Deflection and Elastic Modulus Assessment of Subgrade in Flexible Pavement mixed with Waste Tire Scrap Material

Sujoy Sarkar
Department of Civil Engineering, Jadavpur University, India
sujoyrnd82@gmail.com (corresponding author)

Sumit Kumar Biswas
Department of Civil Engineering, Jadavpur University, India
thesissumit@gmail.com

Saibal Chakraborty
Department of Civil Engineering, Jnan Chandra Ghosh Polytechnic, India
sahilju06@yahoo.co.in

Received: 2 January 2024 | Revised: 19 January 2024 and 23 January 2024 | Accepted: 24 January 2024

 DOI: https://doi.org/10.48084/etasr.6858

ABSTRACT

This study aims to assess the deflection and elastic modulus (E_s) of subgrade in flexible pavements, focusing on a comparative analysis between pavements with clayey soil subgrade and subgrade modified with tire scrap. The research utilized Falling Weight Deflectometer (FWD) for measuring subgrade deflection, essential in evaluating pavement performance. The FWD applied a dynamic load to the pavement, with deflection measurements processed using the KGP-BACK software to calculate the E_s of the pavement subgrade. This approach included assessing the Lower Layer Index (LLI) and E_s of the subgrade. Findings revealed a notable reduction of 37.5% in deflection and 2.68 times increase in E_s for the tire scrap modified subgrade pavement compared to the standard clayey soil subgrade pavement. These results demonstrate significant enhancements in pavement structure, underlining the potential of recycled materials in sustainable civil engineering practices.

Keywords-deflection; elastic modulus; falling weight deflectometer; subgrade

I. INTRODUCTION

The rapid growth in global vehicle numbers has resulted in a parallel increase in waste tire and tube production. This trend is anticipated to approximately yield 2 billion scrap vehicles by 2030, posing significant environmental and waste management challenges [1]. Annually, one billion tires reach the end of their lifespan, with only about half undergoing recycling while the rest end up in landfills [2], where large volumes of scrap tires are accumulated, emphasizing the environmental risks if not managed properly [3]. Often, these tires are disposed of uncontrolledly, exacerbating the rapid depletion of waste disposal sites and leading to severe environmental issues. The use of scrap tires has been increasingly observed in various civil engineering applications. In this regard, authors in [4] investigated the cumulative effect of crumb rubber and steel fiber on the flexural toughness of concrete. The study explores the use of these materials as potential enhancements for concrete properties, particularly in terms of toughness and ductility, which are important for resisting impacts or blast loads. The research delves into the behavior of concrete beams and slabs when combined with steel fiber and crumb rubber, offering insights into the potential of these materials in creating more resilient and sustainable construction materials. However, emerging research in geotechnical engineering provides many possible benefits for repurposing waste tires. These recycled materials boast high tensile strength, durability, toughness, and resistance to aging, making them a viable solution for environmental concerns [5].

Authors in [6] conducted a study on the mechanical properties of waste tire rubber powder for use in civil engineering. They performed physical, chemical, and direct shear tests on different rubber powder sizes, establishing empirical relationships between cohesion, friction angle, and particle size. It was found that a cubic regression model explains these relationships better than linear or quadratic models, offering new perspectives on recycling waste tire materials in construction and engineering. Authors in [7] examine the impact of varying scrap tire rubber contents (10%, 20%, 25%, 50%) on Fergoug sediment and Tizi Tuff soil. Tests considered grain size, Atterberg limits, shear strength, compaction, and CBR. Cohesion, and CBR values were found to decrease with increasing rubber content, while compression and recompression indices increased. Notably, a 75% Tizi Tuff and 25% rubber mix showed contrasting CBR results at different water contents, highlighting the potential of scrap tire, as a reinforcement material in dredged soil, with careful consideration of its impact on compressibility.

Within pavement engineering, flexible pavements are particularly beneficial due to their ability to incrementally strengthen in response to growing traffic loads. Pavements are vital for efficient transportation of passengers, freight, and other community services. A flexible pavement, as a load-bearing structure, comprises layers of various granular materials over a soil subgrade. The durability of these pavements depends on several factors, including the strength of the subgrade soil, material quality, layer thickness, environmental conditions, and traffic characteristics. Ensuring the structural integrity and load-bearing capacity of the pavement subgrade is crucial for distributing loads effectively, mitigating strain on the pavement layers, and potentially extending the lifespan of the pavement. In alignment with IRC115:2014 [8], the Falling Weight Deflectometer (FWD) is a pivotal tool in determining the subgrade deflection and elastic modulus of pavements. This study focuses on comparing the deflection and elastic modulus of flexible pavements with normal clayey soil subgrade and scrap tire mix clayey soil subgrade. Data were collected from previous studies conducted at the Soil Mechanics and Foundation Engineering Division of Jadavpur University, Kolkata, West Bengal, India. This investigation aims to compare existing pavement with scrap tire modified subgrade pavement or modified pavement. The primary objective is to conduct a comparative analysis between the subgrade deflection and elastic modulus of the existing and modified pavement using the FWD system. Recent studies in geotechnical and transportation engineering have emphasized the significance of FWD in assessing soil and pavement conditions.

