Laboratory Investigation of Cement Treated Bases (CTB) and Full-Depth Reclamation (FDR) Mixes.

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ABSTRACT

This study focuses on advancements in road construction technology that reduce aggregate usage, leading to cost savings and energy conservation. It proposes a new method for determining cement and fly ash percentages in stabilizing the base course. The use of Full Depth Reclamation (FDR) with chemical stabilizers enhances strength, reduces water permeability, and increases flexibility.

The study examines compaction, durability, and unconfined compressive strength (UCS) with different cement percentages and stabilizers in FDR. UCS increases with varying cement percentages in CTB but decreases with higher fly ash content and stabilizers in FDR. Durability tests show 5.80% mass loss in wetting-drying cycles of CTB.

Utilizing CTB as a base layer in flexible pavement construction improves cost-effectiveness, durability, and pavement strength. However, a thicker wearing course is required to prevent rutting and cracking. CTB implementation results in cost reductions of 24.48% for high-volume roads and 34.20% for low-volume roads, while incorporating FDR further reduces costs by 30.06% for low-volume roads as compared to conventional method.

In summary, this study explores advancements in road construction technology and highlights the benefits of CTB in flexible pavement construction. The findings emphasize the importance of thickness and demonstrate cost savings through CTB implementation and FDR application.

Keywords: Cement treated bases (CTB), Full-depth Reclamation (FDR), Flexible Pavement,Unconfined Compressive Strength (UCS), Durability.

1. INTRODUCTION

Pavement is a durable surface material that has been laid down in a location to carry vehicular or foot traffic. It is a hard surface. Its main purpose is to evenly disperse the imposed vehicle loads throughout the subgrade's various levels. Over the base and sub-base courses, there is a bituminous surface course. The layers of bituminous or Hot Mix Asphalt (HMA) may be present in the surface course. These pavements distort because of loads acting on them because they have very little flexure strength. A base and a sub-base course are placed over a bituminous surface course to create a standard flexible pavement.

In India, bituminous mix is used as a wearing course in the construction of maximum country's roadways. The granular layer, which is offered as a base layer in most of these roadways, requires a wearing course of a higher thickness to prevent road failure. The cost of building wearing course versus other flexible pavement layers varies significantly. Therefore, choosing a technique for the road's construction that would help reduce the thickness of various road layers will benefit in reducing the cost of constructing the road.

When native soils and aggregates are combined with calculated amounts of Portland cement and water, the result is a type of soil-cement known as cement-treated base. This mixture hardens after compaction and curing to provide a strong and long-lasting material suited for pavement application. CTB can be mixed either at a Ready-Mix Concrete (RMC) facility, transported to the site, spread over the subbase, and then compacted, or it can be mixed on-site and compacted after blending. It serves as the foundation for pavement on highways, streets, parking lots, airports, and areas used for material handling.

In CTB construction, the goal is to achieve a meticulous combination of the various size aggregates with the designated percentage of cement and sufficient water to allow for the layer's necessary compaction. To allow the cement to hydrate and solidify the cement-aggregate mixture, the finished CTB layer needs to be sufficiently cured. Ordinary Portland Cement, Portland Slag Cement, or Portland Pozzolana Cement must all meet the specifications of IS:269, 455 or 1489, respectively, to be used as stabilizing cement. Table 1.1 specifies the properties of CTB as per IRC: 37-2018.

Table 1.1 Properties of CTB

Properties	7-days values
Compressive strength	4.5 to 7 MPa
Modulus of rupture	1.40 MPa
Modulus of elasticity	5000 MPa
Poisson’s ratio	0.25

CTB must have a thickness of at least 100 mm to meet the functional requirement [1]. The MoRTH specs table 400-4 specifies the CTB gradation. The needed design strength should be 1.5 times the laboratory strength value [1]. The cement-treated base material must also satisfy the requirements for durability listed in IRC: 37-2018.

FDR is a recycling method that involves treating all the sections of asphalt pavement and a predetermined amount of subbase material underneath with a specific percentage of cement and chemical stabilizer to create a stabilized base course. It is essentially a cold mix recycling process in which several additives, such as asphalt emulsions and chemical agents (such as calcium chloride, Portland cement, fly ash, and lime), are added to provide a better foundation. Pulverization, additive addition, compaction, and application of a surface or wearing course are the four basic processes involved in this method. If the existing material cannot provide the required properties, new materials may be imported and used in the process.

2. CHARACTERIZATION OF MATERIALS

2.1 Aggregates

Different size aggregates were collected from Patiala local vendor. The aggregates used in the CTB mix design have different sizes, which are 40 mm, 20 mm, 10 mm, and stone dust.

Results of the physical properties of aggregates:

- Combined flakiness and elongation of coarse aggregate: 25.93%
- Aggregate impact value: 14.67%

- Water absorption:

  40 mm aggregate: 0.56%

  20 mm aggregate: 0.63%

  10 mm aggregate: 0.78%

  Stone dust: 1.26%

2.2 Binding material.

The cemented matrix binds the material particles together and is responsible for increased strength. Ordinary Portland cement grade 43 as per Indian Standards IS: 8112, which consists of calcium oxide, calcium silicates, and aluminates, has been procured for research purposes. Potable water conforming to IS: 456 was used for mixing and moist curing of the mixes prepared.

Table 1.2: Physical properties of cement

Property	Value
Specific gravity	3.10
Fineness (%)	3
Water absorption (%)	0.41
Initial setting time (min.)	30

Table 1.3: Chemical composition of cement

Chemical Composition	SiO_2	Al_2O_3	FeO_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
OPC – 43	19.4	3.7	2.8	66.1	2.9	1.8	0.22	0.45	1.9

2.3 Nano Chemicals

The nano chemicals were obtained from the Zydex Industries private limited, Gujrat, India. Two different types of chemicals were used in the study namely Terracil and Zycobond

Terracil:

It's an organ-silane molecule that combines with soil particles to change them from water- loving (Hydrophilic polar) to water-hating (Hydrophobic non-polar) particles. This makes the soil less water-sensitive and allows it to be compacted for greater soil particle interlocking. It provides or develops a permanent water-resistant Nano-coating on all types of soils, aggregates, and other surfaces. Because it chemically bonds to surfaces indefinitely, this siloxane is non-leachable. It generates a strong covalent link structure that allows the treated material to breathe, allowing air to flow through its structure while maintaining thermal insulation freely. Terrasil prevents damage due to the rise of water (capillarity), cracking of soil, and resistance to ultraviolet rays. It is highly soluble in water. [2] and [3] explains the chemical action of Terrasil and surface silicate structure after Terracil reaction. The properties of Terracil are shown in Table no. 1.4.

Zycobond:

Zycobond is a next-generation co-polymer acrylic and nanotechnological additive. It's best used for soil stability, topical irrigation, and surface layer sealing as a rolling and dust treatment. It's a Nano polymer having particles that are less than 90 nanometers in size. It disperses in the soil, bonding the soil particles and providing erosion resistance, dust control, and fatigue resistance. Terrasil combined with Zycobond gives the soil strong bonding characteristics and provides long-term erosion control. Terrasil bonding is durable and long-lasting, and because it resists UV degradation. Properties of Zycobond are shown are the Table no. 1.4.

