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GEOMETRIC & STRUCTURAL DESIGN OF FLEXIBLE RURAL ROAD USING CIVIL 3D AND IIT PAVE SOFTWARE (IRC-37:2018)

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Abstract:
This project highlights the significance of roads in promoting sustainability, economic growth, and social development by improving connectivity. It focuses on the use of AutoCAD Civil 3D software to enhance the efficiency and accuracy of highway geometric design, including horizontal and vertical alignments and cross-sections. Civil 3D simplifies modelling using survey and topographic data from sources like LIDAR and GIS, allowing for quick adjustments and compliance with IRC standards. The software also helps generate corridors, sample lines, and material reports. Additionally, the project involves traffic data collection and CBR testing and for different CBR values to design a flexible pavement using IITPAVE software &IRC-37:2018, ensuring the pavement meets stress and strain criteria at various layers.

Keywords—**Auto Cad Civil 3D, Alignment, DTM, Profile, Corridor, Assembly, Pavement Design, CBR Value.**

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1. INTRODUCTION

The apparent characteristics of roadways, such as curves, gradients, sight distance, and intersections, are the focus of geometric design, a crucial component of highway engineering that ensures efficiency and safety. Previously carried out by hand, this procedure was laborious and prone to mistakes. Because it allows for quicker and more precise 3D modelling utilizing topographic data, AutoCAD Civil 3D has completely changed roadway design. It helps civil engineers save time and money by making it simple to plan, visualize, and alter designs. The program facilitates a range of infrastructure projects and automates design modifications. Road alignment, which is represented by a road's centerline in Civil 3D, is crucial for establishing the highway's course and making sure it is short, easy, safe, and cost-effective.

Highlighting the importance of complying with established norms and standards, this introduction to flexible pavement design provides engineers with a basic understanding of the subject. Flexible pavements, typically made of bituminous materials, consist of multiple layers that distribute traffic loads to minimize stress on the subgrade. The design process mainly involves selecting appropriate materials and determining layer thicknesses to ensure durability and prevent structural failure. Key parameters such as stresses, strains, and deflections are evaluated using inputs like layer thickness, resilient modulus, and Poisson's ratio. For this study, the analysis is carried out using IIT-PAVE 11, an advanced version of the earlier FPAVE software.

AutoCAD Civil 3D: With its sophisticated tools for accuracy and efficiency, AutoCAD Civil 3D is a potent civil engineering program that simplifies the design, modelling, and documentation processes. Rapid 3D modelling, smooth GIS and BIM integration, parametric design for real-time updates, sophisticated corridor design, and cloud-based collaboration are some of the salient characteristics. Roadway and highway design, stormwater and drainage systems, land development, site grading, and even bridge and railway infrastructure are all supported by Civil 3D, which is widely used in civil engineering. It aids engineers in visualizing actual projects, enhancing overall project performance, reducing errors, and improving coordination.

IIT PAVE: A specialized software called IIT PAVE is used to analyse and construct flexible pavements using the linear elastic layering theory. It computes crucial parameters including stresses, strains, and deflections under applied loads and simulates multi-layered pavement systems, taking into account the thickness and material characteristics of each layer. The software generates outputs that assist engineers in evaluating pavement performance based on data entered by users, such as load details and material properties. IIT PAVE is a useful tool for pavement engineers since it provides design optimization to guarantee longevity and structural integrity by simulating different loading scenarios.

2. OBJECTIVES

•To prepare a well-defined alignment of Highway and design horizontal & vertical curves using profile creation tools for given area in Civil-3D environment.

•To model & prepare different geometric elements & to compute the earth work quantities for given alignment.

•To design the flexible pavement with 4 lanes (single and double carriage way), utilizing IRC-37:2018 and IIT PAVE software.

•To compare different CBR values for rural and urban flexible pavement design standards.

3.STUDY AREA ANALYSIS

Paderu of the Eastern Ghats in Andhra Pradesh is the administrative headquarters of ASR district and Paderu Mandal. It has a tropical monsoon climate with average annual rainfall of 1252 mm and temperature varying from 24°C to 35°C. Its topography consists of hills, valleys, and plains with 73% forest and 20.2% agricultural area. The region is confronted with environmental problems like Soil erosion along the slopes, high rainfall, and shifting cultivation. Notwithstanding bountiful natural springs and porous pediment gravels, indigenous farming practices and forest destruction have led to soil degradation.

