ARTICLE 1

Use of IITPAVE Software in Works Audit

Manish Kumar*
Altamash Ghazi*

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Abstract

Works audit conducted by the field audit offices of the Comptroller and Auditor General (CAG) plays a critical role in assessing whether Public Works Departments (PWDs) have planned, designed and executed road projects in an economical, efficient and technically sound manner. A key component of such audit is the scrutiny of pavement design, as deficiencies at the design stage often result in premature road failures or avoidable expenditure. With the adoption of Mechanistic–Empirical pavement design under IRC:37, PWDs now rely extensively on the IITPAVE software for preparation and approval of Detailed Project Reports (DPRs). This article explains the relevance and application of IITPAVE software in works audit. It outlines the audit methodology for examining pavement design adequacy, compliance with IRC guidelines, correctness of design inputs such as traffic, subgrade strength and the economic justification of pavement layer thicknesses. During 2022–23 to 2024–25, the study demonstrates how IITPAVE enables auditors to independently analyse pavement structures and evaluate alternative design scenarios. Audit application of IITPAVE across four road projects identified avoidable expenditure of approximately ₹7.67 crore arising from excess granular layer thickness, non-economical subgrade improvement measures and failure to account for existing pavement layers during strengthening works.

Keywords

Indian Roads Congress, CBR, Million Standard Axles (MSA), DPR, Pavement Design, IITPAVE, Flexible Pavement, Works Audit and Civil Audit.

1.1 Introduction

In accordance with Para 4.1.11 of the Manual of Standing Orders (Audit), an essential element of works audit is the scrutiny of sanctions, to ensure that expenditure on a work is supported by a sanctioned detailed estimate. The sanctioned estimate thus defines the approved scope, quantities, design and cost of a work and forms the primary benchmark for audit scrutiny. Further, Para 46.3.4.3 of the Civil Audit Manual, Vol-II, West Bengal requires a complete examination of selected works to verify that the estimate has been prepared to satisfy the actual technical requirements of the work. Audit is also required to compare sanctioned quantities and designs with actual execution to ensure that no material alteration or excess provision has been made.

In the case of road works, the pavement design contained in the Detailed Project Report (DPR) is a critical component of the sanctioned estimate, as the thickness and composition of pavement layers directly determine project cost and performance. With the adoption of Mechanistic–Empirical

*Principal Accountant General (Audit-II), West Bengal
Email: manishkumar3@cag.gov.in

*Deputy Accountant General, PAG (Audit-II), West Bengal
Email: ghazia@cag.gov.in

pavement[1] design under IRC:37, Public Works Departments (PWDs) now prepare and approve flexible pavement designs using the IITPAVE software[2]. Consequently, scrutiny of the sanctioned estimate and DPR, as envisaged in Para 4.1.11 of MSO, necessarily entails examination of IITPAVE-based flexible pavement design calculations. While Para 46.3.4.3 of the Civil Audit Manual and West Bengal PWD SoR 2018 are West Bengal specific, the IITPAVE based audit methodology is applicable wherever IRC:37 is used. Auditors in other jurisdictions may substitute their local manuals.

Use of IITPAVE in works audit enables Audit to independently verify whether the flexible pavement design underlying the sanctioned estimate is technically adequate, compliant with Indian Roads Congress (IRC)/Ministry of Road Transport & Highway (MoRTH) guidelines and is economical and to also identify cases of unsafe design, overdesign, excess layer thickness or avoidable subgrade upgradation leading to expenditure beyond the legitimate scope of sanction.

Flexible pavement consists of layers, from bottom to top, namely Earthwork (Subgrade), Granular Sub-base (sand, stone dust, moorum *etc.*), Granular Base (Wet Mixed Macadam, Water Bound Macadam), Bituminous layer (Bituminous Macadam, Dense Bituminous Macadam etc) and Bituminous wearing course (Semi-Dense Bituminous Concrete, Bituminous Concrete, Mastic Asphalt *etc*.).

1.2 Background

Pavement design in India was traditionally based on empirical methods. These methods primarily use the load-bearing capacity of the subgrade, expressed as the California Bearing Ratio (CBR) obtained from laboratory tests, along with historical and projected traffic loads measured in million standard axles (msa). While empirical designs are simple to apply, they offer limited flexibility and do not explicitly evaluate the structural behaviour of pavement layers under traffic loading.