Table 1.4 Physical and chemical properties of Terracil and Zycobond:

Properties	**Terracil**	**Zycobond**
Physical State	Liquid	Liquid
Colour	Translucent	Translucent
Odour	Faint Odour	Faint Odour
Boiling Point	Approx. 100ºC	Approx. 100ºC
Flash Point	>70ºC	>70ºC
Density	1-1.02g/ml	1-1.02g/ml
Solubility	Partly Soluble	Partly Soluble
Viscosity	20-200 cP @ 30ºc	20-200 cP @ 30ºc
Incompatible Materials	Metal salts	Metal salts
Oxidizing Property	Not fire propagating	Not fire propagating

3. EXPERIMENTAL WORK AND LABORATORY TEST PROCEDURE

In the current investigation, to study the effect of different percentages of cement & fly ash on the CTB mixes and different percentages of cement and chemical stabilizers with RPM for the FDR mixes, UCS samples were prepared for designing the mix.

For CTB with different percentages of cement and fly ash.

To achieve the desired minimum UCS value of 4.5– 7.0 MPa in 7/28 days, cement content varied from 2% to 5%, whereas fly ash content varied from 1% to 4% are prepared. In total 10 mixes were prepared, which are given in Table 1.5.

Table 1.5 Details of CTB mixtures.

Mixture ID	Coarse & fine aggregate (%)				Additive's content (%)	
	40mm	20mm	10mm	Stone Dust	Cement	Fly Ash
M1	25	16	24	35	2	0
M2					3	0
M3					4	0
M4					5	0
M5					2	1
M6					3	1
M7					4	1
M8					1	2
M9					1	3
M10					1	4

For CTB using FDR with different percentages of cement and chemical stabilizers.

To achieve the desired minimum UCS value of 4.5– 7.0 MPa in 7/28 days, cement content varied from 2% to 5% with 3% of chemical stabilizers content (each of TerraCil & ZycoBond) by the weight of RPM, the mixes are prepared. In total 04 mixes were prepared, which are given in Table 1.6.

Table 1.6 Details of FDR Mixtures.

Mixture ID	Additive's Content (%)		
	Cement	TerraCil	ZycoBond
F1	2	3	3
F2	3		
F3	4		
F4	5		

3.1 Mix design procedure.

The process of creating Cement Treated Base (CTB) involves several steps to ensure the quality and effectiveness of the final product. The first step is to conduct physical and chemical testing of the aggregate, cement, and water to determine their properties. Next, the proportion of materials such as aggregates, dust, and cement are selected based on their weight using the MORTH table 400-4.

Once the materials have been selected, then it is subjected to sieve analysis and compared with the MORTH table 400-4. The Modified Proctor test, as per IS 2720, is then used to measure the Max. Dry Density (MDD) and Optimum Moisture Content of CTB mix with minimum cement content.

Other tests are conducted to determine the Liquid Limit, Plastic Limit, and Plasticity Index, as per IS 2720 (part 5). The Plasticity Modulus and Product are also determined using the same standard. Water absorption of material larger and less than 10mm in size is found according to IS 2386 (part 3). Finally, the cubes are cast using a Vibro Hammer (DLC) to complete the process of creating high-quality CTB by conducting Unconfined Compressive Strength (UCS) test on cubes (ref. fig. 1.1). By following these steps, the CTB can offer the required properties and meet the necessary standards.

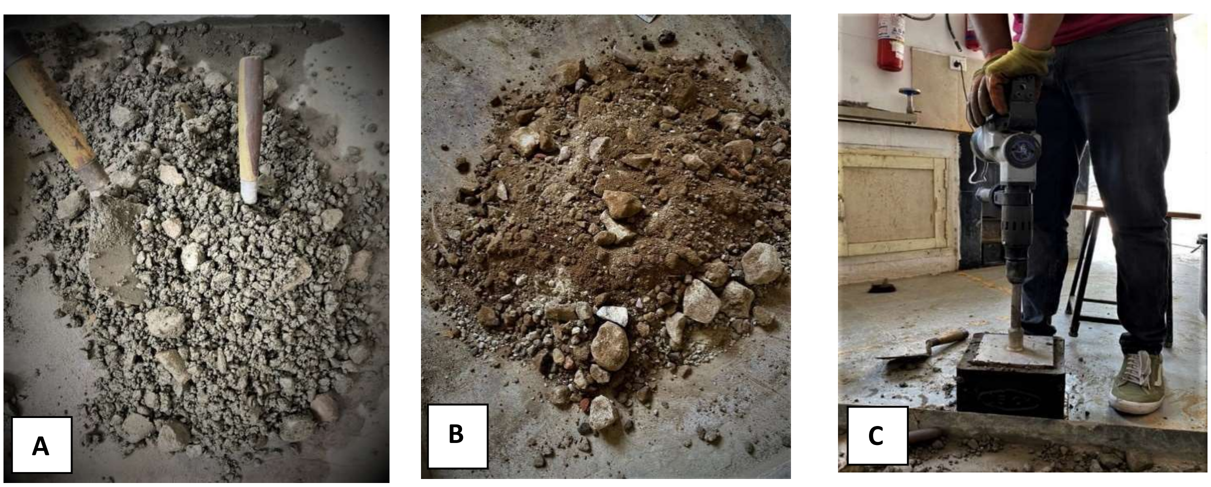

Fig. 1.1 (a) CTB mix (b) RPM (c) DLC Vibro Hammer

3.2 Proctor Compaction Test

This test is in accordance with (IS 2720 (Part 8)). 8. A modified proctor compaction test was carried out to calculate the optimum moisture content and maximum dry density of different control mixes. The apparatus consisted of a mould of volume (2250 cc), and a hammer of weight 4.9kgs with a dropping height of 450mm.

3.3 Unconfined Compression Test

The test involves creating cube-shaped specimens of CTB mixed at its optimum moisture content and replacing a certain aggregate fraction with material of a specific size (ref. fig. 1.2). The specimens are then cured for 7 or 28 days using moist curing methods to allow for a hydration reaction between cement, water, and CTB material, resulting in a hardened cemented matrix.

Curing is important for the structural properties of cement-treated base (CTB) as it allows for hydration reactions to occur. The CTB specimens are cured for seven days by keeping them moist with wet gunny bags. After 7 or 28 days, the specimens are crushed to failure and the load is recorded in a compression testing machine according to IS:516 standards (ref. fig. 1.3).

Fig. 1.2 The prepared cubical specimens of mixtures used.