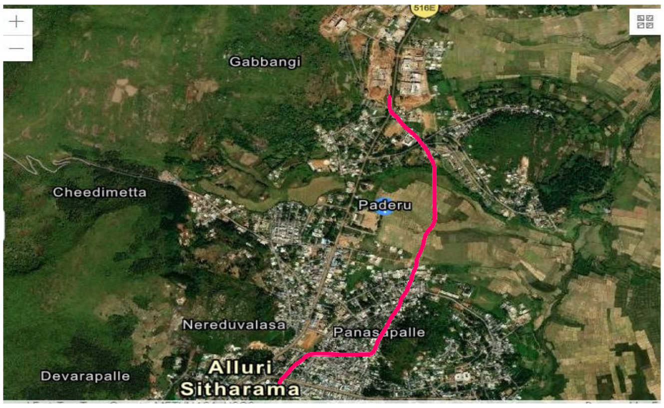
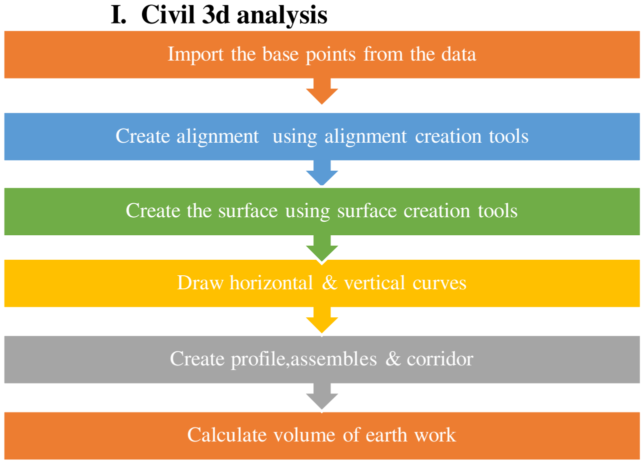


Fig -1: Paderu study area

4.METHODOLOGY

I. Civil 3d analysis



4.1.DATA COLLECTION

To design a highway, vital data are gathered through engineering surveys in four basic steps: map study, field visit (reconnaissance), preliminary survey, and final detailed survey. These surveys give data on land topography, soil, drainage, and site conditions, which are utilized to prepare the Detailed Project Report (DPR). The DPR consists of schedules with site information, suggested alterations, and utility information. Traffic surveys are also carried out to evaluate road capacity and prepare structures such as underpasses where ne cessary. Topographic surveys using drones for quicker, economical, and precise data collection were used in this project. Drones with RGB cameras took aerial photographs with exact coordinates, aiding land mapping, plot planning, and road design. Traffic surveys, or traffic counts, also assisted in road design and safety planning by evaluating vehicle movement and road use.

4.2. SURVEYING

The survey was conducted before initiating the standard road design process, which included location study, reconnaissance, preliminary survey, and final location survey. A location survey primarily provides an overall understanding of the project site. The reconnaissance survey highlights the key features of the terrain but does not provide detailed explanations. The information obtained from this stage is mainly used for planning, scheduling detailed investigations, and shortlisting potential alignments for further modifications in the initial survey. The preliminary survey involves field measurements to process LIDAR data and collect essential information such as Easting, Northing, and Elevations, which are then used to evaluate alternative alignments.

4.3 Analysis

Survey points are imported into the software in compatible file formats such as CSV, TXT, or LAND XML. The points are then utilized to create a surface that represents the terrain or ground conditions. The alignment is drawn on this surface, followed by the generation of both existing and proposed profiles. With multiple tools found in Civil 3D, cross-sections, assemblies, and corridors are thereafter created based on the alignment and profiles.

Details regarding the proposed study methodology along with the use of Autodesk Civil 3D software are presented below.

<u>i) Point group:</u> In land development projects, points serve as the basic reference elements for identifying specific locations and features, such as terrain elevations or design components. Each point carries distinct information, including its easting, northing, elevation, and a short description.

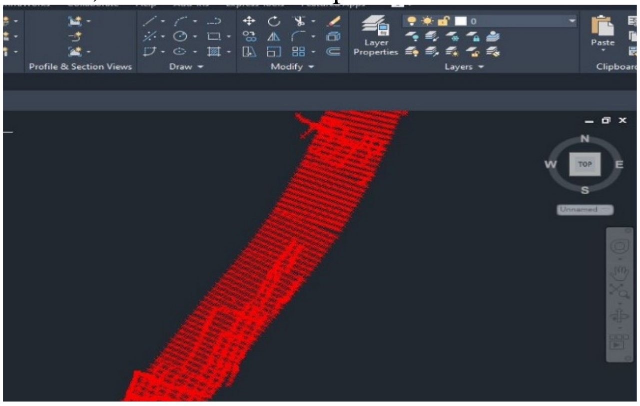


Fig -2: Sample point groups in 13 km stretch for study area

<u>ii)Surface creation:</u> A surface represents a 3D model of the ground, depicting its contours, form, and elevation. In civil engineering, surfaces play a vital role as they represent existing ground conditions, proposed designs, and allow for comparisons between different landforms.

