Laboratory Investigation of Cement Treated Bases (CTB) and Full-depth Reclamation (FDR) mixes.

A Dissertation Submitted in Fulfilment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

IN

INFRASTRUCTURE ENGINEERING

Submitted by

ROHAN KUMAR
(802023014)

Under the supervision of

Dr. Tanuj Chopra
Assistant Professor
Civil Engineering Dept.
TIET Patiala

Prof. Rajesh Pathak
Associate Professor
Civil Engineering Dept.
TIET Patiala

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

DEPARTMENT OF CIVIL ENGINEERING

THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY

(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

JUNE 2022

DECLARATION

I, Rohan Kumar hereby declare that this dissertation entitled **"Laboratory Investigation of Cement Treated Bases (CTB) and Full-depth Reclamation (FDR) mixes."** is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering in Infrastructure Engineering** in the Civil Engineering Department, Thapar Institute of Engineering and Technology, Patiala under the supervision of **Prof. Rajesh Pathak, Associate Professor & Dr. Tanuj Chopra, Assistant Professor** Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of a degree.

Rohan Kumar

(Rohan Kumar)
Roll No.: 802023014

Date: 29/07/2022
Place: Patiala

CERTIFICATE

This is to certify that the above statement made by the student concerned is correct and true to the best of my knowledge and belief.

R Pathak

Prof. Rajesh Pathak
Associate Professor
Department of Civil Engineering
Thapar Institute of Engineering and Technology, Patiala

Dr. Tanuj Chopra
Assistant Professor
Department of Civil Engineering
Thapar Institute of Engineering and Technology, Patiala

ACKNOWLEDGEMENT

A dissertation cannot be completed without the help of many people who have given directly or indirectly through their practical knowledge and constructive criticism to prepare this work. It would not be fair if I didn't say any word of thanks to those whose sincere advice made this period a real educative, enlightening, gratifying, and memorable one.

I extend my deep gratitude to my supervisions, **Prof. Rajesh Pathak, Associate Professor and Dr. Tanuj Chopra, Assistant Professor,** Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala, who permitted me to carry out my research work under their guidance. Their dynamism and diligent enthusiasm have been instrumental in keeping my spirit high. Their knowledge of civil engineering is a benefit to me.

I am immensely thankful to Mr. **Jaspreet Singh and Mr. Amarjit Singh**, lab attendants, for their kind support in my experimental work in the Transportation Engineering Lab of the Department.

I would like to acknowledge **Zydex Industries Pvt. Ltd.** Vadodra, Gujarat, India for sponsoring the Nano-chemicals used in the study. I conscientiously acknowledge the cooperation, assistance and knowledge sharing imparted by the company during this research work.

I would further like to thank my parent, seniors and my classmates for their support and motivation during the entire course of my dissertation work.

Rohan Kumar
(802023014)

ABSTRACT

In the last decades, new road melioration technologies have evolved to abate the utilization of aggregates in new pavement, this helps in abating the construction cost, decimation of natural resources as well as curtailing of energy. This study provides an innovative approach to determining the per cent of cement added for the base course stabilisation along with the certain percentage of class C fly ash and to study the engineering properties of the stabilized mix. Also, with the application of FDR, an effective approach was made to improve the strength of reclaimed pavement material (RPM) by the utilization of TerraCil & ZycoBond, chemical commercial stabilizers along with a certain percentage of cement to reduce moisture damage (water permeability) and enhance the flexibility enabling dimensionally stable non-deforming base. Due to the use of various cement percentages and chemical stabilisers in the case of FDR, aspects related to compaction, durability, and unconfined compressive strength (UCS) are examined. The UCS increased substantially with the addition of different cement per cent in the CTB mix but decreases on increasing fly ash content and stabilizers along with cement in FDR. There was an average mass loss of 5.80% in 12 cycles of wetting-drying have been observed in the durability test of the CTB mix designed.

This study shows how it is beneficial to use the cement-treated base to replace the conventional base material used for the construction of high-volume and low volume-roads. According to the analysis of the sections that were designed, a thicker wearing course is needed because the granular layer's strength is poor in order to prevent roads from failing due to rutting and cracking. There is a significant difference in the cost of construction of wearing course and other layers of flexible pavement. Due to the higher modulus of Cement Treated Base (CTB), the thickness of CTB is significantly less than Granular Base (GSB) layer for same traffic count. CTB is the better alternative to conventional granular base. So, an attempt has been made to investigate the cost of the construction of flexible pavement designed with CTB as a base layer for 50 msa traffic for high-volume roads and 5 msa traffic for low-volume roads. IRC: 37 (2018) was followed to estimate the thickness of different layers of flexible pavement. The cost per kilometre of a road having a flexible pavement designed with CTB base layer was reduced by 24.48% for high-volume roads and 34.20 % for low-volume ones. Further, with the application of FDR, a cost reduction of 30.06% was indicated in the low-volume roads.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Pavement is a durable surface material that has been laid down on 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. Flexible pavements function structurally relatively flexibly under load and have little to no flexural strength. Over the base and sub-base courses, there is a bituminous surface course. One or more 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 almost 90% of the country's roadways. The granular layer is offered as a base layer in the majority of these roadways. Because the fine layer has a low strength, the wearing course of a higher thickness is necessary 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. As a result, stabilised base is advantageous to a conventional granular basis.

Since more than a century ago, stabilising soils and aggregates for paving has been suggested. The State Highway 41 roadbed at Johnsonville in South Carolina was improved with the use of the engineered CTB for the first time in 1935. Every state in the United States and every province in Canada has thousands of kilometres of CTB pavements, which offer good service at cheap maintenance costs.

Additionally, fly ash and aggregate can be used to create a top-notch stabilised base course. These road bases are regarded as combinations with pozzolanic stabilisation. Fly ash concentrations can range from 12 to 14 per cent, and lime concentrations can range from 3 to 5 per cent. Lime may also be substituted with Portland cement to boost early age strengths. The finished product is created, applied, and resembles a cement stabilised aggregate basis.

When compared to the expenses of environmental degradation caused by the use of priceless topsoil, aggregates from rented areas, quarry supplies, and the loss of fertile agricultural land owing to ash deposits, the use of fly ash will be justified by actual savings realised. Due to the potential for toxins to be released into ground and surface water following removal, fly ash disposal is a serious environmental hazard.

1.1 Stabilized Layers

For the construction of road bases or sub-bases, a variety of soils or granular materials are available. They might have inadequate qualities, which would significantly shorten the life of the pavement and cause distress. The qualities may be enhanced by the addition of stabilising substances like bitumen, cement, lime, or even unconventional compounds. Cement-bound materials, among these many stabilised materials, develop a high stiffness and strength, show good performance for pavement serviceability, and display increased durability. Additionally, the efficiency of cement and waste fly ash in stabilisation as well as the factors that may affect stabilisation efficiency were investigated. Significant environmental and financial stability benefits result from the addition of waste fly ash and cement as additives.

1.2 Cement Treated Base (CTB)

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 is bendable because it can either be mixed in an RMC facility and then hauled to the site, spread out over the subbase, and compacted, or it can be mixed in place 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 Puzzolana Cement must all meet the specifications of IS:269, 455 or 1489, respectively, in order to be used as stabilising cement.

Table 1.1 Properties of CTB

Property	7-Days Value
Compressive strength	4.5 to 7 MPa (IRC: SP:89)
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 (IRC: 37-2018). The MoRTH specs table 400-4 specifies the CTB grade. The needed design strength should be 1.5 times the laboratory strength value. The cement-treated base material must also satisfy the requirements for durability listed in IRC: 37-2018, Paragraph 8.2.4.

1.3 Pozzolanic-stabilized mixture (PSM)

When laid and compacted correctly, fly ash stabilised base courses, which are proportional combinations of fly ash, aggregate, and an activator (cement or lime), provide a sturdy and long-lasting pavement base course. Full-depth asphalt, cement-treated, and crushed stone foundation courses can all be replaced with fly ash stabilised base courses at a lower cost. Flexible and rigid pavements can both use fly ash stabilised base courses..

Class C and Class F fly ash are the two categories. Burning newer lignite sub-bituminous coal produces class C coal. Although it is pozzolanic, it also has self-cementing qualities. Class C, often known as high calcium Fly Ash, is predominantly composed of calcium alumino-sulphate glass, quartz, tricalcium aluminate, and free lime (FA FACTS, 2003). Burning older, harder anthracite and bituminous coal produce class F emissions. Less than 20% of the Ash is lime and is pozzolanic. Therefore, for it to react and generate cementitious compounds, it needs a cementing agent like regular Portland Cement (OPC), hydrated lime, and the presence of water. Class F Fly Ash, also known as low calcium Fly Ash, is predominantly composed of alumino-silicate glass, quartz, mullite, and magnetite.

The use of fly ash to stabilise aggregate road bases has a long and successful history. In this application, known as pozzolanic-stabilized mixture (PSM), stabilised aggregate bases are built using a variety of materials and material combinations. Fly ash from the Class C category can be used independently. When combined with lime, portland cement, or cement kiln dust, Class F fly ash can be employed (CKD). Class F fly ash and lime mixes typically contain two to eight percent lime and ten to fifteen percent Class F fly ash. Additionally, the stabilising agent can be created by mixing Class F fly ash with 0.5 to 1.5 percent Type I portland cement.

Table 1.2 Standard classification of Fly Ash (ASTM 618, 1994)

Components	Class F	Class C
$SiO_2 + Al_2O_3 + Fe_2O_3$, Min%	70	50
SO_3, Max%	5	5
Moisture Content, Max%	3	3
LOI, Max%	6	6
Available Alkalis, Max%	1.5	1.5

1.4 Full-depth reclamation (FDR)

Full-depth reclamation (FDR) is a recycling method that creates a stabilized base course by treating all the asphalt pavement sections and a predetermined quantity of the subbase material underneath. It is essentially a cold mix recycling process in which several additives, such as asphalt emulsions and chemical agents, are added to provide a better foundation (such as calcium chloride, Portland cement, fly ash, and lime). Pulverization, additive addition, compaction, and application of a surface or wearing course are the four basic processes in this process. New materials may be imported and employed in the processing if the existing material cannot offer the required depth for the treated base.

Benefits of FDR

- Cross-slope and profile grade correction can be done with the right design and method choice.
- Pavement widening can easily be accomplished.
- FDR can be done for parking lots, low-volume roads, highways, and airports.

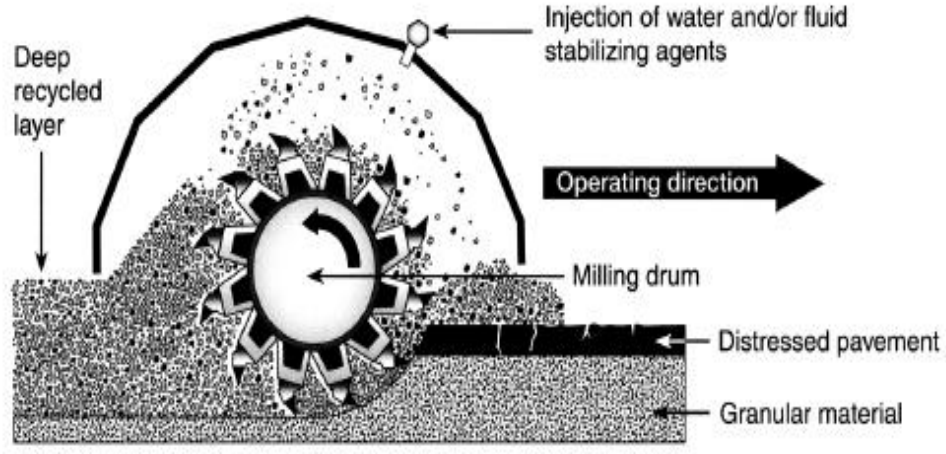


Fig. 1.1 Schematic of Single Machine (FDR)
(MT CARMEL Stabilization group)

1.5 Advantages

The advantages of CTB are:

- CTB offers a base that is firmer and more flavorful than a typical base. Lower deflections translate into less strain on the asphalt surface thanks to a firmer base. This lengthens the lifespan of the pavement and lessens surface irritation, such as fatigue cracking (Fig 1.2).
- Due to the loads' widespread distribution, CTB thicknesses are lower than those needed for traditional bases carrying the same traffic (Fig 1.3).
- Rutting is less of an issue with CTB pavement. Granular material that is unbound will be displaced beneath flexible surface pavements by loads from channelized traffic.
- CTB layer creates a moisture-resistant foundation that keeps water out and maintains better strength levels even when soaked (Fig 1.4).

The advantages of PSM are:

- It significantly increases strength and durability.
- Enables the usage of mediocre or inferior aggregates.
- Improves the utilisation of open-graded base courses.

The advantage of FDR are:

- Reduces project cost.
- Without altering the shape of the pavement or reconstructing the shoulders, the pavement structure can be greatly enhanced.
- Old pavement may be brought back to the desired profile, wheel ruts can be removed, crown and slope can be restored, and potholes, irregularities, and rough spots can be removed.
- The procedure can also accommodate pavement widening works. This method results in a pavement structure that is uniform.
- It can get rid of longitudinal, reflection, and transverse cracking. You can make the ride better.
- Frost's susceptibility may be improved.
- In most applications, a thin overlay or chip seal surface is all that is needed, which results in cheap production costs.
- Engineering costs are low.
- Air quality issues brought on by dust, odours, and smoke are eliminated, and materials and energy are conserved. Since the disposal issue is solved, the procedure is environmentally preferable.

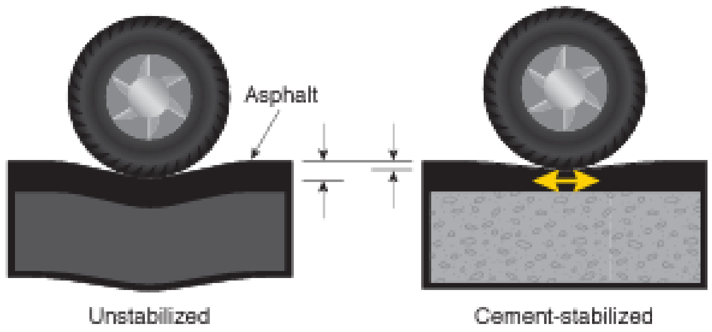


Fig. 1.2 Deflection in unstabilized & stabilized base.
(Portland cement association)

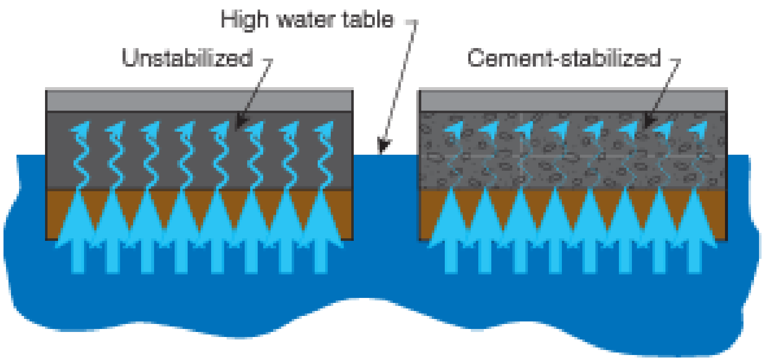


Fig. 1.3 Cement stabilization reduces permeability.
(Portland cement association)

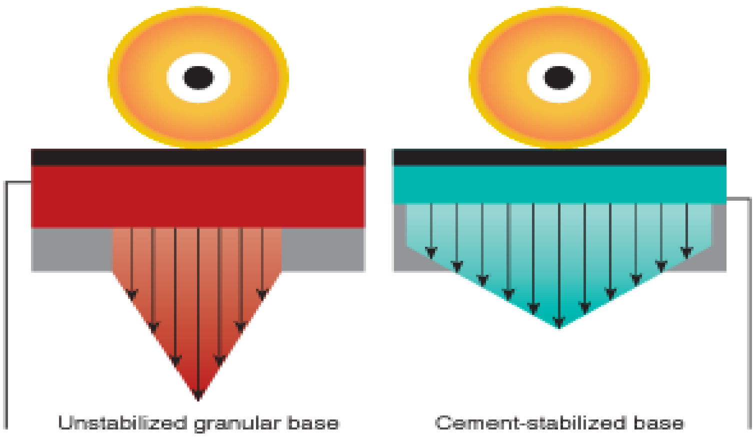


Fig. 1.4 Load distribution area in unstabilized & stabilized base.
(Portland cement association)

2.1 LITERATURE REVIEW ON CEMENT TREATED BASE (CTB)

I. Del Rey et al. (2015) investigated the viability of employing a base layer of CTGM produced with FRA. The six combinations, formed of mixed recycled and recycled RCA, are composed of 0-8 mm FRA and 0-40 mm coarse aggregates. The effects of size and the origin of the aggregates were examined, along with the UCS, modulus of elasticity, and durability characteristics. This is the first investigation into the usage of the fine CDW fraction in the creation of CTGM, which will be utilised as a base layer for roads. It implies that making CTGM with 0–8 mm RA from CDW is doable. Furthermore, dimensional changes and mechanical characteristics of CTGM with FRA are superior to CTGM with coarse recycled aggregates.

Using CDW to generate CTGM with 0-8 mm RA (SC20) for usage as road bases or sub-bases is suggested to be possible by this study. Furthermore, dimensional changes and mechanical characteristics of CTGM with FRA are superior to CTGM with CRA (SC40). Materials that contain more sulphur than the maximum permitted by the Spanish Code are still compliant with the rules. Vehicle traffic is prohibited for the duration of the seven-day field curing process. CTGM will not be carried out when the air temperature is over 35°C, below 5°C, or when there is intense atmospheric precipitation since it is difficult to manage the environmental impacts. To minimise dimensional changes, it is advised to utilise asphalt irrigation or any other approach that inhibits moisture loss during the curing of the CTGM. Transversal pre-cracking will also result from a spread layer that is wider than four metres.

Peerapong Jitsangiam et al. (2016), examined the fatigue characteristics of cement-treated base, a cement-stabilized material for use in pavement construction based on CTB beam test specimens which were prepared and tested in the laboratory. The beam fatigue procedure for asphalt concrete, which was created from the Austroads standard test method AG: PT/T233, was used to evaluate the fatigue properties of the CTB test specimens. The beam-fatigue tests were carried out under constant strain and stress circumstances with test specimens containing varied cement concentrations (3 per cent to 10%). This study demonstrates that the adapted asphalt concrete beam-fatigue test methodology is acceptable for determining the CTB fatigue attribute, which is difficult to obtain without a standard test technique. This would lead to more efficacious use of this material in road pavement design and construction.

The levels of applied strains had a substantial impact on the fatigue characteristics of the CTB test samples. The test findings also revealed the presence of a fatigue tolerance limit, which was discovered when the applied strain level was 150 micro-strains or fewer and the specimens were 5 per cent cement. Because of the larger cement content and initial cyclic flexural stiffness, the fatigue endurance limit rose.

Korakod Nusit and Peerapong Jitsangiam (2016) aimed to characterize damage evolutions of the bound CTB material under two loading regimes of monotonic and cyclic loading. Bound CTB specimens were performed under the testing conditions of different monotonic-compressive loading and cyclic flexural loadings loading. CTB has developed a mechanistic-based fatigue prediction model of CTB. Mechanical fatigue deterioration models of asphalt concrete and regular concrete have been created using continuum damage mechanics (CDM). These models were developed with the presumption that damage evolutions within the mass of materials are the primary cause of fatigue failure.

The damage that CTB undergoes from monotonic compressive loadings depends on the loading rates that are being used. In the cyclic flexural beam testing, the applied strain levels also had an impact on how the CTB material's damage progressed. The suggested natural logarithmic model can be used to estimate CTB damage evolutions. One of the input parameters for the fatigue life prediction model of CTB would be the damage variable. According to analytical findings, the damage variable could be used to determine CTB damage evolutions.

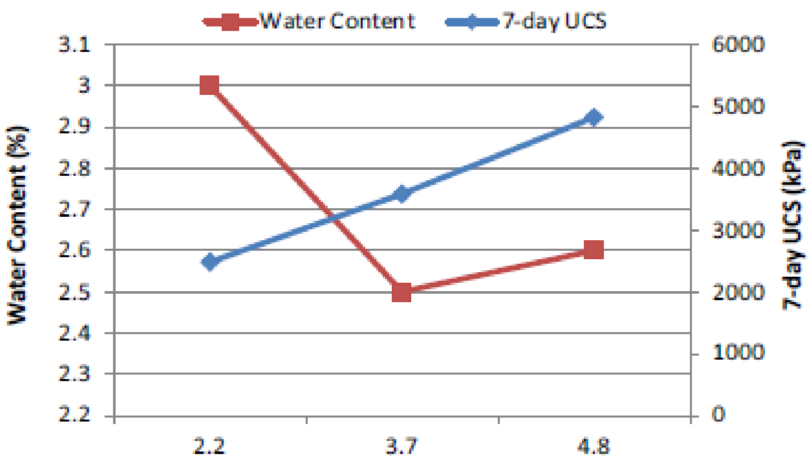
Ningyi Su et al. (2017) investigated the effects of various factors on pavement performance when various types of base courses, such as unbound aggregate base layer, asphalt treated base layer, cement treated base layer, permeable base layer, and recycled pavement base layer, are used in pavement structures. The resilience modulus, material type, base thickness, aggregate gradation, moisture content, and subbase layer property are all influence variables on pavement performance, and they are separated into internal and external causes. Furthermore, with chemically stabilised base pavement, daily temperature cycling is the primary cause of reflecting fissures.

Effect of material type

The key underlying principle of pavement structure is the fatigue performance of semi-rigid materials. The pavement's fatigue life is significantly influenced by the type of material. According to the study, the resilient modulus of cement-fly ash or lime-fly ash stabilised crushed stone was lower than cement stabilised crushed stone at the same curing time, and the coefficient of dry shrinkage of lime-fly ash stabilised crushed stone was 15.2 percent lower than that of cement stabilised crushed stone at an earlier time.

Effect of stabilizers content

The cement content in cement treatment materials was examined to satisfy the strength requirement, improve durability, and decrease moisture susceptibility. It was shown that the value of unconfined compressive strength (UCS) rose along with the cement concentration. CTB shrinkage cracking may appear at cement concentrations of 6 to 8 percent. Materials A and M1's UCS values fell within the predetermined range.



(a) Material A

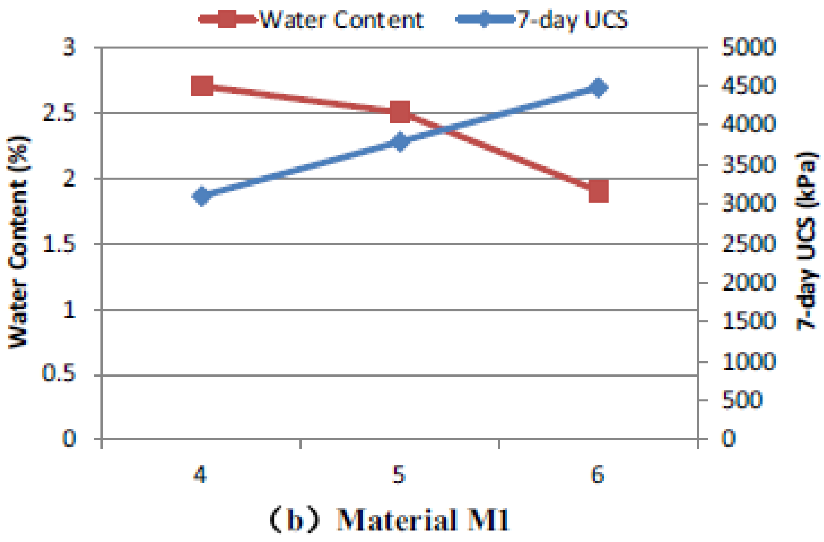


Fig. 2.1 Test results of water content and 7-day UCS: (a) material A; (b) material M1.

Rasha. Abd Al-RedhaGhani et al. (2018) investigated the influence of cement treatement on the sand-gravel mixture by presenting a laboratory investigation aimed to characterize the behaviour of CTAB at various cement portion (0,5,10,and15) % by weight of dry aggregate. Atterberg limits, California Bearing Ratio (CBR) test, unconfined compressive strength tests, and plate load test have been conducted on CTAB mixtures.

In this investigation, it was found that the strength of the cement-treated base was demonstrated by California bearing ratios (CBR) and compressive strengths that were 46 and 58 per cent, respectively, higher than the subbase.

A study by **Khawla H. Shubber et al. (2018)** presented a study on improving the mechanical properties of materials used in pavement construction, stabilized with Portland cement. The study looked at the density, optimum water content, and compression strength of three curing ages days under different situations.

In three parameters, the work looks into Portland cement's potential as a stabiliser when used with base course materials. The first parameter focuses on choosing an ideal percentage of cement addition based on the CTB's maximum dry density, ideal water content, and compressive strength after three curing ages (3, 7, and 28 days); the second parameter examines the impact of replacing half of the aggregate with WPCC and a particular gradation in the chosen ideal percentage of cement on the CTB's maximum dry density, ideal water content, and compressive strength after three curing ages. Studying the impact of aggregate soaking in water for the ideal cement percentage on CTB's on compressive strength in three curing periods is the final step (3,7 &28 days).

Compressive strength for the three ages (3, 7, & 28 days) of CTB containing 50% WPCC (waste Portland cement concrete) is lower than pure base course aggregate. The optimal water content for CTB grew as cement content increased until it reached a value of about 7%. By increasing cement percentage and curing times, CTB's compression strength steadily rose.

By altering the proportions of virgin aggregate (VA), recycled asphalt aggregate (RA), and cement content, **Sridhar Reddy Kasu et al. (2020)** showed the mechanical, durability, and microstructure characteristics of cement treated recycled asphalt (CTRA) bases and sub-bases material. Cylindrical specimens were prepared using the modified proctor method of compaction with different mixes of VA and RA at 2.5, 5.0, 7.5, and 10.0 per cent cement content (per cent by weight of aggregate). To evaluate the performance of combinations during repeated wetting and drying in a tropical setting, durability experiments were conducted.

Experimental findings showed that cement addition to CTRA had a stronger effect on mechanical and durability properties than RA concentration. Although the CTRA mixtures had lower elastic modulus values, it was found that they were more ductile. A detrimental effect on mechanical attributes is indicated by the larger percentage of these products. According to a cost study for a typical pavement section, the cost-savings of the pavement section with CTRA mixtures were reported to be in the range of 26–32% under various cement and RA contents when compared to the pavement section without CTRA. These mixtures have been discovered to be an effective substitute for roller-compacted concrete bases and sub-bases in flexible pavements as well as bases for concrete pavements.

Songtao Lv et al. (2019) used unconfined compressive and flexural strength tests with curing times of 3, 7, 14, 28, 60, and 90 days to reveal the characteristics of strength and fatigue damage in a cement-treated aggregate foundation. Flexural strength fluctuation with curing intervals and loading rates was modelled using a power function. In addition, the flexural fatigue equation and fatigue damage model were established in this work under various curing durations.

The test results showed that the curing periods significantly influence cement-treated aggregate base materials' strength and fatigue performance. The fatigue resistance of cement-treated aggregate foundation materials steadily gets better as the curing times are extended. Therefore, by extending their curing times, cement-treated aggregate base materials' fatigue life can be efficiently increased.

Using the continuum damage mechanical technique, **Peerapong Jitsangiam et al. (2021)** connect theoretically the knowledge of CTB damage behaviour gained from laboratory studies. The Australia Road Research Board conducted four-point bending fatigue-life tests on laboratory CTB specimens and compared the results to full-scale fatigue testing. Three important conclusions were drawn after characterising and comparing the damage evolution curves generated by the two tests.

2.2 LITERATURE REVIEW ON USE OF FLY ASH FOR PARTIAL REPLACEMENT OF CEMENT IN CTB

Michiel Willem Heyns (2016) sought to create a less expensive option by employing Fly Ash as a greater percentage stabilisation agent with a partial mixture of cement/lime in order to lower the price of cement/lime and decrease the amount of Fly Ash that is dumped in landfills. The requirements outlined in the standards used in this study must be followed when using fly ash as a soil stabiliser. The objective is to conclude that fly ash is suitable as a soil stabiliser once the results of the fundamental design processes have been evaluated. The core design phases adhere to the laboratory design techniques suggested by the Committee of Land Transport Officials for evaluating a material's strength, workability, and durability (COLTO, 1998).

The objectives of the study are:

- To determine if Fly Ash can be used as a partial replacement for cement/Lime and what will the cost difference be to investigate the product's qualities and efficiency using various test samples.
- The characterization of Ash and the outcomes of the chemical processes when fly ash is utilised as a stabiliser.

- To give some indication of the efficiency of stabilising using coal fly ash.

Fly Ash's contribution to soil improvement, as shown in this study, gives a significant benefit to engineering practice in the following manner:

- In all the required specified testing, the Fly Ash has shown that it is a viable option for stabilisation projects.
- According to the study, short-term cure, as used in South Africa, had a positive impact on the results compared to reference samples rather than having a negative one.
- The Fly Ash has potential and the ability to enhance pavement properties.
- Fly Ash creates durable and durable material to withstand shear forces.

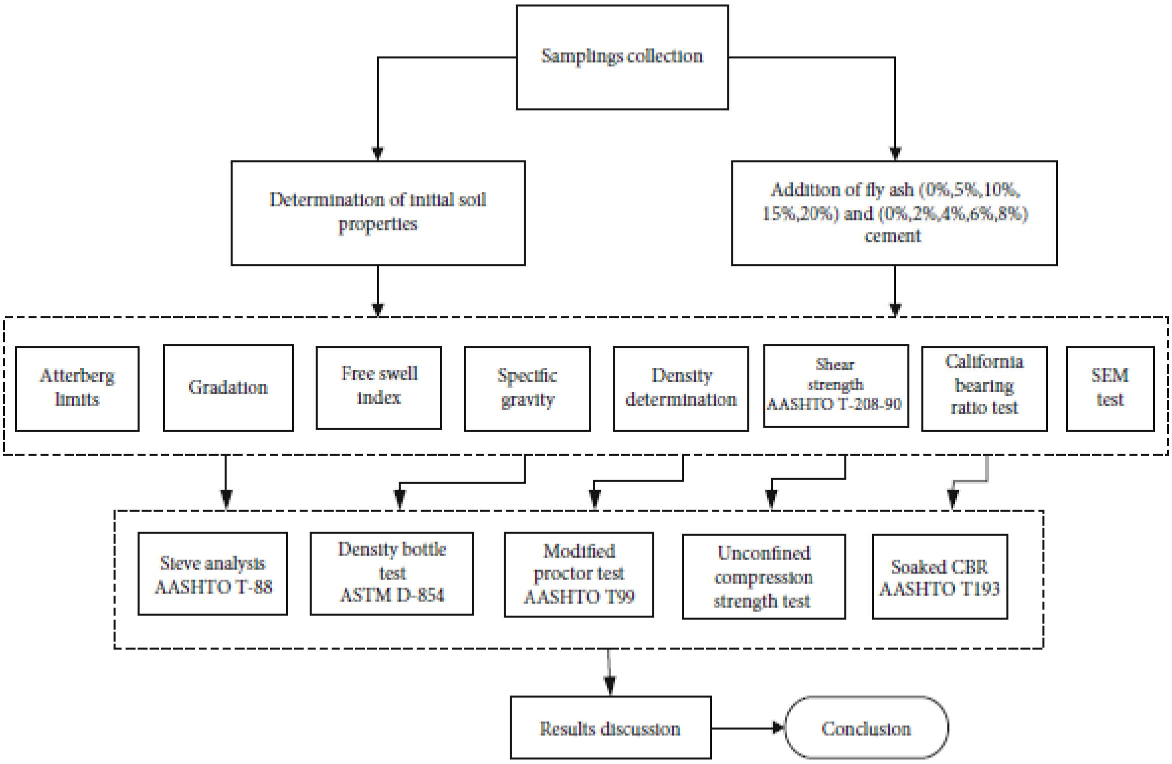


Fig. 2.2 Subgrade soil tests with and without additives.

2.3 LITERATURE REVIEW ON FDR

Andrew Braham (2016) contrasted three full-depth reclamation technologies—asphalt emulsion, asphalt foam, and portland cement—against chip seals, overlays, mill and fill, and full reconstruction. Using life-cycle cost analytic methods, it was shown that user expenses ranged from one-fourth to five times those of the agency. Although full-depth reclamation is cost-effective when compared to previous methods, it was less so on roads with larger ratios of bounded to unbounded material. Finally, at reclamation depths of more than 10 in, traffic capacity rose dramatically. Overall, full-depth reclamation appears to be an economically viable alternative to chip sealing, overlays, mill and fill, and complete reconstruction, assuming the correct traffic and bound pavement depth.

The experimental results of stabilising aggregates and recovered asphalt pavement (RAP) with cement for use as a treated base coarse in the full-depth reclamation (FDR) process were examined by **Ali Reza Ghanizadeh et al. (2018).** In this study, two different kinds of aggregate soils were used. Compaction and unconfined compressive strength (UCS) tests were carried out on a range of RAP to aggregate ratios of 0/100, 20/80, 40/60, and 60/40. Following compaction, the samples were given four different cement concentrations to cure for 7 and 28 days: 3, 4, 5, and 6 percent. The UCS value for the stabilised containing two SP-SC and GW-GC rose by an average of 376 and 410 kPa when a constant RAP percentage and an increase of 1% of Portland cement were anticipated.According to this study, the elastic modulus of the FDR layers can be calculated to be between 9000 and 40,000 kPa depending on the soil type and RAP dose. The results indicate that between 3 and 4 percent for SP-SC soil and between 3 and 5 percent for GW-GC soil is the ideal Portland cement percentage for the construction of FDR layers.

Eskedil Melese et al. (2018) assessed the effects of blended cement, also known as Hydraulic Road Binder, on the strength and durability of FDR pavement materials based on laboratory experiments. Two types of recovered pavement materials and three types of mixed cement were used in the test. In addition, control mixes were made with GU cement. The unconfined compressive strength (UCS) test was used to determine the strength of the stabilised materials. The UCS test was carried out on compacted specimens that had been moist cured for 7 and 28 days with varied binder contents. A freeze-thaw test was used to determine the durability of the product. This test was carried out on compressed specimens with optimal binder content. ANOVA, Fisher's test, and Dunnett's test were used to analyse the results of UCS and freeze-thaw tests in order to ascertain the effects of the blended cement on the strength and durability of the full-depth recovered pavement materials. The investigation's findings suggest that blended cement can offer full-depth reclamation projects similar or perhaps better strength and durability to GU cement.

Rishi Singh Chhabra, et al. (2021) has done work on the sustainable method of utilization of 100% RAP material (up to 300 mm depth) at the site by Full-depth reclamation (FDR) using OPC of grade 43 as per Indian Standards IS: 8112 with Stabilroad (SR) Stabilizer. One of the preliminary research into whether complete recycling of RAP material in FDR technology can be profitable was combining the right amount of cement with the research stabiliser.

The objective was to evaluate the mechanical characteristics of a CTB mixture made completely of RAP material, including its unconfined compressive strength (UCS), moisture-density relationship (MDD-OMC), California bearing ratio (CBR), and durability characteristics. A 15 km test stretch was built to determine the sustainability of the designed mix. Cement and chemical stabiliser was added in various amounts, while RAP materials were added in a set amount, to form the CTB mix. The wetting-drying method studied the durability properties of the core samples for long-term pavement performance. Additionally, FWD calculated the response of the design pavement to the design traffic load in terms of stress, strain, and defection.

The UCS value of 5.28 MPa has obtained a mix containing 4.5% cement and 4% Stabilroad Stabilizer. After 28 days of curing, the UCS was noted as 6.23 MPa. Now it can be concluded that the unconfined compressive strength of the mix can be increased by increasing the curing time from 7 to 28 days.

The CBR value increased as the cement and chemical stabiliser amount increased. Despite the fact that many of the moulds made had CBR values greater than 100 per cent, a mix prepared with 4.5 per cent cement and 4 per cent chemical stabiliser was chosen for future experimental work based on UCS test values as well. All of the samples were thoroughly examined for expansion, and none were found to have increased in size, resulting in good performance even when wet.

A durability analysis on the main sample of the field data revealed no volume change, supporting the durability. Following the durability test, the average residual UCS of stabilised RAP material cores was 4.8 MPa.

To fully grasp the precise field circumstances, the FWD was carried out on-site in a staggered fashion. The largest data spacing used for deflection measurement on a two-lane single carriageway was 500 m. Costs are reduced by 44.54 percent when 100% RAP material is used, together with a certain amount of cement and chemical stabiliser.

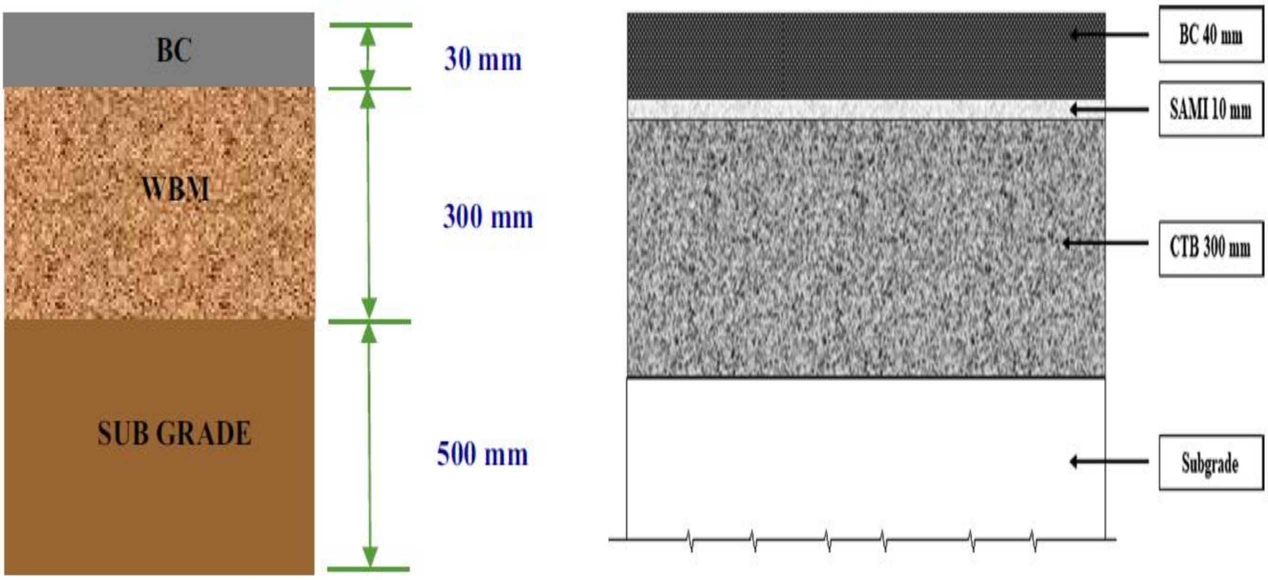


Fig. 2.3 (a) Cross-section of old pavement (b) Detail of new pavement layer.