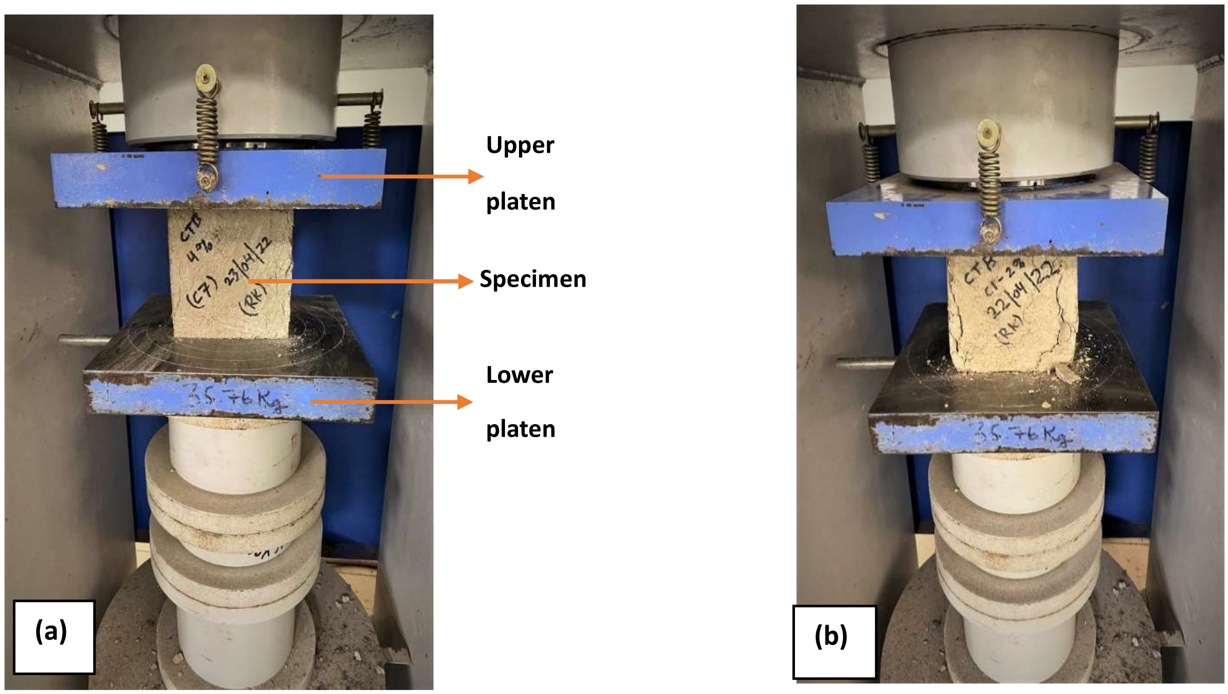

Fig. 1.3 Test setup for (a) Unconfined compressive strength (b) Specimen failure.

3.4 SIEVE ANALYSIS

The data obtained from aggregate size distribution curves is used in determining the blending proportion for the CTB mix design. Table 400 – 4 MoRTH provides the grading limit (different sizes of IS sieves) of material for stabilization with cement.

3.4.1 Blending for CTB

The blending of different aggregate sizes was required to obtain the desired composition for CTB. Table 1.7 & 1.8 shows the blending report of CTB and FDR mix respectively.

Combined gradation of CTB mix.

Table 1.7 Blending Report of CTB.

Sieve Size (mm)	% passing (Trail I)	% passing (Trail II)	Avg. % passing	Mid value	Specified Limits as MoRTH Table 400-4 & IRC sp 37-2018	Upper limit	Lower limit
53	100	100	100	**100**	**100**	**100**	**100**
37.5	100	100	100	**97.5**	**95-100**	**100**	**95**
19	75.6	69.2	72.4	**72.5**	**45-100**	**100**	**45**
9.5	47.2	47.6	47.4	**67.5**	**35-100**	**100**	**35**
4.75	31.8	40.8	36.3	**62.5**	**25-100**	**100**	**25**
0.6	16.2	19.92	18.06	**36.5**	**8-65**	**65**	**8**
0.3	12.4	15	13.7	**22.5**	**5-40**	**40**	**5**
0.075	1.4	1.8	1.6	**5**	**0-10**	**10**	**0**

Combined gradation of FDR mix.

Table 1.8 Gradation Report of RPM.

Sieve Size (mm)	% of passing	Mid value	Specified Limits as MoRTH Table 400-4 & IRC sp 37-2018	Upper limit	Lower limit
53	96.93	**100**	**100**	**100**	**100**
37.5	92.25	**97.5**	**95-100**	**100**	**95**
19	81.90	**72.5**	**45-100**	**100**	**45**
9.5	70.02	**67.5**	**35-100**	**100**	**35**
4.75	54.92	**62.5**	**25-100**	**100**	**25**
0.6	36.25	**36.5**	**8-65**	**65**	**8**
0.3	31.70	**22.5**	**5-40**	**40**	**5**
0.075	3.78	**5**	**0-10**	**10**	**0**

4. RESULTS AND DISCUSSION

The results and outcomes of the study carried out will be discussed in this chapter. This chapter deals with the OMC – MDD relationship for various mix designs, unconfined compressive strength test for different mixes, durability performance and resilient modulus of the cement-treated base layer.

4.1 Effect of replacement of cement with fly ash in CTB mixes.

The graphs in Fig. 1.4 and 1.5 show how the optimum moisture content (OMC) and maximum dry density (MDD) of cement-treated base (CTB) pavement material change with different cement and fly ash contents. Increasing the cement content increases the MDD value, while adding 1% fly ash to the mixture with 2%, 3%, and 4% cement does not significantly change the MDD value. However, when the cement content is kept at 1% and the fly ash content is increased from 2% to 4%, the MDD value decreases.

The mix with 1% cement and 2% fly ash had the highest maximum dry density (2.182 gms/cc) at an optimum moisture content (OMC) of 6.53%. Increasing the cement content from 4% to 5% did not make much difference in MDD. However, increasing the fly ash content from 2% to 4% (while keeping cement at 1%) increased the OMC from 6.53% to 6.74% because fly ash behaves as a cementitious material and can hold more moisture. Increasing the cement content from 2% to 5% decreased the OMC by 2.5%, but the relationships were similar, and there was little change in density in all mixtures.

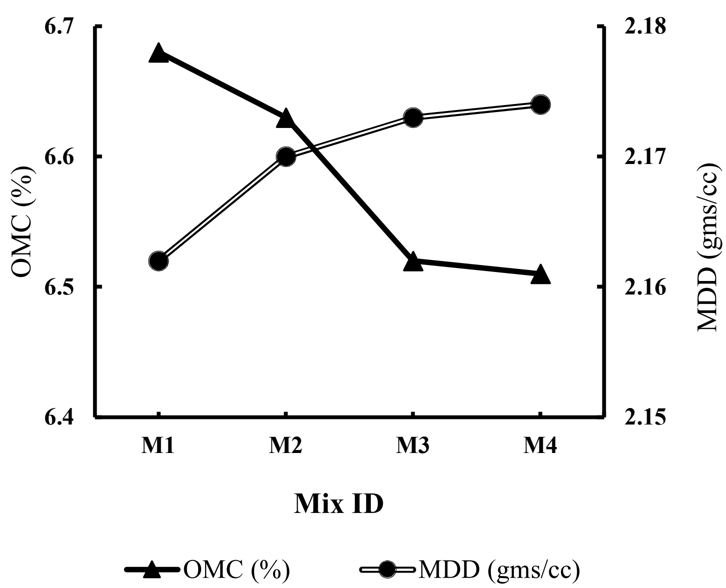

Fig. 1.4 Moisture content and maximum dry density relationships with cement.