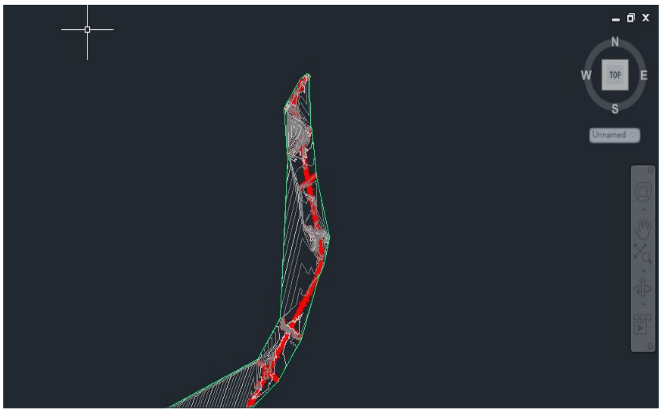


Fig -3: Surface creation for the alignment

<u>iii)Surface creation from DTM:</u> In Civil 3D, a surface can be created from a DTM by importing data files (like Land XML, DEM, TIN, or CSV) into a TIN surface and applying a suitable style to display the terrain.

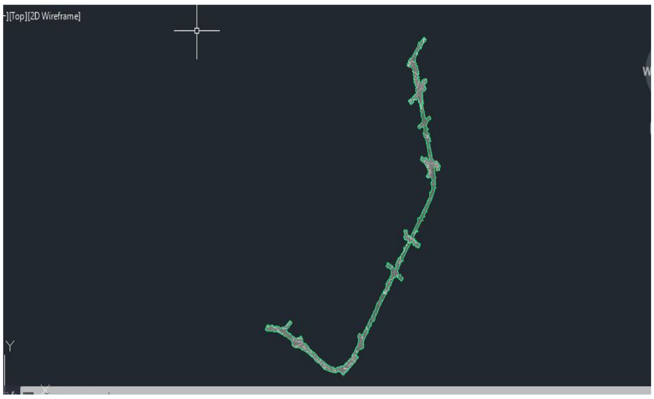


Fig -4: Surface creation with DTM for 13 km

iv)Alignment creation: It defines the centerline or path of the project. In Civil 3D, an alignment is created by selecting Home → Create Design → Alignment, then choosing from options like polyline, layout, or import, and assigning a name, style, and layer to define the road or project path.

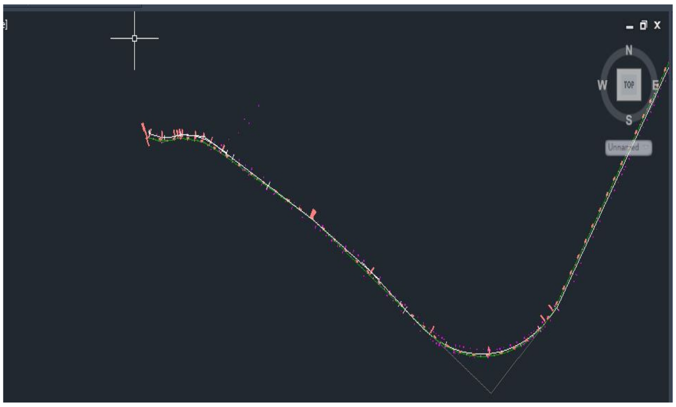


Fig -5: Alignment creation for the study area

Superelevation refers to the outward tilt of the road (raising the outer edge compared to the inner edge) to counteract centrifugal force. It can also be defined as the ratio of the height of the outer edge to the road width**.** It can be calculated using IRC-37,38:2018.

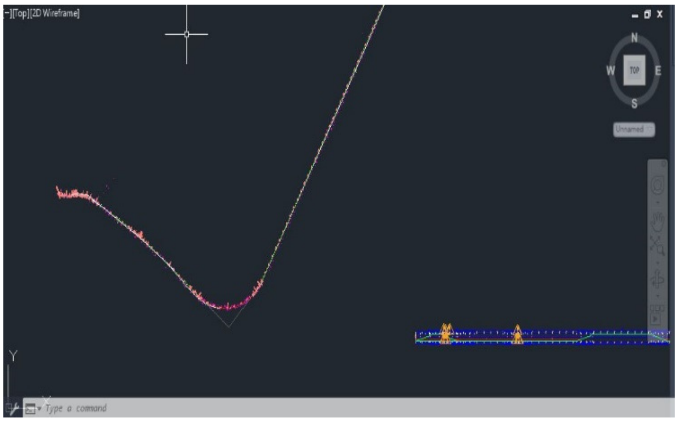


Fig -6: Alignment creation with super elevation

V)Profile creation: A vertical profile represents the elevation of the ground surface along a horizontal alignment. It is created using gradients connected by vertical curves.