Further works on advanced pavement engineering with multi-directional FWD testing on concrete plates, highlighting asymmetry in structural behavior have been conducted. FWD tests at plate centers, measuring vertical deflections in eight directions were carried out. Significant asymmetries were found in a 22-year-old plate, while a new plate showed double-symmetric behavior. The study applied Kirchhoff–Love plate theory and optimized the uniform modulus of subgrade reaction, introducing an auxiliary surface load for more accurate results. Inertia forces were also considered, affecting the effective modulus of subgrade reaction by less than 3.5%. This research enhances pavement engineering by offering a detailed approach to assess structural integrity and asymmetry of concrete plates [9]. The FWD is a widely used non-destructive tool for pavement assessment, valued for its reliability, rapid operation, and user-friendliness. It employs back-calculation methods to compute layer moduli, highlighting the necessity of correction factors for reliable layer modulus determination. Furthermore, the statement references the development of low-cost, indigenous FWD models, particularly emphasizing their potential in pavement engineering, with a special focus on applications in countries like India [10]. This indicates a growing interest in adapting advanced technologies to suit local economic and infrastructural contexts. Authors in [11] focus on using FWD data to assess pavement structural health. Their study covers 97 pavement sections in the South-Central United States, using 3D-Move software for simulating FWD deflection bowls. The research introduces the normalized Comprehensive Area Ratio (CAR) for evaluating pavement structures. It reveals that 3D-Move simulations correlate highly with the actual FWD deflections. The most significant contribution of this study is that it includes a new classification scale for pavement conditions, accounting for different drop loads, which aids in effective pavement maintenance and rehabilitation decisions. In [12], attention is paid to the development of intelligent pavement performance models to enhance the efficiency of highway maintenance and repair. The research highlights the importance of these models in managing pavement maintenance and rehabilitation, considering various factors, such as traffic, environmental, and climatic conditions. The study involves the use of FWD tests to analyze and understand patterns of deterioration in flexible pavements. For assessing the structural conditions of pavement, Deflection Basin Parameters (DBPs) from FWD data are utilized as an efficient alternative. Use of DBPs through finite-element modeling and field analyses, offers a comprehensive view of pavement conditions for rehabilitation decisions [13]. In the technical assessment of flexible pavements, especially those constructed on tropical soils, the bonding state of the subgrade is a critical aspect that can be effectively examined using FWD data. In this context, the deflection measurements obtained from FWD are pivotal, serving as key indicators of the subgrade condition. This emphasis on deflection data is crucial for the early detection of subgrade issues, which is fundamental in maintaining the overall integrity and longevity of the pavement structure [14]. Authors in [15] investigated the use of Reclaimed Asphalt Pavement (RAP) for stabilizing unbound layers in road structures, focusing on four sections of State Main Road A7 from Riga to the Lithuanian border. Utilizing a blend of laboratory and field assessments, including FWD data, the research back-calculated the equivalent modulus of elasticity (E_{eq}) of stabilized RAP. Findings revealed E_{eq} values of 370 MPa at the surface, decreasing to 100 MPa at 60 cm depth, with 67 FWD measurements confirming the effectiveness of cement-stabilized RAP. However, significant variability was noted, with some values reaching up to 4000 MPa, indicating anisotropy. The study concluded that cement-stabilized RAP is technically, economically, and environmentally viable for road construction, but emphasized the need for improved design and construction specifications due to the variability of the results, highlighting the importance of more detailed investigations into pavement structures with stabilized road bases. In [16], an extensive evaluation was conducted on a 20 km segment of the Barnala-Mansa State Highway. The primary tool for this assessment was the FWD, which was employed to gauge the pavement conditions both prior to and following the application of an overlay. The focal point was the calculation of critical parameters, notably the Surface Curvature Index (SCI) and Middle Layer Index (MLI). These indices provide valuable insights into the condition of various pavement layers. Collectively, such studies are instrumental in enhancing the field of pavement engineering. They introduce innovative methodologies that are crucial for the assessment, design, and maintenance of pavement performance. Authors in [17] demonstrated through large-scale models and field tests that geocells reduce surface deflections and vertical pressure on the subgrade. These tests also examined the effect of aspect ratio, indicating improved performance with increased height to diameter ratio.

In the current study, a comprehensive methodology to examine the application of scrap tires in deflection and elastic modulus of pavement subgrades was used. The primary methods and procedures include data collection and experimental studies. Laboratory soaked CBR and thickness data of the pavements were collected from the Soil Mechanics Research Division of the Civil Engineering Department, Jadavpur University, Kolkata. FWD studies on the existing pavement and scrap tire-modified subgrade pavement were conducted to assess the deflection of the subgrade.