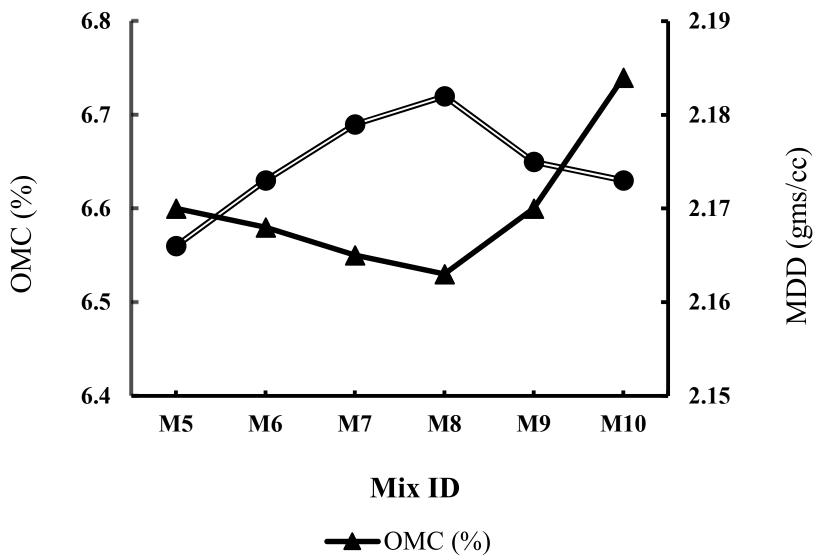

Fig. 1.5 Moisture content and maximum dry density relationships with cement & fly ash.

4.2 Effect of cement with chemical stabilizers in FDR mixes.

This passage discusses the results of an experiment on the effect of different cement percentages on the optimum moisture content (OMC) and maximum dry density (MDD) of reclaimed pavement material (RPM) for cement-treated base. The figure 1.6 shows that the mix with 5% cement had the highest MDD (2.325 gms/cc) at its OMC of 9.40%. Increasing the percentage of cement from 2%-5% resulted in an increase in OMC, but not a significant difference in MDD for mixes prepared with 3% & 4% cement.

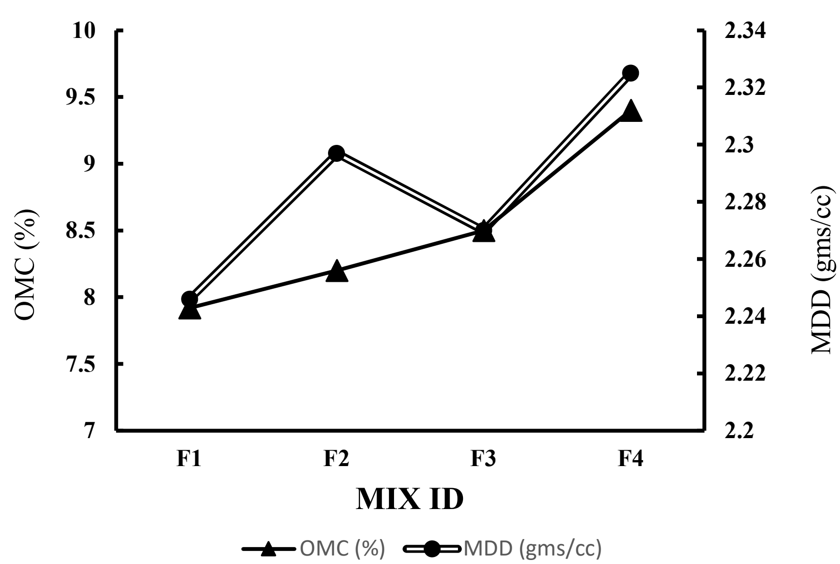

Fig. 1.6 Moisture content and maximum dry density relationships for various mixtures using FDR.

4.3 RESILIENT/ELASTIC MODULUS OF VARIOUS MIXES.

The Elastic Modulus (E) of the CTB may be estimated from the unconfined compressive strength of the material. The resilient/elastic modulus of 28-day cured CTB material can be estimated using equation 7.2 of IRC:37-2018. (Given below)

$$E_{CTB} = 1000 * UCS$$

Where,

UCS = The cementitious granular material's unconfined compressive strength (MPa) after 28 days.

E_{CTB} = Elastic/resilient modulus (MPa) of 28-days cured CTB material.

4.3.1 Unconfined compressive strength (UCS)

Effect of replacement of cement with fly ash in CTB mixes.

The effect of cement content and fly ash addition on UCS test trends are shown in fig. 1.7 & 1.8. The results indicate that the 7-day UCS value decreases with increased fly ash content and increases with an increase in cement content. The same trend is also seen in the case of 28-day UCS values. Further from the figure. 1.7, it can be understood that the mix M1 is not satisfying desired UCS value (7 & 28 days) as per clause 8.2.1 of IRC:37 – 2018. The mixtures M5 to M7 and M2 to M4 satisfy the criteria of minimum unconfined compressive strength of 4.5 MPa for cement and 7 MPa for lime, or lime-fly ash stabilized granular material is recommended for constructing the cement-treated base, ensuring moist curing by IRC: SP:89-2018. The mixture M8 to M10 doesn't meet the required criteria for UCS.

The pozzolanic cementitious material produced by the cement hydration reaction improves the bonding strength of the particles. Besides, the maximum UCS value is inferred at 1% fly ash and 4% cement (M7) in a 7-days curing period and with 4% cement (M3) during a 28-days curing period.

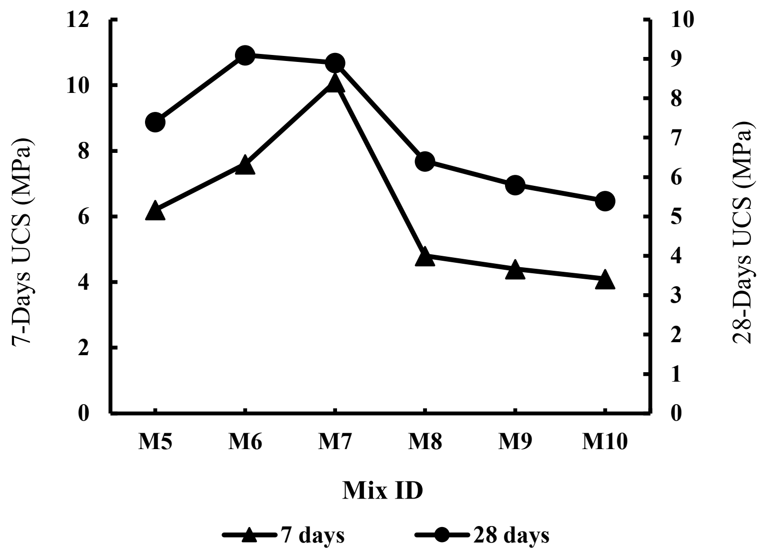

Fig. 1.7 Unconfined Compressive Strength (7 & 28 days) of different mixes of CTB with cement.