To overcome these limitations, the Indian Roads Congress (IRC) introduced a shift towards a Mechanistic–Empirical (M–E) pavement design approach. This approach evaluates pavement performance by computing critical stresses, strains and deflections generated within pavement layers due to wheel loads. In this context, IRC:37 introduced the IITPAVE software as a standard tool for mechanistic analysis of flexible pavements. Its use was first formalised in IRC:37–2012 and subsequently strengthened in IRC:37–2018, which recommends the use of flexible pavement design using IITPAVE. The software is supplied along with the IRC:37 guidelines.

Under the earlier Design Catalogue approach (Chart 1.1), pavement compositions are selected from predefined tables corresponding to broad ranges of traffic and subgrade strength.

[1]The mechanistic-empirical method is based on the mechanical properties of the pavement materials that give a relation between the input, in the form of loading, and the output, in the form of stresses and strains in the pavement.
[2] IIT PAVE is a specialized software developed by IIT Kharagpur (under MORTH research) for analyzing and designing flexible pavements using IRC:37-2012 guidelines. It models pavements as multi-layer elastic systems, calculating critical stresses, strains, and deflections to evaluate fatigue and rutting life.

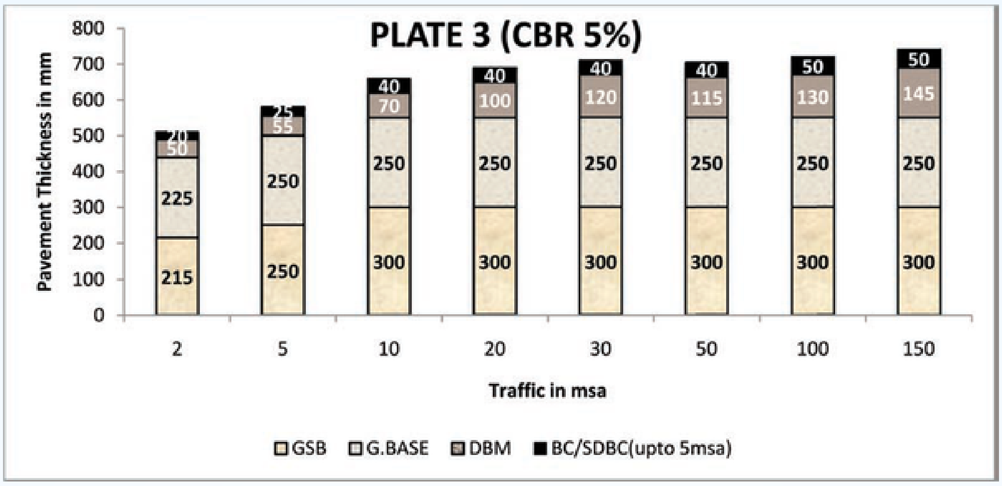

Chart 1.1: Design Catalogue (Source: IRC : 37-2018)

In contrast, IITPAVE enables project-specific pavement design by calculating critical structural responses, namely the horizontal tensile strain at the bottom of the bituminous layer (governing fatigue cracking) and the vertical compressive strain at the top of the subgrade (governing rutting). This allows designers to assess pavement safety and optimise layer thickness based on actual site conditions rather than relying solely on standardised sections.

PWDs in several States, including West Bengal, now explicitly mandate IITPAVE-based analysis in the preparation of DPRs, tender documents and technical sanctions. Consequently, for maintaining technical parity and audit credibility, Works Audit must also adopt IITPAVE wherever issues relating to pavement design adequacy, choice of materials, layer thickness or subgrade upgradation are under examination.

1.3 Understanding IITPAVE

IITPAVE software for flexible pavement design was developed by the Transportation Engineering Division at the Indian Institute of Technology (IIT) Kharagpur, as an advanced, Mechanistic-Empirical tool for analysing pavement structures based on Indian Roads Congress (IRC) guidelines, replacing older methods. It's used by engineers for accurate design by modelling layer stresses, strains and performance under traffic and environmental conditions, helping create more durable roads. The structural analysis performed by IITPAVE is fundamentally based on the Multi-Layer Elastic Theory. The software requires precise material inputs for every defined layer. These inputs include the Resilient Modulus[3] (M_R) and layer-specific Poisson's Ratio[4] (v).

