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Original Article

Assessment of Deflection and In-Situ California Bearing Ratio (CBR) of Clayey Subgrade of Flexible Pavement Reinforced with Waste Tyre Scrap Material

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Abstract *- This study evaluated the deflection and field or in-situ California Bearing Ratio (CBR) of subgrades in flexible pavements, comparing normal soil subgrades with tyre scrap-modified subgrades. It involved laboratory tests (modified proctor compaction and CBR) for assessing load-bearing capacity and strength and field studies using the Dynamic Cone Penetration Test (DCPT), and Falling Weight Deflectometer (FWD) for in-situ CBR and structural capacity evaluation. DCPT provided in-situ CBR values correlated with those for cohesive soils, while FWD focused on measuring subgrade deflection using the Lower Layer Index (LLI). Results indicated a 37.5% reduction in deflection with the tyre scrap-modified subgrade, demonstrating its potential in road construction for improved durability, cost savings, and waste utilization. This finding suggests the viability of tyre scrap in enhancing road infrastructure sustainably and efficiently.*

Keywords *- CBR, DCPT, Deflection, FWD, Subgrade.*

1. Introduction

The rapid growth in global vehicle numbers has brought about a concurrent increase in waste tyres and tube production, a trend projected to result in approximately 2 billion scrap vehicles by 2030. This forecast, as outlined by Dargay et al. [1], raises serious environmental and waste management concerns. The challenge is compounded by the non-biodegradable nature of tyres, which resist decomposition and occupy substantial landfill space, leading to an exacerbated solid waste problem. When disposed of improperly, these tyres pose significant environmental hazards.

Rokade [2] highlighted tyres can release toxic substances, including polycyclic aromatic hydrocarbons, furans, dioxins, and nitrogen oxides, contributing to air pollution, unpleasant odours, and visual pollution. Incineration is an alternative disposal method and generates harmful gases, underscoring the need for more sustainable management practices. From a manufacturing standpoint, these tyres, predominantly made from petroleum-based materials, lack recyclability and biodegradability, further complicating their disposal. However, emerging research in geotechnical engineering, such as the studies by Mashiri et al. [3], has revealed the potential benefits of repurposing waste tyres. These recycled materials exhibit high tensile strength, durability, toughness, and resistance to ageing, presenting a promising solution for environmental concerns. In pavement engineering, flexible pavements offer considerable advantages due to their incremental strength and enable nature to respond to increasing traffic loads. However, these pavements are susceptible to failure modes such as fatigue cracking and rutting deformation.

The structural integrity and stability of pavement subgrade are critical in distributing loads efficiently, reducing strain on the pavement layers, and potentially extending the pavement's lifespan. In line with the guidelines of IRC 115:2014 [4], a Falling Weight Deflectometer (FWD) is employed to determine the subgrade deflection and elastic modulus of pavements. The current study compares in-situ CBR and deflection of pavement subgrades; one is existing pavement, which consists of normal clayey soil subgrade, and another is modified pavement, which consists of scrap tyre mix clayey soil subgrade.

Data for this study have been collected from previous studies conducted at the Soil Mechanics and Foundation Engineering Division of Jadavpur University, Kolkata, West Bengal, India. The primary objective of this study is to conduct a comparative analysis between the subgrade deflection and DCPT-oriented in-situ CBR of existing pavement and pavement with scrap tyre-modified subgrade. For this purpose, a Dynamic Cone Penetrometer (DCP) and automatic trailer-mounted FWD system were utilized. Recent geotechnical and transportation engineering studies underscore the importance of DCPT and FWD in assessing soil and pavement conditions.

Vakili et al. [5] demonstrated that adding lime to marl soil improved its mechanical properties, including UCS and CBR, validating the effectiveness of DCPT in soil behaviour analysis. Nwanya and Okeke [6] used the DCPT in Owerri, southeastern Nigeria, to assess subsurface soils up to 6 meters deep, determining CBR and bearing pressure. The study identified three soil layers with varying densities and resistances.

The penetration resistance ranged from 11.4 to 55.5 mm/blow, revealing loose, medium, and dense soil layers. CBR values increased from 5% to 16% with depth, while average bearing pressures rose significantly from 104.8 to 301.1 KN/m², indicating increasing soil strength with depth.

Sahoo and Reddy [7] studied using DCPT to estimate soil strength, explicitly targeting the correlation between the DCPT results and fine-grained soils' CBR. They conducted laboratory experiments between CBR values and DCP penetration depth across different fine-grained soil types. Their results indicated a significant link between CBR and DCP values for each soil category and within the aggregated dataset. To encapsulate this relationship, they formulated logarithmic equations: Log10 LAB CBR = 2.758 - 1.274 Log10 LAB DCP and Ln CBR = 67.898 - 17.483Ln (field DCP), further confirming the vital link between CBR and DCPT values.

Obaidi and Ashoishi [8] explored the use of the DCPT in Iraq, particularly in gypseous soils that are prevalent in the region. Introduced in the 1950s and recently in Iraq, the DCPT is an efficient method for assessing soil strength. The research focuses on correlating DCPT results with CBR in soils with varying gypsum contents (28-41%). Laboratory and field tests on these soils reveal the significant impact of gypsum on the CBR-DCP relationship, leading to meaningful conclusions for geotechnical explorations.

Alam et al. [9] focused on developing intelligent pavement performance models for efficient highway maintenance and repair. It emphasizes the need for such models to effectively manage pavement maintenance and rehabilitation, considering traffic, environmental, and climatic conditions. The research involved FWD tests to review flexible pavement deterioration patterns.

Rabbi and Mishra [10] utilized Deflection Basin Parameters (DBP) derived from FWD data as an efficient alternative for assessing pavement structural conditions, circumventing the need for precise layer thickness measurements. The study validated DBPs through finite-element modelling and field analyses, offering a comprehensive view of pavement conditions for rehabilitation decisions.