Vishwa V. Beesam et al. (2021) compared the long-term performance of 11 FDR sites erected in Colorado, United States, to ME forecasts. The goal of the article is to suggest input parameters for the ME design of FDR materials that result in trustworthy long-term performance forecasts. Both non-stabilized and emulsion-stabilized FDR projects are included in the analysis. Both the initial IRI and the robust modulus were identified to have substantial impact on ME predictions and were calibrated in two steps. When compared to the ones generated from the current design criteria. IRI forecasts were on average 51 in./mi overestimated with the current design parameters, whereas the specified input parameters minimise this discrepancy to 17 in./mi.

2.4 OBJECTIVES

The key objectives of the study are:

- To determine the per cent of Cement and fly ash added for the base course stabilisation.
- To study the engineering properties and effectiveness of the stabilized mix.
- To determine the most economical section for high-volume and low-volume roads.
- To study the application of the FDR technique for low-volume roads.

2.5 OUTLINE OF DISSERTATION

This dissertation has been characterized into six chapters:

- Chapter 1 is about the general introduction of the pavement and its elements and the basic concept of the stabilized layers & full-depth reclamation (FDR) and its advantages.
- Chapter 2 provides the literature review on the stabilization of the base layer with cement and fly ash and the FDR technique of pavement rehabilitation.
- Chapter 3 includes the methodology of the study and the experimental programs for the materials and their properties.
- Chapter 4 explains the outcomes of the experiments performed.
- Chapter 5 is about the analysis and design of flexible pavement for various combinations.
- Chapter 6 provides conclusions on all the parameters of the dissertation.

3.1 METHODOLOGY

This section briefly summarizes the findings of studies performed for the objectives defined in areas pertaining to cement-treated materials; factors affecting the unconfined compressive strength of cement-treated base samples and durability of the cement-treated base materials. The findings concerning the unconfined compressive strength are evaluated in more detail.

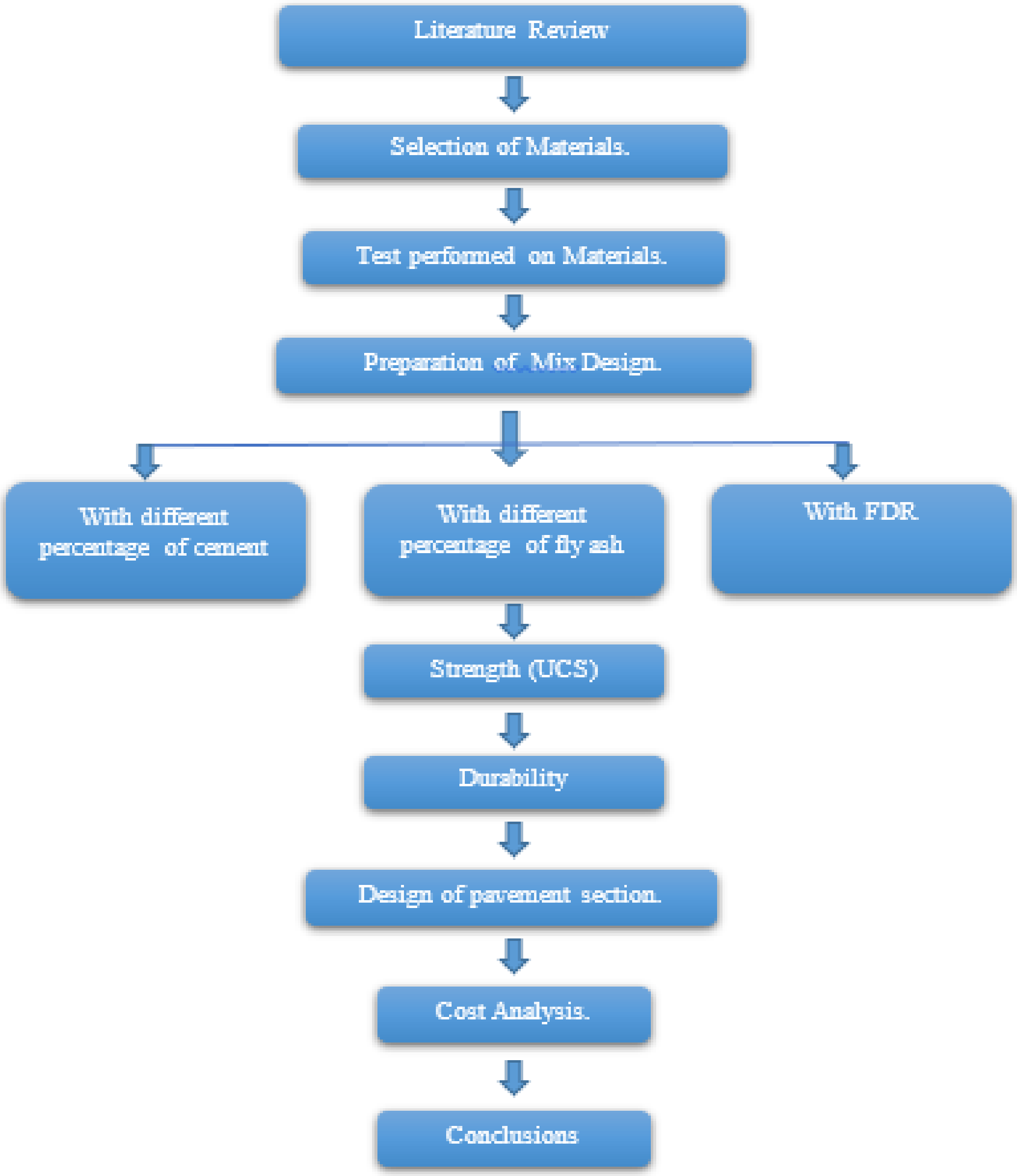


Fig. 3.1 Methodology

3.2 MATERIAL USED

This section explains the materials and procedures used in this investigative study in detail. Different size aggregates were collected from Patiala. Cement (OPC) was collected from Patiala through a local vendor. The aggregates used in the CTB mix design have different sizes, which are 40 mm, 20 mm, 10 mm, and stone dust. Aggregate shape, size and surface texture play an essential role in the CTB mix design. Table 3.1, shown below, shows the various specifications for the physical properties of aggregates for CTB.

Table 3.1: Physical properties of aggregates for CTB

S. No.	Properties	Tests	Description	IS Codes
1.	Grain Size, Analysis and particle shape	Dust	Max 5% passing through 0.075 mm	IS: 2386 Part I
		Combined Flakiness and Elongation index	Max 35%	
2.	Strength	Los Angles abrasion value	Max 30%	IS: 2386 Part IV
		Aggregate impact value	Max 40%	
3.	Durability	Water absorption	Max 2%	IS: 2386 Part III

3.2.1 Properties of aggregates

As discussed in table 4.1, the aggregate shape, size and surface texture of different grades is important because this has more influence on the physical nature of dense-graded mixes than the coarse graded aggregates. Good angularity and rugged texture are required as it helps prevent rutting and fatigue cracking. Cubical particles are adopted more than the flat or round edges and elongated aggregates.

3.2.2 Water absorption

Porosity or water absorption is one of the fundamental properties of aggregates, which should be no more than 2%. Generally, it is supposed that a high absorption rate leads to poor quality in mix design, but for all cases, it is not true; up to 7% max porosity is allowed in various places.

3.2.3 Toughness and abrasion resistance

Aggregate should offer good toughness and abrasion resistance to overcome the aggregate breakdown during construction and after paving under the service life of traffic. If the aggregate breakdown, it will come out from the pavement surface and cause a fractured road surface. So aggregate impact value is maxed up to 27%, and Los abrasion value is up to 35%.

3.4.4 Durability and soundness

Durability is discussed above that it should be durable enough to withstand the traffic efficiently without any weathering. If the aggregates are unsound, the problem of aggregate loss will happen.

3.5.5 Specific gravity

This property of aggregates is used in forming weight-volume modification for knowing the voids parameters in CTB mix design. The weight of a unit volume of sample divided by the weight of an identical volume of water at 23^{o}C is known as specific gravity.

Specific gravity = Weight in gms / volume in ml.

There are three types of specific gravity which are bulk, apparent, and effective.

3.6.6 Results of the physical properties of aggregates

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

  (a) 40 mm aggregate: 0.56%

  (b) 20 mm aggregate: 0.63%

  (c) 10 mm aggregate: 0.78%

  (d) Stone dust: 1.26%

3.3 CEMENT

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 3.2: Physical properties of cement

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

Table 3.3: 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

3.4 FLY ASH

The main components of fly ash are silicon, aluminium, iron, and calcium oxides. In lesser amounts, magnesium, potassium, sodium, titanium, and sulphur are also found. Fly ash is categorised as either Class C or Class F ash depending on how it is utilised as a mineral additive in concrete. The chemical makeup of Class C and Class F fly ash is outlined in American Association of State Highway Transportation Officials (AASHTO) M 295 [American Society for Testing and Materials (ASTM) Specification C 618].

In this study, the class C fly ash is used. When used in portland cement, Class C fly ash can be used as a portland cement replacement ranging from 20-35% of the mass of cementitious material.

Table 3.4 Class C fly ash chemical composition

Properties	Requirements (ASTM C618), %
$SiO_2 + Al_2O_3 + Fe_2O_3$, min	50
SO_3, max	5
Moisture content, max	3
Loss on Ignition, max	6

Advantages of using class C -

- Increases early compressive strength.
- Produces less heat generation during hydration.
- Decreases permeability.
- Increases workability.

3.5 CHEMICAL STABILIZERS

Chemical stabilisers from Zydex named TerraSil and ZycloBond are used as a liquid cement additive. Chemical stabilisers are recommended to be mixed at a rate of 0.5 per cent to 5.0 per cent by weight of cement content (IRC: SP: 89). It is theorized that mixing TerraSil & ZycloBond with cement speeds up the hydration process, resulting in a more stable base.

- ***TerraSil***

  For soil sub-layers and gravel roads, moisture loss is the most significant cause of failure. Water infiltration can cause ruts, cracks, and ravelling by causing the soil to expand and lose cohesiveness. The life cycle cost of pavement is significantly increased when it is exposed to substantial water damage. TerraSil is a simple-to-use soil modification that prevents water from infiltrating soils perpetually. Improving the water-resistance of the soil base/gravel road has a substantial impact on overall life cycle costs. The properties of TerraSil are;

  - Reduces water permeability.
  - Reduces expansivity.
  - Increases compaction.

- ***ZycoBond***

  ZycoBond is a flexible acrylic copolymer with a surface area of 80-90 nm that can be used for bonding. The increased number of contact points ensures flexible nano bonding, which improves fatigue resistance in stabilised soils. When ZycoBond is used in combination with TerraSil, it provides increased strength and flexibility, permitting for dimensionally stable, non-deforming bases.

3.6 RECLAIMED PAVEMENT MATERIAL (RPM)

Reclaimed pavement material was supplied by Zydex Industries from the old distressed pavement section of the rural road of PMGSY. The RPM was taken up to 300 mm depth from the pavement surface.

3.7 MIX DESIGN

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 3.5.

Table 3.5: Detail of CTB mixtures.

Mixture ID	Coarse & fine aggregate (%)				Additive's content (%)	
	40 mm	20 mm	10 mm	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 3.6.

Table 3.6: Detail of FDR mixtures.

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

3.7.1 Mix design procedure.

- Physical and chemical testing of aggregate, cement, and water.
- Selection of Proportion of materials like aggregates, dust and cement (% weight) to form CTB is done with the help of MORTH table 400-4.
- The final CTB undergoes sieve analysis and is compared with MORTH table 400-4. Then, according to IS 2720, the Modified Proctor test is used to measure the Max. Dry Density (MDD) and Optimum Moisture Content of CTB with minimum cement content (Part 8).
- Find Liquid Limit, Plastic Limit and Plasticity Index according to IS 2720 (part 5).
- Plasticity Modulus and Product are determined according to IS 2720 (part 5).
- Water absorption of material larger and less than 10mm in size is found according to IS 2386 (part 3).
- Then cubes are cast with the help of Vibro Hammer (DLC).

Fig. 3.2 (a) CTB mix (b) RPM (c) DLC Vibro Hammer

3.8 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.

3.8.1 Individual gradation of aggregates for CTB

Type of material – 40 mm aggregates

Weight of sample – 5 kg

Table 3.7: Gradation of 40 mm aggregate.

IS Sieve size (mm)	Wt. of material retained (kg)	Cumulative wt. retained (kg)	Cumulative retained (%)	Passing (%)
53.00	0.00	0.00	0	100
37.50	0.150	0.15	3	97
19.00	4.094	4.244	84.88	15.12
9.50	0.726	4.97	99.4	0.6
4.75	0.00	4.97	99.4	0.6
0.600	0.00	4.97	99.4	0.6
0.300	0.002	4.99	99.8	0.2
0.075	0.001	5.00	100	0

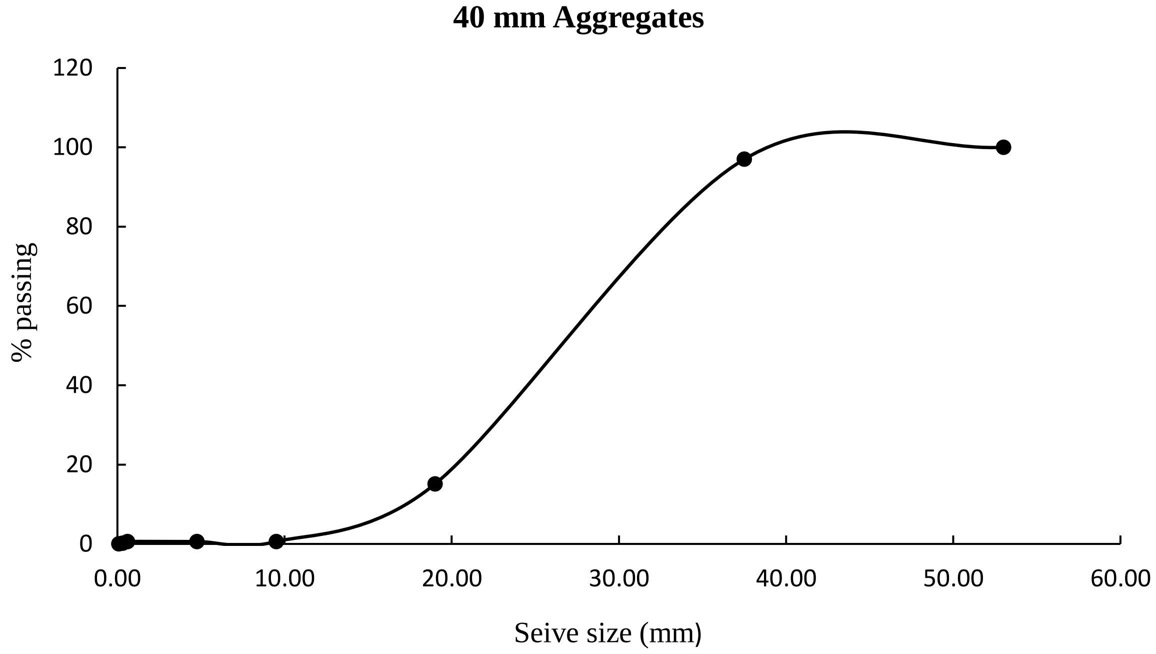


Fig. 3.3 Gradation of 40 mm aggregates

Type of material – 20 mm aggregates
Weight of sample – 5 kg

Table 3.8: Gradation of 20 mm aggregate.

IS Sieve size (mm)	Wt. of material retained (kg)	Cumulative wt. retained (kg)	Cumulative retained (%)	Passing (%)
53.00	0.00	0.00	0	100
37.50	0.00	0	0	100
19.00	0.180	0.18	3.6	96.4
9.50	4.356	4.536	90.72	9.28
4.75	0.45	4.986	99.72	0.28
0.600	0.002	4.988	99.76	0.24
0.300	0	4.988	99.76	0.24

0.075	0	4.988	99.76	0.24

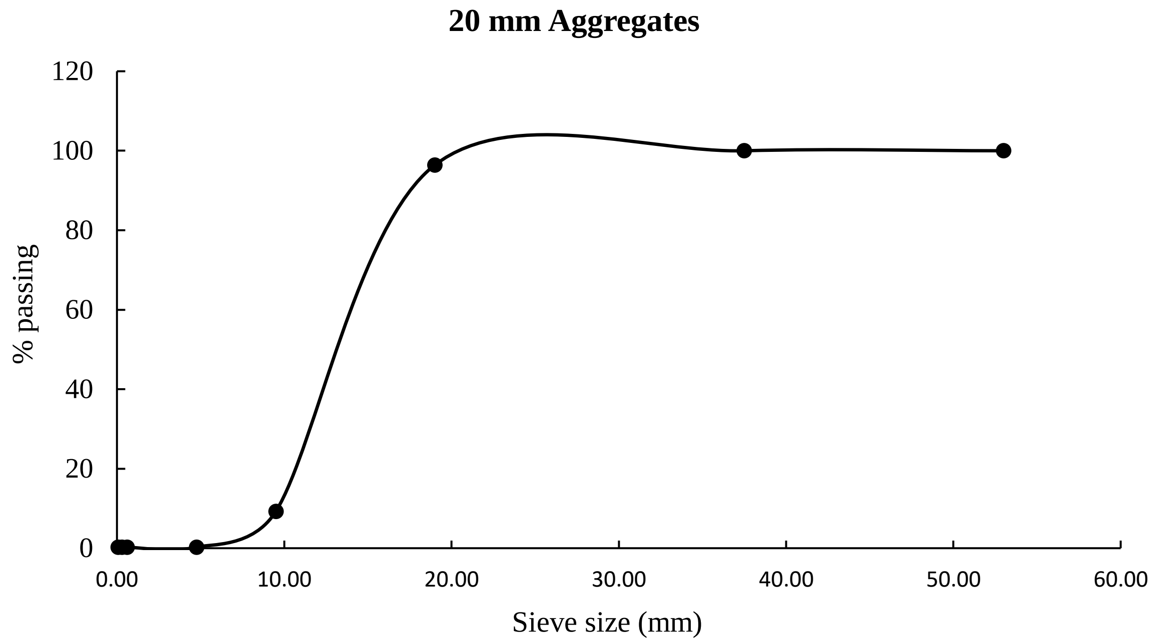


Fig. 3.4 Gradation of 20 mm aggregates.

Type of material – 10 mm aggregates
Weight of sample – 5 kg

Table 3.9: Gradation of 10 mm aggregate.

IS Sieve size (mm)	Wt. of material retained (kg)	Cumulative wt. retained (kg)	Cumulative retained (%)	Passing (%)
53.00	0.00	0.00	0	100
37.50	0.00	0.00	0	100
19.00	0.00	0.00	0	100
9.50	0.928	0.928	18.56	81.44
4.75	3.152	4.08	81.6	18.4

0.600	0.784	4.86	97.28	2.72
0.300	0.084	4.95	98.96	1.04
0.075	0.032	4.98	99.6	0.4
Pan	0.016	5.00	99.92	0.08

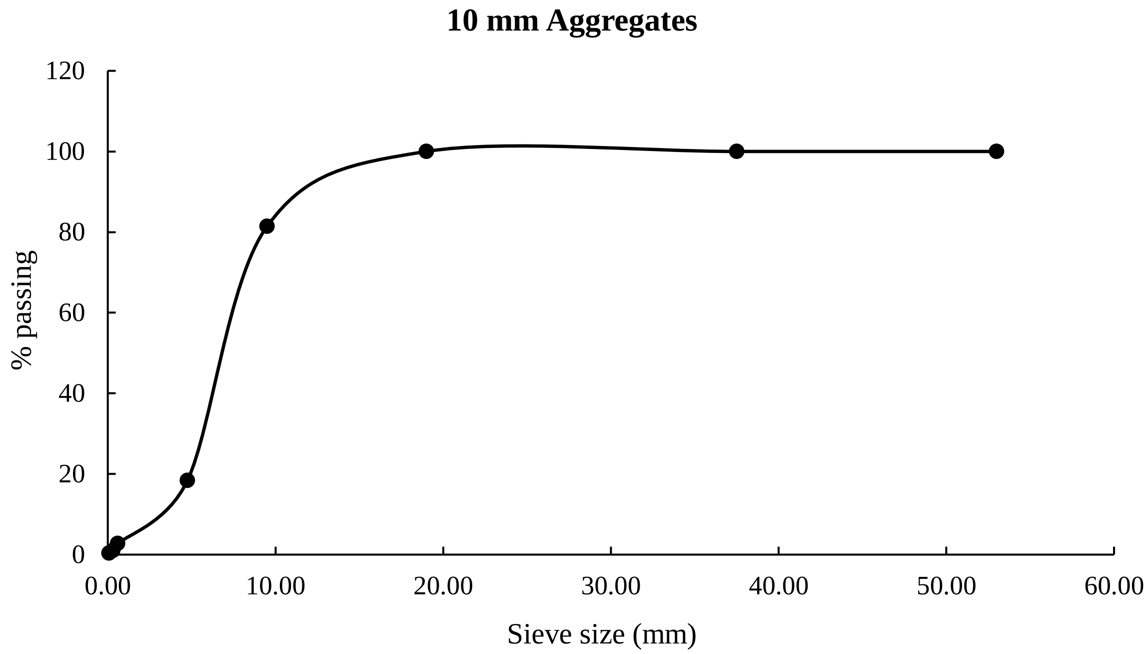


Fig. 3.5 Gradation of 10 mm aggregates.

Type of material – Stone dust
Weight of sample – 5 kg

Table 3.10: Gradation of stone dust.

IS Sieve size (mm)	Wt. of material retained (kg)	Cumulative wt. retained (kg)	Cumulative retained (%)	Passing (%)
53.00	0.00	0.00	0	100
37.50	0.00	0.00	0	100
19.00	0.00	0.00	0	100

9.50	0.00	0.00	0	100
4.75	0.623	0.623	12.46	87.54
0.600	2.210	2.833	56.66	43.34
0.300	0.900	3.733	74.66	25.34
0.075	1.210	4.943	98.86	1.14
Pan	0.037	4.980	99.6	0.40

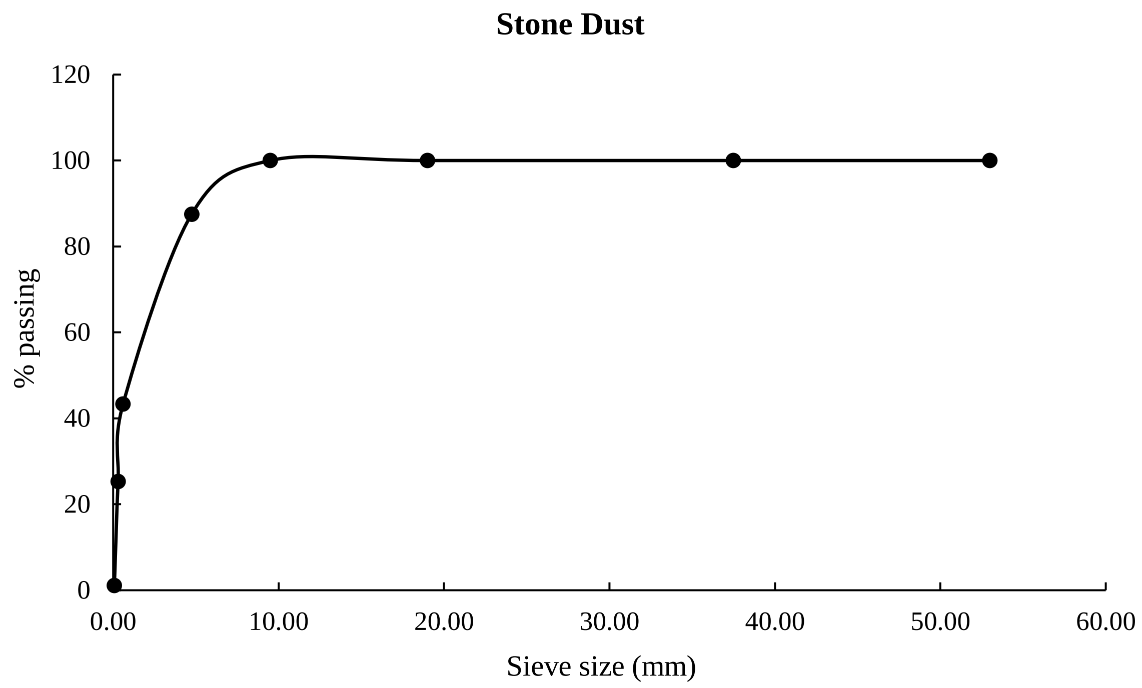


Fig. 3.6 Gradation of stone dust.

3.8.2 Blending for CTB

The blending of different aggregate sizes was required to obtain the desired composition for CTB.

- ***Theoretical Blending***

Table 3.11: Theoretical Blending Report of CTB.

Sieve Size (mm)	% of Passing				% of blending				% of Passing	Mid value	Specified Limits as MoRTH Table 400-4 & IRC sp 37-2018
	40 mm	20mm	10 mm	Dust	40 mm	20 mm	10 mm	Dust			
					25	16	24	35	100		
53	100	100	100	100	25.00	16.00	24.00	35.00	100.00	**100**	**100**
37.5	97	100	100	100	24.25	16.00	24.00	35.00	99.25	**97.5**	**95-100**
19	15.12	96.4	100	100	3.78	15.42	24.00	35.00	78.20	**72.5**	**45-100**
9.5	0.6	9.28	81.44	100	0.15	1.48	19.55	35.00	56.18	**67.5**	**35-100**
4.75	0.6	0.28	18.4	87.54	0.15	0.04	4.42	30.64	35.25	**62.5**	**25-100**
0.6	0.6	0.24	2.72	43.34	0.15	0.04	0.65	15.17	16.01	**36.5**	**8-65**
0.3	0.2	0.24	1.04	25.34	0.05	0.04	0.25	8.87	9.21	**22.5**	**5-40**
0.075	0	0.24	0.4	1.14	0.00	0.04	0.10	0.40	0.53	**5**	**0-10**

- ***Practical/confirmatory combined gradation of CTB***

Table 3.12: Practical 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 3.13: 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**

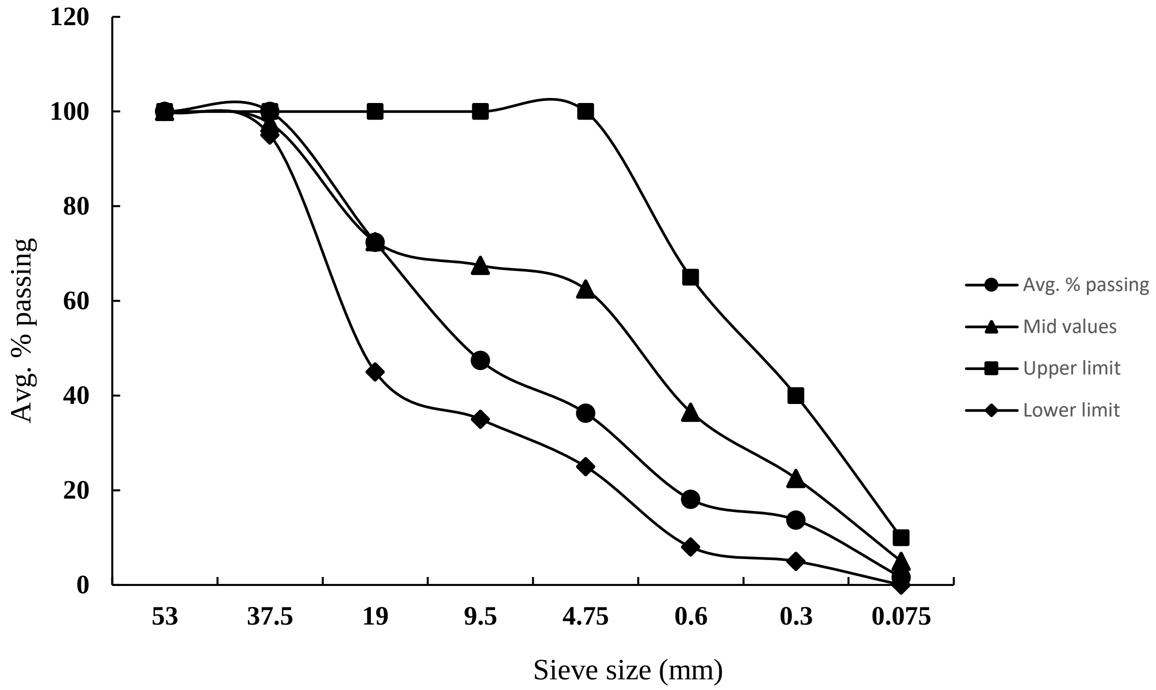


Fig. 3.7 Confirmatory combined gradation.

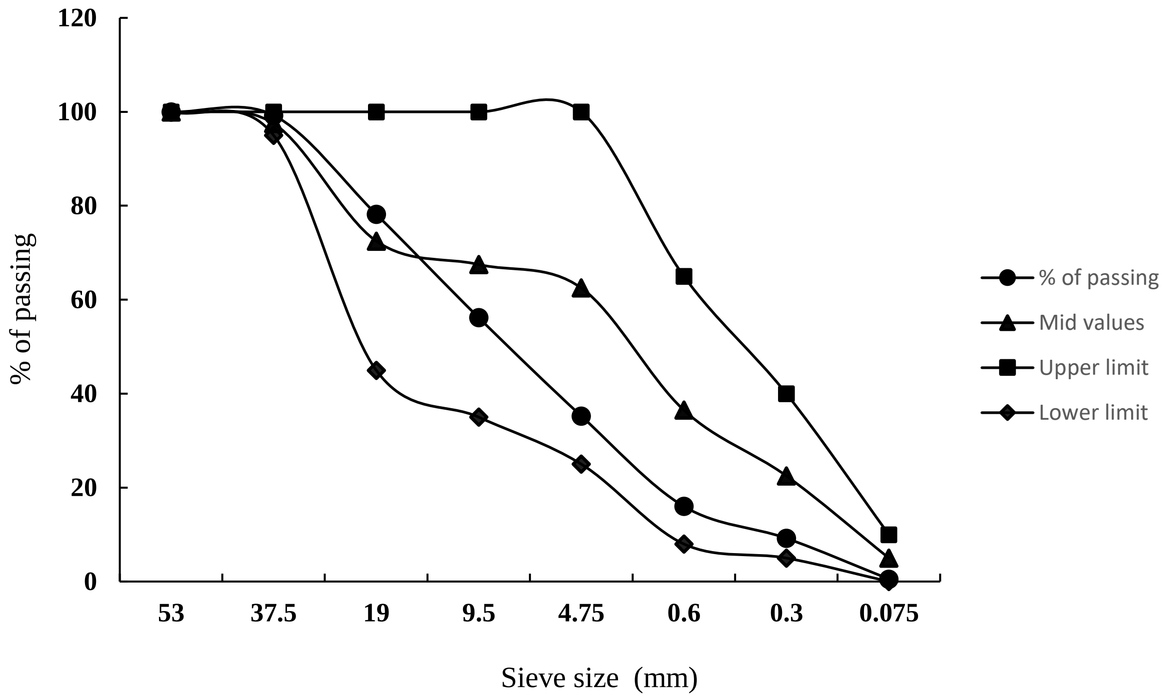


Fig. 3.8 Theoretical blending report.

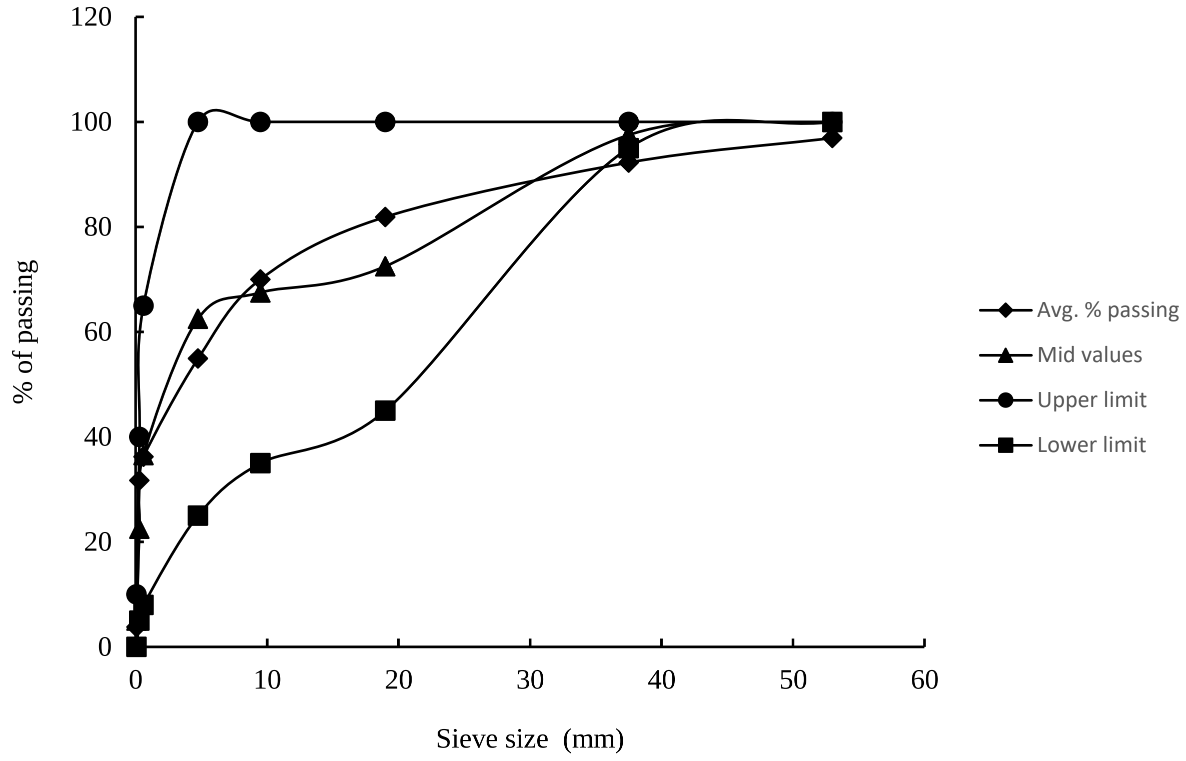


Fig. 3.9 Confirmatory combined gradation of RPM.

3.9 MOISTURE–DENSITY RELATIONSHIP

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for cement-treated base (CTB) mixtures were determined after replacing the aggregate fraction retained on 22.4 mm IS Sieve with the material of 4.75 mm to 22.4 mm size following IS: 2720 (Part VIII). A laboratory compaction test aims to determine the proper amount of mixing water when compacting in the field and the resulting impact of denseness, which can be expected from compaction at the optimum moisture content (OMC). It is important to do a laboratory test that will yield a level of compaction like that discovered using the field method. In this instance, a bigger 150 mm mould with a volume of 2250 cm3 was used to conduct the modified compaction test according to IS: 2720. (Part VIII). Five layers of the CTB mixture were compacted, and each layer received 55 blows from a rammer that weighed 4.9 kg and had a 450 mm free-falling drop. Before adding the materials for the following compacted layer, each layer was scarified to improve interlocking between the layers and reduce specimen cracking. To find the optimum moisture content for the mix design of CTB modified proctor test was performed with different percentages of cement content and fly ash. Table 4.11 shows the test results done with different cement content and fly ash with an increment of 1% and for FDR the cement content varied from 2-4%. The cement used is OPC – Grade 43.

Table 3.14: OMC – MDD test results.