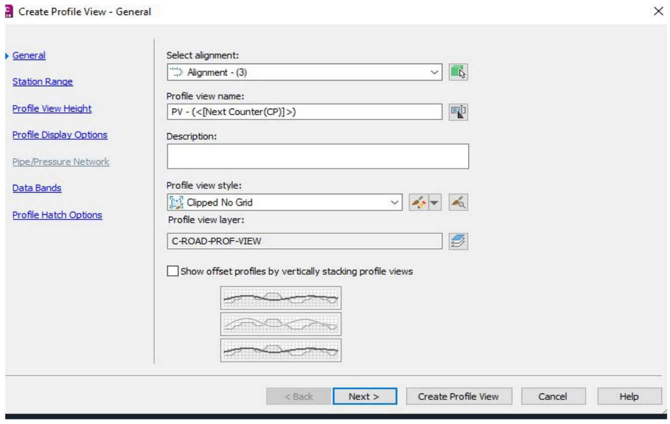


Fig -7: Profile creation tools

In Civil 3D, a profile is created by selecting Home → Create Design → Profile → Create Surface Profile, choosing the alignment and surface, then using Profile View → Create to display the ground profile along the alignment. Using the IRC SP 23)

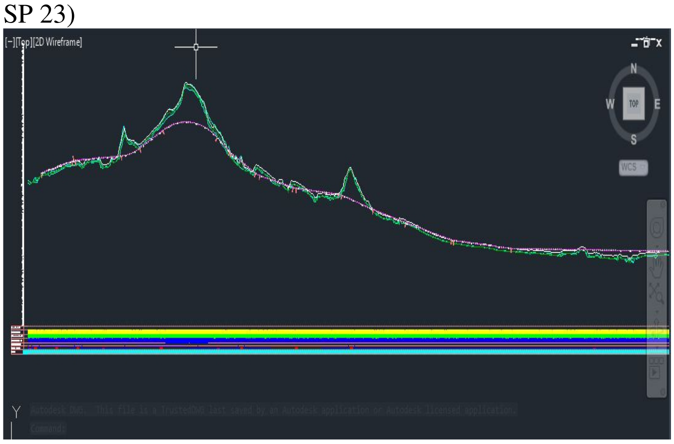


Fig -8: Profile creation from vertical curves vi)Assembly: In Civil 3D, an assembly defines the standard cross-section of a roadway or right-of-way combining subassemblies such as lanes, curbs, shoulders, and sidewalks to form a complete road cross-section applied along the alignment for creating a corridor design.

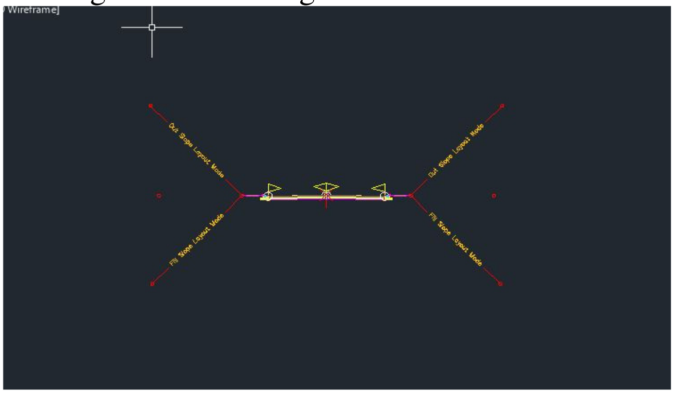


Fig -9:Day lights with 4 lane assembly

vii)Corridor: In Civil 3D, a corridor is a 3D model of a road created by combining an alignment, profile, and assembly. It is built using Home → Create Design → Corridor, then selecting the alignment, profile, and assembly to generate the roadway model.

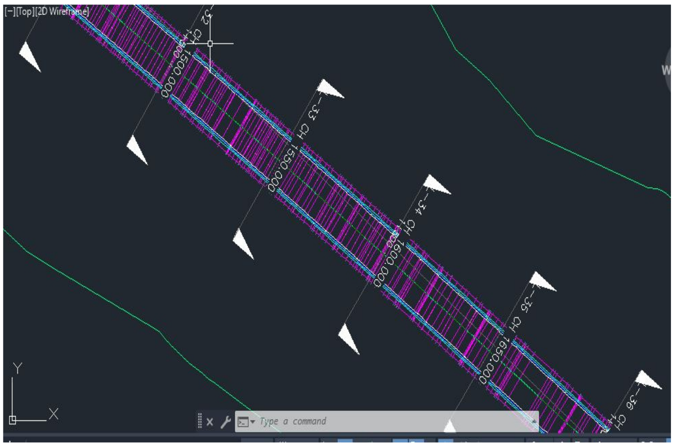


Fig -10:sample of corridor creation in 13 km stretch

viii)Section view: In Civil 3D, section views show cross-sections of a corridor or surface at specified stations. They are created using Home → Profile & Section Views → Section Views → Create Section Views, after defining sample lines along the alignment.