Razali et al. [11] studied the use of FWD in assessing the bonding state of subgrade in flexible pavements, especially in tropical soils. The research highlights deflection as a critical indicator of subgrade condition, emphasizing early detection of subgrade issues for maintaining pavement integrity.

Skels et al. [12] investigated the stabilization of unbound layers with Reclaimed Asphalt Pavement (RAP); this study focuses on design parameters and testing procedures for stabilized RAP in road base layers. It confirms the technical, economic, and environmental feasibility of using cement-stabilized RAP in road construction.

Solanki et al. [13] studied a 20 km stretch of the Barnala-Mansa State Highway using FWD to assess pavement conditions before and after overlay. The study focused on calculating critical parameters like the Surface Curvature Index (SCI) and Middle Layer Index (MLI), offering insights into the condition of pavement layers. These studies collectively contribute to a deeper understanding of pavement engineering, offering innovative methodologies for assessing, designing, and maintaining pavement performance.

Emersleben and Meyer [14] conducted comprehensive model and field experiments on a large scale, which revealed that geocells effectively diminish surface deflections and lessen the vertical pressure exerted on the subgrade. Their investigations also explored how the aspect ratio influences performance, finding that a higher height-to-diameter ratio correlates with enhanced performance.

The present study has used a comprehensive methodology to examine the application of scrap tyres in enhancing the strength and structural performance of pavement subgrades. The primary methods and procedures include data collection and experimental studies. Laboratory-soaked CBR of the existing pavement and traffic data have been collected from the Soil Mechanics Research Division of the Civil Engineering Department, Jadavpur University, Kolkata. Various laboratory studies on the existing pavement and scrap tyre-modified subgrade pavement were conducted, complemented by field studies such as FWD and DCPT.

This research investigates the use of waste tyre scrap to enhance the strength of soft, cohesive subgrade in flexible pavements. It focuses on improving subgrade strength and structural performance, specifically regarding CBR and subgrade deflection. The study employs in-situ CBR evaluations using DCPT and FWD tests to assess these improvements comprehensively.

By comparing the effects of tyre scrap on flexible pavement subgrades, the research aims to provide a detailed understanding of how waste tyre materials can be effectively used in pavement construction. This approach promises to enhance pavement strength and performance and contributes to sustainable construction practices by recycling waste materials.

2. Background of the Present Study

In this study, the required data for further analysis was obtained from prior research conducted by the Soil Mechanics and Foundation Engineering Division at Jadavpur University, Kolkata, West Bengal, India. In continuation of that research, the present work has been conducted. The prior study was done on a specific roadway segment under the Public Works Department (PWD) in West Bengal.

The road segment from Jibantala Bazar to Taldi Bazar near Canning (District-South 24 Parganas, West Bengal, India) starts at Jibantala crossing market (coordinates: Latitude 22°20’37.7” N, Longitude 88°36’29.6” E) and ends at Taldi Bazar near the railway station (coordinates: Latitude 22°25’11.8” N, Longitude 88°39’44.4” E), covering 12.45 km. Soil samples, described as ‘brownish grey silty clay,’ were collected along the road for laboratory testing. These tests included determining the soaked CBR and other studies, with a design CBR value of 3.36 found for this road section.

Further, soil samples were selected from subgrade locations with soaked CBR values close to the design CBR. The innovative part of the study experimented with scrap tyre pieces of various sizes (10 mm x 10 mm, 15 mm x 15 mm, 20 mm x 20 mm, 25 mm x 25 mm and 30 mm x 30 mm) mixed with soil in proportions from 5% to 30%. The best improvement in CBR value, to 8.90, was observed with tyre scraps of 15mm x 15mm at 10% of the dry weight of the soil.

Based on these findings, a 30m long and 5.5m wide flexible pavement section was constructed 20 m from the existing pavement. The model pavement was built using the optimal mix of tyre scrap (15 mm x 15 mm) at 10% by dry weight, blended with soil from different locations near the existing subgrade.

This approach adheres to the guidelines of IRC 37:2018, aiming to replicate the CBR values observed in laboratory tests with tyre mix soil under actual field conditions. This process serves to validate laboratory findings. The composition of the original and modified pavements is detailed in Table 1. Based on the information presented in Table 1, the thickness of the modified pavement has been reduced by 90mm compared to the original, untreated subgrade soil.

2.1. The Present Study

This study has been divided into laboratory and field components to examine and compare the performance between the existing and modified pavements. The current study selected a specific 30m stretch of the Jibantala-Taldi Road, precisely between the 3.00 km to 3.03km chainage.

This segment was chosen due to its CBR value of 3.00 km, which was 3.39 as per laboratory tests. This value is remarkably similar to the intended design value of 3.36, ensuring that the segment represents the subgrade strength of the entire road.

The modified model pavement length was 30m; hence, a 30m length was also considered for the old pavement for further study. This methodological approach ensured a precise evaluation of the impact of tyre scrap on pavement quality. Table 2 shows the different chainage points under study.

3. Experimental Studies

This study, which encompassed laboratory and field components, investigated existing and modified pavements. Sample collection and FWD and DCPT measurements were conducted at the specified chainage points for both types of pavements, as detailed in Table 2.

