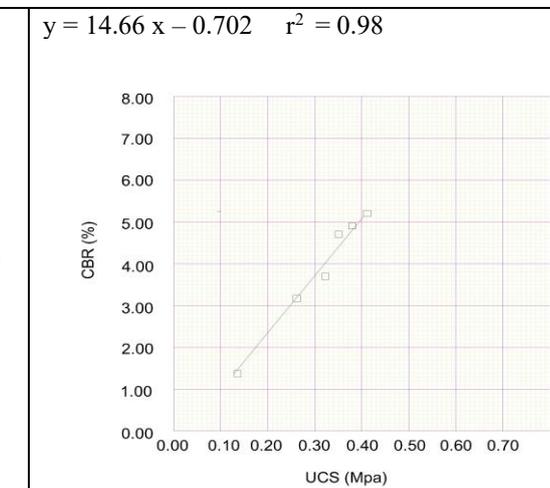$y = 14.66\ x – 0.702 \quad r^2 = 0.98$

Fig 11. Correlation between UCS and CBR

7. Development of Nomograph

The relationship between free swell ratio (FSR) and soil strength can be effectively illustrated through nomographs, as shown in Fig. 12. The nomograph for this study was prepared using AutoCAD. Separate scales were developed for each parameters, and the chart presents UCS and CBR values in relation to their corresponding FSR measurements. These nomographs provide a clear and user friendly way to interpret the connections among FSR, UCS and CBR as demonstrated by the index line.
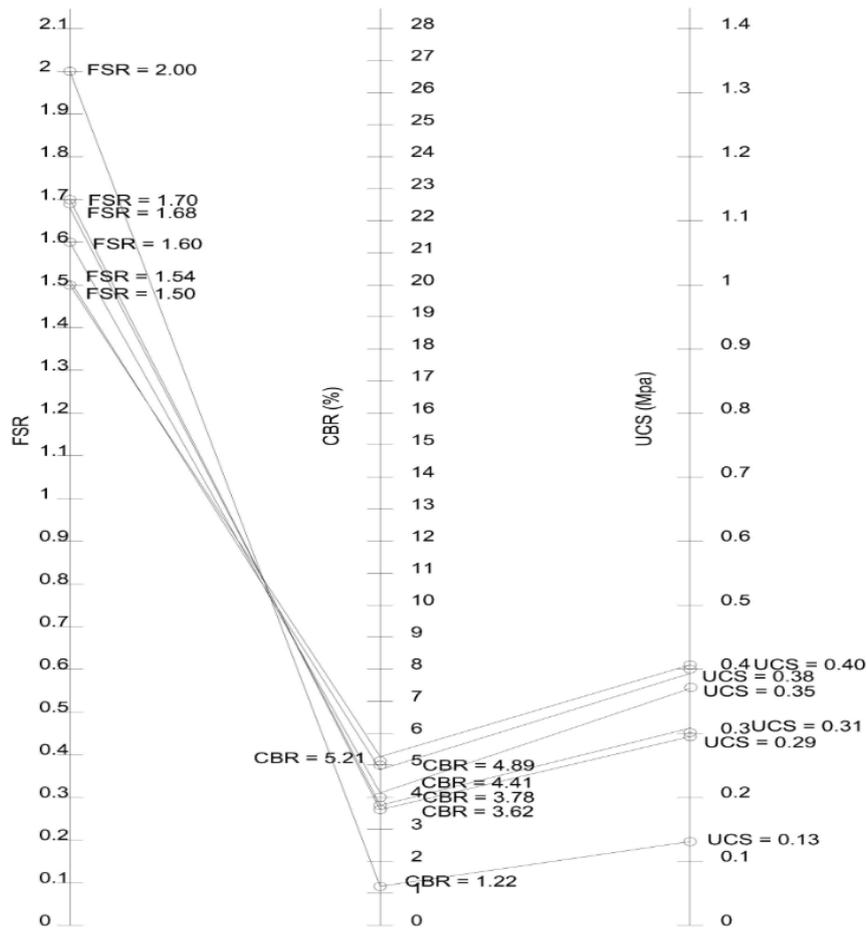
Fig 12. Nomographs of strength properties

8. Conclusion

The present study focused on assessing strength and pavement design parameters based on UCS - CBR and ESAL values. Key findings derived from this investigation are presented below.