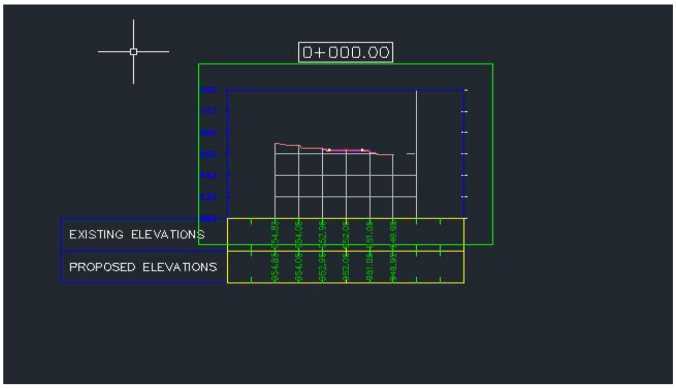


Fig -11: Sample of section view for 50 m interval

Table1. Total volume report for 13 km study area

Station	Cut Area (Sq.m.)	Cut Volume (Cu.m.)	Reusable Volume (Cu.m.)	Fill Area (Sq.m.)	Fill Volume (Cu.m.)	Cum. Cut Vol. (Cu.m.)	Cum. Reusable Vol. (Cu.m.)	Cum. Fill Vol. (Cu.m.)	Total Cum. Net Vol. (Cu.m.)
All stations	382742.6	13117700	13117700	31999.63	1600480.7	4181092946	4.181E+09	168791518	4012301428

II. Pavement design (structural design)

Flexible pavement using the CBR method consists of processed materials arranged in layers above the soil subgrade. The main goal of this road is to transfer the weight of vehicles to the lower layers. The pavement should provide enough skid resistance, a smooth surface for riding, less noise pollution, and better reflection. The main job of the pavement structure is to decrease the stress caused by wheels. Different layers have specific functions that help ensure the subgrade's capacity is not exceeded.

Pavements are generally classified into two major types: Flexible Pavements and Rigid Pavements. This study provides an overview of these pavement categories along with the common modes of their failure. Inadequate or improper design of pavements often leads to structural or functional failures, which in turn deteriorate ride quality and overall service performance.

The design of flexible pavements is carried out following an empirical approach as specified in IRC:37-2018 guidelines. These guidelines rely primarily on the CBR value of the subgrade soil and standard design charts to determine the required pavement thickness. In the present study, the flexible pavement design has been performed using IITPAVE software, ensuring compliance with IRC standards. The selected case study focuses on a 13 km road stretch at Paderu, Andhra Pradesh.

Flexible pavements are modelled as elastic multilayer systems, and their performance is evaluated using the mechanistic-empirical approach incorporated in IITPAVE. The software conducts stress analysis to compute the critical strains and stresses within different pavement layers. Two major performance criteria are considered:

The overall project methodology consists of the following key steps:

1. Defining the characteristics of the road sections through the Road Network Manager to establish geometric and structural parameters.
2. Identifying and classifying the vehicle categories expected to operate on the road network for accurate traffic analysis and design considerations.
3. Assigning traffic volumes and applying appropriate traffic growth rates.
4. Defining maintenance strategies and improvement measures, along with their unit costs.
5. Conducting a comparative analysis of the improved scenario (with project implementation) against the base scenario (without project implementation).

Data Collection

For the pavement design, a variety of traffic and soil data were collected.

The data collection phase for the project included traffic surveys and geotechnical investigations of the subgrade soil.

The major components were as follows:

- Classified Traffic Volume Counts: Manual traffic counts were carried out at two locations along the project corridor over a continuous 24-hour period, recording vehicle movements in both directions.
- Axle Load Survey: Conducted on regular working days for 24 hours, this survey utilized portable weighing pads to record axle loads of vehicles in both directions. For pavement design purposes, only vehicles with a gross vehicle weight of 30 KN (3 tonnes) and above were considered.
- Turning Movement Survey: Manual surveys were undertaken for 12 hours, covering both morning and evening peak periods. These observations provided insights into traffic turning behaviour at intersections and helped identify the need for junction improvements.
- Subgrade Soil Testing: Soil samples of approximately 15 kg were collected from each test pit along the alignment. Laboratory tests included field dry density, grain size distribution, modified Proctor compaction, and 4-day soaked CBR determination. Among these, the CBR test was particularly important, as it directly governs the pavement thickness design.
- Pavement Design and Analysis: The traffic survey data was processed to estimate the daily traffic volume, which was then converted into design traffic in terms of cumulative standard axles (MSA). Pavement thickness design was carried out as per IRC:37-2018 guidelines and validated using the IITPAVE software, ensuring compliance with mechanistic-empirical principles.

The design traffic (N) was computed using the following equation:

$N=365\times A\times D\times F\times(1+r)n-1r$

Where:

- A = initial traffic at the time of construction completion
- r = annual traffic growth rate
- n = design life (in years)
- D = lane distribution factor
- F = vehicle damage factor

The initial traffic in the year of road completion was estimated using:

$A=P\times(1+r)$

- IITPAVE Software Analysis

After determining the pavement thickness using *IRC:37-2018* guidelines, the design was validated through IITPAVE software, which evaluates whether the selected layer thicknesses can safely resist the anticipated stresses and strains.

The analysis considered the following parameters:

1. Relationship between resilient modulus and effective CBR value.
2. Design CBR = 5.0%.
3. Design traffic = 11 MSA.
4. Bitumen types: VG-40 for DBM and PMB 70/10 for SMA.
5. Final pavement layer composition obtained through interpolation from the IRC:37-2018 Pavement Design Catalogue.