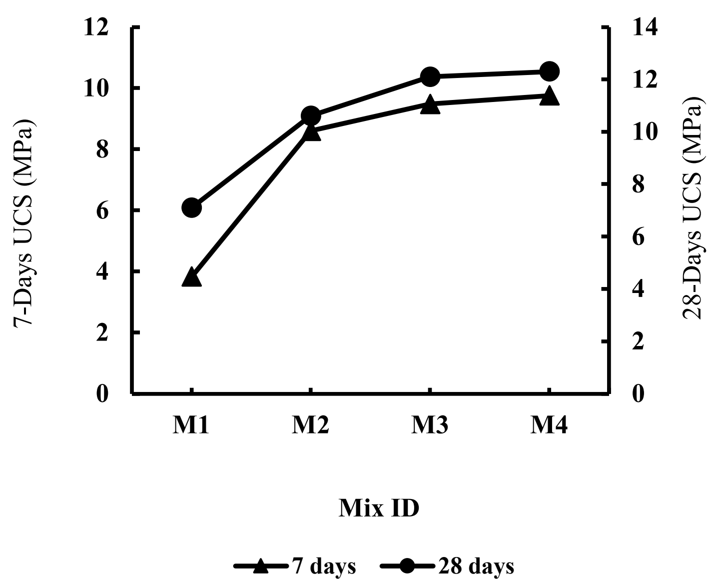

Fig. 1.8 Unconfined Compressive Strength (7 & 28 days) of different mixes of CTB with cement.

Effect of cement with chemical stabilizers in FDR mixes.

The effect of cement content and chemical stabilizer addition on UCS test trends are shown in fig. 1.9.

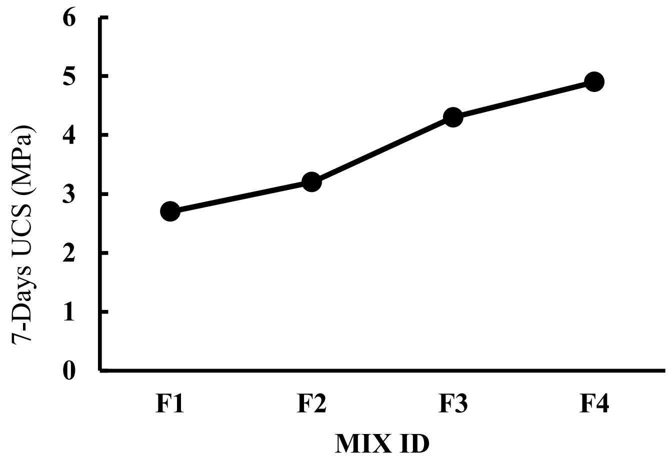

Fig. 1.9 Unconfined Compressive Strength (7-days) of different mixes of FDR with cement & chemical stabilizers.

4.3.2 Resilient Modulus.

For different types of mixes of CTB with cement and cement & fly ash.

From fig 2.1 & 2.2, it is observed that the values of resilient modulus of mixes M1, M5, M8, M9 & M10 is not suitable for designing flexible pavement due to the requirement of considering an elastic modulus of 5000 MPa for pavement analysis. This elastic modulus should be used when analysing pavement with a CTB layer that has unconfined compressive strength values ranging between 4.5 to 7 MPa. However, such values are not observed with the use of M10. (Clause 8.2.1 of IRC:37-2018). Further, it is observed that the values of resilient modulus are increasing with the increasing percentage of cement, and after adding 1% of fly ash, it follows the same trend.

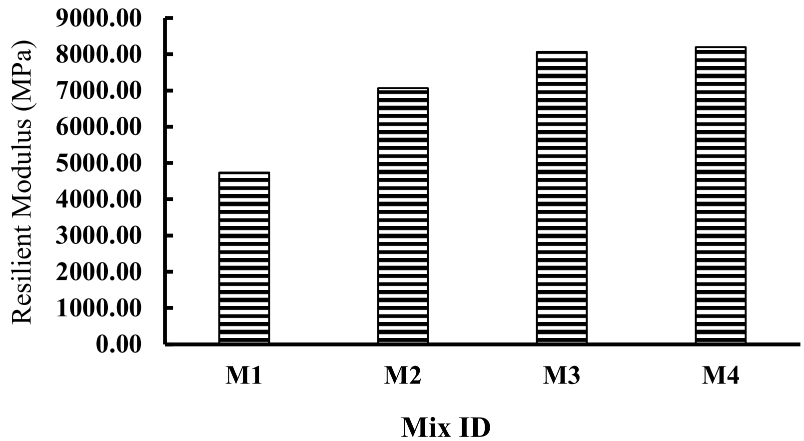

Fig. 2.1 Resilient Modulus versus different mixes of CTB with cement.

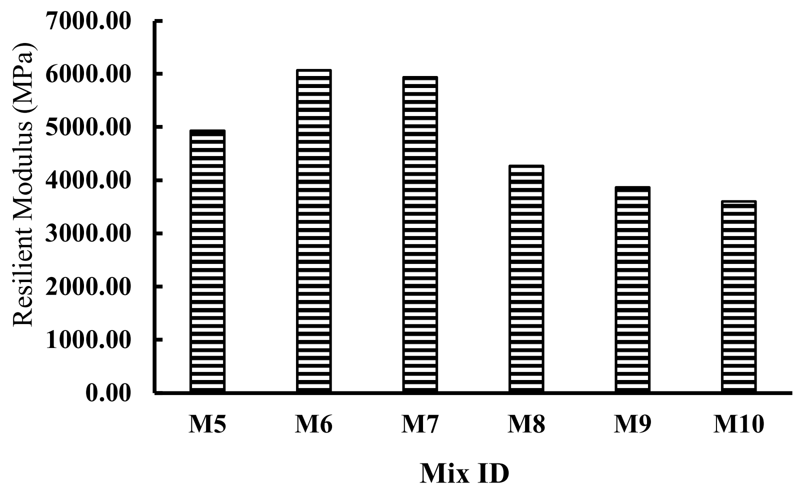

Fig. 2.2 Resilient Modulus versus different mixes of CTB with cement & fly ash.

For different types of mixes of CTB with cement & chemical stabilizers (FDR).

From fig 2.3, it is observed that the value of the resilient modulus of mixes increases with an increasing percentage of cement, but the content of chemical stabilizers is fixed at 3% respectively.