Table 1. Different layer pavement thickness for normal and tyre scrap mixed soil

Category	Layers	Thickness of Pavement Components for Existing Road Subgrade	Thickness of Pavement Components for Scrap Tyre-Modified Subgrade
Bituminous Layer	BC	40mm	30mm
	DBM	80mm	50mm
Granular Layer	WMM	250mm	250mm
	GSB	200mm	150mm
Total Thickness		570mm	480mm
Difference in Thickness		90mm	

Table 2. Test points and chainage

Sl. No.	Pavement Type	Selected Chainage (m) for/Lab Test and DCPT Test	Test Points			
			1st Point	2nd Point	3rd Point	4th Point
1	Existing Pavement	3.00×10^3m to 3.03×10^3m	At 3.00×10^3m	At 3.01×10^3m	At 3.02×10^3m	At 3.03×10^3m
2	Modified Pavement	0.00 m to 0.30m	At 0.00m	At 0.01m	At 0.02m	At 0.03m

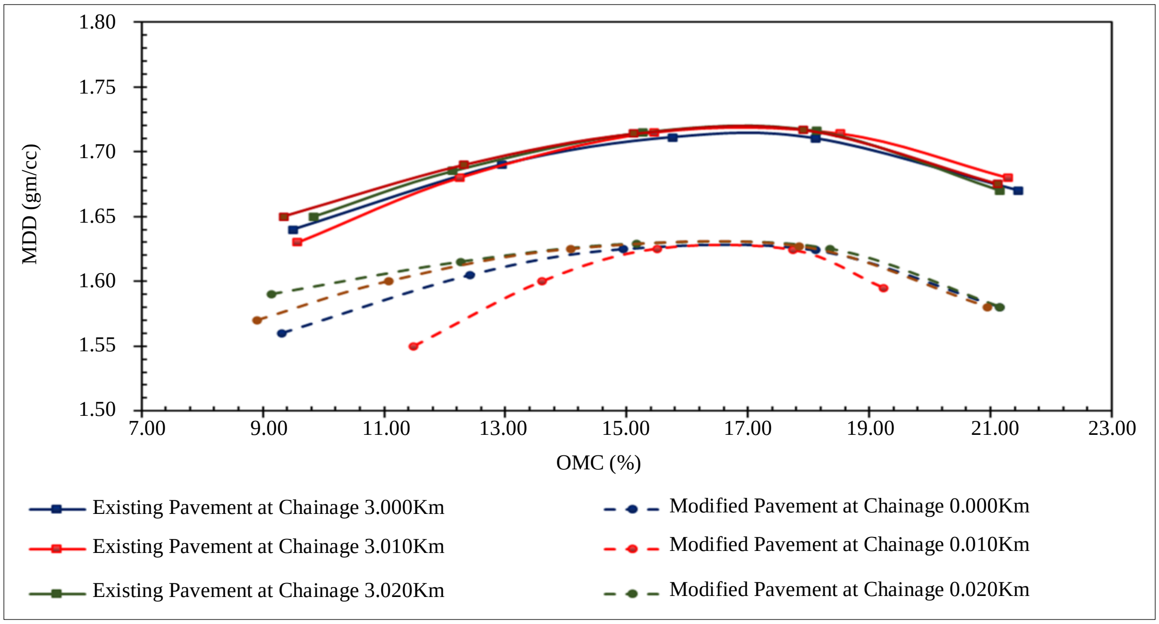

Fig. 1 Variation in modified proctor for different pavements

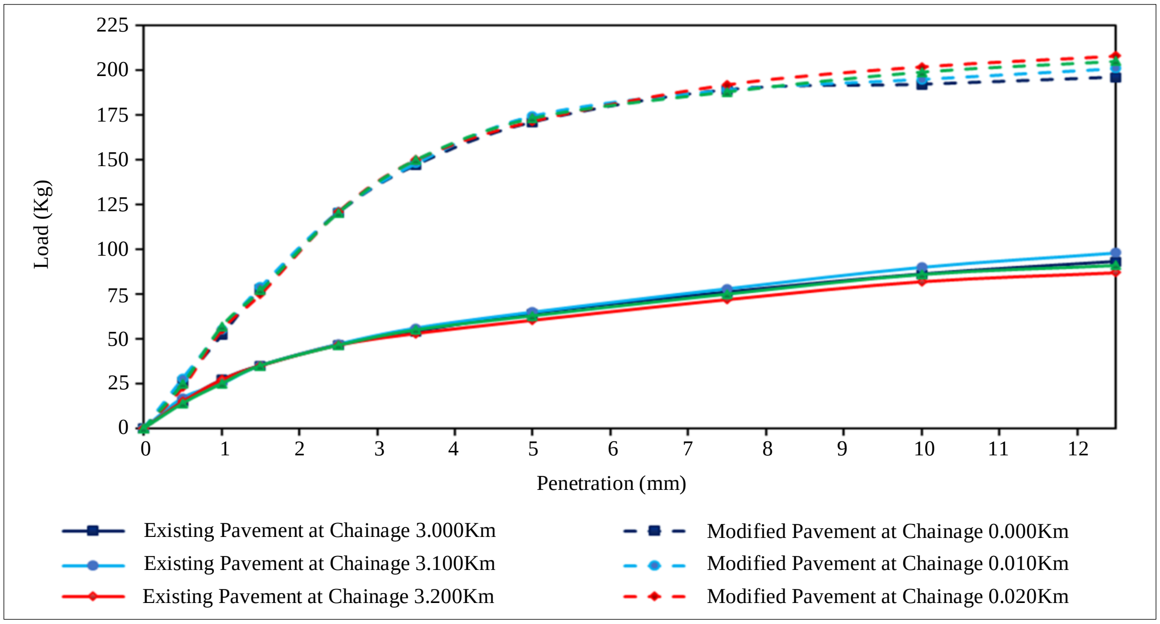

Fig. 2 Variation in CBR for different pavements

Table 3. Modified proctor and CBR test results for existing and modified subgrade soil

Sl. No.	Chainage (Km)	Side	Visual Classification of Soil	OMC (%)	MDD Density (gm/cc)	Lab CBR % (Soaked)
CBR Values for Existing Pavement						
1	3.00×10^3m	L/S	Brownish Grey Silty Clay	17.11	1.714	3.40
2	3.01×10^3m	L/S	Brownish Grey Silty Clay	17.09	1.719	3.43
3	3.02×10^3m	L/S	Brownish Grey Silty Clay	17.09	1.720	3.37
4	3.03×10^3m	R/S	Brownish Grey Silty Clay	17.06	1.720	3.39
CBR Values for Subgrade Modified Pavement						
5	0.00m	L/S	Brownish Grey Silty Clay	16.59	1.629	8.79
6	10.00m	R/S	Brownish Grey Silty Clay	16.61	1.628	8.84
7	20.00m	L/S	Brownish Grey Silty Clay	16.59	1.631	8.83
8	30.00m	R/S	Brownish Grey Clayey Silt	16.62	1.631	8.80

3.1. Laboratory Studies

3.1.1. Test Program

Various laboratory tests have been done to determine the critical characteristics of original and tyre-modified soil. In this context, it is notable that the existing road under study (Jibantala - Taldi) falls under the significant district road category as per PWD.