Surface course= 50 mm, Binder course=30 mm, Water Bound Macadam (WBM)= 200 mm, Cement treated sub-base= 300 mm

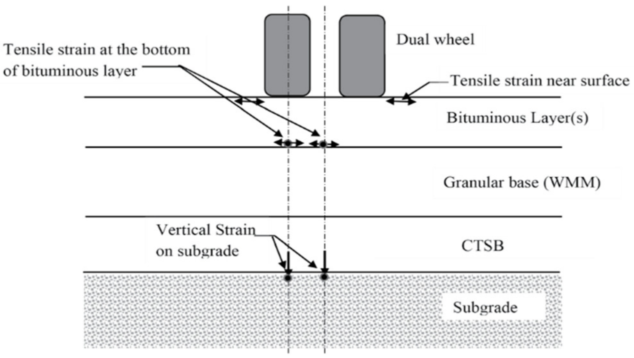


Fig -12: The selected pavement composition consists of bituminous layers, a granular base (WMM), and a cement-treated sub-base (CTSB). The structural evaluation emphasizes the critical strain locations, corresponding to a subgrade strength of 10% CBR.

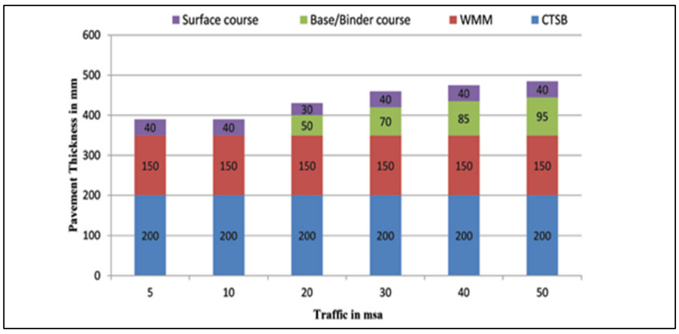


Fig -13: Graph showing the pavement composition from IRC For CBR 5%

6. Pavement Temperature: 35 °C
7. Resilient Modulus (MR):
   - Subgrade = 10×CBR=50 MPa
   - WMM = 208 MPa (IRC:37-2018, Table 11.1)
   - BC & DBM with VG-40 Bitumen = 3000 MPa (IRC:37-2018, Tables 9.2 & 11.1)
8. Poisson's Ratio: Subgrade = 0.35 (IRC:37-2018, Table 11.1)
   - WMM = 0.35 (IRC:37-2018, Table 11.1)
   - BC & DBM with VG-30 Bitumen = 0.35 (IRC:37-2018, Table 11.1)
9. Single Wheel Load: 20,000 N
10. Tire Pressure: 0.7 MPa
11. Number of Points for Stress Analysis: 4.0
12. Permissible Allowable Strains (for the above traffic):
   - Allowable tensile strain at the bottom of the bituminous layer (as per IRC:37-2018 empirical equation).

– Nf = 0.5161 x C x 10-4 x (1/εt)3.89 x (1/MR)0.854 (For 90% Reliability)

εt = 0.0005915

Allowable Compressive Strain at top of sub grade

– Nr = 1.41 x 10-8 x (1/εv) 4.5337 (For 90% Reliability)

εv = 0.0004386.

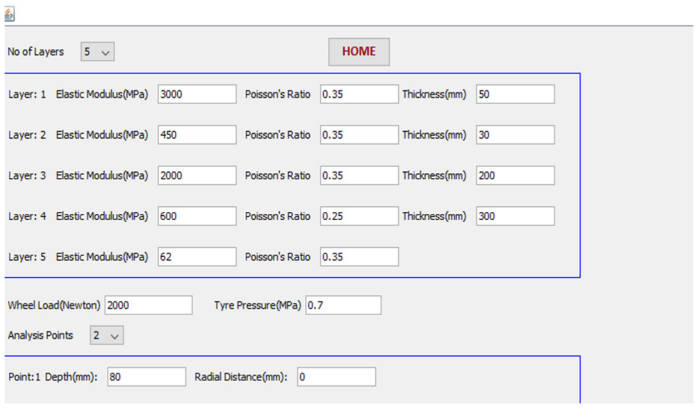


Fig -14:pavement layer details reference table

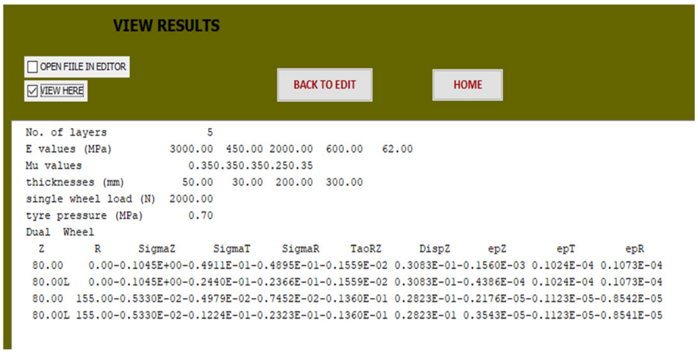


Fig -15: IIT PAVE result showing stress, strain values @80 mm depth

Strain Results from IITPAVE Analysis for the Selected Pavement Composition

a. The maximum tensile strain at the bottom of the bituminous layer was found to be 0.0008541, which is less than the allowable value of 0.0008872. Hence, the pavement is safe against fatigue cracking.

b. The maximum compressive strain at the top of the subgrade layer was obtained as 0.0004386, which is below the permissible limit of 0.0005915. Thus, the pavement is safe against rutting failure.