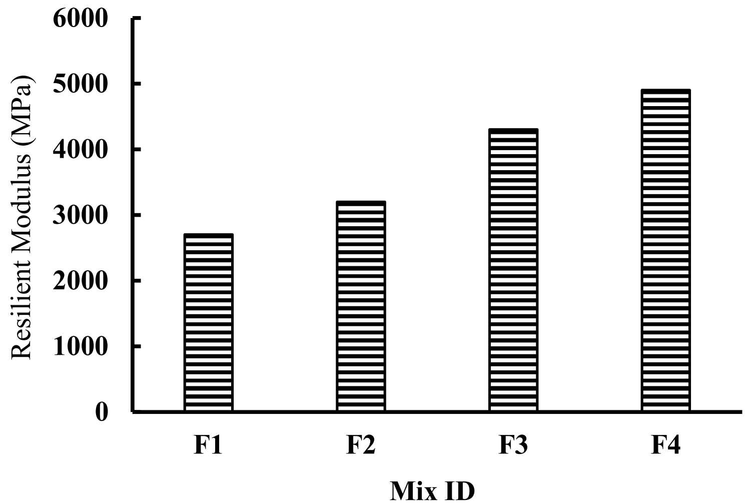

Fig 2.3 Resilient Modulus versus different mixes of CTB with cement & chemical stabilizers (FDR).

4.4 DURABILITY

To investigate how moisture and dryness affect a mix's long-term performance, wetting and drying studies were conducted in accordance with IRC: SP: 89. To imitate the field performance during curing and prior to the building of another pavement layer, cylindrical samples were treated to alternate wetting and drying for a maximum of 12 cycles. (ref. fig. 2.4)

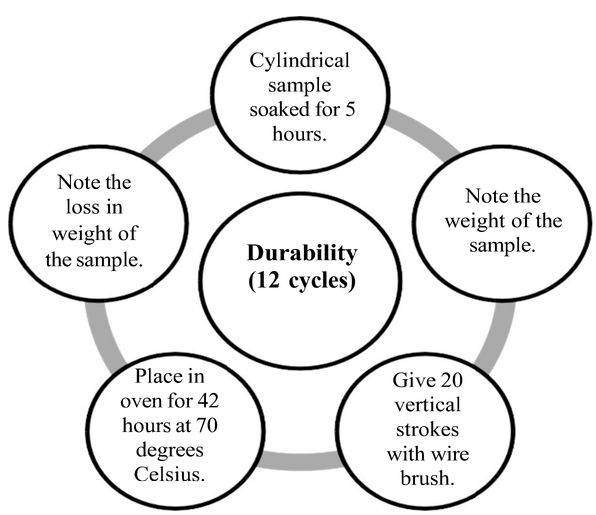

Fig 2.4 Durability cycle.

The study found that the mix M6 was less durable compared to other mixes tested. Mixtures M2, M3 & M4 (higher cement content and no fly ash) were found to be more durable. The results from figure 2.5 show that all mixtures tested had a mass loss between 4.85% to 6.78%, and none had a mass loss of more than 14% after 12 cycles. From the durability test, optimum cement and fly ash content is re-confirmed.

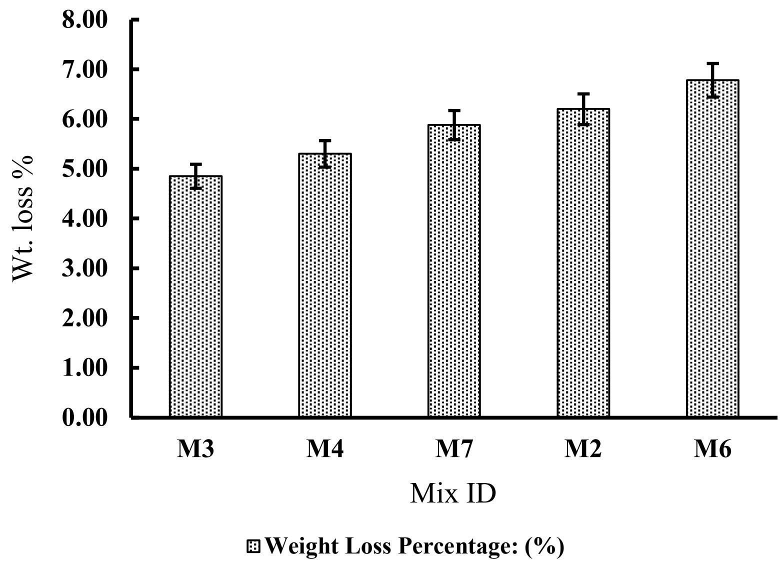

Fig. 2.5 Percentage of weight loss during the wetting and drying process.

5. PAVEMENT ANALYSIS AND DESIGN

Pavement design involves ensuring the pavement functions structurally throughout its designated service life. Roughness, cracking, and rutting are major indicators of pavement performance. Performance models use empirical or mechanistic-empirical methods to forecast pavement performance based on distresses, such as stresses, strains, and deflection, determined according to a prescribed process.

The linear elastic layered theory is used to analyse pavements modelled as a multi-layer system. The subgrade is considered semi-infinite, and the above levels have an unlimited horizontal extent but a finite thickness. Elastic modulus, Poisson's ratio, and layer thickness are necessary inputs for computing stresses, strains, and deflection generated by the applied load. The IITPAVE software was used for pavement analysis. The IRC: 37-2018 guidelines recommend choosing pavement sections that meet stress and strain limits to prevent excessive damage during their service life.

5.1 Pavement Design Procedure

Selecting a trail composition.

The expected functional requirements of the layers in a high-performance pavement, such as a strong subgrade, a well-drained sub-base, a strong crack, rutting, and moisture damage resistant bituminous base, and a bituminous surfacing that is resistant to rutting, top-down cracking, and damages caused by exposure to the environment, should guide the designer in selecting pavement composition.

Bituminous Mix Design and the mix resilient modulus.

The physical requirement and characteristics of the material should be inspected, as well as the procurement of the material element for the mix. Trials and testing should be used to determine an appropriate proportioning of the blended materials, with the resilient modulus being determined according to the procedures specified in the IRC: 37-2018.

Selecting layer thickness.

The minimum thickness specified in IRC: 37-2018 should be considered in determining the trial thickness of various layers that comprise the pavement.

Structural Analysis of the selected pavement structure.

This is to be done by IITPAVE software considering standards as per table 1.9.

Table 1.9 Standard condition for pavement analysis using IITPAVE (IRC: 37-2018)

Analysis Conditions	
Material response model	Linear elastic model
Layer interface condition	Fully bonded (all layers)
No. of wheels	Dual wheel
Wheel load	20 kN on each single wheel (two wheels)
Contact stress for critical parameter analysis	0.56 MPa for tensile strain in bituminous layer and vertical compressive strain on subgrade; 0.80 MPa for the cement-treated base.
Critical mechanistic parameters	
Bituminous Layer	Tensile strain at the bottom
Cement treated base	Tensile stress and tensile strain at the bottom
Subgrade	Compressive strain at the top

Computing the allowable strains/stresses.

The fatigue and rutting performance (limited strain) models specified in IRC: 37-2018 are used to determine the allowed strains in the bituminous layer and subgrade for the selected design traffic.

Subgrade rutting criteria.