The software calculates the structural responses (stresses, strains and deflection) resulting from traffic load. Fatigue crack (Figure 1.1) often initiating at the bottom of the bituminous layer and propagating upwards, is a load-related distress mechanism caused by repetitive tensile strain. The critical structural response that governs this failure is the horizontal tensile strain (ε_t) computed by IITPAVE at the bottom interface of the lowest bituminous layer.

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[3]The resilient modulus is a key parameter that quantifies the elasticity and stiffness of the pavement layers under repeated loading.
[4] Poisson's Ratio is a measure of a material's deformation when subjected to stress. It is defined as the ratio of lateral strain (deformation perpendicular to the applied force) to axial strain (deformation parallel to the applied force).

Figure 1.1: Crack of pavement due to Fatigue strain

Source: https://uppwd.gov.in/site/writereaddata/siteContent/20190424201015351912.pdf

There is another kind of failure known as rutting (Figure 1.2). Rutting represents the accumulation of irrecoverable plastic deformation primarily within the unbound granular and subgrade layers, leading to depressions in the pavement surface. The structural response that dictates this failure mode is the vertical compressive strain (ε_v) computed at the critical location, the top of the subgrade layer.

Figure 1.2: Surface depression due to rutting strain

(Source:https://uppwd.gov.in/site/writereaddata/siteContent/20190424201015351912.pdf

A pavement is considered safe if IITPAVE-computed strains are below allowable limits, calculated using IRC-prescribed fatigue and rutting equations. These strains are measured at critical locations in the pavement. The locations are marked as I and II in Figure 1.3.

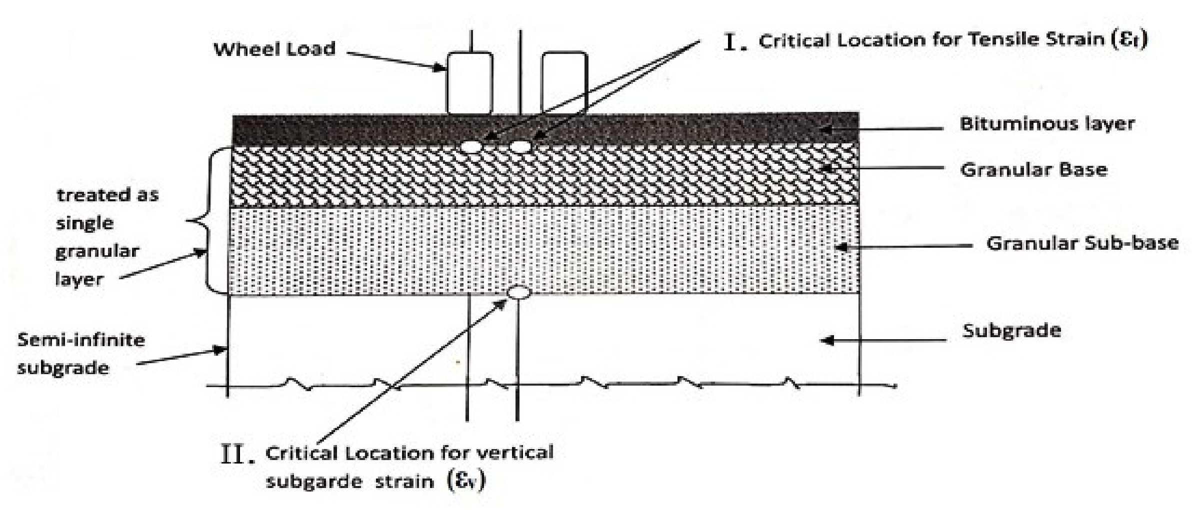

Figure 1.3: Horizontal tensile strain and vertical compressive strain

(Source: IRC: 37-2012)

Moreover, in some cases, there can be a significant difference between the CBR values of the soils used in the subgrade and in the embankment layer below the subgrade. Alternatively, the subgrade may be laid in two layers, each layer material having different CBR value. In such cases, the design should be based on the effective CBR value of a single layer subgrade which is equivalent to the combination of the subgrade layer(s) and embankment layer.