Therefore, a modified proctor compaction test has been adopted to determine the OMC and MDD, as specified in clause 6.1 of IRC:37-2018 [15]. In this study, the conducted tests include - a) the Modified Proctor Compaction test as per I.S.: 2720 (Part 8): 1983 [16] and b) the CBR test as per I.S.: 2720 (Part 16): 1987 [17].

3.1.2. Test Results

The soil samples have been collected and transported to the Soil Mechanics Lab. of Jadavpur University for further analysis. Modified proctor and CBR tests were performed on the collected samples. CBR test measures the load-bearing capacity and strength of road subgrade. Laboratory tests at the specified chainage have been illustrated in Table 3.

3.1.3. Discussion on Laboratory Test Results

Figure 1, and Figure 2 show the modified proctor and CBR curve for both the pavements. It has been observed from Table 3, and Figure 1 that the MDD of soil–tyre scrap mixtures reduced marginally. This reduction is attributed to the lower density of waste tyres compared to clayey soil.

Due to the high absorption capacity of waste tyre scrap mix soil, the OMC increases as the amount of tyre content increases, as studied by Md. Zain et al. [18], and Akbarimehr et al. [19]. From the data shown in Figure 2, and Table 3, the minimum soaked CBR for the modified subgrade is 8.79. This was achieved with 10% tyre scrap at 15mm x 15mm. Consequently, there is a significant improvement of approximately 161% or 2.61 times compared to the minimum soaked CBR value of 3.37 obtained for the original subgrade soil.

3.2. Field Studies

In the current study, various field tests were methodically conducted, encompassing various aspects of subgrade performance. DCPT performed on the pavements as it provides data on the subgrade strength in terms of in-situ CBR. The test involves driving a cone into the ground using a standard weight dropped from a known height and recording the penetration depth per blow.

The FWD Test was carried out to assess the structural performance of the pavement by measuring its response to a load similar to that of a standard truck axle. The basic methodology of FWD operation is dropping a known load onto the pavement, and sensors measure the deflection response of the pavement structure.

3.2.1. In-Situ CBR Determination by DCPT

The scope of the current research study of DCPT testing encompasses four (4) different chainage points, as specified in Table 2. To assess subgrade strength characteristics by DCPT, 1m x 1m test pits were excavated at 10.0m intervals, organized in a staggered pattern.

Within each of these test pits, the DCPT method was utilized to determine the in-situ CBR of the subgrade. Notably, the subgrade maintains a consistent thickness of 500mm. A typical DCPT arrangement described by Salgado and Yoon [20] has been shown in Figure 3.

Results from the DCPT include a series of blow counts corresponding to the penetration depth. Given that these blow counts are cumulative, the DCPT results are typically presented as incremental values. This is defined as,

$$PI = \Delta Dp / \Delta BC$$

Where, PI represents the DCP penetration index, measured in units of length per blow count, ΔDp = penetration depth, ΔBC = blow counts corresponding to penetration depth ΔDp.

The Penetration Index (PI) values represent DCPT characteristics at certain depths. Figure 4 shows a typical DCPT results. A correlation has been applied to convert DCPT result into CBR values for cohesive soils. In cases where the visual assessment confirms the coherent nature of subgrade soil, the Harrison [21] formula has been utilized for this conversion. However, to ensure a comprehensive comparison of CBR values, calculations were also performed using formulas proposed by Kleyn [22] and Livneh et al. [23], as specified in Table 4.

Discussion on DCPT Obtained In-Situ CB

Table 5 shows that, based on the DCP tests conducted along the road stretches, in-situ CBR values have been calculated. In-situ CBR, corresponding to laboratory CBR values, is presented in Table 6.

From Table 6, observations indicate that, for the existing pavement, laboratory CBR values range from 3.37 to 3.43, while for the tyre scrap modified subgrade pavement, they range from 8.79 to 8.84. In contrast, the DCPT values range from 3.82 to 4.50 for the existing pavement and 9.21 to 9.40 for the subgrade-modified pavement.

Figure 5 shows a comparison bar chart between in-situ CBR and Laboratory CBR. From Table 6, and Figure 5, it is evident that there is no significant difference between the laboratory values and in-situ CBR values for the existing pavement. This may be due to the presence of nearby water bodies.

Laboratory and DCPT CBR values generally exhibit a consistent trend along the road stretch. In most instances, the DCPT CBR values slightly surpass the laboratory CBR values studied by Bandyopadhyay and Bhattacharjee [24]. The original minimum in-situ CBR value mentioned is 3.82, resulting from DCPT on the original soil without any modifications. After modifying the subgrade with scrap tyres, the minimum in-situ CBR value improved to 9.21.

The improvement stated is about 141%, or 2.41 times the original CBR value, which suggests a significant increase in the strength and likely the load-bearing capacity of the modified subgrade pavement compared to the original soil condition.