- Fly ash is an inexpensive byproduct of coal fired facility, and its utilization minimizes environmental pollution.
- The results of variation in LL, PL, FSI, and FSR with variation in fly ash percent are consistent with those of variation in SL at the same fly ash percent.
- The fly ash percent yielding the maximum SL percent value can be considered as the ideal quantity of fly ash.
- Sufficient improvement in soil strength was obtained by incorporating 20 percent fly ash into the expansive soil.
- Accurate estimation of ESAL using an automatic traffic count classifier (ATCC) reduces pavement thickness by 31.57 percent. Hence, it optimizes the project cost.
- The UCS value is 0.412 MPa and is adequate for a fly ash-stabilized subgrade in a low-volume rural road, as the design traffic is less than 0.251 msa.
- A strong linear relationship was observed between index properties and soil strength parameters.
- Regression analysis showed that the linearity index (R^2) ranged between 0.71 to 0.99, demonstrating a strong linear relationship between the variables.
- Nomographs are easy and simple to estimate soil strength properties instantly.

Refrences

[1] Nelson, J., and Miller, D. J. (1997). Expansive soils: Problems and Practice in Foundation and Pavement Engineering.

[2] Cokca, E (2001), "Use of Class C fly ash for the stabilization of an expansive soil" ASCE Journal of Geotechnical and Geoenvironmental Engineering. Vol. 127, Issue 7, pp 568-573.

[3] Pandian, N.S., Krishna, K.C. and Sridharan, A.(2001) "California Bearing Ratio Behaviour of Soil/Fly ash Mixtures," Journal of Testing and Evaluation, 29(2) 220-226.

[4] Zhang Ji-ru and CAO Xing (2002) "Stabilization of Expansive soil by Lime and Fly ash", Journal of Wuhan University of Technology – Mater. Sci. Ed. Vol. 17, No. 4.

[5] Phanikumar, B.R. and Sharma, R.S. (2004) "Effect of Fly Ash on Engineering Properties of Expansive Soils", Journal of Geotechnical and Geo-environmental Engineering, 130(7), 764-767.

[6] K. Prakash and K. Sridharan (2004) "Free Swell Ratio and Clay Mineralogy of Fine-Grained Soils". Geotechnical testing journal. Vol. 27, No. 2.

[7] A. Sridharan and Shivapullaiah Puvvadi (2005) " Mini Compaction Test Apparatus for Fine Grained Soils", Geotechnical testing journal. Vol. 28, No. 3.

[8] Phanikumar, B.R. and Sharma, R.S. (2007) "Volume Change Behavior of Fly Ash-Stabilized Clays", Journal of Materials in Civil Engineering, 19(1):67-74.

[9] Fusheng Zha . Songyu Liu . Yanjun Du . Kerui Cui (2008) "Behavior of expansive soils stabilized with fly ash", Nat Hazards (2008) 47: 509-523.

[10] Er. Niroj Kumar Mishra, (2012) "Strength Characteristics of Clayey Sub-Grade Soil Stabilized with Fly Ash and Lime for Road Works", Indian GeoTech Journal (July-September 2012) 42(3): 206-211

[11] IRC:SP-72-2015 "Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads". June 2015

[12] Amadi, A. A., and Osu, A. S. (2018). Effect of Curing Time on Strength Development in Black Cotton Soil-Quarry Fines Composite Stabilized with Cement Kiln Dust (CKD). Journal of King Saud University-Engineering Sciences, 30(4), 305-312.

[13] IRC:SP-89(Part-II)-2018 "Guidelines for the Design of Stabilized Pavements"2018.

[14] Ikeagwuani, C. C., Obeta, I. N., and Agunwamba, J. C. (2019). Stabilization of Black Cotton Soil Subgrade Using Sawdust Ash and Lime. Soils and Foundations, 59(1), 162-

[15] Chitragar, S. F., Shivayogimath, C. B., and Mulangi, R.H. (2021). Study on Strength and Volume Change Behavior of Stabilized Black Cotton Soil with Different pH of Soil-Lime Mixes for Pavement Subgrade. International Journal of Pavement Research and Technology, 14(5), 543-548.

[16] B.A.Chethan, A.U.Ravi Shankar, (2021) "Strength and Durability Characteristics of Cement and Class F Fly Ash-Treated Black Cotton Soil", Indian GeoTech Journal (October 2021) 51(5): 1121-1133.