Mixture ID	Modified Proctor Test	
	OMC (%)	MDD (gms/cc)
M1	6.68	2.162
M2	6.63	2.170
M3	6.52	2.175
M4	6.51	2.177
M5	6.60	2.166
M6	6.58	2.173
M7	6.55	2.179
M8	6.53	2.182
M9	6.60	2.175
M10	6.74	2.173
F1	7.92	2.246
F2	8.20	2.297
F3	8.50	2.270
F4	9.40	2.325

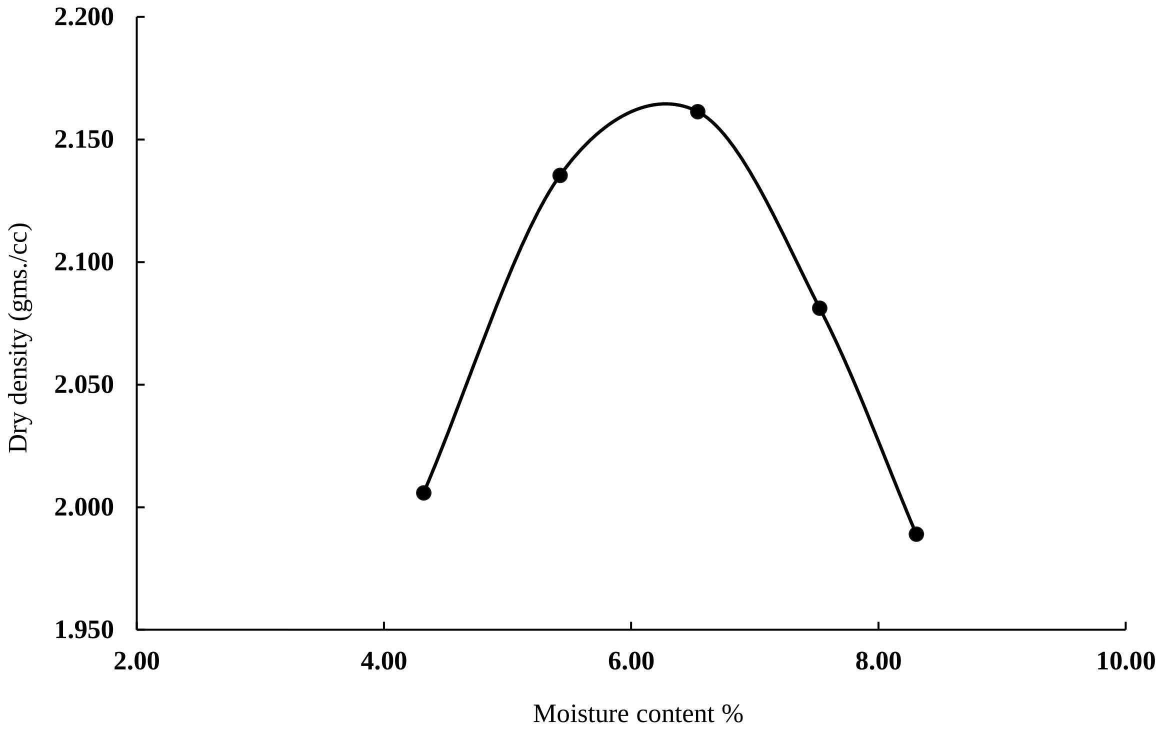


Fig. 3.10 OMC – MDD relationship with 2% cement.

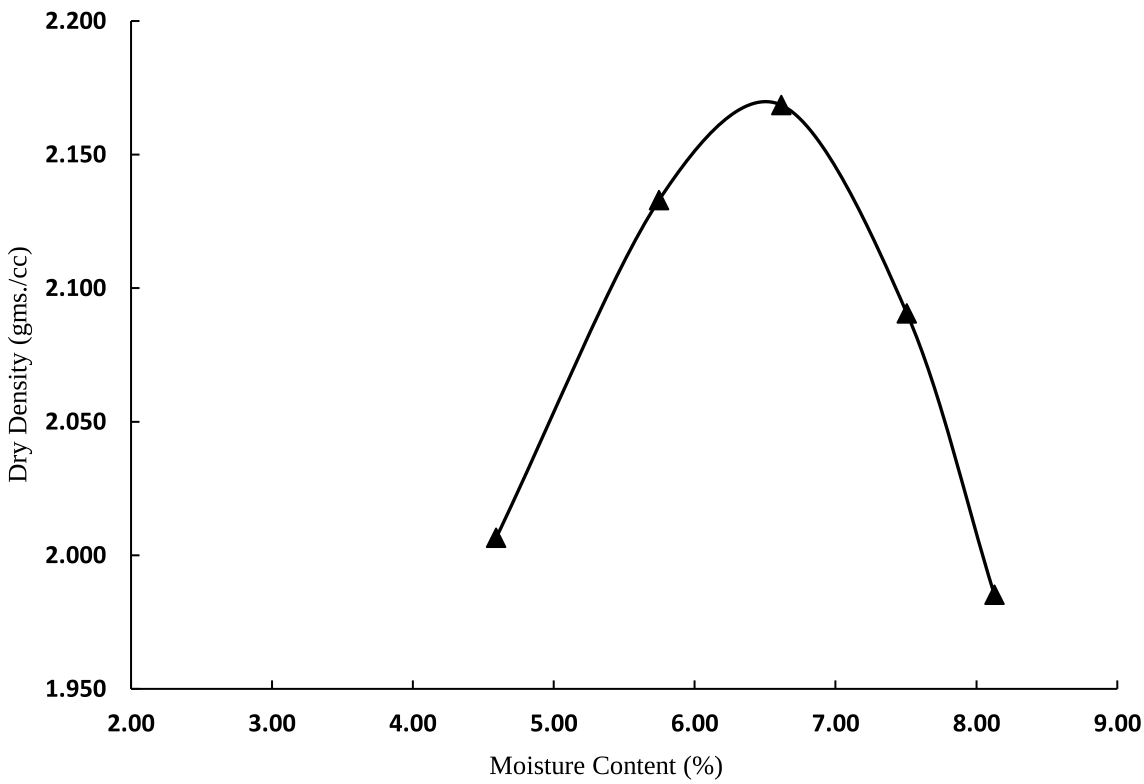


Fig. 3.11 OMC-MDD relationship with 3% cement.

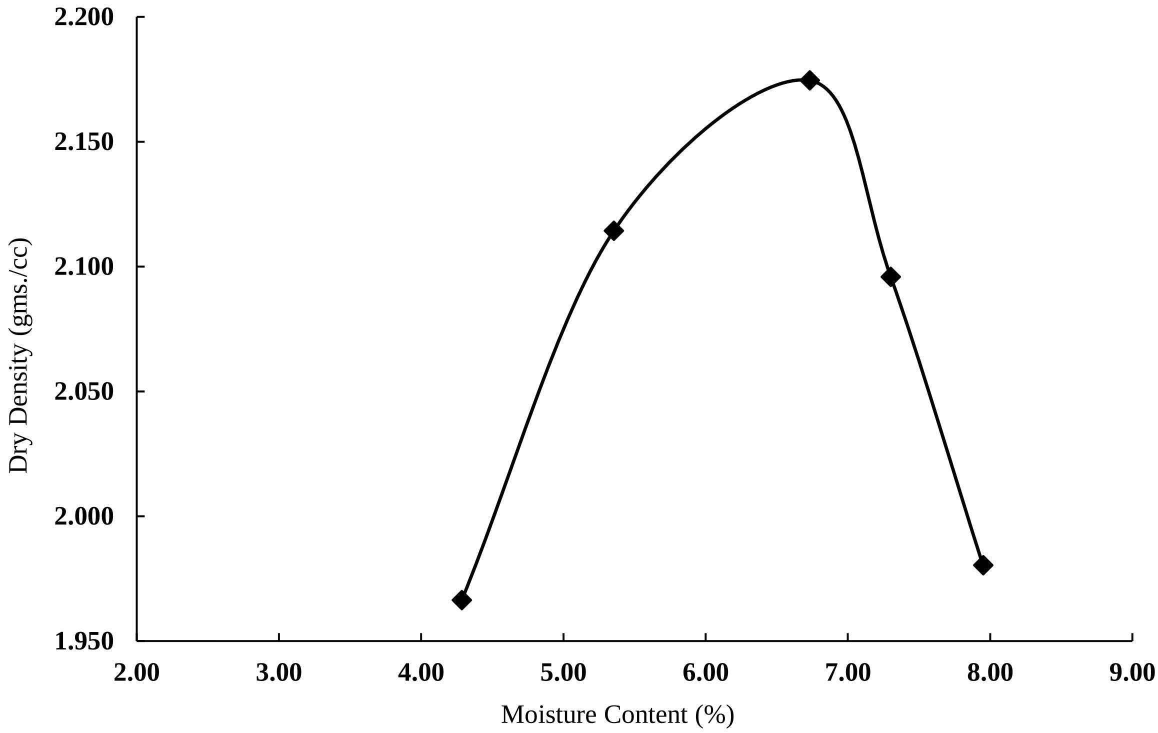


Fig. 3.12 OMC-MDD with 4% cement.

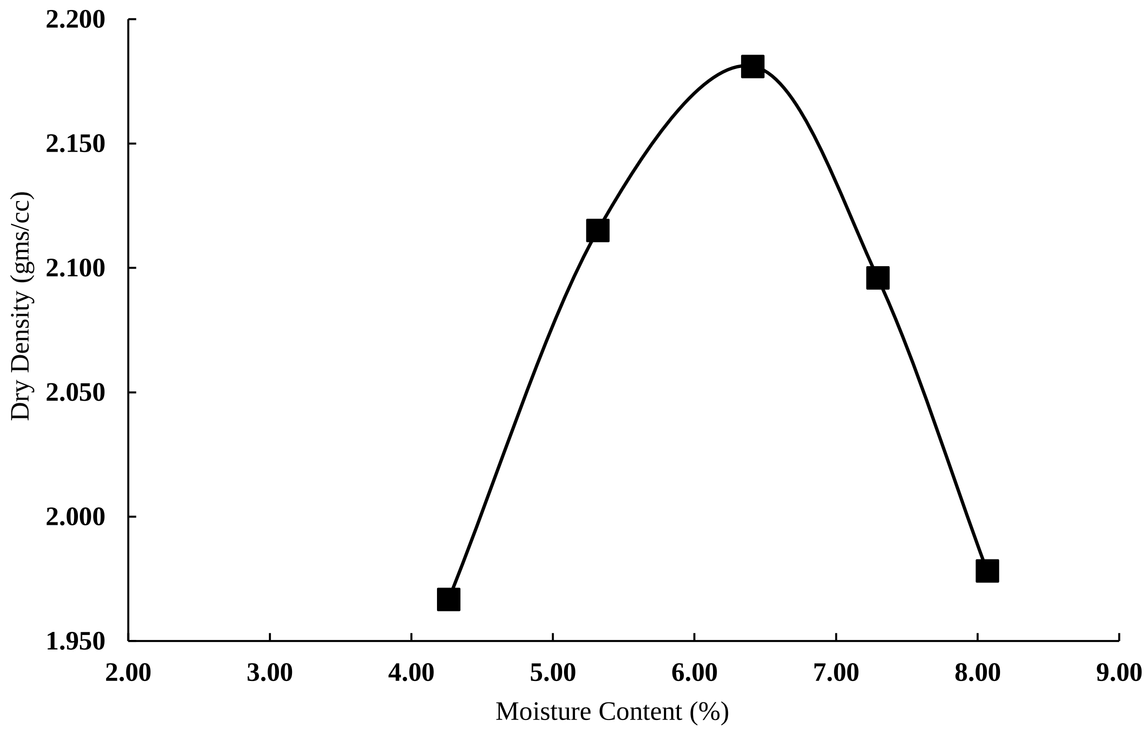


Fig. 3.13 OMC – MDD relationship with 5% cement.

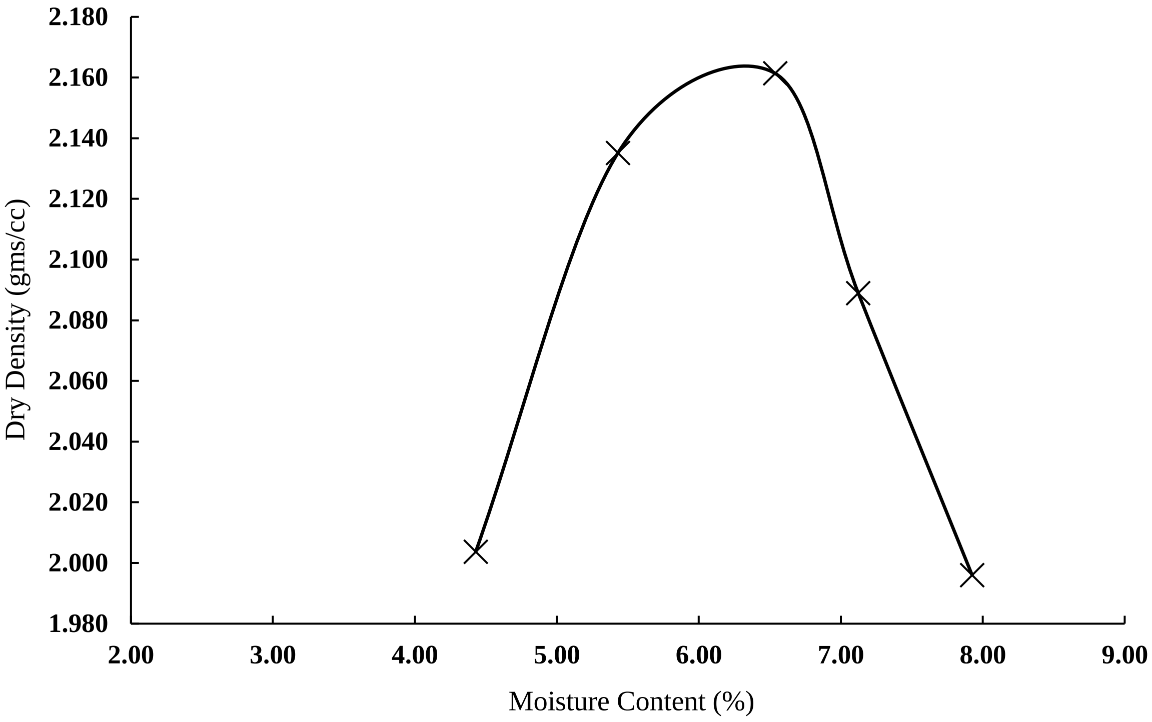


Fig. 3.14 OMC – MDD relationship with 2% cement & 1% fly ash.

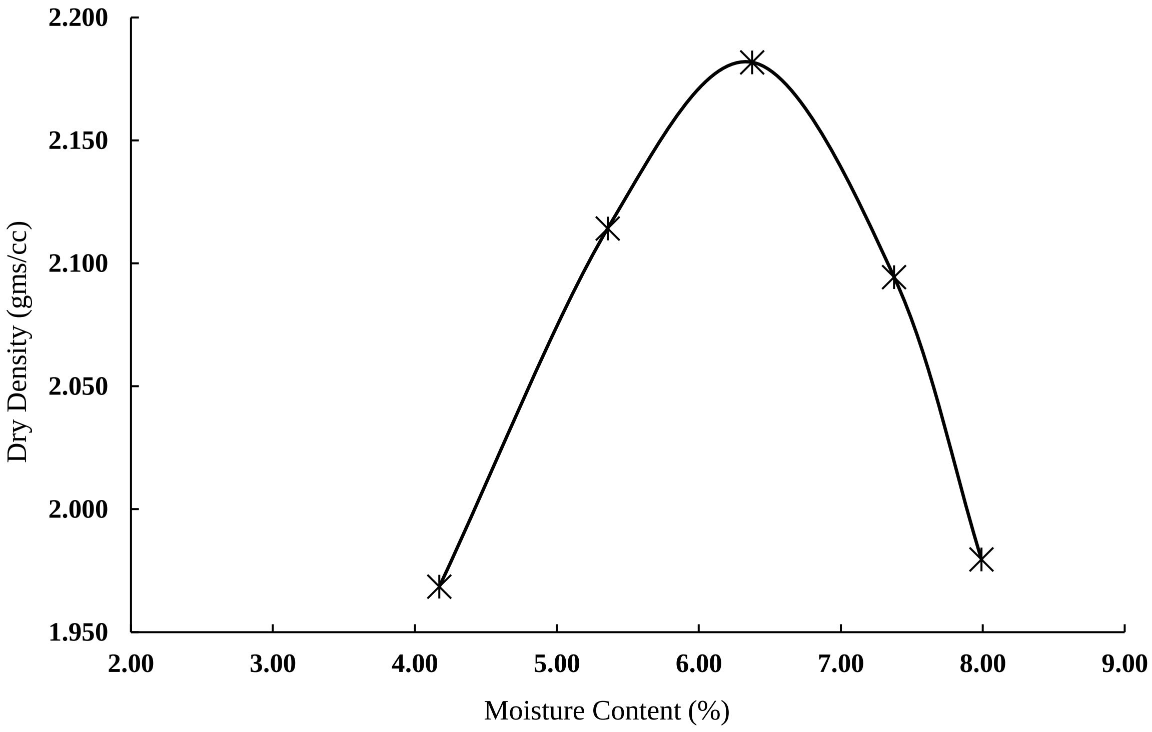


Fig. 3.15 OMC – MDD relationship with 3% cement & 1% fly ash.

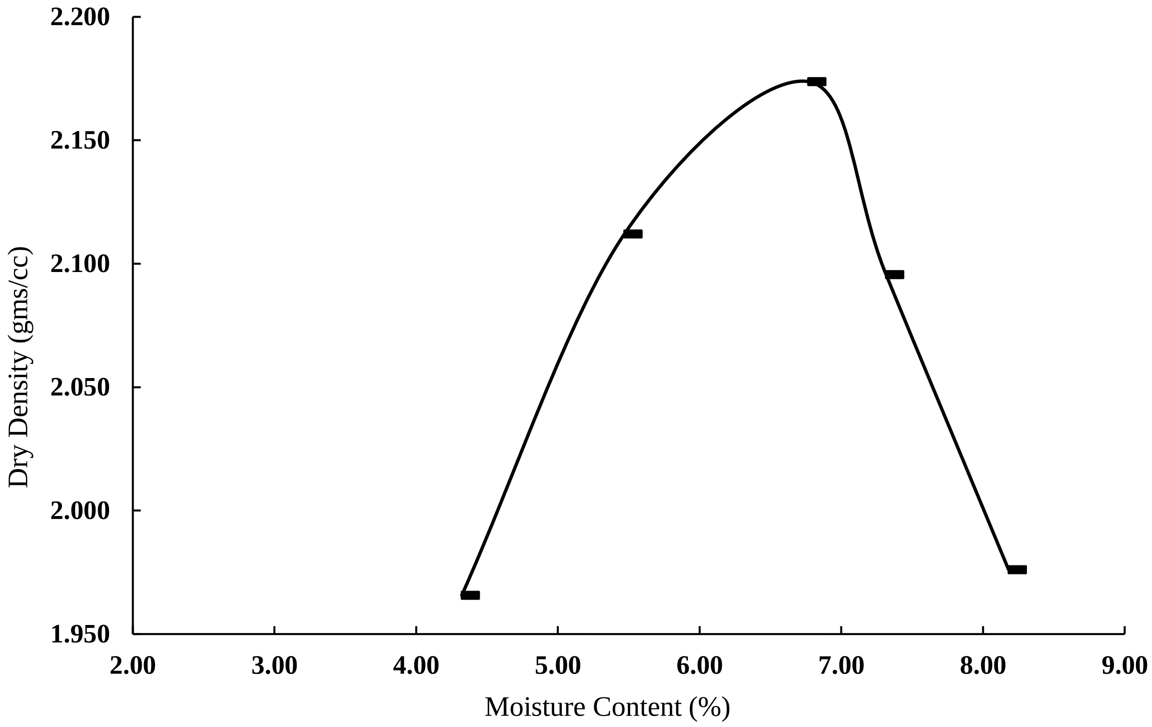


Fig. 3.16 OMC – MDD relationship with 4% cement & 1% fly ash.

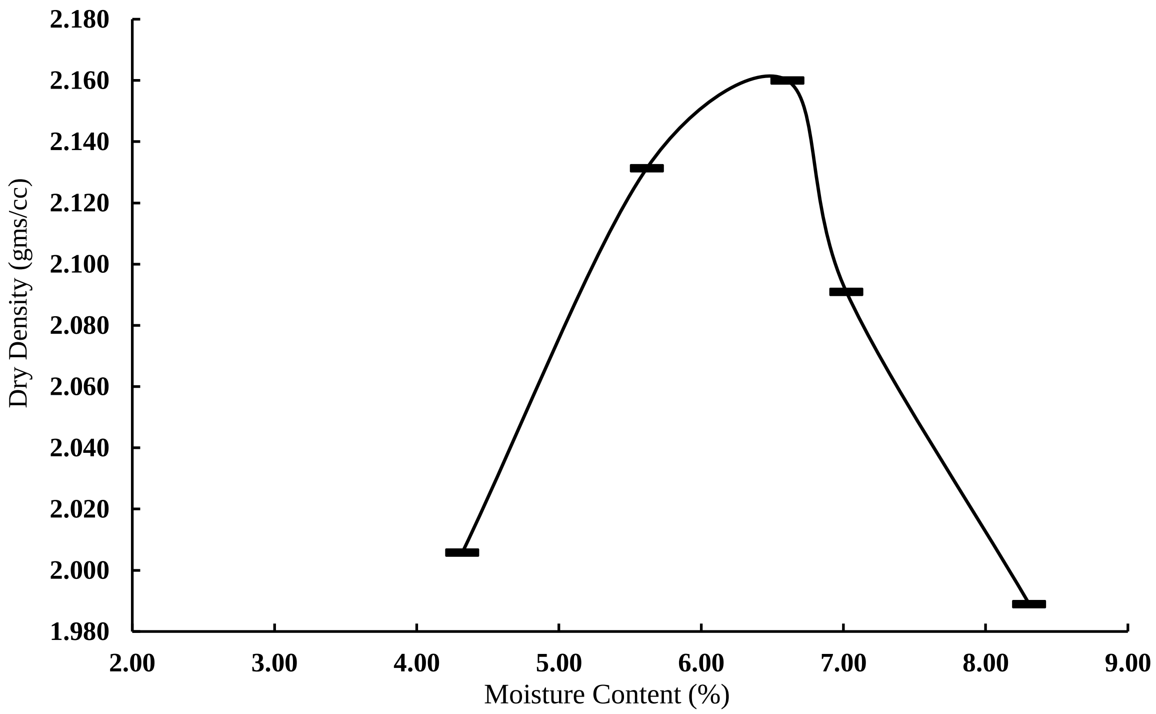


Fig. 3.17 OMC – MDD relationship with 1% cement & 2% fly ash.

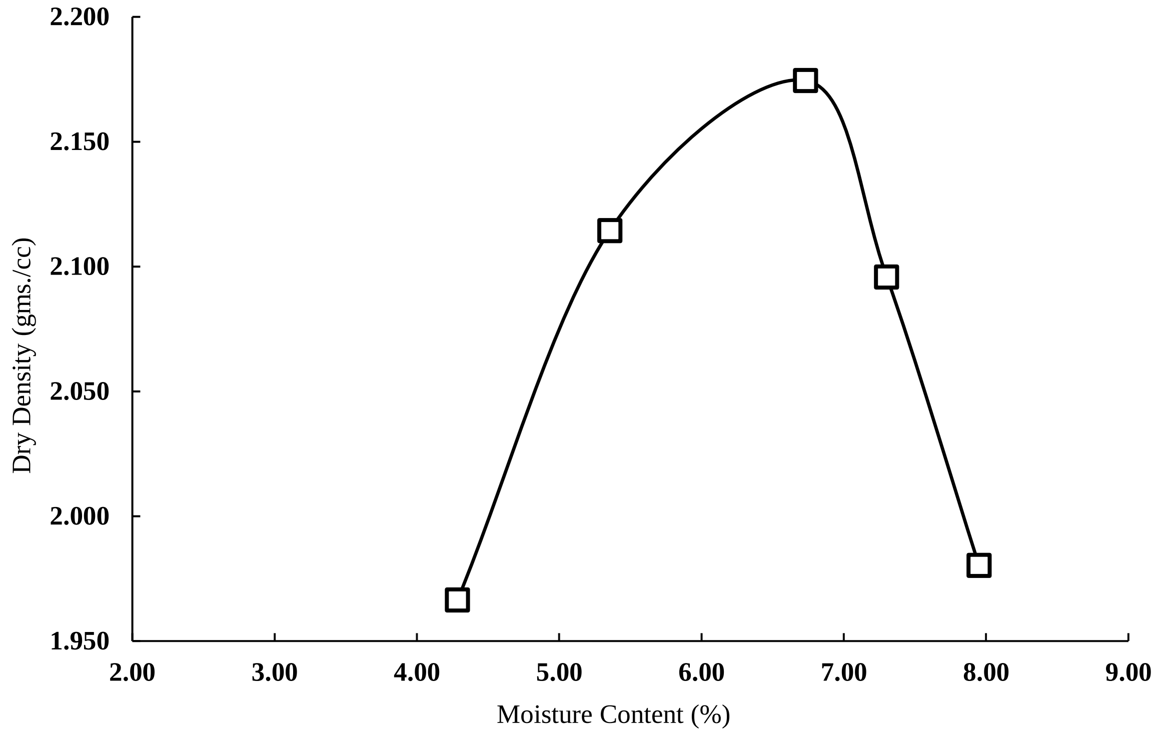


Fig. 3.18 OMC – MDD relationship with 1% cement & 3% fly ash.

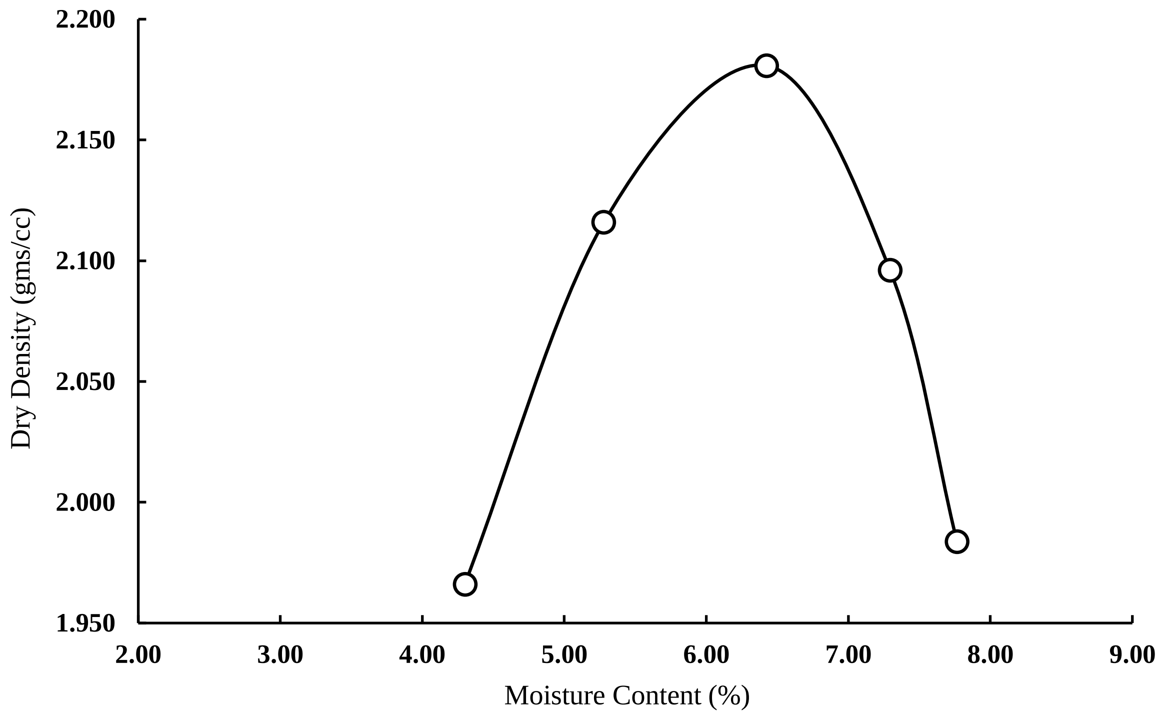


Fig. 3.19 OMC – MDD relationship with 1% cement & 4% fly ash.

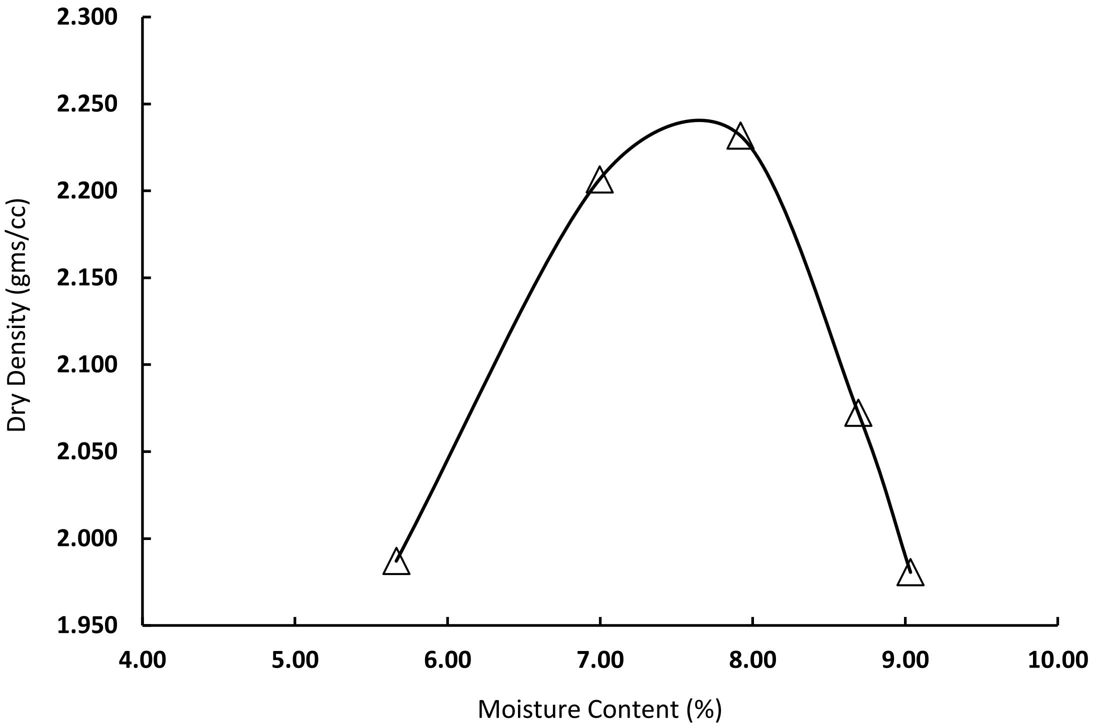


Fig. 3.20 OMC – MDD relationship of RPM with 2% cement.

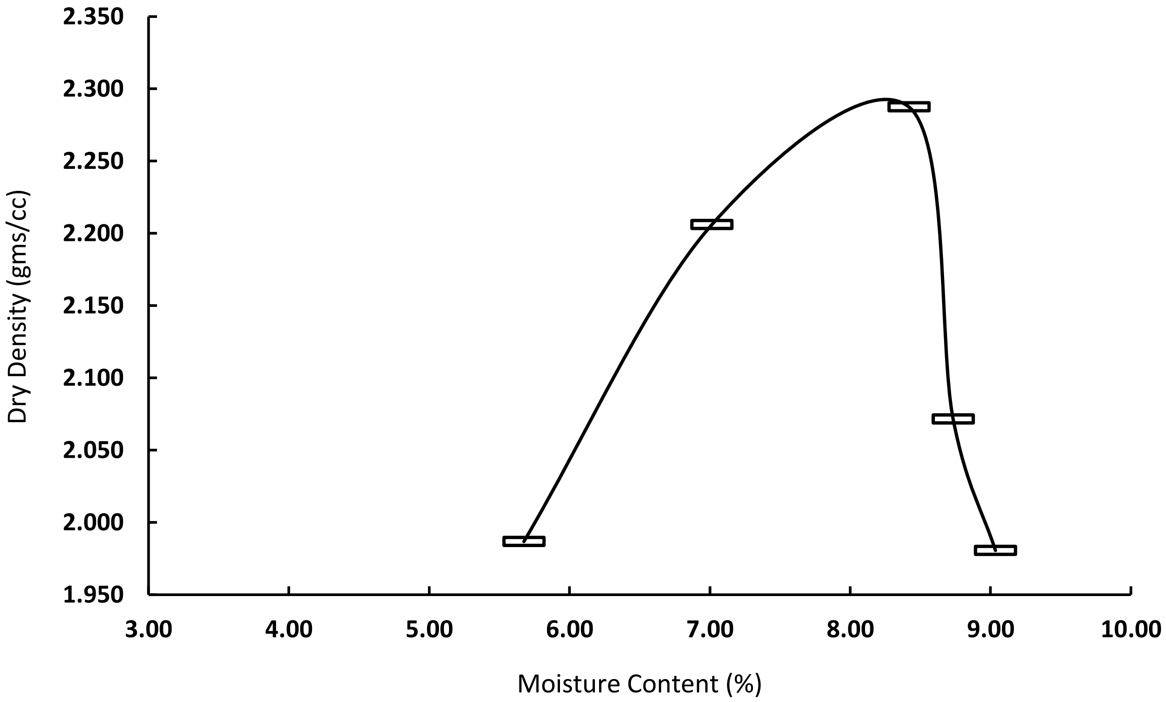


Fig. 3.21 OMC – MDD relationship of RPM with 3% cement.

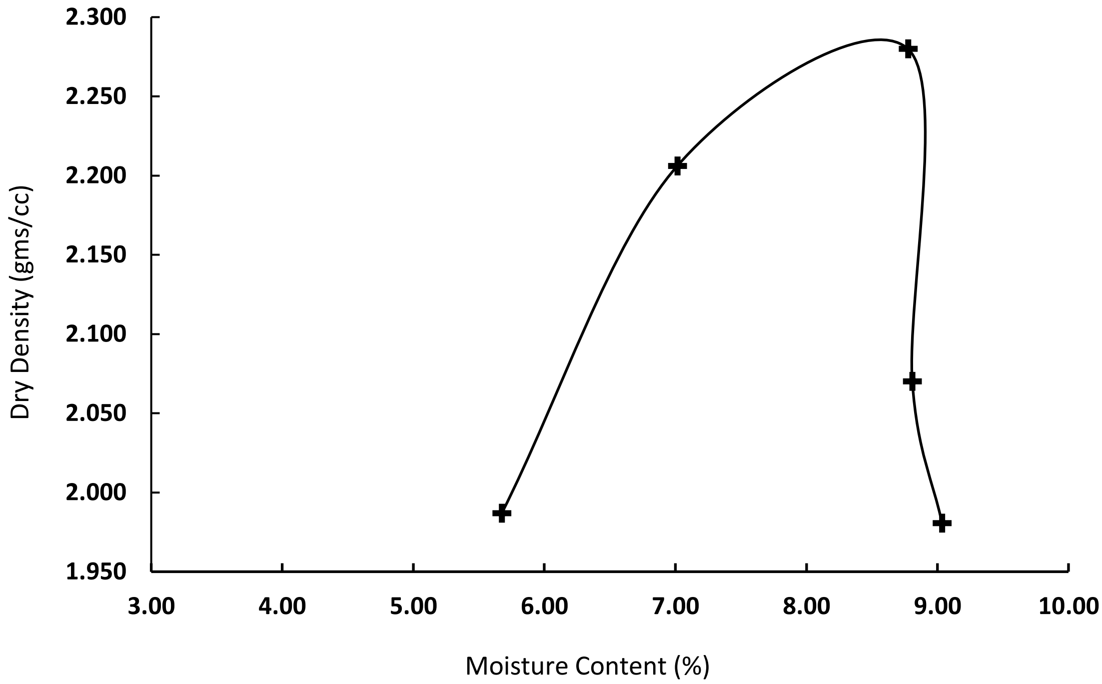


Fig. 3.22 OMC – MDD relationship of RPM with 3% cement.

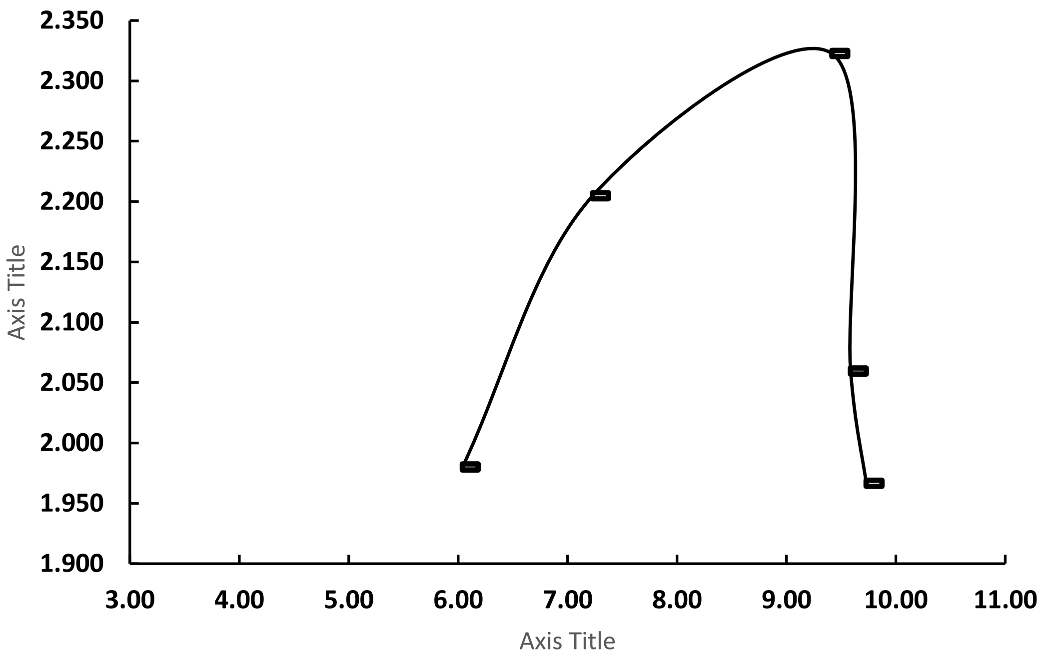


Fig. 3.23 OMC – MDD relationship of RPM with 5% cement.

3.10 UNCONFINED COMPRESSIVE STRENGTH

Many highway agencies have used unconfined compressive strength (UCS) to characterize the strength of the cement-treated base. On cube specimens of size 150 mm, prepared by mixing the CTB mix at its Optimum Moisture Content (OMC) in accordance with IS: 2720 (Part VIII), the Unconfined Compressive Strength (UCS) test was conducted. The aggregate fraction retained on the 22.4 mm IS Sieve was replaced with the material of 4.75 mm to 22.4 mm size. Utilizing a vibratory hammer to prepare the test samples, they were moist cured for seven days under wet gunny bags. For cement, water, and CTB material to hydrate together in a reaction, proper curing ensures that there is enough water in the compacted test specimen. When moisture is present, the cement hydrates create hydrated compounds that finally solidify over time to produce a cemented matrix. The specimens were cured for 7 days & 28 days moist curing using gunny bags.