Using IITPAVE software, the maximum surface deflection (expressed as 'δ') can be determined and the effective Resilient Modulus (M_R) of the equivalent single layer and consequently the effective CBR of the combined layer is derived using the equations provided in IRC:37. These are then used to calculate ε_v and ε_t.These values are then used to determine if they are below the allowable limits prescribed by IRC.

Thus, IITPAVE provides a comprehensive framework for assessing structural adequacy, safety and economy of pavement designs, making it a powerful tool not only for designers but also for audit scrutiny of DPRs and sanctioned estimates.

1.4 Use of IITPAVE in Audit

For independent verification of pavement designs using IITPAVE, audit teams obtain the required design inputs from primary engineering records maintained by the executing department. The principal inputs include subgrade strength (CBR), projected traffic load (msa), pavement layer thickness and material properties such as resilient modulus (MR) and Poisson's ratio (ν). These parameters are typically derived from the Detailed Project Report (DPR), laboratory test reports, traffic census data and technical sanction documents.

Use of IITPAVE in works audit enables derivation of technical and financial audit observations relating to design adequacy, IRC compliance, economy of pavement composition and avoidable expenditure on subgrade improvement, as detailed below.

(i) Inadmissible / Unsafe Designs in DPR
Audit may establish:
- DPR not prepared scientifically,
- strains exceeded allowable values,
- inadequate design leading to premature distress.

(ii) Verification of Departmental Compliance with IRC Guidelines
Check whether DPR or design approval:
- followed IRC:37-2012 or 2018,
- used IITPAVE when required,
- used correct input parameters for CBR, M_R (Resilient Modulus), traffic loading and Poisson's ratio.

(iii) Excess Layer Thickness / Non-economical Pavement Design
Audit can use IITPAVE to demonstrate:
- thinner pavement structure is sufficient, or
- PWD used non-optimal combination of layer thicknesses (as detailed in Annexure -1)

(iv) Avoidable Expenditure on Subgrade Upgradation
By calculating effective CBR, Audit can verify:
- correctness of material chosen for improving subgrade,
- whether cheaper alternatives could achieve the same CBR (as detailed in Annexure-2),
- excess cost due to over-thickening of subgrade-improvement layers.

1.5 Rationale for Using IITPAVE in Audit
I. PWD itself uses IITPAVE for DPR preparation, tender conditions and technical estimates. Therefore, audit observations gain legitimacy when based on the same tool.

II. IITPAVE enables calculation of continuous values not discrete values (catalogue-based), optimisation of pavement thickness, helping identify excess layering.

III. The tool calculates effective CBR, enabling Audit to verify whether the selected material for subgrade upgradation was economical and technically justified.

1.6 IITPAVE Application
In the following cases, IITPAVE software was applied by audit to independently verify pavement design parameters and assess compliance with Indian Roads Congress (IRC) guidelines, thereby enabling identification and quantification of avoidable expenditure.

A) Reference- Audit Reports:
i) Excess thickness of non-bituminous layers (Audit Report 2023-24): Audit used IITPAVE to analyse traffic loading, sub-grade strength and design requirements as per IRC norms and compared the technically required thickness of non-bituminous layers with the thickness actually executed. The analysis revealed execution of excess thickness beyond design necessity, resulting in avoidable expenditure of ₹2.15 crore.

ii) Selection of non-economical borrowed material for sub-grade upgradation (Audit Report 2024-25): IITPAVE was applied to evaluate alternative pavement design scenarios using different sub-grade materials. The software analysis showed that the selected borrowed material led to a higher pavement cost compared to more economical options capable of meeting the same design requirements, resulting in avoidable expenditure of ₹1.79 crore.

B) Reference-Inspection Reports:

i) Non-consideration of existing pavement layer while providing Wet Mix Macadam (WMM). (Inspection Report 2023-24): Audit used IITPAVE to assess the pavement design by incorporating the existing layer strength and thickness into the design input parameters. The analysis demonstrated that failure to account for the existing layer led to unnecessary provision of additional WMM thickness, causing avoidable expenditure of ₹1.82 crore.

ii)Execution of excess thickness of granular layers (Inspection Report 2022-23): By inputting actual traffic and sub-grade parameters into IITPAVE, audit determined the optimum thickness of granular layers required as per IRC guidelines. Comparison with the executed thickness revealed excess provision of granular layers, resulting in avoidable extra expenditure of ₹1.91 crore.