II. DATA COLLECTION AND SITE SELECTION

A. Background

The necessary data for analyzing FWD results were collected from prior research conducted by the Soil Mechanics and Foundation Engineering Division of the Jadavpur University. This research involved a detailed examination of a specific roadway segment under Public Works Department (PWD) in West Bengal. The roadway, stretching from Jibantala Bazar to Taldi Bazar near Canning (District-South 24 Parganas, West Bengal, India), initiates at 0.00 km near Jibantala crossing the market (coordinates: Latitude 22°20'37.7" N, Longitude 88°36'29.6" E) and concluding at Taldi Bazar near the railway station (Latitude 22°25'11.8" N, Longitude 88°39'44.4" E), covering a total distance of 12.45 km. This road belongs to the PWD of the Government of West Bengal. During the research, soil samples, termed as road chainage, were collected at various points along the length of the road. These samples, which are brownish grey silty clay, were taken to the laboratory for testing to determine their soaked California Bearing Ratio (CBR) and other metrics (Table I). The design CBR was obtained from Table I by following Clause 6.2.2 of IRC:37-2018 [18]. The results yielded a design CBR value of 3.36 for this particular road section. Additionally, soil samples were specifically selected from road subgrade locations where the soaked CBR closely aligned with the design CBR value. The innovative aspect of the study involved experimenting with various sizes of scrap tire pieces, ranging from 10 mm × 10 mm to 30 mm × 30 mm, mixed with the collected soil in proportions varying from 5% to 30%. The optimum improvement in CBR value was noted with 15mm × 15mm tire scraps at 10% weight of the soil, achieving a CBR of 8.90. Based on these laboratory findings, a 30 m long and 5.5 m wide flexible pavement section was constructed by following the design methodology of IRC 37:2018. This construction was situated 20 m away from the existing pavement and utilized the optimally determined tire scrap mix combined with original soil collected from the selected areas. The purpose of this construction was to replicate the laboratory-obtained CBR values of the tire mix soil under field conditions, thereby validating the laboratory results.

TABLE I. LABORATORY TEST RESULTS ON ROAD SOIL WITH RESPECT TO CHAINAGE

Chainage (m)	Description of soil	Modified proctor		Soaked CBR (%)
		MDD (gm/cc)	OMC (%)	
100	Grey clayey silt	1.760	15.18	3.80
1000	Grey silty clay/ clayey silt	1.751	15.25	3.75
2000	Brownish grey silty clay	1.741	16.80	3.62
3000	Grey silty clay	1.724	17.06	3.39
4000	Grey silty clay	1.720	17.42	3.15
5000	Grey silty clay	1.710	18.14	3.05
6000	Brownish grey silty clay	1.730	16.50	3.30
7000	Grey silty clay/ clayey silt	1.728	17.12	3.45
8000	Brownish grey silty clay	1.750	15.60	3.75
9000	Grey silty clay	1.740	15.86	3.57
10000	Brownish grey silty clay	1.740	16.20	3.55
11000	Grey silty clay	1.730	17.16	3.41
12000	Grey silty clay	1.730	16.90	3.28
12450	Greyish brown silty clay	1.730	17.05	3.40

B. Site Selection

The focus was on the 3.00 km to 3.03 km stretch of Jibantala-Taldi Road, chosen for its smooth surface and uniform cross-section, which is ideal for FWD tests. Data from Jadavpur University supported this site selection. Both the modified and existing pavements, each 30.00 m in length, were divided into four equal segments of 10 m for testing, allowing for direct performance comparison. This methodological approach ensured a precise evaluation of the impact of tire scrap on pavement quality. Table II shows the different chainage points under study.

TABLE II. TEST POINTS AND CHAINAGE

Pavement type	Selected chainage for FWD test (m)	FWD test points			
		1st point	2nd point	3rd point	4th point
Existing pavement	3.00×10^3 to 3.03×10^3	3.00×10^3 m	3.01×10^3 m	3.02×10^3 m	3.03×10^3 m
Modified pavement	0.00 to 30.00	0.00 m	10.00 m	20.00 m	30.00 m

C. CBR Test results

For further processing in FWD and to account for the worst-case scenario, the minimum CBR values obtained from laboratory tests were considered. It is worth noting that laboratory CBR values were used in FWD analysis for the Barnala - Mansa Section of SH13 in the district of Barnala, Punjab, India, which spans a length of 20 km [16].

D. Pavement Details

Table III shows different layer pavement thickness values, for existing and modified subgrade acquired from Soil Mechanics Research Division of Jadavpur University. IITPAVE software was used for obtaining pavement thickness. Both pavements have a subgrade depth of 0.5 m.

TABLE III. DIFFERENT LAYER PAVEMENT THICKNESS FOR NORMAL AND TYRE SCRAP MIXED SOIL

Category	Layers	Pavement thickness	
		Existing road subgrade	**Scrap tire modified subgrade**
Bituminous Layer	Bituminous Concrete (BC)	40 mm	30 mm
	Dense Bituminous Macadam (DBM)	80 mm	50 mm
Granular layer	Wet Mix Macadam (WMM)	250 mm	250 mm
	Granular Sub Base (GSB)	200 mm	150 mm
Total thickness		570 mm	480 mm
Difference in thickness		90 mm	

III. EXPERIMENTAL STUDY

A. Testing Procedure and Methodology

The FWD is key Non-Destructive Testing (NDT) equipment for evaluating pavement strength, capable of calculating the elastic modulus of individual layers [19-20]. In the current study, the primary objective is to conduct a comparative analysis between the subgrade deflection and elastic modulus of existing and modified pavement. For the purpose of conducting the FWD survey, a loading force within the range of 0-100 kN is utilized. This range allows the FWD to efficiently simulate various types of vehicles loads on the pavement surface. In FWD study, the setup includes deflection sensors or geophones which are strategically placed at specific distances from the canter of the loading plate. According to IRC 115:2014, the distances are - 0 mm (D0), 300 mm (D1), 600 mm (D2), 900 mm (D3), 1200 mm (D4), 1500 mm (D5), and 1800 mm (D6). These sensors have been used to measure the surface deflection resulting from dropped weights, such as 40kN (0.56 MPa contact stress) over a contact area of 150 mm radius. The loading time of the FWD typically ranges between 25 to 30 ms. A typical FWD schematic representation is illustrated in Figure 1.