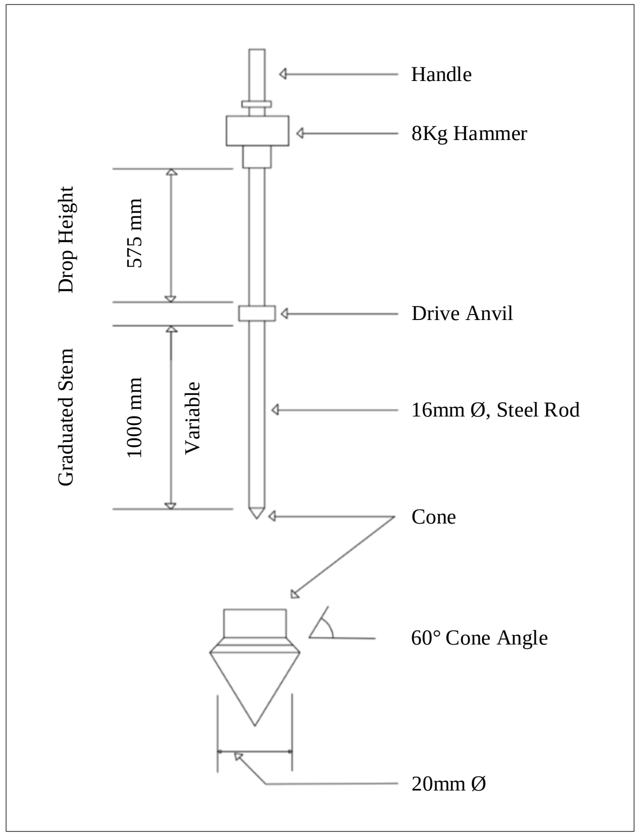

Fig. 3 Schematic diagram of the DCP instrument [20]

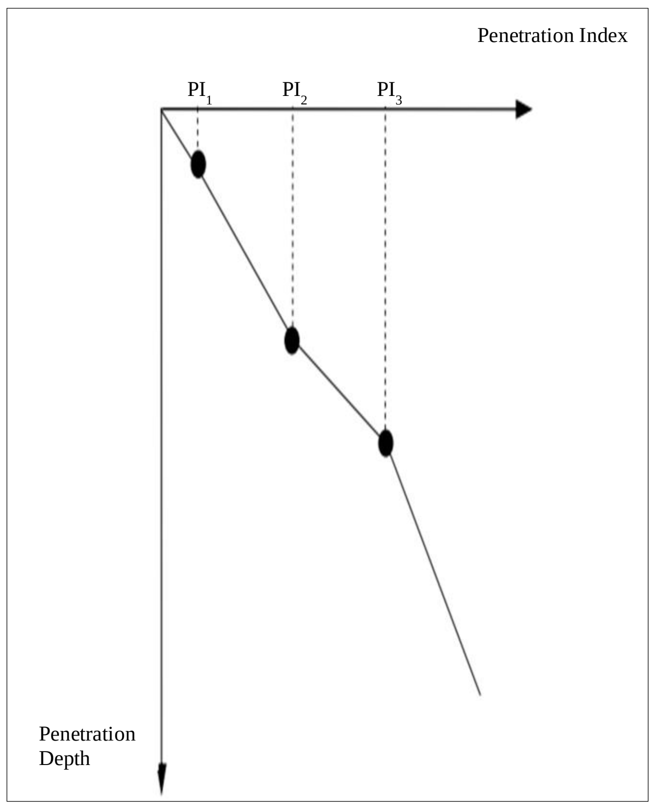

Fig. 4 Typical DCP test result

Table 4. Correlations between CBR and PI

Author	Correlation	Field or Laboratory Based Study	Material Tested
Kleyn (1975)	log(CBR)=2.62-1.27log(PI)	Laboratory	Unknown
Harison (1987)	log(CBR)=2.56-1.16log(PI)	Laboratory	Cohesive
Livneh et al. (1994)	log(CBR)=2.46-1.12log(PI)	Field and Laboratory	Granular and Cohesive

Table 5. Summary of DCPT test results

Sl. No.	Chainage (in m)	Side	Visual Classification of Soil	Average CBR by Harrison	Average CBR by Kleyn	Average CBR by Livneh	DCPT Inferred CBR
For Existing Pavement							
1	3.00×10^3	L/S	Brownish Grey Silty Clay	4.99	**3.82**	4.60	3.82
2	3.01×10^3	L/S	Brownish Grey Silty Clay	5.01	**3.83**	4.62	3.83
3	3.02×10^3	L/S	Brownish Grey Silty Clay	5.10	**3.91**	4.69	3.91
4	3.03×10^3	R/S	Brownish Grey Silty Clay	5.80	**4.50**	5.32	4.50
For Scrap Tyre-Modified Subgrade Pavement							
5	0.00	L/S	Brownish Grey Silty Clay	11.16	9.21	10.00	9.21
6	10.00	R/S	Brownish Grey Silty Clay	10.26	9.30	10.09	9.30
7	20.00	L/S	Brownish Grey Silty Clay	11.27	9.33	10.10	9.33
8	30.00	R/S	Brownish Grey Clayey Silt	11.37	9.40	10.18	9.40

Table 6. Comparison table between field and laboratory CBR

Sl. No.	Chainage (in m)	Lab CBR % (Soaked)	DCPT Inferred CBR
CBR Values for Existing Pavement			
1	3.00×10^3	3.40	3.82
2	3.01×10^3	3.43	3.83
3	3.02×10^3	3.37	3.91
4	3.03×10^3	3.39	4.50
CBR Values for Subgrade Modified Pavement			
5	0.00	8.79	9.21
6	0.01	8.84	9.30
7	0.02	8.83	9.33
8	0.03	8.80	9.40