In the cement treated base (CTB) example, curing has an impact on the structural attributes. It is a known fact that curing is important because the hydration reaction within the CTB layer cannot begin without water. The gunny sacks are kept moist for seven days, as stated in the pertinent specifications. The test specimens were destroyed in the compression testing equipment after 7/28 days, and the load was then recorded using IS:516.

Table 3.15: UCS test results

Mixture ID	Avg. UCS (N/mm^2)	
	7 days	28 days
M1	3.83	7.1
M2	8.60	10.6
M3	9.48	12.1
M4	9.76	12.3
M5	6.2	7.4
M6	7.6	9.1
M7	10.1	8.9
M8	4.8	6.4
M9	4.4	5.8
M10	4.1	5.4

F1	2.7	-
F2	3.2	-
F3	4.3	-
F4	4.9	-

Fig. 3.24 The prepared cubical specimens of all the mixtures used in the study.

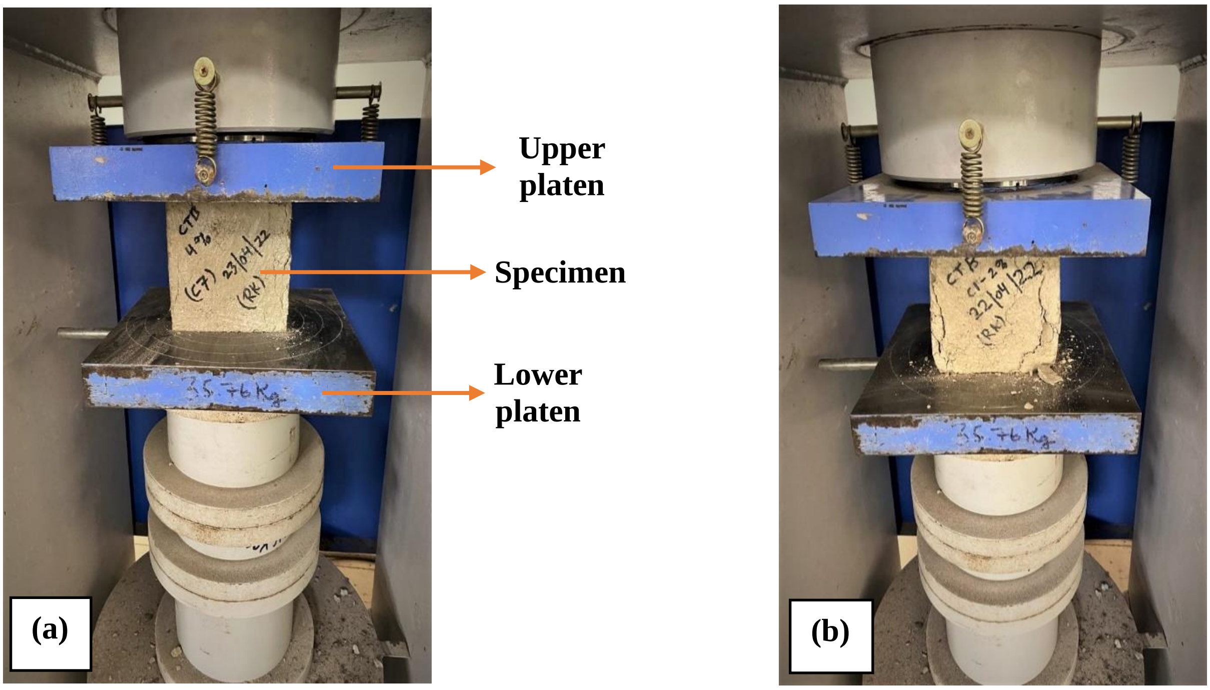
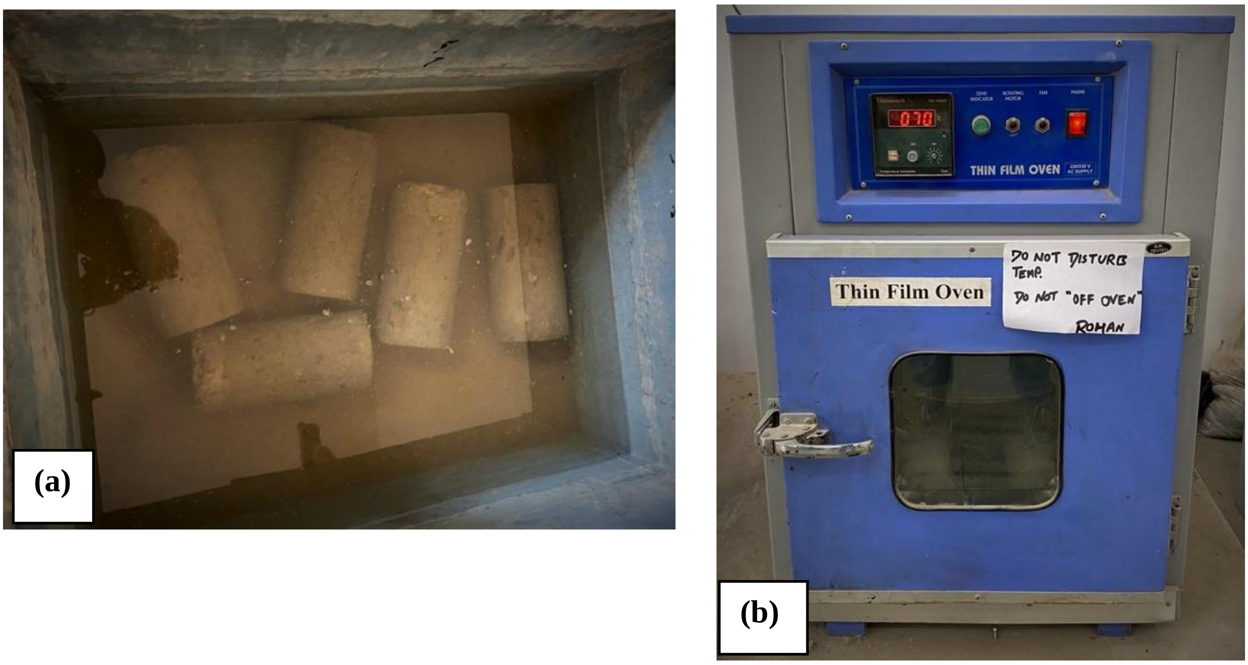


Fig. 3.25 Test setup for (a) Unconfined compressive strength (b) Specimen failure.

3.11 DURABILITY

A durability test (wetting and drying) was performed under IS: 4332 (Part IV) to understand the resistance of compacted stabilised materials under adverse weather conditions. The minimum cementitious material in the bound base layer should be such that in a wetting and drying test, the loss of weight of the stabilized material does not exceed 14 per cent after 12 cycles of wetting and drying.

Cylindrical samples were created to perform a wetting and drying test in the lab. The cylindrical sample's durability test was conducted using the "Wetting and Drying" method due to the surrounding conditions at the project site. Before being used, the material was soaked for five hours. The sample was taken out of the water tank, weighed, and given 20 vertical strokes with a wired scratch brush firmly around the sample before being measured again and then put in an oven for 42 hours at 70 degrees Celsius, making up one whole 48-hour cycle. After each cycle, the weight loss in the sample was determined with the help of a wire-scratch brush applying 20 vertical strokes twice on the sides and four strokes given at each end. After each cycle, the loss in weight of the sample was noted.



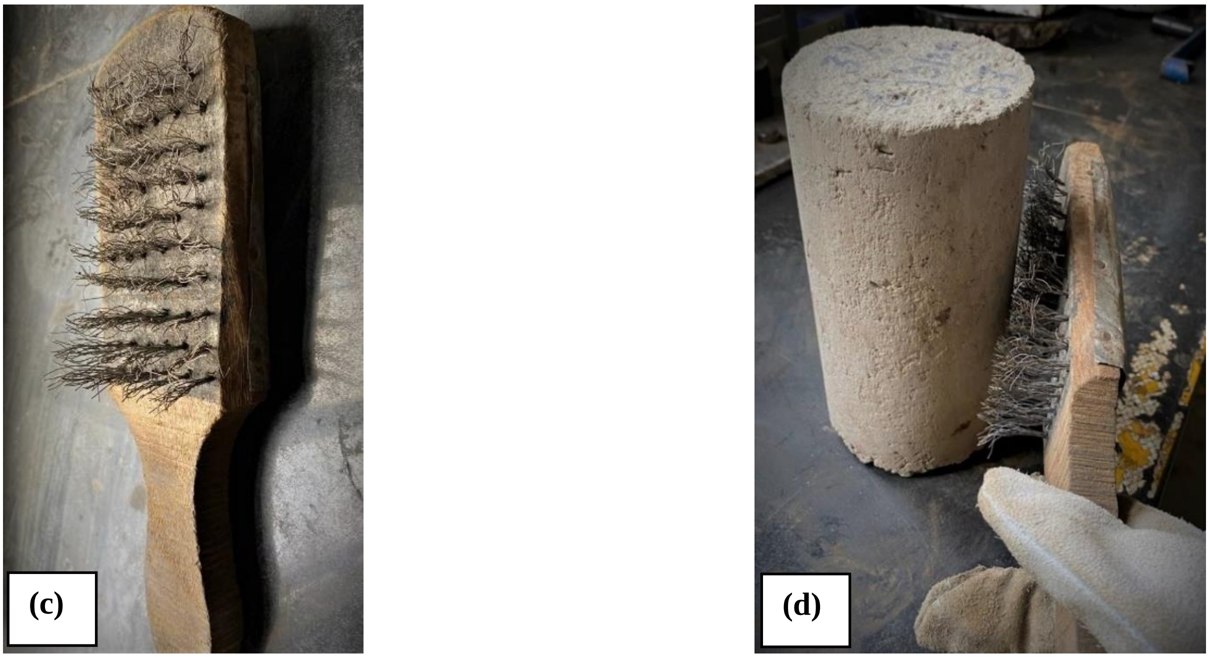


Fig. 3.26 Various stages of durability test; (a) wetting (b) drying (c) wired brush (d) specimen with the brush.

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 COMPACTION CHARACTERISTICS

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

Fig. 4.1 & 4.2 shows the variations in optimum moisture content (OMC) and maximum dry density (MDD), respectively, with different cement and fly ash contents for the cement-treated base (CTB) pavement material. Trial mixes were made using cement content from 2% to 5%, whereas fly ash content varied from 1% to 4%. It can be understood that upon increasing the cement content, the MDD value of the mixture increases, whereas upon adding 1% fly ash to the mixture with 2%, 3% & 4% of cement, respectively, the value of MDD increases with 0.78 % which is not a significant change. Also, while keeping the cement at 1% and increasing the fly ash per cent from 2-4 %, the MDD value decreases.

Further, the mix prepared with 1% cement and 2% fly ash showed a maximum dry density value (2.182 gms/cc) corresponding to its OMC (6.53%). However, not much difference was observed for MDD in mixes prepared with 4% & 5% cement nevertheless, OMC tends to increase from 6.53% to 6.74% while increasing the percentage of fly ash from 2-4% (keeping cement at 1%) because fly ash was found to behave as a cementitious material; hence its moisture carrying capacity also increased. Also, it is observed that on increasing the cement percentage from 2-5%, the OMC decreases by 2.5%. However, the relationships are similar, with a little density change in all the mixtures.

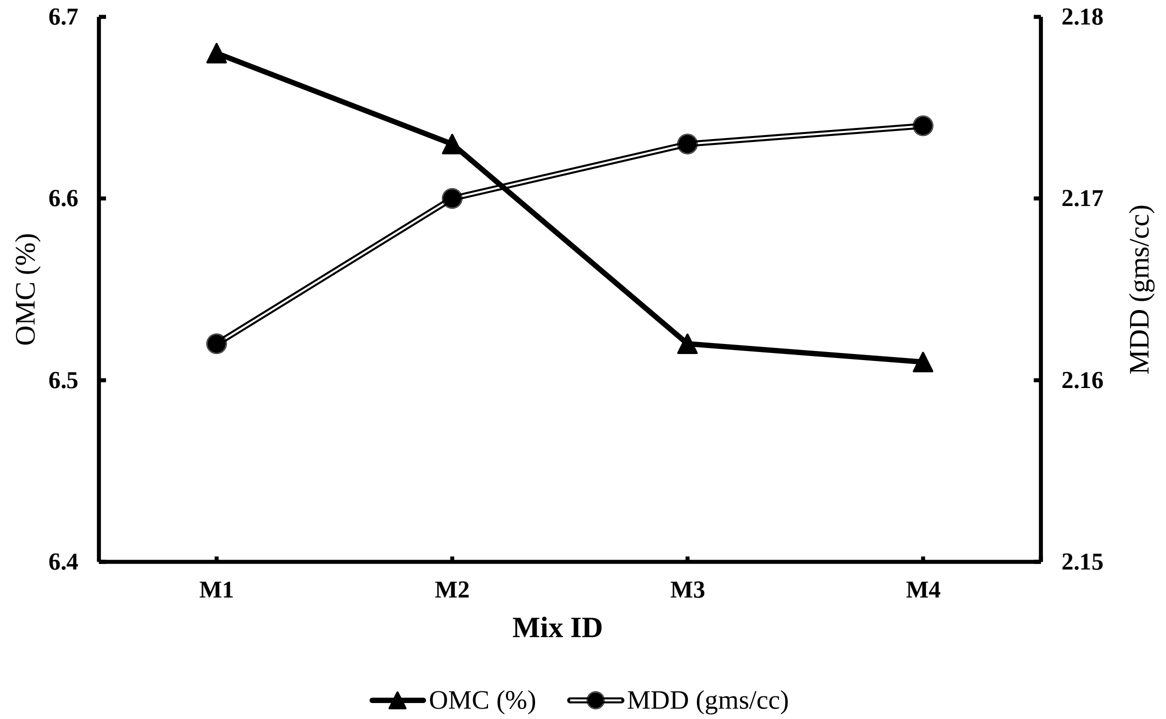


Fig. 4.1 Moisture content and maximum dry density relationships with cement.

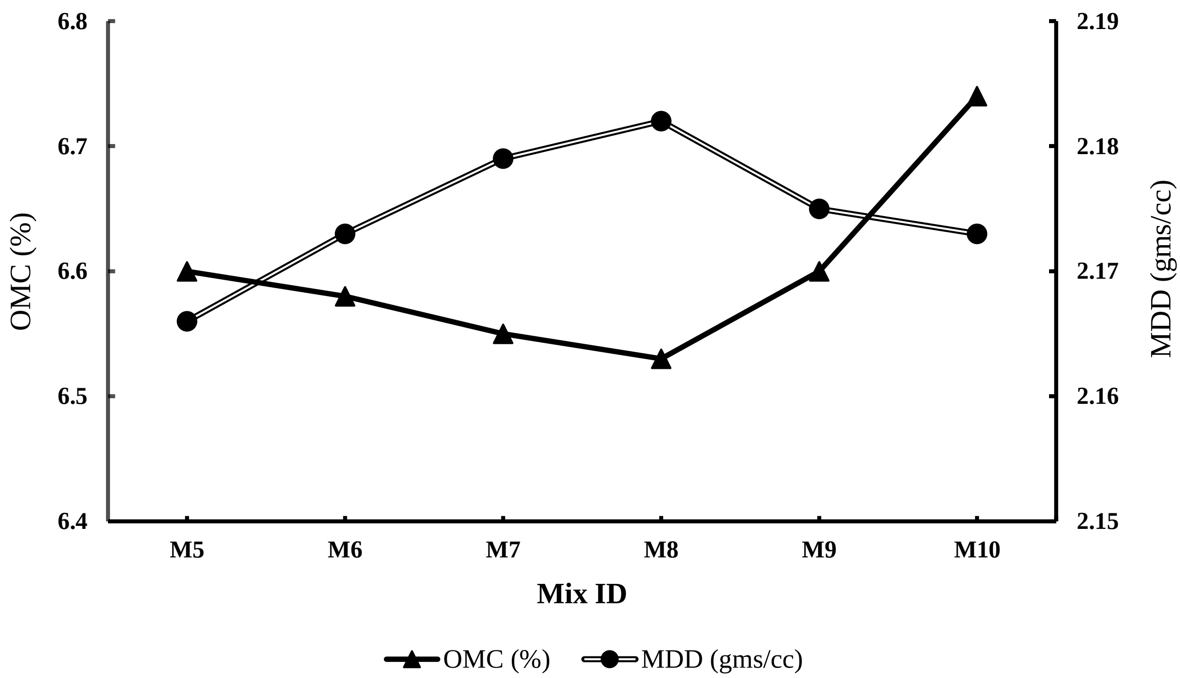


Fig. 4.2 Moisture content and maximum dry density relationships with cement & fly ash.

4.1.2 Effect of cement with chemical stabilizers in FDR mixes.

Fig. 4.3 shows the variations in the optimum moisture content (OMC) and maximum dry density (MDD) of RPM (reclaimed pavement material) with different percentages of cement contents for the cement-treated base. From the figure, it can be understood that the mix prepared with 5% cement showed a maximum dry density value (2.325 gms/cc) corresponding to its OMC (9.40%). However, not much difference was observed for MDD in mixes prepared with 3% & 4% cement nevertheless, OMC tends to increase from 7.92% to 9.40% while increasing the percentage of cement from 2-5%.

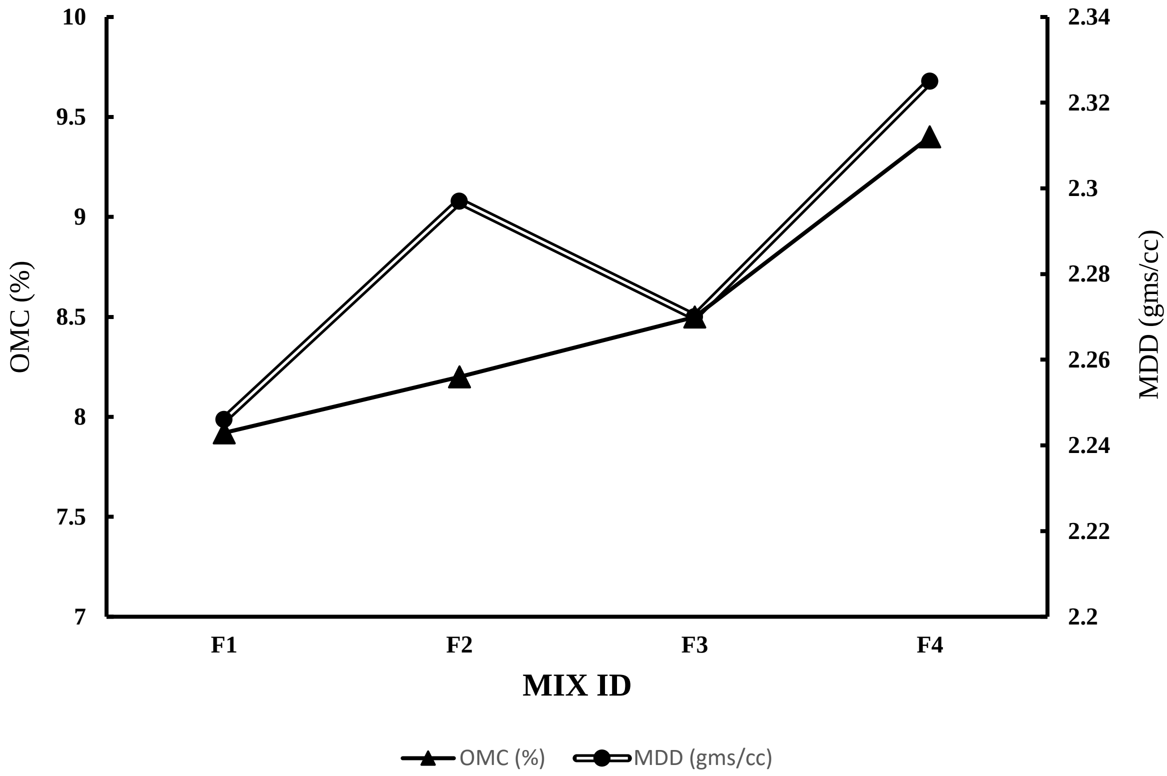


Fig. 4.3 Moisture content and maximum dry density relationships for various mixtures using FDR.

4.2 RESILIENT/ELASTIC MODULUS OF VARIOUS MIXES.

The Elastic Modulus (E) of the CTB may be estimated from the unconfined compressive strength (UCS) 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. It's important to ensure that the average laboratory strength is at least 1.5 times the required (design) field strength.

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

4.2.1 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. 4.4 & 4.5. 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, it can be understood that the mix (M1) with 2% cement content is not satisfying desired UCS value (7 & 28 days) as per clause 8.2.1 of IRC:37 – 2018. The mixture with a higher proportion of cement (2-4%) & 1% fly ash and mixture with a cement content of 3-5% 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 with a higher proportion of fly ash (2-4%) & 1% cement 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. The amount of pozzolanic cementitious material increases and hardens with the extension of curing time, significantly enhancing the compressive strength of treated soil. 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.

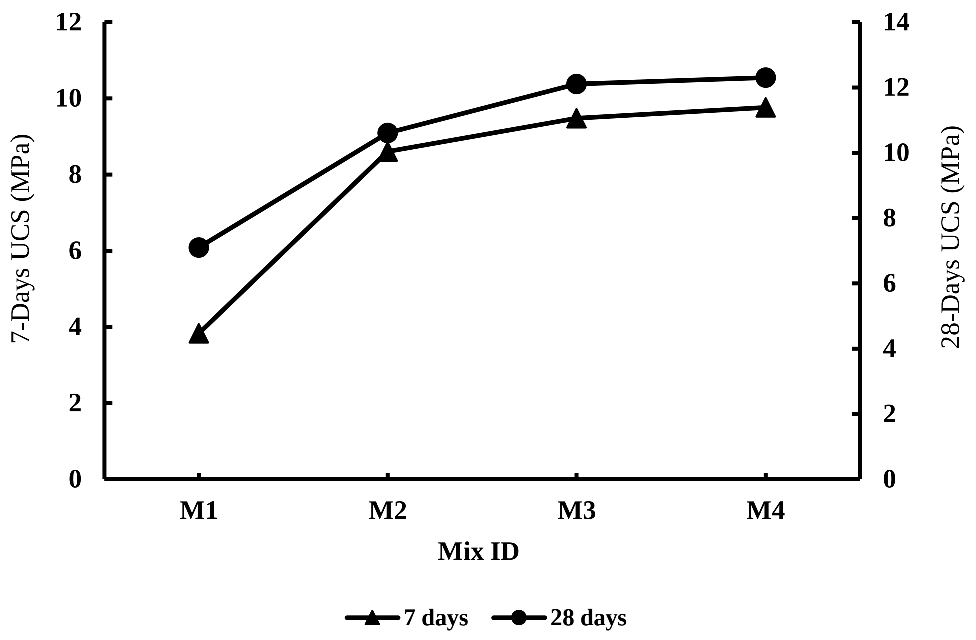


Fig. 4.4 Unconfined Compressive Strength (7 & 28 days) of different mixes of CTB with cement.

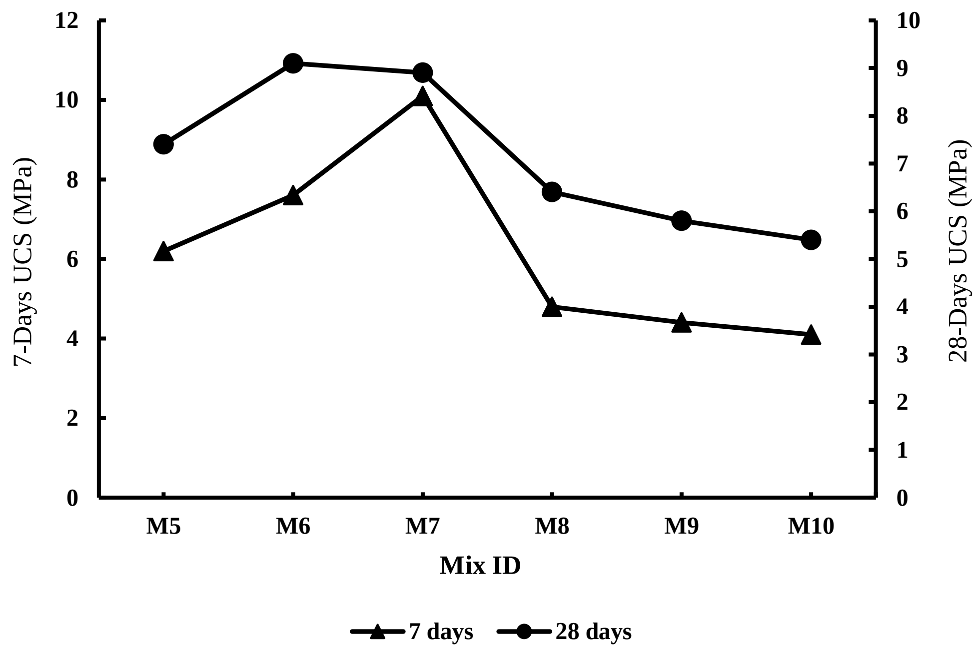


Fig. 4.5 Unconfined Compressive Strength (7 & 28 days) of different mixes of CTB with cement.

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. 4.6. The results indicate that the 7-days UCS values increase with an increasing percentage of cement.

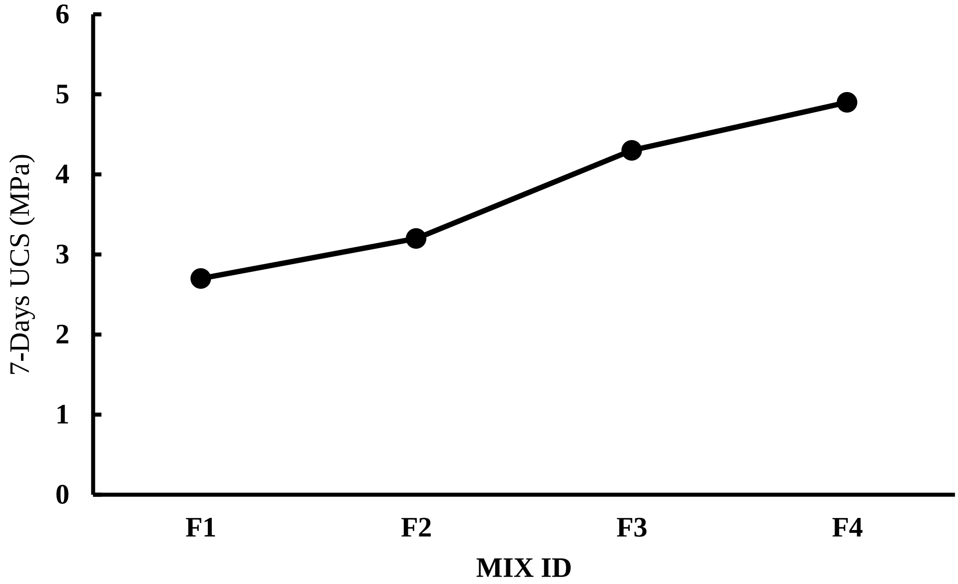


Fig. 4.6 Unconfined Compressive Strength (7-days) of different mixes of FDR with cement & chemical stabilizers.

Table 4.1 Resilient Modulus for different types of mixes of CTB with cement.

Mix ID	Resilient Modulus (MPa)
M1	4733.33
M2	7066.67
M3	8066.00
M4	8200.67

Table 4.2 Resilient Modulus for different types of mixes of CTB with cement and fly ash.

Mix ID	Resilient Modulus (MPa)
M5	4933.33
M6	6066.67
M7	5933.33
M8	4266.67
M9	3866.67
M10	3600.00

Table 4.3 Resilient Modulus for different types of mixes of FDR with cement & chemical stabilizers

Mix ID	**Resilient Modulus (MPa)**
F1	2700
F2	3200
F3	4300
F4	4900

From fig 4.7 & 4.8, it is observed that the values of resilient modulus of mixes M1, M5, M8, M9 & M10 cannot be used for the design of flexible pavement as the 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. But with increasing the content of fly ash while keeping the cement at 1%, the value of resilient modulus decreases.

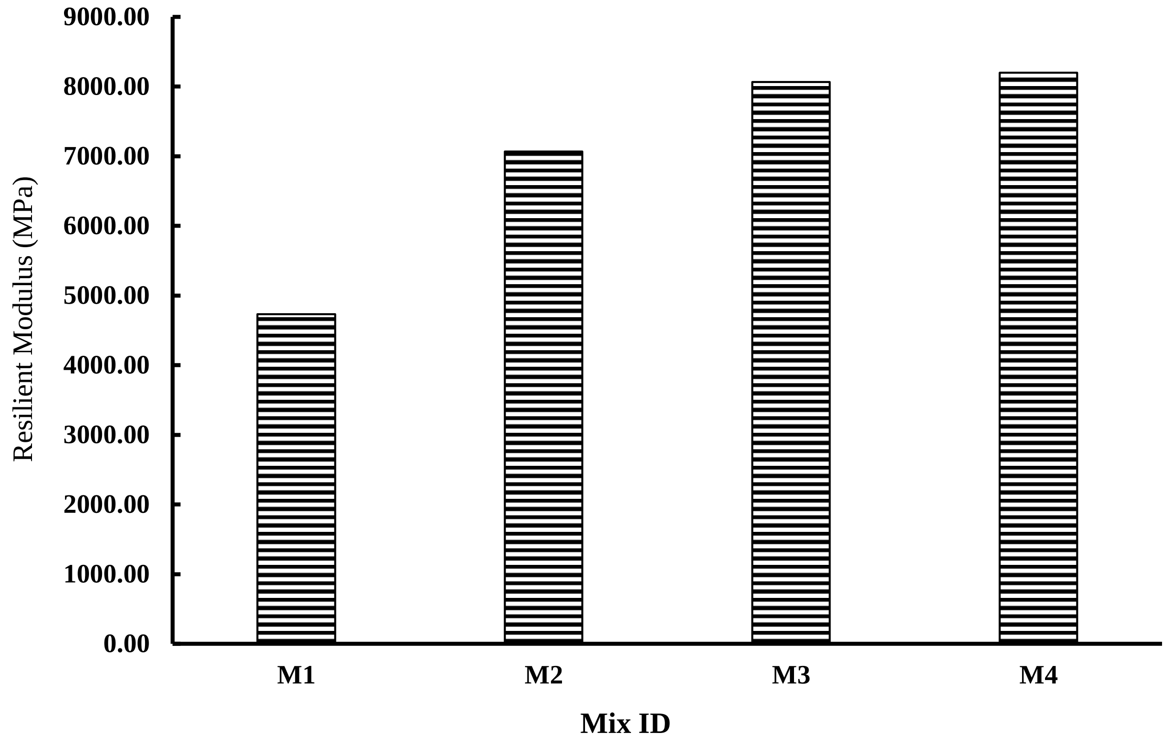


Fig 4.7 Resilient Modulus versus different mixes of CTB with cement.

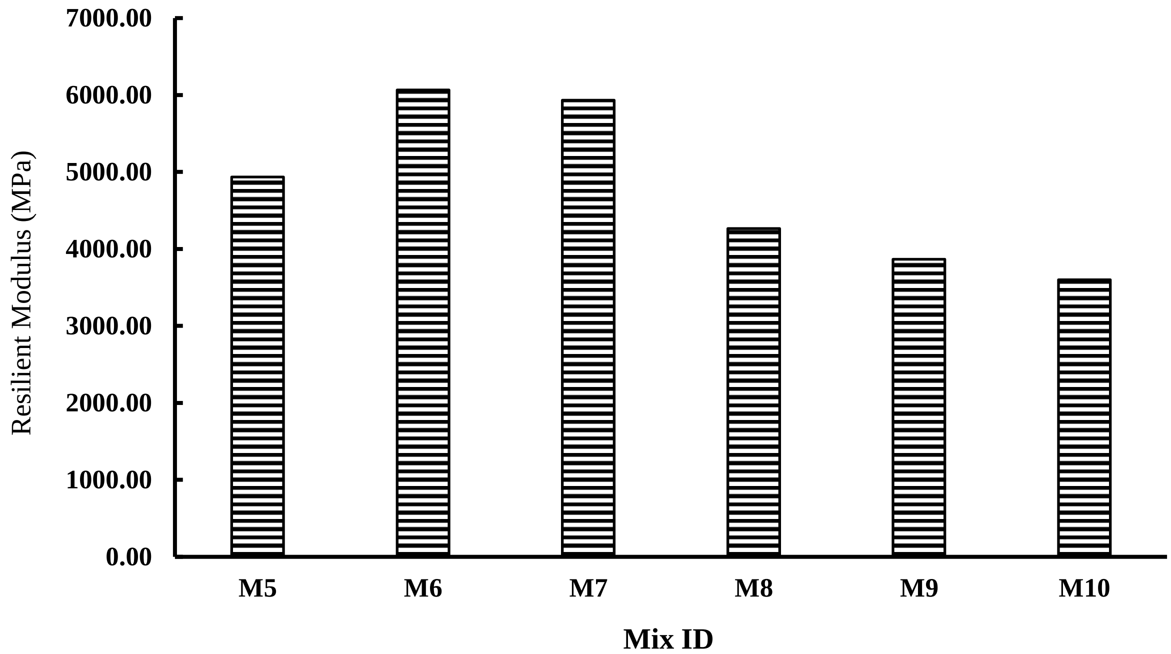


Fig 4.8 Resilient Modulus versus different mixes of CTB with cement & fly ash.

From fig 4.9, 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.

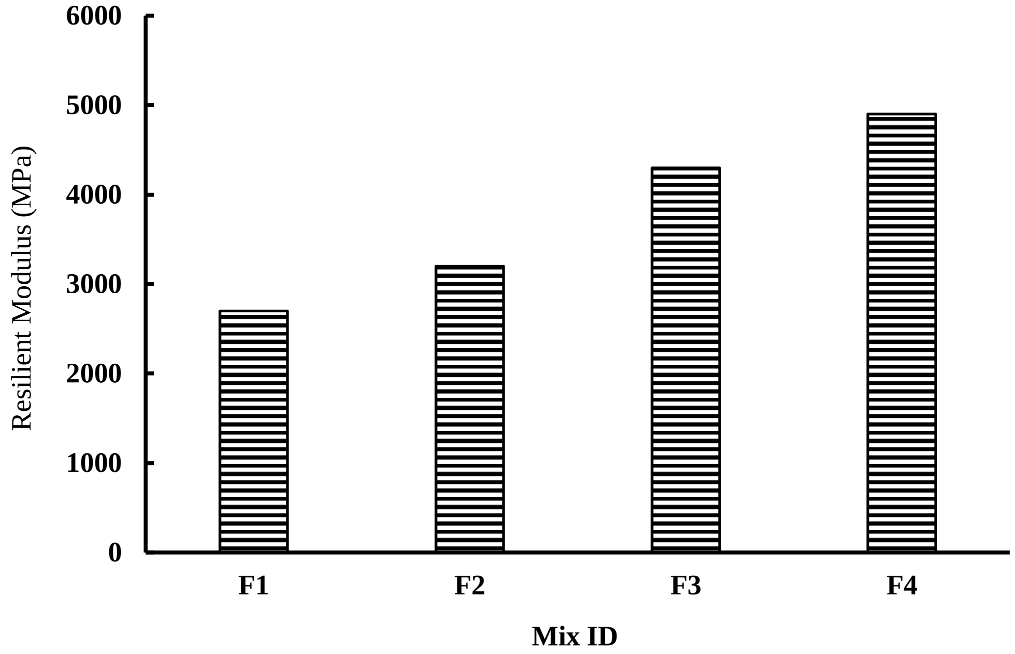


Fig 4.9 Resilient Modulus versus different mixes of CTB with cement & chemical stabilizers (FDR).

4.3 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: 1989. 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.

In comparison to the other mixes investigated in this study, the mix with 3% cement and 1% fly ash was revealed to be less durable. As expected, the mixtures with 3%, 4% and 5% cement content and zero per cent fly ash are found to be more durable. The per cent mass loss of all mixtures considered in this study was found to be in the range of 4.85 to 6.78 %, as shown in the bar chart with error bars representing standard error as shown in fig. 4.7. at the end of 12 cycles, mixtures having a mass loss of more than 14% did not occur in this study. From the durability test, optimum cement and fly ash content are re-confirmed.

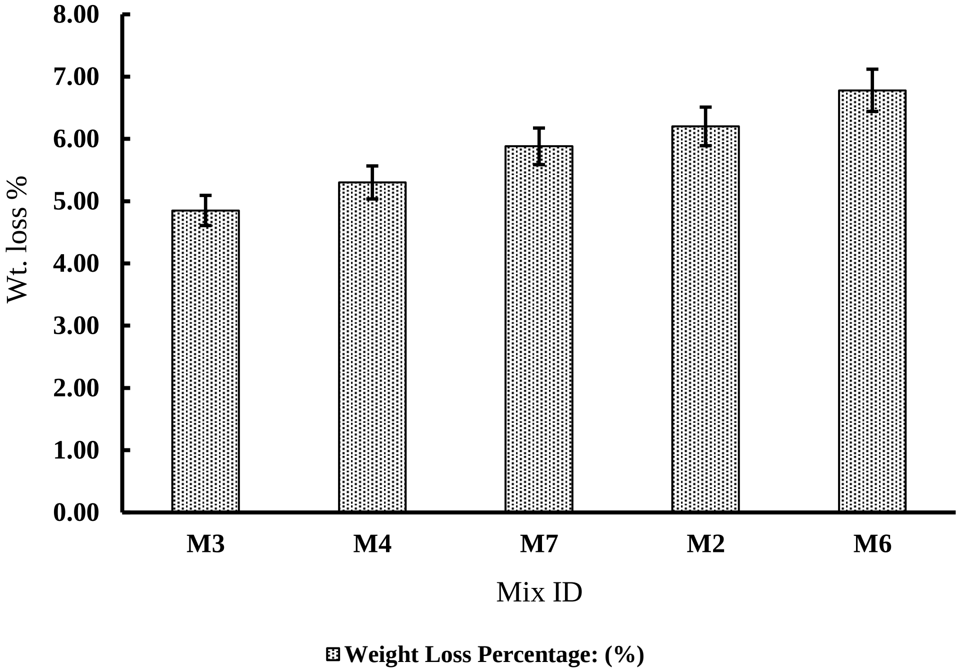


Fig. 4.10 Percentage of weight loss during the wetting and drying process.