According to the IRC: 37-2018 rules, a critical rutting situation is defined as a rut depth of 20 mm or greater measured along the wheel paths. Equations 3.1 and 3.2 of IRC: 37-2018 for 80 percent and 90 percent reliability levels indicate the equal number of standard axle load (80 kN) repetitions that the pavement can serve before the crucial average rut depth of 20 mm.

$$N_R = 4.1656 * 10^{-08} [1/\varepsilon_v]^{4.5337} \quad \text{(for 80\% reliability)}$$

$$N_R = 1.4100 * 10^{-08} [1/\varepsilon_v]^{4.5337} \quad \text{(for 90\% reliability)}$$

Where,

N_R = subgrade rutting life

ε_v = vertical compressive strain at the top of the subgrade

Fatigue cracking for bituminous layer

Fatigue cracking with a total area of 20% or more of the paved surface area of the section under evaluation is considered a critical condition. Equations 3.3 and 3.4 of IRC: 37-2018, respectively, for80 percent and 90 percent reliability, offer the equal number of standard axle load repetitions that the pavement can service before the critical condition of the cracked surface area of 20% or more occurs.

$$Nf = 1.6064*C*10^{-04} [1/\varepsilon t]^{3.89} * [1/MRm]^{0.854} \quad \text{(for 80\% reliability)}$$

$$Nf = 0.5161*C*10^{-04} [1/\varepsilon t]^{3.89} * [1/MRm]^{0.854} \quad \text{(for 90\% reliability)}$$

Where,

C = 10^M, and M = $4.84\left(\frac{V_{be}}{V_a+V_{be}} - 0.69\right)$

Va = per cent volume of air void in the mix used in the bottom of bituminous layerVbe = per cent volume of effective bitumen in the t mix used in the bottom of bituminous layer

Nf = fatigue life of bituminous layer

εt = maximum horizontal tensile strain at the bottom of bituminous layer

MRm = resilient modulus (MPa) of the bituminous mix

Fatigue performance models for Cement Treated Base (CTB)

In the case of a pavement with a CTB layer, the CTB layer's fatigue performance should be evaluated using equation 3.5 of IRC: 37-2018.

$$\textbf{N = RF}\left[\frac{(\frac{113000}{E^{0.804}}+191)}{\varepsilon_t}\right]^{12}$$

Where,

RF = reliability factor for cementitious material for failure against fatigue

= 1 for expressways, national highways, state highways and urban roads and for other categories of the road if the design traffic is more than 10 msa

= 2 for all other cases

N = no. of standard axle load repetitions which the CTB can sustain

E = elastic modulus of CTB material (MPa)

ε_t = tensile strain at the bottom of CTB layer (micro strain)

Iterations

Changing the layer thicknesses for a few iterations until the strains computed by IITPAVE are less than the allowable strains derived from performance models may be required.

Reliability

For expressways, NH, SH, and urban roads, guidelines recommended a 90 percent reliability performance calculation for subgrade rutting and fatigue cracking of the bituminous layer. Other types of roads should have 90 percent reliability for design traffic of 20 msa or more, and 80 percent reliability for design traffic of less than 20 msa.

Note: The minimum thickness, as specified in the guidelines (IRC: 37-2018), shall be provided to ensure the required functional requirement of the layers.

5.2 Thickness comparisons.

The below four cases are considered based on IRC 37-2018 and the thickness comparison of different layers of the flexible pavement for high-volume and low-volume roads are shown in figure 2.6 & 2.7 respectively.

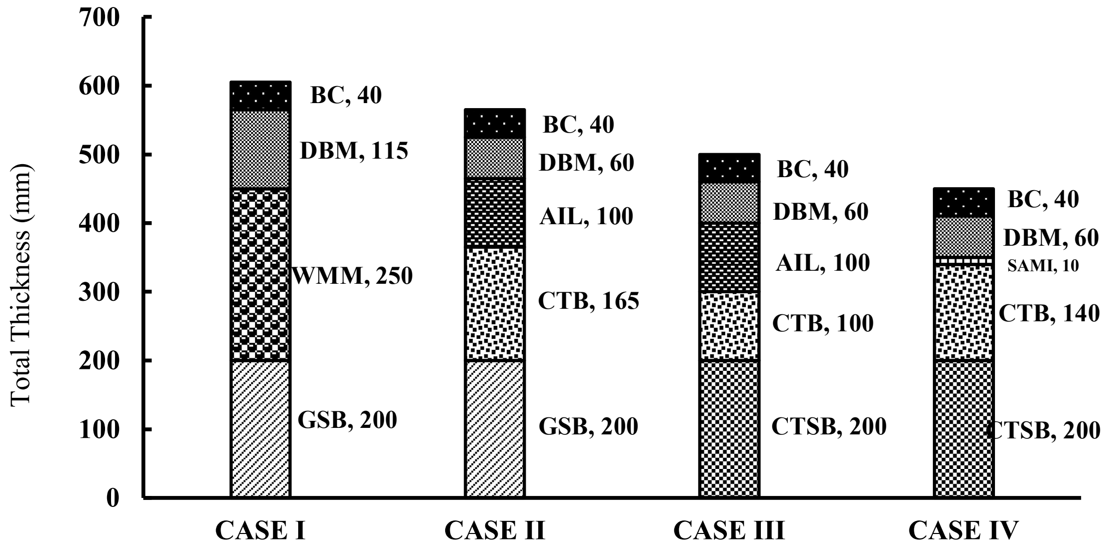

Fig. 2.6 Thickness comparison of high-volume road.

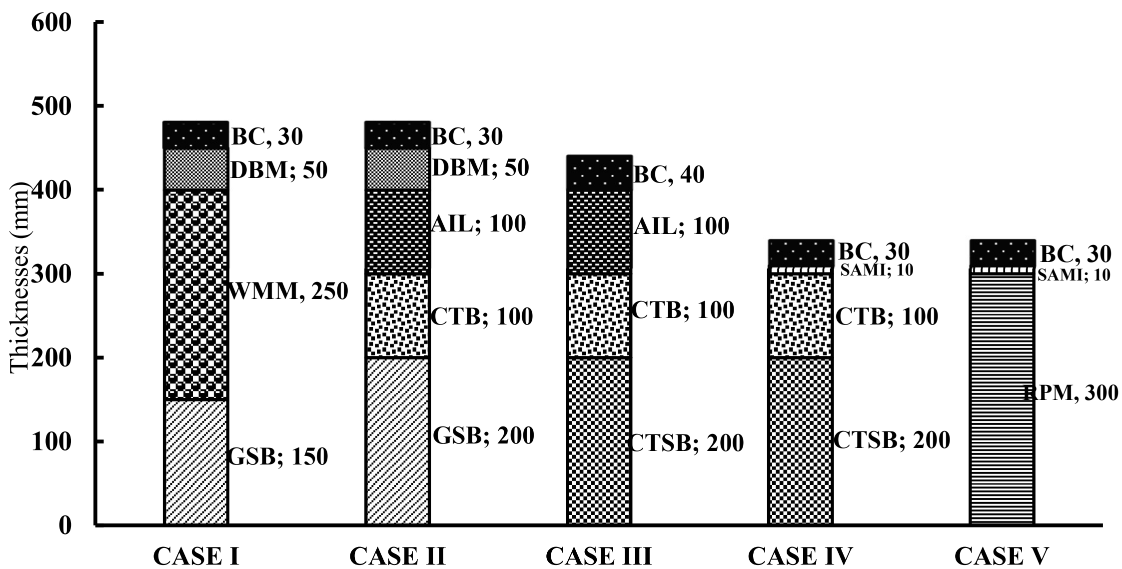

Fig. 2.7 Thickness comparison of low volume road.