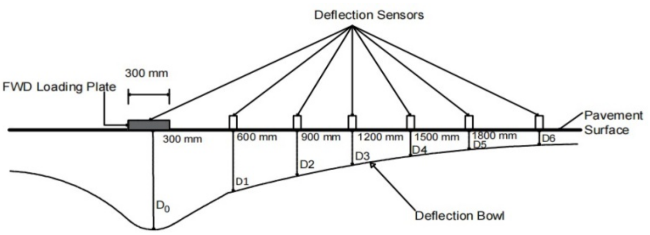

Fig. 1. Typical representation of FWD operation.

B. Testing Frequency

In the present work, FWD is applied to measure the subgrade deflection of the pavements, in line with the procedures outlined in Section 3 of IRC 115: 2014 [8]. This analysis involves testing at various locations as described in Table I. For both pavements, the intermediate distance for testing is 10 m. The referenced studies [21-22] conducted a technical analysis focusing on the deflection bowls captured during FWD testing across various typical South African pavement structures. These structures included granular, bituminous, and cemented base pavements. The FWD testing was characterized by applying a load of 40 kN or exerting a contact pressure of 565.9 kPa. To ensure comprehensive coverage and detailed mapping of pavement conditions, high-density FWD surveys were strategically performed at intervals ranging from 5 to 10 m. This approach was meticulously designed to encompass both the outer and inner wheel tracks, covering the slow, fast, and shoulder lanes of these roads. Such a methodical and detailed approach in the FWD survey provided an in-depth understanding of the pavement behavior under load, which is essential for evaluating the structural integrity and serviceability of these roads.

C. FWD Test Results for Existing and Modified Subgrades

The deflection data from four points as specified in Table I, were gathered specifically for pavement performance analysis. These data points are presented in Tables IV and V.

TABLE IV. SUMMARY OF AVERAGE DEFLECTION (EXISTING SUBGRADE)

Chainage (m)	Distance from load center (mm)						
	0	300	600	900	1200	1500	1800
	Deflection (mm)						
	D0	D1	D2	D3	D4	D5	D6
3.00×10^3	0.519	0.322	0.197	0.099	0.063	0.048	0.022
3.01×10^3	0.509	0.324	0.217	0.109	0.065	0.047	0.037
3.02×10^3	0.529	0.340	0.236	0.093	0.063	0.047	0.038
3.03×10^3	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

TABLE V. SUMMARY OF AVERAGE DEFLECTION (FOR MODIFIED SUBGRADE)

Chainage (m)	Distance from load center (mm)						
	0	300	600	900	1200	1500	1800
	Deflection (mm)						
	D0	D1	D2	D3	D4	D5	D6
0.00	0.412	0.172	0.078	0.051	0.029	0.019	0.013
10.00	0.422	0.165	0.080	0.049	0.027	0.021	0.018
20.00	0.387	0.150	0.075	0.044	0.038	0.025	0.015
30.00	0.393	0.158	0.074	0.051	0.025	0.022	0.012
Average deflection	0.404	0.161	0.077	0.049	0.030	0.022	0.015

The study compares the two pavements by dividing each into four equal segments and by establishing specific Reference Change (RC) points for further analysis. Both pavements are 30 m long, but with different chainages. To simplify deflection data representation, the chainages are categorized as RC1 (0.00 m for modified and 3×10^3 m for existing pavement), RC 2 (10 m for modified and 3.01×10^3 m for existing pavement), RC 3 (20 m for modified and 3.02×10^3 m for existing pavement), and RC 4 (30 m for modified and 3.03×10^3 m for existing pavement). Figure 2 portrays the deflection data collected at these intervals. In this study, the primary focus is dedicated to the analysis and comparison of subgrade deflection and elastic modulus. To competently characterize the subgrade condition and gauge its performance, deflections have been measured at two key distances: 1200 mm (referred to as D1200) and 1500 mm (referred to as D1500). The difference between these two deflections is referred to as the Lower Layer Index (LLI), which is a deflection bowl parameter derived from the results of deflection tests [23, 24].

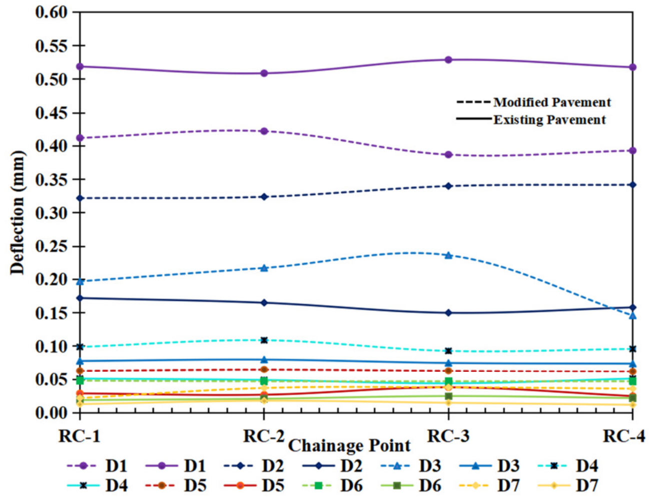

Fig. 2. Graphical presentation of the deflection of both pavements.