5.1 DESIGN PRINCIPLES

Pavement design includes specifying how a pavement will function and perform structurally throughout its designated service life. Roughness produced by variations in surface profile, cracking of layers confined by bituminous or cementitious materials, rutting of unbounded/unmodified subgrade, granular layers, and bituminous layers are the major indicators for functional and structural performance of the pavement. Performance models, either entirely empirical or mechanistic-empirical, forecast pavement performance by describing distresses in terms of stresses, strains, and deflection determined according to a prescribed process.

For the analysis of pavements that are modelled as a multi-layer system, the linear elastic layered theory is chosen. The subgrade is semi-infinite, with all above levels having an unlimited horizontal extent but a finite thickness. The pavement inputs necessary for the computation of stresses, strains, and deflection generated by the applied load are elastic modulus, Poisson's ratio, and the thickness of each layer. The pavement analysis was carried with the IITPAVE software.

The guidelines (IRC: 37-2018) recommend that pavement sections be selected in such a way that they satisfy the limiting stresses and strains as per the performance models to ensure that the magnitude of distresses remains below acceptable levels during the service life period.

5.2 PAVEMENT DESIGN PROCEDURE

5.2.1 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.

5.2.2 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.

5.2.3 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.

5.2.4 Structural Analysis of the selected pavement structure

This is to be done by IITPAVE software.

Table 5.1 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

5.2.5 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, for 80 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.

$$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t]^{3.89} * [1/M_{Rm}]^{0.854} \quad \text{(for 80\% reliability)}$$

$$N_f = 0.5161*C*10^{-04} [1/\varepsilon_t]^{3.89} * [1/M_{Rm}]^{0.854} \quad \text{(for 90\% reliability)}$$

Where,

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

V_a = per cent volume of air void in the mix used in the bottom of bituminous layer

V_{be} = per cent volume of effective bitumen in the t mix used in the bottom of bituminous layer

N_f = fatigue life of bituminous layer

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

M_{Rm} = 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.

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

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)

5.2.6 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.

5.2.7 Cumulative fatigue damage analysis

The application of axle loads of different categories and significance levels over the design life period causes cumulative fatigue damage to the CTB layer. Equation 3.6 of IRC: 37-2018 determines the fatigue life N_{fi} of the CTB material when subjected to a specified number of applications (n_i) of axle load of class i during the design period.

$$\log_{10} N_{fi} = \frac{0.972-\left(\sigma_t / M_{Rup}\right)}{0.0825}$$

Where,

N_{fi} = fatigue life of CTB material which is the maximum repetitions of axle load class 'i' the CTB material can sustain

σ_t = tensile stress at the bottom of CTB layer for the given axle load class

M_{Rup} = 28-days flexural strength of the cementitious base

σ_t / M_{Rup} = stress ratio

Using equation 3.7 of IRC: 37-2018, the cumulative fatigue damage caused by different repetitions of the axle load of different categories and magnitudes estimated to be applied on the pavement during its design period is assessed.

CFD = $\sum \left(\boldsymbol{n_i} / \boldsymbol{N_{fi}} \right)$

Where,

n_i = expected repetitions of the axle load of class 'i'

N_{fi} = fatigue life

NOTE: If the estimated CFD is less the 1.0, the design is considered to be acceptable. If the value of CFD is more than 1.0, the pavement section has to be revised.

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.

5.3 DESIGN OF FLEXIBLE PAVEMENT AND ANALYSIS

5.3.1 High-volume Road.

- Design traffic – 50 msa
- Effective CBR – 8%

CASE I: A pavement section with bituminous layer(s), granular base and GSB.

The flexible pavement with WMM & GSB composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations. (Ref.: Figure 12.4; IRC: 37-2018)

Layer	Thickness (mm)
Bituminous Concrete (BC)	40
Dense Bituminous Macadam (DBM)	115
Granular Base (WMM)	250

GSB	200

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.2.

Table 5.2: Input Parameter considered in Flexible Pavement with WMM & GSB.

Description	**Value considered**	**Reference**
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous, subgrade & GSB	7.2.2, point no. (vi) IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Unbound Layer E-Value GSB, (MPa)	Eq. 7.1 of IRC:37-2018	
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	
Poisson's Ratio	Bituminous Layer: 0.35 Granular base: 0.35 GSB: 0.35 Sub-grade: 0.35	

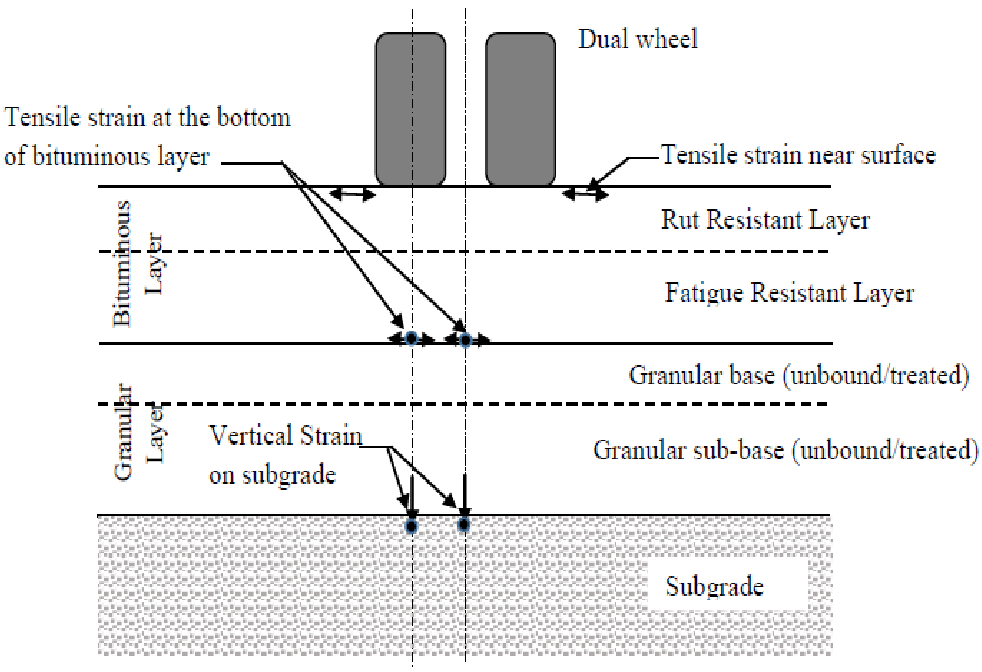


Fig. 5.1: A pavement section with bituminous layer(s), granular base and GSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 90% reliability)

$N_R = 1.4100 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.2 of IRC:37-2018)

$50 \times 10^6 = 1.4100 \times 10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 371.6 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 90% reliability)

$N_f = 0.5161*C*10^{-04} [1/\varepsilon_t]^{3.89} * [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.4 of IRC:37-2018)

$50 \times 10^6 = (1.2123 \times 10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 178.11 \times 10^{-6}}$

The input-output results of IITPAVE for CASE I. *(Annex – I)*

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.3.

Table 5.3: Flexible Pavement thicknesses: CASE I

Allowable Strain		Recommended Pavement Composition (mm)				Obtained Strains		Remarks
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	BC	DBM	WMM	GSB	**Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**Safe**
178.11×10^{-6}	371.6×10^{-6}	40	115	250	200	177×10^{-6}	295.6×10^{-6}	

CASE II: **A pavement section with bituminous layer(s), granular crack relief layer, CTB, and GSB.**

The flexible pavement with CTB & GSB composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations. (Ref.: Figure 12.36; IRC: 37-2018)

Layers	**Thickness (mm)**
Bituminous Concrete (BC)	40
Dense Bituminous Macadam (DBM)	60
Granular Crack Relief (AIL)	100
Cement Treated Base (CTB)	165
Granular Sub-base (GSB)	200

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.4.

Table 5.4: Input Parameter considered in Flexible Pavement with CTB & GSB

Description	**Value considered**	**Reference**
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade 0.80 for CTB stress & strain calculation	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Aggregate Interface Layer (MPa)	450	
Unbound Layer E-Value GSB, (MPa)	Eq. 7.1 of IRC:37-2018	
Cement-treated Base (MPa)	8066	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018
Poisson's Ratio	Bituminous Layer: 0.35 GSB: 0.35 CTB: 0.25 Sub-grade: 0.35	

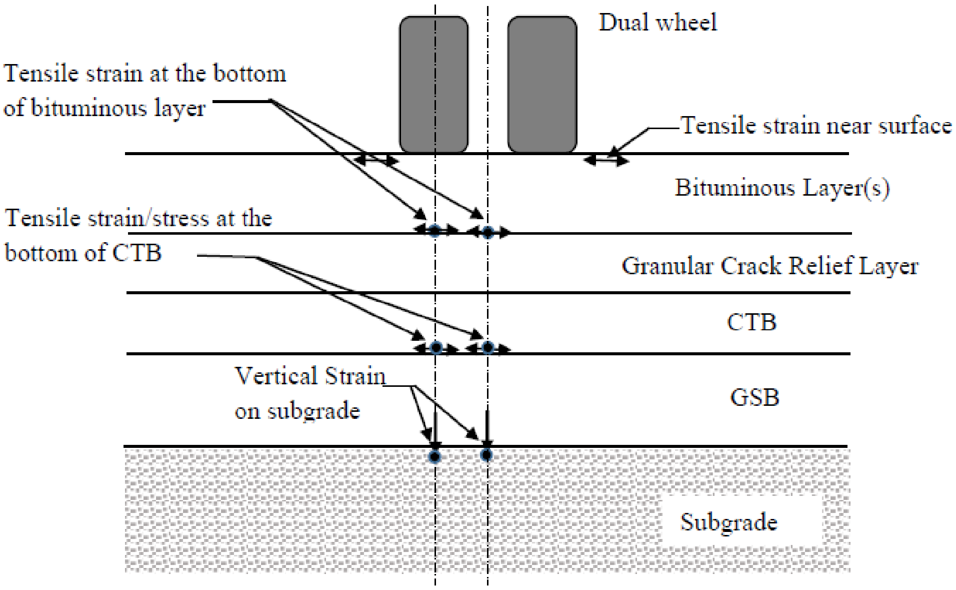


Fig 5.2: A pavement section with bituminous layers(s), granular crack relief layer, CTB and GSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 90% reliability)

$N_R = 1.4100 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.2 of IRC:37-2018)

$50 \times 10^6 = 1.4100 \times 10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 371.6 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 90% reliability)

$N_f = 0.5161 * C * 10^{-04} [1/\varepsilon_t]^{3.89} * [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.4 of IRC:37-2018)

$50 \times 10^6 = (1.2123 \times 10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 178.11 \times 10^{-6}}$

Fatigue Performance Model for Cement Treated Base (CTB)

Tensile strain at the bottom of the CTB layer.

$$N = RF \left[\frac{\left(\frac{113000}{E^{0.804}} + 191\right)}{\varepsilon_t} \right]^{12}$$ (Ref.: Eq. 3.5 of IRC:37-2018)

$$50 \times 10^6 = 1 \left[\frac{\frac{113000}{8066^{0.804}} + 191}{\varepsilon_t} \right]^{12}$$

$$\boldsymbol{\varepsilon_t = 62.24 \times 10^{-6}}$$

The input-output results of IITPAVE for CASE II. *(Annex - I)*

The results and recommended pavement thicknesses based on the above analysis are presented in table 5.5.

Table 5.5: Flexible Pavement section: CASE II

Allowable Strain			Recommended Pavement Composition (mm)					Obtained Strains			Remarks
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**BC**	**DBM**	**AIL**	**CTB**	**GSB**	**Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t**	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**Safe**
178.11×10^{-6}	62.24×10^{-6}	371.6×10^{-6}	40	60	100	165	200	125.1×10^{-6}	55.2×10^{-6}	179×10^{-6}	

CASE III: **A pavement section with bituminous layer(s), granular crack relief layer, CTB, and CTSB.**

The flexible pavement with CTB & CTSB composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations. (Ref.: Figure 12.12; IRC: 37-2018)

Layer	**Thickness (mm)**
Bituminous Concrete (BC)	40
Dense Bituminous Macadam (DBM)	60
Granular Crack Relief Layer (AIL)	100
Cement Treated Base (CTB)	100
Cement Treated Sub-base (CTSB)	200

Specifications and Input parameters considered as per guidelines for flexible pavement design given in table no. 5.6.

Table 5.6: Input Parameter considered in Flexible Pavement with CTB & CTSB

Description	Value considered	Reference
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade 0.80 for CTB stress & strain calculation	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Aggregate Interface Layer (MPa)	450	
Cement treated sub-base (MPa)	600	
Cement treated Base (MPa)	8066	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018
Poisson's Ratio	Bituminous Layer: 0.35 CTB: 0.25 CTSB: 0.25 Sub-grade: 0.35	

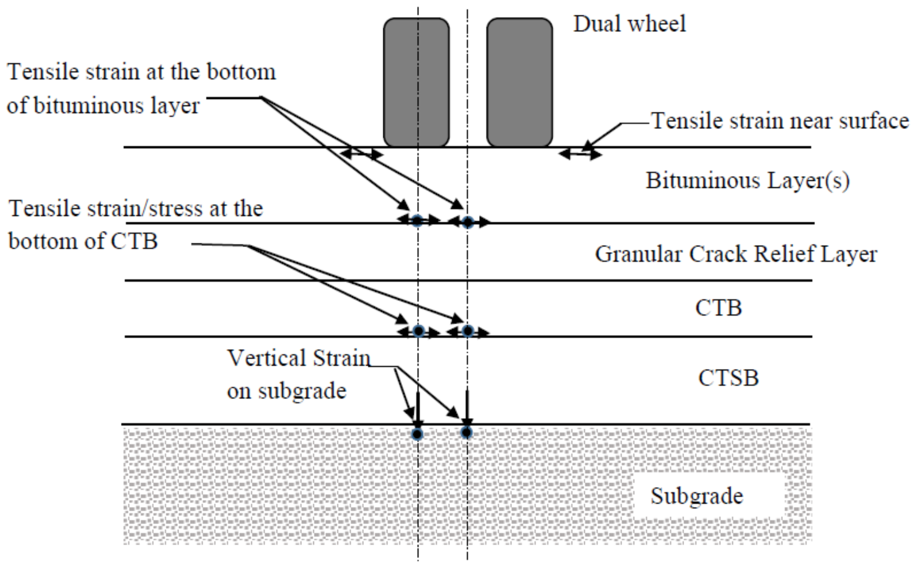


Fig 5.3: A pavement section with bituminous layer(s), granular crack relief layer, CTB and CTSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 90% reliability)

$N_R = 1.4100 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.2 of IRC:37-2018)
$50 \times 10^6 = 1.4100\times10^{-08} [1/ \varepsilon_v]^{4.5337}$
$\boldsymbol{\varepsilon_v = 371.6 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 90% reliability)

$N_f = 0.5161*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.4 of IRC:37-2018)
$50\times10^6 = (1.2123\times10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$
$\boldsymbol{\varepsilon_t = 178.11 \times 10^{-6}}$

Fatigue Performance Model for Cement Treated Base (CTB)

Tensile strain at the bottom of the CTB layer.

$$N = RF \left[\frac{\left(\frac{113000}{E^{0.804}}+191\right)}{\varepsilon_t}\right]^{12}$$ (Ref.: Eq. 3.5 of IRC:37-2018)

$$50\times10^6 = 1 \left[\frac{\frac{113000}{8066^{0.804}}+191}{\varepsilon_t}\right]^{12}$$

$$\boldsymbol{\varepsilon_t = 62.24 \times 10^{-6}}$$

The input-output results of IITPAVE for CASE III (A). *(Annex - I)*

The results and recommended pavement thicknesses based on the above analysis are presented in table 5.7.

Table 5.7: Flexible Pavement section: CASE III

Allowable Strain			**Recommended Pavement Composition (mm)**					**Obtained Strains**			**Remarks**
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**BC**	**DBM**	**AIL**	**CTB**	**CTSB**	**Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t**	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	
178.11×10^{-6}	62.24×10^{-6}	371.6×10^{-6}	40	60	100	100	200	129.1×10^{-6}	53.1×10^{-6}	253.4×10^{-6}	**Safe**

CASE IV: **A pavement section with bituminous layer(s), SAMI crack relief layer, CTB, and CTSB.**

The flexible pavement with CTB & CTSB composition is calculated for the recommended design traffic VG-40 grade bitumen) is considered for pavement design. The following pavement composition is proposed for calculations. (Ref.: Figure 12.20; IRC: 37-2018)

Layer	**Thickness (mm)**
Bituminous Concrete (BC)	40
Dense Bituminous Macadam (DBM)	60
SAMI	_
Cement Treated Base (CTB)	140
Cement Treated Sub-base (CTSB)	200

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.8.

Table 5.8: Input Parameter considered in Flexible Pavement with SAMI, CTB & CTSB

Description	**Value considered**	**Reference**
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade 0.80 for CTB stress & strain calculation	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
SAMI	NA	
Cement-treated sub-base (MPa)	600	
Cement-treated Base (MPa)	8066	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018
Poisson's Ratio	Bituminous Layer: 0.35 CTB: 0.25 CTSB: 0.25 Sub-grade: 0.35	

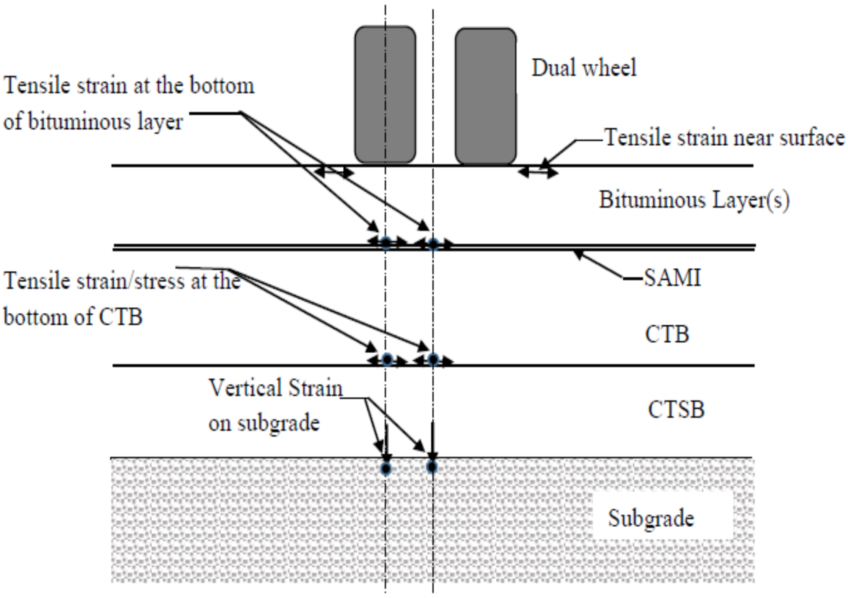


Fig 5.4: A Pavement section with bituminous layer(s), SAMI crack relief layer, CTB and CTSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 90% reliability)

$N_R = 1.4100 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.2 of IRC:37-2018)

$50 \times 10^6 = 1.4100\times10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 371.6 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 90% reliability)

$N_f = 0.5161*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.4 of IRC:37-2018)

$50\times10^6 = (1.2123\times10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 178.11 \times 10^{-6}}$

Fatigue Performance Model for Cement Treated Base (CTB)

Tensile strain at the bottom of the CTB layer.

$N = RF\left[\frac{(\frac{113000}{E^{0.804}}+191)}{\varepsilon_t}\right]^{12}$ (Ref.: Eq. 3.5 of IRC:37-2018)

$$50\times10^6 = 1\left[\frac{\frac{113000}{8066^{0.804}}+191}{\varepsilon_t}\right]^{12}$$

$$\boldsymbol{\varepsilon_t = 62.24 \times 10^{-6}}$$

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.9.

Table 5.9.: Flexible Pavement section: CASE IV

Allowable Strain			Recommended Pavement Composition (mm)					Obtained Strains			Remarks
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	Horizontal Tensile Strain Under CTB (Fatigue); ε_t	Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v	BC	DBM	SAMI	CTB	CTSB	Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	Horizontal Tensile Strain Under CTB (Fatigue); ε_t	Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v	
178.11×10^{-6}	62.24×10^{-6}	371.6×10^{-6}	40	60	0	140	200	20.9×10^{-6}	59×10^{-6}	231.7×10^{-6}	**Safe**

5.3.2 Low-volume Road.

- Design traffic – 5 msa
- Effective CBR – 8%

CASE I: A pavement section with bituminous layer(s), granular base and GSB.

The flexible pavement with WMM & GSB composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations.

Layer	**Thickness (mm)**
Bituminous Concrete (BC)	30
Dense Bituminous Macadam (DBM)	50
Granular Base (WMM)	250
GSB	150

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.10.

Table 5.10: Input Parameter considered in Flexible Pavement with WMM & GSB

Description	**Value considered**	**Reference**
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous, subgrade & GSB	7.2.2, point no. (vi) IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Unbound Layer E-Value GSB, (MPa)	Eq. 7.1 of IRC:37-2018	
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	
Poisson's Ratio	Bituminous Layer: 0.35 Granular base/sub-base: 0.35 Sub-grade: 0.35	

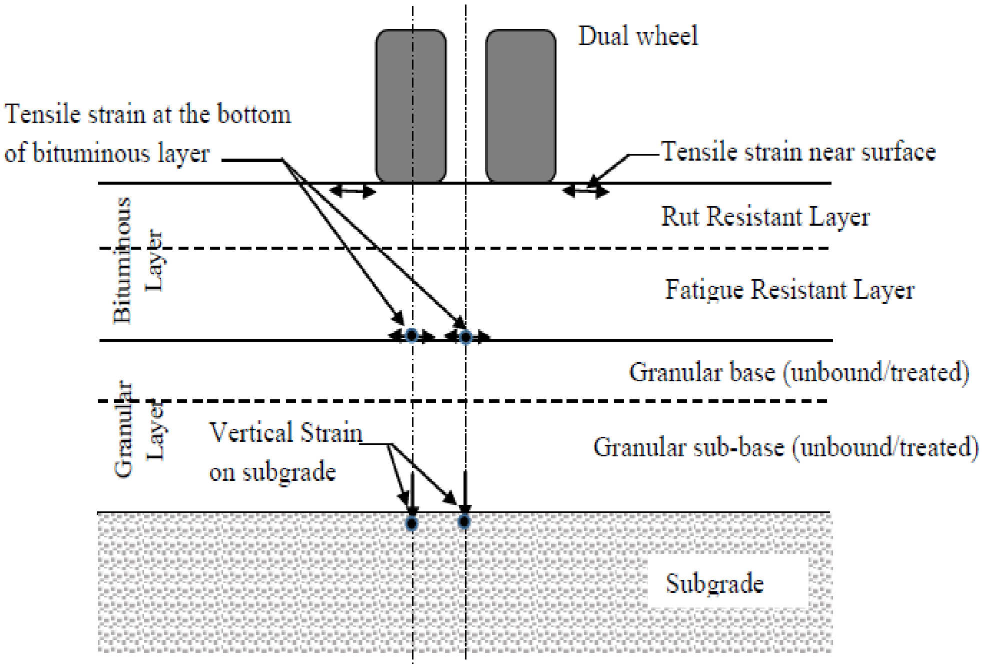


Fig. 5.5: A pavement section with bituminous layer(s), granular base and GSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 80% reliability)

$N_R = 4.1656 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.1 of IRC:37-2018)

$05 \times 10^6 = 4.1656\times10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 784.3 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 80% reliability)

$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.3 of IRC:37-2018)

$05\times10^6 = (5.068\times10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 464.99 \times 10^{-6}}$

The input-output results of IITPAVE for CASE I. *(Annex – I)*

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.11.

Table 5.11: Flexible Pavement thicknesses: CASE I

Allowable Strain		**Recommended Pavement Composition (mm)**				**Obtained Strains**		**Remarks**
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	BC	DBM	WMM	GSB	**Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**Safe**
464.99×10^{-6}	784.3×10^{-6}	30	50	250	150	362.5×10^{-6}	670×10^{-6}	

CASE II: **A pavement section with bituminous layer(s), granular crack relief layer, CTB, and GSB.**

The flexible pavement with CTB & GSB composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations.

Layers	**Thickness (mm)**
Bituminous Concrete (BC)	30
Dense Bituminous Macadam (DBM)	50
Granular Crack Relief (AIL)	100
Cement Treated Base (CTB)	100
Granular Sub-base (GSB)	200

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.12.

Table 5.12: Input Parameter considered in Flexible Pavement with CTB & GSB

Description	Value considered	Reference
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade 0.80 for CTB stress & strain calculation	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Aggregate Interface Layer (MPa)	450	
Unbound Layer E-Value GSB, (MPa)	Eq. 7.1 of IRC:37-2018	
Cement-treated Base (MPa)	6066.67	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018
Poisson's Ratio	Bituminous Layer: 0.35 GSB: 0.35 CTB: 0.25 Sub-grade: 0.35	

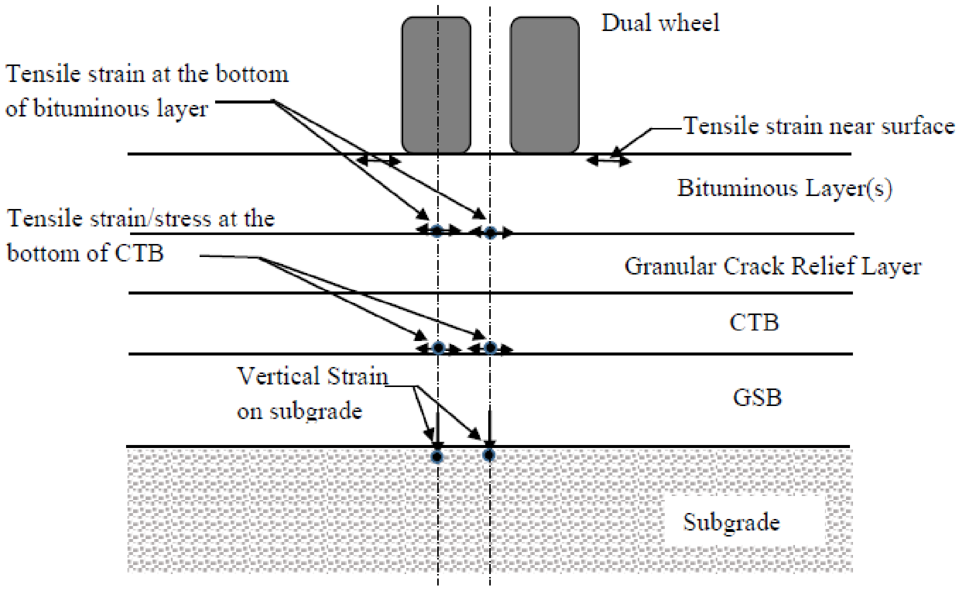


Fig 5.6: A pavement section with bituminous layers(s), granular crack relief layer, CTB and GSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 80% reliability)

$N_R = 4.1656 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.1 of IRC:37-2018)

$05 \times 10^6 = 4.1656 \times 10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 784.3 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 80% reliability)

$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t]^{3.89} * [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.3 of IRC:37-2018)

$05 \times 10^6 = (5.068 \times 10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 464.99 \times 10^{-6}}$

Fatigue Performance Model for Cement Treated Base (CTB)

Tensile strain at the bottom of the CTB layer.

$$N = RF \left[\frac{\left(\frac{113000}{E^{0.804}} + 191\right)}{\varepsilon_t} \right]^{12}$$ (Ref.: Eq. 3.5 of IRC:37-2018)

$$05 \times 10^6 = 1 \left[\frac{\frac{113000}{6066.67^{0.804}} + 191}{\varepsilon_t} \right]^{12}$$

$$\boldsymbol{\varepsilon_t = 162.44 \times 10^{-6}}$$

The input-output results of IITPAVE for CASE II. *(Annex – I)*

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.13.

Table 5.13: Flexible Pavement section: CASE II

Allowable Strain			**Recommended Pavement Composition (mm)**					**Obtained Strains**			**Remarks**
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**BC**	**DBM**	**AIL**	**CTB**	**GSB**	**Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t**	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**Safe**
464.99×10^{-6}	162.44×10^{-6}	784.3×10^{-6}	30	50	100	100	200	142.4×10^{-6}	100.3×10^{-6}	313.3×10^{-6}	

CASE III: **A pavement section with bituminous layer(s), granular crack relief layer, CTB, and CTSB.**

The flexible pavement with CTB & CTSB composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations.

Layer	**Thickness (mm)**
Bituminous Concrete (BC)	40
Dense Bituminous Macadam (DBM)	-
Granular Crack Relief Layer (AIL)	100
Cement Treated Base (CTB)	100
Cement Treated Sub-base (CTSB)	200

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.14.

Table 5.14: Input Parameter considered in Flexible Pavement with CTB & CTSB

Description	**Value considered**	**Reference**
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade 0.80 for CTB stress & strain calculation	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Aggregate Interface Layer (MPa)	450	
Unbound Layer E-Value GSB, (MPa)	Eq. 7.1 of IRC:37-2018	
Cement treated Base (MPa)	6066.67	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018
Poisson's Ratio	Bituminous Layer: 0.35 CTB: 0.25 CTSB: 0.25 Sub-grade: 0.35	

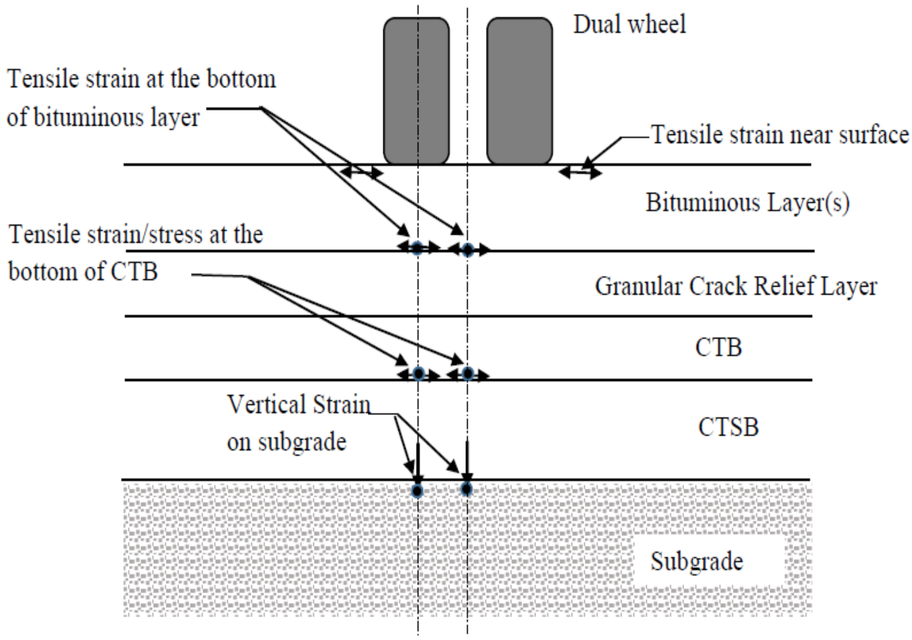


Fig 5.7: A pavement section with bituminous layer(s), granular crack relief layer, CTB and CTSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 80% reliability)

$N_R = 4.1656 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.1 of IRC:37-2018)

$05 \times 10^6 = 4.1656\times10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 784.3 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 80% reliability)

$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.3 of IRC:37-2018)

$05\times10^6 = (5.068\times10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 464.99 \times 10^{-6}}$

Fatigue Performance Model for Cement Treated Base (CTB)

Tensile strain at the bottom of the CTB layer.

$$N = RF \left[\frac{\left(\frac{113000}{E^{0.804}}+191\right)}{\varepsilon_t}\right]^{12}$$ (Ref.: Eq. 3.5 of IRC:37-2018)

$$05\times10^{6} = 1\left[\frac{\frac{113000}{6066.67^{0.804}}+191}{\varepsilon_t}\right]^{12}$$

$$\boldsymbol{\varepsilon_t = 162.44 \times 10^{-6}}$$

The input-output results of IITPAVE for CASE III. *(Annex – I)*

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.15.

Table 5.15: Flexible Pavement section: CASE III

Allowable Strain			Recommended Pavement Composition (mm)					Obtained Strains			Remarks
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	Horizontal Tensile Strain Under CTB (Fatigue); ε_t	Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v	BC	DBM	AIL	CTB	CTSB	Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	Horizontal Tensile Strain Under CTB (Fatigue); ε_t	Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v	Safe
464.99×10^{-6}	162.44×10^{-6}	784.3×10^{-6}	40	-	100	100	200	122×10^{-6}	79.04×10^{-6}	336.3×10^{-6}	

CASE IV: **A pavement section with bituminous layer(s), SAMI crack relief layer, CTB, and CTSB.**

The flexible pavement with CTB & CTSB composition is calculated for the recommended design traffic VG-40 grade bitumen) is considered for pavement design. The following pavement composition is proposed for calculations.

Layer	Thickness (mm)
Bituminous Concrete (BC)	30
Dense Bituminous Macadam (DBM)	-
SAMI	-
Cement Treated Base (CTB)	100

Cement Treated Sub-base (CTSB)	200

Specifications and Input parameters considered as per guidelines for flexible pavement design given in table no.5.16.

Table 5.16: Input Parameter considered in Flexible Pavement with SAMI, CTB & CTSB

Description	**Value considered**	**Reference**
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade 0.80 for CTB stress & strain calculation	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa) (BC & DBM layer)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
SAMI	NA	
Unbound Layer E-Value GSB, (MPa)	Eq. 7.1 of IRC:37-2018	
Cement-treated Base (MPa)	6066.67	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018
Poisson's Ratio	Bituminous Layer: 0.35 CTB: 0.25 CTSB: 0.25 Sub-grade: 0.35	

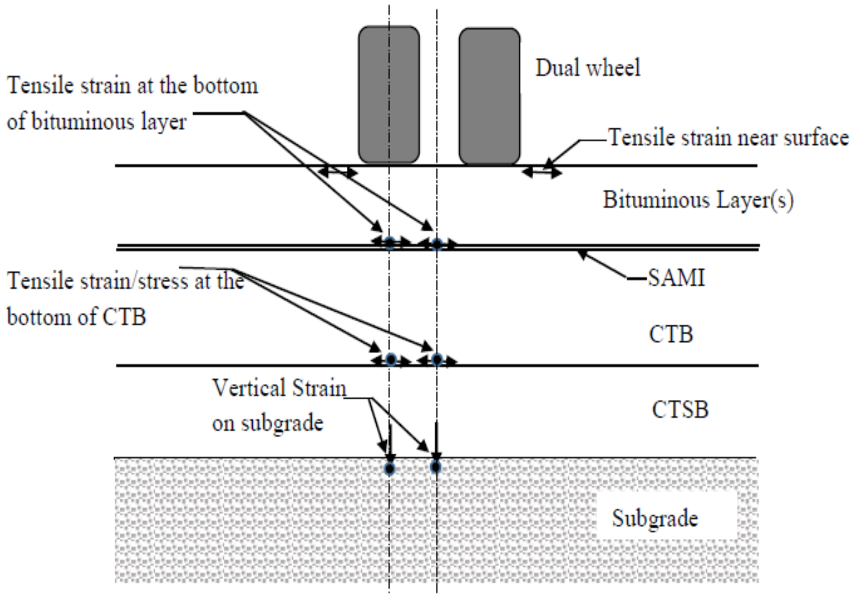


Fig 5.8: A Pavement section with bituminous layer(s), SAMI crack relief layer, CTB and CTSB showing the locations of critical strains. (IRC: 37-2018)

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 80% reliability)

$N_R = 4.1656 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.1 of IRC:37-2018)

$05 \times 10^6 = 4.1656 \times 10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 784.3 \times 10^{-6}}$

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 80% reliability)

$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.3 of IRC:37-2018)

$05\times10^6 = (5.068\times10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 464.99 \times 10^{-6}}$

Fatigue Performance Model for Cement Treated Base (CTB)

Tensile strain at the bottom of the CTB layer.

$$N = RF \left[\frac{\left(\frac{113000}{E^{0.804}} + 191\right)}{\varepsilon_t} \right]^{12}$$ (Ref.: Eq. 3.5 of IRC:37-2018)

$$05\times10^{6} = 1\left[\frac{\frac{113000}{6066.67^{0.804}}+191}{\varepsilon_t}\right]^{12}$$

$$\boldsymbol{\varepsilon_t = 162.44\times10^{-6}}$$

The input-output results of IITPAVE for CASE IV. *(Annex – I)*

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.17.

Table 5.17: Flexible Pavement section: CASE IV

Allowable Strain			Recommended Pavement Composition (mm)					Obtained Strains			Remarks
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**BC**	**DBM**	**SAMI**	**CTB**	**CTSB**	**Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t**	**Horizontal Tensile Strain Under CTB (Fatigue); ε_t**	**Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v**	**Safe**
464.99×10^{-6}	162.44×10^{-6}	784.3×10^{-6}	30	-	-	100	200	90.41×10^{-6}	117.6×10^{-6}	453.7×10^{-6}	

CASE V: **A pavement section with stabilized reclaimed pavement material (RPM), SAMI and subgrade using FDR.**

The flexible pavement with stabilized RPM & SAMI composition is calculated for the recommended design traffic with VG-40 grade bitumen is considered for pavement design. The following pavement composition is proposed for calculations.

Layer	**Thickness (mm)**
Bituminous Concrete (BC)	30
SAMI	-
Stabilized RPM	300

Specifications and Input parameters are considered as per guidelines for flexible pavement design given in table no. 5.18.

Table 5.18: Input Parameter considered in Flexible Pavement with stabilized RPM.