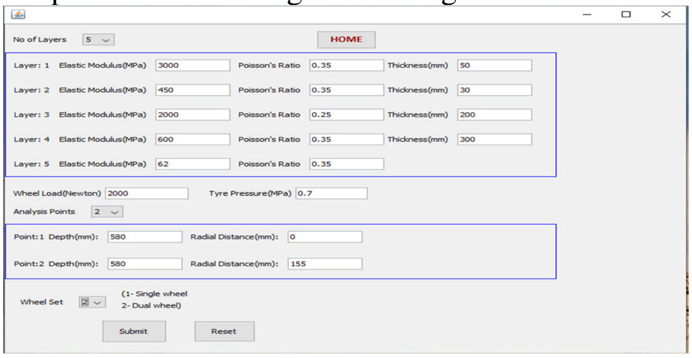


Fig -16: IIT PAVE reference data for different layers

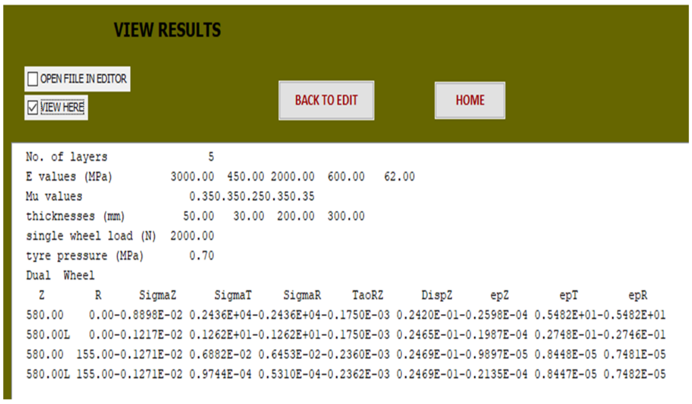


Fig -17: IIT PAVE result showing stress, strain values @ 580 mm depth

CBR value 10 %

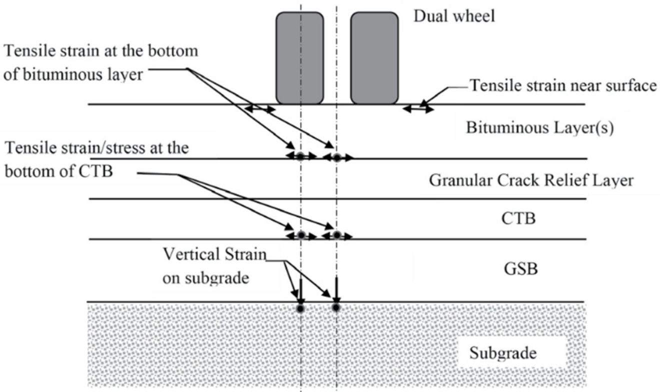


Fig -18: The pavement section consists of bituminous layer(s) over a granular base (WMM) and a cement-treated sub-base (CTSB). The analysis highlights the critical strain locations for a subgrade with 10% CBR.

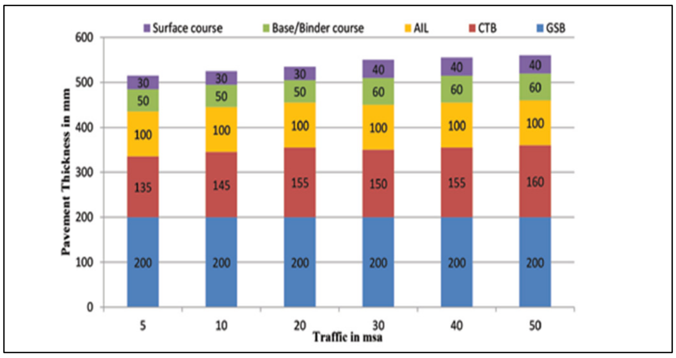


Fig -19: Graph of pavement layers from IRC for CBR 10%

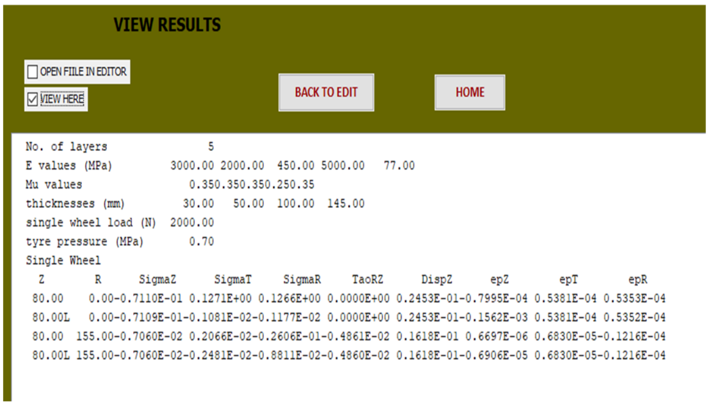


Fig -20: IIT PAVE showing stresses & strains @80 mm depth(10% CBR)