1.7 Conclusion

Works audit of road projects necessarily involves technical scrutiny of pavement designs, as the DPR and sanctioned estimate are now predominantly based on IITPAVE calculations in accordance with IRC:37. By analysing critical structural responses such as fatigue and rutting strains, IITPAVE enables a more accurate assessment of pavement safety and performance than traditional reliance on empirical design tables alone. The software also facilitates optimisation of pavement layer thickness and material selection, helping to identify cases of overdesign, non-economical specifications and avoidable expenditure without compromising structural adequacy. Accordingly, use of IITPAVE in works audit strengthens the assessment of design adequacy, compliance with IRC guidelines, economy and effectiveness of flexible pavement works.

Data Availability
No new data has been introduced.

Ethics Statement
All necessary ethical and research integrity principles have been duly adhered to.

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Conflict of Interest
The authors declare no conflict of interest.

Acknowledgement

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2. Indian Roads Congress. (2012). IRC:37-2012: Tentative guidelines for the design of flexible pavements.

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Annexure-1, Article 1

1. Objective

The objective of the audit examination was:

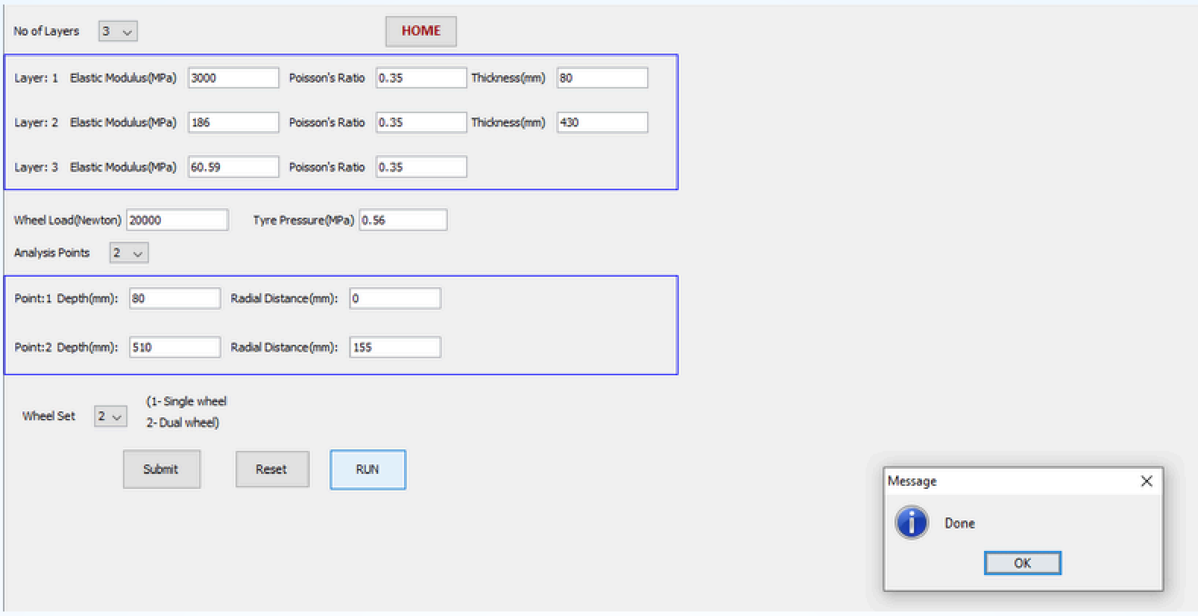
- To verify whether the pavement composition adopted in the DPR complied with **IRC:37–2018 design requirements**.
- To assess whether the **granular layer thickness provided by the department was technically necessary** for the projected traffic and subgrade strength.
- To determine whether **avoidable expenditure resulted from overdesign of pavement layers**.