Description	Value considered	Reference
Wheel Configuration	Dual Wheel	Table 3.1 of IRC:37-2018
Spacing Between the wheels (mm)	310	Annex I of IRC:37:2018
A load of Single Wheel (kN)	20	Table 3.1 of IRC:37-2018
Tire Pressure (MPa)	0.56 for Bituminous & subgrade	Table 3.1 of IRC:37-2018
Bituminous Layer E-Value (MPa)	3000MPa – VG-40	Table 11.1 of IRC:37-2018
Stabilized RPM (MPa) E-Value (MPa)	4900	Ref.: Table 4.1 of Chapter 4
Subgrade Layer E-Value (MPa)	Eq. 6.1 & 6.2 IRC:37-2018	Table 11.1 of IRC:37-2018

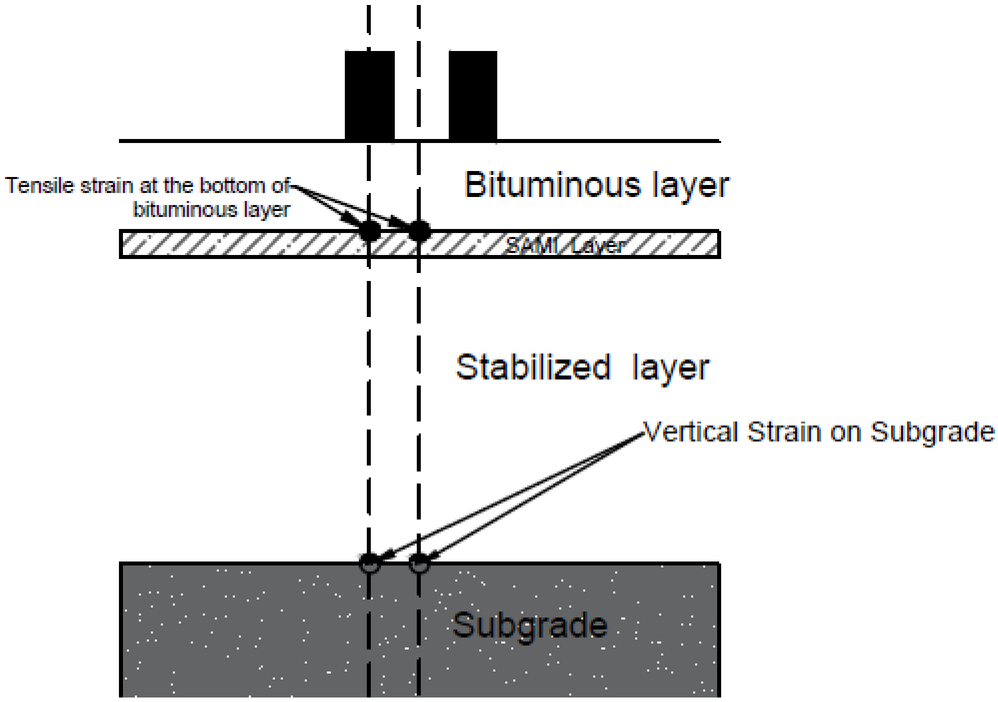


Fig 5.9: A Pavement section with bituminous layer, SAMI crack relief layer and stabilized RPM layer showing the locations of critical strains.

Fatigue Cracking Criteria for Bituminous Layer

Maximum horizontal tensile strain at the bottom of bituminous layer. (For 80% reliability)

N_f = 1.6064*C*10^{-04} $[1/\varepsilon_t]^{3.89}$* $[1/M_{Rm}]^{0.854}$ (Ref: Eq. 3.3 of IRC:37-2018)

$05\times10^6 = (5.068\times10^{-4}) \times [1/\varepsilon_t]^{3.89} \times [1/3000]^{0.854}$

$\boldsymbol{\varepsilon_t = 464.99 \times 10^{-6}}$

Subgrade Rutting Criteria

Vertical compressive strain on the top of subgrade. (For 80% reliability)

$N_R = 4.1656 * 10^{-08} [1/\varepsilon_v]^{4.5337}$ (Ref: Eq. 3.1 of IRC:37-2018)

$05 \times 10^6 = 4.1656\times10^{-08} [1/ \varepsilon_v]^{4.5337}$

$\boldsymbol{\varepsilon_v = 784.3 \times 10^{-6}}$

The input-output results of IITPAVE for CASE V. *(Annex – I)*

The results and recommended pavement thicknesses based on the above analysis are presented in Table 5.19.

Table 5.19: Flexible Pavement section: CASE V

Allowable Strain		Recommended Pavement Composition (mm)			Obtained Strains		Remarks
Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v	BC	SAMI	Stabilized RPM	Horizontal Tensile Strain Under Bituminous Layer (Fatigue); ε_t	Vertical Compressive Strain on Top of Subgrade (Rutting); ε_v	
464.99×10^{-6}	784.3×10^{-6}	30	-	300	49.61×10^{-6}	197.1×10^{-6}	**SAFE**

5.3.3 Thickness comparisons.

The thickness comparison of different layers of the flexible pavement for low and high-volume roads are as follows.

High Volume Road

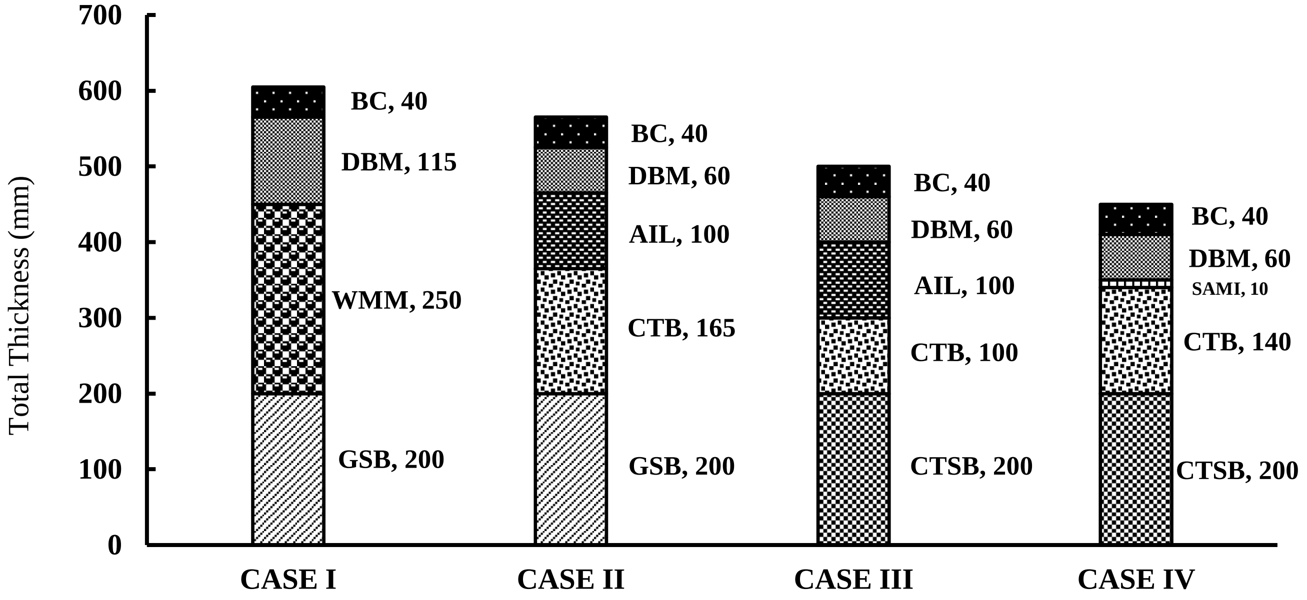


Fig. 5.10 Thickness comparison of high-volume road.

- *Low Volume Road*

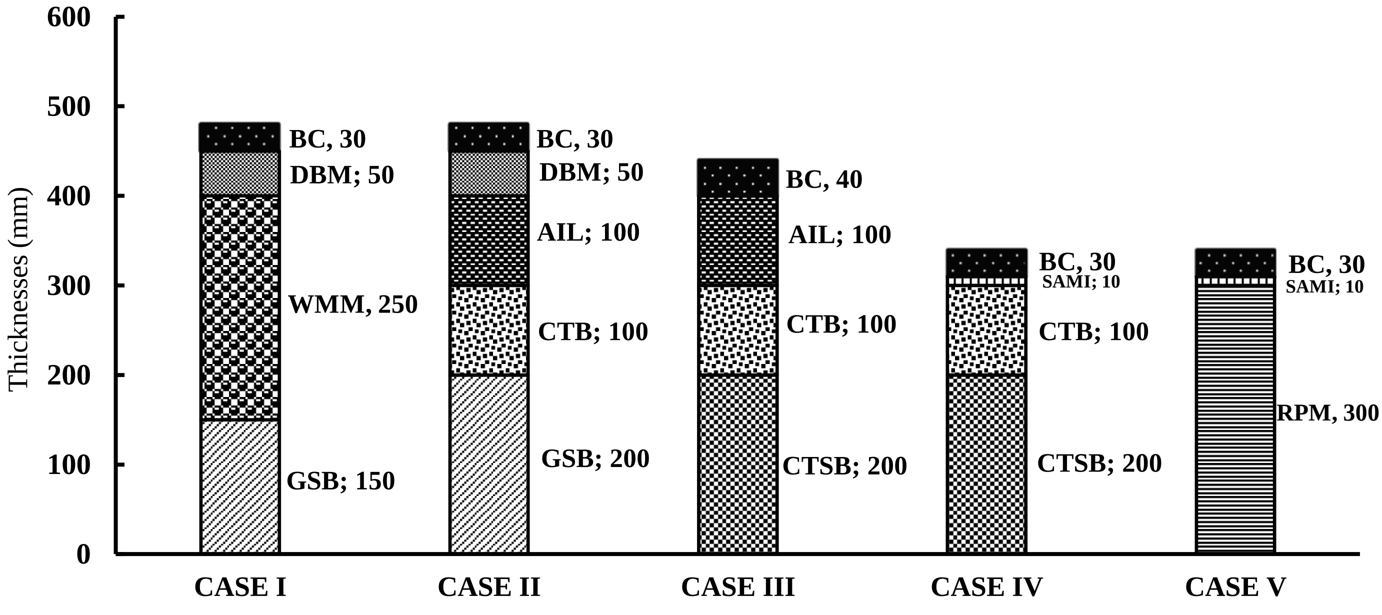


Fig. 5.11 Thickness comparison of low volume road.

5.4 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%

- ***High Volume Road***

Table 5.20: Cost per km for high-volume roads.

Layers	Thickness (mm)	Width (m)	Length (m)	Quantity (m^3)	Cost Incurred (INR)	Amount (Lacs)	Total (Lacs)
CASE I: A pavement section with bituminous layer(s), granular base and GSB.							
BC	40	7	1000	280	13420.70	37.57	**208.35**
DBM	115			805	11000.90	88.56	
WMM	250			1750	2766.90	48.42	
GSB	200			1400	2414.50	33.80	
CASE II: A pavement section with bituminous layer(s), granular crack relief layer, CTB, and GSB.							
BC	40	7	1000	280	13420.70	37.57	**175.44**
DBM	60			420	11000.90	46.20	
AIL	100			700	2766.90	19.37	
CTB	165			1155	3333.40	38.50	
GSB	200			1400	2414.50	33.80	
CASE III: A pavement section with bituminous layer(s), granular crack relief layer, CTB, and GSB.							
BC	40	7	1000	280	13420.70	37.57	**167.33**
DBM	60			420	11000.90	46.20	
AIL	100			700	2766.90	19.37	
CTB	100			700	3333.40	23.33	
CTSB	200			1400	2918.70	40.86	

CASE IV: A pavement section with bituminous layer(s), SAMI crack relief layer, CTB, and GSB.							
BC	40	7	1000	280	13420.70	37.57	**157.34**
DBM	60			420	11000.90	46.20	
SAMI	10			70	53	0.037	
CTB	140			980	3333.40	32.67	
CTSB	200			1400	2918.70	40.86	

- *Low Volume Road*

Table 5.21: Cost per km for low-volume roads.

CASE I: A pavement section with bituminous layer(s), granular base and GSB.							
Layers	**Thickness (mm)**	**Width (m)**	**Length (m)**	**Quantity (m^3)**	**Cost Incurred (INR)**	**Amount (Lacs)**	**Total (Lacs)**
BC	30	7	1000	210	13420.70	28.18	**140.45**
DBM	50			350	11000.90	38.50	
WMM	250			1750	2766.90	48.42	
GSB	150			1050	2414.50	25.35	
CASE II: A pavement section with bituminous layer(s), granular crack relief layer, CTB, and GSB.							
BC	30	7	1000	210	13420.70	28.18	**143.18**
DBM	50			350	11000.90	38.50	
AIL	100			700	2766.90	19.37	
CTB	100			700	3333.40	23.33	
GSB	200			1400	2414.50	33.80	
CASE III: A pavement section with bituminous layer(s), granular crack relief layer, CTB, and GSB.							
BC	40	7	1000	280	13420.70	37.57	**121.13**
DBM	-			-	-	-	
AIL	100			700	2766.90	19.37	
CTB	100			700	3333.40	23.33	
CTSB	200			1400	2918.70	40.86	

CASE IV: A pavement section with bituminous layer(s), SAMI crack relief layer, CTB, and GSB.							
BC	30	7	1000	210	13420.70	28.18	**92.41**
DBM	-			-	-	-	
SAMI	10			70	53	0.037	
CTB	100			700	3333.40	23.33	
CTSB	200			1400	2918.70	40.86	

- *Using full-depth reclamation (FDR)*

Table 5.22: Cost per km for low-volume roads using FDR.

CASE V: A pavement section with stabilized reclaimed pavement material (RPM), SAMI and subgrade.							
Layers	**Thickness (mm)**	**Width (m)**	**Length (m)**	**Quantity (m^3)**	**Cost Incurred (INR)**	**Amount (Lacs)**	**Total (Lacs)**
BC	30	7	1000	210	13420.70	28.18	**98.23**
SAMI	10			70	53	0.037	
Stabilized RPM	300			2100	3334	70.01	

5.5 COST BENEFITS

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 result of the cost comparison of in situ stabilization and the traditional method, as shown in tables 5.20 & 5.21, have further strengthened the confidence in using stabilization with cement for high volume and low volume roads. The was incurred (per km) was analyzed, adopting the cost provided by PWD Uttarakhand. For the current study, transportation and labour cost was excluded.

From figure 5.11, it is clear 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. 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).

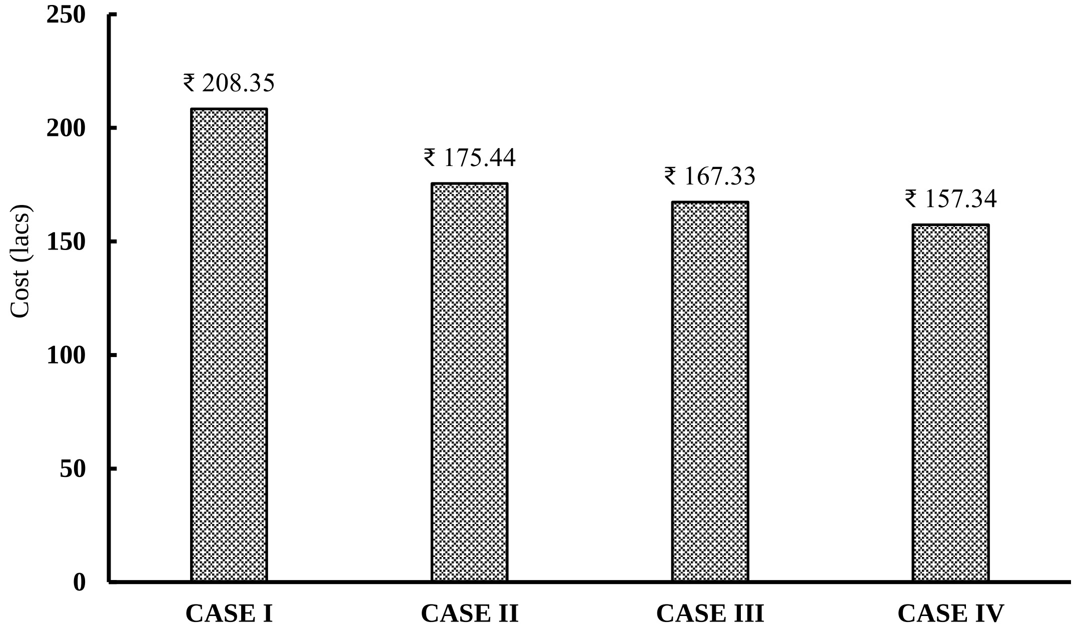


Fig. 5.12 Cost analysis of high-volume road.

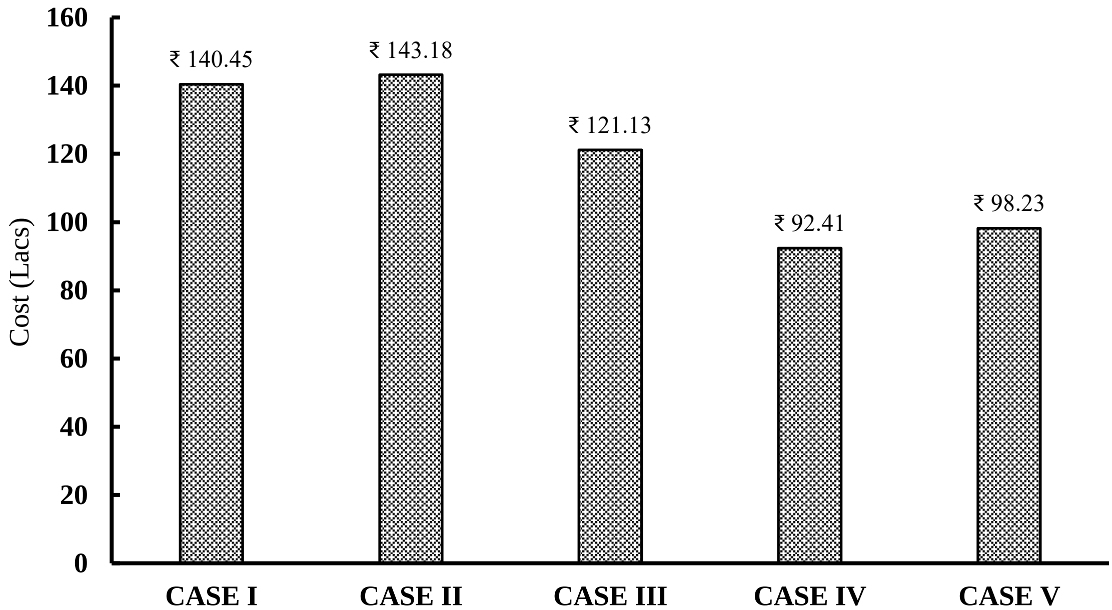


Fig. 5.13 Cost analysis of low-volume road.

- ***Designed pavement sections:***

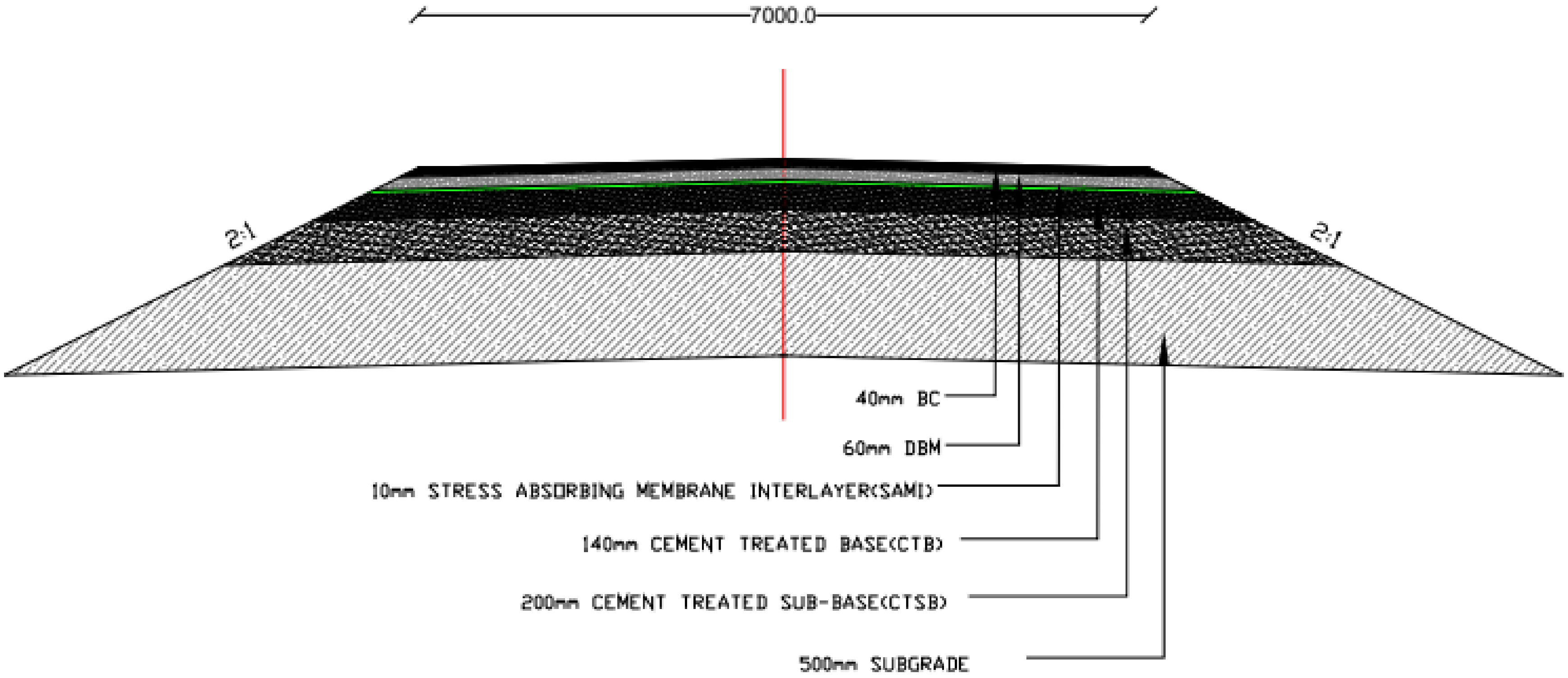


Fig. 5.14 Designed pavement section for the high-volume road.

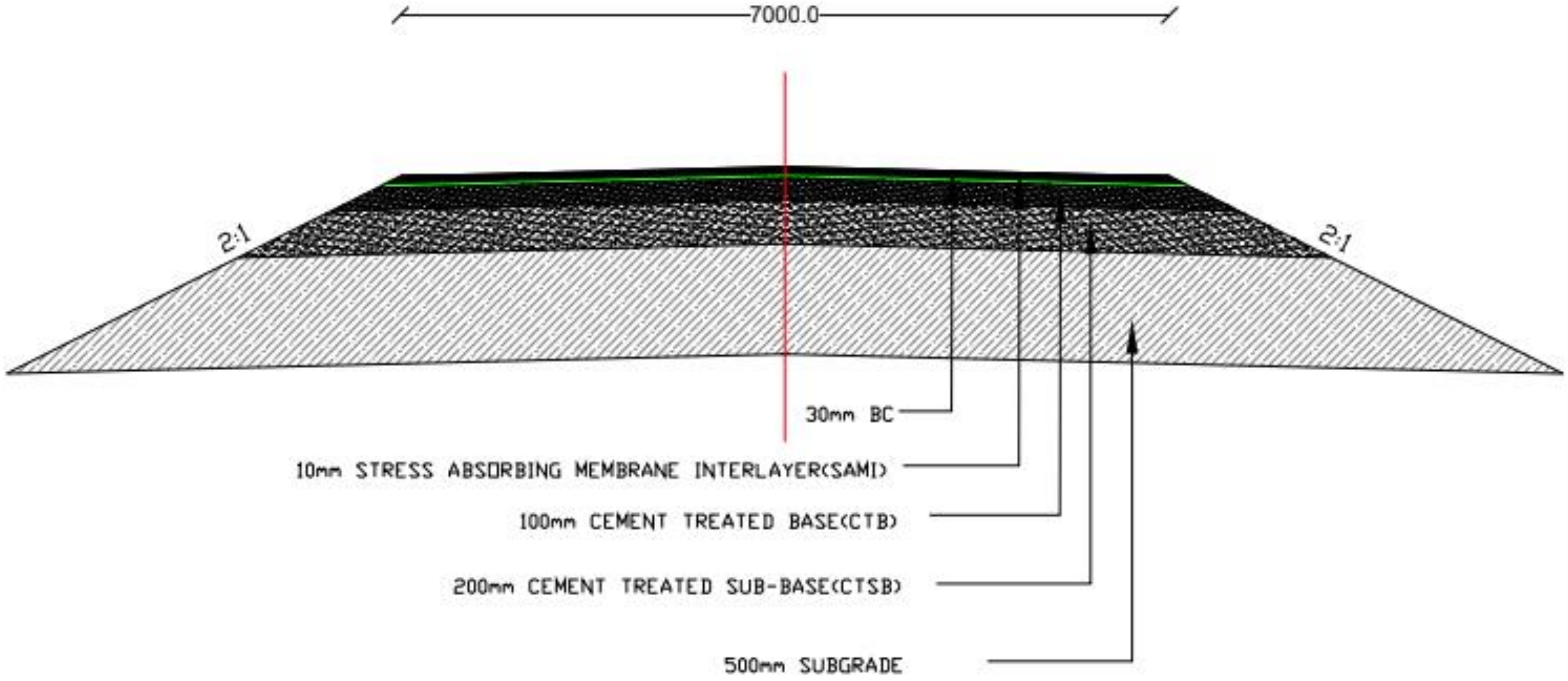


Fig. 5.15 Designed pavement section for the low-volume road.

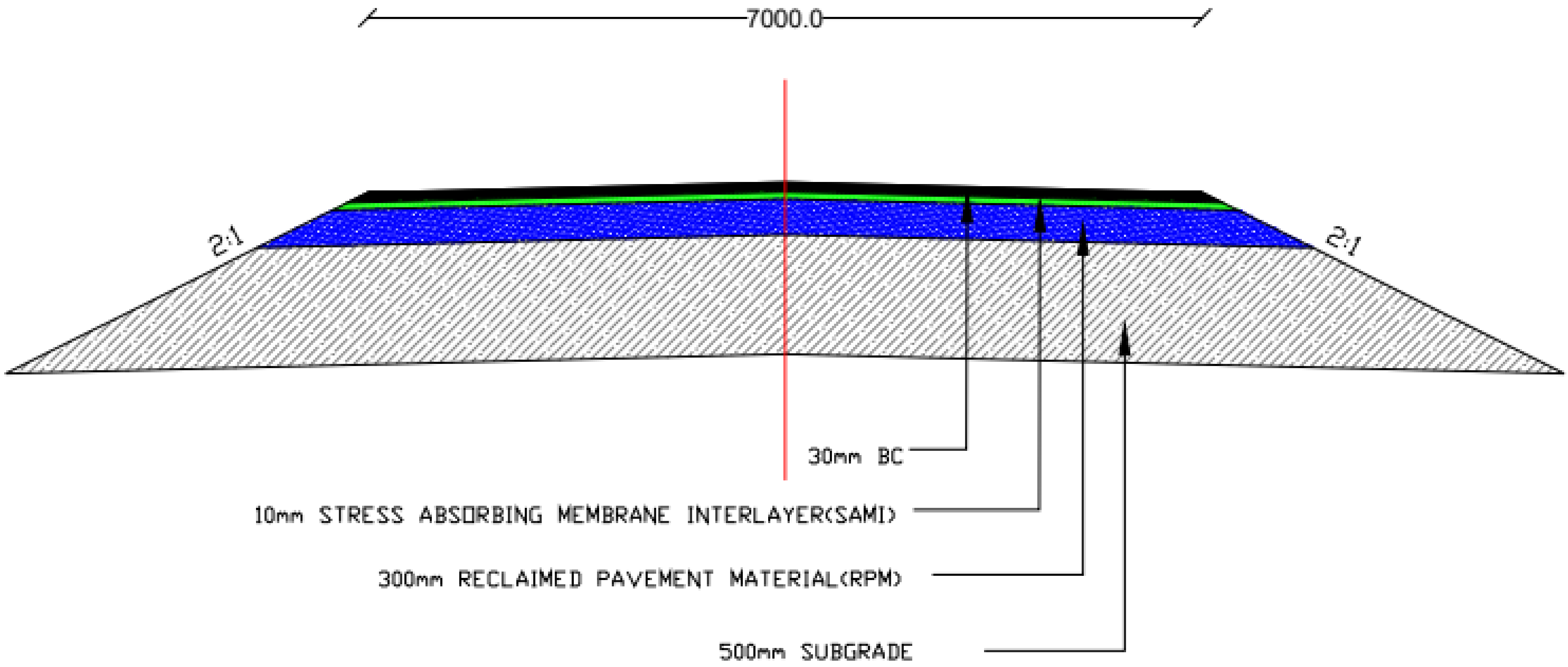


Fig. 5.16 Designed pavement section for the low-volume road using FDR

CHAPTER – 06
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:

1. There is no significant effect of partial replacement of cement with fly ash on compaction characteristics such as OMC-MDD relationships.

2. The 7-days UCS values decrease with increased fly ash content and increases with an increase in 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).

3. 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.

4. 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).

5. The value of resilient modulus increases with the increasing percentage of cement. In the case of FDR, the mix with 5% cement and 3% chemical stabilizers (each of TerraCil & ZycoBond) have the highest resilient modulus.

6. The mixes with 4% cement (M3), 3% cement & 1% fly ash (M6) and 5% cement in FDR (F4) meets 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.

7. 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).

8. 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.

9. 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.

10. 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.

11. 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.

REFERENCES

[1] Adresi, M., Khishdari, A., Ahmadi, A., & Rooholamini, H. (2019). Influence of high content of reclaimed asphalt on the mechanical properties of cement-treated base under critical environmental conditions. *International Journal of Pavement Engineering*, *20*(9), 1098-1105.

[2] Abd Al-RedhaGhani, R., Al-Jummaily, M. A., & Al-Zerjawi, A. K. STUDY OF CEMENT TREATED BASE AGREAGATE PROPERTIES FOR PAVEMENT STRUCTURE.

[3] Beesam, V. V., & Torres-Machi, C. (2021). Input Parameters for the Mechanistic-Empirical Design of Full-Depth Reclamation Projects. *Transportation Research Record*, *2675*(11), 384-396.

[4] Braham, A. (2016). Comparing life-cycle cost analysis of full-depth reclamation versus traditional pavement maintenance and rehabilitation strategies. *Transportation Research Record*, *2573*(1), 49-59.

[5] Cement-Treated Base (CTB). (n.d.). Cement-Treated Base (CTB); www.cement.org. Retrieved May 31, 2022, from https://www.cement.org/cement-concrete/cement-concrete-applications/cement-based-pavements/cement-treated-base-(ctb).

[6] Chen, D. H., Hong, F., & Zhou, F. (2011). Premature cracking from cement-treated base and treatment to mitigate its effect. *Journal of performance of constructed facilities*, *25*(2), 113-120.

[7] Chhabra, R. S., Ransinchung, G. D. R. N., & Islam, S. S. (2021). Performance analysis of cement treated base layer by incorporating reclaimed asphalt pavement material and chemical stabilizer. *Construction and Building Materials*, *298*, 123866.

[8] Chakravarthi, S., Boyina, A., Singh, A. K., & Shankar, S. (2019). Evaluation of cement treated reclaimed asphalt pavement and recycled concrete pavement bases. *International Journal of Pavement Research and Technology*, *12*(6), 581-588.

[9] Del Rey, I., Ayuso, J., Barbudo, A., Galvín, A. P., Agrela, F., & de Brito, J. (2016). Feasibility study of cement-treated 0–8 mm recycled aggregates from construction and demolition waste as road base layer. Road Mater Pavement Des 17: 678–692.

[10] Ghanizadeh, A. R., Rahrovan, M., & Bafghi, K. B. (2018). The effect of cement and reclaimed asphalt pavement on the mechanical properties of stabilized base via full-depth reclamation. *Construction and Building Materials*, *161*, 165-174.

[11] Heyns, M. W. (2016). *Fly ash as an alternative stabiliser for road pavement materials: a case study in South Africa* (Doctoral dissertation, Bloemfontein: Central University of Technology, Free State).

[12] IRC: 37-2018, Guidelines for the design of flexible pavements, 4th Revision, Indian Roads Congress, New Delhi, India, November 2018.

[13] Joe, M. A., & Rajesh, A. M. (2015). Soil stabilization using industrial waste and lime. *International Journal of Scientific Research Engineering & Technology (IJSRET)*, *4*(7).

[14] Kasu, S. R., Manupati, K., & Muppireddy, A. R. (2020). Investigations on design and durability characteristics of cement treated reclaimed asphalt for base and subbase layers. *Construction and Building Materials*, *252*, 119102.

[15] Lv, S., Xia, C., Liu, H., You, L., Qu, F., Zhong, W., ... & Washko, S. (2021). Strength and fatigue performance for cement-treated aggregate base materials. *International Journal of Pavement Engineering*, *22*(6), 690-699.

[16] Nusit, K., & Jitsangiam, P. (2016). Damage behavior of cement-treated base material. *Procedia engineering*, *143*, 161-169.

[17] MoRTH, Specifications for Road Works and Bridges, Fifth revision., Ministry of Road Transport and Highways, India, 2013.

[18] Melese, E., Baaj, H., Tighe, S., Smith, T., & Zupko, S. (2018). *Laboratory assessment on effects of blended cements on strength and durability of full-depth reclaimed pavement materials*. Paper presented at 2018 Transportation Association of Canada Conference - Innovation and Technology: Evolving Transportation, TAC 2018, Saskatoon, Canada.

[19] Rai, P., Qiu, W., Pei, H., Chen, J., Ai, X., Liu, Y., & Ahmad, M. (2021). Effect of Fly Ash and Cement on the Engineering Characteristic of Stabilized Subgrade Soil: An Experimental Study. *Geofluids*, *2021*.

[20] Singh, G., Jain, S., Tiwari, D., Dave, S. M., & Singh, A. (2020). Assessment of modulus using falling weight deflectometer and cores for stabilized layer. *Materials Today: Proceedings*, *32*, 698-705.

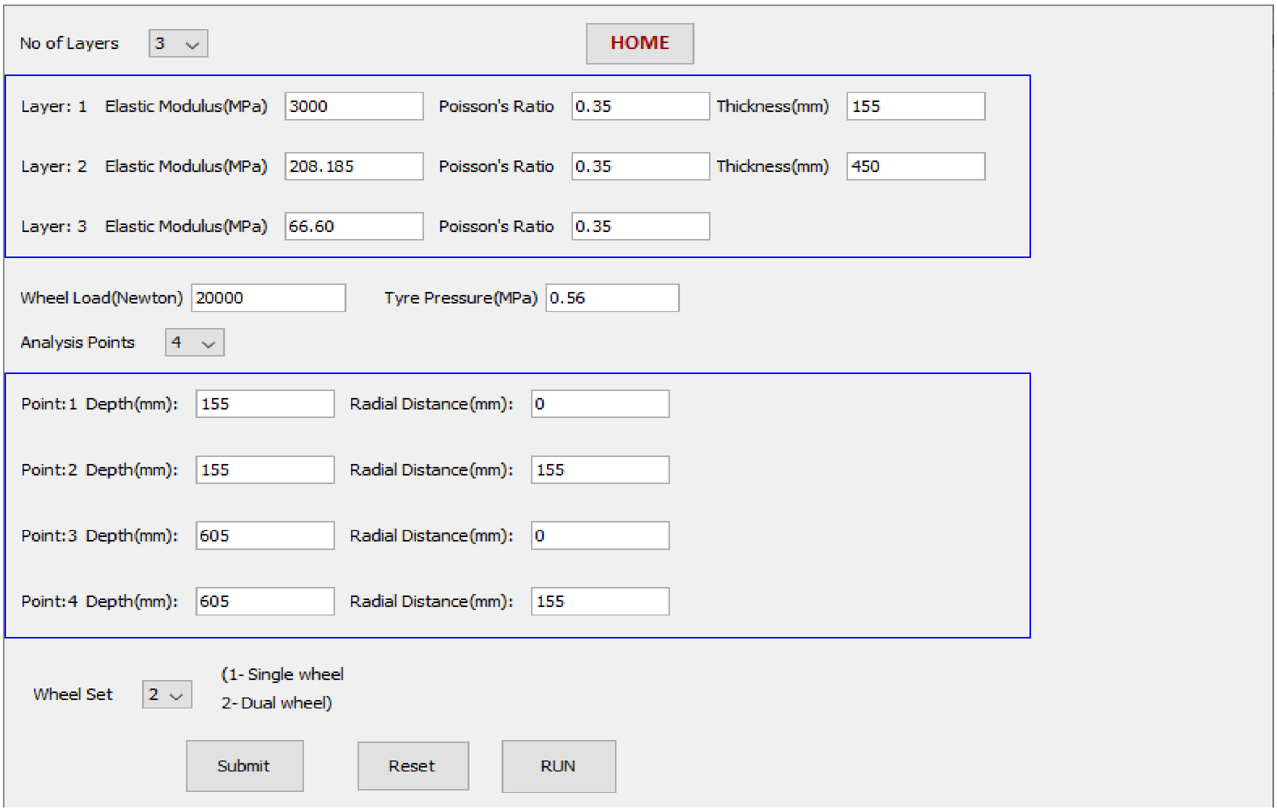
[21] Shubber, K. H., & Mohamed, E. S. H. (2018). Some Mechanical Properties of Cement Treated Base (CTB) In-corporating waste Portland Cement Concrete Under Different Corresponding Conditions. *International Journal of Engineering & Technology*, *7*(4.37), 138-144.

[22] Su, N., Xiao, F., Wang, J., & Amirkhanian, S. (2017). Characterizations of base and subbase layers for Mechanistic-Empirical Pavement Design. *Construction and Building Materials*, *152*, 731-745.