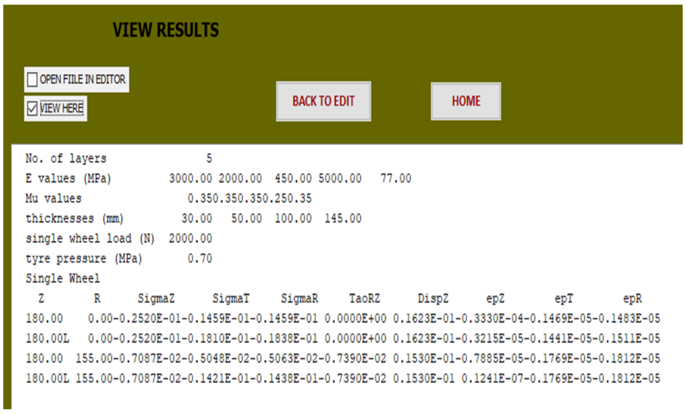


Fig -21: IIT PAVE showing stresses &strains @180 mm depth

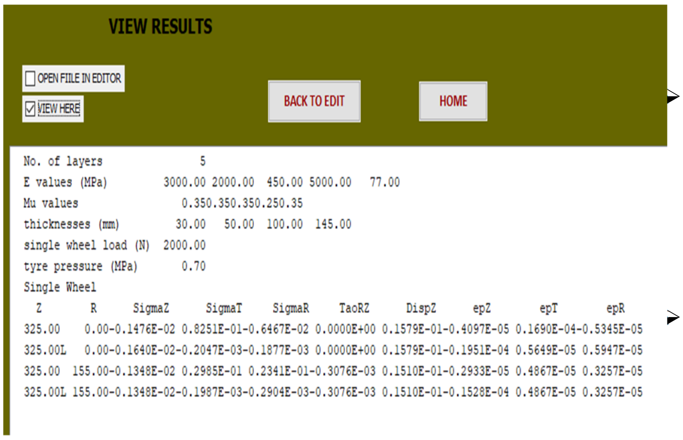


Fig -22: IIT PAVE showing stresses &strains @325 mm depth

3. CONCLUSIONS

For the above project, the study area of Paderu in Andhra Pradesh with 13 km stretches bypass road using civil 3D, design based on IRC:37-2018 and IIT Pave software, the results as follows,

- The geometric design of the proposed roadway was successfully completed using Autodesk Civil 3D in accordance with IRC standards. The alignment was designed for a design speed of 80 km/h, with a minimum horizontal curve radius of 230 m and a maximum superelevation of 7%, ensuring both safety and driving comfort. The carriageway width of 7.0 m with 1.5 m paved shoulders meets the requirements for a 4-lane facility.
- The vertical alignment maintained a maximum gradient of 3.3%, which is within permissible IRC limits. Using Civil 3D, detailed profiles, cross-sections, and corridor models were generated, minimizing manual effort and enhancing accuracy. This demonstrates the effectiveness of Civil 3D in producing economical, precise, and safe road designs in compliance with IRC guidelines.
- An essential part of the alignment design was balancing cut-and-fill quantities. The analysis showed a cut volume of 13,117,700 m³ and a fill volume of 16,004,801 m³, ensuring earthwork balance. The final alignment incorporated 6 horizontal curves and 4 vertical curves.
- The structural design of the pavement was carried out following *IRC:37-2018* guidelines and validated using IITPAVE software. For a design traffic of <20 MSA, a layered flexible pavement system was adopted. The subgrade had an effective CBR of 5% and 10%, corresponding to a resilient modulus of <100 MPa.
- The software analysis confirmed that the selected pavement thickness ensured adequate safety against both fatigue cracking and rutting. The final design provided total pavement thicknesses of 580 mm and 525 mm, which are sufficient to withstand projected traffic loads over a design life of 20 years.
- The IITPAVE validation showed that the tensile strain at the bottom of the bituminous layer and the compressive strain at the top of the subgrade were within the permissible limits of IRC:37-2018, confirming the safety and adequacy of the design.
- A comparative study of different CBR values revealed that an increase in subgrade strength (CBR) results in a reduction in total pavement thickness, thereby optimizing construction costs.
- It was also observed that rural roads, typically designed for lighter traffic of 7–10 MSA, make use of low-cost, locally available materials. In contrast, urban roads are designed for higher traffic volumes exceeding 20–50 MSA, requiring superior-quality materials and providing a longer service life of 15–20 years.

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