Table VI provides a summary of the average deflection for D1200 and D1500 along with the LLI for both types of pavements, offering insights into the performance and condition of subgrade.

TABLE VI. LLI OF THE SUBGRADE LAYER

Pavement type	Chainage (m)	Distance from load center (mm)		LLI (mm)
		1200	1500	(D4-D5)
		Deflection(mm)		
		D4	D5	
Existing subgrade	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	0.029	0.019	0.010
	10.00	0.027	0.021	0.006
	20.00	0.038	0.025	0.013
	30.00	0.025	0.022	0.003
Average LLI for modified pavement subgrade (LLI_{mps}) in mm				0.008

D. Back Calculation of Layer Modulus for Both Pavements

The FWD was employed to apply a dynamic load to the existing pavement, and the response to this load was measured. The obtained deflection values are then utilized in the KGP-BACK software to calculate the elastic modulus of the modelled pavement layers, following the guidelines of IRC: 115-2014 [8]. The layer modulus was back-calculated with KGP-BACK program. The pavements were modelled as three-layer systems with bituminous layer, granular layer, and subgrade. The KGP-BACK program, a specific version of the BACKGA program developed by the transportation engineering section at IIT Kharagpur, India is a vital tool for the back-analysis procedure used to calculate the elastic modulus of pavement surfaces. This calculation relies on deflection measurements obtained from the FWD. The purpose of this procedure is to assess the structural condition of in-service pavements by determining the in situ elastic modulus of different pavement layers. Utilizing normalized data and the additional input parameters specified in Table VII, the KGP-BACK software was employed to derive the pavement layer modulus. The sample input and output of the KGP-BACK for the existing pavement are illustrated in Figures 3 and 4. Using the inputs given in Table VII, the back calculated modulus of each layer is calculated and presented in Table VIII.

TABLE VII. INPUT PARAMETERS FOR KGP-BACK ANALYSIS

Parameters	**Values**	
	Existing pavement	**Scrap tire modified subgrade pavement**
Single wheel load (N)	40000	
Contact pressure (MPa)	0.56 [8]	
Number of deflections	7	7
Radial distance between each geophone (mm)	0, 300, 600, 900, 1200, 1500, 1800	
Design CBR (%)	3.36	8.90
Measured deflections (mm)	As per Table II	As per Table III
Pavement layer thickness (mm)	570	480
Poisson's ratio values	0.5, 0.4, 0.4 (bituminous layer, granular layers, subgrade as per [8])	

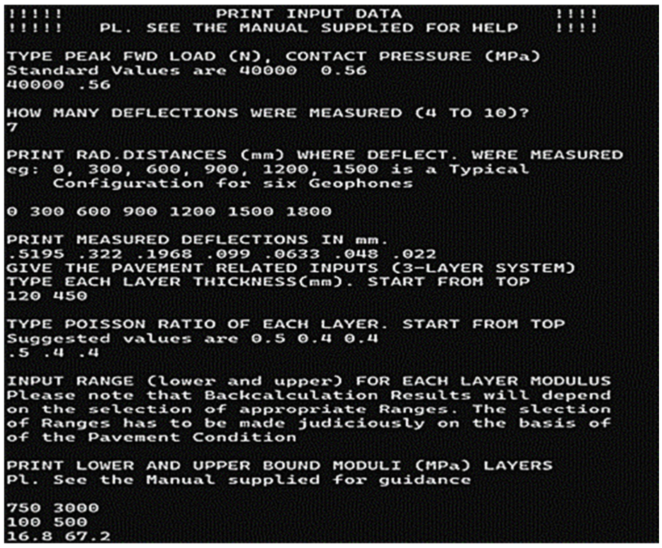

Fig. 3. Input window of KGP-BACK for the existing pavement.

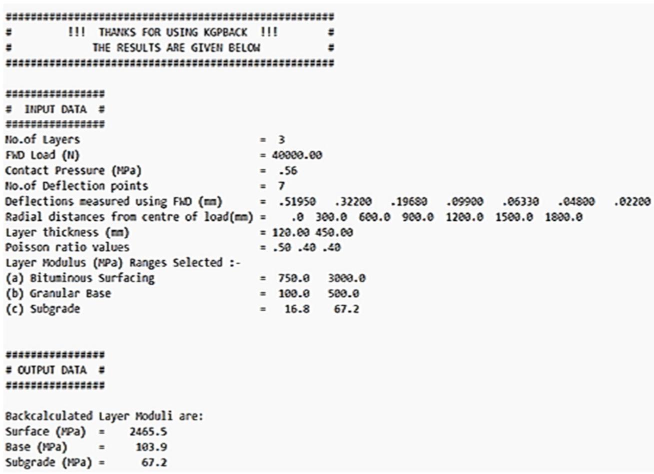

Fig. 4. Output window of KGP-BACK for the existing pavement.