ANNEX I

HIGH VOLUME ROADS

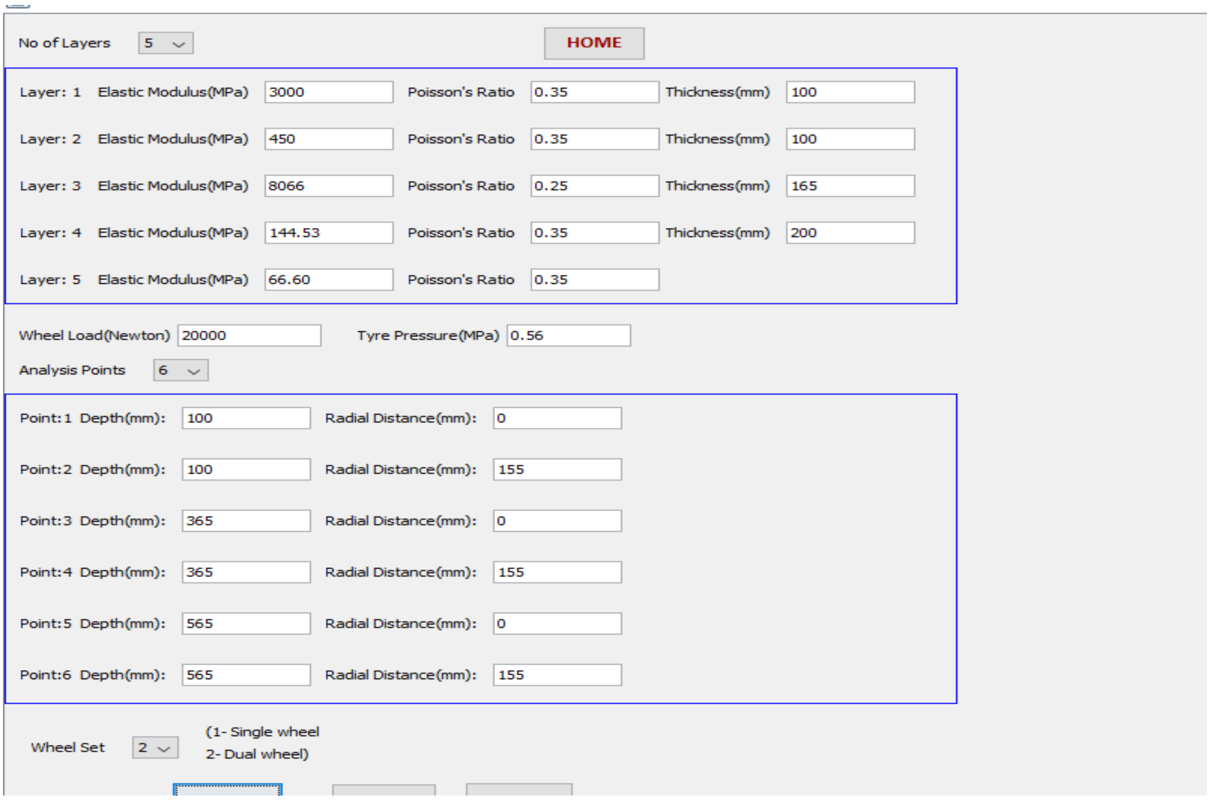
CASE I




```
No. of layers                   3
E values (MPa)          3000.00  208.18   66.60
Mu values                  0.350.350.35
thicknesses (mm)         155.00  450.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R       SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ       epZ        epT        epR
155.00     0.00-0.9796E-01 0.6813E+00 0.5458E+00-0.1431E-01 0.3842E+00-0.1758E-03 0.1749E-03 0.1139E-03
155.00L    0.00-0.9797E-01-0.1808E-02-0.1122E-01-0.1431E-01 0.3842E+00-0.4487E-03 0.1749E-03 0.1139E-03
155.00   155.00-0.8965E-01 0.6134E+00 0.3254E+00-0.4304E-01 0.3949E+00-0.1394E-03 0.1770E-03 0.4737E-04
155.00L 155.00-0.8965E-01-0.2359E-02-0.2234E-01-0.4304E-01 0.3949E+00-0.3891E-03 0.1770E-03 0.4737E-04
605.00     0.00-0.1762E-01 0.2519E-01 0.2244E-01-0.2683E-02 0.2786E+00-0.1647E-03 0.1129E-03 0.9506E-04
605.00L    0.00-0.1770E-01 0.1572E-02 0.7087E-03-0.2683E-02 0.2786E+00-0.2778E-03 0.1129E-03 0.9541E-04
605.00   155.00-0.1874E-01 0.2653E-01 0.2479E-01-0.3375E-02 0.2847E+00-0.1763E-03 0.1173E-03 0.1060E-03
605.00L 155.00-0.1874E-01 0.1623E-02 0.1065E-02-0.3375E-02 0.2847E+00-0.2956E-03 0.1173E-03 0.1060E-03
```

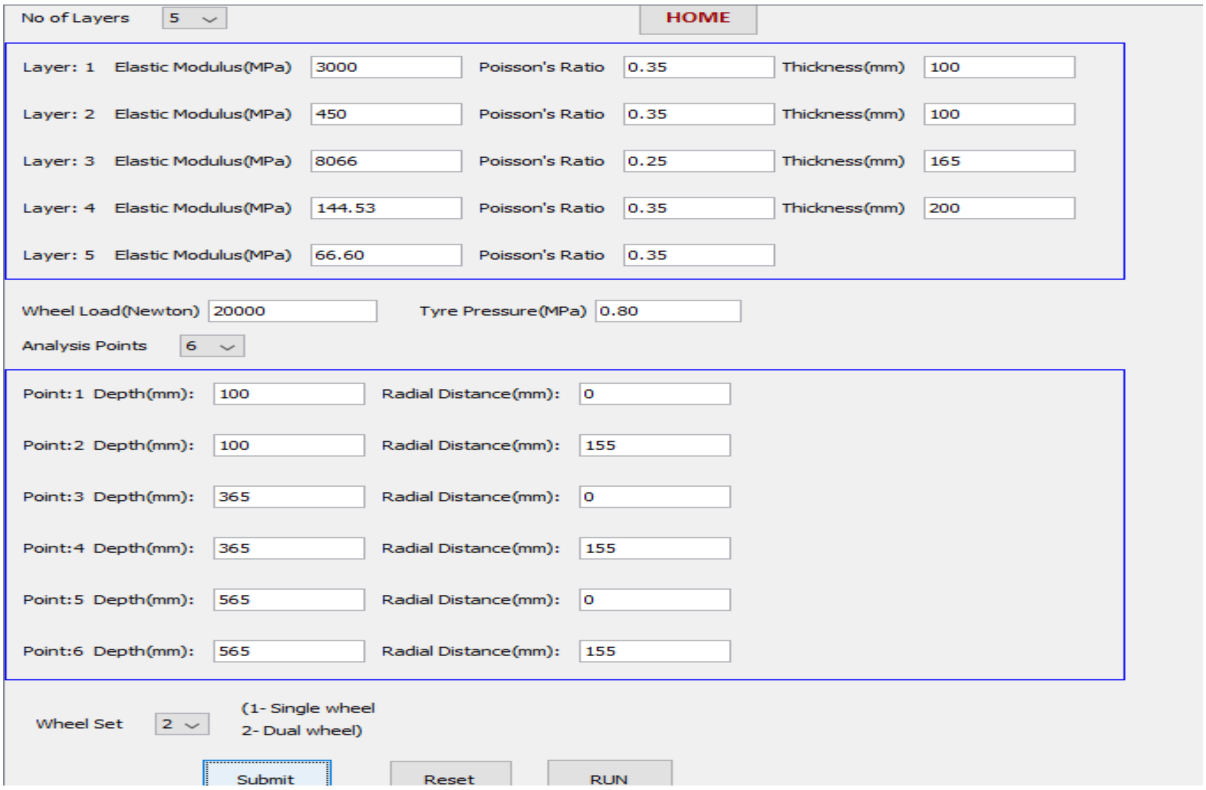
The input – output results of IITPAVE for bituminous & subgrade of CASE I

CASE II




```
No. of layers                 5
E values (MPa)          3000.00  450.00 8066.00  144.53   66.60
Mu values                  0.350.350.250.350.35
thicknesses (mm)         100.00  100.00  165.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT     SigmaR      TaoRZ      DispZ      epZ        epT        epR
100.00    0.00-0.2668E+00 0.3891E+00 0.3060E+00-0.1448E-01 0.2911E+00-0.1700E-03 0.1251E-03 0.8772E-04
100.00L   0.00-0.2668E+00-0.6373E-01-0.7620E-01-0.1448E-01 0.2911E+00-0.4840E-03 0.1251E-03 0.8772E-04
100.00  155.00-0.1822E+00 0.1677E+00-0.2477E+00-0.7732E-01 0.2851E+00-0.5137E-04 0.1060E-03-0.8089E-04
100.00L 155.00-0.1822E+00-0.5822E-01-0.1205E+00-0.7732E-01 0.2851E+00-0.2658E-03 0.1060E-03-0.8089E-04
365.00    0.00-0.1901E-01 0.5126E+00 0.4223E+00-0.3444E-02 0.2528E+00-0.3133E-04 0.5105E-04 0.3706E-04
365.00L   0.00-0.1901E-01 0.3098E-03-0.1188E-02-0.3444E-02 0.2528E+00-0.1294E-03 0.5105E-04 0.3705E-04
365.00  155.00-0.2050E-01 0.5526E+00 0.4745E+00-0.5618E-02 0.2580E+00-0.3438E-04 0.5444E-04 0.4233E-04
365.00L 155.00-0.2050E-01 0.3711E-03-0.9258E-03-0.5618E-02 0.2580E+00-0.1405E-03 0.5444E-04 0.4233E-04
565.00    0.00-0.1173E-01 0.6444E-02 0.5362E-02-0.1444E-02 0.2298E+00-0.1098E-03 0.6001E-04 0.4991E-04
565.00L   0.00-0.1173E-01-0.4373E-03-0.9351E-03-0.1444E-02 0.2298E+00-0.1690E-03 0.6001E-04 0.4992E-04
565.00  155.00-0.1233E-01 0.6849E-02 0.6141E-02-0.1870E-02 0.2333E+00-0.1168E-03 0.6238E-04 0.5577E-04
565.00L 155.00-0.1233E-01-0.4249E-03-0.7507E-03-0.1870E-02 0.2333E+00-0.1790E-03 0.6238E-04 0.5577E-04
```

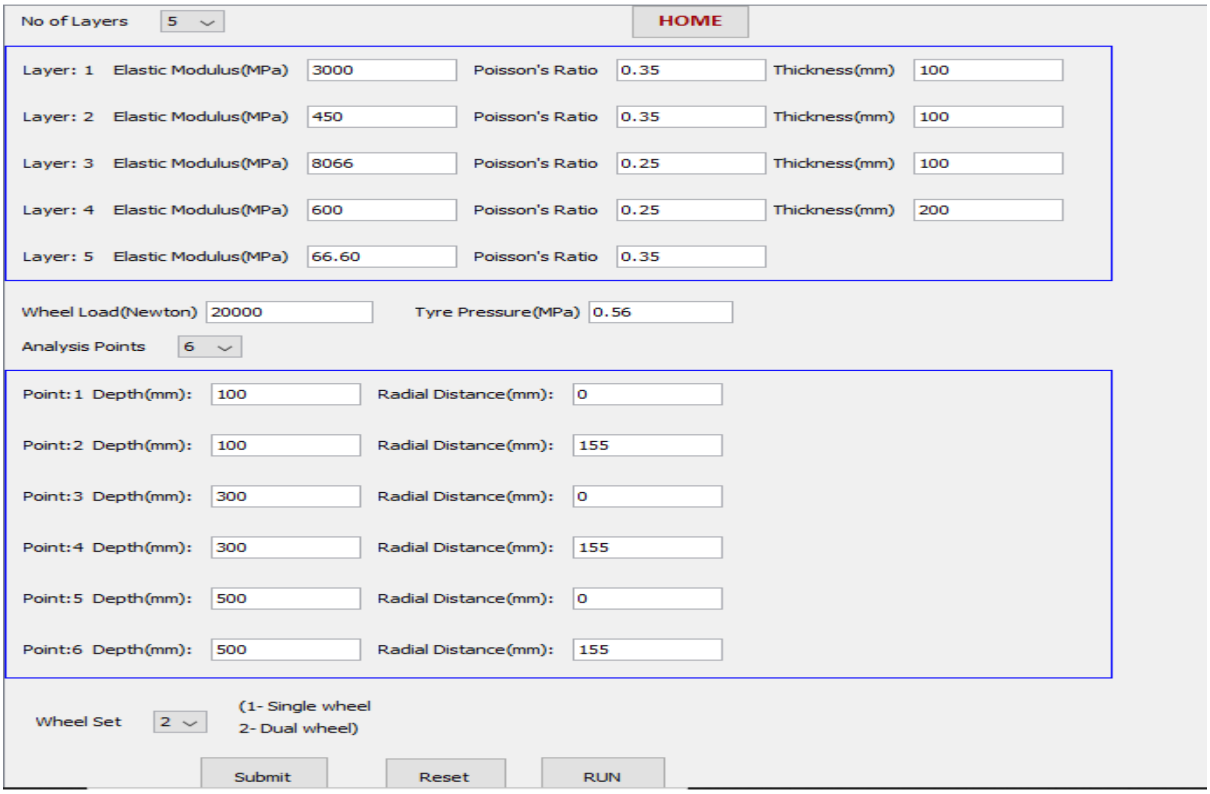
The input – output results of IITPAVE for bituminous & subgrade of CASE II




```
No. of layers                 5
E values (MPa)          3000.00  450.00 8066.00  144.53   66.60
Mu values                  0.350.350.250.350.35
thicknesses (mm)         100.00  100.00  165.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.80
Dual  Wheel
  Z         R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
100.00    0.00-0.3023E+00 0.5200E+00 0.4371E+00-0.1430E-01 0.2960E+00-0.2124E-03 0.1576E-03 0.1203E-03
100.00L   0.00-0.3023E+00-0.6038E-01-0.7281E-01-0.1430E-01 0.2960E+00-0.5682E-03 0.1576E-03 0.1203E-03
100.00  155.00-0.1775E+00 0.1648E+00-0.3107E+00-0.7822E-01 0.2851E+00-0.4214E-04 0.1119E-03-0.1021E-03
100.00L 155.00-0.1775E+00-0.5652E-01-0.1278E+00-0.7822E-01 0.2851E+00-0.2510E-03 0.1119E-03-0.1021E-03
365.00    0.00-0.1920E-01 0.5197E+00 0.4280E+00-0.3482E-02 0.2532E+00-0.3175E-04 0.5176E-04 0.3755E-04
365.00L   0.00-0.1920E-01 0.3531E-03-0.1168E-02-0.3483E-02 0.2532E+00-0.1308E-03 0.5176E-04 0.3755E-04
365.00  155.00-0.2067E-01 0.5601E+00 0.4784E+00-0.5757E-02 0.2585E+00-0.3475E-04 0.5526E-04 0.4259E-04
365.00L 155.00-0.2067E-01 0.4275E-03-0.9290E-03-0.5756E-02 0.2585E+00-0.1418E-03 0.5526E-04 0.4259E-04
565.00    0.00-0.1178E-01 0.6493E-02 0.5383E-02-0.1457E-02 0.2300E+00-0.1103E-03 0.6042E-04 0.5005E-04
565.00L   0.00-0.1178E-01-0.4281E-03-0.9402E-03-0.1457E-02 0.2300E+00-0.1697E-03 0.6043E-04 0.5005E-04
565.00  155.00-0.1239E-01 0.6913E-02 0.6189E-02-0.1894E-02 0.2336E+00-0.1174E-03 0.6284E-04 0.5608E-04
565.00L 155.00-0.1239E-01-0.4112E-03-0.7443E-03-0.1894E-02 0.2336E+00-0.1799E-03 0.6284E-04 0.5608E-04
```

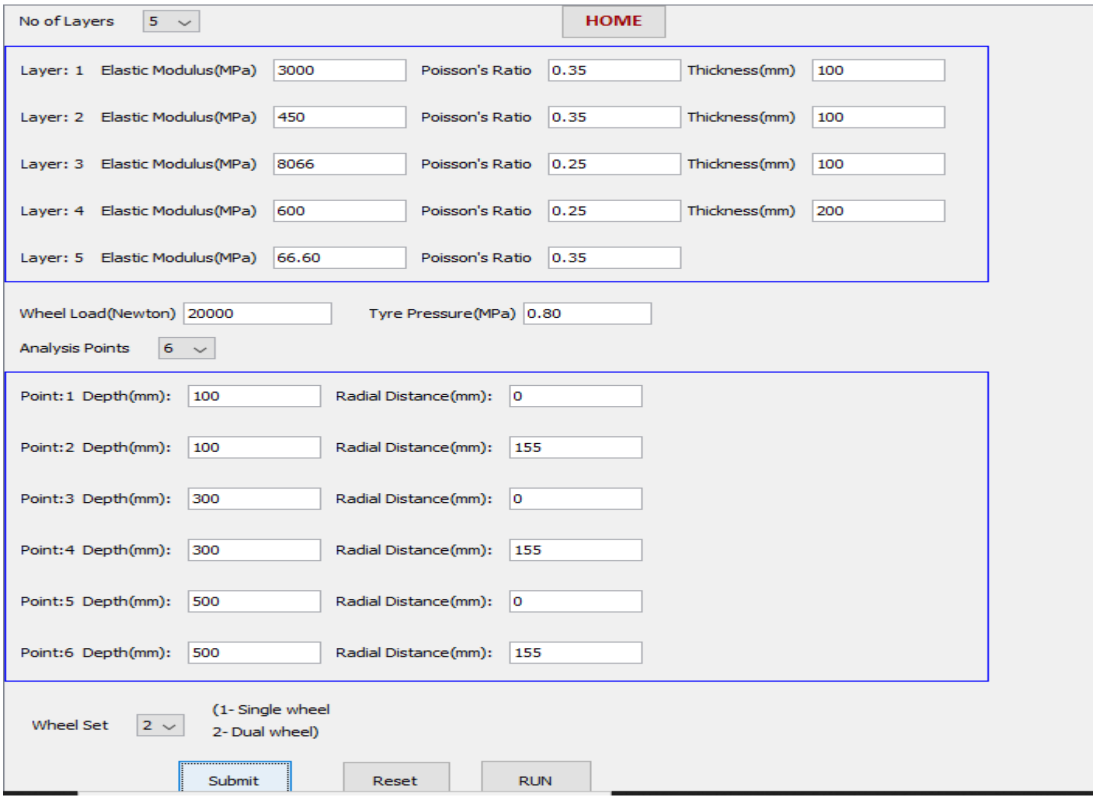
The input – output results of IITPAVE for CTB of CASE II

CASE III




```
No. of layers                 5
E values (MPa)         3000.00  450.00 8066.00  600.00   66.60
Mu values                 0.350.350.250.250.35
thicknesses (mm)        100.00  100.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)       0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ        epT        epR
100.00     0.00-0.2608E+00 0.4091E+00 0.3233E+00-0.1821E-01 0.3095E+00-0.1724E-03 0.1291E-03 0.9046E-04
100.00L    0.00-0.2608E+00-0.5801E-01-0.7088E-01-0.1821E-01 0.3095E+00-0.4793E-03 0.1291E-03 0.9046E-04
100.00   155.00-0.1753E+00 0.1899E+00-0.2274E+00-0.8556E-01 0.3051E+00-0.5405E-04 0.1103E-03-0.7752E-04
100.00L  155.00-0.1753E+00-0.5174E-01-0.1143E+00-0.8556E-01 0.3051E+00-0.2604E-03 0.1103E-03-0.7752E-04
300.00     0.00-0.5142E-01 0.4672E+00 0.3630E+00-0.1712E-01 0.2730E+00-0.3211E-04 0.4826E-04 0.3212E-04
300.00L    0.00-0.5142E-01 0.1889E-01 0.1114E-01-0.1712E-01 0.2730E+00-0.9821E-04 0.4826E-04 0.3212E-04
300.00   155.00-0.5625E-01 0.5044E+00 0.3937E+00-0.3379E-01 0.2800E+00-0.3481E-04 0.5207E-04 0.3493E-04
300.00L  155.00-0.5625E-01 0.2016E-01 0.1193E-01-0.3379E-01 0.2800E+00-0.1071E-03 0.5207E-04 0.3493E-04
500.00     0.00-0.1559E-01 0.6589E-01 0.5600E-01-0.2381E-02 0.2575E+00-0.7676E-04 0.9297E-04 0.7238E-04
500.00L    0.00-0.1558E-01 0.5875E-03-0.4288E-03-0.2381E-02 0.2575E+00-0.2348E-03 0.9297E-04 0.7237E-04
500.00   155.00-0.1666E-01 0.7051E-01 0.6331E-01-0.3427E-02 0.2631E+00-0.8353E-04 0.9807E-04 0.8309E-04
500.00L  155.00-0.1666E-01 0.6787E-03-0.6059E-04-0.3428E-02 0.2631E+00-0.2534E-03 0.9807E-04 0.8309E-04
```

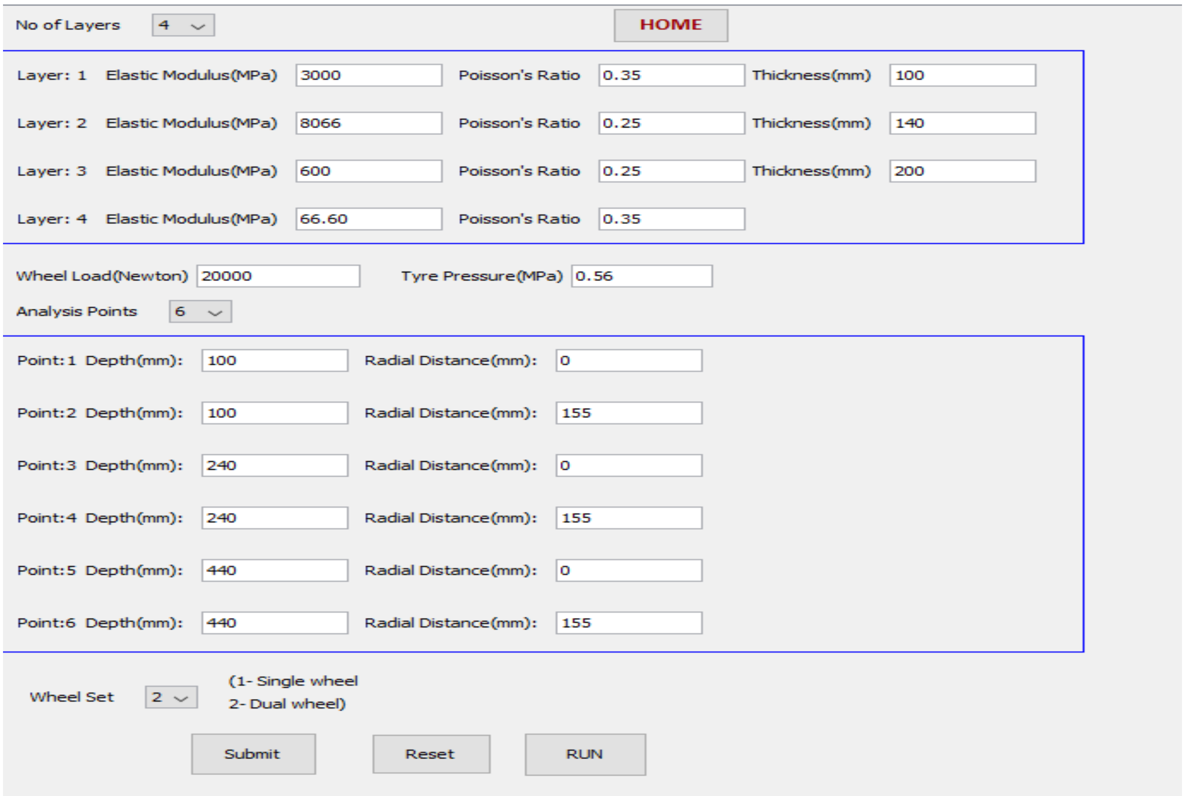
The input – output results of IITPAVE for bituminous & subgrade of CASE III




```
No. of layers              5
E values (MPa)          3000.00  450.00 8066.00  600.00   66.60
Mu values                  0.350.350.250.250.35
thicknesses (mm)         100.00  100.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.80
Dual  Wheel
  Z        R       SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ         epT         epR
100.00     0.00-0.2962E+00 0.5402E+00 0.4547E+00-0.1809E-01 0.3145E+00-0.2148E-03 0.1616E-03 0.1231E-03
100.00L    0.00-0.2962E+00-0.5452E-01-0.6735E-01-0.1809E-01 0.3145E+00-0.5634E-03 0.1616E-03 0.1231E-03
100.00   155.00-0.1704E+00 0.1874E+00-0.2900E+00-0.8675E-01 0.3052E+00-0.4483E-04 0.1162E-03-0.9866E-04
100.00L 155.00-0.1704E+00-0.4990E-01-0.1215E+00-0.8675E-01 0.3052E+00-0.2454E-03 0.1162E-03-0.9866E-04
300.00     0.00-0.5255E-01 0.4776E+00 0.3699E+00-0.1733E-01 0.2737E+00-0.3278E-04 0.4938E-04 0.3268E-04
300.00L    0.00-0.5255E-01 0.1932E-01 0.1130E-01-0.1733E-01 0.2737E+00-0.1003E-03 0.4938E-04 0.3268E-04
300.00   155.00-0.5711E-01 0.5139E+00 0.3964E+00-0.3491E-01 0.2807E+00-0.3529E-04 0.5319E-04 0.3499E-04
300.00L 155.00-0.5711E-01 0.2061E-01 0.1187E-01-0.3491E-01 0.2807E+00-0.1087E-03 0.5319E-04 0.3499E-04
500.00     0.00-0.1570E-01 0.6658E-01 0.5645E-01-0.2407E-02 0.2580E+00-0.7744E-04 0.9399E-04 0.7289E-04
500.00L    0.00-0.1569E-01 0.6210E-03-0.4228E-03-0.2407E-02 0.2580E+00-0.2366E-03 0.9399E-04 0.7284E-04
500.00   155.00-0.1677E-01 0.7123E-01 0.6382E-01-0.3489E-02 0.2635E+00-0.8422E-04 0.9911E-04 0.8367E-04
500.00L 155.00-0.1677E-01 0.7155E-03-0.4610E-04-0.3489E-02 0.2635E+00-0.2553E-03 0.9911E-04 0.8367E-04
```

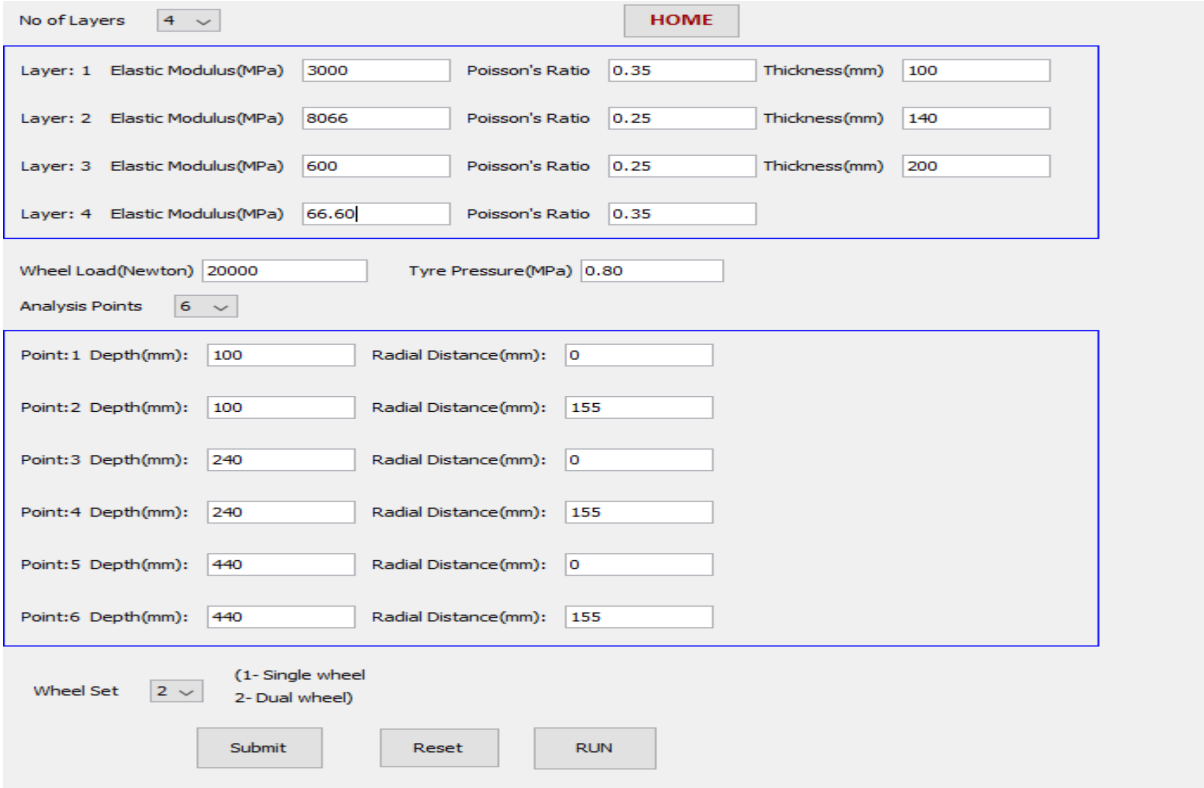
The input – output results of IITPAVE for CTB of CASE III

CASE IV




```
No. of layers                   4
E values (MPa)         3000.00 8066.00  600.00   66.60
Mu values                 0.350.250.250.35
thicknesses (mm)        100.00  140.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)       0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ        epT        epR
100.00    0.00-0.3989E+00-0.2840E+00-0.2726E+00-0.3384E-01 0.2776E+00-0.6804E-04-0.1632E-04-0.1118E-04
100.00L   0.00-0.3989E+00-0.2974E+00-0.2643E+00-0.3384E-01 0.2776E+00-0.3205E-04-0.1632E-04-0.1118E-04
100.00  155.00-0.1083E+00-0.1671E+00-0.1898E+00-0.2179E+00 0.2809E+00 0.5530E-05-0.2090E-04-0.3115E-04
100.00L 155.00-0.1083E+00-0.2829E+00-0.3490E+00-0.2179E+00 0.2809E+00 0.6159E-05-0.2090E-04-0.3115E-04
240.00    0.00-0.4941E-01 0.5405E+00 0.4358E+00-0.1427E-01 0.2735E+00-0.3639E-04 0.5503E-04 0.3881E-04
240.00L   0.00-0.4941E-01 0.2496E-01 0.1717E-01-0.1427E-01 0.2735E+00-0.9990E-04 0.5503E-04 0.3881E-04
240.00  155.00-0.4731E-01 0.5514E+00 0.3933E+00-0.3344E-01 0.2787E+00-0.3515E-04 0.5763E-04 0.3314E-04
240.00L 155.00-0.4731E-01 0.2642E-01 0.1466E-01-0.3344E-01 0.2787E+00-0.9597E-04 0.5763E-04 0.3314E-04
440.00    0.00-0.1452E-01 0.6032E-01 0.5260E-01-0.1997E-02 0.2586E+00-0.7125E-04 0.8467E-04 0.6857E-04
440.00L   0.00-0.1452E-01 0.4307E-03-0.3635E-03-0.1997E-02 0.2586E+00-0.2183E-03 0.8467E-04 0.6857E-04
440.00  155.00-0.1529E-01 0.6384E-01 0.5779E-01-0.2855E-02 0.2633E+00-0.7616E-04 0.8869E-04 0.7608E-04
440.00L 155.00-0.1529E-01 0.5204E-03-0.1015E-03-0.2854E-02 0.2633E+00-0.2317E-03 0.8869E-04 0.7608E-04
```

The input – output results of IITPAVE for bituminous & subgrade of CASE IV

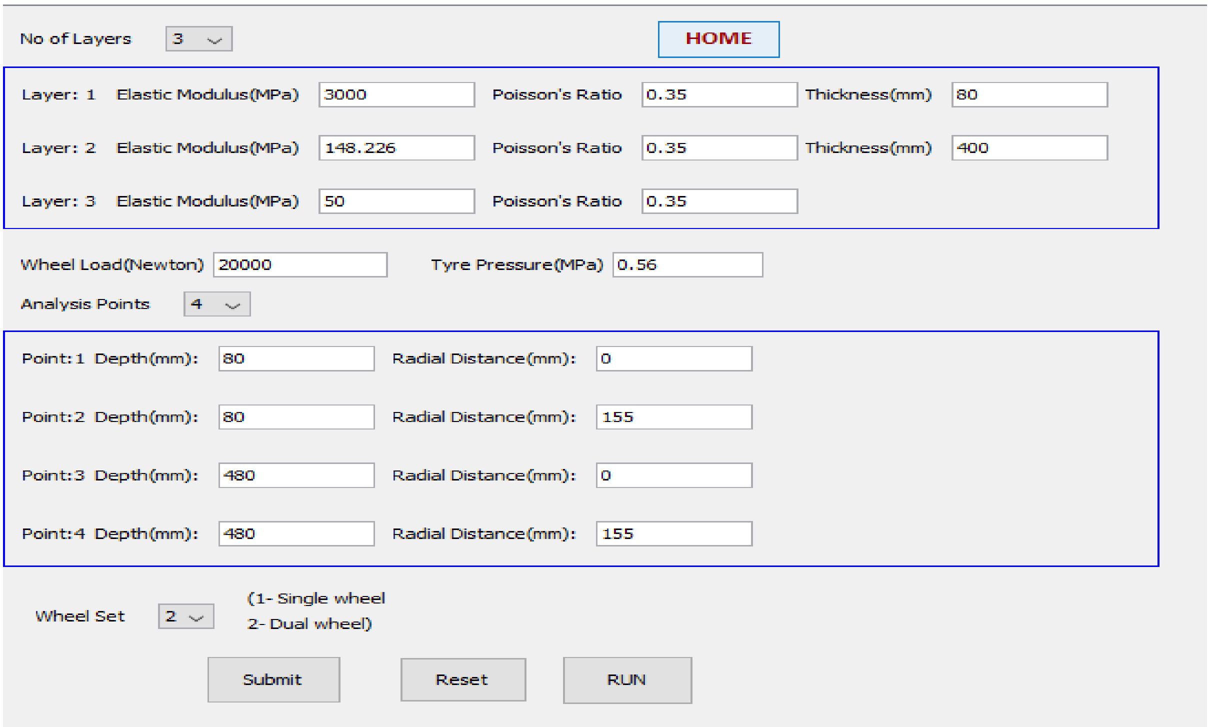



```
No. of layers                4
E values (MPa)          3000.00 8066.00   600.00    66.60
Mu values                  0.350.250.250.35
thicknesses (mm)         100.00  140.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.80
Dual  Wheel
  Z        R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
100.00     0.00-0.5071E+00-0.3243E+00-0.3120E+00-0.3363E-01 0.2790E+00-0.9481E-04-0.1253E-04-0.7008E-05
100.00L    0.00-0.5071E+00-0.2919E+00-0.2563E+00-0.3363E-01 0.2790E+00-0.4588E-04-0.1253E-04-0.7009E-05
100.00   155.00-0.8186E-01-0.1565E+00-0.1838E+00-0.2161E+00 0.2812E+00 0.1241E-04-0.2119E-04-0.3344E-04
100.00L  155.00-0.8186E-01-0.2815E+00-0.3606E+00-0.2161E+00 0.2812E+00 0.9752E-05-0.2119E-04-0.3344E-04
240.00     0.00-0.5145E-01 0.5608E+00 0.4525E+00-0.1437E-01 0.2743E+00-0.3779E-04 0.5710E-04 0.4032E-04
240.00L    0.00-0.5145E-01 0.2585E-01 0.1779E-01-0.1437E-01 0.2743E+00-0.1039E-03 0.5710E-04 0.4031E-04
240.00   155.00-0.4753E-01 0.5614E+00 0.3872E+00-0.3482E-01 0.2792E+00-0.3529E-04 0.5907E-04 0.3208E-04
240.00L  155.00-0.4753E-01 0.2709E-01 0.1414E-01-0.3482E-01 0.2792E+00-0.9640E-04 0.5907E-04 0.3208E-04
440.00     0.00-0.1460E-01 0.6102E-01 0.5284E-01-0.2015E-02 0.2591E+00-0.7178E-04 0.8577E-04 0.6872E-04
440.00L    0.00-0.1460E-01 0.4721E-03-0.3695E-03-0.2015E-02 0.2591E+00-0.2198E-03 0.8577E-04 0.6871E-04
440.00   155.00-0.1536E-01 0.6442E-01 0.5812E-01-0.2908E-02 0.2636E+00-0.7666E-04 0.8955E-04 0.7643E-04
440.00L  155.00-0.1537E-01 0.5538E-03-0.9212E-04-0.2908E-02 0.2636E+00-0.2331E-03 0.8955E-04 0.7646E-04
```

The input – output results of IITPAVE for CTB of CASE IV

LOW VOLUME ROADS

CASE I




```
No. of layers                 3
E values (MPa)          3000.00  148.23   50.00
Mu values                  0.350.350.35
thicknesses (mm)         80.00  400.00
single wheel load (N)  20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R       SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ         epT         epR
 80.00     0.00-0.1919E+00 0.1425E+01 0.1156E+01-0.1909E-01 0.7072E+00-0.3650E-03 0.3625E-03 0.2414E-03
 80.00L    0.00-0.1919E+00-0.2783E-01-0.4113E-01-0.1909E-01 0.7072E+00-0.1132E-02 0.3625E-03 0.2414E-03
 80.00   155.00-0.1469E+00 0.1017E+01 0.1228E+00-0.8184E-01 0.7194E+00-0.1819E-03 0.3418E-03-0.6056E-04
 80.00L  155.00-0.1469E+00-0.2497E-01-0.6915E-01-0.8184E-01 0.7194E+00-0.7691E-03 0.3418E-03-0.6056E-04
480.00     0.00-0.2933E-01 0.3976E-01 0.3284E-01-0.5335E-02 0.4765E+00-0.3693E-03 0.2600E-03 0.1969E-03
480.00L    0.00-0.2934E-01 0.2942E-02 0.6017E-03-0.5334E-02 0.4765E+00-0.6116E-03 0.2600E-03 0.1968E-03
480.00   155.00-0.3191E-01 0.4308E-01 0.3793E-01-0.7809E-02 0.4933E+00-0.4065E-03 0.2764E-03 0.2295E-03
480.00L  155.00-0.3191E-01 0.3146E-02 0.1409E-02-0.7811E-02 0.4933E+00-0.6700E-03 0.2764E-03 0.2295E-03
```