1. **IITPAVE Inputs**

Following data which are required to run the IITPAVE software were collected from the DPR of the project and some standard data from IRC- 37:2018:

Category	**Value**	**Source**
CBR of subgrade soil	6.9%	DPR
msa	10 ((For design life 15 yrs of granular layers) 3.5 (For design life 5 yrs of bituminous layer)	DPR
Layers thickness (executed by the Department)	80 mm bituminous layers **480** mm Granular layers	DPR
Optimal Layers thickness arrived by audit through IITPAVE	80 mm bituminous layers **430** mm Granular layers	DPR
MR (Resilient Modulus)	3000 MPa (for Bituminous layers) 186 MPa (for Granular layers) 60.59 MPa (for Subgrade)	IRC: 37-2018
Poisson's ratio of pavement layers	0.35	IRC: 37-2018
tire pressure	0.56	IRC: 37-2018
wheel load	20000	IRC: 37-2018
Radial distance	155 mm	IRC: 37-2018

The screen shot of the IITPAVE inputs for the instant case is as follows:



2. **Computation of the allowable strains/stresses**

The allowable strains in the bituminous layer and subgrade for the projected traffic loads are estimated using the fatigue and rutting equation given in IRC-37:2018. The inputs to the equations are the design period of pavement in terms of cumulative standard axles (msa), the resilient modulus value of the bottom layer bituminous mix, and the volumetric proportions (air voids and effective binder) of the mix.

Allowable tensile strain (Fatigue),

$N_f = 1.6064 * C * 10^{-4} x [1/(\varepsilon_t)]^{3.89} x [1/M_{R\_Bituminous\ layer}]^{0.854}$ **(equation no. 3.3 of IRC-37:2018)**

Where,

Nf = 3500000

C = 10*M*, and *M* = 4.84 (*Vbe*/*Va*+*Vbe*−0.69)

Va = 4.5, *Vb* = 10.5

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

M_R = 3000

Hence, ε_t (allowable tensile strain) = **0.0004117**

Allowable vertical subgrade strain (Rutting),

N_R = 4.1656 x 10-08 [1/ ε_v] 4.5337 **(equation no. 3.1 of IRC-37:2018)**

where,

N_R = 1000000

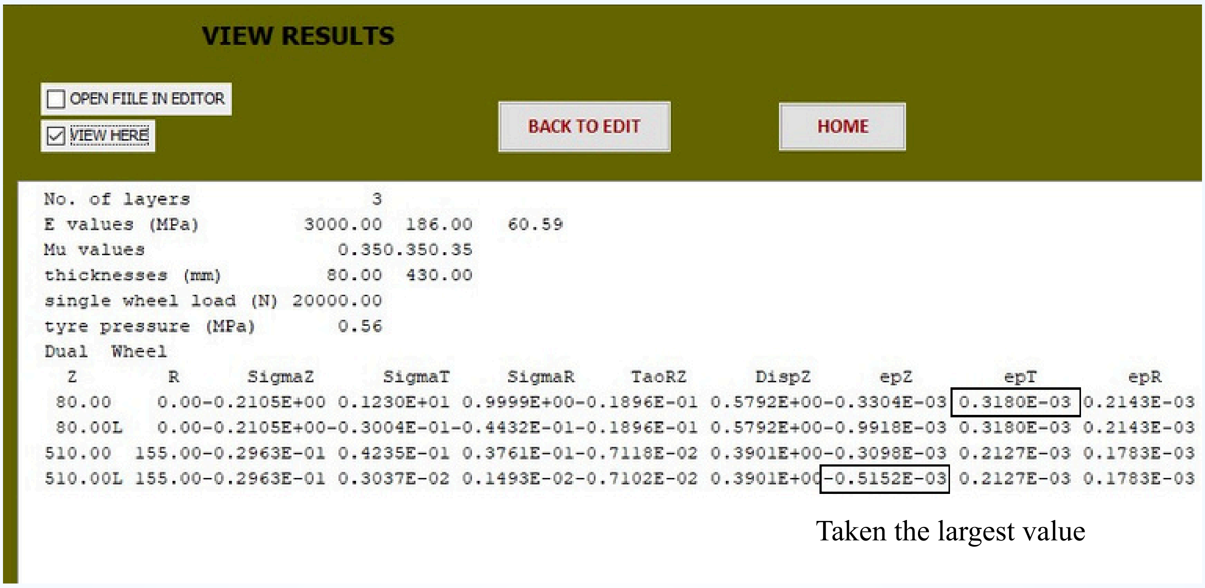
Hence, ε_v (allowable vertical subgrade strain) = **0.0005300**

3. **IITPAVE run**

The IITPAVE software is an elastic multi-layered programme which uses the inputs like the layer thicknesses, the layer moduli (MR), the layer Poisson's ratio values, the standard axle load of 80 kN distributed on four wheels (20 kN on each wheel), and a tyre pressure as 0.56 MPa. The program will output the stresses, strains and deflections at selected critical locations (at the bottom of bituminous layers and at the top of the subgrade) in the pavement from which the values of critical mechanistic parameters (epT and epZ) can be identified as permissible strains/stress for pavement design.