TABLE VIII. BACK CALCULATED LAYER MODULUS VALUES

Pavement type	Back calculated Moduli (MPa)			
	Chainage (m)	**Bituminous**	**Granular**	**Subgrade**
Existing pavement	3.00×10^3	2296.20	102.30	67.20
	3.01×10^3	2975.80	107.80	67.20
	3.02×10^3	2300.60	111.30	67.20
	3.03×10^3	2925.20	189.90	67.20
Modified pavement	0.00	2997.80	176.60	178.00
	10.00	2918.60	189.90	178.00
	20.00	2958.20	232.20	178.00
	30.00	2815.20	186.80	178.00

E. Determination of Corrected Back Calculated Moduli

The back-calculated modulus of the granular, and subgrade layers obtained from software analysis were adjusted using a correction factor for seasonal variation, implemented for the granular and subgrade layers, in accordance with clause 6.5.1 of IRC:115-2014 [8]. Table IX displays the calculation of correction factors and the resulting corrected back-calculated modulus for the granular and subgrade layers, specifically accounting for seasonal variations. Figure 5 shows the corrected back calculated modulus chart for both pavements.

Figure 5 clearly illustrates that in the case of the scrap tire-modified subgrade pavement, there was an increase in the back calculated modulus for each component of the pavement. These back calculated modulus values play a crucial role in the analysis of the in-service pavement and the assessment of its structural condition, as outlined in Clause 6.3.1 of [8].

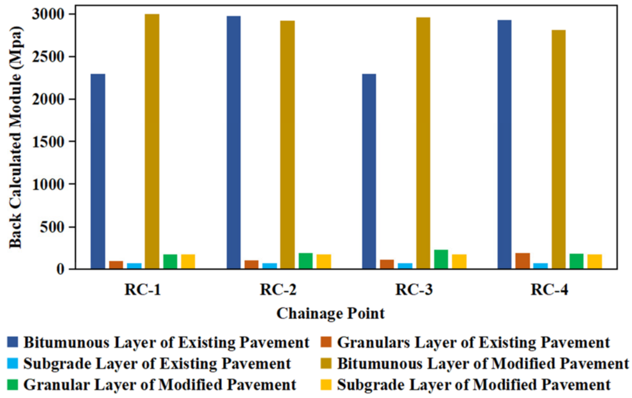

Fig. 5. Corrected back calculated moduli chart for both pavements.

TABLE IX. CORRECTED BACK CALCULATED MODULI FOR GRANULAR (E_{gran_win}) AND SUBGRADE (E_{sub_win}) LAYER OF PAVEMENT

Pavemen type	Chainage (m)	Back calculated E_{sub_win} (MPa)	Back calculated E_{gran_win} (MPa)	Corrected back calculated modulus for subgrade $E_{sub\_mon}=3.351\times(E_{sub\_win})0.7688-28.9$ (MPa)	Corrected back calculated modulus for granular layer $E_{gran\_mon}=3.351\times(E_{gran\_win})0.624-113.857$ (MPa)
Existing pavement	3.00×10^3	67.2	102.30	56.22	75.60
	3.01×10^3	67.2	107.80	56.22	81.89
	3.02×10^3	67.2	111.30	56.22	85.83
	3.03×10^3	67.2	189.90	56.22	164.85
	Average back calculated modulus			56.22	102.04
Modified pavement	0.00	178	176.60	151.11	152.50
	10.00	178	189.90	151.11	164.85
	20.00	178	232.20	151.11	202.11
	30.00	178	186.80	151.11	162.00
	Average back calculated modulus			151.11	170.365

IV. DISCUSSION ON FWD OBTAINED DEFLECTION AND ELASTIC MODULUS

A. Discussion on Subgrade Deflection

In this study, LLI serves for the characterization of the subgrade condition and was proved valuable in predicting the performance and assessing the overall condition [24-26]. To calculate the LLI, the average deflection values of D1200 and D1500 for both pavements were considered according to Table VI. The resulting LLI values are:

- LLI for existing pavement subgrade: LLI_{eps} = 0.016 mm (from Table IX).
- LLI for modified pavement subgrade: LLI_{mps} = 0.008 mm (from Table VIII).

This means that the decrease of LLI for modified pavement with respect to that of the existing pavement becomes:

[(0.016-0.008) ×100/0.016)] %=50 %.

Thus, the obtained data suggest that the improvement, in the form of decrease of LLI, is 50%. Figure 6 depicts the deflection variation of both pavements.

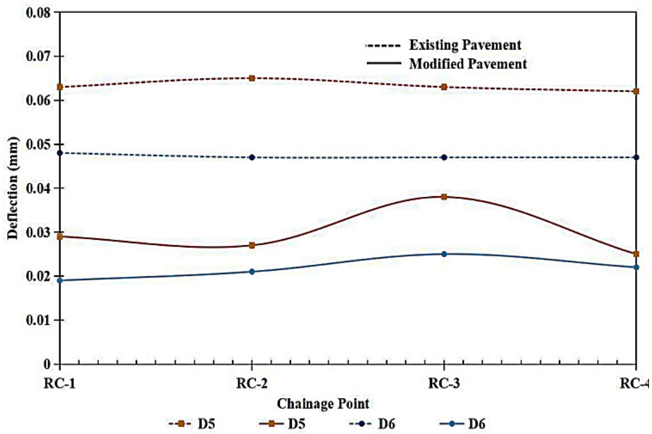

Fig. 6. Deflection variation in subgrade for both pavements.