The input – output results of IITPAVE for bituminous & subgrade of CASE I

CASE II

Layer: 2	Elastic Modulus(MPa) 450	Poisson's Ratio	0.35	Thickness(mm)	100
Layer: 3	Elastic Modulus(MPa) 6066.67	Poisson's Ratio	0.25	Thickness(mm)	100
Layer: 4	Elastic Modulus(MPa) 148.226	Poisson's Ratio	0.35	Thickness(mm)	200
Layer: 5	Elastic Modulus(MPa) 66.60	Poisson's Ratio	0.35		

Wheel Load(Newton) 20000 Tyre Pressure(MPa) 0.56

Analysis Points 6

Point:1 Depth(mm):	80	Radial Distance(mm):	0
Point:2 Depth(mm):	80	Radial Distance(mm):	155
Point:3 Depth(mm):	280	Radial Distance(mm):	0
Point:4 Depth(mm):	280	Radial Distance(mm):	155
Point:5 Depth(mm):	480	Radial Distance(mm):	0
Point:6 Depth(mm):	480	Radial Distance(mm):	155

Wheel Set 2 (1- Single wheel 2- Dual wheel)

Submit Reset RUN

```
No. of layers                5
E values (MPa)          3000.00  450.00 6066.67  148.23   66.60
Mu values                 0.350.350.250.350.35
thicknesses (mm)         80.00  100.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)       0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT      SigmaR     TaoRZ      DispZ      epZ        epT        epR
 80.00    0.00-0.3121E+00 0.4470E+00 0.3688E+00-0.2375E-01 0.3805E+00-0.1992E-03 0.1424E-03 0.1072E-03
 80.00L   0.00-0.3121E+00-0.7577E-01-0.8751E-01-0.2375E-01 0.3805E+00-0.5665E-03 0.1424E-03 0.1072E-03
 80.00  155.00-0.1711E+00 0.1426E+00-0.3862E+00-0.1084E+00 0.3725E+00-0.2862E-04 0.1126E-03-0.1254E-03
 80.00L 155.00-0.1711E+00-0.5692E-01-0.1362E+00-0.1084E+00 0.3725E+00-0.2300E-03 0.1126E-03-0.1254E-03
280.00    0.00-0.3695E-01 0.6708E+00 0.5186E+00-0.6903E-02 0.3372E+00-0.5511E-04 0.9073E-04 0.5937E-04
280.00L   0.00-0.3695E-01-0.1060E-02-0.4503E-02-0.6903E-02 0.3372E+00-0.2361E-03 0.9073E-04 0.5937E-04
280.00  155.00-0.3986E-01 0.7232E+00 0.5528E+00-0.1402E-01 0.3484E+00-0.5915E-04 0.9807E-04 0.6297E-04
280.00L 155.00-0.3986E-01-0.1176E-02-0.5030E-02-0.1402E-01 0.3484E+00-0.2543E-03 0.9807E-04 0.6297E-04
480.00    0.00-0.1978E-01 0.1285E-01 0.1011E-01-0.2947E-02 0.2970E+00-0.1876E-03 0.1095E-03 0.8456E-04
480.00L   0.00-0.1978E-01-0.9101E-04-0.1322E-02-0.2947E-02 0.2970E+00-0.2895E-03 0.1095E-03 0.8456E-04
480.00  155.00-0.2123E-01 0.1389E-01 0.1184E-01-0.4297E-02 0.3046E+00-0.2040E-03 0.1159E-03 0.9722E-04
480.00L 155.00-0.2123E-01-0.5264E-04-0.9728E-03-0.4296E-02 0.3046E+00-0.3133E-03 0.1159E-03 0.9722E-04
```

The input – output results of IITPAVE for bituminous & subgrade of CASE II

Layer: 2	Elastic Modulus(MPa)	450	Poisson's Ratio	0.35	Thickness(mm)	100
Layer: 3	Elastic Modulus(MPa)	6066.67	Poisson's Ratio	0.25	Thickness(mm)	100
Layer: 4	Elastic Modulus(MPa)	148.226	Poisson's Ratio	0.35	Thickness(mm)	200
Layer: 5	Elastic Modulus(MPa)	66.60	Poisson's Ratio	0.35		

Wheel Load(Newton) 20000 Tyre Pressure(MPa) 0.80

Analysis Points 6

Point:1	Depth(mm):	80	Radial Distance(mm):	0
Point:2	Depth(mm):	80	Radial Distance(mm):	155
Point:3	Depth(mm):	280	Radial Distance(mm):	0
Point:4	Depth(mm):	280	Radial Distance(mm):	155
Point:5	Depth(mm):	480	Radial Distance(mm):	0
Point:6	Depth(mm):	480	Radial Distance(mm):	155

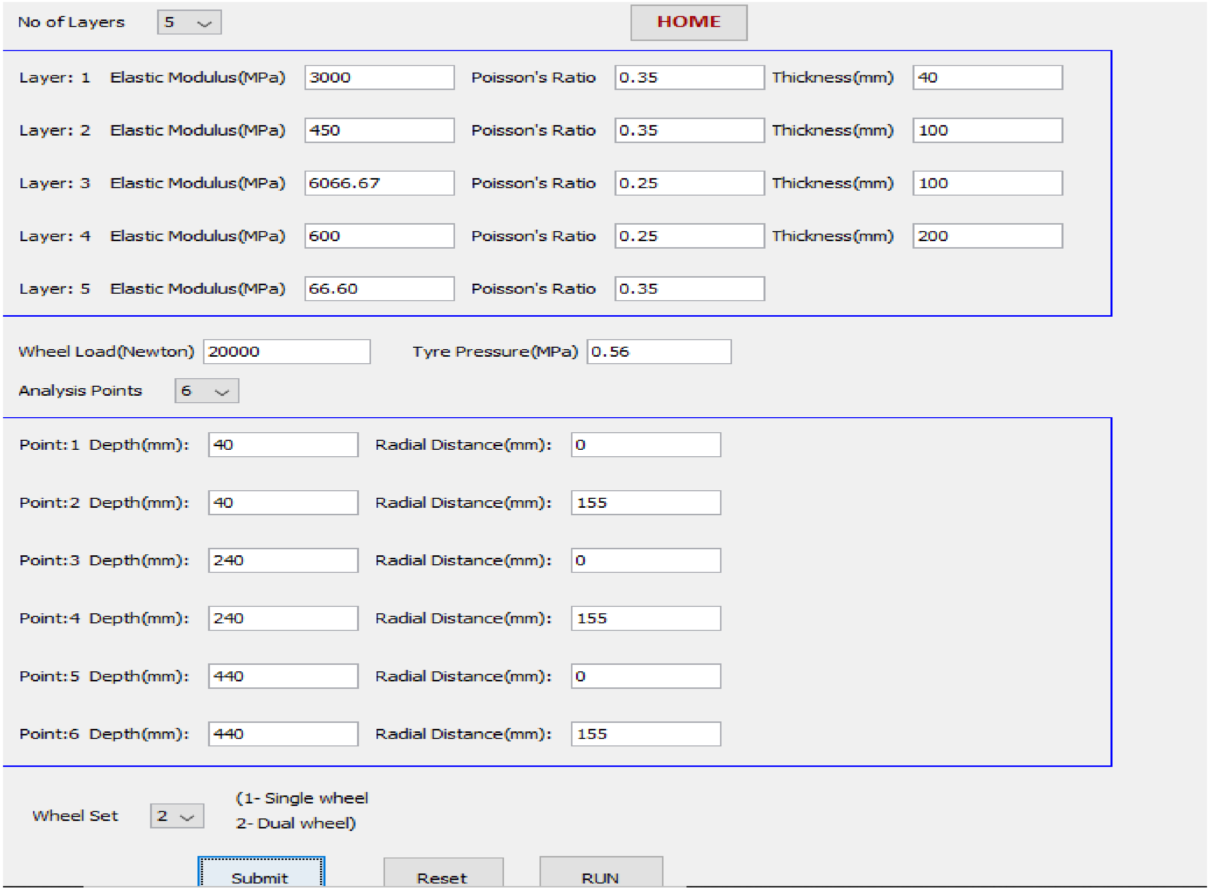
Wheel Set 2 (1- Single wheel
2- Dual wheel)

Submit Reset RUN

```
No. of layers                 5
E values (MPa)          3000.00  450.00 6066.67  148.23   66.60
Mu values                  0.350.350.250.350.35
thicknesses (mm)          80.00  100.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.80
Dual  Wheel
  Z        R       SigmaZ      SigmaT     SigmaR      TaoRZ      DispZ      epZ        epT        epR
 80.00     0.00-0.3657E+00 0.6328E+00 0.5563E+00-0.2372E-01 0.3882E+00-0.2606E-03 0.1887E-03 0.1543E-03
 80.00L    0.00-0.3657E+00-0.7244E-01-0.8392E-01-0.2372E-01 0.3882E+00-0.6910E-03 0.1887E-03 0.1543E-03
 80.00   155.00-0.1623E+00 0.1350E+00-0.4651E+00-0.1081E+00 0.3724E+00-0.1560E-04 0.1182E-03-0.1518E-03
 80.00L  155.00-0.1623E+00-0.5405E-01-0.1441E+00-0.1081E+00 0.3724E+00-0.2067E-03 0.1182E-03-0.1518E-03
280.00     0.00-0.3757E-01 0.6876E+00 0.5296E+00-0.6979E-02 0.3384E+00-0.5635E-04 0.9307E-04 0.6050E-04
280.00L    0.00-0.3757E-01-0.9324E-03-0.4508E-02-0.6979E-02 0.3384E+00-0.2406E-03 0.9307E-04 0.6050E-04
280.00   155.00-0.4033E-01 0.7378E+00 0.5562E+00-0.1450E-01 0.3495E+00-0.5997E-04 0.1003E-03 0.6294E-04
280.00L  155.00-0.4033E-01-0.1045E-02-0.5153E-02-0.1450E-01 0.3495E+00-0.2575E-03 0.1003E-03 0.6294E-04
480.00     0.00-0.1990E-01 0.1303E-01 0.1018E-01-0.2979E-02 0.2976E+00-0.1890E-03 0.1109E-03 0.8488E-04
480.00L    0.00-0.1991E-01-0.4902E-04-0.1327E-02-0.2979E-02 0.2976E+00-0.2917E-03 0.1109E-03 0.8495E-04
480.00   155.00-0.2137E-01 0.1407E-01 0.1196E-01-0.4377E-02 0.3053E+00-0.2057E-03 0.1172E-03 0.9793E-04
480.00L  155.00-0.2137E-01-0.1377E-04-0.9630E-03-0.4376E-02 0.3053E+00-0.3158E-03 0.1172E-03 0.9792E-04
```

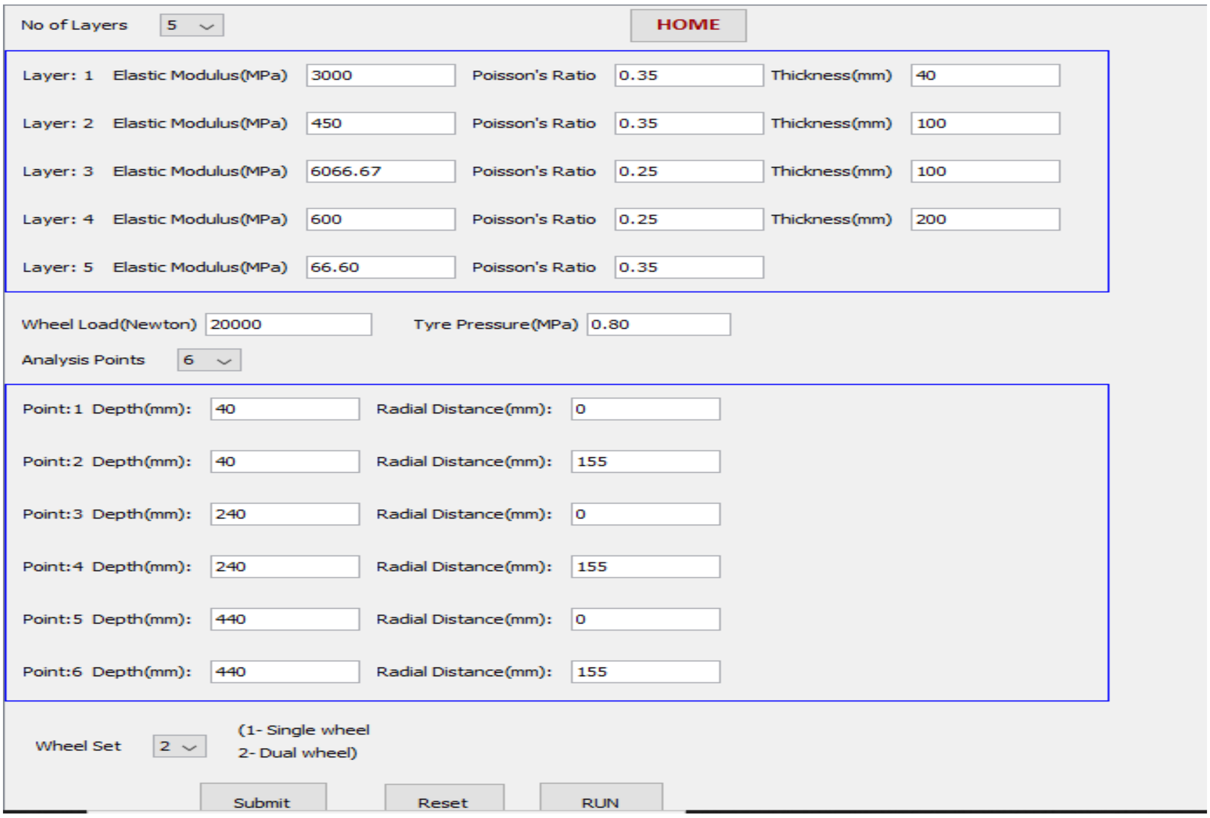
The input – output results of IITPAVE for CTB of CASE II

CASE III




```
No. of layers                    5
E values (MPa)          3000.00  450.00 6066.67  600.00   66.60
Mu values                  0.350.350.250.250.35
thicknesses (mm)          40.00  100.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
 40.00    0.00-0.5070E+00 0.2817E+00 0.2665E+00-0.1158E-01 0.3939E+00-0.2330E-03 0.1220E-03 0.1151E-03
 40.00L   0.00-0.5070E+00-0.1898E+00-0.1921E+00-0.1158E-01 0.3939E+00-0.8297E-03 0.1220E-03 0.1151E-03
 40.00  155.00-0.1205E+00-0.1521E+00-0.8795E+00-0.8413E-01 0.3491E+00 0.8020E-04 0.6595E-04-0.2614E-03
 40.00L 155.00-0.1205E+00-0.7795E-01-0.1871E+00-0.8413E-01 0.3491E+00-0.6157E-04 0.6595E-04-0.2614E-03
240.00    0.00-0.8244E-01 0.5111E+00 0.3840E+00-0.2291E-01 0.3228E+00-0.5048E-04 0.7183E-04 0.4564E-04
240.00L   0.00-0.8244E-01 0.2579E-01 0.1322E-01-0.2291E-01 0.3228E+00-0.1536E-03 0.7183E-04 0.4564E-04
240.00  155.00-0.8066E-01 0.5264E+00 0.3284E+00-0.6001E-01 0.3317E+00-0.4852E-04 0.7657E-04 0.3575E-04
240.00L 155.00-0.8066E-01 0.2784E-01 0.8246E-02-0.6001E-01 0.3317E+00-0.1495E-03 0.7657E-04 0.3575E-04
440.00    0.00-0.2055E-01 0.8898E-01 0.7400E-01-0.3284E-02 0.3009E+00-0.1021E-03 0.1260E-03 0.9481E-04
440.00L   0.00-0.2055E-01 0.1021E-02-0.5198E-03-0.3284E-02 0.3009E+00-0.3111E-03 0.1260E-03 0.9481E-04
440.00  155.00-0.2201E-01 0.9578E-01 0.8310E-01-0.5192E-02 0.3087E+00-0.1112E-03 0.1342E-03 0.1078E-03
440.00L 155.00-0.2202E-01 0.1189E-02-0.1132E-03-0.5193E-02 0.3087E+00-0.3363E-03 0.1342E-03 0.1078E-03
```

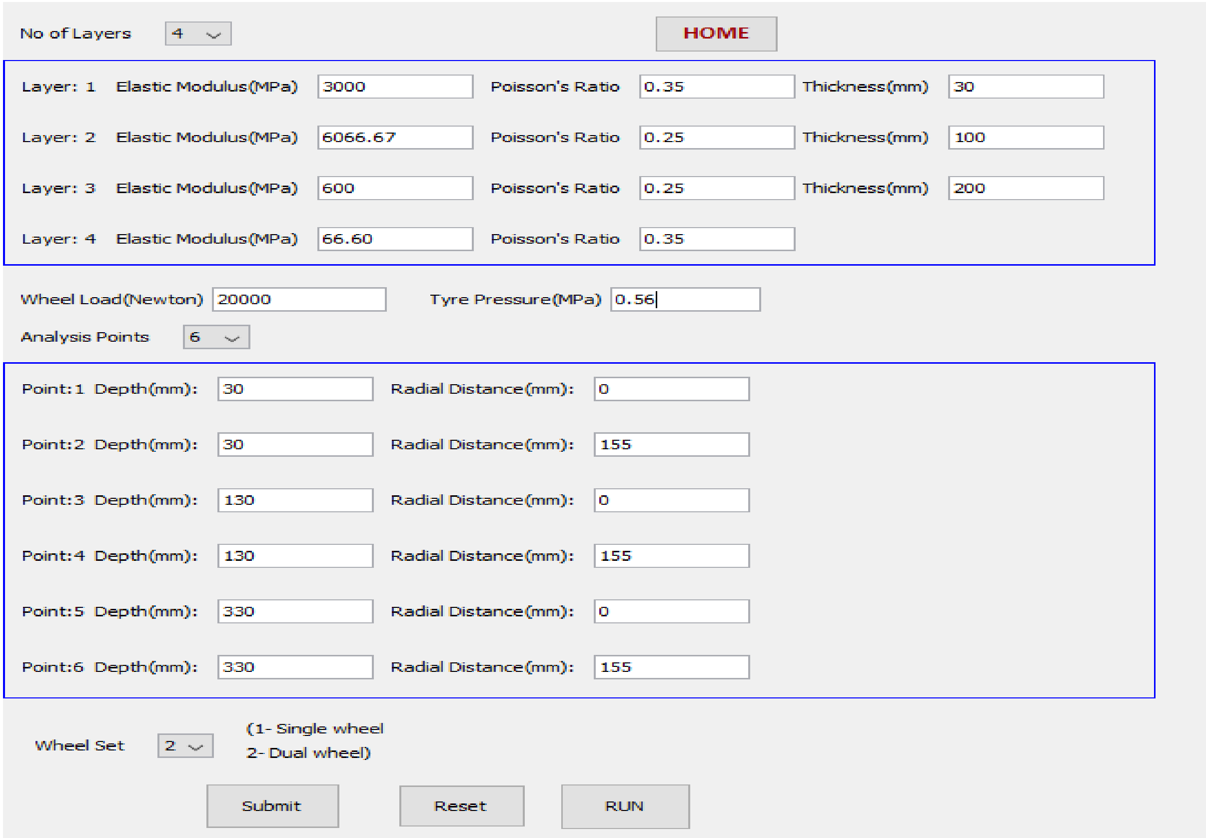
The input – output results of IITPAVE for bituminous & subgrade of CASE III




```
No. of layers                  5
E values (MPa)          3000.00  450.00 6066.67  600.00   66.60
Mu values                  0.350.350.250.250.35
thicknesses (mm)          40.00  100.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.80
Dual  Wheel
  Z         R       SigmaZ      SigmaT      SigmaR      TaoRZ      DispZ      epZ         epT         epR
 40.00     0.00-0.6532E+00 0.6179E+00 0.6054E+00-0.1190E-01 0.4132E+00-0.3605E-03 0.2115E-03 0.2059E-03
 40.00L    0.00-0.6532E+00-0.2063E+00-0.2082E+00-0.1190E-01 0.4132E+00-0.1129E-02 0.2115E-03 0.2059E-03
 40.00  155.00-0.9407E-01-0.1726E+00-0.9486E+00-0.7007E-01 0.3457E+00 0.9945E-04 0.6410E-04-0.2851E-03
 40.00L 155.00-0.9407E-01-0.6895E-01-0.1853E+00-0.7007E-01 0.3457E+00-0.1126E-04 0.6410E-04-0.2851E-03
240.00     0.00-0.8591E-01 0.5334E+00 0.4021E+00-0.2307E-01 0.3240E+00-0.5271E-04 0.7490E-04 0.4784E-04
240.00L    0.00-0.8590E-01 0.2695E-01 0.1396E-01-0.2307E-01 0.3240E+00-0.1602E-03 0.7490E-04 0.4784E-04
240.00  155.00-0.8157E-01 0.5397E+00 0.3226E+00-0.6273E-01 0.3327E+00-0.4898E-04 0.7904E-04 0.3429E-04
240.00L 155.00-0.8157E-01 0.2888E-01 0.7401E-02-0.6273E-01 0.3327E+00-0.1511E-03 0.7904E-04 0.3429E-04
440.00     0.00-0.2072E-01 0.9027E-01 0.7459E-01-0.3320E-02 0.3016E+00-0.1032E-03 0.1280E-03 0.9533E-04
440.00L    0.00-0.2071E-01 0.1096E-02-0.5173E-03-0.3320E-02 0.3016E+00-0.3140E-03 0.1280E-03 0.9530E-04
440.00  155.00-0.2218E-01 0.9698E-01 0.8378E-01-0.5314E-02 0.3094E+00-0.1123E-03 0.1360E-03 0.1085E-03
440.00L 155.00-0.2218E-01 0.1256E-02-0.1007E-03-0.5314E-02 0.3094E+00-0.3391E-03 0.1360E-03 0.1085E-03
```

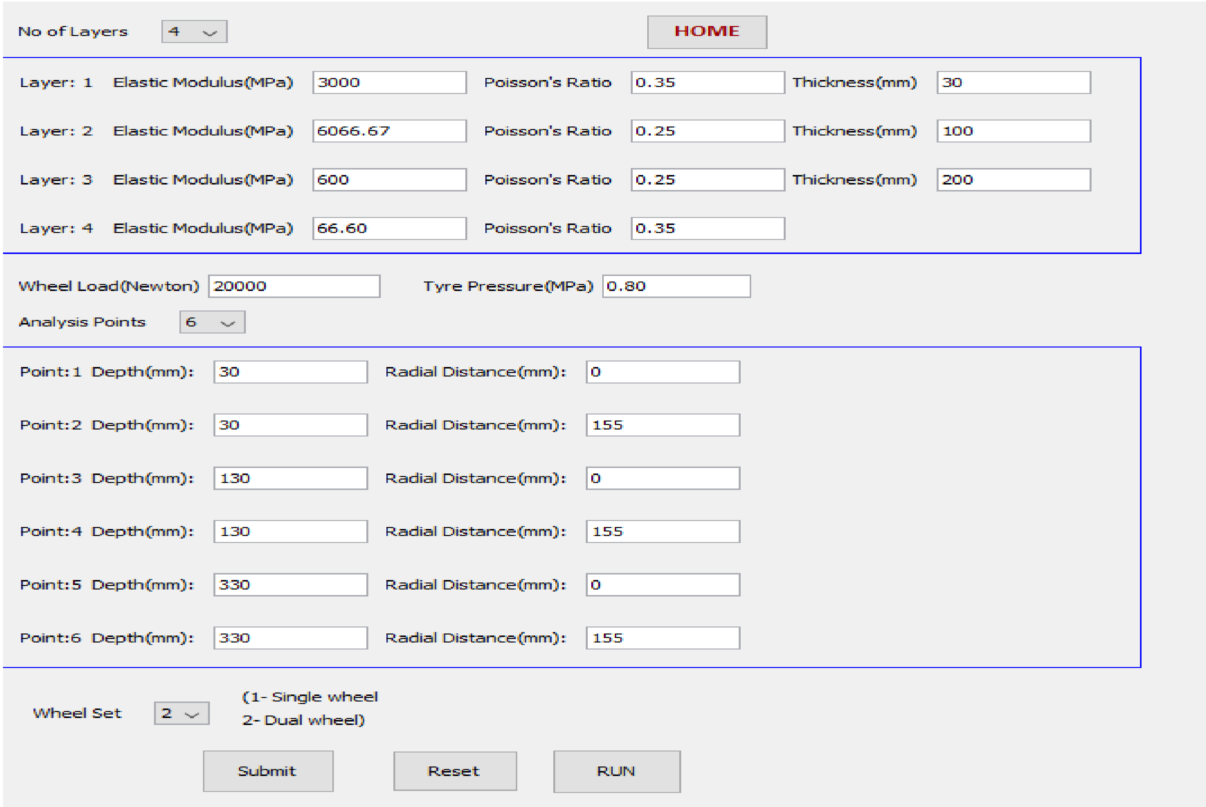
The input – output results of IITPAVE for CTB of CASE III

CASE IV




```
No. of layers                4
E values (MPa)          3000.00 6066.67  600.00   66.60
Mu values                   0.350.250.250.35
thicknesses (mm)          30.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)         0.56
Dual  Wheel
  Z        R       SigmaZ      SigmaT      SigmaR      TaoRZ       DispZ       epZ         epT         epR
 30.00     0.00-0.5263E+00-0.6503E+00-0.5903E+00-0.1917E-01 0.3933E+00-0.3071E-04-0.8648E-04-0.5951E-04
 30.00L    0.00-0.5263E+00-0.8313E+00-0.7004E+00-0.1917E-01 0.3933E+00-0.2364E-04-0.8648E-04-0.5951E-04
 30.00   155.00-0.1603E-01-0.3860E+00-0.3118E+00-0.1555E+00 0.3982E+00 0.7607E-04-0.9041E-04-0.5704E-04
 30.00L  155.00-0.1603E-01-0.6827E+00-0.5207E+00-0.1555E+00 0.3982E+00 0.4695E-04-0.9041E-04-0.5704E-04
130.00     0.00-0.1376E+00 0.7556E+00 0.5905E+00-0.2967E-01 0.3883E+00-0.7815E-04 0.1059E-03 0.7186E-04
130.00L    0.00-0.1376E+00 0.3339E-01 0.1706E-01-0.2967E-01 0.3883E+00-0.2504E-03 0.1059E-03 0.7186E-04
130.00   155.00-0.1043E+00 0.6692E+00 0.2488E+00-0.9538E-01 0.3975E+00-0.5502E-04 0.1044E-03 0.1773E-04
130.00L  155.00-0.1043E+00 0.3487E-01-0.6709E-02-0.9538E-01 0.3975E+00-0.1855E-03 0.1044E-03 0.1773E-04
330.00     0.00-0.2776E-01 0.1222E+00 0.9993E-01-0.4562E-02 0.3563E+00-0.1388E-03 0.1736E-03 0.1272E-03
330.00L    0.00-0.2776E-01 0.1610E-02-0.6796E-03-0.4562E-02 0.3563E+00-0.4216E-03 0.1736E-03 0.1272E-03
330.00   155.00-0.2968E-01 0.1312E+00 0.1105E+00-0.7689E-02 0.3672E+00-0.1502E-03 0.1850E-03 0.1419E-03
330.00L  155.00-0.2967E-01 0.1831E-02-0.2917E-03-0.7689E-02 0.3672E+00-0.4537E-03 0.1850E-03 0.1419E-03
```

The input – output results of IITPAVE for bituminous & subgrade of CASE IV

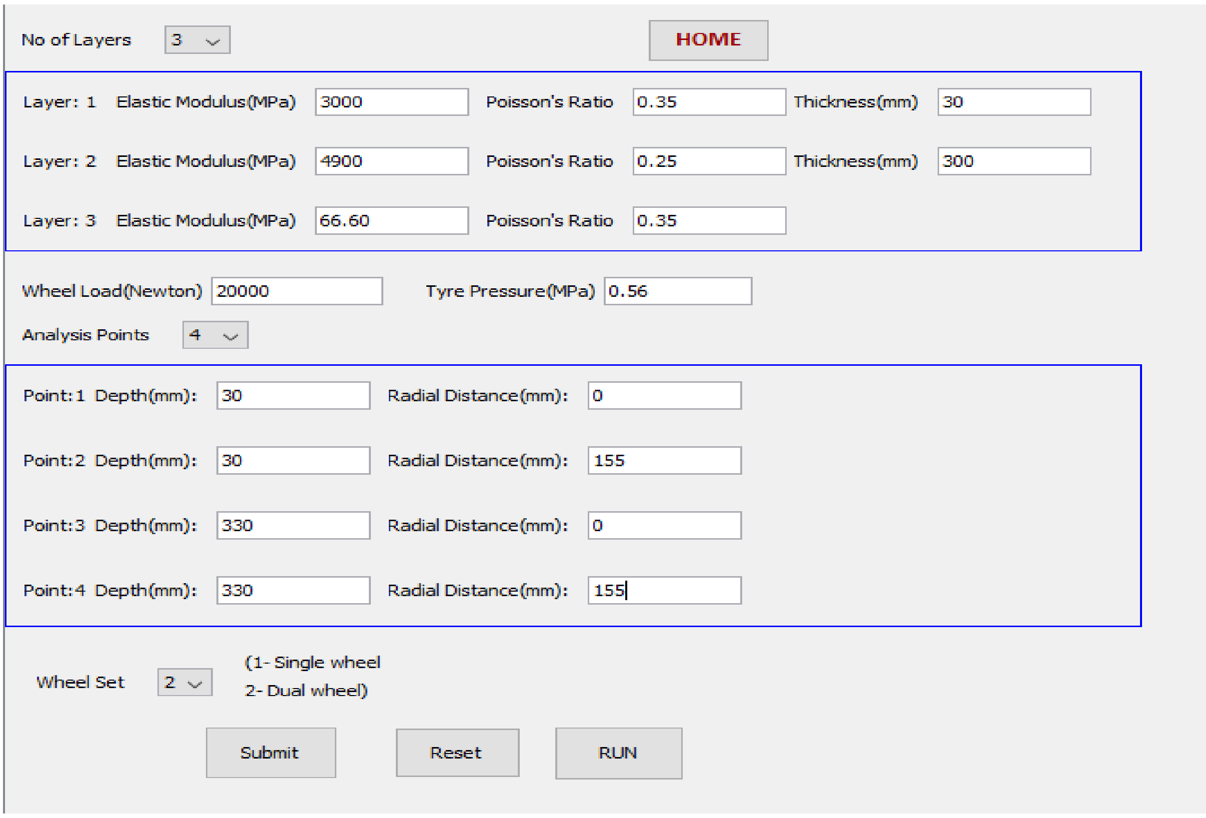



```
No. of layers                 4
E values (MPa)          3000.00 6066.67  600.00    66.60
Mu values                   0.350.250.250.35
thicknesses (mm)          30.00  100.00  200.00
single wheel load (N) 20000.00
tyre pressure (MPa)         0.80
Dual  Wheel
  Z         R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
 30.00     0.00-0.7471E+00-0.7746E+00-0.7133E+00-0.1895E-01 0.3977E+00-0.7545E-04-0.8782E-04-0.6023E-04
 30.00L    0.00-0.7471E+00-0.9147E+00-0.7809E+00-0.1895E-01 0.3977E+00-0.5327E-04-0.8782E-04-0.6023E-04
 30.00   155.00-0.1014E-01-0.3867E+00-0.2943E+00-0.1436E+00 0.3991E+00 0.7608E-04-0.9339E-04-0.5181E-04
 30.00L  155.00-0.1014E-01-0.6915E+00-0.4897E+00-0.1436E+00 0.3991E+00 0.4701E-04-0.9339E-04-0.5181E-04
130.00     0.00-0.1522E+00 0.8447E+00 0.6761E+00-0.2980E-01 0.3908E+00-0.8775E-04 0.1176E-03 0.8290E-04
130.00L    0.00-0.1522E+00 0.3783E-01 0.2116E-01-0.2980E-01 0.3908E+00-0.2782E-03 0.1176E-03 0.8290E-04
130.00   155.00-0.1022E+00 0.6817E+00 0.2051E+00-0.9891E-01 0.3986E+00-0.5339E-04 0.1081E-03 0.9931E-05
130.00L  155.00-0.1022E+00 0.3671E-01-0.1042E-01-0.9891E-01 0.3986E+00-0.1813E-03 0.1081E-03 0.9931E-05
330.00     0.00-0.2804E-01 0.1240E+00 0.1016E+00-0.4606E-02 0.3573E+00-0.1408E-03 0.1760E-03 0.1294E-03
330.00L    0.00-0.2805E-01 0.1694E-02-0.6015E-03-0.4606E-02 0.3573E+00-0.4268E-03 0.1760E-03 0.1294E-03
330.00   155.00-0.2991E-01 0.1330E+00 0.1113E+00-0.7898E-02 0.3682E+00-0.1517E-03 0.1878E-03 0.1425E-03
330.00L  155.00-0.2990E-01 0.1939E-02-0.2966E-03-0.7896E-02 0.3682E+00-0.4577E-03 0.1878E-03 0.1425E-03
```

The input – output results of IITPAVE for CTB of CASE IV

Using full-depth reclamation (FDR)

CASE V




```
No. of layers              3
E values (MPa)         3000.00 4900.00    66.60
Mu values                 0.350.250.35
thicknesses (mm)         30.00   300.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z         R       SigmaZ      SigmaT      SigmaR      TaoRZ       DispZ      epZ         epT         epR
 30.00     0.00-0.5436E+00-0.4994E+00-0.4755E+00-0.8152E-02 0.2685E+00-0.6748E-04-0.4755E-04-0.3681E-04
 30.00L    0.00-0.5436E+00-0.4779E+00-0.4357E+00-0.8152E-02 0.2685E+00-0.6433E-04-0.4755E-04-0.3681E-04
 30.00  155.00-0.2162E-01-0.2418E+00-0.2440E+00-0.8070E-01 0.2646E+00 0.4948E-04-0.4961E-04-0.5061E-04
 30.00L 155.00-0.2162E-01-0.3327E+00-0.3366E+00-0.8070E-01 0.2646E+00 0.2973E-04-0.4961E-04-0.5061E-04
330.00     0.00-0.1393E-01 0.3762E+00 0.3148E+00-0.1568E-02 0.2554E+00-0.3810E-04 0.6143E-04 0.4576E-04
330.00L    0.00-0.1393E-01-0.1623E-02-0.2396E-02-0.1568E-02 0.2554E+00-0.1880E-03 0.6143E-04 0.4576E-04
330.00  155.00-0.1454E-01 0.3974E+00 0.3343E+00-0.2774E-02 0.2597E+00-0.4030E-04 0.6478E-04 0.4869E-04
330.00L 155.00-0.1454E-01-0.1620E-02-0.2413E-02-0.2773E-02 0.2597E+00-0.1971E-03 0.6478E-04 0.4869E-04
```

The input – output results of IITPAVE for CASE I

Ouriginal
by Turnitin

Document Information

Analyzed document	Thesis Report.pdf (D143030859)
Submitted	2022-08-18 06:53:00
Submitted by	Manpreet Singh
Submitter email	manpreetsingh2@thapar.edu
Similarity	13%
Analysis address	manpreetsingh2.thapar@analysis.urkund.com

Sources included in the report

SA	**Thapar Institute Of Engineering And Technology / CAPSTONE REPORT F.pdf** Document CAPSTONE REPORT F.pdf (D75791211) Submitted by: rchaturvedi_be16@thapar.edu Receiver: rchaturvedi_be16.thapar@analysis.urkund.com	3
SA	**Thapar Institute Of Engineering And Technology / Thesis work (2).docx** Document Thesis work (2).docx (D75674249) Submitted by: manpreetsingh2@thapar.edu Receiver: manpreetsingh2.thapar@analysis.urkund.com	3
SA	**Thapar Institute Of Engineering And Technology / Thesis combined.pdf** Document Thesis combined.pdf (D141784664) Submitted by: harsingh@thapar.edu Receiver: harsingh.thapar@analysis.urkund.com	10
W	URL: https://law.resource.org/pub/in/bis/irc/irc.gov.in.037.2019.pdf Fetched: 2021-11-13 01:15:05	12
SA	**Jagan Nath University / Thesis Happy Sharma 03.07.2019 Mtech- Transportation.pdf** Document Thesis Happy Sharma 03.07.2019 Mtech- Transportation.pdf (D54336995) Submitted by: vivek.sharma@jagannathuniversity.org Receiver: vivek.sharma.akshay@analysis.urkund.com	1
SA	**Jagan Nath University / Happy Sharma.docx** Document Happy Sharma.docx (D54622142) Submitted by: vivek.sharma@jagannathuniversity.org Receiver: vivek.sharma.akshay@analysis.urkund.com	2
W	URL: https://manuneethi.in/uploads/files/books/IRC-37-2018.pdf Fetched: 2021-11-19 17:45:06	40
SA	**Rajiv Gandhi Proudyogiki Vishwavidyalaya / thesis...vijay.docx** Document thesis...vijay.docx (D139916867) Submitted by: ashokgagorni@gmail.com Receiver: ashokgagorni.rgpv@analysis.urkund.com	3
SA	**Nityanand Thesis 165139CV161P01.pdf** Document Nityanand Thesis 165139CV161P01.pdf (D142174071)	1