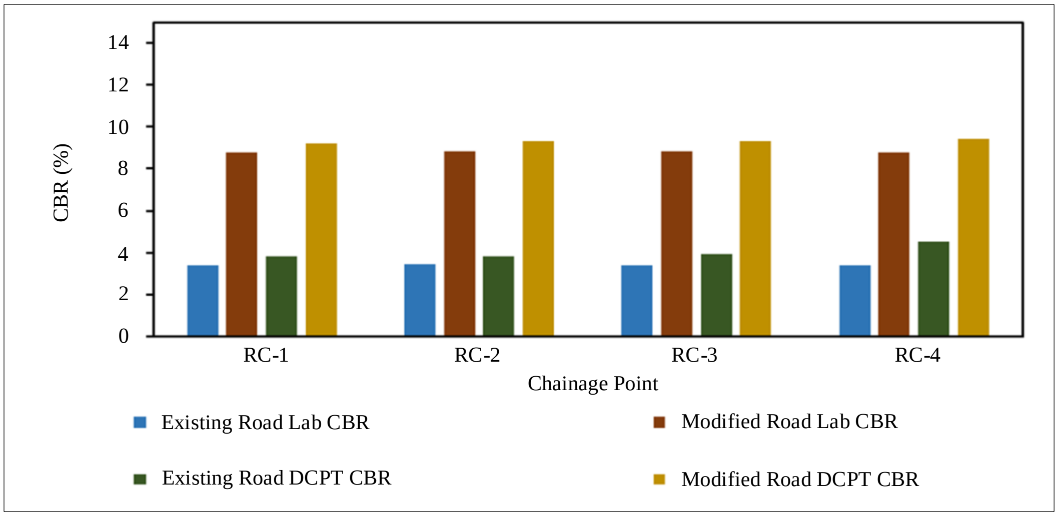

Fig. 5 Comparison bar chart between laboratory CBR and in-situ CBR

3.2.2. Subgrade Deflection Analysis by Falling Weight Deflectometer (FWD)

In this present study, FWD was utilized to evaluate the structural performance of the pavements. A typical cross-section of the scrap tyre-modified pavement has been illustrated in Figure 6.

Testing Procedure & Methodology

Both the pavement sections under this study have a width of 5.50 m. According to Walubita et al. [25] and Solanki et al. [26], FWD is a crucial Non-Destructive Testing (NDT) equipment for evaluating pavement strength, capable of calculating the elastic modulus of individual layers.

The current study's primary objective is to conduct a comparative analysis between the subgrade deflection of existing pavement and pavement modified with scrap tyre material mix subgrade. A fully-automatic trailer-mounted system has been employed to carry out the FWD study on the respective roads.

This specialized FWD system can apply a loading force within the range of 0-75 kN, allowing it to simulate various types of vehicle loads on the pavement surface effectively. In this study, FWD operates with one loading plate and seven geophone numbers placed at multiple offsets from the centre of loading.

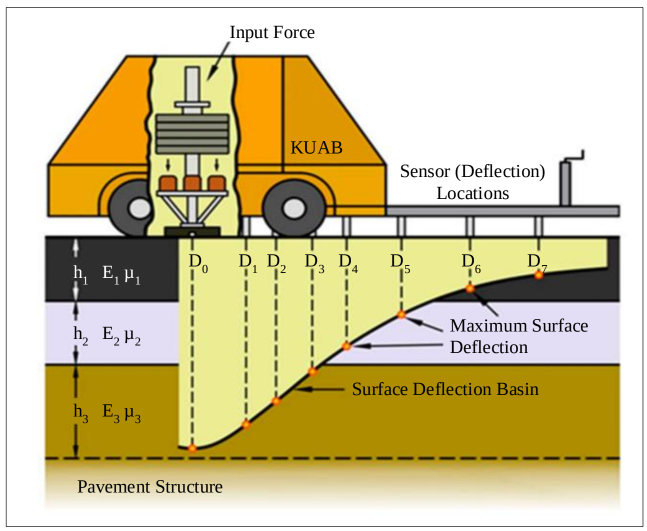

Fig. 6 Schematic representation of FWD operation [27]

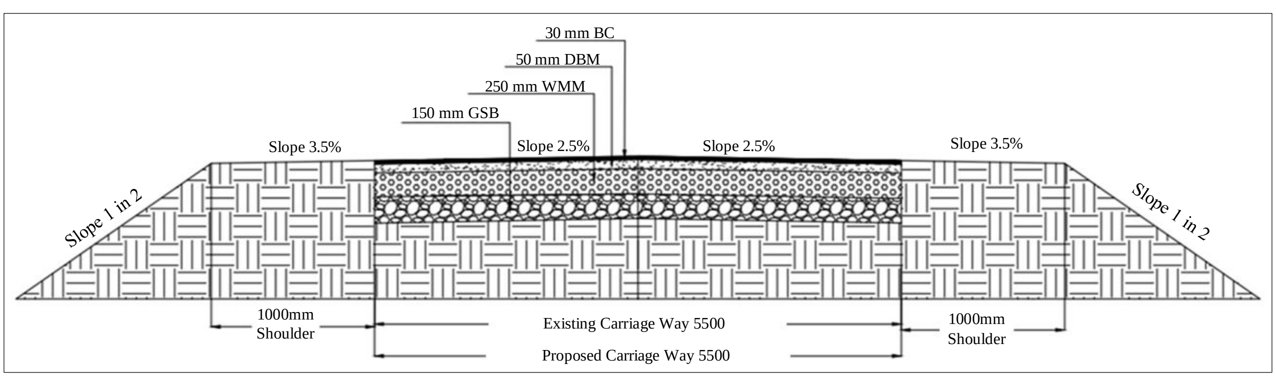

Fig. 7 Typical cross section of pavement for scrap tyre modified subgrade of CBR 8.90

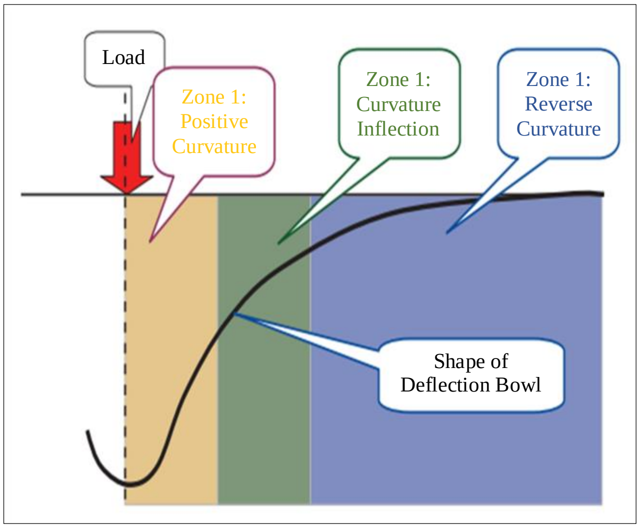

Fig. 8 Curvature zones of a deflection bowl [26]