LLI provides a quantitative measure of the subgrade's ability to distribute loads, while effectively characterizing the stiffness and load-bearing capacity of the subgrade. The LLI values are indicative of the structural integrity of the subgrade [23]. This implies that the LLI is exceptionally capable of identifying possible structural issues in the subgrade. A lower LLI value suggests a stiffer subgrade that is better at distributing loads, thus implying a potentially longer lifespan and reduced maintenance needs [26]. 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 possible issues like rutting or cracking in the overlying pavement layers. The LLI of the modified pavement subgrade suggests a considerable improvement in subgrade stiffness. This could be a result of modifications like the incorporation of materials (scrap tires) that enhance the load-bearing capacity. A stiffer subgrade as indicated by this lower LLI value could lead to better load distribution, reduced strain on the pavement layers, and probably a longer lifespan.

B. Discussion on the Elastic Modulus (Es) of the Subgrade

This study provides crucial insights into the comparative performance of the existing pavement and the scrap tire modified subgrade pavement. Utilizing FWD for deflection measurements and the KGP-BACK software for back-calculating moduli values, the analysis aligns with the standards set forth [8]. For the existing pavement, the elastic modulus (E_{eps}) is measured at 56.22 MPa. This value falls within the typical range (20 to 100 MPa) for conventional pavement structures, indicating a standard level of stiffness. Such a modulus level suggests that the pavement is likely to perform adequately under normal traffic conditions [16]. However, this also implies potential limitations in its load-bearing capacity, possibly making it more susceptible to wear and degradation over time. In contrast, the modified pavement, characterized by an elastic modulus of 151.09 MPa, exhibits a markedly 2.68 times higher stiffness level with respect to the existing pavement, due to the integration of scrap tire rubber. This substantial increase in the modulus points to an enhanced load-bearing capacity and overall structural integrity. Consequently, pavements with such modifications are expected to offer improved durability, resist deformation more effectively, and potentially enjoy a longer service life [24]. The observation that the scrap tire modified pavement has a significantly higher modulus than the existing pavement underscores the effectiveness of using recycled materials in enhancing pavement performance.

V. CONCLUSIONS

The use of scrap tire material in pavement subgrades presents a promising method for enhancing pavement performance. Not only does this approach address environmental concerns related to tire waste, but also contributes to the development of more durable and sustainable road infrastructures. The following conclusions can be drawn from the research findings:

- The lower LLI value of the modified pavement subgrade suggests a considerable improvement in subgrade stiffness, possibly due to the incorporation of materials like scrap tire rubber that enhance load-bearing capacity. This improvement in subgrade stiffness could result in better load distribution, reduced strain on pavement layers, and a possibly longer lifespan.
- The scrap tire modified pavement has 2.68 times higher modulus than the existing pavement, underscoring the effectiveness of utilizing recycled materials for enhancing pavement performance. This suggests that incorporating scrap tire rubber in pavement construction can lead to structural improvements, offering a sustainable and beneficial approach to ameliorate the durability and performance of road surfaces.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Soil Mechanics and Foundation Engineering Division of Jadavpur University, Kolkata, India, for providing essential laboratory equipment, technical support, and valuable data from their prior research. Additionally, the authors are thankful for the opportunity to conduct the FWD test on existing pavements, facilitated by the Public Works Department (PWD) of the Government of West Bengal, India. Their contributions have been instrumental to the success of this project.

REFERENCES

[1] M. Sommer, J. Dargay, and D. Gately, “Vehicle Ownership and Income Growth, Worldwide: 1960-2030,” *The Energy Journal*, vol. 28, pp. 143–170, Oct. 2007, https://doi.org/10.2307/41323125.

[2] S. A. Tahami, A. F. Mirhosseini, S. Dessouky, H. Mork, and A. Kavussi, “The use of high content of fine crumb rubber in asphalt mixes using dry process,” *Construction and Building Materials*, vol. 222, pp. 643–653, Oct. 2019, https://doi.org/10.1016/j.conbuildmat.2019.06.180.

[3] F. D. B. de Sousa, “Devulcanization of Elastomers and Applications,” in *Elastomers*, N. Cankaya, Ed. IntechOpen, 2017, https://doi.org/10.5772/intechopen.68585.

[4] B. H. A. Bakar, A. T. Noaman, and H. M. Akil, “Cumulative Effect of Crumb Rubber and Steel Fiber on the Flexural Toughness of Concrete,” *Engineering, Technology & Applied Science Research*, vol. 7, no. 1, pp. 1345–1352, Feb. 2017, https://doi.org/10.48084/etasr.854.

[5] M. S. Mashiri, J. S. Vinod, M. N. Sheikh, and H.-H. Tsang, “Shear strength and dilatancy behaviour of sand–tyre chip mixtures,” *Soils and Foundations*, vol. 55, no. 3, pp. 517–528, Jun. 2015, https://doi.org/10.1016/j.sandf.2015.04.004.

[6] M. Bekhiti, H. Trouzine, and A. Asroun, “Properties of Waste Tire Rubber Powder,” *Engineering, Technology & Applied Science Research*, vol. 4, no. 4, pp. 669–672, Aug. 2014, https://doi.org/10.48084/etasr.439.

[7] H. Sellaf, H. Trouzine, M. Hamhami, and A. Asroun, “Geotechnical Properties of Rubber Tires and Sediments Mixtures,” *Engineering, Technology & Applied Science Research*, vol. 4, no. 2, pp. 618–624, Apr. 2014, https://doi.org/10.48084/etasr.424.

[8] *IRC 115: Guidelines for Structural Evaluation and Strengthening of Flexible Road Pavements Using Falling Weight Deflectometer (FWD) Technique*. New Delhi, India: Indian Roads Congress, 2014.