4. IITPAVE Outputs

The screen shot of the IITPAVE inputs for the instant case is as follows:



By running the IITPAVE software using the above-mentioned inputs, the IITPAVE outputs derived from which the largest value of epT which implies the permissible tensile strain (**εt)** and the largest value of epZ which implies the vertical subgrade strain (**εv**) derived as **0.0003180** and **0.0005152** respectively, and the IITPAVE generated strain/stress values are within the allowable limit (**0.0004117** and **0.0005300** respectively) as derived from the equation 3.3 and 3.1 of IRC-37:2018, hence, the pavement composition *i.e.* tried by audit using IITPAVE is safe for the road.

5. Comparison with Departmental Design and calculation of extra expenditure

Thus, it is observed that the Department had constructed 480 mm granular layers for the road, whereas audit by IITPAVE analysis established that 430 mm granular layers is safe for the road to withstand the projected traffic. Hence, the Department has executed 50 mm excess granular layers incurring an expenditure of ₹ 2.15 crore.

Calculation of extra expenditure

Excess Quantity executed for granular layers	9,991.75 m3
Item rate allowed including 1% cess	₹ 2,508.11 per m3
Extra expenditure	₹ 2,50,60,408
Less: Contractual rebate (14.26%)	₹ 35,73,614
Net extra expenditure	**₹ 2,14,86,784**

Annexure-2, Article 1

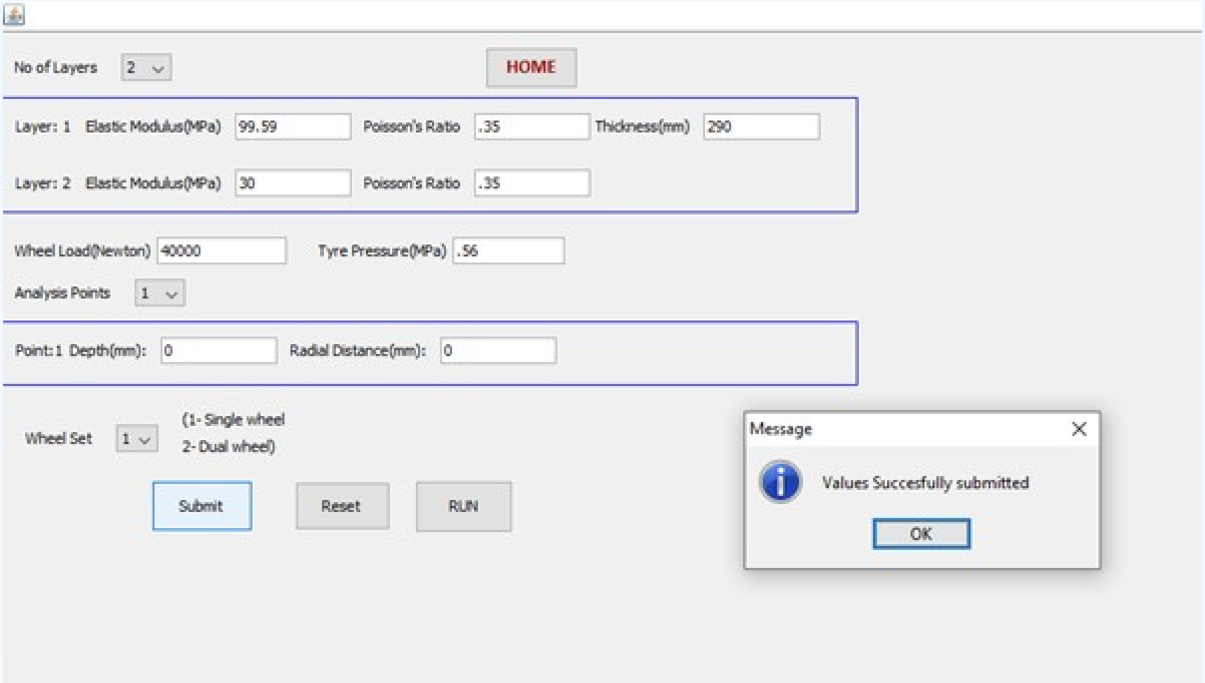
IRC : 37-2018 recommends that the subgrade CBR should be more than 5% in the year of construction of the pavement.