5.3 Cost Analysis

The present study is to estimate the per kilometre construction cost of a road having two lanes single carriageway. The input used for the estimation of cost for a roadway construction project if constructed with pavement designed are given below.

- Length of Road : 1 km
- Width of Road: 7 m
- Design traffic (in msa) : 50 msa (for high volume roads)
  Design traffic (in msa): 05 msa (for low volume roads)
- Effective CBR : 8%

Apart from the environmental benefits, using a cement-treated base layer may reduce the number of trips requirement for natural aggregates and layer thickness. This study emphasized that utilizing studied material will significantly minimize the construction cost compared with the conventional one. The cost incurred (per km) for the study was analysed, using the cost provided by PWD Uttarakhand. For the current study, transportation and labour cost was excluded. Figure 2.8 & 2.9 shows that there is a significant difference in cost among all the four cases of the pavement sections compared. Case IV turns out to be the most economical section for the high-volume road and case IV turns out to be the most economical section for the low-volume roads in the case of construction with virgin aggregates, but it is much more economical and sustainable with the application of the FDR technique (CASE V).

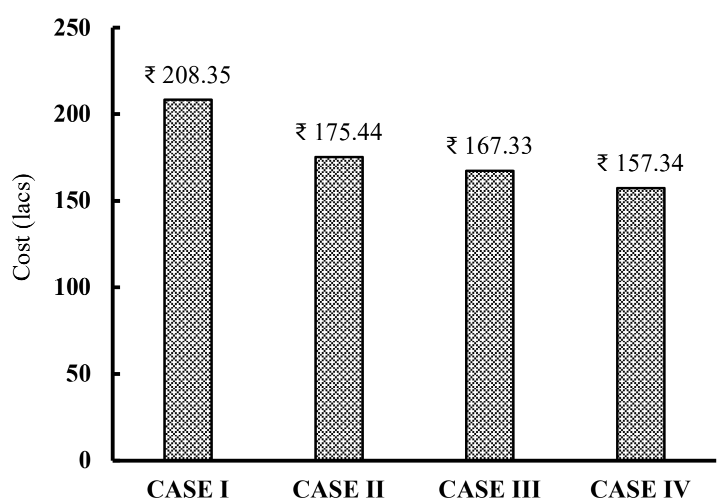

Fig. 2.8 Cost analysis of high-volume road.

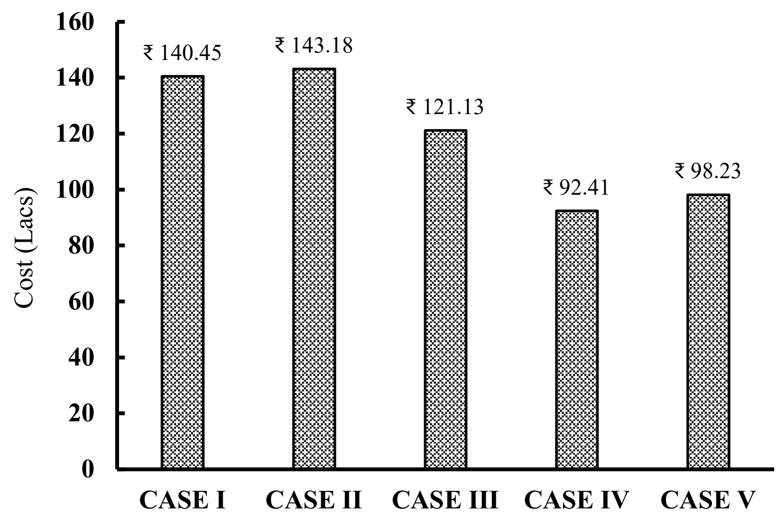

Fig. 2.9 Cost analysis of low-volume road.

6. CONCLUSIONS

In this study, the mix design and analysis of flexible pavement (as per the guidelines of IRC: 37-2018) for high-volume and low-volume roads shows significant results regarding the thickness of different layers and the overall thickness of the pavement section respectively. In addition to this, the cost analysis of all the combinations of the layers contributed a significant point in selecting the most economical section. Important key findings discovered from this study can be concluded as follows:

- There is no significant effect of partial replacement of cement with fly ash on compaction characteristics such as OMC-MDD relationships.
- The 7-days UCS values decrease with increased fly ash content and increases with an increasein cement content. A similar trend was observed in the 28-day UCS values. The mixes with a higher proportion of fly ash in composition with cement content don't meet the required criteria(as per IRC: 37-2018) of UCS for stabilized layer(s).
- Further, in the case of FDR, the UCS increases with the increasing percentage of cement (2- 4%) with 3% of TerraCil & ZycoBond each as chemical stabilizers.
- The durability of the mixes prepared was checked by performing 12 cycles of wetting & drying. The per cent weight loss of all mixes considered in this study was found to be in the range of 4.85 to 6.78% which is less than the permissible values (14% as per IRC:37-2018).

- The value of resilient modulus increases with the increasing percentage of cement. In the caseof FDR, the mix with 5% cement and 3% chemical stabilizers (each of TerraCil & ZycoBond) have the highest resilient modulus.
- The mixes with 4% cement (M3), 3% cement & 1% fly ash (M6) and 5% cement in FDR (F4) meet the design parameters as per the guidelines of IRC: SP: 89. Hence considered for the design of flexible pavement of high-volume and low-volume roads, respectively.
- For the same traffic count, the total thickness of pavement designed with a cement-treated base is 25.62 % less than pavement designed with conventional layer(s) (unbound).
- The reduction of 35.5% in thickness of the bituminous layer of pavement section designed with cement-treated base has resulted in a significant difference in the quantity of bituminous mix required for construction of bituminous layer.
- For the low-volume roads, the application of the FDR technique significantly reduces the total thickness by 29.16% as compared to the conventional section of the pavement. Also, it completely saves the utilization of virgin aggregate as the stabilized reclaimed pavement material (RPM) will be used as the layer just above the subgrade with proper compaction practice. A reduction of 62.5 % of the bituminous layer was also observed.
- The result of the cost estimated for flexible pavement designed with bound and unbound layers indicates that flexible pavement designed with CTB has reduced the construction cost by 24.48% for the high-volume roads and 34.20 % cost for low-volume roads.
- Further, with the application of the FDR technique, a cost reduction of 30.06% was noted after the cost analysis for the low-volume road.

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