[9] R. Díaz Flores, M. Aminbaghai, L. Eberhardsteiner, R. Blab, M. Buchta, and B. L. A. Pichler, “Multi-directional Falling Weight Deflectometer (FWD) testing and quantification of the effective modulus of subgrade reaction for concrete roads,” *International Journal of Pavement Engineering*, vol. 24, no. 1, Dec. 2023, Art. no. 2006651, https://doi.org/10.1080/10298436.2021.2006651.

[10] P. Makwana, “Assessment of Flexible Pavement Using the Falling Weight Deflectometer: A Comprehensive Review,” *International Research Journal of Engineering and Technology*, vol. 10, no. 10, pp. 140–147, Oct. 2023.

[11] N. R. Bastola, M. I. Souliman, S. Dessouky, and R. Daoud, "Structural health assessment of pavement sections in the southern central United States using FWD parameters," *Frontiers in Built Environment*, vol. 8, 2022, https://doi.org/10.3389/fbuil.2022.1026469.

[12] M. Alam, M. Nazim, and S. K. Singh, "Deterioration Pattern of Flexible Pavement with the Help of Falling Weight Deflectometer," *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 8, pp. 737–744, Jun. 2020, https://doi.org/10.35940/ijitee.H6755.069820.

[13] Md. F. Rabbi and D. Mishra, "Using FWD deflection basin parameters for network-level assessment of flexible pavements," *International Journal of Pavement Engineering*, vol. 22, no. 2, pp. 147–161, Jan. 2021, https://doi.org/10.1080/10298436.2019.1580366.

[14] M. Razali, N. A. C. Mahmood, K. A. Hashim, S. Mansor, and N. I. Zainuddin, "The falling weight deflectometer (FWD) for characterization bonding state of subgrade," in *Advances in Civil Engineering and Science Technology*, Penang, Malaysia, Oct. 2018, vol. 2020, Art. no. 020022, https://doi.org/10.1063/1.5062648.

[15] J. Qiu, M. Huurman, M. H. T. Frunt, and R. Gelpke, "Towards high quality re-use of porous asphalt," in *Bearing Capacity of Roads, Railways and Airfields*, 1st ed., A. Loisos, I. Al-Qadi, and T. Scarpas, Eds. London, UK: CRC Press, 2017, https://doi.org/10.1201/9781315100333-167.

[16] U. Solanki, P. Gundaliya, and M. Barasara, "Structural evaluation of flexible pavement using Falling Weight Deflectometer," in *Multi-disciplinary Sustainable Engineering: Current and Future Trends*, P. N. Tekwani, M. Bhavsar, and B. A. Modi, Eds. London, UK: CRC Press, 2016, pp. 141–146.

[17] A. Emersleben and N. Meyer, "Bearing Capacity Improvement of Gravel Base Layers in Road Constructions using Geocells," in *Proceedings of the 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG'08)*, Goa, India, Oct. 2008, pp. 3538–3545.

[18] *IRC 37-2018: Guidelines for the Design of Flexible Pavements*. New Delhi, India: Indian Roads Congress, 2018.

[19] L. F. Walubita *et al.*, "Texas Flexible Pavements and Overlays: Year 1 Report - Test Sections, Data Collection, Analyses, and Data Storage System," Texas Transportation Institute, The University of Texas at El Paso, El Paso, TX, USA, Technical Report: November 2010–September 2011 FHWA/TX-12/0-6658-1, Jun. 2012.

[20] U. J. Solanki, P. J. Gundalia, and M. K. Barasara, "A Review on Structural Evaluation of Flexible Pavements using Falling Weight Deflectometer," *Trends in Transport Engineering and Applications*, vol. 2, no. 1, pp. 1–10, Jan. 2014.

[21] J. H. Maree and R. J. L. Bellekens, *The effect of asphalt overlays on the resilient deflection bowl response of typical pavement structures*. Pretoria, South Africa: Dept. of Transport, Chief Directorate National Roads, 1991.

[22] J. H. Maree and F. Jooste, "Structural classification of pavements through the use of IDM deflection basin parameters," RDAC Report PR, 91, 325, 1999.

[23] E. Horak, "Benchmarking the structural condition of flexible pavements with deflection bowl parameters," *Journal of the South African Institution of Civil Engineers*, vol. 50, no. 2, pp. 2–9, Jun. 2008.

[24] O. Talvik and A. Aavik, "Use of FWD Deflection Basin Parameters (SCI, BDI, BCI) for Pavement Condition Assessment," *The Baltic Journal of Road and Bridge Engineering*, vol. 4, no. 4, pp. 196–202, Dec. 2009, https://doi.org/10.3846/1822-427X.2009.4.196-202.

[25] U. J. Solanki, "A Study on FWD Deflection Bowl Parameters for Structural Evaluation of Flexible Pavement," *Trends in Transport Engineering and Applications*, vol. 4, no. 2, pp. 1–7, Jul. 2019, https://doi.org/10.3759/ttea.v4i2.2873.

[26] L. Fuentes, K. Taborda, X. Hu, E. Horak, T. Bai, and L. F. Walubita, "A probabilistic approach to detect structural problems in flexible pavement sections at network level assessment," *International Journal of Pavement Engineering*, vol. 23, no. 6, pp. 1867–1880, May 2022, https://doi.org/10.1080/10298436.2020.1828586.