Fig. 9 FWD deflection recording on existing Jibantala-Taldi road

In this research, a standard FWD geophone setup includes spacing at various distances: directly beneath the centre of the FWD loading plate (D1 or zero) and at 300mm (D2), 600mm (D3), 900mm (D4), 1200mm (D5), 1500mm (D6), 1800mm (D7). The measurements are taken from these points when weights, such as 40kN corresponding to a contact stress of 0.56 MPa, are dropped. A typical FWD Schematic representation presented by Toth and Primusz [27] has been illustrated in Figure 7. The FWD is used to exert a dynamic force on the existing pavement, and the response of the pavement to this force is recorded. Figure 8 demonstrates that the deflection basin formed under a loaded wheel can be technically segmented into three distinct areas, as outlined by Horak [28].

Testing Frequency

In the present work, FWD is applied to measure subgrade deflection of the pavements, in line with the procedures outlined in Section 3 of IRC 115: 2014 [4]. This analysis involves testing at various locations within the pavement structure to compare existing and modified pavements, as described in Table 2. For both pavements, the intermediate distance for testing is 10m.

Maree and Bellekens [29], and Maree and Jooste [30] examined deflection basins captured in FWD testing, applying a load of 40 kN or a contact pressure of 565.9 kPa. Their study concentrated on various common pavement structures in South Africa, such as granular, bituminous, and cemented base pavements. They conducted intensive FWD surveys at distances between 5 and 10 meters, covering the outer and inner wheel paths of these roads' slow, fast, and shoulder lanes.

FWD Test Results for Existing Pavement and Tyre Scrap-Modified Pavement

FWD tests were conducted for both pavements; Figure 8 illustrates the FWD test and the corresponding deflection records on existing pavement.The deflection data from four points, as specified in Table 2, were explicitly gathered for structural performance analysis of pavement, and these data points are presented in Tables 7, and Table 8 respectively.

Table 7. Summary of average deflection (for existing pavement)

Chainage (m)	Distance from Load Centre (mm)						
	0	300	600	900	1200	1500	1800
	Deflection (mm)						
	D1	D2	D3	D4	D5	D6	D7
3.00×10^3m	0.519	0.322	0.197	0.099	0.063	0.048	0.022
3.01×10^3m	0.509	0.324	0.217	0.109	0.065	0.047	0.037
3.02×10^3m	0.529	0.340	0.236	0.093	0.063	0.047	0.038
3.03×10^3m	0.518	0.342	0.146	0.096	0.062	0.047	0.036
Average Deflection	0.519	0.332	0.199	0.099	0.063	0.047	0.033

The study compares two pavements by dividing each into four equal segments and establishing specific Reference Change (RC) points for further analysis. Both pavements are 0.03km long but have different chainages. To simplify deflection data representation, the chainages are categorized as R.C. 1 (0.00Km for modified and 3.00Km for existing pavement), R.C. 2 (0.01Km for modified and 3.01Km for existing pavement), R.C. 3 (0.02Km for modified and 3.02Km for existing pavement), and R.C. 4 (0.03Km for modified and 3.03Km for existing pavement). Figure 10 illustrates the deflection data collected at these intervals. This study's primary focus is the analysis and comparison of subgrade deflection. To effectively characterize the subgrade condition and gauge its structural performance, deflections have been measured at two critical distances: 1200 mm (D1200) and 1500 mm (D1500). The difference between these two deflections is known as the Lower Layer Index (LLI), a deflection bowl parameter derived from the results of deflection tests. The significance of these measurement points has been highlighted in prior studies conducted by Horak [26], Talvik and Aavik [31], and Solanki et al. [30]. Table 9 summarises the average deflection for D1200 and D1500, along with the LLI for both types of pavements, offering insights into the subgrade's performance and condition.

Table 8. Summary of average deflection (for scrap tyre modified subgrade pavement)

Chainage (m)	Distance from Load Centre (mm)						
	0	300	600	900	1200	1500	1800
	Deflection (mm)						
	D1	D2	D3	D4	D5	D6	D7
0.00m	0.401	0.154	0.076	0.054	0.031	0.020	0.012
10.00m	0.398	0.161	0.073	0.042	0.028	0.018	0.010
20.00m	0.382	0.157	0.079	0.044	0.039	0.027	0.025
30.00m	0.391	0.148	0.068	0.040	0.026	0.019	0.008
Average Deflection	0.393	0.155	0.074	0.045	0.031	0.021	0.014

Table 9. LLI for subgrade layer in both the pavement

Pavement Type	Chainage (m)	Distance from Load Centre (mm)		Lower Layer Index (LLI) in mm
		1200	1500	(D5-D6)
		Deflection (mm)		
		D5	D6	
Existing Pavement	3.00×10^3	0.063	0.048	0.015
	3.01×10^3	0.065	0.047	0.018
	3.02×10^3	0.063	0.047	0.016
	3.03×10^3	0.062	0.047	0.015
Average LLI for Existing Pavement Subgrade (LLI_{eps}) in mm				0.016
Scrap Tyre Modified Subgrade Pavement	0.00	0.031	0.020	0.011
	10.00	0.028	0.018	0.010
	20.00	0.039	0.027	0.012
	30.00	0.026	0.019	0.007
Average LLI for Modified Pavement Subgrade (LLI_{mps}) in mm				0.01

Discussion on FWD Obtained Deflection

This study's Lower Layer Index (LLI) characterizes the subgrade condition. It proves valuable in predicting structural performance and assessing overall condition, as indicated in studies by Horak [26], Talvik and Aavik [31], and Solanki et al. [32]. To calculate the LLI, the average deflection values of D1200 and D1500 for both types of pavements have been considered according to Table 9. The resulting LLI values are described below- LLI for existing pavement subgrade=LLI_{eps}=0.016mm (From Table 9)

LLI for modified pavement subgrade=LLI_{mps}=0.010mm (From Table 9). Figure 11 shows the variation of deflection for subgrade for both pavements, which is 37.5%.