PWD Department executed a widening and strengthening works of a road, and it is observed that the CBR value of existing subgrade was 3% and to upgrade the CBR of the road, 500 mm medium sand layer which has a CBR value 10% was laid on the existing subgrade, resulting in effective CBR values of 6.97 % (analysed by the department through IITPAVE) for the combined subgrade.
Audit tested using IITPAVE software, a mixture of stone dust and fine sand in a 3:1 ratio (item No. 4.16 of PWD SoR-2018) as an alternative material to medium sand for subgrade upgradation. The analysis showed that the mixture of stone dust and fine sand would require lesser thickness of 290 mm to achieve the same effective CBR values obtained using 500 mm of medium sand. Furthermore, it was observed that the Department had already used the same 3:1 stone dust and fine sand mixture for sub-grade upgradation in another nearby road project.
Thus, the department has incurred an avoidable expenditure of ₹1.79 crore by selecting non-economical alternative material for the upgradation of sub-grade soil in road construction.

Use of IITPAVE by audit is detailed below:
The existing subgrade CBR-3%
CBR of stone dust and fine sand mixture-15%
Trial thickness - 290 mm
Wheel load-40000 N
Contact pressure – 0.56 MPa
Using these inputs in IITPAVE software, the maximum surface deflection ('δ') derived **2.414, putting this value in the formulas as stated above get the effective CBR 7.04% i.e. more than that the effective CBR achieved (6.97%) by the department using 500 mm medium sand.**

The input and corresponding output of IITPAVE are given below:
CBR of existing subgrade = 3%
CBR of a mixture of Stone Dust and Fine Sand (mixed in proportion of 3:1 by volume) = 15%.
Trial thickness 290 mm.
Resilient Modulus of existing Sub grade = 10 X 3= 30 (Eqn. 6.1 of IRC:37-2018)
Resilient Modulus of GSB(Mix of stone dust & fine sand) = 17.6 X 15^0.64 = 99.59
(Eqn. 6.2 of IRC:37-2018)

Deflection (δ)	**2.414** (Disp Z of the IIT pave reading below)
Poisson Ratio (μ)	**0.35**
Tire pressure (p)	**0.56** MPa
Radial distance (a)	**150.8 mm**
MR Subgrade = $\frac{2(1-\mu^2)pa}{\delta}$	2*(1-poisson ratio^2)*0.56*150.8/deflection; =148.206/2.414=61.39
CBR > 5	MR of Subgrade =17.6*(CBR)^0.64
	61.39=17.6*(CBR)^0.64
	Then CBR= 7.04% i.e. higher than design CBR.


No of Layers
2
HOME
Layer: 1 Elastic Modulus(MPa) 99.59 Poisson's Ratio .35 Thickness(mm) 290
Layer: 2 Elastic Modulus(MPa) 30 Poisson's Ratio .35
Wheel Load(Newton) 40000 Tyre Pressure(MPa) .56
Analysis Points 1
Point:1 Depth(mm): 0 Radial Distance(mm): 0
Wheel Set 1
(1- Single wheel
2- Dual wheel)
Submit
Reset
RUN
Message
Values Succesfully submitted
OK


VIEW RESULTS
OPEN FILE IN EDITOR
VIEW HERE
BACK TO EDIT
HOME
No. of layers 2
E values (MPa) 99.59 30.00
Mu values 0.350.35
thicknesses (mm) 290.00
single wheel load (N) 40000.00
tyre pressure (MPa) 0.56
Single Wheel
Z R SigmaZ SigmaT SigmaR TaoRZ DispZ epZ epT epR
0.00 0.00-0.5525E+00-0.5579E+00-0.5579E+00 0.0000E+00 0.2414E+01-0.1627E-02-0.1700E-02-0.1700E-02