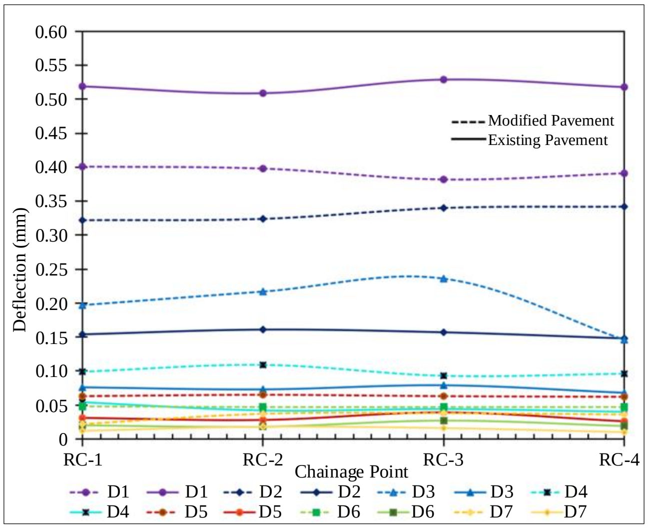

Fig. 10 Graphical presentation of deflection for both the pavements

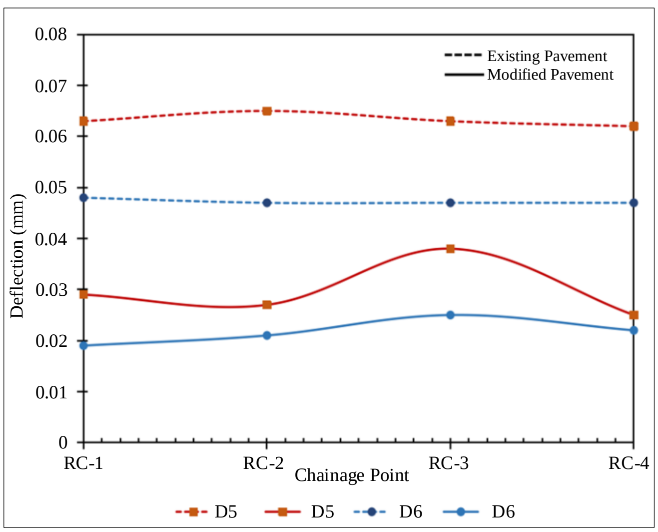

Fig. 11 Deflection variation in subgrade for both the pavements

LLI provides a quantitative measure of the subgrade's ability to distribute loads effectively characterizes the stiffness and load-bearing capacity of the subgrade. The LLI values indicate the structural integrity of the subgrade, as studied by Horak [28]. This implies that the LLI can identify possible structural issues in the subgrade. In Fuentes et al.'s [33] study, a lower LLI value suggests a stiffer subgrade that is better at distributing loads, thus implying a potentially longer lifespan and reduced maintenance needs for the pavement. Here, the LLI of the existing pavement subgrade indicates a relatively less stiff subgrade. This could translate to a higher likelihood of deformations under load, leading to potential issues like rutting or cracking in the overlying pavement layers. LLI of modified pavement subgrade suggests a considerable improvement in subgrade stiffness. This could result from modifications like incorporating materials (e.g., scrap tyres) that enhance the performance. A stiffer subgrade, as indicated by this lower LLI value, could lead to better load distribution, reduced strain on the pavement layers, and potentially a longer lifespan for the pavement.

4. Conclusion

Based on the DCPT-oriented in-situ CBR, laboratory CBR, and pavement subgrade deflection, these conclusions have been drawn-

1) The study assessed subgrades' deflection and in situ CBR in flexible pavements mixed with waste tyre scrap material. The research involved two types of pavements: one with an average soil subgrade and another with a tyre scrap-modified soil subgrade. The experiments were divided into laboratory and field studies, evaluating existing and scrap tyre-modified pavements.
2) Laboratory tests included modified proctor compaction and CBR tests, assessing road subgrade's load-bearing capacity and mechanical strength. Field studies used DCPT and FWD to evaluate subgrade strength in terms of in situ CBR and structural capacity of the pavement. The DCPT method was used to determine in situ CBR values at various points, with a typical arrangement shown in the study. The DCPT results were converted into CBR values for cohesive soils using the Harrison and other established formulas.
3) The FWD study focused on analyzing and comparing subgrade deflection with measurements at critical distances to calculate the Lower Layer Index (LLI), an indicator of subgrade condition and performance. The study demonstrated a significant improvement in pavement performance when the original soil subgrade was mixed with tyre scrap. This was evidenced by a 37.5% reduction in deflection for the tyre scrap-modified pavement compared to the normal soil subgrade. These results indicate the potential of using tyre scrap in road construction to enhance durability and reduce maintenance costs while contributing to waste material utilization. The methodologies and findings provide valuable insights into sustainable and efficient methods for road infrastructure improvement.

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TO WHOM IT MAY CONCERN

This certificate serves to confirm that the laboratory tests related to the study titled "Assessment of Deflection and In-Situ California Bearing Ratio (CBR) of Clayey Subgrade of Flexible Pavement Reinforced with Waste Tyre Scrap Material" have been conducted at the Soil Mechanics Laboratory of Jadavpur University, Kolkata, India. The authors of this work are:

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It is further certified that all relevant data required for the study were collected from the Department of Soil Mechanics and Foundation Engineering at Jadavpur University, Kolkata, India.

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